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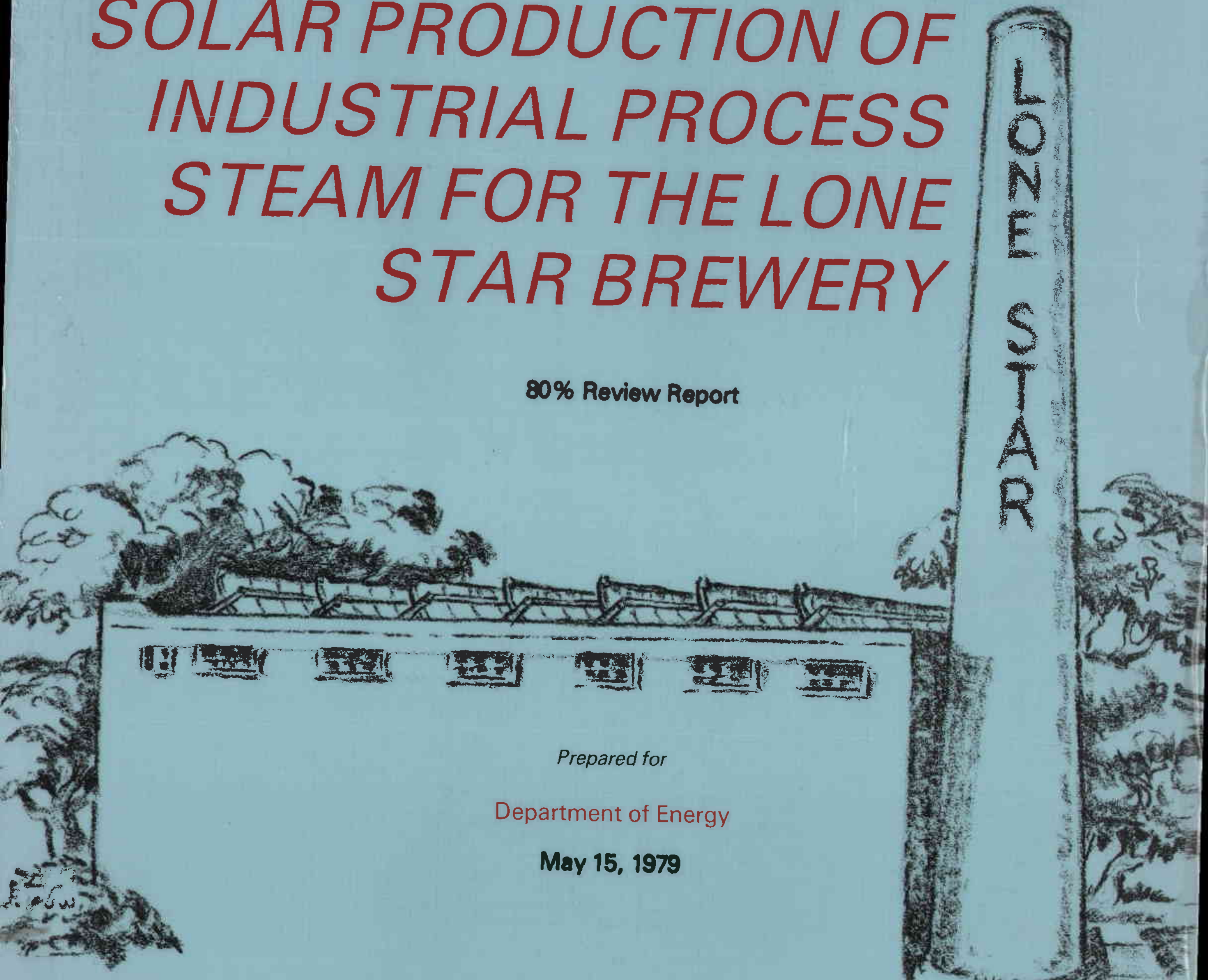
SOLAR PRODUCTION OF INDUSTRIAL PROCESS STEAM FOR THE LONE STAR BREWERY

80% Review Report



Prepared for

Department of Energy

May 15, 1979

SOUTHWEST RESEARCH INSTITUTE
SAN ANTONIO HOUSTON

SOLAR PRODUCTION OF INDUSTRIAL PROCESS STEAM FOR THE LONE STAR BREWERY

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Project No. 02-5476

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APPROVED:

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I. INTRODUCTION

This document is the 80% Review Report for DOE Contract No. ET-78-C-03-2198 (SwRI Project No. 02-5476). The scope of work for this project is to design and analyze a solar energy system for the production of industrial process steam for the Lone Star Brewery. The next phase of this activity will be the construction of the system designed during this first phase. The approach to be taken for the construction phase of this project will be to conduct the project as much as possible according to the standard procedures used by the industrial partner for any other plant expansion project. In this way, the standard building trades will be used for the supplying and installation of all equipment. The only departure from this procedure will be the utilization of a research and development organization to manage the entire project instead of a normal general contractor. This organization is Southwest Research Institute (SwRI), whose major activity is industrial problem solving. This departure is necessary since a solar steam system is not yet a standard industrial item, and the development of this system will further the state-of-the-art for industrial steam systems. It is, therefore, required that an organization experienced in solving industrial problems direct the construction of this demonstration system. In addition to the role of general contractor, SwRI will install a data acquisition system so that the system performance can be determined and recommendations for improvements for future systems can be made.

The system designed during the initial phase of this project was by choice a very simple one. A heat transfer fluid will be pumped through a solar thermal collector field, heated up, and then passed through a standard industrial unfired steam boiler. When the steam pressure in this vessel exceeds the pressure existing in the main plant steam header, solar-produced steam will be injected, which will have the same effect on the existing steam generation system as a reduced load. In this way, no storage system or sophisticated control system is required. This design also provides a safe, reliable, and minimal maintenance system.

As with any other prototype system, this initial system cannot be justified on a purely economic basis. It has been estimated, however, that with the experience and knowledge gained from this installation, along with the projected decrease in collector cost due to mass production and increase in conventional energy cost, a cost-effective system can be designed and built within the next six years without any change in government incentives. This period can be shortened if this mass-produced level of collectors can be reached earlier or if appropriate incentives are increased, such as larger investment tax credits or accelerated depreciation allowances.

One of the key features of this system design is the incorporation of a solar steam system in a conventional industrial location. Most industry is located in large urban centers where the value of land is at a premium and the installation of systems must be considered for roof mounting. The current cost of mounting these systems on existing roof tops appears to be disproportionally high due to the unknown wind loads imposed by a large number of collector rows. Single collector row wind tunnel studies have been conducted and peak wind load conditions have been determined, but the blockage effect of multiple collector rows has not been determined. It is expected that this blockage effect will be substantial. The roof support structure must, therefore, be designed on the worst-case stand-alone condition, or be designed so that the lifting force of one row will be counteracted by the downward force of the next row. The system designed for this project will include a data acquisition system to accurately measure these wind loads of multiple rows so that the building roof modifications in the future do not need to be as overdesigned as they now are. It is also projected that if new industrial construction is designed with these types of systems in mind, then the cost of providing a roof support system will be as economical as current proposed ground-mounted systems if the value of land is considered.

The other key feature of this design is the unmatched visibility afforded to both the general public and the industrial community. A tour of this facility will be available with no prior arrangements from 10:00 a.m. to 5:00 p.m., Monday through Friday, 12 months per year. Since San Antonio, Texas, is one of the country's ten largest cities with a large modern airport providing nonstop service from most of the country's large metropolitan areas, plant engineers from all over the country can fly in, tour the facility, and return the same day or, at worst, stay over one evening. The drive from the municipal airport to the Lone Star Brewery is less than 30 minutes on San Antonio's new modern expressway system. In addition to the ease of making a special plant visit, the Brewery annually receives over 400,000 visitors to tour their present facility. Since SwRI numbers 300 of the nation's largest industries on its current client list, industry representatives that regularly visit the Institute for the solution of a variety of technical problems can very easily tour the solar steam system because both SwRI and the Lone Star Brewery are located in the same city.

A detailed description of the solar steam system is included in this report along with a discussion of the System Performance Analysis, Economic Analysis, Safety Analysis, and Environmental Impact Assessment.

II. INDUSTRIAL PLANT

A. Widespread Application

The industrial partner for this project is the Lone Star Brewing Company. The selection of Lone Star was made for the many advantages listed below. This plant has a large energy requirement which is mainly supplied by natural gas. Natural gas usage averages 12.7 MMcf per month. The brewing industry as a whole has an estimated yearly energy cost of $235 million. Similar industrial applications for process steam consume an estimated 6.6 quads per year (6.6 x 10^{15} Btu). Therefore, the potential for widespread applications of the solar technology developed as a result of this project to similar industrial sites is substantial.

B. Industrial Process Steam System

Lone Star Brewery has a steam requirement of 125 psi and 353°F at approximately 50,000 lb/hr. This steam is manufactured by two 30,000 lb/hr steel shell-and-tube Keystone Boilers with heating surfaces of 3582 ft^2 and a maximum allowable working pressure of 200 psi. These boilers are fired by natural gas with diesel fuel burners installed for use as a supplement in the event of a natural gas curtailment. In addition to the Keystone Boilers, Lone Star also has a 50,000 lb/hr Erie City I.W.I. boiler with a heating surface of 4666 ft^2 and a water wall heating surface of 598 ft^2 that has a maximum allowable working pressure of 160 psi and is fired by natural gas. This boiler is also outfitted with two combination gas and oil burners which have a rating of 30,000 lb/hr. The steam pressure is controlled to a constant 125 psi, 24 hours per day. While the steam flow is not recorded directly, the load requirement can be gauged by variations in steam condensate temperature. A load time history is shown in Figure 1. In this figure, the maximum load of 60,000 lb/hr is represented by the 175°F steam condensate temperature, and the minimum load of 40,000 lb/hr is represented by the 150°F steam condensate temperature, with this value dropped to 6000 lb/hr on the weekend.

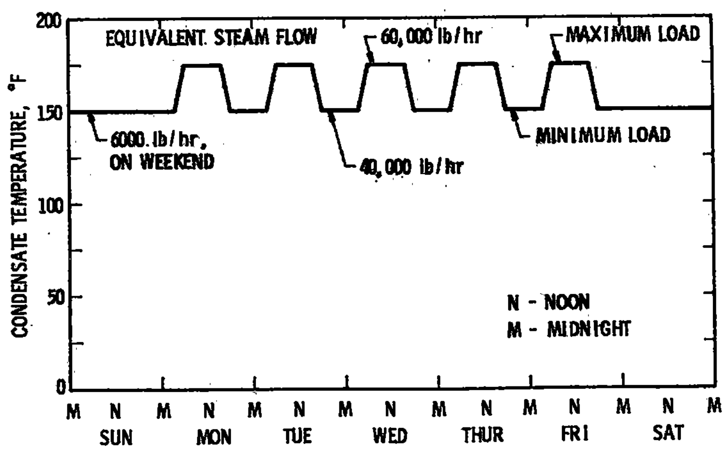


Figure 1. Process Load Time History

C. Solar System Interface

To illustrate how the solar steam generation system will interface with the present process, a simplified schematic drawing of the present steam generation system and the steam feedline from the solar-fired boiler is shown in Figure 2. A sketch of the present condensate return system, along with the condensate feedline to the solar fired boiler, is shown in Figure 3. A block diagram of the solar steam system is shown in Figure 4. With

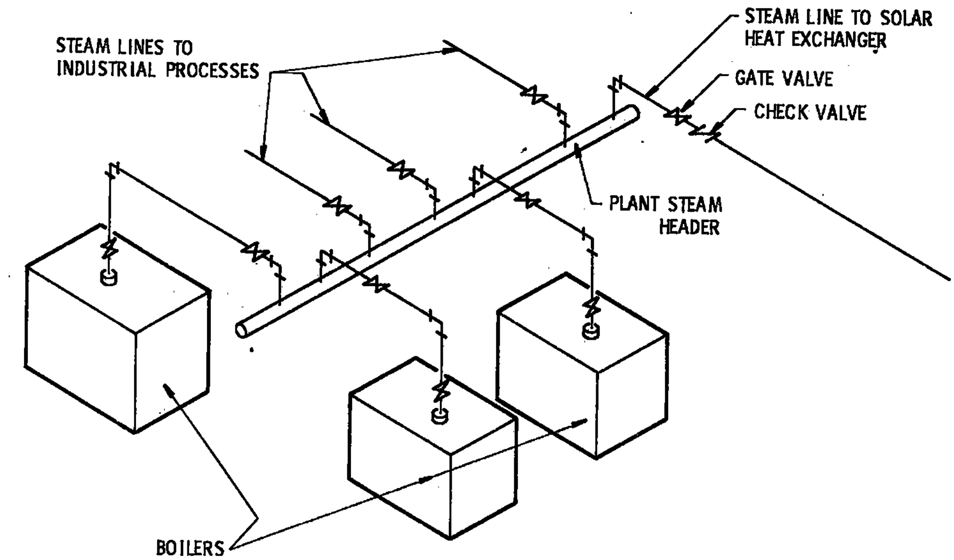


Figure 2. Steam Generation System

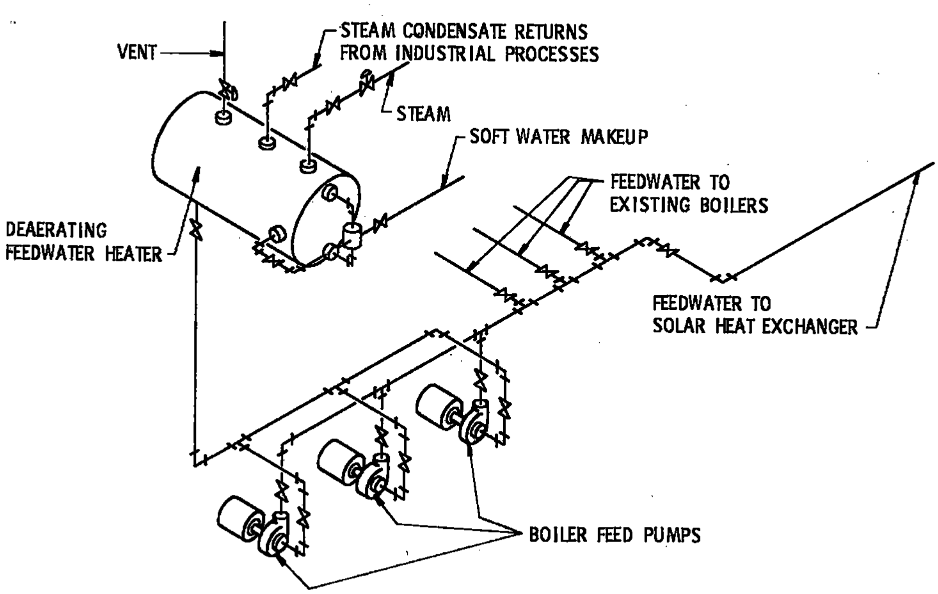


Figure 3. Condensate Feedwater System

these figures for reference, a description of the interface between the solar steam system and the present industrial process follows.

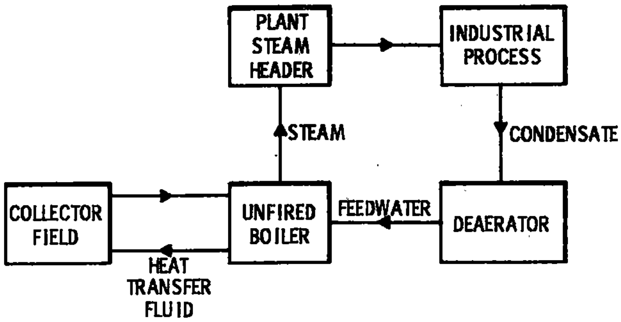


Figure 4. Solar Steam System Block Diagram

Steam is presently generated by three boilers, each producing steam at a gage pressure of 125 psi and a temperature of 353°F. Boilers deliver steam to a common header which feeds the various steam loads. Interface of the solar system with the existing process is to be accomplished by injecting the solar-produced steam into the main steam header that passes through the canning warehouse just below the collector field, thereby minimizing the piping runs between the collector field and boiler, and between the boiler and steam header. The piping which carries this steam will be connected to the plant steam header via a check valve and a gate valve provided in the solar steam line just before its point of connection to the header (Figure 2). The check valve in the solar steam line will serve to prevent plant-produced steam from flowing upstream in the solar line while solar steam is not being produced but, yet, will admit solar-produced steam to the plant header when it is available at the plant pressure of 125 psi. The gate valve in the solar steam line will allow positive manual shutoff of the solar line at any time for required maintenance or adjustment of the system. Interface being accomplished in this manner will allow all of the solar steam to be utilized in the plant processes and will diminish the loads on the existing boilers since their controls are such as to automatically limit their firing to produce a constant pressure at the steam header.

D. Process Utilization

The average steam requirement for the total plant is 50,000 lb/hr, but the steam requirement for the process downstream from where the solar-produced steam will be injected is 6000 lb/hr, seven days per week. The following assumptions were used for estimating the peak performance of a realistic system for this application: the weather is crystal clear with an intensity of 335 Btu/hr-ft^2, 85% of the total radiation is beam radiation, the collector has an efficiency of 63%, the collector area is 9450 ft^2, and 1000 Btu are required per pound of steam. With these assumptions during ideal conditions and no thermal losses in the remainder of the system, the maximum output from the solar collection system is about 1700 lb/hr, which is 28% of the steam load downstream from where this stream will be injected, or 3% of the total plant load.

E. Building Configuration

The overall building configuration is shown in Figure 5. This aerial view shows the available roof area. To mount 9450 ft^2 of tracking solar collectors without significant shading requires about 20,000 ft^2 of roof area. The roof areas on the warehouse buildings (designated A and B in the upper left portion of Figure 5) are 20,171 ft^2 each, the next building to the right (Building C) has a roof area of 12,700 ft^2, Building D has 3040 ft^2, and Building E has a roof area of 5782 ft^2. Warehouse Building A has been selected as the most ideal location for the collector field. This location will place all 9450 ft^2 of collectors in one central location without any shading problem between rows and offers the collectors an unobstructed view of the sun all year long. Th epipe run to the solar-fired boiler, which will be located in the warehouse equipment room directly below the collector field, will be about 30 ft.

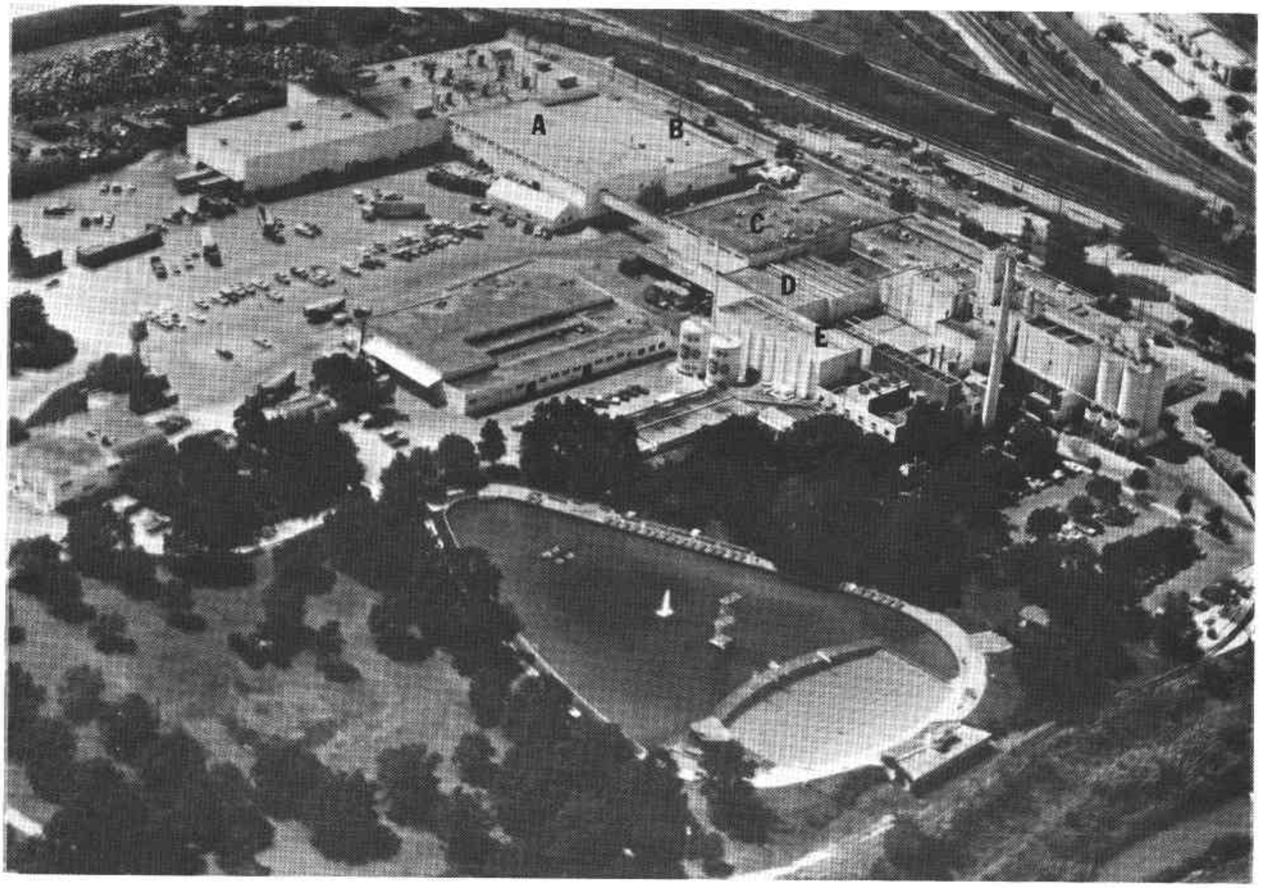


Figure 5. Aerial Photograph of Lone Star's Industrial Plant Site Looking Northwest

F. Climatic Conditions at Industrial Site

Lone Star Brewing Company's industrial plant is located in San Antonio, Texas. The location of this plant site on the edge of the Gulf Coastal Plains results in a modified subtropical climate, predominantly continental during the winter months and marine during the summer months. Normal mean temperatures range from 50.6°F in January to a high of 84.7°F in July. While the summer is hot, with daily maximum temperatures above 90°F over 80 percent of the time, extremely high temperatures are rare, the highest on record being 107°F. Mild weather prevails during much of the winter months, with below-freezing temperatures occurring on an average of about 20 days each year.

San Antonio is situated between a semiarid area to the west and the coastal area of heavy precipitation to the southeast. The normal annual rainfall is 27.54 in. Precipitation is fairly well distributed throughout the year with heaviest amounts during May and September. Hail of damaging intensity seldom occurs, but light hail is frequent in connection with springtime thunderstorms.

Northerly winds prevail during most of the winter, while southeasterly winds from the Gulf of Mexico prevail during the summertime and may be experienced for extended periods during the winter. Rather strong northerly winds occasionally occur during the winter months in connection with "northers." No tornadoes have been experienced in the immediate area. Relative humidity averages above 80 percent during the early morning hours most of the year, dropping to near to well below 50 percent in the late afternoon.

San Antonio, popularly known as the place 'where the sunshine spends the winter,' has about 50 percent of the possible amount of sunshine during the winter months and more than 70 percent during the summer months. Skies are clear more than 35 percent of the time and cloudy about 30 percent. Air carried over San Antonio by southeasterly winds is lifted orographically, causing low stratus clouds to develop frequently during the later part of the night. These clouds usually dissipate before noon with clear skies prevailing a high percentage of the time during the afternoon.

The specific conditions that affect the operation of a solar steam system will be discussed here. Since the ambient weather conditions vary greatly from day to day, the only sound approach to characterizing these conditions is to determine the long-term average values. The pertinent data available from the local weather station are solar radiation measured on the horizontal, percentage of clear-day radiation received, daytime ambient design temperature as calculated from the mean and maximum temperature, and average wind speed. These four long-term average quantities were extracted from the U.S. Department of Commerce Weather Bureau 'Climatological Data: National Summary' for the period of 1953-1974, and are listed in Table I. The long-term average daily total solar radiation for each month and each season are shown in Figure 6.

G. Energy Conservation Plan of Industrial Partner

Lone Star Brewery has pursued energy conservation for many years. The following indicate the major energy saving efforts that have been implemented in the past: the reclaiming of bottlewasher water for irrigating

TABLE I. CLIMATOLOGICAL SUMMARY

San Antonio, Texas
Lat.29° 32′N
Long. 98° 28′W
El.794 Ft

Climatic Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
H, Btu/day-ft^2	980	1234	1528	1636	1895	2192	2288	2045	1724	1414	1076	871	1574
T_a, °F	54	58	66	74	79	85	88	87	82	74	63	56	72
% Possible	48	51	56	58	60	69	74	75	69	67	55	49	62
V, mph	9.0	9.8	10.4	10.7	10.2	10.1	9.3	8.5	8.5	8.4	8.9	8.6	9.4

where: H = Long-term monthly average daily total radiation on a horizontal surface, Btu/day-ft^2;

% Possible = Percentage of clear day insolation received on the average day of the month;

T_a = Long-term monthly average daytime ambient design temperature, °F ($T_a = 0.3T_{max} + 0.7T_{mean}$); and

V = Long-term monthly average daily wind speed, mph.

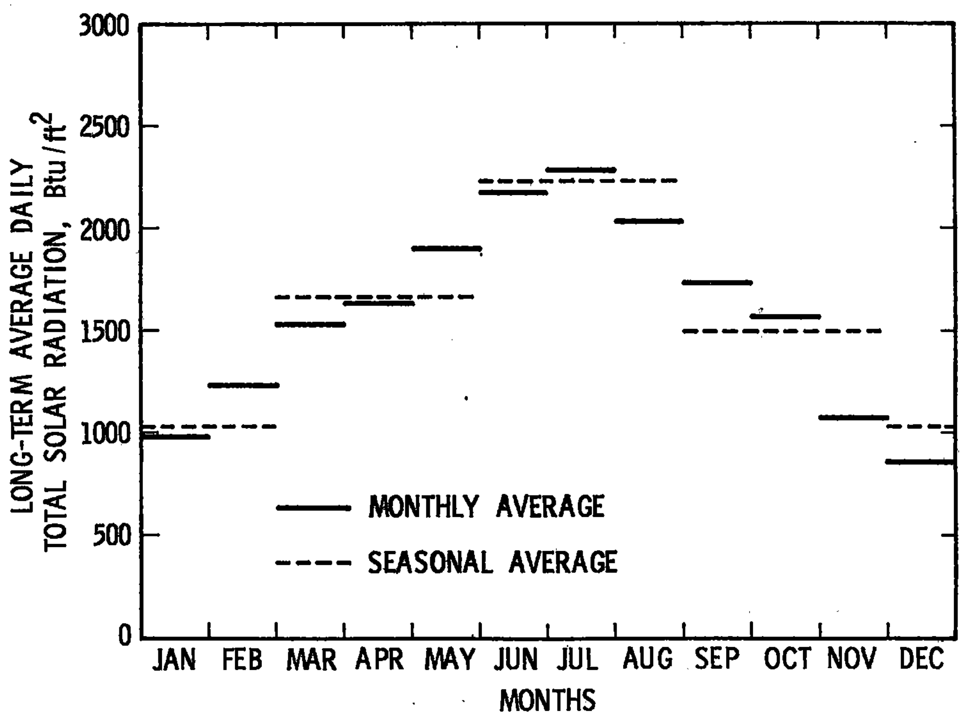


Figure 6. Solar Radiation at the Industrial Site

through an automatic yard sprinkling system; the lowering of hot water temperature in bottle and can warmers from 140°F to 120°F; the sterilizing time in pasteurizing units, product lines, bottle fillers, and can fillers has been reduced from four hours to two hours. The thermostat settings for space heating during the winter has been lowered from 78°F to 68°F, and settings for air conditioning during the summer have been raised from 68°F to 80°F. A comprehensive maintenance program including a shop with 60 craft employees has been initiated to keep equipment at peak efficiency. Plant personnel have recently completed a hot water reclaiming system to preheat brewing water from 80°F to 135°F with hot by-products at 198°F.

H. Visibility of Project

One of the major advantages of this project is the unmatched visibility afforded to both the general public and the industrial community. Lone Star Brewing Company has over 400,000 visitors tour their industrial plant each year, and an additional 40,000 visitors use their party facilities. Plant tours are held from 10:00 AM to 5:00 PM, Monday through Friday, 12 months per year. The Engineering Department at Lone Star also holds special guided tours of their facilities at the request of groups within the construction and trade industries, brewing industries, or an industrial group with similar steam facilities. Groups that have recently toured Lone Star's plant are listed below.

- American Society of Heating, Refrigeration, and Air Conditioning, Engineers' Local Chapter
- Plumbers and Pipefitters Local 142
- Refrigeration and Air Conditioning Training Classes from local trade schools
- Mechanical Contractors Association of San Antonio
- Association of General Contractors of San Antonio

Arrangements have been made with the San Antonio Visitors and Convention Bureau to publicize the project to any incoming convention groups that may have an interest in process steam application. San Antonio has a $300 million per year tourist and convention business with over 7.34 million people visiting the city a year.

In addition to the Lone Star-generated exposure mentioned above, SwRI will also provide significant visibility for this project. Last year SwRI grossed about $30 million in contracts for over 300 industrial clients. This figure has steadily been increasing at a rate of 18% per year. A copy of the brochure developed for this program will be distributed to all of SwRI's project managers so that this effort can be brought to the attention of any of their industrial clients that may have an interest in such a project. The list of SwRI industrial clients represents a major portion of the nation's leading industries which have come to SwRI for solutions to a wide variety of industrial problems.

III. SYSTEM DESIGN

A. Conceptual Design

The conceptual design for this system is by choice a very simple one. We have striven to minimize operation and maintenance problems while, at the same time, providing a workable and economical system. The design concept is to pump a heat transfer fluid through a collector field and then pass this heated fluid through the tube bundle of an unfired steam boiler. The steam produced in the shell of this boiler is then transported to the process steam header under the developed pressure and metered to this header by a standard check valve. Feedwater from the process deaerator, which is fed to the existing boilers by three boiler feed pumps in parallel to a common header, will be tapped for make-up to the solar-fired boiler.

An optimization study was conducted to determine the most cost-effective configuration of the system as well as the optimum size of each system component. The details of this study will be given in the performance analysis section of this report, but the results are as shown in Figure 7. This figure indicates that a collector field

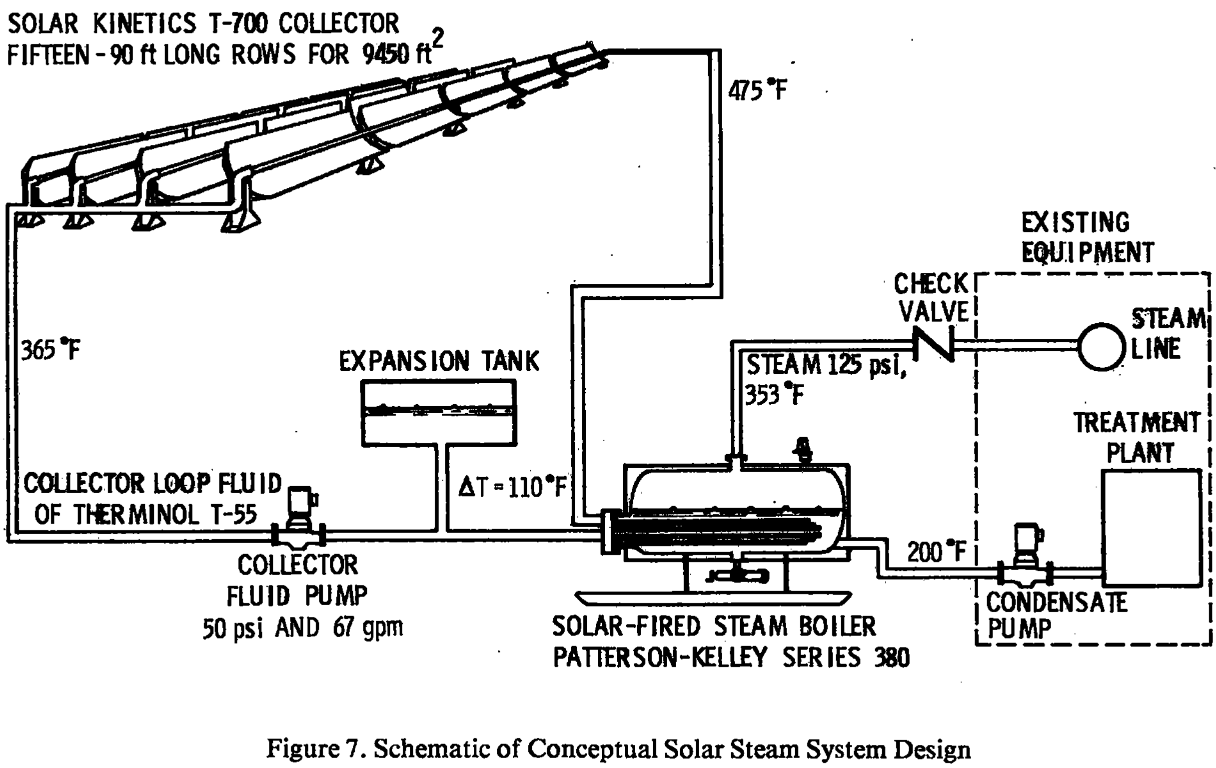


Figure 7. Schematic of Conceptual Solar Steam System Design

configuration of fifteen 90-ft long rows spaced on 13 ft 4 in. centers is the optimum, giving a field size of 9450 ft^2. The collector field flow rate is 67 gpm with a pump head of 50 psi. The collector loop piping is 2-in. welded black steel pipe with 2-in. fiber glass insulation. The temperatures shown in Figure 7 are for ideal conditions of 300 Btu/hr-ft^2 and an ambient temperature of 85°F. The calculated collector inlet temperature is 365°F, and the collector outlet temperature is 475°F. These temperatures give an average collector fluid temperature of 420°F. At these temperatures, the maximum steam flow rate is 1674 lbs/hr, and the maximum energy transfer to produce this amount of steam plus heat the condensate from 200°F to the steam temperature of 353°F is 1.7×10^6 Btu/hr. The yearly system output, therefore, is 3192×10^6 Btu or 3.050×10^6 lbs of steam.

B. Collector Field Design

1. Collector Survey

a. Introduction

Since solar steam systems are not yet cost competitive, a concerted effort has been made in this design project to determine the most cost-effective system possible. The first step in this process is to select the most cost-effective collector, keeping in mind its performance, durability, maintainability, and installation cost. For a process steam system at 125 psi and 353°F, we considered seven candidate collectors. These seven collectors are manufactured by:

(1) Acurex Corporation
(2) General Electric Company
(3) Hexcel Corporation
(4) Honeywell, Inc.
(5) Jacobs-Del Solar Systems, Inc.
(6) Solar Kinetics, Inc.
(7) Suntec Systems, Inc.

Each of these units has certain advantages and disadvantages, and all are comparably priced. One must be careful, however, to determine what equipment is included in the purchase price, what equipment must be supplied by the installer, and whether or not the price of freight is included. The quality of construction for all these units appears good, with only small differences between units. These small differences, however, can have significant implications on performance and cost over the life of the system.

To determine, therefore, the most cost-effective collector for this application, the following procedure was used:

- A request for quotation was solicited.
- Site visits were conducted.
- Installed system costs were estimated.
- The yearly collector performance was calculated.
- The cost per million Btu collected was determined and used as an indicator for selection.

The request for quotation was solicited in the form of a letter to each of the candidate manufacturers asking for the following information:

- Written quote for the purchase of 10,000 ft^2 of collector aperature including a maximum guaranteed escalation rate for the next year.
- Performance data so that collector output at 400°F average receiver temperature can be calculated for a typical weather year in San Antonio, Texas.
- Based on previous system installations, provide an estimate of the number of labor hours required for installing this size system by each labor trade, including special roof preparation required for wind and dead loads.
- Estimated maintenance schedule for the life of the collector field, along with the estimated life of the above collector system.
- Specify any unique features that would indicate a more economical system, a longer system life with lower maintenance, a higher thermal performance over the life of the system, greater durability, and overall quality of workmanship than other available collector systems.

Site visits were then made to at least one installation of each of the candidate collectors. The sites visited were:

(1) Acurex Corporation - Campbell Soup Company in Sacramento, California, and Shallow Well Irrigation System in Willard, New Mexico.

(2) General Electric Company - In-house test facility at the G.E. Valley Forge Plant in Philadelphia, Pennsylvania.

(3) Hexcel Corporation - Indian Hospital in White River, Arizona.

(4) Honeywell, Inc. - Honeywell General Office Building in Minneapolis, Minnesota.

(5) Jacobs-Del Solar Systems, Inc. - Sandia Test Facility in Albuquerque, New Mexico.

(6) Solar Kinetics, Inc. - Shallow Well Irrigation System in Willard, New Mexico, and Sandia Test Facility in Albuquerque, New Mexico.

(7) Suntec Systems, Inc. - Sandia Test Facility and Sandia Total Energy System, both in Albuquerque, New Mexico.

The next step in determining the most cost-effective collector for this application was to estimate the installed system cost. This estimate included the following:

- Purchase price of the collector.
- Estimated labor costs for collector installation.
- Estimated piping costs.

In order to calculate total cost per Btu, the next item determined was the yearly collector performance, which was calculated as outlined in the performance analysis of this report.

Once the installed system cost was estimated and the yearly collector performance was calculated, then the dollars per million Btu's were calculated assuming a 20-year life for each collector system. This value was then used as an indicator to determine the most cost-effective collector available for this application. A summary of these values along with the estimated installed system cost and collector performance calculations are included after the detailed discussion of each of the candidate collectors.

b. Candidate Collector Units

1) Acurex Corporation Model 3001

The Acurex Model 3001 is a reflecting parabolic trough collector with a 6-ft wide aperature, a concentration ratio of 58, and a rim angle of 90°. This unit is constructed in 10-ft modules with vertical steel columns provided between modules to support the system weight of 5.9 lbs/ft^2. Eight of these modules are normally included in a single row with a single drive system in the center of the row. The drive system consists of a fractional horsepower gear motor which turns a large reduction worm and worm gear. Input to the motor is controlled by a shadow band tracker with two silicon photo cells. When the vertical axis of a collector is aimed at the sun, the output from the two cells is balanced and the motor deactivated.

The reflective surface of the parabolic trough is fabricated from ALZAK with a reflectance of 0.75. Once the sunlight is reflected from the surface, it passes through a Pyrex glass jacket and strikes the receiver tube. The receiver is constructed of a 1-1/4-in. mild steel pipe with a black chrome selective surface. The absorptance of this surface is 0.94, and the emittance is 0.18.

The principal advantage of this unit is that it has a fair amount of field experience. Also, the reflective surface of this unit is a relatively stable surface with very small degradation due to exposure. This reflective surface is also very hail resistant because of its 40-mil aluminum skin. The disadvantages of this unit are: low mirror reflectance, receiver tube breakage problems, rusting of the reflective casing, exposed worm gear, low system performance, leakage of the flexible hose connection, and high purchase price. As will be shown later in this report, the cost-effectiveness of this particular unit is significantly less than some of the other candidate collectors, because of its low performance and a high purchase price.

2) General Electric Company Model TC300

The G.E. Model TC300 solar collector is an evacuated tube design with a parabolic trough reflector. The reflector for this unit features a thin glass reflective surface which provides a concentration ratio of about 3. Three of these troughs are combined in parallel in a 45 in. x 16 in. module. Because this collector has a large acceptance angle, no daily tracking is required; however, seasonal adjustments are required four times a year.

The material properties of this unit are: reflectance, 0.86; glass transmittance, 0.85; receiver absorptance, 0.89; emittance, 0.07. An advantage of this type of collector is the elimination of any daily tracking requirements; however, since this unit is not yet in production, it was not considered further.

3) Hexcel Corporation Model 1655

The Hexcel Model 1655 parabolic trough tracking solar collector has the largest aperature of any other candidate collectors considered for this survey. This aperature is 9.75 ft with a rim angle of 72° and a concentration ratio of 72. Reflector panels of this unit are constructed from 3/8-in. aluminum honeycomb assemblies with 1/2-in. aluminum channel protecting the edges. The reflective surface is an aluminized second surface acrylic film, manufactured by the 3M Corporation, designated FEK-244. This surface has a reflectance of 0.84. The reflector support structure is constructed from welded steel tubing that, in combination with the honeycomb reflective backing, provides excellent rigidity against wind buffeting. The tracking system for this assembly is provided by the Suntek sun sensor manufactured by the Delavan Electronics Corporation. The sensing head consists of a shadow band with two phototransistors. The output from these sensors causes an imbalance in the bridge circuit by shading one of the transistors and is restored to balance when an electromechanical drive mechanism advances the position of the collectors so that the vertical axis of the collector is pointed directly at the sun. The drive mechanism is an electric stepping motor that drives the collector via a chain and sprocket assembly. The energy impinging on the reflector is collected by a black chrome coated receiver pipe with spiral internal grooves and an internal plug. The cover for this tube is a half cylinder of Pyrex glass with a back cover of double-layer metal shield coated with a reflective inner surface of ALZAK. The advantages of this unit are the high thermal performance, low weight, low purchase price, and excellent reflector rigidity. The disadvantages are high wind loads, exposed chain drive, potential for hail damage, degradation of plastic film, no flexible hoses are provided, and relatively high field installation costs.

4) Honeywell Corporation Model HCSC-4

The Honeywell collector Model HCSC-4 is a single-axis tracking parabolic concentrating collector. The reflector consists of 1/2 of a parabola. The design of this collector provides a low profile and is stowed in a low drag, mirror face down position. This stow position protects the mirror surface and reduces nighttime reradiation into space. The parabolic structure is a honeycomb sandwich construction to combine high strength and stiffness with lightweight. The reflector is aluminized acrylic and is a product of 3M. The parabolic structure and reflective surface is manufactured for Honeywell, Inc., by the Hexcel Corporation. The mirror structures are constructed of 20-ft long modules allowing collector rows of 80 to 120 ft long. The tracking drive motor is mounted in the middle of each collector row. The thermal energy receiver consists of a black chrome coated absorber tube having a diameter of 1-1/4-in. and constructed of steel. The absorptance of the receiver tube is 0.94, and the emittance is 0.18. The absorber tube is mounted on a galvanized lightweight steel housing and is provided with a calcium silicate insulation on the back side of the receiver and a field-replaceable etched glass window in the front of the receiver tube to reduce thermal losses at the receiver. The tracking mechanical system is a Windsmith gear box, oil encased with a total enclosed fan-cooled motor. Each gear box is provided with a 5000-to-1 self-locking worm gear complete with brake and anti-backlash system. The motor is a fractional horsepower squirrel cage induction type. The controlled tracking system is a Delavan sun sensor modified by Honeywell. At the present time, this unit is not considered a production unit and will, therefore, not be considered further.

5) Jacobs-Del 24-In. Concentrating Collector

The Del collector is a parabolic trough concentrator composed of glass mirror segments. Each segment is a 2-ft long piece of sagged glass formed to the appropriate parabolic shape and back silvered. The silvering is protected from the weather by an inert, nonporous coating on the back side and by the glass on the reflecting side. These mirrors, which have a reflectance of 0.9, are fitted into a parabolic frame with an aperature of 2 ft and a rim angle of 110°. The parabola is composed of four mirror segments with some optical distortion at the edge of each mirror, or eight 1-in. distortion bands. These bands decrease the thermal performance from the theoretically predicted values.

The reflector concentrates the sunlight onto a stationary receiver tube positioned at the focal point and center of rotation of the parabola, which is also the center of gravity of the unit. The fixed 1/2-in. diameter receiver is coated with a selective coating of black chrome which exhibits an absorptance of 0.94 and an emittance of 0.18. This hard-mounted receiver is completely fixed so that no flexible fluid connections are required. Thermal losses from this tube are decreased by a 1.5-in. diameter Pyrex glass tube with a transmittance of 0.9.

The drive system for this unit is a Delavan photoelectric sensor which controls a reversible motor and an enclosed worm gear assembly. This control unit provides stow as well as defocus features to provide a complete hazard avoidance system.

The advantages of this collector are its stationary receiver, its glass reflector, which provides high reflectance and long life, and low wind loads. The disadvantages are a low thermal performance due to low concentration ratio, high unit weight, and high installation costs.

6) Solar Kinetics T-700 Collector

The Solar Kinetics T-700 is a large aperature (7 ft) parabolic trough concentrating solar collector constructed of a rigid monocoque aluminum assembly which provides an excellent strength to weight ratio. The rim angle of this unit is 90° with a concentration ratio of 52. One of the unique features of this collector is the no-lash hydraulic tracking system. This system provides accuracy and durability with two tracking speeds, one for daily tracking of the sun and one for hazard stow operation. The hydraulic accumulator provides the capability to defocus the collector in the event of a loss of power or loss of fluid.

The parabolic reflector is a precisely constructed mirror surface covered with metalized acrylic film which combines weather resistance and high reflectivity. This film is FEK-244, manufactured by the 3M Corporation, with a reflectance of 0.84, a proven life of at least seven years, and a predicted life of over 10 years. The surface reflects the sun's rays onto a 1.63-in. diameter steel tube coated with selective black chrome and a Pyrex glass cover with an O-ring seal for dust and dirt protection. The absorptance/emittance ratio of this coating is 0.94/0.18. After the heat transfer fluid passes through this receiver tube, it is conveyed to the stationary plumbing via an insulated stainless steel flexible hose which allows rotation of the collector without any flow restriction. The reflector rotation is made possible by self-aligning sealed ball bearings which absorb structural loads and misalignment from shifting of the building support without any binding.

The advantages of the T-700 are the hydraulic tracking system, the O-ring receiver cover seal, the rigid reflector assembly, the excellent overall quality, the high thermal performance, and the low installation costs. The overall system was designed with low maintenance and minimal field installation requirements in mind. The only known disadvantage to the selection of this unit is the unknown durability of the acrylic reflective film.

7) *Suntec SLATS Collector*

The SLATS collector (Solar Linear Array Thermal System) is constructed of a fresnel trough reflector. This reflector consists of a field of curved rectangular mirrors that reflect sunlight onto a narrow line image. The mirrors, resembling Venetian blinds, are steered by a linkage system to direct the sun's image onto a linear receiver. The mirror assembly is composed of ten 1-ft wide by 20-ft long segments orientated with the length dimension in the east-west direction and tilted at the latitude of the installation.

The concentration ratio of the unit is 38 with the glass mirror segments exhibiting a reflectance of 0.9. The receiver of this collector is composed of two absorber tubes constructed of 1-1/4-in. Schedule 160 steel tubing enclosed under a glass plate on the reflector side and an insulated box on the other three sides. Each absorber tube is electroplated with a black chrome selective coating.

The advantages of this unit are high mirror reflectance, stationary receiver, and a low thermal loss receiver. The disadvantages are a potential for breakage of the mechanically curved mirrors, large number of moving mirror segments, low thermal performance, high purchase price, and high installation costs.

c. *Survey Summary*

Of the seven candidate collectors discussed above, only five were determined to be production units. This determination was made when two of the seven either could not provide a quote on the purchase price of 10,000 ft^2 of collectors (in the case of the Honeywell unit) or a single module could not be supplied for the exposure test unit until a special production run could be made (in the case of the G.E. unit). The physical and performance characteristics of the remaining five collectors are summarized in Table II. The performance characteristics are given in the form of the absorptance coefficient and the loss coefficient which are indicated in the following equation:

$$\eta = F(\tau\alpha)_e - U \quad \Delta T/I \qquad (1)$$

where η = Efficiency;

$F(\tau\alpha)_e$ = Absorptance coefficient;

U = Loss coefficient;

ΔT = Temperature difference between the average fluid temperature and the surrounding air temperature;

I = Direct normal solar radiation.

TABLE II. PHYSICAL AND PERFORMANCE CHARACTERISTICS OF THE CANDIDATE COLLECTORS

	Acurex	Hexcel	Del	Solar Kinetics	Suntec
Mirror Width	6 ft	9 ft	2 ft	7 ft	10.7 ft
Mirror Length	10 ft	20 ft	8 ft	20 ft	20 ft
Rim Angle	90	72	110	90	Fresnel
Reflectance	0.75	0.84	0.90	0.84	0.90
System Weight	5.9 lb/ft²	3.5 lb/ft²	7 lb/ft²	3.7 lb/ft²	—
Receiver Width	1.25 in.	1.5 in.	0.5 in.	1.63 in.	3.4 in.
Receiver Absorptance	.94	.94	.94	0.94	0.94
Receiver Emittance	.18	.18	.18	0.18	0.18
Drive Mechanism	Worm & Worm Gear	Chain & Sprocket	Worm & Worm Gear	Hydraulic	Chain & Linkage
Tracking System	Acurex	Delavan	Delavan	Delavan	Suntec
Concentration Ratio	58	72	48	52	38
Absorptance Coefficient	0.63	0.69	0.72	0.7	0.68
Loss Coefficient*	0.093	0.088	0.046_1 0.040_2 0.002_3	.075	.119

*Loss coefficients for the Del collector are for a third-order correlation, i.e., $\eta = 0.72 - 0.046\,(\Delta T/I) - 0.040\,(\Delta T/I)^2 + 0.002\,(\Delta T/I)^3$

The performance characteristics for each of the five candidate collectors is shown in Figure 8. These data were then used to calculate the yearly output of 10,000 ft² of collector aperature with 80-ft long rows and a row spacing of two aperatures. A summary of the results of these computer runs is shown in Table III. This table shows the collector output for each month of a typical San Antonio weather year.

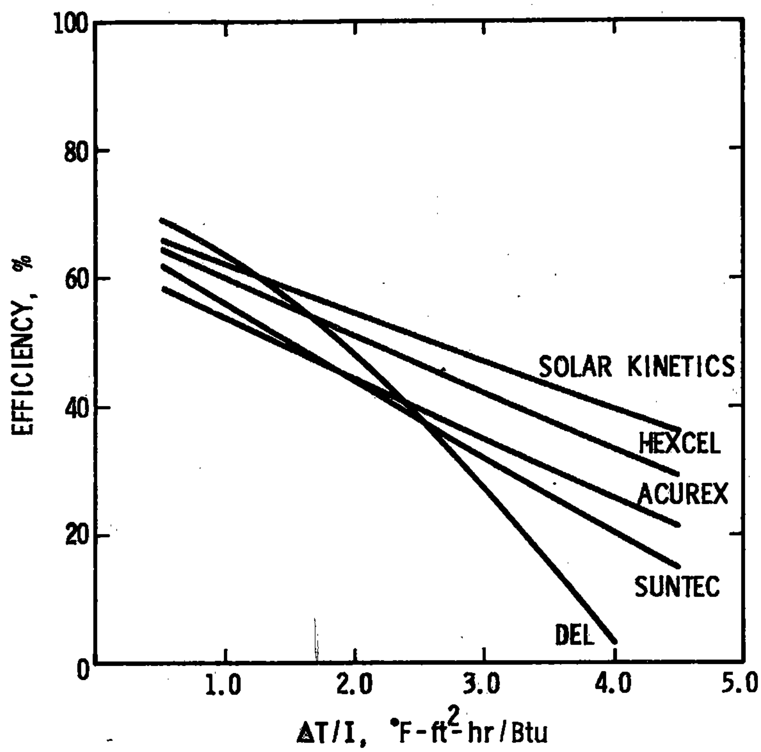


Figure 8. Instantaneous Collector Performance

TABLE III. COLLECTOR PERFORMANCE SUMMARY IN MILLIONS OF BTU'S FOR A 10,000-FT² COLLECTOR FIELD OPERATING AT 400°F

Month	Acurex	Hexcel	Del	Solar Kinetics	Suntec
Jan	75.6	89.0	71.1	102.8	54.9
Feb	98.4	114.8	104.6	129.5	82.6
Mar	174.4	201.6	192.2	220.6	158.1
Apr	195.6	225.1	214.5	242.6	186.8
May	210.1	242.4	228.2	260.5	205.2
Jun	259.2	297.1	289.6	316.9	256.6
Jul	296.9	339.2	337.3	360.6	295.8
Aug	255.7	292.3	288.7	311.9	251.3
Sep	201.1	230.3	225.9	248.6	188.8
Oct	155.3	178.8	168.5	196.8	136.3
Nov	104.6	120.3	110.5	134.6	85.4
Dec	71.2	83.7	68.6	96.4	50.9
Total	2098.1	2414.6	2299.7	2621.8	1952.7

To make a selection of the most cost-effective collector, the next step in the process was the estimation of the collector installation costs. This was accomplished by requesting quotes for the purchase of 10,000 ft^2 of each of the candidate collectors. These quotes had to be based on an assumed number of rows and row lengths. The cost per square foot is effected by the number of collectors per row since the longer the row the less drive hardware required per square foot. In addition to the purchase price of the collectors, the installation costs, and piping costs were all estimated and combined to obtain the total installed cost of the collector field. A list of these costs for each of the collectors is shown in Table IV.

TABLE IV. ESTIMATED INSTALLED COLLECTOR FIELD COSTS PER FT^2

Collector Manufacture	Purchase* Price	Installation Cost	Piping Cost	Total
Acurex	23.85	2.50	3.00	29.35
Hexcel	19.50	3.00	3.00	25.50
Jacobs-Del	20.50	3.20	6.00	30.70
Solar Kinetics	19.00	2.00	3.00	24.00
Suntec	23.00	2.80	3.00	28.80

* Including freight, tracking system, and flexible hose connection.

There are two different methods for determining the most cost-effective collector. The first method is to compare the ratio of installed collector costs to thermal efficiency for the different collectors as a function of the collector operating parameter**, as shown in Figure 9. This method shows that the collector manufactured by Solar Kinetics is the most cost-effective collector available under all conditions. The second method compares the total dollars per million Btu's for each collector by estimating the total Btu output of each collector over its predicted life and estimating the installed costs for each collector. This was done by assuming a twenty-year life for each of the five collectors. A list of costs per million Btu is shown in Table V. This method also indicates that the Solar Kinetics collector is the most cost-effective candidate collector. It must be pointed out, however, that it was assumed that the maintenance and operating costs of all of these collectors is essentially the same. Since there is no reason to expect the maintenance and operating costs of the Solar Kinetics T-700 to be any greater than any of the other candidate collectors, this unit was selected for this application.

** Deffenbaugh, D. M., and Carper, H. J., "Cost-Effective Selection of Flat-Plate Solar Collectors," Proceedings of 1977 Flat-Plate Solar Collector Conference, 1977.

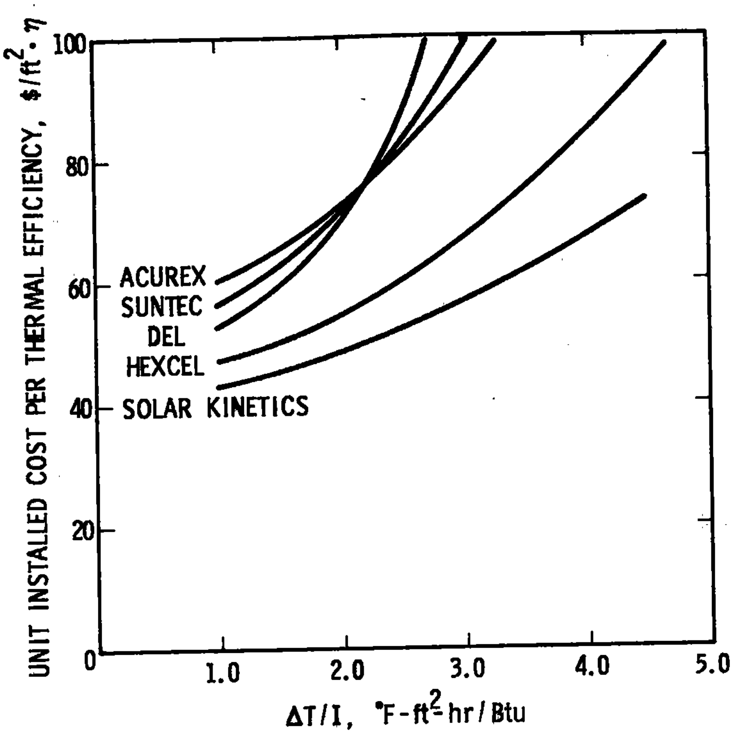


Figure 9. Cost-Effective Indicator for the Candidate Collectors

TABLE V. ESTIMATED DOLLARS PER MILLION BTU FOR A 10,000-FT² COLLECTOR FIELD ASSUMING A 20-YEAR LIFE

Collector Manufacture	Total Unit Cost, $/ft²	Yearly Collector Output, 10^6 BTU	$/$10^6$ BTU
Acurex	32.35	2048.1	7.71
Hexcel	28.50	2414.6	5.90
Jacobs-Del	33.70	2299.7	7.33
Solar Kinetics	27.00	2621.8	5.15
Suntec	31.80	1952.7	8.15

2. Optimum Collection Field Size

The collector field will be located on the roof of the canning warehouse as indicated by the A in Figure 10. A close-up view of this roof is shown in Figure 11. The dimensions of this roof are 201 ft - 8-1/2 in. by 100 ft, with the longer dimension oriented in the east/west direction. The roof is constructed with bar joists running in the north/south direction spaced on 6 ft - 8 in. centers. These bar joists are supported by I-beam girders at the north and south walls plus a single girder down the middle of the building supported on columns.

It was determined that a savings in support structure cost could be made by placing the collector rows directly over every other roof bar joist. Since there are 31 bar joists, the collector field configuration selected consists of fifteen 90-ft long rows on 13 ft-4 in. centers which places the rows on every other bar joist and gives a total collector aperature area of 9450 ft^2.

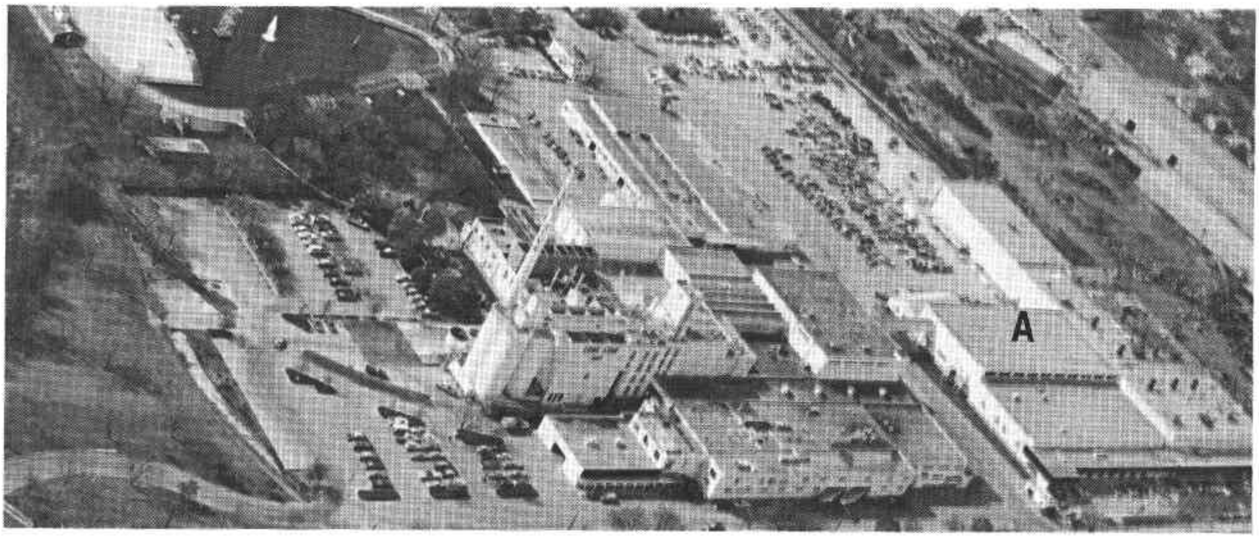


Figure 10. Aerial Photograph of Lone Star's Industrial Plant Site Looking Southwest

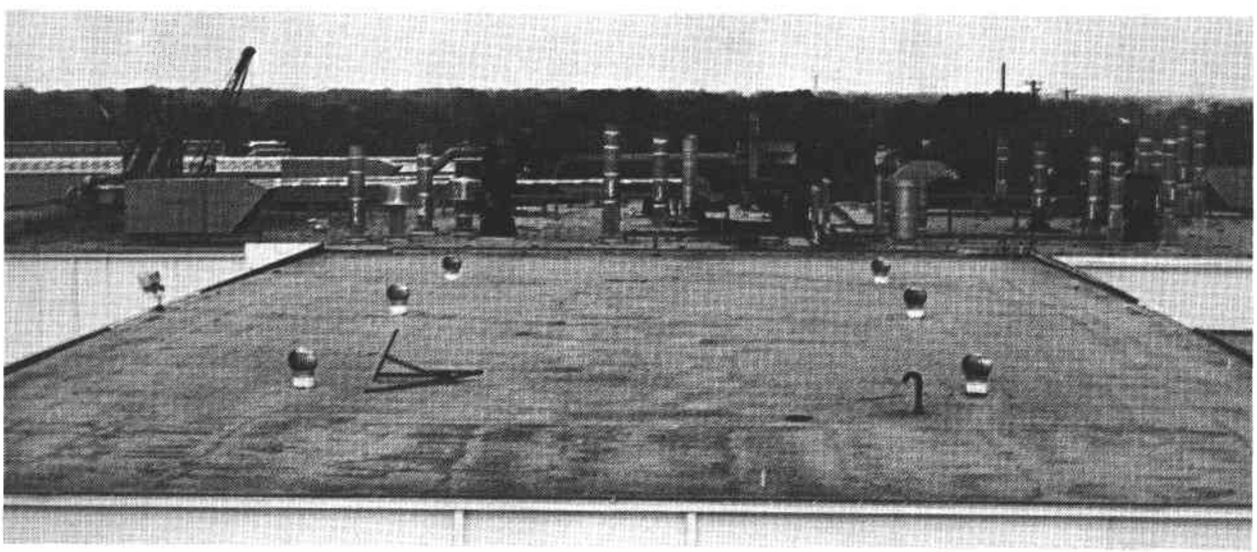


Figure 11. A View Looking Down at the Rooftop of the Warehouse Where the Collector Array Will Be Installed

3. Solar Kinetics T-700

a. Physical Characteristics

The Solar Kinetics T-700 has been chosen as the most cost-effective concentrating solar collector for the present application as outlined above. This collector unit as shown in Figure 12 is a parabolic trough collector manufactured in 10-ft and 20-ft long modules. These modules are connected together to form rows of 80 to 120 feet. Each row tracks the sun about an axis just below the vertex of the parabolic trough. The tracking actuator is located at the center support pylon and mirror modules are connected through the use of flanges and shafts mounted to self-aligning pillow block ball bearings. The connecting drive pins are also the receiver tube stands and at each inner bearing there is a load bearing universal joint to eliminate any bind in the tracking rotational axis.

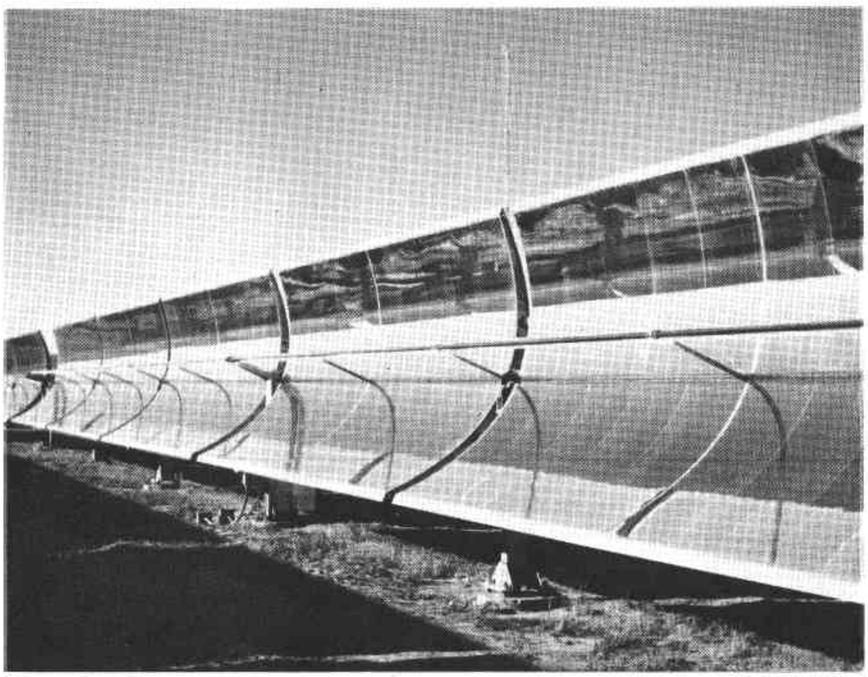


Figure 12. Solar Kinetics T-700 Collectors

The mirror module is constructed using the well-developed and tested Solar Kinetics "monocoque-stressed skin" technique. This form of fabrication provides an excellent strength to weight ratio and the parabolic shape provides excellent torsional rigidity.

The 1-5/8-in. carbon steel receiver tube is plated with black chrome and covered by a Pyrex (7740) glass tube. The entire assembly is mounted to the receiver tube stand through a unique, fully adjustable clamp, as shown in Figure 13.

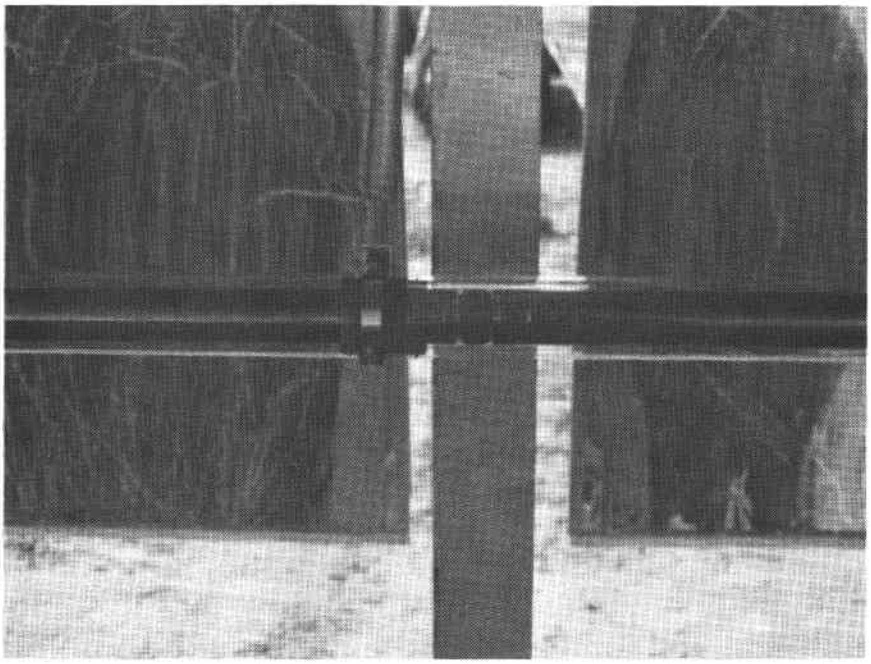


Figure 13. Receiver Tube Mounted Assembly

The receiver tube is fully floating with linear as well as rotational freedom. Each end is terminated with an expansion bellows which is connected to a flexible insulated hose, as shown in Figure 14. The hose

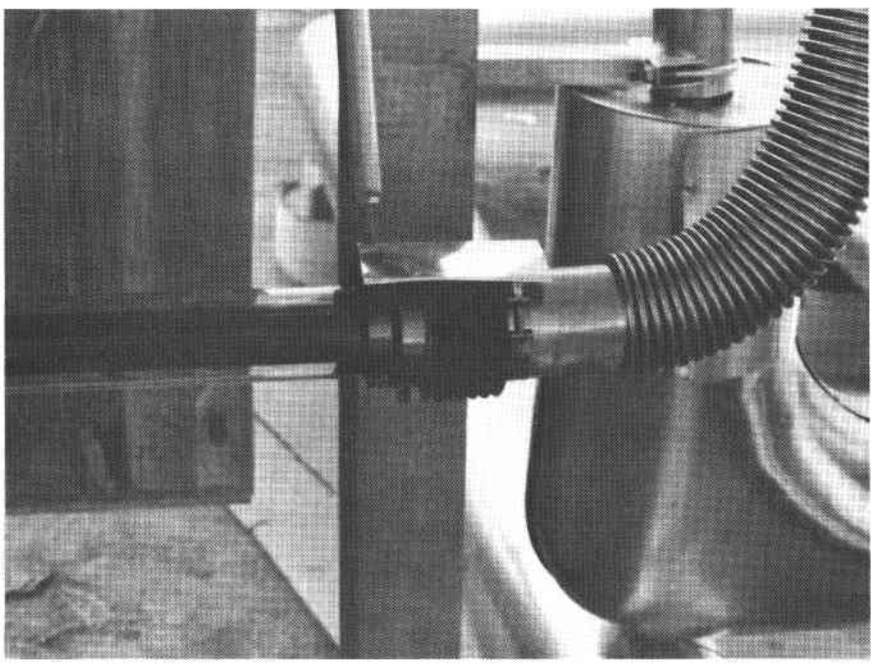


Figure 14. Receiver Tube Expansion Hollows and Hose Assembly

assembly is connected to the pylon support at each end of the row where it connects to the manifold plumbing. The air annulus in each receiver assembly is plumbed together and an outlet fitting is provided at the center to allow air expansion through a dessicator. The reflective surface is an aluminized second surface acrylic sandwich bonded to the mirror sheet metal surface. This film has demonstrated up to 84% specular reflectivity and excellent weather resistance for seven years. Solar tracking is effected through the use of a solid state electronic differential shadow bar device. Figure 15 shows the shadow bar sensing head. The tracking actuator developed at

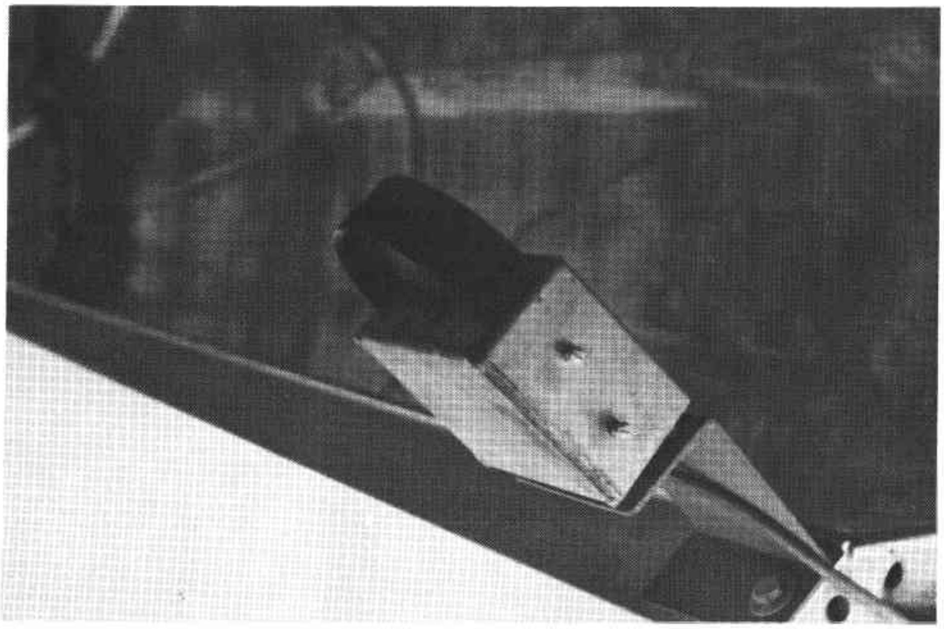


Figure 15. Shadow Bar Sensing Head

Solar Kinetics is a hydraulic drive system and is unique in that it eliminates backlash in the tracking system. Backlash becomes a serious problem with most mechanical trackers since continued wind buffeting wears gears and mechanical drives. When sunrise provides sufficient insolation for system startup, a light switch located at the central control panel provides power to the electronic trackers and each row will track from its inverted 'stow' position (see Figure 16). Tracking continues until the shadow cast from the shadow bar on the tracker is equal on both of the light-sensitive transistors. As the sun moves, the tracker maintains this shadow "deadband" and accurate tracking is accomplished. A hazard-stow relay is provided which will drive the row to the "stow" position should any of the field contact closure devices cause the circuit to the hazard relay coil to lose power. Loss of AC power, nightfall, over temperature fluid condition, high winds, rain, or insufficient flow will cause the collector to defocus by eliminating the automatic tracker and providing a direct stow signal to the drive pylon. A schematic of this central circuit is shown in Figure 17.

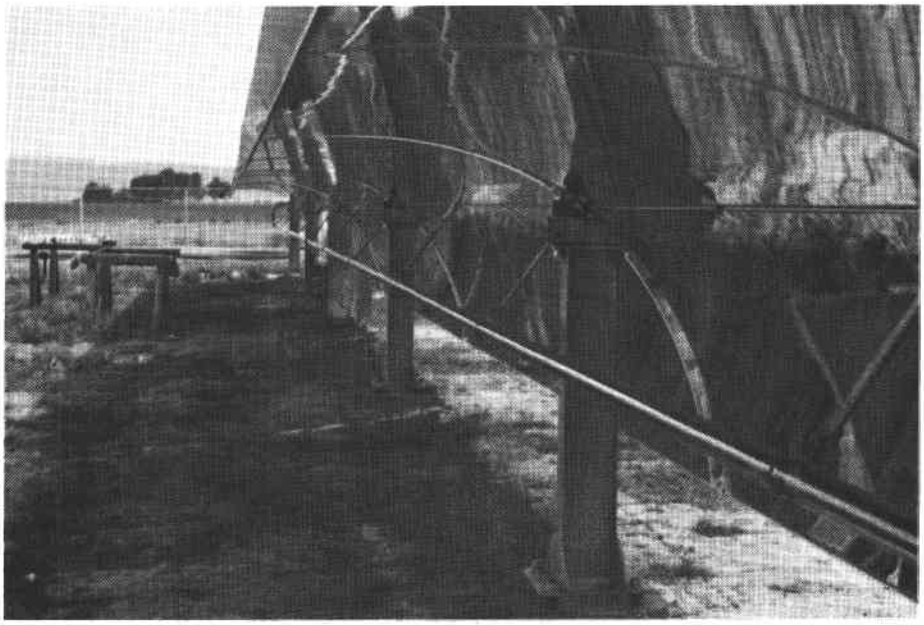


Figure 16. T-700 in the "Stow" Position

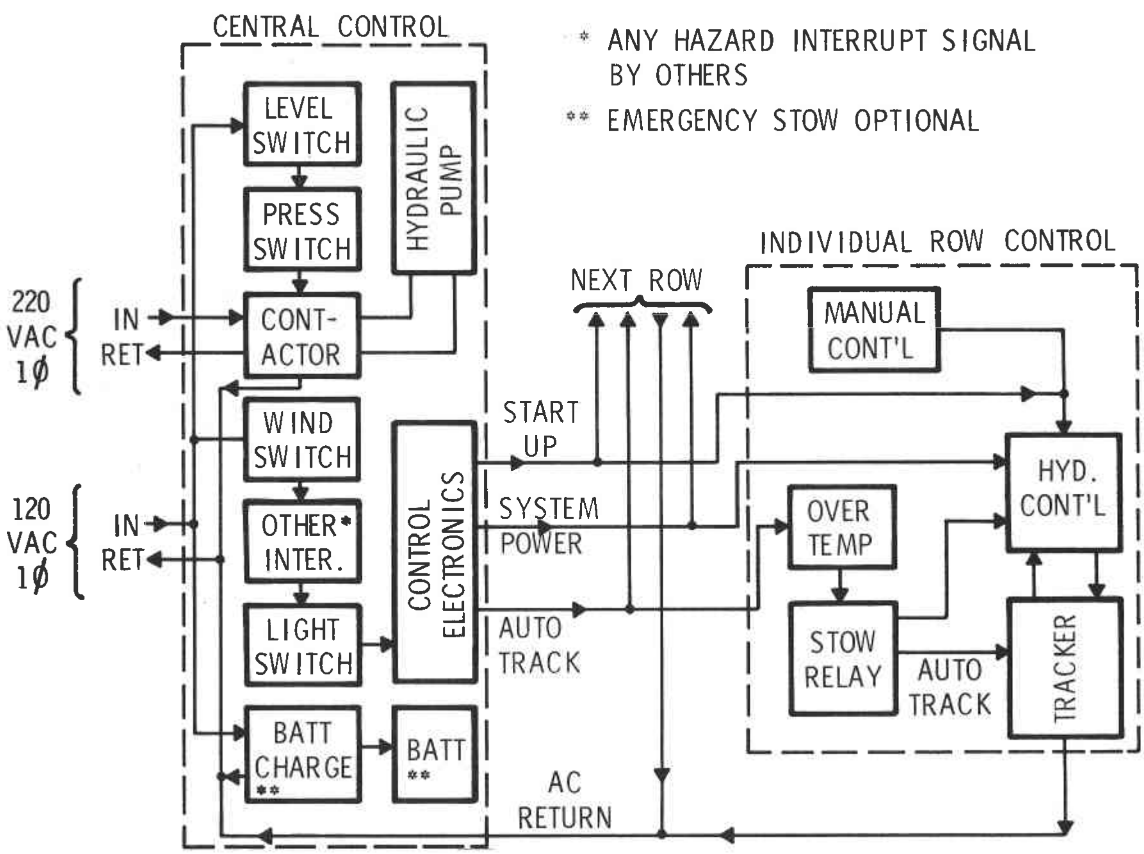


Figure 17. T-700 Control Circuitry

The hydraulic fluid pressure is developed by the central hydraulic power supply which is shown in Figure 18. This pressure is then transmitted to the drive pylons (see Figure 19) via 3/4-in. hydraulic supply

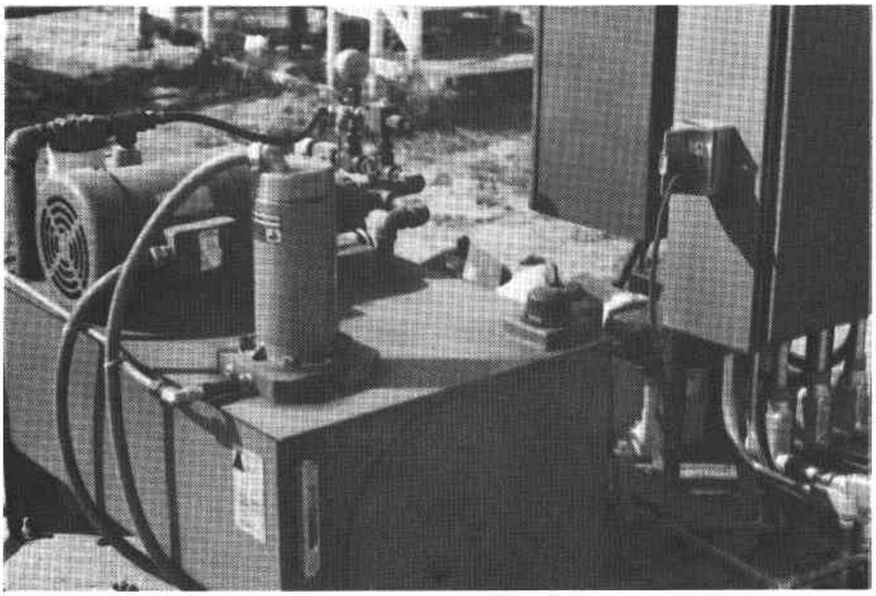


Figure 18. T-700 Hydraulic Power Supply

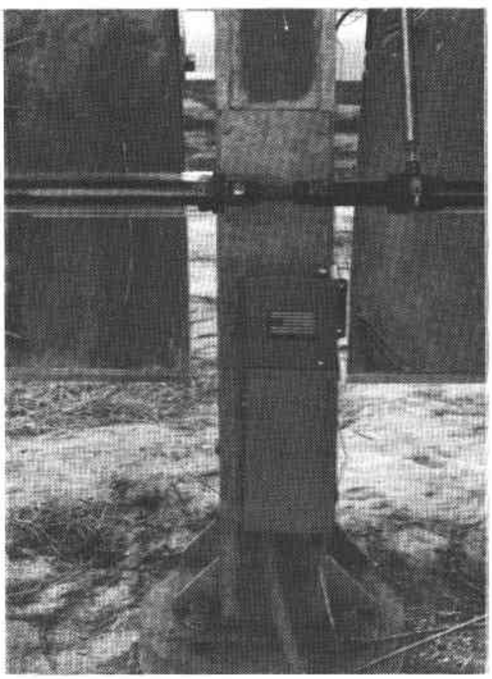


Figure 19. T-700 Drive Pylon

lines. A schematic of the central hydraulic supply system is shown in Figure 20, and a schematic of the hydraulic tracker is shown in Figure 21. The entire collector assembly is rotated about self-aligning, pillow block ball bearings located between each mirror module and mounted on the top of each pylon, as shown in Figure 22. This

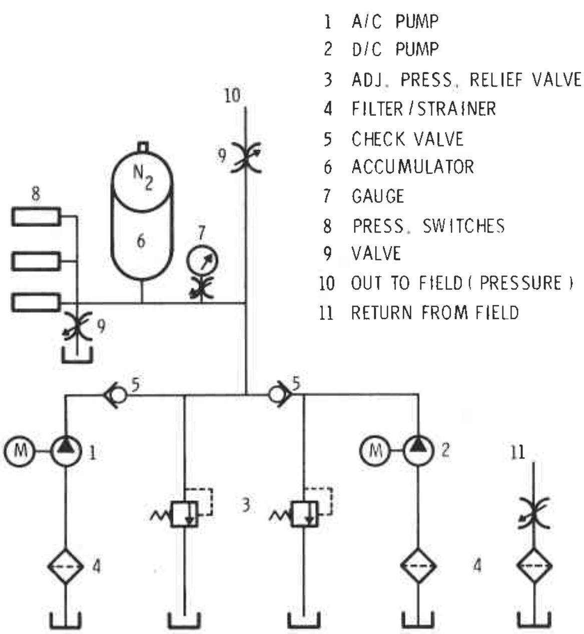


Figure 20. Schematic of the Central Hydraulic Supply System

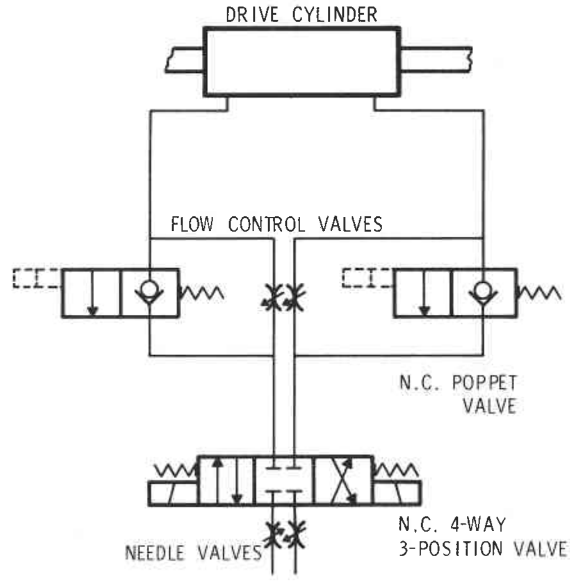


Figure 21. Schematic of the Hydraulic Tracker

arrangement, however, does not provide a perfectly balanced system, so counterweights are required to balance the assembly, and these counterweights are shown in Figure 23. A list of the T-700 physical specifications is shown in Table VI.

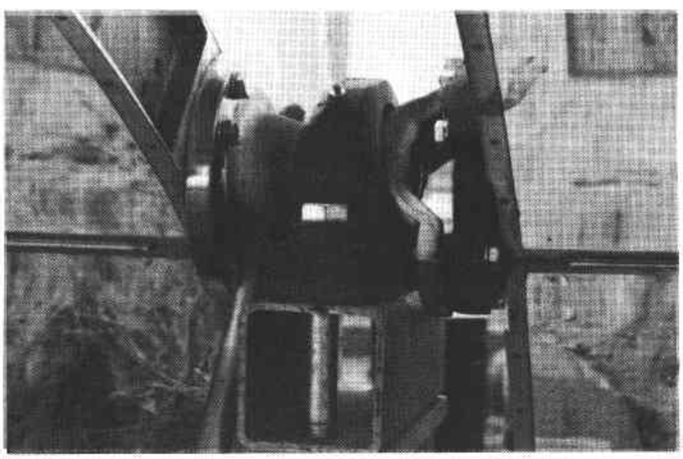


Figure 22. T-700 Bearing Support Assembly

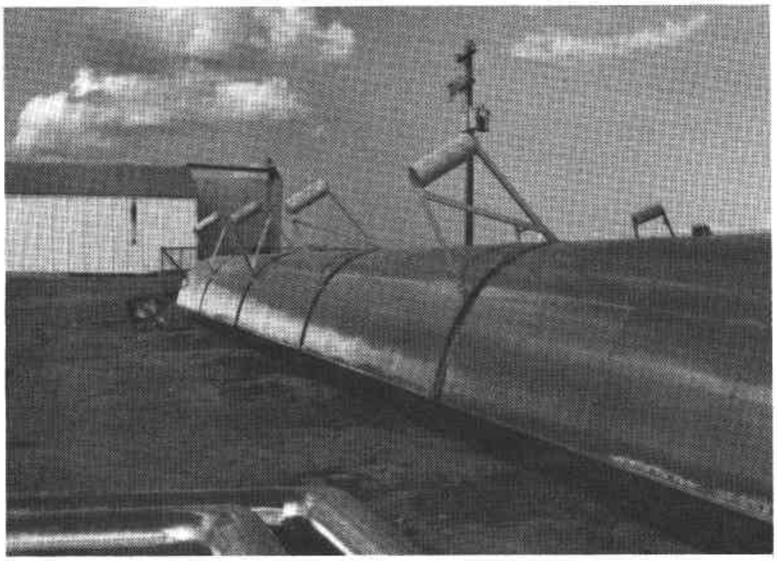


Figure 23. T-700 Counterweight Assemblies

TABLE VI. T-700 PHYSICAL SPECIFICATIONS

Module Width	94″
Module Length	10′ or 20′
Mirror Width	86″
Solar Area ft^2	72 or 144
Mirror Reflectance	.84
Mirror Shape	90° Parabolic
Max. Height (vertical)	100″
Mirror Orientation	N/S
Max.Tracking	210°
Stow Angle	—45°
Rotation Axis Height	53″
System Weight	3.7 lbs./ft^2
End Pylon Static Load	260 lbs.
Center Pylon Static Load	520 lbs.
Pylon Base Mount Bolts	4-1″ 12″ c-c
Pylon Spacing c-c	126″ & 246″
Row Spacing c-c	13′-4″
Max. Row Length	120′
Receiver Tube	1-5/8″ Carbon Steel
Selective Surface	Black Chrome
Absorbtivity	0.94 - 0.97
Emissivity (400°F)	0.12 - 0.18
Receiver Cover	Pyrex Glass (7740)
Cover Transmissivity	0.91
Annulus Size	0.25″
Annulus Medium	Dry Air
Pumping Loss (T-66)	4 psi/100′ 5 gpm
Plumbing Connections	1″ Std. Pipe
Max. Operating Temp.	500°F
Max. Operating Pressure	250 psi

b. Performance Characteristics

The thermal performance of a concentrating solar collector is usually characterized by the unit's thermal efficiency. This efficiency (η) is defined as the total thermal energy transferred to the collector fluid dividied by the direct normal solar radiation impinging on the collector aperature. There are a number of methods used to present these performance characteristics. In general, an efficiency versus operating condition curve is used and a curve is fitted to the data. The main difference in presentation is the operating parameter used. Figure 24 shows the thermal efficiency plotted as a function of average collector temperature, while Figure 25 shows the thermal efficiency versus direct normal solar radiation. Figure 26 shows the efficiency as a function

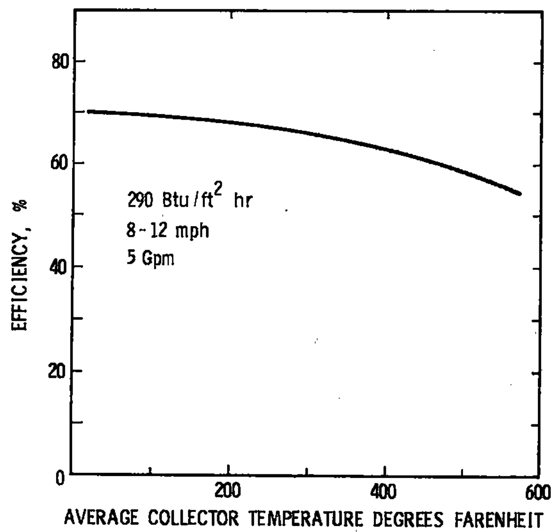


Figure 24. Thermal Efficiency Versus Average Collector Fluid Temperature

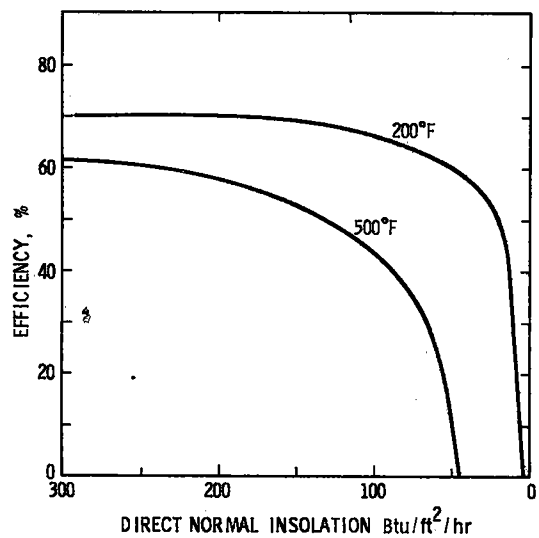


Figure 25. Thermal Efficiency Versus Direct Normal Insulation

of $\Delta T/I$, which is the average fluid temperature above ambient divided by the direct normal solar radiation. Both of the curves in this figure are derived from experimental data, with one being a linear correlation and the other being a second-order correlation. The linear correlation for efficiency (η) in terms of the operating parameter $\Delta T/I$ is

$$\eta = 0.70 - 0.075\,(\Delta T/I), \tag{2}$$

and the second order correlation is

$$\eta = 0.6738 - 0.0164\,(\Delta T/I) - 0.0168\,(\Delta T/I)^2. \tag{3}$$

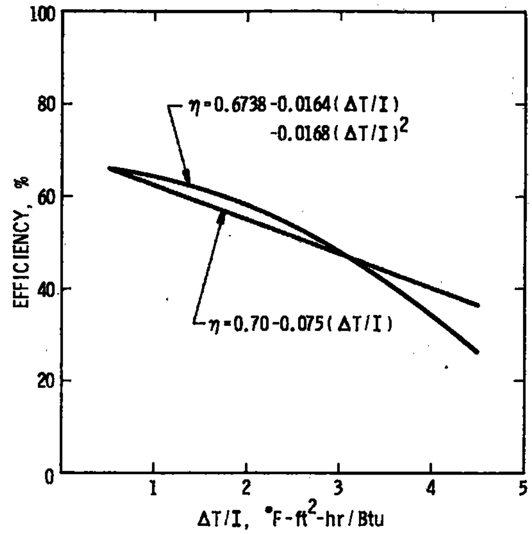


Figure 26. Efficiency Versus Operation Parameter

The maximum practical value for the operating parameter is about 4 occurring with an average collector fluid temperature of 400°F, an ambient temperature of 0°F, and a direct normal solar radiation of 100 Btu/hr-ft^2. A more typical operating condition will be between 1 and 2. These data will be discussed in greater detail in the performance analysis section of this report.

Another important characteristic of the collector system is the pressure loss versus flow rate relationship. This relationship is shown in Figure 27. The minimum recommended flow rate, however, is about 4.5 gpm to assure turbulent heat transfer conditions. The selected flow rate was determined as a part of the optimization study by investigating the tradeoff between pressure loss and heat transferred at high flow rates as well as increased system cost. The optimization study will be discussed in the performance analysis sections of this report.

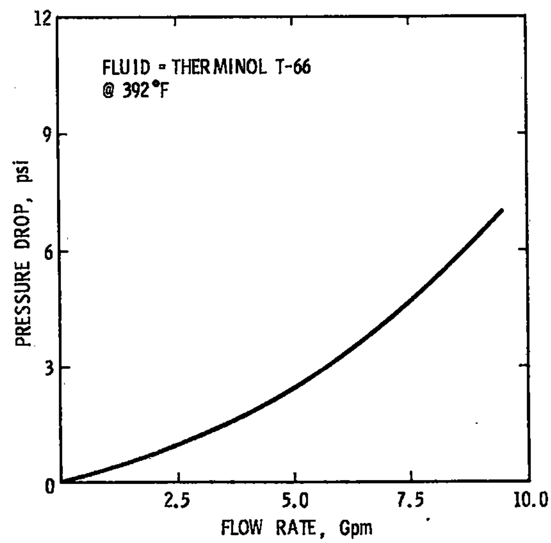


Figure 27. Receiver Tube Pressure Loss Characteristic

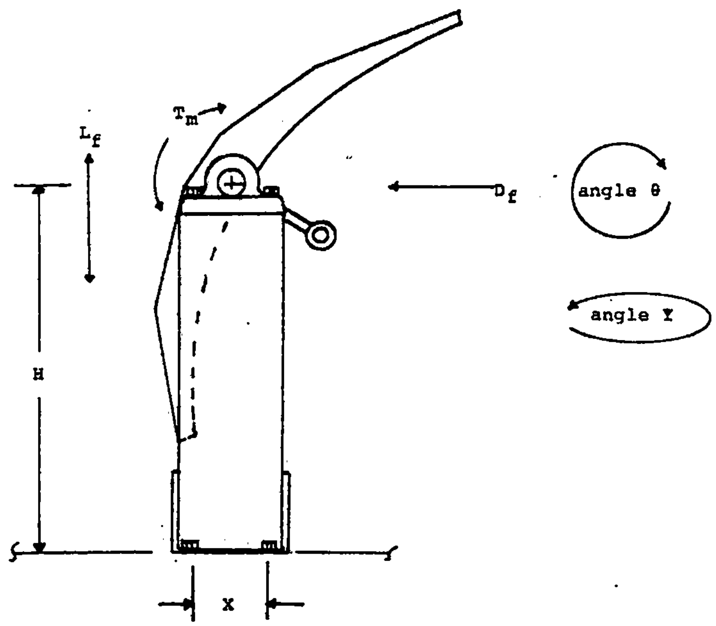
c. Collector Field Installation

The installation procedure for the collector field consists of the following steps:

- Roof modification and installation of pads to accept support pylons.
- Installation and alignment of the support pylons.
- Fastening and alignment of the mirror modules.
- Installation and adjustment of the receiver tube assembly and hoses.
- Connection of the electrical controls and hydraulic power supply plumbing.

1) Roof Modification

Prior to the support pylon installation, the roof structure must be modified to accommodate the added structure loads of the collector field. These loads were determined as summarized in Figure 28 and Table VII.The design drawings for the roof structure modification are shown in Figures 29 through 32. Figures 29 and 32 show the access stairway and visitor walkways along with the roof perimeter pipe railing. Figures



$+L_f$ = lift force
$-L_f$ = down force
θ = pitch angle
Y = yaw angle
D_f = drag force = C_d (psf)(area)
L_f = lift force = C_l (psf)(area)
T_m = torque = C_{mw} (chord)(psf)(area)
Bolt force = $\frac{D_f(H)+T_m}{2(X)} + \frac{L_f}{4}$

θ	Y	C_d	C_l	C_{mw}
-45°	0°	1.4	1.0	0.1
0°	0°	1.0	0	0
60°	0°	0.78	-1.5	0.14
120°	0°	0.5	0.1	-0.28
120°	40°	0.78	0	0.55
180°	0°	1.6	0	0
225°	0°	0.78	0	-0.2

Unit	Ft^2 Area	in. H	in. X	Chord
T-700(10)	72	53	12	7.0'
T-700(20)	144	53	12	7.0'

Figure 28. T-700 Wind Load Characteristics

TABLE VII. T-700 WIND LOAD CALCULATIONS

PSF = 22 @ 90 mph

H = 53" or 4.4'
X = 12" or 1'

ASSUME:

$\theta = -45°$ (stow)

Pylon = Drive unit

$D_f = C_d$ (psf) (area) = 1.4 (22)(144) = 4,435 lbs.

$L_f = C_l$ (psf) (area) = 1.0 (22)(144) = 3,168 lbs.

$T_m = C_{mw}$ (chord) (psf) (area) = 0.1 (7)(22)(144x3) = 6,653 ft. lbs.

$$\text{Bolt Force} = \frac{D_f(H)+T_m}{2(X)} + \frac{L_f}{4} = \frac{(4435)(4.4) + 6653}{2(1)} + \frac{3168}{4}$$

Bolt Force = 13,876 lbs.

Pylons = all others

D_f = 4,435 lbs. L_f = 3,168 lbs. T_m = 0

$$\text{Bolt Force} = \frac{(4435)(4.4) + 0}{2} + \frac{3168}{4} = 10,549 \text{ lbs.}$$

$\theta = 120°$

Pylon = Drive

D_f = 0.78 (22)(144) = 2,471 lbs.

L_f = 0

T_m = 0.55(7)(22)(144x3) = 36,590 ft. lbs.

$$\text{Bolt Force} = \frac{2471(4.4) + 36,590}{2} + \frac{0}{4} = 23,731$$

Assume Wind Loads for Fields to be 67% of Stand Alone Collector Wind Tunnel Data Extensions:

Maximum D_f = 3,000 lbs. Maximum L_f = 2,100 lbs.

Maximum T_m = 24,500 ft. lbs. Maximum B.F.= 16,000 lbs.

30 and 31 illustrate the actual configuration of the pylon support pads. The pylons are supported by four 1-1/8-in. diameter by 5-in. long threaded studs. These studs are welded to a 15-in. by 15-in. by 3/4-in. steel plate, which is welded to a continuous steel I-beam (W10 x 22 lb) running in the east-west direction located just above the roof of the building. These six beams, one for each set of pylons, are supported by 3-in. by 7.58-lb pipe stubs mounted to each of the 31 existing bar joists on 6 ft-8 in. centers. The roof penetrations are sealed with 8-in. by 8-in. 20-gauge pitch pans filled with hot pitch. The loads transmitted to the bar joists through the stub columns will be carried through existing 24-in. wide flange beams (10WF31) in the building through added knee braces to the existing roof support columns (8WF31). In addition to the new knee braces, two new columns will be required at both ends of the center beam. The beam structure along the walls is of sufficient strength to carry the required load so that no new columns are required at these locations.

TABLE VII. T-700 WIND LOAD CALCULATIONS

PSF = 22 @ 90 mph

H = 53" or 4.4'

X = 12" or 1'

ASSUME:

$\theta = -45°$ (stow)

Pylon = Drive unit

$D_f = C_d$ (psf) (area) = 1.4 (22)(144) = 4,435 lbs.

$L_f = C_l$ (psf) (area) = 1.0 (22)(144) = 3,168 lbs.

$T_m = C_{mw}$ (chord) (psf) (area) = 0.1 (7)(22)(144x3) = 6,653 ft. lbs.

$$\text{Bolt Force} = \frac{D_f(H)+T_m}{2(X)} + \frac{l_f}{4} = \frac{(4435)(4.4) + 6653}{2(1)} + \frac{3168}{4}$$

Bolt Force = 13,876 lbs.

Pylons = all others

D_f = 4,435 lbs. L_f = 3,168 lbs. $T_m = 0$

$$\text{Bolt Force} = \frac{(4435)(4.4) + 0}{2} + \frac{3168}{4} = 10{,}549 \text{ lbs.}$$

$\theta = 120°$

Pylon = Drive

D_f = 0.78 (22)(144) = 2,471 lbs.

$L_f = 0$

T_m = 0.55(7)(22)(144x3) = 36,590 ft. lbs.

$$\text{Bolt Force} = \frac{2471(4.4) + 36{,}590}{2} + \frac{0}{4} = 23{,}731$$

Assume Wind Loads for Fields to be 67% of Stand Alone Collector Wind Tunnel Data Extensions:

Maximum D_f = 3,000 lbs. Maximum L_f = 2,100 lbs.

Maximum T_m = 24,500 ft. lbs. Maximum B.F.= 16,000 lbs.

30 and 31 illustrate the actual configuration of the pylon support pads. The pylons are supported by four 1-1/8-in. diameter by 5-in. long threaded studs. These studs are welded to a 15-in. by 15-in. by 3/4-in. steel plate, which is welded to a continuous steel I-beam (W10 x 22 lb) running in the east-west direction located just above the roof of the building. These six beams, one for each set of pylons, are supported by 3-in. by 7.58-lb pipe stubs mounted to each of the 31 existing bar joists on 6 ft-8 in. centers. The roof penetrations are sealed with 8-in. by 8-in. 20-gauge pitch pans filled with hot pitch. The loads transmitted to the bar joists through the stub columns will be carried through existing 24-in. wide flange beams (10WF31) in the building through added knee braces to the existing roof support columns (8WF31). In addition to the new knee braces, two new columns will be required at both ends of the center beam. The beam structure along the walls is of sufficient strength to carry the required load so that no new columns are required at these locations.

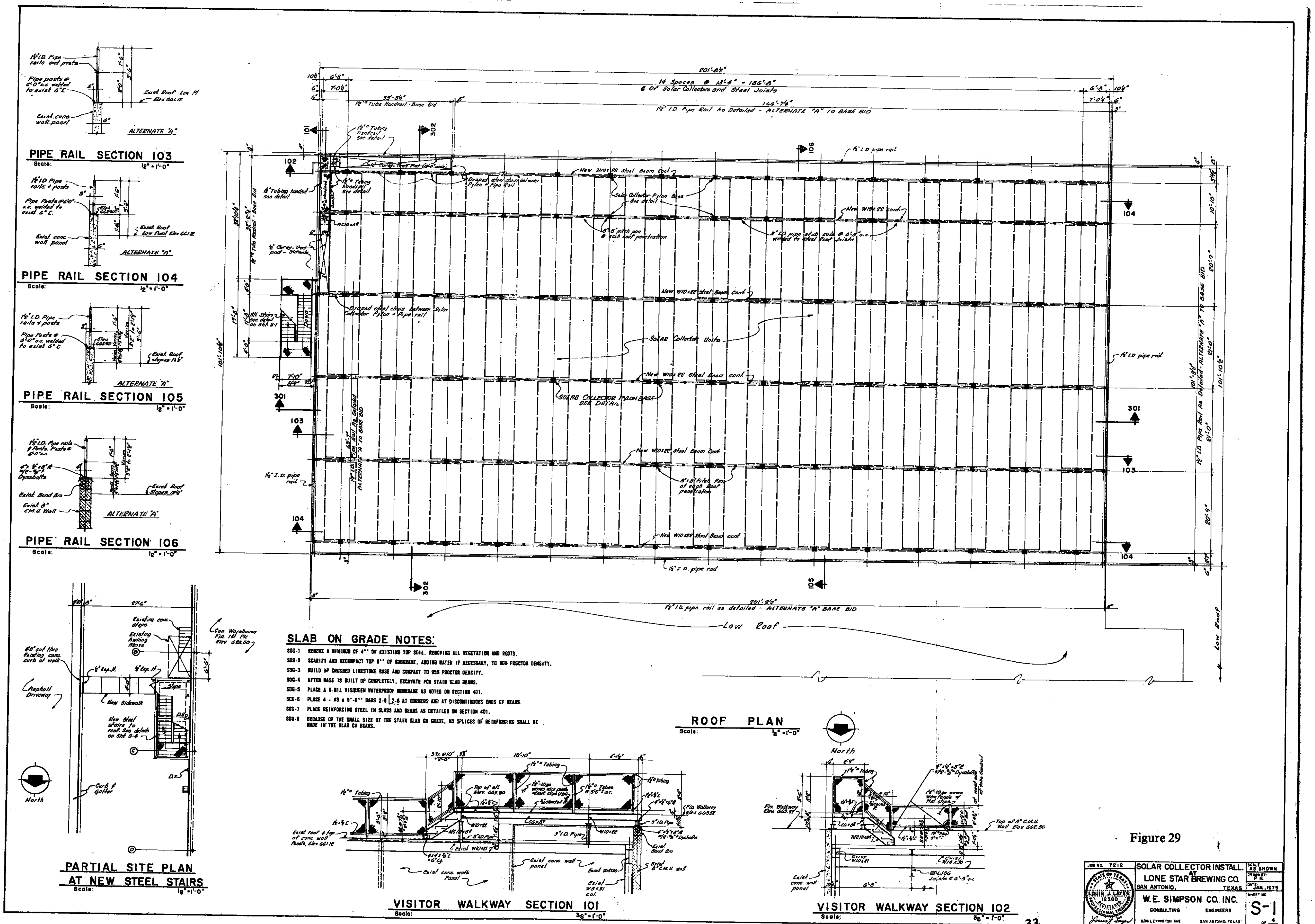

PIPE RAIL SECTION 103
Scale: 1/2" = 1'-0"
PIPE RAIL SECTION 104
Scale: 1/2" = 1'-0"
PIPE RAIL SECTION 105
Scale: 1/2" = 1'-0"
PIPE RAIL SECTION 106
Scale: 1/2" = 1'-0"
ALTERNATE "A"
201'-8 1/2"
14 Spaces @ 13'-4" = 186'-8"
℄ Of Solar Collectors and Steel Joists
1 1/2" I.D. Pipe Rail As Detailed - ALTERNATE "A" TO BASE BID
New W10x22 Steel Beam Cont.
Solar Collector Pylon Base See detail
SOLAR Collector Units
SOLAR COLLECTOR PYLON BASE SEE DETAIL
1 1/2" I.D. pipe rail
Low Roof
ROOF PLAN
Scale: 1/8" = 1'-0"
North
SLAB ON GRADE NOTES:
SOG-1 REMOVE A MINIMUM OF 4" OF EXISTING TOP SOIL, REMOVING ALL VEGETATION AND ROOTS.
SOG-2 SCARIFY AND RECOMPACT TOP 6" OF SUBGRADE, ADDING WATER IF NECESSARY, TO 90% PROCTOR DENSITY.
SOG-3 BUILD UP CRUSHED LIMESTONE BASE AND COMPACT TO 95% PROCTOR DENSITY.
SOG-4 AFTER BASE IS BUILT UP COMPLETELY, EXCAVATE FOR STAIR SLAB BEAMS.
SOG-5 PLACE A 6 MIL VISQUEEN WATERPROOF MEMBRANE AS NOTED ON SECTION 401.
SOG-6 PLACE 4 - #6 x 5'-0" BARS 2-6 | 2-6 AT CORNERS AND AT DISCONTINUOUS ENDS OF BEAMS.
SOG-7 PLACE REINFORCING STEEL IN SLABS AND BEAMS AS DETAILED ON SECTION 401.
SOG-8 BECAUSE OF THE SMALL SIZE OF THE STAIR SLAB ON GRADE, NO SPLICES OF REINFORCING SHALL BE MADE IN THE SLAB OR BEAMS.
PARTIAL SITE PLAN AT NEW STEEL STAIRS
Scale: 1/8" = 1'-0"
Asphalt Driveway
New Sidewalk
North
VISITOR WALKWAY SECTION 101
Scale: 3/8" = 1'-0"
VISITOR WALKWAY SECTION 102
Scale: 3/8" = 1'-0"
JOB NO. 7212
SOLAR COLLECTOR INSTALL. AT LONE STAR BREWING CO.
SAN ANTONIO, TEXAS
SCALE AS SHOWN
DRAWN BY P.H.
DATE JAN., 1979
STATE OF TEXAS
LOUIS J. LAYER
12360
REGISTERED PROFESSIONAL ENGINEER
W.E. SIMPSON CO. INC.
CONSULTING ENGINEERS
SAN ANTONIO, TEXAS
SHEET NO S-1 OF 4

Figure 29

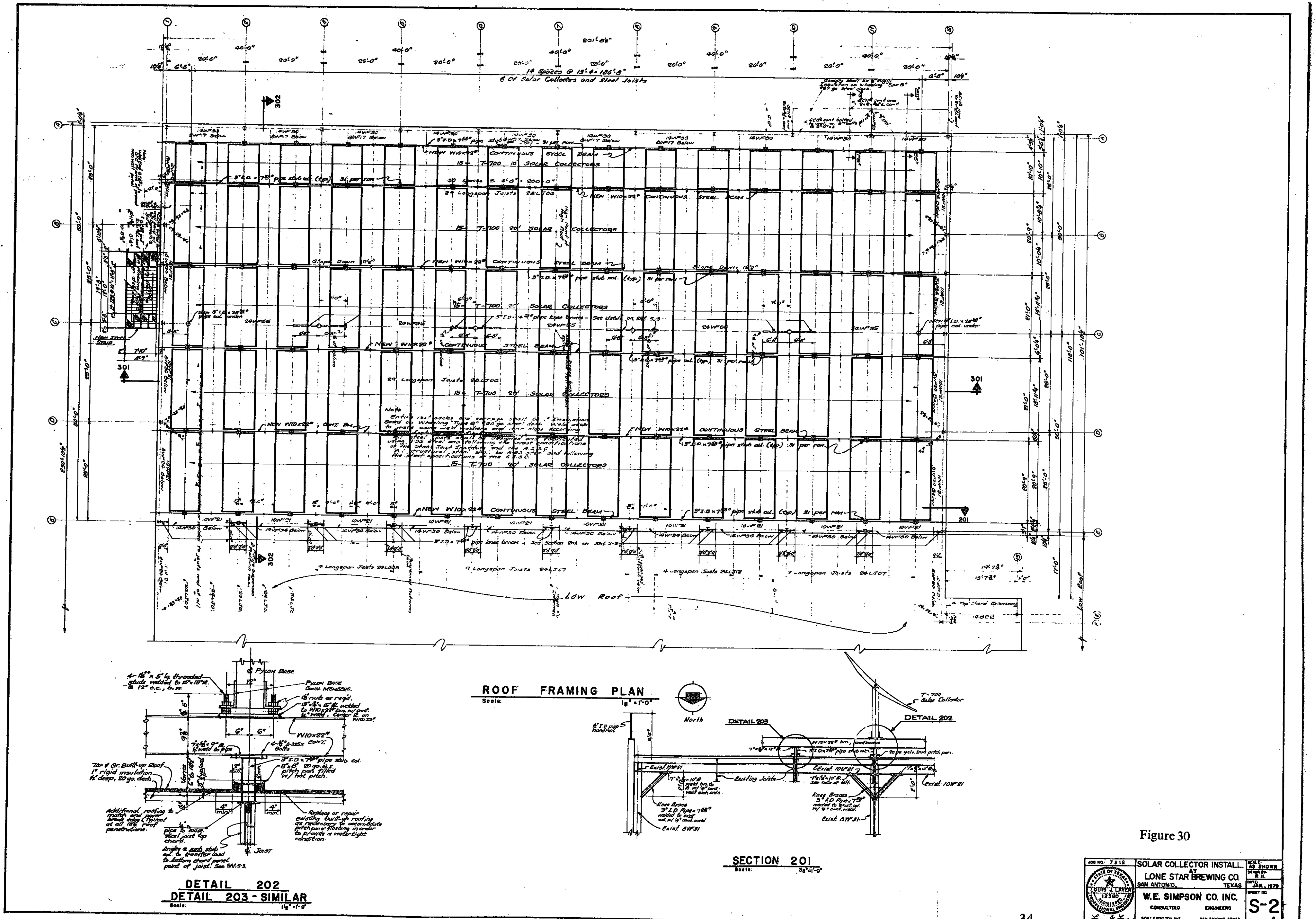
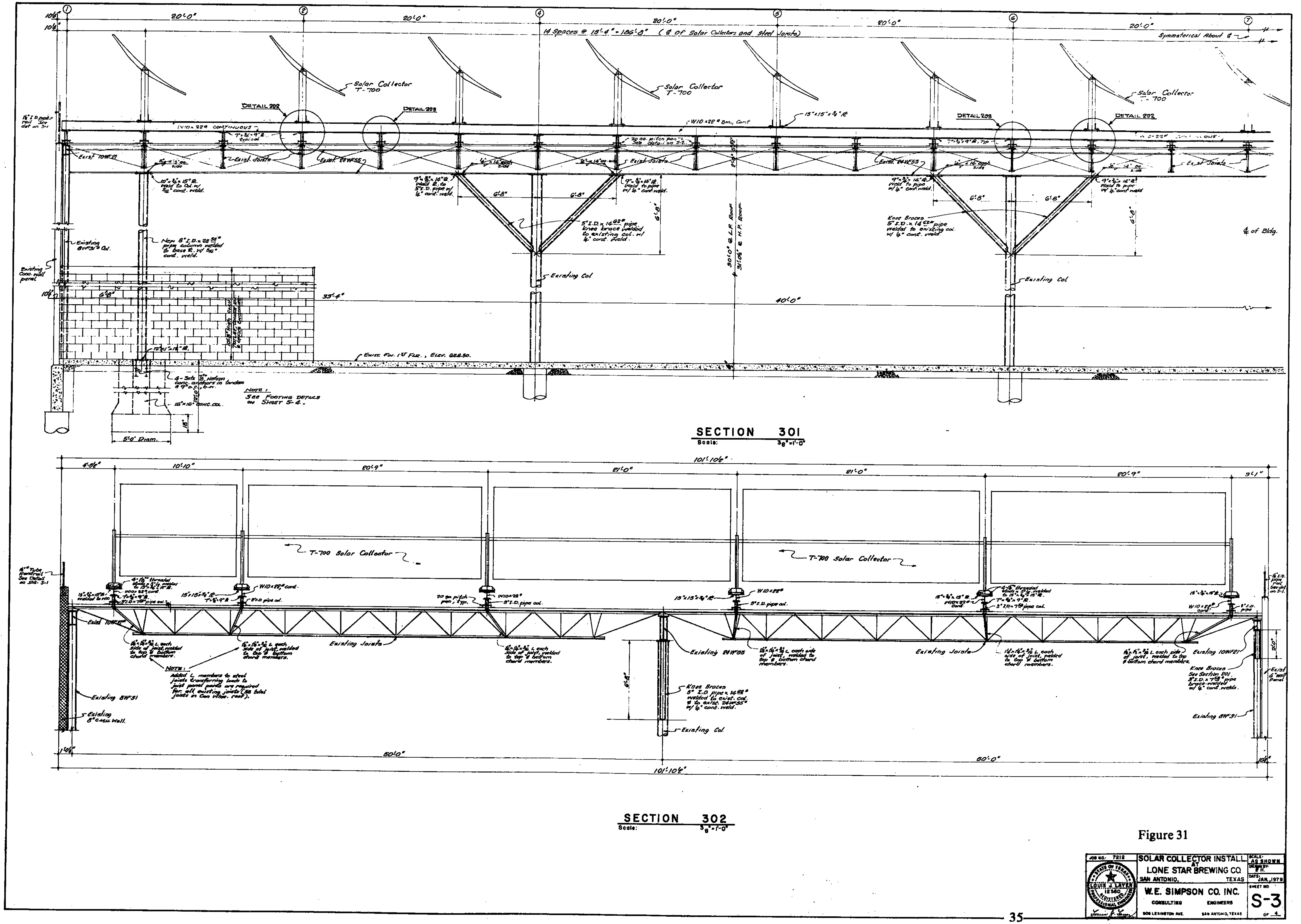
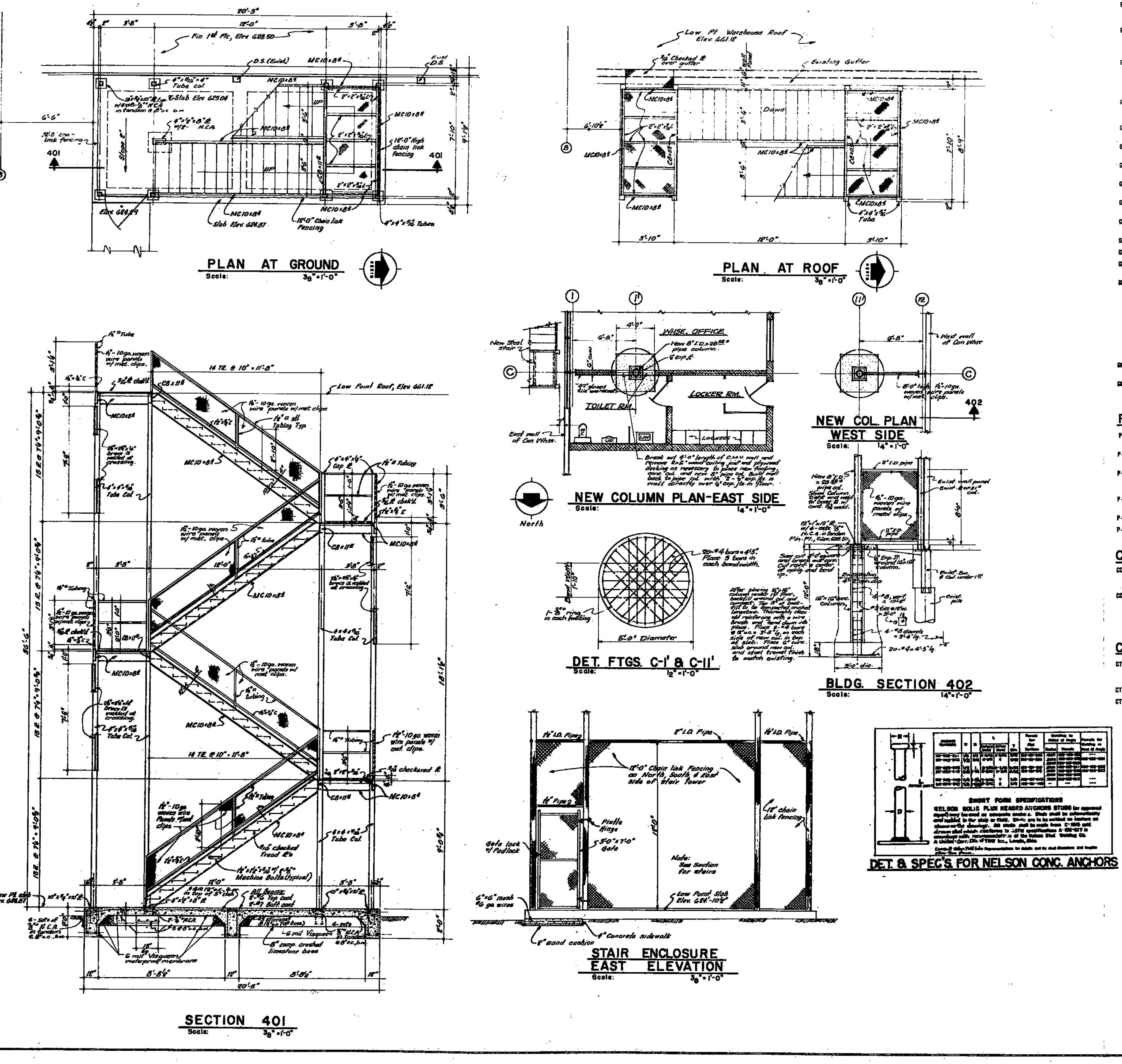

ROOF FRAMING PLAN
North
Low Roof
15 - T-700 20' SOLAR COLLECTORS
NEW W10x22# CONTINUOUS STEEL BEAM
SECTION 201
DETAIL 202
DETAIL 203 - SIMILAR
T-700 Solar Collector
SOLAR COLLECTOR INSTALL. AT LONE STAR BREWING CO.
SAN ANTONIO, TEXAS
W.E. SIMPSON CO. INC.
CONSULTING ENGINEERS
S-2

Figure 30



SECTION 301
Scale: 3/8" = 1'-0"
SECTION 302
Scale: 3/8" = 1'-0"
14 Spaces @ 13'-4" = 186'-8" (℄ of Solar Collectors and Steel Joists)
Symmetrical About ℄
Solar Collector T-700
DETAIL 202
DETAIL 203
Existing Col.
℄ of Bldg.
T-700 Solar Collector
Existing Joists
Existing 24WF55
Existing 10WF21
Existing 8WF31
Knee Braces
NOTE:
SOLAR COLLECTOR INSTALL. AT LONE STAR BREWING CO.
SAN ANTONIO, TEXAS
W.E. SIMPSON CO. INC.
CONSULTING ENGINEERS
SAN ANTONIO, TEXAS
JOB NO. 7212
SCALE: AS SHOWN
DATE: JAN. 1979
SHEET NO. S-3 OF 4
STATE OF TEXAS
LOUIS J. LAYER
12560
REGISTERED PROFESSIONAL ENGINEER

Figure 31



GENERAL NOTES:

GN-1 GENERAL CONTRACTOR SHALL CHECK AND VERIFY ALL DIMENSIONS, EXISTING CONDITIONS, ELEVATIONS, ETC., REPORTING ANY DISCREPANCIES TO THE ENGINEER BEFORE PROCEEDING WITH ANY PHASE OF THE WORK AS HE WILL BE HELD RESPONSIBLE FOR ALL WORK FITTING AS INTENDED BY THE DRAWINGS AND NOTES.

GN-2 ALL CONCRETE SHALL MEET THE SPECIFICATIONS FOR STRENGTH REQUIREMENTS, QUALITY REQUIREMENTS, TEST REQUIREMENTS, ETC., COMPLYING WITH ACI STANDARD 318-71 "BUILDING CODE REQUIREMENTS FOR REINFORCED CONCRETE" AND ACI STANDARD 301-72 "SPECIFICATIONS FOR STRUCTURAL CONCRETE FOR BUILDINGS." ALL CONCRETE SHALL HAVE A MINIMUM 28-DAY COMPRESSIVE STRENGTH OF 3500 PSI. A MINIMUM CEMENT CONTENT OF 5½ SACKS PER CUBIC YARD AND A SLUMP OF 5" TO 6".

GN-3 REINFORCING STEEL SHALL BE FROM NEW BILLET, SHALL HAVE DEFORMATIONS CONFORMING TO ASTM A-615 AND SHALL CONFORM TO THE FOLLOWING ASTM SPECIFICATIONS
A 615 - GR. 40 (1) #2, #3 BARS
A 615 - GR. 60 (1) ALL OTHER REINFORCING
A 185 - (1) WELDED WIRE FABRIC

GN-4 BAR SUPPORT ACCESSORIES SHALL BE PROVIDED IN ACCORDANCE WITH LATEST ACI MANUAL OF STANDARD PRACTICE FOR DETAILING REINFORCED CONCRETE STRUCTURES EXCEPT THAT BEAM REINFORCING SHALL BE SUPPORTED ON PRECAST CONCRETE BLOCKS 3" x 3" x NOT LESS THAN 3" SPACED NOT MORE THAN 4'-0" ON CENTER.

GN-5 REINFORCING STEEL FABRICATOR SHALL PROVIDE COMPLETE PLACING DRAWINGS SHOWING LOCATION AND POSITION OF ALL REINFORCING STEEL.

GN-6 REINFORCING STEEL, UNLESS NOTED OTHERWISE, SHALL HAVE MINIMUM CONCRETE COVER AS FOLLOWS: 1½" FOR BEAM TOP, 2" FOR BEAM SIDES AND 3" FOR BEAM BOTTOMS.

GN-7 NO WELDING OF REINFORCING BARS OR TORCHING TO BEND REINFORCING BARS SHALL BE ALLOWED WITHOUT SPECIFIC APPROVAL OF THE ENGINEER.

GN-8 THE SUBGRADE UNDER THE CONCRETE FLOOR LIMESTONE BASE SHALL BE COMPACTED TO A MINIMUM 90% DRY DENSITY. THE LIMESTONE BASE MATERIAL SHALL BE A MINIMUM OF 8" IN THICKNESS AND SHALL BE COMPACTED TO 95% STANDARD PROCTOR DENSITY.

GN-9 ALL STRUCTURAL STEEL SHALL BE ASTM A-36 STEEL AND SHALL BE FABRICATED AND ERECTED IN ACCORDANCE WITH THE LATEST AISC SPECIFICATIONS. ALL MAJOR CONNECTIONS SHALL BE MADE WITH A325-X BOLTS.

GN-10 ALL WELDS SHALL BE WITH E70XX ELECTRODES, CONFORMING TO AMERICAN WELDING SOCIETY'S (AWS) "STRUCTURAL WELDING CODE" D1.1-72 WITH LATEST REVISIONS.

GN-11 ALL STRUCTURAL STEEL DETAILS AND CONNECTIONS SHALL CONFORM TO THE STANDARDS OF THE AISC.

GN-12 SPLICING OF STRUCTURAL STEEL MEMBERS WHERE NOT DETAILED IS PROHIBITED WITHOUT PRIOR APPROVAL OF STRUCTURAL ENGINEER.

GN-13 ALL STRUCTURAL STEEL SHALL BE CLEANED AND SHOP PAINTED WITH ONE COAT OF PRIMER. STEEL SHALL NOT BE SHOP PRIMED WHERE FIELD WELDING SHALL OCCUR. FIELD PAINT STEEL WITH TWO COATS OF KEELEY'S CRYLICOTE OR AN APPROVED EQUAL.

GN-14 AFTER CUTTING HOLES THROUGH ROOF AND WELDING 3" I.D. STUB COLUMNS TO STEEL ROOF JOISTS AND BEAMS, SET PITCH PANS AND REPAIR BUILT UP ROOF USING MATERIALS CARRYING U.L. LABELS AS FOLLOWS:
a. COAL TAR PITCH: A.S.T.M. D-450
b. PERFORATED TARRED FELTS: COAL TARRED SATURATED FELTS WEIGHING NOT LESS THAN 15 LBS. PER 100 SQ. FT.
c. BASE FLASHING: ASBESTOS BASE REINFORCED FLASHING (CELOTEX AB-20 SPEC)
d. ASPHALT PRIMPER: CELOTEX OR EQUAL
e. ROOF GRAVEL: 5/8" SPECIFICATION GRAVEL (DOUBLE WASHED)
BROOM CLEAN EXISTING ROOF DECK NEEDING REPAIR (AROUND PITCH PANS) AND ON CLEAN SURFACE, INSTALL A THREE (3) PLY, 15 POUND TARRED FELT ROOF MEMBRANE, EMBEDDING EACH PLY WITH NO LESS THAN 25 LBS. OF COAL TAR PITCH. OVER NEW 3 PLY ROOF REPAIR, PLACE TOP POUR OF 75 LB. COAL TAR PITCH AND EMBED SPECIFIED ROOFING GRAVEL AT A MINIMUM RATE OF 400 LBS. PER SQUARE.

GN-15 DURING ROOFING REPAIR OPERATION, SET 20 GA. G.I. PITCH PANS AROUND PIPE COLUMNS AND FILL WITH HOT PITCH. SEE DETAIL FOR PLACING PITCH PANS ON EXISTING ROOF.

GN-16 CONTRACTOR WILL BE RESPONSIBLE FOR ANY ROOF LEAKS AND GUARANTEE THE WORK PERFORMED ON THE ROOF FOR A MINIMUM OF TWO YEARS UPON THE COMPLETION OF THE WORK.

PROCEDURE NOTES:

P-1 GENERAL CONTRACTOR SHALL WORK CLOSELY WITH PERSONNEL OF LONE STAR BREWING CO. KEEPING OPERATIONAL INTERFERENCE TO A MINIMUM.

P-2 PLACE TWO NEW INTERIOR FOOTINGS AND COLUMNS UNDER WAREHOUSE FLOOR AND REPLACE FLOOR SLAB AS INDICATED. CONCRETE SLAB ON GRADE FOR EXTERIOR STAIR SHALL ALSO BE PLACED AT THIS TIME.

P-3 PLACE TWO NEW 8" I.D. STANDARD PIPE COLUMNS AND PLACE ALL KNEE BRACES AS INDICATED ON THE DRAWINGS. ADDING OF STEEL ANGLE MEMBERS ON STEEL JOISTS TO TRANSFER LOADS TO BOTTOM CHORD PANEL POINTS AND ALL OTHER WORK LISTED ABOVE SHALL BE COMPLETED BEFORE ANY WORK ON THE ROOF OF THE BUILDING IS STARTED.

P-4 PLACE EXTERIOR STEEL STAIRWAY SO WORKMEN MAY HAVE EASY ACCESS TO ROOF OF BUILDING TO ERECT SOLAR CONNECTOR SUPPORT FRAMING.

P-5 PLACE DETAILED PIPE RAILING OR TEMPORARY SAFETY RAILING AROUND PERIMETER OF ROOF AREA.

P-6 PROCEED WITH ERECTION OF THE SOLAR COLLECTOR SUPPORT FRAMING AS INDICATED ON SHEETS S-1, S-2, S-3 AND S-4

CONDITIONS OF THE CONTRACT:

CC-1 THE CONTRACTOR SHALL BE SOLELY RESPONSIBLE FOR THE SAFETY OF HIMSELF, HIS EMPLOYEES AND OTHER PERSONS, AS WELL AS FOR THE PROTECTION OF THE SAFETY OF THE IMPROVEMENTS BEING ERECTED AND THE PROPERTY OF HIMSELF OR ANY OTHER PERSON, AS A RESULT OF HIS OPERATIONS HEREUNDER.

CC-2 THE CONTRACTOR SHALL BE FULLY AND COMPLETELY LIABLE, AT HIS OWN EXPENSE, FOR DESIGN, CONSTRUCTION, INSTALLATION AND USE, OR NON/USE OF ALL ITEMS AND METHODS INCIDENT TO PERFORMANCE OF THE CONTRACT, AND FOR ALL LOSS, DAMAGE OR INJURY INCIDENT THERETO, EITHER TO PERSON OR PROPERTY, INCLUDING, WITHOUT LIMITATION, THE ADEQUACY OF ALL TEMPORARY SUPPORTS, SHORING, BRACING, SCAFFOLDING, MACHINERY OR EQUIPMENT, SAFETY PRECAUTIONS OR DEVICES, AND SIMILAR ITEMS OR DEVICES USED BY HIM DURING CONSTRUCTION.

CONCRETE AND COMPACTION TESTING:

CT-1 A TESTING LABORATORY SELECTED BY THE ENGINEER SHALL MAKE THREE (3) COMPRESSION TEST CYLINDERS EACH DAY THAT CONCRETE IS POURED. CYLINDER BREAKS (1 AT 7 DAYS AND 2 AT 28 DAYS) SHALL BE MADE BY THE TESTING LABORATORY AND TEST RESULTS REPORTED TO THE OWNER, CONTRACTOR AND ENGINEER.

CT-2 TWO (2) IN PLACE DENSITY TESTS SHALL BE MADE OF THE COMPACTED SOIL SUBGRADE UNDER STEEL STAIR SLAB ON GRADE.

CT-3 TWO (2) IN PLACE DENSITY TESTS SHALL BE MADE OF THE COMPACTED CRUSHED LIMESTONE BASE MATERIAL UNDER THE STEEL STAIR SLAB ON GRADE.

Figure 32

JOB NO. 7212	SOLAR COLLECTOR INSTALL. AT LONE STAR BREWING CO. SAN ANTONIO, TEXAS	SCALE: AS SHOWN DRAWN BY: F.H. DATE: JAN., 1979
STATE OF TEXAS — LOUIS J. LAYER — 12560 — REGISTERED PROFESSIONAL ENGINEER	W.E. SIMPSON CO. INC. CONSULTING ENGINEERS, 505 LEXINGTON AVE. SAN ANTONIO, TEXAS	SHEET NO. S-4 OF 4

2) Installation of Support Pylons

The installation and alignment of the support pylons will be the next step in the field installation. The double nut technique is used to fasten the bottom of the support pylons and allow for adjustment and alignment, as shown in Figure 33. The pylons will be installed and aligned with a standard transit. Care will

Figure33. Double-Nut Technique Used for Adjustment of Support Pylons

be taken to obtain a true line of sight through the center of the axis of rotation. While the parallel alignment of each row is desirable, the exactness of orientation is not critical. Also, exact levelness of the row is not critical, but it is suggested that the pylons be shot level and straight to the next row whenever possible. When the pylons are aligned and tightened to the support pads, the mirror modules are ready for installation. The drive pylon will be in the stow position and filled with hydraulic fluid to prevent rotation.

3) Mirror Modules

The mirror modules are installed to the drive pylon first and then to the end of each row. An intermediate bearing assembly is bolted to one end of the mirror module with the receiver tube stand on the mirror side. The module is then lowered into position (see Figure 34) and the bearing bolted to the first standard

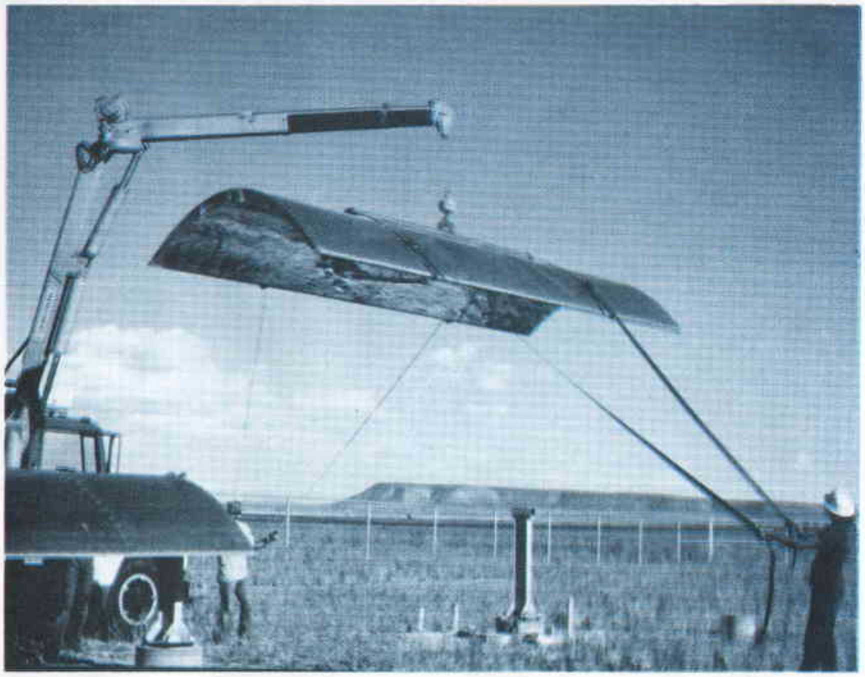


Figure 34. Mirror Modules Being Lowered Into Position

pylon while the other end is bolted to the drive flange. The procedure is repeated for each module out to the end of the row where an end bearing assembly is attached to the end pylon. Care will be taken to align the modules rotationally. The bolt holes are sufficiently oversized to provide some adjustment. The counterweights will then be bolted to the end of each mirror module before installation. The counterweight attaches with two 1-in. bolts and weighs approximately 90 lbs.

4) Receiver Tube Assembly

The fourth step in the installation of the collector field is the installation and adjustment of the receiver tube assembly and hoses. The center receiver tube stand is attached with four bolts and the intermediate receiver tube stands are inserted through the mirror module body and fastened with a nut on the back side. Receiver stands are at 10-ft spacing, and the receiver adjustment brackets are installed into each stand with one bolt and two nuts. The bolt allows height adjustment, while the slotted bracket provides side adjustment. Each bracket will be adjusted to put the center of the receiver at the center of the focus. That point is in the center from each edge of the collector and 22.157 in. up from the bottom of the mirror. A simple pattern or fixture will allow rapid adjustment. Each receiver tube connects to the next with a union that tightens with two wrenches. The glass jacket "O" ring retainer slips over the receiver and is spaced every 10 ft to correspond to the stand and bracket. Two glass tubes are suspended on each receiver tube by the silicone "O" rings, and the entire assembly is clamped to the bracket. The two center receiver tubes should be installed to the special union attached to the central receiver tube stand and then out to the end of each row. The hoses are fastened to the tube with a union, and the expansion bellows are clamped in place. The lower end of the hose assembly is attached to the end pylon with the hose bracket. Each receiver assembly will be pressure tested for leaks at this point. A detailed drawing of this assembly is shown in the collector field design drawings in Figure 35.

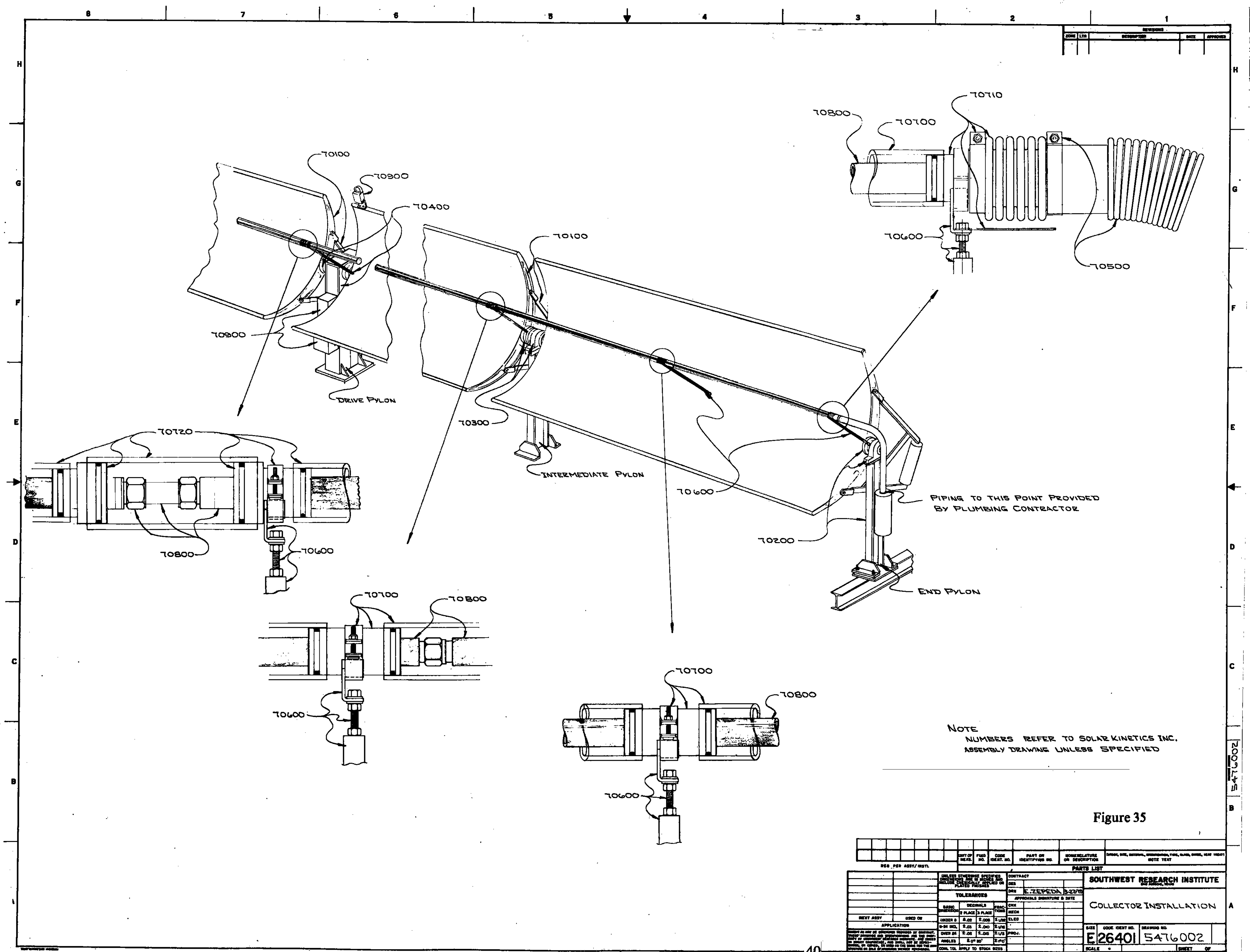
5) Hydraulic Power Supply and Electrical Controls

The last step in the collector field installation process is the connection of the electrical controls and hydraulic power supply plumbing. The shadow bar tracker bracket is bolted onto the collector next to the drive pylon. The shadow bar sensor is bolted to the bracket and aligned lengthwise with the collector. The hydraulic power supply is plumbed in parallel to each drive pylon and connected to the hydraulic fittings at the bottom of each control box. Stainless steel tubing of 3/4-in. diameter will be used for the hydraulic manifold plumbing, the details of which are shown in the collector field design drawings in Figure 36. The control wiring will be routed to each drive pylon control box and appropriate connections made. After all plumbing connections have been accomplished and fluid is flowing through the receiver, the collector automatic focus command will be given. The angular adjustment of the shadow bar tracker is then changed until the receiver is focused to the center of the reflected light. Slight "tweaking" adjustments will be made at each bracket for fine focus. Caution should be taken never to focus the receiver without fluid flow.

To assist in the construction of the system, a set of detailed component design drawings for the Solar Kinetics T-700 is included in Appendix A of this report.

The estimated labor-hours required to perform the above installation are as follows:

	Labor Hours	
	Per Row	Per System (15 rows)
Align and install pylons	8	120
Install mirror modules	8	120
Install counter-weights	3	45
Install hydraulic lines	1.6	24
Connect hydraulics at drive pylon	0.5	7.5
Install receiver assembly	4	60
Install hose assemblies	2	30
Assemble tracker components (control)	4	60
Focus receiver assembly	2	30
Shake down collectors	2	30
System shake down (9450 ft^2)		24
Wire control panel		24
Plumbing of hydraulic power supply		12
Miscellaneous wiring		6
Total		592.5


70100
70900
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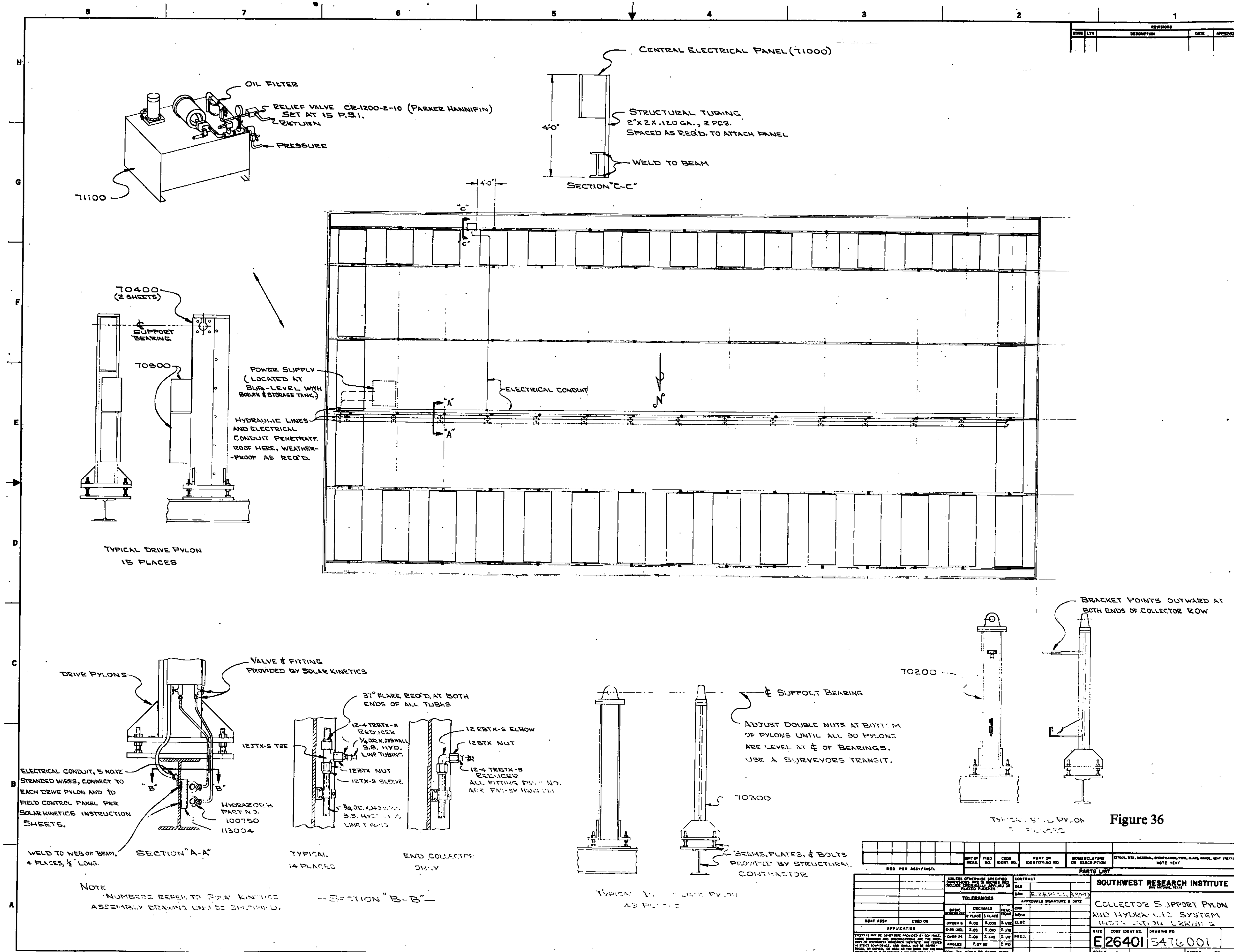
70500
70900
DRIVE PYLON
70300
INTERMEDIATE PYLON
70600
70200
END PYLON
PIPING TO THIS POINT PROVIDED
BY PLUMBING CONTRACTOR
70720
70800
70600
70700
70800
70600
70700
70800
70600
NOTE
NUMBERS REFER TO SOLAR KINETICS INC.
ASSEMBLY DRAWING UNLESS SPECIFIED
PARTS LIST
SOUTHWEST RESEARCH INSTITUTE
E.ZEPEDA
COLLECTOR INSTALLATION
E 26401 5476002
5476002

Figure 35



CENTRAL ELECTRICAL PANEL (71000)
STRUCTURAL TUBING
2"x 2 x .120 GA., 2 PCS.
SPACED AS REQ'D. TO ATTACH PANEL
WELD TO BEAM
4'0"
SECTION "C-C"
OIL FILTER
RELIEF VALVE CR-1200-2-10 (PARKER HANNIFIN)
SET AT 15 P.S.I.
RETURN
PRESSURE
71100
70400 (2 SHEETS)
℄ SUPPORT BEARING
70800
TYPICAL DRIVE PYLON
15 PLACES
POWER SUPPLY (LOCATED AT SUB-LEVEL WITH BOILER & STORAGE TANK)
HYDRAULIC LINES AND ELECTRICAL CONDUIT PENETRATE ROOF HERE, WEATHER-PROOF AS REQ'D.
ELECTRICAL CONDUIT
"A"
"C"
N
DRIVE PYLONS
VALVE & FITTING PROVIDED BY SOLAR KINETICS
12JTX-S TEE
ELECTRICAL CONDUIT, 5 NO.12 STRANDED WIRES, CONNECT TO EACH DRIVE PYLON AND TO FIELD CONTROL PANEL PER SOLAR KINETICS INSTRUCTION SHEETS.
"B"
HYDRAZOR'S PART NO. 100750 113004
WELD TO WEB OF BEAM, 4 PLACES, ½" LONG.
SECTION "A-A"
37° FLARE REQ'D. AT BOTH ENDS OF ALL TUBES
12-4 TRBTX-S REDUCER
¼ O.D. X .035 WALL S.S. HYD. LINE TUBING
12BTX NUT
12TX-S SLEEVE
TYPICAL 14 PLACES
12 EBTX-S ELBOW
12BTX NUT
12-4 TRBTX-S REDUCER
END COLLECTOR ONLY
SECTION "B-B"
NOTE
NUMBERS REFER TO SOLAR KINETICS ASSEMBLY DRAWING UNLESS SPECIFIED.
℄ SUPPORT BEARING
ADJUST DOUBLE NUTS AT BOTTOM OF PYLONS UNTIL ALL 30 PYLONS ARE LEVEL AT ℄ OF BEARINGS. USE A SURVEYORS TRANSIT.
70300
BEAMS, PLATES, & BOLTS PROVIDED BY STRUCTURAL CONTRACTOR
70200
BRACKET POINTS OUTWARD AT BOTH ENDS OF COLLECTOR ROW
PARTS LIST
SOUTHWEST RESEARCH INSTITUTE
COLLECTOR SUPPORT PYLON AND HYDRAULIC SYSTEM
E 26401 5476001

Figure 36

d. *Collector Field Maintenance*

1) *General Maintenance Instructions*

At yearly intervals the pillow block bearings and universal joints should be greased with a lithium base short fiber bearing grease. Sufficient grease should be injected to cause a slight flow past the bearing seals. Glass tubing should be inspected monthly for clearance with the receiver tube brackets. The glass should not contact any metal portion of the bracket or clamp. Aluminum shields should cover the O-ring portion of the assembly. The phototransistors in the tracking sensor heads should be wiped free of dust with a soft cloth at quarterly intervals. Batteries supplied are calcium chloride type and are maintenance free. The terminals should be checked occasionally for corrosion and cleaned if required. Hydraulic fluid level should be checked monthly. The hydraulic fluid filter should be changed yearly.

2) *Mirror Cleaning Instructions*

As with any optical system, solar collectors operate best when components of the system are clean. The factory recommends periodic rinsing of the mirror surface and receiver cover with deionized water. If weather conditions permit, exposing the mirror surface to mild rainfall will also reduce dust accumulations. Depending on conditions, the following detergent cleaning procedure should be used biannually or quarterly. Clean with a pressure washer with a nozzle pressure of 400-800 psi. The Malsbary C-310 is recommended. Detergent use solution should be 0.1-0.3% active detergent at the washer nozzle. This detergent level creates a moderate sudsing action. Excessive detergent solution should be avoided. The detergent should be a nonionic biodegradable type such as Union Carbide UCON 15-5-9, Rhom & Haas Triton X-100, or Jefferson Surfonic N-95. These detergent liquids are nondrying for thorough rinsing. Under no conditions should any detergent solution be allowed to dry on the mirror before rinsing. A deionized water rinse should immediately follow the pressure wash. The factory does not recommend any phosphate- or silicate-based detergent systems. There should be no mechanical agitation of the mirror surface; i.e., no mopping or wiping of the mirror. In addition, the pressure wash spray should be kept near a 90° angle with the mirror and the spray not directed at low angles against the edges of the applied film. The water temperature should not exceed 120°F. The receiver cover should be hand wiped using good glass cleaning practice.

3) *Materials Degradation*

The durability of the materials of construction for the T-700 collector is excellent with the possible exception of the reflector coating. This coating is an acrylic film manufactured by the 3M Corporation. The estimated degradation of absorber coating, transparent absorber cover, and the reflector surface are shown in Figure 37 as a function of years exposed to ambient weather.

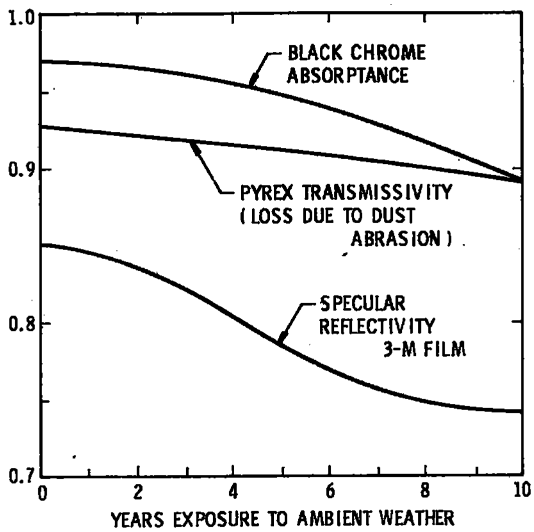


Figure 37. T-700 Materials Degradation Estimates

C. Heat Transfer Fluid

1. Fluid Survey

Numerous heat transfer fluids are available with physical properties applicable to this application. However, the selection of the collector field heat transfer fluid for this project must consider that the industrial process is a food industry. It is, therefore, required that the toxicity of the different fluids also be evaluated in any selection process, and that once a fluid is selected, this fluid must then be submitted to the industrial partner at Lone Star Brewery for approval.

A survey was conducted and 23 heat transfer fluids were identified. A listing of these fluids, along with the physical characteristics, cost, and toxicity of each, are shown in Table VIII. The price per gallon is based on quotes for supplying the fluid in quantities of 400 gallons. The list of candidate fluids can be shortened initially by observing the useful temperature range assuming an unpressurized system. The useful range must extend from about 20°F to 500°F, so that the number of potential candidates is reduced from 23 to 11. The physical properties of the fluids that impact on the design of the fluid handling system are viscosity, density, thermal expansion, specific heat, freeze point, flash point, and autoignition temperature. The first four of these properties will determine the equipment sizing of the pump, heat exchanger, and expansion tank, while the last three are items effecting safety. The final two items in the table are indicators of fluid toxicity.

The term LD_{50} signifies that 50% of the animals in a controlled test who were given the specified oral dosage died. For example, a 150-lb (70 kg) animal having an LD_{50} of 15 g/kg would require the oral ingestion of

TABLE VIII. HEAT TRANSFER FLUID PROPERTY SUMMARY

Fluid Specification	Supplier	Unit Cost ($/gal)	Useful Temperature Range (°F)	Viscosity (CS) 0°F	Viscosity (CS) 100°F	Viscosity (CS) 200°F	Viscosity (CS) 400°F	Density (lb/gal)	Thermal Expansion (%/°F)	Specific Heat (Btu/lb-°F)	Freeze Point (°F)	Flash Point (°F)	Autoignition Temp. (°F)	LD_{50} (g/Kg)	Toxicity
BRAYCO 888	Bray Oil Co.	4.56	-100 to 550	500	6.29	1.91	.5	6.7 @ 60°F	-	0.55	-80	325	-	-	-
Dowtherm A	Dow Chemical Co.	8.61	60 to 750	-	2.49	1.05	.42	7.54 @ 400°F	.00048	.5 @ 400°F	54	255	1150	4.0	Slightly Toxic
Dowtherm G	Dow Chemical Co.	9.70	20 to 700	-	13.6	2.86	.71	8.02 @ 400°F	.00047	.48 @ 400°F	<20	305	1030	4.0	Slightly Toxic
Dowtherm LF	Dow Chemical Co.	9.60	-25 to 600	23.4	2.94	1.02	.42	7.47 @ 400°F	.00053	.514 @ 400°F	<-25	260	1020	4.0	Slightly Toxic
Dowtherm J	Dow Chemical Co.	6.46	-100 to 575	2.0	.824	.471	.20	5.90 @ 400°F	.00065	.545 @ 400°F	<-100	145	806	4.0	Slightly Toxic
Siltherm 444	Dow Corning Corp.	21.12	-50 to 350	55	15.0	7.3	2.9	7.0 @ 300°F	.00060	.42 @ 392°F	-50	450	-	0.5	Slightly Toxic
Drewsol	Drew Chemical Co.	15.25	-28.5 to 230	-	16.0	5.8	-	9.27 @ 200°F	.00020	.87	-28.5	None	-	-	-
Caloria HT-43	Exxon Corp.	1.41	15 to 600	-	40.0	7.0	1.5	7.16 @ 60°F	.00029	.60 @ 400°F	15	425	750	10.0	Practically Nontoxic
H-30-C	Marks Enterprises	6.00	-40 to 620	310	17.0	4.3	-	6.96 @ 100°F	.00045	.50	-40	370	-	34.6	Nontoxic
H-30	Marks Enterprises	5.40	-40 to 560	1,500	29.0	5.5	-	6.96 @ 100°F	.00033	.57	-40	310	-	34.6	Nontoxic
Sunsafe 100	NPD Energy	3.78	0 to 222	-	1.52	.55	-	8.75 @ 60°F	.00028	.87 @ 60°F	0	None	-	0.5	Slightly Toxic
Sunsafe 130	NPD Energy	5.32	-30 to 230	-	2.24	.75	-	8.92 @ 60°F	.00030	.80 @ 60°F	-30	None	-	0.5	Slightly Toxic
Sunsafe 200	NPD Energy	3.85	0 to 218	-	1.94	.58	-	8.59 @ 60°F	.00030	.92 @ 60°F	0	None	-	30.0	Nontoxic
Sunsafe 230	NPD Energy	5.46	-30 to 225	-	3.27	.91	-	8.67 @ 60°F	.00034	.86 @ 60°F	-30	None	-	30.0	Nontoxic
Therminol T-44	Monsanto	8.20	-60 to 425	125	2.7	1.3	.85	7.67 @ 100°F	.00045	.476 @ 100°F	-80	405	705	13.0	Practically Nontoxic
Therminol T-55	Monsanto	3.15	0 to 600	1,400	26.9	4.85	1.03	7.32 @ 100°F	.00049	.472 @ 100°F	-40	350	675	15.8	Nontoxic
Therminol T-60	Monsanto	7.30	-60 to 600	65	4.9	1.75	.62	8.33 @ 100°F	.00046	.450 @ 100°F	-90	310	835	13.0	Practically Nontoxic
Therminol T-66	Monsanto	8.85	0 to 650	50,000	30.0	4.3	.97	8.34 @ 100°F	.00039	.380 @ 100°F	-18	355	705	10.2	Practically Nontoxic
Sun-Temp	Resource Tech. Corp.	3.75	-40 to 500	563	12.0	2.48	.90	7.5 @ 72°F	.00040	.56	-40	380	824	44.9	Nontoxic
Thermia 33	Shell Oil Co.	1.87	20 to 550	-	50.0	7.2	2.0	7.33 @ 60°F	-	.56 @ 300°F	+10	455	-	-	-
Sunsol 60	Sunworks	5.83	-20 to 228	38	6.7	-	-	8.64 @ 60°F	-	-	-20	-	-	-	-
UCAR 17	Union Carbide	3.90	0 to 350	57	10	-	-	9.4 @ 68°F	.00034	.56 @ 68°F	0	260	-	-	-
PAO-13C	Uniroyal	7.50	-40 to 400	5,000	100	14	2.5	6.98 @ 68°F	.00042	.50 @ 68°F	-55	555	N.A.	32.0	Nontoxic

1050 g or 1.3 quarts to be fatal. The National Academy of Sciences Committee on Hazardous Materials has correlated these values of LD_{50} with different levels of toxicity for human beings. The levels are as follows:

Nontoxic	—	$LD_{50} > 15$ g/kg
Practically Nontoxic	—	5 g/kg $< LD_{50} <$ 15 g/kg
Slightly Toxic	—	0.5 g/kg $< LD_{50} <$ 5 g/kg
Moderately Toxic	—	50 mg/kg $< LD_{50} <$ 500 mg/kg
Toxic	—	$LD_{50} <$ 50 mg/kg

These designations are included in the last column of Table VIII.

If only fluids that are classified as nontoxic are further considered, the list of candidate fluids is shortened to these fluids.

1. Marks H-30-C @ $6.00/gal (nontoxic)
2. Therminol T-55 @ $3.15/gal (nontoxic)
3. Sun-Temp @ $3.75/gal (nontoxic)

Of these three fluids all are acceptable from the standpoint of freeze point, viscosity, flash point, and toxicity. The Sun-Temp has a maximum recommended operating temperature of 500 F, which is not very much above the 475°F maximum calculated operating temperature. This condition would lead one to question the life of this fluid under the above operating conditions. The Marks H-30-C appears to be ideally suited for this application but the cost of this fluid is double the cost of the Therminol T-55. The Therminol T-55 is also acceptable for this application and would be a more cost-effective selection then either the Marks Fluid or Sun-Temp fluid. On a subjective basis, according to data provided by the manufacturers, the Therminol T-55 has been more thoroughly tested and more widely used than the other two fluids. The track record for this fluid was a big plus since more experience has been shown for applications with this heat transfer fluid. A sample of this fluid was then submitted to the Lone Star Brewery for Testing and was determined to be acceptable to them. The Therminol T-55 was, therefore, chosen for use in this solar process steam system.

2. Therminol T-55

a. Physical Properties

Therminol T-55, marketed by the Monsanto Company, has an operating range of 0°F to 600°F and a pour point of -40°F. This fluid offers good viscosity characteristics with minimum pumpable temperatures of -5°F for a centrifugal pump and -10°F for a positive displacement pump. A list of physical properties for Therminol T-55 is given in Table IX, and a list of property variations with temperature is given in Table X. The pressure drop characteristics for this fluid are shown in Figure 38, plotted as Δp in psi per 100 ft of pipe at a fluid temperature of 600°F versus flow rate in gallons per minute. For calculations on the heat exchanger, Figure 39 shows the convective heat transfer film coefficient in Btu/hr-ft^2-°F at a fluid temperature of 600°F as a function of flow rate in gallons per minute.

TABLE IX. THERMINOL T-55 PHYSICAL PROPERTIES

Composition	—	Synthetic Hydrocarbon Mixture
Appearance	—	Clear Yellow Liquid
Operating Range, °F	—	0° to 600°
Pour Point, °F	—	-40°
Moisture Content	—	250 ppm, maximum
Viscosity, cs		
• at minimum operating temperature	—	1610
• 100°F	—	26.9
• at maximum operating temperature	—	0.60
Specific Gravity		
• at minimum operating temperature	—	0.915
• at 100°F	—	0.878
• at maximum operating temperature	—	0.691
Coefficient of Thermal Expansion, %/°F	—	.00049
Specific Heat, Btu/lb-°F		
• at 0°F	—	0.420
• at 100°F	—	0.472
• at maximum operating temperature	—	0.718
Thermal Conductivity, Btu/hr-ft°F		
• at 0°F	—	0.0813
• at 100°F	—	0.0784
• at maximum operating temperature	—	0.0630
Heat of Vaporization, Btu/lb	—	84.4
Flash Point, COC, °F	—	350°
Fire Point, COC, °F	—	410°
AIT, °F	—	675°
Boiling Range		
• 10%, °F	—	635°
• 90%, °F	—	734°
Minimum Pumpable Temperature, °F		
• Centrifugal Pump, 300 cp	—	25°
• Centrifugal Pump, 2000 cp	—	-5°
• Positive Displacement Pump	—	-10°

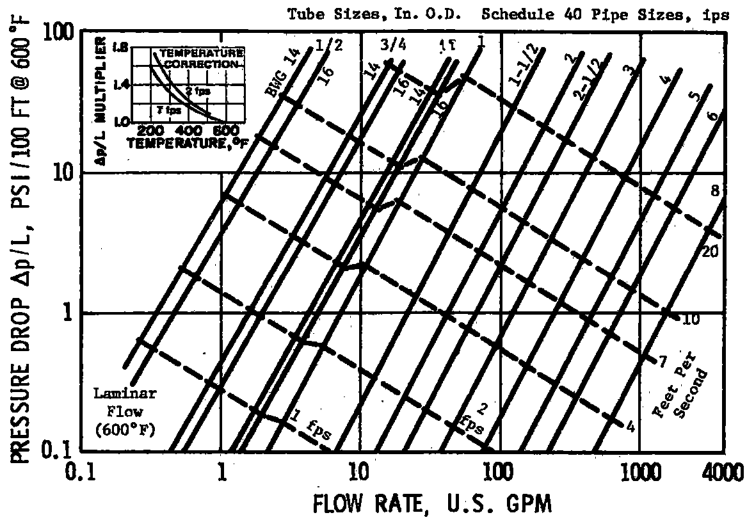


Figure 38. Pressure Drop Data for Therminol T-55 Under Turbulent Flow Conditions Inside Clean Round Tubing and Piping

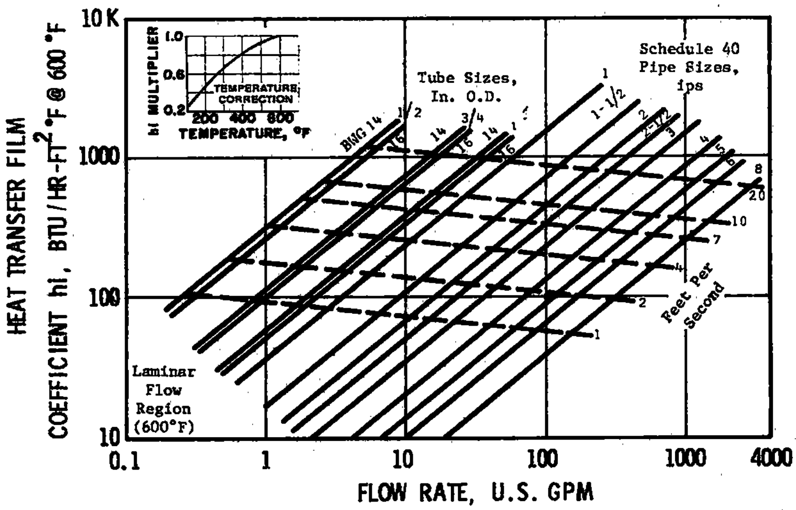


Figure 39. Heat Transfer Coefficients for Therminol T-55 Under Turbulent Flow Conditions Inside Clean Round Tubing and Piping

TABLE X. VARIATIONS OF THERMINOL T-55 PROPERTIES AS A FUNCTION OF TEMPERATURE

Temperature (°F)	Density (lb/gal)	Specific Heat (Btu/lb-°F)	Thermal Conductivity (Btu/hr-ft-°F)	Viscosity Absolute (lb/hr-ft)	Viscosity Kinematic (cSt)	Vapor Pressure (torr)
0	7.57	0.431	0.0764	3070	1400	
50	7.41	0.453	0.0749	263	122	
100	7.26	0.476	0.0733	56.6	26.9	
150	7.10	0.498	0.0717	20.3	9.86	
200	6.95	0.521	0.0701	9.77	4.85	0.2
250	6.79	0.543	0.0684	5.62	2.86	0.7
300	6.64	0.566	0.0666	3.64	1.89	2.3
350	6.48	0.588	0.0647	2.55	1.36	6.9
400	6.33	0.611	0.0627	1.90	1.03	18.2
450	6.17	0.633	0.0606	1.47	0.82	43
500	6.02	0.656	0.0583	1.19	0.68	93
550	5.86	0.678	0.0559	0.98	0.58	187
600	5.71	0.700	0.0533	0.83	0.50	352
650	5.55	0.723	0.0505	0.72	0.45	626

*Maximum recommended bulk temperature: 600°F.

b. System Design, Safety, and Handling

Therminol T-55 is designed for use in nonpressurized, indirect heating systems, where it delivers efficient, dependable process heat with no need for high pressures or costly venting equipment. Since this fluid is not classified as fire-resistant, the use of protective devices will be considered during the detailed system design process. To minimize fluid oxidation, the fluid expansion tank will be blanketed with an inert atmosphere and a pressure relief valve. This fluid offers long service life within its recommended operating temperature range. A thermal life prediction test has been conducted which indicates a life of 45 years of continuous 24-hr per day use when used in systems operating below 500°F. Therminol T-55 is noncorrosive to metals commonly used in the design of process heat systems; therefore, no special materials are required when selecting piping, pumps, and heat exchangers. This heat transfer fluid is nontoxic by ingestion in single doses and by single dermal applications according to NAS classifications. It is a slight eye irritant and produces only a trace of skin irritation on prolonged contact. Although no special handling precautions appear necessary, as with any industrial chemical, good industrial practices and personal hygiene should be observed in handling to minimize exposure. In case of contact, flushing eyes or skin with plenty of water is required. Because of its low volatility, T-55 does not present an inhalation hazard at ambient temperatures such as those encountered in transferring cold fluid from shipping containers to the heat transfer system. Vapor emitted by T-55 heated to elevated temperatures may be mildly irritating and cause discomfort on prolonged exposure. In heat transfer installations, the fluid will be used in a closed, nonpressurized system free from leaks and with the expansion tank vent trapped so as to condense any vapors. Consequently, there should be little or no opportunity for worker exposure to vapors.

c. *Toxicity*

Therminol T-55 has an oral LC_{50} of 15.8 g/kg to albino rats and a dermal LD_{50} of 7.94 g/kg to albino rabbits. According to NAS classifications, this fluid is nontoxic by ingestion in single doses and by single dermal applications.

The undiluted product is a slight irritant to rabbit skin (average score of 1.0 on a scale of 8) but practically nonirritating to the rabbit eye (average score of 6.0 on a scale of 110). A group of male rats survived a six-hour exposure to air near saturation with vapor of this material at room temperature. They exhibited no adverse signs during the exposure and subsequent ten-day observation period.

Groups of 20 male and 20 female albino rats were fed diets containing levels of 100 ppm, 300 ppm, or 1000 ppm Therminol T-55 for 90 days.A similar group of rats of both sexes served as controls. During the study no differences in behavior, survival, final body weight, body weight gain or food intake between test and control animals were noted. No adverse alterations in hematology (hematocrit levels, erythrocyte, hemoglobin, and total and differential leukocyte counts), blood chemistry (blood urea nitrogen, fasted blood glucose concentrations and serum alkaline phosphatase and glutamine-pyruvic transaminase activities), or urinalyses (glucose and albumin concentrations, pH, specific gravity and microscopic examination) were noted.

On termination of the feeding study, 15 animals of each sex were sacrificed and autopsied by gross examination. Weights of liver, kidney, spleen, gonads, heart, and brain of each rat were determined and recorded. A microscopic examination of tissues and organs (approximately 32 per animal) from ten rats of each sex from both the control and 1000 ppm Therminol T-55 group was conducted. There was no relevant gross or microscopic pathology and no significant differences between test and control animals in either organ weights or their ratios to body or brain weights.

Separate groups of White Leghorn chickens (4 males and 20 females per group) were fed diets containing 30 ppm, 100 ppm, or 300 ppm of T-55 for 12 weeks, after which the birds were returned to a Therminol-free diet for an additional four weeks. A similar group of 24 birds served as controls. No abnormalities in body weight gain, food consumption, survival, or behavioral reactions were noted. No adverse effects in egg production or egg quality (defects, breakage, weight, shell thickness, specific gravity) related to ingestion of Therminol T-55 were noted. No differences in the viability (hatching of chicks during the study) or body weight gain in the F_1 generation (chicks) were seen. No relevant gross pathological abnormalities were determined for either the parents or the F_1 generation birds.

d. Fouling and System Cleanout

While Therminol T-55 has a select-stable chemistry, conditions can develop to precipitate fouling of heat exchangers, pumps, and valves which may require a system cleanout. The most common causes of Therminol system fouling are:

- Overheating the heat transfer fluid
- Contamination by process chemicals or other heat transfer fluids
- Oxidation of the heat transfer fluids

Therminol T-55 can be affected by oxidation conditions. Should extensive oxidation occur by air contacting hot fluid, a carbonaceous residue will form and adhere loosely to the system heating surfaces requiring cleanout of the system. Thermal breakdown of T-55 is less common than oxidation of these fluids, but can create carbonaceous deposits within the system. Contamination of Therminol by process fluids or other heating media may contribute to fouling of the system. Incompatibility of the chemistries involved dictate changing to fresh fluid and reclamation or disposal of the contaminated fluid.

Four methods of 'cleaning' a system are recommended, depending upon the degree of fouling or incompatability of the contaminant in the system:

(1) Draining of old fluid and recharging with fresh fluid. This method is the easiest and least expensive. Solids in the fluid can be removed by a hot and rapid draining. Addition of new fluid provides a small degree of cleaning action on slightly fouled heating surfaces.

(2) Fluid flush. This method involves flushing the system with a small amount of the Therminol to be used to fill the system. Isolation of system components is desirable to avoid using large quantities of flushing fluid. This method is effective for new systems where surfaces are not heavily fouled.

(3) Solvent cleaning. This method is useful to clean or flush a lightly soiled system. Chlorinated solvents are to be avoided. Typical solvents used are:

- Xylol
- Kerosene
- Benzene

(4) Chemical cleaning. This method is effective in cleaning heavily fouled heating surfaces. The following chemicals should be used:

- Oakite cleaning products
- Caustic soda and soda ash

The following cautions are recommended for chemical cleaning:

- Mechanical agitation by high velocity flow or air injection is necessary to loosen difficult soils.
- Cleaning products must be completely removed from the system prior to charging with fresh fluid.

- All water must be completely removed to preclude startup pumping problems.
- Certain metals in the system (copper and aluminum) may be affected by the cleaning agents used.

D. Piping System

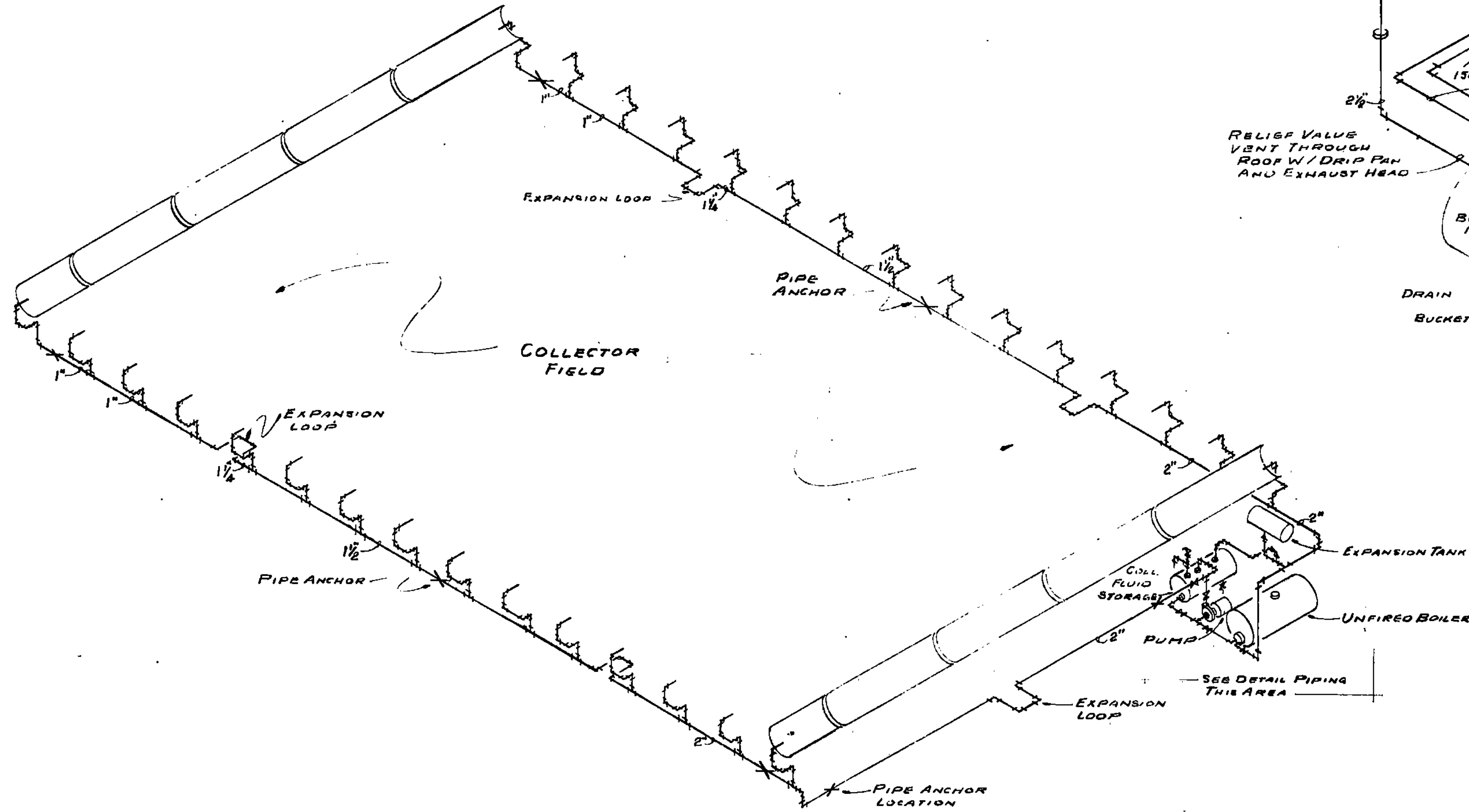
1. Description

As was indicated in the conceptual design, the system configuration includes a roof-mounted collector field, a solar-fired boiler, a heat transfer fluid circulation pump, and all the associated system piping. A set of detailed design drawings showing the piping system is included in Figures 40 and 41. Figure 40 includes an isometric drawing of how the complete system fits together. The heat transfer fluid flows from the pump through a supply header to the collector field consisting of fifteen 90-ft long collector rows. It then returns to the solar-fired boiler via a return header, and finally back to the pump. Figure 40 also shows the detailed design of the collector row pipe connections, the expansion tank, the steam and condensate return piping, and the details of the boiler connection including the boiler, pump, and storage tank.

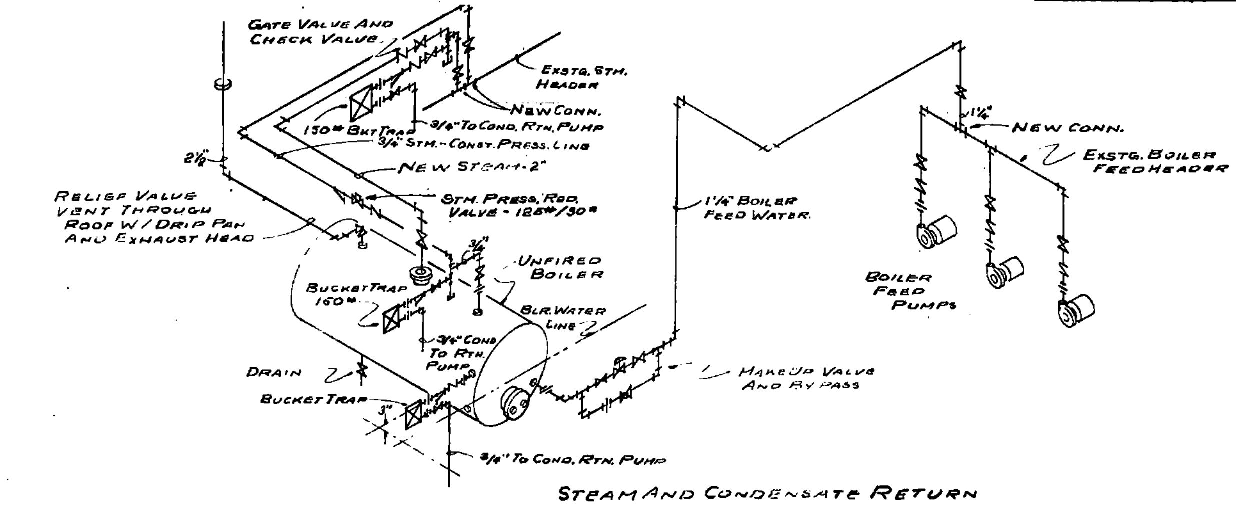
Just upstream of the solar-fired boiler, an expansion tank is included with a nitrogen blanket to minimize any oxidation in the system as well as provide for thermal expansion of the heat transfer fluid. At the boiler, a small by-pass loop is provided with a three-way modulating valve to prevent a condition of extracting heat from the boiler during the initial startup period. The boiler and control valve are both outfitted with flange connections upstream and downstream for ease of access when maintenance is required. The system pump is located immediately downstream of the boiler and is also outfitted with flanges upstream and downstream for ease of maintenance. With the appropriate valves opened, the entire fluid capacity of the collector field can be pumped into a holding tank when system maintenance is required. After maintenance is completed, the above valves can be closed and another set open, so that the heat transfer fluid can be pumped back to the collector field. In this way, the heat transfer fluid can be conserved during system maintenance operations.

On the steam side of the boiler, condensate is supplied to the boiler by the existing boiler feed pumps via a new boiler feedline. The flow rate in this line will be controlled by a float valve in the shell side of the boiler to provide makeup water as steam is generated. The generated steam is then injected into the main steam header. The flow of steam is controlled by a check valve so that whenever the pressure in the boiler exceeds that of the steam main, a check valve opens and the solar-produced steam is injected into the process steam system. In order to select the location of the injection point, one only needs to make sure that the process downstream of that point can accept 100% of the solar-produced steam 365 days per year. With this consideration in mind, it was determined that the steam main located directly below the collector field met this requirement, and was selected for the injection point.

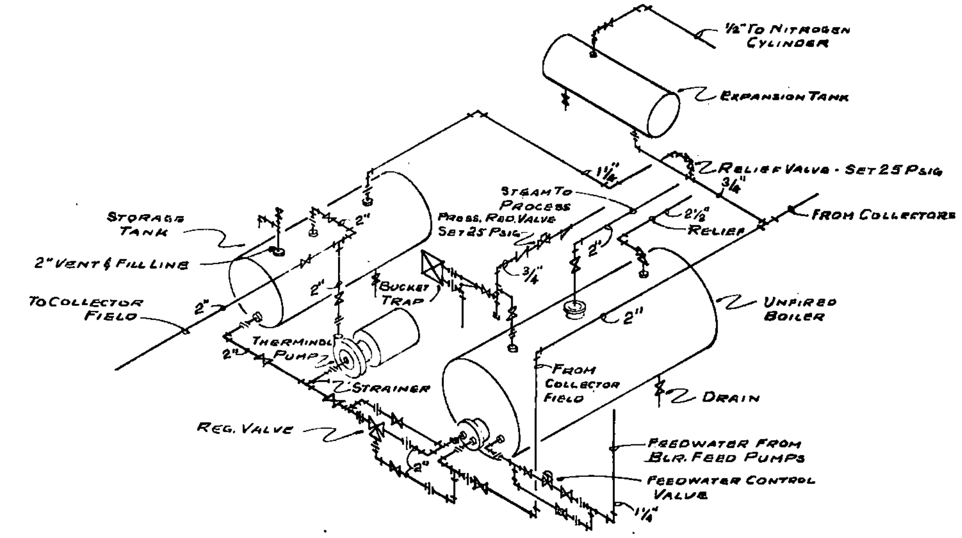
For safety reasons, as outlined in the safety analysis section of this report, the pressure on the shell side of the boiler will always be kept to a pressure slightly above the pressure of the tube side. This will be accomplished by a pressure-reducing valve connected to the steam header and set at 25 psig. To prevent a buildup of condensate in the boiler, a condensate trap will be included and installed at a liquid level above the level dictated by the float valve. The details of this arrangement are shown in Figure 40.



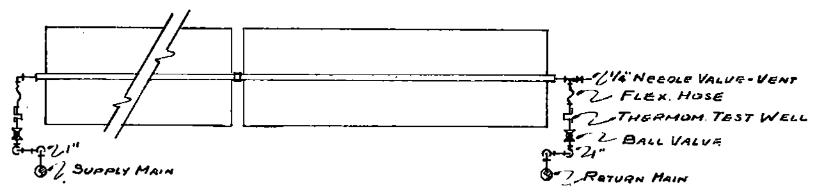
Collector Loop Piping
No Scale



Steam And Condensate Return Piping
No Scale

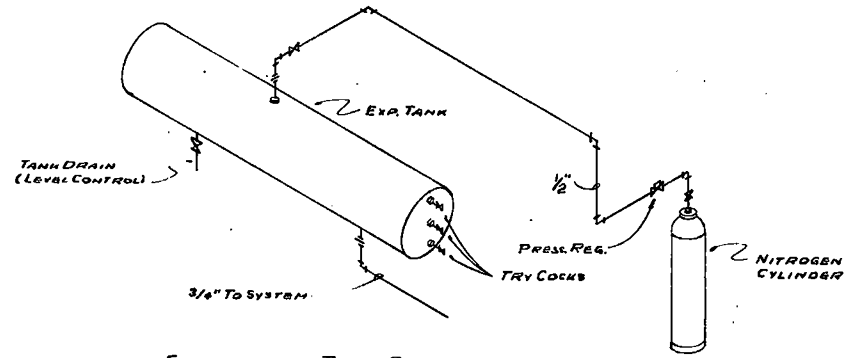


Detail At Boiler
No Scale



Piping Connections At Collector Rows
No Scale

Equipment Schedule		
Item	**Manufacturer**	**Description**
Therminol Pump	Viking Pump	Model L4124, 2" x 2" - 10 HP - 230/3/60 - 420 RPM - 68 GPH - 61 Psig Head 125#-650° F. Const.
Unfired Boiler	Patterson-Kelley	Model HO 3610 - 1862#/HR 140 Psig Stm - 68 GPM Therminol 475°F To 365°F.
Storage Tank	Wendland Mfr.	42"Ø x 96" Long - 125# ASME Const. - 520 Gal. Capacity - Horizontal
Expansion Tank	Manchester	16"Ø x 74" Long - 60 Gallon - 125# ASME Const.
Collectors	Solar Kinetics	Model T-700 - 1⅝" Steel W/Black Chrome Receiver - Hydraulic Tracking
Steam Traps	Anderson-Ibec	Model 219B - ¾" - 200# Const. - Cap. 1890#/HR At 15# Press. Diff.
Relief Valves	Kunkle	Fig. 910 - ¾" x 1¼" - Carbon Steel Body - SS Trim



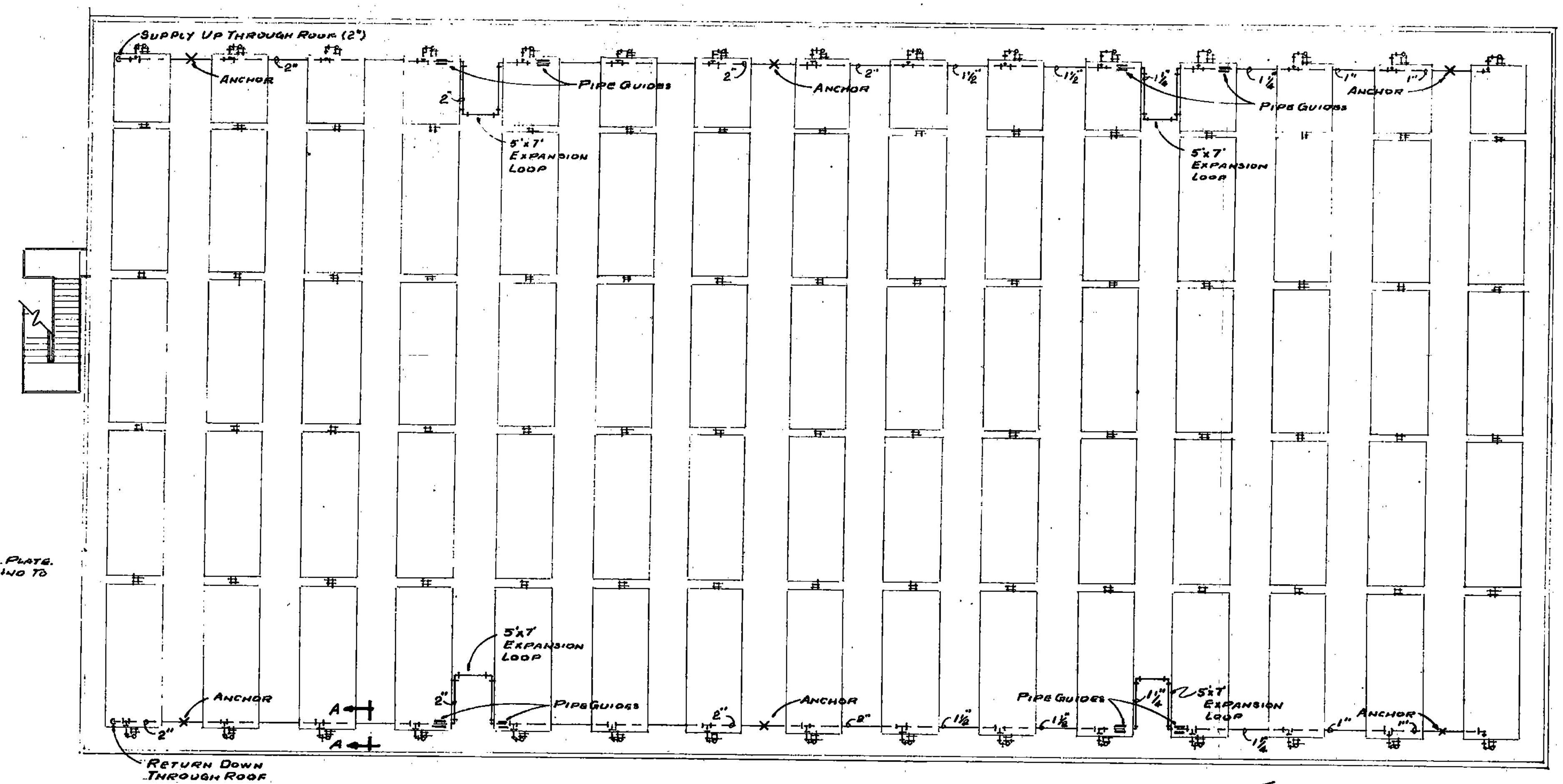
Expansion Tank Detail
No Scale

Figure 40

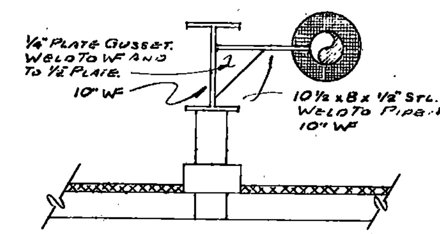
Plumbing & Heating Co.
San Antonio Texas

Drawn	Piping Details	Date
HED	Lone Star	4 Mar 79
Scale: Noted	Brewing Company	Sheet 1 of 2
Job No. 423	San Antonio Texas	

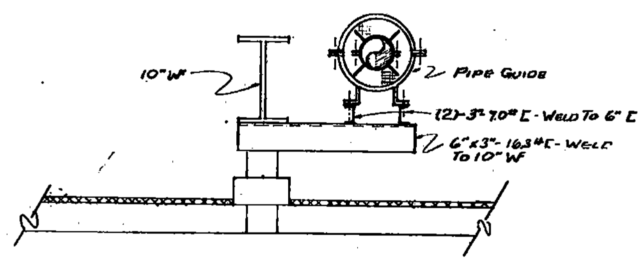
Rev. 4/27/79 - HED



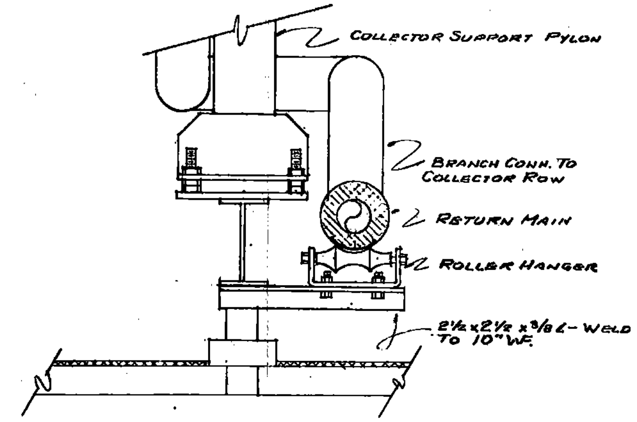
ROOF PIPING PLAN
SCALE: 1/8"=1'-0"



DETAIL AT PIPE ANCHOR
SCALE: 1½"=1'-0"



DETAIL AT PIPE GUIDE
SCALE: 1½"=1'-0"



SECTION A-A
PIPE HANGER DETAIL
SCALE: 1½"=1'-0"

Figure 41

JUD Plumbing & Heating Co. SAN ANTONIO TEXAS		
DRAWN HED	COLLECTOR PIPING	DATE 3 MAR '79
SCALE NOTED	LONE STAR	SHEET 2 of 2
JOB NO. 428	BREWING COMPANY	
	SAN ANTONIO TEXAS	

Rev. 4/27/79 HED

The collector row piping connections are detailed in Figures 40 and 41. The thermal expansion of the piping system is accommodated by expansion loops with piping guides located on both sides of the expansion loop and pipe anchors located halfway between each loop. Details of pipe guides and pipe anchors are shown in Figure 41. To accommodate thermal expansion between the pipe header and the stationary connection at the end of the flexible hose, an expansion loop is included as shown in Section AA of Figure 41. On both ends of the collector row, a ball valve and a thermometer test well are included. The ball valve will serve as both a shutoff and a balancing valve with thermometers inserted in the test well being used to assure equal temperature and thereby equal flow in all of the collector rows. At the connection between the flexible hose and the absorber tube, a 1/4-in. needle-vent valve will be included to provide a path for venting of trapped air during startup.

As a part of the optimization study a number of collector field flow rates were investigated and it was determined that the system performance was not greatly affected by this flow rate. The size of the system headers was, therefore, reduced by specifying a flow rate that was above the minimum recommended by the collector manufacturer and yet allows the smallest and therefore the most economical piping system. The smaller the piping, the lower the cost for not only the piping itself but also the valves, fitting, hangers, and insulation. The final pipe size selected was a two-inch main. Another item investigated was the pipe insulation thickness, which leads to a pipe insulation thickness of two inches.

2. Piping and Valves

The piping system will be constructed of Schedule 40 seamless carbon steel pipe (ASTM A 53, Type S, Grade B, material). This piping will be assembled by welding and using standard weight weld fittings (ASTM A 234, Grade WPB material, USAS B-16.9 dimensions). All flanges will be USAS 300-lb forged steel (ASTM A 181 material, USAS B-16.5 dimensions). Extreme care will be taken to provide a leak-free system, even at the flanges, since the high temperatures encountered in this application will produce internal stresses which could cause leaks at flange joints. The 300-lb welding neck flanges will be used to reduce the possibility of flange face warping during welding and compression of spiral-wound gaskets. A leak-free system is more critical at higher temperatures due to a possible fire hazard in insulation materials. The subject of potential fire hazards will be discussed under the following section on pipe insulation.

The valves specified for this application will also be 300-lb butt-welded to reduce the need for flange connections. The most important consideration, however, for the selection of valves is the temperature and pressure rating of the valve seals and packing.

Various types of packing are used to seal valve stems in high-temperature systems. Flexible metal or solid graphite packing is recommended due to its proven life in similar applications. Graphite or Teflon impregnated, short fiber asbestos gasketing has been used on previous systems, but leak-free service is not always achieved at higher temperatures with this type packing. Generally, five rings of packing are required on valve stems to assure a reasonable seal. The use of metal bellows stem seals on valves is a possibility and would, of course, provide absolute leak-free service, but this type seal is more expensive than the conventional flexible stem packing discussed above.

3. Insulation

Fires have occurred in insulation materials that have been soaked with heating fluids at apparent temperatures of 500-600°F, which is well below the autoignition temperature of most commercial heating fluids. Tests indicate that magnesia, calcium silicate, and silicate-bonded asbestos insulations are subject to this problem. While the exact mechanism by which such fires occur is not fully understood, the most probable explanation is that a slow exothermal oxidation reaction between hydrocarbon-type heating fluids and air inside the voids of the insulation starts at about 500°F. Such a reaction is believed to occur because the combination of the large heating fluid surface exposed on the insulation fibers, poor heat dissipation conditions, and the formation of low flash point oxidation products, can cause a temperature buildup in the saturated insulation mass resulting in ignition of the material when exposed to air.

Calcium silicate, asbestos, and magnesium oxide insulation can saturate with almost their original weight of leakage fluid. This saturation when spread over the large surface area within the insulation at high temperature can give rise to oxidation of heating fluid and the formation of lower boiling, more combustible, decomposition products. Subsequent ignition of the fluid within the insulation system can result.

An alternate insulation, cellular glass, tends to resist saturation by the heat transfer fluid and is, therefore, a safer insulation to use. Cellular glass is not normally the most economical insulation for most applications because of its higher installation cost and its tendency to crack when thermally shocked. The use of cellular glass insulation does not insure that insulation fires will not develop, but the amount of fluid that can saturate the insulation system and be oxidized is greatly reduced.

The insulation system must be designed to minimize fire problems in the event of fluid leakage. The following precautions will be taken to minimize the fire hazard potential in the insulation systems.

- Every precaution will be taken to install and maintain a leak-free piping system. The number of flanges will be held to a minimum.
- On horizontal runs of pipe with welded joints, standard high-temperature fiberglass insulation will be used.
- On vertical runs of piping where occasional leak sources can develop at flanges and valves, protective, tight- fitting caps will be installed below flanges and valves to divert any fluid leakage to the outside of the insulation system.
- Valve stems will be installed horizontal so that any stem leakage does not enter insulation.
- On those sections of piping where control valves and instrument fittings are attached and where leakage is a potential problem, cellular glass insulation or metal shielded insulation will be installed to minimize or eliminate any potential saturation of leakage fluid into the insulation system.
- On jacketed vessels where leakage due to metal failure can occur, a heavy gauge metal foil barrier will be installed between the jacket surface and the insulation system.

It should be pointed out, however, that even though these precautions will be taken, the operating range of the system will be below 500°F so that no fire hazard is anticipated.

4. Installation Techniques

The following is an outline of the installation techniques to be conducted during the field construction of the system.

The roof of the building which will support the collectors will be prepared by cutting through built-up roofing to steel members underneath. Structural attachments which will accept collector bases will then be installed. The roof will be repaired with pitch pockets at collector support penetrations and the pitch pockets stripped into existing roofing.

During the wait for collectors, steam and feedwater piping will be run from the location of the solar-fired boiler to the collector field. New piping within the building areas will be supported from building structures using roller clevis hangers to allow for pipe movement. Where piping is run across the roof of the building, it will be supported by structural steel supports tied into the building roof structures in the same manner as the collector supports. Pipe hangers for roof-mounted piping will be roller bracket hangers.

Anchors fashioned from structural steel members will be installed at the proper points to confine and direct pipe expansion. Piping guides will be installed around piping on either side of expansion members.

After steam and feedwater piping is run to the collector field areas, it will be capped and pressure tested to prove its integrity. Following the pressure test, the piping will be insulated.

Upon arrival at the job site, the collectors will be installed by the following process:

- Support members will be set in place on structural attachments previously installed, utilizing a motor crane of sufficient reach.
- Reflectors will be set in place on supports, aligned, and secured.
- Continuing to use the motor crane, the receiver tubes and covers will be carefully set using a specially improvised sling to avoid damage to tubes or covers. As tubes are set and aligned, they will be attached using compression tube fittings to form continuous lengths of tubing. Tubes and covers will be secured in place.
- Following installation of receiver tubes and covers, the crane may be dismissed and piping connections made to flex connections at each end of collector rows.
- Following piping connections, each row of collectors will be pressure tested.

When the solar-fired boiler is received at the site, it will be set in place and all piping connections made. Following piping connections and pressure testing, the boiler and its associated piping will be pressure tested.

Following receipt of the collector fluid pump at the site, it will be mounted adjacent to the boiler and securely bolted down. Collector fluid connections will be installed and tested. Electrical wiring connections will be made to the pump at this time.

As accessory items such as the expansion tank and storage tank are received, they will be installed, tested, and insulated. The entire system should be pressure tight at this time, and trim such as thermometers, gauges, relief valves, flow control valves, and air release valves may be installed.

Following trim installation, all controls, control wiring, interlock wiring, and data acquisition instruments are to be installed, together with their associated piping and wiring. Collector tracking mechanisms and their wiring should be installed at this time and all wiring checked.

Following final checkout, the collector loop will be filled with the high-temperature heat transfer fluid and a reserve amount of fluid placed in the storage tank.

The collector fluid pump will then be started, checked for rotation, and the fluid circulated while venting air from the system until it is free of all entrained air. All operating controls will be set and checked at this time and carefully monitored for proper operation. After satisfactory operation is achieved, the system may be operated under close supervision and careful attention paid to operating parameters and to the functioning of safety devices.

In order to minimize installation costs of factory-fabricated equipment requiring particular care in final installation, the following procedure has, in our experience, worked well:

- When purchasing equipment, arrange for the services of a trained factory man to be available for the first week of the installation period. At the same time, arrange for the same man to return to the job at completion.
- Installation labor is to be performed by a local contractor under the initial supervision of the factory technician.
- The factory technician is to return to job on completion of machinery installation and either certify that it is properly installed or request the necessary changes to allow him to make such a certification.

Factory personnel cannot install equipment as economically as can local contractors with good mechanics. Additionally, factory personnel are away from home and are living on expenses paid by the customer. It is desirable, however, to maintain the responsibility of the factory for proper installation.

E. Engineered Equipment

1. Pump

a. *Capacity*

The capacity of the pumping system was determined in the system optimization study to be equal to the minimum flow rate through the collectors that gives a turbulent flow condition. This minimum flow rate is 4.5 gpm per collector row or 67.5 gpm for a 15-row collector system. The fluid density at the design condition is 6.2 lb/gal, which gives a mass flow rate of 25,110 lb/hr.

b. *Viscosity*

There are three values of viscosity that must be considered for the selection of a pump. The first is the viscosity at the normal operating temperature, which is about 1 cs (32 SSU), or the viscosity of water at standard conditions. The second value of viscosity is the viscosity of the fluid in the pump during cold startup. Since the pump will be located in a heated warehouse, the maximum viscosity that the pump will be subjected to will be about 60 cs (260 SSU). The third viscosity is the viscosity of the fluid in the outside piping which will be at a temperature below 25°F only 1% of the time, so that the cold startup viscosity for the piping is 187 cs (840 SSU).

c. *Pump Head*

The pump head under the design conditions can be determined by assuming an average viscosity since the viscosity versus temperature relationship between 365°F and 475°F is linear. For this condition, the pressure drop through the system is determined, as shown in Table XI, to be equal to 55 psi. For the cold startup condition, the fluid viscosity in the indoor piping is selected for a temperature of 70°F, and the outdoor piping is selected for a temperature of 25 °F. The pressure drop calculation for this condition is summarized in Table XII, and the cold startup pressure drop is 125 psi.

d. *Class and Type*

There are basically three classes of pumps available for this application: centrifugal, rotary, and reciprocating. Since the system requires a steady flow, the reciprocating class of pump will not be further considered. The two remaining classes are the centrifugal and rotary. The performance characteristics of a centrifugal

TABLE XI. PRESSURE DROP CALCULATION AT THE SYSTEM DESIGN CONDITION

Pipe Dia. (in.)	Pipe Length (ft)	Flow Rate (gpm)	Viscosity (SSU)	Δp/ft (psi/ft)	Δp (psi)
2	200	50	32	.02	4.0
1-1/2	225	25	32	.02	4.5
1-1/4	10	10	32	.008	0.1
1-5/8	100	4.5	32	--	4.0
2	300	67	32	.04	12.0
Heat Exchanger		67	32	--	30.0
				Total	55 psi

TABLE XII. PRESSURE DROP CALCULATION AT COLD STARTUP

Pipe Dia. (in.)	Pipe Length (ft)	Flow Rate (gpm)	Viscosity (SSU)	Δp/ft (psi/ft)	Δp (psi)
2	200	50	840	.138	27.6
1-1/2	225	25	840	.190	42.8
1-1/4	10	10	840	.138	1.4
1-5/8	100	4.5	840	.038	3.8
2	300	67	260	.61	18.3
Heat Exchanger		67	32	--	30.0
				Total	125 psi

pump are such that a variable range in capacity and head can be accommodated within a certain range. If a pump is sized to dead-head at a pressure above the cold startup condition, the design condition with the lower head and higher capacity will be at a less than optimum efficiency range for the pump and a greater parasitic power loss will be exhibited. The rotary pump, on the other hand, exhibits the performance characteristics of providing a wide range of heads at a constant capacity. For the cold startup condition, the pump horsepower required will be high but will be greatly reduced during normal operating conditions. The cold startup horsepower will be about 10 bhp, and the normal operating condition horsepower will be about 4 bhp. Another item to be considered is that since the system temperature will vary with solar input, the system viscosity and, consequently, the system head will also vary. It is, therefore, advantageous to have a pump that can supply a relatively constant capacity with a changing head requirement. A rotary class pump will, therefore, be used for this design.

After investinating a number of types of pumps, the positive displacement rotary pump constructed with the simple gear-within-a-gear principle supplied by Viking Pump Division of Houdaille Industries, Inc, was selected. The only limiting factors to peak performance of this pump are that the liquid pumped must be comparatively clean and that the viscosity variation in the pump be kept within a factor of 20 to 1. Since the system will be a closed system with adequate strainer capacity, the Therminol will be kept relatively clean, and since the pump will be located in a heated warehouse, the fluid temperature range within the pump will be from 70°F to about 380°F. This temperature range gives a Therminol viscosity range of 32 SSU to 260 SSU or a viscosity range of about 8 to 1.

The operational characteristics of this type of pump are that with every revolution of the pump shaft, a definite amount of liquid enters the pump through the suction port and fills the space between the teeth of the rotor and the idler gears. A crescent-shaped spacer splits the flow of liquid as it is moved smoothly to the discharge port. The idler gear, which carries the liquid between its teeth and the inside surface of the crescent, rotates on the pin supported by the pump head. The rotor gear, which carries the liquid between its teeth, travels between the casing and the outside surface of the crescent and is connected to the pump shaft. Figure 42 shows a

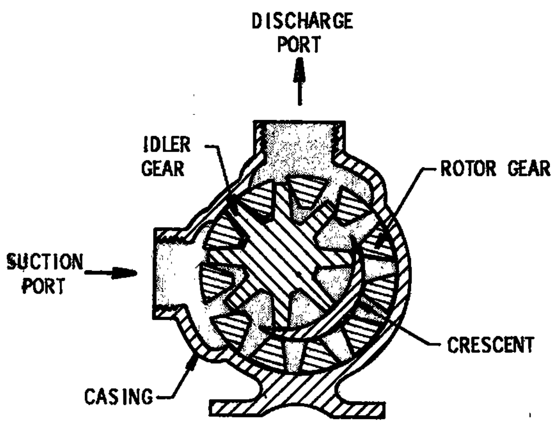


Figure 42. Viking Rotary Gear Pump

sketch of the internal configuration of this type of pump. In this way, the gear-within-a-gear principle provides a smooth positive displacement of the hot Therminol. These operating characteristics indicate the need for providing a clean system as well as one without a large variation in fluid viscosity due to the clearance required in the gear mesh and the advantage of providing a constant flow at a variable head.

e. Size

The pump size for the type of pump selected is based on the capacity and fluid viscosity during the worst operating condition and the normal operating condition. The normal operating condition is 55 psi, 67.5 gpm, and 400°F (viscosity of 32 SSU), and the cold startup condition is 125 psi and 70°F (viscosity 260 SSU). The cold startup capacity can be somewhat lower than the operating condition. The pump performance curve for a Viking L4124 size pump is shown in Figure 43. This curve indicates a drive speed of 420 rpm at a head of 55 psi and 73 gpm, which gives an input horsepower of 4 bhp. At the same drive speed and at a head of 125

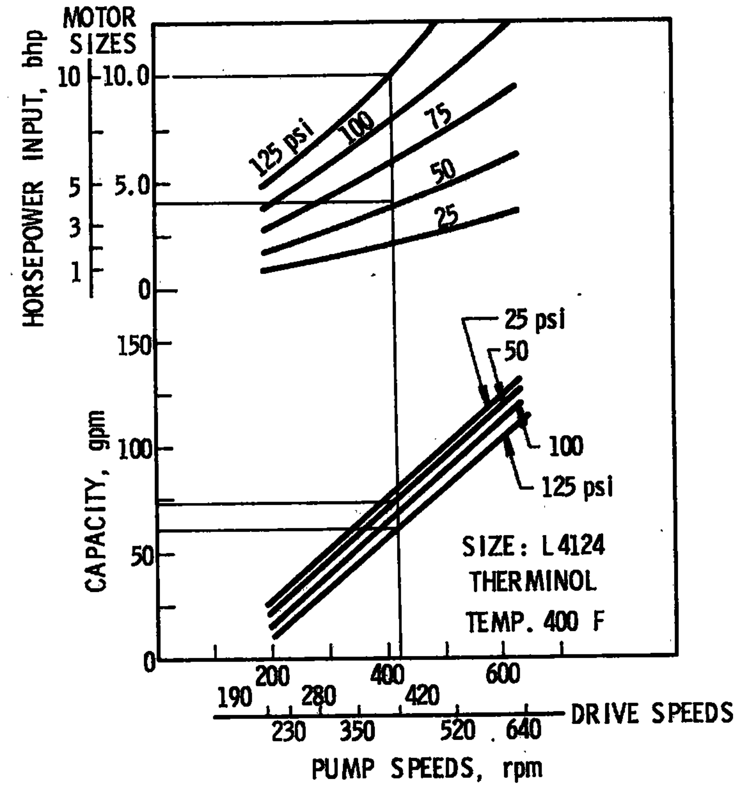


Figure 43. Pump Performance Curves

psi, the capacity is 62 gpm and the input horsepower is 10 bhp. The pump size selected is, therefore, an L4124 with a 10 bhp motor and a reduction drive unit to give 420 rpm.

f. Materials of Construction

The standard cast iron construction is acceptable for this application with the addition of Teflon seal seat gaskets, Teflon shaft sealing members, and NI-Resist seal seats. The Teflon mechanical seal parts give a temperature capability of between 450°F and 500°F, which is above the 380°F expected maximum fluid at the pump.

2. **Solar-Fired Steam Boiler**

The solar-fired steam boiler will be a liquid-to-steam exchanger, commonly known as an unfired boiler. This exchanger will have the solar-heated Therminol on the tube side and the steam condensate from the water treatment plant supplied to the shell side for steam production. The unit selected from this application is a Patterson-Kelley Series 380 steam generator, as shown in Figure 44.

The selected steam generator is a skid-mounted unit. It has lifting lugs for hoisting into place, and it can also be moved on rollers or by sliding. It requires no special foundation. Once in place, it needs only to be hooked up. All controls are connected and pretested. The shell is already covered with 2-in. high-density fiber insulation which is protected by a heavy zinc-plated sheet steel jacket. A discussion of different design features follow.

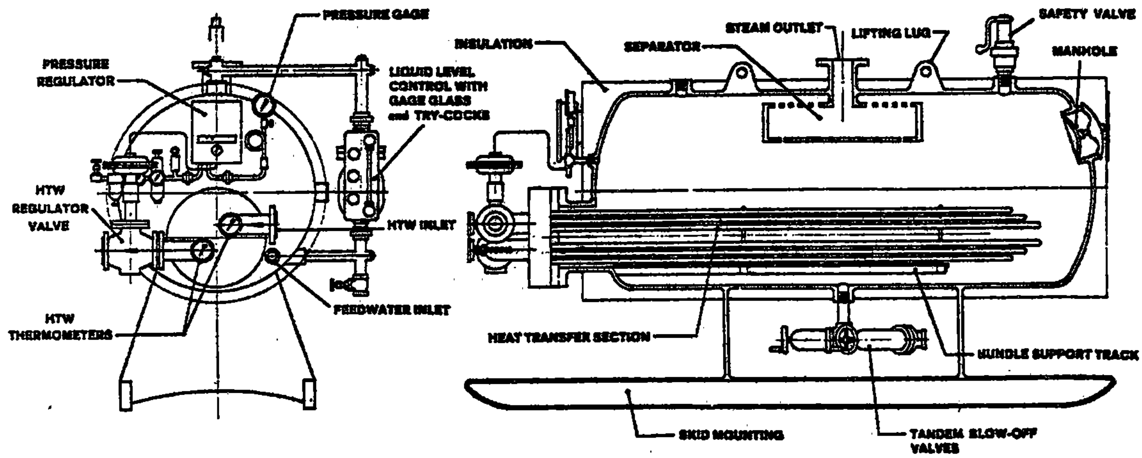


Figure 44. High-Temperature Water-To-Steam Series 380
Unfired Steam Generator

a. *Shell*

The tank or shell is amply porportioned to store a large volume of water at saturated steam pressure. Intermittent feedwater injection has little or no effect on steam output. Plenty of area is available for steam disengagement at rated capacity. Water entrained in emerging steam is removed at the steam separator, which utilizes inertia forces at sharp changes of flow direction. The shell is designed, constructed, and stamped to requirements of the ASME Code, Section VIII, for Unfired Pressure Vessels. Reinforced manholes are provided in all units. Units for service at pressure higher than 50 psig are fully x-rayed and stress-relieved after fabrication. They are ASME stamped for a maximum steam generating pressure of 150 psig.

b. *Heat Transfer Section*

Tube bundles for circulating high-temperature heat transfer fluids are all of the single tube sheet U-tube design. They are all capable of operating without damage in the event the steam generator is run absolutely dry. They have the complete flexibility to withstand sudden injection of cold feedwater while they are at steam-generating temperature. Standard 3/4-in. O.D. tubing is used in the tube bundle. It is arranged in a square pattern on 1-in. pitch so that tube exteriors can be cleaned mechanically without difficulty. Generously thick tube supports maintain tube alignment in the bundle. These full disc supports rest on tracks inside the shell. Whenever the bundle must be pulled for inspection or service, the supports slide on the tracks. The bundle stays properly aligned, and the job of handling it is very much simplified by this convenient arrangement.

c. Standard Fittings and Controls

The Series 380 package is supplied completely with accessory components of proven excellence. Connections for the heat transfer fluid are all standard ASA flanged nozzle in 2-in. size and larger. The pressure control system delivers a pneumatic or electrical call-for-heat signal to the heat transfer fluid regulator valve. A pressure gauge is supplied and installed on the front of the shell. Liquid level controls deliver electrical or mechanical action to the feedwater pump or valve. Because the Series 380 can tolerate wide fluctuations in water level, a modulating feedwater system is not necessary. An ASME gauge glass assembly is installed to permit visual inspection of water level. Thermometers are installed in the high-temperature heat transfer fluid piping or steam gauges on steam supply piping to monitor performance of the unit. Safety valves are provided and installed per ASME Section I Boiler Code. Blow-off valves in the ASME tandem arrangement are installed on the bottom of the shell.

d. Steam Controls

A properly sized and selected steam regulator valve is furnished for the system pressure and generator capacity required. It may operate pneumatically, electrically, or hydraulically. Bypass connections can also be installed. Necessary strainers and steam traps are installed.

e. Heat Transfer Fluid Controls

Heat transfer fluid will be available at ample pressure to take care of circulation through the Series 380 heat transfer section. Control requirements are satisfied by a two-way or three-way V-port valve that operates automatically in response to generator steam pressure.

F. Control System

The system configuration is simple by design to minimize the automatic controls necessary for a successful operation. The majority of the controls included in this system are either part of the collector system package or part of the boiler system package, the details of which are included with the description of both of these systems. To summarize the overall control system, an outline of the automatic control system operation will be given here.

When the light intensity on a stationary phototransistor exceeds 100 Btu/hrft^2, the collector loop heat transfer fluid pump is turned on. Once flow is supplied to the collectors, the control system will "wake" the entire collector field from its "stowed" position and rotate the collectors to a position where the collectors are about facing the sun. The shadow band trackers on each collector row then take over and fine tunes the collector position. This fine tuning is accomplished by a shadow band tracker that will rotate until the output of two phototransistors separated by a shadow band is balanced. This system also provides hazard protection so that if any of the following conditions occur the collectors are returned to their stow positions. These hazard conditions are: high winds, over-temperature, over-pressure, rain, A/C power loss, and loss of flow.

In the collector loop the overall pressure is controlled by a nitrogen blanket on the expansion tank so that a net positive pressure of about 10 psi is supplied to the suction side of the collector loop pump. A pressure relief valve is provided in the expansion tank piping so that in the event the pressure exceeds 25 psi, the excess pressure is relieved by dumping fluid into the fluid storage tank. The only other control feature in the collector loop piping is a modulating control valve supplied as part of the solar-fired boiler package. This valve will modulate the flow through the boiler tube bundle and bypass the bundle, if the temperature in the vessel is greater than the Therminol temperature, to prevent a condition of extracting heat from the vessel during cold startup.

On the shell side of the boiler, the vessel is supplied with treated condensate delivered by the existing feedwater pumps. The flow to the boiler is controlled by a float valve to provide a constant fluid level in the shell side of the vessel. The solar-produced steam is then metered to the main steam header via a standard check valve; therefore, when the pressure in the boiler exceeds that in the main steam header, solar-produced steam is injected into the industrial process. To provide a safe condition for the boiler, the vessel is ASME certified for 150 psi operation and provided with safety relief valves to assure that the vessel pressure does not exceed this limit. The vessel is also provided with an additional condensate level control in the event the float valve malfunctions.

To summarize, great care was taken in the overall system design to make the system as simple as possible, thereby minimizing the need for sophisticated automatic controls. The controls that are included will provide all of the needed automation, as well as, adequate safety features in the event of component malfunctions.

IV. SYSTEM ANALYSIS

A. Performance Analysis

The system performance analysis was conducted for two major reasons. The first reason was to optimize the size of each of the system components. This optimization is extremely important for a system of this type because the life cycle cost of this system is dominated by the initial installation cost of the system. It is, therefore, necessary to optimize the system flow rate, heat exchanger size, and pipe insulation thickness, so that excessive size equipment is not specified as would be the case with standard engineering practice.

The second reason for conducting the performance analysis was to predict the system performance over the life of the system for use in the economic analysis. The results of which would give the total natural gas conserved by the system and the financial impact of that savings.

A number of performance models are available to estimate long-term average performance of solar energy collectors, which would fulfill the needs of the system prediction task of this analysis. To accomplish the task of optimizing the complete system configuration, however, only one acceptable model was available. This model is a modified version of the well known TRNSYS Program (a Transient Simulation Program) developed by the Solar Energy Laboratory at the University of Wisconsin under contract to NSF and ERDA. The modifications to this program were made at Trinity University and included subroutines to read the SOLMET weather tapes, to convert the solar radiation available on a stationary horizontal surface to that on a tracking surface, and a concentrating solar collector model. To streamline the use of the above model, the three additional subroutines to TRNSYS were combined in a separate program called SOCOSIM (a Solar Collector Simulation Program) for use when only the collector performance was required.

1. System Optimization Study

The initial step in the system optimization study was to determine the orientation of the collector field. A number of collector types were simulated at both a north-south configuration and an east-west configuration. These simulations showed that while an east-west configuration gave a more constant output throughout the year, a north-south configuration collected more total energy. During the winter the east-west configuration out-collected the north-south configuration, while the north-south configuration out-collected the east-west configuration during the spring, summer and fall. The yearly collected energy of the east-west orientation was about 75% of the energy collected by the north-south orientation. Since the industrial plant can always utilize 100% of the energy supplied by the solar system, the distribution of the energy supply throughout the year was of no concern. The remainder of the performance analysis will, therefore, be based on a north-south collector field configuration.

The next step in the system optimization was the selection of the most cost-effective solar collector. The results of this study are outlined in the collector survey section of this report. As illustrated in Table V of that section the Solar Kinetics T-700 is the most efficient, least expensive and most cost-effective candidate collector. The monthly output of each of these candidate collectors is shown in Table III.

The third step in the system optimization was the determination of the optimum system flow rate, piping insulation thickness, and boiler heat transfer area. The approach taken for this study was similar to that taken for the collector field optimization. The thermal performance of a number of configurations were calculated and compared on a $/10[6] BTU basis assuming a twenty year life. This study was conducted with an assumed standard configuration of:

- Boiler UA of 14,000
- Therminal Flow Rate of 6.5 gpm per row
- Collector Loop Pipe Insulation of 2 inches

Each of these parameters was then varied independently to determine the optimum value.

The results of this study are shown in Table XIII. The configurations with the asterisk signify the optimum value for each parameter. The first three configurations show the effect of various boiler sizes. These data indicate that the smaller the heat transfer area the more cost-effective the system as long as the outlet temperature from the collector does not exceed the maximum permissible for the collector or heat transfer fluid, i.e., 500°F. The next four system configurations are for collector loop piping insulation. These results indicate that a pipe insulation of 2 inches is the most cost-effective. This condition occurs because the maximum insulation thickness available is 2 inches, so that the 3-inch and 4-inch configurations are achieved by multiple layers. The

TABLE XIII. SYSTEM OPTIMIZATION STUDY

Configuration	Boiler UA, Btu/hr-°F	Flow Rate, gpm	Insulation in.	Cost $	10^6 Btu	$/10^6$ Btu
1*	12	6.5	2	341,378	59,275	5.759
2	14	6.5	2	342,388	59,420	5.762
3	18	6.5	2	344,408	59,462	5.792
4	14	6.5	1	340,884	58,525	5.825
5*	14	6.5	2	342,388	59,420	5.762
6	14	6.5	3	344,645	59,774	5.766
7	14	6.5	4	348,656	59,926	5.815
8*	14	4.5	2	340,768	59,316	5.745
9	14	6	2	342,388	59,379	5.766
10	14	6.5	2	342,388	59,420	5.762
11	14	7	2	342,388	59,420	5.762

* Optimums

last four system configurations show the effects of various system flow rates. The major cost difference between the four options occurs when the system piping can be decreased from 2-1/2 inches to 2 inches. The optimum flow rate is, therefore, the minimum recommended by the collector manufacturer. The optimum system configuration consists of:

- Boiler UA of 12,000
- Therminol Flow Rate of 4.5 gpm per row
- Collector Loop Pipe Insulation of 2 inches

This configuration will now be used in the remainder of the system performance analysis.

2. System Performance Study

To accurately reflect the optimum system performance three analyses were completed. The first analysis was conducted for the maximum instantaneous condition. For this analysis the assumed conditions were:

- Direct Normal Solar Radiation = 285 Btu/hr ft^2
- Ambient Temperature = 95°F
- Therminol Flow Rate = 67.5 gpm (25,111 lb/hr)
- Condensate Supply Temperature = 200°F
- Steam Temperature = 353°F

If it is also assumed that the thermal pipe losses are a small percentage of the total energy collected then the following set of five equations and five unknowns must be solved:

$$\eta = 0.6738 - 0.0164\left[\frac{\frac{T_o + T_I}{2} - T_a}{I}\right] - 0.0168\left[\frac{\frac{T_o + T_I}{2} - T_a}{I}\right]^2 \qquad (4)$$

$$Q = \eta I A \qquad (5)$$

$$Q = m_h C_p \left[T_o - T_I\right] \qquad (6)$$

$$Q = (UA)\left[\frac{(T_I - T_{CN}) - (T_o - T_{ST})}{\ell n \left[\frac{T_I - T_{CN}}{T_o - T_{ST}}\right]}\right] \qquad (7)$$

$$Q = m_{stm} C_c \left[T_{ST} - T_{CN}\right] + m_{stm} L_V \qquad (8)$$

where

η	= Collector thermal efficiency
T_o	= Outlet temperature of the collector, °F
T_I	= Inlet temperature of the collector, °F
T_a	= Ambient temperature = 95°F
I	= Direct normal solar radiation = 285 Btu/hr ft^2

Q	= Energy collected, Btu/hr
A	= Collector area = 9450 ft^2
m_h	= Mass flow rate of the collector fluid = 25111 lb/hr
C_p	= Specific heat of the collector fluid = 0.622 Btu/lb °F
(UA)	= Heat exchanger parameter = 12,000 Btu/hr °F
m_{stm}	= Mass flow rate of steam, lb/hr
C_c	=specific heat of the condensate = 1 Btu/lb °F
L_V	= Latent heat of vaporization = 868 Btu/lb
T_{ST}	= Steam temperature = 353°F
T_{CN}	= Condensate temperature = 200°F

For these conditions the solution to this set of equations is

η	= 0.633
Q	= 1.7×10^6 Btu/hr
T_o	= 475°F
T_I	= 365°F
m_{stm}	= 1683 lb/hr

To calculate all-day system performance these equations are combined with equations to determine incident angle effects, solar radiation data as determined from the SOLMET weather tapes, system controls, and thermal losses from the system piping. This complete set of equations is solved by the TRNSYS program on an hour-by-hour basis throughout the day. Table XIV shows the hourly variation of the system parameters for a typical day. The collection period for this day is about 9 hrs with the system operational from 8 A.M. to 5 P.M.

TABLE XIV. SYSTEM PERFORMANCE FOR A TYPICAL DAY

Time	lbstm, lb/hr	QC, 10^6 Btu/hr	QP, 10^6 Btu/hr	HSOL, Btu/hr ft^2	ISOL, Btu/hr ft^2	TCO, °F	TCI, °F	TCA, °F	TAMB, °F
7	0	0	0	32.2	0	47	47	47	47
8	1190	1.224	.0271	98.7	204.5	435	355	395	53
9	1324	1.358	.0275	168.5	226.4	450	362	406	61
10	1330	1.362	.0273	227.9	228.5	450	362	406	66
11	1332	1.353	.0271	269.0	227.9	450	362	406	71
12	1339	1.366	.0264	289.5	229.3	451	362	406	74
1	1363	1.396	.0270	283.3	233.1	454	364	409	74
2	1396	1.450	.0271	264.5	237.0	458	365	412	79
3	1406	1.428	.0271	225.7	235.5	459	366	412	80
4	758	0.782	.0245	167.8	210.1	403	352	378	81
5	0	0	0	97.4	0	80	82	80	80
6	0	0	0	28.6	0	78	78	78	78
7	0	0	0	0	0	73	73	73	73
Daily	11,438	11.7	0.241	2153.1	2032.3	446	361	403	71

The initial startup does not provide the steady-state temperature until about 9 A.M. This analysis does not account for the thermal capacitance effect of the fluid system, but the energy required to heat up the 350 gallons in the system pipes and collector field only requires about 0.525×10^6 Btu. Under normal conditions this amount of energy can be collected in about 25 minutes. The system performance for a typical day is plotted in Figure 45.

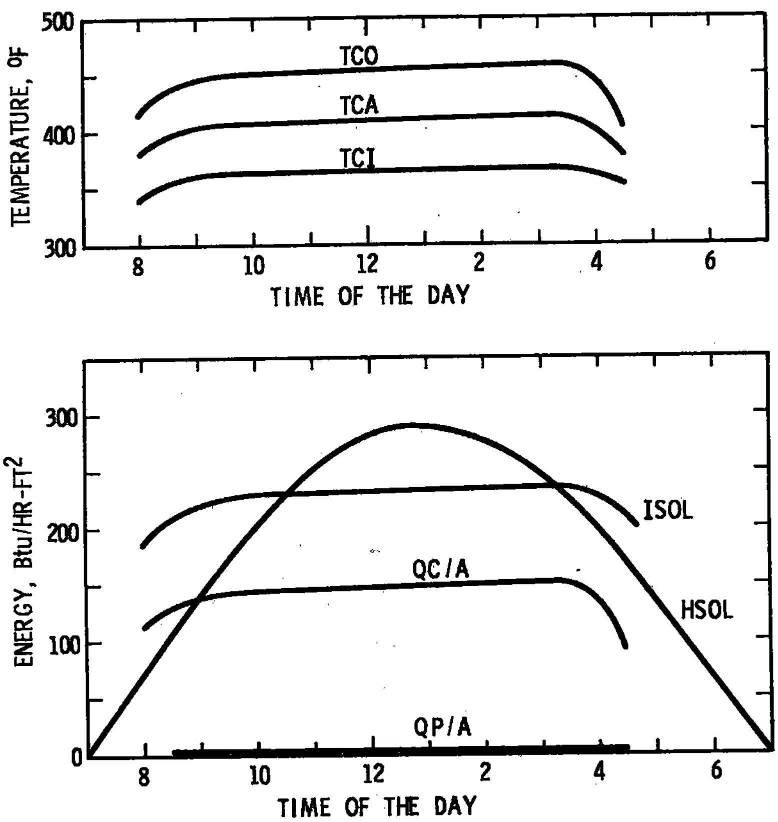


Figure 45. Typical System Performance

This figure illustrates the relatively steady-state operation of the system during the daily collection period. Even though the incident solar radiation on a stationary horizontal surface (HSOL) varies throughout the day, the system performance is relatively constant because the direct normal solar radiation available to a tracking surface (ISOL) is relatively constant. The steady-state system performance is determined by the energy collected, (QC) and the system temperatures of collector fluid outlet temperature (TCO), collector fluid inlet temperature (TCI), and collector fluid average temperature (TCA). This steady-state condition occurs largely due to the constant environment conditions of relative humidity, haze, and cloudy cover. For a day when these conditions are not as constant the system operation will vary with variations in solar energy input.

To determine the long range operating characteristics of the system, the system model was run for a SOLMET weather year. The results of this study are summarized for each month and are shown in Table XV. If the yearly average solar radiation shown here is compared with the actual measurements taken by the Weather Bureau as shown in Table I of this report, these data are about 4% lower than the actual measurements for a statistically average year. The total steam production and energy collected will, therefore, be modified to account for this inaccuracy. The total steam production is, therefore,

$$\text{Lbstm} = 2915.7\left(\frac{1574}{1504}\right) = 3.05 \text{ MM lb/yr} \quad (9)$$

and the total energy collected is

$$\text{QC} = 3045.9\left(\frac{1574}{1504}\right) = 3192 \text{ MM Btu/yr} \quad (10)$$

To verify that the system pipe insulation is of sufficient thickness, the total thermal pipe loss was compared to the total energy collected by the collector and was found to be only 2.4% of the total energy collected by the collector field.

Energy Delivered (M Btu/mo)

TABLE XV. SYSTEM PERFORMANCE FOR AN AVERAGE YEAR

Month	lbstm, 10^3 lbs/month	QC, 10^6 Btu/month	QP (Pipe loss) 10^6 Btu/month	HSOL, Btu/day ft^2	ISOL, Btu/day ft^2
Jan	142.3	150.2	5.5	915	1290
Feb	147.4	154.7	4.4	1103	1225
Mar	204.9	214.0	5.0	1523	1414
Apr	211.5	220.5	4.8	1676	1406
May	235.8	245.6	5.2	1725	1563
Jun	340.1	354.1	7.5	2030	2096
July	382.9	398.5	8.2	2084	2332
Aug	359.5	374.5	8.0	1892	2365
Sep	314.8	328.8	7.7	1678	2269
Oct	257.1	268.5	6.3	1452	1850
Nov	179.3	188.4	5.6	1070	1527
Dec	140.1	148.1	5.4	875	1350
Yearly	2915.7	3045.9	73.6	1504	1714

B. Economic Analysis

There are several capital budgeting techniques which could be used to determine the feasibility of investing in solar equipment. They include the net present value (NPV) method, the internal rate of return (IRR) method, the Payback Period, the present value (PV) method, and annual costs (AC) or life-cycle costs method. These last two techniques, PV and AC, are really slight variations of the NPV technique used for capital budgeting decisions.

The NPV, IRR, PV, and AC methods are discounted cash flow techniques while the payback period does not assign any time value to money. Future returns (NPV, IRR, and Payback Period) are normally defined as net profits after taxes, plus depreciation, that result from a project. That is, one is interested in net cash flows. For a solar equipment investment project, returns are defined as the after tax savings, resulting from fuel savings, plus tax shielded depreciation.

The NPV is defined as the summation of the present values of the net cash inflow minus the net cash outflow in each year or time period. For most investments, such as an investment in solar equipment, a net cash outflow occurs only when the equipment is purchased. Thus, one has

$$NPV = \frac{CF_1}{(1+k)} + \frac{CF_2}{(1+k)^2} + \frac{CF_3}{(1+k)^3} + \ldots + \frac{CF_n}{(1+k)^n} - I_o \qquad (11)$$

or

$$NPV = \sum_{t=1}^{n} \left[\frac{CF_t}{(1+k)^t} \right] - I_o \qquad (12)$$

where

CF = cash flow in each year, subscripts 1, 2 . . . n denote the year an event occurs,

k = firm's cost of capital, and

I_o = initial investment

The decision rule is to accept a project as long as the NPV is positive. If a decision is to be made between two projects, accept the one with the highest NPV. If one wants to account for risk when using the NPV technique, one can add a risk premium to the cost of capital value or use a certainty-equivalent cash flow, that is, revise the cash flows downward until the risk portion of the cash flows have been eliminated.

The IRR technique is similar to the NPV technique except that one sets equation (12) above equal to zero and solves for k. The decision rule is to choose any project which as a return greater than the firm's cost of capital. Companies which use the IRR technique usually have a minimum IRR, significantly greater than the firm's cost of capital, which they will accept. The IRR method is cumbersome to calculate and indeterminant solutions may result under some circumstances. It also assumes that benefits, or savings, will be reinvested in investments which will yield the same or higher internal rate of return. The IRR method would favor a small investment that has a high rate of return and low net present value over a large investment with a moderate rate of return and a high net present value.

Finally, the payback period is the number of years it takes a firm to recover its initial investment from net cash flows. The payback method has several important weaknesses which distort the evaluation. It does not take into account the timing of cash flows and the magnitude of total benefits (i.e., total energy cost reductions over the period of analysis) or total costs. The payback method ignores benefits which accrue after the payback date.

All things considered, the NPV method is, in most cases, a reliable approach to evaluating a capital investment in solar equipment. This is a suitable method for evaluating solar equipment investments versus investments in conventional systems since solar systems generally involve a larger investment cost than conventional systems, but give rise to less operating costs than conventional systems. That is, they result in savings (or benefits) in the form of reduced energy costs. The NPV method thus maximizes the value of the firm. Since the PV and NPV techniques are really the same and since the AC technique is closely patterned after the NPV and PV techniques, proper use of the PV and AC techniques also maximizes the value of the firm, and they, therefore, are also viable techniques for evaluating investments in solar equipment.

In any capital investment decision, it is important to isolate the relevant costs. That is, one must determine the costs which relate to an investment in solar equipment, including support equipment, and the costs which relate to an investment in a purely conventional non-solar system which would be used for the same tasks. These include: (1) system acquisition costs, including search costs, purchase prices, delivery costs, and installation costs; (2) system repair and replacement costs; (3) maintenance costs; (4) operating costs, comprising mainly energy costs; (5) insurance; (6) taxes; and (7) salvage values, net of removal and disposal costs. It is not difficult to realize that total cost data, as opposed to incremental cost data, help prevent the omission of relevant costs and allow the analyst greater flexibility in the method of analysis. In making choices among alternate investments when building a new facility, the use of total cost data is by far the most appropriate. If, however, a decision is to be made as to whether to add solar capacity to a plant which already has adequate power, the use of incremental cost data is most appropriate since the previous investment in the conventional system is a sunk cost (irrelevant cost) and the addition of a solar system will result in fuel savings to offset the additional (incremental) cost of the solar system.

1. Financial Analysis for Investments in Solar Systems

For purposes of evaluating the economic feasibility of an investment in a solar system at the Lone Star Brewery, we feel that the NPV technique offers the most promise. The NPV for an investment in a solar system can be expressed as:

$$NPV = -I_o - B - Q + \frac{S}{(1+i)^n} - \sum_{j=1}^{n} \frac{R_j - \bar{S}_j}{(1+i)^n} - (1-\bar{t})\, M \sum_{j=1}^{n} \left[\frac{1+r_1}{1+i}\right]^j$$

$$- (1-\bar{t})\, I_n \sum_{j=1}^{n} \left[\frac{1+r_2}{1+i}\right]^j - (1-\bar{t})\, F_1 \sum_{j=1}^{n} \left[\frac{1+r_3}{1+i}\right]^j - (1-\bar{t})\, F_2 \sum_{j=1}^{n} \left[\frac{1+r_4}{1+i}\right]^j$$

$$- (1-\bar{t})\, t \sum_{j=1}^{n} \frac{G_j}{(1+i)^j} + \bar{t} \sum_{j=1}^{L} \frac{D_j}{(1+i)^j} + C \qquad (13)$$

NPV	=	Net present value cost of the process heating system over period n,
I_o	=	initial investment costs, including costs of acquisition, delivery, and installation of the process heating system,
B	=	initial investment costs for system-related building modifications (if modifications are cost-reducing, such as solar panels in place of portions of roof, B, will be subtracted from costs),
Q	=	value of building space occupied by heating system components, evaluated as building cost/sq ft. × number sq. ft. occupied,
S	=	remaining value of the heating system(s) at the end of the period of analysis,
i	=	annual discount rate in nominal (market) terms,
n	=	period of analysis in years, (may be the life of the system or a shorter designated period),
R_j	=	replacement and repair costs in year j at present prices, including costs of replacing or repairing any part of the system,
$\bar{S}_j$	=	salvage value in year j, where $j \leq n$, at present prices, of replaced parts,
R_j-$\bar{S}_j$	=	net replacement and repair costs in year j,
$\bar{t}$	=	corporate income tax rate,
M	=	estimated annual maintenance cost at present prices,
r_1	=	annual rate of change in maintenance costs,
I_n	=	net annual cost of damage at present prices; that is, $I + \bar{L} - \bar{C}$, where I is the anual insurance premium, $\bar{L}$ is the annual damage loss, and $\bar{C}$ is the annual insurance reimbursements,
r_2	=	annual rate of change in net cost of damage,
F	=	estimated energy cost at present prices; subscripts indicate different sources of energy, e.g., F_1 might indicate #2 heating oil and F_2 might indicate electricity cost.
r_3, r_4	=	annual rate of change in real price of energy, where subscripts indicate different sources of energy,
t	=	the property tax rate,
G_j	=	the assessed value of the heating system in year j, in present dollars. This formula would cover both the case of constant real assessed value for the process heating system and the case of changing real assessed valued over time.
D	=	depreciation in year j, in present dollars,
L	=	depreciation life of the process heating system in years, usually less than n, and
C	=	present value of the investment tax credit.

Since NPV examines yearly cash flows, the firm can readily use the financial analysis information in the assessment of its capital budgeting requirements, both for plant and equipment and for working capital. In comparing investments in a process heating system in new plants, one will choose among conventional systems alone, solar systems alone, and convention/solar system combinations. In all cases, the NPV for the system will be negative, but properly performed NPV for the entire plant (taking into account other costs and the benefits derived from selling production output) will be positive or the investment will not be made.

For the investment in a solar system at the Lone Star Brewery, however, the conventional process system is already available and can provide all of the energy requirements of the plant. In this case, the purpose of adding a solar system is to supplement the plant energy requirements and thus obtain fuel savings. The previous investment in the conventional system is therefore a sunk cost and does not enter into the financial decision unless part of the conventional system can be sold and thus lower the amount of "new" money required to build and install the solar system. The financial investment in this case becomes an incremental analysis, and energy savings are introduced by allowing fuel savings to replace fuel costs in the above equation; i.e. values of F_1 and F_2 are negative (fuel savings) or zero (no fuel cost for energy from the sum). All other costs and savings for the solar investment are introduced as they appear. Thus, if a sufficient amount of fuel costs are saved, the NPV of the solar investment at the Lone Star Brewery could be a positive value.

The NPV technique described above can be used to determine the IRR for an investment in a process heating systems. To do this, one varies the discount factor until the NPV equals zero, at this point the discount factor is equal to the IRR. Dickinson and Freeman* recommend that the IRR technique be used to evaluate solar investments. As mentioned previously, there are several reasons why the NPV technique is more appropriate. The IRR method is cumbersome to calculate and indeterminant solutions may result under some circumstances. It also assumes that benefits or savings will be reinvested in investments which will yield the same or higher internal rate of return. The IRR method would favor a small investment that has a high rate of return and a low net present value over a large investment with a moderate rate of return and a high net present value. The NPV method, on the other hand, maximizes the value of the firm. Since investments in a process heating system is long term investment, it requires a considerable initial investment costs and result in long term benefits. One of the major arguments for using the NPV (PV or AC) methods is that the financial analyst has a great amount of flexibility in using either total costs or incremental costs. For the solar equipment investment at the Lone Star Brewery, the total cost of the solar equipment and incremental benefits (fuel savings) can easily be evaluated. Also, investment in the initial process heating system in a new plant (solar only, conventional only, or solar/conventional combination) can easily be financially evaluated using total costs. The NPV and IRR in this later case would always be negative. However, the investment in process heating systems would have to be made to reap the benefits of production. Since the process energy or HVAC output requirements are usually known in advance, several systems could be evaluated using the IRR or NPV methods. The IRR would be a negative value, would suggest an investment having the least negative IRR, and would provide little more information. The NPV would also be negative, would suggest an investment having the least negative NPV, and would also indicate the present value of the cost of the investment, and thus how much the present value of the firm will be decreased by the investment. The costs to the firm can thus be better evaluated using the NPV method. Also, the advertising advantage to the firm for using solar systems versus the present value costs to the firm can best be evaluated using the NPV method of financial analysis.

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*W.C. Dickinson and H.J. Freeman, "An Economic Methodology For Solar-Assisted Industrial Process Heat Systems: The Effect of Government Incentives," Lawrence Livermore Laboratory, UCRL-52254, June 1977.

Our financial analysis for solar investments also differ from that of the Dickinson and Freeman method in that we use a nominal (or market) discount rate. This allows us to easily vary the expected rates of increase in maintenance and repair costs, r_1, net annual cost of damage, r_2, and energy costs, r_3 and r_4, at different rates. That is, the rate of increase in energy costs can be larger than the other rates of increase in costs. Also, we feel that most businessmen will relate more readily to this approach since they have had to cope with inflation and have a better conceptual feel for the investment when the effect of inflation is allowed to remain in market terms. This readily allows the businessman to predict his future cash flow needs, and thus better prepares him for the future. Also, the discount factor to use in the NPV method is the after tax average cost of capital which the businessman should be able to estimate. Thus, the investment funding is not limited to equity funds as the Dickinson and Freeman method assumed; but includes both equity funding and debt financing in compliance with the firm's target capital structure.

2. System Economics

For this analysis, the system costs that would be incurred to purchase and install the actual steam system will be the only costs included. Any costs due to providing visitor access, installing a data acquisition system, and project management activities to meet DOE requirements will not be included. The estimated cost of the solar steam system is $431,700. This cost includes parts and labor for the solar collector field, solar-fired boiler, system pump, heat transfer fluid, expansion tank, storage tank, piping, insulation, electrical wiring, building roof modification, and various miscellaneous items. The value of the occupied building and land space will be assumed to be zero, since all of the equipment will be mounted either on the roof or on an existing steel support structure above existing mechanical equipment. The salvage value of the equipment will be assumed to be zero, and the market value at the end of the 20-year operating period will be $18,000. The industrial partner's assumed cost of capital will be 10% with a total corporate income tax rate of 51%. Since one of the big unknowns in the collector selected is the life of the reflective film, and since the film has exhibited a life of at least seven years, we have assumed that this film will gradually be replaced over a five-year period starting in the eighth year. The cost of this film replacement was estimated at about $3 per ft^2 or $6,000 per year for five years. We feel that this estimate of film life and the cost required for replacement is indeed conservative and that the results of the economic analysis will, therefore, be conservative. The annual maintenance cost will be assumed equal to $3,600 per year with an escalation rate of 8% per year. The solar-produced steam has an energy value of about 3 billion Btu's per year. A natural gas boiler efficiency of 60% is assumed, and the current cost of this gas is $2.50 per Mcf with an assumed escalation rate of 10% per year.

The above assumptions were substituted into the equation for net present value and yielded an NPV of about —$150,000 over the 20-year life of the system. The after tax cash flows along with the present values of these cash flows are shown in Table XVI. It is obvious that this system cannot be justified on a purely economic basis. It is predicted that at some time in the future this situation will change. To determine when this will occur, a sensitivity analysis was conducted to test the following parameters: fuel cost, fuel cost escalation rate, and collector cost reduction. The net present value versus the cost of fuel is plotted in Figure 46 as a function of fuel escalation rate. This figure shows that unless a fuel escalation rate of over 16% per year can be expected over the life of the system, this parameter alone will not improve the economic situation of this investment. The next

TABLE XVI. INVESTMENT CASH FLOW FOR CURRENT SYSTEM DESIGN

Year	After Tax Cash Flows	Present Value of After Tax Cash Flows
0	—345368	—345368
1	26831	24392
2	25143	20779
3	23730	17829
4	22577	15420
5	21669	13455
6	20996	11852
7	20549	10545
8	14323	6682
9	14314	6071
10	14520	5598
11	14943	5238
12	16355	5211
13	23914	6927
14	25637	6751
15	27539	6593
16	29641	6451
17	31962	6323
18	34525	6210
19	37354	6108
20	49281	7325

Total Net Present Value of After Tax Cash Flows = —149602

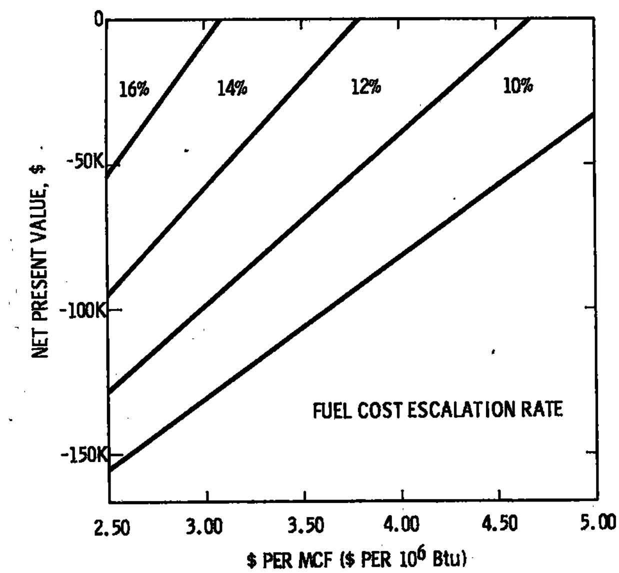


Figure 46. Net Present Value Versus Cost of Energy as a Function of Fuel Cost Escalation Rate

parameter is the predicted cost reduction of the collectors. If the collectors can be mass-produced at about $3 per lb, then the cost of the collectors can be reduced by about 50%. Figure 47 is a plot of net present value versus fuel cost as a function of collector cost reduction. This plot illustrates the fact that this system would not be cost effective today even if the collectors were free. If the collectors were mass-produced by the time fuel costs increase to $4.50 per Mcf, then the investment would give a net present value of zero and an internal rate of return equal to the cost of capital of 10%. It is clear that this parameter alone will not significantly impact the decision to invest in solar steam systems either.

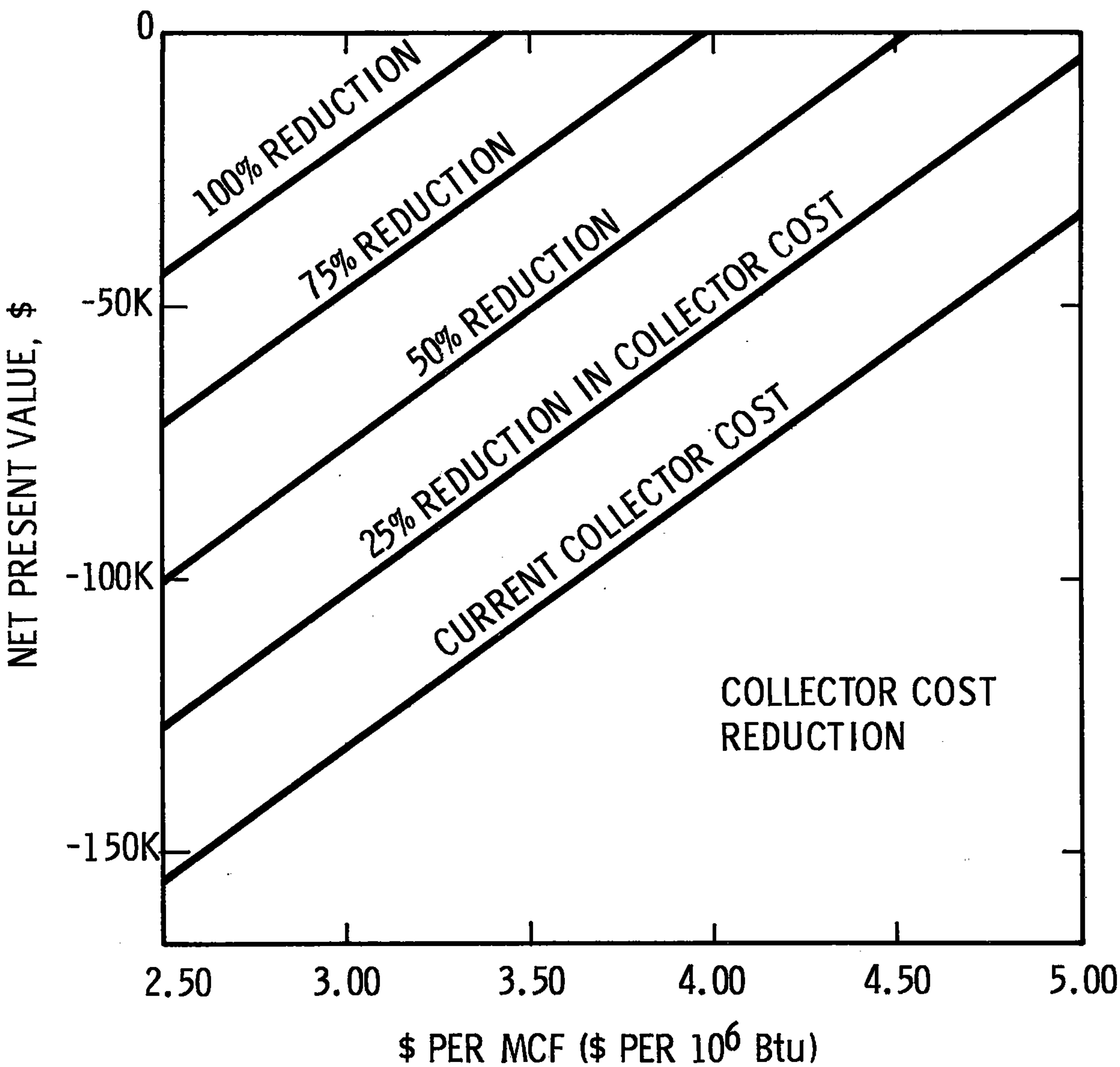


Figure 47. Net Present Value Versus Cost of Energy as a Function of Reduction in Collector Cost

The above two parameters are items that planners really have no control over. It is instructive, therefore, to investigate the sensitivity of the current and proposed government incentives on the time period in which the construction of these units will be cost effective. Figure 48 is a plot of the number of years required before the initiation of construction would give a zero net present value (NPV) at various investment tax credits and accelerated depreciation schedules. This figure was developed at the current cost of collectors and system installation, as well as a 10% assumed fuel escalation rate. At the current 20% investment tax credit (TC) and no accelerated depreciation schedule (DS), it will be about 8.5 years before the initiation of such a project will be warranted for pure economic reasons. It can be seen,however, that if a combination of a 40% TC and a five year DS was enacted, this type of system would be cost effective today. One must realize that business requires more than a 10% return on investment before large investments in solar steam systems will be made, but this level will serve to show when these types of investments can be expected to begin.

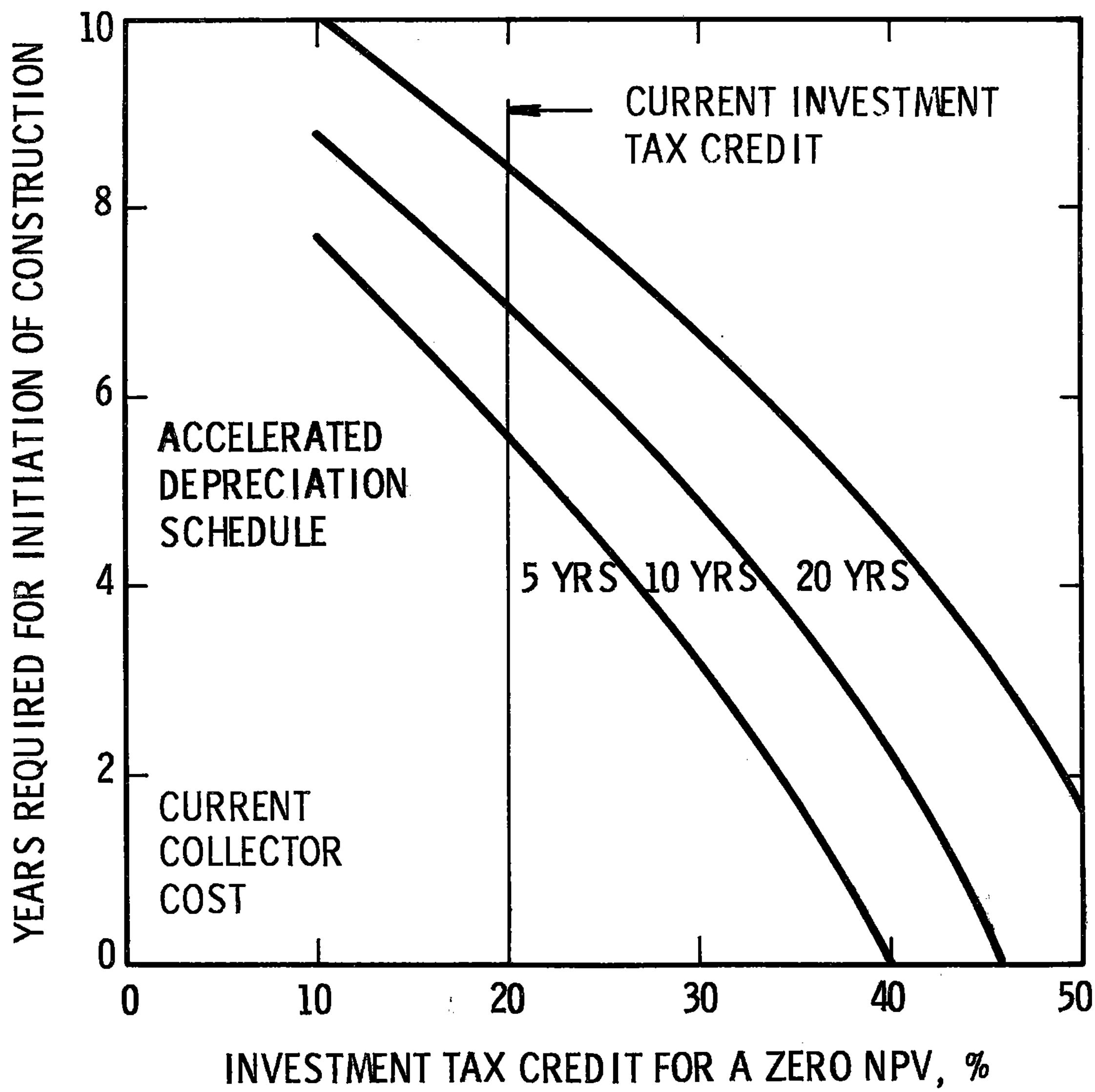


Figure 48. Years Required for Initiation of a Construction Project to Yield a Zero NPV as a Function of TC and ADS at Current Collector Costs

The one item that can be expected to improve is the cost of the collectors, if these types of investments become widespread. To test the combined effect of these incentives with the cost of a mass-produced collector (i.e. 50% collector cost reduction), Figure 49 was plotted. This figure shows the number of years required before the initiation of construction would give a zero NPV as a function of TC and DS. At the current TC of 20% and no accelerated DS, the mass production of collectors would make this type of system cost effective in about six years. An accelerated DS of five years would shift this period to less than two years. The problem, however, is to get the price of collectors to their mass-produced level. To accomplish this, we recommend that a combination of a higher investment tax credit and an accelerated depreciaion schedule be enacted so that the production levels can be increased. When this point is reached, the investment tax credit can be reduced back to

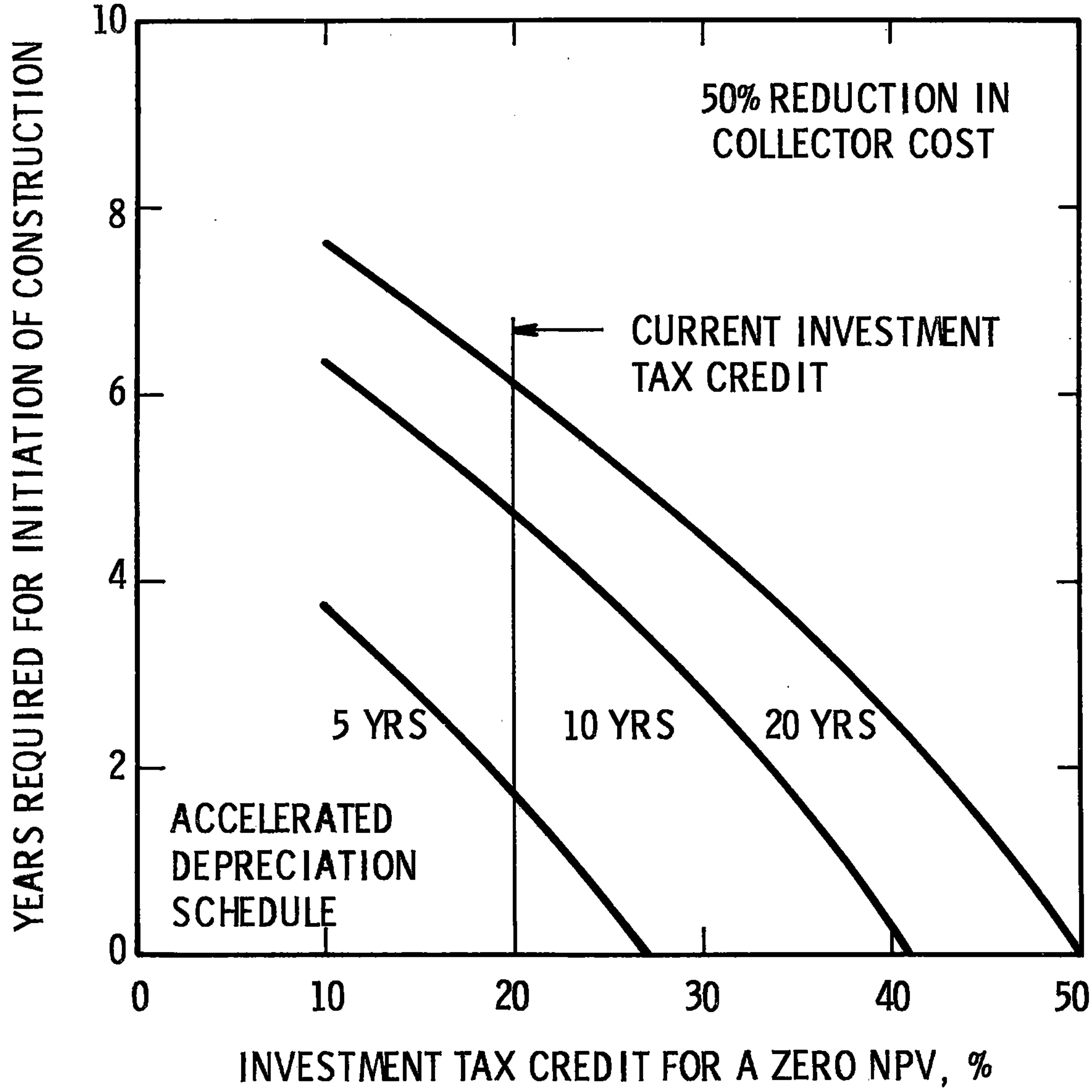


Figure 49. Years Required for Initiation of a Construction Project to Yield a Zero NPV as a Function of TC and ADS at a 50% Collector Cost Reduction

the current level of 20%, and eventually phased out. The recommended incentive scenario would give the investment cash flow next year, as shown in Table XVII, with an NPV of $14,000 and an IRR of 11%. For the condition with a reduced TC equal to the current level, in three years with a mass-produced collector price the NPV will be $4,244, an IRR of 10%, and the cash flow will be as shown in Table XVIII. We feel that this incentive scenario will provide the needed push to make this valuable energy source competitive with all the other subsidized conventional forms of energy.

TABLE XVII. CASH FLOW SCHEDULE FOR TC OF 40% AND DS OF FIVE YEARS WITH A MASS PRODUCED COLLECTOR PRICE

Year	After Tax Cash Flows	Present Value of After Tax Cash Flows
0	—259020	—259020
1	93683	85166
2	58972	48737
3	38441	28882
4	31214	21320
5	32004	19872
6	9052	5110
7	10017	5140
8	5082	2371
9	6259	2655
10	7559	2914
11	8995	3153
12	10581	3371
13	18332	5310
14	20266	5337
15	22401	5363
16	24758	5388
17	27359	5413
18	30231	5437
19	33401	5461
20	45701	6793

Total Net Present Value of After Tax Cash Flows = 14174

TABLE XVIII. CASH FLOW SCHEDULE FOR TC OF 20% AND DS OF FIVE YEARS WITH A MASS-PRODUCED COLLECTOR PRICE

Year	After Tax Cash Flows	Present Value of After Tax Cash Flows
0	—262861	—262861
1	74705	67914
2	48625	40186
3	33371	25072
4	28280	19316
5	29332	18213
6	12358	6976
7	13637	6998
8	9047	4221
9	10602	4496
10	12316	4748
11	14206	4979
12	16289	5190
13	24586	7122
14	27117	7141
15	29907	7160
16	32982	7178
17	36372	7196
18	40108	7214
19	44224	7231
20	57563	8556

Total Net Present Value of After Tax Cash Flows = 4244

C. Safety Analysis

1. Introduction

The system safety analysis will be divided into four sections: Product Contamination, Fire Hazards, Safety Control, and Worker and Visitor Safety. Since this application is a food processing industry, extreme care will be taken to assure that no foreign substances are introduced into the food product. The heat transfer fluid will be a hydrocarbon; therefore, all precautions will be taken to prevent any potential fire hazard. To eliminate any possibility of damaging the solar collectors and solar-fired boiler, a system of safety controls will be included to prevent any unsafe conditions such as overpressure and overtemperature. In addition to these operational safety measures, care will be taken to assure a safe condition for workers and visitors when either is on the warehouse roof where the collectors are located.

2. Product Contamination

As outlined in the heat transfer fluid selection section of this report, the fluid selected is Therminol T-55 manufactured by Monsanto. This fluid is classified as nontoxic with LD_{50} of 15.8 g/kg, but it is felt that every precaution must be taken to prevent the possibility of introducing this foreign substance into the food product. The first line of defense will be in the selection of the solar-fired boiler. This boiler will be a Patterson-Kelley Series 380 unfired steam generator; it was selected for its high quality of construction thereby minimizing the possibility of developing a crack in the tubes or tube sheet. The second line of defense is that under normal operating conditions the pressure on the steam side of the boiler is at a much higher pressure (140 psig compared to 15 psig) than the Therminol side. If a crack does occur in the tube bundle, high pressure condensate will leak into the Therminol and an overpressure control on the collector system will shut down the system. If this control malfunctions and the steam side of the boiler cools off, this pressure will be maintained above about 50 psig by a pressure reducing valve (PRV) connected to the steam main. In the event that this third line of defense fails, i.e., a malfunction of the PRV, then Therminol will leak into the shell side of the boiler. Since the boiler will also be outfitted with a vacuum relief valve, the pressure differential for Therminol flow will be the slight overpressure (10 to 15 psig) existing on the Therminol expansion tank.

If this leakage does occur, the Therminol, being lighter than water, will float on the water surface. Since the boiling point of the Therminol is in excess of 635°F at atmospheric pressure, the Therminol will not boil but will only be carried over by evaporation (fourth line of defense). This evaporation will only be a problem once the system is back at operating pressure and the check valve to the steam main is open. Here again the overpressure control on the Therminol side should shut down the collector system and activate a warning on the system monitor. In the unlikely event that all of the above safeguards malfunction and the Therminol is carried over with the steam, a 99.5% separator is included in the top of the steam boiler as the fifth line of defense. Any Therminol that does get past this separator will be condensed in the steam traps located along the main steam header (sixth line of defense). Since there is no live injection of the steam directly into the product downstream of this boiler, any Therminol that is carried passed the steam traps will be injected into the deaerator, the seventh and last line of defense. The operation of the deaerator is as follows (see Figure 50). The condensate initially flows into the mixing section of the deaerator where any Therminol carried over will be separated and will float on the surface of the condensate. The condensate is then pumped from the bottom of this section, passed through a heat exchanger, and then sprayed into the deaerating section of this device, the upper surface of which is allowed to overflow back into the mixing section. The boiler feed is then pumped from the bottom of the deaerating section. Any Therminol that does get carried over into this device will end up floating on the surface of the condensate in the mixing section. Since the shell of this device is vented to the atmosphere, any small trace of Therminol floating on the water surface will eventually evaporate and be vented to the atmosphere, thereby preventing the carry-over of any Therminol to the remainder of the steam plant.

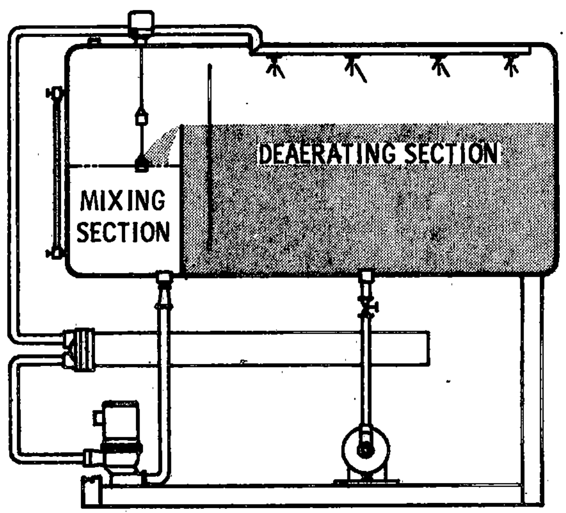


Figure 50. Existing Process Deaerator

The basic scheme of keeping an overpressure on the shell side of the solar-fired boiler is suggested by HEW Regulation 21 CFR Part 212, "For Current Good Manufacture Practice in the Manufacturing, Processing, Packing, or Holding of Large Volume Parenterals." In addition to this main line of defense, all of the other six lines of defense are included to insure the industrial partner that the chances of any product contamination are practically nonexistent.

3. Fire Hazard

The selection of the heat transfer fluid was made with potential fire hazards in mind. Therminol T-55 has an autoignition temperature (AIT) of 675°F, a fire point of 410°F, and a flash point of 350°F. Since the system will always be operated below the AIT, there will never be a problem with spontaneous ignition. The system, however, will be operated with some sections of the system above the fire point, so the extra precautions will be taken for that part of the system. The fire point is defined as the lowest temperature at which the fluid vaporizes rapidly enough to form above its surface an air-vapor mixture which burns continuously when ignited by a small flame. Since the Therminol will be enclosed in a sealed closed-loop system, the only problem with the fire point will be in the event of a system leak. If this were to occur, the fluid leakage would be in the form of a liquid at a temperature only slightly higher than the fire point. This liquid would be cooled as it came in contact with the environment; therefore, any vapor given off would be at a temperature below the fire point. The flash point is defined as the lowest temperature at which the fluid vaporizes rapidly enough to form above its surface an air-vapor mixture which will flash momentarily when ignited by a small flame. Since the majority of the system will be operated above this temperature, care will be taken to eliminate any combustible material in the vicinity of the fluid piping.

Another hazard that is not quite understood at this time but has been experienced in hot heat transfer fluid systems is insulation fires. These fires have occurred in insulation materials that have been soaked with heat transfer fluids at apparent temperatures of 500 to 600°F, which is well below the autoignition temperature of the fluids. Tests indicate that magnesia, calcium silicate, and silicate-bonded asbestos insulations are subject to this problem. While the exact mechanism by which such fires occur is not fully understood, the most probable explanation is that a slow exothermal oxidation reaction between hydrocarbon-type heating fluids and air inside the voids of the insulation starts at about 500°F. Such a reaction is believed to occur because the combination of the large heating fluid surface exposed on the insulation fibers, poor heat dissipation conditions, and the formation of low flash point oxidation products can cause a temperature buildup in the saturated insulation mass resulting in ignition of the material when exposed to air.

Calcium silicate, asbestos, and magnesium oxide insulation can saturate with almost their original weight of leakage fluid. This saturation when spread over the large surface area within the insulation at high temperature can give rise to oxidation of the heat transfer fluid and the formation of lower boiling, more combustible decomposition products. Subsequent ignition of the fluid within the insulation system can result.

An alternate insulation, cellular glass, tends to resist saturation by the heat transfer fluid and is, therefore, a safer insulation to use. Cellular glass is not normally the most economical insulation for most applications because of its higher installation cost and its tendency to crack when thermally shocked. The use of cellular glass insulation does not insure that insulation fires will not develop, but the amount of fluid that can saturate the insulation system and be oxidized is greatly reduced. The best preventative to insulation fires is, of course, to provide a leak-free system, and this will be greatly facilitated by having as much of the system as possible welded instead of threaded or flanged. Certain major components such as the pump and boiler will need to be connected with flanges for ease of maintenance. These flange connects will be assembled with great care, and the insulation caps surrounding them will be isolated so that the volume of insulation subjected to saturation will be minimized. These flanges, as well as all valves and seals where occasionally leak sources can develop, will be encased by protective, tight-fitting caps to divert any fluid leakage to the outside of the insulation system. Valve stems will be installed horizontally so that any stem leakage does not enter the insulation. In addition, in all of these areas cellular glass insulation with metal shields will be installed to minimize or eliminate any potential saturation by the leaking fluid. Even though these precautions will be taken, the operating range of the system will be below 500°F so that no fire hazard is anticipate.

4. **Safety Control**

As was pointed out in the system design section of this report, both the collector system and the steam boiler are equipped with complete safety controls to prevent dangerously high temperatures or pressures. These controls are not only necessary for assuring long system life, but also to prevent any unsafe conditions that would lead to equipment failure. The collector system is equipped with a hazard-stow relay, which will drive the collector system to the "stow" position; i.e., a position in which the sun is no longer focused on the absorber tube thereby eliminating the energy input required to sustain a high temperature or pressure. The hazard-stow relay is activated should any of the field contact closure devices cause the circuit to the relay coil to lose power. The field contact closure devices are for loss of AC power, high winds, insufficient flow, rain, insufficient light level (nightfall or stormy weather), overtemperature fluid conditions, overpressure, or low fluid level in the expansion tank. The solar boiler is equipped with automatic controls to prevent any overpressures or underpressures. Since the boiler will be designed and installed per ASME Section I Boiler Code, the above controls will insure that the system remains within the pressure range stamped on the boiler shell. The blow-off valves will be installed in the ASME tandem arrangement as a safeguard to any equipment malfunctions.

5. **Worker and Visitor Safety**

To insure the safety of both maintenance workers and visitors to the demonstration site, a pipe rail will be installed completely around the collector field. As an added precaution for visitors, a controlled access will be installed, as pointed out in the collector field design section of this report. This controlled access will include a steel stairway with a chain-link fence enclosure and a visitors' walkway around the south end of the first three collector rows. The walkway will be bordered by a railing with woven-wire panels. The location of the walkway on the south end of the collector rows will prevent any dangerous reflections from the collectors striking site visitors. A small chain will be draped between the collector rows and the ends of the walkway to discourage any visitors from wandering through the collector field unescorted.

V. DATA COLLECTION SYSTEM

A. Data Collection and Evaluation Plan

The objective of the Data Acquisition System (DAS) is to collect adequate data to properly evaluate the solar process steam system performance. In order to accomplish this objective, the following parameters must be determined:

- Solar radiation available to the collector field
- Environmental conditions effecting the thermal loss characteristics of the collector field
- Thermal energy collected by the collector field
- Thermal energy transferred to the steam boiler
- Steam Production
- Thermal energy losses from the system pipe runs
- Parasitic energy required for pumping and collector tracking
- Total natural gas saved

Since most of these parameters cannot be measured directly, primary measurements must be made and used to derive these parameters. Care must, therefore, be taken to assure adequate accuracy of these derived quantities by making accurate measurements of the primary quantities.

1. Data Collection Plan

a. *Solar Radiation Available*

To determine the solar radiation available to the collector field, measurements must be taken by instrumentation mounted on a tracking surface, with the same acceptance angle as the collector. This will be accomplished by mounting two pyranometers on one of the collector rows, one to measure the total radiation on that tracking surface and one equipped with a shadow band that measures that portion of the sky that the collector does not see. The shadow band will be parallel to the axis of the collectors (north-south) and has a width such that the band of sky blocked is equal to that band that the collector "sees." In this way the difference between the two will be the total energy available to the collector. In addition to these two measurements, a third measurement will be taken to determine the total solar radiation on a stationary horizontal surface for comparison with the standard measurements taken at NOAA weather bureau stations. This measurement will help provide input to the modeling effort. When the tracking surface is horizontal, the total radition measured can be compared with the stationary horizontal value to provide some redundance in the solar radiation measurement.

b. *Environmental Conditions*

The environmental conditions other than solar radiation that effect the thermal loss characteristics of the collector field are the wind speed and direction, relative humidity, rainfall, and ambient temperature. The wind speed and direction not only effect the convective loss from the absorber tube but also tracking accuracy of the reflector. The wind velocity will be measured using a six-cup wind anemometer, and the direction will be measured using a single-fin aerodynamic vane. The relative humidity is one of the determining factors that effects the magnitude of the direct normal beam radiation available to the collector. This measurement will be made with a probe based upon the capacitance change of a polymer-thin film capacitor. The rainfall measurement will be used to correlate the potential performance degradation due to dirt buildup on the reflectors and absorber covers. The rainfall will be measured by a remote recording rain gage using two chrome-plated brass buckets which alternately fill and tip causing a momentary closure of a mercury switch. The ambient temperature provides the driving force for thermal losses in not only the collector absorber tube but also the system piping. The ambient temperature measurement will be sensed by an RTD shielded from direct sunlight.

c. *Thermal Energy Collected*

To determine the thermal energy collected by the collector field, the following measurements must be taken: collector fluid inlet temperature ($T_{f,i}$), collector fluid outlet temperature ($T_{f,o}$), and the volume flow rate through the collectors. The volume flow rate must then be converted to mass flow rate ($\dot{m}$) by multiplying by the density at the average fluid temperature. The fluid specific heat (C_p) at that same temperature is then combined with the mass flow rate and temperature rise through the collector to calculate the total energy collected (Q_c) by the system as follows:

$$Q_c = \dot{m}\, C_p \Delta(T_{f,o} - T_{f,i}) \tag{14}$$

The volume flow rate measurement will be made with two turbine flow meters so that there will be adequate redundancy. The fluid temperatures will be sensed with RTD's. In addition to the collector field performance, one row will be instrumented with a flow meter and RTD's to determine the single row thermal performance. The thermal energy transferred to the boiler and the thermal energy losses by the system piping runs will be determined in similar fashion by measuring various flow rates and fluid temperatures.

d. *Steam Production*

The objective of the entire solar system is the production of process steam. This steam flow will be determined by measuring the differential pressure across a venturi tube to obtain the volume flow, and the mass flow will be determined by combining the volume flow with the steam quality, which is defined by measuring the steam temperature and pressure. The procedure for determining this derived quantity will be the standard ASME methods as described in "Fluid Meters, Their Theory and Application." As a check on the steam flow, the feedwater condensate will also be measured. This measurement will be made with a turbine flow meter and converted to mass flow by measuring the temperature and determining the density.

e. *Parasitic Losses*

The parasitic losses of the pump motors and hydraulic pump drive motor will be needed to determine the net energy provided by the system. These components will be in the form of AC electric power and will be measured by an AC wattmeter.

f. Collector Wind Load

The collector wind loads on both the first and middle rows will be measured to determine the wind blockage effect on total loads transmitted to the building. This measurement will be taken by installing strain gages on various bolts that support the collector pylons throughout the field. With the double-nut installation technique, the bolts supporting the collector pylons will either be in tension or compression, therefore the stresses in this bolt can be simply determined by measuring strain. Since wind speed and direction will be taken simultaneously, a correlation can be developed for wind loading as a function of wind speed and direction.

As will be noted by the above discussion, all of the major system parameters will be determined by redundant measurements. This is being done to verify any potential malfunctions of the primary sensors as well as provide a means for scheduling recalibration of these sensors in the event that they drift out of limits before the scheduled calibration time. This method will lend a great deal of confidence to the system measurement system. The location of the sensors is shown in Figure 51. The numbering sequence is shown in Table XIX. The signals from each of these primary sensors will be sampled by a microprocessor-controlled data logger and the raw data stored on digital tape. The control unit will also perform digital integration as well as limited on-site processing for selected parameters, and will have programable scaling and time scan interval. In addition to placing this data on tape, it will also be addressable from a CRT display for system shakedown and debugging.

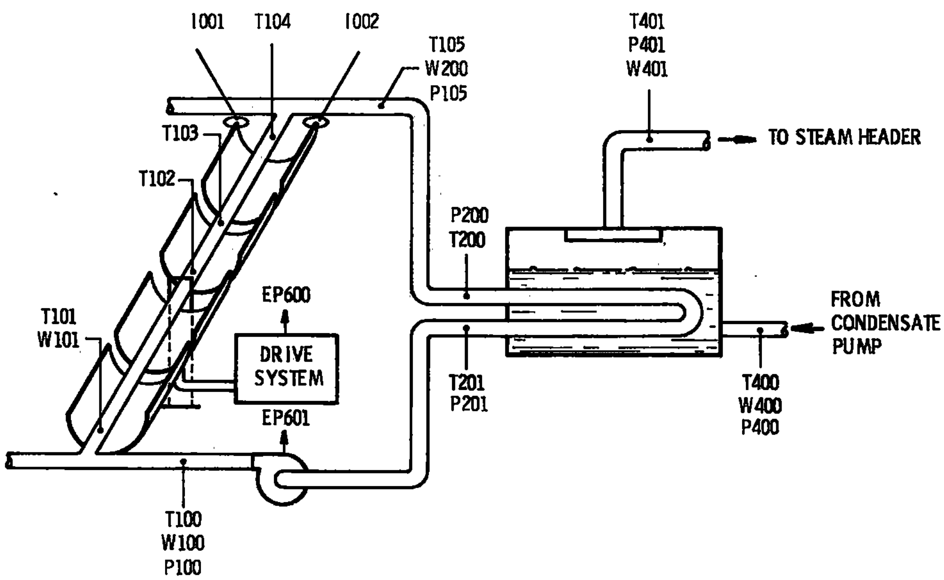


Figure 51. Location of Primary Sensors

TABLE XIX. INSTRUMENTATION LAYOUT

Designation	Location	Description of Quantity Being Measured
T100	Array inlet	Field inlet temperature
T101	Row inlet	Collector inlet temperature
T102	20-ft section inlet	Section inlet temperature
T103	20-ft section outlet	Section outlet temperature
T104	Row outlet	Collector outlet temperature
T105	Array outlet	Field outlet temperature
T200	Boiler solar inlet	Boiler inlet temperature
T201	Boiler solar outlet	Boiler outlet temperature
T400	Boiler process inlet	Condensate temperature
T401	Boiler process outlet	Steam temperature
W100	Array inlet	Field flow rate
W101	Row inlet	Row flow rate
W200	Array outlet	Boiler solar flow rate
W400	Boiler process inlet	Condensate supply flow rate
W401	Boiler process outlet	Steam flow rate
P100	Array inlet	Field inlet pressure
P105	Array outlet	Field outlet pressure
P200	Boiler solar inlet	Boiler inlet pressure
P201	Boiler solar outlet	Boiler outlet pressure
P400	Boiler process inlet	Condensate supply pressure
P401	Boiler process outlet	Steam pressure
EP600	Hydraulic system motor	Hydraulic system power consumption
EP601	Solar fluid pump	Solar circulation power consumption
I001	Collector aperture	Total insolation at aperture
I002	Collector aperture	Diffuse insolation at aperture
I003	Weather station	Total horizontal insolation
V001	Weather station	Wind speed
D001	Weather station	Wind direction
T001	Weather station	Ambient temperature
RF001	Weather station	Rainfall
RH001	Weather station	Relative humidity

Based on our past experiences and discussions with other solar investigators, a sufficient sampling rate for this system is about one minute, but due to the flexibility of this data acquisition system, the initial sampling rate will be set at 30 seconds with the capability to sample even faster. Once the initial data is reduced, it is anticipated that the sampling rate will be decreased to minimize the amount of raw data collected.

2. Uncertainty Analysis

In order to assure acceptable accuracy of the derived quantities, an uncertainty analysis was performed to determine what accuracies of the primary measurements were required. The first step in this analysis is to investigate the sensitivity of the derived quantities to the measured quantities. If the instrumentation precision errors are assumed to be absolute limits, then the accuracy of the derived quantity can be determined by expanding the functional relationship for this quantity in a Tayler series and neglecting the second order and larger terms. For example, to determine the error in deriving the thermal energy transfer to the collector fluid by the collector field, Equation (14) will be expanded in a Taylor series as follows:

$$\Delta Q_c = \left| \frac{\partial Qc}{\partial m} \Delta m \right| + \left| \frac{\partial Qc}{\partial T_{f,o}} \Delta T_{f,o} \right| + \left| \frac{\partial Qc}{\partial T_{f,i}} \Delta T_{f,i} \right|$$

where

$$\frac{\partial Qc}{\partial m} = C_p\ (T_{f,o} - T_{f,i}) = 68 \text{ Btu/lb}$$

$$\frac{\partial Qc}{\partial T_{f,o}} = mC_p = 15{,}619 \text{ Btu/hr}^\circ\text{F}$$

$$\frac{\partial Qc}{\partial T_{f,i}} = -mC_p = -15{,}619 \text{ Btu/hr}^\circ\text{F}$$

$$\Delta m = 63 \text{ lb/hr}$$

$$\Delta T_{f,o} = 0.1^\circ\text{F}$$

$$\Delta T_{f,i} = 0.1^\circ\text{F}$$

Therefore,

$$\Delta Q_c = 7{,}393 \text{ Btu/hr}$$

The percent accuracy for these conditions where

$$Q_c = 25{,}111 \text{ lb/hr } (0.622 \text{ Btu/lb}^\circ\text{F})\ 110^\circ\text{F}$$

and

$$Q_c = 1.718 \times 10^6 \text{ Btu/hr}$$

is, therefore,

$$\text{Error} = \pm 0.4\%$$

If one assumes that the errors are random and uncorrelated, then the precision errors can be calculated by a statistical method where

$$\Delta Q_c = \left[\left(\frac{\partial Q_c}{\partial m}\Delta m\right)^2 + \left(\frac{\partial Q_c}{\partial T_{f,o}}\Delta T_{f,o}\right)^2 + \left(\frac{\partial Q_c}{\partial T_{f,i}}\Delta T_{f,i}\right)^2\right]^{1/2}$$

and

$$\text{Error} = \pm 0.28\%$$

For both the absolute limit method and the statistical method, the precision errors are less than 1% for the design conditions. A summary of measurement errors for all of the types of measurements in this data acquisition system are shown in Table XX. With these measurement errors, the errors for the derived quantities are listed in Table XXI.

TABLE XX. MEASUREMENT ACCURACY

Type Measurement	Accuracy
Temperature	0.05°F
Flow	0.25%
Pressure	0.25%
Wattage	0.5%
Wind Speed Direction	1%
Humidity	2%
Rainfall	0.5%
Solar Radiation	1%

TABLE XXI. DERIVED QUANTITY ACCURACY

Quantity	Design Condition Accuracy
Thermal Energy Collected	±0.28%
Thermal Energy to Boiler	±0.28%
Steam Production	±0.25%
Collector Field Efficiency	±0.67%
Parasitic Power	±0.50%
Solar Radiation	±1.0%

Since the sampling error will be a function of the actual thermal performance of the system and since the proposed data acquisition system will have the flexibility to vary the sampling rate, a parametric study will be conducted after the system is constructed to determine the most accurate rate at which to sample the data. This parametric study will be performed by sampling data at 30-second intervals and then analyzing this data at 30-second, 1-minute, 2-minute, and 5-minute points to ascertain the longest period which gives the same results as the next shortest period. In this way, the sampling rate will be chosen to minimize the amount of data taken and, at the same time, assure optimum data accuracy.

3. Data Evaluation Plan

The data evaluation plan will be conducted on an hourly, daily, and monthly basis. The following parameters will be analyzed on an hourly basis: solar radiation available to the tracking collector; thermal energy collected ($m\ C_p\Delta T$ across the collector field); collector field inlet and outlet temperatures; ambient temperature, wind speed and direction; collector field efficiency, thermal energy delivered to the boiler; feedwater condensate temperature and flow rate; steam temperature, pressure, and flow rate; parasitic power; total energy delivered to the process; and natural gas saved. These data will also be summarized on a daily and monthly basis. The system performance will be monitored using the above set of parameters to determine the performance degradation as well as any operational problems of the system. These data will also be compared to the system modeling program to both test the model and determine areas for system modification. In addition to tabulating the above data, curves will be plotted and used in the monthly progress report as indicators of system performance. As the data is collected, each parameter will be compared to a limit value to serve as a back-up for the system control system and flagged to the operator so that prompt corrective action can be taken. In addition, the data processing program will compare each parameter to a performance correlation to anticipate potential performance problems. In this way, the actual performance of a solar steam system can be determined as a function of ambient weather conditions. These performance data will then be used to improve system operational techniques, control strategy, and component sizing. Recommendation can then be made to improve future system designs by using the actual system performance and the actual system installed cost.

B. Instrumentation System

To determine the performance characteristics of the solar collector system, data will be collected from a large number of weather instruments, temperature sensors, pressure sensors, flow meters, and electric motors. The data collection system (DCS) design provides the necessary hardware to collect and reduce performance data in accordance with the ASHRAE Standard 93-77 (ANSI B198.1-1977) entitled "Methods of Testing to Determine the Thermal Performance of Solar Collectors." The DCS design is divided into the following subsystems:

- Primary Sensors
- Data Logger
- Data Reduction
- Status Monitor Display

A block diagram of the DCS is shown in Figure 52.

1. Primary Sensors

The function of the primary sensors is the conversion of measurable physical parameters into electrical or digital signals representing the parameters' magnitude. The selection of sensors is divided into the following categories:

- Temperature
- Pressure
- Flow

- Electrical Power
- Weather

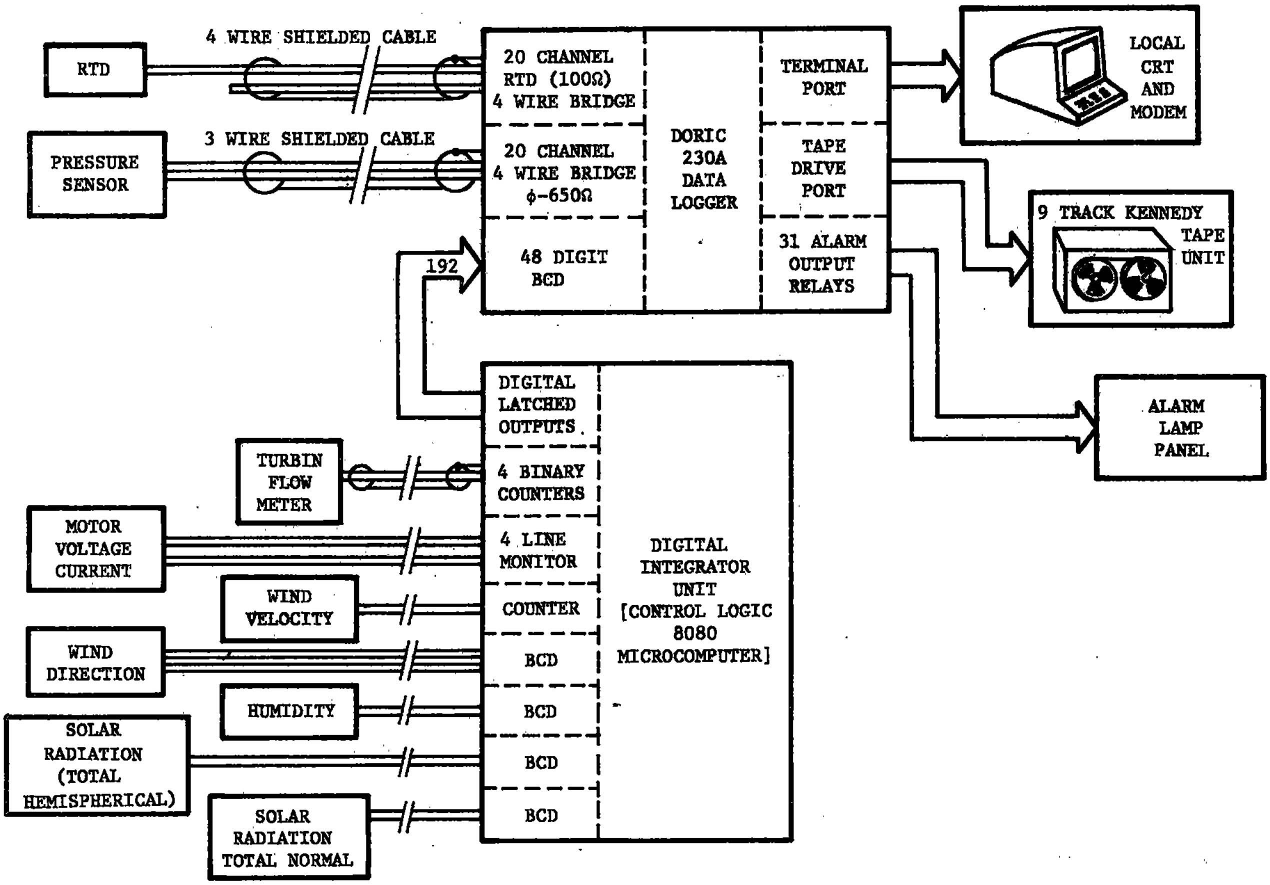


Figure 52. Data Collection System

a. *Temperature Measurement*

Temperature measurements are required on the solar heat transfer fluid, process steam, condensate return, and ambient air. The required DCS accuracy and precision for these measurements are as follows:

	Accuracy	Precision
Absolute Temperature	±0.9°F	±0.36°F
Temperature Difference	±0.18°F	±0.18°F

These accuracies will be maintained for an 18-month period; thus the temperature sensor must have a long-term stability with drift less than ±0.09°F. The length of lead wire from the sensor to the data logging system will require special consideration. To meet these specifications, Platinum Resistance Transducers (RTD) will be used in this system since thermocouples would require extensive development. The RTD sensing element is made of high-purity platinum wire wound upon a ceramic core. The wound core is then stress-relieved and immobilized against strain or damage. Temperature is then related to the change of resistance in the platinum wire. This provides a sensor with high accuracy, sensitivity, and stability with an operating range between —450° F to 1220°F. The sensing element is mounted in a stainless steel sheath to provide good thermal transfer and protection against moisture and the process medium. Since the 1/8-in. diameter sheaths are pressure tight, they are inserted directly into the collector piping and process steam lines using 316 stainless steel compression fittings. The placement of the transducers within the piping will be according to ASHRAE Standard 41.1-74 entitled 'Standard Measurement Guide: Section on Temperature Measurement.'' The RTD is connected to the data logger via standard copper wire. Compensation for the resistance effects caused by the lead wire is provided by using a redundant set of lead wires connected to the opposite side of the measurement bridge, as shown in Figure 53. The location of temperature sensors is outlined in the Data Collection and Evaluation Plan. At each temperature location a redundant RTD will be installed which provides a rapid method for locally checking temperatures on the solar collector field without disturbing the recorded temperature sensors. The RTD sensors are commercially available from several manufacturers. The selected devices for this design are from Omega Engineering, Inc.

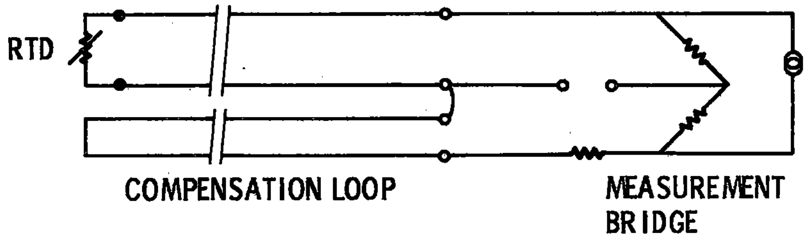


Figure 53. RTD Connection Circuit

b. Pressure Measurement

Measurement of pressure requires determining the force acting on a surface. Methods of pressure measurements range from manometers to electromechanical transducers. Manometers use the pressure difference across a liquid column for measurement. Automatic measurements are limited, therefore, to electromechanical transducers. Since the strain characteristics of a diaphragm constrained on its circumference are well established for evenly-distributed loading, and the measurement of strain is a standard procedure, typical electromechanical pressure transducers are constructed using two cavities isolated from each other with a diaphragm. One side of the transducer receives fluid pressures transmitted by the process liquid or gas, whereas the other side is vented to the atmosphere, sealed at a pressure, or sealed under vacuum. If the cavity is vented to the atmosphere, the transducer indicates gage pressure (psig). The other cases are sealed (psis) and absolute (psia), respectively. Another type measurement produces the pressure difference between two ports (psid). Thus the ports on each side of the diaphragm are used for the measurement. The evaluation of the solar collector performance requires both gage and difference pressure measurements. Transducers which measure these pressures are described by the following characteristics:

- Linearity (or Nonlinearity)
- Repeatability
- Hysteresis
- Sensitivity
- Full Scale Output (SPAN)
- Zero Balance (OFFSET)
- Temperature Range
- Thermal Zero Shift
- Thermal Sensitivity Shift

Several of these characteristics are combined to yield a total error. These are linearity, repeatability, hysteresis, thermal zero shift, and thermal sensitivity shift. The total error is used to express the transducer accuracy. Static gage pressure measurement will be accurate to ± 2% of reading, whereas differential pressures will be measured with an accuracy of ± .05 psid. Since the pressure differential is considerably less than the loop operating pressure, the transducers for the two types of measurement require different full-scale ranges and sensitivities. The transducers use strain gage bridge measurements; therefore, the data logger signal conditioning cards are adjusted for full-scale output and zero balance. Since the loop operating temperature is on the order of 400°F and will fluctuate over a large range, special installation techniques will be used. Pressure tap holes in loop piping will not exceed 1/16 in. in diameter. From this tap, a tube will be installed to the transducer. This tube will provide dissipation of heat, such that the temperature variation of the transducer is less than 100°F.

The differential pressure measurements will have two ranges: ± 30 psid and ± 50 psid. The location of these transducers is given in the Data Collection and Evaluation Plan. The instrument chosen for the pressure measurements is the Dynisco Model DPT 361 J which has the following characteristics:

- Accuracy — ± .25% full scale
- Repeatability — .2% full scale
- Compensated Temperature Range — -65 to 250°F
- Thermal Effects of Zero — ± .01 % full scale/°F
- Thermal Effects on Sensitivity — ± .02% of reading/°F

The gage pressure measurements will have a range of 0 to 100 psig. The location of these transducers is also given in the Data Collection and Evaluation Plan. The Dynisco Model 310 JAW was chosen for these measurements and has the following characteristics:

- Accuracy — ± .25% full scale
- Repeatability — .2% full scale

- Compensated Temperature Range — -65 to 250°F
- Thermal Effects on Zero — ± .01% full scale/°F
- Thermal Effects on Sensitivity — ± .02% of reading/°F

c. *Flow Measurement*

Flow of the heat transfer fluid through the solar collector loop requires measurement accuracies of ± 1% of the measured value. Since the heat transfer fluid will remain in a liquid phase, a turbine-type flow meter will be used. The turbine flow meter is an electromechanical, volumetric transducer which generates a pulse train related to flow. Since the flow meter is inserted into the solar loop, the transducer is rated for temperature service up to 600°F and a maximum pressure drop of 4 psi at maximum flow. To provide the required accuracies, a meter with a linearity of ± .25% of reading and repeatability of ± .02% of reading was selected. The selected flow meter for total system flow has a linear range of 14.0 to 240 gpm, and for a single collector row has a linear range of 3.7 to 15 gpm. The location of the flow measurements is discussed in the Data Collector and Evaluation Plan. Since the measured signals are located at a long distance from the data logging system, each flow meter contains a signal amplifier. This amplified signal is a series of pulses whose frequency is related to the flow rate. The frequency signal requires conversion to a parallel digital signal and integration over a 10-second period by the Digital Integrator Unit (DIU) before being converted to BCD data and stored by the data logger. The DIU will be discussed with the Data Logger section.

To provide a check on the production of steam from the unfired boiler, the steam mass flow rate will also be determined. The calculation of the steam mass flow rate requires the measurement of steam volumetric flow rate, temperature, and pressure. Temperature and pressure are used to determine steam quality and are measured using an RTD and a pressure transducer as used for the other system measurements. The volumetric flow rate will be measured using a vortex shedding meter (Vort-X-Cel Model 3050) which utilizes an oscillating disc sensor element. The alternating differential pressure across the flow element moves the disc and a standard magnetic pickup detects the movement. The resulting signal has an accuracy of ±1%, a repeatability of ±.1%, and a linearity of ±1%. This signal, along with the temperature and pressure, is used by the signal processor and mass flow computer for calculation of steam mass flow rate. The resulting output is a binary coded digital signal proportional to the flow rate.

To ensure performance, the meter will be installed in a straight unobstructed run of 10X diameter upstream and 5X diameter downstream piping. Pressure and temperature taps will be located 4X diameter upstream and 2X diameter downstream, respectively.

d. *Electrical Power Measurements*

The electrical power required by pump motors will be measured using a Nationwide Electronics Model DW1880 power sensor. Voltage is tapped from AC line and current in the high side line. The output of the EIA is input to a digital panel meter which converts the signal to BCD output. This BCD data is then input to the DIU. The unit provides the following specifications

Range	0 to 19.99 watts
Voltage	50 to 250 RMS volts
Accuracy	.5% F.S. at 25°C

e. *Weather Measurements*

The weather measurements required for performance evaluation of the collector system are:

- Ambient Dry Bulb Temperature
- Wind Speed and Direction
- Relative Humidity
- Rainfall
- Solar Radiation

1) *Ambient Dry Bulb Temperature*

The ambient temperature will be measured using an RTD probe housed in a well-ventilated instrumentation shelter, as outlined in Weather Bureau Circular B entitled "Instructions for Climatological Observers."

2) *Wind Speed and Direction*

The wind velocity will be measured to ± 1% using a six-cup high-response, low-threshold wind anemometer. The six-cup assembly eliminates pulsing at low wind velocities as well as reducing errors due to nonhorizontal wind flow. To provide low threshold and maximum resolution, a frictionless tachometer employing a high-frequency oscillator and receiver is used. The output pulse train is input to the DIU. This high-frequency tachometer embodies several advantages over the commonly-used light chopper system. There are no light bulbs or photocells to burn out; power consumption is low; and the system is insensitive to moisture condensation or dust deposition. This provides a maintenance-free life of well over five years of continuous operation. The wind direction will be measured using a single-fin aerodynamic vane. The vane features a low-density, high-structural-strength foam plastic tail coated with a high-density epoxy and bonded to a stainless steel rod. A stainless steel counterbalance, located close to the center of rotations, permits maximum response to wind fluctuations with minimum overshoot. The tail has an airfoil shape with dimensions of 4 in. wide by 12 in. high by 1/4 in. thick at the center and 1/8 in. thick at the tip. The center of the tail is normally 12 in. from axis of rotation. The vane rotates on a stainless steel shaft mounted in miniature stainless steel precision bearings. The output is from a 1000-ohm low-torque potentiometer. The resistance change is used in the DIU to produce a frequency proportional to wind direction. The wind vane has the following characteristics:

- Dead Band — 3°
- Damping Ratio — .4

- Distance Constant — 3.5
- Threshold — .75 mph
- Potentiometer Linearity — .5%
- Resolution — .72°

The wind measurement will be made in accordance with Weather Bureau Circular B, as listed above.

3) Relative Humidity

Relative humidity will be measured at ± 2% accuracy using a probe based upon the capacitance change of a polymer-thin film capacitor. A 1-micron thick dielectric polymer layer absorbs water molecules through a thin metal electrode and causes capacitance changes proportional to relative humidity. Since the sensor is based on bulk effect, dust and dirt do not easily influence its operation. The sensor is mounted in a small probe which contains all electronics necessary to provide a millivolt output which is converted to frequency and input to the DIU. The probe will be mounted in the instrumentation shelter with the ambient air probe.

4) Rainfall

The remote recording rain gage uses two chrome-plated brass buckets which alternately fill and tip causing a momentary closure of a mercury switch. Calibration is accomplished by adjustment of bucket supports or bucket counterbalance. The calibration sensitivity is typically .01 in. with a .5% accuracy at .5 in./hr rainfall rate. The switch closures are counted by the DIU and the rain fall calculated. The wind anemometer, wind vane, relative humidity sensor, and rainfall gage are all commercially available. The selected instruments for this design are manufactured by Weather Measure Corporation.

5) Solar Radiation

The solar radiation measurements will be conducted according to ASHRAE Standard 93-77 (ANSI B 198.1-1977) entitled "Methods of Testing to Determine the Thermal Performance of Solar Collectors." Two measurements are required. The first is the total shortwave radiation from both the sun and the sky which will be measured using a pyranometer. The second measurement is the direct component from the sun which will be determined by measuring the sky (diffuse) component using a shadow band on a second pyranometer. A more detailed discussion of these measurements is included in the Data Collection and Evaluation Plan.

The selected precision spectral pyranometer is produced commercially by Eppley Laboratories, Inc., for the measurement of total sun and sky radiation, and with the incorporation of a shading arrangement to screen off the sun, the diffuse sky component. The pyranometer is composed of a circular multijunction Eppley thermopile of plated copper-constantan wire which is temperature compensated to render response essentially independent of ambient temperature. This instrument is supplied with a pair of removable precision ground and polished concentric hemispheres of Schott WG7 optical glass. The WG7 glass is transparent from a wavelength of 285 to 2800 mμ. With this arrangement, instrument characterisitcs are as follows:

- Sensitivity — 9 microvolts per watt-meter^{-2}
- Impedance — 650 ohms
- Receiver — Circular 1 cm^{-2}, coated with Parson's black optical lacquer
- Temperature Dependence — ± 1% over a range -20 to ±40° C
- Linearity — ± .5% from 0 to 2800 watts m^{-2}
- Response — 1 sec
- Cosine — ± 1% from 0-70° Zenith angle; ± 3% from 70-80° Zenith angle
- Orientation — No effect on instrument
- Mechanical Vibration — Up to 20 g's
- Calibration — Integrating hemisphere (1 cal cm^{-2} min^{-1}) ambient 25°C: Calibration reference Eppley primary standard group of Angstrom pyrheliometers reproducing the International Pyrheliometric Scale.

To ensure these specifications, the installation site for the pyranometers will be free from any significant obstruction above the plane of the sensing element and also will be readily accessible. If practicable, the instrument will be located such that (a) a shadow will not be cast on it at any time, (b) it is not close to light-colored walls or other objects likely to reflect sunlight onto it; and (c) it is not exposed to artificial radiation sources.

Since the pyranometers will be in continuous operation, they will be inspected once a week. At these inspections, the outer hemisphere will be wiped clean and dried with a lint-free soft cloth. Since the dust particles are abrasive, special care will be required since scratches can alter appreciably the original transmission properties of the material and, hence, the radiometer calibration. To obtain the highest calibration accuracies, the units will be sent back to Eppley every six months on a rotating basis. A spare pyranometer will, therefore, be required to prevent a loss of data during the period the units are being calibrated. Since the output signal of the pyranometer is approximately 9 microvolts per watt-meter^{-2}, the output will be amplified and converted to frequency at the pyranometer location. This frequency signal will then be input to the DIU.

f. *Strain Gage Measurement*

Since the effects of loading resulting from wind-induced dynamics on the solar collector array require major design efforts to reinforce the support structure on roof installations, data will be collected to determine these effects. The load data required to analyze forces on the roof structure will be obtained by instrumenting selected bolts which fasten the solar collector pylons to the roof. Selected instrumented bolts will provide loading data along the first and last row of collectors and a representative set of collector supports in the remaining rows of the collector array.

The use of the bolts as load cells for the measurement of loads is accomplished by determining the stress in the bolt. Since stress is a function of strain, modulus of bolt material, and bolt cross-sectional area, the load will be determined by measuring the strain with the other two parameters being known. Bolt strain will be measured by bonding strain gages on the bolt. The 350Ω strain gages used will be sensitive only in the axial direction of the bolt with a dummy gage included for temperature compensation. Two gages will be wired as two legs of a measuring bridge with two 350Ω completion resistors forming the four-terminal bridge to the data logger. The ratio of the fractional change in gage resistance due to strain and the fractional change in length (strain), commonly know as gage factor, will be approximately 2. Since a load of 30 pounds on a 1.125-in. diameter bolt results in a 1μ in./in. (microstrain) elongation of the bolt, with a single gage the resolution of the measurement for the Doric Data Logger will be 60 pounds.

The instrumented bolts will require calibration to set zero and gain in the data logger both during initial installation and at six-month intervals. To calibrate, a bolt will be removed from its installed position and zero adjusted. Then the bolt will be placed in a special calibration fixture which will be hydraulically loaded to 1000 pounds from a small pump and the gain set at this time. Since the environmental conditions on the bolts are not controlled, the expected measurement errors of load will be ±3%.

2. Data Logger

The data logger provides the on-site intelligence for controlling the tasks of scanning, digitizing, storing, displaying and alarming the data collection. To meet the requirements of flexibility in input and output programming, signal conditioning and digitizing accuracy, system reliability and expansion capability, the Doric 230A Data Logger was selected. The Doric 230A is a microprocessor base data logger with built-in clock. Since the data logger is microprocessor based, data will be scaled to engineering units before storage or display. Also the scanning time intervals are easily programmed from seconds to hours. The data logging system input and output configuration consists of the following subunits:

- RTD Input (20 channels)
- 4-wire Bridge Input (20 channels)
- BCD Input (48 digits)
- 9-Track Tape Control and Output
- Local Data Monitor and Keyboard (RS232)
- Remote Data Monitor and Keyboard (RS232)
- Alarm Outputs

This system has expansion capability of 60 channels of analog voltage or resistance channels in the main frame plus 100 other channels in an expansion chassis. Expansion is in groups of 20 with each group containing the scanning multiplexer, preamplifier and 16 bit analog-to-digital converter. The present system does not require analog signal inputs; however, a 20-channel unit is available.

This system contains 40 channels for the measurement of resistance type sensors. The characteristics of the transducers are as follows:

	Range	Resolution	Accuracy
4-wire Ω100 RTD	-216°C to +346°C	.01°C	.01°C
4-wire Ω650 Bridge	0 to 650Ω	.01Ω	.01Ω

Other data is input from the DIU as BCD data, with a total of 48 digits as follows:

- 4 Flow (3-digit)
- 2 A-C Power (4 digit)
- 2 Pyranometers (4 digit)
- 1 Wind Speed (3 digit)
- 1 Rainfall (3 digit)
- 1 Wind Direction (3 digit)
- 1 Humidity (3 digit)
- 1 Spare Channel (3 digit)

The 9-track Tape Control and Output Port is used to store data on an Incremental Kennedy write only 9-track magnetic tape recorder at 800 CPI on 10-1/2' reels. The port allows programming of record lengths from 256 to 4096 characters per block with either ASCII or EBCDIC coded characters. Data output to this port, as well as the scan rate, are independent of other output ports.

Both local and remote RS232 data ports are provided for operator monitoring and control. The local port allows viewing of instantaneous data scans at periodic intervals or on request. Programming from the port is controlled by password techniques. As configured this terminal will be a CRT with keyboard and RS232 interface. Since the terminal will be in the room with the data logger, the two will be directly coupled. A terminal port on the CRT will be coupled to 202C type modem allowing remote terminals the same operational modes as the local terminal. The Remote RS232 port will be coupled directly to a 202C modem, which will allow direct network communication between the SwRI PDP11/70 computer facility and the data logger via the phone system on Data Access Arrangement (DAA). This network allows real time analysis of data using the PDP 11/70. Access to data files of processed data is executable from either the on-site location or any other remote terminal using 300 baud data transfer rate on an acoustic coupler modem or 103C DAA link. Both FORTRAN IV PLUS and BASIC languages are available on the PDP 11/70 under the DEC RSX11/M operating system. The computer facility also supports several utility programs, International Mathematical and Statistics Library (IMSL) general purpose graphics library, and HASP Network hardware and software. Since this computer system is in the same city as the on-site data-logger and will contain the programs for data reduction of data tapes and the on-line real time data collection capability, the network between the on-site data logger and SwRI computer facility provides superior capabilities and does not require an on-site processor to perform the hourly and daily data summaries.

Alarm limits are programmed in the data logger with alarm conditions being output to local terminal and a set of relays. The relays are used to set lamps on the Status Monitor Display. The Doric Data Logger will be in a rack mount enclosure 12.1 in. high x 19.0 in. wide x 4.0 in. deep. The operating temperature is 32 F to 120 F at a 90% RH non-condensing environment.

3. Digital Integrator Unit

The Digital Integrator Unit (DIU), as shown in Figure 54, is a microprocessor-based instrument which receives frequency data or binary coded data (BCD), performs digital integration, and then outputs 3- to 6-digit BCD. Each input into the DIU has a corresponding output yielding a total of 48 BCD digits output. The DIU is designed using a commercially-available microcomputer from Control Logic. Special interface cards allow conversion of frequency to binary words. The software required for controlling input channels and for integrating the data will be stored on EPROM. This system provides the multichannel requirements of the DCS, as well as flexibility in the programming for the different types of sensor inputs. This specially-designed unit also provides flexibility in assignment of output digits as previously discussed.

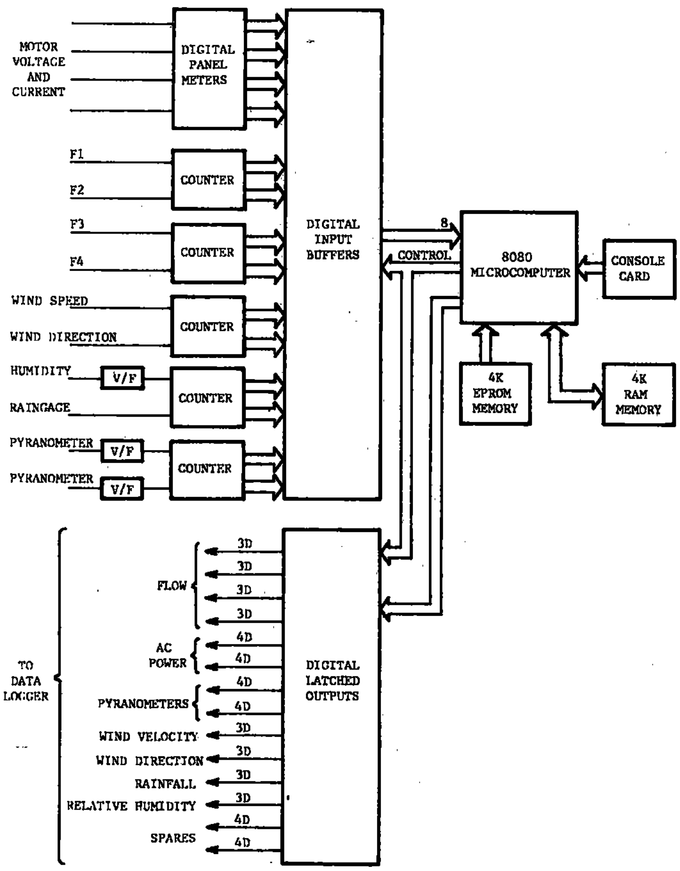


Figure 54. Digital Integration Unit

4. Data Reduction

Since the data for evaluation are stored on 9-track tapes at the solar steam plant, processing of data requires that the tape on the DCS be removed on a weekly or biweekly interval and replaced with a blank tape. The data tape will then be transported to the SwRI computer facilities for processing. The computer facility is a multiuser system using a PDP 11/70 minicomputer. Data processing will consist of the following:

- Copy Tape
- Process Data to Hourly Means
- Print Hourly Means of Data
- Store Hourly Means on Process Variable Tape

Once the original tape is copied, it is placed in archival storage. The copy will then be used to implement the data evaluation plan. The data which is processed to hourly means provides data for interim evaluations of the system performance. From these evaluations, maintenance requirements will be observed before system component failure. Also cursory evaluations during initial startup will provide information to better adjust sample intervals and alarm settings. The hourly means will be stored on a process variable data tape for analysis as required.

5. Status Monitor Display

The status monitor display consists of an alarm lamp panel, local CRT display, and remote CRT display. Alarm signals from the DCS will provide visual display of a process variable which is out of bounds by lighting an indicator lamp. The lamp display will contain a solar loop piping diagram with the indicator lamps positioned at their locations. This allows quick visual indication of sensor failures or system malfunctions. The local CRT will provide current operation values of the system parameters at programmed intervals. Coupled with the local CRT is a Modem which allows remote terminals or computers to access the system parameter values. These terminals have the capability of requesting data samples or using the programmed time intervals. Remote terminals will also be used for reprogramming the DCS system if necessary.

6. Data Acquisition Equipment List

A list of the data acquisition instrumentation system required for the system described above is listed in Table XXII along with the model numbers, manufacturer, description, price and delivery.

TABLE XXII. LIST OF DATA ACQUISITION INSTRUMENTATIONS

Quantity	Model	Manufacturer	Description	Price	Delivery
1	2302(F)-12(2)-07(107)-31(1)-34-36(1)-7403-04-09	Doric Scientific	Data logger with 20-channel RTD and 20-channel strain gage inputs and 2 communication ports (tape and terminal)	$6,410	6 weeks
1	2303-04-17(4)	Doric Scientific	Data logger satellite with 48-digit BCD inputs	$4,275	6 weeks
1	1610/360	Doric Scientific	Incremental Kennedy write only 9-track magnetic tape recorder with 800 CPI and 10-1/2 in. reels	$6,895	6 weeks
1	ADM 3A	Leier Siegler	Local CRT with 24-line option and addressable cursor	$859	2 weeks
3	UDS-202C	Universal Data Systems	EIA-RS232 asynchronous modem with auto answer	$ 745 ea	2 weeks
1	CGS MICRO	Control Logic	8080-Based industrial microcomputer with 16K RAM memory, 4K ROM memory, 48 4-bit output ports, 24 8-bit input ports	$4,600	6 weeks
1	30-2304	BUD	69-7/8 in. x 24-1/6 in. x 61-1/4 in. Upright panel cabinet, blank front panels, rack shelves	$ 675	
3	DAA	Southwestern Bell	Private line lease	$40/mo	2 weeks
1	Interface Cards	SwRI	Materials to build interface from sensor to DIU	$1,000	
3	7202	ITT Snyder	Barton 7000 series liquid turbine meter with 2-in. 150-lb ANSI flanged body; material: 3.S.-rotormaterial, 430 S.S.-bearings; tungsten carbide sleeve; hydrodynamically balanced; flow range 15 to 240 GPM; linearity .25% at reading; pickup coil amplifier included	$ 785	10 weeks
1	7101	ITT Snyder	Same as Model 7202 except flow range of 3.7 to 60 GPM	$ 690	10 weeks
30	PR-11-2-100-1/8-6-1/2E	Omega	RTDwith 1/8 S.S.; sheath includes compression fitting for mounting	$ 75 ea	4 weeks
8	APT310JAW-1C-E84-E89	Dynisco	0-100 psi pressure transducer ±.5% temperature compensation	$ 390 ea	4 weeks
2	DW 1880	National Wide Electronics	Electrical power sensor and digital meter with BCD output	$500	2 weeks
1	W103-A/6SS	WeatherMeasure Corp.	Wind Anemometer	$ 500	5 weeks
1	W104-2	Weather Measure Corp.	Wind Vane	$ 500	4 weeks
1	HM 111-P	Weather Measure Corp.	Relative Humidity Sensor	$ 478	4 weeks
1	P501-1	Weather Measure Corp.	Remote Recording Rain Gage	$ 285	5 weeks
4	PSP	Eppley Laboratory Inc.	Precision spectral pyranometer with extra Schott glass outer hemisphere	$1,460 ea	6 weeks
1	SBS	Eppley Laboratory Inc.	Shadow band	$ 900	6weeks
1	3050	Vort-x-cell	vortex shedding meter	$1100	6 weeks
			Total	$45967	

VI. ENVIRONMENTAL IMPACT ASSESSMENT

A. Description of the Proposed Action

The proposed action is the construction of a solar process steam system for the Lone Star Brewing Co. of San Antonio, Texas. The design concept for this system is to pump a nontoxic, noncorrosive heat transfer fluid through a solar collector array and then pass this fluid through the tube bundle of an unfired steam boiler. The steam produced in the shell of this boiler is then transported to the process steam header under the developed pressure and metered to this header by a standard check valve. Feedwater from the existing process deaerator, which is fed to the existing boilers by three boiler feed pumps in parallel to a common header, will be tapped for make-up to the solar-fired boiler. Since the potential magnitude of the environmental impact for this simple system will be extremely small, the depth and scope of this analysis will also be small.

B. Description of the Existing Environment

1. Climatic Conditions At the Industrial Site

Lone Star Brewing Company's industrial plant is located in San Antonio, Texas. The location of this plant site on the edge of the Gulf Coastal Plains results in a modified subtropical climate, predominantly continental during the winter months and marine during the summer months. Normal mean temperatures range from 50.6°F in January to a high of 84.7°F in July. While the summer is hot, with daily maximum temperatures above 90°F over 80 percent of the time, extremely high temperatures are rare, the highest on record being 107°F. Mild weather prevails during much of the winter months, with below-freezing temperatures occurring on an average of about 20 days each year.

San Antonio is situated between a semiarid area to the west and the coastal area of heavy precipitation to the southeast. The normal annual rainfall is 27.54 inches. Precipitation is fairly well distributed throughout the year with heaviest amounts during May in the spring and September in the fall. Hail of damaging intensity seldom occurs, but light hail is frequent in connection with the springtime thunderstorms.

Northerly winds prevail during most of the winter, while southeasterly winds from the Gulf of Mexico prevail during the summertime and may be experienced for long periods during the winter. Rather strong northerly winds occasionally occur during the winter months in connection with "northers." Relative humidity averages about 80 percent during the early morning hours most of the year, dropping below 50 percent in the late afternoon.

San Antonio has about 50 percent of the possible amount of sunshine during the winter months and more than 70 percent during the summer months. Skies are clear more than 35 percent of the time and cloudy about 30 percent. Air carried over San Antonio by southeasterly winds is lifted orographically, causing low stratus clouds to develop frequently during the later part of the night. These coulds usually dissipate before noon with clear skies prevailing a high percentage of the time during the afternoon.

2. Land Use At the Industrial Site

The industrial site itself is zoned for heavy industry, with light industrial designations immediately to the north and south. Scattered commercial activities border the industrial site on the west and southwest quadrants. Immediately east, across the San Antonio River, a mixture of open space, light industrial, heavy industrial, and single family residential land uses prevail. The open space use is Roosevelt Park, alleged to be the area where Teddy Roosevelt trained the "Rough Riders." This Park is the entrance to the Missions of San Antonio Parkway, recently designated by Congress as a National Park and slated for significant open-space use development by the National Park Service. The increase in tourism associated with this type of development will enhance the visibility of the project.

C. Potential Environmental Impact

1. Air and Water Pollution

The only possible impact on the surrounding air and water table would be due to the leakage of the system heat transfer fluid. The quantity of this fluid will be small so that even if a system failure were to occur, no significant impact would be imposed on the surrounding industrial environment. As an additional safeguard, the volatility of the heat transfer fluid is low, so the air pollution would be minimized. The contamination of the local water supply will be virtually impossible since the fluid used is nontoxic to prevent the contamination of the food product produced at this plant.

2. Product Contamination

Since this plant is a member of the food producing industry, any contamination of the product or product packaging must be avoided. The heat transfer fluid selected has been tested and found to be nontoxic. A safety system, however, has been designed to minimize the possibility of this fluid from contaminating the product. A detailed discussion of this safety system is outlined in the safety analysis section of this report.

3. Water Usage

No significant water usage will be required as a part of this system. The small amount needed will be for monthly or bimonthly washing of the collectors. The estimated water usage is about 300 or 400 gallons of water per month which is a small fraction of the water used by the existing industrial plant.

4. Noise Impact

It is possible that noise generated as a result of construction activities will increase noise levels to an impactive degree. The predominant industrial activities at the site, however, generate a relatively high dBA level under present working conditions; it would be unlikely, therefore, that the intermittant noise, within a generally narrow time frame generated through construction activities, would have a significant impact.

5. Energy Impact

The impact of the proposed action on the energy usage of the industrial plant is the major reason for constructing this system. This system is estimated to conserve about three million cubic feet of gas per year for the industrial plant, which is a very positive impact.

6. Land Usage

If the solar collector field were mounted on the ground, this land would need to be purchased or land for planned plant expansion would need to be purchased. Since the collector field will be roof-mounted, no long-range impact on land usage will be felt, and the surrounding valuable urban land can be used for more productive purposes.

D. Coordination With Federal, State, Regional or Local Plans

Since the proposed solar process steam system is in line with the current national energy plan, it is unlikely that existing federal, state, regional or local plans would hinder the construction of the proposed action. The local area already has a number of large solar energy conversion systems operational, and the responses of the state, regional, and local government officials has been very supportive for these types of projects.

E. Description of Alternatives

The alternatives to the proposed system are (1) continue to use the existing gas-fired system, (2) construct the proposed system but use a pressurized water heat transfer loop, (3) construct a fuel-oil steam system, and (4) construct an electrically-heated boiler using either coal or nuclear energy as the primary energy source. None of the above alternatives has a more positive impact on the surrounding environment than does the proposed solar steam system, therefore, the current proposed action would be the most environmentally advantageous selection.

VII. SUMMARY

This report outlines the detailed design and system analysis of a solar industrial process steam system for the Lone Star Brewery. The industrial plant has an average natural gas usage of 12.7 MMcf per month. The majority of this energy goes to producing process steam of 125 psi and 353°F at about 50,000 lb/hr, with this load dropping to about 6000 lb/hr on the weekends. Since the maximum steam production of the solar energy system is about 1700 lb/hr, the industrial process can accept all of the solar-produced steam.

The climatic conditions at the industrial site give 50% of the possible amount of sunshine during the winter months and more than 70% during the summer months. The long-term yearly average daily total radiation on a horizontal surface is 1574 Btu/day-ft^2, the long-term yearly average daytime ambient temperature is 72 F, and the percentage of clear day insolation received on the average day of the year is 62%.

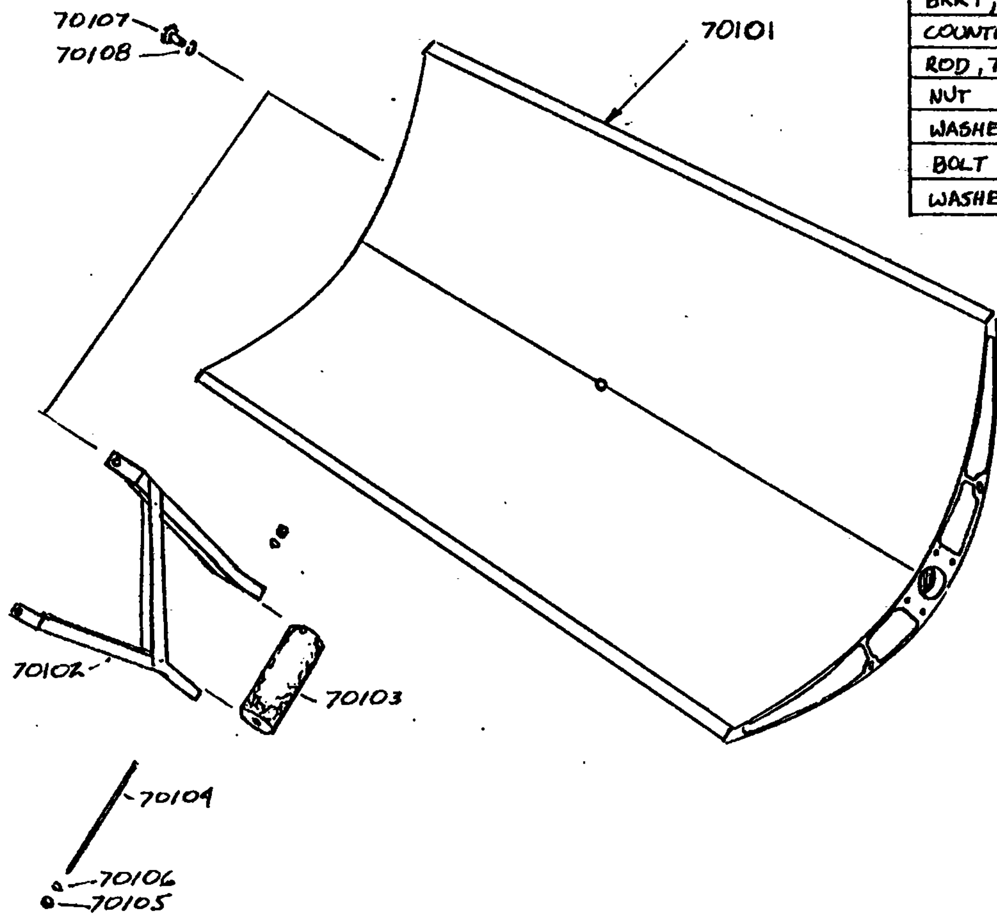
The solar steam system will consist of 9450 ft^2 of Solar Kinetics T-700 collectors arranged in fifteen 90-ft long rows through which 67.5 gpm of Therminol T-55 is pumped. This hot Therminol then transfers the heat collected to a Patterson-Kelley Series 380 unfired steam boiler. The solar-produced steam is then metered to the industrial process via a standard check valve.

The thermal performance of this system is projected to produce about 3 million lb's of steam during an average weather year, which is approximately 3 billion Btu's. As with any prototype system, this steam system cannot be justified for purely economic reasons. It is estimated, however, that if the cost of the collectors can be reduced to a mass production level of $3 per lb then this type of system would be cost effective in about six years with the current government incentives and a fuel escalation rate of 10%. This period can be shortened by a combination of an increased investment tax credit and an accelerated depreciation. For example, a five-year accelerated depreciation coupled with a 40% investment tax credit would provide a climate for collector manufacturers to invest in capital improvements for mass production today.

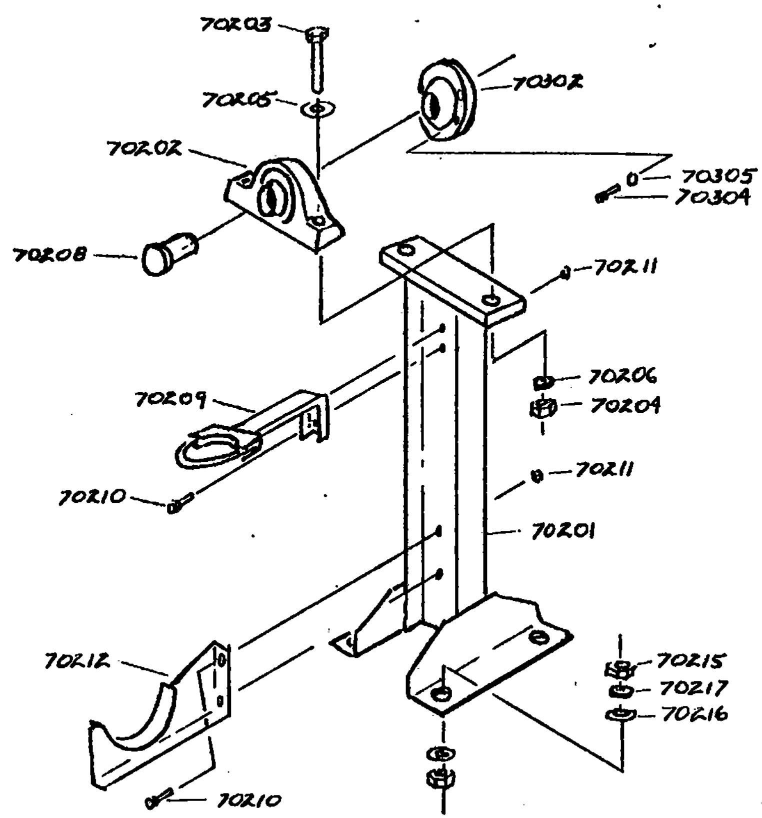
The above economic climate combined with widely visible demonstration projects to educate both industry and the general public to the technical feasibility of solar industrial process steam systems would provide the needed push to bring industrial solar energy systems to the marketplace. The solar steam system designed during this project would provide the required exposure to industry and the general public, since the Lone Star Brewery receives over 400,000 visitors annually to tour their present facility and is firmly committed to widely publicizing this solar demonstration project.

APPENDIX A. COLLECTOR DETAILED DRAWINGS

DESCRIPTION	P/N	QTY
MIRROR MODULE	70101	1
BRKT, CNTRWT	70102	1
COUNTER WEIGHT	70103	1
ROD, THD	70104	1
NUT	70105	2
WASHER, LOCK	70106	2
BOLT	70107	2
WASHER, LOCK	70108	2

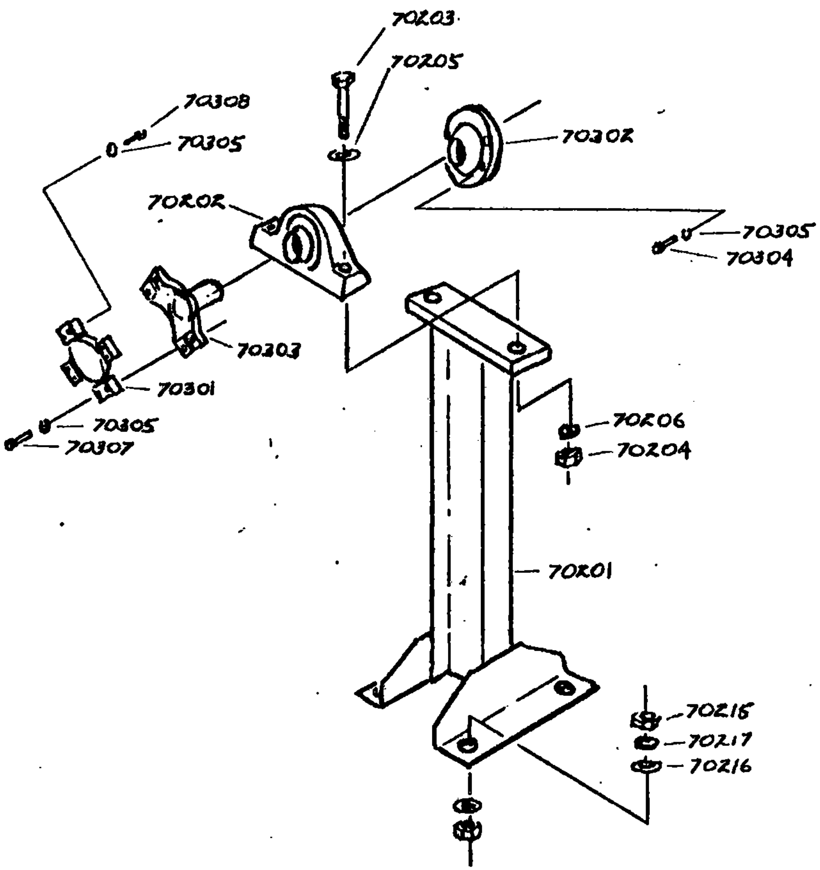


SOLAR KINETICS INC. | MIRROR ASSY | 70100



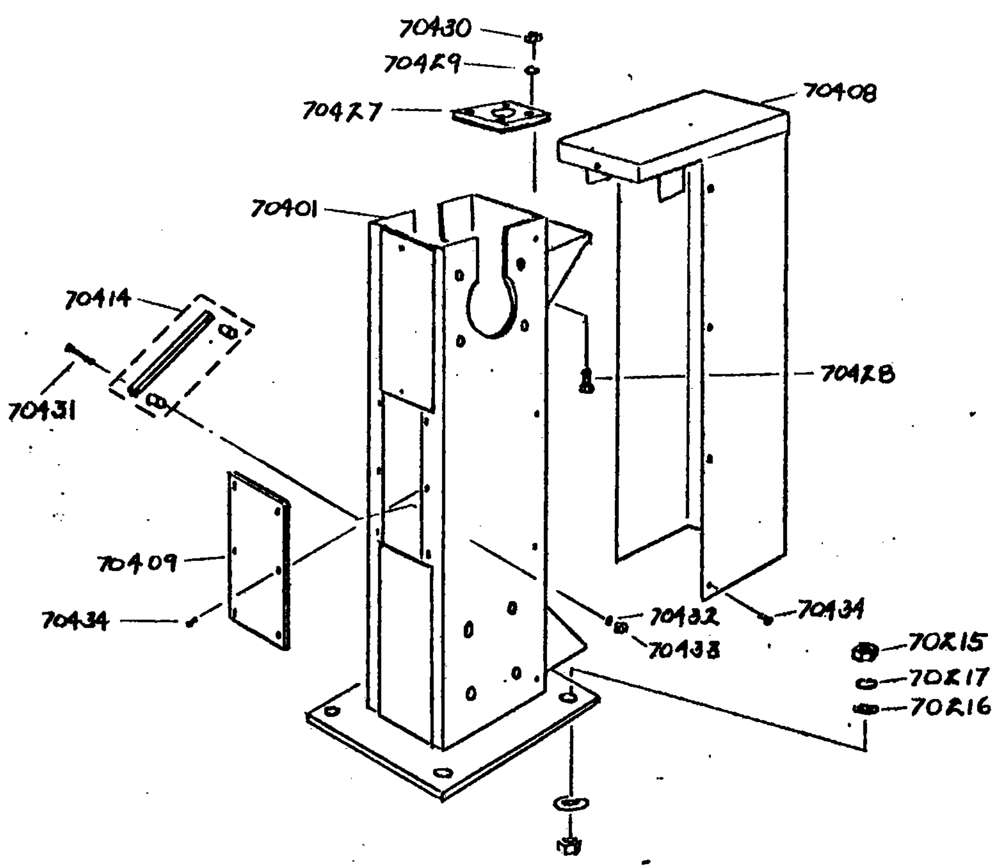
DESCRIPTION	P/N	QTY
PYLON	70201	1
BEARING	70202	1
BOLT	70203	2
NUT	70204	2
WASHER, FLAT	70205	2
WASHER, LOCK	70206	2
STUB SHAFT	70208	1
FLEX HOSE BRKT	70209	1
BOLT	70210	4
NUT	70211	4
MANIFOLD SUPPORT	70212	1
NUT	70215	8
WASHER, FLAT	70216	8
WASHER, LOCK	70217	4
A-FLANGE	70302	1
BOLT	70304	4
WASHER, LOCK	70305	4

SOLAR KINETICS INC.	END PYLON	70200



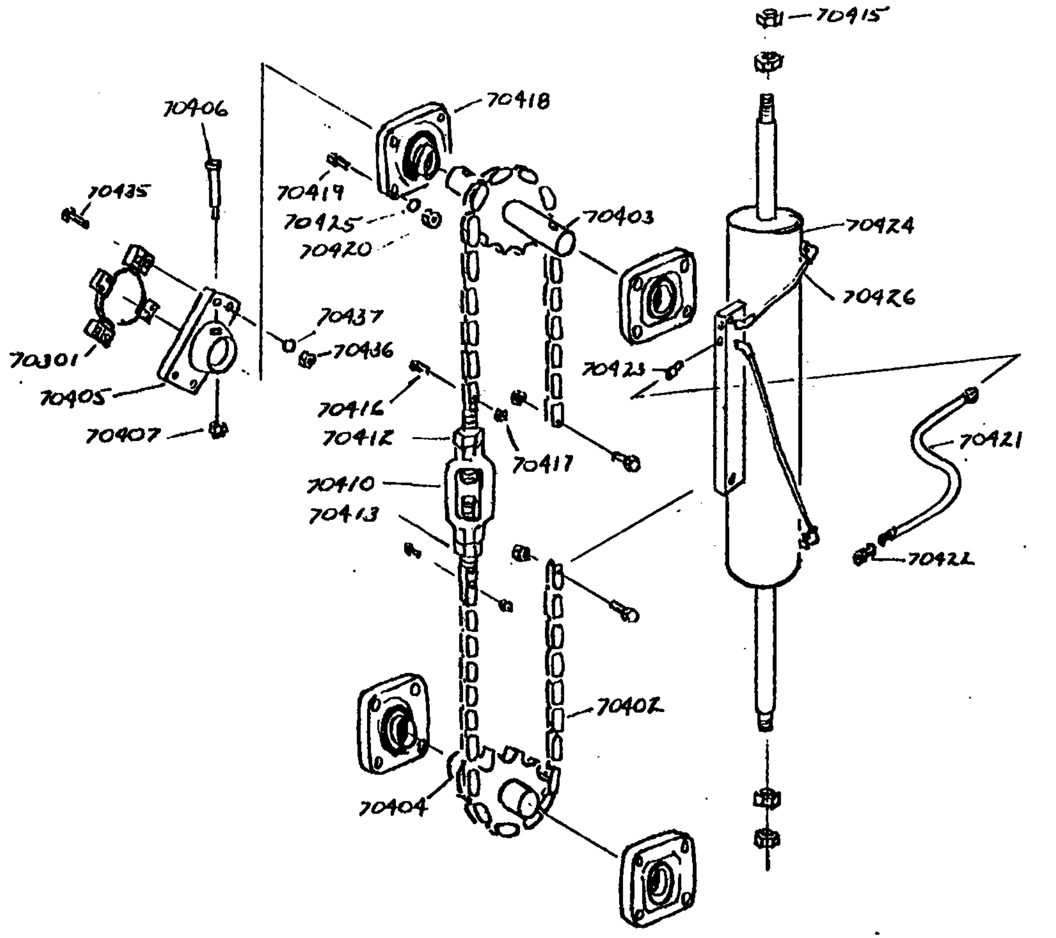
DESCRIPTION	P/N	QTY
U-JOINT	70301	1
A-FLANGE	70302	1
B-FLANGE	70303	1
BOLT	70304	4
WASHER, LOCK	70305	12
BOLT	70307	4
BOLT	70308	4
BOLT	70203	2
WASHER, LOCK	70206	2
WASHER, FLAT	70205	2
NUT	70204	2
NUT	70215	8
WASHER, LOCK	70217	4
WASHER, FLAT	70216	8
PYLON	70201	1
BEARING	70202	1

SOLAR KINETICS INC.	INTERMEDIATE PYLON	70300



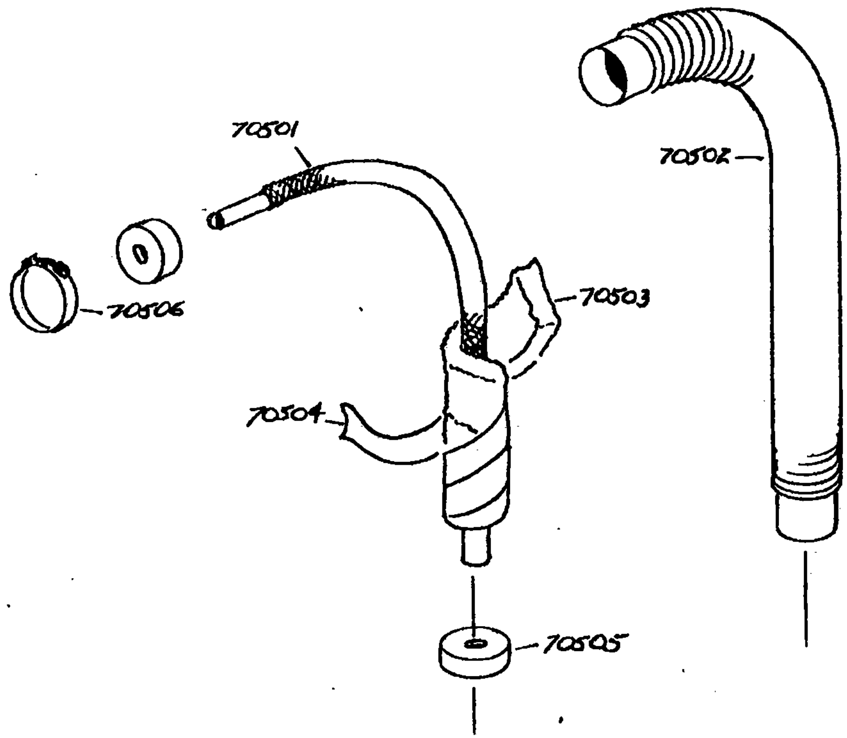
DESCRIPTION	P/N	QTY
DRIVE PYLON HSG	70401	1
COVER, CYL	70408	1
COVER, FRONT	70409	1
HOSE GUIDE ASSY	70414	1
CYL TOP PLATE	70427	1
BOLT	70428	4
WASHER, LOCK	70429	4
NUT	70430	4
BOLT	70431	2
WASHER, LOCK	70432	2
NUT	70433	2
BOLT	70434	15
NUT	70215	8
WASHER, FLAT	70216	8
WASHER, LOCK	70217	4

SOLAR KINETICS INC. | DRIVE PYLON HOUSING | 70400



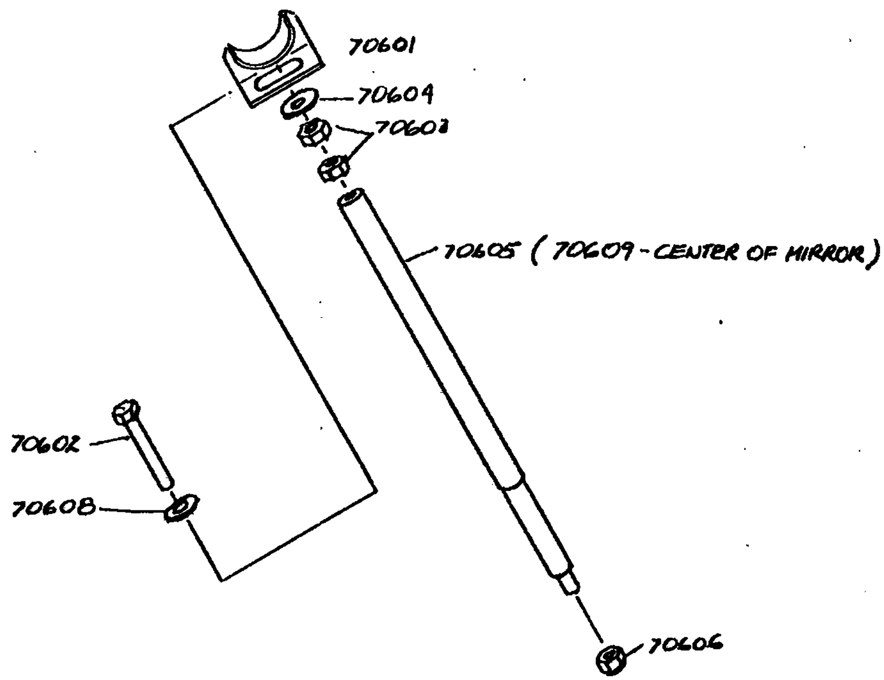
DESCRIPTION	P/N	QTY.
CHAIN	70402	2
TOP SHAFT	70403	1
BOTTOM SHAFT	70404	1
U-JOINT FLANGE	70405	2
DRIVE PIN	70406	2
NUT, LOCK	70407	2
TENSIONER	70410	1
NUT, JAM R/H	70412	1
NUT, JAM L/H	70413	1
NUT, CYL SHAFT	70415	4
BOLT	70416	2
NUT, LOCK	70417	2
BEARING	70418	4
BOLT	70419	16
NUT	70420	16
HOSE, HYD	70421	2
CONN, BLKHD	70422	2
CONN, CYL-HOSE	70423	2
CYLINDER	70424	1
WASHER, LOCK	70425	16
TUBE, HYD	70426	1
U-JOINT	70301	2
BOLT	70435	8
WASHER, LOCK	70437	8
NUT	70436	8

SOLAR KINETICS INC.	DRIVE PYLON MECHANICAL	70400



DESCRIPTION	P/N	QTY
HOSE	70501	1
COVER	70502	1
INSULATION	70503	1
TAPE	70504	1
SPACER	70505	2
CLAMP	70506	1

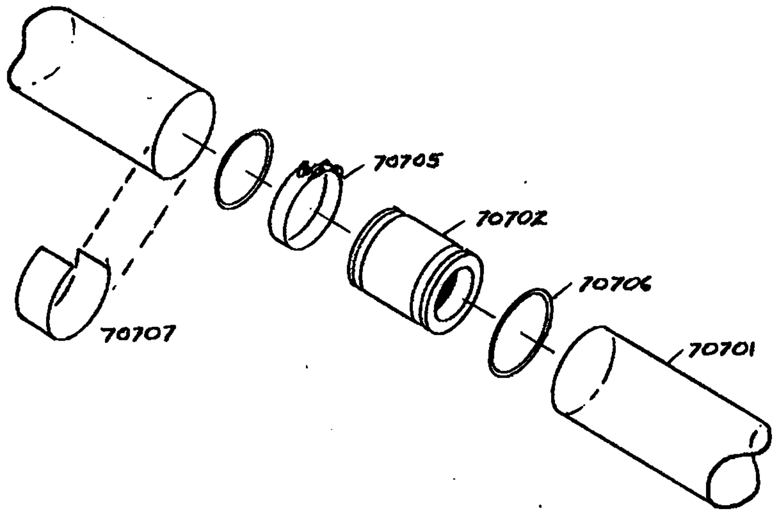
SOLAR KINETICS INC.	END FLEX HOSE ASSY	70500



DESCRIPTION	P/N	QTY
BRACKET	70601	1
BOLT, ADJ	70602	1
NUT, JAM	70603	2
WASHER, FLAT	70604	1
STAND, REC	70605	1
NUT, LOCK	70209	1
WASHER, FLAT	70608	1
STAND, REC, INT	70609	1

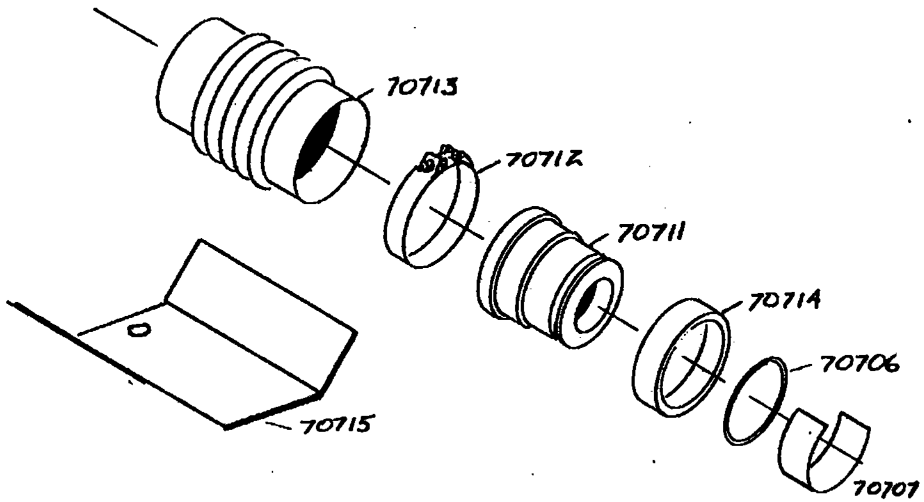
SOLAR KINETICS INC.	RECEIVER BRACKET	70600

DESCRIPTION	P/N	QTY
TUBE, GLASS 64mm	70701	
RET, O-RING	70702	1
CLAMP	70705	1
O-RING	70706	2
SHIELD	70707	2

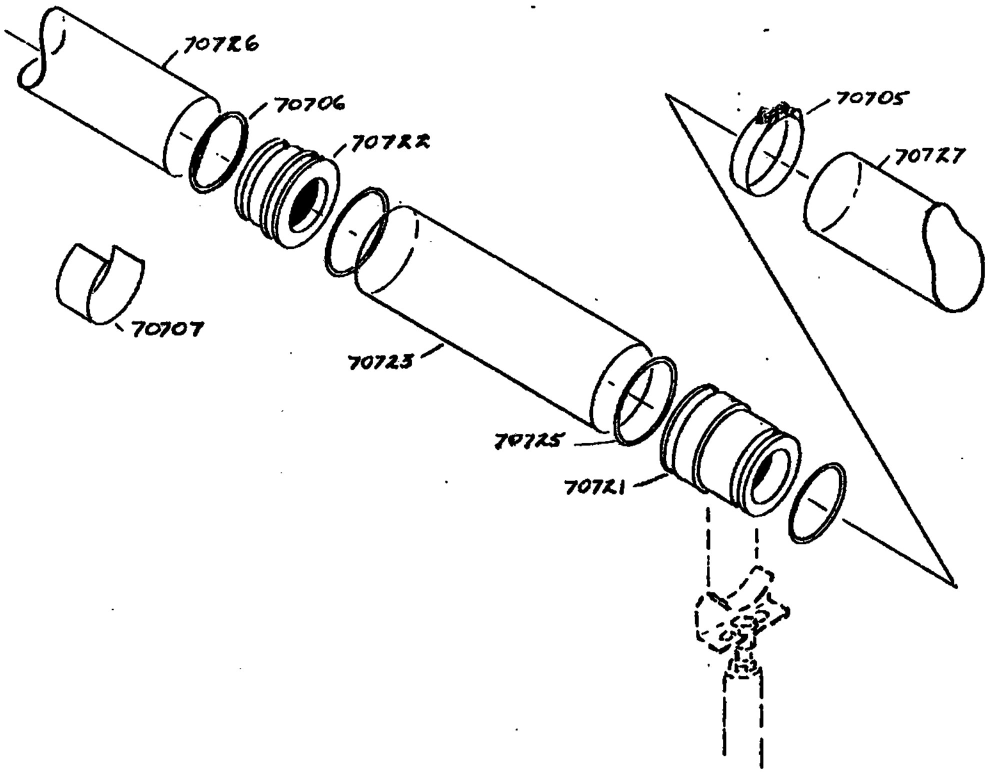


SOLAR KINETICS INC. | INTERMEDIATE O-RING RETAINER | 70700

DESCRIPTION	P/N	QTY
RET., O-RING	70711	1
CLAMP	70712	1
BELLOWS	70713	1
O-RING	70706	1
SLEEVE	70714	1
SHIELD	70707	1
SHIELD	70715	1

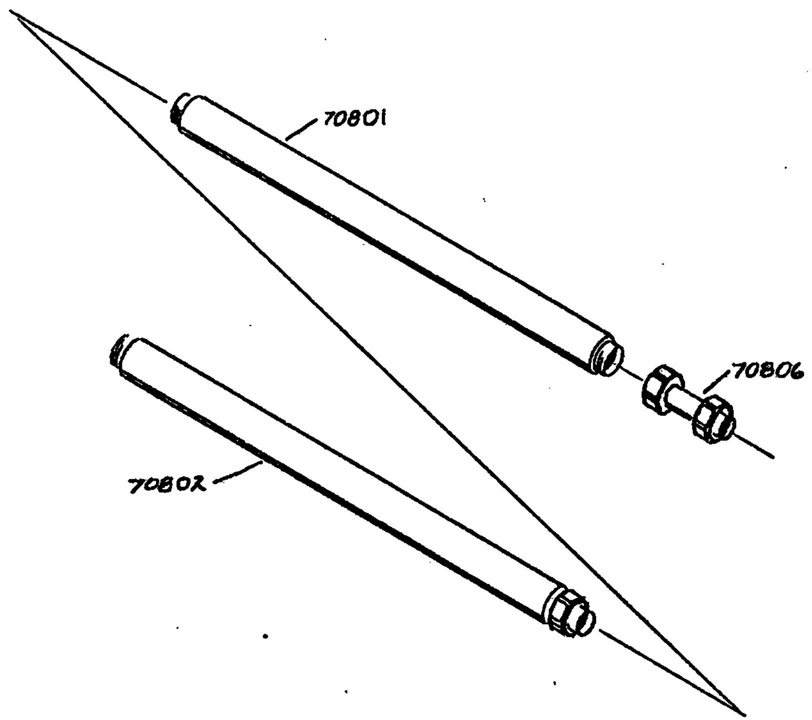


SOLAR KINETICS INC. | END O-RING RETAINER | 70710



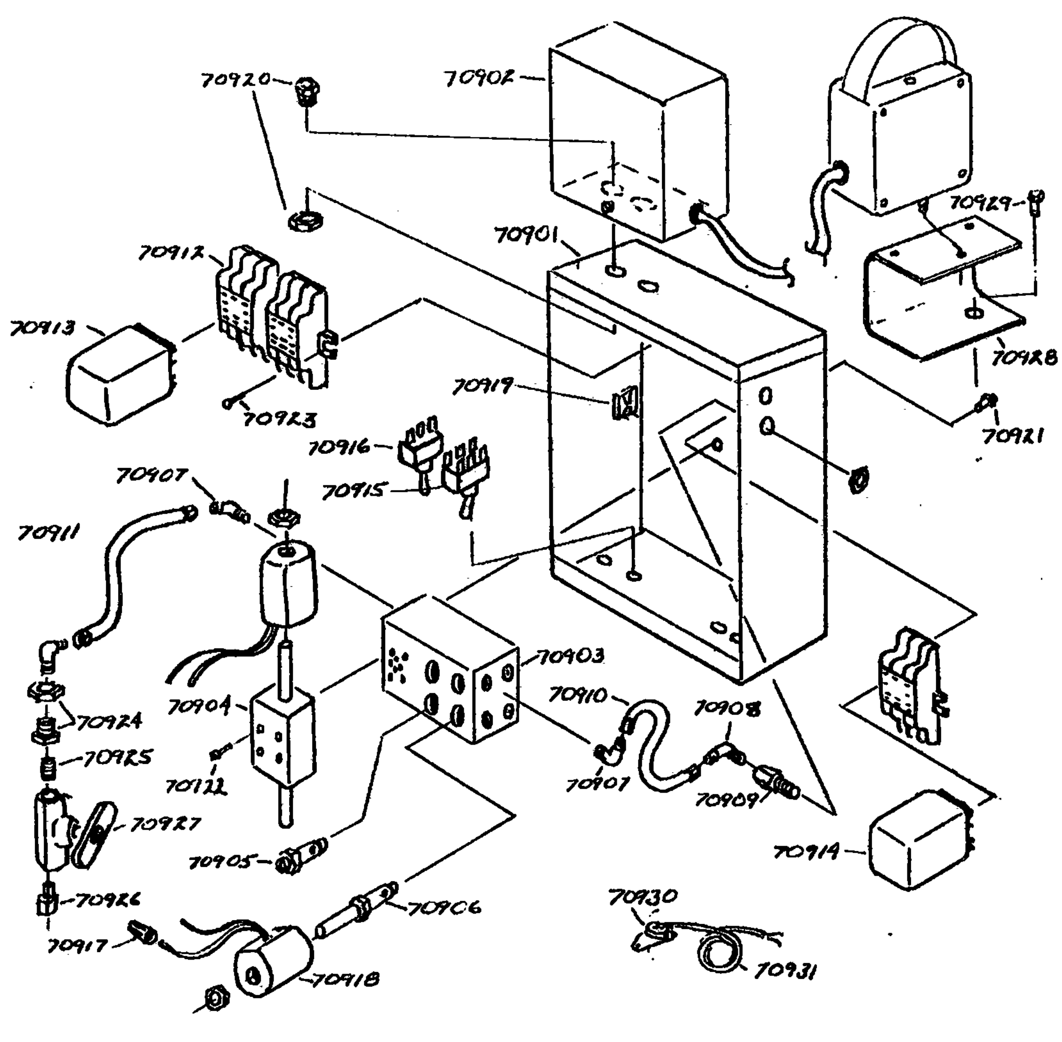
DESCRIPTION	P/N	QTY
TEFLON ADAPTER	70721	1
TEFLON ADAPTER	70722	1
TUBE, GLASS, 75MM	70723	1
O-RING	70724	2
O-RING	70725	2
CLAMP	70705	1
TUBE, GLASS 64MM	70726	1
TUBE GLASS 64MM	70727	1
SHIELD	70707	4

SOLAR KINETICS INC.	RECEIVER JACKET ASSY, CENTER	70720



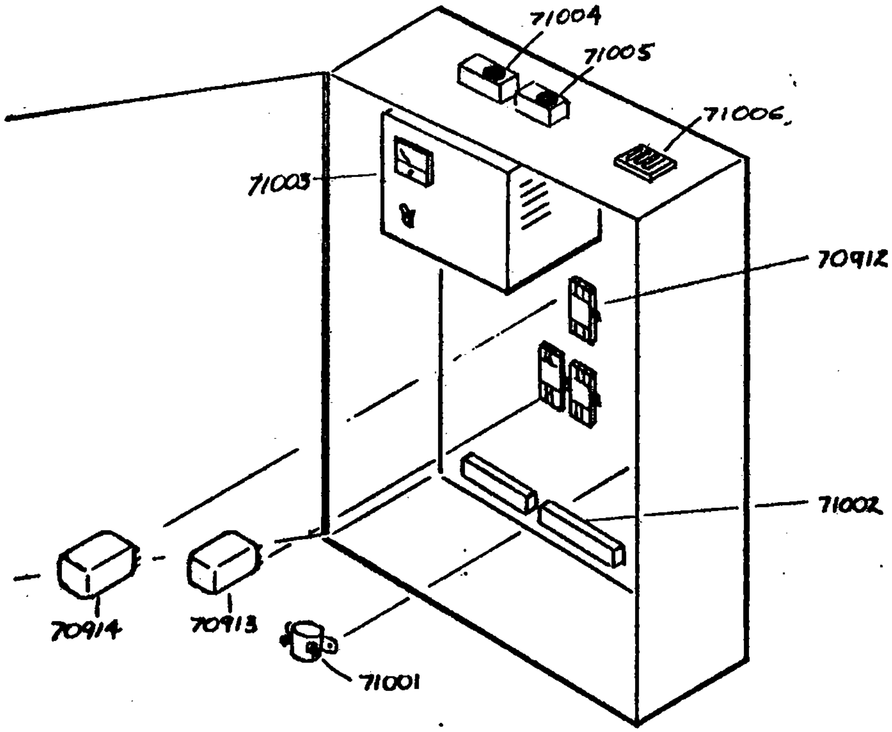
DESCRIPTION	P/N	QTY
REC TUBE	70801	
REC TUBE	70802	
UNION, CENTER	70806	

SOLAR KINETICS INC. | RECEIVER TUBE | 70800



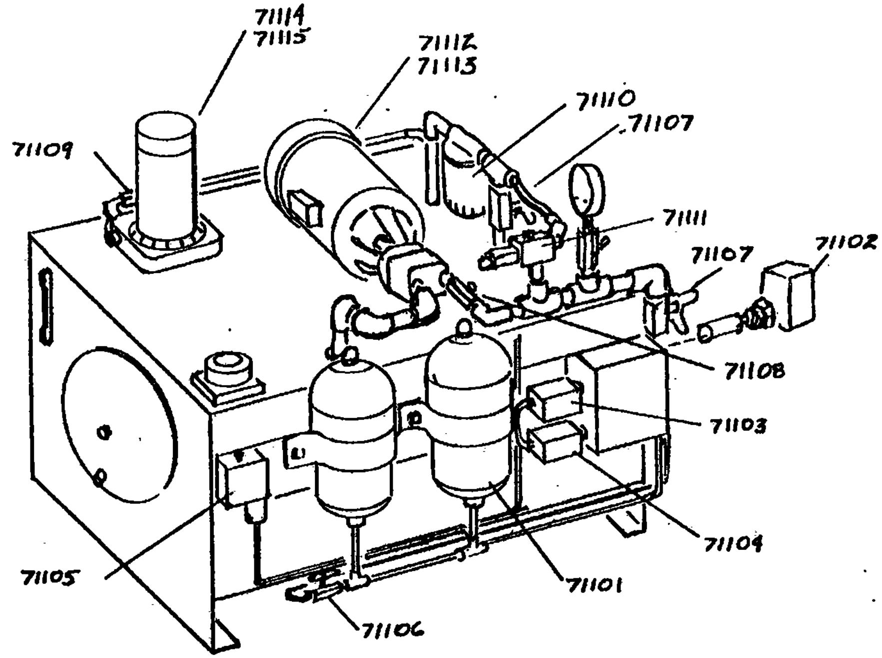
DESCRIPTION	P/N	QTY
BOX	70901	1
TRACKER	70902	1
SUBPLATE	70903	1
VALVE, 4-WAY	70904	1
VALVE, NEEDLE	70905	2
VALVE, BYPASS	70906	2
FITTING, HYD	70907	6
FITTING, HYD	00908	2
FITTING, HYD	70909	2
HOSE, HYD	70910	2
HOSE, HYD	70911	2
BASE, RELAY	70912	3
RELAY, 120VAC	70913	2
RELAY, 24VDC	70914	1
SWITCH, DPDT	70915	1
SWITCH, SPST	70916	1
NUT, WIRE	70917	3
COIL, SOLENOID	70918	4
PAD, TY-WRAP	70919	11
NIPPLE, CHASE	70920	2
BOLT	70921	2
BOLT	70922	4
SCREW	70923	5
FITTING, HYD	70924	2
FITTING, HYD	70925	2
FITTING, HYD	70926	2
VALVE	70927	2
BRACKET	70928	1
BOLT	70929	1
SWITCH, TEMP	70930	1
WIRE, SHIELDED	70R31	1

SOLAR KINETICS INC.	HYDRAULIC + ELECTRICAL CONTROLS	70900



DESCRIPTION	P/N	QTY
RELAY, 24 VDC	71001	1
BLOCK, TERM	71002	2
RELAY BASE	70912	3
RELAY, 120 VAC	70913	2
RELAY, 24 VDC	70914	1
PWR SUPPLY, 24 VDC	71003	1
SWITCH, LIGHT	71004	1
SWITCH, LIGHT	71005	1
SWITCH, RAIN	71006	1

SOLAR KINETICS INC. | CENTRAL ELEC. PANEL | 71000



DESCRIPTION	P/N	QTY
ACCUMULATOR	71101	2
SWITCH, LEVEL	71102	1
" PRESS 600-700	71103	1
" PRESS 700-1000	71104	1
" MAN RST	71105	1
VALVE, BLEED	71106	1
" , OUTPUT	71107	2
" RETURN	71108	1
" CHECK	71109	1
FILTER, OIL	71110	1
PRESS REGULATOR	71111	1
KIT, SEAL	71112	1
COUPLING	71113	1
KIT, SEAL	71114	1
COUPLING	71115	1

SOLAR KINETICS INC.	HYDRAULIC POWER SUPPLY	71100