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3X COMPOUND PARABOLIC CONCENTRATING (CPC) SOLAR ENERGY COLLECTOR

Final Technical Report

By
Robert W. Ballheim

April 25, 1980

Work Performed Under Contract No. AC04-78CS04239

Chamberlain Manufacturing Corporation
Research and Development Division
Waterloo, Iowa

U.S. Department of Energy

Solar Energy

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Robert W. Ballheim
Principal Investigator

25 April 1980

FINAL TECHNICAL REPORT
CONTRACT DE-AC04-78CS04239

Prepared for
The Department of Energy
Albuquerque Operations Office

This work was supported by the Solar Heating and Cooling Research and Development Branch, Office of Conservation and Solar Applications, U. S. Department of Energy.

Chamberlain

Chamberlain Manufacturing Corporation
Research and Development Division

ABSTRACT

Chamberlain engineers designed a 3X compound parabolic concentrating (CPC) collector for the subject contract. The collector is a completely housed, 105.75 x 44.75 x 10.23-inch, 240-pound unit with six each evacuated receiver assemblies, a center manifold and a one-piece glass cover. A truncated version of a CPC trough reflector system and the General Electric Company tubular evacuated receiver have been integrated with a mass producible collector design suitable for operation at 250 to 450°F. The key criterion for optimization of the design was minimization of the cost per BTU collected annually at an operating temperature of 400°F. The reflector is a 4.1X design truncated to a total height of 8.0 inches with a resulting actual concentration ratio of 2.6 to 1. The manifold is an insulated area housing the fluid lines which connect the six receivers in series with inlet and outlet tubes extending from one side of the collector at the center.

The reflectors are polished, anodized aluminum which are shaped by the roll form process. The housing is painted, galvanized steel, and the cover glass is 3/16-inch thick tempered, low iron glass. The collector requires four slope adjustments per year for optimum effectiveness.

Chamberlain produced ten 3X CPC collectors for the subject contract. Two collectors were used to evaluate assembly procedures, six were sent to the project officer in Albuquerque, New Mexico, one was sent to Argonne National Laboratory for performance testing and one remained with the Company.

A manufacturing cost study was conducted to estimate limited mass production costs, explore cost reduction ideas and define tooling requirements. The final effort discussed in this report shows the preliminary design for application of a 3X CPC solar collector system for use in the Iowa State Capitol complex.

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1. INTRODUCTION

On 1 May 1978, Chamberlain initiated efforts to develop a mass producible, nontracking, high temperature 3X compound parabolic concentrating (CPC) solar collector with evacuated receiver. Company engineers designed a completely housed, 105.75 x 44.75 x 10.23-inch, 240-pound unit with six each reflector assemblies, a center manifold and a one-piece glass cover. Ten prototype collectors were produced utilizing this design.

Completion of the subject contract included a performance/cost analysis, component design, performance prediction and verification testing, and a manufacturing cost study. A preliminary design for application of the system to the Iowa State Capitol complex was also undertaken.

This work has been supported by the Solar Heating and Cooling Research and Development Branch, Office of Conservation and Solar Applications, U. S. Department of Energy.

2. COLLECTOR ASSEMBLY DESCRIPTION

The collector assembly is shown in Figure 1. The overall dimensions are 105.75 x 44.75 x 10.23 inches, and the total weight is 240 pounds. It is a completely housed unit with a center manifold and a one-piece glass cover. It contains six each 45-inch long CPC cusp-shaped reflector assemblies design matched to the General Electric evacuated receiver which has a 1.75-inch diameter absorber. The reflector is a 4.1X design truncated to a total height of 8.0 inches with a resulting actual concentration ratio of 2.6 to 1. The manifold is an insulated area housing the fluid lines which connect the six receivers in series with inlet and outlet tubes extending from one side of the collector at the center. The fluid line is 0.25-inch outside diameter x 0.020 wall stainless steel tubing.

The reflectors are polished, anodized aluminum shaped by the roll form process, resulting in low reflector production labor costs and a very consistent and accurate contour. The housing is painted, galvanized steel. The cover glass is 3/16-inch thick tempered, low iron content glass treated to reduce reflection losses.

The collector requires four slope adjustments per year for optimum effectiveness.

In the following sections, design rationale is discussed in detail for all major components including the reflectors, reflector supports, the housing and cover glazing. The basic assembly operations are briefly described below. The collector box is assembled inverted over a male plug to control interior dimensions. The reflectors are assembled to the reflector supports with rivets at the bottom of the troughs and hook springs at the top. Two individual reflector modules are then centered in the collector

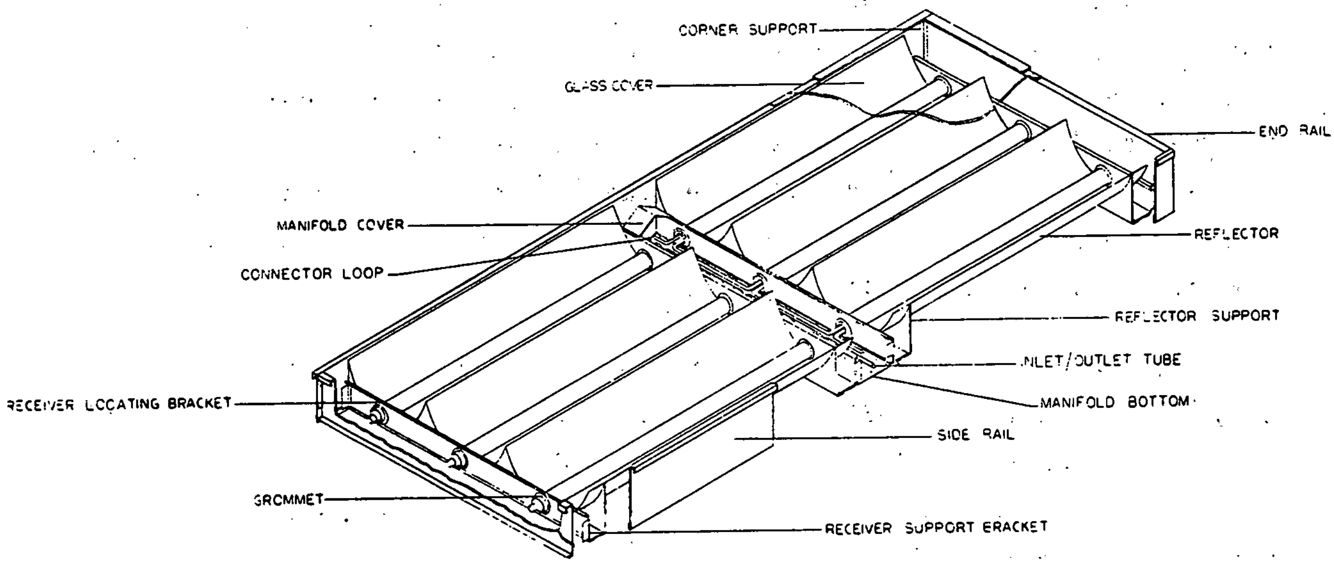

Figure 1. Collector Assembly

box and spot welded in place, spaced the proper distance apart by the manifold bottom. Flexible grommets are installed in receiver locating brackets, and the glass evacuated shrouds are subsequently installed between two receiver locating brackets. The fin/tube heat transfer assemblies are then partially inserted into the shrouds and connected in series by brazing the manifold tubes between each successive fin/tube unit. Inlet/outlet tubes are installed along with the connector loop connecting the right-hand and left-hand receiver sections. Following completion of the brazing, the fin/tube assemblies are inserted the rest of the way into the shrouds. This assembly is then baked to drive off any solvent remaining in the anti-scratch coating inside the shroud. The complete receiver assembly is then placed in the box, positioned relative to the reflectors and attached by self-tapping screws to the receiver support bracket. In this same assembly step the inlet/outlet tubes are inserted through Teflon® insulating bushings in the side of the collector. Insulation of the area is completed, and the manifold and end covers are installed. EPDM (ethylene propylene diene monomer) foam tape with adhesive on one side is applied to the top surface of the box, and the cover glass is positioned. A bead of RTV silicone rubber is laid at the outside glass/box interface, and the cover angle is attached using screws through it and into the vertical outer edge of the box as shown in Figure 2.

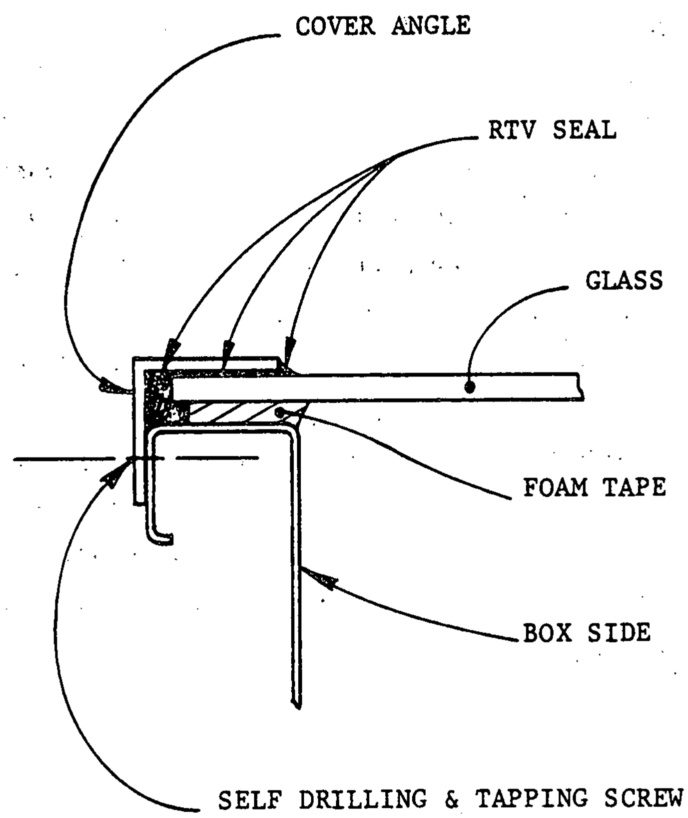

Figure 2. Cover Assembly

3. REFLECTOR DESIGN AND MANUFACTURE

3.1 Reflector Material Selection

The selection of reflector material required consideration in several areas: material cost and availability as of June 1978, reflectivity, adaptability to mass production techniques, durability under all expected collector environments, and the influence of design and material on collector cost effectiveness. Chamberlain's experience in the design and production of reflector systems under Argonne National Laboratories, Contract 31-109-38-3496, and in assembling a 1.5X CPC prototype under a Company-funded program indicated that a formed metal reflector attached to two or more bulkhead-type support structures offered the best combination of reflector surface accuracy and low production costs. There are two methods of manufacture which could utilize this concept:

- Form the reflector out of an inexpensive material such as galvanized steel and attach a thin film reflector material to it.

- Form the reflector out of reflective material such as polished aluminum.

Investigation of the first option indicated that metalized plastic films such as 3M Scotchcal 5400, FEK 163, and FEK 244, could not withstand likely internal collector temperatures. Data from 3M Company indicated that their films are rated at 175°F maximum temperature. The temperature of the reflector near the receiver will be about 75°F above ambient under normal operating conditions and will exceed 250°F under stagnation conditions. The reflector's temperature exceeding 250°F at the latter point is evident when one considers that, under stagnation, collector heat losses equal insolation input. Most of these losses originate as radiation from the receiver to the glass tube. The losses from the glass tube go to the cover glass, reflectors, and air inside the collector. In turn, the losses from the reflectors and glass tubes will be much like those from the absorber plate in a single glazed collector which, under a 300 BTU/hr-ft^2 insolation rate input, will have a plate temperature of approximately 200°F over ambient. Temperatures over 175°F cause the film to shrink and subsequently peel from the metal backing form. The reflectivity of 3M FEK-244 is 0.85 to 0.87, and the quoted cost was $.85 to $1.00 per square foot. Additional labor costs involved in applying the film to the shaped form was estimated to be at least $10 per collector, allowing 4 man-minutes per trough for each of six troughs and equaling about $0.30 per square foot in material cost. Company investigators are also concerned about the difficulty involved in applying the material to the form which has a fairly small radius at the bottom of the cusp where wrinkles and stretching are likely to occur.

The second method involves forming a reflective material to the proper shape. Several types of materials were examined including polished aluminum, plated steel and polished stainless steel. The reflectivity of chrome or nickel-plated steel and polished stainless steel is quite low, approximately 0.60 for the Air Mass 2 spectrum. Other plating processes, such as silver with protective coating, were considered to be too expensive and were rejected. Chamberlain investigators studied several polished aluminum products on the market which have their origin in the lighting industries. Manufacturers' data are quoted below.

> ®King-Lux pre-anodized coil"... is a super high-purity based aluminum, electro-chemically processed to obtain extraordinarily high quality surfaces. A multitude of finishes are available ranging from lustrous metallics to varying degrees of satin matte

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®Proprietary term of Kingston Industries Corporation, New York, New York.

in a full spectrum of colors. With precise control of the transparent anodic oxide film, a range of predetermined physical and performance characteristics can be obtained for specific uses. This film acts as a protective barrier to all atmospheric attacks and is highly abrasion resistant. The metal surface has a ductile tough non-flaking layer that can be postformed with negligible surface disturbance.

"The surface of Type No. C4 (specular) has an extra high total reflectance factor of 87.4% in the visible region of the spectrum. The low diffuse component is only 2.84%. Therefore, the King-Lux Type No. C4 reflector sheet has the ability to reflect without image distortion and with full directional control of the energy source. This property is found in both sheet and coil.

"The King-Lux Reflector Sheet or Coil has a standard anodic thickness of 2 microns. This acts as a formidable protective barrier to weathering. The diamond hard coating resists abrasive cleaning in maintenance assuring long-life surface effective reflectivity.

"Kingston Industries Corporation can deliver all material with a polyethelene peel-off for a mar-free fabricated finish. Coil and sheet can be stored for a long period with no difficulty in removing the strippable layer."

Alcoa® Type 1 lighting sheet "... is the highest quality lighting sheet produced by Alcoa. It is made from high-purity clad Alcoa reflector sheet and offers the most uniform appearance and highest reflectivity of the two types of Alcoa lighting sheet. It is supplied in both Specular and Diffuse grades.

"Alcoa Type 1 - Lighting Sheet Specular is a flat sheet product made from bright-rolled Alcoa reflector sheet having a high-purity cladding. After it is Alzak finished, this sheet provides 83 percent reflectivity and a very high degree of specularity."

® Registered trademark of the Aluminum Company of America, Pittsburgh, Pennsylvania.

Alcoa Coilzak® lighting sheet "... is an Alzak processed reflector material produced from specially developed alloys and processed in coil form. Coilzak lighting sheet approaches the quality of Type 1 lighting sheet yet the cost is lower due to the economies of coil processing. The three standard types of Coilzak sheet are Specular, Semi-Specular and Diffuse and they are available either as coiled or cut-to-length sheet.

"Coilzak Lighting Sheet Specular is made from bright-rolled reflector quality coiled sheet developed specifically to give good finishing response when processed in coil form. This type of Coilzak Lighting Sheet has a guaranteed minimum total reflectivity of 80 percent (compared to 83 percent for Type 1 - Specular) and a specularity level suitable for many applications."

As can be seen from the above data, the reflectivity of the three types of material varies from 0.874 for King-Lux to 0.83 for Alcoa Type 1 and 0.80 for Coilzak. Prices quoted in mid-1978 for large quantities (greater than 100,000 square feet) were $1.45, $2.20, and $0.74 respectively, with the King-Lux and Coilzak prices being for material in coil form and the Alcoa Type 1 in precut standard sizes, all in 0.020-inch thick material. The King-Lux material is rated for exterior marine service while the quoted reflectance properties above are for mild interior service in the case of the Alcoa products. Reflectivity for the Type 1 sheet for exterior marine service is given as 0.78. Coilzak reflectivity for exterior marine service is not given, but it is probably about 0.75.

The durability of these three products under the collector environment is not known. However, Chamberlain has investigated the effects of ultraviolet and humidity weathering on King-Lux. Table 1 summarizes these results.

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TABLE 1. REFLECTANCE PROPERTIES OF KING-LUX TYPE C-4 (INCLUDING WEATHERING TESTS)

EXPOSURE TIME (hours)	SOLAR REFLECTANCE (percent)
0	86.7
175	86.7
343	85.8
536	87.0
704	87.3
871	87.3
4151	87.4

The reflectivity of the material in Table 1 was measured using a Lion Precision Corporation Model R25C reflectometer with a weighting factor applied to correspond to the Air Mass 2 (AM2) solar spectrum. The samples were cycled between 6 hours of ultraviolet light at 130°F followed by 6 hours of 100-percent humidity at 100°F in a Q-Panel ultraviolet weathering tester.

Conclusions

Company analysts rejected thin films as unacceptable because: 1) they do not offer an advantage in reflectivity, 2) they do not have a significant cost advantage when assembly costs are considered, and 3) they have durability problems under likely collector environments. The Alcoa Type 1 material was eliminated because of its higher cost and lower reflectivity when compared directly to King-Lux. The problem became: King-Lux's high reflectivity versus Coilzak's low price. The results of the cost effectiveness study, Section 10, indicate that the advantage lies with King-Lux in a cost versus performance comparison; King-Lux also appears to have greater durability than the other products.

3.2 Reflector Design Analysis

The reflector design process was based on the following parameters which were considered fixed for this program:

- The receiver would be tubular with an absorber diameter of 1.75 inches.
- The reflector would be a cusp-type nonimaging CPC designed for use with a tubular receiver as defined in Reference 1.
- The concentration ratio would be between 2:1 and 4:1.
- Six or less collector slope adjustments per year would be acceptable.
- Standard size reflector material would be used to insure availability and low material cost.

The collector math model described in Section 10 was used to predict heat gains for many reflector designs. The reflector parameters used in that analysis included the following:

- Concentration ratios of 3.5X, 4.1X, 4.7X, and 5.2X with four slope adjustments per year; and 4.7X, 5.2X, and 6.2X with six slope adjustments per year.
- Truncation heights used were 4, 6, 8 and 10 inches.

- Reflectivity was considered to be all specular and included values of 0.75, 0.81 and 0.87.

- Reflector error was introduced to determine the effect of not having a perfectly shaped reflector. This error was induced by adding either 1 or 2 degrees to the incident angle of each ray entering the collector.

- Receiver placement error was set at 0 and 0.06 inch. The purpose of this setting was to check the effect of assembly error on the performance of each reflector configuration. This error consisted of moving the receiver laterally out of the center of the reflector trough, resulting in some rays missing the receiver that would normally strike it. Investigators expected this error to have a greater effect on collectors with larger truncation heights and/or smaller acceptance angles.

Conclusion

The reflector design selected as optimum from a collector cost effectiveness standpoint was a 4.1X concentration ratio cusp-type nonimaging CPC truncated to a height of 8 inches with a resulting concentration ratio of 2.6X. The collector will require four slope adjustments of 22 degrees each per year. Company engineers found that reflector error caused significant reduction in heat gain for the higher concentration ratio reflector systems. Additional discussion of reflector error effects is presented in Section 10.

Figure 3 shows the reflector design selected. With this design, the costs and complexity of roll form tooling were minimized. If the design had

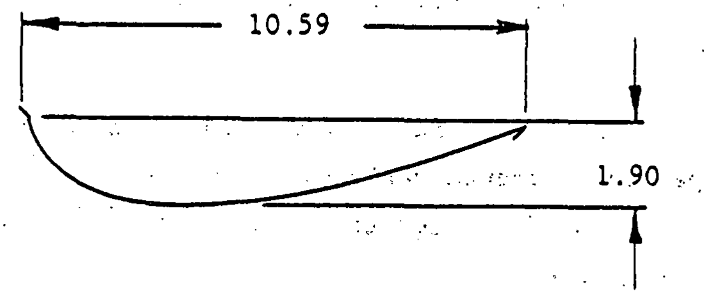


Figure 3. Selected Reflector Configuration

required roll forming the full trough of the reflector in one operation: 1) tooling costs would have been much higher, and 2) extensive tooling modifications would have been needed to roll the proper shape. Relevant reflector design drawings are included in Appendix A.

3.3 Reflector Production Tooling

Chamberlain selected roll-forming as the optimum process for reflector fabrication because this process yields consistently accurate shapes at a low production cost. Shop personnel built roll-form tooling as part of an effort to demonstrate the feasibility of using this process to form the required smooth wide arcs. They modified the rolls, utilized eight roll stations, and obtained an accurately shaped, mass producible reflector despite initial tooling difficulties. Precutting the material to length eliminated the cost of trim tooling but resulted in some minor end flare problems. Rolling the reflector from a continuous strip of material and cutting it to length at the end of the process using flying cutter techniques, common throughout the industry, would eliminate end flare. Material feed rate was 50 feet per minute. Each collector required 12 pieces of formed reflector approximately 4 feet long. Sufficient reflector material for one collector, then, could be shaped and cut to length in less than 1 minute of production time, and enough for approximately 500 collectors could be completed in one, 8-hour day. As a tooling cost reduction measure, temporary setups were used to make the holes for attaching the reflector to the reflector support.

4. HOUSING ASSEMBLY DESIGN

Chamberlain designed the housing as a low cost, durable assembly which gives the collector both rigidity and protection from the environment. Galvanized steel was selected as a better material than aluminum for major housing components due to cost and strength advantages. Calculated weights for various heights of aluminum and galvanized steel housings are recorded in Table 2. The aluminum housing weighed approximately 2 pounds per square foot less than the steel housing but would have cost $0.50 to $1.00 per square foot more to produce. The overall dimensions of the final design housing were 105.75 x 44.75 x 10.23 inches.

TABLE 2. COLLECTOR TOTAL WEIGHT
(IN POUNDS)

	Box Height				
Material	4 In.	6 In.	8 In.	10 In.	12 In.
Aluminum	101	122	153	170	186
Galvanized Steel	128	157	195	235	260

All exterior surfaces were painted to insure maximum endurance. The box sides and ends were designed to be roll formed under high production rates but were adaptable to brake forming on a press for low production quantities which do not justify the high initial cost for roll-form tooling.

As shown in Figure 4 and Photo No. 11189, the sides, ends and bottom pieces all interlock or overlap when assembled. They are fastened together by spotwelding after the box has been squared up on an assembly fixture. The box is assembled upside down on a flat table to insure proper alignment of the top surfaces at the corners. This alignment provides an even base for

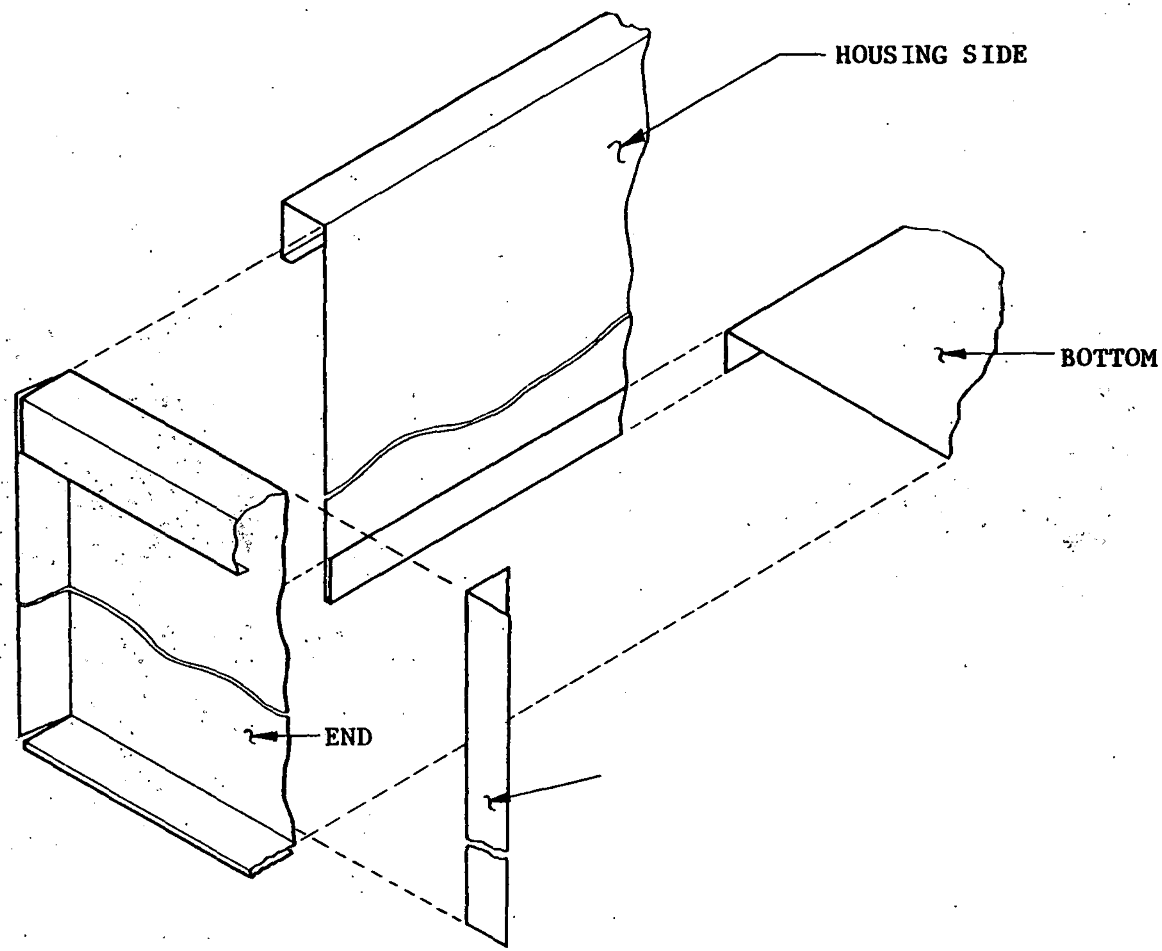
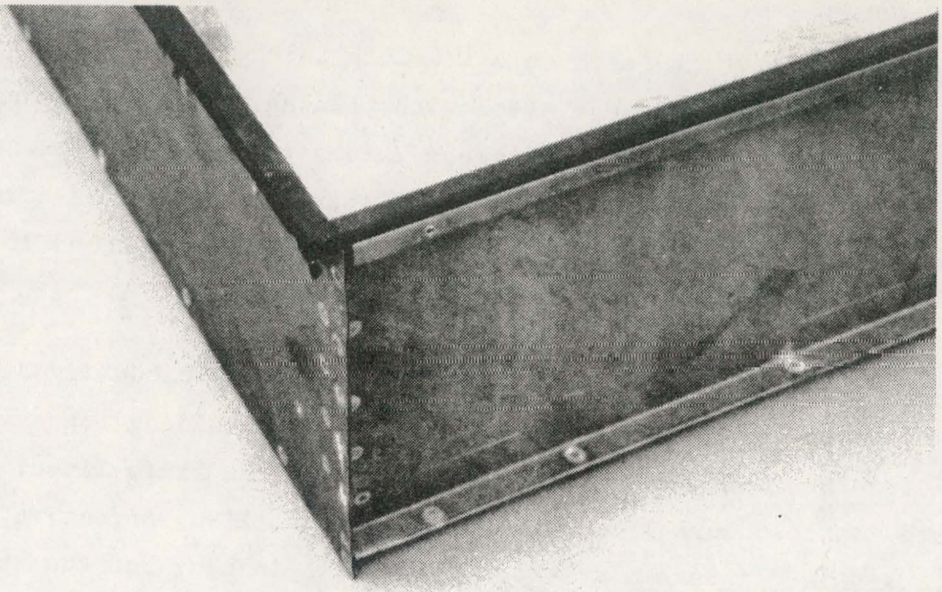


Figure 4. Exploded View of Housing Assembly



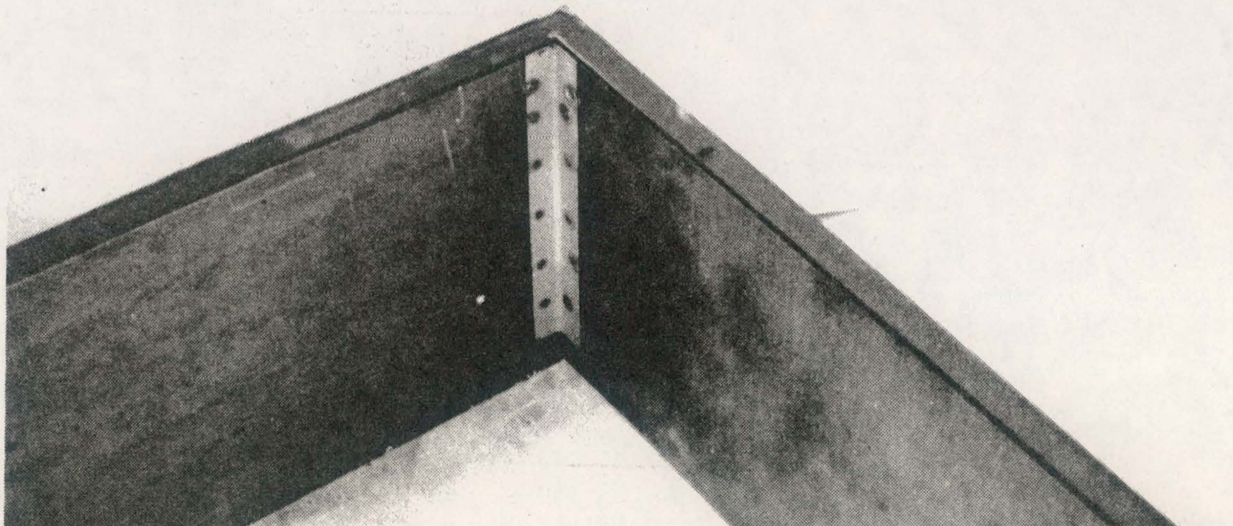


PHOTO NO. 11189

ABOVE: TYPICAL HOUSING CORNER ASSEMBLY

BELOW: INTERNAL CORNER SUPPORT ADDED FOR REINFORCEMENT.

the cover glass which rests on a 1/8-inch thick foam tape seal. The box sides and ends are 20 gauge steel with paintable quality, galvanized, zinc coating. The box bottom is 25 gauge galvanized steel. Internal corner supports, as shown in Photo No. 11189, are secured to each corner as a reinforcement for added box strength. Holes can be punched in the exterior overlap area at the corners for mounting purposes.

Also included as part of this task was the manifold housing design. The height of the manifold was reduced to decrease shading losses while at the same time providing effective insulation for the fluid lines. By using a peaked manifold cover, as shown in Photo No. 11190, effective insulation thickness is maintained at about 2-1/2 to 3 inches, but the shading effect of a flat cover is eliminated. Further discussion of this design is included in Section 6 of this report. Relevant design drawings appear in Appendix A.

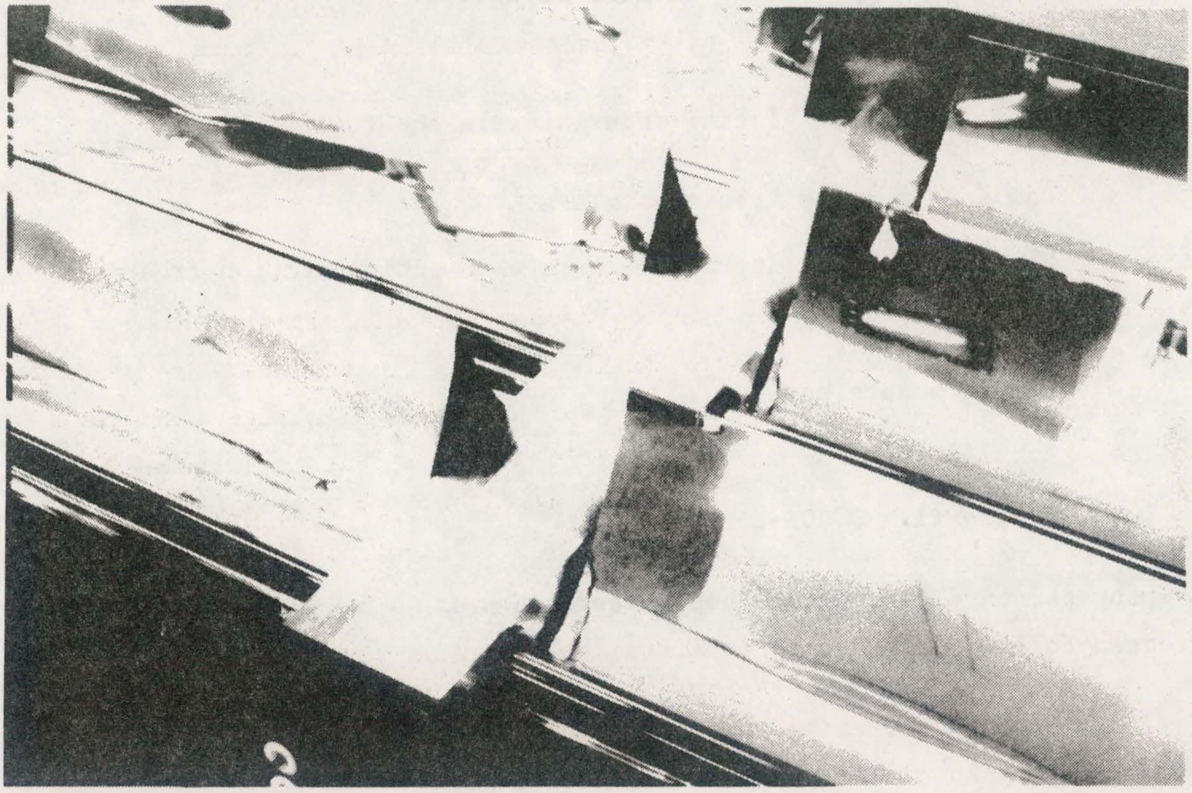


PHOTO NO. 11190

PEAKED MANIFOLD COVER CAUSES MINIMUM SHADING LOSSES DURING EARLY HOUR AND LATE HOUR OPERATION.

5. GLAZING SELECTION

Considered for collector glazing material were the following:

- Low iron content, tempered glass.
- Low iron content, tempered glass with antireflection treatment.
- Waterwhite glass.
- Polycarbonate sheet.
- Acrylic sheet.
- Teflon film 0.001-inch thick.

Company personnel evaluated these materials using a sequential elimination process following the criteria listed below in the order shown:

1. Expected lifetime must be 20 years without significant deterioration in either physical or optical properties.

2. Cost effectiveness considerations: a) the effects on collector producibility, b) the base material cost, and c) the transmissivity of the material for Air Mass 2 spectrum.

3. Chamberlain investigators considered a one-piece cover for the collector to be highly desirable from a production and performance viewpoint. The size required, 105.75 inches long by 44.75 inches wide, dictated that the thickness of the glass cover be at least 3/16 inch. A one-piece cover allowed the use of a lower center manifold. A lower center manifold reduced both shading effects and cover assembly time and also helped reduce the number of weather sealing problems.

Company analysts eliminated 0.001-inch Teflon film because it does not have the necessary mechanical properties. A much thicker film would meet the requirements, but the cost/transmissivity ratio would not be competitive with glass.

Polycarbonate and acrylic optical properties were known to deteriorate when exposed to outside environments. The better of these two would be the acrylic material, but its transmissivity was known to drop approximately 10 percent over a 20-year period (Reference 2). The cost effectiveness study indicated that this 10-percent decrease would represent an approximately 15-percent decrease in collector performance. The advantage of these materials, especially the polycarbonates, lay in their resistance to breakage. However, this advantage outweighed neither weathering problems nor cost. The plastics were eliminated in favor of glass.

The waterwhite glass, Sunadex®, had a very low iron oxide content of less than 0.01 percent and, consequently, had a higher transmissivity than other types of glass, 91.3 percent for a 3/16-inch thickness. Not only was the cost of this glass, as shown in Table 3, quite high, but its stippled surface on one side tended to diffuse the transmitted light. The effect of such diffusion on collector performance has been shown to be negligible. Work reported by the University of Chicago indicates that, for a collector of this type and concentration ratio, the diffusing effect does not cause a significant loss in the number of rays striking the receiver (Reference 11). This product was eliminated, however, because its cost was equal to the cost of antireflection-treated, low iron content glass which has even higher transmissivity.

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TABLE 3. GLASS COVER MATERIAL COST AND TRANSMISSIVITY FOR 3/16-INCH THICK GLASS AND AIR MASS 2 SOLAR SPECTRUM

Glass Product	Cost Per Sq. Ft. 40,000 Lbs. Min.[a]	Transmissivity (Advertised)
Sunadex	$1.11	.913
Lo-Iron	.70	.878
Lo-Iron With Antireflection Treatment	1.10	.93 to .95 (Reference 3)

[a] Includes 15-percent surcharge for glass longer than 84 inches.

The low iron content glass originally evaluated in this program, Lo-Iron, had an iron oxide content of less than 0.05 percent and had a transmissivity of 87.8 percent for 3/16-inch thick material. An etching treatment, which greatly reduced reflection losses off the glass surface, could be applied to Lo-Iron. This antireflective treatment was developed at Honeywell and was commercially available from Nor-Ell, Inc., St. Paul, Minnesota. The projected near term cost for treating large quantities of glass was $0.40 per square foot (Reference 3). This treatment could increase the transmissivity of the glass by 5 to 7 percent. The results of the cost effectiveness study indicated that each 1-percent increase in cover transmissivity was worth about $0.20 per square foot. This option was obviously cost effective. Company personnel decided that the cover material would be Lo-Iron glass with Nor-Ell antireflective treatment.

Three months after Chamberlain placed an order, the manufacturer notified the Company that Lo-Iron was no longer available. It had been replaced by Solatex®, a similar product manufactured by a different process. Solatex had a stippled surface similar to Sunadex and an iron content similar to Lo-Iron. Nor-Ell, Inc. informed Chamberlain that the antireflective treatment would have the same effect on the transmissivity of Solatex as on

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Lo-Iron (Reference 12). The cost effectiveness factor appeared equal for both products. Chamberlain selected Solatex as the material to be used in prototype production collectors.

Unfortunately, Nor-Ell's antireflective treatment did not measurably increase transmissivity, and the prototype test collectors suffered a substantial loss in performance. Cover glass transmittance was checked in front of a radiometer and comparing the output to the output produced without the glass in place. Four each 12-inch square samples and two glass covers were tested in this manner. The transmittance was found to be between 0.894 and 0.911, the average being 0.904. The only information available from the manufacturer stated that the transmittance would be slightly better than for Lo-Iron.

6. INTERNAL MANIFOLD DESIGN

The two major considerations during the manifold design process were: 1) design the plumbing connections to provide for mass production assembly, and 2) design the manifold to provide effective insulation against heat loss from the manifold tube while not causing excessive shading problems for the receiver.

The fin/tube assembly, which functioned as the heat removal mechanism, consisted of a stainless steel U-tube and a thin aluminum cylindrical fin. As shown in Photo No. 11191, one side of the U-tube was clamped securely to the fin and the other side was allowed to remain free. Some freedom of movement between fin/tube assemblies was necessary to enable proper positioning of individual receivers with respect to their own reflector troughs. Company personnel secured this freedom of movement by connecting a fixed tube on one fin/tube assembly to the free tube on the adjacent assembly.

The fin/tube assemblies were connected with transition tubes assembled as shown in Photograph No. 11192. The design of the transition tubes, in which the major portion of the tubing ran down the geometric center of the manifold cross section, provided maximum insulation thickness around the tubes. The inlet and outlet connection areas were designed to allow a systems installer to use whatever type connection he/she preferred. The tubes were run through insulating bushings in the side of the collector.

The fin/tube assembly design allowed the inlet and outlet tubes to be moved approximately 3/4 inch in either direction. This allowance permitted: 1) shipping and handling without protruding tubes, and 2) easy access for assembling a connector or brazing directly into the system.

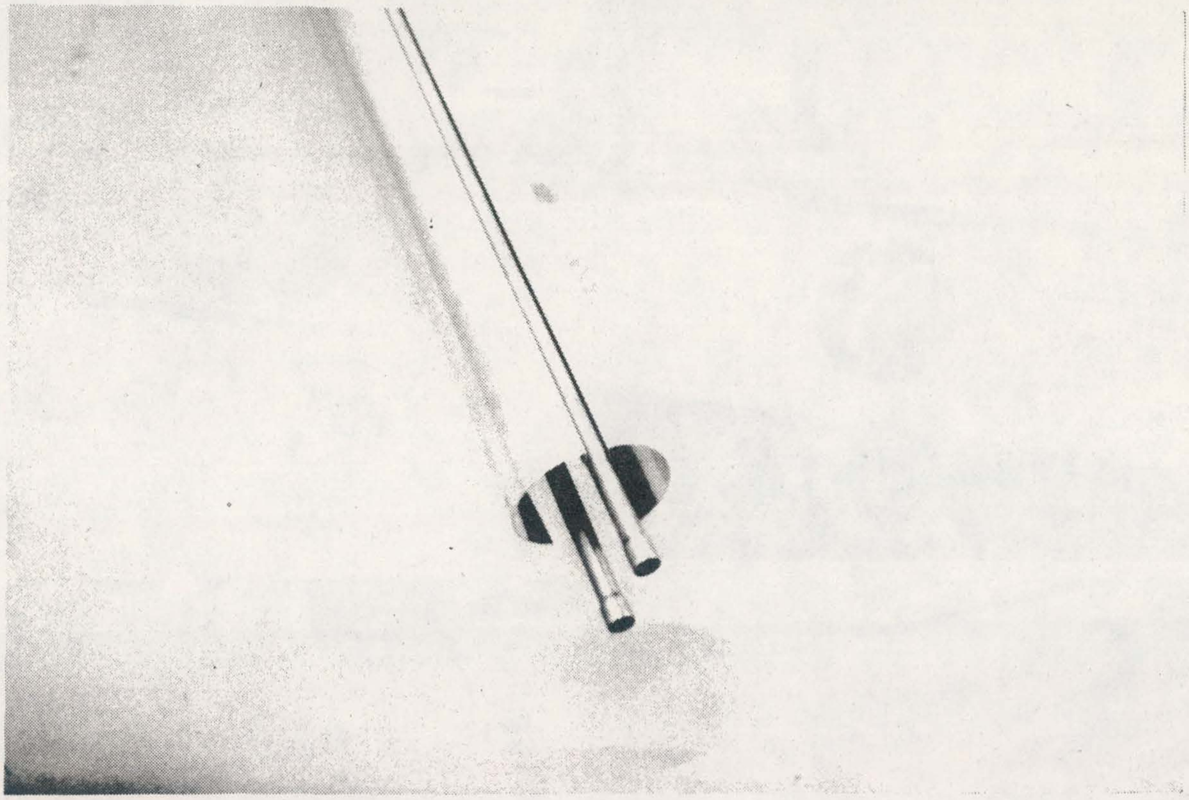
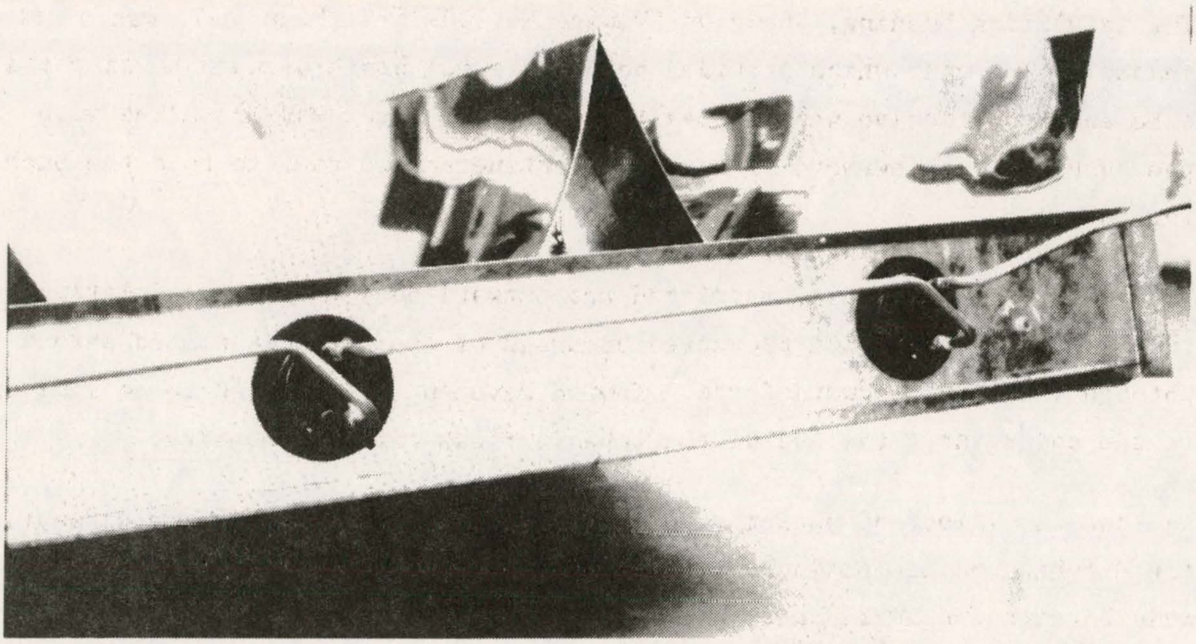


PHOTO NO. 11191

FIN/TUBE ASSEMBLY SHOWING FIXED AND FREE SIDES OF FLUID-CARRYING U-TUBE.



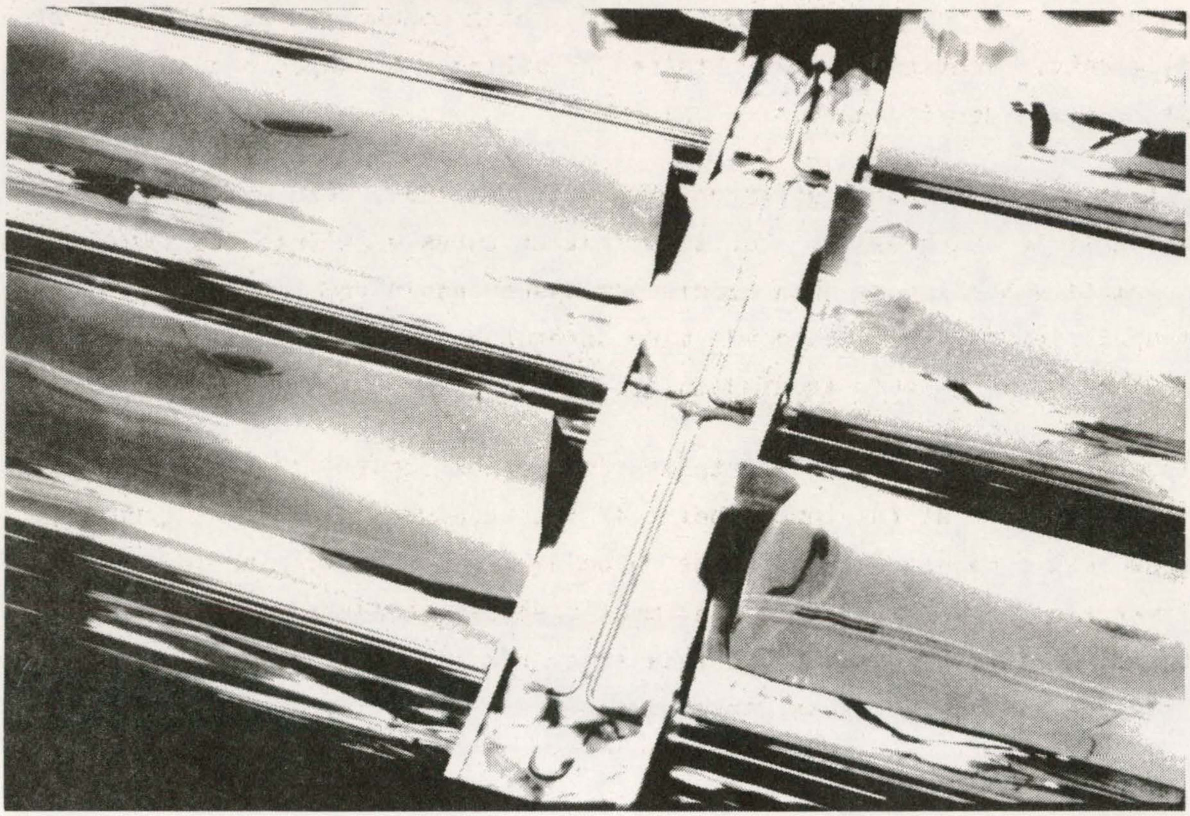


PHOTO NO. 11192

ABOVE: TRANSITION TUBE ASSEMBLY

BELOW: INTERNAL MANIFOLD ASSEMBLY WITH BOTTOM LAYER OF INSULATION INSTALLED.

The insulating bushing, shown on Drawing No. J8178-3, Page A-7, was a hat-shaped Teflon unit which provided both a thermal break between housing and tube and an effective weather seal when the collector was installed with the bushing side downward. Tinnerman fasteners were used to hold the bushing in place.

Tinnerman fasteners also restricted the outward movement of the inlet/outlet tubes. This restriction prevented breakage of the glass evacuated shroud through excessive outward force. Inward movement was assumed to be limited to the point where the end of the tube is flush with the housing.

Because the inlet and outlet tubes were both attached to the free side of the U-tube, the connection for two assembled 4-foot by 4-foot modules was made between two fixed tubes. This connection requirement called for a certain amount of flexibility in the plumbing connection to allow for misalignment. Flexibility was obtained by making a U-shaped bend in the plumbing connection tube.

All plumbing connections, except the U-shaped tube, were made prior to assembly in the housing. The inlet/outlet tubes were inserted through the insulating bushing as each module was assembled in the housing. The U-shaped plumbing connection was made after the two reflector/receiver assembly modules were secured in the housing.

The fin/tube assembly was installed in the collector with the fixed sides of the U-tubes at the lowest point of the receiver. Ray tracing results show that a major portion of the incoming light rays were reflected to the lower side of the receiver under most operating conditions. By locating the fixed side of the tube in this area, the length of the conductive path from the fin to the tubes was minimized.

To provide a design for reducing thermal losses from the manifolding to a minimum, several considerations were made. First, an estimate of the thermal losses from the manifold was made by assuming the following:

- The average manifold pipe temperature was 400°F, and the average temperature outside the manifold was 100°F (approximately 3/4 of the manifold area was inside the collector housing where temperatures were approximately 75°F above ambient under normal operating conditions).

- Since the major portion of the pipes outside the glass shrouds were receiver-to-receiver transition pieces, investigators assumed that most controllable losses could be found in this area. These pipes lay within 1/2 inch of each other for most of their length and thus were assumed to be losing heat as a single pipe. The total length of these transition tubes was assumed to be 36 inches. The losses occurring from the transition tubes as they exit from the evacuated glass shrouds and proceed to the center of the manifold were not calculated because they cannot be controlled and would be very difficult to calculate accurately. However, these losses could be reduced by bending the end of the fixed tube on the fin/tube assembly up, away from the glass shroud. This modification to the fin/tube assembly could be made if General Electric Company determines that it can be done cost effectively.

- Insulation was low binder content fiberglass, as used in Chamberlain's flat plate collectors, type AWX-HT-26 made by Owens-Corning. By compressing the insulation to about 60 percent of its unrestrained volume, Owens-Corning states that a k-factor of 0.345 BTU/hr-ft^2-°F/in. is obtained when the mean temperature is 250°F.

The manifold cover was peaked to provide a minimum of 2-1/2 inches of insulation around the tubes while not causing additional shading of the receivers as would result if the entire manifold was increased in height. The original manifold design was rectangular, extending to the height of the box. The manifold height was reduced to the minimum required for receiver support in order to eliminate excessive shading of the receivers at hours other than solar noon. The width of the manifold area was 6 inches, and the height at the edges was 4 inches with a height at the peak of 5.5 inches. In the assembly operation, a 5-inch thick layer of fiberglass insulation was placed under the manifold piping and another 5-inch thick layer was added on top before the manifold cover was put in place. Additional insulation was packed in the ends of the glass shrouds to restrict convective losses at the open end of the evacuated shroud.

Total thermal losses from the manifold pipes were calculated to be a maximum of 90 BTU per hour under normal operating conditions for the configuration discussed above. This is about 3.4 BTU/hr/ft^2 active area.

The inlet/outlet tubes were spaced 1-1/2 inches apart on the vertical and are located 2.88 and 4.38 inches from the bottom edge of the housing in the center of the 105.75-inch length of the side. They were 0.25-inch outside diameter by 0.020-inch wall, stainless steel tubing.

Relevant design drawings are included in Appendix A.

7. REFLECTOR SUPPORT ASSEMBLY DESIGN

The reflector supports served both as a method of positioning the reflector trough with respect to the absorber and as a device to "fine tune" the shape of the roll-formed reflector material. In order to obtain the most accurate reflector shape, Company personnel decided to stamp the cusp-shaped portion of the supports to insure that this surface would be accurate and could be used to help form the reflector. Figure 5 shows the configuration of the support.

The reflectors were attached to the support directly under the receiver with a pop rivet. The rivets were inserted through prepunched holes in the reflectors and through a hole drilled in the tab on the support as shown in Figures 5 and 6. The reflectors were pulled down onto the support by hooking one end of a wire through and over the reflector at the peak and hooking the other end to a spring, with a tension of about 15 pounds, attached to the support. An edge reinforcement was required to prevent deformation of the reflectors where they were attached to the supports at the sides of the collector. The reinforcement was a piece of the reflector material which was bent over the top edge of the reflector and placed under the hooked anchor wire as shown in Photo No. 11193.

The deliverable collectors contained a third reflector support, added, as shown in Photo No. 11194, to attain an accurate reflector shape. The reflectors, as formed in the roll-form machine, had a slight end-to-end bow that could be eliminated with a tooling modification. However, because the tooling had already been delayed, the reflectors were accepted in the interest of maintaining both schedule and budget. Chamberlain analysts do not anticpate that the third support will be required in production. The support was not included in the final production drawing package included in Appendix A.

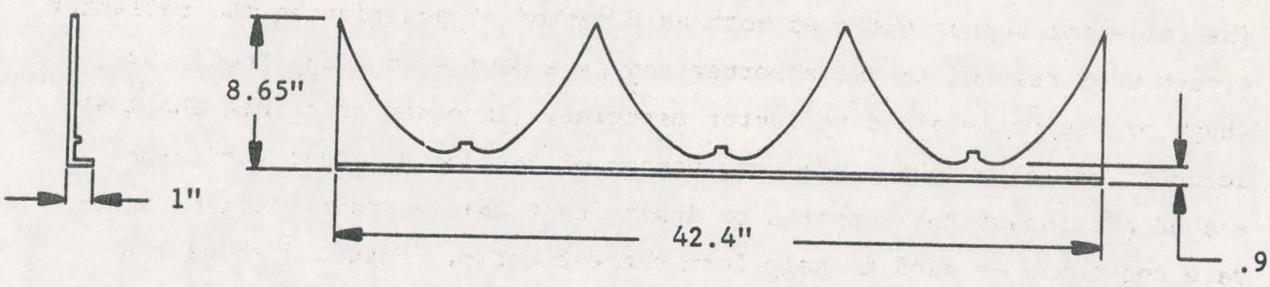


Figure 5. Reflector Support Configuration

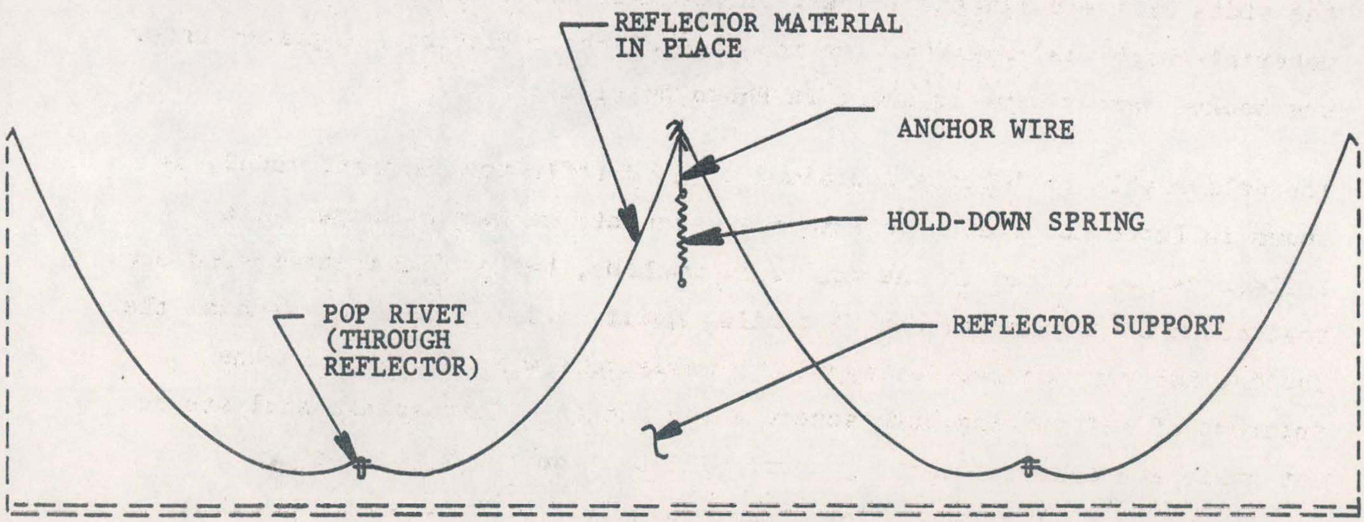
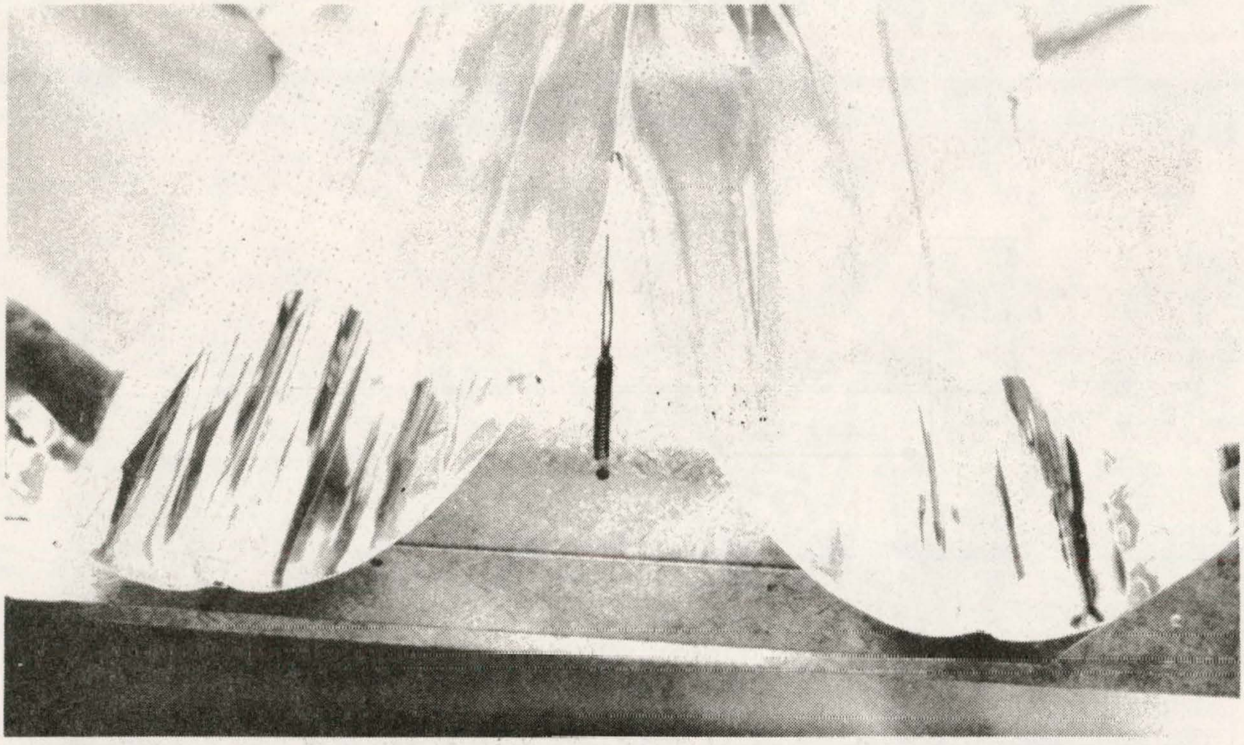


Figure 6. Reflector Support Assembly



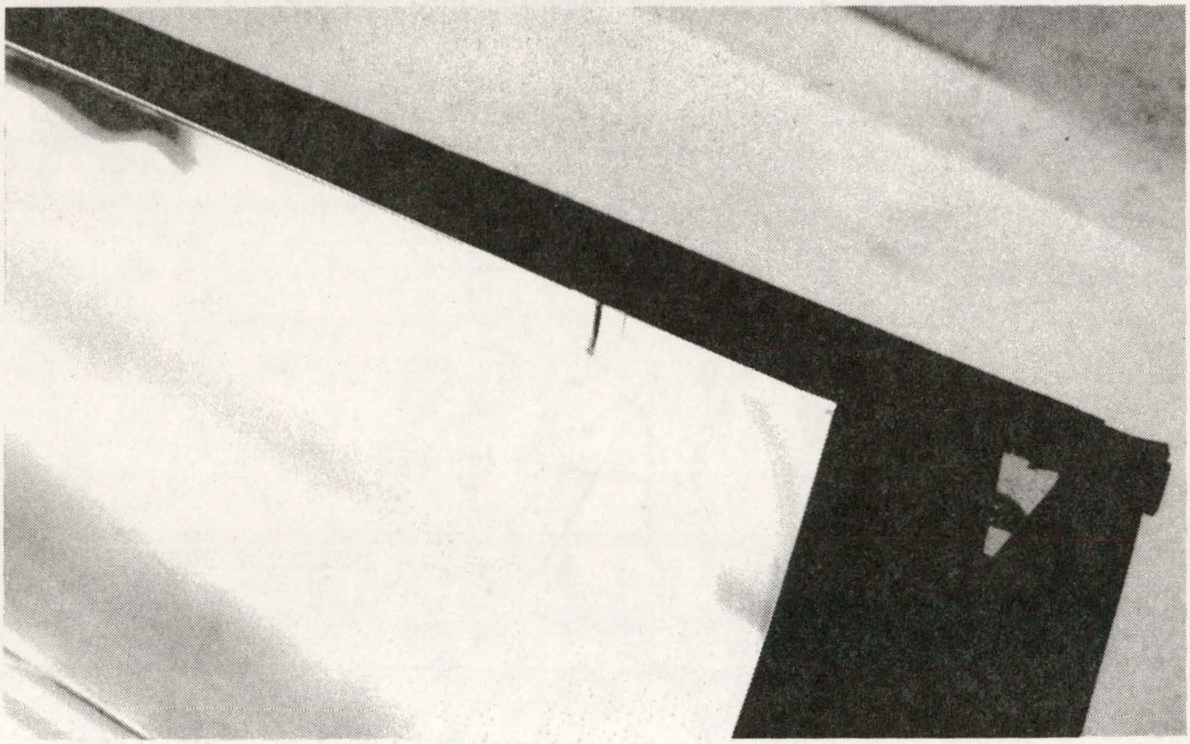


PHOTO NO. 11193

ABOVE: REFLECTOR AND SUPPORT ASSEMBLY, SPRING AND ANCHOR WIRE
BELOW: REFLECTOR EDGE REINFORCEMENT ASSEMBLY.

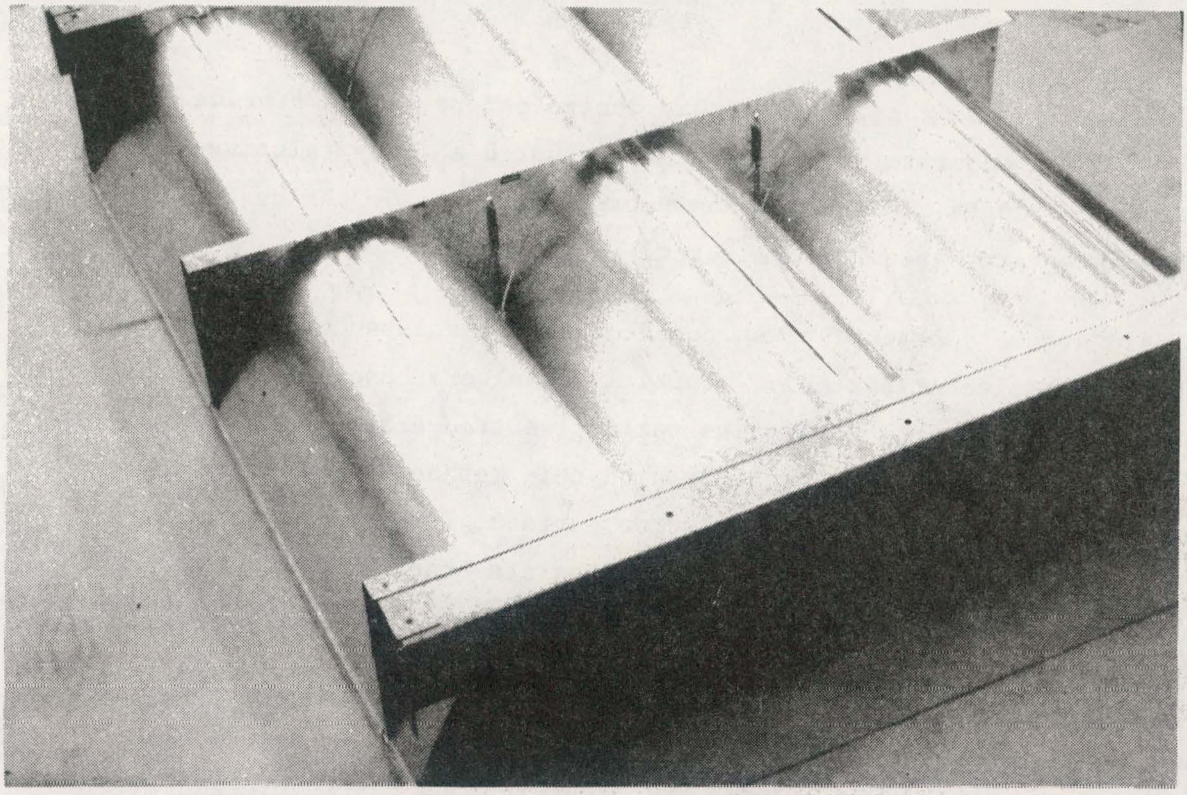


PHOTO NO. 11194

VIEW OF INVERTED REFLECTOR ASSEMBLY WITH THIRD SUPPORT AS REQUIRED IN PROTOTYPE ASSEMBLY.

8. RECEIVER ASSEMBLY DESIGN

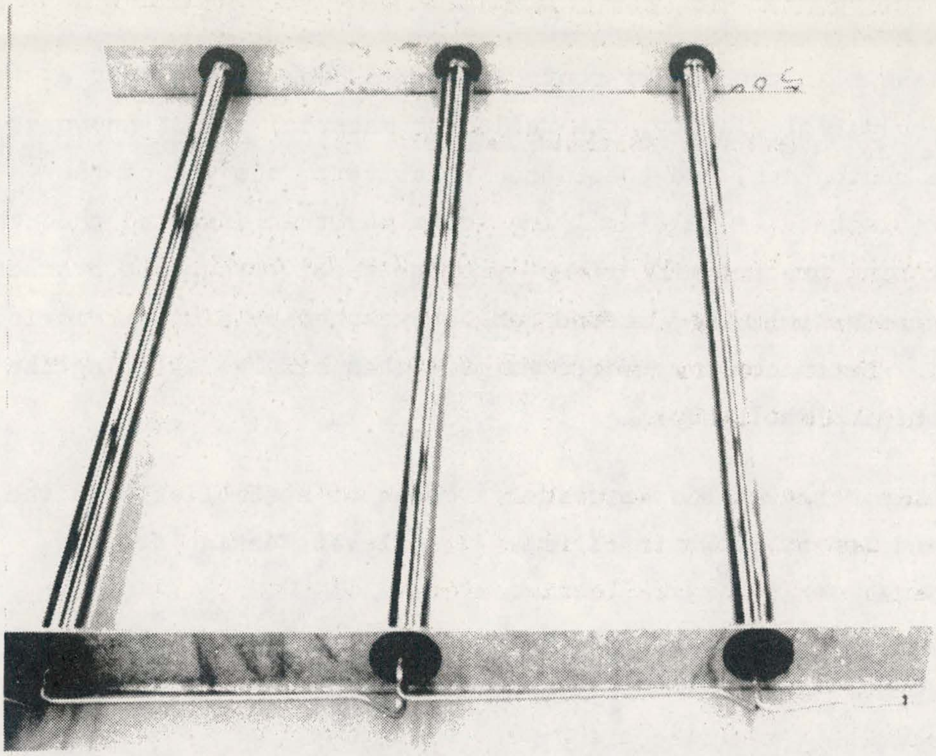
The purpose of the receiver assembly design effort was to provide a low cost means of accurately mounting the evacuated shrouds relative to their respective troughs. The following paragraphs describe the design and how it was integrated into the collector.

The main assembly objective was to accurately locate and fasten the shrouds within the reflector assembly. Initial ideas were based on positioning each receiver properly within its reflective trough and then fastening it in place. There were two problems with this method: 1) It required a fixture that fit against the reflector surface, for locating the proper shroud position; and 2) It required a separate bracket and at least two fasteners for each shroud at each end of each receiver.

Trial assembly efforts indicated that small reflector shape errors could cause large shroud placement errors. Positioning and fastening each end of each receiver was time consuming and, therefore, a costly procedure.

Both problems were solved by using a single bracket at each end of each group of three shrouds and locating the position of that bracket relative to the reflector support bracket rather than the reflector surface. A fixture was used to accurately stamp the three holes used to hold the grommets and receivers. The troughs in the reflector support bracket were stamped with each trough accurately positioned relative to its neighbor.

Photo No. 11195 shows the receiver subassembly as it appears immediately before assembly to the reflector. The receiver locating bracket fastened to the reflector support/receiver support bracket assembly is also shown.



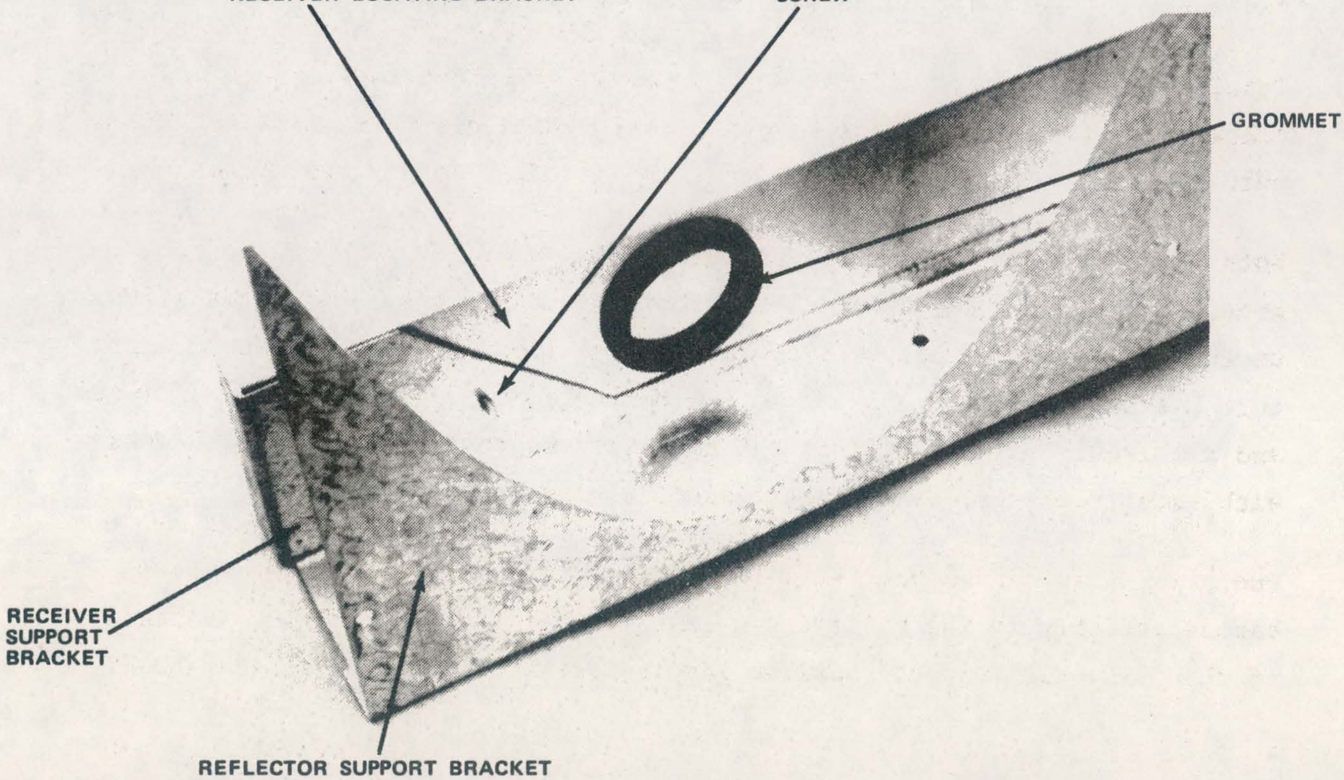


PHOTO NO. 11195

ABOVE: RECEIVER SUBASSEMBLY

BELOW: RECEIVER LOCATING BRACKET AND GROMMET IN ASSEMBLY WITH REFLECTOR SUPPORT AND RECEIVER SUPPORT BRACKET.

The assembly, as shown at the top of Photo No. 11195, was placed over a reflector subassembly (for clarity, the reflector material is not shown at the bottom of the photograph) and positioned relative to the end of the reflector support bracket. A self-drilling screw was then inserted through a hole in the locating bracket and driven into the receiver support bracket at either end of the assembly. A shroud can be detached by simply removing these two screws. Reattachment required no more than simply replacing the screws in their original holes.

The receiver locating bracket also provided a means of assembling both the manifold bottom and top as shown in Figure 7. Relevant design drawings appear in Appendix A.

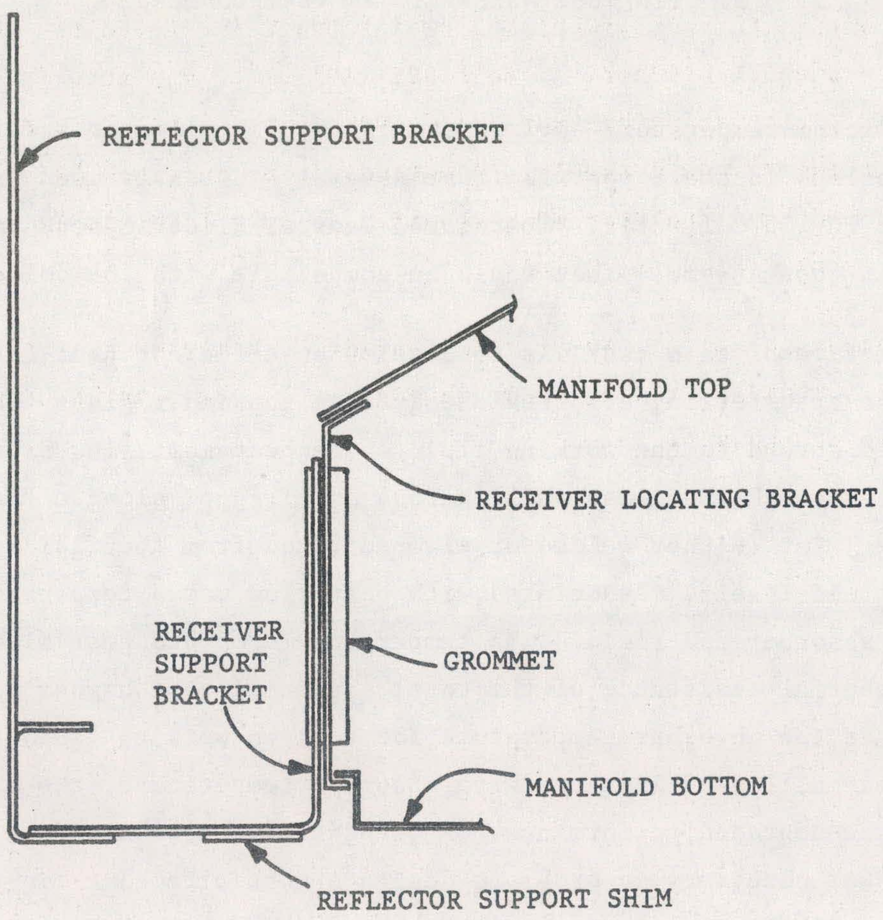


Figure 7. Receiver, Reflector and Manifold Assembly Details

9. FIN/TUBE MANUFACTURING DEVELOPMENT

The predicted temperature environment of the 3X collector presented oxidation problems in the copper fin/tube assembly currently used in the General Electric TC-100 collector. Therefore, General Electric personnel designed a new fin/tube assembly that would be compatible with the collector.

The objective of this task was to develop an efficient heat transfer mechanism for transferring absorbed energy from the inner glass tube of the evacuated shroud to the working fluid. The heat must flow from the absorber coating, through the glass wall, across an air gap, along a fin, through a fin/tube joint (either welded or clamped), and from the fluid-carrying tube to the fluid itself. Associated with heat flow was a temperature drop between absorber and fluid. The temperature drop and heat flow were related by the thermal resistance of the total assembly: the higher this resistance, the higher the absorber temperature for a given working fluid temperature. Since thermal losses increase with absorber temperature, the absorber-fluid resistance degraded performance. A quantitative assessment of this performance penalty was necessary in order to design a cost effective fin/tube joint for the collector.

Thermal resistance can always be reduced by adding dollars to collector cost. However, long-term expense could be lessened by installing more collectors in a given application rather than continuing to increase the efficiency of each collector.

The theoretical effect of this resistance to heat flow on the efficiency of the receiver and thus the collector is characterized in Figure 8 . The value Z, given as the ordinate in this figure, is equal to the theoretical efficiency of a receiver with thermal resistance as shown on the abscissa

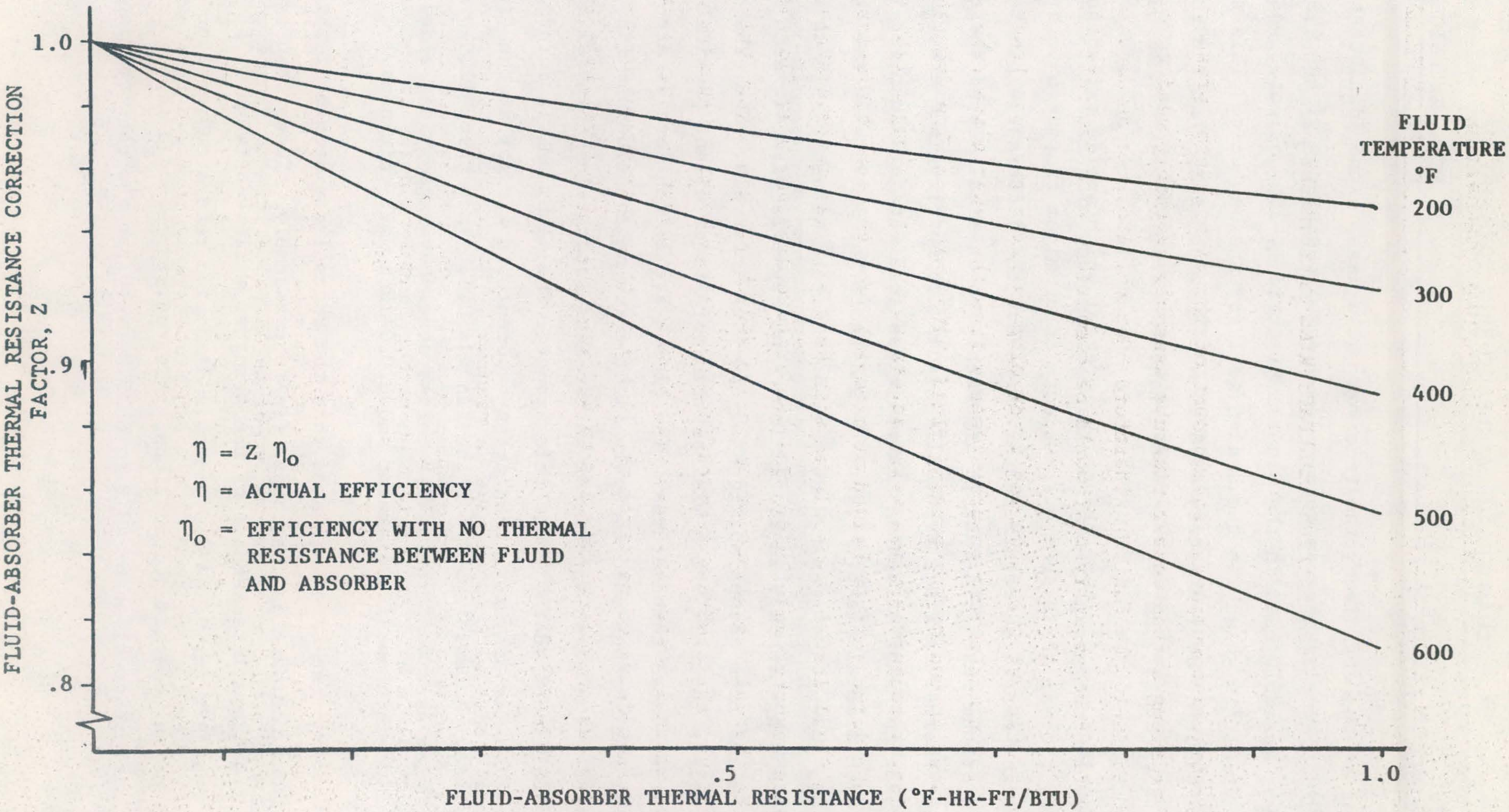


Figure 8. Theoretical Effect on Collector Efficiency of Thermal Resistance of the Receiver

divided by the efficiency the receiver would have in the ideal case where the thermal resistance was zero. The thermal resistance of the copper fin/tube assembly used in the General Electric TC-100 collector was about 0.4°F-hr/BTU/ft which was the design goal for the new unit. This results in a K value of approximately 0.95 at 400°F which means that the thermal resistance costs 5 percent in performance.

For the improved fin/tube assembly, material which avoids oxidation and yet has low thermal resistance was needed. An aluminum fin mated to a stainless steel tube met these requirements. However, the different expansion coefficients of the materials made it impossible to chemically bond the two without thermal cycling, eventually leading to buckling and cracking. An alternate means of attaching the stainless steel and aluminum was to join them with a metal clamp. Figure 9 and Photo No. 11196 show the design that was tested and accepted as the new fin/tube assembly. It utilized an aluminum fin which was in two 22-inch long segments with six each fin springs and tube clamps spaced at 3-1/2-inch intervals. The tube clamp material is Inconel® which was selected for its excellent physical properties at elevated temperatures. The clamps are 1 inch long as are the thin Inconel fin springs used to apply light force on the aluminum fin, pressing it against the glass shroud for better heat conduction. General Electric personnel found that without this support, the aluminum fin deformed under stagnation temperatures, causing an unacceptable air gap at the fin/glass interface. Material used for the fin was 0.020-inch thick 1100-0 aluminum. The tubing used was type 304 stainless steel beverage grade welded tubing with 0.25-inch outside diameter and 0.020-inch wall thickness.

Laboratory test data indicated that the thermal resistance of this design was about the same as the copper fin/tube assembly. These results indicated that the thermal resistance of the absorber will be between 0.35° and 0.40°F-hr/BTU/ft. (The foot in this dimension refers to receiver length.) Under normal operating conditions, this resistance would result in a temperature difference of about 40°F to 60°F between the absorber coating and the

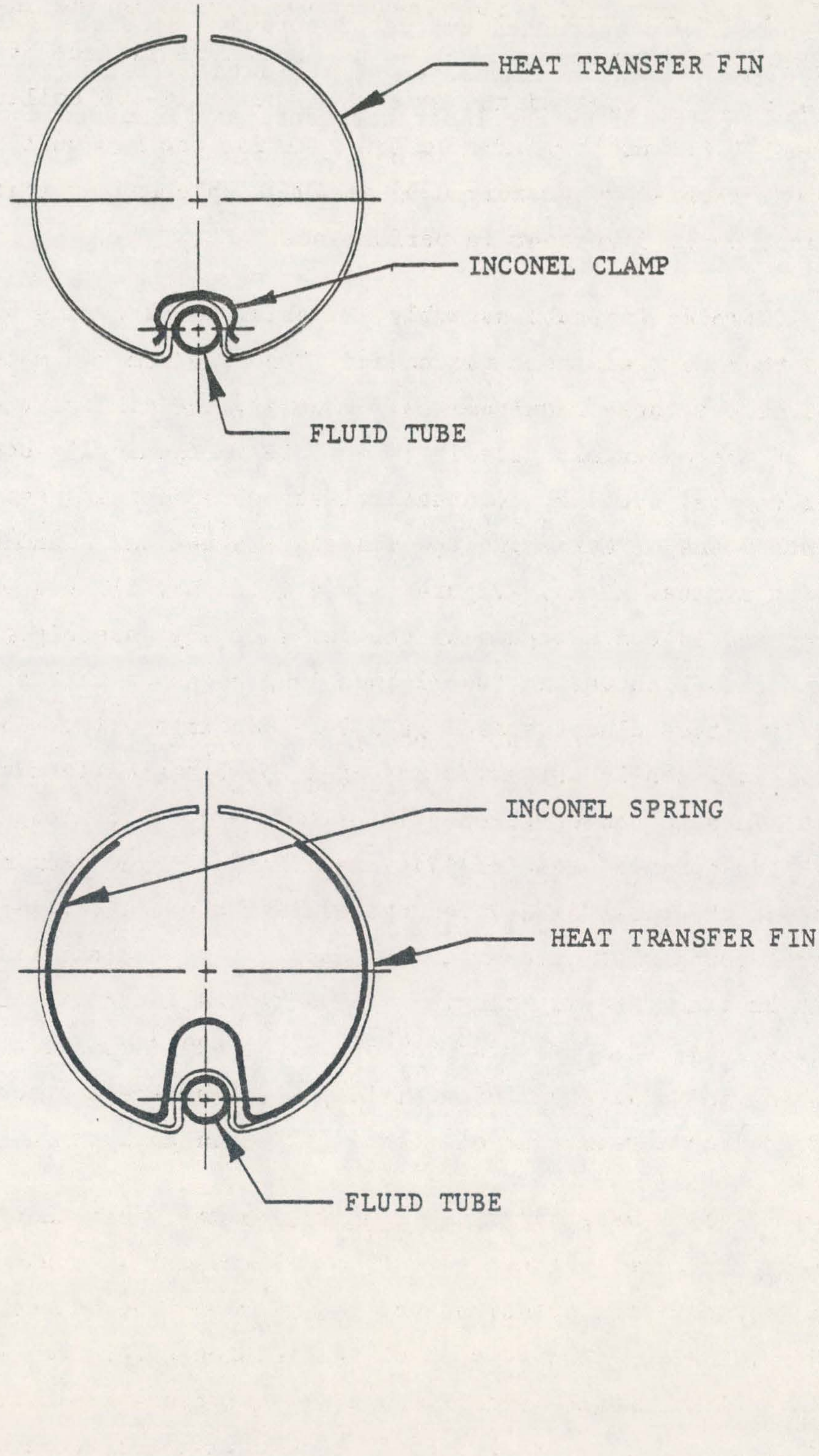


Figure 9. Fin/Tube Assembly

fluid. Thermal resistance was also checked under actual test conditions by using a specially constructed evacuated shroud. Section 13.3 includes these test results and a discussion of the data. Testing verified the performance predicted by the laboratory data as discussed above.

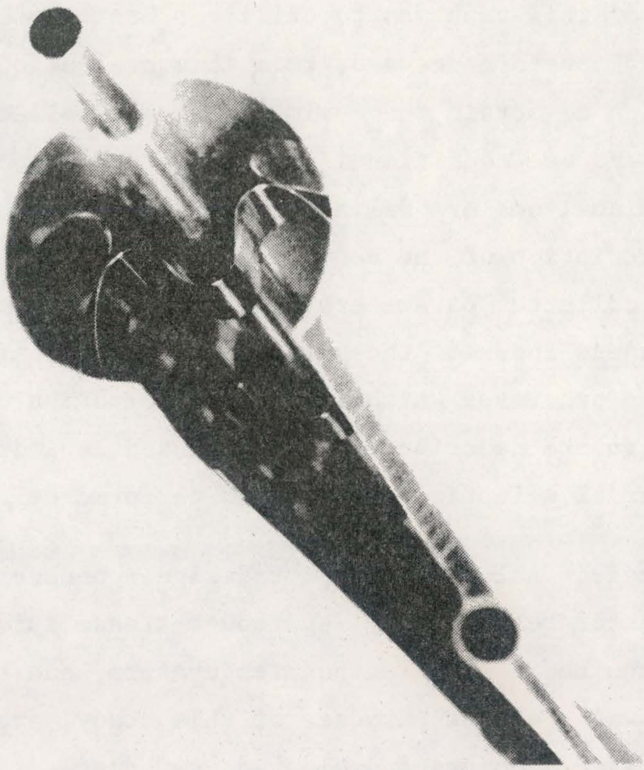


PHOTO NO. 11196

FIN/TUBE ASSEMBLY

10. PERFORMANCE/COST ANALYSIS FOR DESIGN OPTIMIZATION

The objective of this task was to utilize a basic math model to evaluate collector annual performance and, from this evaluation, to optimize the collector design to obtain the maximum BTU gain/collector cost ratio under the specified end use conditions. The analytical procedures and rationale used for these analyses are delineated in detail on the following pages. A complete description of the basic computer model is presented with a discussion of collector parameters and their effect on performance and the cost effectiveness index of the various collector configurations studied. Decision making processes which led to the selection of the recommended collector design are described. Also included is a discussion of the effect of material selection on cost and performance.

Parameters studied included reflector design (concentration ratio and height), reflector reflectivity, and cover transmissivity. The planned application required a 400°F output temperature, and the location was Des Moines, Iowa. For the purposes of this study, average monthly ambient temperatures for Des Moines and clear day 40-degree latitude hourly insolation data for the 21st of each month was used with the collector outlet temperature assumed to be a constant 400°F. All cost effectiveness analyses were based only on collector costs. The system installation costs associated with installing and operating additional square footage of collector was not considered in the selection of optimum collector design.

Collector Cost

Labor and material costs were estimated for four different collector sizes corresponding to reflector truncation heights of 4, 6, 8 and 10 inches. Costs were estimated as the minimum selling price under reasonable production volume, i.e., more than 250 collectors per month. These costs were a near linear function of the housing height which is a direct function of the reflector truncation height. The costs shown in Figure 10 are for a collector with a galvanized steel housing, antireflection-treated tempered glass cover, 0.020-inch thick polished aluminum reflectors, six General Electric receivers and a 4.1X cusp-type CPC reflector system. Preliminary examination of collector performance data indicated that this configuration would most likely be selected; therefore, it was used as a baseline for the cost effectiveness evaluation for all designs.

Collector Performance

Collector performance was evaluated using a heat gain math model which utilized the equation below for the energy gain calculation. Heat gains were calculated for each hour for the 21st day of each month and summed to obtain annual heat gain.

$$HG = \tau_1 \tau_2 \alpha \rho^n \gamma \% I W F - RL \quad (1)$$

where:

- HG = heat gain in BTUs per square foot aperture
- τ_1 = transmissivity of cover glazing
- τ_2 = transmissivity of outer receiver tube
- α = absorptivity of coating on receiver tube
- ρ = reflectivity of reflector material
- n = average number of reflections
- γ = diffuse insolation usability factor which is assumed to be equal to beam ratio + the product of the diffuse ratio times sin (acceptance half angle)
- $\%$ = proportion of all entering rays that strike the absorber
- I = insolation rate
- W = factor used to account for reflection losses off the receiver
- F = receiver shading factor
- RL = heat losses, which are considered to be only by radiation

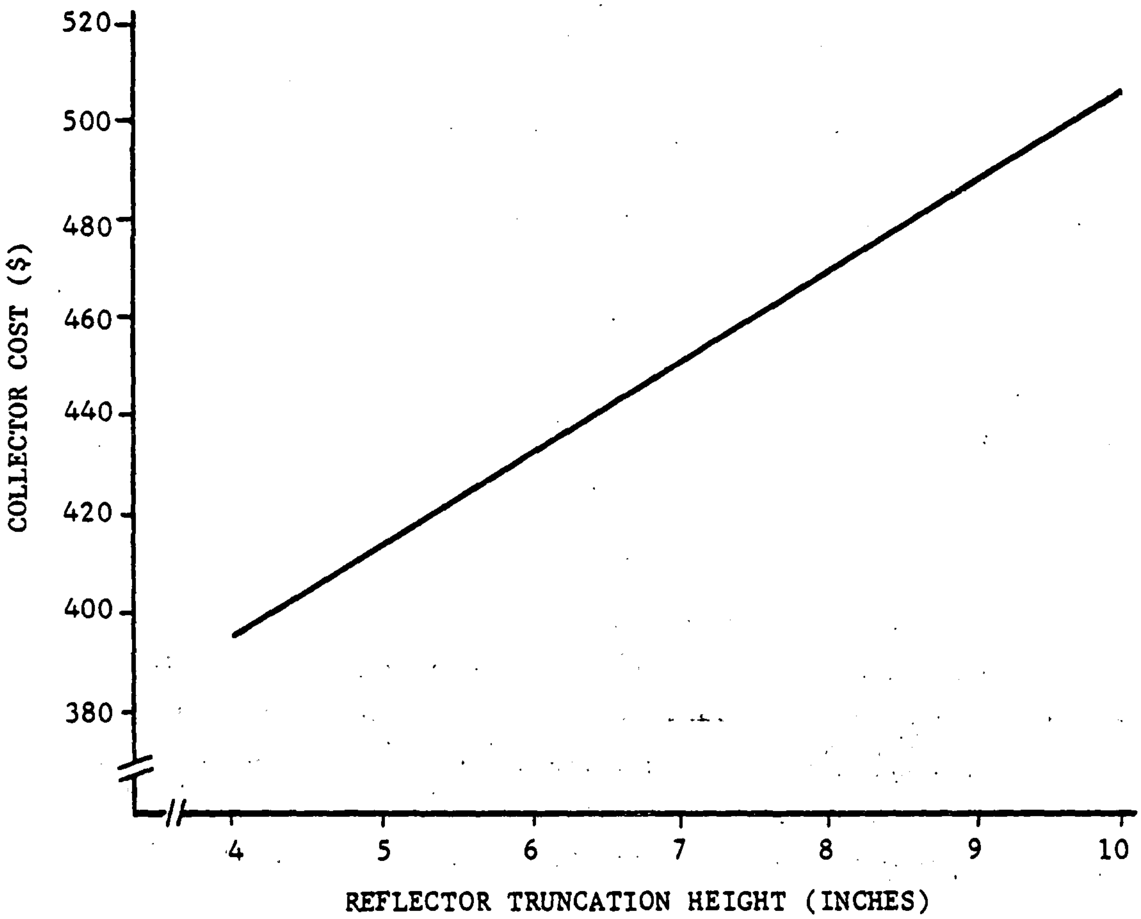


Figure 10. Estimated Collector Selling Price Versus Reflector Truncation Height

A discussion of each parameter listed above in Equation (1) follows:

- τ_1 - The transmissivity of the cover glazing was assigned values of 0.88, 0.91 and 0.95 percent. These values corresponded to the transmissivity of 3/16-inch thick low iron glass, 3/16-inch thick waterwhite (no iron content) glass and antireflective surface-treated 3/16-inch thick low iron content glass.

- τ_2 - The transmissivity of the outer receiver tube was assigned values of 0.89 and 0.92 percent. Chamberlain later tested the transmissivity of a piece of the outer tube and found it to be 0.90 to 0.91.

- α - The absorptivity of the coating on the receiver was given by General Electric Company as 0.89.

- ρ - The reflectivity of the reflector material was assigned values of 0.75, 0.81 and 0.87, each assumed to be all specular. Company analysts felt that this range covered both the lowest acceptable value and also the highest economically feasible value for available materials.

- n - The average number of reflections before a ray of light reaches the receiver was calculated for each hourly condition. This value was calculated in a separate computer program which traced 100 rays entering across the aperture at the prescribed angle for the hourly calculation and output the average number of reflections to collection.

- % - This was also an output of the ray tracing program. It was the percentage of the rays entering the aperture that were reflected and hit the absorber for the prescribed angle. It was close to 1.00 for all angles of incidence less than the acceptable half angle. Rays within the acceptance angle missed the absorber either because they passed under it where part of the reflector was removed to make room for the outer glass of the receiver or because of prescribed reflector or receiver placement errors which were inputs to the ray tracing program.

- γ - This factor was used to compensate for the fact that all the diffuse portion of the insolation was not utilized by the CPC. Analysts assumed that the CPC would use all of the beam radiation and a portion of the diffuse equal to the diffuse component multiplied by the sine of the acceptance half angle for the reflector design being studied.

- I - The insolation rate in BTUs/hr-ft^2 that was assumed to be incident on the collector front surface. Insolation data were taken from ASHRAE 93-77 tables for 40° latitude. Insolation rates are given for 30, 40, 50 and 60-degree collector slopes, and these data were used for incident radiation on the collector by using the data nearest to the actual slope of the collectors for any given time of the year. For example, for the 4.1X collector which requires four slope adjustments per year, the slope is varied from latitude + 22° to latitude + 0° to latitude - 22° to latitude + 0° on specific days of the year to obtain the maximum time of useful solar input. In January, then, the collector slope would be latitude +22°, equalling 62° in Des Moines. Insolation data for 40° latitude and 60° slope were used for the incident radiation. The ratio of beam radiation to total was assumed to be constant for all hours and months, and calculations were made for three different beam ratios: 0.70, 0.78 and 0.85. While this method is not exact, analysts considered it valid because all cost effectiveness decisions were made on a model-to-model comparison basis that reduces the need for absolute accuracy.

- W - This factor was used to account for reflection losses, from the receiver outer glass tube and the absorber coating, resulting from high angles of incidence when the sun is not directly south of the collector. It was an approximation only and did not directly include effects of the approach angle of the rays coming from the reflector in the north-south plane which strike the outer glass and absorber surface at varying angles of incidence. The approximation used in this study was $W = (\cos \omega)^{.25}$, ω = hour angle.

- F - The receiver and reflector were shaded by both the ends of the housing and the center manifold when the sun is not directly south of the collector. This effect became more extreme as the hour angle increased. The inclusion of this factor pointed out the need for a significant design change in the center manifold area. The proposed collector was made up of two 4-foot by 4-foot modules with separate glass covers. This design caused significant shading losses in the morning and afternoon hours because the box was so deep and because the manifold end of the receiver had an effective absorbing area to within 1/2 inch of the end of the receiver. The shading problem was greatly reduced by using a center manifold that was much lower than the box sides and ends and by eliminating the two-piece glazing. As a result of the redesign, the shading problem became significant only before 9 a.m. and after 3 p.m.

- RL - Because the receiver was evacuated, analysts assumed that all heat losses from the absorber would occur by radiation only. These losses would be from the absorber to the outer glass tube of the receiver. The losses from the outer glass tube were of concern only in determining the temperature of the glass to which the absorber surface esd emitting. Laboratory tests at Chamberlain indicated that, under operating conditions (absorber temperature about 375°F greater than ambient), the outer glass temperature was about 75°F higher than ambient. The emissivity of the absorber surface at a temperature of 430°F was determined to be 0.07 by General Electric Company. Radiation losses for this study were calculated using the above data, the average monthly ambient temperatures for Des Moines, Iowa, and an assumed average absorber surface temperature of 430°F with the formula shown below. The losses per square foot of absorber surface are calculated and divided by the concentration ratio to convert to losses per aperture area.

$$RL = \frac{J}{ACON}\,\sigma\,(T_p^4 - T_g^4)$$

RL = radiation losses in BTUs per square foot of aperture per hour

ACON = actual concentration ratio after truncation

σ = Stefan-Boltzmann constant = 0.1714×10^{-8} BTU/hr-ft^2-°R^4

T_p = average absorber surface temperature, assumed to be 430°F for this cost effectiveness study (890°R)

T_g = average temperature of the outer glass tube on the receiver to which the absorber emits. The temperature was assumed to be 75°F higher than the average monthly ambient temperature.

$$J = \frac{1}{\frac{1}{\varepsilon_1} + \frac{A_1}{A_2}\,\frac{(1 - \varepsilon_2)}{\varepsilon_2}}$$

ε_1 and ε_2 are the emissivity of the absorber surface and the outer glass tube respectively and A_1 and A_2 are the areas of the respective surfaces (Reference 8).

Reflector/Receiver Configurations Studied

The following paragraphs delineate the various collector physical considerations included in this study.

- Investigators assumed that the collector would be a nontracking design which would not require more than six adjustments per year and would have an overall concentration ratio of about 3 to 1. With this in mind the following designs were studied:

  - Four slope adjustments per year with design concentration ratios of 3.5, 4.1, 4.7 and 5.2X, each truncated at four different heights: 4, 6, 8, and 10 inches.

  - Six slope adjustments per year with design concentration ratios of 4.7, 5.2, and 6.2X, each truncated at four different heights: 4, 6, 8 and 10 inches.

- Reflector contour inaccuracies were induced into the ray tracing program by reducing the acceptance angle of each design by both 1 and 2 degrees. Chamberlain personnel thought that 1 degree was probably quite optimistic and preferred to use 1-1/2 or 2 degrees as a more realistic estimate for mass production tolerance. Any error in setting the slope of the collector is also reflected here.

- Manufacturing errors in the placement of the receiver relative to the reflector assembly were also considered. These errors were induced into the ray tracing program by positioning the receiver off the true center position. Errors of 0.03 and 0.06 inch were used. Company investigators thought that 0.06 inch was a more realistic estimate of this error.

Performance Study Results

The collector performance calculations discussed above were compared to ascertain the effect of the various design parameters on the annual performance of the collector. Tables 4, 5 and 6 are copies of three of the many pages of computer printout from the cost effectiveness study. These performance figures were for 100-percent clear day sun and were considered valid on a comparative basis but not indicative of expected output under real weather conditions. The computer model was later expanded and adapted to utilize National Oceanic and Atmosphere Administration (NOAA) weather tapes to more accurately predict annual gain under realistic operating conditions. A discussion of this model and initial results are presented in Section 12.1. Tables 4, 5, and 6, respectively, show data generated for: 1) the 4.1X truncated at 8 inches with a reflector error of 1 degree and tube placement error of 0.06 inch, 2) the 4.1X truncated at 8 inches with a reflector error of 2 degrees and tube placement error of 0.06 inch, and 3) the 4.1X truncated at 6 inches with a reflector error of 2 degrees and tube placement error of 0.06 inch. The data columns reading across the page from left to right are identified as follows:

Annual H.G. Coll - Annual heat gain in BTUs for the collector, that is, the heat gain per square foot multiplied by the active length of the receiver (3.71 feet) times the width of one reflector trough times the number of receivers per collector (6).

Input Con - This is the design concentration ratio which is equal to $1/\sin(\theta_a)$ where (θ_a) is the acceptance half angle.

Calc. Con - The calculated concentration after truncation to the specified height. It is equal to the trough width divided by the circumference of the absorber.

TABLE 4. SAMPLE OF PERFORMANCE PARAMETRIC STUDY OUTPUT FOR 4.1X TRUNCATED TO 8-INCH HEIGHT WITH 1° REFLECTOR ERROR

CPC HEAT GAIN PERFORMANCE

ANNUAL H.G. COLL	INPUT CON	CALC. CON	TRUN HT.	WIDTH	CON. ERROR	TUBE ERROR	COV. TAU	TUBE TAU	ALPHA	RHO	DIR. RATIO	EMISS	ANNUAL H.G. FT.
5307111.	4.10	2.60	8.28	14.27	1.00	-0.06	0.88	0.89	0.89	0.75	0.70	0.07	200585.
5857583.	4.10	2.60	8.28	14.27	1.00	-0.06					0.78	0.07	221390.
6341605.	4.10	2.60	8.28	14.27	1.00	-0.06					0.85	0.07	239684.
5874037.	4.10	2.60	8.28	14.27	1.00	-0.06				0.81	0.70	0.07	222012.
6472444.	4.10	2.60	8.28	14.27	1.00	-0.06					0.78	0.07	244629.
6998273.	4.10	2.60	8.28	14.27	1.00	-0.06					0.85	0.07	264505.
6444858.	4.10	2.60	8.28	14.27	1.00	-0.06				0.87	0.70	0.07	243587.
7090900.	4.10	2.60	8.28	14.27	1.00	-0.06					0.78	0.07	268004.
7656522.	4.10	2.60	8.28	14.27	1.00	-0.06					0.85	0.07	289382.
5544289.	4.10	2.60	8.28	14.27	1.00	-0.06		0.92		0.75	0.70	0.07	209549.
6114199.	4.10	2.60	8.28	14.27	1.00	-0.06					0.78	0.07	231089.
6615659.	4.10	2.60	8.28	14.27	1.00	-0.06					0.85	0.07	250042.
6131304.	4.10	2.60	8.28	14.27	1.00	-0.06				0.81	0.70	0.07	231736.
6751391.	4.10	2.60	8.28	14.27	1.00	-0.06					0.78	0.07	255172.
7295460.	4.10	2.60	8.28	14.27	1.00	-0.06					0.85	0.07	275736.
6722995.	4.10	2.60	8.28	14.27	1.00	-0.06				0.87	0.70	0.07	254099.
7391209.	4.10	2.60	8.28	14.27	1.00	-0.06					0.78	0.07	279355.
7975896.	4.10	2.60	8.28	14.27	1.00	-0.06					0.85	0.07	301453.
5546984.	4.10	2.60	8.28	14.27	1.00	-0.06	0.91	0.89		0.75	0.70	0.07	209651.
6117117.	4.10	2.60	8.28	14.27	1.00	-0.06					0.78	0.07	231200.
6618774.	4.10	2.60	8.28	14.27	1.00	-0.06					0.85	0.07	250160.
6134236.	4.10	2.60	8.28	14.27	1.00	-0.06				0.81	0.70	0.07	231847.
6754567.	4.10	2.60	8.28	14.27	1.00	-0.06					0.78	0.07	255292.
7298837.	4.10	2.60	8.28	14.27	1.00	-0.06					0.85	0.07	275863.
6726161.	4.10	2.60	8.28	14.27	1.00	-0.06				0.87	0.70	0.07	254219.
7394623.	4.10	2.60	8.28	14.27	1.00	-0.06					0.78	0.07	279484.
7979527.	4.10	2.60	8.28	14.27	1.00	-0.06					0.85	0.07	301590.
5792246.	4.10	2.60	8.28	14.27	1.00	-0.06		0.92		0.75	0.70	0.07	218921.
6383350.	4.10	2.60	8.28	14.27	1.00	-0.06					0.78	0.07	241262.
6902947.	4.10	2.60	8.28	14.27	1.00	-0.06					0.85	0.07	260900.
6401301.	4.10	2.60	8.28	14.27	1.00	-0.06				0.81	0.70	0.07	241940.
7043540.	4.10	2.60	8.28	14.27	1.00	-0.06					0.78	0.07	266214.
7606155.	4.10	2.60	8.28	14.27	1.00	-0.06					0.85	0.07	287479.
7014175.	4.10	2.60	8.28	14.27	1.00	-0.06				0.87	0.70	0.07	265104.
7705169.	4.10	2.60	8.28	14.27	1.00	-0.06					0.78	0.07	291221.
8309788.	4.10	2.60	8.28	14.27	1.00	-0.06					0.85	0.07	314075.
5866814.	4.10	2.60	8.28	14.27	1.00	-0.06	0.95	0.89		0.75	0.70	0.07	221739.
6464367.	4.10	2.60	8.28	14.27	1.00	-0.06					0.78	0.07	244324.
6989410.	4.10	2.60	8.28	14.27	1.00	-0.06					0.85	0.07	264168.
6482497.	4.10	2.60	8.28	14.27	1.00	-0.06				0.81	0.70	0.07	245009.
7131397.	4.10	2.60	8.28	14.27	1.00	-0.06					0.78	0.07	269535.
7699590.	4.10	2.60	8.28	14.27	1.00	-0.06					0.85	0.07	291010.
7101741.	4.10	2.60	8.28	14.27	1.00	-0.06				0.87	0.70	0.07	268414.
7799585.	4.10	2.60	8.28	14.27	1.00	-0.06					0.78	0.07	294789.
8410200.	4.10	2.60	8.28	14.27	1.00	-0.06					0.85	0.07	317868.
6123778.	4.10	2.60	8.28	14.27	1.00	-0.06		0.92		0.75	0.70	0.07	231451.
6742778.	4.10	2.60	8.28	14.27	1.00	-0.06					0.78	0.07	254847.
7286299.	4.10	2.60	8.28	14.27	1.00	-0.06					0.85	0.07	275389.
6761820.	4.10	2.60	8.28	14.27	1.00	-0.06				0.81	0.70	0.07	255566.
7433071.	4.20	2.60	8.28	14.27	1.00	-0.06					0.78	0.07	280937.
8020416.	4.10	2.60	8.28	14.27	1.00	-0.06					0.85	0.07	303136.
7402418.	4.10	2.60	8.28	14.27	1.00	-0.06				0.87	0.70	0.07	279778.
8123784.	4.10	2.60	8.28	14.27	1.00	-0.06					0.78	0.07	307043.
8754980.	4.10	2.60	8.28	14.27	1.00	-0.06					0.85	0.07	330899.

TABLE 5. SAMPLE OF PERFORMANCE PARAMETRIC STUDY OUTPUT FOR 4.1X TRUNCATED TO 8-INCH HEIGHT WITH 2° REFLECTOR ERROR

CPC HEAT GAIN PERFORMANCE

ANNUAL H.G. COLL	INPUT CON	CALC. CON	TRUN HT.	WIDTH	CON. ERROR	TUBE ERROR	COV. TAU	TUBE TAU	ALPHA	RHO	DIR. RATIO	EMISS	ANNUAL H.G. FT.
5281670.	4.10	2.60	8.28	14.27	2.00	-0.06	0.88	0.89	0.89	0.75	0.70	0.07	199623.
5830151.	4.10	2.60	8.28	14.27	2.00	-0.06					0.78	0.07	220354.
6311649.	4.10	2.60	8.28	14.27	2.00	-0.06					0.85	0.07	238552.
5842880.	4.10	2.60	8.28	14.27	2.00	-0.06				0.81	0.70	0.07	220835.
6437850.	4.10	2.60	8.28	14.27	2.00	-0.06					0.78	0.07	243322.
6961635.	4.10	2.60	8.28	14.27	2.00	-0.06					0.85	0.07	263119.
6406533.	4.10	2.60	8.28	14.27	2.00	-0.06				0.87	0.70	0.07	242138.
7049381.	4.10	2.60	8.28	14.27	2.00	-0.06					0.78	0.07	266435.
7612366.	4.10	2.60	8.28	14.27	2.00	-0.06					0.85	0.07	287713.
5517990.	4.10	2.60	8.28	14.27	2.00	-0.06		0.92		0.75	0.70	0.07	208555.
6085117.	4.10	2.60	8.28	14.27	2.00	-0.06					0.78	0.07	229990.
6584973.	4.10	2.60	8.28	14.27	2.00	-0.06					0.85	0.07	248882.
6098313.	4.10	2.60	8.28	14.27	2.00	-0.06				0.81	0.70	0.07	230489.
6715781.	4.10	2.60	8.28	14.27	2.00	-0.06					0.78	0.07	253826.
7257588.	4.10	2.60	8.28	14.27	2.00	-0.06					0.85	0.07	274304.
6683190.	4.10	2.60	8.28	14.27	2.00	-0.06				0.87	0.70	0.07	252595.
7348290.	4.10	2.60	8.28	14.27	2.00	-0.06					0.78	0.07	277732.
7930252.	4.10	2.60	8.28	14.27	2.00	-0.06					0.85	0.07	299728.
5520675.	4.10	2.60	8.28	14.27	2.00	-0.06	0.91	0.89		0.75	0.70	0.07	208657.
6088025.	4.10	2.60	8.28	14.27	2.00	-0.06					0.78	0.07	230100.
6588087.	4.10	2.60	8.28	14.27	2.00	-0.06					0.85	0.07	249000.
6101224.	4.10	2.60	8.28	14.27	2.00	-0.06				0.81	0.70	0.07	230599.
6718944.	4.10	2.60	8.28	14.27	2.00	-0.06					0.78	0.07	253946.
7260950.	4.10	2.60	8.28	14.27	2.00	-0.06					0.85	0.07	274431.
6686341.	4.10	2.60	8.28	14.27	2.00	-0.06				0.87	0.70	0.07	252714.
7351686.	4.10	2.60	8.28	14.27	2.00	-0.06					0.78	0.07	277861.
7933865.	4.10	2.60	8.28	14.27	2.00	-0.06					0.85	0.07	299865.
5765051.	4.10	2.60	8.28	14.27	2.00	-0.06		0.92		0.75	0.70	0.07	217893.
6353259.	4.10	2.60	8.28	14.27	2.00	-0.06					0.78	0.07	240124.
6871447.	4.10	2.60	8.28	14.27	2.00	-0.06					0.85	0.07	259710.
6367004.	4.10	2.60	8.28	14.27	2.00	-0.06				0.81	0.70	0.07	240644.
7006715.	4.10	2.60	8.28	14.27	2.00	-0.06					0.78	0.07	264822.
7566992.	4.10	2.60	8.28	14.27	2.00	-0.06					0.85	0.07	285998.
6973013.	4.10	2.60	8.28	14.27	2.00	-0.06				0.87	0.70	0.07	263549.
7660786.	4.10	2.60	8.28	14.27	2.00	-0.06					0.78	0.07	289543.
8262589.	4.10	2.60	8.28	14.27	2.00	-0.06					0.85	0.07	312289.
5839349.	4.10	2.60	8.28	14.27	2.00	-0.06	0.95	0.89		0.75	0.70	0.07	220701.
6433958.	4.10	2.60	8.28	14.27	2.00	-0.06					0.78	0.07	243175.
6957598.	4.10	2.60	8.28	14.27	2.00	-0.06					0.85	0.07	262966.
6447861.	4.10	2.60	8.28	14.27	2.00	-0.06				0.81	0.70	0.07	243700.
7094207.	4.10	2.60	8.28	14.27	2.00	-0.06					0.78	0.07	268129.
7660039.	4.10	2.60	8.28	14.27	2.00	-0.06					0.85	0.07	289515.
7060170.	4.10	2.60	8.28	14.27	2.00	-0.06				0.87	0.70	0.07	266843.
7754763.	4.10	2.60	8.28	14.27	2.00	-0.06					0.78	0.07	293095.
8362530.	4.10	2.60	8.28	14.27	2.00	-0.06					0.85	0.07	316066.
6094662.	4.10	2.60	8.28	14.27	2.00	-0.06		0.92		0.75	0.70	0.07	230351.
6711857.	4.10	2.60	8.28	14.27	2.00	-0.06					0.78	0.07	253678.
7253414.	4.10	2.60	8.28	14.27	2.00	-0.06					0.85	0.07	274147.
6726165.	4.10	2.60	8.28	14.27	2.00	-0.06				0.81	0.70	0.07	254219.
7394627.	4.10	2.60	8.28	14.27	2.00	-0.06					0.78	0.07	279484.
7979532.	4.10	2.60	8.28	14.27	2.00	-0.06					0.85	0.07	301591.
7359445.	4.10	2.60	8.28	14.27	2.00	-0.06				0.87	0.70	0.07	278154.
8077448.	4.10	2.60	8.28	14.27	2.00	-0.06					0.78	0.07	305291.
8705705.	4.10	2.60	8.28	14.27	2.00	-0.06					0.85	0.07	329037.

TABLE 6. SAMPLE OF PERFORMANCE PARAMETRIC STUDY OUTPUT FOR 4.1X TRUNCATED TO 6-INCH HEIGHT

CPC HEAT GAIN PERFORMANCE

ANNUAL H.G. COLL	INPUT CON	CALC. CON	TRUN. HT.	WIDTH	CON. ERROR	TUBE ERROR	COV. TAU	TUBE TAU	ALPHA	RHO	DIR. RATIO	EMISS	ANNUAL H.G. FT.
4641261.	4.10	2.29	6.01	12.57	2.00	-0.06	0.88	0.89	0.89	0.75	0.70	0.07	199118.
5143178.	4.10	2.29	6.01	12.57	2.00	-0.06					0.78	0.07	220651.
5585025.	4.10	2.29	6.01	12.57	2.00	-0.06					0.85	0.07	239607.
5118699.	4.10	2.29	6.01	12.57	2.00	-0.06				0.81	0.70	0.07	219600.
5661882.	4.10	2.29	6.01	12.57	2.00	-0.06					0.78	0.07	242904.
6140262.	4.10	2.29	6.01	12.57	2.00	-0.06					0.85	0.07	263427.
5597018.	4.10	2.29	6.01	12.57	2.00	-0.06				0.87	0.70	0.07	240121.
6181435.	4.10	2.29	6.01	12.57	2.00	-0.06					0.78	0.07	265194.
6692799.	4.10	2.29	6.01	12.57	2.00	-0.06					0.85	0.07	287132.
4857518.	4.10	2.29	6.01	12.57	2.00	-0.06		0.92		0.75	0.70	0.07	208395.
5377101.	4.10	2.29	6.01	12.57	2.00	-0.06					0.78	0.07	230686.
5836386.	4.10	2.29	6.01	12.57	2.00	-0.06					0.85	0.07	250390.
5351669.	4.10	2.29	6.01	12.57	2.00	-0.06				0.81	0.70	0.07	229595.
5915872.	4.10	2.29	6.01	12.57	2.00	-0.06					0.78	0.07	253800.
6410377.	4.10	2.29	6.01	12.57	2.00	-0.06					0.85	0.07	275016.
5848821.	4.10	2.29	6.01	12.57	2.00	-0.06				0.87	0.70	0.07	250924.
6452937.	4.10	2.29	6.01	12.57	2.00	-0.06					0.78	0.07	276841.
6981538.	4.10	2.29	6.01	12.57	2.00	-0.06					0.85	0.07	299519.
4859977.	4.10	2.29	6.01	12.57	2.00	-0.06	0.91	0.89		0.75	0.70	0.07	208501.
5379776.	4.10	2.29	6.01	12.57	2.00	-0.06					0.78	0.07	230801.
5839242.	4.10	2.29	6.01	12.57	2.00	-0.06					0.85	0.07	250513.
5354334.	4.10	2.29	6.01	12.57	2.00	-0.06				0.81	0.70	0.07	229710.
5918758.	4.10	2.29	6.01	12.57	2.00	-0.06					0.78	0.07	253924.
6413446.	4.10	2.29	6.01	12.57	2.00	-0.06					0.85	0.07	275147.
5851683.	4.10	2.29	6.01	12.57	2.00	-0.06				0.87	0.70	0.07	251047.
6456022.	4.10	2.29	6.01	12.57	2.00	-0.06					0.78	0.07	276974.
6984821.	4.10	2.29	6.01	12.57	2.00	-0.06					0.85	0.07	299660.
5083606.	4.10	2.29	6.01	12.57	2.00	-0.06		0.92		0.75	0.70	0.07	218095.
5623281.	4.10	2.29	6.01	12.57	2.00	-0.06					0.78	0.07	241248.
6099210.	4.10	2.29	6.01	12.57	2.00	-0.06					0.85	0.07	261666.
5596993.	4.10	2.29	6.01	12.57	2.00	-0.06				0.81	0.70	0.07	240120.
6181407.	4.10	2.29	6.01	12.57	2.00	-0.06					0.78	0.07	265192.
6692769.	4.10	2.29	6.01	12.57	2.00	-0.06					0.85	0.07	287131.
6112070.	4.10	2.29	6.01	12.57	2.00	-0.06				0.87	0.70	0.07	262218.
6736781.	4.10	2.29	6.01	12.57	2.00	-0.06					0.78	0.07	289019.
7283402.	4.10	2.29	6.01	12.57	2.00	-0.06					0.85	0.07	312470.
5151597.	4.10	2.29	6.01	12.57	2.00	-0.06	0.95	0.89		0.75	0.70	0.07	221012.
5697602.	4.10	2.29	6.01	12.57	2.00	-0.06					0.78	0.07	244436.
6178249.	4.10	2.29	6.01	12.57	2.00	-0.06					0.85	0.07	265057.
5671051.	4.10	2.29	6.01	12.57	2.00	-0.06				0.81	0.70	0.07	243297.
6261261.	4.10	2.29	6.01	12.57	2.00	-0.06					0.78	0.07	268618.
6777691.	4.10	2.29	6.01	12.57	2.00	-0.06					0.85	0.07	290774.
6191236.	4.10	2.29	6.01	12.57	2.00	-0.06				0.87	0.70	0.07	265614.
6822139.	4.10	2.29	6.01	12.57	2.00	-0.06					0.78	0.07	292681.
7374182.	4.10	2.29	6.01	12.57	2.00	-0.06					0.85	0.07	316364.
5385883.	4.10	2.29	6.01	12.57	2.00	-0.06		0.92		0.75	0.70	0.07	231063.
5952794.	4.10	2.29	6.01	12.57	2.00	-0.06					0.78	0.07	255385.
6449644.	4.10	2.29	6.01	12.57	2.00	-0.06					0.85	0.07	276700.
5925350.	4.10	2.29	6.01	12.57	2.00	-0.06				0.81	0.70	0.07	254207.
6535454.	4.10	2.29	6.01	12.57	2.00	-0.06					0.78	0.07	280382.
7069293.	4.10	2.29	6.01	12.57	2.00	-0.06					0.85	0.07	303284.
6463068.	4.10	2.29	6.01	12.57	2.00	-0.06				0.87	0.70	0.07	277276.
7115239.	4.10	2.29	6.01	12.57	2.00	-0.06					0.78	0.07	305255.
7685887.	4.10	2.29	6.01	12.57	2.00	-0.06					0.85	0.07	329737.

Trun Ht. - The truncation height, in inches, of the reflector as it is carried in the ray tracing program. Because of the way the reflector surface was generated by the ray tracing program, the truncation height was always slightly greater than the specified truncation height.

Width - The width, in inches, of a reflector trough at the given truncation height.

Con. Error - The reflector error, in degrees, due to contour inaccuracies.

Tube Error - The tube placement error, in inches, off the true center of the reflector.

Cov. Tau - The transmissivity of the cover glazing.

Tube Tau - The transmissivity of the outer glass tube of the receiver.

Alpha - The absorptivity of the absorbing surface on the receiver.

Rho - The total reflectivity of the reflector material which was assumed to be all specular.

Dir. Ratio - The ratio of the insolation beam component to the total insolation.

Emiss - The hemispherical emissivity of the absorber surface.

Annual H.G. Ft. - The annual heat gain, in BTUs per square foot, of aperture.

Examination of the data indicated the following performance trends developed in this parametric study.

- Errors due to inaccurate reflector contours significantly affected performance, and as expected, the effect of the errors was much more evident for collectors with smaller acceptance angles. In fact, this effect steered investigators toward the 4.1X rather than the 4.7X design because of concern over possible manufacturing problems in holding tolerances in the assembly operation. The acceptance half angle for the 4.1X and the 4.7X are 14.1 degrees and 12.3 degrees, respectively. According to the results, very little effect was observed on the 3.5X and 4.1X by increasing the ray error from 1 to 2 degrees, but for the 4.7X and 5.2X the effect was much more pronounced. At the 8-inch truncation height, the effect of increasing reflector error is shown in Tables 4 and 5 to be 0.6 percent for the 4.1X and 5 percent for the 4.7X. A substantial amount of energy was obviously gained when the rays were near the maximum acceptance angle. The error effects did not appear to be directly related to truncation height.

- Errors in receiver tube placement relative to the reflectors did not affect the performance to the degree that the reflector error did. The difference in performance between errors of 0.03 and 0.06 inch was less than 1/2 percent in most cases. Company analysts think maintaining a tolerance of $\pm$ 0.06 inch in tube placement under mass production assembly operations should present no problems.

- Changes in cover glazing transmissivity had a significant effect on collector performance as expected. Table 6 is a typical example of all performance results relative to varying cover transmissivities. Results of computer modeling indicated that the performance of the collector under ideal insolation conditions increased about 1.4 percent for each 1-percent increase in cover transmissivity. As the insolation rate decreases, the effect would be even greater and would eventually make the difference between losing or gaining energy under marginal operating conditions.

- The same reasoning as used above applies to the outer receiver tube transmissivity. Although this design is considered fixed, a significant increase in performance could be obtained by treating the glass to reduce reflection losses. Chamberlain's experience in treating this type of glass tube shows that a high rate of breakage occurs when using the etching technique developed by Honeywell Corporation.

- The reflectivity of the reflector material has an even greater effect on performance than cover glazing transmissivity. An increase of 1 percent in reflectivity will result in about a 1.65-percent increase in thermal performance. This effect is essentially independent of other parameters. The model did not consider the difference between specular and diffuse reflectivity. Calculations were based on the assumption that reflectivity is all specular. Although this will not be the case, Chamberlain personnel considered it a good measure of the effect of varying reflectivity. This consideration was included in the final reflector material selection.

- The ratio of beam to total insolation affected the overall collector performance but did not influence the effect of the other parameters in this study. The smaller the acceptance angle, the greater the effect of varying this ratio. For example, for a 4.1X truncated to 2.6X (8 inches high), changing the beam ratio from 0.85 to 0.78 caused a reduction in performance of about 8 percent. A similar change for a 5.2X truncated to 2.7X (8 inches high) resulted in a decrease in performance of about 9 percent. This phenomenon is simply a result of the method used in the computer model to determine the portion of the diffuse insolation that can be utilized by a CPC.

Performance/Cost Analysis Results

The method used to determine the optimum collector configuration consisted of a two-part analysis: 1) determine the most cost effective reflector system design based on the specified end use condition (location: Des Moines, Iowa; collector outlet temperature: 400°F; year round usage), and 2) determine, on a cost effectiveness basis, the optimum glazing and reflector materials. These analyses are discussed in the following paragraphs.

The reflector system design was selected based on the curves presented in Figures 11, 12, and 13. These curves were generated by combining the collector thermal performance data discussed in the previous paragraphs with the collector cost data shown in Figure 10. These data were based on collector cost only; no provision was made for system costs in this study. Examination of Figures 11, 12, and 13 indicates the following trends.

- There is a definite "peaking out" in cost effectiveness in the 8 to 9-inch truncation height range. This is probably the result of: 1) increased end shading effects as the housing gets deeper and 2) the slope of the reflector at this height being steep enough that a given increase in reflector height costs more in dollars than the additional width provides in performance.

- A comparison of Figures 11 and 12 shows that an increase in reflector error from 1 to 2 degrees causes a much greater decrease in performance for higher concentration ratio collectors than for lower concentration ratio reflectors. Note the comparatively drastic decrease in performance for both the 4.7X and 5.2X designs. This comparison indicates that there is a significant amount of collector annual gain occurring when the projected angle of the sun is in the 10 to 12-degree range. The 4.1X, 4.7X and 5.2X designs have acceptance half angles of 14.1, 12.3 and 11.1

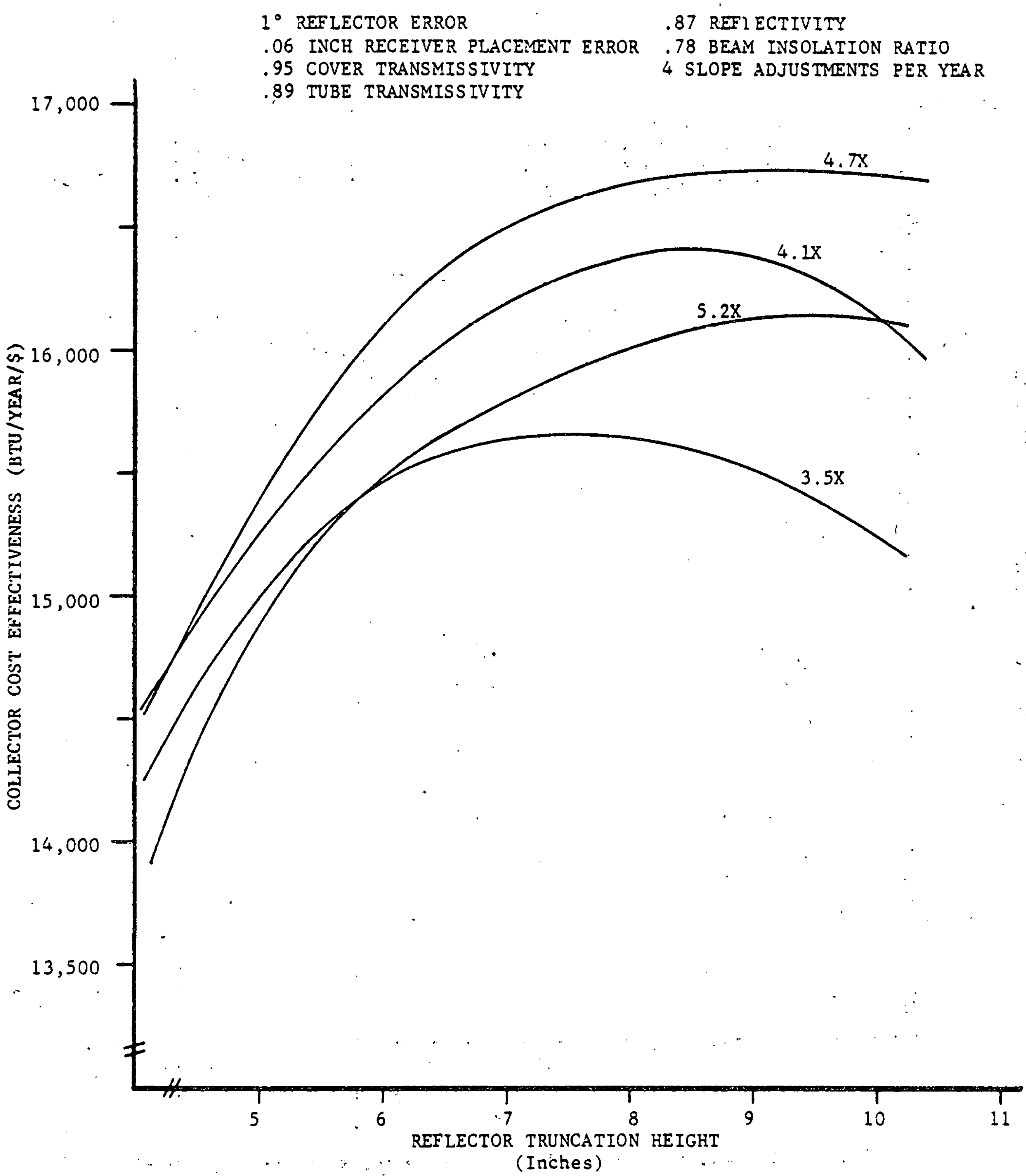


Figure 11. Collector Cost Effectiveness Versus Reflector Truncation Height for Given Design Concentration Ratio

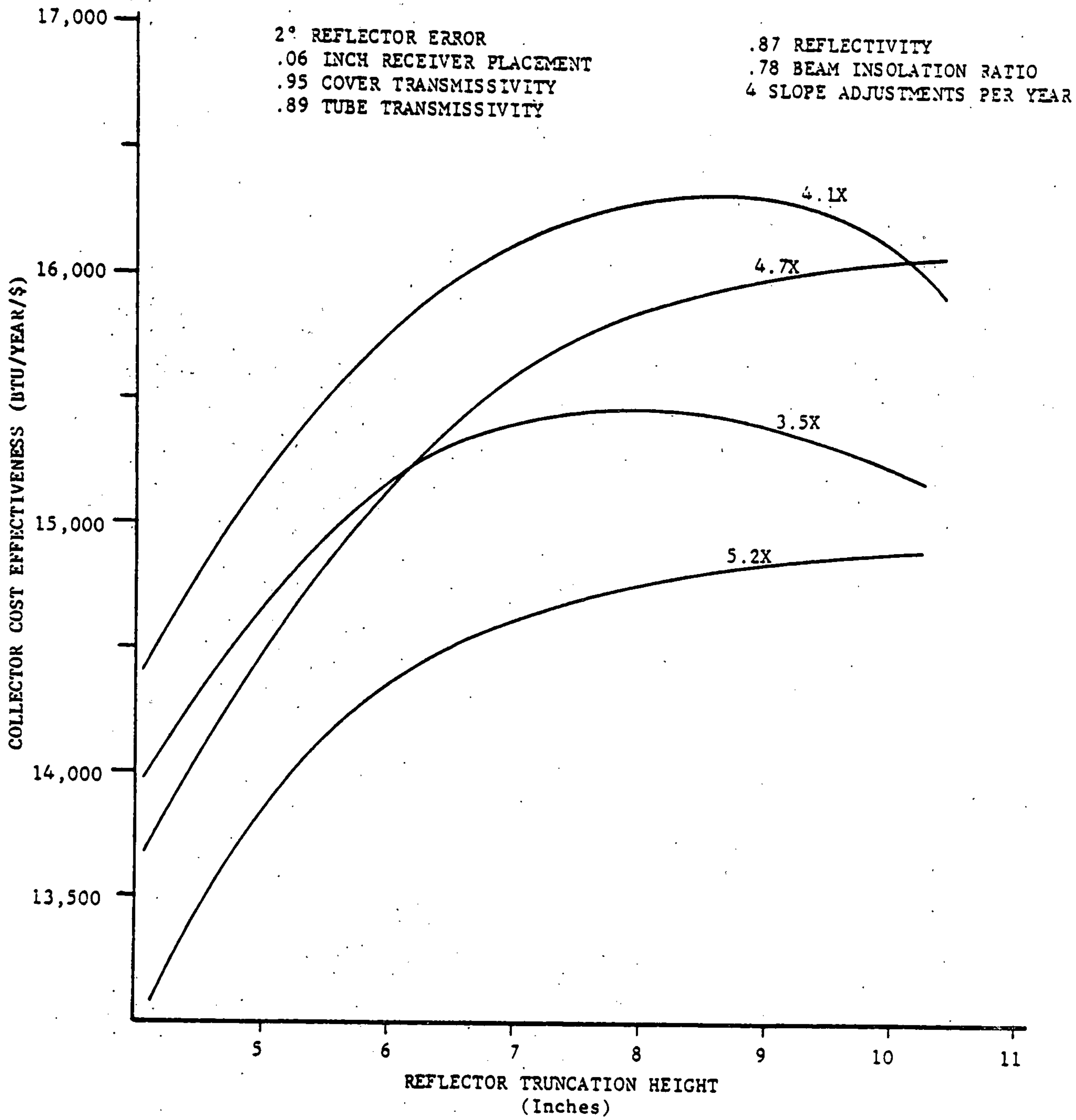


Figure 12. Collector Cost Effectiveness Versus Reflector Truncation Height for Given Design Concentration Ratio

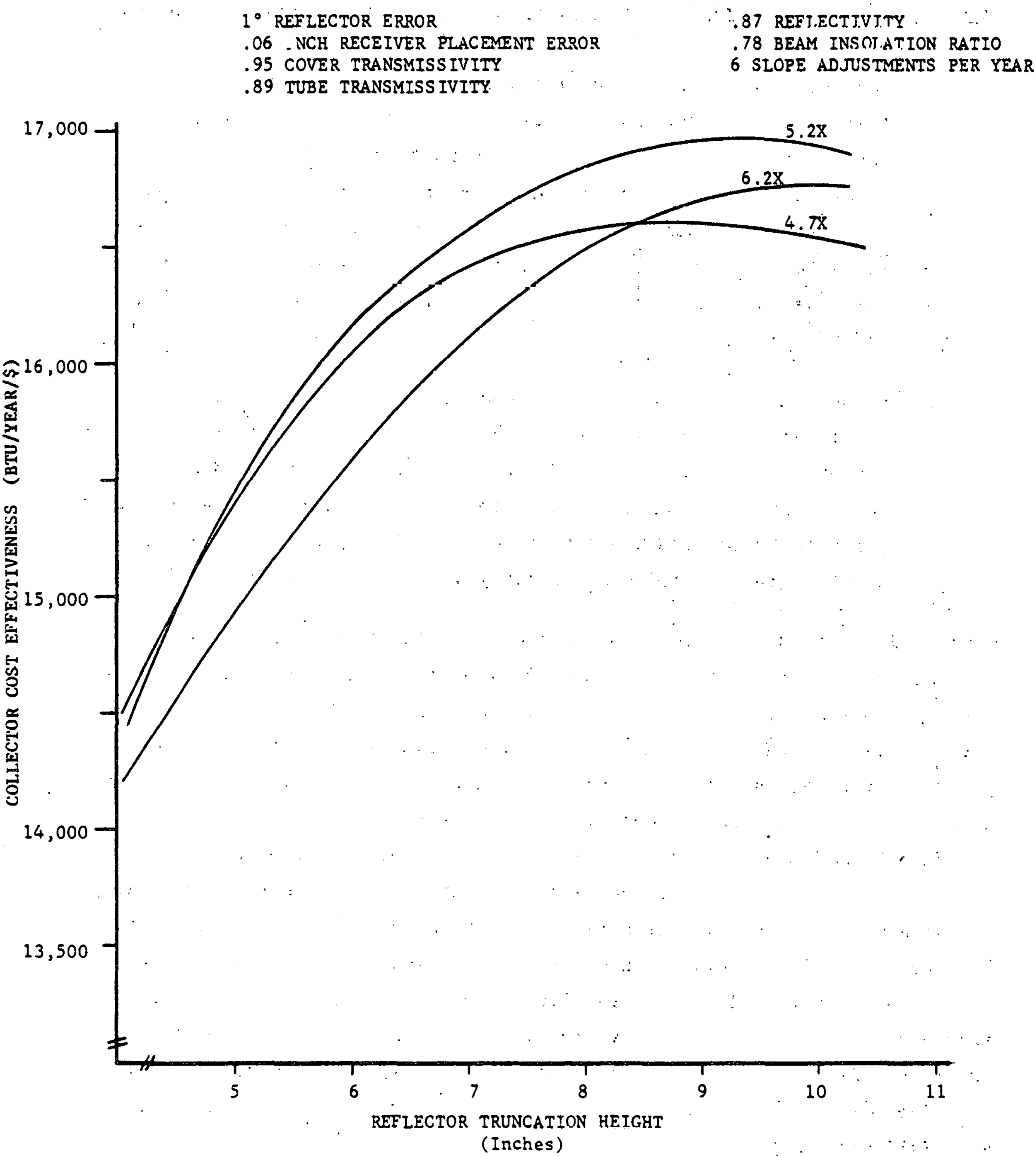


Figure 13. Collector Cost Effectiveness Versus Reflector Truncation Height for Given Design Concentration Ratio

degrees respectively. Manufacturing costs associated with maintaining a high degree of accuracy in the reflector shape may be excessively high, but this factor cannot be determined until hardware is actually built under mass production methods. The error effect evident in these figures, however, strongly influenced Chamberlain's decision to use the 4.1X rather than the 4.7X which had a slightly higher cost effectiveness index with the 1-degree reflector error.

- Figure 13 shows cost effectiveness data assuming six adjustments of collector slope each year. The 5.2X, in this case, is 2.7 percent better than the 4.1X with four adjustments per year. The performance data for a 2-degree reflector error for six adjustments per year would probably result in the effect being the same as it was for the four adjustments per year as discussed above.

Company investigators decided to use the 4.1X with four slope adjustments per year rather than the other "best" design, a 5.2X with six slope adjustments because a cost effectiveness increase of only 2.7 percent did not seem to justify the requirement for two additional slope adjustments each year. Cost effectiveness data indicated that, in either case, a truncation height of 8 to 9 inches was optimal, and the actual calculated concentration of the 5.2X and the 4.1X at a height of 8 inches was nearly the same, 2.7X and 2.6X respectively. This fact indicated that thermal performance would depend almost entirely on the optical efficiency of the two concentrators. The average daily collection time for the 4.1X and 5.2X over the year was nearly equal, 8.76 and 8.60 hours (Reference 9) respectively, so neither item had an advantage. The fact that the 4.1X could tolerate a greater error in reflector accuracy before showing significant performance degradation implied that it would be a better performer under real manufacturing and field use conditions.

Determining the optimum glazing material was a straightforward procedure once the reflector system, and thus the collector physical size and cost, were fairly well prescribed. As discussed in Section 5, analysts chose glass as the cover material. The question then became one of selecting among three options:

1) Low iron content glass at $0.70 per square foot.

2) Waterwhite glass which has no iron content at $1.11 per square foot.

3) Low iron glass with an antireflective treatment at $0.70 + $0.40 = $1.10 per square foot.

The transmissivity of each was assumed to be 0.88, 0.91 and 0.93 to 0.95 percent respectively. Obviously, waterwhite glass was not competitive with the low iron with antireflective treatment in terms of transmissivity per dollars invested. As pointed out previously, the performance of the collector increased by about 1.4 percent for each 1-percent increase in transmissivity of the glazing. Then, given a total collector cost of $470 for the 4.1X truncated at 8 inches, one can calculate that the antireflective treatment which will increase the transmissivity by 5 to 7 percent (Reference 3) is worth at least 5 x 1.4% x $470 = $32.90 per collector in increased performance. The collector required 32.2 square feet of glass; therefore, if the cost of the antireflective treatment was less than $1.02 per square foot, it would be cost effective. The process cost was, in fact, $0.40 to $0.50 per square foot (Reference 3) plus shipping charges. This option was obviously cost effective, and Chamberlain selected 3/16-inch thick Lo-Iron tempered glass from ASG Industries, Kingsport, Tennessee, and had it surface treated by NorEll, Inc., St. Paul, Minnesota to reduce reflection losses.

The same type of reasoning as used above was applied to the selection of reflector material. Collector performance was increased by about 1.65 percent for each 1-percent increase in reflectivity. At the projected cost of $470 per collector, each increase of 1 percent in reflectivity was worth $7.75 in collector cost. There are 48 square feet of reflector material used for production of the collector. Each increase of 1 percent in reflectivity was worth $0.16 per square foot of reflector material. As discussed in Section 3.1, two competitive products, King-Lux and Coilzak, have reflectivities of 0.874 and 0.80 and cost $1.45 and $0.74 respectively. The 7.4-percent difference in reflectivity was worth $1.18 per square foot of material, and King-Lux was chosen as most cost effective.

This analysis is considered to have adequately defined the optimum collector configuration. Investigators realize that a more accurate analysis on an absolute scale, using real weather data entering actual insolation diffuse and beam components which are available on the NOAA weather tapes and hourly ambient temperatures, could have been done. However, the time and cost required for such an analysis were prohibitive. Chamberlain modified the model to use NOAA tapes to calculate predicted annual gain under real hourly weather conditions and recorded the results in Section 12.

11. PRODUCTION OF PROTOTYPE COLLECTORS

Ten prototype collectors were built at the Chamberlain Research and Development Division. Six of these collectors were sent to the Contracting Officer at Albuquerque, New Mexico. Three of these six had previously been sent to General Electric Company in Valley Forge, Pennsylvania for thermal performance verification testing. One of the remaining four units was sent to Argonne National Laboratory in Argonne, Illinois for test purposes. One unit was retained at Chamberlain for future product development work, and two units were used for preliminary prototype assembly.

The purpose of this effort was two-fold: 1) to build enough collectors to make future production problems more visible and 2) to have collectors on hand to provide for any test needs that might have occurred.

The collector component production and assembly required more shop time than should have been necessary due to: 1) limited amounts of production tooling available and 2) problems with the reflector roll form tooling and the production of the fin/tube assemblies at General Electric.

Figure 14 shows the process sequence involved in the assembly of the collector. The chart is self-explanatory, and the entire assembly process is defined from housing assembly through packing for shipping.

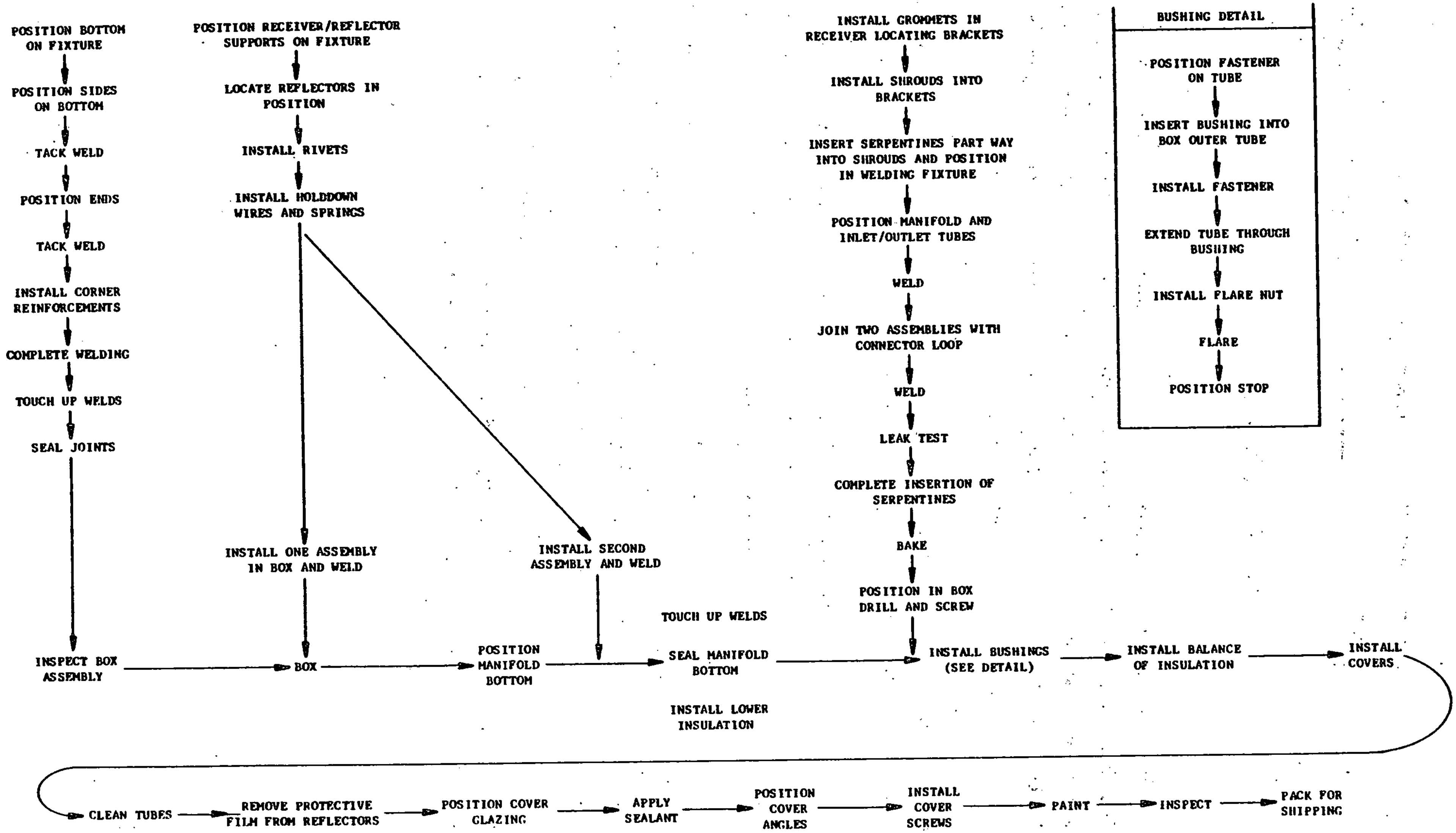


Figure 14. Assembly Procedure - Process Flow

12. PREDICTED COLLECTOR PERFORMANCE

Chamberlain modified the computer model described in Section 10 to predict collector performance in terms of annual heat gain and instantaneous performance. Annual thermal performance under real hourly weather conditions was calculated for end use application in Des Moines, Iowa. The model is discussed and calculation procedures shown in the following paragraphs. Collector instantaneous efficiency versus inlet temperature is analyzed for three different insolation levels, and the analytical procedure is defined.

12.1 Performance Predictions on an Annual Basis

The purpose of this task was to predict, on an annual basis, thermal performance in terms of total collector heat gain under real time and weather conditions. The model discussed in Section 10 was modified to use hourly weather data (direct insolation, diffuse insolation, ambient temperature) available from the National Oceanic and Atmosphere Administration (NOAA). Performance predictions were based on the purpose defined for the selected collector design, which was to supply 400°F fluid for heating and air conditioning the State Capitol Complex at Des Moines, Iowa with a year-round energy requirement. The annual heat gain predicted for the collector under these conditions was 181,436 BTU/yr-ft^2, or in terms of total energy gained per collector, 4,767,600 BTU/yr-collector. Figure 15 is a copy of the computer model output which shows the heat gain per square foot of aperture by the month for an entire year.

The annual calculations assume that the collector slope angle is varied four times a year as shown below.

23 February - 19 April: Slope = 41-1/2° off horizontal
20 April - 22 August: Slope = 19-1/2° off horizontal
23 August - 18 October: Slope 41-1/2° off horizontal
19 October - 22 February: Slope = 63-1/2° off horizontal

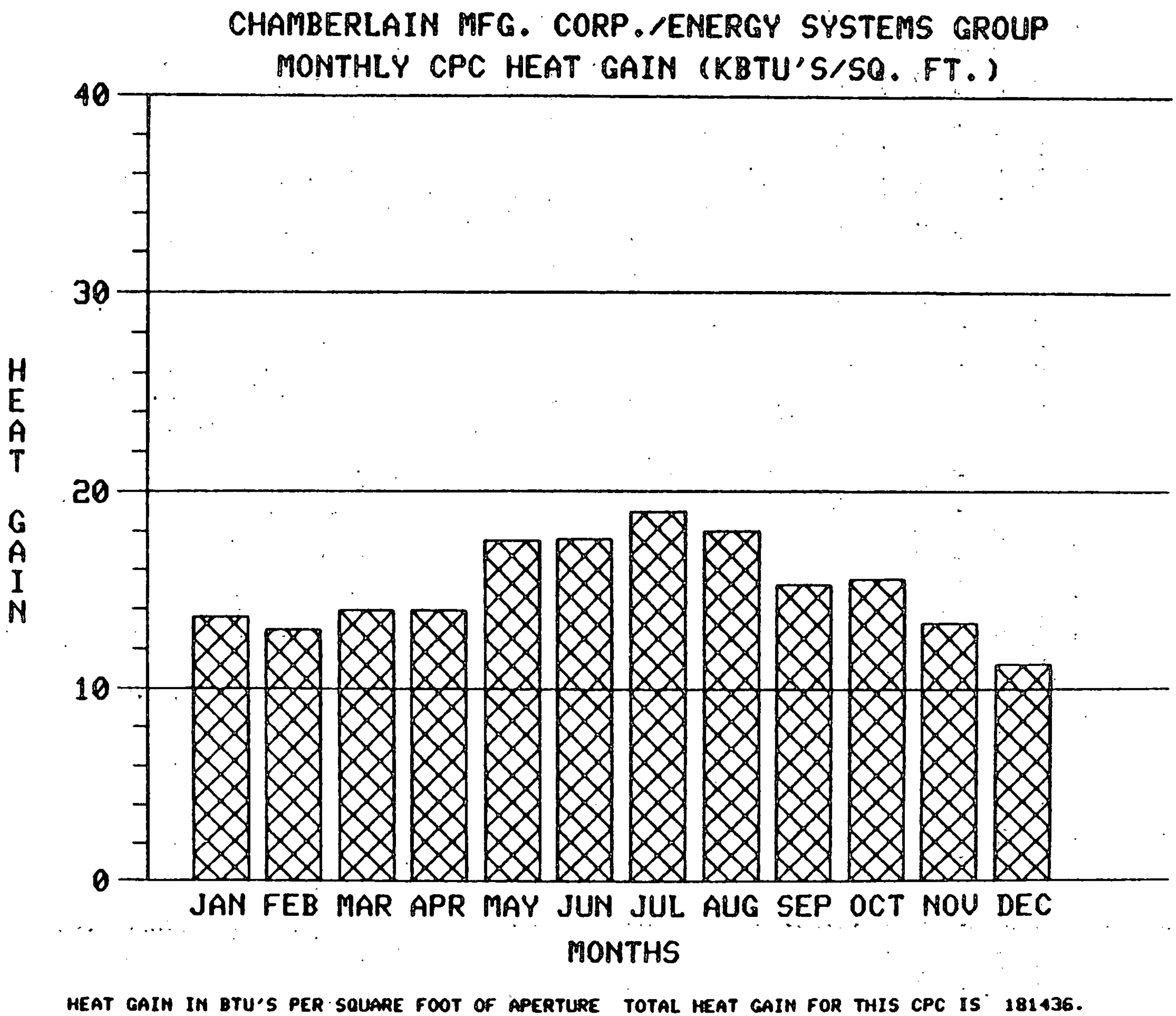


Figure 15. Predicted Annual Heat Gain for Average Hourly Weather Conditions, Des Moines, Iowa

The heat gain model used in this study was the same as the model discussed in Section 10 with some modifications as discussed below. The following values were used for calculating annual gain under real weather conditions.

τ_1 - cover transmissivity = .94

τ_2 - receiver tube transmissivity = .91

α - absorptivity of receiver = .89

ρ - reflectivity of reflector = .87

Manufacturing assembly errors were imposed on the model. An error of 0.06 inch in lateral displacement of the receiver and a 1-degree error in reflector surface accuracy was used in heat gain calculations.

Analysts used the hourly weather data tape for a typical Omaha, Nebraska meteorological year because no data of this type were available for Des Moines. The Omaha data matched Des Moines weather because: 1) Omaha is located 120 miles west and 20 miles south of Des Moines, 2) all other cities for which hourly data were available are substantially further from Des Moines and have different weather patterns, and 3) examination of NOAA meteorological data for the two cities indicated that their insolation and temperature conditions are comparable. Tables 7 and 8 are copies of typical weather data collected during previous years for the two cities as furnished by NOAA. Average monthly and annual temperatures were quite close, Omaha having an ambient temperature 2 or 3 degrees above Des Moines' ambient temperature. The only comparison available for relative insolation conditions are "Percent of possible sunshine" and "Mean sky cover, tenths, sunrise to sunset." Examination of these data indicated that the Omaha region consistently has about one to four percent more insolation than the Des Moines area. Because of close geographical proximity and common weather characteristics, investigators considered the Omaha data useful for predicting performance on an annual basis in the Des Moines area.

TABLE 7. NOAA WEATHER DATA FOR DES MOINES, IOWA

Meteorological Data For The Current Year

Station: DES MOINES, IOWA # 14933 MUNICIPAL AIRPORT Standard time used: CENTRAL Latitude 41° 32' N Longitude 93° 39' W Elevation (ground) 938 feet Year 1976

Month	Temperature °F Averages: Daily maximum	Daily minimum	Monthly	Extremes: Highest	Date	Lowest	Date	Degree days Base 65 °F: Heating	Cooling	Precipitation in inches, Water equivalent: Total	Greatest in 24 hrs	Date	Snow, Ice pellets: Total	Greatest in 24 hrs.	Date
JAN	34.2	11.5	22.9	56	23	-10	8	1297	0	0.23	0.20	25	2.4	2.0	25
FEB	44.3	23.9	34.1	62	27	6	4	890	0	2.43	1.60	20-21	11.8	10.5	20-21
MAR	49.2	30.1	39.7	78	19	14	6	780	0	3.04	1.26	4	0.9	0.9	4
APR	66.7	46.6	55.4	82	14	31	12	302	19	7.76	3.08	17-18	0.0	0.0	
MAY	71.6	49.8	60.7	88	20	33	3	160	36	2.84	1.27	16	T	T	2
JUN	82.1	60.6	71.4	91	13	52	19	4	203	7.25	3.00	27-28	0.0	0.0	
JUL	87.1	67.3	77.2	97	9	55	17	0	385	1.87	0.98	21-22	0.0	0.0	
AUG	84.8	62.7	73.8	95	26	51	7	1	283	2.26	1.42	11	0.0	0.0	
SEP	77.4	54.0	65.7	91	7	44	30	76	104	1.00	0.44	19	0.0	0.0	
OCT	59.7	37.3	48.5	92	1	21	22	527	20	1.11	0.54	4-5	T	T	19
NOV	43.5	21.7	32.6	71	18	-1	30	964	0	0.10	0.09	26-27	1.1	0.8	26-27
† DEC	33.3	10.3	21.8	64	18	-12	31	1333	0	0.12	0.03	28	2.8	0.8	5
YEAR	61.1	39.5	50.3	97	JUL 9	-12	DEC 31	6334	1050	30.01	3.08	APR 17-18	19.0	10.5	FEB 20-21

Month	Relative humidity, pct. (Local time) Hour 00	Hour 06	Hour 12	Hour 18	Wind Resultant: Direction	Speed m.p.h.	Average speed m.p.h.	Fastest mile: Speed m.p.h.	Direction	Date	Percent of possible sunshine	Average sky cover, tenths, sunrise to sunset	Number of days, Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog, visibility ¼ mile or less	Temperature °F Maximum (b): 90° and above	32° and below	Minimum: 32° and below	0° and below	Average station pressure mb, Elev. 963 feet m.s.l.
JAN	66	70	52	58	29	5.5	13.6	35	NW	15	62	5.5	9	11	11	2	1	0	1	0	9	31	7	984.4
FEB	71	73	55	57	31	2.4	12.4	38	NE	20	64	6.3	7	8	14	8	2	3	2	0	5	22	0	980.0
MAR	67	70	55	54	28	2.4	13.3	40	NW	12	58	7.1	8	4	19	7	0	1	2	0	2	19	0	978.0
APR	68	75	53	48	13	2.8	11.4	34	S	16	64	5.8	8	12	10	8	0	6	0	0	0	2	0	981.7
MAY	61	70	45	44	33	0.2	10.4	38	SW	5	65	6.2	8	9	14	8	0	4	0	0	0	0	0	980.4
JUN	65	70	48	44	17	4.4	10.7	46	S	14	78	3.9	13	13	4	9	0	8	0	2	0	0	0	980.4
JUL	68	73	50	51	19	2.2	8.7	31	NW	14	75	5.4	10	10	11	7	0	8	0	10	0	0	0	981.4
AUG	68	75	50	51	15	4.5	8.9	34	W	13	72	4.8	13	8	10	4	0	4	0	8	0	0	0	984.1
SEP	65	73	46	45	13	1.1	8.6	33	SW	6	70	5.2	11	8	11	6	0	4	0	2	0	0	0	983.1
OCT	64	73	47	50	31	1.2	8.9	34	SW	14	59	5.7	12	5	14	8	0	0	0	1	0	11	0	984.1
NOV	60	65	43	47	29	5.6	10.8	29	NW	9	71	5.1	8	16	6	3	0	0	0	0	7	26	3	984.4
† DEC	64	67	52	58	28	4.0	10.9	31	N	19	63	5.9	7	13	11	5	0	0	0	0	17	31	7	982.7
YEAR	66	71	50	51	25	1.3	10.7	46	S	JUN 14	67	5.6	114	117	135	75	3	38	5	23	40	142	17	982.1

† DATA CORRECTED AFTER PUBLICATION OF THE MONTHLY ISSUE.

Normals, Means, And Extremes

Month	Temperatures °F Normal: Daily maximum	Daily minimum	Monthly	Extremes: Record highest	Year	Record lowest	Year	Normal Degree days Base 65 °F: Heating	Cooling	Precipitation in inches, Water equivalent: Normal	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year
(a)				37		37					37		37		37	
J	27.5	11.3	19.4	62	1967	-24	1970	1414	0	1.14	4.39	1960	0.07	1954	2.97	1960
F	32.5	15.8	24.2	73	1972	-20	1958	1142	0	1.05	2.99	1951	0.13	1968	1.77	1961
M	42.5	25.2	33.9	83	1968	-22	1962	964	0	2.31	5.37	1961	0.41	1971	2.42	1945
A	59.7	39.2	49.5	90	1970	9	1975	465	0	2.94	7.76	1976	1.05	1942	3.80	1974
M	70.9	50.9	60.9	98	1967	30	1967	186	59	4.21	7.53	1950	1.23	1949	2.79	1954
J	79.8	61.1	70.5	100	1956	38	1945	26	191	4.90	14.19	1947	1.13	1963	5.50	1947
J	84.9	65.3	75.1	105	1955	47	1971	0	317	3.28	10.51	1958	0.04	1975	5.14	1958
A	83.2	63.4	73.3	102	1954	40	1950	13	270	3.30	10.47	1954	0.71	1953	6.18	1975
S	74.6	54.0	64.3	101	1939	26	1942	94	73	3.07	10.19	1961	0.41	1950	4.47	1961
O	64.9	43.6	54.3	95	1963	14	1972	350	18	2.14	7.29	1941	0.03	1952	2.81	1947
N	46.4	29.2	37.8	76	1965	-3	1964	816	0	1.42	4.60	1952	0.03	1969	3.35	1952
D	32.8	17.2	25.0	69	1946	-16	1963	1240	0	1.09	2.90	1941	0.12	1976	1.46	1973
YR	58.3	39.7	49.0	105	JUL 1955	-24	JAN 1970	6710	928	30.85	14.19	JUN 1947	0.03	NOV 1969	6.18	AUG 1975

Month	Snow, Ice pellets: Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity pct. (Local time) Hour 00	Hour 06	Hour 12	Hour 18	Wind: Mean speed m.p.h.	Prevailing direction	Fastest mile: Speed m.p.h.	Direction	Year	Pct. of possible sunshine	Mean sky cover, tenths, sunrise to sunset	Mean number of days, Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog, visibility ¼ mile or less	Temperatures °F Max. (b): 90° and above	32° and below	Min.: 32° and below	0° and below	Average station pressure mb. Elev. 963 feet m.s.l.
(a)	37		37		15	15	15	15	27	19	26	26		26	27	27	27	27	37	37	37	27	15	15	15	15	4
J	19.8	1942	19.8	1942	76	77	70	71	11.7	NW	66	NW	1953	51	6.6	8	7	16	7	2	*	2	0	18	30	9	985.7
F	21.3	1962	12.1	1950	78	80	68	68	11.8	NW	56	W	1952	54	6.4	8	5	15	7	2	*	2	0	14	27	4	982.2
M	18.8	1948	8.5	1957	74	79	63	61	13.1	NW	66	S	1953	54	6.9	6	8	17	10	2	2	2	0	6	22	*	978.9
A	15.1	1973	10.4	1973	71	79	57	54	13.3	NW	76	W	1965	55	6.7	7	7	15	10	*	4	1	*	*	7	0	979.5
M	0.2	1944	0.2	1944	71	79	56	53	11.6	SE	70	W	1955	60	6.5	7	9	15	11	0	7	1	1	0	*	0	977.9
J	0.0		0.0		74	81	57	55	10.5	S	76	NW	1953	67	5.9	8	11	11	11	0	10	1	4	0	0	0	978.5
J	0.0		0.0		75	81	56	56	9.0	S	73	W	1968	71	5.3	10	12	9	9	0	8	1	9	0	0	0	981.0
A	0.0		0.0		78	84	57	57	8.8	S	60	SSE	1960	70	5.2	11	10	10	9	0	7	1	6	0	0	0	982.3
S	T	1942	T	1942	79	85	60	61	9.6	S	55	NW	1953	64	5.3	12	6	12	9	0	5	1	1	0	*	0	983.5
O	2.4	1967	2.4	1967	71	79	54	56	10.5	S	56	W	1952	64	5.1	12	7	12	7	*	3	1	*	0	5	0	983.6
N	13.5	1968	11.8	1968	75	79	64	66	11.7	NW	72	W	1952	50	6.5	7	8	15	6	1	1	2	0	3	19	*	982.4
D	23.9	1961	11.0	1961	78	80	71	72	11.5	NW	61	SW	1951	45	6.9	7	6	18	7	2	*	3	0	15	29	3	982.8
YR	23.9	DEC 1961	19.8	JAN 1942	75	80	61	61	11.1	NW	76	W	APR 1965	60	6.1	103	96	166	106	10	50	17	21	56	137	16	981.5

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 110 in July 1936 and earlier; lowest temperature -30 in January 1884; maximum monthly precipitation 15.79 in June 1881; maximum monthly snowfall 37.0 in January 1886.

(a) Length of record, years, through the current year unless otherwise noted, based on January data.
(b) 70° and above at Alaskan stations.
* Less than one half.
T Trace.

NORMALS - Based on record for the 1941-1970 period.
DATE OF AN EXTREME - The most recent in cases of multiple occurrence.
PREVAILING WIND DIRECTION - Record through 1963.
WIND DIRECTION - Numerals indicate tens of degrees clockwise from true north. 00 indicates calm.
FASTEST MILE WIND - Speed is fastest observed 1-minute value when the direction is in tens of degrees.

TABLE 8. NOAA WEATHER DATA FOR OMAHA, NEBRASKA

Meteorological Data For The Current Year

Station: OMAHA, NEBRASKA # 14942 EPPLEY AIRFIELD Standard time used: CENTRAL Latitude: 41° 19' N Longitude: 95° 54' W Elevation (ground): 977 feet Year: 1976

Month	Temperature °F: Averages: Daily maximum	Daily minimum	Monthly	Extremes: Highest	Date	Lowest	Date	Degree days Base 65 °F: Heating	Cooling	Precipitation in inches: Water equivalent: Total	Greatest in 24 hrs.	Date	Snow, Ice pellets: Total	Greatest in 24 hrs.	Date
JAN	38.0	12.9	25.5	60	23	-11	7	1219	0	0.11	0.05	30	1.8	1.0	30
FEB	49.8	25.1	37.5	75	27	7	6	791	0	1.39	0.43	16	7.1	4.1	1-2
MAR	52.1	28.6	40.4	85	19	10	5	757	0	2.13	1.10	29-30	4.2	3.9	4
APR	69.1	44.5	56.8	87	14	26	1	261	21	2.98	0.79	23-24	0.0	0.0	
MAY	74.0	46.3	60.2	89	20	27	3	177	34	3.55	1.69	22-23	0.0	0.0	
† JUN	86.4	58.9	72.7	100	11	47	19	4	240	2.84	1.08	26-27	0.0	0.0	
JUL	90.9	67.0	79.0	103	9	52	5	0	440	1.52	0.92	26-27	0.0	0.0	
AUG	90.1	62.5	76.3	101	26	48	28	0	358	0.62	0.45	14	0.0	0.0	
SEP	80.6	54.2	67.4	97	3	39	29	61	139	1.64	0.73	24-25	0.0	0.0	
OCT	61.7	35.3	48.5	94	1	18	17	522	17	1.35	0.63	3-4	1.4	1.4	18
NOV	46.6	19.9	33.3	72	18	-4	28	947	0	0.03	0.02	30	0.5	0.4	30
DEC	37.7	10.4	24.1	69	18	-15	30	1265	0	0.21	0.12	5-6	2.8	1.3	7
YEAR	64.8	38.8	51.8	103	JUL 9	-15	DEC 30	6004	1249	18.37	1.69	MAY 22-23	17.8	4.1	FEB 1-2

Month	Relative humidity, pct.: Hour 00 (Local time)	Hour 06	Hour 12	Hour 18	Wind: Resultant: Direction	Resultant: Speed m.p.h.	Average speed m.p.h.	Fastest mile: Speed m.p.h.	Direction	Date	Percent of possible sunshine	Average sky cover, tenths, sunrise to sunset	Number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog, visibility ¼ mile or less	Temperature °F: Maximum: (b) 90° and above	Maximum: 32° and below	Minimum: 32° and below	Minimum: 0° and below	Average station pressure mb: Elev. 982 feet m.s.l.
JAN	70	74	56	58	31	4.1	11.2	34	NW	19	71	5.5	11	9	11	4	1	0	0	0	10	31	4	984.1
FEB	75	74	53	57	35	2.3	10.5	41	N	21	62	6.0	9	8	12	6	2	3	1	0	4	22	0	979.3
MAR	70	75	57	54	33	2.1	11.5	41	S	23	56	6.6	8	5	18	7	1	3	1	0	3	21	0	977.3
APR	69	77	52	48	15	2.8	11.2	58	S	16	58	6.1	10	5	15	9	0	6	0	0	0	2	0	980.4
MAY	73	80	50	48	07	1.2	9.9	35	NW	2	68	5.7	10	8	13	7	0	4	1	0	0	2	0	979.3
† JUN	73	78	49	48	17	5.1	11.2	34	NW	26	75	4.2	11	16	3	8	0	8	1	10	0	0	0	978.3
JUL	75	81	53	52	16	4.0	9.2	34	N	15	59	5.7	8	10	13	6	0	6	0	17	0	0	0	980.0
AUG	76	83	51	49	15	5.5	9.4	33	NW	14	70	4.8	12	11	8	5	0	7	0	18	0	0	0	982.1
SEP	71	79	52	50	13	2.4	10.0	26	NW	26	71	5.1	13	6	11	8	0	4	1	10	0	0	0	982.1
OCT	80	85	52	54	35	1.8	9.4	30	NW	15	60	5.6	10	8	13	7	1	3	0	[illegible]	0	11	0	983.7
NOV	71	77	47	50	32	3.7	9.8	32	NW	26	66	4.2	12	11	7	2	0	0	0	0	5	26	3	985.1
DEC	75	81	59	63	31	2.3	8.9	34	NW	19	60	5.3	11	8	12	4	2	0	0	0	14	31	8	982.7
YEAR	73	79	53	53	18	0.4	10.2	58	S	APR 16	65	5.4	125	105	136	73	7	44	5	57	36	146	15	981.2

† DATA CORRECTED AFTER PUBLICATION OF THE MONTHLY ISSUE.

Normals, Means, And Extremes

Month	Temperatures °F: Normal: Daily maximum	Daily minimum	Monthly	Extremes: Record highest	Year	Record lowest	Year	Normal Degree days Base 65 °F: Heating	Cooling	Precipitation in inches: Water equivalent: Normal	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Snow, Ice pellets: Maximum monthly	Year	Maximum in 24 hrs.	Year
(a)				41		41					41		41		41		41		41	
J	32.7	12.4	22.6	69	1944	-22	1974	1314	0	0.76	3.70	1949	0.05	1943	1.52	1967	25.7	1936	13.1	1949
F	38.5	17.4	28.0	78	1972	-19	1975	1036	0	0.98	2.97	1965	0.10	1968	2.24	1954	25.4	1965	18.3	1965
M	47.7	26.4	37.1	89	1968	-16	1948	865	0	1.59	5.96	1973	0.12	1956	1.45	1959	27.2	1948	13.0	1948
A	64.4	40.1	52.3	93	1965	5	1975	391	10	2.97	6.45	1951	0.23	1936	2.56	1938	8.6	1945	8.6	1945
M	74.4	51.5	63.0	99	1939	27	1976	148	86	4.11	10.33	1959	0.56	1948	3.58	1964	2.0	1945	2.0	1945
J	83.1	61.3	72.2	105	1953	39	1945	20	236	4.94	10.81	1947	1.03	1972	3.48	1942	0.0		0.0	
J	88.6	65.8	77.2	114	1936	44	1972	0	378	3.71	9.60	1958	0.46	1975	3.37	1958	0.0		0.0	
A	87.2	64.0	75.6	110	1936	43	1967	6	334	3.97	9.12	1959	0.62	1976	3.40	1959	0.0		0.0	
S	78.6	54.0	66.3	104	1939	30	1942	71	110	3.27	13.75	1965	0.41	1953	6.47	1965	T	1961	T	1961
O	69.1	42.6	55.9	96	1938	13	1972	301	19	1.93	4.99	1961	T	1952	3.13	1968	7.2	1941	7.2	1941
N	50.9	29.1	40.0	80	1964	-9	1964	750	0	1.11	4.05	1948	0.03	1976	2.53	1948	12.0	1957	8.7	1957
D	37.8	18.1	28.0	72	1939	-15	1976	1147	0	0.84	3.30	1941	T	1943	1.79	1941	19.9	1969	10.2	1969
YR	62.8	40.2	51.5	114	JUL 1936	-22	JAN 1974	6049	1173	30.18	13.75	SEP 1965	T	OCT 1952	6.47	SEP 1965	27.2	MAR 1948	18.3	FEB 1965

Month	Relative humidity pct.: Hour 00 (Local time)	Hour 06	Hour 12	Hour 18	Wind: Mean speed m.p.h.	Prevailing direction	Fastest mile: Speed m.p.h.	Direction	Year	Pct. of possible sunshine	Mean sky cover, tenths, sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog, visibility ¼ mile or less	Temperatures °F: Max.: (b) 90° and above	Max.: 32° and below	Min.: 32° and below	Min.: 0° and below	Average station pressure mb.: Elev. 982 feet m.s.l.
(a)	13	13	13	13	41	15	41	41		41	41	41	41	41	41	41	41	41	13	13	13	13	4
J	74	76	65	67	11.1	NNW	57	NW	1938	55	6.1	9	8	14	7	2	*	2	0	14	30	8	982.7
F	74	76	61	62	11.5	NNW	57	NW	1947	55	6.3	7	8	13	7	2	*	2	0	9	26	2	981.6
M	71	76	57	54	12.7	NNW	73	NW	1950	55	6.6	7	8	16	9	2	1	1	0	4	21	*	977.7
A	68	76	53	48	13.2	NNW	65	NW	1937	58	6.3	7	9	14	9	*	4	1	*	*	5	0	978.2
M	71	79	54	50	11.4	SSE	73	NW	1936	62	6.2	7	10	14	12	*	8	1	2	0	*	0	977.0
J	75	81	55	52	10.6	SSE	72	N	1942	68	5.6	8	12	10	11	0	10	*	8	0	0	0	977.1
J	77	82	56	54	9.1	SSE	109	N	1936	75	4.8	12	12	7	9	0	8	1	14	0	0	0	979.8
A	79	86	58	57	9.2	SSE	66	N	1944	72	4.7	13	10	8	9	0	8	1	10	0	0	*	980.5
S	82	87	61	60	9.7	SSE	47	E	1948	67	4.8	13	7	10	8	0	5	1	3	0	*	0	982.2
O	76	82	54	56	10.1	SSE	62	NW	1966	67	4.7	13	8	10	6	*	3	1	*	0	6	0	982.4
N	77	81	62	65	11.2	SSE	56	NW	1951	52	6.0	9	7	14	5	1	1	2	0	2	20	*	982.0
D	78	80	67	71	10.8	SSE	52	NW	1938	49	6.4	8	8	15	6	2	*	2	0	11	29	2	982.1
YR	75	80	59	58	10.9	SSE	109	N	JUL 1936	62	5.7	113	107	145	99	9	48	15	38	40	138	13	980.3

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Lowest temperature -32 in January 1884; maximum precipitation in 24 hours 7.03 in August 1903; maximum monthly snowfall 29.2 in March 1912.

(a) Length of record, years, through the current year unless otherwise noted, based on January data.
(b) 70° and above at Alaskan stations.
* Less than one half.
T Trace.

NORMALS - Based on record for the 1941-1970 period.
DATE OF AN EXTREME - The most recent in cases of multiple occurrence.
PREVAILING WIND DIRECTION - Record through 1963.
WIND DIRECTION - Numerals indicate tens of degrees clockwise from true north. 00 indicates calm.
FASTEST MILE WIND - Speed is fastest observed 1-minute value when the direction is in tens of degrees.

In modifying the computer model described in Section 10, Company personnel:

1) adapted the program to use weather data tapes from NOAA to input hourly insolation rates and ambient temperatures;

2) used heat transfer data for the receiver to calculate the average receiver temperature for each hourly condition and thus, more accurately determine the radiation losses off the receiver; and

3) included internal manifold heat losses for the collector in addition to the radiation losses off the receiver for collector heat gain calculations.

The hourly insolation data given in the NOAA weather tapes were used in the following manner.

- Direct beam insolation and total radiation on a horizontal surface (standard year corrected radiation) were read off the data tape.

- Because diffuse data were not available on tape, it was calculated by converting (with standard conversion methods outlined in Reference 10) the direct beam radiation to find the beam component on a horizontal surface. This value was then subtracted from the "standard year corrected radiation" on a horizontal surface to find the diffuse component on a horizontal surface. This diffuse component was then multiplied by (1 + cos (tilt angle))/2 to estimate the amount of diffuse insolation on the south facing collector at the proper tilt angle off horizontal (Reference 10). Ground reflectance was ignored because, in the end use application, the collector array will be located on a south facing hillside which is about 40 degrees off horizontal; therefore, the collectors are approximately parallel to the ground even in the winter months when collector slope is 62 degrees.

- To estimate the amount of the diffuse component that strikes the receiver, the calculated diffuse component was multiplied by the sine of the acceptance half angle for the collector.
- Direct beam radiation was converted to find the beam component incident on the south facing collector for the tilt angle at which the collector is adjusted for that time of the year.

The average receiver temperature was calculated in this model by using the results of the fin/tube development task reported in Section 9. The thermal resistance to the transfer of energy from the absorber to the fluid was assumed to be .35°F-hr/BTU/ft (the foot dimension refers to the length of the receiver), making the temperature of the receiver emitting surface a function of the amount of energy per unit time being transferred to the fluid. The BTU/ft^2-hr gain for the collector was first calculated assuming a receiver temperature of 420°F. The gain determined from the approximation was then used to determine a better estimate of the average receiver temperature using the above resistance for the receiver. The collector outlet temperature was assumed to be 400°F at all times, with an average fluid temperature of 390°F. The average receiver temperature was calculated by multiplying the approximated gain per square foot times the aperture area covered by a 1-foot long segment of receiver times .35°F-hr/BTU and adding 390°F. This receiver temperature was then used to determine radiation losses from the receiver for that hourly condition, and the heat gain was recalculated.

Heat losses from the center internal manifold area were included in this model. As discussed in Section 6, these losses will be approximately 3 BTU/hr-ft^2.

12.2 Instantaneous Performance Predictions

Theoretical instantaneous performance for the collector is shown in Figure 16. Thermal efficiency based on aperture area is presented as a

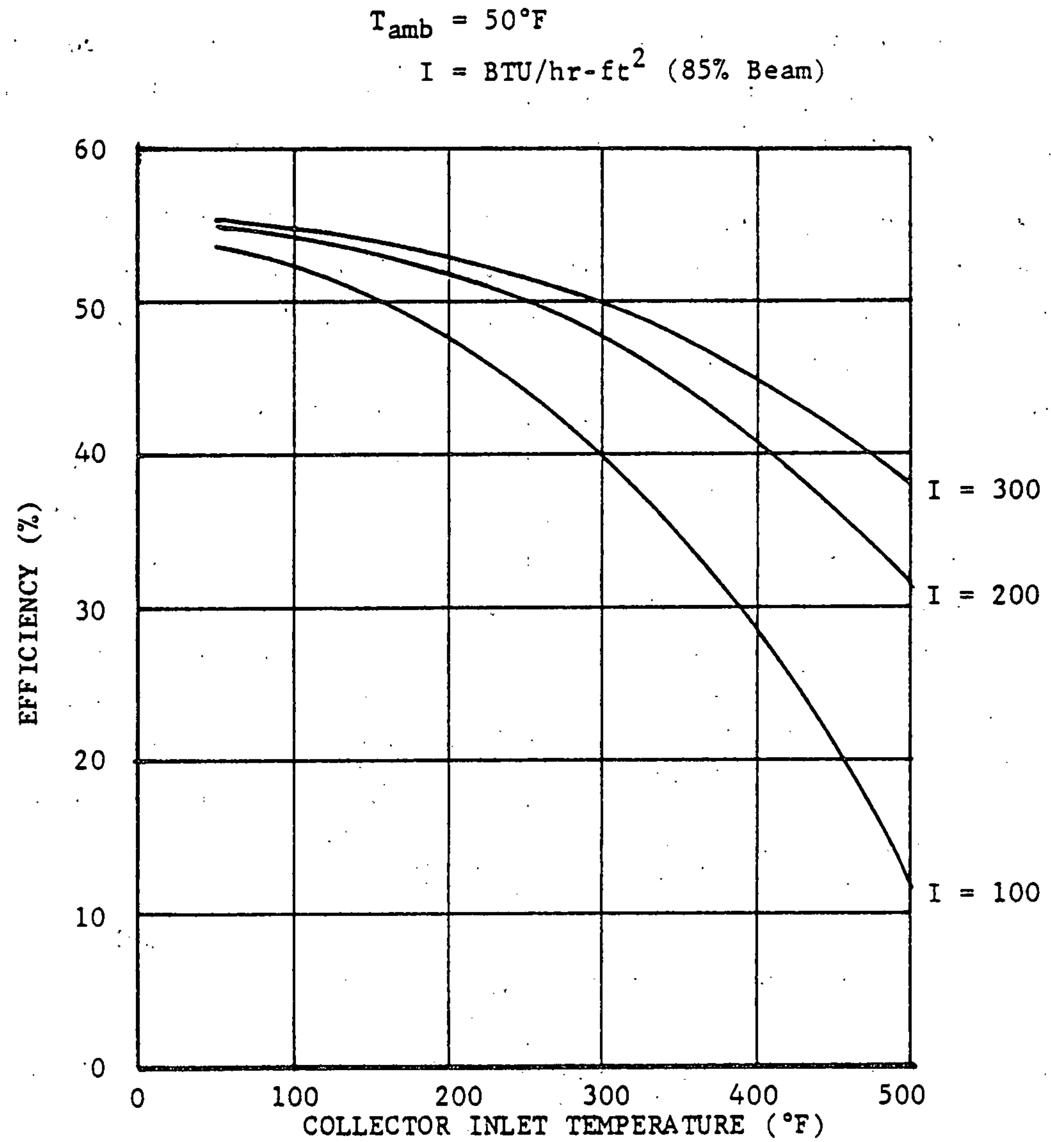


Figure 16. Predicted Collector Instantaneous Efficiency Based on Aperture Area as a Function of Inlet Temperature

function of collector inlet fluid temperature for three insolation levels (100, 200, and 300 BTU/hr-ft^2) with an ambient temperature of 50°F. Insolation is assumed to be 15 percent diffuse and 85 percent beam with an incidence angle of 0 degrees to the collector. The curves were generated by application of the computer model discussed in Sections 10 and 12.1. Because the inlet temperature was varied over a large range of values, analysts defined the hemispherical emissivity of the absorber coating as a function of the operating temperature of the collector. Measured values for the optical coating are shown in Figure 17 as a function of the absorber temperature. The only other modification to the computer model was to vary the temperature difference between ambient and the outer tube of the receiver as a function of the collector operating temperature and the insolation rate. Preliminary calculations indicate that the temperature inside the collector housing, and thus the temperature of the outer receiver tube, can be estimated as a function of the insolation rate. Tube temperature was assumed to be 25, 50 and 75 degrees greater than ambient for insolation rates of 100, 200 and 300 BTU/hr-ft^2, respectively.

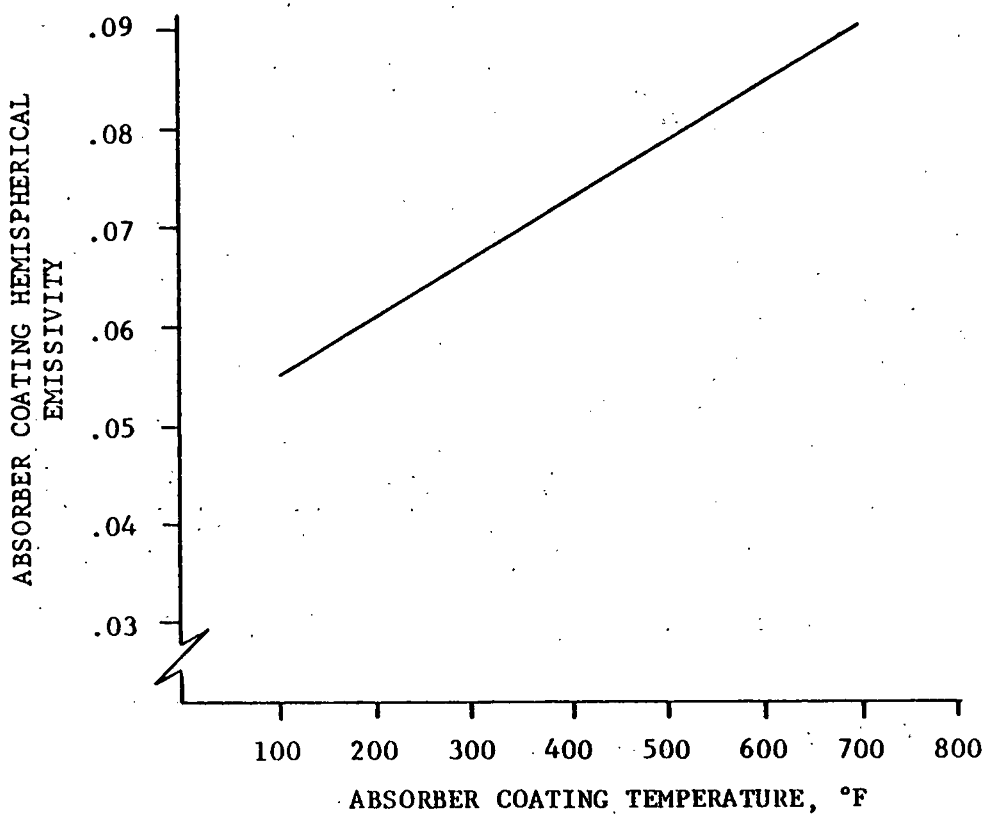


Figure 17. Hemispherical Emissivity of the Absorber Coating on the General Electric Evacuated Shroud

13. PERFORMANCE VERIFICATION

The purpose of this section is to present and discuss thermal performance verification and the receiver thermal resistance tests. Results were used to construct a performance model which is shown to be accurate over the range of test conditions.

Thermal performance tests were conducted to verify predicted collector performance and to establish a credible thermal performance efficiency rating for the collector over a large range of operating conditions. Consistent test results were obtained over a fluid inlet temperature range of 108°F to 363°F with insolation direct ratios varying from 0.68 to 0.84. Tests were also conducted to: 1) establish the thermal resistance of the General Electric evacuated shroud and fin/tube assembly, 2) establish the temperature of the outer glass tube of the receiver, and 3) determine the ability of the collector to withstand repeated exposure to stagnation conditions. Data obtained from these tests enabled investigators to establish a verified thermal performance curve for total insolation values of 300 to 330 BTU/ hr-ft^2. The thermal efficiency established in this test program is shown graphically in Figure 18 in Section 13.2.

Due to cost and schedule overruns caused by both technical problems and weather at the test site, the test series and data reduction were terminated before completion of the planned test series. However, the data obtained is more than adequate to demonstrate the thermal performance characteristics of the collector over a wide range of operating conditions. The above problems also produced available data on only one of the two test collectors, and those data are limited to conditions where the total insolation was above 300 BTU/hr-ft^2.

13.1 Performance Test Plan

Thermal performance tests were conducted in Valley Forge, Pennsylvania by General Electric Company to verify predicted collector performance. Collectors tested in this phase of the program during June 1979 were two of ten produced under the subject contract. Photograph No. 11229, on the following page, shows the collectors as mounted in the test laboratory at General Electric.

The collectors were mounted on a fixed, south facing rack at 17° off horizontal, making them normal to the rays of the sun at solar noon. The collectors were plumbed in series within the test circuit, and 400-psig pressurized water was pumped through them at 0.30 gallons per minute. Inlet and outlet temperatures were monitored with platinum resistance thermometers. Total insolation in the plane of the collector and the insolation direct component were recorded. Data accuracy was as listed below.

Inlet temperature	± 0.5°F
Outlet temperature	± 0.5°F
$T_{out} - T_{in}$	± 0.2°F
Flow Rate	± 0.5 percent
Total insolation	± 2.5 percent
Direct insolation	± 2.5 percent
Ambient air temperature	± 4.0°F

These data were recorded every five minutes from 8 a.m. until 3 p.m. solar time. Table 9 shows the test sequence as defined in the test plan. The goals of the test series were as follows:

- Conduct three tests at near ambient temperature, 100°F, to determine the optical efficiency of the collector under 10, 20 and 30-percent diffuse conditions (Test Nos. 1, 4 and 7).

TABLE 9. PERFORMANCE AND STAGNATION TEST MATRIX

TEST NO.	FLOW RATE (gpm)	INLET TEMPERATURE (°F)	INSOLATION $BTU/hr\text{-}ft^2$	COMMENTS
1	.3	100	320, 10% Diffuse	
2	.3	300	320, 10% Diffuse	
3	.3	400	320, 10% Diffuse	
4	.3	100	320, 20% Diffuse	
5	.3	300	320, 20% Diffuse	
6	.3	400	320, 20% Diffuse	
7	.3	100	320, 30% Diffuse	
8	.3	300	320, 30% Diffuse	
9	.3	400	320, 30% Diffuse	
10	0	-	300-350	Stagnation
11	.3	100	320, 10% Diffuse	
12	.3	400	320, 10% Diffuse	

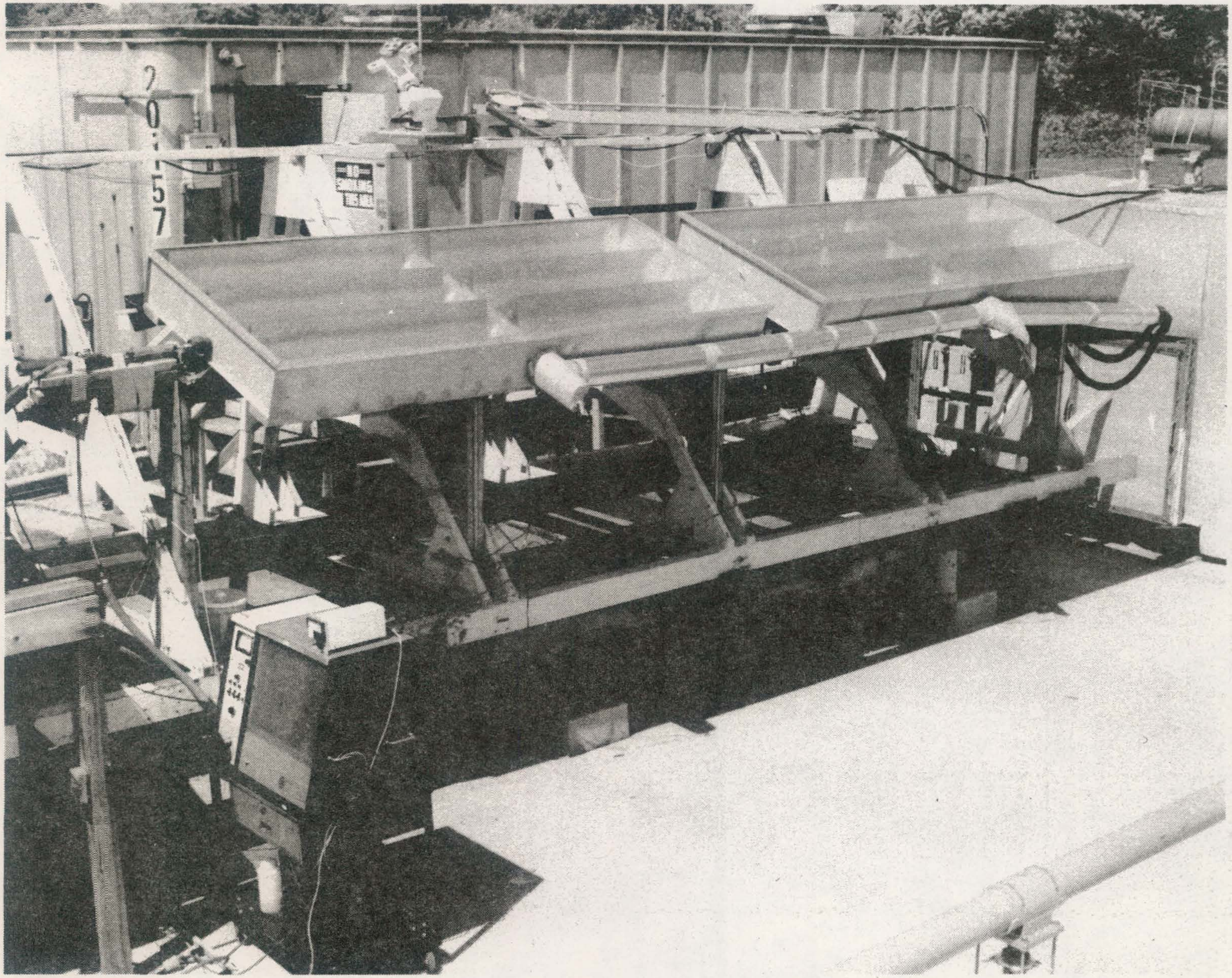


PHOTO NO. 11229

COLLECTOR TEST SETUP AT GENERAL ELECTRIC SOLAR LABORATORY.

- Conduct six tests, three each at 300°F and 400°F, to determine collector thermal efficiency under design operating conditions (Test Nos. 2, 3, 5, 6, 8 and 9).

- Conduct a stagnation test to determine the ability of the collector to withstand the stagnation environment. Under actual operating conditions, the collector might be exposed to stagnation because of system problems (Test No. 10).

- Conduct two tests following stagnation to verify poststagnation performance stability (Test Nos. 11 and 12).

13.2 Performance Test Results

Thermal performance test data for the seven tests conducted is shown in Tables 10 through 15 on the following pages. All relevant recorded test data are presented with additional calculated entries for informational purposes. Three values for insolation are shown:

1) Total insolation in the plane of the collector as measured with a pyranometer.

2) Beam insolation as measured with a normal incidence pyrheliometer.

3) Aperture insolation which is a calculated value considered to be equal to the insolation that can strike the absorber either directly or by reflection. For this collector, the accepted value is equal to the beam insolation plus 24 percent (1/4.1) of the diffuse portion of the insolation.

Three values for efficiency have been calculated:

1) Efficiency based on the total insolation.

2) Efficiency based on only the beam portion of the insolation.

(Text continued on Page 89)

TABLE 10. THERMAL PERFORMANCE DATA TEST NOS. 1 AND 2

DATE: 12 JUNE

AMBIENT TEMP: START - 63.14 DEG. F
FINISH - 66.59 DEG. F

TIME EDT	T (IN) DEG F	DELTA T DEG F	FLOW RATE LBS/HR	SP. HT. BTU/LB-DEG	TOT GAIN BTU	INSOLATION TOTAL BTU/HR-SQ FT	INSOLATION BEAM BTU/HR-SQ FT	INSOLATION APERTURE BTU/HR-SQ FT	DIFFUSE %	EFFICIENCY BASED ON IT	EFFICIENCY BASED ON IB	EFFICIENCY BASED ON IA
1200.	268.	26.30	142.749	1.017	3823.	321.	277.	288.	14.	0.455	0.527	0.507
1205.	268.	26.50	141.816	1.017	3827.	329.	279.	291.	15.	0.444	0.524	0.502
1210.	269.	26.00	145.548	1.017	3854.	326.	278.	290.	15.	0.451	0.529	0.508
1215.	270.	26.90	145.548	1.017	3987.	329.	278.	290.	16.	0.463	0.547	0.524
1220.	269.	27.50	143.215	1.017	4011.	329.	276.	289.	16.	0.465	0.555	0.530
1225.	268.	27.30	143.215	1.017	3981.	331.	278.	291.	16.	0.459	0.547	0.522
1230.	267.	27.30	140.416	1.017	3904.	329.	276.	289.	16.	0.453	0.540	0.516
1235.	269.	26.70	145.548	1.017	3957.	331.	277.	290.	16.	0.456	0.545	0.521
1240.	269.	27.60	142.749	1.017	4012.	333.	279.	292.	16.	0.460	0.549	0.524
1245.	268.	27.70	146.481	1.017	4132.	334.	279.	292.	16.	0.472	0.565	0.539
1250.	267.	28.00	145.548	1.017	4150.	335.	280.	293.	16.	0.473	0.566	0.540
1255.	269.	27.40	139.017	1.017	3879.	336.	280.	294.	17.	0.441	0.529	0.504
1300.	269.	27.80	145.548	1.017	4120.	336.	280.	294.	17.	0.468	0.562	0.536
1305.	267.	27.90	135.285	1.017	3844.	334.	278.	292.	17.	0.439	0.528	0.503
1310.	268.	27.30	148.347	1.017	4124.	335.	280.	293.	16.	0.470	0.562	0.536
1315.	269.	27.40	140.883	1.017	3931.	333.	276.	290.	17.	0.451	0.544	0.518
*1320.	268.	30.30	145.548	1.017	4491.	334.	279.	292.	16.	0.513	0.614	0.586
*1325.	267.	30.80	141.816	1.017	4448.	333.	279.	292.	16.	0.510	0.609	0.581
*1330.	268.	29.90	144.615	1.017	4403.	332.	279.	292.	16.	0.506	0.602	0.576
*1335.	269.	30.20	144.615	1.017	4447.	332.	280.	293.	16.	0.511	0.606	0.580
*1340.	267.	30.30	144.615	1.017	4462.	329.	277.	290.	16.	0.518	0.615	0.588
*1345.	267.	29.60	143.682	1.017	4331.	323.	271.	284.	16.	0.512	0.610	0.583
*1350.	269.	29.30	141.816	1.017	4231.	327.	278.	290.	15.	0.494	0.581	0.557
*1355.	268.	29.60	142.749	1.017	4303.	326.	280.	291.	14.	0.504	0.587	0.564
*1400.	267.	29.40	144.615	1.017	4330.	322.	277.	288.	14.	0.513	0.597	0.574

* Cover glass removed.

Test 1 - 1200 through 1315
Test 2 - 1320 through 1400

TABLE 11 THERMAL PERFORMANCE DATA TEST NO. 3

DATE: 13 JUNE

AMBIENT TEMP: START - 68.46 DEG. F
FINISH - 72.05 DEG. F

TIME EDT	T (IN) DEG F	DELTA T DEG F	FLOW RATE LBS/HR	SP. HT. BTU/LB-DEG	TOT GAIN BTU	INSOLATION (BTU/HR-SQ FT) TOTAL	BEAM	APERTURE	DIFFUSE %	EFFICIENCY BASED ON IT	IB	IA
1200.	185.	27.10	147.951	1.002	4023.	323.	277.	288.	14.	0.475	0.554	0.533
1205.	185.	27.20	149.885	1.002	4090.	322.	271.	283.	16.	0.485	0.576	0.551
1210.	187.	26.90	152.786	1.002	4124.	327.	275.	288.	16.	0.481	0.572	0.547
1215.	188.	27.10	149.885	1.002	4075.	324.	271.	284.	16.	0.480	0.574	0.548
1220.	188.	27.30	149.885	1.002	4105.	327.	271.	285.	17.	0.479	0.578	0.550
1225.	188.	27.50	151.819	1.002	4189.	330.	269.	284.	18.	0.484	0.594	0.563
1230.	188.	27.60	150.852	1.002	4177.	332.	269.	284.	19.	0.480	0.593	0.561
1235.	188.	28.10	146.017	1.002	4117.	335.	271.	287.	19.	0.469	0.580	0.548
1240.	188.	27.70	151.819	1.002	4219.	307.	244.	259.	21.	0.525	0.660	0.621
1245.	187.	27.90	152.786	1.002	4277.	338.	268.	285.	21.	0.483	0.609	0.573
1250.	187.	28.10	147.951	1.002	4171.	346.	251.	274.	27.	0.460	0.634	0.581
1255.	187.	17.90	150.852	1.002	2709.	67.	20.	31.	70.	1.543	5.170	3.287
1300.	187.	15.90	147.951	1.002	2360.	367.	268.	292.	27.	0.245	0.336	0.308
1305.	187.	12.40	146.984	1.002	1829.	96.	33.	48.	66.	0.727	2.115	1.443
1310.	187.	21.20	152.786	1.002	3250.	344.	266.	285.	23.	0.361	0.466	0.435
1315.	187.	27.10	149.885	1.002	4075.	339.	269.	286.	21.	0.459	0.578	0.544
1320.	187.	25.60	148.918	1.002	3825.	347.	263.	283.	24.	0.421	0.555	0.515
1325.	187.	27.50	150.852	1.002	4162.	356.	264.	286.	26.	0.446	0.602	0.555
1330.	186.	16.90	150.852	1.002	2558.	312.	269.	279.	14.	0.313	0.363	0.349
1335.	186.	27.50	146.984	1.002	4055.	381.	267.	295.	30.	0.406	0.580	0.525
1340.	186.	20.60	146.984	1.002	3038.	371.	265.	291.	29.	0.313	0.438	0.399
1345.	186.	27.80	152.786	1.002	4262.	378.	266.	293.	30.	0.430	0.611	0.555
1350.	186.	21.10	150.852	1.002	3194.	356.	267.	289.	25.	0.342	0.457	0.422
1355.	186.	26.90	148.918	1.002	4019.	353.	272.	292.	23.	0.435	0.564	0.526
1400.	186.	26.60	146.984	1.002	3923.	332.	267.	283.	20.	0.451	0.561	0.529

Test 3 - 1200 through 1235

TABLE 12. THERMAL PERFORMANCE DATA TEST NO. 4

DATE: 14 JUNE

AMBIENT TEMP: START - 76.74 DEG. F
FINISH - 76.90 DEG. F

TIME EDT	T (IN) DEG F	DELTA T DEG F	FLOW RATE LBS/HR	SP. HT. BTU/LB-DEG	TOT GAIN BTU	INSOLATION TOTAL (BTU/HR-SQ FT)	INSOLATION BEAM (BTU/HR-SQ FT)	INSOLATION APERTURE (BTU/HR-SQ FT)	DIFFUSE %	EFFICIENCY BASED ON IT	EFFICIENCY BASED ON IB	EFFICIENCY BASED ON IA
1200.	133.	22.80	150.705	0.996	3427.	293.	208.	229.	29.	0.446	0.629	0.572
1205.	133.	20.50	156.615	0.996	3202.	255.	172.	192.	33.	0.479	0.711	0.636
1210.	133.	23.30	153.660	0.996	3571.	318.	243.	261.	24.	0.429	0.561	0.522
1215.	133.	27.00	153.660	0.996	4138.	44.	20.	26.	55.	3.589	7.896	6.108
1220.	133.	27.60	155.630	0.996	4284.	329.	269.	284.	18.	0.497	0.608	0.576
1225.	133.	27.60	149.720	0.996	4121.	329.	268.	283.	19.	0.478	0.587	0.556
1230.	133.	27.80	153.660	0.996	4260.	328.	270.	284.	18.	0.496	0.602	0.572
1235.	133.	27.90	156.615	0.996	4358.	328.	270.	284.	18.	0.507	0.616	0.585
1240.	132.	28.20	155.630	0.996	4377.	328.	268.	283.	18.	0.509	0.623	0.591
1245.	132.	28.20	156.615	0.996	4405.	328.	271.	285.	17.	0.513	0.620	0.590
1250.	133.	28.10	153.660	0.996	4306.	328.	271.	285.	17.	0.501	0.606	0.577
1255.	133.	28.10	151.690	0.996	4251.	329.	270.	284.	18.	0.493	0.601	0.571
1300.	133.	28.30	149.720	0.996	4226.	330.	270.	285.	18.	0.489	0.597	0.567
1305.	133.	28.20	150.705	0.996	4238.	327.	270.	284.	17.	0.495	0.599	0.570
1310.	133.	28.10	156.615	0.996	4389.	326.	268.	282.	18.	0.514	0.625	0.594
1315.	133.	28.00	157.600	0.996	4401.	326.	269.	283.	17.	0.515	0.624	0.594
1320.	133.	28.00	152.675	0.996	4263.	325.	267.	281.	18.	0.501	0.609	0.579
1325.	133.	27.90	156.615	0.996	4358.	324.	267.	281.	18.	0.513	0.623	0.592
1330.	133.	27.70	155.630	0.996	4299.	322.	265.	279.	18.	0.510	0.619	0.588
1335.	133.	27.70	154.645	0.996	4272.	321.	266.	279.	17.	0.508	0.613	0.584
1340.	133.	27.50	157.600	0.996	4322.	319.	266.	279.	17.	0.517	0.620	0.591
1345.	133.	27.00	157.600	0.996	4244.	316.	263.	276.	17.	0.513	0.616	0.587
1350.	133.	27.00	149.720	0.996	4032.	316.	263.	276.	17.	0.487	0.585	0.558
1355.	133.	26.80	147.750	0.996	3949.	315.	265.	277.	16.	0.479	0.569	0.544
1400.	133.	26.60	156.615	0.996	4155.	313.	263.	275.	16.	0.507	0.603	0.576

Test 4 - 1230 through 1400

TABLE 13. THERMAL PERFORMANCE DATA TEST NO. 5

DATE: 15 JUNE

AMBIENT TEMP: START - 79.10 DEG. F
FINISH - 82.87 DEG. F

TIME FDT	T (IN) DEG F	DELTA T DEG F	FLOW RATE LBS/HR	SP. HT. BTU/LB-DEG	TOT GAIN BTU	INSOLATION TOTAL (BTU/HR-SQ FT)	INSOLATION BEAM (BTU/HR-SQ FT)	INSOLATION APERTURE (BTU/HR-SQ FT)	DIFFUSE %	EFFICIENCY BASED ON IT	EFFICIENCY BASED ON IB	EFFICIENCY BASED ON IA
1200.	363.	20.30	134.750	1.057	2895.	295.	208.	229.	29.	0.375	0.531	0.482
1205.	364.	19.70	133.875	1.057	2791.	297.	207.	229.	30.	0.359	0.515	0.465
1210.	364.	20.40	133.000	1.057	2872.	297.	204.	227.	31.	0.369	0.537	0.484
1215.	353.	20.40	132.125	1.057	2853.	298.	204.	227.	32.	0.365	0.534	0.480
1220.	364.	19.70	131.250	1.057	2737.	298.	203.	226.	32.	0.351	0.515	0.462
1225.	365.	20.30	136.500	1.057	2933.	295.	203.	225.	31.	0.379	0.551	0.497
1230.	363.	21.00	135.625	1.057	3014.	300.	202.	226.	33.	0.384	0.570	0.509
1235.	364.	20.20	131.250	1.057	2806.	302.	204.	228.	32.	0.355	0.525	0.470
1240.	365.	20.70	130.375	1.057	2856.	301.	203.	227.	33.	0.362	0.537	0.480
1245.	363.	21.30	132.125	1.057	2979.	303.	204.	228.	33.	0.375	0.557	0.498
1250.	363.	20.90	135.625	1.057	3000.	305.	206.	230.	32.	0.375	0.556	0.498
1255.	364.	21.10	133.000	1.057	2970.	304.	207.	231.	32.	0.373	0.548	0.491
1300.	363.	21.40	128.625	1.057	2913.	304.	206.	230.	32.	0.366	0.540	0.484
1305.	363.	21.20	137.375	1.057	3082.	306.	209.	233.	32.	0.384	0.563	0.506
1310.	365.	21.00	133.875	1.057	2976.	305.	208.	232.	32.	0.372	0.546	0.490
1315.	363.	21.20	131.250	1.057	2945.	302.	205.	229.	32.	0.372	0.548	0.492
1320.	364.	20.70	133.875	1.057	2933.	302.	205.	229.	32.	0.371	0.546	0.490
1325.	364.	20.60	129.500	1.057	2823.	303.	206.	230.	32.	0.356	0.523	0.469
1330.	363.	21.20	133.875	1.057	3004.	301.	204.	228.	32.	0.381	0.562	0.504
1335.	364.	20.00	134.750	1.057	2852.	302.	206.	229.	32.	0.360	0.528	0.475
1340.	364.	20.30	130.375	1.057	2801.	293.	201.	223.	31.	0.365	0.532	0.478
1345.	363.	20.40	134.750	1.057	2909.	298.	208.	230.	30.	0.373	0.534	0.483

Test 5 - 1200 through 1400

TABLE 14. THERMAL PERFORMANCE DATA TEST NO. 6

DATE: 6/20/79

AMBIENT TEMP: START - 76.70 DEG. F
FINISH - 79.40 DEG. F

TIME EDT	T (IN) DEG F	DELTA T DEG F	FLOW RATE LBS/HR	SP. HT. BTU/LB-DEG	TOT GAIN BTU	INSOLATION TOTAL (BTU/HR-SQ FT)	INSOLATION BEAM (BTU/HR-SQ FT)	INSOLATION APERTURE (BTU/HR-SQ FT)	DIFFUSE %	EFFICIENCY BASED ON IT	EFFICIENCY BASED ON IB	EFFICIENCY BASED ON IA
1200.	350.	18.70	128.615	1.047	2521.	313.	235.	254.	25.	0.307	0.410	0.379
1205.	349.	22.10	130.389	1.047	3021.	316.	237.	256.	25.	0.365	0.487	0.450
1210.	348.	19.60	137.485	1.047	2825.	326.	244.	264.	25.	0.331	0.442	0.408
1215.	350.	22.20	134.824	1.047	3138.	315.	244.	261.	23.	0.380	0.491	0.458
1220.	349.	23.80	136.598	1.047	3408.	318.	249.	266.	22.	0.409	0.522	0.489
1225.	348.	24.40	135.711	1.047	3472.	322.	249.	267.	23.	0.411	0.532	0.497
1230.	350.	23.70	133.050	1.047	3306.	323.	244.	263.	24.	0.391	0.517	0.479
1235.	349.	24.50	135.711	1.047	3486.	292.	202.	224.	31.	0.456	0.659	0.594
1240.	348.	23.70	129.502	1.047	3218.	318.	220.	244.	31.	0.386	0.558	0.504
1245.	350.	23.30	134.824	1.047	3293.	320.	224.	247.	30.	0.393	0.561	0.508
1250.	350.	24.50	132.163	1.047	3395.	338.	251.	272.	26.	0.383	0.516	0.476
1255.	348.	26.10	128.615	1.047	3519.	350.	260.	282.	26.	0.384	0.517	0.476
1300.	349.	25.60	132.163	1.047	3547.	347.	240.	266.	31.	0.390	0.564	0.509
1305.	349.	25.00	130.389	1.047	3417.	351.	235.	263.	33.	0.372	0.555	0.495
1310.	348.	22.90	129.502	1.047	3109.	310.	189.	219.	39.	0.383	0.628	0.543
1315.	349.	6.30	134.824	1.047	890.	114.	6.	32.	95.	0.298	5.665	1.051
1320.	348.	10.40	133.937	1.047	1460.	107.	1.	27.	99.	0.521	55.738	2.076
1325.	349.	2.40	132.163	1.047	333.	105.	1.	26.	99.	0.121	12.692	0.481
1330.	348.	13.70	135.711	1.047	1949.	342.	205.	238.	40.	0.218	0.363	0.312
1335.	349.	20.90	129.502	1.047	2838.	342.	204.	238.	40.	0.317	0.531	0.456
1340.	349.	13.10	136.598	1.047	1876.	112.	1.	28.	99.	0.639	71.603	2.551
1345.	348.	13.80	131.719	1.047	1906.	89.	1.	22.	99.	0.817	72.736	3.238
1350.	350.	11.90	132.163	1.047	1649.	90.	2.	23.	98.	0.699	31.466	2.682
1355.	348.	6.40	136.598	1.047	917.	202.	113.	135.	44.	0.173	0.310	0.260
1400.	349.	5.00	131.276	1.047	688.	80.	2.	21.	97.	0.328	13.132	1.249

Test 6 - 1200 through 1305

TABLE 15. THERMAL PERFORMANCE DATA TEST NO. 7

DATE: 6/26/79

AMBIENT TEMP: START - 75.26 DEG. F
FINISH - 77.36 DEG. F

TIME EDT	T (IN) DEG F	DELTA T DEG F	FLOW RATE LBS/HR	SP. HT. BTU/LB-DEG	TOT GAIN BTU	INSOLATION TOTAL (BTU/HR-SQ FT)	INSOLATION BEAM (BTU/HR-SQ FT)	INSOLATION APERTURE (BTU/HR-SQ FT)	DIFFUSE %	EFFICIENCY BASED ON IT	EFFICIENCY BASED ON IB	EFFICIENCY BASED ON IA
1200.	106.	29.50	157.251	0.996	4626.	306.	255.	267.	17.	0.577	0.692	0.660
1205.	106.	30.00	158.240	0.996	4734.	313.	260.	273.	17.	0.577	0.695	0.662
1210.	107.	30.20	154.284	0.996	4647.	312.	258.	271.	17.	0.568	0.687	0.654
1215.	107.	30.30	149.339	0.996	4513.	315.	260.	273.	17.	0.547	0.662	0.630
1220.	107.	30.40	149.339	0.996	4528.	314.	258.	272.	18.	0.550	0.670	0.636
1225.	108.	30.60	152.306	0.996	4648.	317.	260.	274.	18.	0.560	0.682	0.648
1230.	108.	30.50	150.328	0.996	4573.	316.	256.	271.	19.	0.552	0.682	0.645
1235.	108.	30.40	151.317	0.996	4588.	313.	251.	266.	20.	0.559	0.698	0.658
1240.	108.	30.60	151.317	0.996	4618.	319.	255.	271.	20.	0.553	0.691	0.651
1245.	109.	30.60	154.284	0.996	4708.	319.	254.	270.	20.	0.563	0.708	0.666
1250.	109.	30.30	150.328	0.996	4543.	315.	250.	266.	21.	0.550	0.694	0.652
1255.	109.	30.30	157.251	0.996	4752.	320.	253.	269.	21.	0.567	0.717	0.673
1300.	109.	30.50	156.262	0.996	4753.	329.	252.	271.	23.	0.551	0.720	0.670
1305.	110.	30.90	152.306	0.996	4694.	330.	253.	272.	23.	0.543	0.708	0.659
1310.	110.	31.20	157.251	0.996	4893.	65.	253.	207.	-289.	2.873	0.738	0.902
1315.	110.	31.10	152.306	0.996	4724.	252.	170.	190.	33.	0.715	1.061	0.949
1320.	111.	31.40	149.339	0.996	4677.	334.	227.	253.	32.	0.534	0.786	0.705
1325.	111.	18.60	150.328	0.996	2789.	293.	181.	208.	38.	0.363	0.588	0.511
1330.	111.	27.80	149.339	0.996	4140.	351.	241.	268.	31.	0.450	0.656	0.590
1335.	112.	17.20	150.328	0.996	2579.	98.	1.	25.	99.	1.004	98.424	3.991
1340.	112.	7.80	152.306	0.996	1185.	115.	3.	30.	97.	0.393	15.074	1.492
1345.	112.	12.20	151.317	0.996	1841.	118.	15.	40.	87.	0.596	4.685	1.751
1350.	112.	21.70	146.372	0.996	3168.	378.	243.	276.	36.	0.320	0.498	0.438
1355.	112.	14.90	147.361	0.996	2190.	115.	5.	32.	96.	0.727	16.716	2.626

Test 7 - 1200 through 1305

Cover glass removed all data.

3) Efficiency based on the aperture insolation as defined above. This is a valuable method of presenting CPC performance data because it reduces the effect of varying diffuse ratios.

The test data on Tables 10 through 15 is shown as instantaneous readings at five-minute intervals. Because of minor deviations in ambient conditions (insolation characteristics) and in the test circuit (flow rate and inlet temperature), it is necessary to average a group of data points over a fairly large period of time to eliminate these transient effects on the efficiency calculations. It is also necessary to eliminate some of the individual data points because of wide variations in the insolation striking the collector. To this end, a group of test points was selected out of each two-hour recorded data set which was used to establish the thermal efficiency for each specific test condition. This group of data is designated on each data table as a time interval.

Figure 18, on the following page, shows these test results of the Chamberlain 3X collector in the traditional format of efficiency versus $\Delta T/I$. The efficiency values are based on aperture insolation, and ΔT is the difference between the inlet temperature and ambient temperature. The solid line drawn on this graph represents a series of data points calculated using the math model discussed in Section 12.2 which has been modified to match actual test results. A discussion of that model follows.

It is possible to match the performance test results with theoretical calculations by making the following assumptions and using the math model discussed in Section 12.2.

- The effective $\tau\alpha$ product is 0.59. This includes the cover glass and outer glass tube transmittance, the reflector reflectance and the absorber absorptance. This represents a reduction from the predicted value of 0.66 in Section 12.1.

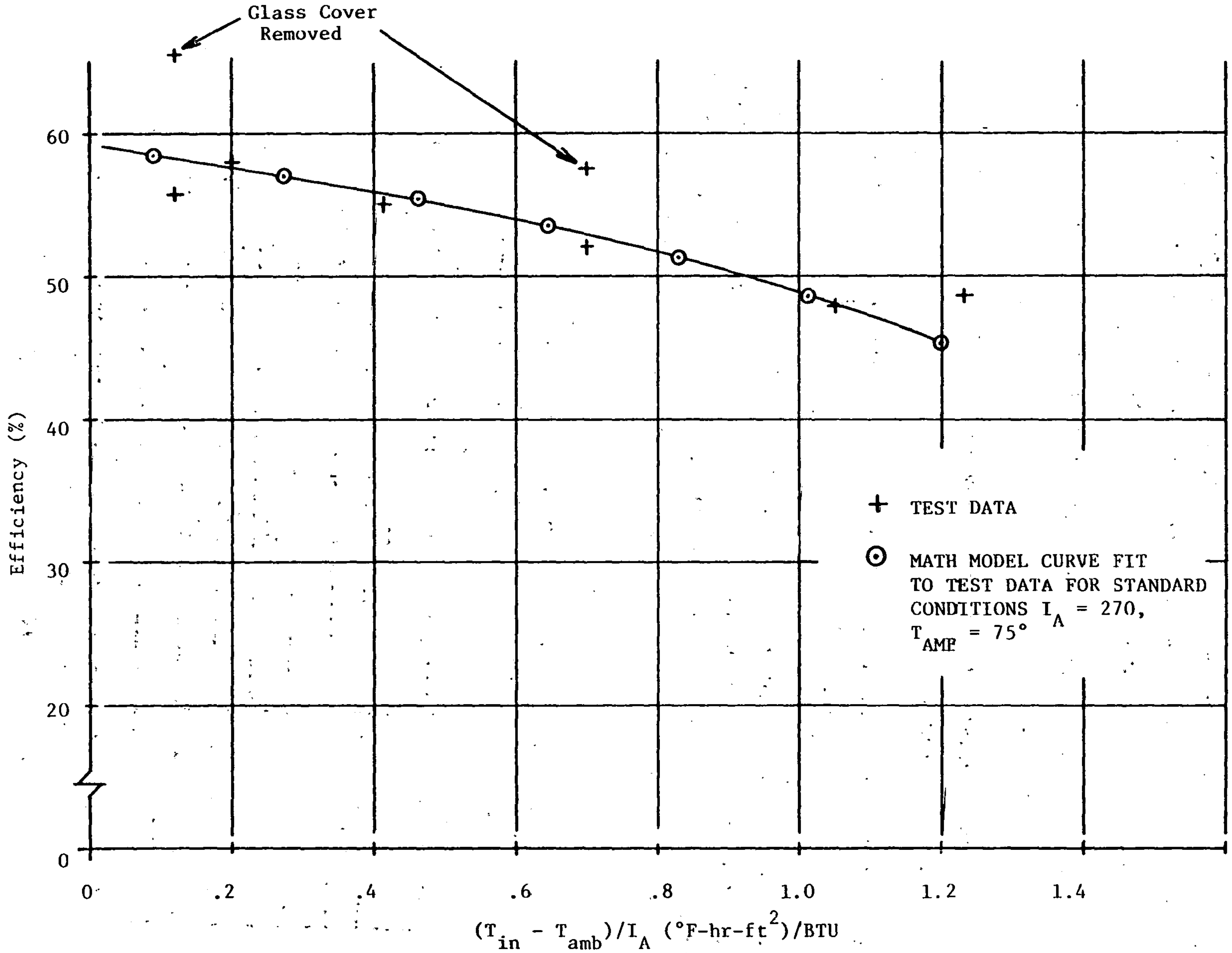


Figure 18. Chamberlain 3X CPC Thermal Efficiency versus Aperture Insolation

- The thermal resistance of the fin/tube-shroud assembly is 0.40 hr-ft-°F/BTU. This value has been increased from 0.35 as a result of receiver tests discussed in Section 13.3.

- The collector can utilize all beam radiation and 24 percent of the diffuse (1/4.1).

- The outer glass tube of the shroud is 75°F warmer than the ambient air temperature.

- Manifold and all other heat losses per square foot of aperture are equal to $(T_{in} - T_A)/50$ BTU.

The test data for each individual test condition and the above assumptions were utilized to predict a theoretical efficiency for each data point shown in Table 16. As can be seen, the theoretical points are extremely close to the actual test results under very diverse temperature and insolation conditions.

TABLE 16. COMPARISON OF THEORETICAL DATA AND TEST RESULTS BASED ON ACTUAL TEST DATA AND CONDITIONS

TEST NO.	TEST EFFICIENCY*	THEORETICAL EFFICIENCY*
1	.521	.526
2**	.577	.588
3	.551	.559
4	.580	.575
5	.487	.467
6	.480	.482
7**	.656	.648

* Based on I_A = Direct insolation + 24 percent of diffuse and an aperture area of 26.2 square feet.

** Cover glass removed.

The line shown on the graph in Figure 18 represents the theoretical performance of the collector based on the model discussed above for an aperture insolation of 270 BTU/hr-ft^2 and an ambient temperature of 75°F. This graph is considered to be a very accurate representation of the actual performance of the Chamberlain 3X CPC collector.

The more standard method of presenting efficiency is to use a second degree curve fit to the test data. This has been done using the least squares method. The resulting equation is $EFF = .617 - .189\ \Delta T/I + .064\ (\Delta T/I)^2$. This curve is concave upward and is not an acceptable definition of the collector performance. If the data from Test No. 5 is not used, the equation becomes $EFF = .604 - .127\ \Delta T/I + .009\ (\Delta T/I)^2$, which is almost a straight line but is still concave upward. With the limited data available, it appears that the curve shown in Figure 18 that was generated by the math model is the most accurate definition of the collector performance at this time. This line can be characterized by the equation $EFF = .587 - .043\ \Delta T/I - .058\ (\Delta T/I)^2$.

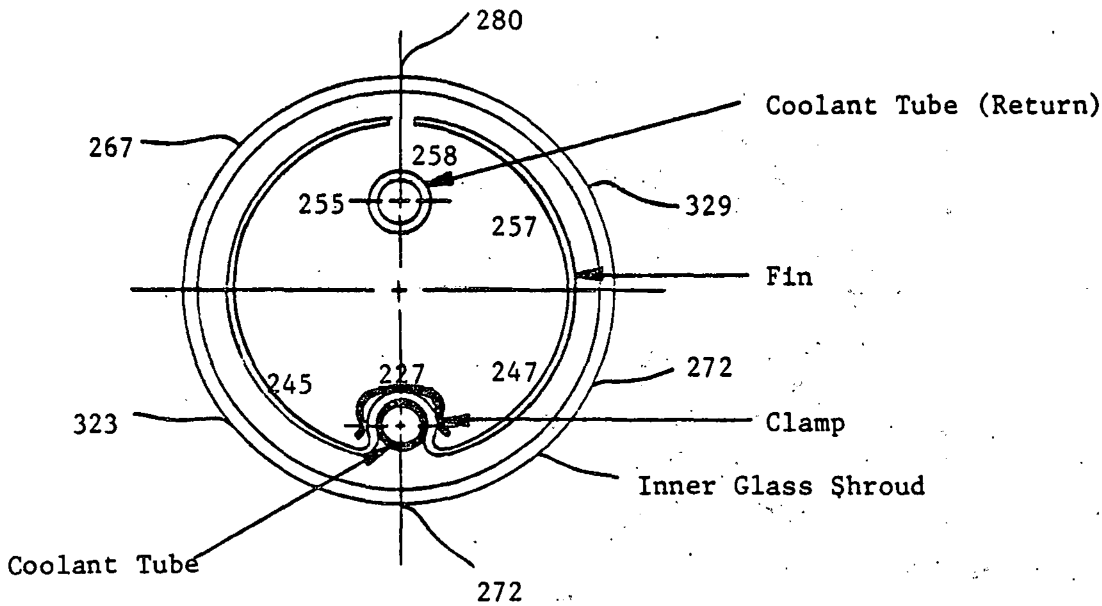
13.3 Receiver Test

This test was conducted by General Electric in conjunction with the performance verification tests to accurately define the thermal resistance of the shroud-fin/tube assembly from absorber to fluid. The thermal resistance to heat flow from the abosrber surface to the working fluid is a critical parameter in the analysis of a solar collector, especially a concentrating collector. The heat loss off the absorbing surface in an evacuated receiver is dependent on the temperature of the absorber surface. Ideally, this surface would be the same temperature as the fluid carrying the heat out of the collector (in this case, the thermal resistance of the absorber would be 0). However, there are, in actuality, several junctions and materials that offer resistance to the flow of heat from the absorber to the fluid in the General Electric evacuated shroud and fin/tube assembly. The absorber is a dielectric selective coating deposited on the surface of 1.75 inch outer diameter glass tube (0.043-inch wall thickness). Heat loss from the absorber is by long-wave radiation to the outer tube. Heat flows from the absorber to the working fluid across the inner glass thickness, across any air gap between the inner tube and the heat transfer fin, along the developed length of the fin, through the fin-tube junction (clamped region) and finally, through the coolant tube wall thickness. The thermal resistance of this assembly determines the temperature difference between absorber and fluid.

Previous studies on the thermal resistance of the General Electric fin/tube assembly have theoretically investigated the resistance of a uniform air gap and both a uniform and nonuniform insolation flux. Experimental studies investigated an actual air gap, but only with a uniform heat flux. This section describes a test aimed at quantifying the thermal resistance under actual field conditions. The temperature distribution around the absorber tube and heat transfer fin were measured under the actual heat flux conditions with the collector undergoing outdoor performance testing. The results of this test were in excellent agreement with theoretical calculations.

The instrumented shroud had six thermocouples cemented to the absorber surface at one plane located 20 inches from the domed end. A set of adjacent thermocouples was attached to the aluminum fin. The absorber is the standard four-layer selective coating. The coating was removed and thermocouples mounted to the glass with Sauereisen® refractory cement. The outer and inner glass tubes were joined by a standard Dewar® seal on one end. On the opposite end, the inner tube was domed and the outer tube was fitted with a plug. The plug contains a vacuum port and a seal through which the thermocouple wires leave the shroud. A pump was used to maintain a vacuum in the annulus adjacent to the absorber coating.

Figures 19 and 20 show the temperature distribution around the absorber-fin assembly. Shown in each figure are the insolation, fluid temperature, energy collected per foot of receiver, average absorber temperature and fluid-absorber ΔT. The energy collected was determined by measuring the flow rate and temperature rise across the collector.



T_{fluid} = 231°F

Insolation = 276 BTU/hr-ft^2

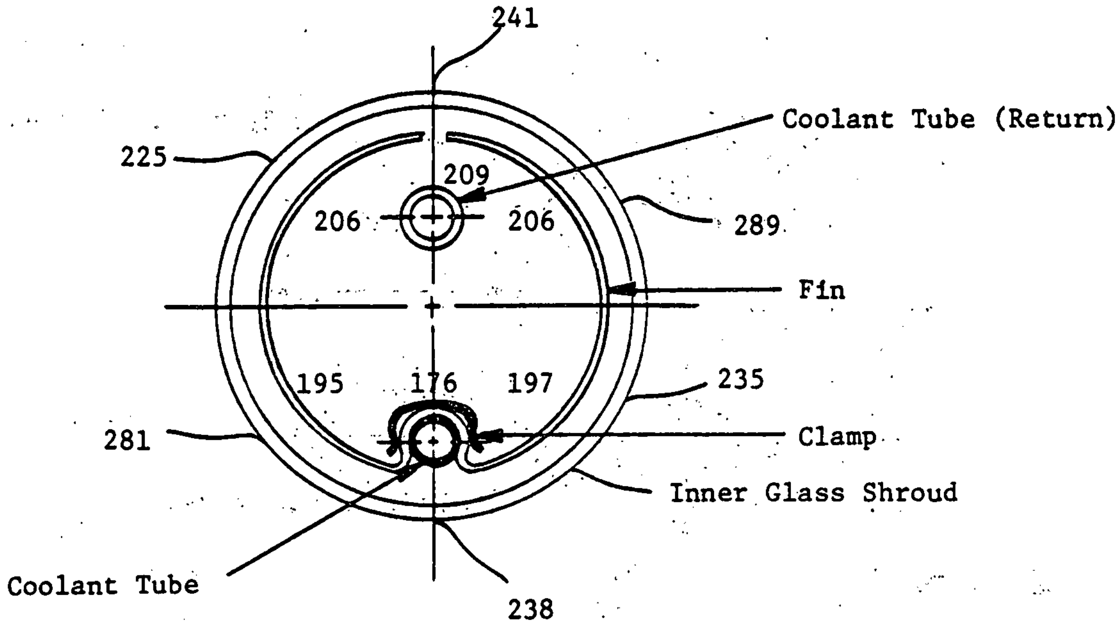
Energy collected per foot of receiver = $\frac{170 \text{ BTU}}{\text{hr-ft}}$

Average absorber temperature = 290°F

Fluid-absorber temperature = 290°F

Fluid-absorber ΔT = 59°F

Figure 19. Absorber-Fin Temperature Distribution



T_{fluid} = 178°F

Insolation = 285 BTU/hr-ft^2

Energy collected per foot of receiver = $\frac{172\ \text{BTU}}{\text{hr-ft}}$

Average absorber temperature = 251°F

Fluid-absorber ΔT = 73°F

Figure 20. Absorber-Fin Temperature Distribution

The thermal resistance of the assembly, R, is defined by

$$R = \frac{\Delta T}{Q/L}$$

where Q/L is the heat flux per foot of receiver and ΔT is the fluid-absorber temperature difference. For the conditions of Figure 19 R is 0.35; for Figure 20 R is 0.42 hr-ft-°F/BTU.

13.4 Additional Laboratory Tests

To supplement the curtailed test program at General Electric two very basic tests were conducted during July 1979 in the Chamberlain Solar Laboratory to: 1) determine the temperature of the outer glass shroud under operating conditions, and 2) determine the ability of the collector to withstand exposure to stagnation conditions. For both tests, one of the prototype collectors was attached to a two-axis tracking mount.

Since Chamberlain did not have high temperature test capability, the test to determine outer glass tube temperature was conducted with the fluid passing through the subject receiver at 120°F. Two thermocouples were attached to the outer glass tube on one of the receivers, and water was pumped through the collector. One thermocouple was attached at the top of the outer glass tube and the other 90 degrees off the top. With a total insolation rate of 298 BTU/hr-ft^2 and an ambient temperature of 81°F, the temperature of the outer tube measured 131°F at the top and 196°F at the side of the tube. In this case, the major source of energy causing the tube to be warmer than ambient was the reflectivity losses off the reflectors and absorber surface. However, under actual operating conditions of 400°F, the radiation losses off the absorber became significant, and investigators assumed that an associated rise in tube temperature would occur. For the purposes of defining this variable in the math model, they assumed that the outer glass tube of the evacuated shroud would be 75°F greater than ambient. This is a conservative estimate; the gradient is probably 100°F with a fluid inlet temperature of 400°F.

Because the stagnation test was not conducted as planned at General Electric, the collector was exposed to stagnation conditions at the Chamberlain laboratory. The collector was attached to a two-axis tracking mount and was exposed daily for 16 consecutive days in July and August 1979. The tests started at 8 a.m. each day and ended at sunset. The collector underwent six days of exposure during which the absorber temperature reached at least 700°F for a minimum of two hours. The maximum absorber temperature during these tests was 784°F. This temperature was measured by inserting a thermocouple into the outlet tube that is connected to the clamped tube in the fin/tube assembly. The thermocouple was inserted to a point about 24 inches from the open end of the evacuated shroud.

The collector showed no visible sign of deterioration due to the exposure. Company investigators had no way to thoroughly examine collector operation either before or after the test, but all indications show no major changes in operational characteristics of the collector would have occurred. General Electric has stated that the absorber coating would break down at temperatures over 750°F, but once again, there was no evidence of any deterioration. All other components in the collector are designed to survive stagnation exposure.

13.5 Discussion of Test Results

The thermal performance of the test collector is quite close to the theoretical performance predicted earlier in the program and discussed in Section 12.2. Two major changes in that theoretical model should be made because of design modifications and a re-evaluation of the optical properties of the receiver: 1) the cover glass transmittance should be changed from 0.94 to 0.90 because the antireflective treatment on the glass did not increase transmittance (see Section 5) and 2) the absorptance of the receiver absorber surface is now specified by General Electric as 0.85 instead of the previously assumed value of 0.89. These changes drop the predicted value of $\tau\alpha = (\tau_1\ \tau_2\ \alpha\ \rho^n) = (.94 \times .91 \times .89 \times .87) = .662$ to a value of $(.90 \times .91 \times .85 \times .87) = .605$. This value is in close agreement with the test data which indicates an actual value of 0.59. The heat loss coefficient of the collector appears to be a little higher than expected, but there is not enough data at the higher operating temperatures to permit an accurate assessment of this collector property. Note that the efficiency calculated in Test No. 5 is better than the curve fit. This test was run under very diffuse insolation conditions (32 percent), and the result indicates one of two things:

- The collector can utilize much more of the diffuse insolation than the assumed 24 percent, or
- The heat loss coefficient of the collector is lower than is indicated by the math model.

The collector performance in Test Nos. 2 and 7, in which the collector was tested with the glass cover removed, indicates that there is no detrimental effect caused by the stippled surface on the glass cover. The results of Test Nos. 1 and 2 provide a direct comparison of the performance of the collector with and without the glass cover. The cover was removed while Test No. 2 was progressing, and the increase in performance that was immediately evident must be attributed directly to the increased energy transmitted to the receiver. The change in performance indicated that the cover glass had an effective transmittance of 0.906, which is in very close agreement with the previously measured value of 0.904 (Section 5).

The major areas where performance improvements could be attained are the cover glass and the receiver. The reflector system appears to be quite functional, and production costs are not excessive. The receiver and cover could easily be improved by treating the outside tube and the cover to reduce reflective losses. Further improvement would require a totally different receiver concept, but the losses associated with the present design, both in absorptance and thermal resistance, could be eliminated by using a metal absorber with integral fluid passageways and a black chrome absorber surface. It is likely that the efficiency of the collector could be improved by 25 percent. The change would be cost effective if the collector cost did not go up more than 25 percent.

14. MANUFACTURING COST STUDY

The purpose of this task was to provide a manufacturing cost estimate for the collector under a reasonable production rate. The task was broken down into three areas.

14.1 Cost Data
14.2 Cost Reduction Ideas
14.3 Tooling Requirements

Company personnel selected 100 collectors per month as a realistic production rate on which to base cost data. This rate includes six full-time workers, each specializing in a specific area. The cost data includes purchased parts, component raw materials and production hours, and collector assembly labor.

Cost reduction ideas are presented to call attention to the most promising areas where improvements can be made. Because the costs of material and purchased parts were dealt with in the cost effectiveness analysis, the cost reduction discussion includes mainly labor operations.

Tooling necessary for a limited mass production line is delineated with a brief description of the requirement and estimated cost for each.

14.1 Cost Data

The objective of this task was to estimate total manufacturing costs for the collector, assuming a limited mass production facility was available. For the purposes of this study, Company analysts assumed a production rate of 100 collectors per month. They also assumed Chamberlain's use of the tooling built under the present program. The estimates of labor time required for component manufacture and subassembly and assembly operations are based mainly on engineering estimates. Some input from the prototype assembly of the ten deliverable collectors was used, but its value was limited due to the small number of assemblies made and the now obvious need for additional tooling.

The task of defining collector manufacturing costs was broken down into the following categories:

- Purchased parts
- Component production
- Collector assembly operations

Purchased parts are listed in Table 18 on the following page. Table 19 shows the raw materials costs required for each collector component manufactured and the labor hours associated with each item. Table 20 delineates collector assembly operations with respective labor hours required for each. Table 17, below, is a cost summary sheet which combines all cost data into a total direct cost to produce each collector under the defined conditions.

TABLE 17. MANUFACTURING COST SUMMARY

Raw Materials	$136	
Purchased Parts	217	
Shrinkage	18	$371
Shop Manufacturing Labor	$ 83	
Engineering Labor	15	98
TOTAL DIRECT COST		$469

TABLE 18. COLLECTOR PURCHASED PARTS

PART	DRAWING NO.	COST PER COLLECTOR
Fin/Tube Assembly and Evacuated Shroud	J8178-29	$151.62
Glass Cover	J8178-30	44.06
Rivet	J8178-44	.16
Spring	J8178-24	3.26
Grommet	J8178-32	4.80
Insulating Bushing	J8178-26	2.40
Retainer, Insulating Bushing	J8178-33	.25
Retainer, Inlet/Outlet Tube	J8178-34	.12
Screws	J8178-46	1.30
Foam Tape		1.50
Insulation	J8178-47	.80
Paint and Miscellaneous Assembly Hardware		7.00
	TOTAL	$217.27

TABLE 19. COMPONENT PRODUCTION

PART	DRAWING NO.	MATERIAL	MATERIAL COST	PRODUCTION MAN-HOURS PER COLLECTOR
Bottom	J8178-6	26 ga. Paintable Galv. Steel	$ 9.34	.13
Side Rail	J8178-4	20 ga. Paintable Galv. Steel	9.63	.32
End Rail	J8178-5	20 ga. Paintable Galv. Steel	3.97	.35
Corner Support	J8178-40	20 ga. Galvanized Steel	.19	.06
Reflector Support, Receiver Support Bracket	J8178-9	18 ga. Galvanized Steel	12.68	.64
Receiver Locating Bracket	J8178-36	18 ga. Galvanized Steel	3.23	.26
Manifold Bottom	J8178-39	20 ga. Galvanized Steel	1.02	.10
Manifold Cover	J8178-12	20 ga. Galvanized Steel	1.02	.11
End Covers	J8178-31	20 ga. Galvanized Steel	1.02	.06
Reflectors	J8178-7	Kinglux	69.60	.51
Transition Tubes, Connector, Inlet/Outlet Tube	J8178-22, -23, -37, -27, -28	1/4 O.D. Stainless Steel Tubing	8.33	.53
Cover Angle Side, Cover Angle End	J8178-18 J8178-19	1 x 1 x 1/16 Alum. Angle	15.60	.18
TOTAL COMPONENT PRODUCTION			$135.63	3.25 hrs

TABLE 20. COLLECTOR ASSEMBLY OPERATIONS

DESCRIPTION	MAN-HOURS PER COLLECTOR
Build Housing	1.22
Reflector Subassembly	1.42
Receiver Subassembly	1.38
Reflector and Receiver Assembly Installation Into Housing	1.18
Clean Reflectors, Receivers, Glass Cover, Install Gasket and Cover	1.35
Paint Housing and Package	.94
TOTAL ASSEMBLY DIRECT HOURS	7.49

This cost summarizes all data discussed earlier plus a five-percent scrap and shrinkage allowance and an indirect labor item which provides for process engineering and production line management. The table does not include overhead, general/administration and fee inputs because these items are extremely variable and depend on the type of production facility utilized, the production load of that facility at the time of manufacture and the accounting procedures used to determine the selling cost of a production item. These costs would typically depend on the manufacturer's attitude toward the product, a factor which would control the distribution of the fixed and variable plant overhead and the fee. These items would add from 0 to 400 dollars per collector to the total direct cost. Special tooling and production line setup costs are not included because they would be typically spread over a production period of three to ten years, rendering the effect on individual collector cost inconsequential. The prices specified in the tables are for large quantities and could increase significantly for small orders. Most of the listed costs were obtained during the middle of calendar year 1978.

14.2 Cost Reduction Ideas

One of the basic criteria for the collector design effort was to specify the most cost effective components in terms of BTUs delivered per dollar spent. All cost reduction efforts discussed below were made with this criteria in mind.

The total direct cost as calculated in Table 17 shows that purchased parts and raw material make up $371 of the total $469 cost. Further examination revealed three major items requiring approximately 75 percent of the materials investment: the fin/tube evacuated shroud assemblies at $152, the cover glass at $44, and the reflector material at $70. Of these items, the cover glass and the reflector material selections were the most cost effective of the available options, and the receiver assembly is part of the baseline design which was selected as the best tubular evacuated receiver available.

Chamberlain considers the General Electric receiver to be the best on the market for this application, and it is doubtful that another source for a comparable product will be discovered in the near future. Unless General Electric chooses to substantially reduce its selling price, there is little room for cost reduction.

By using the next lighter gage material for each item, the cost of galvanized steel parts could be reduced by about 25 percent. No attempt was made in this program to select the optimum gage material. The aluminum cover angle costs $16 and could be replaced with a prepainted 18-gage angle at a savings of about $10 per collector. The stainless steel tubing specified for the manifold area is seamless. The fin/tube assembly uses welded tubing. Using welded tubing in the manifold area would mean a savings in material cost of four to five dollars per collector. However, the added risk of leakage along welded tubing presents a problem. No other items appear to benefit by a change in material or part specifications. Further analysis should be made before changing any specifications for the items discussed.

As stated in Section 14.1, labor cost estimates were based mainly on engineering judgment at a specified production rate of 100 units per month. Obviously, this is an area where substantial cost variance exists. If production rates increase significantly, an automated full assembly line may be justified, causing a substantial reduction in labor time required. The presented costing assumes a work force of six people, four working on the assembly operation and two on component production. This arrangement requires a lot of job switching and much more part handling than would be required in a full assembly line. However, a constant production quantity greater than 100 units per month does not seem justifiable at this time.

14.3 Tooling Requirements

Tooling built under this contract includes: roll form tooling for shaping the reflector, a die to stamp the cusp shape on the reflector support, and a die to stamp the holes in the receiver locating bracket. Additional tooling needed to support a production rate of 100 collectors per month includes at least the following:

Item		Estimated Cost
Housing Assembly Fixture		$1000
Receiver Support Bracket Die		3000
Reflector Assembly Fixture		1200
Receiver Assembly Fixture		1200
Paint Mask		400
Reflector Hole Punch		1400
Manifold Tubing Bend Fixtures		1500
	TOTAL	$9700

A brief description of the intended purpose of each of these tools appears below.

Housing assembly fixture: This is essentially a plug upon which the housing would be assembled in an inverted position. It should assure "squared-up" assembly of the sides, proper box depth, and alignment of the top surface of the sides and ends.

Receiver support bracket die: This die would be used to stamp the shape of the part. The machining on this part was excessive during prototype production.

Reflector assembly fixture: This would hold the reflectors in an inverted position while the reflector supports were assembled.

Receiver assembly fixture: This would hold the evacuated shrouds in place while the receiver locating brackets were assembled, the fin/tube assemblies were inserted and the manifold parts were brazed.

Paint mask: This fixture would be used to protect the glass cover and cover angles while the housing was painted.

Reflector hole punch: This would be used to punch the two rivet holes and the two anchor wire holes in the reflector.

Manifold tubing bend fixtures: These would allow rapid and accurate forming of the transition tubes, inlet/outlet tubes and connector.

15. PRELIMINARY PHASE II SYSTEM DESIGN

The scope of this task was to provide preliminary system design inputs for a 2000-square-foot prototype collector installation at the state Capitol complex in Des Moines, Iowa. The State of Iowa is actively pursuing means of augmenting the natural gas-fired, steam generators used for heating and cooling a complex of eight buildings at the state Capitol. One 2000-foot pilot system has already been installed, and plans call for the installation of another system of like dimensions in the near future. The collector developed under this program was designed specifically for state Capitol complex use.

The complex includes the Capitol and state office buildings with a power plant connected to each building, the nearest being 1000 feet from the plant, by a network of tunnels. A single Trane absorption chiller cools most of the complex. Three large natural gas-fired, steam generators produce saturated steam at 100 psig with a condensate return of 190°F to heat the complex. Since the natural gas supply is interruptible, approximately 200,000 gallons of oil provide a back-up energy supply. A back-up electricity generator is available for use in case the primary electricity source cannot function. Due to the extremely large capacity of this system, central plant interface hardware will have a built-in capacity to accept and process all output from the 2000-square-foot array without sophisticated controls and/or high temperature storage. Several acres of land ideally suited for solar collectors lie immediately south of the power plant. Much of this land lies at a 40-degree slope falling away from the plant due south and overlooking a little-used railroad storage yard. The natural slope of the land would minimize intercollection shadowing without a high price for elevated structures. Collectors would be almost invisible from the complex, but well within walking distance for visitors. The railroad right of way to the south provides a relatively secure buffer zone to prevent encroachment of buildings to the south in the foreseeable future.

Four major areas of discussion are included in following sections:

15.1 Fluids Analysis
15.2 Methods of Counteracting Stagnation Conditions
15.3 System Concept Design
15.4 Phase II Program

Three fluid compositions are identified as potential collector coolants. Several methods for preventing damage to the collector array due to stagnation are discussed, and a preliminary system design is presented with estimated installation costs. A preliminary estimate of an accelerated program schedule is also presented.

15.1 Fluids Analysis

15.1.1 Introduction

This section details the results of a survey made to identify potential collector fluids and the selection of one fluid for use in a 3X concentrating solar collector. A search was conducted, ending in June 1978, among manufacturers of fluids identified for collector application and other fluids which indicated potential application, applying the following considerations for each:

- Viscosity - The allowable fluid viscosity limit for a 3X solar collector was identified in an earlier General Electric study. The report concluded that any fluid with a viscosity less than 0.055 ft^2/hr at operating temperature was acceptable on the basis of thermal performance. This limit was used as a screening element in comparing the various candidate fluids (see Table 21).

- Thermal conductivity - Prior study by General Electric concluded that the thermal conductivity at operating temperature should

TABLE 21
IDENTIFICATION OF POTENTIAL FLUIDS EVALUATED

FLUID	TYPE	MANUFACTURER/SUPPLIER
1. Therminol 44	Modified Ester Based	Monsanto Industrial Chem. Co.
2. Therminol 55	Syn. Hydrocarbon Mixture	Monsanto Industrial Chem. Co.
3. Therminol 60	Polyaromatic Compounds	Monsanto Industrial Chem. Co.
4. Therminol 66	Modified TER Phenyl	Monsanto Industrial Chem. Co.
5. Dowtherm G	Mixt. of Di & Tri aryl Ethers	Dow Chemical
6. Dowtherm HP	Aromatic Oil	Dow Chemical
7. Dowtherm J	Alkylated Aromatic	Dow Chemical
8. Caloria HT43	Refined Petroleum Oil	Exxon Co.
9. Mobiltherm 600	Petroleum (Mineral) Oil	Mobil Oil Corp.
10. Mobiltherm 603	Petroleum (Mineral) Oil	Mobil Oil Corp.
11. Sun 21	Paraffinic Oil	Sun Oil Co.
12. R Temp	High Molecular Weight Paraffinic Oil	RTE Corp.
13. MCS 1958	Developmental Chlorinated, Organic Fluid	Monsanto Industrial Chem. Co.
14. Drewsol	Water Miscible, Organic Heat Transfer Fluid/ Corrosion Inhibitor	Drew Chemical Co.
15. Sun-Temp	Nonaqueous Heat Transfer Fluid	Resource Technology Corp.
16. H-30c	Synthetic Hydrocarbon	Mark Enterprises, Inc.
17. Uniroyal PAO	Synthetic Polyalphaolefin	Uniroyal Chemical
18. Synfluids	Synthetic Polyalphaolefin	Gulf Oil Chemicals Co.
19. Ethyl ESH Series	Synthetic Polyalphaolefin	Ethyl Corp.
20. Syltherm 800	Stripped Silicone Oil + Additive	Dow Corning Corp.
21. UCON HTF 500	Partially Water Soluble UCON-Fluid	Union Carbide

be greater than 0.05 BTU-ft/hr-ft^2°F for thermal performance. This limit was incorporated into the screening process.

- Operating temperatures - Peak operating temperature was estimated at 400°F. Maximum stagnation temperature was given as 870°F for the 3X collector configuration. Based on Des Moines, Iowa weather data and extremes of ± 30°F, the lowest temperature would be about -8°F. A temperature of -10°F was arbitrarily established as the minimum for a pour or freeze point of the fluid to be evaluated further, and was factored into the screening process.

- Flammability properties - Since the average operating temperature was estimated as 400°F, Company analysts considered requiring flash and fire points significantly above 400°F to be appropriate. Properties of all candidate fluids are included in Table 22.

- Boiling or distillation temperature - From the standpoint of preventing high pressure buildup during operation, fluids showing a boiling or distilling temperature as high above 400°F as possible were emphasized.

- Other considerations - Data and information, in addition to the above, were collected for comparative purposes on the following elements:

  (1) Thermal Properties:
  - Recommended use temperature range
  - Autoignition temperature
  - Specific heat
  - Coefficient of expansion

  (2) Physical Properties:
  - Density
  - Vapor pressure

TABLE 22

THERMAL PROPERTIES

FLUID	USE TEMP., °F	FLASH POINT °F	FIRE POINT, °F	AUTO IGNITION POINT, °F	Cp BTU/lb.°F @400°F	K @400°F	COEF. OF EXPANSION, ML/ML/°C
1. Therminol 44	- 50 to 425	405	438	705	0.574	0.0651	8.0×10^{-4}
2. Therminol 55	0 to 600	355	410	675	0.611	0.0627	8.7×10^{-4}
3. Therminol 60	- 60 to 600	310	320	835	0.543	0.0681	8.2×10^{-4}
4. Therminol 66	0 to 650	355	382	705	0.534	0.0612	7.0×10^{-4}
5. Dowtherm G	12 to 650	305	315	>1,030	0.478	0.0720	-
6. Dowtherm HP	15 to 550	420	460	880	0.640	0.0705	-
7. Dowtherm J	-100 to 575	145	155	806	0.595	0.0680	-
8. Caloria HT43	15 to 600	400	~450	-	0.599	0.0555	-
9. Mobiltherm 600	- 5 to 600	350	390	-	0.560	0.0620	-
10. Mobiltherm 603	20 to 600	380	430	-	0.650	0.0695	-
11. Sun 21/25	0 to 600	440	490	715	0.650	0.0683	-
12. R Temp	- 20 to -	545	594	1,004	0.46(77°F)	0.0750	8.5×10^{-4}
13. MCS 1958	- 40 to 500	360	None	1,080	0.384	0.0550	4.4×10^{-4}
14. Drewsol	- 29 to 230	None	-	-	0.7 (77°F)	-	(to 500°F)
15. Sun-Temp	- 40 to 671	380	-	824	0.56 (77°F)	0.0700	-
16. H - 30C	- 40 to 620	360	-	-	0.60(250°F)	0.07-.075 (212°F)	-
17. UCON HTF 500	- 35 to 500	500	600	750	0.560	0.081	-
18. Uniroyal PAO-LV	- 80 to 600	395	425	-	0.50 (68°F)	0.0726 (68°F)	7.5×10^{-4}
19. Uniroyal PAO-10	- 40 to 600	400	500	-	0.50 (68°F)	0.0726 (68°F)	7.5×10^{-4}
20. Uniroyal PAO-20E	- 35 to 600	530	585	-	0.50 (68°F)	0.0726 (68°F)	7.5×10^{-4}
21. Synfluid PAO 4cs	-100 to 600	445	495	710	0.669	0.0737 (300°F)	4.5×10^{-4}
22. Synfluid PAO 6cs	- 90 to 600	465	520	710	0.590	0.0729	4.2×10^{-4}
23. Ethyl PAO ESH-4	<- 90 to 600	435	475	740	0.69 (392°F)	0.065 (392°F)	4.5×10^{-4}
24. Ethyl PAO ESH-6	<- 90 to 600	460	510	760	0.59 (392°F)	0.067 (392°F)	4.2×10^{-4}
25. Syltherm 800	- 40 to 795	310	380	820	0.460	0.072	-
26. Water	32 to -	None	None	None	1.080	0.382	-

(3) Operational Characteristics:
Materials compatibility
Temperature stability
Toxicity
Pollution potential
Disposibility
Maintenance/monitoring
Cost

As a result of the survey, 25 nonaqueous organic fluids were selected for comparative evaluation with each other and with water.

The types and manufacturers or suppliers of the potential fluids are listed in Table 21. Available data on the thermal properties of these fluids are given in Table 22. The properties covered include recommended use temperature, flash and fire points, autoignition point, specific heat and thermal conductivity at 400°F, and coefficient of expansion. Table 23 lists the physical properties which include available data on boiling point, pour or freeze point, and density, viscosity, and vapor pressure at 400°F. In Table 24, the screening process applied to all the fluids is delineated. The five fluids evolved in Table 24 are then compared in Table 25 for operational considerations such as materials compatibility, temperature stability, toxicity, pollution potential, disposability, maintenance and monitoring requirement, and cost per gallon.

15.1.2 Fluids Selection Process

Data and characteristics shown in the various tables included in this report were obtained from brochures and letters to or telephone conversations with manufacturers of the candidate fluids. The only experimental work performed was the fluid-asphalt shingle compatibility test on several available fluid samples, which is shown in Table 25. A discussion of major areas of the selection process follows.

TABLE 23
PHYSICAL PROPERTIES

FLUID	B. P., °F	POUR/ FREEZING POINT, °F	DENSITY, lb/FT^3, @ 400°F	VISCOSITY, FT^2/HR, 400°F	VAPOR PRESSURE, mm Hg, 400°F
1. Therminol 44	638 (10%)	- 80 (P)	48.7	0.0329	5.5
2. Therminol 55	635 (10%)	- 40 (P)	47.3	0.0399	18.2
3. Therminol 60	550 (10%)	- 90 (P)	54.6	0.0240	65.0
4. Therminol 66	643 (10%)	- 18 (P)	55.0	0.0376	20.0
5. Dowtherm G	575	- 18 (P)	59.6	0.0277	1.3 PSIA
6. Dowtherm HP	695	15 (P)	46.8	0.045	0.3 PSIA
7. Dowtherm J	358	<-100	44.4	0.0077	25.3 PSIA
8. Caloria HT43	700 (1%)	15 (P)	52.7	0.0568	28.5
9. Mobiltherm 600	645 (10%)	0 (P)	53.7	0.0454	200.0
10. Mobiltherm 603	705 (10%)	20 (P)	46.8	0.0473	75.0
11. Sun 21/25	720 (1%)	0/5 (P)	47.4	0.030	-
12. R Temp	-	- 22 (P)	54.6 (77°F)	0.0853	-
13. MCS 1958	620	- 40.5 (P)	70.5	0.0223	25.0
14. Drewsol	230	- 28.5	70.9 (77°F)	-	-
15. Sun-Temp	671	- 40.0	-	-	21.0
16. H-30C	620	- 40.0	46.2 (300°F)	0.0775 (300°F)	-
17. UCON HTF 500	-	- 35.0 (P)	56.7	0.1300	-
18. Uniroyal PAO-LV	-	- 80.0 (P)	51.9 (68°F)	0.0202	-
19. Uniroyal PAO-10	-	- 40.0 (P)	52.0 (68°F)	0.0581	-
20. Uniroyal PAO-20E	-	- 35.0 (P)	52.4 (68°F)	0.0853	-
21. Synfluid PAO-4cs	743 (10%)(1)	-100.0 (P)	45.0	0.0430	4.1
22. Synfluid PAO-6cs	802 (10%)(1)	- 90.0 (P)	45.1	0.0543	3.8
23. Ethyl ESH-4	779 (10%)(2)	- 90.0 (P)	43.7	0.0465	1.0
24. Ethyl ESH-6	819 (10%)(2)	- 90.0 (P)	44.1	0.062	0.7
25. Syltherm 800	> 670	- 40.0	48.4	0.050	<760 (670°F)
26. Water	212	32.0	52.7	0.0061	247 PSIA

Notes:
(1) Vacuum Distillation @ 1mm Hg adjusted to 760 mm.
(2) Vacuum Distillation @ 1mm Hg.
(P) Pour Point.

TABLE 24

SCREENING PROCESS

FLUIDS WITH K>0.05, BTU-FT./HR.FT.²°F	FLUIDS WITH VISCOSITY <0.055 FT.²/HR.	FLUIDS WITH POUR/FREEZE POINTS, °F<-10°F	FLUIDS WITH FLASH/FIRE POINTS, >400°F	10% DISTILLATION RANKING, °F	RANKING OF RECOMMENDED USE BULK TEMP., °F	VAPOR PRESSURE RANKING, mm Hg @ 400°F	RANKING OF Cp @ 400°F
Therminol 44	Water - 0.0061	Synfluid 4cs, -100	MCS 1958: 360, None	Synfluid 6cs - 802	Ethyl ESH-4 - 600	Ethyl ESH-4 - 1.0	Ethyl ESH-4 - 0.69
Therminol 55	Dowtherm J - 0.0077	Dowtherm J, -100	Synfluid 6cs, 465,520	Ethyl ESH-4 - 779	Synfluid 4cs - 600	Synfluid 6cs - 3.8	Synfluid 4cs - 0.67
Therminol 60	PAO-LV - 0.0202	Synfluid 6cs, - 90	Synfluid 4cs, 445,495	Synfluid 4cs - 743	Synfluid 6cs - 600	Synfluid 4cs - 4.1	Synfluid 6cs - 0.59
Therminol 66	MCS 1958 - 0.0223	Ethyl ESH-4, - 90	Ethyle ESH-4, 435,475	Therminol 44 - 638	MCS 1958 - 500	Therminol 44 - 5.5	Therminol 44 - 0.57
Dowtherm G	Therminol 60 - 0.0240	Therminol 60, - 90	Therminol 44, 405,438	MCS 1958 - 620	Therminol 44 - 425	MCS 1958 - 25	MCS 1958 - 0.38
Dowtherm HP	Dowtherm G - 0.0277	Therminol 44, - 80					
Dowtherm J	Sun 21 - 0.0300	PAO-LV, - 80					
Caloria HT43	Therminol 44 - 0.0329	MCS 1958, - 40.5					
Mobiltherm 600	Therminol 66 - 0.0376	Therminol 55, - 40					
Mobiltherm 603	Therminol 55 - 0.0399	Syltherm 800, - 40					
Sun 21	Synfluid 4cs - 0.0430	Therminol 66, - 18					
P Temp	Dowtherm HP - 0.0450	Dowtherm G, - 18					
MCS 1958	Mobiltherm 600 - 0.0454						
Sun-Temp	Ethyl ESH-4 - 0.0465						
M - 3CC	Mobiltherm 603 - 0.0473						
UCON HTF 500	Syltherm 800 - 0.0500						
PAO-LV	Synfluid 6cs - 0.0540						
PAO-10							
PAO-20E							
Synfluid - 4cs							
Synfluid - 6cs							
Ethyl ESH-4							
Ethyl ESH-6							
Syltherm 800							
Water							

TABLE 25
COMPARATIVE OPERATIONAL CHARACTERISTICS

	ETHYL ESH-4	SYNFLUID 4cs	SYNFLUID 6cs	THERMINOL 44	MCS 1958
MATERIALS COMPATIBILITY					
Effect on Metals (M^{G}/CM^{2}, 100 Hrs. @ 200°F):					
Al.	<-0.1	-	-	S to 400°F	ND
Cu	<-0.1	{-0.04 -0.22(3)	{-0.03 -0.09(3)	S to 400°F	ND
Steel	<-0.1	-0.05(3)	-0.66(3)	S	ND
Effect on Elastomers @ 200°F:					
Butyl Rubber (1)	+225	+225.49	-180.43	ND	ND
Neoprene (2)	-13	-13.32	-11.09	Fell Apart (4)	ND
Buna N (2)	-3.0	-3.05	-3.41	+28 (4)	ND
Silicone (1)	+17	+17.03	+10.59	+37 (4)	ND
Building Materials Asphalt Roofing	Light Yellowish Coloration (5)	Light Yellowish Coloration (5)	Very Light Yellowish Coloration (5)	ND	Immediate Attack At RT
Reaction with Air	ND	See Temp. Stability	See Temp. Stability	When Hot May Oxidize in Air. N_2 Blanketing Recommended.	ND
Reaction with Water	ND	Resistant to Hydrolysis, 96 Hrs. @ 200°F shows -0.1% Change in Viscosity.		Moisture Removal Recommended.	ND
TEMPERATURE STABILITY	ND	No Decomposition up to 611°F. Cincinnati Millicron Hydraulic Fluid Test, 168 Hrs. @ 300°F in air, shows 6-7% increase in Viscosity and 1-5MGS/100 ML Sludge.		Max. Bulk Temp. 425°F; Max Film Temp. 475°F	Successful Loop Tests >1,900Hrs @ 500°F
TOXICITY	Higher Viscosity Similar Hydrocarbon showed Oral LD50 (Mouse) is 57400MG/Kg. WT. Considered Nontoxic orally & dermally. Avoid contact with eyes.	Acute Oral LD50 (Rats) is >33600MG/KG Wt; TLV of $5MG/M^3$ for Oil Mist, Ordinary skin Contact Nontoxic; Avoid eye Contact & Prolonged Fume Inhalation. Considered relatively harmless.		Oral LD50 (Rats) is 13000MG/KG Wt; Dermal LD_{50} (Rabbits) is >7900MG/Kg Wt. Practically Nontoxic by ingestion in single doses & single Dermal Applications. Hot Vapors may be mildly irritating on prolonged exposure.	Acute Oral LD50 (Rats) is 8000 Mg/Kg Wt. Practically Nontoxic by Single Dose Ingestion.
POLLUTION POTENTIAL	No Serious Problem	No Serious Problem	No Serious Problem	No Serious Problem	ND
DISPOSABILITY	ND Should be Similar to Synfluids	Absorb & Scrape Up; Incinerate under Controlled Conditions, Observe Federal Spill & Water Quality Regulations; Biodegradable.		Observe Local Regulations	Biodegradable
FLUID MONITORING	ND Should be Similar to Synfluids	Fluid Analysis Every 3 Mos. in 1st Year, then Every 6 Mos.			ND
COST, $/GAL., 55 Gal. Drums	5.50	5.50	5.50	8.20	10 - 16

Notes:
(1) % Swell
(2) % Shrinkage
(3) 168 Hrs. @ 300°F in Air
(4) 166 Hrs. @ 302°F
(5) No Immediate Attack. Observations Made After One Hour Immersion @ RT.
ND - No Data
S - Satisfactory

- Flammability

Of the candidates, water is the only fluid without a flammability characteristic. Drewsol is indicated as nonflashing, but shows a high temperature limitation of only 230°F. MCS 1958 shows a flash point less than 400°F, but no fire point. Using requirements of greater than 400°F for the flash and fire points, pour or freeze points less than -10°F, and viscosity less than .055 ft^2/hr at 400°F in the screening process leaves only the Synfluids, Ethyl's ESH-4, and Therminol 44. MCS 1958 also was included based on its fire resistance which is considered to be of greater significance by the Solar Energy Industries Association (Reference 4) than the flash point. This approach is in contrast with the National Bureau of Standards' interim requirement (Reference 5) which states that "liquids used in solar-powered equipment shall not be heated to temperatures greater than 100°F below their flash points under either operating or nonflow conditions."

The following is given in Reference 6:

> "It is anticipated that the flash point requirement may be changed by the Department of Housing and Urban Development (HUD) to the less stringent provision given below recognizing the differing levels of hazard presented by different types of installations. However, before such changes can be made, HUD procedures require public review and comment.
>
> Proposed Revision
>
> "The Flash Point of a liquid heat transfer fluid shall equal or exceed each of the following temperatures:
>
> A. 100°F;
>
> B. 50°F above the maximum design operating temperature of the solar system;

C. 1) 200°F below the maximum stagnation temperature attained during the test required by Section S-515-2.1.2, provided that the collector manifold assembly is located outside the building and exposed to the weather;

2) The maximum stagnation temperature, as defined above, in all other manifold configurations."

"The rationale for the different values in item C is that a system leak under no-flow conditions is most likely to occur in the collector or in the collector manifold assembly. A lower flash point liquid will be acceptable when the manifold assembly is external to the building, since there is a significant lower hazard of ignition under such conditions. Where a leak could occur in an enclosed area which might have an ignition source (attic-located heater, fan, or other electrical device for instance), there is a higher hazard justifying a higher safety standard."

Even the proposed revision would be severely restrictive and difficult to apply in selecting a potentially usable nonaqueous-type fluid. However, if the fire points of fluids which are above 400°F are compared, MCS 1958 and the polyalphaolefin-type apparently offer a good margin (greater than 50°F) of safety above the 400°F operating temperature:

Fluid	Fire Point, °F
MCS 1958	None
Synfluid 6cs	520
Synfluid 4cs	495
Ethyl ESH-4	475
Therminol 44	438

The only one of the above fluids that would provide fire resistance at the no-flow temperature of 850°F appears to be MCS 1958. However, this fluid, with a flash point of 360°F, could not pass even the proposed revised requirement of 570°F. Therminol 44 is not classified as a fire resistant fluid. In this regard, the Monsanto literautre (Reference 7) specifically advises the use of protective devices to minimize fire risk. In addition, consultation with an insurance company is advised for guidance on the selection and sizing of fire protection equipment to safeguard the installation.

Leakage at high temperatures is an especially important consideration, particularly if the fluid passes into open cell insulation material. Therminol fluids exhibit a slow auto-oxidation reaction with air trapped inside the voids of the insulation at about 500°F. A possible catalysis occurs with insulating material ingredients, such as magnesium oxide, silicate-bonded asbestos or calcium silicate, that can result in ignition of the fluid. A possible fire can be prevented by removing and replacing the fluid-soaked insulation as soon as possible. Researchers claim that this effect seems to occur less with closed cell insulation.

- Materials Compatibility

Table 25 shows the only available data on compatibility of the five fluids, resulting from the screening in Table 24, with aluminum, copper, and steel. The data for 200°F and 300°F exposures for Ethyl ESH-4, Synfluid 4cs and 6cs indicate no gross attack, a satisfactory condition for Therminol 44 at 400°F, but no data are available for the developmental fluid MCS 1958. At 200°F, the Synfluid 6cs appears to show less effect on butyl rubber, neoprene, Buna N and silicone elastomers than the 4cs polyalphaolefins. Therminol 44 caused severe attack at 300°F on neoprene and significant swelling of Buna N and silicone.

A 1-inch by 1-inch section of typical asphalt shingle material was immersed at room temperature in each of five fluids available. The polyalphaolefins showed no immediate effect, while MCS 1958 attacked the asphalt sample, immediately turning black. After one hour, the Synfluid 6cs developed only a very light yellowish coloration in the original clear, waterwhite fluid, while the 4cs Synfluid and ESH-4 showed a light yellowish coloration. Therminol 44 was not tested, but if its reactivity is similar to Therminol 66, the effect on asphalt roofing material would be similar to MCS 1958. Only water and silicone fluids appear to be compatible with asphaltic roofing materials.

For open systems involving exposure to air and moisture, the nonaqueous fluids in general appear to be limited to 300°F. For higher temperature exposures, nitrogen blanketing and moisture removal from the system are ordinarily recommended.

- Temperature Use Range

While water shows many advantages as a heat transfer fluid, it has disadvantages in the low temperature limit of 32°F and in developing high vapor pressures at elevated temperatures; therefore, it requires a different system design approach. The nonaqueous fluids overcome these disadvantages but are susceptible to oxidation at high temperatures in air. A closed system, preferably with nitrogen blanketing, can significantly prevent organic fluid oxidative effects and extend their stability life. For example, even some silicone fluids exposed to air will increase in viscosity, as the temperature rises above 300°F, until a gel is formed within a few hundred hours at 250°C (482°F). If air is excluded or nitrogen blanketing is used, the silicone fluid will operate up to 250°C for extended periods of time with very little change in the original properties.

- Temperature Stability

There was very little data available on the long term stability of any of these fluids. Most of the statements made were qualitative, indicating that exposure of the fluid below the maximum temperature in closed systems will give excellent stability. Gulf reported that no decomposition was observed at temperatures up to 611°F for the polyalphaolefins. Performance of the Cincinnati Milacron Hydraulic Fluid test for 168 hours at 300°F in air, showed a six to seven percent increase in viscosity and one to five milligrams of sludge per 100 milliliters fluid (100 milligrams of sludge was considered the maximum for this test).

For Therminol 44, the recommended maximum bulk temperature is 425°F, while the maximum film temperature is 475°F.

- Toxicity

Based on the data included in Table 25 and using the widely accepted Sterner & Hodge acute toxicity classification system (Table 26), Therminol 44 and MCS 1958 may be considered practically nontoxic, while the three polyalphaolefins are relatively harmless, sometimes being referred to as synthetic mineral oils. The levels of toxicity shown in Table 26 refer to ingestion in a single dose. Single dermal applications are also considered relatively harmless for the polyalphaolefins. However, precautions are given to avoid prolonged vapor inhalation and eye contact. Hot vapors may be mildly irritating on prolonged exposure for the polyalphaolefins, Therminol 44, and MCS 1958.

- Pollution Potential and Disposibility

Each fluid listed in Table 26 has been described as not presenting a serious pollution hazard. A precaution is given in Reference 9 that Therminol fluids should be vented outside a building. No information was available on the developmental fluid MCS 1958. While water definitely does not present a pollution hazard, any corrosion inhibitors selected should be restricted to the nonpolluting type.

TABLE 26

STERNER & HODGE ACUTE TOXICITY

TERMINOLOGY & CORRELATION

ACTIVE TOXICITY CLASS	LD50 RAT ORAL AMOUNT/KG. WT. (1)	PROBABLE LETHAL ORAL DOSE FOR MAN
Extremely Toxic	1 mg.	A Taste
Highly Toxic	1-50 mg.	1 Teaspoon
Moderately Toxic	50-500 mg.	1 Ounce
Slightly Toxic	0.5-5 g.	1 Pint
Practically Non-Toxic	5-15 g.	1 Quart
Relatively Harmless	>15 g.	>1 Quart

Notes:

(1) LD50 is the lethal dose for 50% of the animals in a test group.

Ref: Solvents and Safety, J. M. Nielsen, Material Information Services, GE CR&D Center, Schenectady, N. Y., 1977.

No detailed information was obtained on the disposal of Therminol 44 or MCS 1958. The Material Safety Data Sheets (Form OSHA-20) prepared for the Synfluid polyalphaolefin fluids describe a procedure for spillage or leakage involving absorbing and scraping up, incinerating under controlled condition, and observing Federal spill and water quality standards. This procedure is a general one and undoubtedly applicable to many organic fluids. The economics of reclamation of any fluid would depend on the extent of contamination, the initial fluid cost, and the cost of reprocessing including packaging and delivery.

- Fluid Monitoring

Suggested monitoring frequency of fluids is given in Table 25. In the absence of data on the long term stability life of any of these fluids, quarterly sampling and testing during the first year is a wise precaution for maintaining close surveillance of the fluid in the early stages of a new application. The tests recommended are intended to detect the presence of contamination and degradation products and to develop some indication of the decomposition rate. After the first year of testing, the results should give a better indication for the necessary follow-on sampling frequency.

- Fluid Costs

The per gallon cost of the fluids shown in Table 25 is given for 55-gallon quantities. To bring the total cost for fluid used in a collector system into perspective, one must approximate the total fluid inventory. If 100 serpentines were involved in an installation, and about 1/3 gallon of fluid for each collector, the chart on the following page represents the comparative minimum fluid costs for an estimated total requirement of about 40 gallons.

FLUID	ESTIMATED TOTAL COST (in Dollars)
ESH-4	220
Synfluid 4cs	220
Synfluid 6cs	220
Therminol 44	328
MCS 1958	520

As shown above, the polyalphaolefin fluids offer a significant cost savings.

15.1.3 Screening of Fluids

To identify the optimum fluids for the application described in Section 15.1.1 from among the 26 selected for consideration, the screening process detailed in Table 24 was followed. Specific requirements identified for thermal conductivity and viscosity were used as the first two screening steps. Pour/freeze point and flash/fire point limits were arbitrarily selected and used as the second and third screening steps. This procedure resulted in the selection of five fluids: three saturated polyalphaolefin types, ESH-4, Synfluids 4cs and 6cs, and Therminol 44 and MCS 1958. These fluids were then ranked in the order of decreasing specific heat at 400°F, increasing vapor pressure at 400°F, decreasing temperature for the ten-percent distillation point, and decreasing recommended use bulk temperature to identify the fluids showing superior properties. The five fluids were further compared for operational characteristics in Table 25, and rated in a preferential order in Table 27 for each property and other considerations. Numbers were assigned for each consideration in a preferential order, 1 being the most preferable and 5 the least preferable. The ratings for each fluid were then added for a total value, showing the fluid with the lowest total as the most preferential. On the basis of the properties, materials compatibilities, toxicity, and cost, the polyalphaolefin type fluids ESH-4, Synfluids 4cs and 6cs emerge as preferable for the 3X collector operating

TABLE 27

RATING OF SCREENED FLUIDS FOR SPECIFIC CONSIDERATIONS

	ESH-4	SYNFLUID 4cs	SYNFLUID 6cs	THERMINOL 44	MCS 1958
Viscosity	4	3	5	2	1
Pour/Freeze Point	2	1	2	3	4
Flammability Props.	4	3	2	5	1
Distillation Props.	2	3	1	4	5
Max. Use Temp.	1	1	1	3	2
Vapor Pressure	1	3	2	4	5
Cp	1	2	3	4	5
K	2	1	1	3	4
Materials Compat.	2	2	1	3	3
Toxicity	1	1	1	2	3
Cost	1	1	1	2	3
Total Rating	21	21	20	35	36

Notes:
Numbers correspond to relative preferential rating for each consideration.
1 = Most Preferable
5 = Least Preferable
Based on Data in Tables, 2, 3, 4, 5, and 6.

conditions. While this type of fluid should show excellent stability up to 550°-600°F, exposure to the estimated stagnation temperature of 870°F should be avoided. Based on available data, the base stock Synfluids apparently begin to decompose at 611°F. It is quite possible that the addition of a small amount (approximately 0.1 percent) of oxidation inhibitor can increase the temperature resistance, but this approach would require experimental investigation.

Principal applications of the polyalphaolefin fluids have been in crankcase oils (Mobil 1 and Delvac 1), gear oils, hydraulic fluids, and compressor and gas turbine lubricants. The Ethyl Corporation is making plans to expand their production of these fluids. The Gulf Oil Chemicals Company is now manufacturing Synfluid 4cs and 6cs at a rate of about 500,000 gallons per year in their semi-works at Harmarville, Pennsylvania. A new 5,000,000-gallon per year Synfluid plant is due to begin operation near Houston in early 1980.

15.1.4 Conclusions and Recommendations

While water shows the best heat transfer properties, low cost, and no flammability or toxicity problems, the low temperature limit of 32°F without a drain-down system design and high vapor pressure at 400°F resulted in its elimination during the screening process.

Based on the overall requirements applied to the 25 nonaqueous fluids selected for evaluation, only five fluids emerge as potential candidates:

Ethyl ESH-4
Gulf Synfluids 4cs and 6cs
Monsanto's Therminol 44, MCS 1958

A comparison of overall properties and other considerations for the five fluids, as detailed in Table 27, shows the superiority of the polyalphaolefin-type fluids ESH-4, Synfluids 4cs and 6cs over Therminol 44 and

MCS 1958. The ratings applied to the polyalphaolefin fluids indicate that there are small differences among them, Synfluid 6cs being slightly superior overall. If the viscosity requirement is the prime consideration, Ethyl ESH-4 or Synfluid 4cs could be used.

While the viscosity of Synfluid 6cs is marginal compared to the stipulated requirement, it provides the highest flash and fire points, boiling point, and thermal conductivity, and the best overall materials compatibility. Its specific heat is slightly lower than the Ethyl and Synfluid 4cs fluids, but it is comparable on toxicity levels and cost, which is significantly lower than the cost of Therminol 44 or MCS 1958. The chemical stability of Synfluid 6cs, being a higher molecular weight blend, undoubtedly would be for a longer period of time, particularly if exposed to an operating temperature of 400°F under a blanket of nitrogen. However, since the decomposition temperature of the Synfluids has been found to be 611°F, exposure to the predicted stagnation temperature of 870°F must be avoided for long life stability.

If Synfluid 6cs, Synfluid 4cs or Ethyl ESH-4, is used in a test loop, a regular sampling and monitoring program is recommended. An initial sample should be taken after charging and circulating in the system, and then monthly sampling should be conducted. These samples should then be analyzed for the following:

Viscosity
Acid number
Appearance
Composition - carbon number distribution

Based on the test results obtained over a 6-month period, some prediction could be made for a longer interval monitoring period, e.g., every six or 12 months.

15.2 Methods of Counteracting Stagnation Conditions

Stagnation temperatures occur when the collector absorber is unable to transfer collected solar energy to the collector coolant and the system must reject this energy to the ambient environment. The inability to transfer heat in a normal manner may be due to a loss of coolant flow (hence the term "stagnation") or the loss of a heat sink for the collector coolant. The stagnation temperature predicted for this collector is approximately 800°F for the maximum possible insolation condition.

In the study discussed in the previous section, three fluid compositions were identified as potential collector coolants: Synfluid 4cs, Synfluid 6cs, and Ethyl ESH-4. These fluids will start vaporizing at about 500°F and 1 atmosphere pressure and be fully vaporized at about 800°F. Investigators do not know what repeated exposures to these temperatures would do to the stability, characteristics and usefulness of these fluids; therefore, they determined how repeated exposures can be avoided in the system until more high temperature experimental data are available.

There are three general failure modes that could result in stagnation temperatures: 1) loss of electrical power to the coolant pumps stopping coolant circulation, 2) a malfunction in the steam generating subsystem, preventing the transfer of heat from the collector coolant, and 3) a rupture of the collector coolant containment requiring the shutdown of coolant circulation. In attempting to shield the collector fluid from these failure modes, there are two alternatives: 1) prevent stagnation from occurring and 2) allow stagnation in the collector, but protect the fluid from the resulting temperatures. How each of these might be accomplished is discussed in the paragraphs below.

15.2.1 Preventing Stagnation

Providing auxiliary power is an obvious possibility for offsetting the loss of electrical power. The power required to operate the collector coolant pump and systems controls, and reject the collected energy through a natural convection, air-cooled radiator is estimated to be 1.5 to 3.0 kilowatt hours for the demonstration system. This amount of power can be supplied for a number of hours by a battery-inverter subsystem of reasonable size and cost. Most power outages are of relatively short duration, but in the event of a prolonged outage, the battery source would allow emergency operation for the remainder of the day until other procedures, such as covering or draining the collectors, could be accomplished manually to protect the system. The auxiliary power might be supplied by an existing emergency unit which would be satisfactory if the power outage was general for the area, but not if it was localized to the solar system only. If localized failure cannot be prevented by redundant circuits, then the battery-inverter auxiliary source is recommended. The inclusion of an auxiliary power source is only a partial solution to the larger problem of preventing stagnation temperature conditions because it would have no effect on the latter two failure modes presented.

Malfunctioning of the steam generating subsystems occurs when the normal heat transfer from the collector loop is interrupted. The consequences of this failure can be circumvented by providing an emergency heat rejection subsystem in parallel with the steam generating subsystem. Due to the high operating temperature level of the collector loop, the maximum required heat rejection rate can be obtained with a natural convection, air-cooled radiator. The required air-side surface area for an extended fin radiator is estimated to be about 0.35 square feet per square foot of collector area. For this program's system, this means a surface area of approximately 700 square feet. A three-way diverting valve would switch the coolant flow from the steam generator to the heat rejection radiator. This emergency heat rejection subsystem would be actuated whenever the controls subsystem detected an overtemperature condition in the collector loop for any reason. The requisite for its operation is the ability to circulate the collector fluid in its loop. The emergency subsystem should also be activated in the event of utility power loss so that auxiliary power would not have to supply electrical power to the steam generating subsystem.

One way of preventing stagnation conditions for all three failure modes is to shield the absorber element from the sun with an opaque cover over each collector. Previous studies at General Electric have investigated ways of accomplishing the covering action both manually and automatically. A spring-loaded rolled up industrial shade of vinyl nylon material was found to be the most cost effective method. The covering action would be done manually, or automatically with either a solenoid-actuated or thermostatically-actuated release. Manual covering would probably be too slow and impractical. The collector absorbers would reach 600°F about five minutes after the start of a stagnation incident. Since the demonstration system will run without an operating crew, it is not likely that a crew would arrive and be able to cover the 60-odd collectors in this time period. Manual installation of the covers is practical only when the collector array is being prepared for long-term shutdown. An automatically-released roll up shade installation was estimated to cost at least $4.00 per square foot of collector area, not including the equipment and operating costs of the actuators. If the actuators are normally "on" solenoids, there would be a constant electric power use and cost. A thermostatic actuator would not need electric power and could respond to a localized condition; a blocked passageway in a given collector, for example. Resetting the cores would require manual operation of a portable tool to rewind and recock the spring-loaded mechanism.

Another method of precluding stagnation conditions for all three failure modes is to "defocus" the collector by changing its tilt angle. The CPC-type of collector has a narrow acceptance angle for the incoming radiation, about 14 degrees for the design. This characteristic requires tilt angle adjustment about four times a year to maximize annual energy collection. At any time of the year, decreasing the tilt angle to the horizontal about 45 degrees would lower the insolation reaching the absorber element so that high stagnation temperatures could not occur. Gas spring rods, similar to the tailgate lifts on station wagons, actuated by rechargeable pneumatic cylinders are the most cost effective way of achieving the defocusing of the CPC-type collector. The cost is estimated at approximately $2.00 per square foot of collector area. The mounting structure of the collectors would have to accommodate the required rotation and provide seasonal adjustment of the linkage between the collector and the gas spring rod. A nitrogen gas cylinder and distribution manifold to each of the pneumatic actuators would also be required. Resetting the collector tilt angle would be accomplished in the same way that seasonal adjustments are made.

15.2.2 Protecting Collector Fluid from Stagnation Temperatures

Allowing the collector absorber elements, and not the collector fluid, to reach stagnation temperatures requires the removal of the fluid from the collector passages. This can be done by either natural drainage or forced purging with a compressed gas.

Draining the collectors at the start of a stagnation condition could protect some of the fluid from the resulting temperature levels. It would require a receiver tank below the grade level of the collector array and connecting valves to the array headers. Opening the valves would allow the displacement of cover gas in the drain tank with fluid from the collector array, and vice versa.

Two problems with this method are the time required for the drainage and the completeness of the fluid removal from the collectors. Because of the serpentine arrangement and small diameter of the collector passages, the time required to drain the collectors to a central tank will probably exceed the 5-minute grace period before the 600°F temperature level is reached in the absorbers. Providing multiple receiver tanks throughout the array would lessen the required time for the full scale system.

The vertical orientation of the U-tube serpentine in each absorber shroud hampers the complete drainage of the fluid from the collector. Some fluid would always be left in the lower leg of the tube. One factor alleviating this condition is the slightly pressurized inert gas cover in the collector loop expansion tank. This cover gas, replenished from a supply cylinder, could help purge the collector array from both ends toward the central drain tank. This action would remove some of the fluid that would not normally drain from the lower leg of the U-tube.

Another factor helping to remove the undrained fluid would be the initial stages of vaporization as the fluid heated up. This "boiling" would start around 500°F, and the large change in volume accompanying the vaporization would scrub the remaining fluid from the absorber region into the headers. Thus, most of the bulk fluid would be removed from the stagnation temperature area.

A general disadvantage for any fluid removal scheme is the film of fluid left on the walls of the collector tubing. This film will experience the stagnation temperature and either vaporize "cleanly" or decompose and perhaps leave a residue on the tube walls. Tests will be required to evaluate this possibility.

Forcing the fluid from the collectors by injecting compressed nitrogen gas at the top central crossover junction in each collector would remove the fluid fast enough to protect it from stagnation temperatures. The fluid could be displaced to the expansion tank; hence, a separate drainage tank is not necessary but perhaps still desirable. When purging is complete, return of the fluid into the collectors due to expansion tank pressure must be avoided, either with shutoff valves on the array main headers or by releasing the cover gas pressure in the expansion tank.

Injecting gas at each header would require a valve at each collector and a compressed gas distribution system. Satisfactory purging action may be achieved by introducing the compressed gas at the array inlet header and displacing the fluid in the direction of normal coolant flow to the expansion tank. This would undoubtedly take longer and the purging action would not be as complete as with the previous system, but the much simpler arrangement makes it the more practical design.

The greatest disadvantage to the forced purging procedure is that, in the event of a physical break in the collector coolant loop, a leak could be transformed into a pressurized stream of hot fluid. This would result in most of the loop coolant being sprayed into the immediate area, aggravating cleanup and pollution prevention.

15.2.3 Recommendations

- Provide an auxiliary power supply in the system design to allow continued operation of the system in the event of utility power loss.
- Incorporate an air-cooled radiator assembly as an emergency heat rejection subsystem. This subsystem would be in a bypass loop around the steam generator subsystem.
- Provide a receiver tank below grade in the center of the collector array to allow natural drainage of the collector fluid into the tank. Allow the cover gas in the expansion tank to help purge the collector fluid into the receiver tank. Allow initial vaporization in the collectors to displace the remaining fluid into the receiver tank.
- Perform tests on the candidate collector fluids to determine their behavior under repeated exposures of temperatures in the ranges of 400°F to 900°F.

15.3 System Concept Design

Figure 21 shows the proposed system schematic diagram. In operation, the collector coolant is pumped at a constant flow rate in a closed loop through the collectors to the steam generator and back to the pump. An expansion tank at the pump inlet allows space for fluid expansion and provides for a slight loop pressurization above ambient produced by an inert cover gas. Two bypasses around the steam generator are furnished: one contains an emergency heat rejection radiator and the other is used during startup and shutdown operations when the collector loop temperature is below the steam generator temperature.

The steam generator is an unfired unit boiler with a liquid-liquid heat exchange coil in place of the usual fossil-fired burner. As the water in the tank is heated, its vapor pressure increases until it just exceeds the steam pressure in the main system. At that point, the check valve CV3 opens, due to the slight pressure differential, and releases the solar steam to the main system. As steam is generated, the falling water lever is detected and the condensate valve and pump are activated to replenish the water inventory.

The proposed system design is simple in concept and efficient in operation. Steam is generated at the lowest possible useful pressure with only a simple water level control as the only active control in the steam subsystem. Likewise, the collector loop operates at its lowest possible temperature, adjusting naturally to the quantity of energy collected and the steam generator temperature. In this loop, no active control of loop conditions is necessary. With the loop operating at its lowest possible temperature, collector efficiency is always maximized for the existing insolation conditions.

15.3.1 Collector Loop Features

The following is an enumeration of pertinent design and/or control features in the proposed collector loop design.

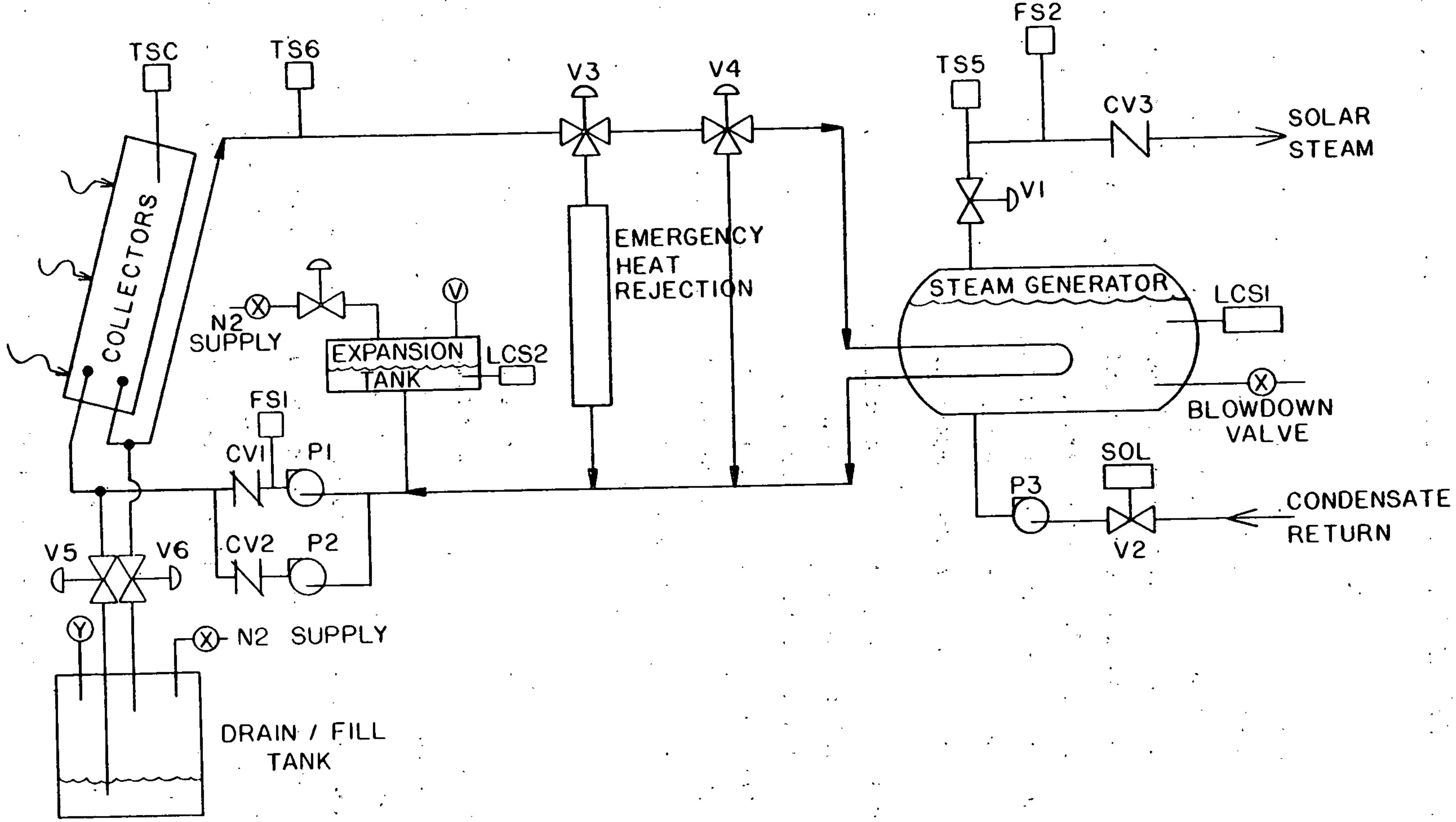


Figure 21. Proposed Phase II System Diagram

1) Two solar integrators operating in parallel turn on pump P1 when the solar insolation, integrated over a 15-minute time period, exceeds a set point. Two minutes later, pump P2 is prepared for operation. Subsequently, a failure in flow from P1, as detected by flow switch FS1, will automatically activate pump P2.

2) Although not shown on the figure, an auxiliary power supply provides system power in the event of a power failure.

3) Valve V4 is a thermostatically-controlled valve which will divert flow around the steam generator until the collector coolant temperature reaches a level above the operating temperature of the steam generator. Anytime the coolant temperature level falls below the set point, due to low insolation conditions, V4 will divert the flow around the generator.

4) Valve V3 is activated and the collector coolant diverted to the emergency heat rejection radiator whenever TS5 and TS6 detect overtemperature conditions in either the steam or collector loops. A manual switch can also be used to activate V3 at any time.

5) Drain valves V5 and V6 are opened whenever thermal switch TSC in the collectors detects an incipient stagnation condition, or level control switch LCS2 in the expansion tank detects a system leak through loss of coolant inventory. At the same time that the valves are opened, pumps P1 and P2 are deactivated to limit the quantity of fluid which could be exposed to stagnation conditions. A manual switch is also provided to activate the draindown system.

6) The maximum cover gas pressure in the expansion tank is controlled by the spring-loaded vent valve at a few psi above

ambient pressure. A minimum pressure is maintained by the pressure regulation valve on the nitrogen supply system at slightly above ambient pressure.

15.3.2 Steam Loop Features

1) The steam generator is a common, unfired package unit with an integrated condensate feed pump subsystem.

2) Shutdown valve V1 is closed whenever the collector loop pump is turned off, thus minimizing thermal losses from the steam generator to the transport piping.

3) The level control switch controls solenoid valve V2 and condensate pump P3 to maintain the water level in the steam generator between set limits.

4) Flow switch FS2 operates an indicator light denoting that solar-generated steam is being supplied to the main system.

15.4 Phase II Program

Design requirements were that the Phase II system would be a scaled down version of a large Phase III system which means that automatic controls, displays, 20-year life, and other similar features are needed. These requirements result in design activities that are of the same scope as those needed for the Phase III system.

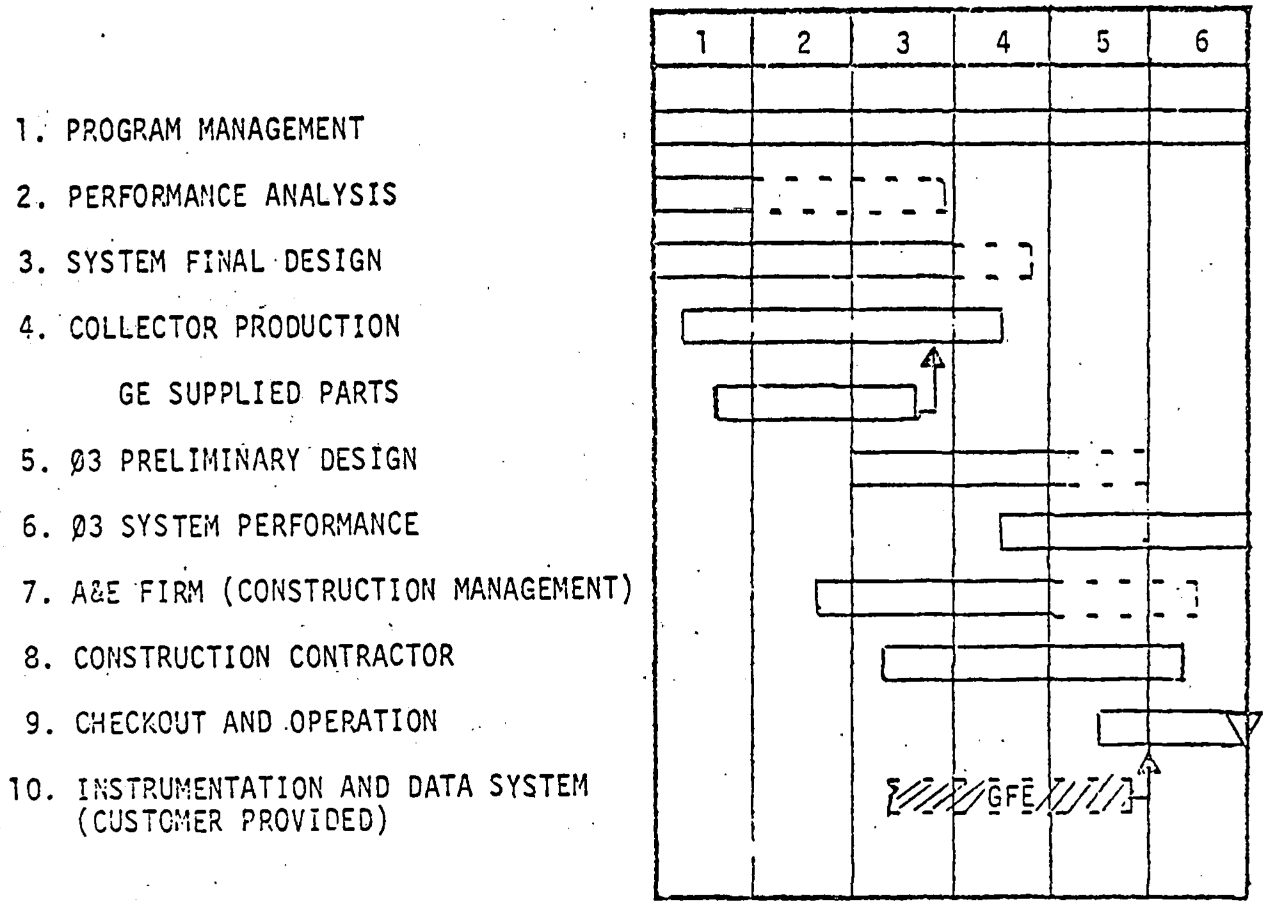
A preliminary cost estimate for the installation of the 2000-square foot pilot array is broken down as follows:

System Design		$ 25,000
Installation		50,000
Collector Production		150,000
	TOTAL	$225,000

The estimate assumes that the State will provide direct program management and all necessary site preparation. All collector racks, piping, controls, insulation, and so on are included in the above installation cost. Stagnation control requirements can be as extensive as desired, but the cost of this protection is not included in the estimate.

An accelerated program schedule is shown in Table 28. Investigators assumed that once the funds became available, the State would want to proceed as quickly as possible with system installation. This schedule would provide an installed and operating system six months after initiation of the program.

TABLE 28. PHASE II PROGRAM (ACCELERATED SCHEDULE)



16. CONCLUSIONS

The thermal performance of the collector is very good in the operating range of 250 to 450°F. Theoretical performance was predicted, and the model was proven to be exceptionally accurate.

Thermal performance verification tests conducted over a wide range of conditions provided consistent results.

There were no negative effects on performance caused by the stippled surface of the cover glass.

The cost effectiveness, in terms of energy output per dollar cost, has been optimized for the specified operating temperature of 400°F. The collector could be mass produced for a competitive cost, 18 to 30 dollars per square foot of aperture.

There is considerable room for performance improvement in the receiver and the cover glass. Reflectance losses off the cover and outer tube of the receiver could be reduced drastically if a fairly economical and durable antireflective treatment were available. The receiver absorbing surface and the heat transfer mechanism is inherently poor and offers room for more than considerable improvement.

The collector is a totally enclosed weatherproof unit which ensures that the optical properties of the reflector system and the receiver will remain stable through its 20-year minimum service life. The collector requires only four slope adjustments per year for optimum annual output; therefore, maintenance costs will be minimal.

17. RECOMMENDATIONS

The cost effective, mass producible collector developed for the subject contract should be field tested where required operating temperatures are 300 to 400°F. One such field test location is the Iowa State Capitol complex. The Department of Energy has rejected a proposal to install a 2000-square-foot prototype system at this site. The Company recommends a re-examination of the proposition in light of recent international developments. With a potential size of 200,000 to 400,000 square feet of collector area, the proposed system could be the largest of its kind in the world.

Funding for new receiver design and development efforts should be found. The performance of the CPC collector could be improved from 20 to 30 percent with a receiver incorporating changes as discussed in Section 13. Currently, the Company is undertaking a low level effort to develop an improved receiver, but without encouragement from the Department of Energy, this effort will remain low level. Chamberlain is aware of other companies' efforts to build an improved receiver; efforts which cannot be fully developed due to economic problems.

Research and development activity which combines and applies existing technologies to solar collector design and manufacture should be encouraged. The unsolicited proposal, submitted by Chamberlain in August 1979, for the design and fabrication of an improved evacuated receiver which could increase the efficiency of the 2.6X collector by 30 percent is one such activity.

NOMENCLATURE

A - Aperture area

A_1 - Area of absorber surface

A_2 - Area of outer glass receiver tube

ACON - Concentration ratio after truncation

F - Receiver shading factor

HG - Collector heat gain

I - Insolation rate

k - Thermal conductivity

n - Average number of reflections

RL - Radiation heat loss per ft^2 per hour

T_g - Temperature of outer glass

T_p - Temperature of absorber surface

W - Factor used to account for reflection losses off the outer glass of the receiver and the absorber

Z - Fluid-absorber thermal resistance correction factor

α - Absorptivity

γ - Diffuse insolation usability factor

ϵ_1 - Emissivity of absorber surface

ϵ_2 - Emissivity of outer glass receiver tube

ρ - Reflectivity

σ - Stefan-Boltzmann constant

τ_1 - Transmissivity of collector glazing

τ_2 - Transmissivity of outer glass receiver tube

ω - Hour angle

REFERENCES

1. A. Rabl, "Solar Concentrators with Maximal Concentration for Cylindrical Absorbers," Applied Optics, Vol. 15, No. 7, July 1976.

2. Sandia Laboratories, Report SAND 74-0241, "Effect of Aging on Acrylic Sheet."

3. Private Communication with David Zuel, Nor Ell, Inc., St. Paul, Minnesota, 16 June 1978 and 27 February 1979.

4. Letter from S. H. Butts, President of Solar Energy Industries Association to D. Waksman, National Bureau of Standards, 12 August 1977.

5. "Interim Performance Criteria for Solar Heating and Cooling Systems in Commercial Buildings," National Bureau of Standards, Report No. NBSIR 76-1187, November 1976.

6. Memorandum to Solar Transfer Fluid Manufacturers from D. C. Moore, HUD, 19 December 1977.

7. "Therminol Heat Transfer Fluids," Monsanto Industrial Chemical Company.

8. Frank Kreith, Principles of Heat Transfer, 3rd Edition, p. 260.

9. A. Rabl, "Comparison of Solar Concentrators," Solar Energy, Vol. 18, pp 93-111, 1976.

10. J. A. Duffie, W. A. Beckman, Solar Energy Thermal Processes, pp 14-55.

11. M. Collares-Pereira, et al, Compound Parabolic Concentrators with Nonevacuated Receivers: Prototype Performance and a Larger Scale Demonstration in a School Heating System, University of Chicago, Enrico Fermi Institute; presented to the International Solar Energy Society, New Delhi, India, January 1978.

APPENDIX A

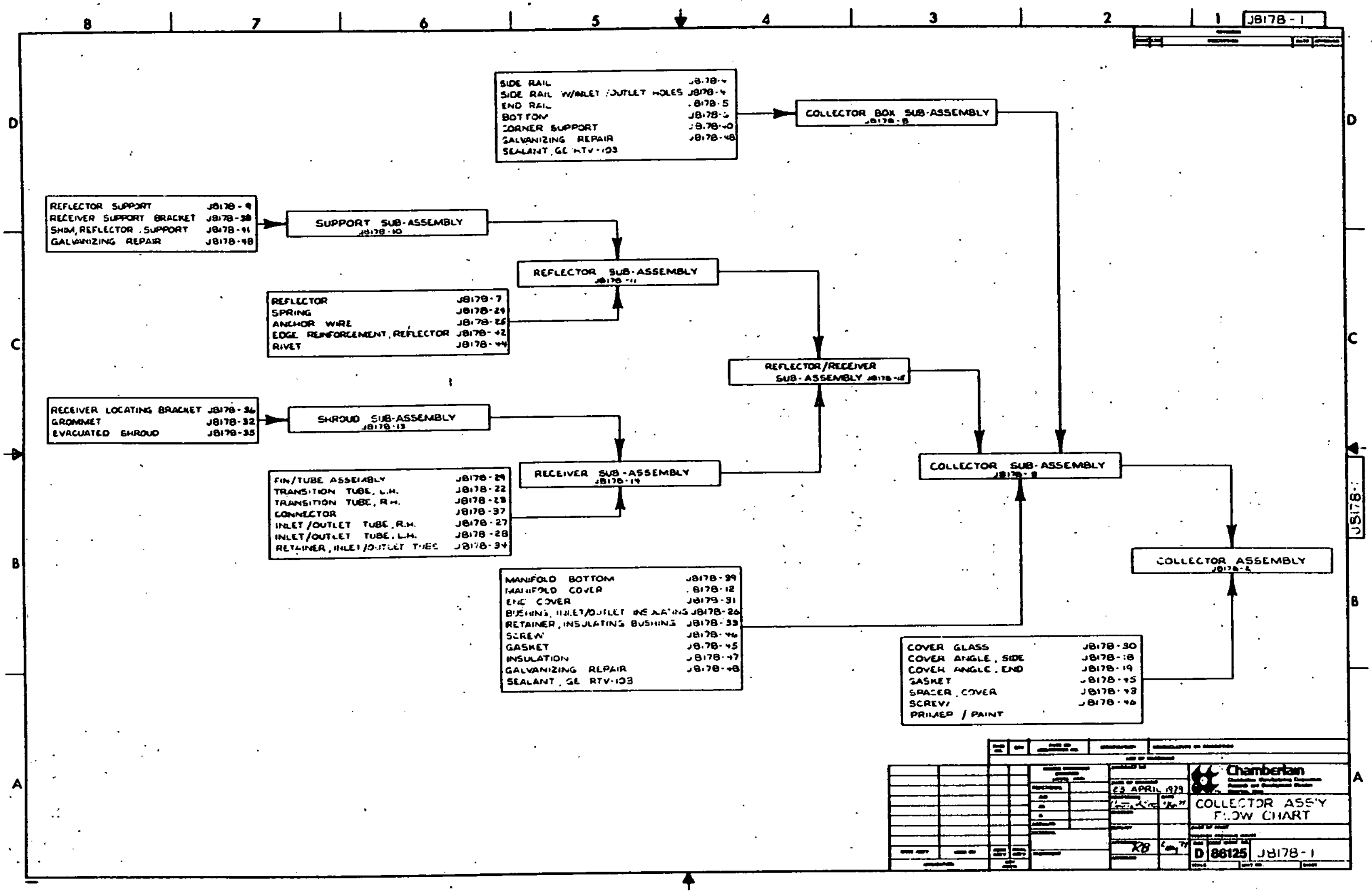
CHAMBERLAIN DRAWING PACKAGE

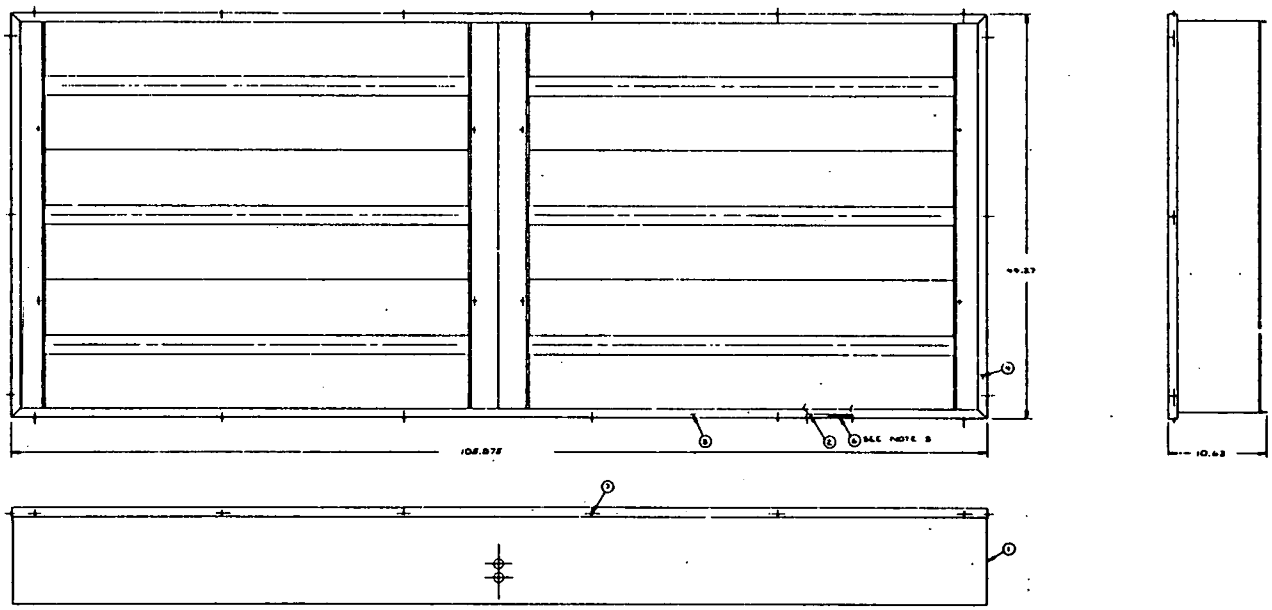
TABLE 29. DRAWINGS

NUMBER	DESCRIPTION	PAGE
J8178-1	Collector Assembly Flow Chart	A-3
J8178-2	Collector Assembly	A-4
J8178-3	Collector Subassembly	A-5
J8178-4	Side Rail	A-7
J8178-5	End Rail	A-8
J8178-6	Bottom	A-9
J8178-7	Reflector	A-10
J8178-8	Collector Box Subassembly	A-12
J8178-9	Reflector Support	A-13
J8178-10	Support Subassembly	A-14
J8178-11	Reflector Subassembly	A-15
J8178-12	Manifold Cover	A-16
J8178-13	Shroud Subassembly	A-17
J8178-14	Receiver Subassembly	A-18
J8178-15	Receiver/Reflector Subassembly	A-19
J8178-18	Cover Angle - Side	A-20
J8178-19	Cover Angle - End	A-21
J8178-22	Transition Tube - Left-Hand	A-22
J8178-23	Transition Tube - Right-Hand	A-23
J8178-24	Spring	A-24
J8178-25	Anchor Wire	A-25
J8178-26	Bushing, Inlet/Outlet Insulating	A-26

TABLE 29 (Continued)

NUMBER	DESCRIPTION	PAGE
J8178-27	Inlet/Outlet Tube - Right-Hand	A-27
J8178-28	Inlet/Outlet Tube - Left-Hand	A-28
J8178-29	Fin/Tube Assembly	A-29
J8178-30	Cover, Glass	A-30
J8178-31	End Cover	A-31
J8178-32	Grommet	A-32
J8178-33	Retainer, Insulating Bushing	A-33
J8178-34	Retainer, Inlet/Outlet Tube	A-34
J8178-35	Evacuated Shroud	A-35
J8178-36	Receiver Locating Bracket	A-36
J8178-37	Connector	A-37
J8178-38	Receiver Support Bracket	A-38
J8178-39	Manifold Bottom	A-39
J8178-40	Corner Support	A-40
J8178-41	Shim, Reflector Support	A-41
J8178-42	Edge, Reinforcement Reflector	A-42
J8178-43	Spacer, Cover	A-43
J8178-44	Rivet	A-44
J8178-45	Gasket	A-45
J8178-46	Screw	A-46
J8178-47	Insulation	A-47
J8178-48	Galvanizing Repair	A-48


SIDE RAIL J8178-4
SIDE RAIL W/INLET /OUTLET HOLES J8178-4
END RAIL J8178-5
BOTTOM J8178-6
CORNER SUPPORT J8178-40
GALVANIZING REPAIR J8178-48
SEALANT, GE RTV-103
COLLECTOR BOX SUB-ASSEMBLY J8178-8
REFLECTOR SUPPORT J8178-9
RECEIVER SUPPORT BRACKET J8178-38
SHIM, REFLECTOR SUPPORT J8178-41
GALVANIZING REPAIR J8178-48
SUPPORT SUB-ASSEMBLY J8178-10
REFLECTOR SUB-ASSEMBLY J8178-11
REFLECTOR J8178-7
SPRING J8178-29
ANCHOR WIRE J8178-26
EDGE REINFORCEMENT, REFLECTOR J8178-42
RIVET J8178-44
REFLECTOR/RECEIVER SUB-ASSEMBLY J8178-15
RECEIVER LOCATING BRACKET J8178-36
GROMMET J8178-32
EVACUATED SHROUD J8178-35
SHROUD SUB-ASSEMBLY J8178-13
RECEIVER SUB-ASSEMBLY J8178-14
FIN/TUBE ASSEMBLY J8178-29
TRANSITION TUBE, L.H. J8178-22
TRANSITION TUBE, R.H. J8178-23
CONNECTOR J8178-37
INLET/OUTLET TUBE, R.H. J8178-27
INLET/OUTLET TUBE, L.H. J8178-28
RETAINER, INLET/OUTLET TUBE J8178-34
COLLECTOR SUB-ASSEMBLY J8178-8
MANIFOLD BOTTOM J8178-39
MANIFOLD COVER J8178-12
END COVER J8179-31
BUSHING, INLET/OUTLET INSULATING J8178-26
RETAINER, INSULATING BUSHING J8178-33
SCREW J8178-46
GASKET J8178-45
INSULATION J8178-47
GALVANIZING REPAIR J8178-48
SEALANT, GE RTV-103
COLLECTOR ASSEMBLY J8178-4
COVER GLASS J8178-30
COVER ANGLE, SIDE J8178-18
COVER ANGLE, END J8178-19
GASKET J8178-45
SPACER, COVER J8178-43
SCREW J8178-46
PRIMER / PAINT
Chamberlain
23 APRIL 1979
COLLECTOR ASS'Y FLOW CHART
D 86125 J8178-1



NOTES
1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING".
2. UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES.
3. ITEM 6 TO BE INSERTED BETWEEN EDGE OF GLASS AND SIDE RAIL AT FINAL ASSEMBLY. ITEM TO BE THREE PLACES, CENTER AND BOTH ENDS, AND ON INLET/OUTLET SIDE OF COLLECTOR.

8	AR			PRIMER AND PAINT
7	16	J8178-46		SCREW
6	3	J8178-43		SPACER, COVER
5	AR	J8178-48		GASKET
4	2	J8178-19		COVER ANGLE, END
3	2	J8178-18		COVER ANGLE, SIDE
2	1	J8178-20		COVER GLASS
1	1	J8178-3		COLLECTOR SUB-ASSEMBLY

SEE SUB-ASSY

Chamberlain

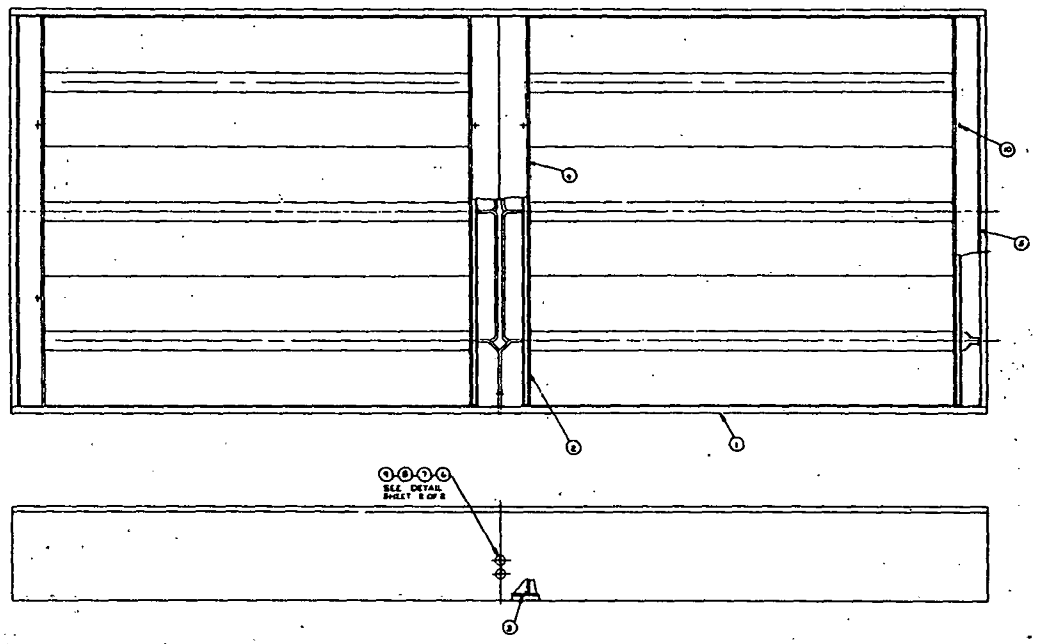
COLLECTOR ASSEMBLY

E 86125 J8178-2

J8178-2

A-4

J8178-3



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2. UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES.
3. REPAIR ALL SPOTWELD AREAS AND OTHER BREAKS IN GALVANIZE SURFACES WITH GALVANIZE REPAIR MATERIAL.

14	AR			SEALANT, GE RTV-102 OR EQUIV.
13	AR	J8178-48		GALVANIZING REPAIR
12	AR	J8178-47		INSULATION
11	AR	J8178-45		GASKET
10	16	J8178-46		SCREW
9	2	J8178-22,2		INLET/OUTLET TUBE
8	2	J8178-39		RETAINER, INLET/OUTLET TUBE
7	2	J8178-38		RETAINER, INSULATING BUSHING
6	2	J8178-26		BUSHING, INLET/OUTLET, INSULATING
5	2	J8178-31		END COVER
4	1	J8178-12		MANIFOLD COVER
3	1	J8178-39		MANIFOLD BOTTOM
2	1	J8178-8		REFLECTOR/RECEIVER SUB-ASSEMBLY
1	1	J8178-6		COLLECTOR BOX SUB-ASSEMBLY

Chamberlain

27 MAR

SEE DETAIL

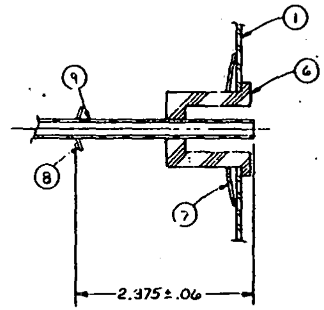
COLLECTOR SUB-ASSEMBLY

E 86126 J8178-3

J8178-3

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED



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2. UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE INCHES.

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9	1	J8178-27-28		INLET/OUTLET TUBE
8	1	J8178-34		RETAINER, INLET/OUTLET TUBE
7	1	J8178-33		RETAINER, INSULATING BUSHING
6	1	J8178-26		BUSHING, INLET/OUTLET INSULATING
1	1	J8178-8		COLLECTOR BOX SUB-ASSY

LIST OF MATERIALS

NEXT ASSY | USED ON — APPLICATION | NEXT ASSY | FINAL ASSY — QTY REQ'D

UNLESS OTHERWISE SPECIFIED LIMITS ARE: FRACTIONAL .000 .00 .0 ANGULAR

MATERIAL

TREATMENT

CONTRACT NO.

DATE OF DRAWING 14 MARCH 79

DRAFTSMAN P STOCKS DATE 3-14-79

CHECKER

QUALITY

APPROVED TCB 21 Mar 79

APPROVED

Chamberlain
Chamberlain Manufacturing Corporation
Research and Development Division
Waterloo, Iowa

INLET/OUTLET DETAIL

DATE OF PRINT

DESTROY PREVIOUS ISSUES

SIZE C CODE IDENT NO. 86125 J8178-3

SCALE FULL UNIT WT. SHEET 2 OF 2

J8178-3

J8178-4

ZONE	LTR	DESCRIPTION	DATE	APPROVED
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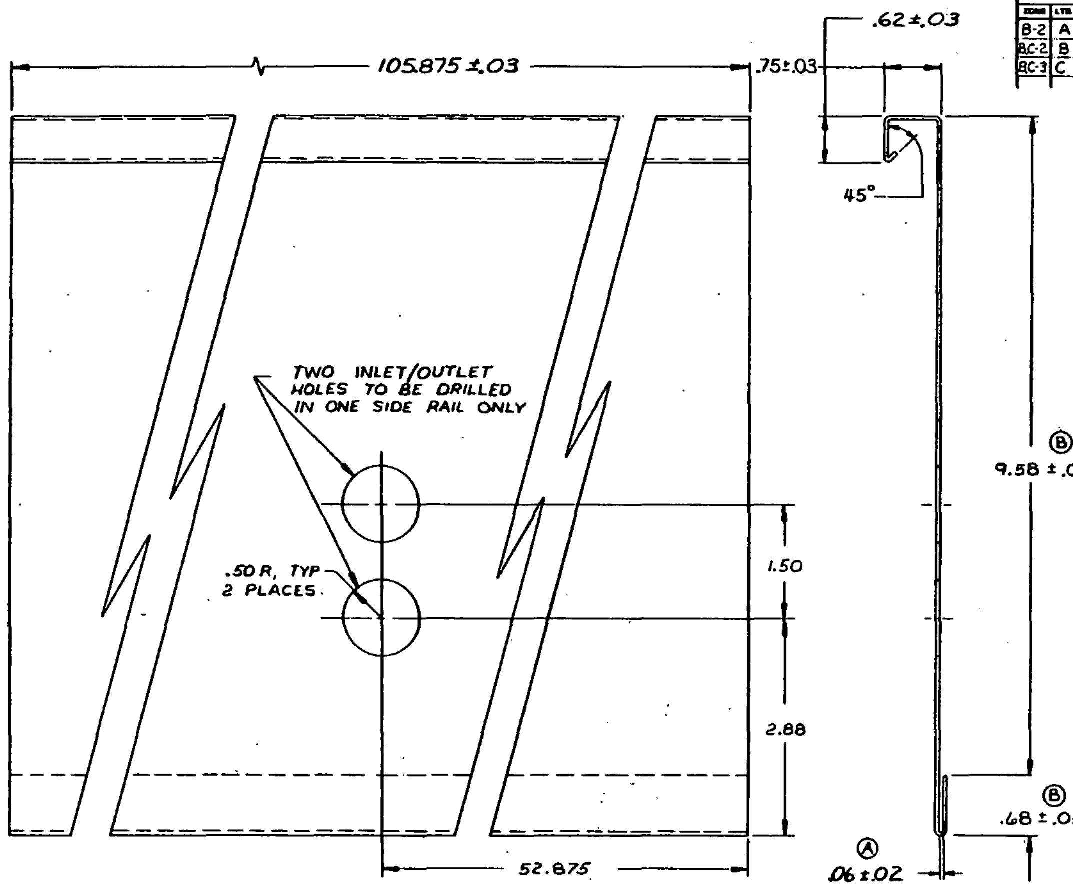
BC-2	B	WAS .75 ± .10 & WAS 9.10 ± .03	9 APR 79	
BC-3	C	ADDED INLET/OUTLET HOLES	4 APR 79	



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2- UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
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   HARDNESS: ROCKWELL "B" 35-60
   COATING DESIGNATION: G90
   BLANK WIDTH: 12.00
4- ALL BEND RADII .03.

FIND NO.	QTY	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED LIMITS ARE: FRACTIONAL .000 .00 .0 ANGULAR

MATERIAL: NOTE 3
TREATMENT

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CONTRACT NO. 4239
DATE OF DRAWING 13 JULY 1978
DRAFTSMAN GGB — DATE 13 JULY 78
CHECKER
QUALITY
APPROVED KB — 20 JUL 78
APPROVED

Chamberlain
Chamberlain Manufacturing Corporation
Research and Development Division
Waterloo, Iowa

SIDE RAIL

DATE OF PRINT
DESTROY PREVIOUS ISSUES

SIZE C | CODE IDENT NO. 86125 | J8178-4

SCALE FULL | UNIT WT. | SHEET

J8178-5

REVISIONS

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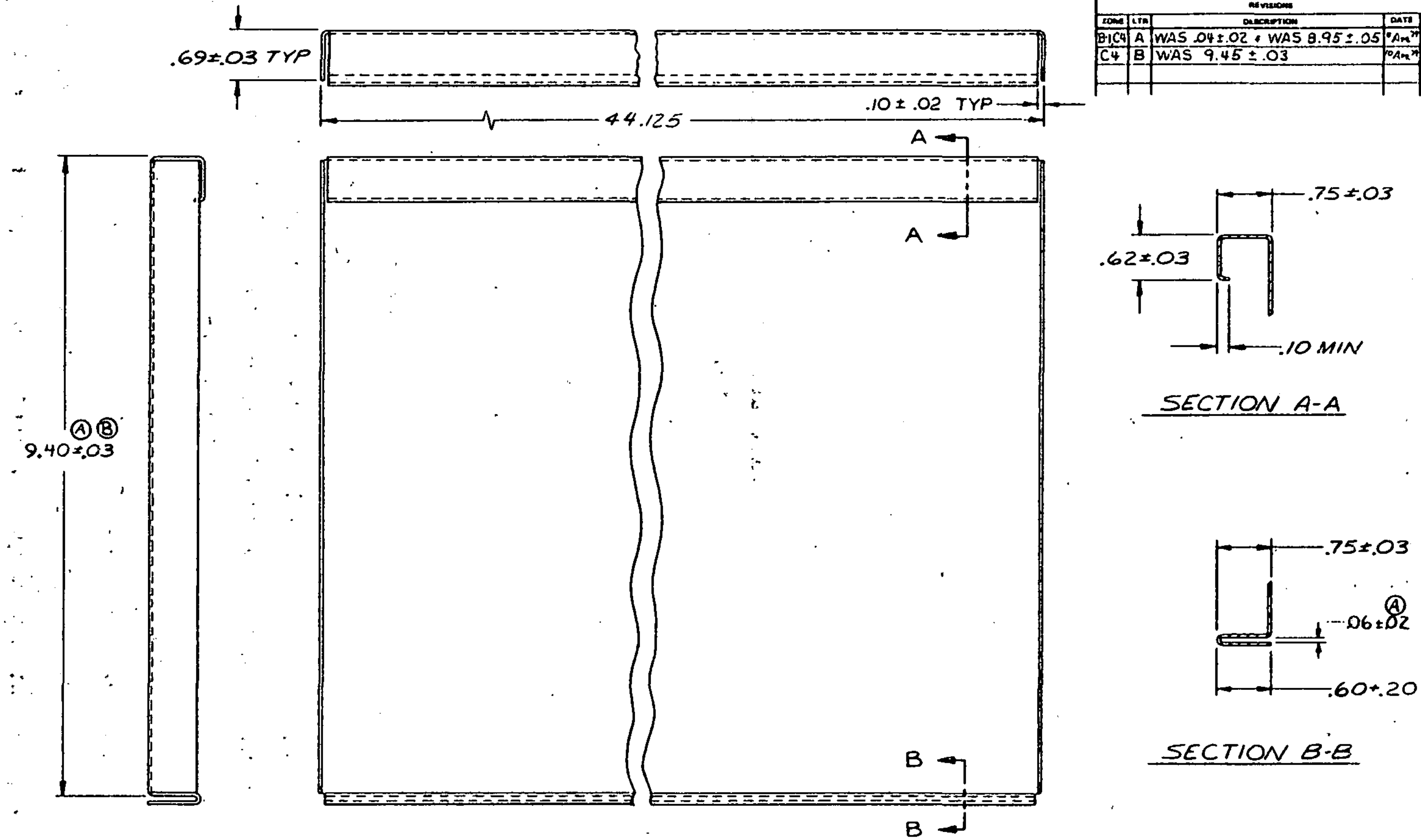

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   HARDNESS: ROCKWELL "B" 35-60
   COATING DESIGNATION: G 90
   BLANK WIDTH: 12.00
4- ALL BEND RADII .03.

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DATE OF DRAWING	14 July '78
DRAFTSMAN	GGB — DATE 10 July 78
CHECKER	
QUALITY	
APPROVED	CB 20 Jul 78
APPROVED	
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NEXT ASS'Y / FINAL ASS'Y	QTY REQ'D

Chamberlain
Chamberlain Manufacturing Corporation
Research and Development Division
Waterloo, Iowa

END RAIL

DATE OF PRINT

DESTROY PREVIOUS ISSUE:

SIZE C | CODE IDENT NO. 86125 | J8178-5

SCALE FULL | UNIT WT. | SHEET

J8178-6

REVISIONS				
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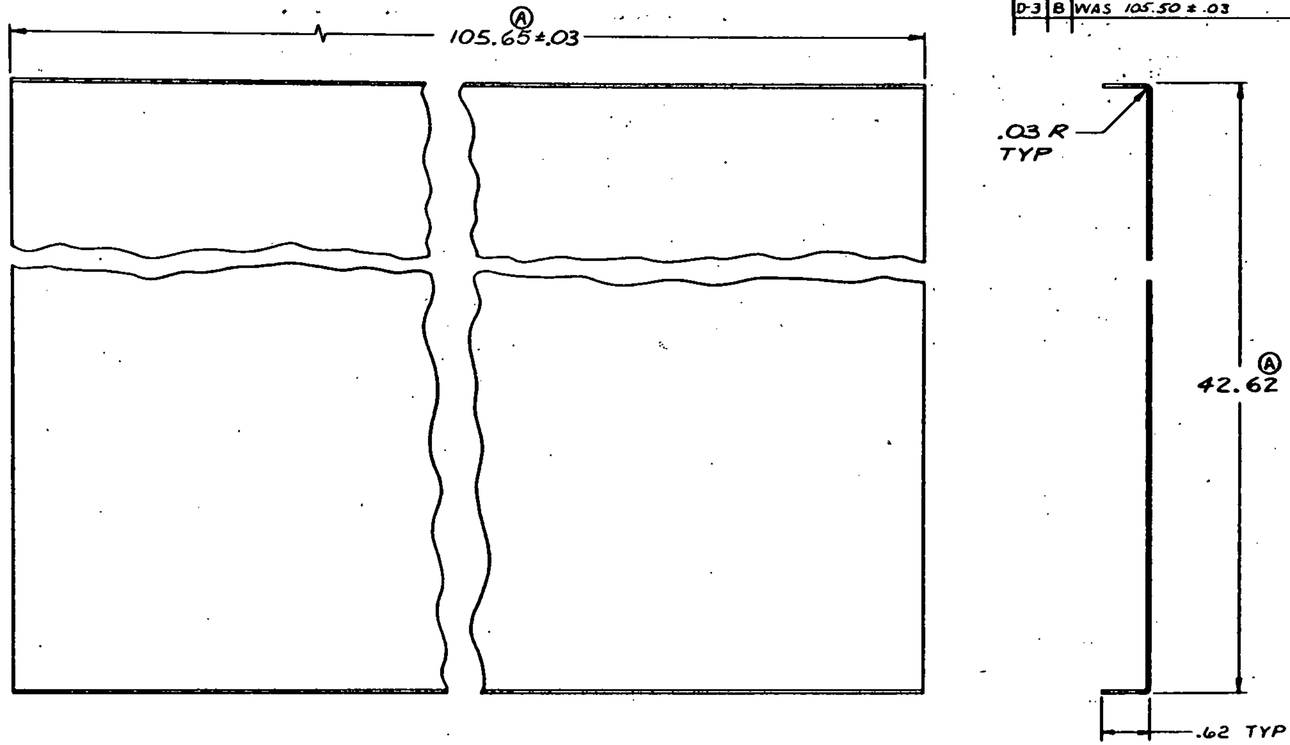
D-3	B	WAS 105.50 ± .03		RB



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2- UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.

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THICKNESS: .021 NOMINAL (26GA)
HARDNESS: ROCKWELL "B" 35-60
COATING DESIGNATION: G90

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LIST OF MATERIALS				

UNLESS OTHERWISE SPECIFIED LIMITS ARE:	FRACTIONAL / .XXX / .XX / .X / ANGULAR
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TREATMENT	
CONTRACT NO.	
DATE OF DRAWING	13 JULY 1978
DRAFTSMAN	GGB
DATE	13 JULY 78
CHECKER	
QUALITY	
APPROVED	RB
APPROVED	
Company	Chamberlain — Chamberlain Manufacturing Corporation, Research and Development Division
Title	BOTTOM
DATE OF PRINT	
DESTROY PREVIOUS ISSUES	
SIZE	C
CODE IDENT NO.	86125
Drawing no.	J8178-6
SCALE	FULL
UNIT WT.	
SHEET	
NEXT ASS'Y / USED ON / APPLICATION	
NEXT ASS'Y / FINAL ASS'Y / QTY REQ'D	

J8178-6 B

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	DEAD SOFT	8-18	

J8178-7

X,Y COORDINATES FOR CURVE SURFACE (AS INDICATED)

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0.0100	-1.1131
0.0200	-1.1131
0.0300	-1.1131
0.0400	-1.1131
0.0500	-1.1131
0.0600	-1.1131
0.0700	-1.1131
0.0800	-1.1131
0.0900	-1.1131
0.1000	-1.1131
0.1100	-1.1130
0.1200	-1.1130
0.1300	-1.1130
0.1400	-1.1130
0.1414	-1.1130
0.1504	-1.1217
0.1590	-1.1302
0.1694	-1.1390
0.1795	-1.1474
0.1899	-1.1550
0.2006	-1.1645
0.2117	-1.1730
0.2232	-1.1811
0.2356	-1.1899
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0.2597	-1.2066
0.2727	-1.2149
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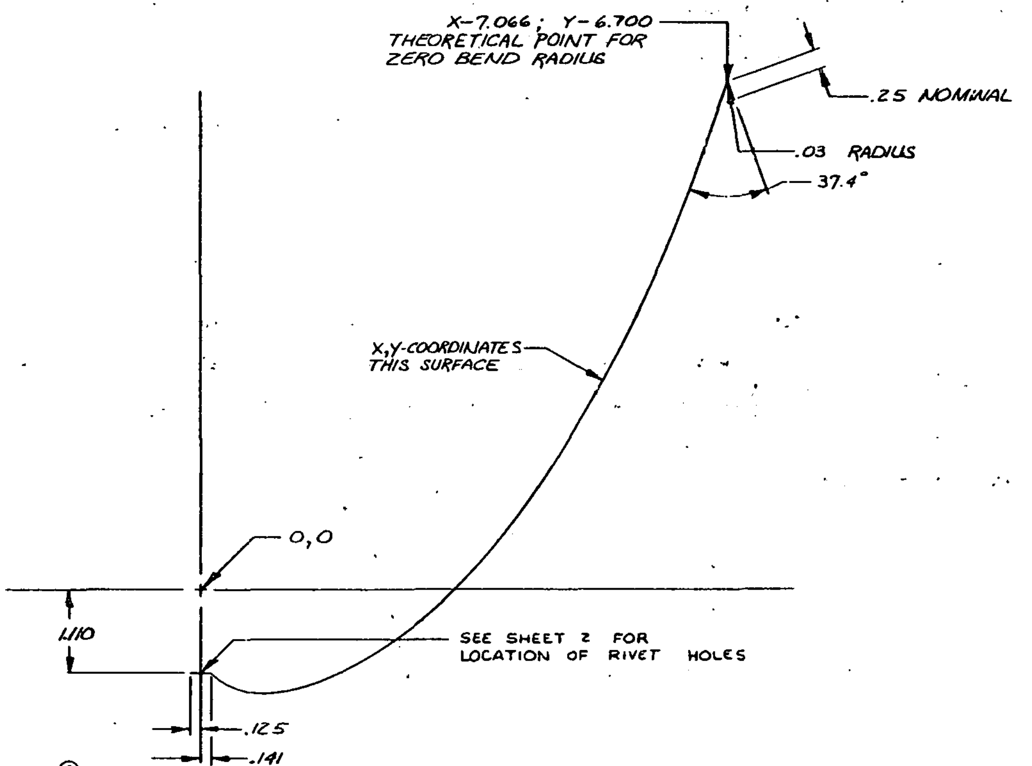


1. MATERIAL : KINGLAX TYPE C-4, .020 THK, Ⓐ(TEMPER H-18) WITH .002 VINYL PEEL OFF;(TOTAL THK. .022)
2. BLANK WIDTH: 12.0 INCHES
3. REFLECTOR LENGTH: 46.18 ± .06 INCHES

FIND NO.	QTY	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED LIMITS ARE: FRACTIONAL .000 .00 .0 ANGULAR

MATERIAL: SEE NOTE 1

TREATMENT

CONTRACT NO. 4239

DATE OF DRAWING 14 JULY 1978

DRAFTSMAN NJH DATE 14 July 78

CHECKED

QUALITY

APPROVED RB 17 Jul 78

APPROVED

NEXT ASSY | USED ON | APPLICATION | NEXT ASSY | FINAL ASSY | QTY REQ'D

Chamberlain — Chamberlain Manufacturing Corporation, Research and Development Division, Waterloo, Iowa

REFLECTOR

DATE OF PRINT

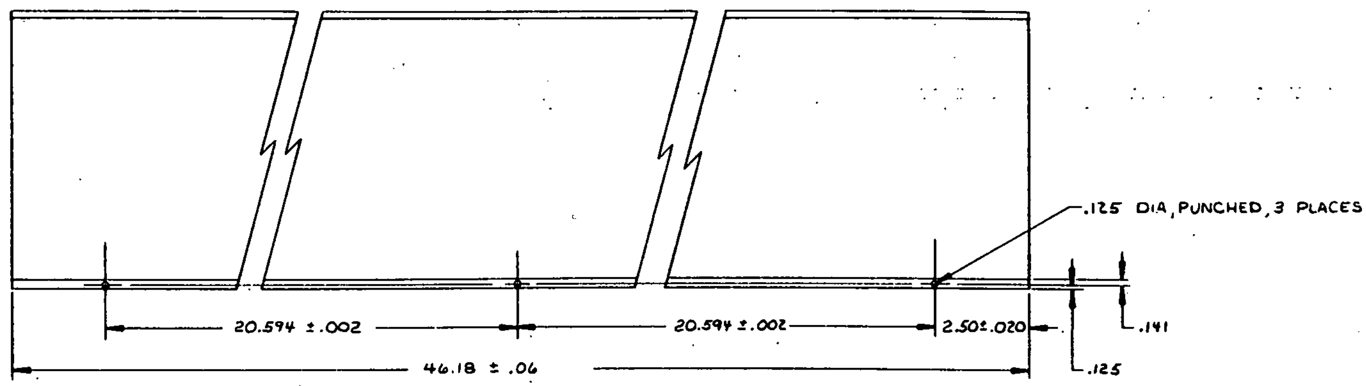
DESTROY PREVIOUS ISSUES

SIZE C CODE IDENT NO. 86125 J8178-7

SCALE | UNIT WT. | SHEET 1 OF 2

J8178-7 REV A

J8178-7



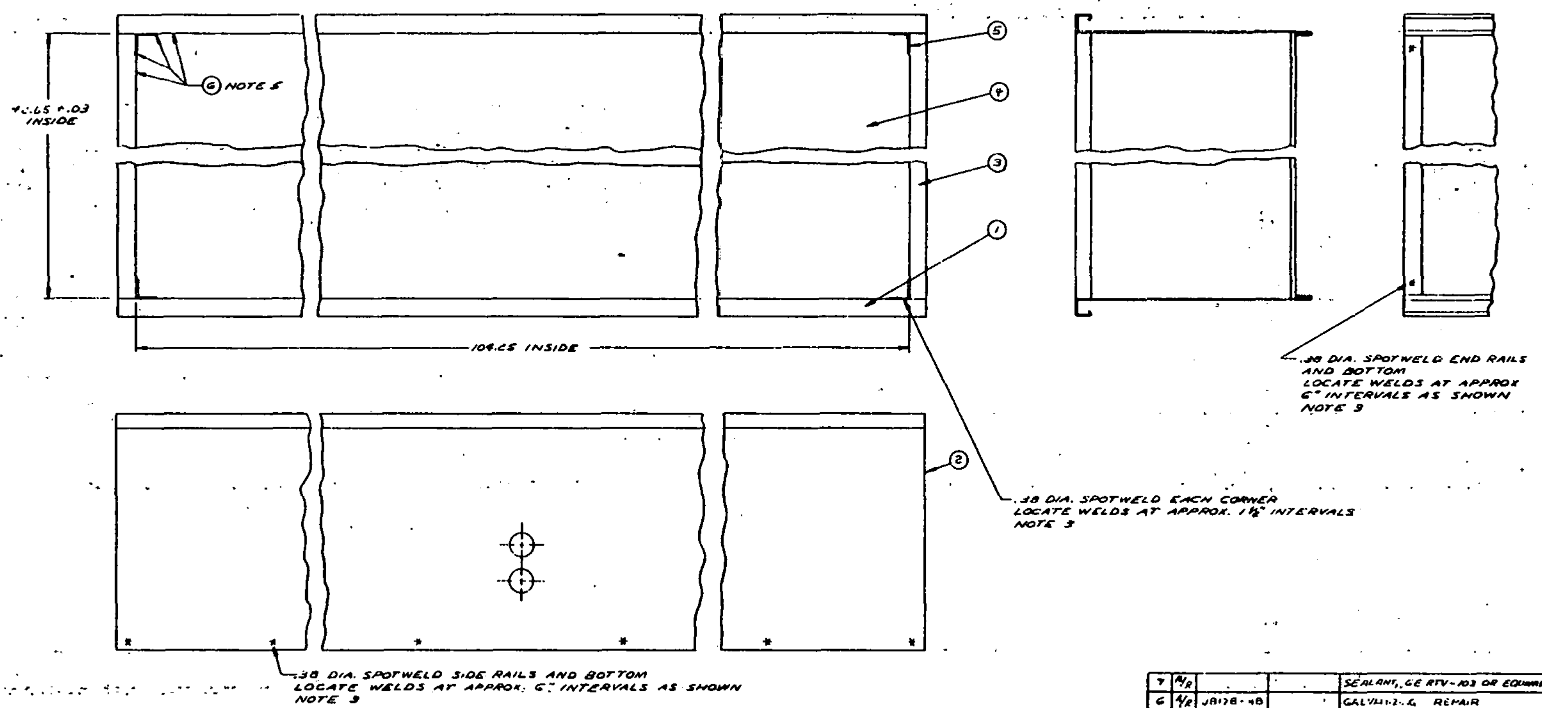
NOTES:

1. MATERIAL .020 THK, KINGLAX TYPE C 4, (TEMPER H18) WITH .002 VINYL PEEL-OFF; (TOTAL THK .022)
2. BLANK WIDTH : 12.0 INCHES
3. SEE SHEET 1 FOR CONTOUR.

DATE OF DRAWING	18 JULY 78
MATERIAL	NOTE 1
APPROVED	PB 20 Jul 78
	Chamberlain
TITLE	REFLECTOR (TOP VIEW)
SIZE	C
CODE IDENT NO.	86125
DRAWING NO.	J8178-7
SCALE	1/2
SHEET	2 OF 2

J8178-7

J8178-8



NOTES:

1- INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING.
2- UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3- REPAIR ALL SPOTWELD AREAS AND OTHER BREAKS IN GALVANIZE SURFACES WITH GALVANIZING REPAIR MATERIAL.
4- MAXIMUM .015 MISALIGNMENT PERMISSIBLE BETWEEN TOP SURFACES OF SIDE RAILS AND END RAILS AT EACH BOX CORNER.
5- APPLY SEALANT TO ALL INTERIOR JOINT LINES AS SHOWN FOR LEAKPROOF CONSTRUCTION.

ITEM NO.	QTY	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION
7	A/R			SEALANT, GE RTV-103 OR EQUIVALENT
6	A/R	J8178-48		GALVANIZING REPAIR
5	4	J8178-40		CORNER SUPPORT
4	1	J8178-6		BOTTOM
3	1	J8178-5		END RAIL
2	1	J8178-4		SIDE RAIL W/INLET/OUTLET HOLES
1	2	J8178-4		SIDE RAIL

LIST OF MATERIALS

SEE DETAILS

12 February '79

P STOCKS 2-13-79

KB

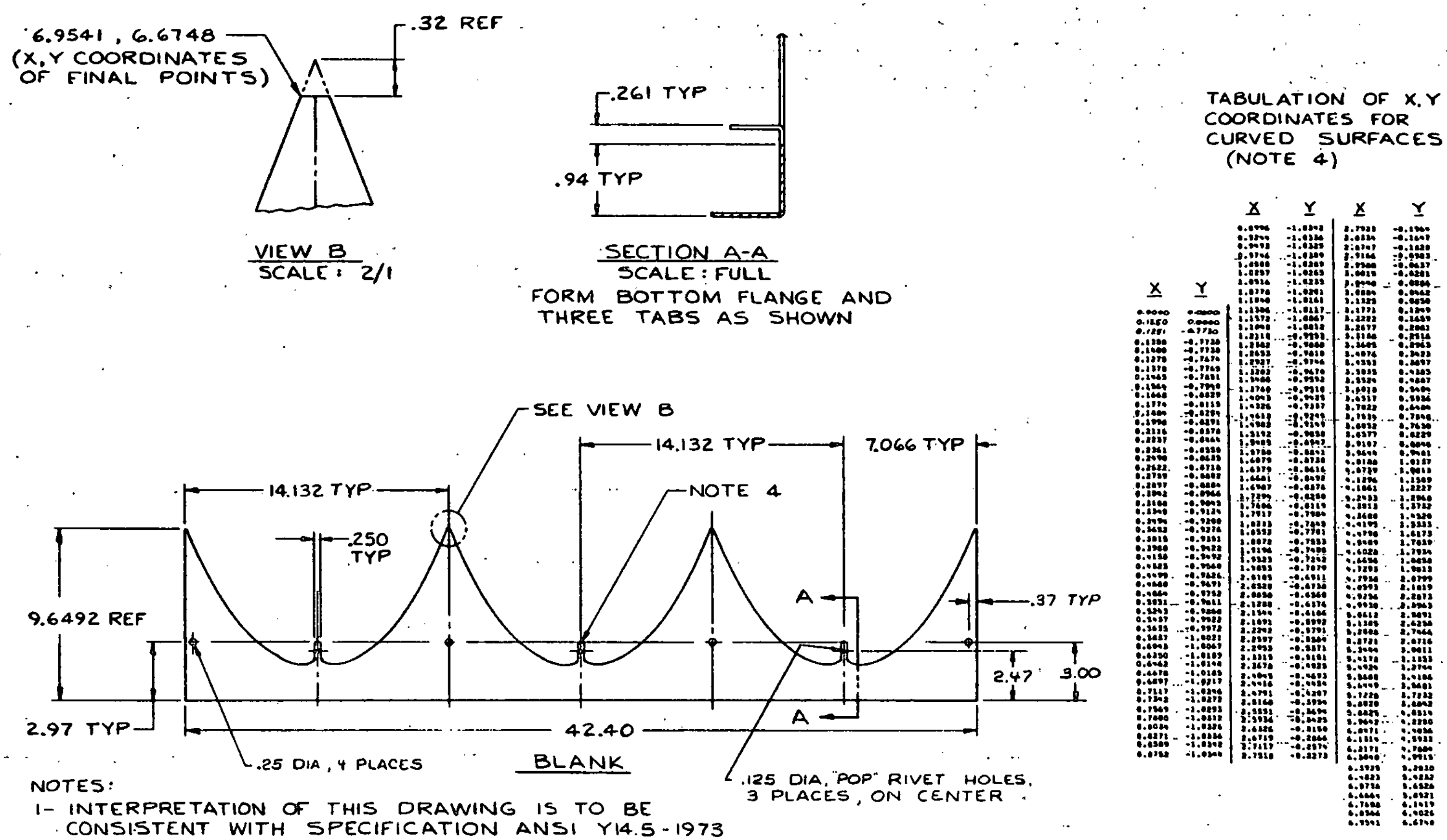
Chamberlain

COLLECTOR BOX SUBASSEMBLY

D 86125 J8178-8

SCALE 1/2

J8178-9



NOTES:

1- INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING".
2- UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3- MATERIAL: STEEL SHEET, ZINC COATED (GALVANIZED), COMMERCIAL QUALITY PER ASTM A526-71
   THICKNESS: .050 NOM. (18 GA)
   HARDNESS: ROCKWELL "B" 35-60
   COATING DESIGNATION: G90
4- ORIGIN OF COORDINATES (0,0) FOR EACH CURVE AT END OF TAB ON CENTERLINE.

FIND NO.	QTY	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED LIMITS ARE: FRACTIONAL .000 .00 .0 ANGULAR

MATERIAL: NOTE 3

TREATMENT

CONTRACT NO. 4239

DRAFTSMAN GGB — DATE 17 JULY 78

CHECKER

QUALITY

APPROVED RB — 17 JUL 78

APPROVED

Chamberlain — Chamberlain Manufacturing Corporation, Research and Development Division

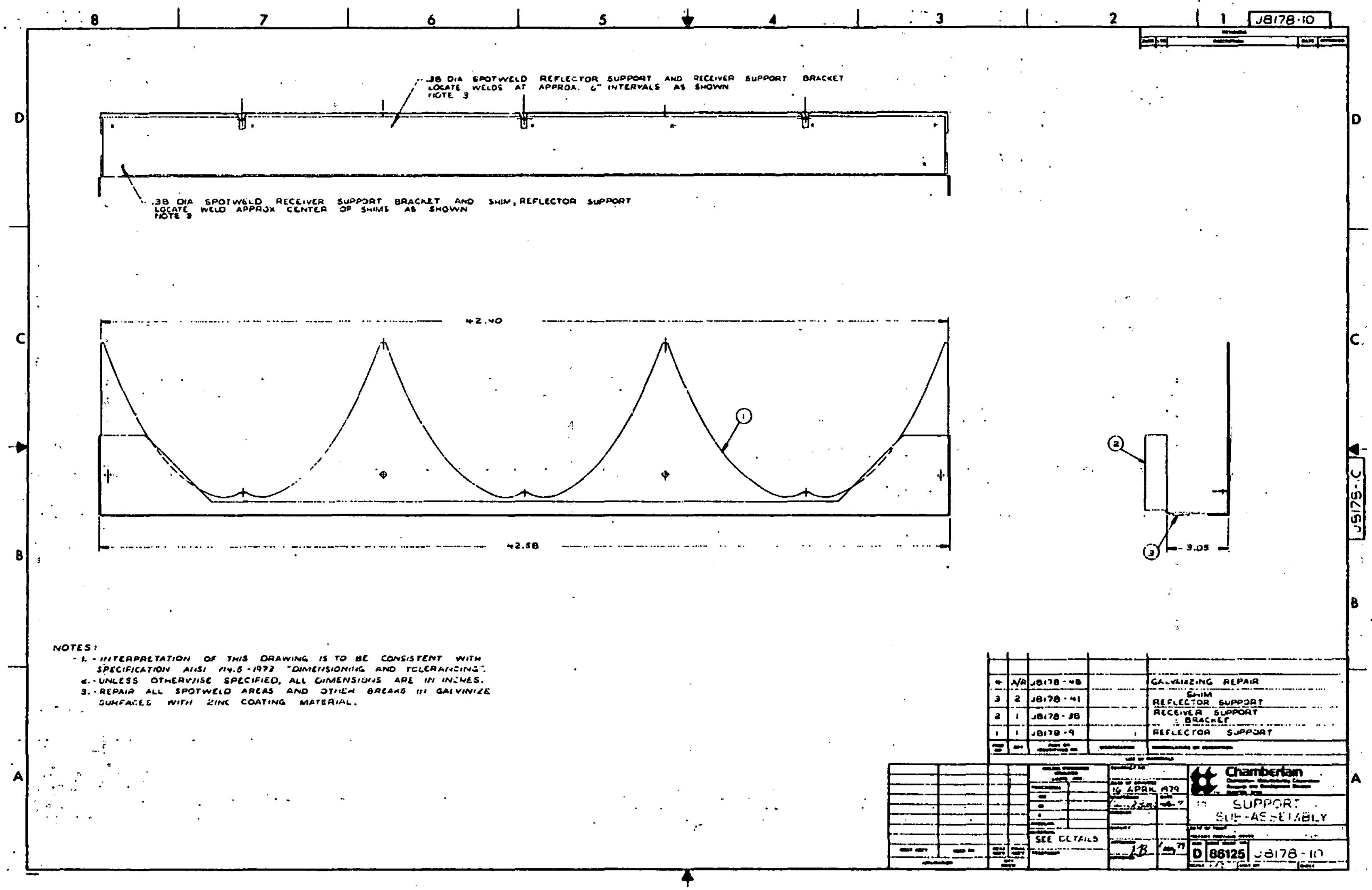
REFLECTOR SUPPORT

SIZE C — CODE IDENT NO. 86125 — J8178-9

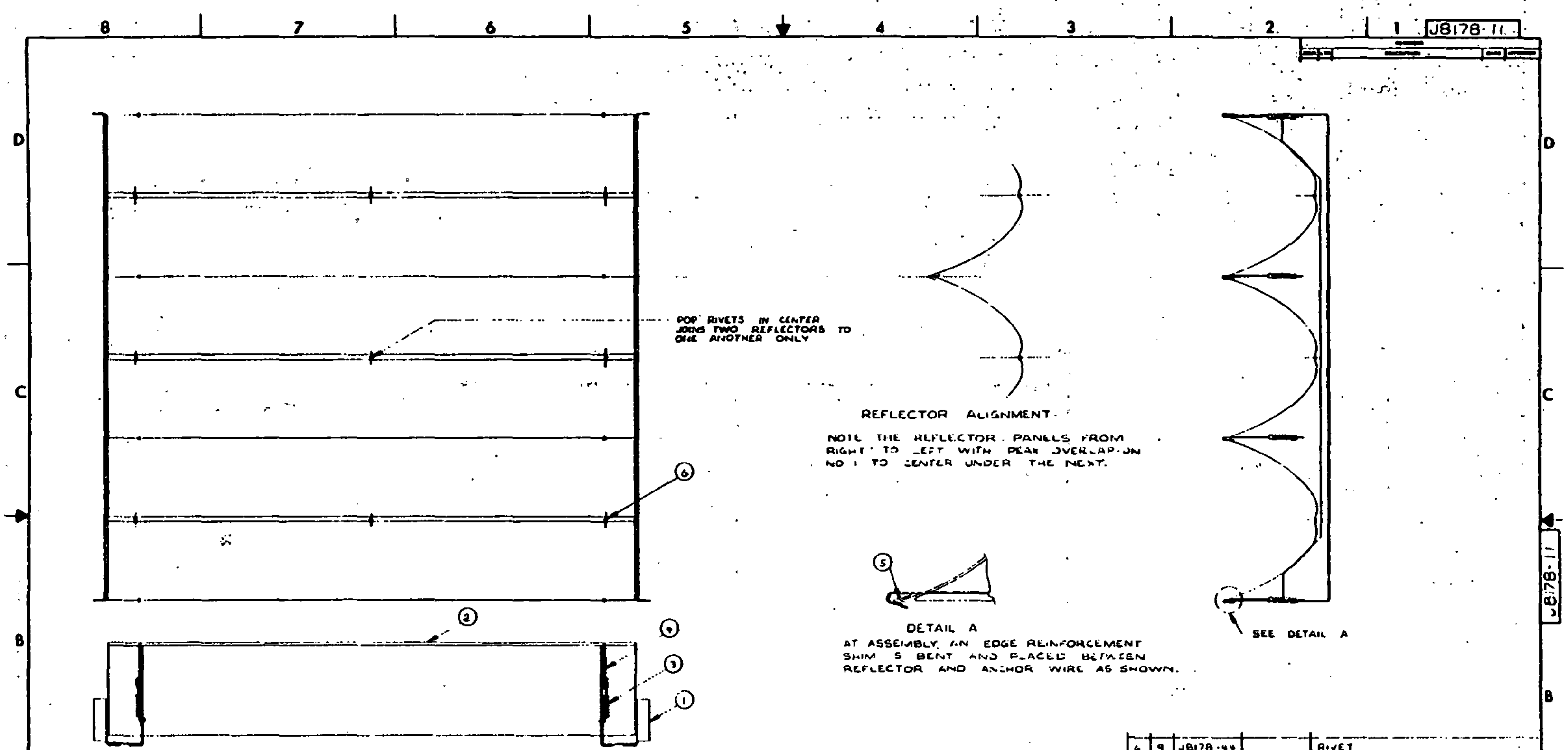
SCALE 1/4 — UNIT WT. — SHEET

NEXT ASS'Y — USED ON — APPLICATION — QTY REQ'D

A-13



J8178-10
.38 DIA SPOTWELD REFLECTOR SUPPORT AND RECEIVER SUPPORT BRACKET
LOCATE WELDS AT APPROX. 6" INTERVALS AS SHOWN
NOTE 3
.38 DIA SPOTWELD RECEIVER SUPPORT BRACKET AND SHIM, REFLECTOR SUPPORT
LOCATE WELD APPROX CENTER OF SHIMS AS SHOWN
NOTE 3
42.40
42.58
3.05
J8178-C
NOTES:
1. - INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING".
2. - UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3. - REPAIR ALL SPOTWELD AREAS AND OTHER BREAKS IN GALVINIZE SURFACES WITH ZINC COATING MATERIAL.
4 N/R J8178-48 GALVANIZING REPAIR
3 2 J8178-41 SHIM REFLECTOR SUPPORT
2 1 J8178-38 RECEIVER SUPPORT BRACKET
1 1 J8178-9 REFLECTOR SUPPORT
SEE DETAILS
16 APRIL 1979
Chamberlain
SUPPORT SUB-ASSEMBLY
D 86125 J8178-10



NOTES:

1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING".
2. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3. APPROXIMATELY .125 CLEARANCE REQUIRED IN ASSEMBLY BETWEEN END OF EACH REFLECTOR AND SUPPORT SUB-ASSEMBLY. (RECEIVER LOCATING BRACKET MUST FIT INTO THIS AREA IN FINAL ASSEMBLY.)
4. ASSEMBLE REFLECTORS TO REFLECTOR SUPPORTS WITH POP RIVETS. HOLES TO BE LOCATED IN ASSEMBLY TO COMPLY WITH REQUIREMENTS OF NOTE 3.
5. EACH REFLECTOR TO BE PULLED DOWN TO CONFORM TO SHAPE OF REFLECTOR SUPPORT. LOCATE HOLES IN ASSEMBLY AT TOP OF EACH REFLECTOR ADJACENT TO REFLECTOR SUPPORT AND ATTACH WIRE LOOP. ATTACH HELICAL EXTENSION SPRING BETWEEN WIRE LOOP AND REFLECTOR SUPPORT SUCH THAT SPRING TENSION WILL PROVIDE RETENTION OF REFLECTOR.

6	9	J8178-44		RIVET
5	4	J8178-42		EDGE REINFORCEMENT, REFLECTOR
4	8	J8178-25		ANCHOR WIRE
3	8	J8178-24		SPRING
2	6	J8178-7		REFLECTOR
1	2	J8178-10		SUPPORT, SUB-ASSEMBLY

SEE DETAILS

18 APRIL 1979

KB

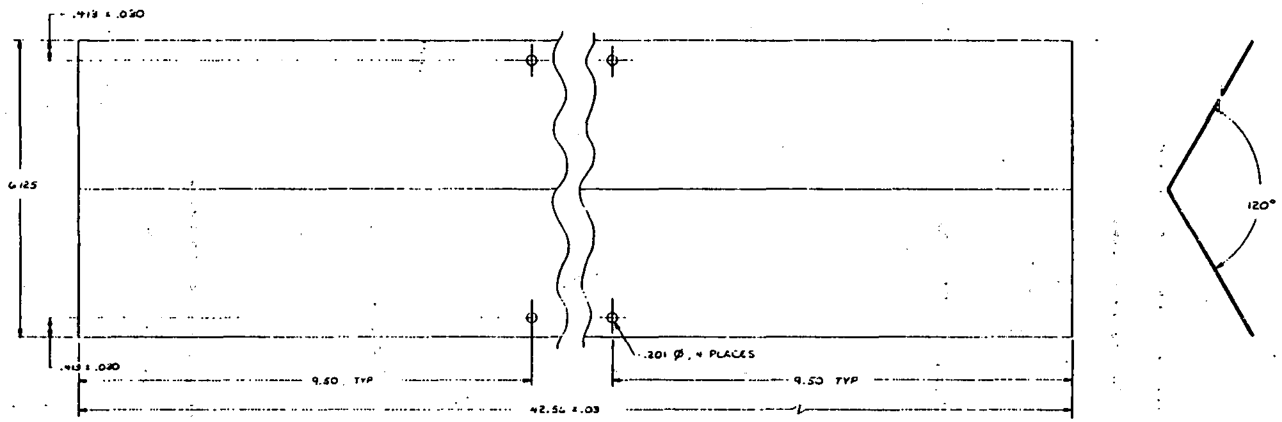
Chamberlain

REFLECTOR SUB-ASSEMELY

D 86125 J8178-11

A-16

J8178-12



NOTES:

1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING".
2. UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES.
3. ALL BEND RADII .03.
4. MATERIAL: STEEL SHEET, ZINC COATED (GALVANIZED), COMMERCIAL QUALITY PER ASTM A526-71
   THICKNESS: .030 NOMINAL (22) GA
   HARDNESS: ROCKWELL "B" 35-60
   COATING DESIGNATION: G90
5. BLANK SIZE: 43.25 ± .03 BY 6.15 ± .03.

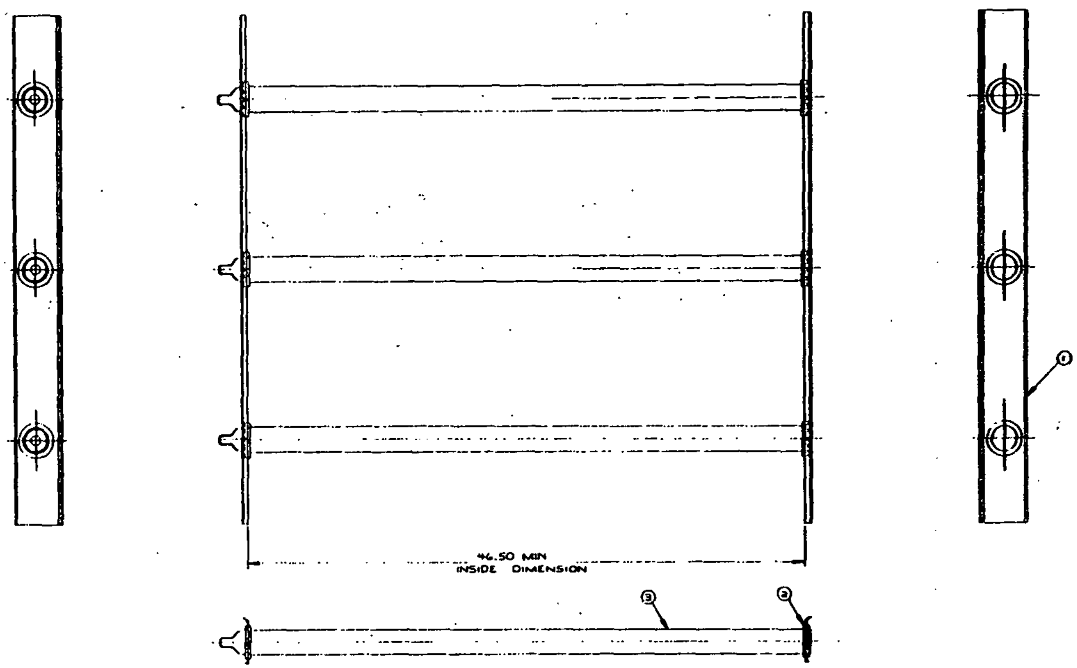
NOTE 4

13 FEBRUARY 79

Chamberlain

MANIFOLD COVER

D 86125 J8178-12



NOTES:
1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING".
2. UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES.

3	6	J8178-35		EVACUATED SHROUD
2	6	J8178-32		GROMMET
1	2	J8178-36		RECEIVER LOCATING BRACKET

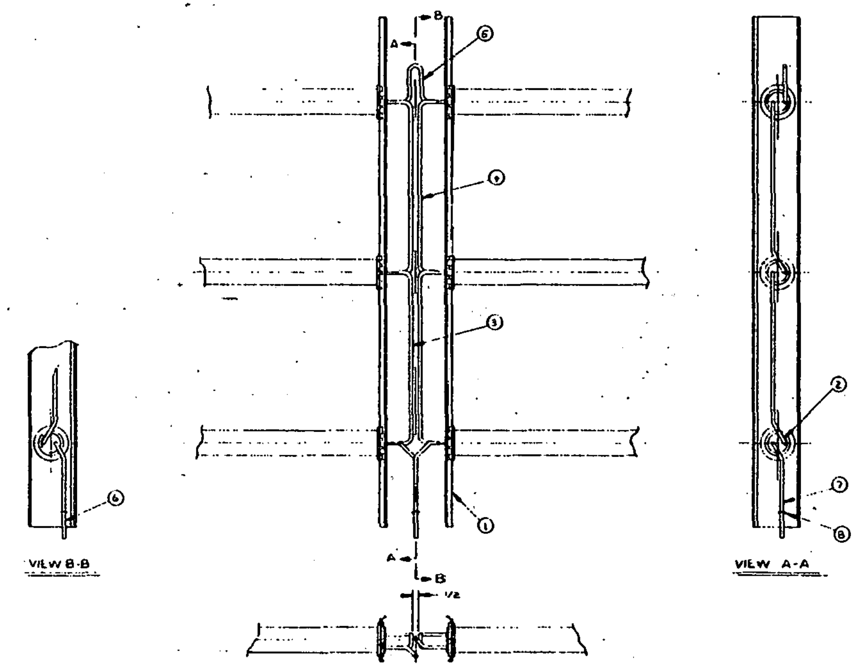
Chamberlain

SEE DETAILS

2 MARCH 1979

SHROUD
SUB-ASSEMBLY

D 86125 J8178-13



NOTES:
1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING".
2. UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES.

8	2	JB178-34		RETAINER, INLET/OUTLET TUBE
7	1	JB178-28		INLET/OUTLET TUBE, L.H.
6	1	JB178-27		INLET/OUTLET TUBE, R.H.
5	1	JB178-37		CONNECTOR
4	2	JB178-23		TRANSITION TUBE, R.H.
3	2	JB178-22		TRANSITION TUBE, L.H.
2	6	JB178-24		FIN/TUBE ASSEMBLY
1	2	JB178-3		SHROUD SUB ASSEMBLY

Chamberlain

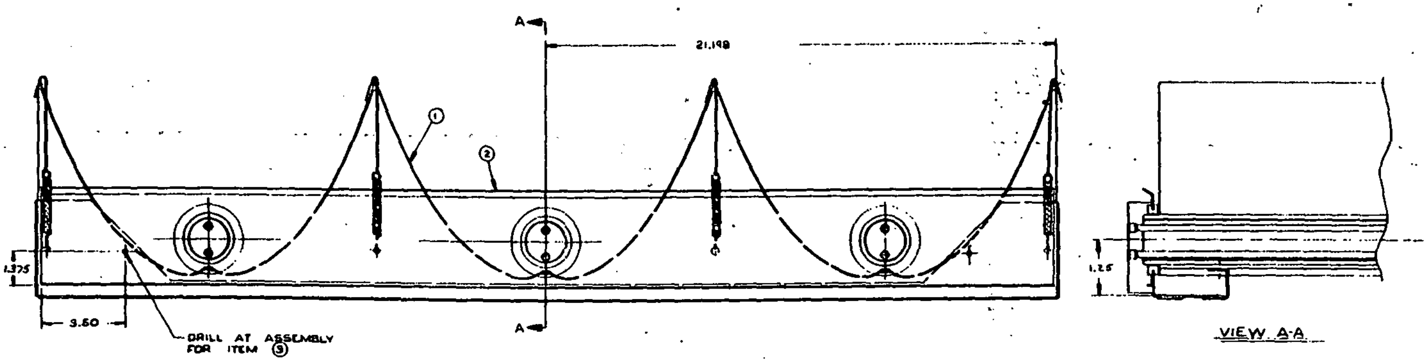
6 MARCH 1979

SEE DETAILS

RECEIVER SUB ASSEMBLY

D 86125 JB178-14

J8178-15



NOTES:
1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING."
2. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.

3	4	J8178-46	SCREW
2	1	J8178-14	RECEIVER SUB-ASSEMBLY
1	2	J8178-11	REFLECTOR SUB-ASSEMBLY

Chamberlain

24 APRIL 1979

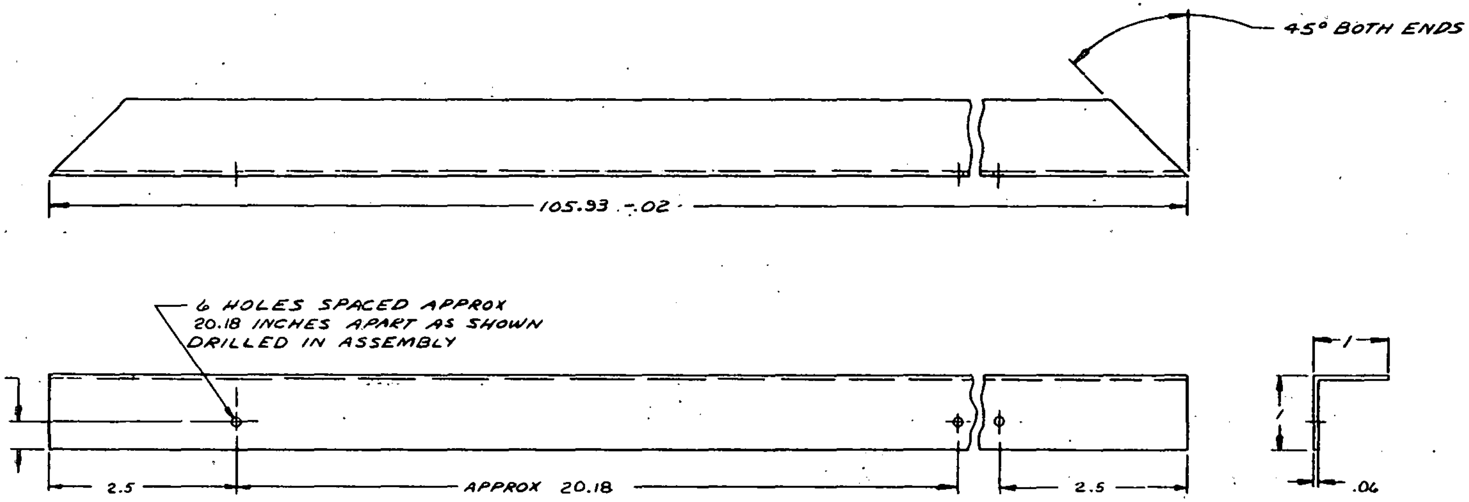
RECEIVER / REFLECTOR SUB-ASSEMBLY

D 86125 J8178-15

SCALE 1/2

J8178-15

J8178 - 18



NOTES:
1- INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING."
2- UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES.
3- MATERIAL: ALUMINUM ANGLE, SHARP CORNER, ALLOY 6063-T52 PER FEDERAL SPECIFICATION QQ-A-200/9 NOMINAL SIZE IN INCHES: 1 X 1 X .062.

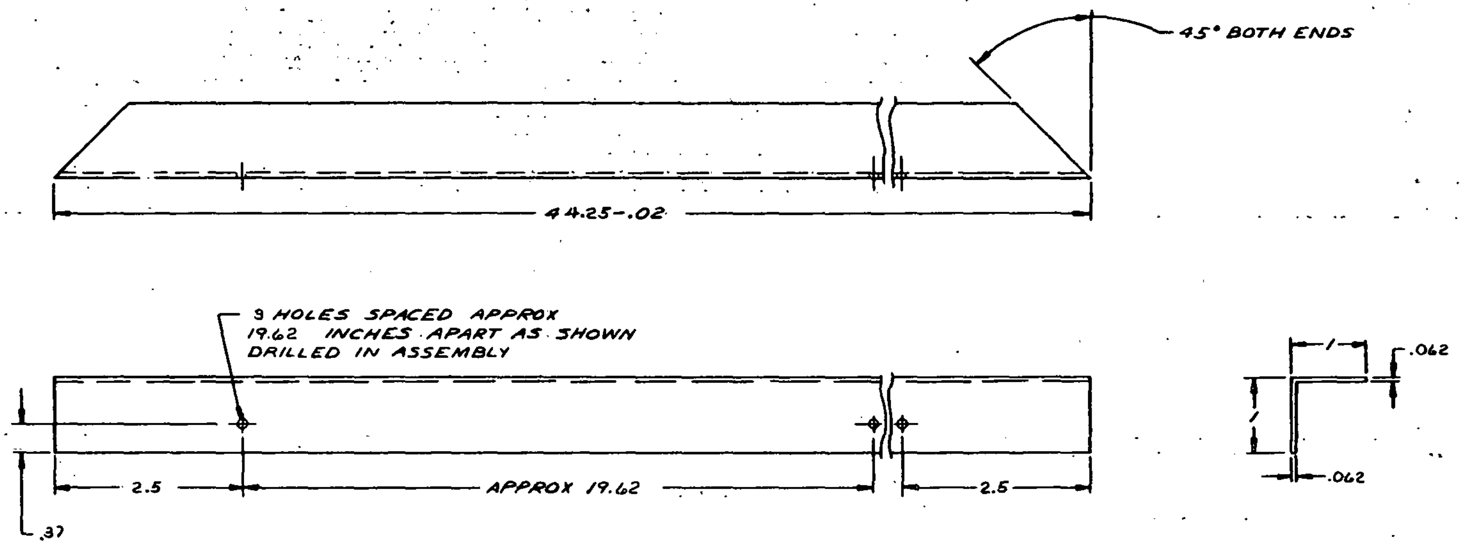
Chamberlain

COVER ANGLE - SIDE

DATE OF DRAWING	16 FEBRUARY '79
DRAFTSMAN	P STOCKS
DATE	2-16-79
MATERIAL	NOTE 3
APPROVED	RB
SIZE	C
CODE IDENT NO.	86125
DWG NO.	J8178 - 18
SCALE	FULL
SHEET	1 OF 1

J8178 - 18

J8178-19



NOTES:
1- INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING."
2- UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3- MATERIAL: ALUMINUM ANGLE, SHARP CORNER, ALLOY 6063-T52 PER FEDERAL SPECIFICATION QQ-A-200/9 NOMINAL SIZE IN INCHES: 1 X 1 X .062.

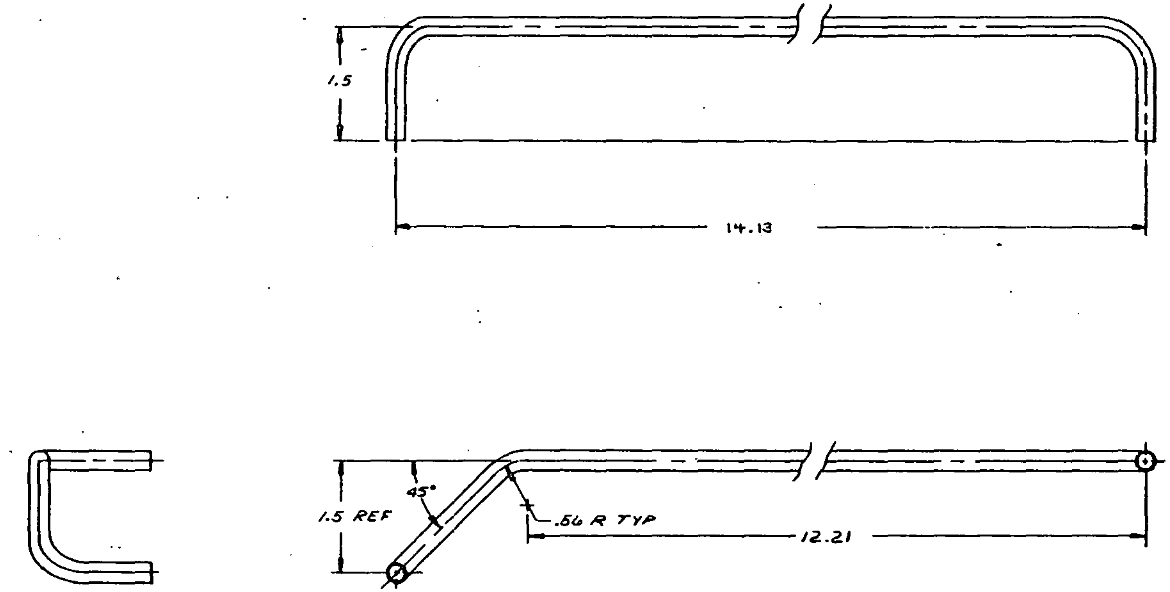
Chamberlain Manufacturing Corporation, Research and Development Division

COVER ANGLE-END

Date of drawing: 16 FEBRUARY 79
Draftsman: P STOCKS — Date: 2-16-79
Material: NOTE 3
Approved: KB 28 Feb 79
Size: C — Code ident no.: 86125 — J8178-19
Scale: FULL — Sheet 1 of 1

J8178-19

J8178-22



NOTE:

1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5 – 1973 "DIMENSIONING AND TOLERANCING."
2. UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES.
3. MATERIAL: STAINLESS STEEL TUBING, SEAMLESS,
   .250 O.D. x .016 .010 WALL x 13.1 LONG
   S.S. TYPE AISI 301, 304, OR 316L.

FIND NO.	QTY	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION

LIST OF MATERIALS

Chamberlain — Chamberlain Manufacturing Corporation, Research and Development Division, Waterloo, Iowa

TRANSITION TUBE L.H.

UNLESS OTHERWISE SPECIFIED LIMITS ARE:	FRACTIONAL / .000 / .00 / .0 / ANGULAR
MATERIAL	SEE NOTE 3
TREATMENT	
CONTRACT NO.	
DATE OF DRAWING	21 FEBRUAR. 79
DRAFTSMAN	P. STOCKS
DATE	2-21-79
CHECKER	
QUALITY	
APPROVED	RB 1 MAR 79
APPROVED	- -
DATE OF PRINT	
DESTROY PREVIOUS ISSUES	
SIZE	C
CODE IDENT NO.	86125
DRAWING NO.	J8178-22
SCALE	FULL
UNIT WT.	
SHEET	1 OF 1

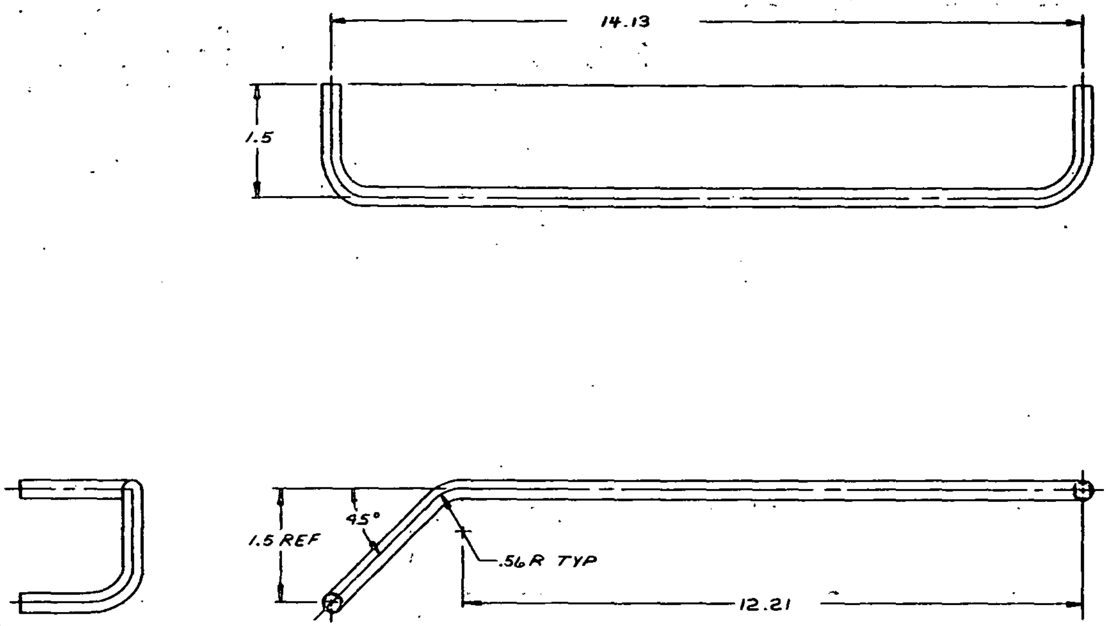
NEXT ASS'Y	USED ON	NEXT ASS'Y	FINAL ASS'Y
APPLICATION		QTY REQ'D	

REVISIONS: ECNO | LTR | DESCRIPTION | DATE | APPROVED

J8178-22

J8178-23

ZONE	LTR	REVISIONS DESCRIPTION	DATE	APPROVED



NOTE:
1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING."
2. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3. MATERIAL: STAINLESS STEEL TYPE AISI 301, 304, OR 316L. .250 O.D. x .035/.040 WALL TUBING, SEAMLESS.

FIND NO.	QTY	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED LIMITS ARE:	FRACTIONAL, .000, .00, .0, ANGULAR
MATERIAL	SEE NOTE 3
TREATMENT	
CONTRACT NO.	
DATE OF DRAWING	21 FEBRUARY 79
DRAFTSMAN	P STOCKS — DATE 2-21-79
CHECKER	
QUALITY	
APPROVED	RB — 1 May 79
APPROVED	

Chamberlain — Chamberlain Manufacturing Corporation, Research and Development Division

TRANSITION TUBE R. H.

DATE OF PRINT
DESTROY PREVIOUS ISSUES

SIZE	CODE IDENT NO.	
C	86125	J8178-23

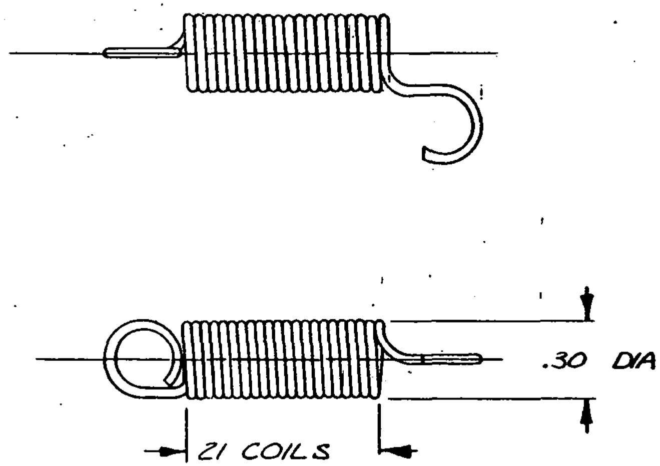
SCALE FULL | UNIT WT. | SHEET 1 OF 1

NEXT ASS'Y | USED ON | NEXT ASS'Y | FINAL ASS'Y
APPLICATION | QTY REQ'D

J8178-23

J8178-24

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



NOTE:

1. SPRING MATERIAL: STAINLESS STEEL
SPRING WIRE DIAMETER: .049.

FIND NO.	QTY	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION

LIST OF MATERIALS

NEXT ASS'Y	USED ON	NEXT ASS'Y	FINAL ASS'Y
APPLICATION		QTY REQ'D	

UNLESS OTHERWISE SPECIFIED LIMITS ARE:
FRACTIONAL
.000
.00
.0
ANGULAR
MATERIAL: SEE NOTE
TREATMENT

CONTRACT NO.
DATE OF DRAWING: 18 JANUARY '79
DRAFTSMAN: NJH — DATE: 18 Jan 79
CHECKER
QUALITY
APPROVED: RB — 18 Jan 79
APPROVED

Chamberlain
Chamberlain Manufacturing Corporation
Research and Development Division
Waterloo, Iowa

SPRING

DATE OF PRINT
DESTROY PREVIOUS ISSUES

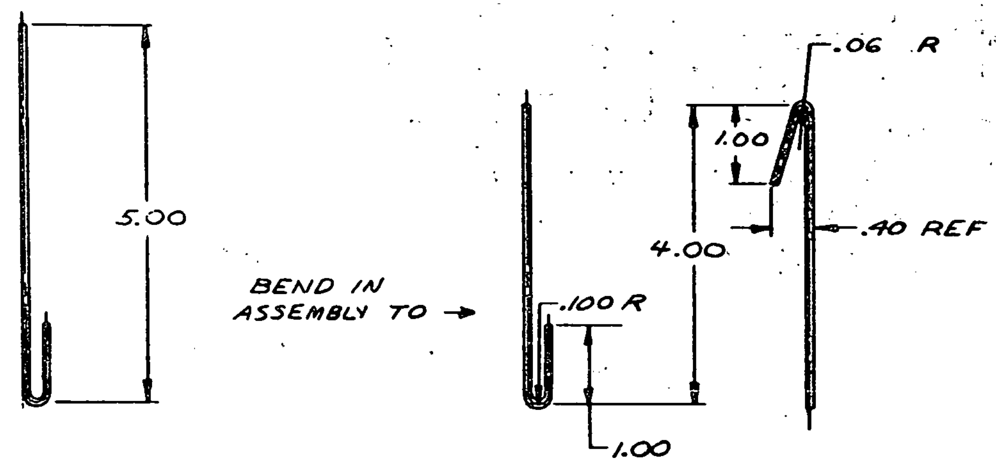
SIZE	CODE IDENT NO.	
B	86125	J8178-24

SCALE 2/1 | UNIT WT. | SHEET

J8178-25

REVISIONS

SYM.	E.C.N.	FROM	BY	CK.	DATE



NOTES:

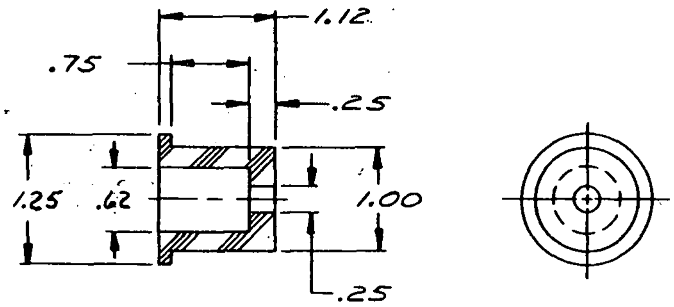
1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING."
2. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3. MATERIAL: 22 GA. (.049) MUSIC WIRE.

DESTROY PREVIOUS ISSUES

MATERIAL	UNLESS OTHERWISE SPECIFIED LIMITS ARE		NAME	
SEE NOTE 3			ANCHOR WIRE	DRAWN P STOCKS — DATE 3-13-79
PHYSICAL REQUIREMENTS	FRAC.		**Chamberlain** MANUFACTURING CORPORATION WATERLOO, IOWA	CHECKED
	.000			APPROVED RB — 13 MAR 79
	.00			SCALE NTS
	.0			DATE OF PRINT
	ANGULAR			DWG. NO. J8178-25

J8178-26

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



NOTES:

1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING."
2. UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES.

FIND NO.	QTY	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION

LIST OF MATERIALS

NEXT ASS'Y	USED ON	NEXT ASS'Y	FINAL ASS'Y
APPLICATION		QTY REQ'D	

UNLESS OTHERWISE SPECIFIED LIMITS ARE:
FRACTIONAL
.000
.00
.0
ANGULAR
MATERIAL: TEFLON® ROD
TREATMENT

CONTRACT NO.
DATE OF DRAWING
DRAFTSMAN: P STOCKS — DATE: 3-19-79
CHECKER
QUALITY
APPROVED: RB — 21 MAR 79
APPROVED

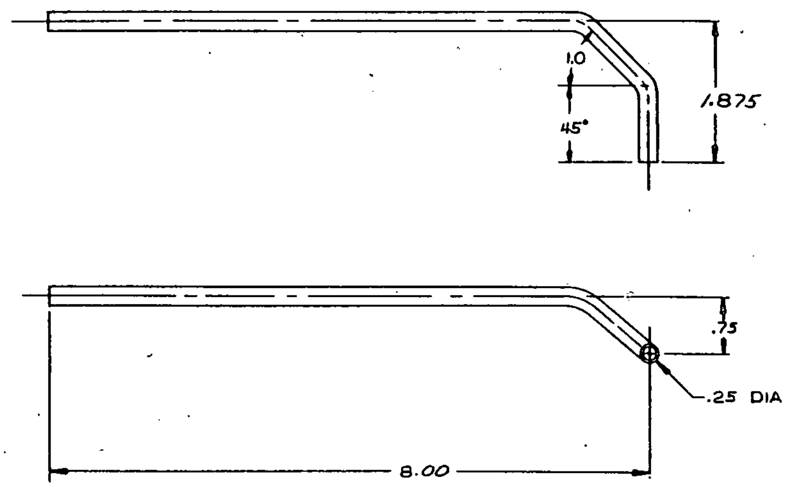
Chamberlain
Chamberlain Manufacturing Corporation
Research and Development Division
Waterloo, Iowa

BUSHING, INLET/OUTLET INSULATING

DATE OF PRINT
DESTROY PREVIOUS ISSUES

SIZE: B — CODE IDENT NO.: 86125 — J8178-26
SCALE: FULL — UNIT WT. — SHEET 1 OF 1

J8178-27



NOTES:

1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING."
2. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3. MATERIAL: STAINLESS STEEL TUBING, SEAMLESS, .250 O.D. × .035/.049 WALL S.S. TYPE AISI 301, 304, OR 316L.

FIND NO.	QTY	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED LIMITS ARE: FRACTIONAL .000 .00 .0 ANGULAR

MATERIAL: NOTE 3

TREATMENT

CONTRACT NO.

DATE OF DRAWING: 15 MARCH 1979

DRAFTSMAN: P. STOCKS DATE: 3-15-79

CHECKER

QUALITY

APPROVED: KB 15 Mar 79

APPROVED

Chamberlain
Chamberlain Manufacturing Corporation
Research and Development Division
Waterloo, Iowa

INLET / OUTLET TUBE R.H.

DATE OF PRINT

DESTROY PREVIOUS ISSUE

SIZE C CODE IDENT NO. 86125 J8178-27

SCALE FULL UNIT WT. SHEET 1 OF 1

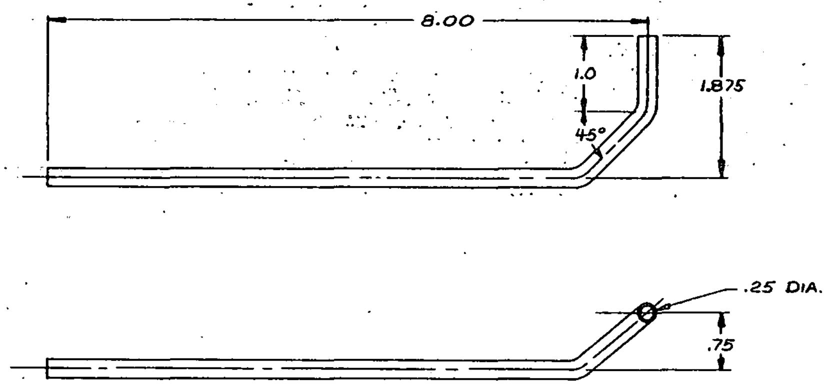
NEXT ASS'Y | USED ON | NEXT ASS'Y | FINAL ASS'Y

APPLICATION | QTY REQ'D

A-27

J8178-27

J8178-28



NOTES:

1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING."
2. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3. MATERIAL: STAINLESS STEEL TUBING, SEAMLES, TYPE AISI 301, 304, OR 316L. .250 O.D. x $^{.016}_{.010}$ WALL

FIND NO.	QTY	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED LIMITS ARE: FRACTIONAL .000 .00 0 ANGULAR

MATERIAL: NOTE 3

TREATMENT

NEXT ASS'Y | USED ON | NEXT ASS'Y | FINAL ASS'Y

APPLICATION | QTY REQ'D

CONTRACT NO.

DATE OF DRAWING: 15 MARCH 73

CRAFTSMAN: P. STOCKS DATE: 3-15-73

CHECKER

QUALITY

APPROVED: KB 22 MAR 73

APPROVED

Chamberlain

INLET / OUTLET TUBE L.H.

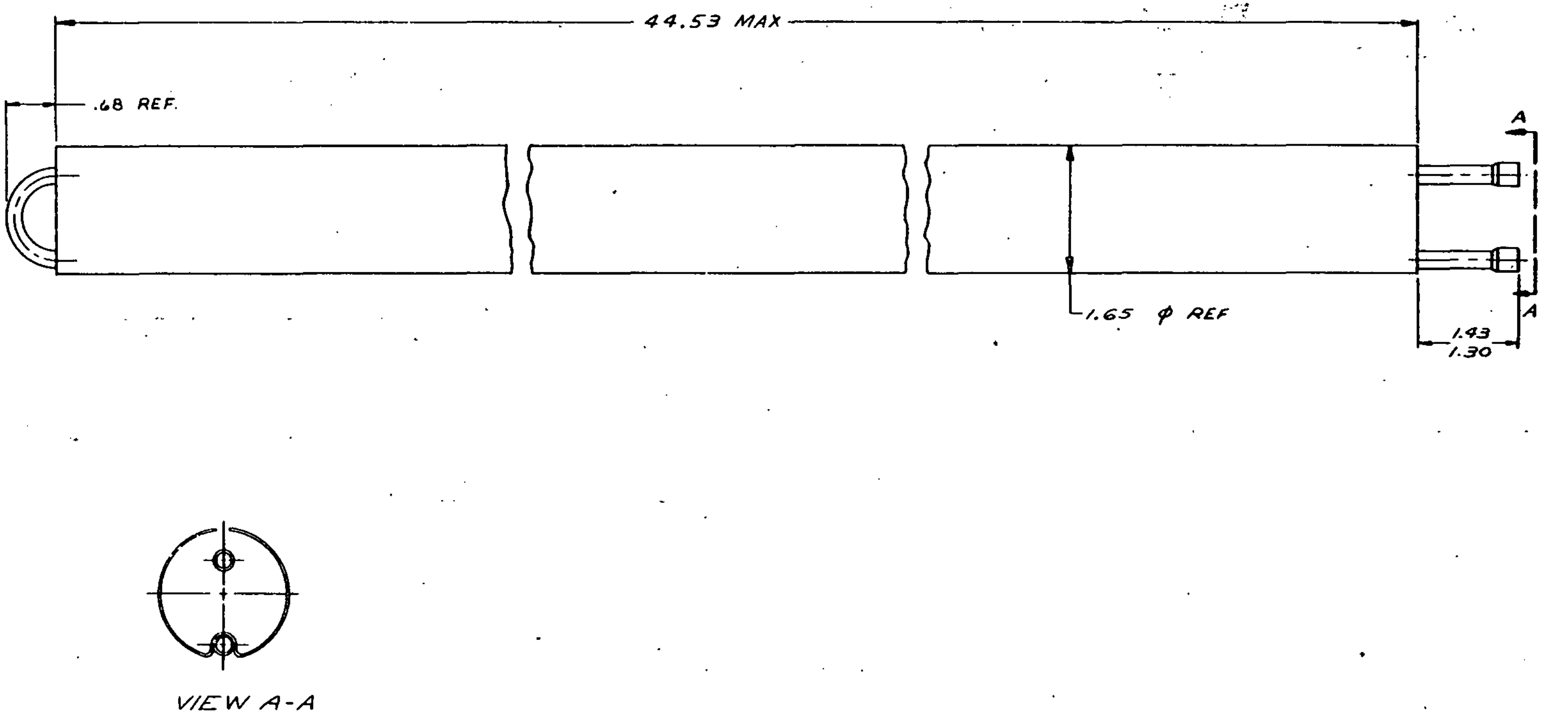
DATE OF PRINT

DESTROY PREVIOUS ISSUES

SIZE: C CODE IDENT NO: 86125 J8178-28

SCALE: FULL UNIT WT. SHEET 1 OF 1

J8178-28



REF GE DWG NO 189C8154

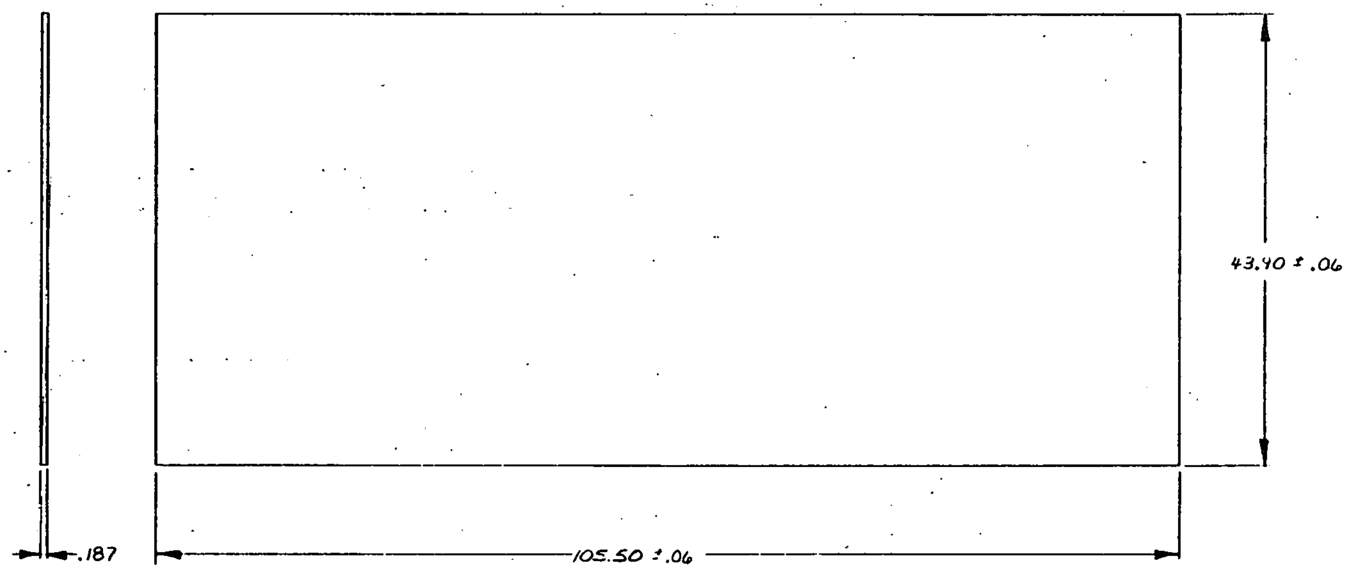
NOTES:
1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING."
2. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.

Chamberlain

FIN/TUBE ASSEMBLY

DATE OF DRAWING	14 MARCH 79
DRAFTSMAN	P. STOCKS
DATE	3-13-79
APPROVED	RB 26 Mar 79
SIZE	C
CODE IDENT NO.	86125
DWG NO.	J8178-29

J8178-30

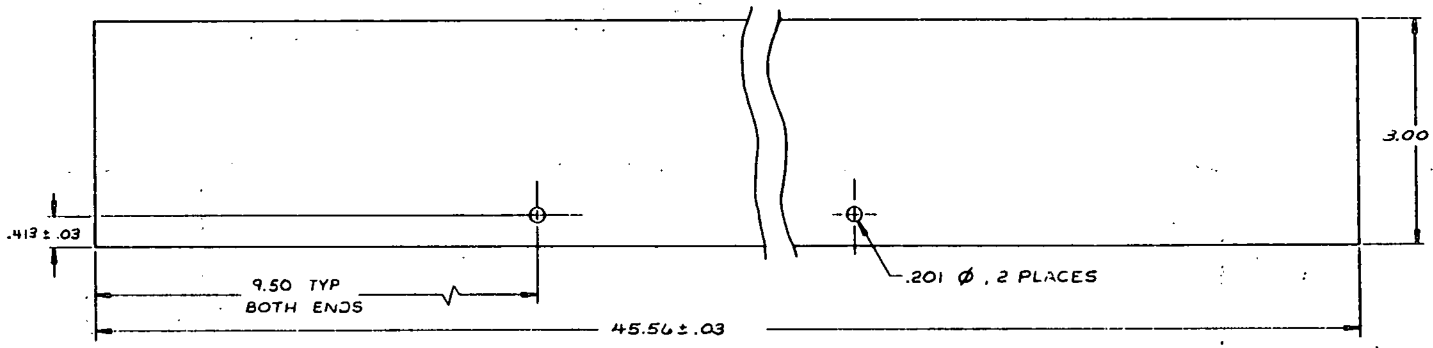


NOTE:

1. INTERPETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING."
2. UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES.
3. SOLATEX™ TEMPERED GLASS MFGD BY ASG INDUSTRIES, INC OR EQUIV..

LIST OF MATERIALS	
DATE OF DRAWING	1 MARCH 1971
DRAFTSMAN	NJH
DATE	1 MAR 79
MATERIAL	NOTE 3
APPROVED	KB 1 MAR 79
	Chamberlain — Chamberlain Manufacturing Corporation, Research and Development Division
TITLE	COVER, GLASS
SIZE	C
CODE IDENT NO	86125
DWG NO	J8178-30
SCALE	NONE

J8178-31



NOTES:

1. INTEPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING."
2. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3. ALL BEND RADII .03.
4. MATERIAL: STEEL SHEET, ZINC COATED (GALVINIZED), COMMERCIAL QUALITY PER ASTM A526-71
   THICKNESS: .036 NOMINAL (20 GA.)
   HARDNESS: ROCKWELL "B" 35-60
   COATING DESIGNATION: G90

FIND NO.	QTY	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED LIMITS ARE: FRACTIONAL; .000; .00; .0; ANGULAR

MATERIAL: NOTE 4

TREATMENT

NEXT ASS'Y | USED ON | NEXT ASS'Y | FINAL ASS'Y

APPLICATION | QTY REQ'D

CONTRACT NO.

DATE OF DRAWING: 28 MARCH 79

DRAFTSMAN: P STOCKS — DATE: 3-28-79

CHECKER

QUALITY

APPROVED: KB — 30 MAR 79

APPROVED

Chamberlain
Chamberlain Manufacturing Corporation
Research and Development Division
Waterloo, Iowa

END COVER

DATE OF PRINT

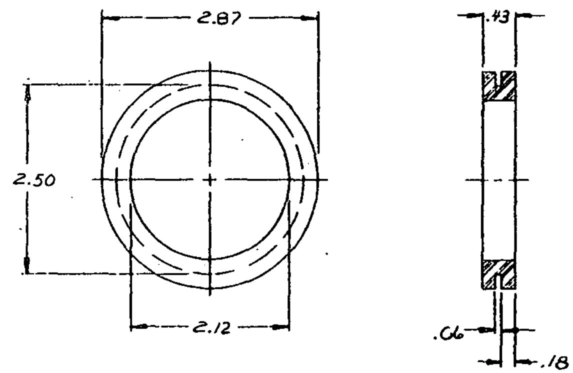
DESTROY PREVIOUS ISSUES

SIZE: C — CODE IDENT NO.: 86125 — J8178-31

SCALE: FULL — UNIT WT. — SHEET 1 OF 1

J8178-31

J8178-32



NOTES:

1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5 – 1973 "DIMENSIONING AND TOLERANCING."
2. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3. MATERIAL: ATLANTIC INDIA RUBBER COMPANY - CHICAGO PART NO. 2805 OR EQUIVALENT.

LIST OF MATERIALS

MATERIAL: SEE NOTE 3

DRAFTSMAN: P STOCKS DATE: 3-7-79

Chamberlain

GROMMET

SIZE C CODE IDENT NO 86125 J8178-32

SCALE FULL SHEET 1 OF 1

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

EATON CORPORATION
TINNERMAN® FASTENER
NO. C17120-017-04
OR EQUIVALENT

UNLESS OTHERWISE SPECIFIED LIMITS ARE:	CONTRACT NO.		Chamberlain Chamberlain Manufacturing Corporation Research and Development Division Waterloo, Iowa
FRACTIONAL	DATE OF DRAWING 6 MARCH 1979		
.000	DRAFTSMAN C.K. Betts	DATE 6 Mar 79	RETAINER, INSULATING BUSHING
.00	CHECKER		
.0			
ANGULAR	QUALITY		DATE OF PRINT DESTROY PREVIOUS ISSUES
MATERIAL	APPROVED TB	9 MAR 79	SIZE A · CODE IDENT NO. 86125 · J8178-33
TREATMENT	APPROVED		SCALE · UNIT WT. · SHEET

ACME REPRODUCTION — Waterloo, Iowa N26032

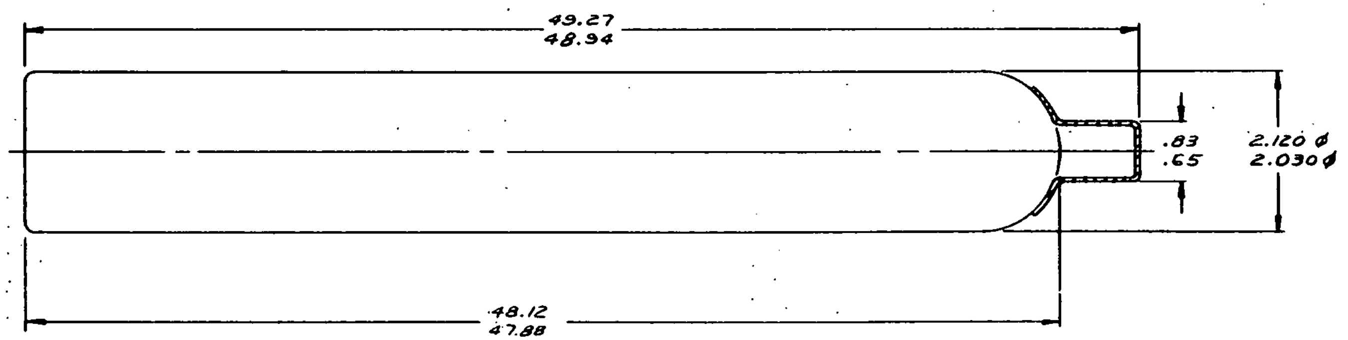
REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

EATON CORPORATION
TINNERMAN® FASTENER
NO. C181-017-04
OR EQUIVALENT

UNLESS OTHERWISE SPECIFIED LIMITS ARE:		CONTRACT NO.		Chamberlain Chamberlain Manufacturing Corporation Research and Development Division Waterloo, Iowa
FRACTIONAL		DATE OF DRAWING 6 MARCH 1979		
.000		DRAFTSMAN C.A. Bettis	DATE 6 Mar '79	RETAINER, INLET/OUTLET TUBE
.00		CHECKER		
.0				
ANGULAR		QUALITY		DATE OF PRINT DESTROY PREVIOUS ISSUES
MATERIAL		APPROVED KB	10 MAR 79	SIZE A / CODE IDENT NO. 86125 / J8178-34
TREATMENT		APPROVED		SCALE / UNIT WT. / SHEET

ACME REPRODUCTION — Waterloo, Iowa N26032

J8178-35



NOTES:
1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING."
2. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.

REF GE DWG NO 17SC9899

Chamberlain

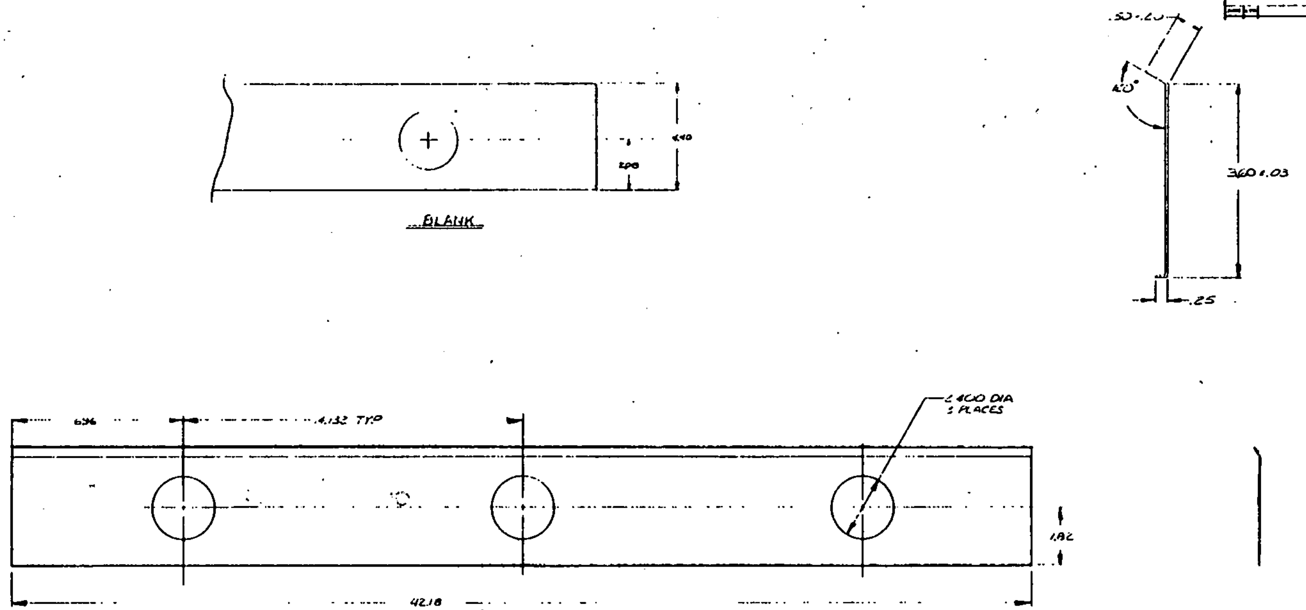
DATE OF DRAWING: 19 FEBRUARY 79
DRAFTSMAN: P. STOCKS — DATE: 2-19-79
APPROVED: RB 24 FEB 79

EVACUATED SHROUD

SIZE: C — CODE IDENT NO: 86125 — J8178-35

J8178-35

A-35



NOTES:

1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING."
2. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3. MATERIAL: STEEL SHEET, ZINC COATED (GALVANIZED)
   COMMERCIAL QUALITY PER ASTM A526-71
   THICKNESS: .050 NOMINAL (18 GA)
   HARDNESS: ROCKWELL "B" 35-60
   COATING DESIGNATION: G90

SEE NOTE 3

22 JANUARY 1979

NJH

Chamberlain

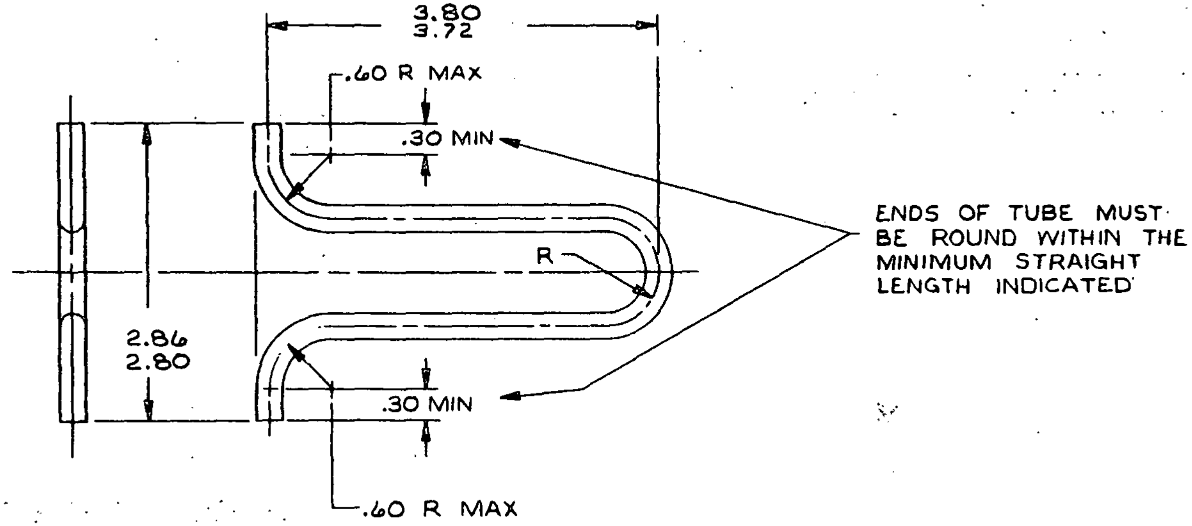
RECEIVER LOCATING BRACKET

D 86125 J8178-36

SCALE NONE

J8178-37

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



NOTE:
1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING."
2. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3. MATERIAL: .250 O.D. × .025/.020 WALL TUBING, SEAMLESS, TYPE AISI 301, 304 OR 316L STAINLESS STEEL

FIND NO.	QTY	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION

LIST OF MATERIALS

UNLESS OTHERWISE SPECIFIED LIMITS ARE: FRACTIONAL .000 .00 .0 ANGULAR

MATERIAL: NOTE 3

TREATMENT

CONTRACT NO.

DATE OF DRAWING: 2 APRIL 1979

DRAFTSMAN: [signature] DATE: 4 Apr 79

CHECKER

QUALITY

APPROVED: KB 4 APR 77

APPROVED

Chamberlain — Chamberlain Manufacturing Corporation, Research and Development Division, Waterloo, Iowa

CONNECTOR

DATE OF PRINT

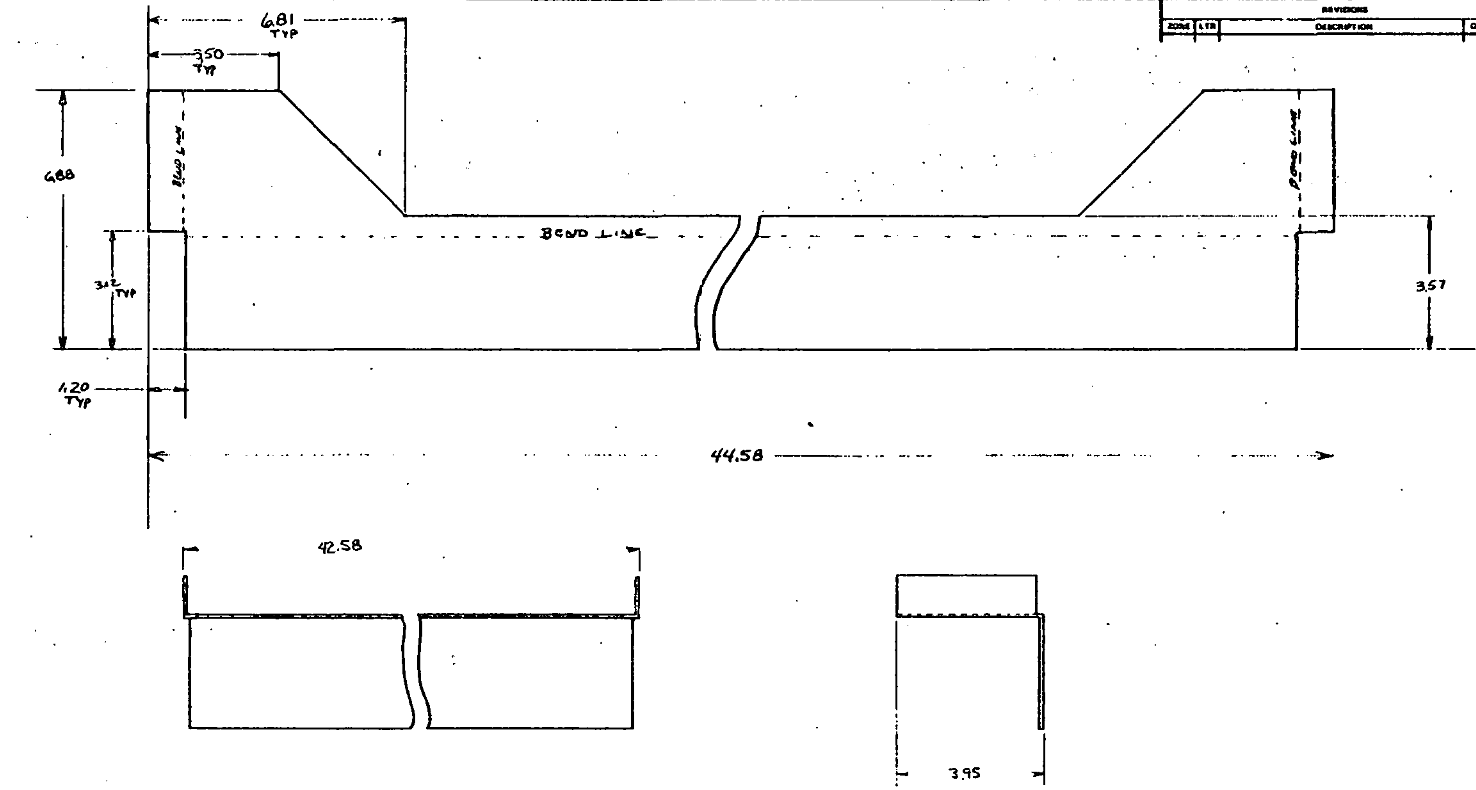
DESTROY PREVIOUS ISSUES

SIZE: B CODE IDENT NO.: 86125 J8178-37

SCALE: FULL UNIT WT. SHEET

NEXT ASS'Y | USED ON | NEXT ASS'Y | FINAL ASS'Y

APPLICATION | QTY REQ'D



NOTES:

1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING".
2. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.
3. MATERIAL: STEEL SHEET, ZINC COATED (GALVINIZED), COMMERCIAL QUALITY PER ASTM A526-71 (18 GA.).
4. ALL BEND RADII .03.

FIND NO.	QTY	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION

LIST OF MATERIALS

Chamberlain — Chamberlain Manufacturing Corporation, Research and Development Division

RECEIVER SUPPORT BRACKET

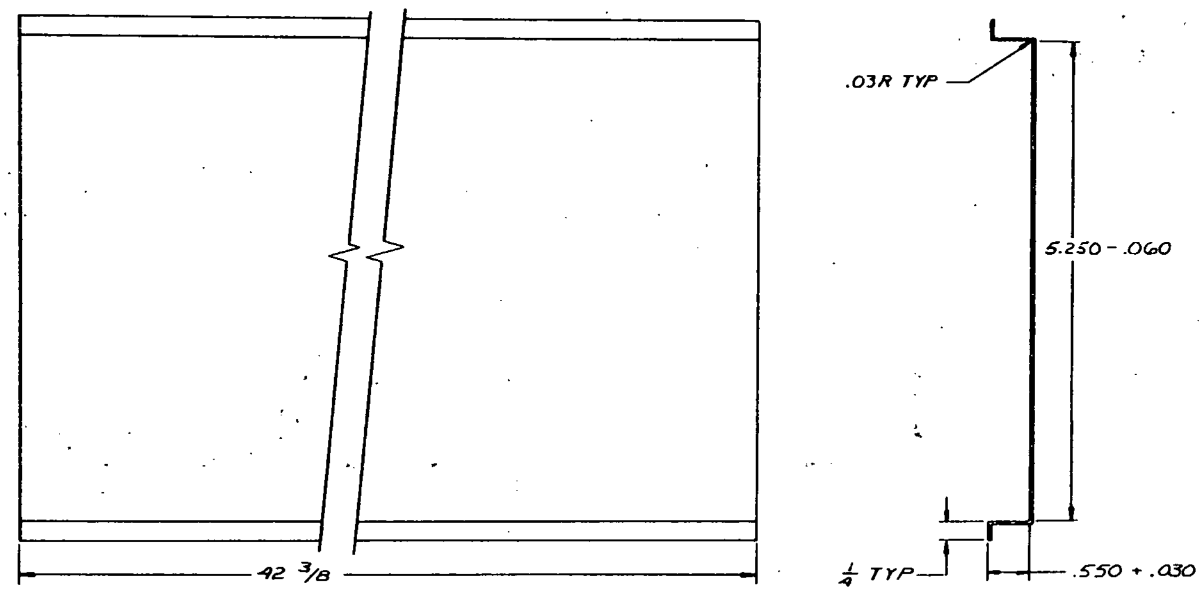
DATE OF DRAWING: 13 APRIL 1979

MATERIAL: NOTE 3

SIZE: C CODE IDENT NO: 86125 J8178-38

SCALE 1/2

J8178 - 39



NOTES:

1 - INTERPRETATION OF THIS DRAWING TO BE CONSISTENT WITH SPEC, ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING."

2 - UNLESS OTHERWISE SPEC, ALL DIMENSIONS ARE IN INCHES.

3 - MATERIAL : STEEL SHEET, ZINC COATED (GALVANIZED), COMMERCIAL QUALITY PER ASTM A526-71.
THICKNESS : .021 NOMINAL (25 GA)
HARDNESS : ROCKWELL "B" 35-60
COATING DESIGNATION : G 90

FIND NO.	QTY	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION

LIST OF MATERIALS

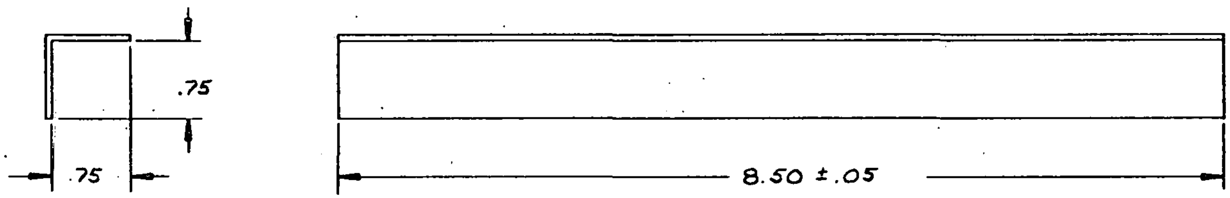
Chamberlain	Chamberlain Manufacturing Corporation, Research and Development Division, Waterloo, Iowa
CONTRACT NO.	
DATE OF DRAWING	23 APRIL 1979
DRAFTSMAN	J.A.L.
DATE	9-23-79
CHECKER	
QUALITY	
APPROVED	RB 24 APR 79
APPROVED	
UNLESS OTHERWISE SPECIFIED LIMITS ARE: FRACTIONAL / .000 / .00 / 0 / ANGULAR	
MATERIAL	SEE NOTE 3
TREATMENT	
TITLE	MANIFOLD BOTTOM
DATE OF PRINT	DESTROY PREVIOUS ISSUES
SIZE	C
CODE IDENT. NO	86125
DRAWING NO.	J8178 - 39
SCALE	1/1
UNIT WT.	
SHEET	

NEXT ASS'Y | USED ON | NEXT ASS'Y | FINAL ASS'Y — APPLICATION — QTY REQ'D

A-39

J8178-40

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



NOTES:

1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING".
2. UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES.
3. MATERIAL: STEEL SHEET, 18 GA, ZINC COATED (GALVINIZED) COMMERCIAL QUALITY PER ASTM A526-71.

FIND NO.	QTY	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION

LIST OF MATERIALS

NEXT ASS'Y	USED ON	NEXT ASS'Y	FINAL ASS'Y
APPLICATION		QTY REQ'D	

UNLESS OTHERWISE SPECIFIED LIMITS ARE:
FRACTIONAL
.000
.00
.0
ANGULAR
MATERIAL: SEE NOTE 3
TREATMENT

CONTRACT NO.
DATE OF DRAWING: 15 MARCH 1979
DRAFTSMAN: CAB | DATE: 15 Mar 79
CHECKER
QUALITY
APPROVED: RB | 15 Mar 79
APPROVED

Chamberlain
Chamberlain Manufacturing Corporation
Research and Development Division
Waterloo, Iowa

CORNER SUPPORT

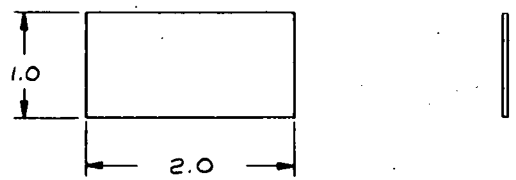
DATE OF PRINT
DESTROY PREVIOUS ISSUES

SIZE	CODE IDENT NO.	
B	86125	J8178-40

SCALE FULL | UNIT WT. | SHEET

J8178-41

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



NOTES:

1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING."
2. UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES.
3. MATERIAL: STEEL SHEET, 18 GA, ZINC COATED (GALVANIZED), COMMERCIAL QUALITY PER ASTM A526-71.

FIND NO.	QTY	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION

LIST OF MATERIALS

NEXT ASS'Y	USED ON	NEXT ASS'Y	FINAL ASS'Y
APPLICATION		QTY REQ'D	

UNLESS OTHERWISE SPECIFIED LIMITS ARE:
FRACTIONAL
.000
.00
.0
ANGULAR
MATERIAL: SEE NOTE 3
TREATMENT

CONTRACT NO.
DATE OF DRAWING: 14 MARCH 1979
DRAFTSMAN: [signature] DATE: [illegible]
CHECKER
QUALITY
APPROVED: RB 14 MAR 79
APPROVED

Chamberlain
Chamberlain Manufacturing Corporation
Research and Development Division
Waterloo, Iowa

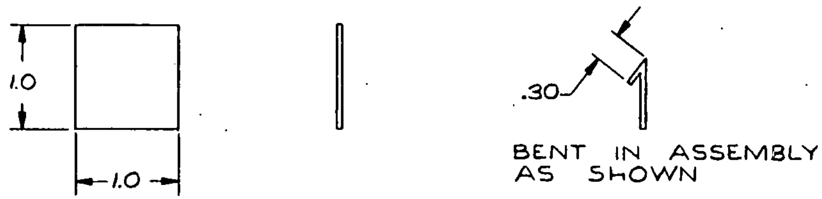
SHIM, REFLECTOR SUPPORT

DATE OF PRINT
DESTROY PREVIOUS ISSUES

SIZE	CODE IDENT NO.	
B	86125	J8178-41
SCALE	UNIT WT.	SHEET

J8178-42

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



NOTES:

1. INTERPRETATION OF THIS DRAWING IS TO BE CONSISTENT WITH SPECIFICATION ANSI Y14.5-1973 "DIMENSIONING AND TOLERANCING".
2. UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES.
3. MATERIAL STEEL SHEET, 18 GA, ZINC COATED (GALVINIZED) COMMERCIAL QUALITY PER ASTM A526-71.

FIND NO.	QTY	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION

LIST OF MATERIALS

NEXT ASS'Y	USED ON	NEXT ASS'Y	FINAL ASS'Y
APPLICATION		QTY REQ'D	

UNLESS OTHERWISE SPECIFIED LIMITS ARE:	
FRACTIONAL	
.000	
.00	
.0	
ANGULAR	
MATERIAL	SEE NOTE 3
TREATMENT	

CONTRACT NO.		
DATE OF DRAWING	15 MARCH 1979	
DRAFTSMAN	CRC	DATE 15 Mar 79
CHECKER		
QUALITY		
APPROVED	RB	15 Mar 79
APPROVED		

Chamberlain
Chamberlain Manufacturing Corporation
Research and Development Division
Waterloo, Iowa

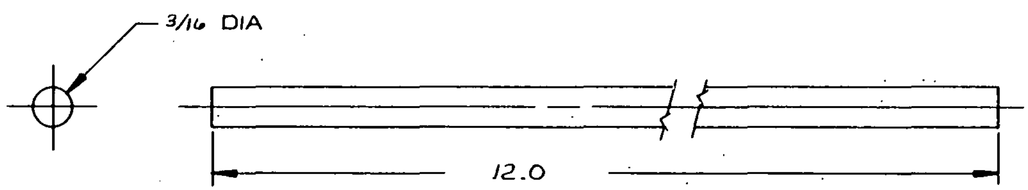
EDGE, REINFORCEMENT REFLECTOR

DATE OF PRINT
DESTROY PREVIOUS ISSUES

SIZE	CODE IDENT NO.	
B	86125	J8178-42
SCALE FULL	UNIT WT.	SHEET

J8178-43

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



NOTE:
MATERIAL: 3/16 DIA x 12.0 LG
WOODEN DOWEL
QTY : 3

FIND NO.	QTY	PART OR IDENTIFYING NO.	SPECIFICATION	NOMENCLATURE OR DESCRIPTION

LIST OF MATERIALS

NEXT ASS'Y	USED ON	NEXT ASS'Y	FINAL ASS'Y
APPLICATION		QTY REQ'D	

UNLESS OTHERWISE SPECIFIED LIMITS ARE:
FRACTIONAL
.000
.00
.0
ANGULAR
MATERIAL SEE NOTE
TREATMENT

CONTRACT NO.
DATE OF DRAWING 5 MARCH 1979
DRAFTSMAN CRB. Jr. DATE 5 Mar 79
CHECKER
QUALITY
APPROVED RB 6 MAR 79
APPROVED

Chamberlain
Chamberlain Manufacturing Corporation
Research and Development Division
Waterloo, Iowa

SPACER, COVER

DATE OF PRINT
DESTROY PREVIOUS ISSUES

SIZE	CODE IDENT NO.	
B	86125	J8178-43

SCALE FULL | UNIT WT. | SHEET

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

"POP" RIVET 1/8" DIA
5052 ALUMINUM RIVET BODY
DOME HEAD, 7178 ALUMINUM
BREAK STEM MANDREL,
1/8" MAXIMUM GRIP RANGE

UNLESS OTHERWISE SPECIFIED LIMITS ARE:	CONTRACT NO.		Chamberlain Chamberlain Manufacturing Corporation Research and Development Division Waterloo, Iowa
FRACTIONAL	DATE OF DRAWING 6 MARCH 1979		
.000	DRAFTSMAN CRBetts	DATE 6 Mar 79	RIVET
.00			
.0	CHECKER		
ANGULAR	QUALITY		DATE OF PRINT DESTROY PREVIOUS ISSUES
MATERIAL	APPROVED RB	10 MAR 79	SIZE A · CODE IDENT NO. 86125 · J8178-44
TREATMENT	APPROVED		SCALE · UNIT WT. · SHEET

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

1/8" THK x 3/4" WIDE,
EPDM RUBBER FOAM
CLOSED CELL TAPE,
ADHESIVE ONE SIDE

UNLESS OTHERWISE SPECIFIED LIMITS ARE:		CONTRACT NO.		Chamberlain Chamberlain, Manufacturing Corporation Research and Development Division Waterloo, Iowa		
FRACTIONAL		DATE OF DRAWING 5 MARCH 1979				
.000		DRAFTSMAN [signature]	DATE 5 Mar 79	GASKET		
.00						
.0		CHECKER				
ANGULAR						
MATERIAL		QUALITY		DATE OF PRINT DESTROY PREVIOUS ISSUES		
		APPROVED RB	10 MAR 79	SIZE A	CODE IDENT NO. 86125	J8178-45
TREATMENT		APPROVED		SCALE	UNIT WT.	SHEET

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

SELF DRILLING SHEET METAL SCREW
HEX HEAD, ZINC PLATED STEEL
.190 DIA x .50 LG

UNLESS OTHERWISE SPECIFIED LIMITS ARE:		CONTRACT NO.		Chamberlain — Chamberlain Manufacturing Corporation, Research and Development Division, Waterloo, Iowa
FRACTIONAL		DATE OF DRAWING 5 MARCH 1979		
.000		DRAFTSMAN CRBetts	DATE 5 Mar 79	SCREW
.00		CHECKER		
.0				
ANGULAR		QUALITY		DATE OF PRINT
MATERIAL				DESTROY PREVIOUS ISSUES
TREATMENT		APPROVED RB	6 MAR 79	SIZE A — CODE IDENT NO. 86125 — J8178-46
		APPROVED		SCALE — UNIT WT. — SHEET

ACME REPRODUCTION — Waterloo, Iowa N26032

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

5" THICK
FIBER BLANKET INSULATION
OWENS CORNING AWX-HT-26
OR EQUIVALENT

UNLESS OTHERWISE SPECIFIED LIMITS ARE:	
FRACTIONAL	
.000	
.00	
.0	
ANGULAR	
MATERIAL	
TREATMENT	

CONTRACT NO.	
DATE OF DRAWING 6 MARCH 79	
DRAFTSMAN CRBetti	DATE 6 Mar 79
CHECKER	
QUALITY	
APPROVED RB	10 MAR 79
APPROVED	

Chamberlain
Chamberlain Manufacturing Corporation
Research and Development Division
Waterloo, Iowa

INSULATION

DATE OF PRINT
DESTROY PREVIOUS ISSUES

SIZE	CODE IDENT NO.	
A	86125	J8178-47
SCALE	UNIT WT.	SHEET

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

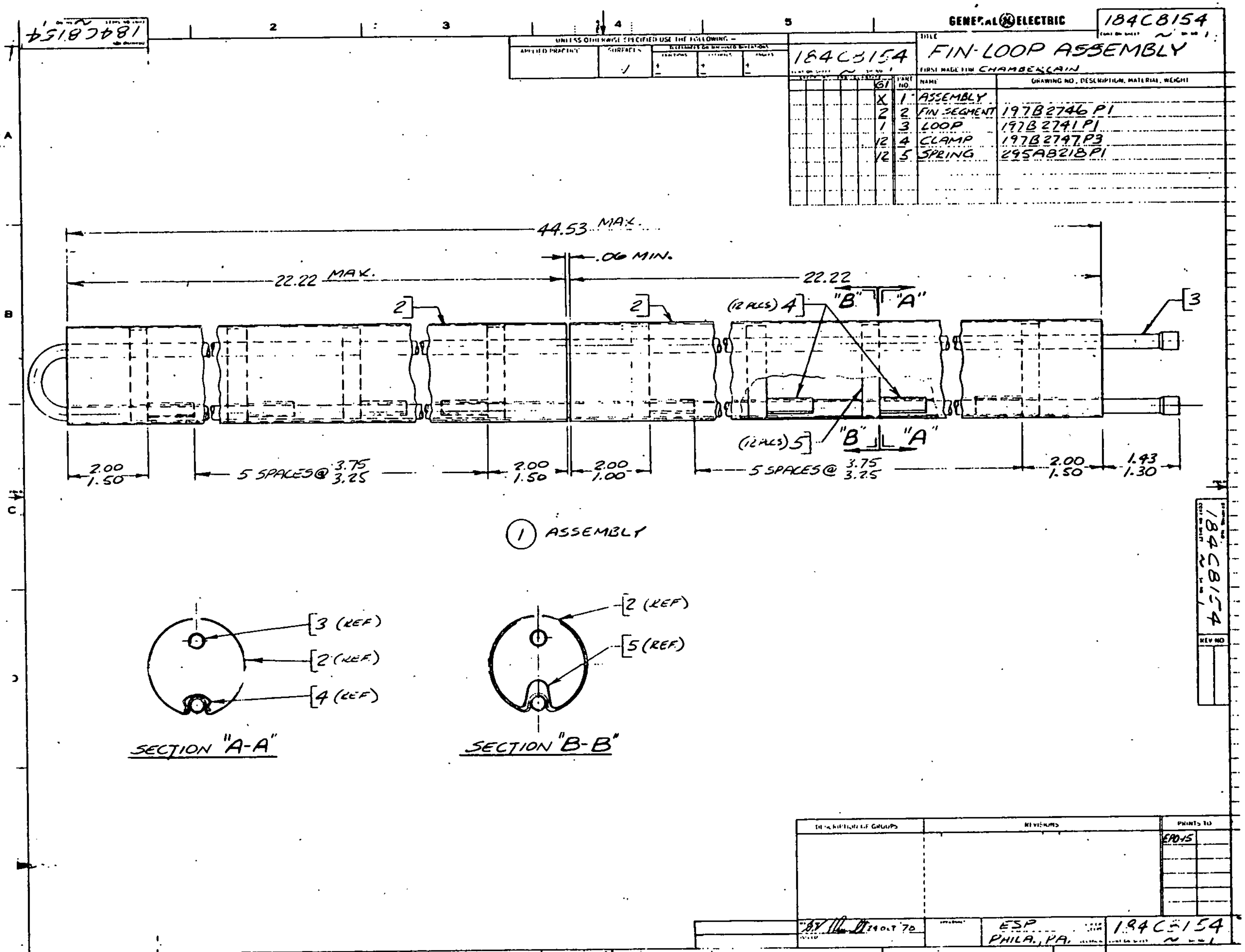
COLD GALVINIZING COMPOUND
ZRC CHEMICAL PRODUCTS CO.
21 NEWPORT AVE.
QUINCY, MASS. 02171
OR EQUIVALENT

SOURCE CONTROL DWG.

UNLESS OTHERWISE SPECIFIED LIMITS ARE:	CONTRACT NO.	Chamberlain — Chamberlain Manufacturing Corporation, Research and Development Division, Waterloo, Iowa
FRACTIONAL	DATE OF DRAWING: 6 MARCH 1979	
.000	DRAFTSMAN: CR Betti — DATE: 6 Mar '79	GALVANIZING REPAIR
.00	CHECKER	
.0		
ANGULAR	QUALITY	DATE OF PRINT — DESTROY PREVIOUS ISSUES
MATERIAL	APPROVED: RB — 10 MAR 79	SIZE: A — CODE IDENT NO.: 86125 — J8178-43
TREATMENT	APPROVED	SCALE — UNIT WT. — SHEET

APPENDIX B

GENERAL ELECTRIC
RECEIVER DRAWINGS


GENERAL ELECTRIC
184C8154
FIN-LOOP ASSEMBLY
FIRST MADE FOR CHAMBERLAIN
UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING
APPLIED PRACTICE
SURFACES
PART NO.
NAME
DRAWING NO., DESCRIPTION, MATERIAL, WEIGHT
X 1 ASSEMBLY
2 2 FIN SEGMENT 197B2746 P1
1 3 LOOP 197B2741 P1
12 4 CLAMP 197B2747 P3
12 5 SPRING 295A8218 P1
44.53 MAX.
.06 MIN.
22.22 MAX.
22.22
"B" "A"
(12 PLCS) 4
(12 PLCS) 5
2.00 / 1.50
5 SPACES @ 3.75 / 3.25
2.00 / 1.00
2.00 / 1.50
1.43 / 1.30
1 ASSEMBLY
3 (REF)
2 (REF)
4 (REF)
5 (REF)
SECTION "A-A"
SECTION "B-B"
DESCRIPTION OF GROUPS
REVISIONS
PRINTS TO
EP0-15
24 OCT 70
ESP
PHILA., PA.
REV NO

175C9899

GENERAL ELECTRIC 175C9899

UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING –

ENVELOPE, EVACUATED TUBULAR COLLECTOR (SHROUD)

FIRST MADE FOR SHAC

THERMAL COATING NOTE –

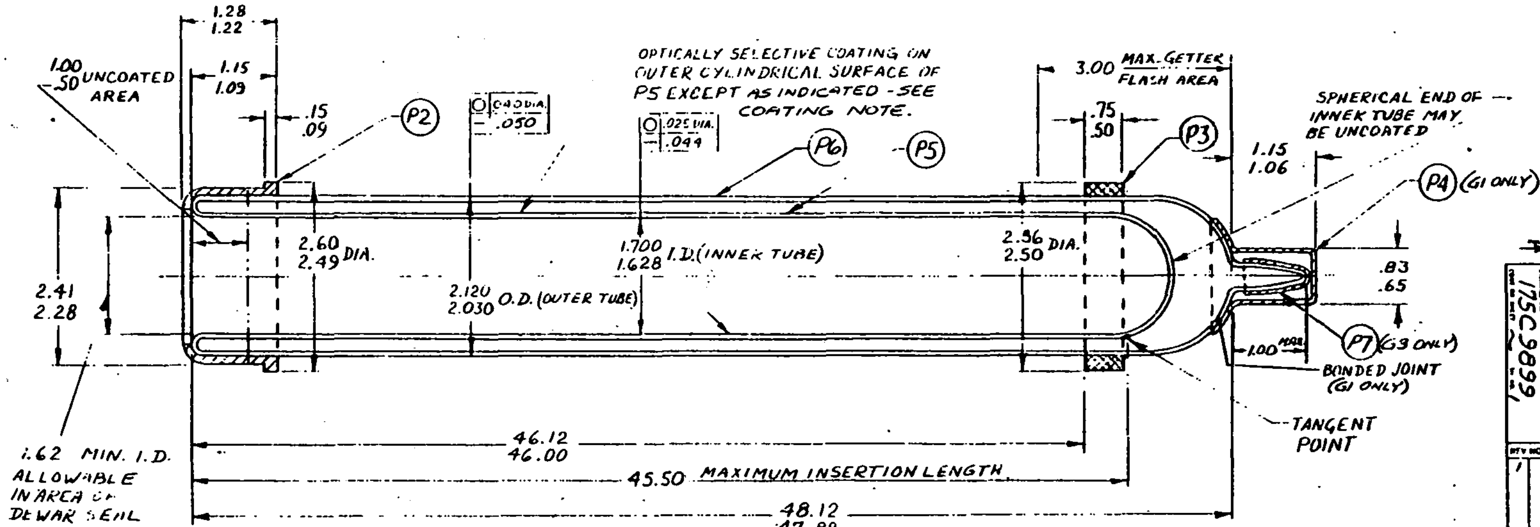
THE AVERAGE PROPERTIES OF THE THERMAL COATING ARE AS FOLLOWS:–

NORMAL EMITTANCE – 0.04 MAXIMUM AT 100°C IN THE SPECTRAL RANGE OF 2.0 TO 30.0 MICRONS.

ABSORBTIVITY – 0.85 MINIMUM IN THE SPECTRAL RANGE OF 0.39 TO 1.722 MICRONS.

EXCEPTIONS TO THE ABOVE ARE PERMISSABLE BASED ON EQUIVALENT PERFORMANCE AS FOLLOWS:–
EMISSIVITY MAY INCREASE IN THE RATIO OF 0.01 FOR EACH 0.06 INCREASE IN ABSORBTIVITY.

G3	G2	G1	PART NO	NAME	DRAWING NO., DESCRIPTION, MATERIAL, WEIGHT
X	X	X	1	ENVELOPE	
1	1	1	2	GROMMET	ETHYLENE PROPYLENE RUBBER ASTM D-2000, TYPE & CLASS AA OR BA
1	1	1	3	CUSHION RING	ETHYLENE PROPYLENE RUBBER ASTM D-2000, TYPE [illegible] AA OR BA
		1	4	TIP-OFF PROTECTOR	HARD PLASTIC
1	1	1	5	INNER TUBE	008 LIME GLASS
1	1	1	6	OUTER TUBE	008 LIME GLASS
1			7	TIP-OFF PROTECTOR	273A8086P2



– INSIDE DIA. OF P5 PROTECTED WITH APPROX. .007 THICKNESS OF ANTI-SCRATCH COATING.

G1 ENVELOPE
G2
G3

DESCRIPTION OF GROUPS	REVISIONS	PRINTS TO
	1 EN978-10-809 G.F. SCHMIDT	EPD-15

[illegible] 1/26/78 · [illegible] 1/31/78

ESP PHILA. PA. 175C9899

175C9899 /

APPENDIX C

PAPER PRESENTED TO THE
INTERNATIONAL SOLAR ENERGY SOCIETY
ANNUAL MEETING
MAY 1979

DEVELOPMENT OF A 3X CPC WITH EVACUATED RECEIVER

Robert W. Ballheim
Chamberlain Manufacturing Corporation
Research and Development Division
Waterloo, Iowa 50705

ABSTRACT

This paper presents some of the considerations involved in the design and development of a 2.6X compound parabolic concentrator (CPC) with an evacuated receiver. A truncated version of a CPC trough reflector system and the General Electric Company tubular evacuated receiver have been integrated with a mass producible collector design suitable for operation at 250 to 450°F. The key criterion for optimization of the design was minimization of the cost per BTU collected annually at an operating temperature of 400°F. A ray tracing program was used in conjunction with a heat gain math model to compare the effect of collector parameters on the annual performance of the collector. The parameters studied included CPC acceptance angle, truncation height, reflector error, receiver placement error, glazing transmissivity, receiver tube transmissivity, reflector material reflectivity, and insolation diffuse/beam ratio. An optimum design is selected and performance predictions on an annual basis are presented for specified design conditions.

1. COLLECTOR DESCRIPTION

The collector assembly is shown in Figure 1. Overall dimensions are 44.2 x 105.8 x 9.9 inches. It is a completely housed unit with a center manifold and a glass cover. It contains six each 45-inch long CPC cusp-shaped (Ref. 1) reflector assemblies design-matched to the General Electric evacuated receiver, which has a 1.75-inch diameter absorber. The reflector is a 4.1X design truncated to a total height of 8.0 inches with a resulting actual concentration ratio of 2.6 to 1. The

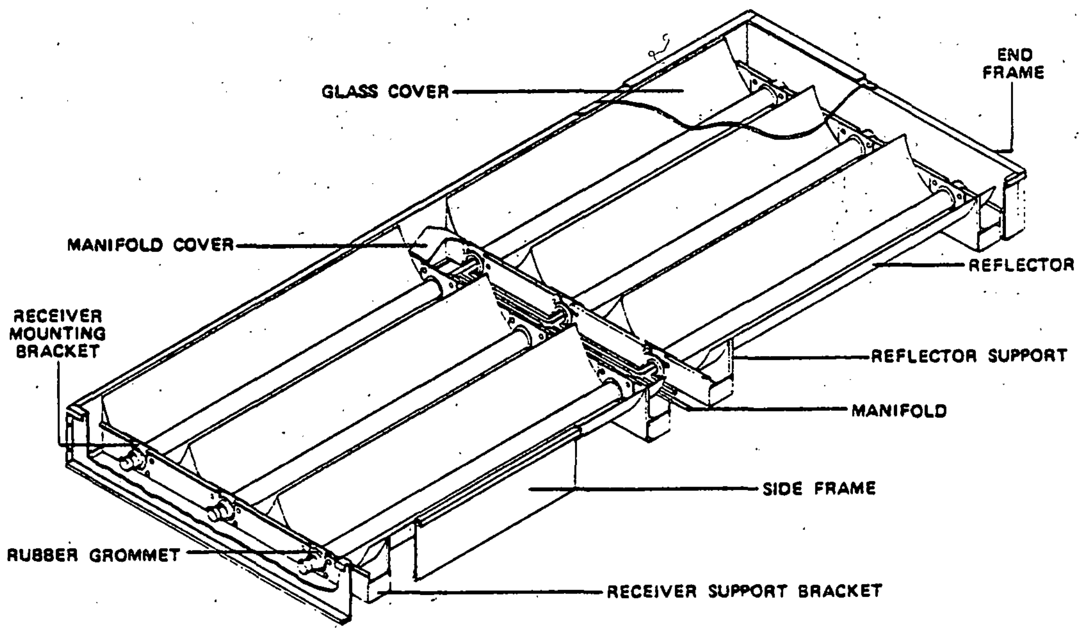


Fig. 1. Collector Assembly

manifold is an insulated area housing the fluid lines which connect the six receivers in series with inlet and outlet tubes extending from one side of the collector at the center. The fluid line is 1/4-inch O.D. x .020 wall stainless steel tubing.

The reflectors are polished, anodized aluminum which are shaped by the roll form process. This results in low production labor costs and a very consistent and accurate reflector contour. The housing is painted, galvanized steel. The cover glass is 3/16-inch thick tempered, low iron glass treated to reduce reflection losses.

The collector requires four slope adjustments per year for optimum effectiveness.

2. REFLECTOR DESIGN CONSIDERATIONS

The reflector design process was based on several concepts that were considered fixed for this program. Those items included the following:

- The design would be optimized for operation at 400°F.

- The receiver would be tubular with an absorber diameter of 1.75 inches.

- The reflector would be a cusp-type non-imaging CPC designed for use with a tubular receiver as defined in Reference 1.

- The concentration ratio would be between 2:1 and 4:1.

- Six or less collector slope adjustments per year would be acceptable.

The following reflector parameters were studied in comparison to their effect on annual performance and the total production cost of the collector.

- Concentration ratios of 3.5X, 4.1X, 4.7X and 5.2X with four slope adjustments per year; and 4.7X, 5.2X and 6.2X with six slope adjustments per year.

- Truncation heights used were 4, 6, 8 and 10 inches.

- Reflectivity was considered to be all specular and included values of .75, .81 and .87.

- Reflector contour error was introduced to determine the effect of not having a perfectly shaped reflector. This error was induced by adding either 1° or 2° to the incident angle of each ray entering the collector.

- Receiver placement error was set at 0 and .06 inch. The purpose of this was to check the effect of assembly error on the performance of each reflector configuration. This error consisted of moving the receiver laterally out of the center of the reflector trough, resulting in some rays missing the receiver that would normally strike it. It was expected that this error would have a greater effect on the collectors with larger truncation heights and/or smaller acceptance angles.

3. PERFORMANCE/COST ANALYSIS

A basic math model was used to evaluate collector annual performance to optimize the collector design to obtain the maximum BTU gain/collector cost ratio under specified conditions. Parameters studied included reflector design (concentration ratio and height), reflector error, receiver placement error, glazing transmissivity, receiver outer glass tube transmissivity, reflector material reflectivity and insolation diffuse/beam ratios. These heat gains were then compared with the specific costs associated with each of the collector components to select the most cost effective configuration, with an additional consideration being mass producibility of the collector.

For the purpose of this study, average monthly ambient temperatures for Des Moines, Iowa and clear day 40° latitude hourly insolation data for the 21st of each month were used with the collector output temperature, assumed to be a constant 400°F. All cost effectiveness analysis was based only on collector costs. The system installation costs associated with installing and operating additional square footage of collector was not considered in the selection of optimum collector design.

3.1 Collector Cost

Labor and material costs were estimated for five different collector sizes corresponding to reflector truncation heights of 4, 6, 8 and 10 inches. The costs were estimated as our minimum selling price under reasonable production volume; i.e., more than 250 collectors per month. These costs were a near linear function of the housing height which is a direct function of the reflector truncation height. The costs shown in Figure 2 are for a collector with a galvanized steel housing, anti-reflection treated tempered glass cover, .020-inch thick polished aluminum reflectors, six General Electric receivers and a 4.1X cusp type CPC reflector system. Preliminary examination of the collector performance data indicated that this configuration would most likely be selected, so that design was used as a baseline for the cost effectiveness evaluation for all designs.

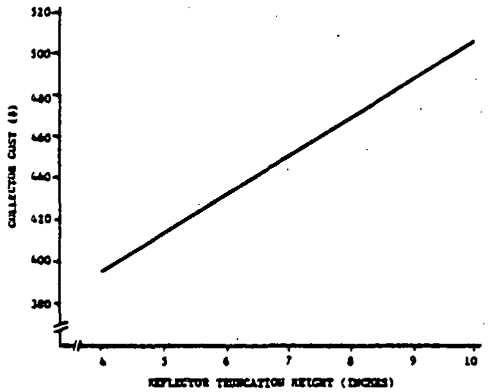


Fig. 2. Estimated Collector Selling Price Under Mass Production Versus Reflector Truncation Height.

3.2 Collector Performance

Collector performance was evaluated using a heat gain math model which utilized the following equation for the energy gain calculation.

$$HG = \tau_1 \tau_2 \alpha \rho^n \gamma \% I WF - RL$$

where:

- HG = heat gain in BTU's per ft^2 active area
- τ_1 = transmissivity of cover glazing
- τ_2 = transmissivity of outer receiver tube
- α = absorptivity of coating on receiver tube
- ρ = reflectivity of reflector material
- n = average number of reflections before reaching receiver for each hourly condition being calculated
- γ = diffuse insolation usability factor which is assumed to be equal to beam ratio + diffuse ratio times sin (acceptance half angle)
- $\%$ = proportion of all entering rays that strike the absorber for the hour being calculated
- I = hour insolation rate taken from ASHRAE tables for collector slope
- W = factor used to account for additional reflection losses off the receiver for each hour angle ω; in this study the approximation $W = (\cos \omega)^{.25}$ was used
- F = receiver shading factor, caused by the collector housing at early and late hours
- RL = heat losses, which are considered to be only by radiation off the absorber.

Hourly heat gain calculations were made using clear day insolation rates on the 21st day of each month and summed up to obtain an annual gain for each collector design studied. A ray trace program was utilized to determine for each hourly calculation the portion of rays entering the aperture that reach the absorber and the average number of reflections to collection. Although this method used only clear day insolation and in some cases is not exact, it is felt that for the comparison of the effect of various design parameters it is completely valid.

Examination of the resulting performance data indicated the following trends:

- Changes in the cover glazing transmissivity had a very significant effect on collector performance as would be expected. The performance of the collector under ideal insolation conditions increased about 1.4% for each 1% increase in cover transmissivity. As the insolation rate decreases the effect would be even greater and would eventually make the difference between losing or gaining energy under marginal operating conditions. This also applies to the outer receiver tube transmissivity. Although that design is considered fixed, it does appear that a significant increase in performance could be obtained by treating the glass to reduce reflection losses.

- The reflectivity of the reflector material has an even more significant effect on performance than does the cover glazing transmissivity. An increase of 1% in reflectivity will result in about a 1.65% increase in thermal performance. This effect is essentially independent of the other parameters. The calculations are based on the assumption that the reflectivity is all specular. Although this will not be the case it is considered to be a good measure of the effect of varying the reflectivity.

- The ratio of beam to total insolation affected the overall collector performance but did not influence the effect of the other parameters in this study. The smaller the acceptance angle, the greater will be the effect of varying this ratio. For example, for a 4.1X truncated to 2.6X (8 inches high) changing the beam ratio from .85 to .78 caused a reduction in performance of about 8.0%. A similar change for a 5.2X truncated to 2.7X (8 inches high) resulted in a decrease in performance of about 9.0%.

- Errors due to inaccurate reflector contours showed varying effects on performance, and as expected the effect of the errors was much more evident for the collectors with the smaller acceptance angle. At the 8-inch truncation height the performance reduction resulting from increasing the reflector error from 1° to 2° is 0.6% for the 4.1X and 5.0% for the 4.7X. The error effects did not appear to be directly related to truncation height.

• Errors in receiver tube placement relative to the reflectors did not affect the performance to the degree that the reflector error did. The difference in performance between errors of .03 and .06 was less than 1/2% in most cases.

3.3 Performance/Cost Analysis Results

The reflector system design was selected based on the curves (as in Figure 3) which were generated by combining the collector thermal performance data discussed in the previous paragraphs with the collector cost data shown in Figure 2. These data are based on collector cost only; no provision is made to include system costs in this study. Examination of the data indicated the following trends:

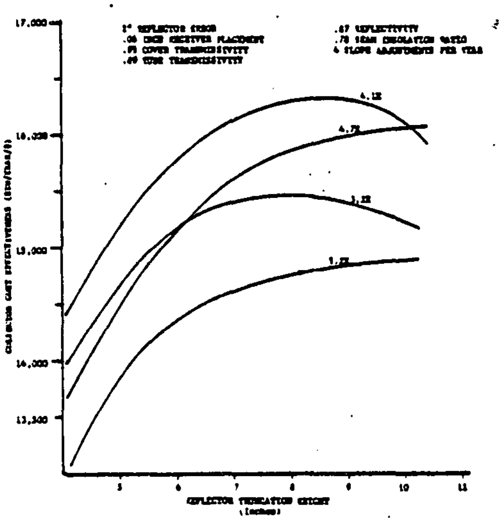


Fig. 3. Collector Cost Effectiveness Versus Reflector Truncation Height for Given Design Concentration Ratio.

• There is a definite "peaking out" in cost effectiveness in the 8 to 9-inch truncation height range. This is probably the result of the increased end shading effects as the housing gets deeper and the fact that the slope of the reflector at this height is steep enough that a given increase in reflector height costs more in dollars than the additional width provides in performance.

• Comparison of the data showed that an increase in reflector error from 1° to 2° causes a much greater decrease in performance for the higher concentration ratio collectors. This indicates that there is a significant amount of energy gain occurring when the projected angle of the sun is in the 10-12° range. The 2° reflector error would then cause a significant drop in usable insolation for a collector with an acceptance half angle of less than 14°. The 4.1X, 4.7X and 5.2X designs have acceptance half angles of 14.1, 12.3 and 11.1°, respectively. This trend was a definite influence on the final design selection.

• There was a slight advantage to making six slope adjustments per year rather than four. The 5.2X design was 2.7% more cost effective than the 4.1X with four adjustments assuming 1° reflector errors in both cases. Performance analysis for 2° reflector error and six slope adjustments was not completed, but it was assumed that the 5.2X would suffer the same effect as the 4.7X discussed above.

4. CONCLUSIONS

The 4.1X with four slope adjustments per year was selected as the most cost effective design. The other "best" design was a 5.2X which required six slope adjustments per year. The 5.2X had a slightly higher cost effectiveness (2.7%), but that did not seem to justify the requirement for the additional two slope adjustments per year. The cost effectiveness data indicated that in either case a truncation height of 8 to 9 inches was optimal and the actual calculated concentrations of the 5.2X and the 4.1X at a height of 8 inches were nearly the same: 2.7X and 2.6X, respectively. That implies that the heat loss characteristics of the design would be nearly equal and that the thermal performance would depend almost entirely on the optical efficiency of the two concentrators. The average daily collection times for the 4.1X and 5.2X over the year were nearly equal, 8.76 and 8.60 hours (Ref. 2), respectively, so there was no advantage for either in this case. The fact that the 4.1X could tolerate a greater error in reflector accuracy before showing significant performance degradation implied that it would be a better performer under real manufacturing and field use conditions.

The determination of the optimum glazing material was straightforward once the reflector system, and thus the collector physical size and cost, were fairly well prescribed. As pointed out previously, the performance of the collector increased by about 1.4% for each 1% increase in transmissivity of the glazing. Then, given a total collector cost of $470 for the 4.1X truncated at 8 inches, we can calculate that the anti-reflective treatment which will increase the transmissivity by 5% to 7% (Ref. 3) is worth at least 5 x 1.4% x $470 = $32.90 per collector in increased performance. The collector requires 32.2 ft^2 of glass, so if the cost of the anti-reflective treatment is less than $1.02/$ft^2$, it would be cost effective. The process cost

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is in fact \$.40 to \$.50/ft² (Ref. 3) at the treating facility, plus shipping charges. This is obviously a very cost effective option and the decision was made to use a low iron content glass treated to reduce reflection losses.

The same type of reasoning was used on the selection of the reflector material. The performance of the collector was increased by about 1.65% for each 1% increase in reflectivity. At the projected cost of \$470 per collector each increase of 1% in reflectivity is worth \$7.75 in collector cost. There are 48 ft² of reflector material used for production of the collector. Therefore, each increase of 1% in reflectivity is worth \$.16 per square foot of reflector material. Two competitive products were identified in the program which met the production requirements: (1) Kinglux® Type C-4 manufactured by Kingston Industries Corporation, New York, New York; and (2) Alcoa Coilzak Lighting Sheet Specular manufactured by Aluminum Company of America, Pittsburgh, Pennsylvania. They have reflectivities of .874 and .80 and cost \$1.45 and \$.74 respectively. The 7.4% difference in reflectivity is worth 1.18 ft² of material and Kinglux® was chosen as the most cost effective material.

5. ANNUAL PERFORMANCE

The computer heat gain model previously discussed was modified to use hourly weather data (direct insolation, diffuse insolation, ambient temperature) available from the National Oceanic and Atmosphere Administration. The performance predictions were based on supplying 400°F fluid with a year-round energy requirement at Omaha, Nebraska. The annual heat gain predicted for the collector under these conditions is 181,436 BTU/yr-ft², or in terms of total energy gained per collector, 4,767,600 BTU/yr-collector. Figure 4 is a copy of the computer model output which shows the heat gain per square foot of aperture by the month for an entire year.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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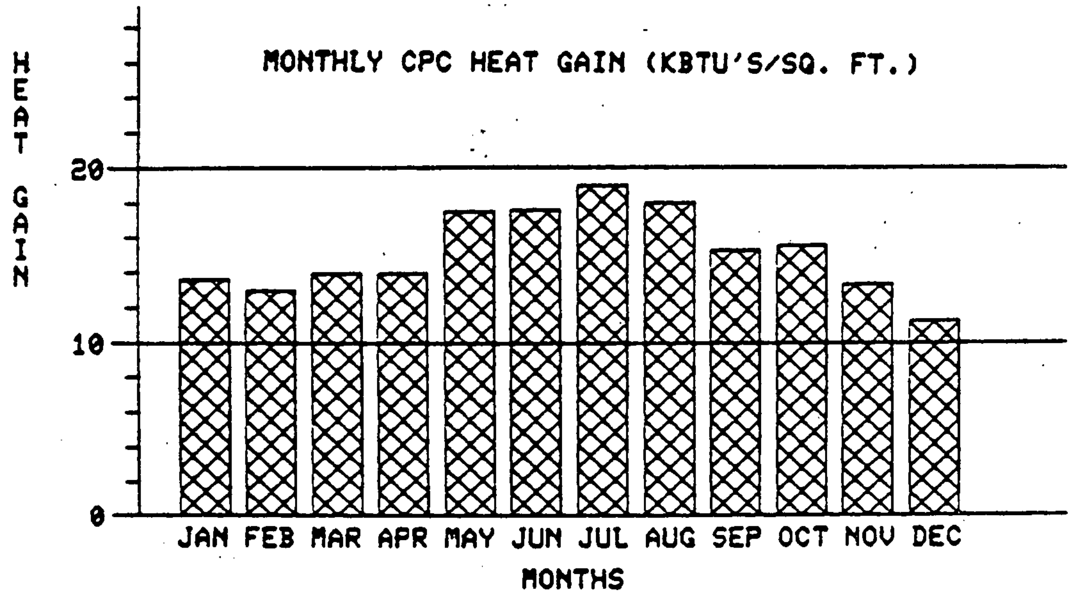
(3) Private Communication with David Zuel, Nor-Ell, Inc., St. Paul, Minnesota, 16 June 1978.



HEAT GAIN IN BTU'S PER SQUARE FOOT OF APERTURE TOTAL HEAT GAIN FOR THIS CPC IS 181436.

Fig. 4. Predicted Annual Heat Gain for Average Hourly Weather Conditions, Omaha, Nebraska.