MASTER

Dr. 2219

DOE/SF/10750-1 2

D157-250
NTIS-25

DOE/SF/10736-1/2
Distribution Category UC-62

SOLAR INDUSTRIAL RETROFIT SYSTEM

NORTH COLES LEVEE NATURAL GAS PROCESSING PLANT

FINAL REPORT

TECHNICAL REPORT

July 1980

Prepared for the

U. S. DEPARTMENT OF ENERGY

As part of

Contract No. DE-AC03-79SF10736

by

Northrup, Incorporated
and
ARCO Oil and Gas Co.

FOREWORD

This report was prepared for the Department of Energy under Contract No. DE-AC03-79SF10736. It presents the results of a ten (10) month study to develop a site specific conceptual design of a solar retrofit system for the ARCO Oil and Gas Company North Coles Levee Natural Gas Processing Plant near Bakersfield, California.

The guidance and support of the Department of Energy Program Manager, Fred Corona, and the technical assistance and support of Jim Gibson of Sandia National Laboratories were of great benefit in the performance of this study and their contributions are hereby acknowledged.

The authors of the report are the persons responsible for performing the design and analysis work and include; F. A. Blake, A. J. Anderson, R. J. Thomas and R. L. Henry of Northrup, Inc. and H. E. Wold, W. S. Deinlein and Louis Hartmangruber of ARCO Oil and Gas Co.

The report is bound in two books. One is the technical report of the conceptual design effort and the other is an appendicies which contains quantities of supporting data and methods too voluminous for inclusion in the technical report. Section 1 of the technical report, "Executive Summary" is also published under separate cover.

The technical report is organized into seven major sections.

Section 1	Executive Summary
Section 2	Introduction
Section 3	Selection of Perferred System
Section 4	Conceptual Design
Section 5	Subsystem Characteristics
Section 6	Economic Analysis
Section 7	Development Plan

The appendicies book contains seven subjects that directly relate to the design work.

Appendix A	Systems Requirement Specification
Appendix B	Environmental Impact Assessment

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES

SECTION 1.0

EXECUTIVE SUMMARY

This volume summarizes project work performed by Northrup, Inc., a subsidiary of the Atlantic Richfield Company, for the U. S. Department of Energy (DOE) under DOE Contract No. DE-AC03-79SF10736 during the period September 15, 1979 - July 15, 1980. The purpose of the project was to develop a site-specific conceptual design for a practical and cost-effective solar retrofit system to supply process heat for a representative petroleum industry application.

The application selected for the project is the processing of natural gas to:

- Extract natural gas liquids and produce propane, butane and gasoline from them.
- Condition the residue natural gas for marketing.

The process requires heat in the 193 to 304°C (380-580°F) range which is readily achievable with concentrating solar thermal systems. The application is also ideal for solar retrofit because many natural gas processing plants utilize a heat transfer oil which permits an extremely simple interface with the fired oil heaters normally used.

The solar retrofit conceptual design was developed for the ARCO Oil and Gas Company's North Coles Levee Natural Gas Processing Plant No. 8 located near Bakersfield, California. This plant uses gas-fired heaters and gas turbine exhaust heat to heat oil which is then cascaded through a series of reboilers thus supplying process heat at several required temperatures.

1.1 BACKGROUND

This project is part of the U. S. Department of Energy Solar Repowering/Industrial Retrofit Program.

1.1.1 Objective

The objective of the project was to develop a site-specific conceptual design for a practical and cost-effective solar retrofit system to supply process heat for a representative petroleum industry application. The particular application selected for the project is the ARCO Oil and Gas Company's North Coles Levee Natural Gas Processing Plant No. 8 located near Bakersfield, California.

1.1.2 Technical Approach

The technical approach employed by the design team in developing the conceptual design of the solar retrofit system for the North Coles Levee Plant started with establishing preliminary Systems Requirements Specification (SRS) based upon general technical requirements set forth in the contract statement of work, the plant requirements, and the heliostat-central receiver concepts originally proposed. Tradeoff analyses were then performed to determine the system configuration. These tradeoff analyses included collector field size and arrangement, receiver type and configuration, piping arrangement, solar-fossil interface, augmentation temperatures, control approaches and related issues affecting subsystem configurations and major component selection.

Once the subsystem configurations, major components, operating conditions and control approaches were selected, the overall conceptual design was completed in sufficient detail to develop reliable performance estimates and to estimate detailed design and construction costs. An economic evaluation based on a 20-year life-cycle-cost analyses was performed, and environmental and safety assessments were prepared. Finally, a development plan for a phased program leading to system operation in 1984 was prepared.

1.1.3 Design Team

In addition to Northrup, Inc., the design team included the industrial partner, ARCO Oil and Gas Company, also a subsidiary of the Atlantic Richfield Company. Northrup, Inc. served as prime contractor with overall project management responsibility, and was also responsible for the solar system design (collector field, receiver and controls), the performance and economic analyses, and preparation of the development plan. ARCO Oil and Gas Company, in addition to providing general technical assistance and design concurrence, had specific responsibility for the receiver loop design, the solar-fossil interface design, and the environmental and safety assessments.

1.1.4 Design Concept

Figure 1-1 presents an artist's rendering depicting the solar retrofit system installed at the North Coles Levee Plant. An array of 320 Northrup II heliostats (being developed under separate DOE funding) occupies a 120^{o} circular sector with a radius of 304.8 m (1000 ft) requiring a total enclosed land area of 97,288 m^2 (24 acres). Each heliostat has a mirror surface area of 52.6 m^2 (566 ft^2) and is computer controlled (open loop) to maintain focus on a single cavity type central receiver mounted atop a 61m (200 ft) steel tower due south of the heliostat field. The receiver incorporates standard heat exchanger panels to absorb the concentrated solar radiation.

Heat transfer oil used by the natural gas processing plant (located behind the tower in Figure 1-1) is directed through the receiver panels where it is heated to $293^{o}C$ ($560^{o}F$) when the solar system is in operation. At design conditions (noon, summer solstice) the solar system will supply 9518 KW_t (32.5×10^6 Btu/hr.), or approximately 90 percent of the heat normally supplied by the plant's existing gas-fired heaters. The gas-fired heaters, which are throttled and kept on line to compensate for solar interruptions, supply the balance of heat and maintain a uniform outlet temperature of $301^{o}C$ ($575^{o}F$).

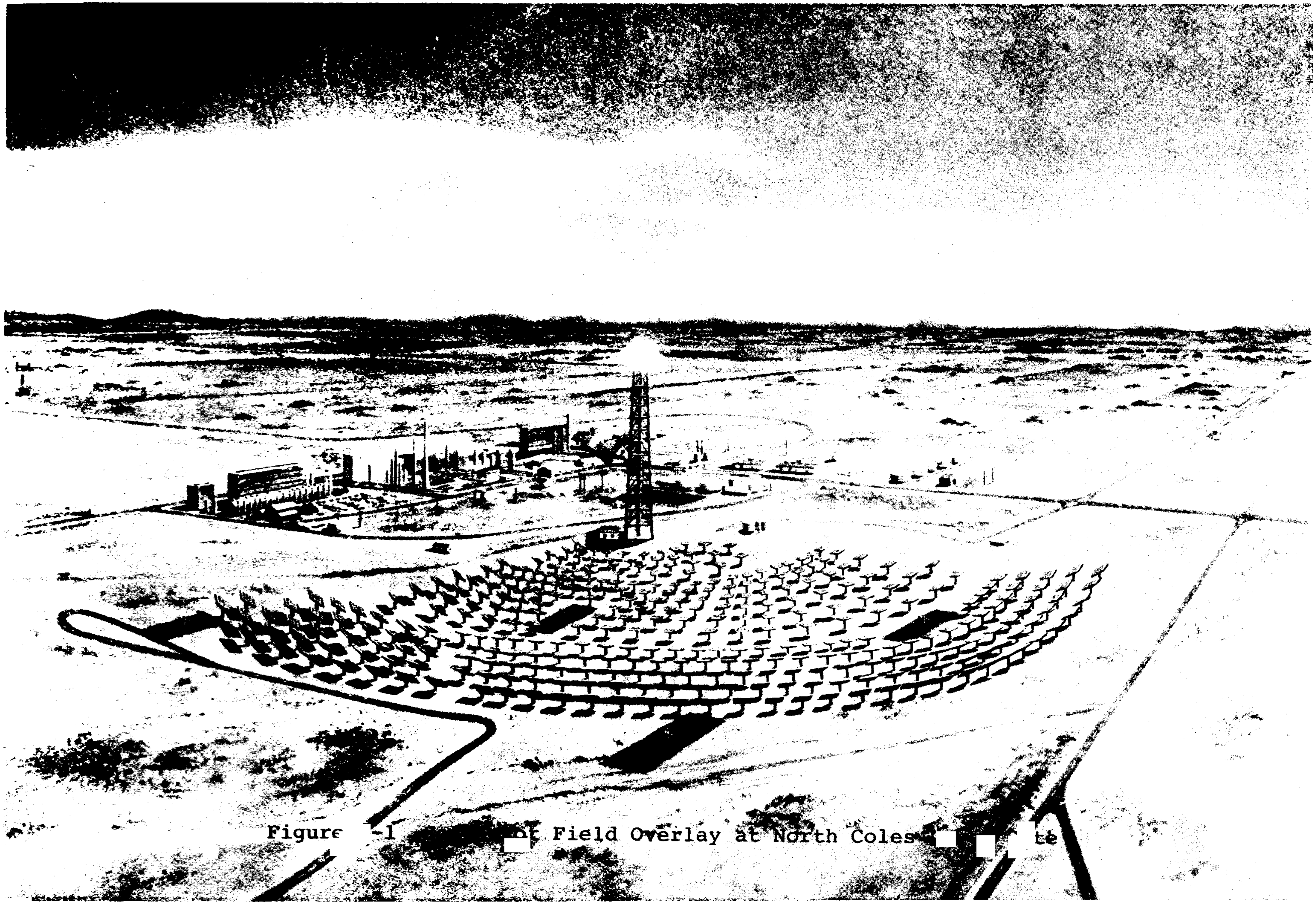


Figure -1 of Field Overlay at North Coles te

On an annualized basis, the solar retrofit system will supply 24.4 percent of the total process heat requirements that otherwise would be supplied by the gas-fired heaters. Based upon an assumed cost of $\$100/m^2$ for production heliostats and taking maximum advantage of applicable tax credits, the energy supplied by the solar system over a 20-year life cycle would cost 47 percent less than the same amount of energy supplied by natural gas.

1.2 SITE DESCRIPTION

1.2.1 Location

The site for the installation of the solar collector/receiver system is adjacent to the North Coles Levee Natural Gas Processing Plant No. 8 which is located approximately 35.4 km (22 mi.) west of Bakersfield, Kern County, California. This places it near the southern end of the San Joaquin Valley. The floor of the valley at this location is flat and relatively level and the soils are loose well-drained loam containing rock fragements.

1.2.2 Climate

The general climate of the plant area is warm and semiarid. The normal rainfall is around .15 m (6 in.), 90% of which falls from October through April. Winters are mild and tend to be fairly humid with intermittant foggy conditions. Summer skies are clear and conditions are usually hot and dry. Annual average direct normal solar insolation is between 6 and 7 kwh/m^2 daily.

The seasonal average clear day conditions obtained from the U.S. Weather Service in Bakersfield are as follows:

Clear	202 days
Partly Cloudy	78 days
Cloudy	85 days (includes 22 days of heavy fog)
Precipitation	.254 mm (0.01 in) 36 days
Thunder showers	3 days

1.2.3 Plant Process

The plant is a refrigerated absorption oil plant that recovers propane, butane, and gasoline from raw natural gas. A simplified flow diagram of the process is presented in Figure 1.2. The process consists of the raw gas from the field being dehydrated and bubbled through an oil that absorbs the hydrocarbons with molecular chains longer than methane. The absorption oil is then flowed sequentially through the deethanizer where the ethane fraction is removed; the strippers where the natural gas liquids are separated from the absorption oil; the depropanizer where the propane fraction is removed; and finally to the debutanizer where the butane is removed leaving raw natural gasoline. The separation process at each station is powered by the selective application of heat energy. For safety reasons the entire process avoids the direct use of flame and is powered instead by a heat medium oil (HMO) that is heated remotely and circulated to the stripper deethanizers, depropanizer and debutanizer reboilers (See Figure 1.2). The system operates between 193°C (380°F) and 301°C (575°F). The process heat is supplied by a combination of two fired heaters and one heat recovery unit that operates on waste heat from a continuously operated gas turbine. Nominally, $8.00 \times 10^3 m^3$ (2.1×10^6 gal) of HMO are circulated through the system daily; 73% of which is heated by the fired heaters. These heaters consume .33 m^3/s (1.0×10^6 scfd) of natural Gas. The solar system is designed to displace a significent portion of this natural gas consumption.

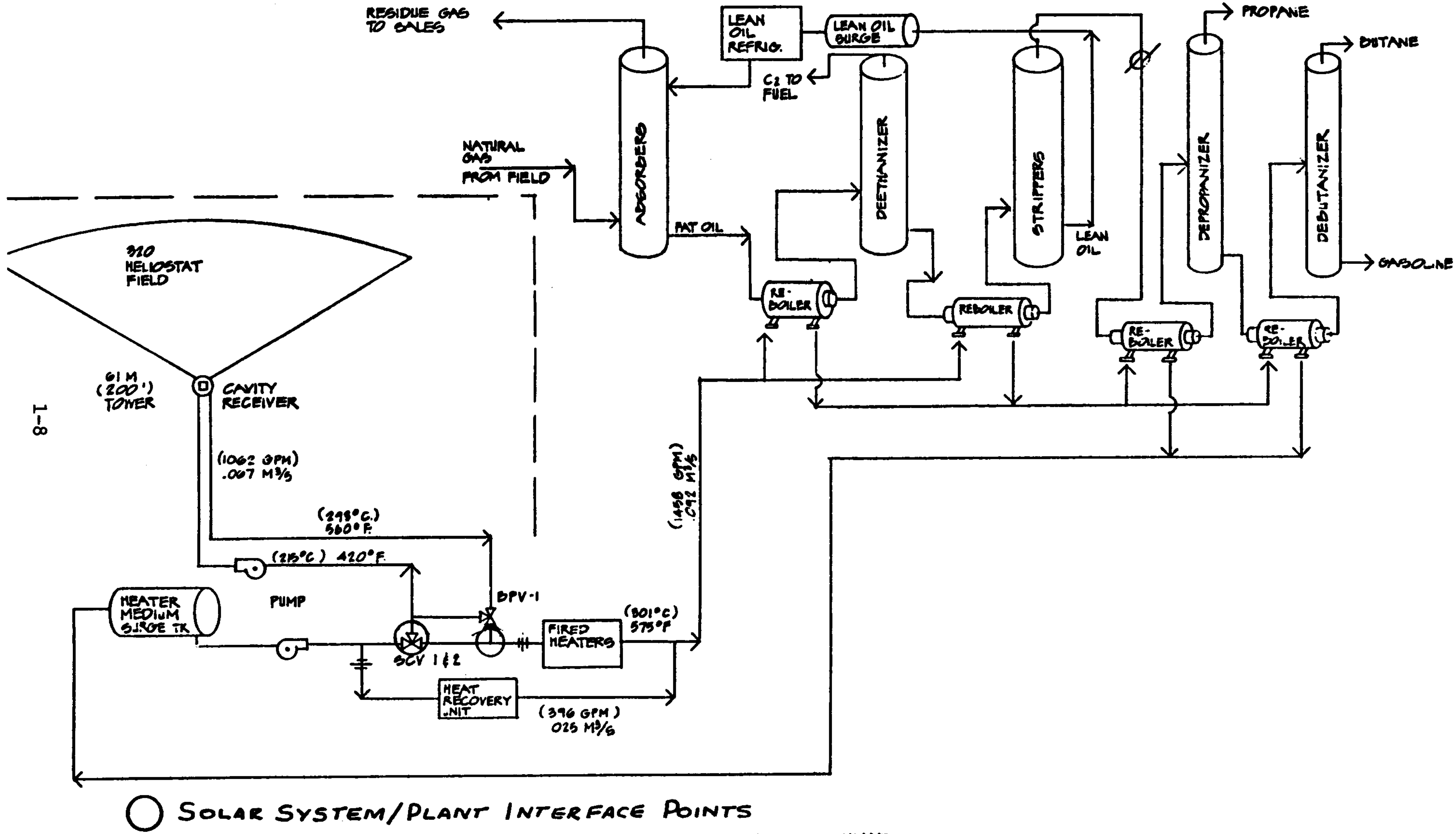


Fig 1-2 North Coles·Levee Industrial Retrofit

Flow Diagram

1.3 PROJECT SUMMARY

Programmatic

The project began on September 15, 1979 and was scheduled for completion on June 15, 1980. There has been a subsequent modification (A) that extended the period of performance until July 15, 1980.

The funding level was established at $310,526 which includes all direct, overhead and G&A costs and fee. This sum provided for 9,935 manhours along with relatively small amounts for computer usage and travel.

During the course of the design and analysis, all major milestones were accomplished on schedule and the contract completed well within the budgeted funds.

Technical

The central purpose guiding the design effort during the course of the project has been to develop the most efficient process heat system for minimum cost, within land use and other site specific constraints. This has been accomplished through the judicious selection of parametric and tradeoff analyses involving the collector field configurations, receiver types, system interface, augmentation temperatures, and control strategies. Critical evaluation and utilization of the results of these analyses have produced a system that has significant value not only for the North Coles Levee site, but for many other sites that utilize similar process heat applications.

The more important performance and operational characteristics of the system that contribute to the unique design are as follows.

. All solar energy collected is utilized, except for small transfer losses.

. The control system is simple, straight forward and minimizes the use of control valves, pumps, and other active components.

- The fired heaters are maintained at operating temperatures providing the system with excellent response to solar startup, shutdown and cloud transient conditions.

- The range of operating temperatures (215-296^{o}C) and pressures 6.9 x 10^2 kPa (100 psi) permits the use of low cost carbon steel for the embossed receiver panels, pipes, valves and fittings.

- The same fluid serves as both receiver and heat transfer fluid.

- Minimum impact on normal plant operation and procedures.

- The collector field configuration permits continued use of the land for its primary purpose-production of oil and natural gas.

- Easily adaptable to power additional processes or enhanced and secondary oil recovery if this should be desirable or necessary.

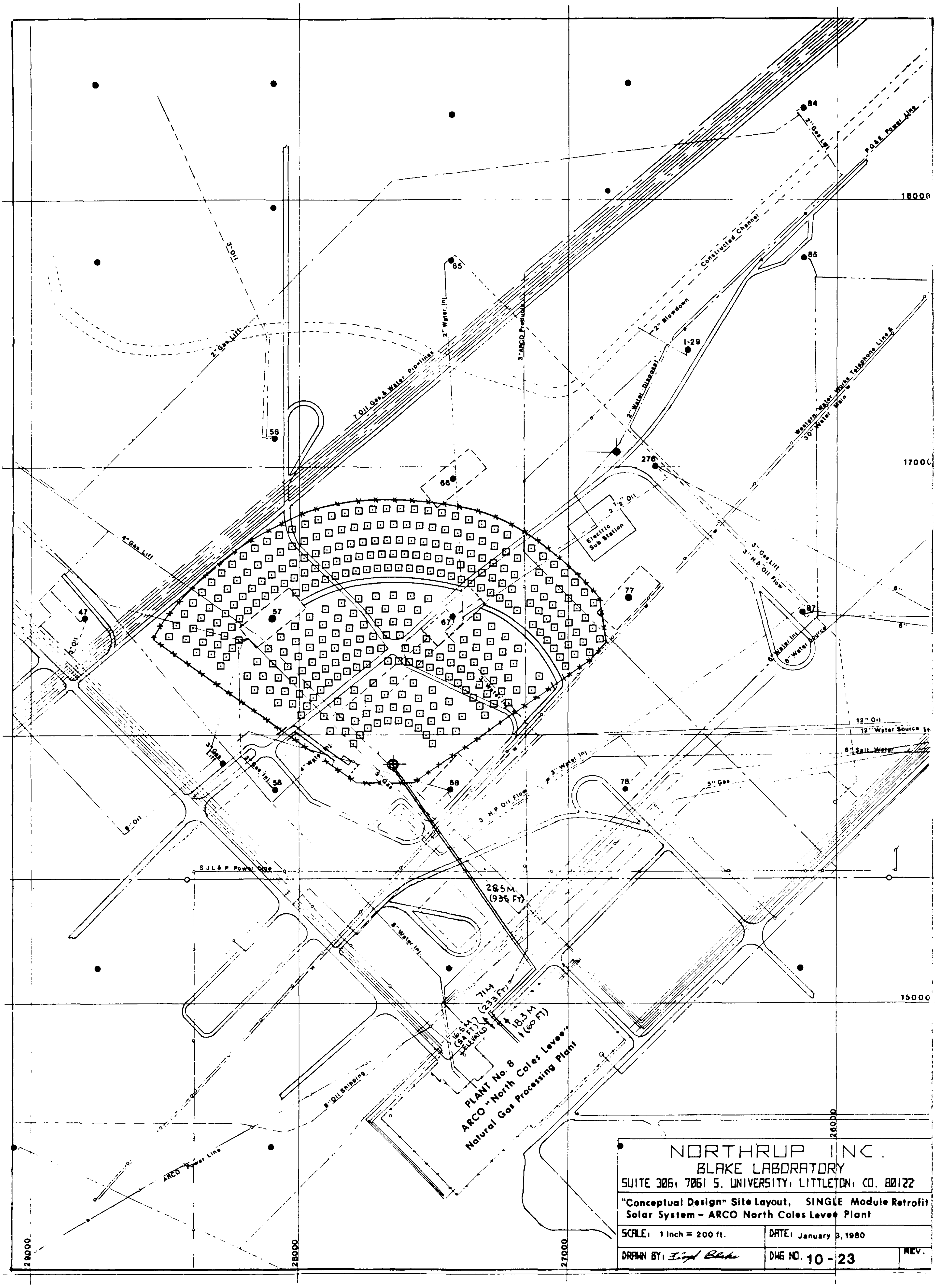
1.4 CONCEPTUAL DESIGN

The flow relationship between the solar process heat system and the existing plant is shown in Figure 1-2. In order to facilitate the design and analysis process, the solar plant has been divided into three interdependent systems. These are: the collector system, composed of the heliostats and associated field and unit control system; the receiver system, which contains the receiver and tower; and the receiver loop, that includes the riser and downcomer, interconnect piping, and the control valves and associated instrumentation.

The collector field is composed of 320 heliostats arranged in a radial stagger configuration and located north of a single cavity receiver with the aperture centerline 61 m (200 ft.) above ground level, Figure 1-3. The receiver is positioned atop a 3-legged steel tower. The tower mounted riser and downcomer are connected to the existing heat medium oil system near the inlet to the fired heaters by a 381 m (1250 ft.) above grade piping run.

Collector System

The heliostat selected for the design of the North Coles Levee process heat system is the Northrup II, Figure 1-4. It is a dual axis tracking heliostat with a pedestal mount. The normal stow position is vertical but under anticipated extreme high wind conditions, it is driven to a horizontal orientation with the reflective surfaces facing up. The gross face area of the heliostat is approximately 7.62 m (25 ft. x 25 ft.) with mirror module spacing and edge treatment the net reflective area is 52.6 m^2 (566 ft^2). Each mirror is nominally 4 feet by 12 feet with a 3 inch depth. 12 modules comprise the mirror array for each heliostat. The mirror support rack consists of open roof-type trusses which are combined with tubular members which connect to the drive unit. The drive unit is gear-driven with separate motors



NORTHRUP INC.
BLAKE LABORATORY
SUITE 306, 7061 S. UNIVERSITY, LITTLETON, CO. 80122
"Conceptual Design" Site Layout, SINGLE Module Retrofit Solar System - ARCO North Coles Levee Plant
SCALE: 1 inch = 200 ft.
DATE: January 3, 1980
DRAWN BY:
DWG NO. 10 - 23
REV.
PLANT No. 8
ARCO "North Coles Levee" Natural Gas Processing Plant
285 M (935 FT)
71 M (233 FT)
18.3 M (60 FT)
16.5 M (54 FT)
Electric Sub Station
Constructed Channel
PG&E Power Line
S J L & P Power Line
ARCO Power Line
Western Water Works Telephone Line & 30" Water Main
7 Oil Gas & Water Pipelines
3" ARCO Products
2" Blowdown
2" Gas Lift
4" Gas Lift
3" Gas Lift
3" H.P. Oil Flow
8" Water Inj
6" Water Source
12" Oil
12" Water Source
8" Salt Water
8" Oil Shipping
18000
17000
15000
28000
27000
26000

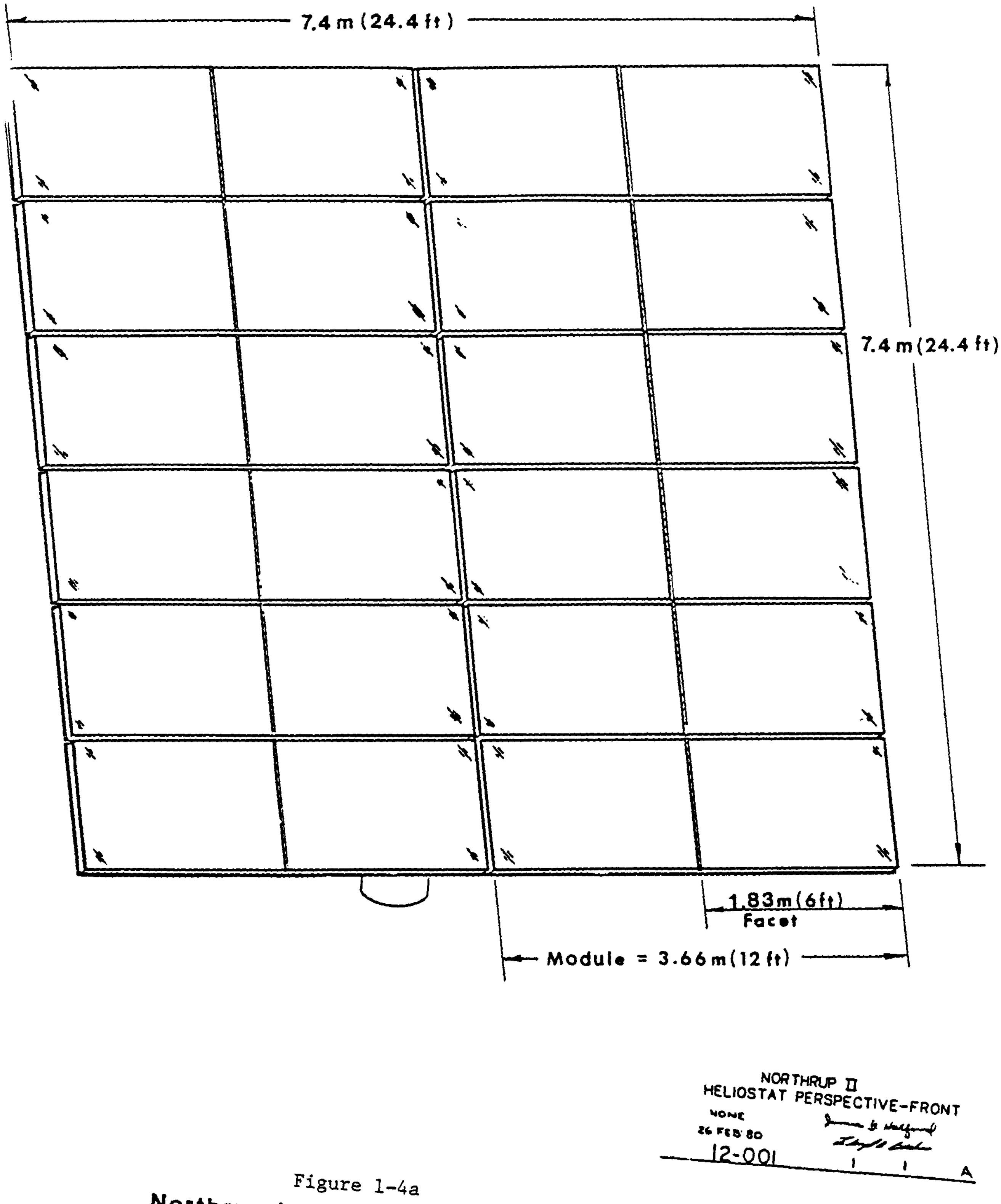


Figure 1-4a

Northrup II Heliostat Front View

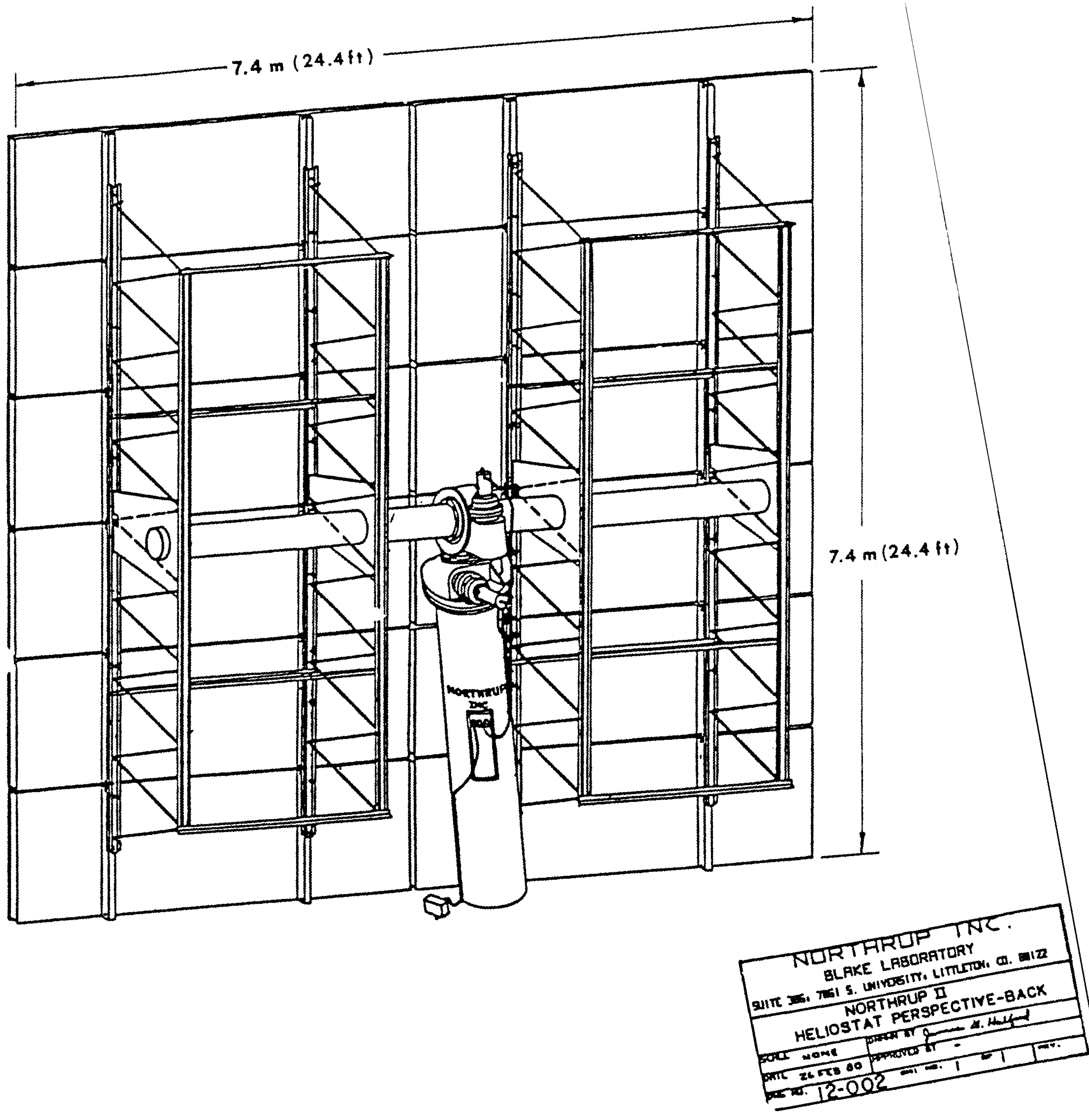


Figure 1-4 b

Northrup II Heliostat - Back View

and gear systems for azimuth and elevation. The foundation for the drive consists of a one-piece cylindrical pipe which is driven into the soil at the site by conventional pile-driving techniques.

The Northrup drive unit incorporates independent azimuth and elevation sections into a unified housing. Both of these drive elements are identical in terms of motor, input-stage, and output stage gearing. The basic drive concept is keyed to the use of D-C stepper motors which provide both motive power (torque) and position control (precise incremental rotation); i.e., no encoders or other continuous position sensors are required. Stepper motors interface well with digital minicomputers and microprocessors, and are able to deliver an accurate rotational increment of 1.8 angular degrees per motor step. An intermediate, printed circuit board device known as a translator provides the sequencing and switching logic which converts pulses from a minicomputer or microprocessor into motor steps, therefore allowing step rate, direction, and number of steps to be controlled by external logic. With proper translator selection, stepping rates as high as 2000 steps/second can be accurately achieved.

The control software for the Northrup II heliostats consists of two packages; one in the control room handling the external data processing, communication, and control and one at the heliostat, handling the internal data processing, communication and direct motor control.

Receiver System

Both a flat plate external receiver and a cavity receiver were analyzed during the project. The selection of the unit field configuration (320 heliostats) dictates that the receiver will be a north-facing cavity type. The flow rate through the receiver has been established at 6.7×10^{-2} m^3/sec (63,750 gal/hr) of heat medium oil (HMO). The normal operation range for the HMO will be 215.5^o

to 293° C (420°F to 560°F). The receiver is being sized to deliver 9.518 MW_t at the point of interface with the existing plant system.

In general, the receiver geometry is a circular arc segment; 120° included angle on a 7.3 m (24 ft) radius; approximately 9.1 m (30 ft) in height; with the aperture centerline 61 m (200 ft) above ground level. An isometric view of the receiver is shown in Figure 1-5.

The design incorporates standard sized heat exchanger panels with reduced and protected fin areas for high flux uses. The panels are available in a wide variety of metals, sizes, flow patterns, manifold connections, pass sizes and embossing patterns.

The Arcoles Analyzer was used to evaluate the system parameters for a number of panel sizes, physical arrangements, and flow patterns to establish an optimum balance and efficiency within the design criteria. A summary of the analyses results are presented below.

Max. Fin Temp.	659° F
Max. Tube Temp.	628° F
Max. Oil Temp.	600° F
Max. Thermal Stress	21,484 psi

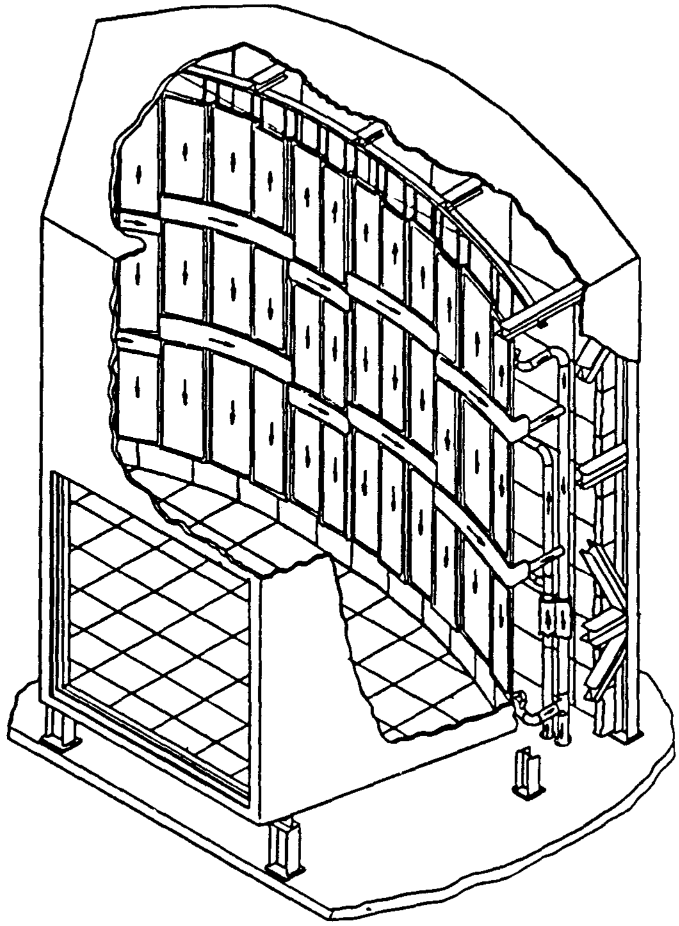
HEAT TRANSFER DATA

TIME/DAY	355	80	173
8:00	88.69	89.54	88.4
10:00	90.33	90.08	88.95
12:00	90.26	90.41	89.36

RECEIVER EFFICIENCY (%)

The number and arrangement of the heliostats dictated an optimum tower height that would place the receiver aperture centerline 61 m (200 ft.) above grade. Steel towers are more cost effective in this height range. The initial tower analysis was performed using the SNLL cost algorithms. A four-legged tower designed to survive in UBC earthquake Zone 4 (0.5g average ground acceleration) and 40.2 m/s (90 mph) wind conditions (Bakersfield area from 100 yr. recurrence interval chart in ANSI-A58.1-1972) was selected for this analysis.

A quote for a three legged tower that would survive under the same conditions was received from Unarco-Rohn. While the actual cost of the



9.518 MW_t Receiver

Fig 1-5

tower structure was significantly higher than that predicted by the SLL equations, the tower costs quoted for the foundation, accessories, engineering and fee resulted in a much lower overall installed cost for the UNarco-Rohn Standard RS-222-C tower ($563,922 vs. $749,560). As a result this tower was selected for the North Coles Levee conceptual design. Figure 1-6 presents a sketch of the RS-222-C tower and shows the service platform and receiver location.

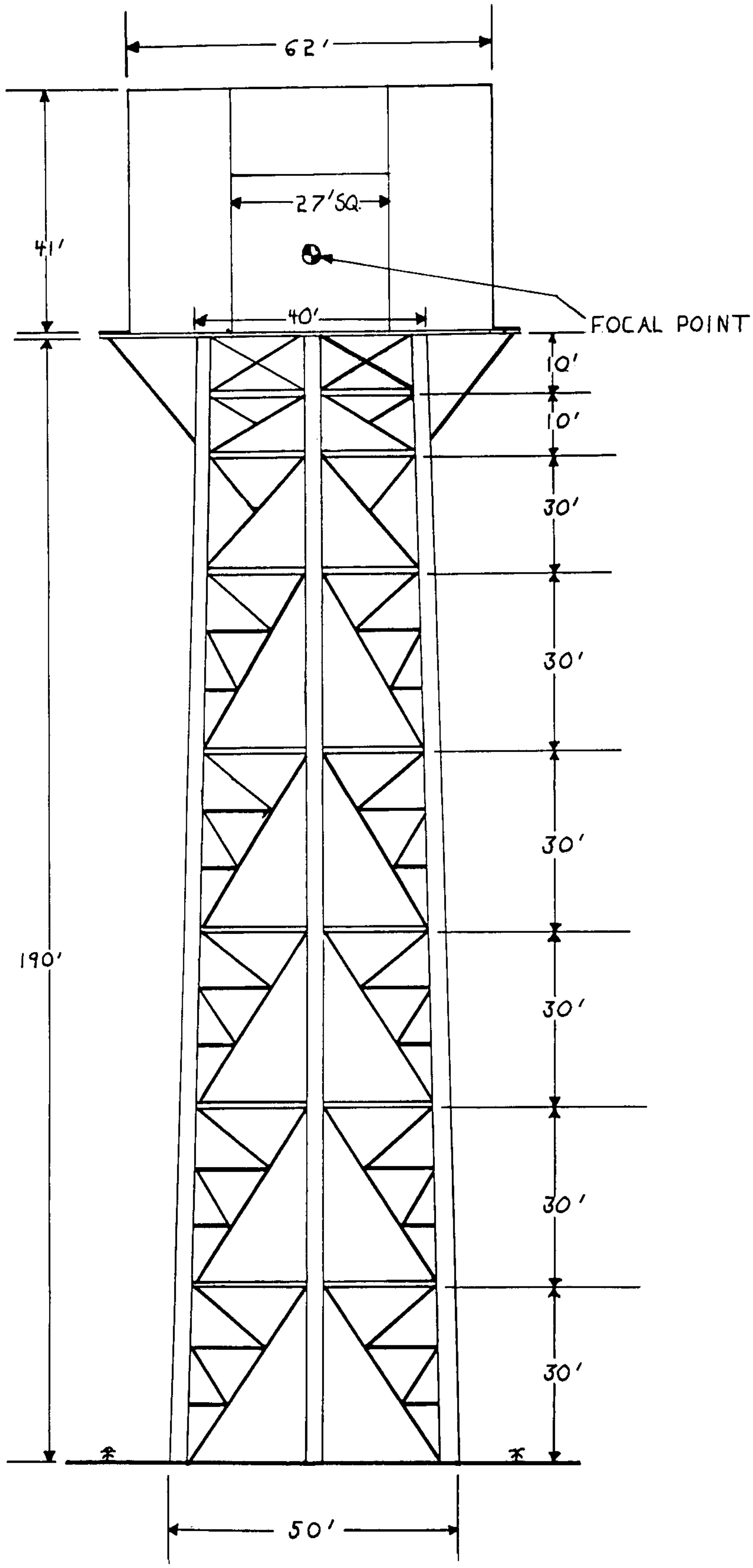
Receiver Loop

The receiver loop contains the riser and downcomer, the piping run between the tower and the existing plant interface, and the interface and bypass control valves. The length of each leg of the piping run 457.2 m (1500 ft.) including the 60.96 m (200 ft.) vertical section. The riser, which carries the HMO from ground level up to the receiver and the downcomer, which returns the HMO to ground level are simply uniform extensions of the linear interconnect piping run.

The relatively low temperatures and pressures to which the system is subjected permits the use of inexpensive Schedule 40 Carbon Steel pipe for the receiver loop piping. A nominal .201 m (8 in.) pipe was selected.

A piping layout showing the piping between the plant and the tower is presented in Figure 1-7. Figure 1-8 shows the actual plant hook up. Both expansion joints and loops were considered. While the loop configuration requires less maintenance, the additional cost of the piping and insulation and the pressure drop penalty (which in turn effects pump costs) eliminated this configuration from further consideration. The pressure drop vs. cost trade off was also the factor that determined the selection of pipe size. Temperatures and pressures were the key consideration in the selection of pipe type and code requirement.

System control is very simple and straightforward. Except for emergencies or major malfunctions, the HMO system is in continuous operation and the temperature of the oil to the process is controlled by automatic control valves located at the inlet to the fired heaters. These valves control the fuel supply to the heaters.



9.5 MW_T RECEIVER-TOWER

Fig 1-6a

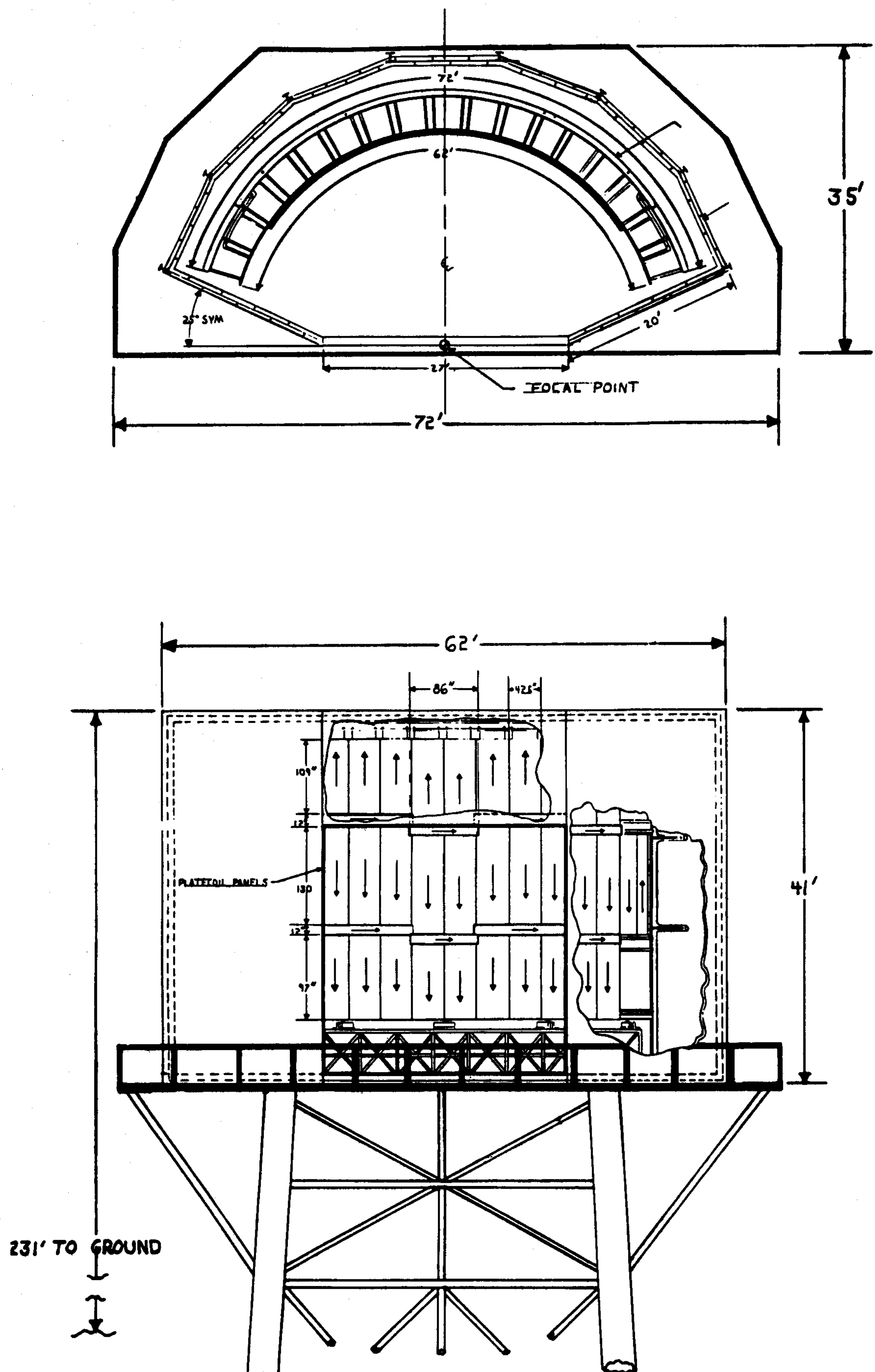


Fig 1-6b 9.5 MW_t Receiver - Tower

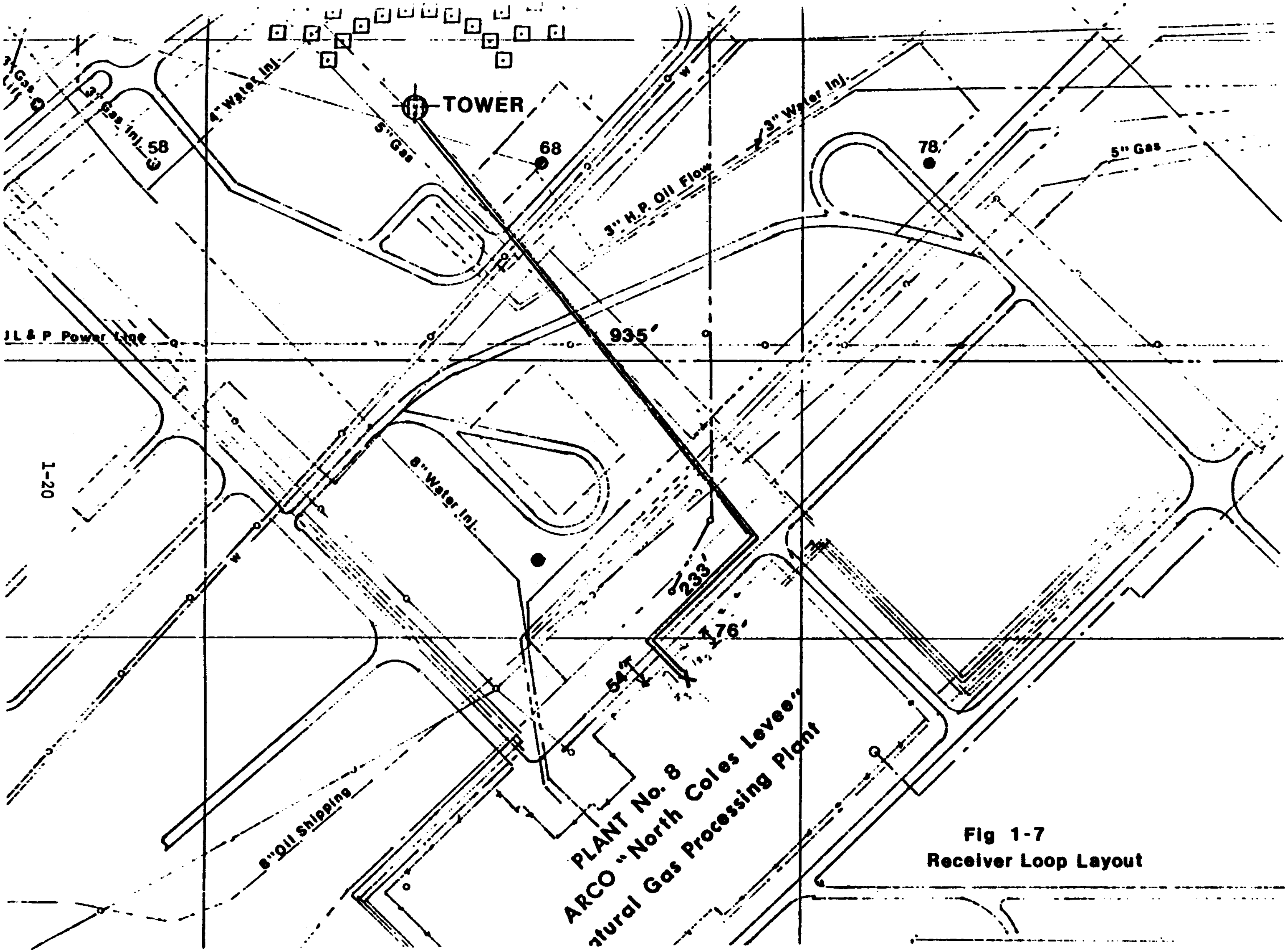
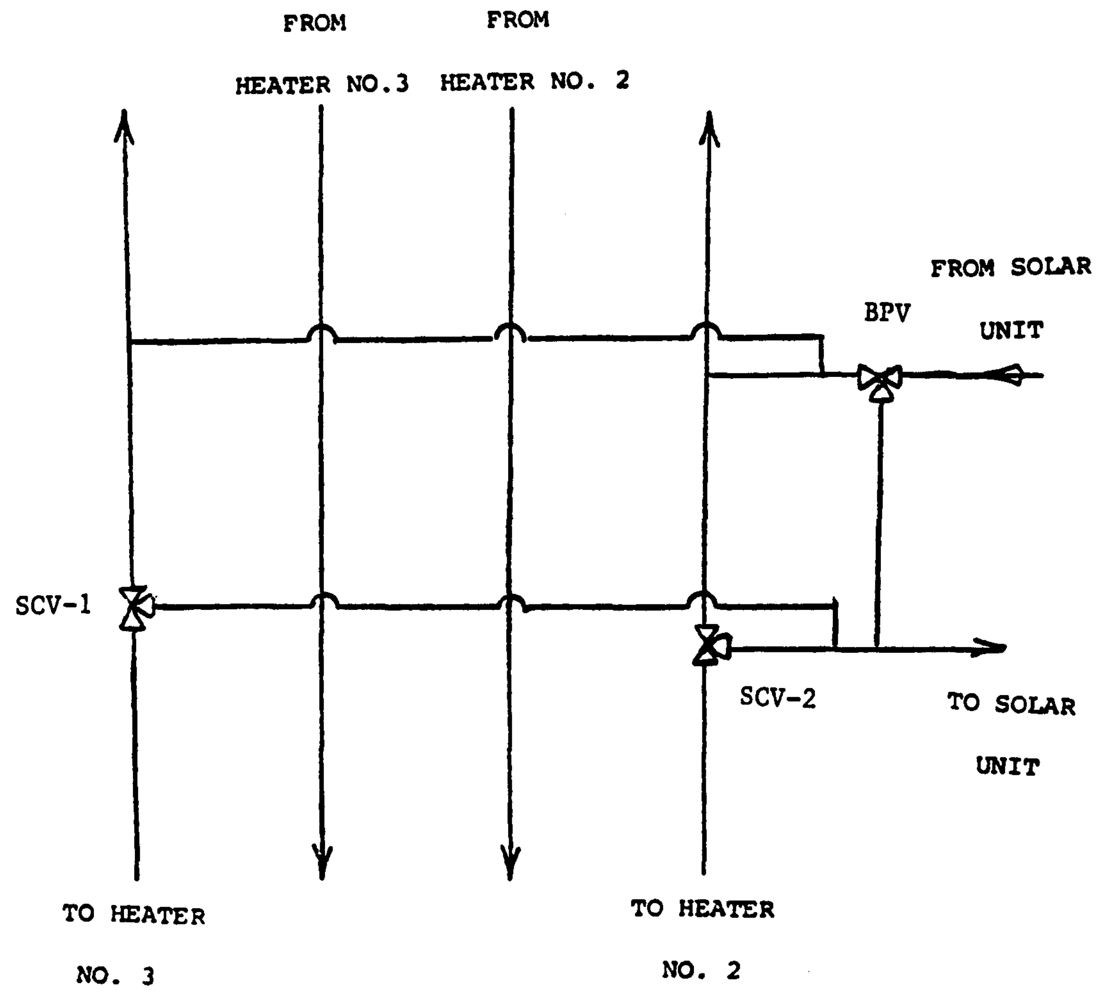


Fig 1-7
Receiver Loop Layout



SYSTEM CONTROL VALUES*

SCV-1	- Temperature Control Valve - 4 in. Reverse Acting
SCV-2	- Temperature Control Valve - 4 in. Reverse Acting
BPV	- Temperature Control Valve - 6 in. Direct Acting

* Air actuated with manual over-ride

Figure 1-8

The receiver loop interfaces with the existing HMO system between the plant pump discharge and fired heaters. A flow diagram of the process, HMO and solar system interface was shown in Figure 1-2. During periods of sufficient insolation, all the HMO that normally flows to the fired heaters is diverted through the receiver and back to the heaters. The heaters then "top-off" the heat required to maintain their outlet temperature of 301°C (575° F). Fuel flow to the heaters is automatically controlled to supply only enough heat to meet the Δ T requirement, or to carry the entire plant load during periods of insufficient insolation. During periods of insufficient insolation, the control valves are closed and the system returns to fossil operation. If, overnight or during long periods of cloud passage, the temperature of the oil in the solar system falls below the minimum system temperature of 215.5° C (420°F), the pump in the receiver loop is turned on and the fluid in the loop is recirculated through the receiver until it reaches the plant system temperature.

Table 1.4-1

CONCEPTUAL DESIGN SUMMARY TABLE

Prime Contractor:	Northrup, Inc.
Major Subcontractor:	ARCO Oil and Gas Company
Site Process:	Natural gas processing utilizing hydrotreated light cycle oil at a temperature of 301° C (575° F).
Site Location:	ARCO North Coles Levee Natural Gas Processing Plant No. 8 located 35 km (22 miles) west of Bakersfield, Calif.
Design Point:	9,518 kW_t (32.5 x 10^6 BTU/hr) at noon summer solstice.
Receiver:	
Fluid:	Hydrotreated light cycle oil
Configuration:	Cavity
Type:	Once through forced circulation
Elements:	Heater only,
Output Fluid Temp:	293° C (560°F)
Output Fluid Pressure:	552 kPa (80 psi)
Heliostats:	
Number:	320
Individual Mirror Area	52.6 m^2 (566 ft^2)
Cost:	\$301/m^2 (average)
Type:	Northrup, Inc., Northrup II
Field Configuration	North
Storage:	None
Total Project Cost:	a. Based on heliostat price of \$301/m^2: (19 heliostats @ \$414/m^2 and 301 @ \$294/m^2) \$8,336,034
	b. Based on heliostat price of \$230/m^2: \$6,448,056.
Construction Time	18 months

CONCEPTUAL DESIGN SUMMARY TABLE (Continued)

Solar Plant Contribution at Design Point:	9.518 mW_t
Solar Fraction (Annual):	24.4%*
Annual Fossil Energy Saved:	21,336 barrels of oil equivalent
Type of Fuel Displaced:	Natural Gas
$\frac{\text{Annual Energy Produced}}{\text{Total Heliostat Mirror Area}}$	1.34 $mWh_t m^2$
$\frac{\text{Capital Cost}}{\text{Annual Fuel Displaced}}$	$368/$mWh_t$
Site insolation (direct Normal):	
Annual Average	2.488 mWh/m^2
Source:	Barstow Weather Tape (1976) x .9
Site Measurements:	Start Date Feb. 7, 1980 Continuing 1/2 hour data reduction

*24.4% of the process heat normally supplied by natural gas. Part of the total process heat utilized is supplied by exhaust heat from a turbine which would otherwise be wasted. It would be counter-productive to replace this part by solar; hence it was not considered in calculating the solar fraction.

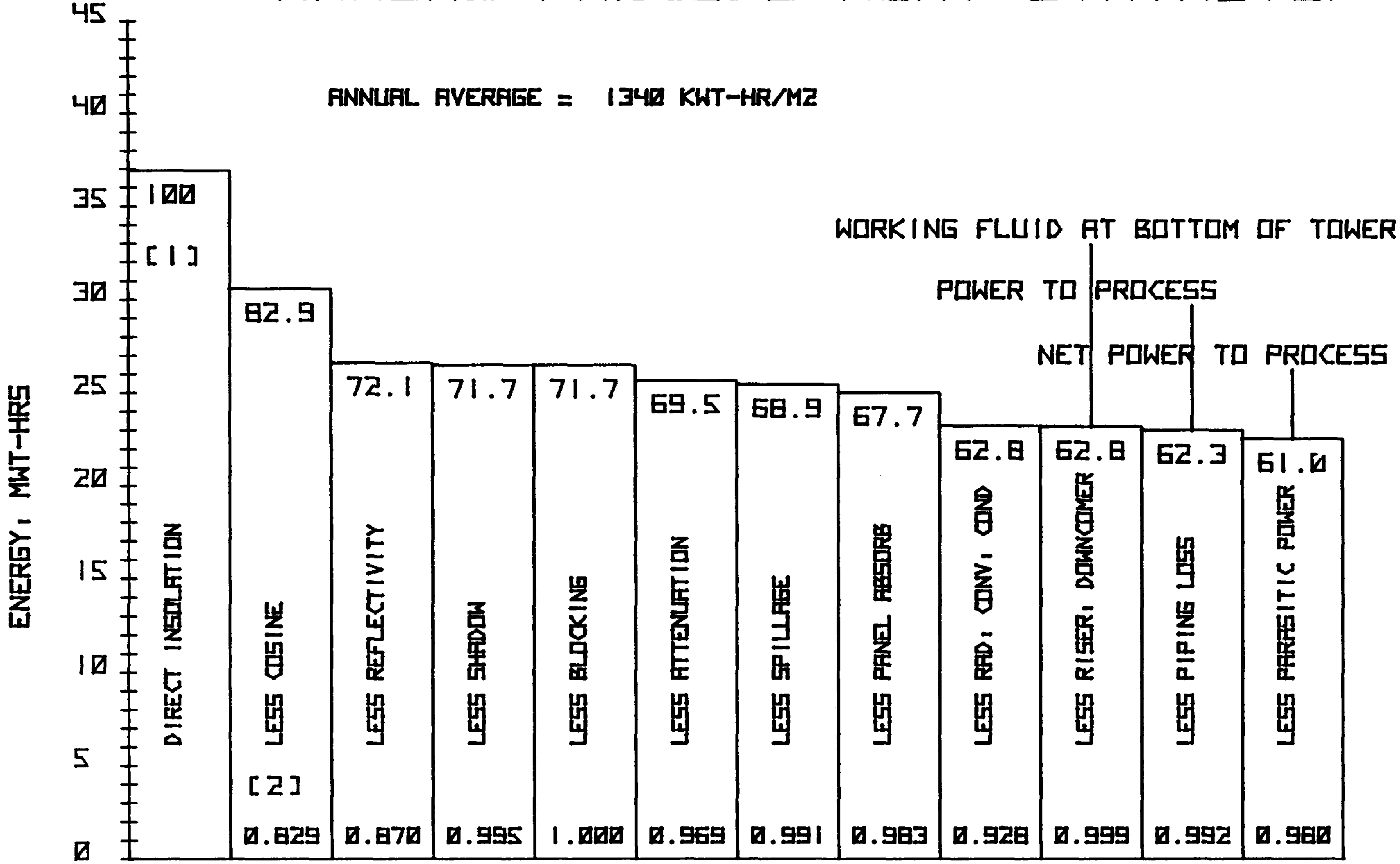
Table 1.5-1

Solar System Annual Energy Projection - Coles Levee Natural Gas Processing Plant

Delivery Point In System	Total Energy		Specific Energy	
	kWht / Yr	BTU / Yr	kWht / m^2	BTU / ft^2
1. Potential Insolation above 500 KW/m^2	36.91×10^6	1.259×10^{11}	2193	6.95×10^5
2. To Receiver Cavity	25.43×10^6	8.679×10^{10}	1510.8	4.79×10^5
3. To "Heat Medium Oil" Loop	23.196×10^6	7.917×10^{10}	1378.1	4.37×10^5
4. To Process "Heat Medium Oil"	22.988×10^6	7.846×10^{10}	1365.7	4.33×10^5
5. Net Benefit to Plant after accounting for Parasitic Power Equivalent Heat	22.55×10^6	7.698×10^{10}	1340.0	4.25×10^5

Fig 1-9

ANNUAL PROCESS HEAT STAIRSTEP



[1] - NET CYCLE EFFICIENCY AT EACH POINT

[2] - EFFICIENCY OF EACH CONVERSION STEP

1.6 ECONOMIC FINDINGS

The total capital cost of the North Coles Levee solar installation is made up of three parts, the Design Phase, the Owner's cost and the Construction cost. The breakdown and total cost is:

1.	Design Phase	$ 1,658,762
2.	Owner's Cost	118,973
3.	Construction Cost	6,558,299
		$ 8,336,034

The project construction costs are summarized in Table 1.6-1.

Table 1.6-1

CONSTRUCTION COST SUMMARY

5100	Site Improvements		$ 95,390
5200	Site Facilities		138,605
5300	Collector System		4,840,602
5400	Receiver System		1,176,411
	5410 Receiver	$612,489	
	5420 Tower	563,922	
5900	Receiver Loop System		792,553
	Total Construction Costs		$ 7,043,561
	Reduced by items common to development module (Ref. SRS Table 9)		485,262
	NET CONSTRUCTION PHASE COST		$ 6,558,299

The evaluation of the economic feasibility of this project involves the use of several variables and assumptions, each of which can affect the answer significantly. The final decision to construct this project is a matter of judgement relative to the set of assumptions and forecasts into the future, and the goals which the participants wish to accomplish.

If viewed strictly from the standpoint of economic returns, in competition with wholesale natural gas the project is marginal, in that the rate of return on the investment is in the neighborhood of 6% to 10%, coupled with moderate risk. For risks of this nature, an investor normally would demand about 15% return.

However this project should be viewed at least partially from the standpoint of it being part of the early stages of development of a new energy source to offset the rapidly escalating price of fossil fuels. Therefore, an expenditure with a lower rate of return is justifiable, in that, as these systems are installed, operated, and improved, learning should increase, costs should decrease, and rates of return should increase. This project can accomplish a significant step in this process while returning a small to moderate rate of return on investment, which is a desirable situation. Our conclusion is that the project should be undertaken.

In order to evaluate the project economically, a set of values was assigned to each input parameter. These values were selected to be what we believe the real situation will be at the time of installing and operating the North Coles Levee project. These values are specified in Table 1.6-2.

Table 1.6-2

ECONOMIC ASSUMPTIONS

Initial System Cost	$8.34 million
Cost of Money Use - Interest Rate	11.5%
System Life	20 years
1st Year Operation & Maintenance (O & M)	$218,044
O & M Escalation Rate	8% per year
Federal Depreciation Period	11 years
Federal Depreciation Formula	DDB + SYD
California Depreciation Period	3 years
California Depreciation Formula	S.L.
Federal Income Tax Rate	46%
California Income Tax Rate	3.5%
Solar Energy Into Process	76,981 mil. Btu
Burner Efficiency	62.5%
Gas Price (at meter) Escalation Schedule	11% SNLL ARCO AVG.
Federal & California Tax Credits	10%, 15%, 10%

Using this set of assumptions, the following results are obtained:

	GAS ESCALATION SCHEDULE	
	11% SNLL	ARCO AVG.
Rate of Return	6.0%	9.2%
Energy Cost (20 yr. avg)		
. Solar	2.07 ¢/kWh_t	2.07 ¢/kWh_t
. Gas	2.27 ¢/kWh_t	3.00 ¢/kWh_t

Figure 1-10 and 1-11 illustrate the yearly trends and comparison of solar vs. gas energy cost.

Fig. 1-10 ECON CASE C, COLES, PILOT PROD HELIOSTAT DOE GAS ESCALATION SCHEDULE

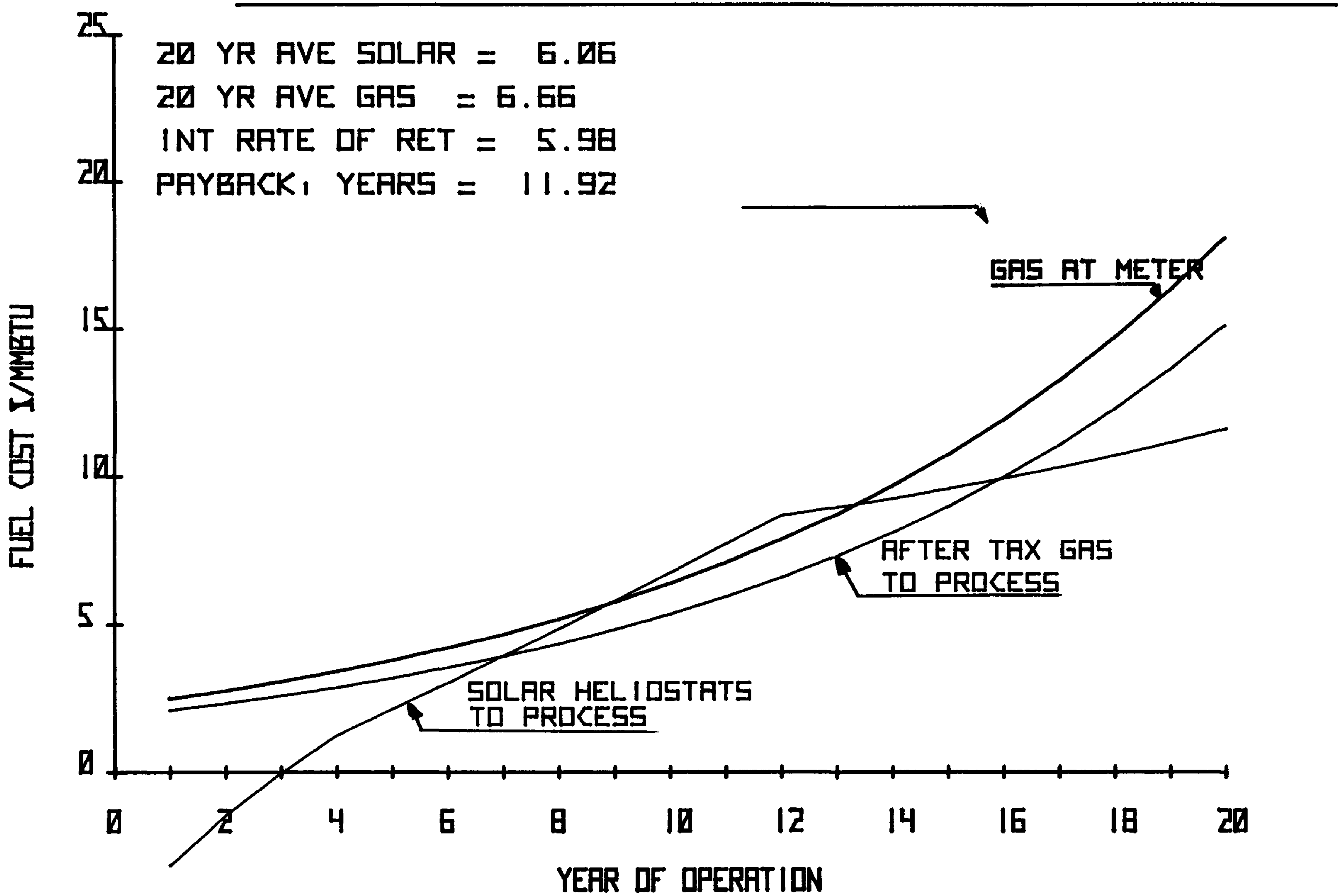
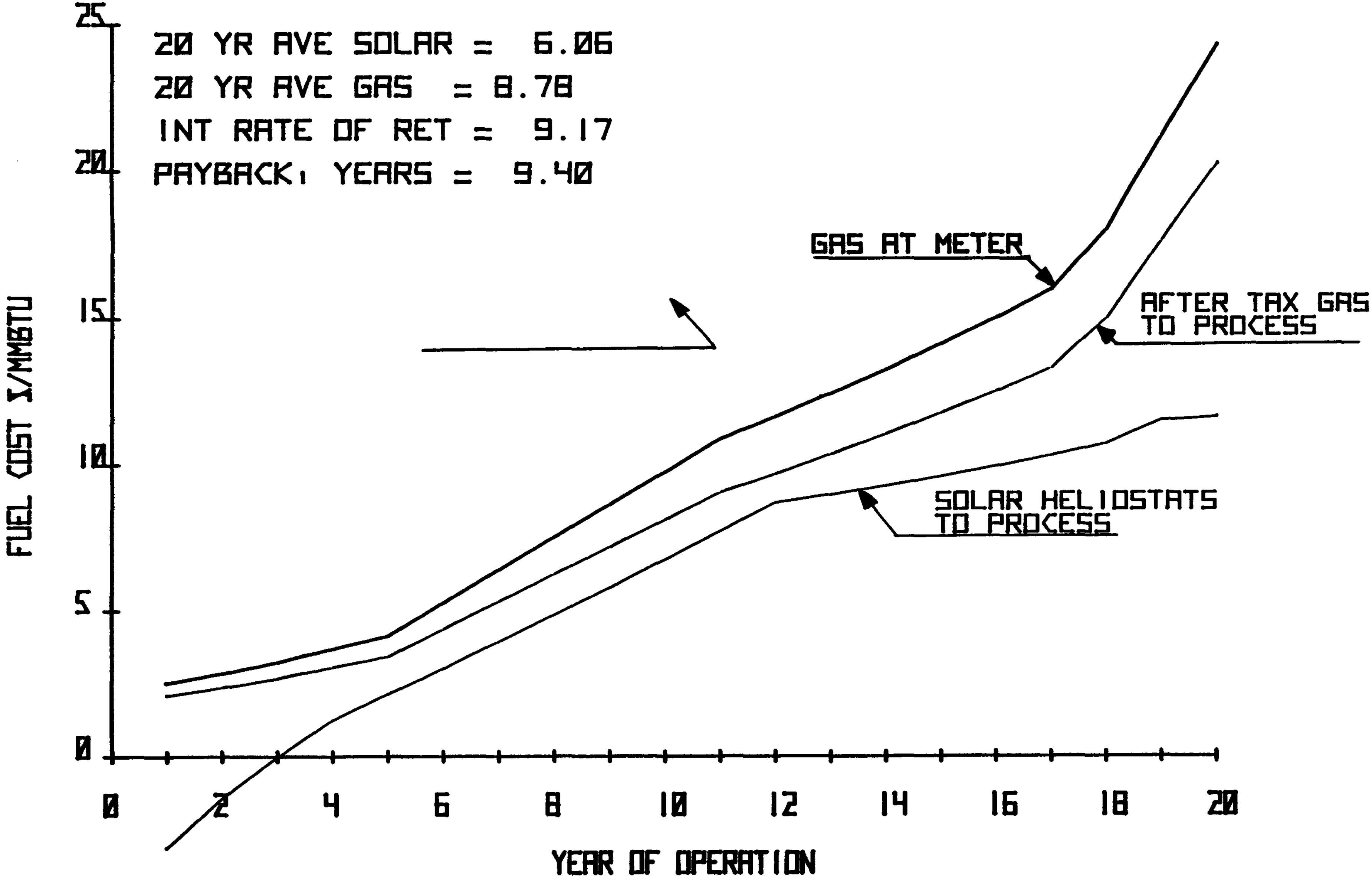


Fig. 1-11 ECON CASE D: COLES: PILOT PROD HELIOSTAT ARCO BASE CASE GAS ESCALATION SCHEDULE



1.7 DEVELOPMENT PLAN

A phased development plan has been prepared which begins with the final design phase and culminates in an extended joint user/DOE operational phase. The phases that have been identified are presented along with their respective periods of performance in Figure 1-12.

Figure 1-12
DEVELOPMENT PLAN SCHEDULE

PHASE	ACTIVITY	1981	1982	1983	1984	1985	1986	1987	1988	1989
I	Final Design	12 mo.								
II	Construction		18 mo.							
III	Startup & Checkout				3 mo.					
IV	Performance Validation				3 mo.					
V	Joint Operations						60 mo.			

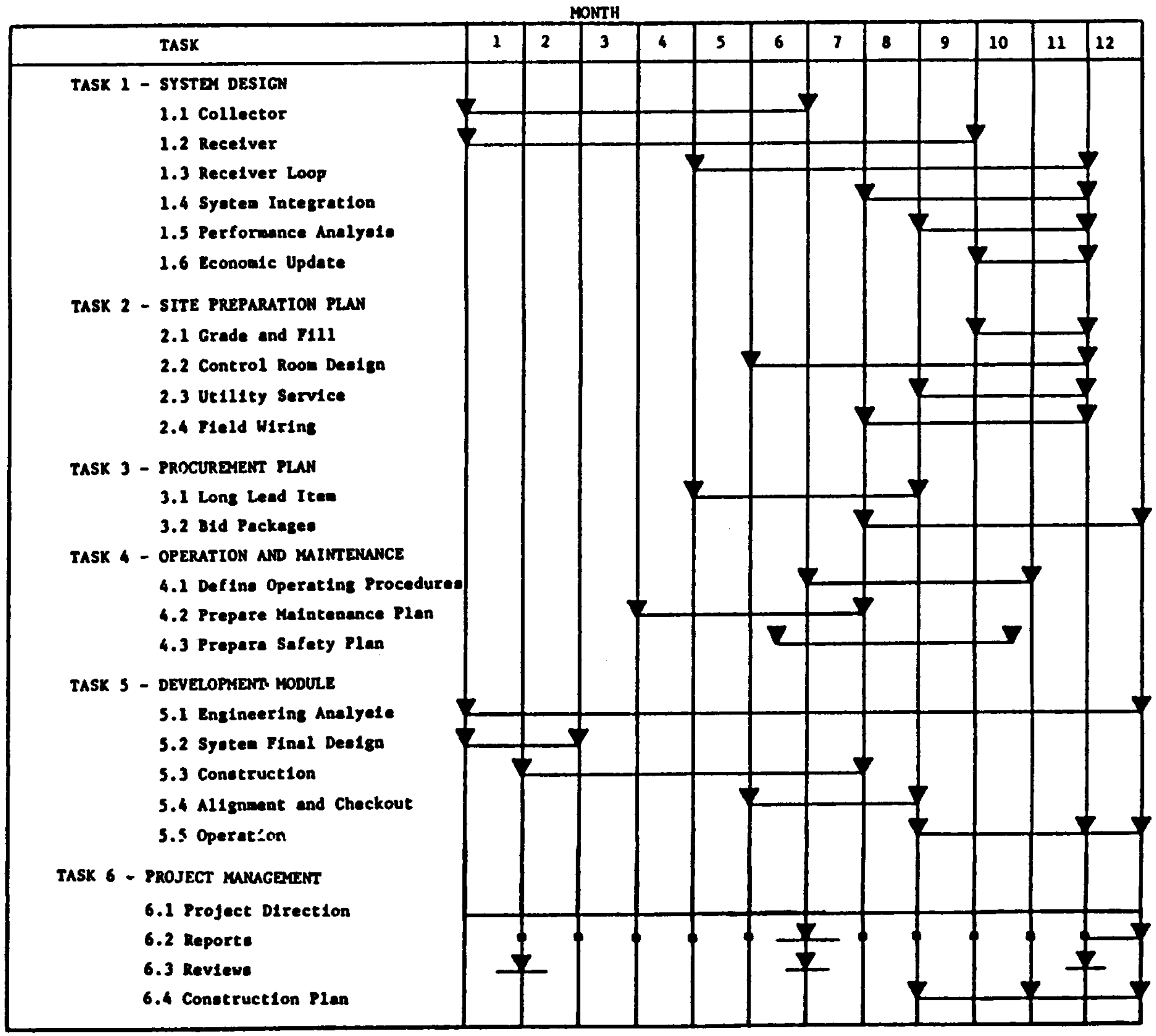
This schedule is consistant with the one presented in the DOE Solar Repowering/ Industrial Retrofit Program Element Plan, except that the two subphases, preliminary and final design, have been combined into a single final design phase. As a result, the period of performance for this site specific design is projected to be 12 months. This period of performance is justified on the basis of the relatively small and simplified system configuration and the extent to which existing technology has been incorporated into the design. The detailed design and construction phases have been planned in more detail in order to establish construction costs and schedules.

1.7.1 Detailed Design Phase

The task outline and schedule for this phase are presented in Figure 1-13. The 6 tasks and 24 subtasks provide for the final design of the solar system in sufficient detail to permit the development of

FIGURE 1-13

DESIGN PHASE SCHEDULE



all subsystem bid packages and the actual system construction during the next phase. Also provided are a set of detailed plans to assure the completion of the construction effort on schedule and with budgeted funds. These plans include a procurement plan, preliminary O & M plans and a detailed construction phase plan. An analysis of the effort required to accomplish all tasks within the 12 month performance period, shows that 162 manmonths is required.

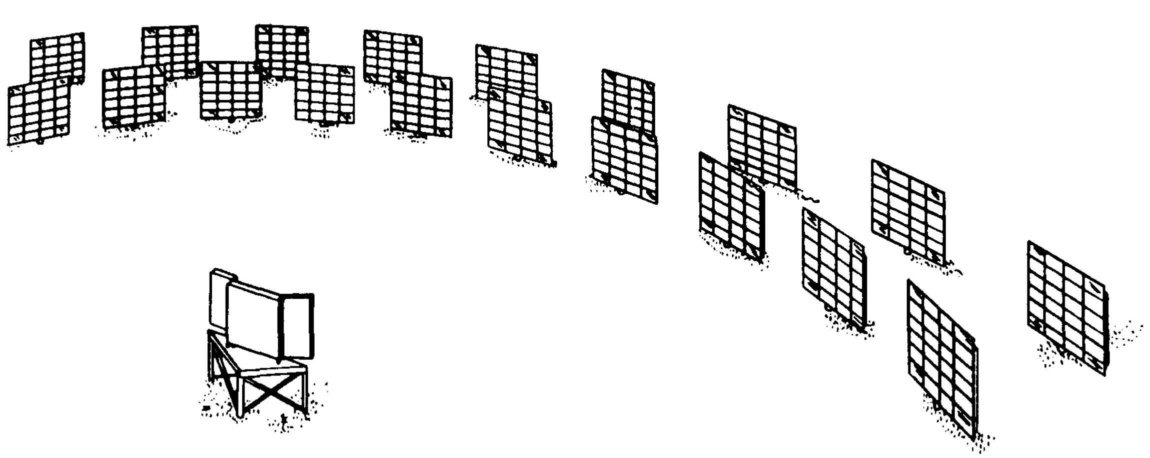
Since the design of the system has emphasized the use of existing technology and standard components, there have been no Subsystem Research Experiments identified. The advancement of solar technology is considered to be at the system level and as a result the design team has proposed the design, construction and operation of a Development Module during the design phase.

1.7.2 Development Module

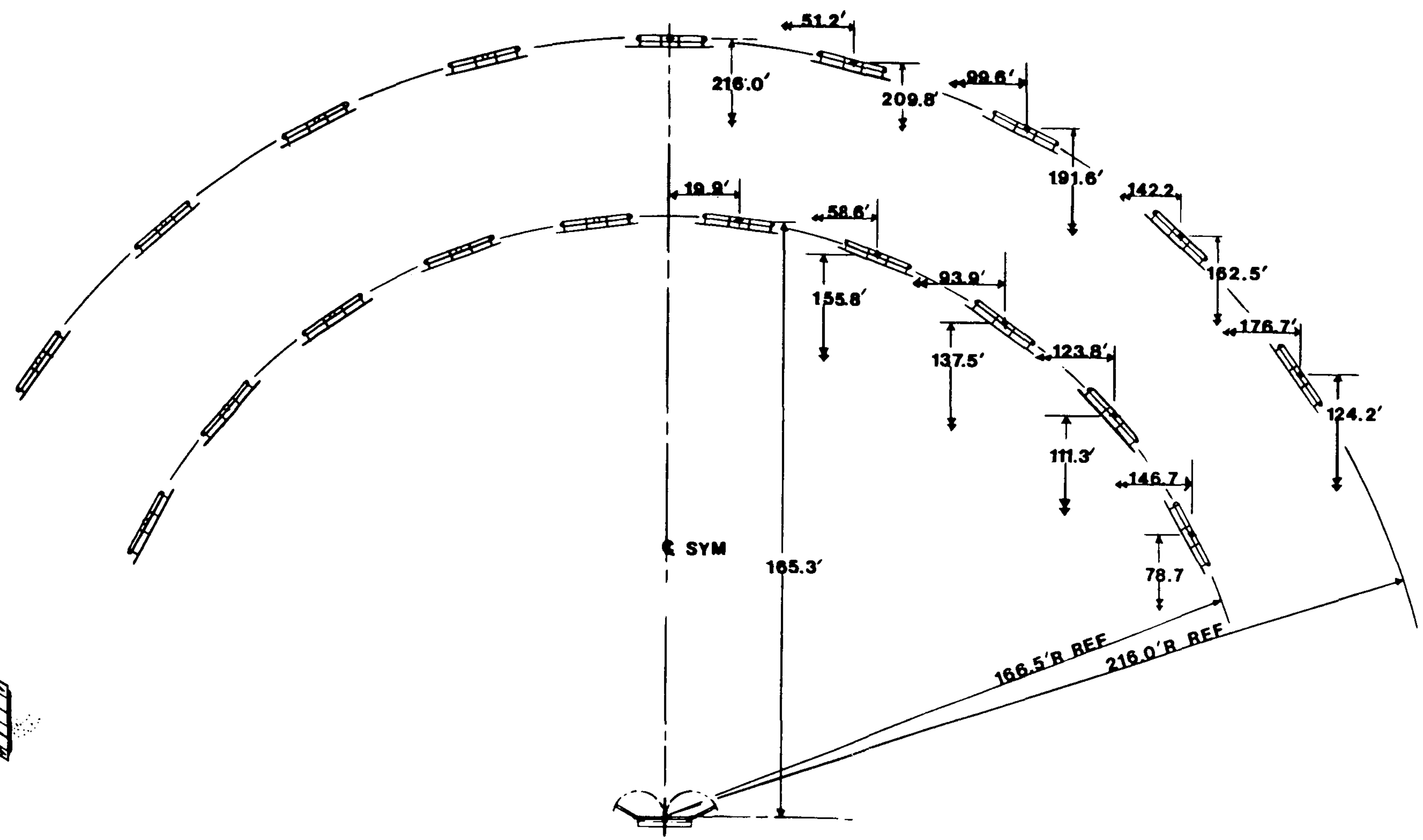
The purpose of operating the development module, which is a scaled down version of the solar retrofit system, would be to validate performance calculation, establish operational and safety procedures, develop control strate-ies, and provide a firm data point relative to construction cost estimates.

The Development Module will consist of two rows of heliostats (19) in a radial stagger arrangement with spacing between the 10 heliostats in the front row sufficient to allow the 9 heliostats in the back row to also focus on a ground level receiver. The receiver would be a flat plate configuration made up of the standard heat exchanger panels proposed for the 9.518 MW_t receiver. This field would be installed at the site of the full field. In fact, the heliostats would be the first two rows of the full field. The receiver loop and all valves and controls would be a scale down of the full sized loop and will operate in the same manner.

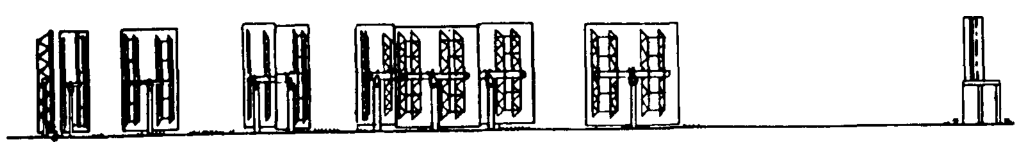
Figure 1-14 presents plan, elevation and isometric views of the Development Module.



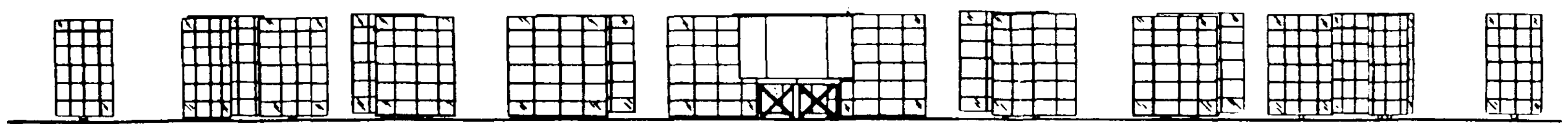
Perspective



Plot Plan



Looking East



Looking North

Figure 1-14

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES	BLAKE LABORATORY SUITE 306, 726, S UNIVERSITY, LITTLETON, CO 80.22
TOLERANCES	NINETEEN HELIOSTAT DEVELOPMENT MODULE
X = ± .125	

A cost analysis has been performed and shows that the Module can be constructed for $693,838 exclusive of the design and operational costs which are estimated to be $226,340.

1.7.3 Construction Phase

The construction phase is scheduled for an 18 month period immediately following the design phase. Figure 1-15 presents the schedule and milestone plan developed to show that the system construction can be completed within the alloted time period. The initial 3 months are devoted to bid advertising, sub contractor response, and contract award. The next 9 to 12 months provide time for subsystem installation and integration. The last three months are used for subsystem alignment and checkout.

1.7.4 Post Construction Phases

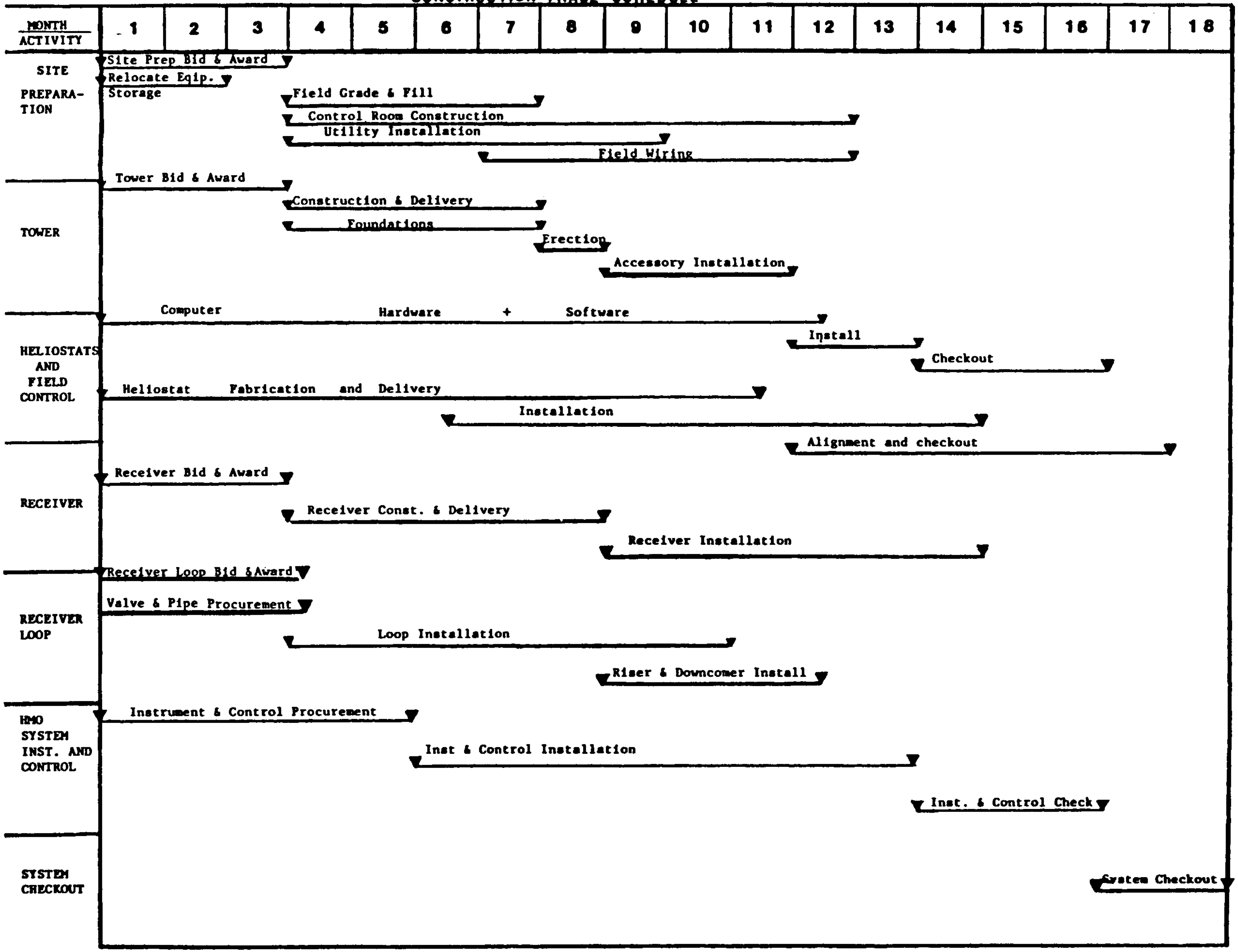
There are three phases of project activity following the completion of system construction. The first is a short three month startup and checkout phase during which the user checks the operation and performance of all major components and subsystems relative to specifications. During this period the system is brought on-line using special operating procedures to assure the safety of personnel and hardware. Special runs will be made to establish the effect of solar operation on routine plant procedures.

The next phase is a 3-month performance validation phase during which a variety of special runs are made to permit system performance and acceptance tests to be made under operating conditions.

The last phase is a joint user/DOE operating phase covering an extended period of 60 months. During this time the plant will operate on a routine basis. In addition, large quantities of data related to all aspects of system operation and performance will be obtained and analyzed to firmly establish the system economics and reliability and provide a data base for future process heat system design.

FIGURE 1-15

CONSTRUCTION PHASE SCHEDULE



1.8 SITE OWNER"S ASSESSMENT

The following site owner's assessment was prepared by ARCO Oil and Gas Company's California District Gas Superintendent who is responsible for the North Coles Levee Natural Gas Processing Plant.

"This investigation of the use of solar power for process heating at the North Coles Levee gas plant shows that mechanically and technically, it has the potential to furnish large quantities of heat. Our original assumption was that construction of a solar facility would be pretty much a Research and Development type project that we could only enter into with financial aid from the Department of Energy. It is true that the economics are not as good as we normally require for our capitallized projects, since payout and rate of return do not meet present corporate guidelines. Therefore, Arco Oil and Gas Company cannot proceed with installation of the facility on its own, but the information will provide Corporate Management with enough data so that they can determine the degree of financial support that might be needed before a construction phase could be approved.

An advantage that solar energy has is that, once the equipment is installed, the raw material - sunshine - is never going to go up in price, while raw materials - fuels - for all other known heating equipment, with the possible future exception of fusion reactors, will continue to escalate. So, while it is true that equipment costs, installation costs and maintenance costs may continue to escalate indefinitely, this will be true for any heating system that we can envisage. Therefore, use of solar energy with its zero-cost fuel may become increasingly attractive and economic for industrial heating purposes.

Using solar energy to heat our heat transfer fluid (we call this fluid "heat medium oil") is the simplest way to use solar energy at North Coles Levee. Tie-in to the existing system is simple, control is simple, and the transition between sunlight hours and dark, or between sunny skies and cloudy skies is simple. And as long as there is enough sunlight to add heat to the system, it will be used, and will reduce natural gas consumption by a comparable BTU equivalent. The configuration using the central receiver is excellent, since it reduces both land requirements and piping costs from that required for multiple receivers. The system will operate easily and safely, and certainly will have no adverse environmental impacts.

1.8.1 Present Fuel Situation

Natural gas is becoming more scarce and higher in price each year - a trend that is quite certain to continue. The North Coles Levee field has already been in the position of having to purchase natural gas for its operations for several years - it does not produce enough gas to furnish its own energy needs. Just as an example, gas is so expensive and in such short supply that gas lift for oil wells is no longer economical. Coles Levee oil wells are being converted to mechanical lift as rapidly as possible, in spite of the fact that operating costs for gas lifted wells are much lower than for mechanically lifted wells except for one thing - natural gas fuel costs. Air Pollution Control District, Air Resources Board and Environmental Protection Agency regulations make alternative fuels expensive and difficult to use, since installation of exhaust scrubbers or catalytic converters, or finding some way of making emission trade-offs of some sort are often necessary to obtain the necessary approvals.

1.8.2 Solar Possibilities

Because of these things, any energy source that can take the place of some natural gas deserves thorough consideration. Certainly solar energy has some drawbacks. The quantity of solar heat falling on each square meter of the earth's surface is limited, and rather large land areas are needed to install the equipment that is required to concentrate this heat in a receiver that can convert it to useful energy. And of course the sun only shines during part of the day, and little or not at all on some days. Equipment for utilizing solar heat is not yet mass-produced, and therefore expensive. But outweighing these things, many areas in the western United States have plenty of land available, and these areas generally have a very high percentage of sunny days. Equipment for using solar energy has been designed, built and thoroughly tested, and there is no technological problem that would preclude successful operation.

Atlantic Richfield operates twenty five natural gas processing plants and is a participant in more than fifty plants that are operated by co-owners. Not all of these would be candidates for solar heating applications, of course, but many of them could be. Eight or ten ARCO plants and fifteen to twenty co-owner operated plants may have the proper conditions and land positions to make solar energy attractive. We have made no survey of total industry potential, or even just oil industry potential, but there certainly are several thousand industrial facilities that have potential uses for solar heat. Applications include heating of fluids for heat transfer uses, boiler feedwater heating, steam generation for processing heating and power generation, combustion air preheat for gas turbines, boilers and heaters, air heating for agricultural product drying, such as corn, walnuts, etc., and for many other uses limited only by man's ingenuity in designing methods to use the solar heat.

1.8.3 Plant Future

The chief uncertainty at the present time is the Life of the North Coles Levee plant. Current gas production decline rates in the areas serving the plant indicate that as these trends continue, seven to ten years might be as long as we could expect to operate the facility, at least in its present form. However, we are continually trying to obtain more outside gas for processing, and are optimistic that we will be successful. We are currently fractionating outside natural gas liquids for other companies, handling 50,000 gallons to 150,000 gallons per day at the present time. We expect to continue this service indefinitely, and we may add a butane splitter to our fractionation system so that we can separate iso-butane from normal butane. Addition of this unit will enable us to offer additional service and attract more fractionation customers. Additional drilling in the North Coles Levee field, and possibly other areas in the vicinity, may prove up new deeper production that could extend plant life for many years.

In any case, by the time that it will be necessary to commit funds to a construction phase for the solar project, we should know the results of our efforts to obtain other outside natural gas and natural gas liquid products for processing. We hope that within a few months we will be able to predict a plant life that will extend well beyond the years required for payout of a solar facility.

1.8.4 Conclusions

The work that has been done on this project has demonstrated that solar heating at the North Coles Levee plant could save natural gas fuel, but that payout is long and rate of return is quite low. It has demonstrated that the solar project is compatible with the existing facilities operationally and environmentally, and that there are no safety hazards or other detrimental characteristics. We have not yet reached a conclusion on plant life; however, by the time that the final design and construction phase needs to be entered into, we should be able to predict this with sufficient accuracy to properly determine its impact. This coupled with the final economics, will enable both ARCO Oil and Gas and Corporate Managements to evaluate the project worth and decide on our future course of action.

This work has been invaluable in that it demonstrates that many industrial facilities might benefit from the application of solar power, and that solar power may make a significant contribution to the nation's energy needs in the future.

2.0 INTRODUCTION

This report was prepared by Northrup, Inc. and ARCO Oil and Gas Company to present the results of a study conducted to develop the conceptual design of a solar powered industrial process heat system through the application of solar central receiver technology. The project is a part of the Department of Energy's Solar Repowering/ Industrial Retrofit Program and was performed under Contract No. DE-AC03-79SF10736. The study was entitled "Solar Industrial Retrofit System-North Coles Levee Natural Gas Processing Plant."

The period of performance began on September 15, 1979 and ended on July 15, 1980.

The prime contractor was Northrup, Inc., 302 Nichols Dr., Hutchins, Texas 75141 with subcontracted work performed by ARCO Oil and Gas Co., 4121 South H St., Bakersfield, California 93304. The Principal Investigator was Roy L. Henry. The purpose of the project was to develop a site-specific conceptual design for a practical and cost-effective solar retrofit system to supply process heat for a representative petroleum industry application.

The application selected for the project is the processing of natural gas to:

- Extract natural gas liquids and produce propane, butane and gasoline from them.
- Condition the residue natural gas for marketing.

The process requires heat in the 193 to 304^{o}C (380-580^{o}F) range which is readily achievable with concentrating solar thermal systems. The application is also ideal for solar retrofit because many natural gas processing plants utilize a heat transfer oil which permits an extremely simple interface with the fired oil heaters normally used.

The solar retrofit conceptual design was developed for the ARCO Oil and Gas Company's North Coles Levee Natural Gas Processing Plant No. 8 located near Bakersfield, California. This plant uses gas-fired heaters and gas turbine exhaust heat to heat oil which is then cascaded through a series of reboilers thus supplying process heat at several required temperatures.

2.1 STUDY OBJECTIVE

The objective of the project was to develop a site-specific conceptual design for a practical and cost-effective solar retrofit system to supply process heat for a representative petroleum industry application. The particular application selected for the project is the ARCO Oil and Gas Company's North Coles Levee Natural Gas Processing Plant No. 8 located near Bakersfield, California.

2.2 TECHNICAL APPROACH AND UNIT SELECTION

The technical approach employed by the design team in developing the conceptual design of a solar retrofit system for the North Coles Levee Plant started with establishing preliminary System Requirements Specifications (SRS) based upon general technical requirements set forth in the contract statement of work, the plant requirements, and the heliostat-central receiver concepts originally proposed. Tradeoff analyses were then performed to determine the system configuration. These tradeoff analyses included collector field size and arrangement, receiver type and configuration, piping arrangement, solar-fossil interface, augmentation temperatures, control approaches and related issues affecting subsystem configurations and major component selection.

Once the subsystem configurations, major components, operating conditions and control approaches were selected, the overall conceptual design was completed in sufficient detail to develop reliable performance estimates and to estimate detailed design and construction costs. An economic evaluation based on a 20-year life-cycle-cost analyses was performed, and environmental and safety assessments were prepared. Finally, a development plan for a phased program leading to system operation in 1984 was prepared.

2.3 SITE LOCATION

The North Coles Levee Natural Gas Processing Plant No. 8 is located in Kern County, California, about 161 km (100 miles) north of Los Angeles, about 35.4 km (22 miles) southwest of the City of Bakersfield, and in the southern end of the San Joaquin Valley. The proposed project site is confined to an area adjacent to Plant No. 8.

The southern end of the North Coles Levee Oil Field borders on State Highway 119 between Taft and State Highway 99. State Highway 119 has an interchange with Interstate Highway 5 about 3.2 km (2 miles) east of the field boundary.

Figure 2.3-1 presents a map of the area and shows the location of the plant relative to the city of Bakersfield.

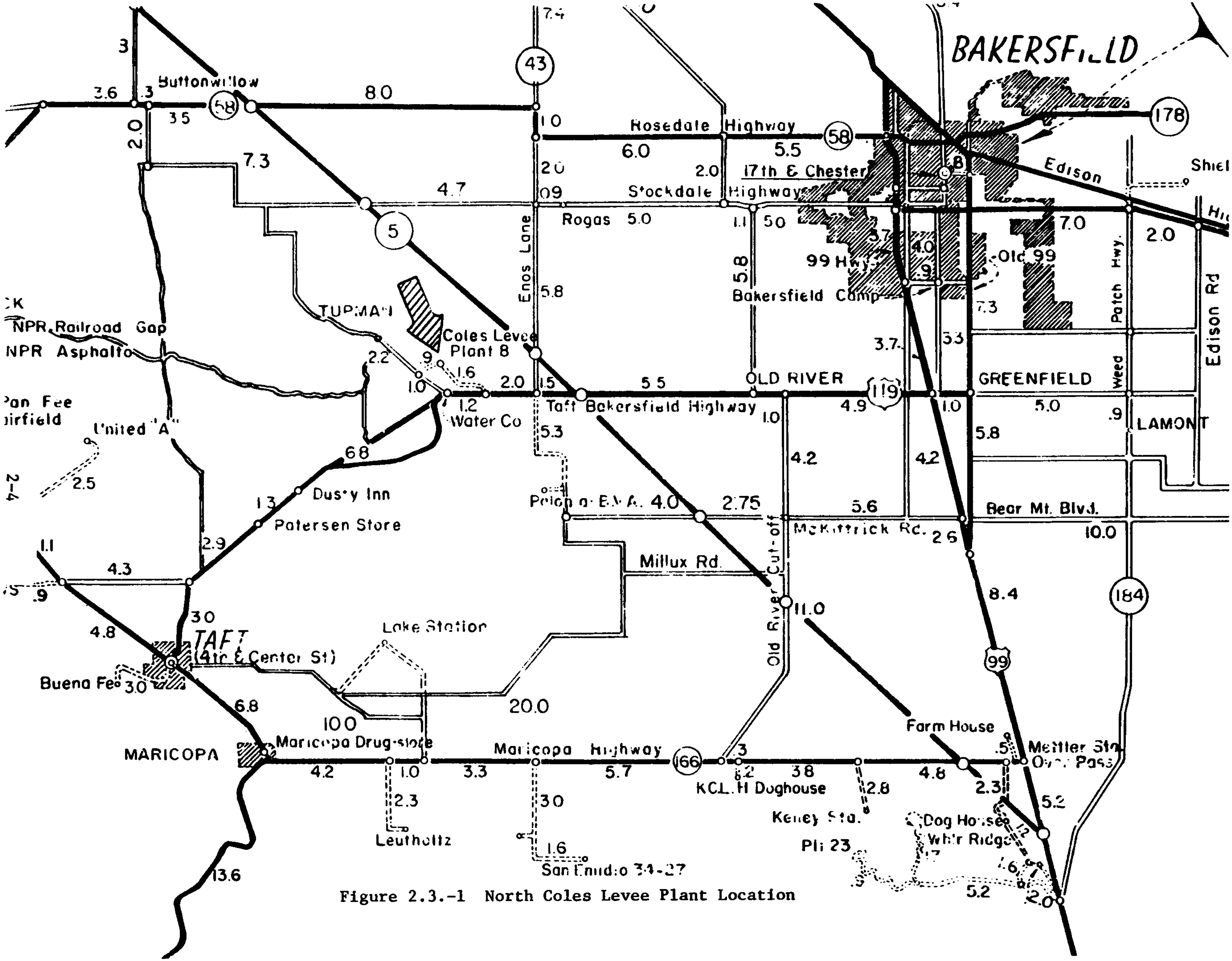


Figure 2.3.-1 North Coles Levee Plant Location

2.4 SITE GEOGRAPHY

The North Coles Levee Natural Gas Processing Plant is engaged primarily in the processing of natural gas from surrounding gas fields. However, the area contains a large number of oil producing wells. Consequently, there are also gas lift enhanced oil recovery and water flood secondary recovery facilities located at the plant site. The plant area, including these facilities and associated temporary storage facilities, occupies $7.03 \times 10^6 m^2$ (17.4 acres). The plant is located within the North Coles Levee Oil Field which encompasses approximately $2.02 \times 10^7 m^2$ (5000 acres). The Oil field including the plant is leased from the property owner, Tenneco West, Inc.

The solar collector field including the tower occupies $9.7 \times 10^4 m^2$ (24 acres) and will be located within the oil field, due north and approximately 285 m (935 ft) from the plant perimeter fence. The collector field area includes all or portions of 3 oil wells and associated maintenance pads. Written agreements with Tenneco have secured the surface use of the selected area for the installation of the solar process heat facility.

The North Coles Levee Oil Field is located on the San Joaquin Valley floor at the southern tip of the Elk Hills. It is situated on a portion of an ancient lake bed with an average elevation of 91.4 m (300 ft) above sea level.

The soils of the North Coles Levee area are characteristic of a semiarid region that has hot, dry summers and mild, somewhat moist winters. The representative soil is a loose, light-colored, well drained loam containing rock fragments. Like most soils developed in a semiarid region, they contain an abundance of gypsum or alkaline salts.

Naturally occurring geologic conditions at North Coles Levee Field that could result in hazards include erosion, subsidence, flooding, and corrosive soils.

The loose soils and sediments existing on the surface are easily erodible. Little natural vegetation is present to prevent further erosion during winter rains. These rains could also cause local flooding.

The soils that occur throughout the area of the North Coles Levee Field have demonstrated corrosion potential for unprotected iron and steel. Present corrosion prevention measures include elevation of pipe above the ground on supports and coating buried pipe with protective materials.

No known active fault zones cross the North Coles Levee Field or are near the project site, and no earthquake epicenters of Richter magnitude greater than 4.0 have been recorded as occurring on the North Coles Levee Field.

2.5 CLIMATE

The North Coles Levee Field area is partially surrounded by mountainous terrain on three sides. The surrounding topography has a significant influence on the general climate. The Sierra Nevada Mountains, located to the northeast, insulate the Central Valley from the cold polar air that moves southward over the continent during the winter. The Tehachapi Mountains, forming the southern boundary, force moist air emanating from the northwest and north to rise, thus promoting heavier precipitation on the windward slopes. This also causes a higher frequency of cloudiness over the foothill areas. The coastal ranges, situated due west of the North Coles Levee area, tend to shield the local region from the true marine environment that dominates some 80 km (50 miles) to 113 km (70 miles) to the west. Because of the nature of the encompassing terrain, large climatic variations can exist within relatively short distances of the study area.

The general climate of the North Coles Levee study area is warm and semiarid. Nearly 90% of all precipitation (about 15 cm (6 inches) annually) falls from October through April. Winters are mild and tend to be fairly humid. As a result, nocturnal fog is frequently experienced during December and January. Occasionally, dense foggy conditions persist during the day as radiational fog (induced by nocturnal cooling) is trapped in the valley regions by large-scale high pressure systems. During the winter season, warm, dry south and southwesterly flow is occasionally observed as drainage winds emanating from Tehachapi Pass move into the Central Valley regions. Summer skies are clear and conditions are usually hot and dry.

Monthly normal temperatures reange from approximately 7°C (45° F) in January to 30°C (85° F) during July. Record temperatures have been observed to exceed 43° C (110° F) during the Summer and drop below 5.6° C (22°F) during the Winter.

Wind speeds between 2.1 m/sec (6.9 ft/sec) and 3.6 m/sec (11.8 ft/sec) are experienced most often at North Coles Levee. Wind speeds in excess of 10.8 m/sec (35.4 ft/sec) are rarely experienced but have been observed to be sustained for as long as 6 consecutive hours.

The cloud cover conditions for Bakersfield based on seasonal mean averages obtained from the U.S. Weather Service are as follows:

Clear	202 days
Partial cloud Cover	78 days
Total cloud cover*	85 days

*Includes 22 days of fog with less than 402 m (.25 mile) visibility.

2.6 EXISTING PLANT DESCRIPTION

The North Coles Levee Gas Plant occupies 68.8 x 10^3m2 (17 acres) and is located approximately 22 miles west of Bakersfield on Hwy. 119. It was orginally built in 1940, and the process chain consisted of 1 absorber, 2 strippers (primary and secondary), and 1 depropanizer. It had a capacity of 6.55 m^3/s (20 x 10^6 cfd) at 3.45 x 10^3 kPa (500 psig).

In 1947-49, the plant was expanded to process 16.39 m^3/s (50 x 10^6 cfd). The additional equipment and vessels included a refrigeration system, a deethanizer, 2 debutanizers, 2 absorbers, 2 strippers (primary and secondary) and a depropanizer. In 1953 another absorber was installed to bring the plant capacity to 24.58 m^3/s (75 x 10^6 cfd).

The last expansion took place in 1957-58 when 2 high pressure 10.34 x 10^3 kPa (1500 psig) abosrbers were installed, and the refrigeration system enlarged. This brought the plant up to 65.53 m^3/s (200 x 10^6 cfd). No expansions are planned in the near future. Since 1958, the only construction at the plant site has been revisions and expansions to individual systems within the plant.

The plant has three separate functions which interface with one another. The gas lift system (Plt. 21) is used to artificially lift oil from the reservoir. Compressors are used to compress natural gas. The gas is piped to the wells and injected down the casing. Gas lift valves then allow the gas to enter the tubing, and mix with the oil. This lowers the oil density and allows the reservoir pressure to force the oil up the tubing. The gas is then separated from the oil and sent back to the compressors to be recycled. Some gas will also be produced from the reservoir and any gas not needed for lift spills over to the processing plant. Plant 21 is located to the east of Plant 8 (processing facilities).

Another plant function is water injection. Water is pumped into the oil reservoir to help maintain reservoir pressure by replacing the produced oil. This is a secondary recovery technique and is called water flood. The exhaust gas from the turbine that powers the water pump is one source of heat for the heat medium oil.

The third function of the plant is to process gas. The process area is called Plt. 8 and is a refrigerated absorption plant. It consists of 6 absorbers, 1 deethanizer, 2 primary strippers, 2 secondary strippers, 2 depropanizers, 2 debutanizers, an absorption oil system, a refrigeration system, a steam system, and a heat medium oil system. All are inter-related.

The raw natural gas comes from the field after being separated from the produced oil. It comes to the plant in two lines. One is at about 3.45×10^3kPa (500 psig) and the other about 2.07×10^3kPa (300 psig). Both are sent through scrubbers to remove any liquids, then the lower pressure line is compressed at Plant 21 to process pressure 3.45×10^3 kPa (500 psig). It joins the gas from the high pressure line goes to a dehydrator then to the absorber. In the absorber, the gas contacts absorption oil which is refrigerated to -7°C (20°F). This oil absorbs almost all the C_{5+} (gasoline) and C_4 (butane), a large percent of C_3 (propane) and a small amount of C_2 (ethane). The gas leaves the absorber and is sold without further treating.

The absorption oil and the recovered hydrocarbons leave the absorber and go through a series of heat exchangers which heat up the oil and products. The oil and products then go to the deethanizer, and most of the absorbed ethane is cooked out of the oil, and is mixed into the plant fuel system. The oil and remaining products leave the deethanizer and go to the primary stripper. Here, more heat is added to cook out almost all the recovered products. The oil goes to the secondary stripper and the rest of the recovered products are cooked out. The oil is now ready to be cooled and sent to the absorber again. The recovered hydrocarbons which have been cooked out of the oil are condensed and sent to the depropanizer. The mixture is heated and the propane goes off the top to be condensed and sent to product storage. The liquid hydrocarbons out of the depropanizer are sent to the debutanizer. Here, the mixture is again heated and the butane goes off the top and raw gasoline comes out the bottom. Both streams are cooled and sent to product storage. The liquids are then sold as three separate products, propane, butane, and gasoline.

The plant is manned 24 hours a day and seven days a week. Depending on the shift, there will be six to ten men in the plant at all times for operations. In addition repair and maintenance men are at the plant on daylight shift.

The refrigeration system is used to cool the absorption oil down to $-7^{o}C$ ($20^{o}F$). It uses propane which is compressed then condensed. The propane is sent through a heat exchanger as a liquid and removes heat from the absorption oil. Some propane is "boiled" off in the exchanger, this is again collected, compressed, and condensed to be used again.

A plant steam system is used as a heat source and an energy source. Steam is generated by boilers which use about .08 m^3/s (250×10^3cft) and by waste heat units. The boilers supply only about 34% of the required steam, and the waste heat units furnish the rest. The steam is used by the debutanizer and the glycol regenerator for heat, and by some steam turbine pumps for energy.

Another system used to supply heat is called the heat medium oil system. Due to the high volatility of the plant products, a direct flame as a heat source is not desirable. Therefore, heat must be furnished through some other method. This method uses an oil which is fairly stable at high temperatures. It is heated from the system's low temperature of $193^{o}C$ ($380^{o}F$) to the high temperature of $302^{o}C$ ($575^{o}F$). This is done by 2 gas fired heaters and a heat recovery unit which uses turbine exhaust heat. The two gas fired heaters supply about 73% of the required heat for the heat medium oil system. They use about .33 m^3/s (1×10^6cfd) for fuel. The other 27% of the heat is furnished by the heat recovery unit.

The flow through the system is about .09 m^3/s (2,100,000 Gal/Day) with .025 m^3/s (570,000 Gal/Day) going through the waste heat unit, .04 m^3/s (910,000 Gal/Day) through the #2 heater and .027 m^3/s (620,000 gal/day.) through the #3 heater.

The proposed solar project is concerned with replacing some of the heat that the fired heaters currently supply.

2.7 EXISTING PLANT PERFORMANCE SUMMARY

The North Coles Levee Plant operates continuously, processing gas produced from oil fields in the southern part of the San Joaquin Valley. There were four power outages during 1979 that shut down plant operations for a total of about 10 hours. No other unscheduled outages occurred. Scheduled outages affected only certain sections of the plant at any one time, so that plant throughput and liquid production were not substantially reduced. The plant operated 99.89% of the year.

The plant used 51.542 x $10^6 m^3$ (1,819,971 x 10^3 cf) of gas as fuel in 1979. The process area used 21.684 x $10^6 m^3$ (765,665 x 10^3cf) and the compressor area used 29.858 x $10^6 m^3$ (1,054,306 x 10^3cf). The plant processed 375.03 x $10^6 m^3$ (13,242,421 x 10^3cf) of wet gas during 1979. Plant Production for 1979 was as follows:

Propane	98,790 m^3	(26,100,000 gallons)
Butane	61,695 m^3	(16,300,000 gallons)
Gasoline	29,145 m^3	(7,700,000 gallons)

In addition to the above liquid production 60,560 m^3 (16,000,000 gallons) of unfractionated natural gas liquids were trucked into the plant from various plants which have fractionation equipment that is inadequate to make a directly usable product. Finished products delivered to customers from these sources were:

Propane	3,785 m^3	(1,000,000 gallons)
Butane	29,900 m^3	(7,900,000 gallons)
Gasoline	26,875 m^3	(7,100,000 gallons)

Total liquids delivered from the plant for the year were therefore 250,190 m^3 (66,100,000 gallons). Approximately 211,960 m^3 (56,000,000 gallons) were delivered to trucks and trailers, while 38,230 m^3 (10,000,000 gallons) were sent via pipeline to our railroad loading facilities 12.87 kilometers (8 miles) northeast of the plant.

The plant operating expense was $23,740,000 for 1979, and the expenses for the next two years will probably not be higher. This is because much of this past years expense was one time costs. Without the solar project, the expenses should run about $23,700,000 for the next two years, then escalate at about 3% above general inflation for the rest of the plant life.

2.8 PROJECT ORGANIZATION

The organization formed to accomplish the system design and evaluation consisted of two subsidiaries of the Atlantic Richfield Company (ARCO); Northrup, Inc. and ARCO Oil and Gas Co.

Northrup had the overall responsibility for the management of the project and the specific responsibility for the conceptual design of the solar collector system. This included the design of the solar collector field configuration, the receiver subsystem, the collector tracking subsystem, all trade studies related to the analysis and selection of these subsystems and the integrated system design. In addition, Northrup had lead responsibility for those tasks related to the system costs and economic analysis and the project development plans. ARCO Oil and Gas Company supported these activities by providing the site specific data and information required to accomplish these tasks. They also provided the expertise relative to the operation of the North Coles Levee Plant and the effects of operational parameters on solar system design.

Arco Oil and Gas had the lead responsibility for all tasks that directly impact plant functions and operations. These included the solar/non-solar interfaces such as instrumentation, master control, and mechanical linkages. Also included were the functional plant requirements, any potential limitations, environmental impacts and final plant performance estimates. Northrup supported these activities by developing the required solar performances, hardware configurations, and other data that effected plant operation and performance.

Roy L. Henry had the overall project management responsibility with Floyd A. Blake directing the technical design effort. Harry E. Wold of ARCO Oil and Gas Co. was the site sensitive project leader and had responsibility for all project activity related to the North Coles Levee Plant.

2.9 FINAL REPORT ORGANIZATION

This report is bound in two books. One is the technical report of the conceptual design effort and the other is an appendicies which for the most part, contains quantities of supporting data and methods too voluminous for inclusion in the technical report.

The technical report is organized into seven major sections.

Section 1 Executive Summary This section provides executive level summary of the project scope, activities and results. This section is available under separate cover.

Section 2 Introduction This section presents an overview of the project. Particular emphasis is placed on the site characteristics and plant operations and performance.

Section 3 Selection of Perferred System This section is devoted to establishing the basis for selecting the components, subsystems and system level characteristics incorporated into the conceptual design configuration.

Section 4 Conceptual Design This section presents a detailed description of the solar system. Also presented are system functional requirements; operational, maintenance and performance characteristics; costs; and environmental and safety considerations.

Section 5 Subsystem Characteristics This section as the name implies presents an in depth description of the major subsystems. Topics of discussion are similar to those itemized under Section 4.

Section 6 Economic Analysis This section presents the results of an economic analysis based on system capital cost, fuel costs and performance. Also included are discussions of methods and assumptions used in the analysis

Section 7 Development Plan This section presents a phased plan for the design, construction and operation of the Solar Retrofit System.

The Appendicies contain seven subjects that directly relate to the design work.

Appendix A	Systems Requirements Specification
Appendix B	Environmental Impact Assessment
Appendix C	Heliostat Performance Data
Appendix D	Solar Flux Maps
Appendix E	Receiver Performance Maps
Appendix F	Receiver Selective Surface vs Black Paint Trade off Stud
Appendix G	Collector Trade Data

SECTION 3.0

SELECTION OF PREFERRED SYSTEM

The preferred system was configured as a maximum performance, minimum cost, and minimum impact integration of the most desirable subsystem configurations established in the early trade off evaluations.

Primary among the subsystem selections was the "Single" tower north field radial stagger layout collector. This configuration rated nearly even with the towerless receiver collector on capital cost, but outperformed the flat field by 7 percent on an annual basis.

Using the cavity receiver directly heating the "heat medium oil" as it entered the process provided the simplest hardware system and control system. Use of ASME qualified commercially available panels to line the heat exchanging wall substantially lowered receiver cost.

The "constant flow - variable temperature" control mode which couples the solar collector and plant heat medium oil system in series yields the maximum solar energy displacement of fossil fuel and enables continued use of the plant temperature control which senses the fired heaters outlet temperature.

Storage was judged to be non-beneficial for the Coles Levee application. Impacts on necessary heat medium oil volume (factors of 20 to 45 times present volume), on tankage (factors of 40 to 80 times current tankage) and on heliostat net effectiveness (reduced 17 percent by storage losses) combined to support the storage deletion decision.

The final major system selection item was the location of the tower and solar collector to best fit the operating oil field adjacent to the plant. The location finally selected enabled positioning the heliostat field between the major trunk pipeline running diagonally S-W to N-E and the Western water works 30 inch main and telegraph line.

3.1 TRADE STUDIES

Trade study analyses were performed to establish the preferred configuration of the collector, receiver, and heat augmentation loop operational mode. Options to be evaluated on the collector were "tower" and "towerless" module configurations and variations within each to establish the optimum approaches to be evaluated. Within the "tower" module concept variable module sizes from 1) a single module large enough to handle the full rating, to 2) double modules of comparable total capacity, to 3) quadruple modules were compared. The single module was clearly optimum on the basis of minimum plant cost economic criteria.

Within the "towerless" module concept the layout of the rows, straight and circular staggered were compared on the basis of performance and economic criteria. The circular staggered layout was optimum due to its substantially lower land use and corresponding economic impact.

Options to be evaluated on the receiver were "exposed" and "cavity" configurations and variations within each to assure that competing optimums were evaluated. Primary criteria were performance and cost. For the "exposed" receiver the trade was between use of a selective surface and black paint with the advantage being established for selective surfaces expected to be available in the near term. For the cavity receiver a trade off on basic cavity size was essentially an evaluation of flux levels versus size with selection being based on a size which reduced surface flux to 260 W/m^2. The aperture size trade study evaluated and combined the performance characteristics associated with optical spillage, surface absorption, convection, and radiation.

Operating temperature options for the heat augmentation loop range from "variable between 193°C (380°F) and 299°C (570°F)" to "controlled at 243°C (470°F)" and"controlled at 299°C (570°F)". The clear favorite due to design and operation simplicity is the "variable temperature" option.

The trade off collector field options screened in the final evaluation are illustrated to scale in Fig. 3.1-1. For competitive evaluation, performance for each of the "tower" module configurations was normalized to a size of 437 heliostats. They were all sized 12 to 15 percent larger to enable heliostat deletions required by existing field wells, electric line poles, and piping. Figures 3.1-2, 3.1-3, 3.1-4, and 3.1-5 show the varied candidate collector locations in the producing field adjacent to the "North Coles Levee Natural Gas Processing Plant". Figure 3.1-5 shows the "single module" in the finalized form and illustrates the heliostat deletions to accomodate the existing field's configuration.

Both cost and performance characteristics were used to establish the basis for the trade off selection between the four candidate field layout approaches. The system cost for each layout was established, using 437 heliostats in each. Included in the system cost were the heliostats (unit cost of $\$230/m^2$)*, towers (Sandia tower cost model), receivers, piping and wiring. These system costs are shown in Table 3.1-1 and ranged from lows of $\$6.248 \times 10^6$ for the twenty three flat field modules and $\$6.898 \times 10^6$ for the double tower and $\$7.914 \times 10^6$ for the quad towers.

Combining the capital costs with the performance characteristic of each layout was done using the annual average geometric efficiencies. Efficiencies varied between .7639 (flat modules) and .8331 (quad towers) with the double tower and single tower approaching the quad tower value. The final cost-performance "parameter of merit", the normalized cost indicated the single tower to be the clear optimum selection by a margin of 7.7% over the flat field, 9.1% over the double tower and 25.0% over the quad tower.

Figures 3.1-6, 3.1-7, 3.1-8 and 3.1-9 contain geometric performance for the flat field radial layout, the quad tower

*Sandia Laboratories, Jim Gibson memo dated Nov 6, 1979 layout, the double tower layout, and the single tower layout respectively, for the full range of azimuth and elevation angles of the sun which would be encountered in the continental U.S..

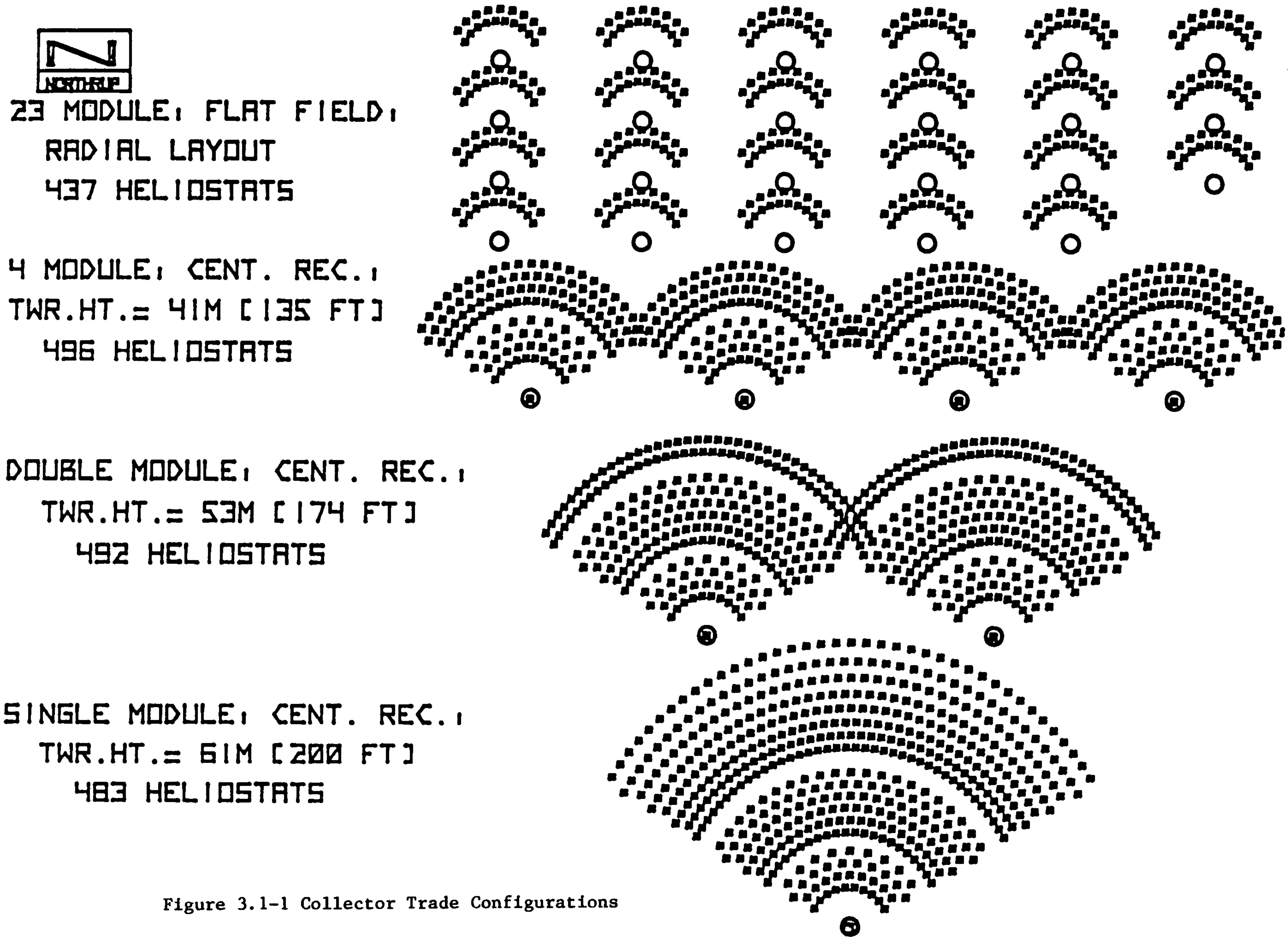


Figure 3.1-1 Collector Trade Configurations

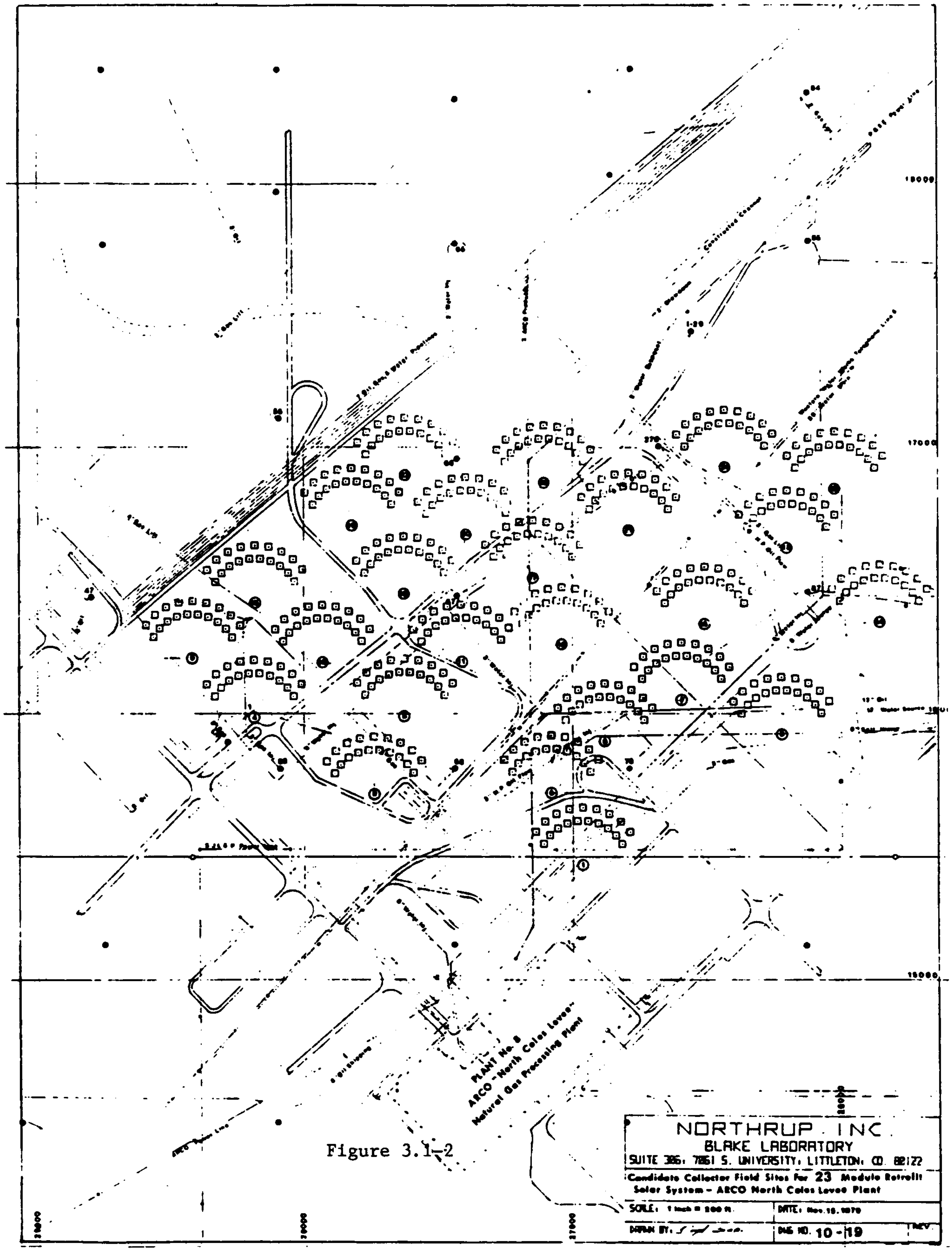

PLANT No. 8
ARCO - North Coles Levee
Natural Gas Processing Plant
NORTHRUP INC.
BLAKE LABORATORY
SUITE 305, 7851 S. UNIVERSITY, LITTLETON, CO. 80122
Candidate Collector Field Sites for 23 Module Retrofit Solar System - ARCO North Coles Levee Plant
SCALE: 1 inch = 200 ft.
DATE: Nov. 15, 1979
DRAWN BY:
DWG NO. 10-19
REV.

Figure 3.1-2

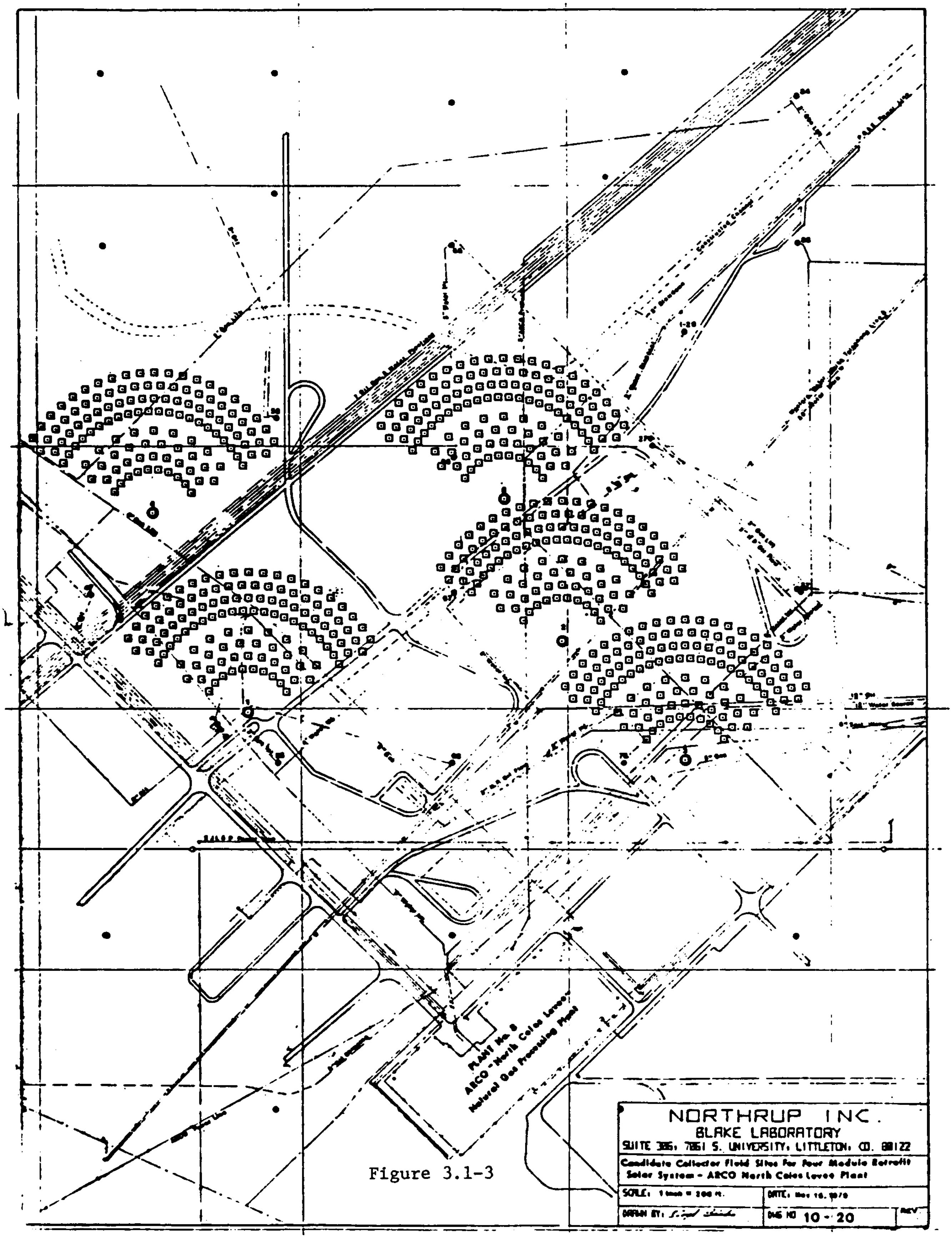

PLANT No. 8
ARCO - North Coles Levee
Natural Gas Processing Plant
NORTHRUP INC.
BLAKE LABORATORY
SUITE 305, 7861 S. UNIVERSITY, LITTLETON, CO. 80122
Candidate Collector Field Sites For Four Module Retrofit Solar System - ARCO North Coles Levee Plant
SCALE:
DATE:
DRAWN BY:
DWG NO 10 - 20
REV.

Figure 3.1-3

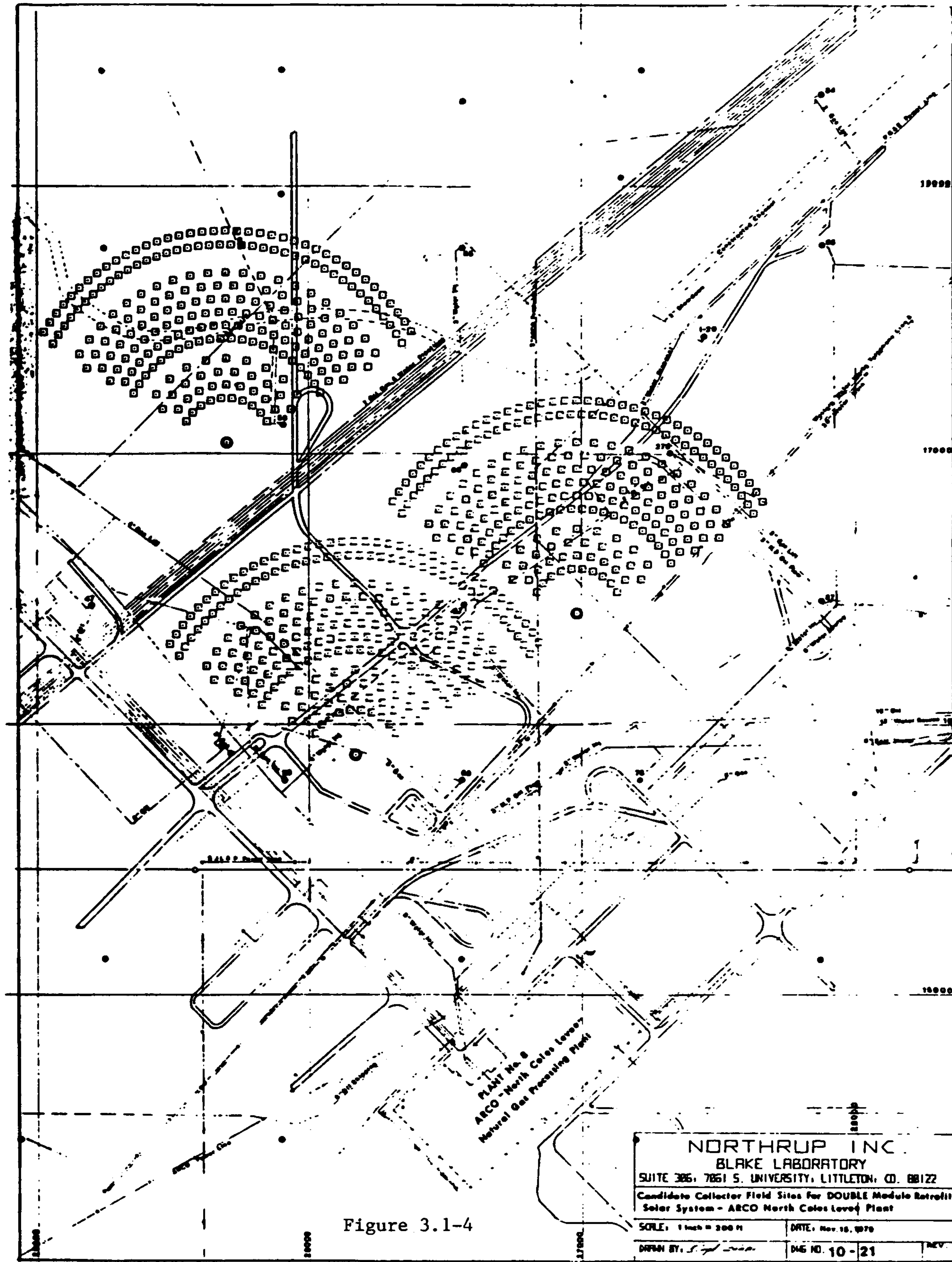

NORTHRUP INC.
BLAKE LABORATORY
SUITE 306, 7861 S. UNIVERSITY, LITTLETON, CO. 80122
Candidate Collector Field Sites For DOUBLE Module Retrofit Solar System - ARCO North Coles Levee Plant
SCALE: 1 inch = 200 ft
DATE: Nov. 15, 1979
DWG NO. 10 - 21
REV
PLANT No. 8
ARCO - North Coles Levee
Natural Gas Processing Plant
17000
16000

Figure 3.1-4

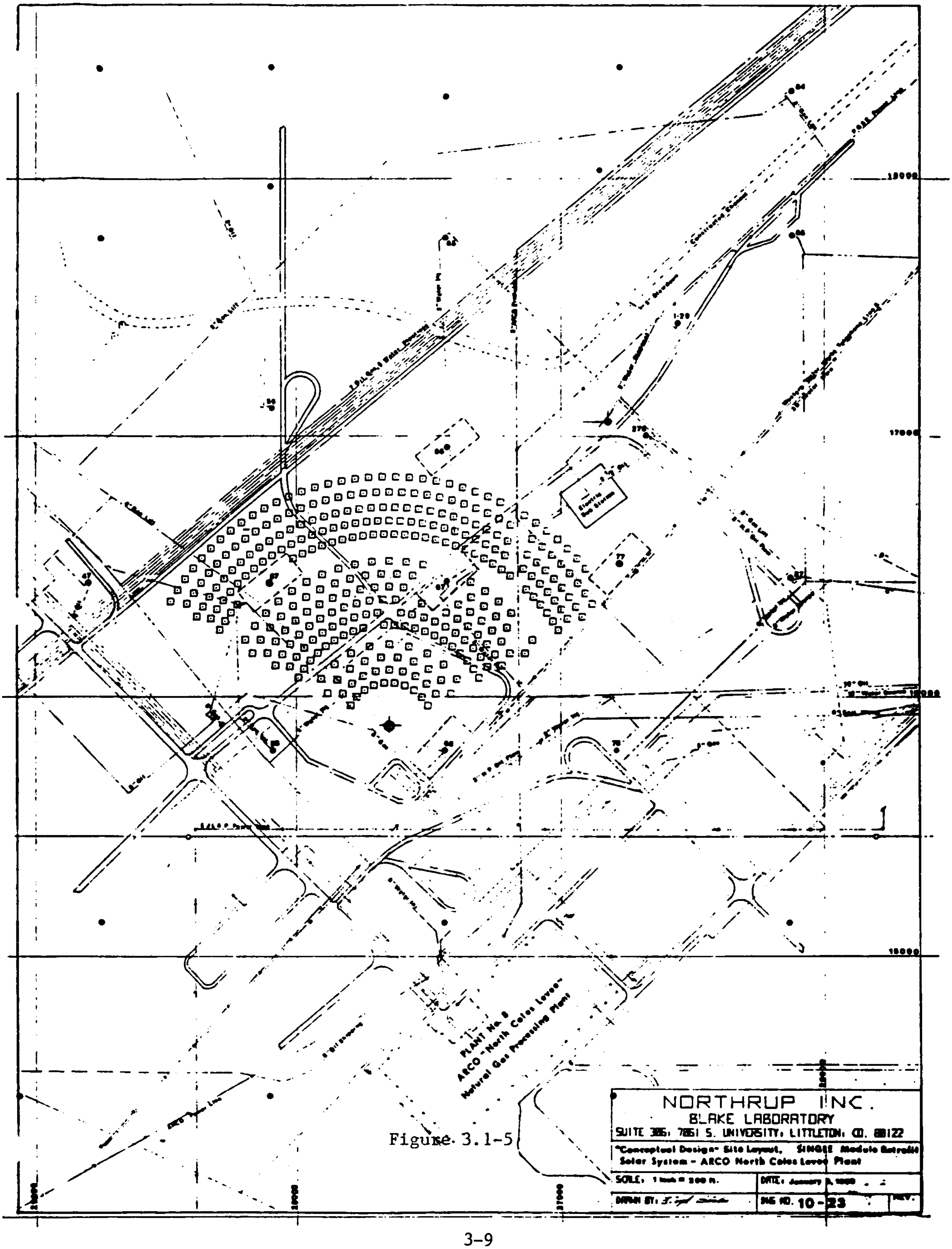

NORTHRUP INC.
BLAKE LABORATORY
"Conceptual Design" Site Layout,
Solar System - ARCO North Coles Levee Plant
SCALE:
DATE:
DWG NO. 10-23
REV.
PLANT No. 8
ARCO "North Coles Levee"
Natural Gas Processing Plant

Figure 3.1-5

TABLE 3.1-1 - COLES LEVEE APPLICATION LAYOUT TRADE OFF SUMMARY

	FLAT FIELD	QUAD TOWERS	DOUBLE TOWERS	SINGLE TOWER
$C_{HELIOSTAT}\ (@\$230/m^2)^*$	5,378,500	5,378,500	5,378,500	5,378,500
C_{TOWERS} (Sandia model)	0	2,020,712	1,113,016	623,603
$C_{RECEIVER}$	344,712	179,506	213,698	188,054
C_{PIPING}	495,364	301,587	164,005	81,698
C_{WIRING}	29,179	33,731	28,706	27,817
C_{TOTAL}	6,247,755	7,914,036	6,897,925	6,299,672
$\eta_{GEOMETRIC,\ ANNUAL}$	763899	.833121	.83144	.829824
$C_{NORMALIZED}$	8,178,771	9,499,264	8,296,359	7,591,575
ENERGY ANNUAL	3.457×10^7	3.76216×10^7	3.754452×10^7	3.7422×10^7
SPECIFIC CAPITAL COST $/ANNUAL KWT	0.18073	.21036	.18373	0.16834
RATIO w/SINGLE	1.07735	1.2496	1.09140	1.00

* Analysis Value for First Plant

Figure 3.1-6

GEOMETRIC PERFORMANCE EFFICIENCY
RADIAL LAYOUT, 216/166.5 FT ROWS

NORTHRUP

AZIMUTH ANGLE, DEGREES

SOLAR ELEVATION, DEGREES	0	30	60	75	90	110
89.5	0.7104	0.7100	0.7091	0.7086	0.7080	0.7070
65	0.8281	0.8137	0.7748	0.7486	0.7182	0.6742
45	0.8934	0.8697	0.8030	0.7569	0.7048	0.6301
25	0.9239	0.8759	0.7864	0.7297	0.6636	0.5641
15	0.8517	0.7927	0.7037	0.6553	0.6025	0.5067
5	0.7384	0.6469	0.5597	0.5126	0.5014	0.4177

AVE. ANNUAL EFF. = 0.7639   ENERGY = 3.4570×10^7 KWT-HRS

Figure 3.1-7

GEOMETRIC PERFORMANCE EFFICIENCY
COLES LEVEE QUAD MOD: 41M [135FT] TWR

AZIMUTH ANGLE, DEGREES

SOLAR ELEVATION, DEGREES	0	30	60	75	90	110
89.5	0.8152	0.8148	0.8141	0.8136	0.8131	0.8123
65	0.9020	0.8890	0.8526	0.8281	0.8011	0.7645
45	0.9455	0.9244	0.8636	0.8219	0.7754	0.7104
25	0.9454	0.9187	0.8560	0.8006	0.7376	0.6468
15	0.8695	0.8572	0.8037	0.7480	0.6879	0.5973
5	0.7299	0.7315	0.6798	0.6417	0.6177	0.5019

AVE. ANNUAL EFF. = 0.8331 ENERGY = 3.7622×10^7 KWT-HRS
[437 HELIOSTATS]

Figure 3.1-8

GEOMETRIC PERFORMANCE EFFICIENCY
COLES LEVEE DOUBLE MOD, 53M [174FT] TWR

AZIMUTH ANGLE, DEGREES

SOLAR ELEVATION, DEGREES	0	30	60	75	90	110
89.5	0.8120	0.8116	0.8109	0.8104	0.8099	0.8092
65	0.8991	0.8861	0.8496	0.8251	0.7981	0.7615
45	0.9426	0.9215	0.8611	0.8194	0.7727	0.7077
25	0.9482	0.9208	0.8531	0.7978	0.7346	0.6442
15	0.8904	0.8690	0.8015	0.7452	0.6871	0.5931
5	0.7467	0.7384	0.6815	0.6494	0.6211	0.5034

AVE. ANNUAL EFF. = 0.8314

ENERGY = 3.7544×10^{7} KWT-HRS
[437 HELIOSTATS]

Figure 3.1-9

GEOMETRIC PERFORMANCE EFFICIENCY
COLES LEVEE SINGLE MOD, 61M [200FT] TWR

NORTHRUP

AZIMUTH ANGLE, DEGREES

SOLAR ELEVATION, DEGREES	0	30	60	75	90	110
89.5	0.8005	0.8001	0.7993	0.7988	0.7983	0.7975
65	0.8904	0.8770	0.8399	0.8148	0.7872	0.7498
45	0.9363	0.9147	0.8537	0.8111	0.7635	0.6970
25	0.9510	0.9231	0.8494	0.7932	0.7286	0.6363
15	0.9194	0.8904	0.8082	0.7493	0.6848	0.5877
5	0.7704	0.7383	0.6934	0.6545	0.6187	0.5085

AVE. ANNUAL EFF. = 0.8298   ENERGY = 3.7422×10^7 KWT-HRS
[437 HELIOSTATS]

3.2 SYSTEM SIZE

The system size is based on the production of the maximum amount of energy that can be effectively utilized in supplying process heat energy, based on plant requirements, with consideration for other sources of energy that would be wasted if replaced by energy from the solar system.

Total daily HMO circulation through the system averages 7.95×10^3 m^3 (2,100,000 gal). The system capacity is approximately 7.57×10^1 m^3 (20,000 gal.), divided almost evenly between the surge tank (37.9 m^3 (10,000 gal)) and the piping system. The system level is maintained at approximately 6.81 m^3 (18,000 gal.) which requires that each segment of the fluid circulate through the system 117 times each day.

There are various inlet and outlet temperatures maintained at the several processes by system by-pass valves and loops. All HMO outlets from the process reheaters and reboilers return to the surge tank, which remains at an average temperature of 216°C (420°F). The HMO is pumped from the surge tank to a Nordberg Heat Recovery Unit (HRU) and two natural gas fired heaters where each of these units raises the HMO temperature to 305°C (575°F). The $7.95 \times 10^3 m^3$ (2.1×10^6 gal./day) flow rate combined with the ΔT of 86.1°C (155°F) results in a calculated average energy production of $1.45 \times 10^4 kw_t$ (4.94×10^7 Btu/hr).

Of this total energy production, approximately 33% is furnished by the HRU which utilizes the heat rejected from the 5500 hp Nordberg Gas Turbine that is used as prime mover for the compressor used in a water flood project. This rejected heat is available 24 hours per day and would be wasted if not utilized in the heat medium system. For this reason, this energy was not considered as replacable by solar, as no fossil fuel displacement would result.

The flow rate through the HRU averages $2.12 \times 10^3 m^3$ (560,000 gal) per day. This flow combined with the 77.8°C (140°F) ΔT produces $3.86 \times 10^3 kw_t$ (1.31×10^7 Btu/hr).

The remainder 1.06×10^4 kw_t (3.631×10^7 Btu/hr) is delivered to the system by the fired heaters.

There is an additional limitation on the amount of energy to be supplied by the solar system. The heat supplied by the fired heaters is controlled relative to system demand by control of fuel gas to the heater burners. Adequate control is accomplished quite easily and automatically, within the narrow limits of the normal operating range, by a TRC valve in the fuel line which is controlled by the HMO outlet temperature. However, complete start-up from a cold or complete fuel shut-off condition is a somewhat complicated and lengthy process involving safety systems, alarm systems, flame provers, pilot burners, torch lighters and main burners. In order to eliminate the daily (or even more often in the case of cloud transients) burner shut-down and start-up process or a complete redesign of the existing control system, it was decided that the heaters would remain in service, but operating at a maximum turndown of 10 to 1. In order that the remaining heat not be wasted during periods of high solar insolation, the decision was made to design the solar system such that the constant flow of HMO through the heaters would be retained and the solar system sized to return to HMO to the system at a maximum temperature that would still allow the fired heaters, operating at maximum turndown level, to utilize the energy produced to "top-off" the HMO to meet the 301°C (575°F) process temperature requirement. This design criteria greatly simplifies the control system and minimizes installation and operational interference with routine plant operations while remaining compatible with the existing safety system and associated procedures.

In order to fully utilize the energy produced when the fossil system is operating at minimum, the solar system was sized to supply sufficient energy to increase the HMO temperature from 216°C (420°F) to 293°C (560°F) and return it to the inlet of the fired heaters where the temperature is increased to the required 301°C (575°F).

Combining the 0.067 m^3/s (1,530,000 gal/day) flowing through the fired heaters with the ΔT requirememt of 77.8°C (140°F) and the specific heat (0.595 Cal./gm °C) of the HMO produces a maximum heat replacement of 9.518 Mw_t (3.249 x 10^7 Btu/hr.).

The solar system was sized and components selected that would deliver this quantity of heat to the plant system at noon on the summer solstice. Combining all sources of heat loss during collection, conversion, and transport with north field radial stagger collector performance efficiencies resulted in a collector field size of 320 heliostats.

The thermal load sizing calculations based on the Heat Medium Oil system characteristics and constraints are summarized in Figure 3.2-1. Examples are given for the two solar augmentation temperature-flow options, "Partial Flow-Full ΔT" and "Partial ΔT-Full Flow." The latter was selected for its simplicity of control and minimum impact on the equipment and operation of the present system.

Process heat stairstep energy balance charts for the summer noon design point, equinox noon, and winter noon are shown on Figures 3.2-2, 3.2-3 and 3.2-4. Combined solar system efficiencies for the three days at noon are 61.4, 67.1 and 70.2 percent respectively.

The annual average combined efficiency is 53.8%.

Figure 3.2-1

BASIS FOR 9.52 MWt SOLAR MODULE SIZE

TOTAL HEAT MEDIUM OIL FLOW - PLANT 8	2,100,000 Gal/Day
Less Oil Heated in Recovery Heaters	- 570,000 Gal/Day
NET H.M. OIL TO GAS FIRED HEATERS	1,530,000 Gal/Day
Less 10% Minimum Load Heating	153,000 Gal/Day
NET H.M. OIL POTENTIALLY HEATED BY ALTERNATIVE ENERGY SYSTEM	1,377,000 Gal/Day 63,750 Gal/Hour
UNIT FLOW RATE OF AVAILABLE H.M. OIL	57,375 Gal/Hour

METHOD 1: THERMAL LOAD DEVIATION (Partial flow-full ΔT)

Q_{solar} = 57,375 Gal/Hr x (575-420) ^{o}F x 6.07 #/Gal x .60 Btu/# - F

Q_s = 32.37×10^6 Btu/Hr

Q_s = 9,484 KWt

METHOD 2: THERMAL LOAD DERIVATION (partial Δt - full flow)

Q_{solar} = 63750 Gal/Hr x 560-420) ^{o}F x 6.07 #/Gal x .60 Btu/# - ^{o}F

Q_s = 32.49×10^6 Btu/hr

Q_s = 9518 Kwt

Figure 3.2-2

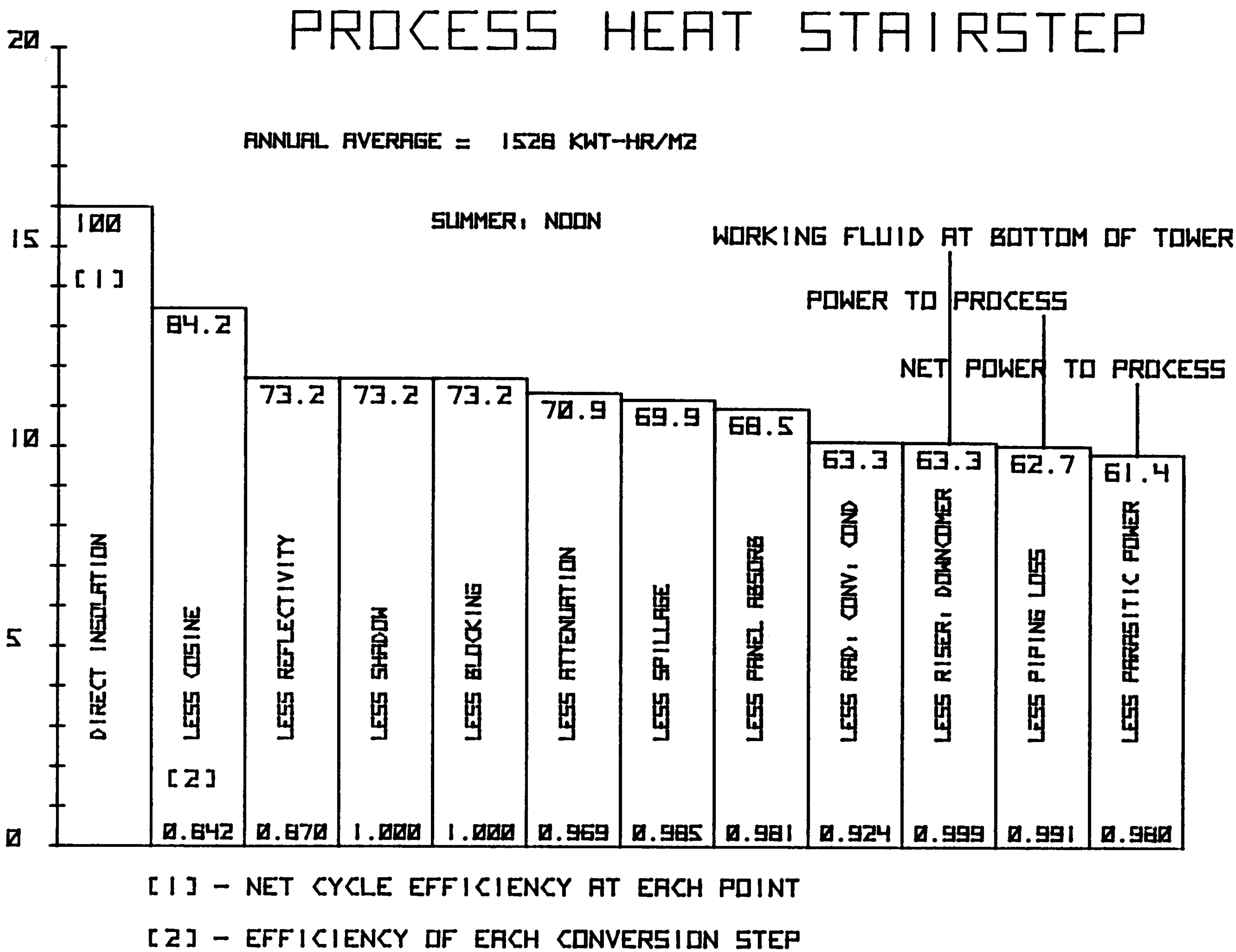
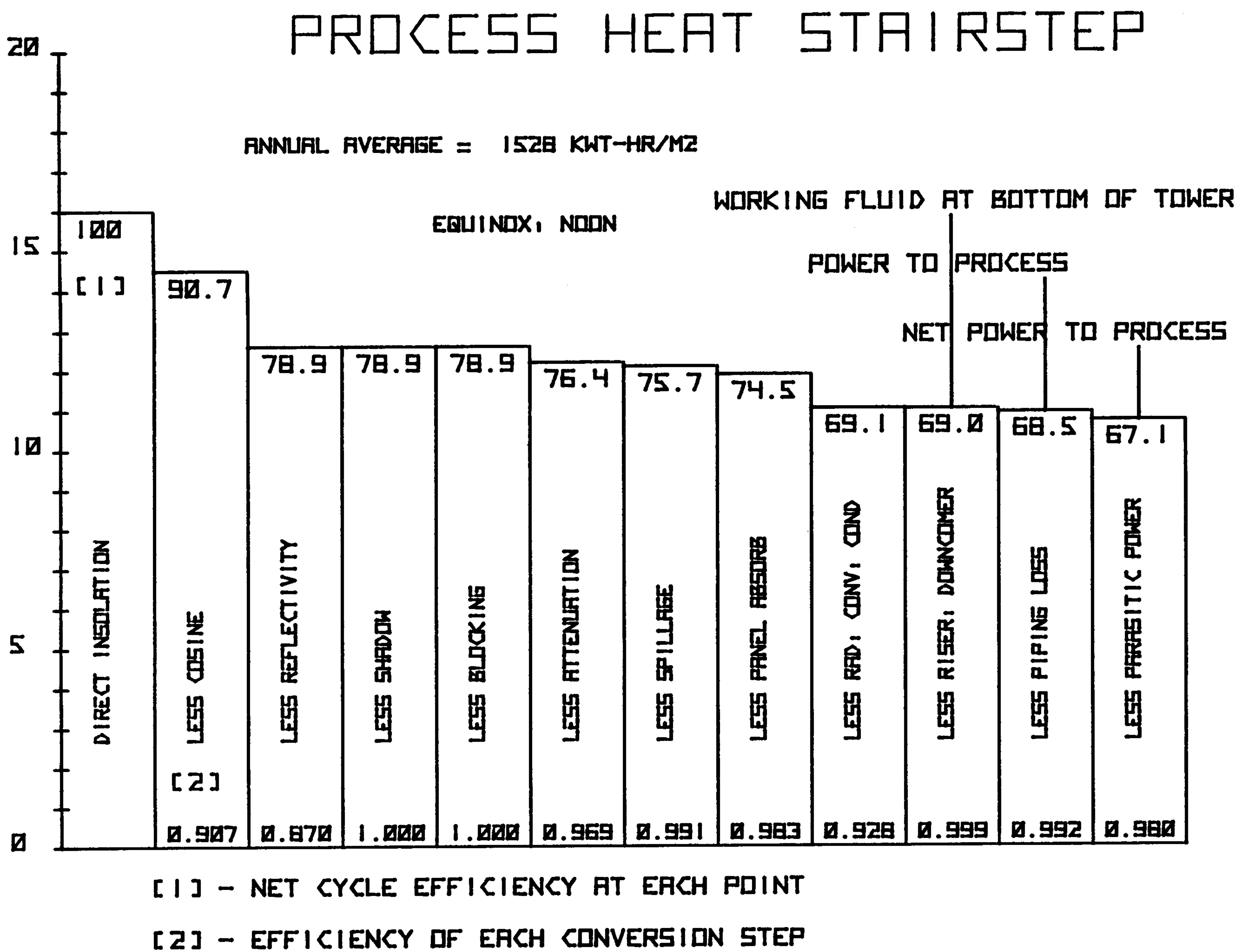
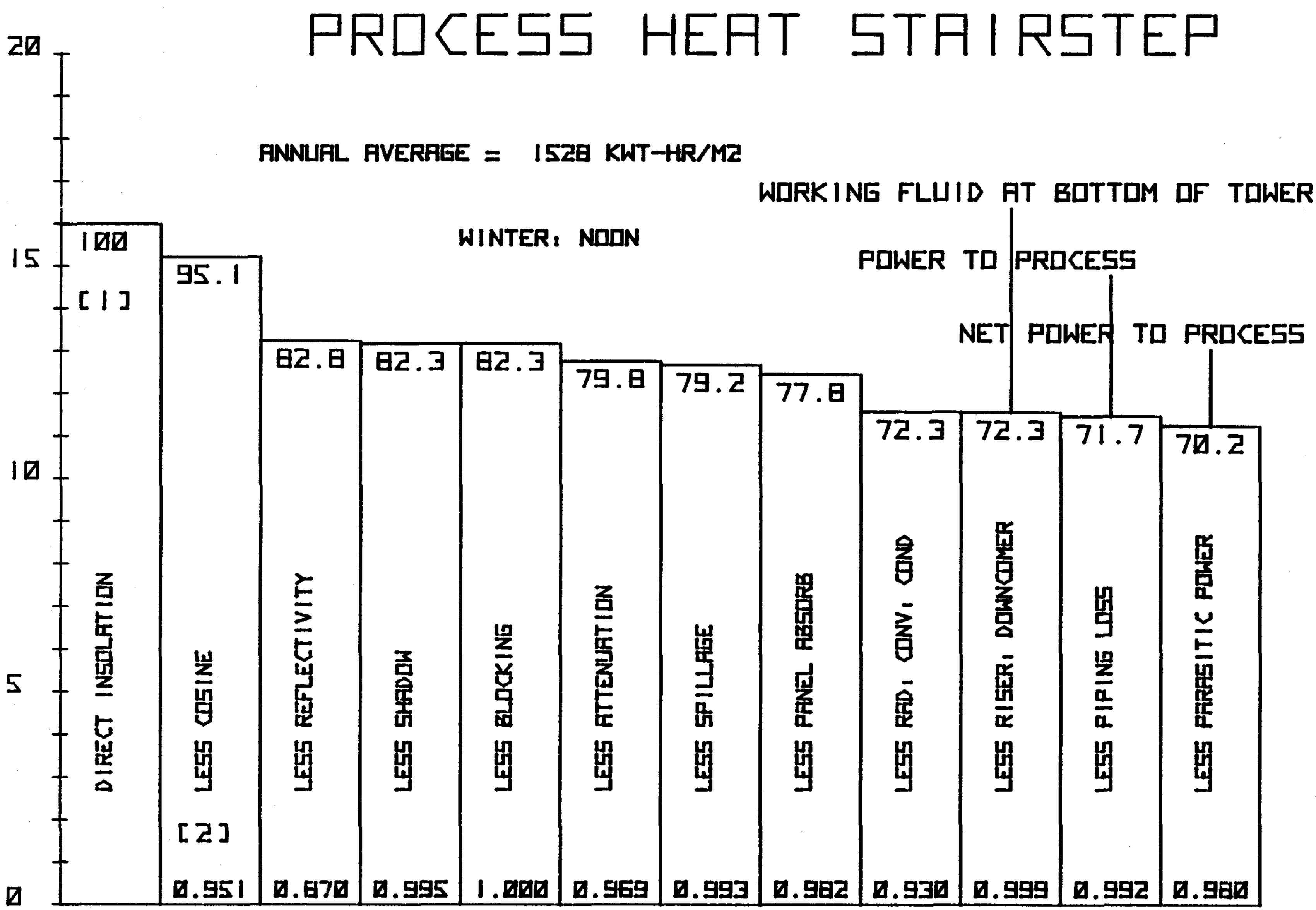

PROCESS HEAT STAIRSTEP
ANNUAL AVERAGE = 1528 KWT-HR/M2
SUMMER: NOON
WORKING FLUID AT BOTTOM OF TOWER
POWER TO PROCESS
NET POWER TO PROCESS
20
15
10
5
0
100
[1]
84.2
73.2
73.2
73.2
70.9
69.9
68.5
63.3
63.3
62.7
61.4
DIRECT INSOLATION
LESS COSINE
[2]
LESS REFLECTIVITY
LESS SHADOW
LESS BLOCKING
LESS ATTENUATION
LESS SPILLAGE
LESS PANEL ABSORB
LESS RAD, CONV, COND
LESS RISER, DOWNCOMER
LESS PIPING LOSS
LESS PARASITIC POWER
0.842
0.870
1.000
1.000
0.969
0.985
0.981
0.924
0.999
0.991
0.980
[1] - NET CYCLE EFFICIENCY AT EACH POINT
[2] - EFFICIENCY OF EACH CONVERSION STEP

Figure 3.2-3



PROCESS HEAT STAIRSTEP
ANNUAL AVERAGE = 1528 KWT-HR/M2
EQUINOX: NOON
WORKING FLUID AT BOTTOM OF TOWER
POWER TO PROCESS
NET POWER TO PROCESS
20
15
10
5
0
100
[1]
90.7
78.9
78.9
78.9
76.4
75.7
74.5
69.1
69.0
68.5
67.1
DIRECT INSOLATION
LESS COSINE
[2]
LESS REFLECTIVITY
LESS SHADOW
LESS BLOCKING
LESS ATTENUATION
LESS SPILLAGE
LESS PANEL ABSORB
LESS RAD: CONV: COND
LESS RISER: DOWNCOMER
LESS PIPING LOSS
LESS PARASITIC POWER
0.907
0.870
1.000
1.000
0.969
0.991
0.983
0.928
0.999
0.992
0.980
[1] - NET CYCLE EFFICIENCY AT EACH POINT
[2] - EFFICIENCY OF EACH CONVERSION STEP

Figure 3.2-4



[1] - NET CYCLE EFFICIENCY AT EACH POINT

[2] - EFFICIENCY OF EACH CONVERSION STEP

3.3 TECHNOLOGY FOR PREFERRED SYSTEMS

The North Coles Levee process heat system utilizes four areas of central receiver technology. These are: the heliostats, the receiver, the heat transport medium and the receiver tower. The basic philosophy in developing the system has been to incorporate subsystems and components that either are standard or state-of-the art requiring no significant technology development or advancement.

- Heliostats The heliostats selected for the project are the Northrup II, described in detail in section 5.1. These heliostats are being developed under a DOE Second Generation Heliostat Contract and, while exibiting the latest in heliostat technology, require no major development break through in order to be available for installation at the North Coles Levee site within the scheduled time period.

- Receiver The receiver design utilizes a single cavity configuration. The heat exchanger portion of the system is a series-parallel flow arrangement of standard embossed panels that are used extensively as exchangers in a wide variety of industrial processes. While this application of the panels is unique, calculations have shown that this configuration can operate in the cavity environment for the entire 30-year system design life without significant degredation or failure. In addition to the utilization of standard components, the receiver contains no operational elements or controls.

- Heat Transfer Medium The heat transfer fluid selected is designated Hydrotreated Light Cycle Oil produced by ARCO's Watson Refinery for this purpose. This oil has been used successfully at the North Coles Levee Plant since 1940. The reasons for this selection include; economy ($0.50/gal), many years operating experience in this plant, does not require special containment materials and it is an ARCO product.

- <u>Tower</u> The receiver tower selected is a three-legged free-standing steel structure produced by Unarco-Rohn of Peoria, Ill. While there will be special engineering required to accomodate the receiver size and weight, the structure will be made-up of readily available tower components.

All aspects of the technology required for the fabrication and installation of these subsystem will be available to accomodate the construction of the North Coles Levee solar process heat system in the 1983 time frame.

3.4 SYSTEM CONFIGURATION

The basic objectives driving the configuration of the North Coles Levee system are attainment of highest economic performance of the solar energy system with minimum impact on the existing plant. The selection of the 320 heliostat radial stagger field configuration was based on a trade study which is described in Section 3.1.

The receiver design was based on the utilization of standard heat exchanger panels in a configuration that is economical while maintaining the required reliability and performance standards (Section 5.2).

The receiver loop design described in Section 5.4 was developed to provide a simplified control system and minimum interference with normal plant operations through the use of standard materials and components.

The three-legged tower was selected because it meets the structural requirements and it is an adaptation of existing tower components and offers economy with respect to towers designed for this specific purpose. (Section 5.3).

The HMO was selected because it has performed satisfactorily for many years at the North Coles Levee Plant. It also offers economy and it is produced at the nearby ARCO Watson refinery. (Section 5.4).

The rationale for configuring the solar system without a solar thermal storage subsystem is as follows:

The solar system chosen consists of a collector and receiver network which can match the burner capacity while the sun in shining at rated intensity. On an annual basis this system saves 24.4 percent of the 10.34×10^6 (365×10^6 cf) of gas burned by the "Heat Medium Oil" heaters. The projected capital investment for this first 24.4% segment is 8,336,000.

Use of thermal storage was found to be unacceptable during the system trade off study. A step function drop in the economic performance of the system results with the first increment of storage addition. The capital cost of an added solar storage system matching the performance of the real time solar system is approximately 1.6 times the cost of the real time solar system. Costs for added oil in the system, added insulated tankage and added heliostats form the cost increment.

SECTION 4.0

CONCEPTUAL DESIGN

This section presents a system level analysis of the North Coles solar retrofit system. It begins with a description of the system conceptual design and includes presentations of the functional requirements, operating characteristics and system performance. Both the capital and operating and maintenance costs are discussed. Other topics presented include system safety and environmental and regulatory considerations.

4.1 SYSTEM DESCRIPTION

The North Coles Levee solar process heat system is composed of four major subsystems. These are; the collector, the receiver, the tower and the receiver loop. A plan view of the system is shown in Figure 4.1-1.

The collector field is a radial stagger configuration containing 320 heliostats located within a circular sector of 2.09 rad.(120^{o}) included angle and 304.8 m (1000 ft) radius. The sector is symmetrical about a North-South radius which passes through the tower center located at the arc center of curvature. As shown in the figure, there are small areas that contain no heliostats. These areas are provided for oil well service and clearance for overhead power and communication lines.

The heliostat used in the field design is the Northrup II being developed under a DOE contract. Each heliostat has 52.8 m^2 (566 ft^2) of reflective surface area. Heliostat control is provided by a two-level open loop system using computer controlled stepper motors for tracking and slewing.

The system uses a single cavity, non-canted north facing receiver. The active portion of the receiver is an arc segment 18.9 m (62 ft) long by 9.14 m (30 ft) on a radius of 7.3 m (24 ft) with respect

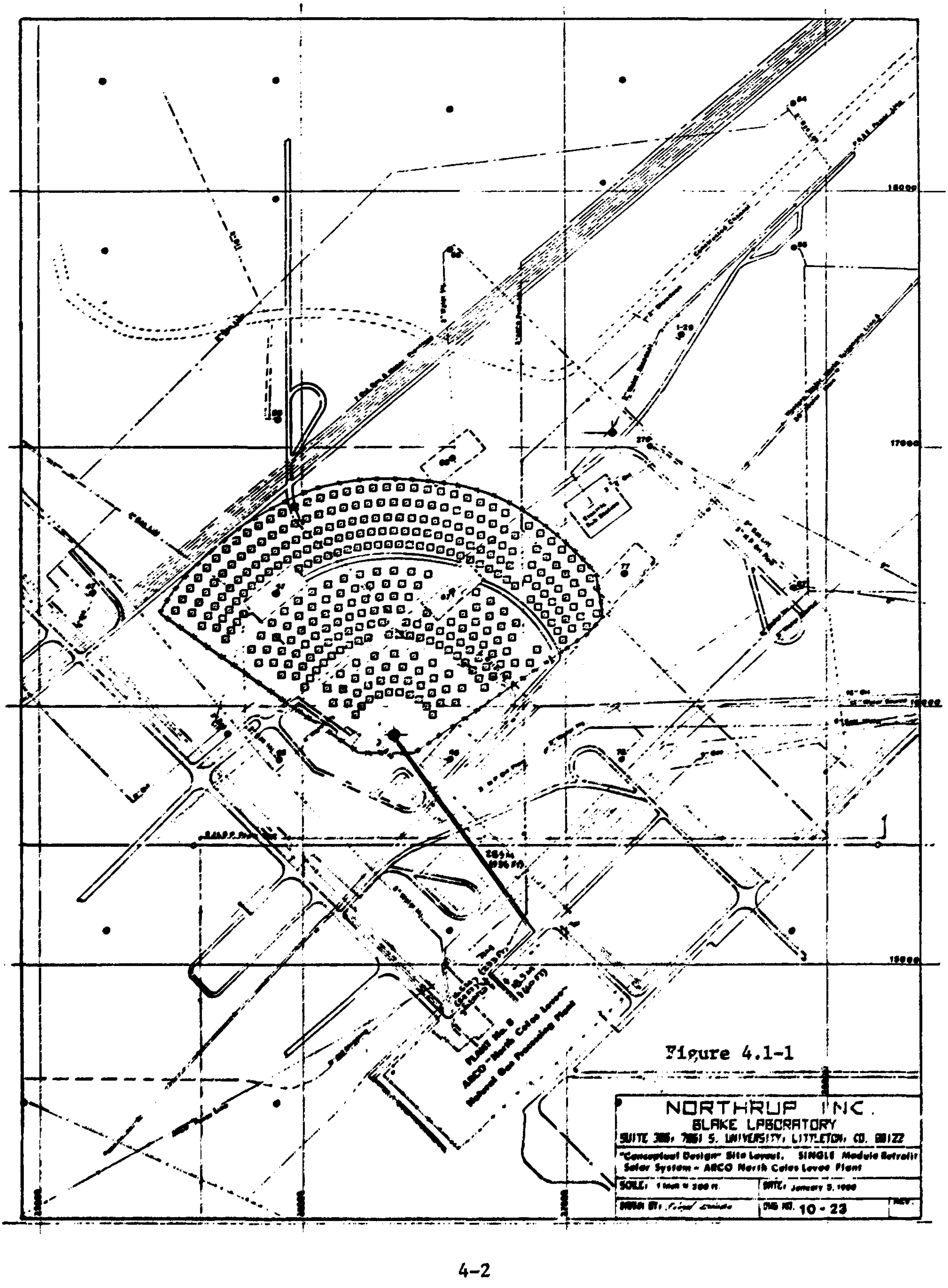

NORTHRUP INC.
BLAKE LABORATORY
"Conceptual Design" Site Layout, SINGLE Module Retrofit Solar System - ARCO North Coles Levee Plant
DWG NO. 10 - 23

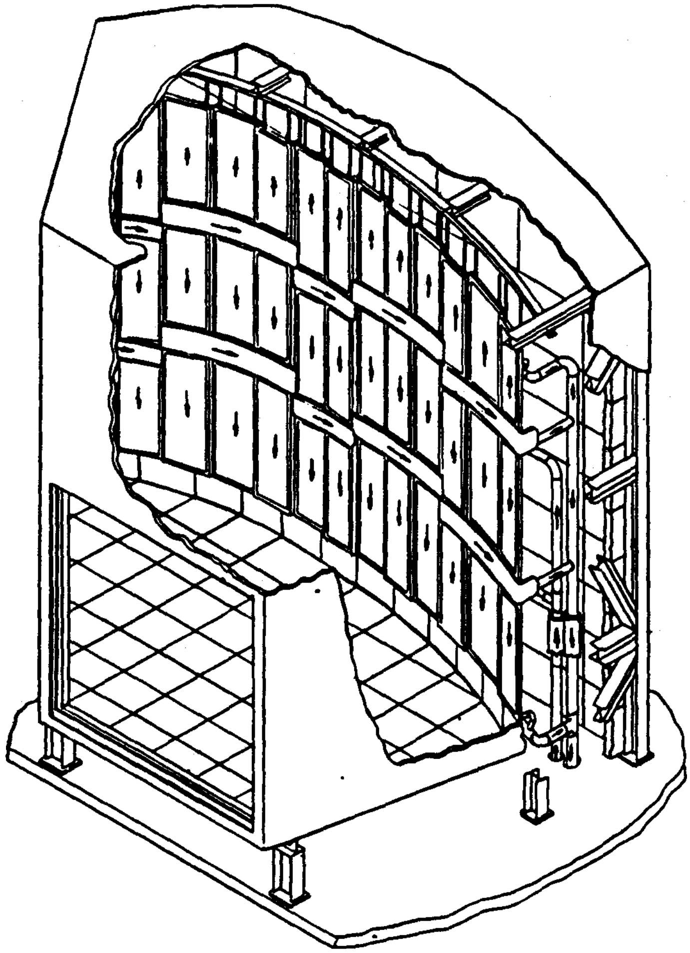
Figure 4.1-1

to the aperture plane. It is made up of standard embossed and welded heat exchanger panels. (Figure 4.1-2) The active receiver is housed in a metal clad insulated housing with a 8.2 m (27 ft) square north facing aperture. HMO flow through the receiver and receiver loop is constant and no active controls are required on the receiver unit.

The receiver is mounted on a three-legged steel tower of sufficient height 56.4 m -(185 ft) to place the center of the aperture plane 61 m (200 ft) above the ground surface. The tower is provided with a service elevator, safety ladder, obstruction lighting, lightning protection for the receiver and maintenance lighting.

The receiver loop is a 457 m (1500 ft) piping run (each way) between the plant HMO system interface and the receiver inlet and outlet manifolds. (Figure 4.1-1) This loop contains the HMO flow control valves that automatically direct the HMO flow through the receiver or directly to the fired heater depending upon the insolation conditions. The loop also contains a booster pump to compensate for pressure losses within the receiver and loop, and to circulate the HMO within the loop in order to bring the HMO up to operating temperature during startup. System control is provided by the automatic control valves at the interfaces of the loop with the plant system. Control is extremly simple because the three-way valves (3) can either block the plant flow to the fired heaters for solar operation or isolate the solar system for normal plant operation. Flow rate control is not required. All operating components are provided with manual controls for operator control of the solar system. Other than changing the direction of HMO flow to the fired heaters, the solar system operator has no control of the plant HMO or process system.

Figure 4.1-2



9.518 MW_t Receiver

4.2 CONCEPTUAL DESIGN FUNCTIONAL REQUIREMENTS

4.2.1 Performance

The solar retrofit system has been designed to meet the following performance requirements.

1. Rating of Solar Retrofit System

   Rating = 9.518 MW_t (32.49 x 10^6 Btu/hr) To Plant Heat Medium Oil System

2. Rated Operating Conditions

   Insolation = 0.95 kW/m^2 minimum

   Solar Angle = Noon of Summer Solstice and all angles resulting in average field cosine above 0.84.

   Energy Delivery Temperature = 215°C (420°F) minimum; 293°C (560°F) maximum

   Environmental Conditions = 0 to 12 m/s (27 mph) wind; 0 to 50°C (32 to 122°F) temp.

3. System Flow Rate .067 m^3/s (1065 gpm)

4.2.2 System Design Life

The solar energy system for the ARCO North Coles Levee facility is designed for a life of 30 years. The critical or life-limited components of the system are the heliostat drive unit (tooth wear), the heat transfer oil pump (impeller erosion), and the receiver Platecoil panels (thermal stress-fatigue).

The heliostat drive unit employs a worm and gear set as the output stage for both the azimuth and elevation axis. The gear has a 0.428 m (16.87 inch) pitch diameter, and the as-built-worm-to gear mesh backlash is 1×10^{-4}m (0.004 inch) which results in a potential pointing error of 0.38 mrad. At a slant range of 305 m (1000 ft), this backlash could cause an on-target error of 0.23 m (0.76 ft). Over a 30 year life (10,000 cycles) it is estimated that gear tooth wear would at most triple this backlash to 3×10^{-4} m (0.012 inch) which, in turn, would increase the potential on-target error to 0.7 m (2.28 ft) for the heliostat at maximum slant range. While this error could most likely be tolerated, it is planned to eliminate its effect by software compensation. Maximum wear would occur in the elevation gear due to the ever-present gravity moment. Fortunately, the resulting backlash gap is always loaded in one direction by the gravity loads and can be easily accounted for by an adjustment of the position switch, or by a software correction. Azimuth gear wear should be minimal because there are no gravity loads on this gear, and because the wind loads in the azimuth direction are greatly reduced by the elevation angles encountered during normal daily operation.

The heat transfer oil pump has a useful life of 15 years even with normal seal and bearing maintenance/replacement. Therefore, a replacement pump is included in the maintenance cost analysis.

The receiver Platecoil panels experience a relatively high thermal stress cycle during each heat-up and cool-down cycle. This stress is caused by the local temperature gradient which exists between the flow passage front face, rear face, and the adjacent non-wetted fin. For a given Platecoil configuration and flow rate, the stress is approximately proportional to the heat flux. Therefore, the panels located near the receiver center are subjected to the maximum thermal stress. It is estimated that a receiver would experience an average of 1000 thermal cycles per year due to normal diurnal operation and cloud passages, or 30,000 cycles over a 30 year lifetime. Figure 4.2-1 presents the S-N fatigue life curve for the carbon steel panels. The worst-case thermal stress for the peak flux central panels is 151.7 x 10^6 Pa (22,000 psi). Figure 4.2-1 shows a cycle life capability of 300,000 cycles at this stress level.

One of the advantages of the Platecoil panel concept for the receiver is ease of replacement. If a given panel or group of panels were inadvertanly over-stressed and warpage occurred, the damaged panel can be easily removed by cutting two 1½-inch Schedule 40 pipes, lifting the panel from its hangers, installing a new panel in its place, and re-welding the supply and return pipes.

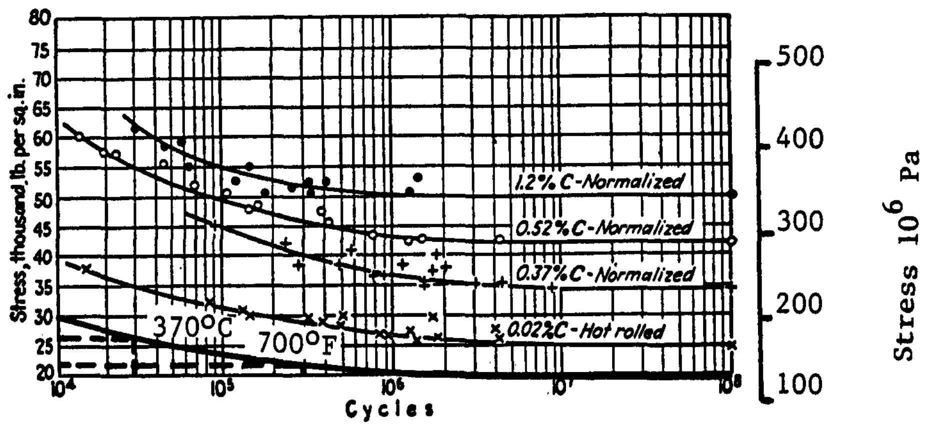


Figure 4.2-1

S-N Curves For Carbon Steel

4.2.3 Design Point

The design point for sizing the retrofit solar system was based on matching the displaceable fossil fuel's thermal contribution to the "heat medium oil" system. Solar energy was to be supplied directly to the process oil just prior to its entry into the fired heaters which controlled the oil outlet temperature at 301°C (575°F). Due to the maximum turn down limitations of the fired heaters the magnitude of the displaceable fuel was established to be 90% of that used by the heaters. The thermal load equivalent was 9.52 MW_t (32.5×10^6 Btu/hr) and this was established as the design point rated load.

For the collector, sizing was based on meeting the rating with the poorest noon geometric performance of the year (summer solstice) and an insolation level of .95 KW/m^2.

Under these conditions the solar system would receive oil at 215°C (420°F) and discharge it to the inlet of the fired heaters at 293°C (560°F).

4.2.4 Plant Instrumentation and Control Philosophy

Simplicity is the key word for the instrumentation and control of the HMO loop portion of the solar unit. The ideal condition is to gather and record all useful data to effect the control, and to control as few elements as possible. This has been done for the HMO flow through the solar unit. The only control is to divert the HMO flow to the solar receiver, or to bypass the solar unit. The temperatures and flow rate of the HMO will be recorded.

4.3 DESIGN AND OPERATING CHARACTERISTICS

This section presents the design and operating characteristics of the solar process heat system. The combined plant and solar system operating modes are outlined. A flow diagram is presented to illustrate HMO flow through both the solar and process systems. The system thermal energy balance based on the energy stairstep technique is discussed. Also presented are the instrumentation requirements and the control system operating characteristics.

4.3.1 Operating Modes

The addition of the solar system provides the plant with a total of three operating modes. The existing mode is fossil fuel operation only and the two new modes are: solar and fossil and solar/fossil.

Fossil Operating Mode: In this mode, the plant HMO system operates in the usual manner. The control valves in the solar receiver loop are positioned to isolate the HMO within the loop. The loop pump is off and the heliostats are stowed. This is the normal overnight and extended cloud cover mode.

Solar and Fossil Operating Mode: In this mode, both plant and solar systems are operating independently. The solar system is isolated from the plant system by the control valves. The heliostats are focused on the receiver and the loop pump is circulating the HMO within the loop. This mode is used to bring the temperature of the HMO within the loop up to surge tank temperature prior to moving into the solar/fossil operating mode. This is the normal startup operating procedure.

Solar/Fossil Operating Mode: In this mode, the control valves block the plant HMO lines to the fired heater and divert the HMO through the solar receiver and return it to the fired heaters. The heliostats are focused on the receiver and the loop pump is in operation. The fired heaters remain in the plant loop to compensate for HMO temperature differentials between solar output and process requirements. This is the normal operating mode during periods of sufficient insolation. However, this mode continues in operation in the absence of insolation until the loop return temperature falls to within 2.8^{o}C (5^{o}F) of the surge tank temperature, at which time the controls automatically place the plant in the fossil operating mode.

The system operating controls and procedures for abnormal and emergency conditions are described in Section 4.3.4.

4.3.2 Flow Diagrams

The basic schematic flow diagram for the solar augmented natural gas processing operation selected for the ARCO Coles Levee plant is shown in Figure 4.3-1. The loop currently in operation starts at the heat medium surge tank, the low temperature tankage point. Low temperature oil 215°C (420°F) is now pumped directly to the fired heaters and heat recovery unit. Hot oil, 301°C (575°F) from the heater's outlets is pumped through the sequence of process heat reboilers and returned to the surge tank.

For the solar augmentation modification, the oil line ahead of the fired heaters is tapped and the loop to the solar receiver is inserted in series. The configuration change from "plant only" to "solar augmented plant" is controlled by 3 way system control valves (SCV 1 and 2) and a 3-way by-pass valve (BPV-1).

An increased depth flow diagram of the "plant only" system is included as Figure 4.3-2. The solar interface tie in points are designated with an "X".

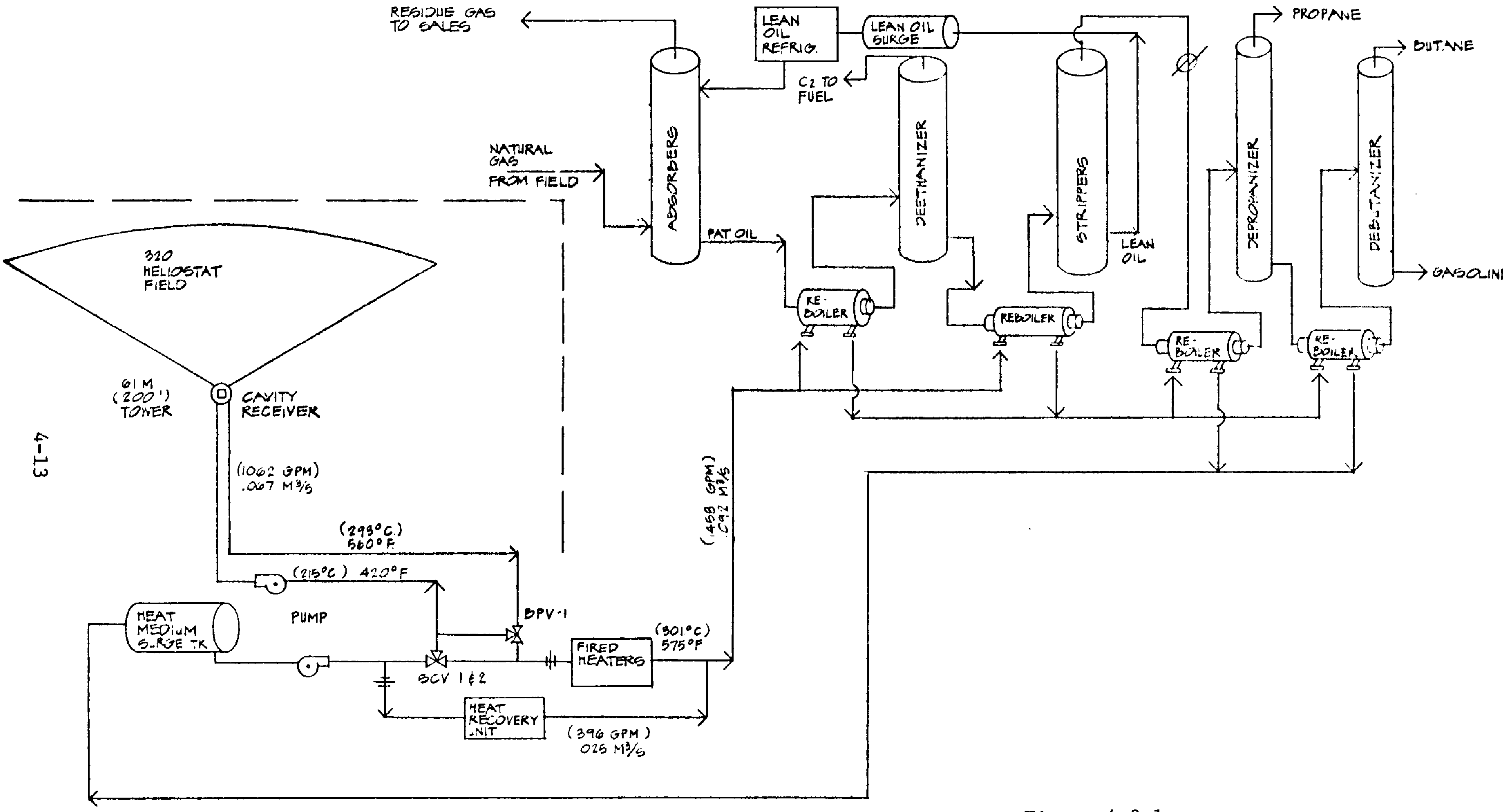


Figure 4.3-1

BPV = BYPASS VALVE
SCV = SYSTEM CONTROL VALVE

Flow Diagram For Solar
Augmented Natural Gas Processing
Coles Levee

4.3.3 Thermal Energy Balance

The thermal energy balance for the conceptual design system has been periodically updated using the stairstep technique illustrated for the design point (summer solstice noon) in Fig. 4.3-3. Eleven energy loss stages operate in series between the potential input power (95 kW/m^2 x mirror area, m^2) and the power delivered to the process.

The first six items involve performance factors of collector components and collector subsystem as a whole. These include:

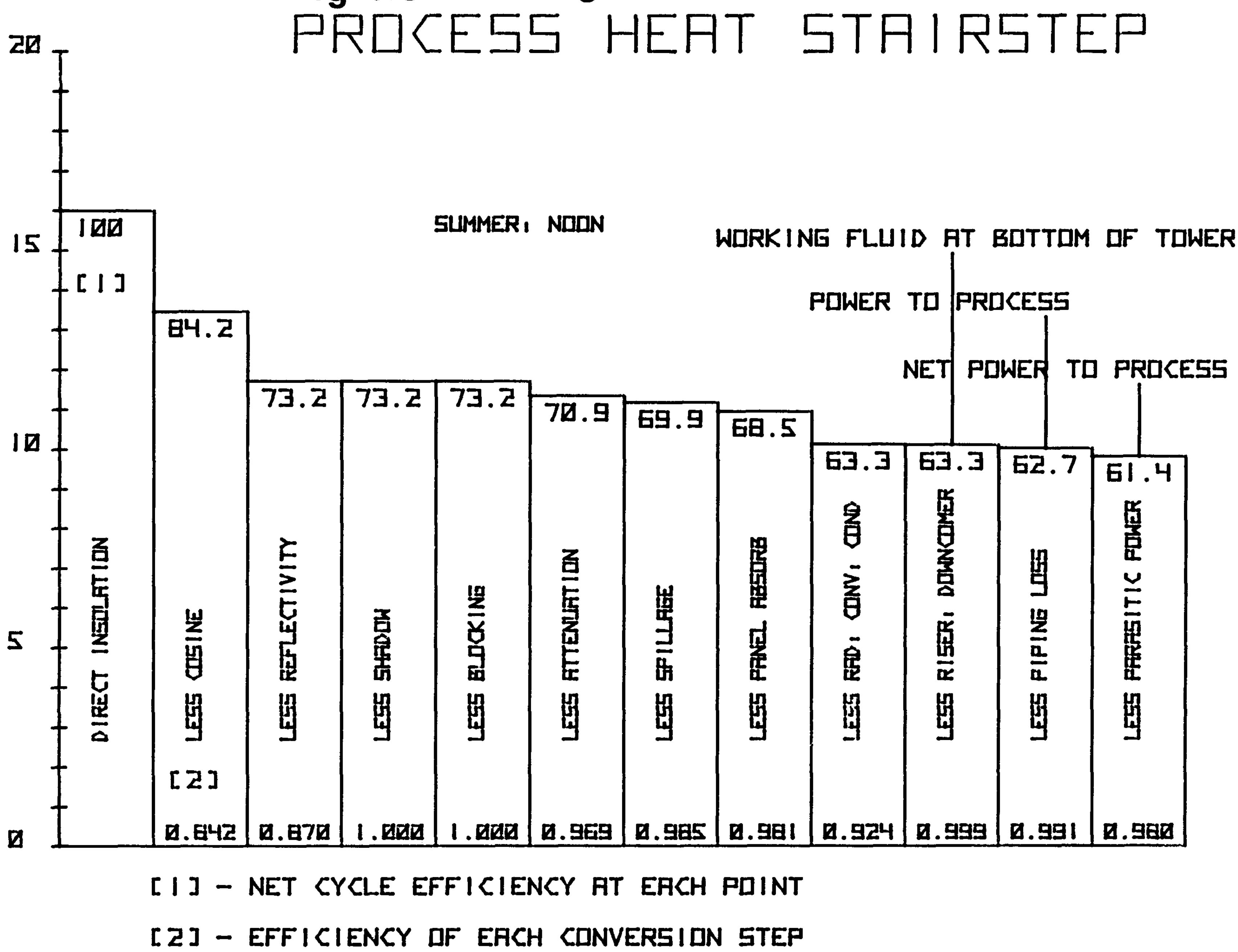
1) the average cosine based on the cosines of each heliostat in the field; 2) the mirror reflectivity; 3) shadowing of heliostats by other heliostats or the tower; 4) blocking of the reflected beams by other heliostats; 5) loss thru atmospheric attenuation of the reflected beam; and 6) spillage at the aperture. Except for aperture spillage all six are items under control of the collector subsystem design. The combined collector efficiency for the design point is .699 and it averaged .689 for the year.

Two items on the stairstep represent the thermal performance of the receiver, 7) the panel absorptivity and 8) the combined radiation, convection and conduction losses. For the design point the receiver efficiency is .906 and it averaged .912 for the year.

The final two items directly involved in the thermal energy train are the riser-downcomer and horizontal piping conduction losses. These were .990 for the design point and only a trace different at .991 for the year.

The final column of the energy balance is an assessment against the solar system of the parasitic power energy equivalent, taken as 2 percent of the output

Fig 4.3-3 Design Point



4.3.4 Instrumentation

Instrumentation will be added to the current plant control to allow monitoring of the solar unit, and a status of the control valve positions at the plant-solar loop interface. The instrumentation will include valve position, heat meadium oil (HMO) temperature and pressure in the supply and return lines, and flow rate. An annunciator panel will also be provided to warn of low flow rate, receiver over-temperature, receiver fire, and heliostat status (on-line, off, stowing, park, and/or power loss). The current philosophy is to not permit any control function to be performed on the solar unit or interface valving from the plant. However, a direct-line communication system will be installed to permit rapid coordination of problems and status between the plant and the solar control operator.

The solar control building will have the same annunciator system to provide both audio and visual alarm warnings. Instrumentation will include control valve position (% open), control temperature setting, and temperature readout of the two control temperatures (surge tank temperature, and by-pass valve BPV upstream temperature). The oil flow rate to the receiver will be recorded at the meter, and visually displayed on a gauge in the solar control console. Likewise, the receiver loop pump suction and discharge pressure will be visually displayed on console gauges.

The receiver temperature status will be recorded on Honeywell Electronik 15, 24 channel multipoint strip chart recorders. A total of 7 such recorders, providing 168 temperature read-outs are included in the design (and cost analysis). All recorders will be ordered with the control option such that a high panel fin temperature, high panel outlet temperature, fire indication thermocouple, etc can result in a relay action (one set of contacts will open, one set will close) to either sound an alarm, drop the flux curtain, initiate heliostat stow, or other control function.

Hence, these units provide a control function, a visual readout, and a printed record. While it may seem excessive for one operator to monitor 168 parameters, in actual practice it is very easy because the channel-by-channel printout creates a trend-pattern on the chart where the previous 30 minutes of operation are visible. The departure of any parameter from its norm disrupts this pattern and is readily apparent by casual observation. So, in reality, the operator is not monitoring 168 individual parameters, but in fact is watching for a sudden pattern change.

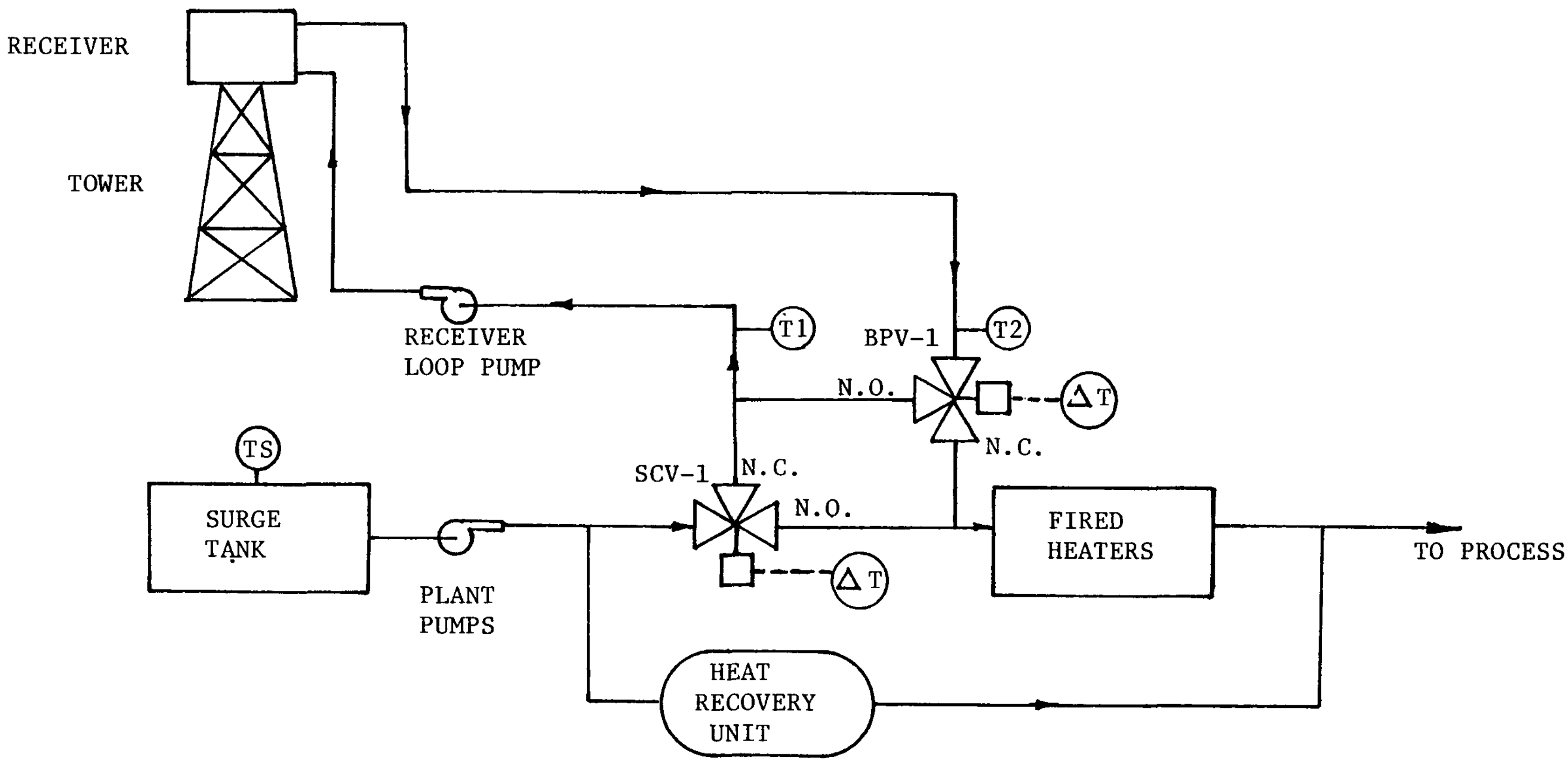
Heliostat status is provided by the computer and the peripheral plotter, screen, and printer. Therefore, the costing of this system was included in the collector subsystem computing equipment rather than as a separate instrumentation system. The output status will include heliostat number, mode (operating, standby, off-line, or stowed), clock time, and azimuth and elevation angle.

4.3.5 Controls

The entire receiver loop is controlled by two valves, the system control valve (SCV-1) and the bypass valve (BPV-1). Figure 4.3.5-1 shows a system schematic with the location of these valves. Both valves are pneumatically actuated 3-way units which are non-modulating. An actuation signal causes the normally open (N.O.) part to close, and normally closed (N.C.) to open. The valves only change the routing of the flow, not the flow rate. Both valves are always actuated in unison by the temperature differential ΔT = T2-TS, or by manual control from the solar console. The receiver loop pump is similarly controlled by a manual switch on the console. This arrangement of the two 3-way valves and the receiver pump permits three modes of operation:

Mode 1-Plant-Only Mode: In this mode, the receiver pump is off, and valves SCV-1 and BPV-1 are in the "normal" position. This is the normal overnight mode. The heliostats are stowed, the receiver loop is off, and the plant is circulating the heat medium oil internally.

Figure 4.3.5-1
Receiver Loop Control Valve Schematic



NOTE: 1). TWO VALVES ARE USED FOR SCV-1 BECAUSE PARALLEL LINES CURRENTLY EXIST AT THIS POINT

2). THE ΔT FOR CONTROL OF SCV-1 AND BPV-1 = T2-TS

Mode 2-Plant and Solar Mode: In this mode, the receiver pump is on, and valves SCV-1 and BPV-1 are in the "normal" position. This is the mode at morning start-up. The plant is still circulating the heat medium oil internally, and the receiver loop is flowing in the recirculating (bypass) mode for the purpose of bringing the loop oil and hardware up to the minimum operating temperature of 215.6 C (420 F).

Mode 3-Solar/Plant Mode: In this mode, the receiver pump is on, and valves SCV-1 and BPV-1 are actuated. All of the oil flow, 0.067 m^3/s (1064 gpm), is routed to the solar receiver, and then back to the plant. This is the normal daytime operating mode. Since the oil returning to the plant may be below the desired operating temperature of 301.7 C (575 F), the oil is routed through the fired heaters for the final heating increment. The system remains in this mode through-out the day, through cloud passages, and even after heliostat operation terminates in the evening provided that the oil returning to the plant is 2.8 C (5 F) above the surge tank. If this temperature differential drops below 2.8 C (5 F), the valves automatically cycle back to the "normal" position for Mode 2 bypass operation. At the end of the day, this action is followed by the receiver pump shutdown which secures the receiver loop, and places the plant back in its normal Mode 1 condition for overnight operation.

The abnormal or emergency controls are those which are provided to protect the solar unit and the plant. These are discussed in the appropriate sub-system sections, and are summarized as follows:

1. Anomoly-High Receiver Inlet Temperature: If the receiver inlet temperature exceeds 226.7 C (440 F), it is likely that the panel temperature or oil outlet temperature will soon exceed acceptable limits. The corrective action is to remove some (or all) of the heliostats, and to place them in a standby mode off target. No other action is required.

2. <u>Anomoly-High Receiver Panel Temperature</u>: If any receiver panel temperature exceeds 365.6 C (690 F), the flux curtain will deploy to block the aperture plane, and the heliostats will be driven to a stow position. The receiver pump loop will remain on, and the available stored energy in the fluid will be delivered to the plant prior to solar loop shutdown.

3. <u>Anomoly-Loss of Electrical Power</u>: The flux curtain will deploy to block the aperture plane, and the control valves will shuttle back to the "normal" position for internal plant operation. Since power has been lost, the receiver pump cannot be operated, and the heliostats cannot be taken off-target. However, the reflected beams will gradually drift off-target due to the earth's rotation.

4. <u>Anomoly-High Panel Outlet Oil Temperature</u>: If any receiver panel outlet temperature exceeds 318.3 C (605 F), the flux curtain will deploy to block the aperture plane, and the heliostats will be driven to a stow position. The receiver pump will remain on until the return oil temperature - supply oil temperature differential falls below 2.8 C (5 F).

5. <u>Anomoly-High Receiver Ceiling Temperature</u>: If the temperature sensors located above the receiver panel-piping zone reach 538.7 C (1000 F), it will be assumed that a fire exists in the receiver. The heliostats will be taken off-target, the cavity doors will close, the receiver pump will be turned off, the control valves will shuttle for internal plant operation, and the receiver fire system will be activated. The fire extinguishing system is a Halon 1301 system which results in the flooding of the cavity with an extinguishing vapor. The inadvertant actuation of this system will not cause any receiver damage.

6. <u>Anomoly-Low Receiver Flow Rate</u>: If the receiver flow rate falls below 0.060 m^3/s (958 gpm), the heliostats will

be stowed, the receiver pump shut down, and the control valves switched to internal plant operation. The primary reason for the complete solar shutdown and return to plant-only operation is that the low oil flow would be detrimental to the plant operation, and the flow restriction could be in the receiver loop.

4.3.6 System Design Characteristics Summary

A tabular summary of the key design and operating characteristics for the system configuration are presented in Table 4.6.3-1.

Table 4.3.6-1

Summary of System Design Characteristics

I.	SYSTEM LEVEL	
	Design Point	9.518 MW_t Noon, Summer Solstice
	Design Insolation	950 W/m^2
	Average Annual Efficiency	.5385
	Solar Fraction	24.4%
	Natural Gas Replaced (Annual)	3.17×10^6 m^3 (112×16^6 ft^3)
	Equivalent Barrels of Oil (Annual)	21,236
	Availability (during sunshine)	.98
	Lifetime	30 years
II.	COLLECTOR FIELD	
	Heliostat	Northrup II
	Number of Heliostats	320
	Mirror Area	16.832 m^2 (181,120 ft^2)
	Field Size	9.73×10^4 m^2 (24 acres)
	Configuration	North, Radial Stagger
III.	RECEIVER	
	Type	Single Cavity
	Aperture	Square, 67.73 m^2 (729 ft^2)
	Absorber Material	Embossed welded steel panels
	Absorber Width	18.85 m (61.84 ft)

	Absorber Height	9.14 m (30 ft)
	No. of Panels	56
	Weight (dry)	66,325 kg (146,180 lbs)
	Elevation (Centerline Aperture	61 m (200 ft)
	Pressure In	931 kPa (135 psi)
	Pressure Out	551.7 kPa (80 psi)
	Temperature In	215.5 (420^{o}F) Nominal
	Temperature Out	293.3^{o}C (420^{o}F) Nominal
	HMO Flow Rate	.067 m^3/s (1062.5 gal/min)
	Active Controls	None
	Average Efficiency (Annual)	89.59%
IV	TOWER	
	Configuration	3-legged
	Height	56.4 m (185 ft)
	Structure	Tubular Steel
V.	RECEIVER LOOP	
	Length	4.57.2 m (1500 ft) each way
	Material	Schedule 40 carbon steel
	Size	.2 m (8 in)
	Operation Control	Pneumatic 3-way valves
	Storage	None
	Heat Transfer Medium	ARCO Hydrotreated Light Cycle Oil
	Volume (plus receiver)	34 m^3 (9000 gal.)

4.4 SITE REQUIREMENTS

This section describes the preparation of the land area for installation of the solar collector field and tower. Also presented is a description of modifications and additions to the plant during the construction of the system.

4.4.1 Site Preparation

The proposed site for the solar project is relatively flat, and much of the area is covered with grass. A pipe and equipment storage yard presently lies within the solar project's proposed boundaries. All the material will be relocated nearby, and should be moved within three weeks of the starting time. Filling of a few low spots will be required before construction begins. The leveling and filling should require about a week. Part of this work can be done concurrent with the storage yard relocation.

4.4.2 Existing Facilities Modified and New Facilities Added

The existing facilities will have minor modifications. The plant control room will have some instrumentation added to monitor the solar unit. An annunciator panel will be installed to inform of fire, high temperature or low flow. Temperature gauges will also be added to show the inlet and outlet temperature of the solar receiver. Present plans do not provide for any solar system control equipment to be placed in the plant control room.

The existing HMO system will have some modifications at the solar unit tie-in point. The tie-in and piping system is shown in Figure 4.4-1. A 3-way valve will be installed in each heater feed line, SCV 1 and SCV 2. To allow for maintenance and repair of control valves, there will be isolation valves (A through G) and bypass lines. The solar unit bypass valve (BPV) will allow solar loop warmup. The new pumps (1 and 2) can be isolated by valves (H through K). The system has drain valves (L and M). There are no provisions for storage facilities to be used during nighttime or cloudy day conditions. However, there will be a 37.85 m^3 (10,000 gallon) tank to drain the solar loop if needed.

A control building will be constructed. It will be a metal structure, 6.1 m x 12.2 m (20 ft x 40 ft) and will be two stories high. It will be on the west side of the solar collector field. One half of the first floor will be used for parts storage. There will be a garage size door and a regular door into this storage area. The rest of the first floor will have two bathrooms, an office area, and serve as a lobby. There will be one entrance into the area. The second floor will have the solar unit control and monitoring console and record storing facilities. There will be a .914 m x 1.219 m (3 ft x 4 ft) window at each end of the building, and two .914 m x 2.438 m (3 ft x 8 ft) windows overlooking the heliostat field. All windows will be a special glass to combat the hazard of the heliostats inadvertently reflecting light into the control room. Options for the glass selection include reflective or polarized glass or a combination of both. The building will be insulated and have heating and cooling. A parking area will be paved on the west side of the control building. This location will be shielded from the heliostats by the building.

A 2.438 m (8 ft) chain link fence with three strands of barbed wire will be installed around the perimeter of the solar collector field and tower. It will be about 1,265 m (4150 ft) long with about 625 m (2050 ft) of it interlaced with slats. This is to prevent the mirror glare from accidentally reaching personnel working in the plant and surrounding areas. There will be two large access gates, one 2.438 m x 3.657 m (8 ft x 12 ft) and a double gate 2.438 m x 6.096 m (8 ft x 20 ft). The smaller gate will be power operated with controls both at the gate and the control building. The larger gate will be for oil well access and will normally remain locked. In addition to these large gates, there will be two employee access gates, each

2.438 m x 1.219 m (8 ft x 4 ft).

Some roads will have to be built to give access to the oil wells within the collector field. Less than 804.6 m (.5 mi) of roads will be required.

A .91 m (3 ft) high berm will be constructed around the base of the tower to contain any oil spill. This would give a capacity of over 90.84 m^3 (24,000 gallons) which greatly exceeds the volume of the solar unit piping of 34.07 m^3 (10,000 gallons).

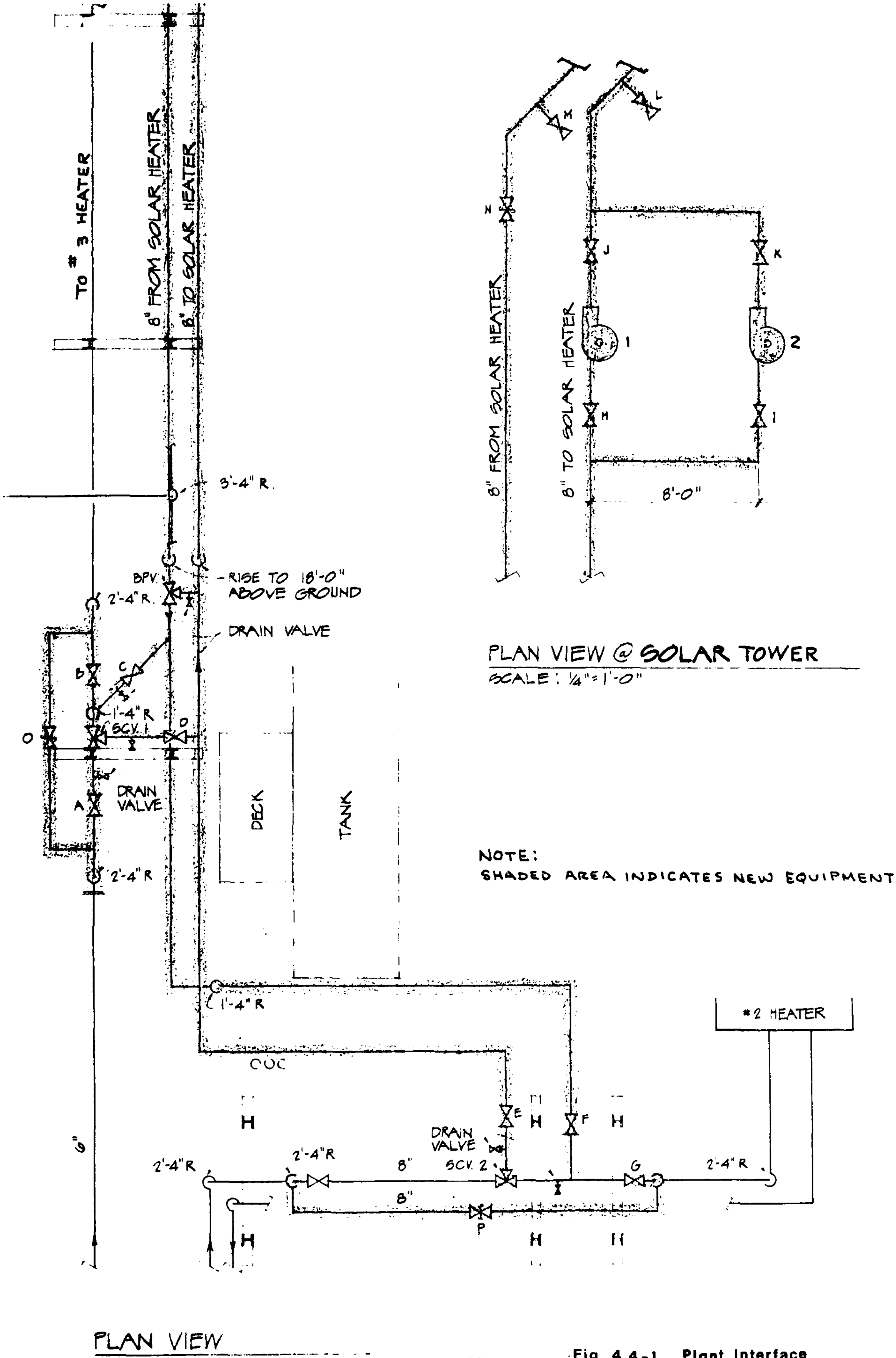


Fig 4.4-1 Plant Interface

4.5 System ?erformance

Data on the solar system performance for the 320 Northrup II heliostat collector, the firect oil heating cavity receiver and the receiver loop system conceptual design is summarized in staristep form in Figure 4.5-1.

A major supporting element of the annual diagram is the geometric efficiency matrix which is integrated against the hourly direct insolation model to derive the annual average efficiency and total energy. The applicable geometric efficiency table for the selected conceptual design is shown in Fig. 4.5-2.

Potential system input energy at levels above 500 kWm_t/m^2, which was established as the operating threshold for the analysis, is 36.91 x 10^6 kWh_t for the 16,832 m^2 (181,178 ft^2) collector.

Energy delivered by the collector to the cavity of the receiver is 1510 $kWh_t m^2$ of mirror area and 25.43 x 10^6 kWh_t for the full collector. The overall collector efficiency of .689 is the composite of the cosine, reflectivity, shading, blocking, atmospheric attenuation, and spillage efficiencies.

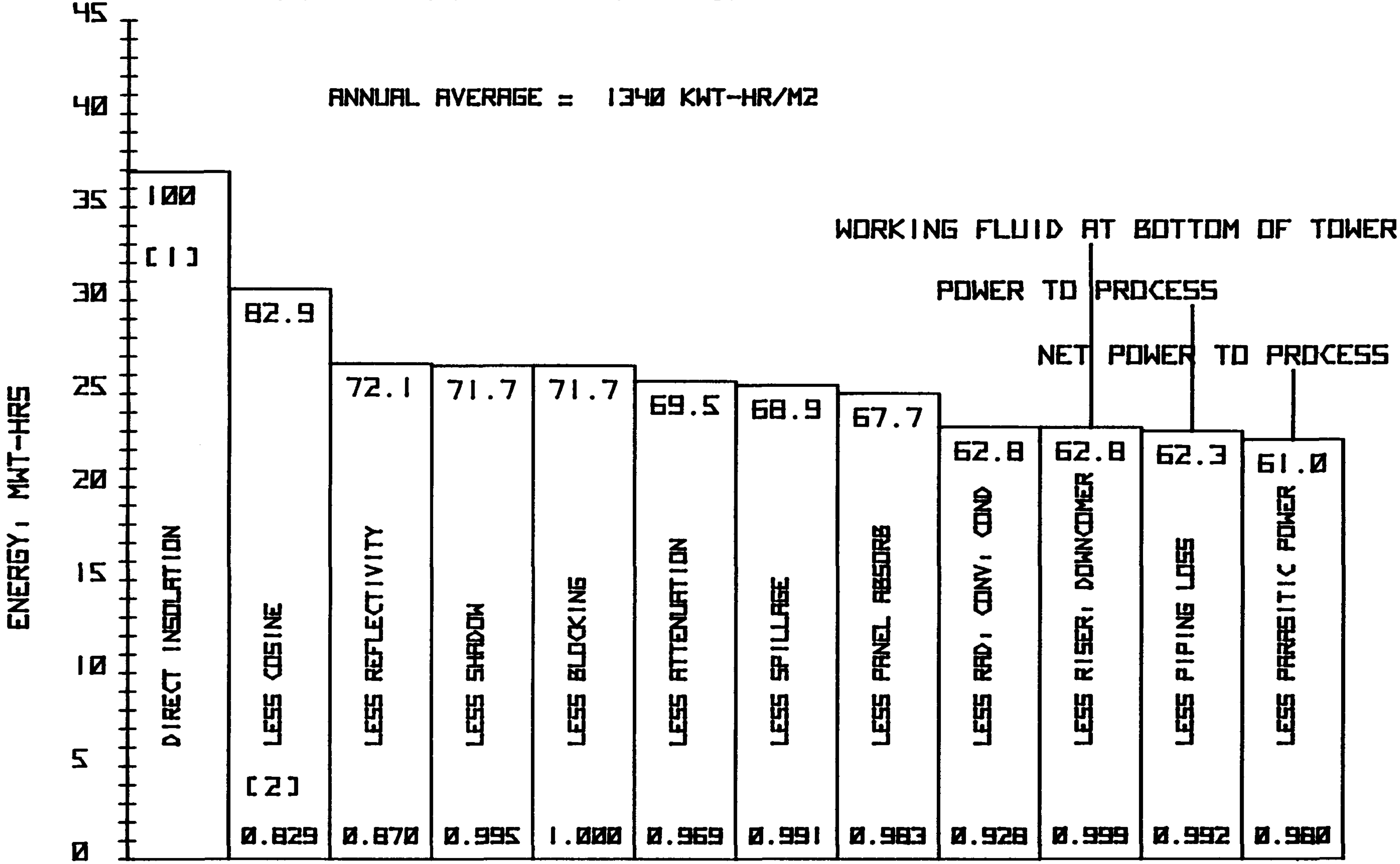
Energy delivered by the receiver to the "heat medium oil" transport loop is 1378 kWh_t/m^2 of mirror area and 23.196 x 10^6 kWh_t total. The effective receiver efficiency is .912.

Loop delivered energy is 1366 $kWh_t m^2$ and 22.99 x 10^6 kWh_t total. Loop efficiency = .991. A further equivalent efficiency against the system is the thermal equivalent of the parasitic power used by the system. The net benefit to the plant on an annual basis is 1340 kWh_t/m^2 or 22.55 x 10^6 kWh_t total. Overall solar system efficiency on the annual basis is .611.

The equivalent fossil energy saved by the system is determined by dividing the "net Benefit" energy by the burner efficiency. In terms of barrels of oil, the fossil fuel displacement of the Coles Levee Retrofit Solar System is 21,236 barrels per year. In terms of fuel saved per heliostat, the value is 66.4 barrels of crude oil equivalant per heliostat per year.

Fig 4.5-1

ANNUAL PROCESS HEAT STAIRSTEP



[1] - NET CYCLE EFFICIENCY AT EACH POINT

[2] - EFFICIENCY OF EACH CONVERSION STEP

Fig 4.5-2

GEOMETRIC PERFORMANCE EFFICIENCY
COLES LEVEE SINGLE MOD, 61M [200FT] TWR

AZIMUTH ANGLE, DEGREES

SOLAR ELEVATION, DEGREES	0	30	60	75	90	110
89.5	0.8005	0.8001	0.7993	0.7988	0.7983	0.7975
65	0.8904	0.8770	0.8399	0.8148	0.7872	0.7498
45	0.9363	0.9147	0.8537	0.8111	0.7635	0.6970
25	0.9510	0.9231	0.8494	0.7932	0.7286	0.6363
15	0.9194	0.8904	0.8082	0.7493	0.6848	0.5877
5	0.7704	0.7383	0.6934	0.6545	0.6187	0.5085

AVE. ANNUAL EFF. = 0.8298   ENERGY TO PROCESS = 22.555 X 10^6 KWT-HRS

[320 HELIOSTATS]

4.6 PROJECT CAPITAL COST SUMMARY

The total capital cost of the North Coles Levee solar installation is made up of three parts, the Design Phase, the Owner's cost and the Construction cost. The breakdown and total cost is:

1.	Design Phase	$1,658,762
2.	Owner's Cost	118,973
3.	Construction Cost	6,558,299
		$ 8,336,034

4.6.1 Basis of Estimate

All costs are based on 1980 labor and material rates. No allowance is made for inflation during future years.

Costs are included for the Design phase which includes the project engineering and planning work and the construction and operation of a 19-heliostat development module.

Costs are included for owners expenses such as permits, lease payments, and main plant lost time due to start-up. Capital costs do not include sales tax, spares, and personnel training.

The detail construction labor and materials during the construction phase are priced primarily on the unit basis according to R. S. Means 1980 Building Construction Cost Data, which uses a 30-largest city average index. Adjustments were then made to correspond to the site location at Bakersfield. The cost of major mechanical equipment, large subcontracts, and major bulk materials are based on written and telephone quotes obtained from suppliers for budgetary estimates.

The total costs include all direct costs including materials, subcontracts, labor and installation, shipping and subcontractors overhead and profit. They include all indirect costs incurred by the general contractor, engineering effort during construction, procurement, construction management, adjustment for site-dependent productivity, contingency and fee.

4.6.2 Construction Cost Codes.

The construction costs are presented according to the Cost Code accounting system. The detail worksheets are included in Appendix A, System Requirement Specification, Tables 11- 16.

The geographic and schematic boundaries for the construction cost codes are presented in Figures 4.6.2-1 and 4.6.2-2 respectively. Because of the difficulty involved in illustrating the cost code interfaces by this method, the following lists are presented to identify what items are included in each account.

5100 Site Improvements

- Site clearing and rough grading
- Sewer, water, power, phone, gas lines
- Roads

5200 Site Facilities

- Control Building
- Security Fence

5300 Collector System

- Heliostats
- Pedestals
- Power System
- Heliostat Control System

5400 Receiver System

- Receiver

  Structure
  Panels
  Internal Receiver Piping
  Insulation
  Instruments
  Cavity Door and Flux Curtain
  Fire System

- Tower

  Foundation
  Structure
  Elevator
  Lightning protection
  Lighting and obstruction lights

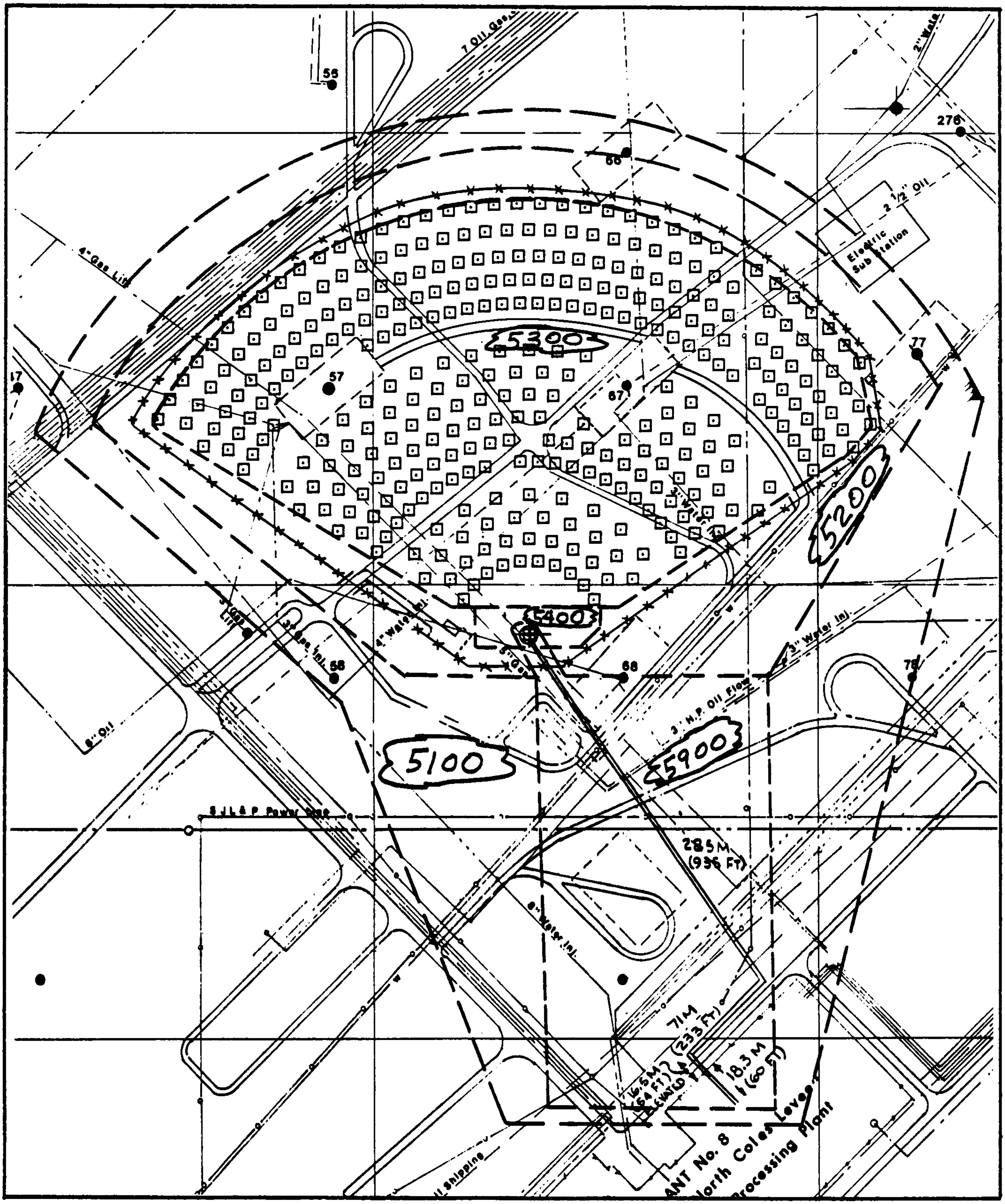
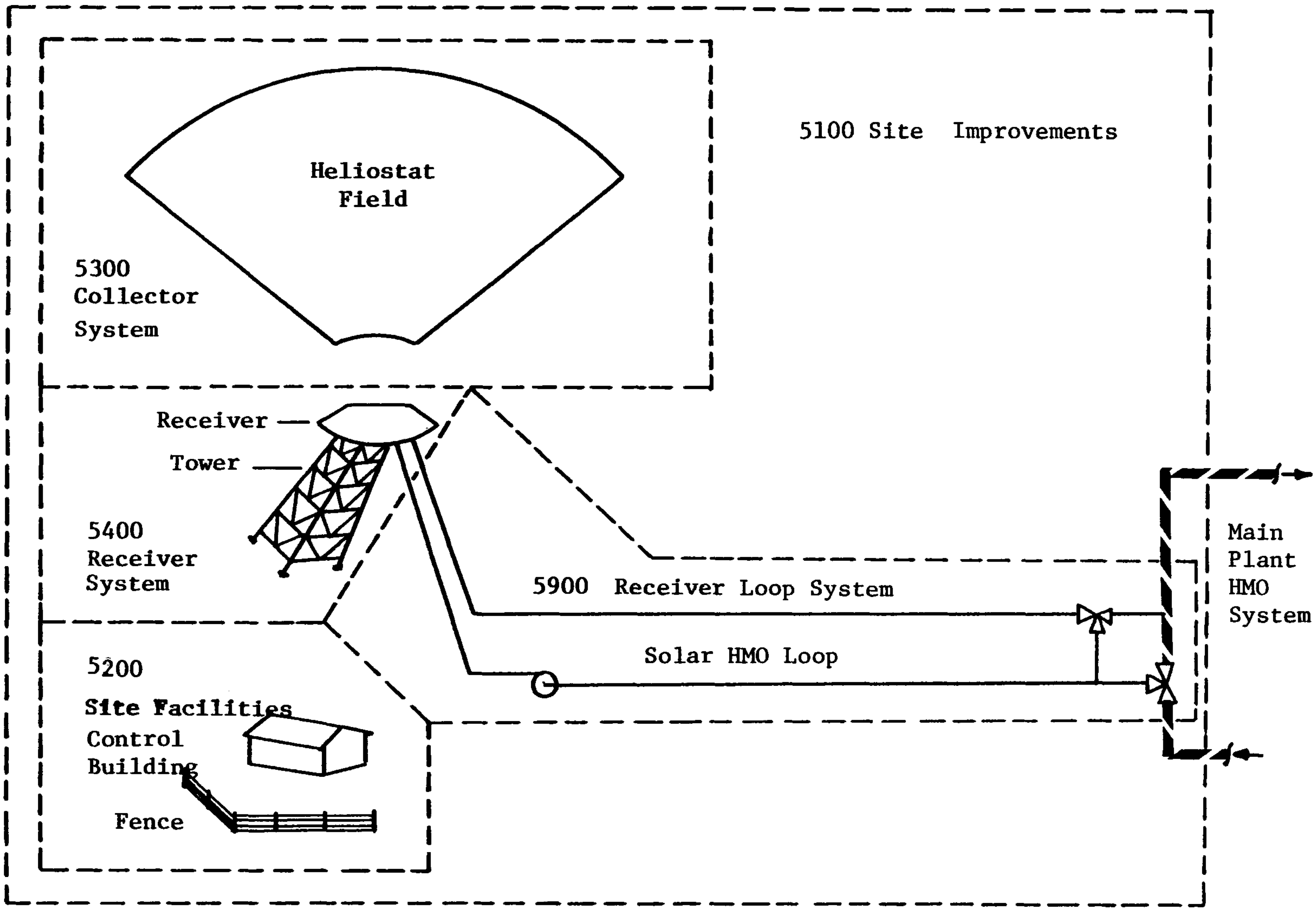


Figure 4.6.2-1
Construction Cost Code
Geographic Boundaries

Figure 4.6.2-2

Construction Cost Code

Schematic Boundaries



5900 Reciever Loop System

- Piping, fittings, valves, insulation, supports
- Pumps
- Plant tie-in
- Drain and storage tank
- Controls and instrumentation

4.6.3 Capital Cost Summary

The Design Phase Cost is summarized in Table 4.6.2-1.
The Owner's Cost summary is presented in Table 4.6.2-2.
The project Construction Cost is summarized in Table 4.6.2-3.

Table 4.6.2-1

DESIGN PHASE COST SUMMARY

Engineering & Planning		$ 964,924
System Design	$518,200	
Site Preparation Plan	71,476	
Procurement Plan	41,694	
O & M Procedures & Plans	35,738	
Development Module	226,340	
Project Management & Reports	71,476	
Development Module Construction Cost		693,838
Total Design Phase		$1,658,762

Table 4.6.2-2

OWNER'S COST SUMMARY

Land Lease	$ 7,500
Governmental Approval	10,055
Consumable Supplies	7,500
Start up Costs	52,200
Taxes and Insurance	0
Total Direct Costs	77,255
Overhead	30,902
G & A	10,816
Total Owner's Costs	$ 118,973

Table 4.6.2-3

CONSTRUCTION COST SUMMARY

5100	Site Improvements		$ 95,390
5200	Site Facilities		138,605
5300	Collector System		4,840,602
5400	Receiver System		1,176,411
	5410 Receiver	$612,489	
	5420 Tower	563,922	
5900	Receiver Loop System		792,553
	Total Construction Costs		7,043,561
	Reduced by items common to development module (Ref. SRS Table 9)		485,262
	NET CONSTRUCTION PHASE COST		6,558,299

4.7 OPERATIONS AND MAINTENANCE COSTS AND CONSIDERATIONS

The annual operating and maintenance costs for the North Coles Levee solar project is $218,044 which represents 2.54% of the total capital cost of $8.58 million.

A summary of the annual operating and maintenance cost is presented by cost code in Table 4.7-1.

Table 4.7-1
OPERATION AND MAINTENANCE
COST SUMMARY

OM100 Operations			$ 154,082
OM110 Operating Personnel		78,375	
OM120 Operating Consumables		45,534	
OM130 Fixed Charges		30,173	
OM200 Maintenance Materials			27,852
OM210 Spare Parts		13,518	
OM212 Collector Equipment	8,854		
OM213 Receiver Equipment	1,597		
OM215 Non-Solar Energy Subsystem Equipment	3,067		
OM220 Materials for Repairs		2,288	
OM230 Other		12,046	
OM300 Maintenance Labor			36,110
OM310 Scheduled Maintenance		13,340	
OM320 Corrective Maintenance		22,770	
Total Operation and Maintenance Cost			$ 218,044

4.7.1 Basis of Estimate

This estimate is based on a detail analysis of operating and maintenance requirements which is presented in accordance with the Operations and Maintenance Cost Codes in Appendix A, System Requirement Specification Tables 21 thru 30. The estimate is based on the following:

(a) Labor rates and material costs are based on 1980 rates, thus representing a first year estimate, with no allowance for inflation during future years.

(b) The detail estimates are made for bare costs and adjusted for G & A and overhead. A lower overhead rate was used for those items which would fit into existing plant operations as an add-on.

The estimate includes provision for operating personnel, consumables , fixed charges, maintenance materials and maintenance labor.

Operating Personnel

The solar plant will be operated basically with its own separate crew, with about 10% additional contribution from the existing N.C.L. crew. The basic crew will consist of one operating engineer and two operator/technicians, one electrical and one mechanical. The time contribution of each crew member is approximately as follows;

Operating Engineer	75% plant operation
	25% maintenance supervision
Operator/Technician (Electrical)	75% plant operation
	25% scheduled and corrective maintenance
Operator/Technician (Mechanical)	50% plant operation
	50% scheduled and corrective maintenance including mirror washing.
Existing N.C.L. Personnel	8 hours per week plant operation

This schedule for manning the plant during peak production times allows for an operator to be devoted solely to operation approximately 75% of the time during summer days and 100% of the time during winter days. This scheme is believed to be conservative as the plant is capable of operating at least semi-automatically. The major driving factor in selecting this size crew is the requirement to have a qualified operator in attendance during all hours of operation. This potentially requires a total attendance of 105 hours during a peak summer week which equates to 2.63 8-hour shifts. A staggered shift arrangement is obtainable to accomplish 100% attendance during daylight hours with a 3-man crew.

Consumables

The consumable supplies include make-up heat medium oil estimated at the rate presently consumed in the existing plant. Conventional utilities, gasoline, oil, deionizing chemicals, chart paper, and miscellaneous make up the remaining requirements.

Fixed Charges

The property on which the solar installation will be situated is owned by Tenneco West, Inc., and annual surface lease payments will be required. The amount of these payments has not been negotiated, but a range has been established from preliminary discussions. The range is $3000.00 to $12,000.00, so an average value of $7500.00 has been selected for this estimate.

The cost of insurance has been estimated by using the ratio of property and casualty insurance to net assets currently existing in the ARCO Oil and Gas Division, under whose ownership this facility would fall. This ratio was applied to an increased asset value of $8.5 million, to obtain an estimate of annual insurance premiums.

Property taxes are assumed to not apply for the purposes of this estimate. At the present time a property tax is levied on capital assets at the rate of 1.0% to 1.25% of the asset value, by the state of California. However, a Senate bill, S.B. 1306 is currently under consideration, which, if passed, will relieve owners of this tax requirement for solar installations. The probability of passage is believed to be good enough that the assumption of no tax is used in this estimate.

Spare Parts

The needs for spare parts were estimated in three categories, collector subsystem, receiver subsystem, and all others. The needs were established by determining the "annual failure rate" or "frequency of occurance" for replacing the parts of the system. This rate is expressed as a percent of parts or assemblies that will fail during given years of operation. Then multiplying by the cost of the part or assembly, a required allocation of cost is derived.

Maintenance Equipment

Certain additions to the existing inventory of maintenance equipment would be required as a result of the solar system installation. These additions consist of washing equipment, partial use of a maintenance van or pickup, and a small inventory of tools and specialized equipment.

The largest single need is for equipment to wash soiled mirrors on a regular basis. A washing rig and equipment for water deionizing and storage would be the major expenditure. The equipment and procedure would be similar to the concept outlined by Northrup, Inc. in volume I of the Design Report for the Second Generation Heliostat Development, April 30, 1980. The major difference for a North Coles Levee washing system is that it would be less elaborate, the rig would not be automatically guided, and it would be less automated. This is due to the large difference in system size, approximately 5% of the larger system.

The cost of this additional maintenance equipment was ammortized over a 30 year period to establish an annual cost.

Maintenance Labor

The labor associated with maintaining the solar system was divided into scheduled and corrective maintenance. Scheduled maintenance consists of primarily mirror washing, painting, equipment lubrication, and routine inspection and repair of sensing and control equipment. Corrective maintenance is that which is required when failures or malfunctions occur. Of course, the 320 heliostats will require the largest portion of this effort.

4.8 SYSTEM SAFETY

The system safety considerations for the North Coles Levee installation include both the system hardware, and personnel in the vicinity.

A major consideration is the potential danger of the inadvertant focusing of a heliostat or group of heliostats on personnel, on a damageable target, or on a point in the air-space through which aircraft might pass.

The latter of these factors has been the subject of an extensive study and test program conducted by Sandia Laboratories. Their results indicate a high degree of safety can be achieved in the operation of the heliostat field by incorporating software safety techniques which preclude the inadvertant concentration of a large amount of solar flux at any localized spot in the air-space above or near the site. Furthermore, they have demonstrated (by means of actual fly-overs at the CNRS facility in Odeillo, France and later at the CRTF facility in Albuquerque) that a pilot could function satisfactorily after a relatively slow-speed pass through such a high-flux region. The major psysiological problem was a brief 3-4 second, period of flash-blindness which neither the FAA nor the participating pilots and observers considered to be a problem.

During facet alignment, a 5 milliwatt helium-neon (HE-NE) laser will be employed. OSHA standards permit personnel to operate with the laser beam area at this power level, provided that dark glasses are worn. Crew training, warning signs and lights, and adherence to procedures will be required to enforce this rule.

A major concern during both installation and check-out and during the operational phase is eye retinal burning caused by the accidental viewing of a reflected beam with the observer at or near the focal point. At this point, the images from 12 facets would be superimposed resulting in a relatively high flux. It is likely that the observer would voluntarily look-away, or involuntarily blink soon enough to avoid injury. Although permanent damage should not result, retinal burning is very painful, and recovery could take several weeks. Again, training, warning signs and lights, cordoned-off beam paths, and adherence to procedures is manditory. Additionally, the 8-foot site shielding fence should be installed prior to heliostat installation to provide further protection for personnel in adjacent areas.

The other major concern regarding the reflected beams is that of accidental targeting on a damageable item such as on a leg of the tower. Theoretically, such an occurrence can be prevented by the computation software which would "walk" each heliostat on or off of the receiver along a safe path which would be non-coincident with the reflected beams from other heliostats in critical hardware areas. However, from a practical standpoint, some unusual circumstances are conceivable where the unlikely could in fact actually occur with potentially serious consequences. This will be examined in detail in the design phase, and if necessary, critical areas such as the tower legs might be required to be insulated to assure survival for short exposure to high flux.

During operation, personnel will not be permitted on the tower, nor on the ground within a zone beneath the tower where a falling hot oil deluge might cause injury. Small leaks from the receiver would likely spray and cool before reaching the ground, and as such, are not considered to be a problem.

Oil leaks within the receiver present a hazard to the receiver hardware because of the relatively high probability of ignition and fire. The presence of a fire will be detected by 538 C (1000 F) sensors located in the receiver ceiling above the panel-piping zone. A fire indication will initiate the following sequential events:

1. Deployment of the flux-curtain

2. Heliostats positioned to off-target standby.

3. Cavity door closure

4. Receiver pump "off" and valve shuttle to isolate the solar oil loop from the plant loop.

5. Activation of the cavity fire extinguishing system.

The fire system is included in the receiver cost analysis, and is a Halon 1301 system which functions by flooding the cavity with a non-combustible vapor.

The flux curtain mentioned above is a safety feature which enables the incoming flux beam to be quickly blocked. It would be deployed if pump power were lost, or if panel overheating occurred. The curtain is fabricated from Nextel 312 cloth which can withstand the maximum aperture plane flux without damage or degradation. The curtain is stowed in a rolled-up configuration above the aperture plane, and is retained by a solenoid latch powered "on". The loss of power to this solenoid will cause a gravity drop to occur. The cost of this curtain system is included in the receiver cost analysis.

A less critical safety feature from the solar system standpoint is a low flow rate alarm. This event would result in the heliostats being taken to a standby aiming point off-target, cavity door closure, receiver pump shutoff, and valve shuttle to transfer flow to the "plant-only" mode. Since the receiver is already protected from low flow rate via the over-temperature sensors, the low flow shutdown is primarily aimed at protecting the processing plant; i.e., low flow would indicate a starving of the plant loop, so the solar loop would be bypassed because it might be the cause of a problem.

4.9 PROJECT ENVIRONMENTAL IMPACT ASSESSMENT

No significant long-term adverse impact on the environment by this project is anticipated. The site selected for this project affords close proximity to the plant while requiring the least disturbance to the existing environment. The site is presently being used for oilfield operations. There will be no significant alteration to its present use by the installation of the solar industrial retrofit system.

The construction of this project may generate 1.8 tons of air pollutants. The effects on local air quality by this amount of emissions are considered to be small and of minor consequence. The operation of the solar retrofit system will not cause the emission of any air contaminants. It will reduce emissions by replacing some of the fuel gas used to generate heat in Plant No. 8. This reduction may amount to 9 to 10 tons per year.

It is not expected that there would be any permanent environmental impacts resulting from this solar energy retrofit project. There may be some short-term impacts to air quality, noise levels, drainage patterns, and solid waste disposal during the construction and dismantling of the project. Local workers will be used in all phases of the project; therefore, there would be no additional demands on housing, schools, police, fire, or health services in the area. The aesthetics of the area may be altered to some degree by the equipment used in this solar retrofit project. This equipment has architectural features which resemble the existing natural gas processing plant and the drilling rigs which have been operating in the North Coles Levee Field for many years. Asthetic impacts caused by constructing this project would be minimal because of the context in which the project's equipment appears. A potential glare problem created by the mirrors may or may not exist. This will be evaluated during the operation of this project. A leak or blowout in the piping carrying the heat medium oil could create a potential temporary impact to soil contacted by the spilled oil. Cleanup of an oil spill would restore the soil to a condition similar to what it was prior to the spill.

Fossil fuels presently used to supply the nation's energy needs are depletive resources. The use of solar energy to augment the nation's energy supply will conserve fossil fuel. No action to develop environmentally and economically acceptable uses of solar energy would avoid the short-term adverse environmental effects of this project, but it would be of minor benefit compared to the gain that the development of solar energy retrofit heat generating systems would bring to the national interest. A complete Environmental Impact Assessment for the North Coles Levee site is presented in appendix B.

4.10 INSTITUTIONAL AND REGULATORY CONSIDERATIONS

Prior to starting construction, approval must be gained from Government Agencies.

A building permit must be obtained from the Kern County Building Inspection Department. An application for permit will be submitted, and will require about four weeks for approval. The fees will be about $6000. One of the requirements for gaining approval is submitting two copies of all drawings after they have been approved by a California Registered Engineer.

The Kern County Planning Department also requires filing for a permit and part of the necessary information is an environmental assessment. Since the solar project will have minimal environmental impact, the time required for approval should not be over six weeks. A fee of $550 will be charged.

Due to the height of the tower, the Federal Aviation Administration must be informed of the project. This must be done at least thirty days before a construction permit is filed. The FAA regulations require that the tower be properly equipped with obstruction lights.

All other applicable safety regulations and design requirements will be met in the design and construction of the solar unit.

SECTION 5.0

SUBSYSTEM CHARACTERISTICS

The solar process heat system for the Coles Levee Natural Gas Processing Plant consists of four subsystems, the collector, the receiver, the tower, and the receiver loop. Controls for the operating subsystems, the collector, receiver and receiver loop are incorporated into their respective subsystems.

Solar energy is collected and concentrated by the collector subsystem and transmitted optically to the cavity of the receiver in radiant energy form. Radiant energy striking the panels of the receiver is converted to thermal energy which is transmitted to the plant process heat system by the heat medium oil of the receiver loop subsystem.

Central location of the controls for the three subsystems is planned in the solar operation's building located a short distance west of the tower.

5.1 Collector Subsystem

The collector subsystem consists of 320 Northrup II heliostats in a 120^{o} arc north field layout with specific modification's to accomodate working oil wells, power lines, and pipelines on the site. Figure 5.1-1 shows a perspective of how the collector would appear in operation viewed from a helicopter south of the tower and above the tower such that the view is along a 50^{o} upward tilted plane.

The circular spacings evident between rows 4 and 5 (from the tower) and between rows 10 and 11 are the result of take up rows in the layout. Rows 5 and 11 revert back to the circumferential heliostat spacing as row 1. This places some heliostats in the rows 4 and 10 radially in line with row 5 and 11 heliostats causing variable degrees of blocking. The take up row radial space is increased to eliminate the localized blocking.

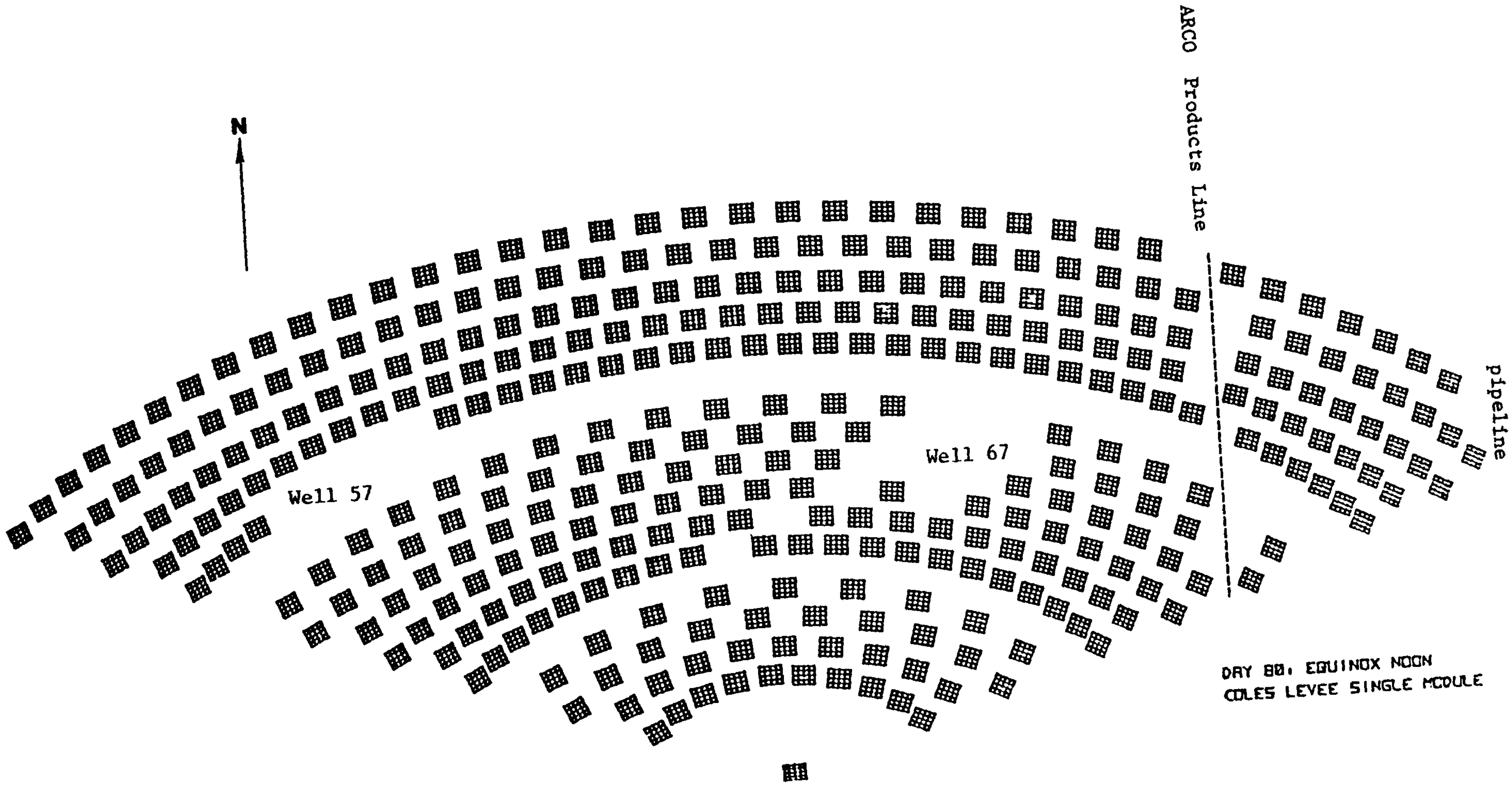


Figure 5.1-1

Perspective View of Collector Subsystem

Clearance for well 57 caused deletion of 6 heliostats in the west end of row 11. Clearance for well 67 caused the deletion of eight heliostats in the central area of rows 8, 9, and 10. The linear clearance near the east end is for a power line and the cropped corner on the east end is from the combined effect of well clearance and pipeline clearance.

5.1.1 Major Collector Components

Major collector subsystem components include the 320 Northrup II heliostats and the control system to operate the heliostats.

Northrup II Heliostat Description

The Northrup heliostat is a dual axis unit having a central support pedestal and drive mount. Twelve mirror modules are mounted to a primary structure consisting of four truss purlins, cross bracing and two torque tubes. Except for clearance spaces between mirror modules, the heliostat presents a continuous mirrored face with no central slot or void regions. The total envelope face area is 55.3 m^2 (595.1 ft^2). The small clearance spaces between mirror modules and the mirror edge protective molding reduce this total to a net reflective area of 52.8 m^2 (568 ft^2). Each of the twelve mirror modules have two mirror facets, so this total reflective area is achieved by an array of twenty-four individual mirror elements. Figures 5.1-2 and 5.1-3 present a perspective view of the front and back of the Northrup heliostat.

The Northrup heliostat has a face envelope which measures 7.43 m (24.38 ft) high and 7.44 m (24.41 ft) wide. The minimum ground clearance is 0.15 m (0.5 ft) when the heliostat is in the vertical stow position. The Northrup heliostat is designed to be stowed in <u>any</u> position from vertical to face-up-horizontal, and as such provides maximum power outage/storm protection. The normal stow position is vertical for the purpose of natural rain washing. The alternate face-up-horizontal stow will be employed to avoid sand abrasion if high winds are encountered or forecast.

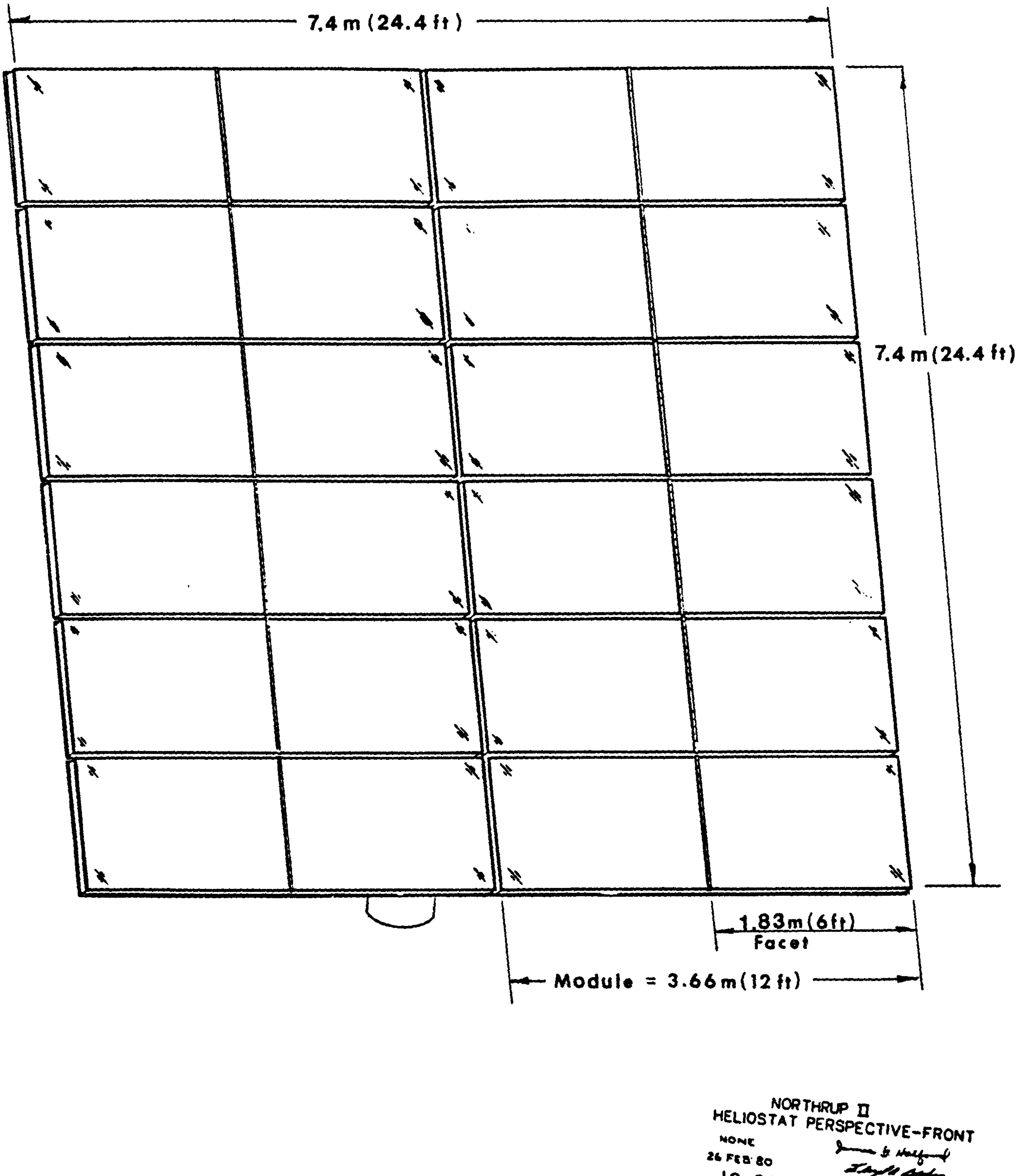


Figure 5.1-2
Northrup II Heliostat Front View

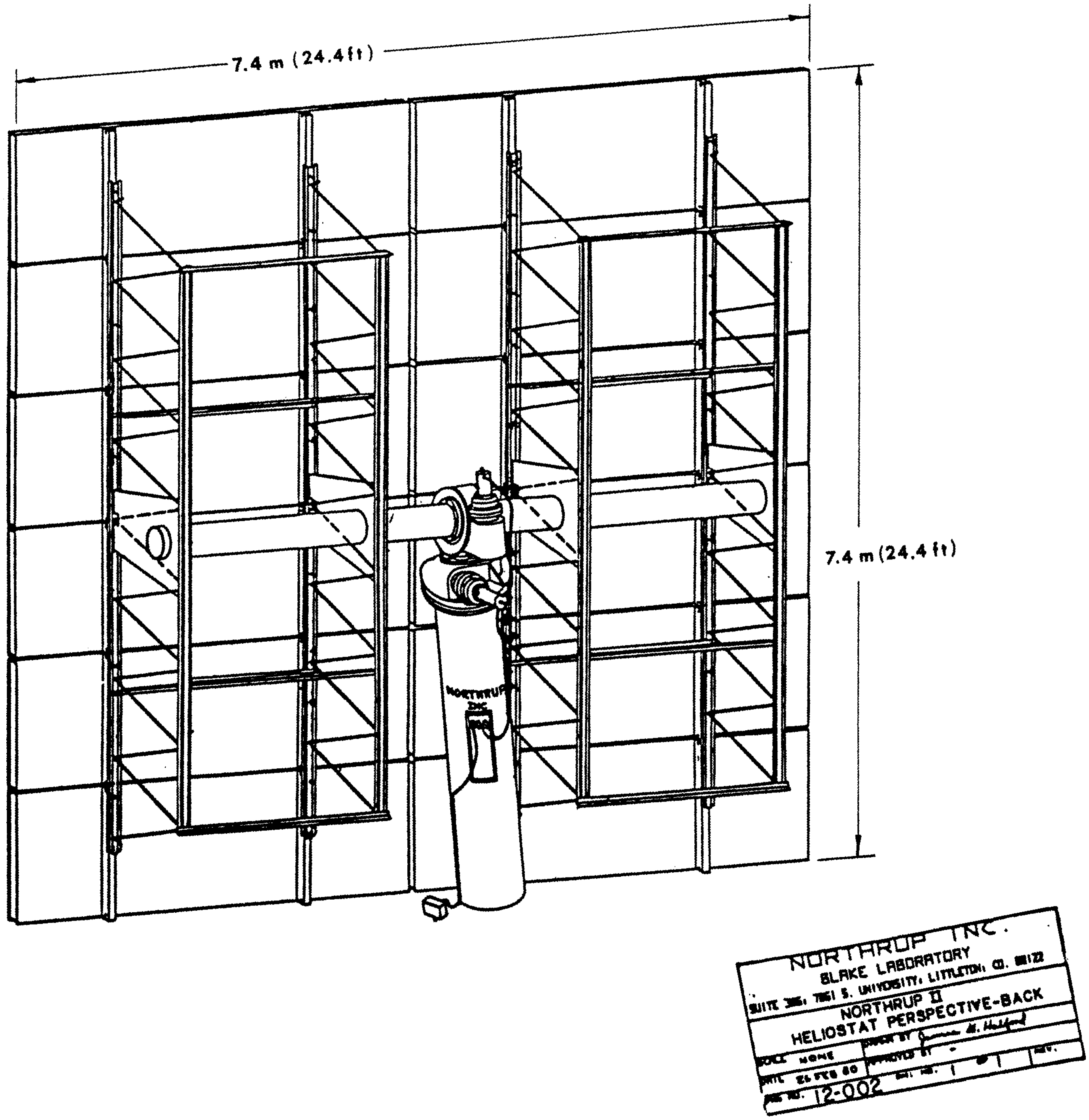


Figure 5.1-3
Northrup II Heliostat - Back View

The reflecting surface is comprised of twelve mirror modules each 1.22 m (4.0 ft) high and 3.66 m (12.0ft) wide arranged in a 2 module wide x 6 module high pattern on the heliostat. All mirror modules are identical; i.e., there are no position-unique differences. Each mirror module is faced with two 1.22 m (4.0 ft) x 1.83 m (6.0 ft) mirrors so a frontal view of the Northrup Heliostat exhibits a 24 facet appearance.

The mirror modules are attached to four main vertical beams, each of which is 0.75 m (2.46 ft) deep and 6.40 m (21.0 ft) long. The beam depth was governed by drive clearance considerations with the exceptional bending stiffness being a desireable side benefit. These four main beams interface with the drive unit by means of two transverse torque tubes. The heliostat assembly thus achieved may be visualized as identical left and right-hand subassemblies, each consisting of two beams, one torque tube, and six mirror modules. Such a left or right subassembly can in fact be physically removed from or installed on a heliostat as an integral unit.

The Northrup drive unit incorporates independent azimuth and elevation sections into a unified housing. Both of these drive elements are identical in terms of motor, input-stage, and output stage gearing. The basic drive concept is keyed to the use of D-C stepper motors which provide both motive power (torque) and position control (precise incremental rotation); i.e., <u>no</u> encoders or other continuous position sensors are required. Stepper motors interface well with digital minicomputers and microprocessors, and are able to deliver an accurate rotational increment of 1.8 angular degrees per motor step. An intermediate, printed circuit board device known as a translator provides the sequencing and switching logic which converts pulses from a minicomputer or microprocessor into motor steps, therefore allowing step rate, direction, and number of steps to be controlled by external logic. With proper translator selection, stepping rates as high as 2,000 steps/second can be accurately achieved.

The Northrup drive unit employs a planetary type speed reducing first stage, and a worm-gear type speed reducing output stage. The total over-all speed reduction is 18,018:1, so a single motor pulse step of 1.8 angular degrees is reduced to approximately 0.0001 angular degrees of heliostat motion. The planetary first stage was selected because it provides a high reduction ratio and high torque capability in a compact sized unit. The output worm-gear stage was selected because of its self-locking/no back-drive capability (the worm can drive the gear, but the gear cannot back-drive the worm), moderately high ratio reduction, and high torque capability.

The drive unit is mounted to a flanged steel pile. The pile is a straight-cylinder, hollow pipe shape which is driven in place with a vibratory hammer. Any misalignment of the pile flange relative to true horizontal is removed by a simple rotational adjustment of a matched pair of tapered, gasket-shims.

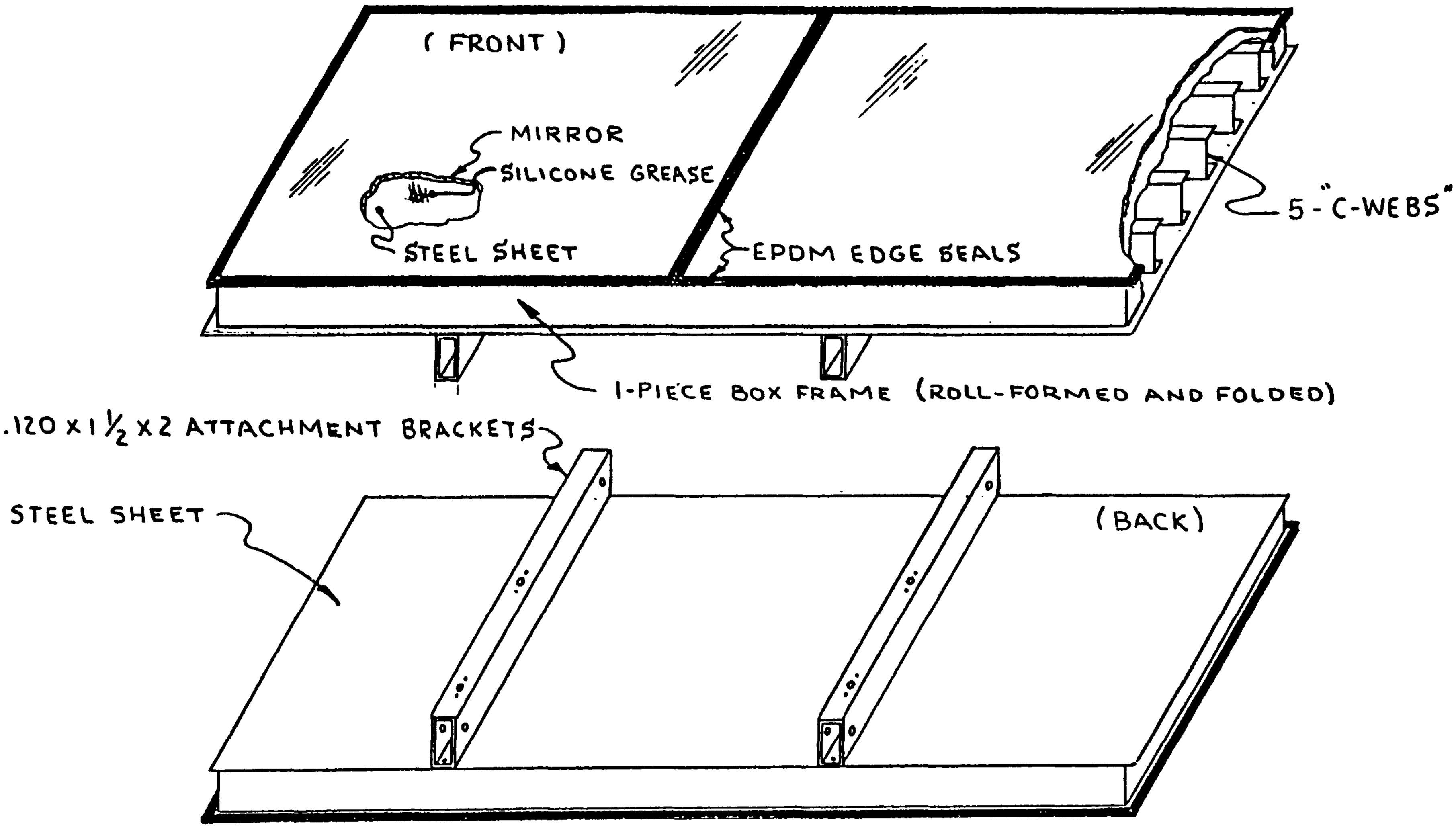
MIRROR MODULES

The mirror module design for the Northrup heliostat is based on using an all-steel mirror support structure. This structure is composed of a 26 gage (0.022") galvannealed steel sheet, longitudinal "C" - stringers formed from 28 gage (0.019") galvanized steel and having a height of 7.62 cm (3.0 inches), and a 28 gage galvanized steel backing sheet. These structural elements are adhesively bonded together to form a slab-like substrate measuring approximately 1.22 m (4.0 ft) high x 3.66 m (12.0 ft) wide and 7.62 cm (3.0 inches) thick.

The glass mirror is not bonded to the substrate, but adheres to it via a thin layer of silicone grease. The silicone grease is highly water repellant, non-volatile, and extremely inert. It provides a high degree of adhesion, but still permits relative differential thermal expansion and contraction between the mirror and steel substrate. Of equal importance is the fact that the silicone grease also provides an added measure of protection of the mirror silvering against humidity-condensation or rain water damage. An EPDM edge seal is bonded around the entire module glass-substrate edge to preclude water penetration. This edge seal also serves as a compliant attachment to maintain the glass mirror position on the substrate. A pictorial representation of the mirror module construction is shown on Figure 5.1-4.

The fabrication sequence for assembling a mirror module is somewhat unique. The unit is built-up beginning with the mirror. A flat, smooth granite surface block is used to establish the required flat shape. The mirror facets are laid face down on this flat surface and positioned by means of alignment stops attached to the block. The backside of the mirror is then coated with a thin film (.002") of silicone grease using a rubber roller. The mirror backing sheet (26 gage galvannealed steel) is similarly coated with grease on an adjacent table. The backing sheet is applied to the glass mirrors so the two greased faces contact each other. The backing sheet is very flexible and is progressively laid-down and simultaneously rolled to minimize air entrapment during this mirror-grease-sheet assembly operation. The flatness of this initial assembly is maintained by the underlying surface block.

The 5 longitudinal "C" - stringers are now bonded to the mirror backing sheet using an acrylic structural adhesive. Similarly, the "C" - section box frame which forms the mirror module sides and ends is also adhesively bonded to the mirror backing sheet. Again, the flatness of this initial assembly is maintained by the underlying surface block. The backside sheet (28 gage galvanized steel) is next bonded to the "C" - stringers and "C" - box frame thereby completing the module slab. The adhesive cure time is very rapid (approximately 5 minutes), so the unit can be removed from the surface block in a relatively short time.



NORTHRUP MIRROR MODULE CONSTRUCTION

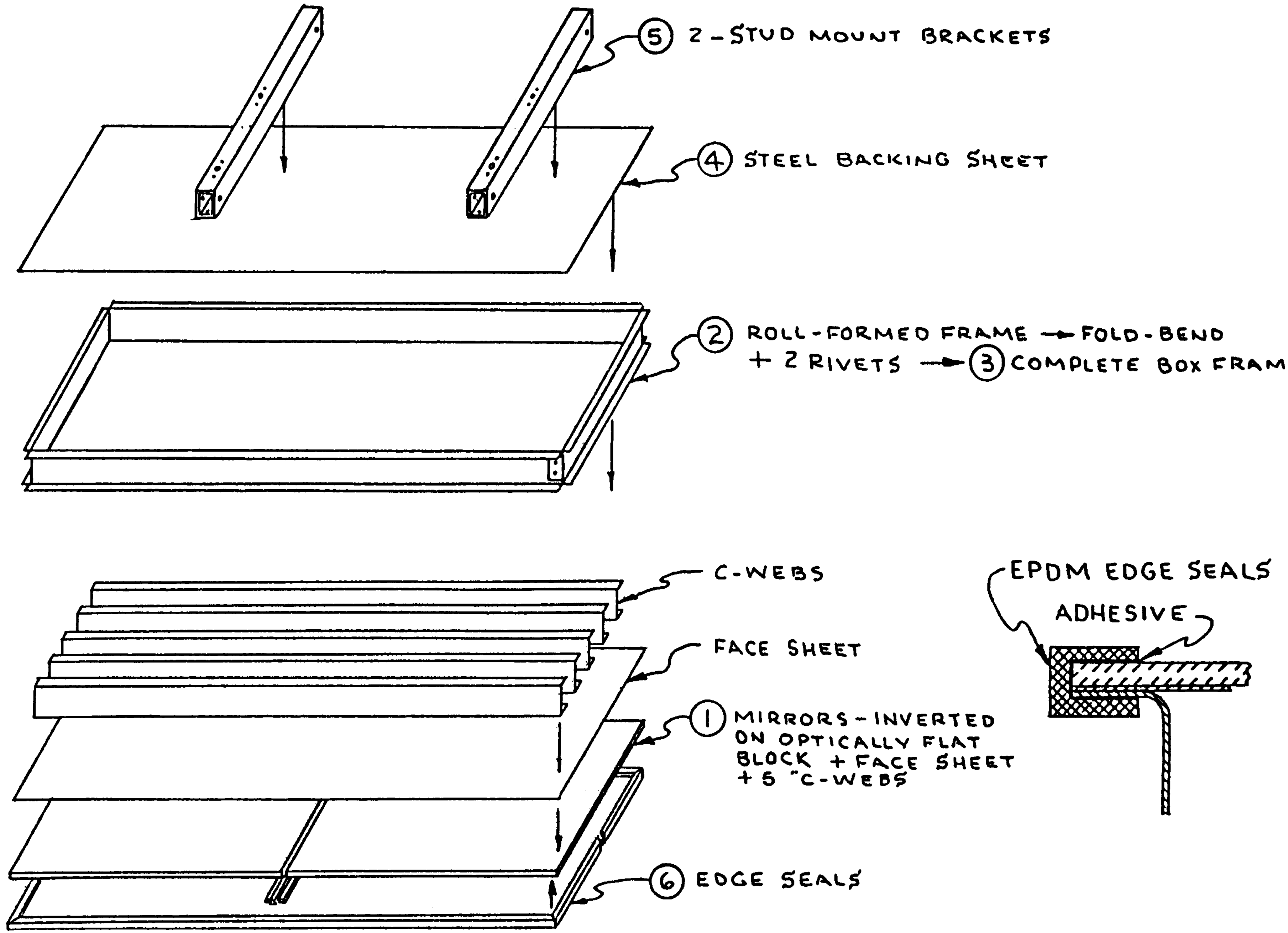
FIGURE 5.1-4

The final assembly operations include adhesively bonding and riveting rectangle supports on the backside, and adhesively bonding the EPDM edge seal to the mirror and substrate lip. Figure 5.1-5 shows a pictoral representation of the mirror module assembly operation.

The mirror facet proposed for the prototype Northrup heliostats are 1.22 m (4.0 ft) x 1.83 m (6.0 ft) x 2.39 mm (0.094 inch) thick. The material is low iron, soda lime float glass having a reflectivity of 0.87. The second surface silvered layer is protected by a layer of commericial mirror backing paint, plus a protective overcoat of an acrylic paint. The silicone grease coating serves as an additional protective layer.

The grease compound selected is DOW CORNING #4 Silicone Compound. It is a grease-like compound similar in consistency to petrolatum. The material contains an inert silica filler in combination with polydimethyl silicone fluid. It has excellent dielectric properties, is highly water repellent, resistant to oxidation, essentially non-toxic and non-melting, and has shown little tendency to dry out in service. Silicone 4 Compound will retain much of its room temperature consistency from -40 C to 204 C (-40 F to 400 F). Practically non-volatile, it is odorless and resistant to a wide range of metals and chemicals, and is often used to lubricate plastic and rubber components.

The silicone grease compound is applied to both the mirror back and the steel support sheet prior to rolling these members together. The steel support sheet is 26 gage (0.022 inch thick) and is zinc-coated galvannealed. Galvannealed sheets are heat treated after coating to produce a smooth surface of iron-zinc alloy. The heat treatment eliminates the normal zinc spangle pattern found on hot-dripped galvanized sheets. The smooth surface characteristic of galvannealed sheet enables good glass-to-support sheet adhesion to be acheived with less silicone compound (approximately 0.004" silicone grease thickness is required). The zinc coating weight is "light commercial"



⑤ 2-STUD MOUNT BRACKETS
④ STEEL BACKING SHEET
② ROLL-FORMED FRAME → FOLD-BEND
+ 2 RIVETS → ③ COMPLETE BOX FRAM
C-WEBS
FACE SHEET
① MIRRORS-INVERTED ON OPTICALLY FLAT BLOCK + FACE SHEET + 5 "C-WEBS
⑥ EDGE SEALS
EPDM EDGE SEALS
ADHESIVE

and averages .60-.80 ounce/square foot (approximately .006 inch zinc thickness on each side).

The remaining sheet metal members of the mirror module are fabricated from 28 gage (0.019 inch thick) galvanized steel. These members include the longitudinal stringers, the box frame, and the backing sheet. All of these members are adhesively bonded together using an acrylic structural adhesive, Versilok-201, manufactured by Hughson Chemicals (Lord Corporation; Erie, Penn.). This adhesive provides a practical method for accomplishing the required build-up of glass-sheet-stringers-sheet with a surface block support for flatness control. Versilok-201 adhesive is relatively insensitive to surface cleanliness, and can even be applied to oily metal surfaces with little loss of bond strength. The shear strength of the bonded joint varies from 9 MPa (1300 psi) for galvanized steel to 42 MPa (6000 psi) for SAE 1010 cold rolled steel. This adhesive is a two-component system. The components may be mixed together and applied, or a no-mix method may be employed. With the no-mix method the activator can be applied to one or both of the surfaces to be bonded. The activator-coated surface can be used immediately or stored for several months. In either case, nothing happens until the second component, an adhesive resin, is applied to the metal being bonded to the activator-coated surface, and the coated surfaces are mated. The gel time after contact is 6-8 minutes, and the unit can be safely handled in 15 minutes (i.e., 1000 psi shear strength is attained in this time period).

Rack Structure

The rack structure is assembled from the standard truss purlins (main beams), pipe (torque tubes) and steel angle (cross bracing). The truss purlins selected are of a standard, commercial design and are in fact being mass produced by the Butler Manufacturing Co., (Kansas City, Mo.). Their design is a very material-efficient one; a 6.4 m (21.0 ft) truss having a depth of 0.75 m (2.46 ft) only weighs 51 Kg (113 lb). The complete beam is fabricated from 2.0 mm (0.078") sheet metal. The sheet stock is received in a 1.22 m (4.0 ft) width x coil length. The coils are slit in two widths, one for forming the chord members, and the other for forming the web tubing. The chord stock is roll-formed to produce the shape shown in Figure 5.1-6. This shape offers good compression chord stability (the compression flanges of beams tend to buckle horizontally sideways if the beam is too long or too deep). An additional advantage of this chord shape is that the beams can be nested together to minimize shipping volume; the nested shipping width is only 103 mm (4.05 inches) versus the true width of 142 mm (5.60 inches).

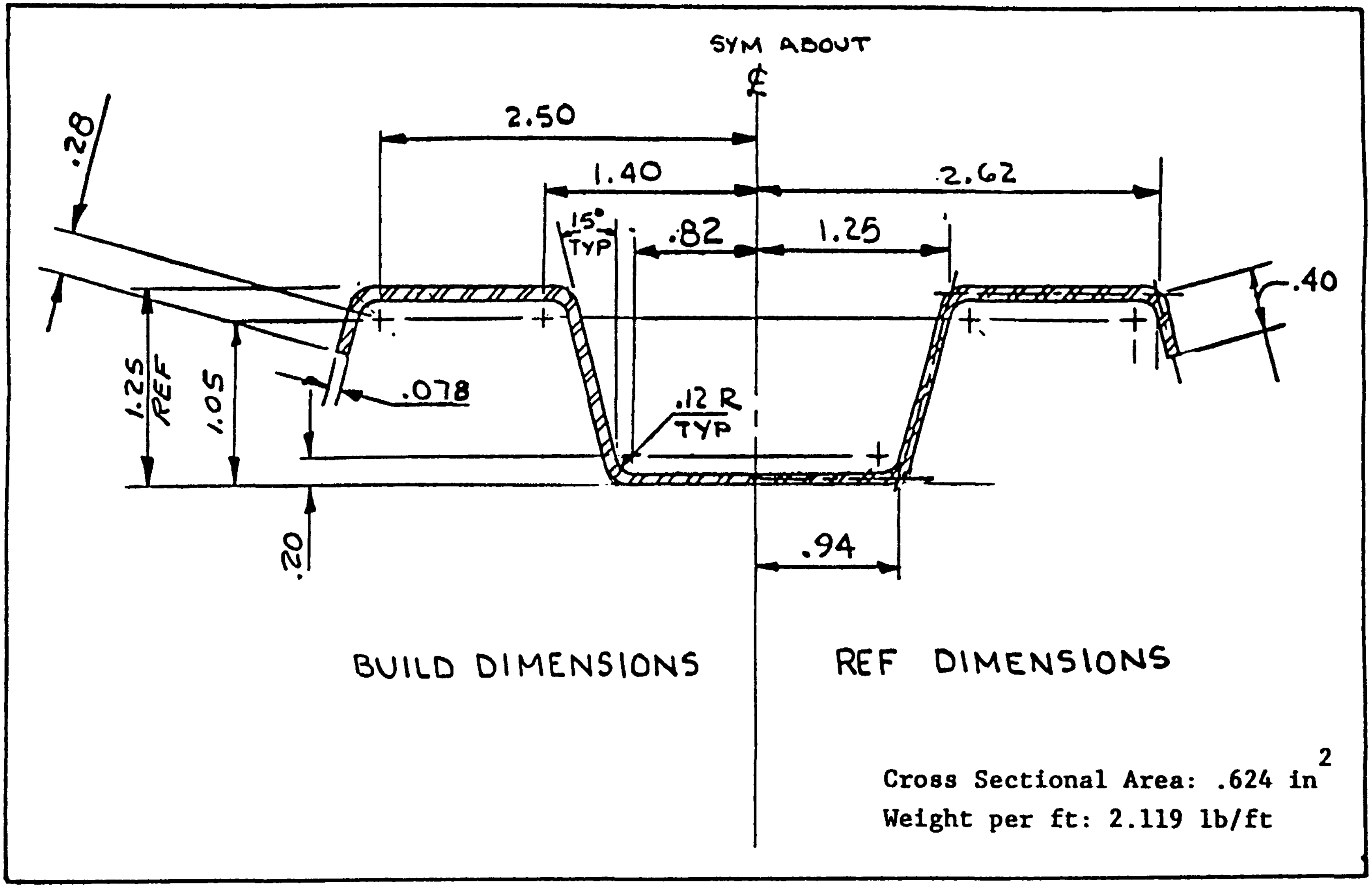
The tube stock is roll-formed into a 25.4 mm (1.0 inch) diameter tube shape, and is seam-welded to form a continuous tube. The tubes are then zig-zag bent to form the tubing into the triangular web pattern. The final operation is to resistance-weld the tubing to the top and bottom chord members. Only 17 resistance welds are required to assemble the tubing web and chords for a Northrup truss, all of which are accomplished in a single, one-shot, operation. The beams are then electro-painted in a dip tank. The completed beam contains approximately $40 of material and a direct labor input of 0.5 man-hours.

The torque tube is fabricated from a piece of 12-inch, schedule 20 steel pipe. The true dimensions of this pipe are 0.324 m (12.75 inch) O.D. and 0.311 m (12.25 inch) I.D. A trade-off study was performed early in the program which showed that an economic optimum tube (inertia per unit weight/cost) should be on the order of 0.406 m (16 inch O.D.) and 2.3 mm (0.090 inch) wall thickness. However, physical constraints governed by the interface with the drive unit forced this diameter down to the present size; i.e., the added cost of the current, heavier torque tube is more than compensated for by a lower cost drive unit.

Each torque tube is flanged at the end which interfaces with the drive unit, and is attached to the drive with 12-5/8" - 11 UNC screws. Two trapezoidal shaped plates are welded to the torque tube, one at the

Figure 5.1-6

BUTLER TRUSS PURLIN - CHORD DETAIL



non-flanged end. These plates form the interface with the truss members, and are welded to the truss top and bottom chords at the field site. Since these plates serve to rigidize the truss chords relative to each other, shear deflections are virtually eliminated. Although the shipping volume is penalized with this design (versus the alternate approach of making these shear plates a part of the truss), it was believed that better perpendicularity and position location could be achieved by welding the plates to the torque tube in the factory, and then performing a final straightening and machining cut after welding. Figure 5.1-7 shows a pictorial representation of the torque tube.

After assembling the trusses, torque tubes, and cross brace members in the site assembly building, the mirror modules are next installed and pre-canted using a mechanical fixture. The attachment method and canting adjustment is accomplished by three - 3/8" - 24 UNF studs and nuts. Mirror module-to-truss misalignment of the studs and holes is accomodated by the floating nut plates which permit $\pm$ 0.76 mm ($\pm$ 0.030 inch) lateral float. Stud angular misalignment introduced by module canting is accomodated by the use of spherically shaped nuts and washers (commercially available items). Figure 5.1-8 illustrates the mirror module attachments.

Drive Unit

The heliostat drive unit is being designed and fabricated by the Winsmith Division of UMC Industries, Inc. of Springville, N. Y. It is a unified azimuth and elevation drive system in a common housing. The azimuth and elevation motions are independent and can be individually driven.

The motive input power for the azimuth and elevation drive section is a pair of permanent magnet D-C stepper motors manufactured by the Superior Electric Co; Bristol, Connecticut. The motors selected are Model M 112-FJ326 units. Stepper motors offer precise incremental rotation in 1.8 angular degree step increments, variable speed (via the number of steps or pulse exitations per second), and high torque output. Although a

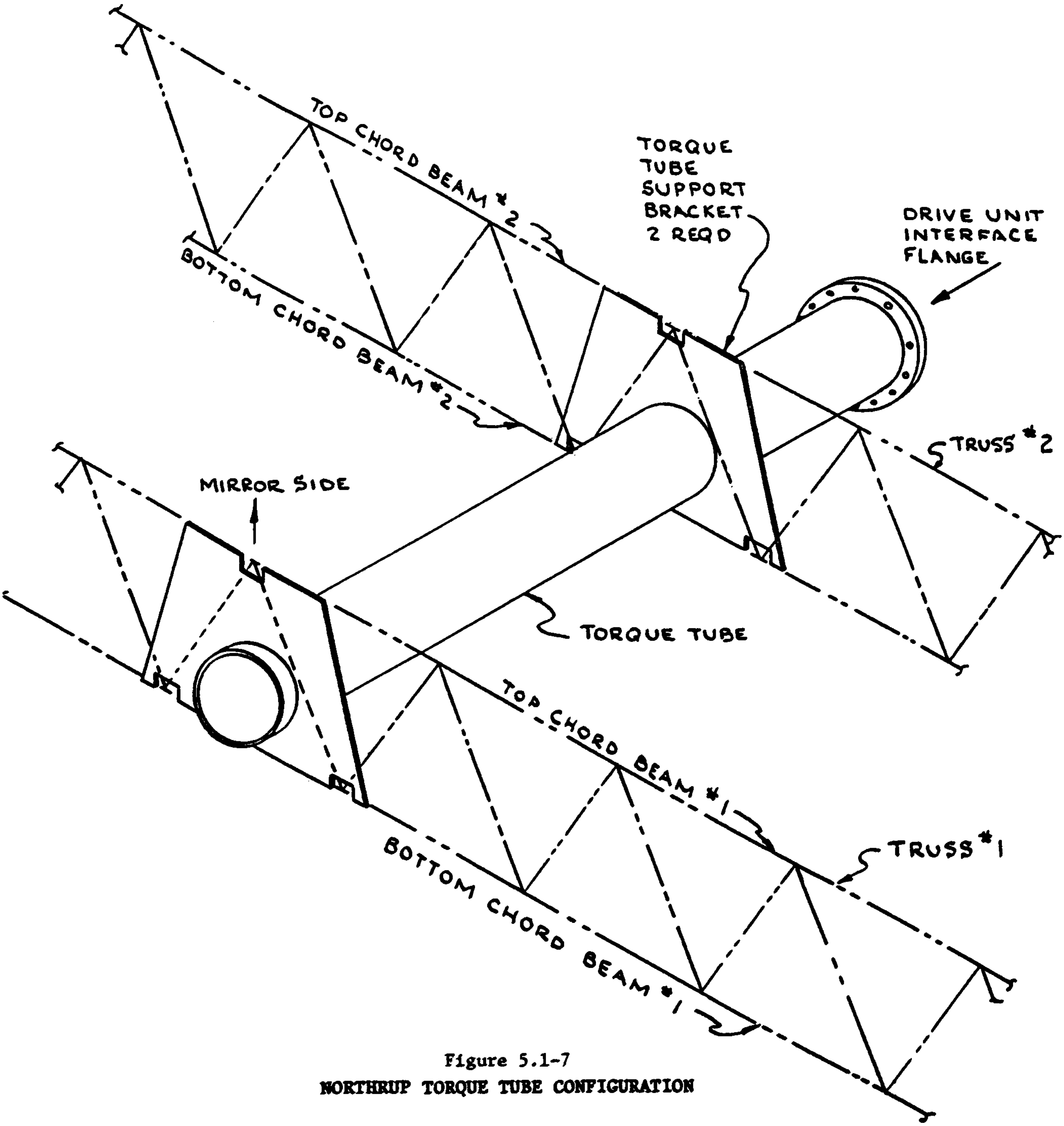
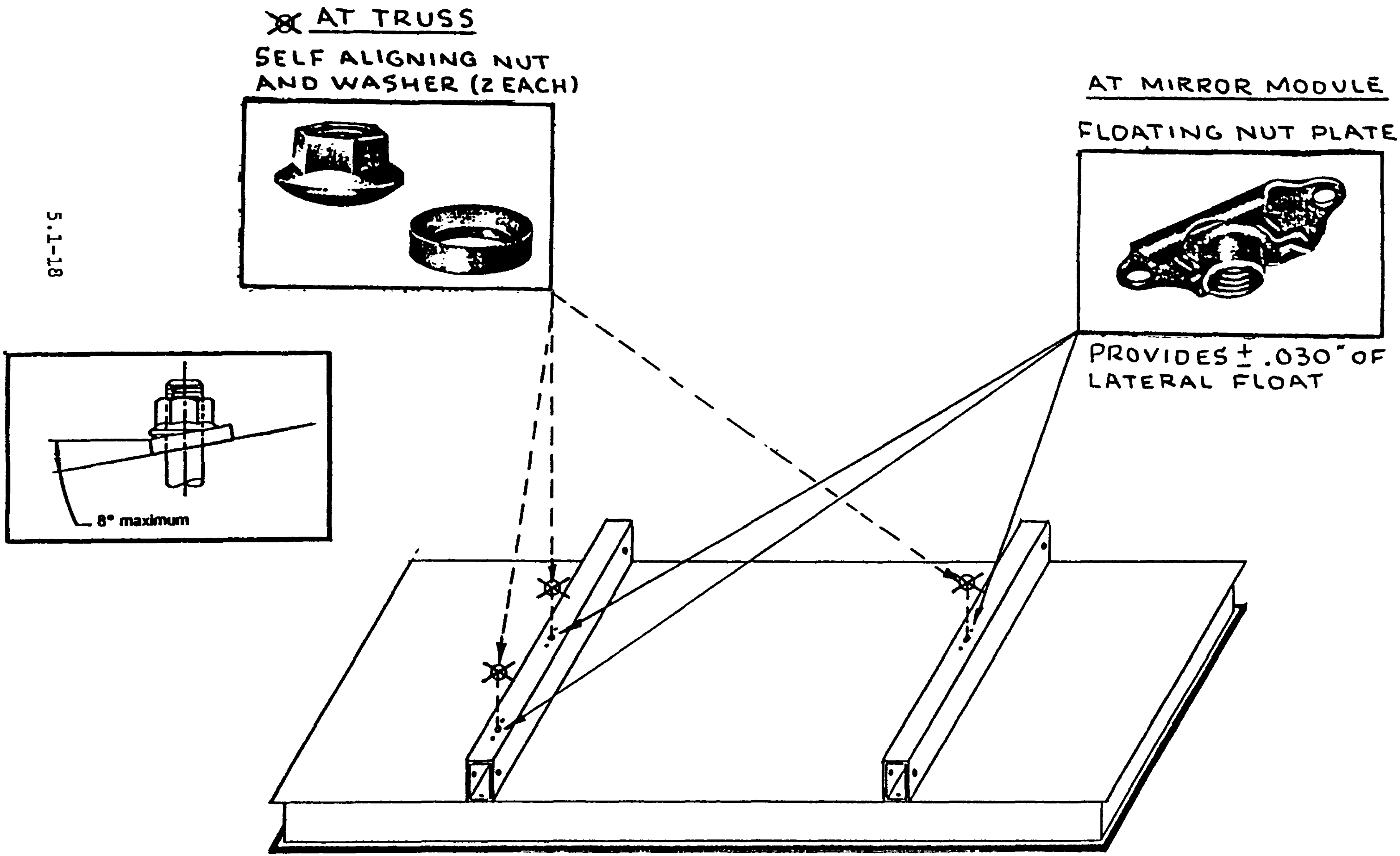


Figure 5.1-7
NORTHRUP TORQUE TUBE CONFIGURATION



MIRROR MODULE ATTACHMENT METHOD
Figure 5.1-8

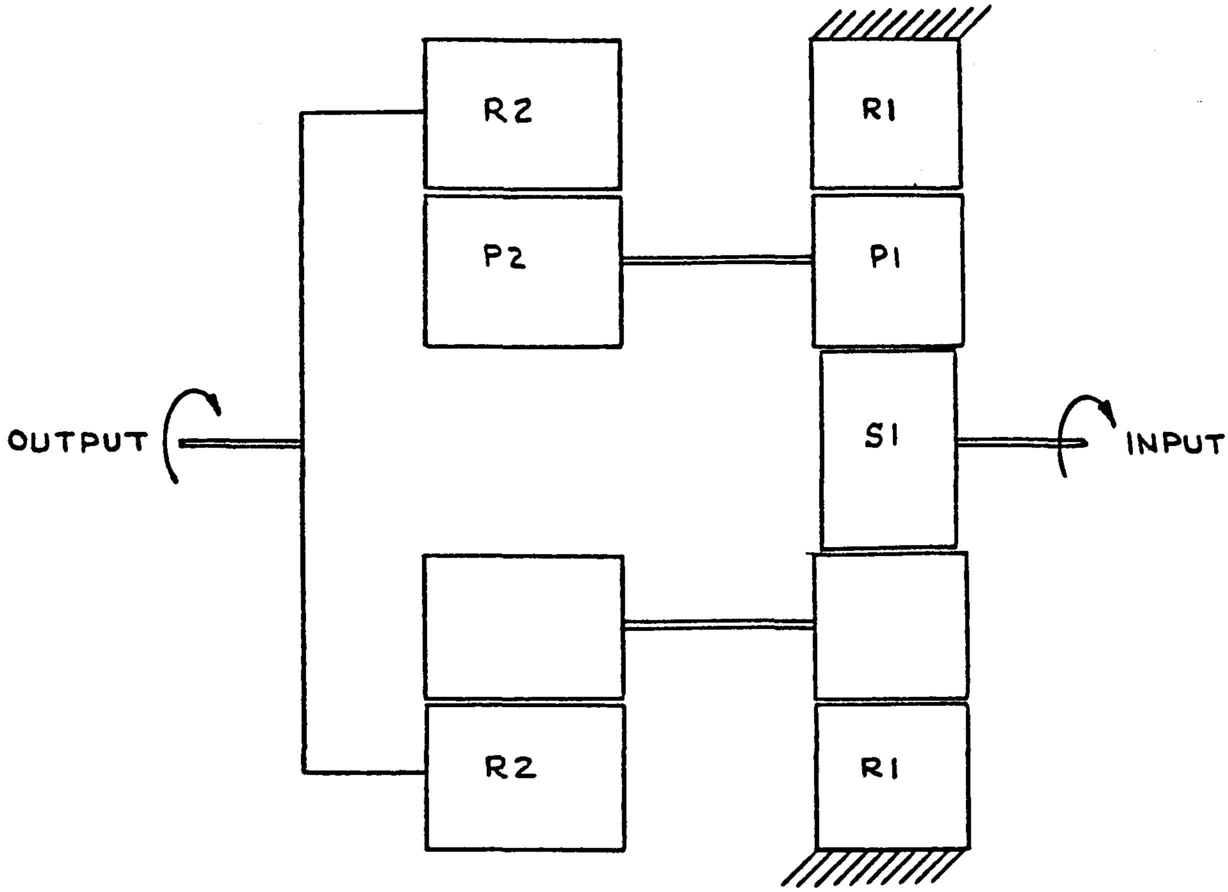
stepper motor does not carry a horsepower rating per se (because it is a variable with stepping rate of 2000 steps/sec (600 rpm). Using position switches to "baseline" the heliostat starting position, any subsequent position can be determined by a simple pulse count. Therefore, position encoders are not required.

The azimuth and elevation drive gears are all identical to each other in terms of type tooth form, and ratio. However, there are physical differences between the azimuth and elevation output gears since they have structural functions and interface requirements which are different. The first speed reduction stage is a planetary gear system, and the second stage (output stage) is a worm and gear type.

The planetary stage has a speed reduction ratio of 450.45:1. Figure 5.1-9 shows a schematic representation of the planetary system and the speed reduction computation. It should be noted that the planet gears (denoted by P1 and P2) represent a set of two gears which revolve around the sun gear S1. The internal ring gear denoted R1 is stationary, and the ring gear R2 is the output gear.

The worm and gear output stage provides an additional 40:1 speed reduction. The worm has a 79.3 mm (3.121 inch) pitch diameter and 7.7 degree lead angle, and is fabricated from C1117 carbon steel, carburized and ground. The gear pitch diameter is 0.429 m (16.879 inches), the face width is 60.0 mm (2.362 inches), and is fabricated from SP-80 cast iron (nodular cast iron, 80 ksi yield strength, 100 ksi ultimate strength). The normal pressure angle for this gear set is 28°, and the diametral pitch is 2.37 (teeth per inch of gear pitch diameter).

The main output stage bearings for the drive unit are unique in that only a single support bearing is used in each the azimuth and elevation portions of the drive. The bearing selected is a ball unit, Type "X", 4-point contact manufactured by the Keene Corp. (Kayden Bearing Division, Muskegon, Mich.). The azimuth and elevation bearings are identical; the Kaydon part number is KG 160XPO, and is 0.457 m (18.0 inch) OD x 0.406 m (16.0 inch ID).



NUMBER OF TEETH

GEAR	NO.
S1	10
P1	40
R1	89
P2	40
R2	91

$$\text{RATIO} = \frac{1 + R1/S1}{1-\left(\frac{R1}{P1} \times \frac{P2}{R2}\right)} = \frac{1+89/10}{1-\left(\frac{89}{40} \times \frac{40}{91}\right)} = 450.45$$

Figure 5.1- 9
Northrup Heliostat Drive Unit
Planetary Speed Reduction Stage

The drive unit is oil-filled and completely sealed to prevent moisture penetration and condensation. An expansion chamber is included in the design to accommodate expansion and/or contraction of the lubricant and case. The drive unit case is grey cast iron for production economy. Figure 5.1-10 provides a perspective view of the Northrup-Winsmith drive unit.

Drive Motor and Controls Description

The heliostat controls consist of a control electronics unit, translators, and stepper motors.

The control electronics (CE) consist of a microprocessor controller that communicates with a central computer, receives serial data commands and outputs step sequences to a stepper motor translator. The CE also interfaces with limit or position switches to obtain reference positions and limit warnings. A manual control capability is provided to run the heliostat manually. The interface to the central controller is a differential current line driver/receiver pair. Data rate is software controllable from 300 to 9600 baud. A block diagram of the controls is shown in Figure 5.1-11. The processor is a 6502 that communicates to RAM, ROM, I/O, and a serial communications unit through an 8 bit data bus, 16 bit address bus and appropriate control lines. The firmware is contained in a 2948 by 8 bit EROM (part no. 2716).

The communications is accomplished with a 6850 asynchronous communications interface adapter (ACIA). This unit includes select, enable, read/write, interrupt and bus interface logic to allow data transfer over the bus. Serial data is transmitted and received by the asynchronous data interface and converted to parallel data that is handled by the processor. The functional configuration of the ACIA is programmed via the data bus during system initialization.

The 6532 chip provides the RAM, I/O, and timing. It is comprised of a 128 x 8 static RAM, two software controlled 8 bit bi-directional data ports, and a software programmable interval

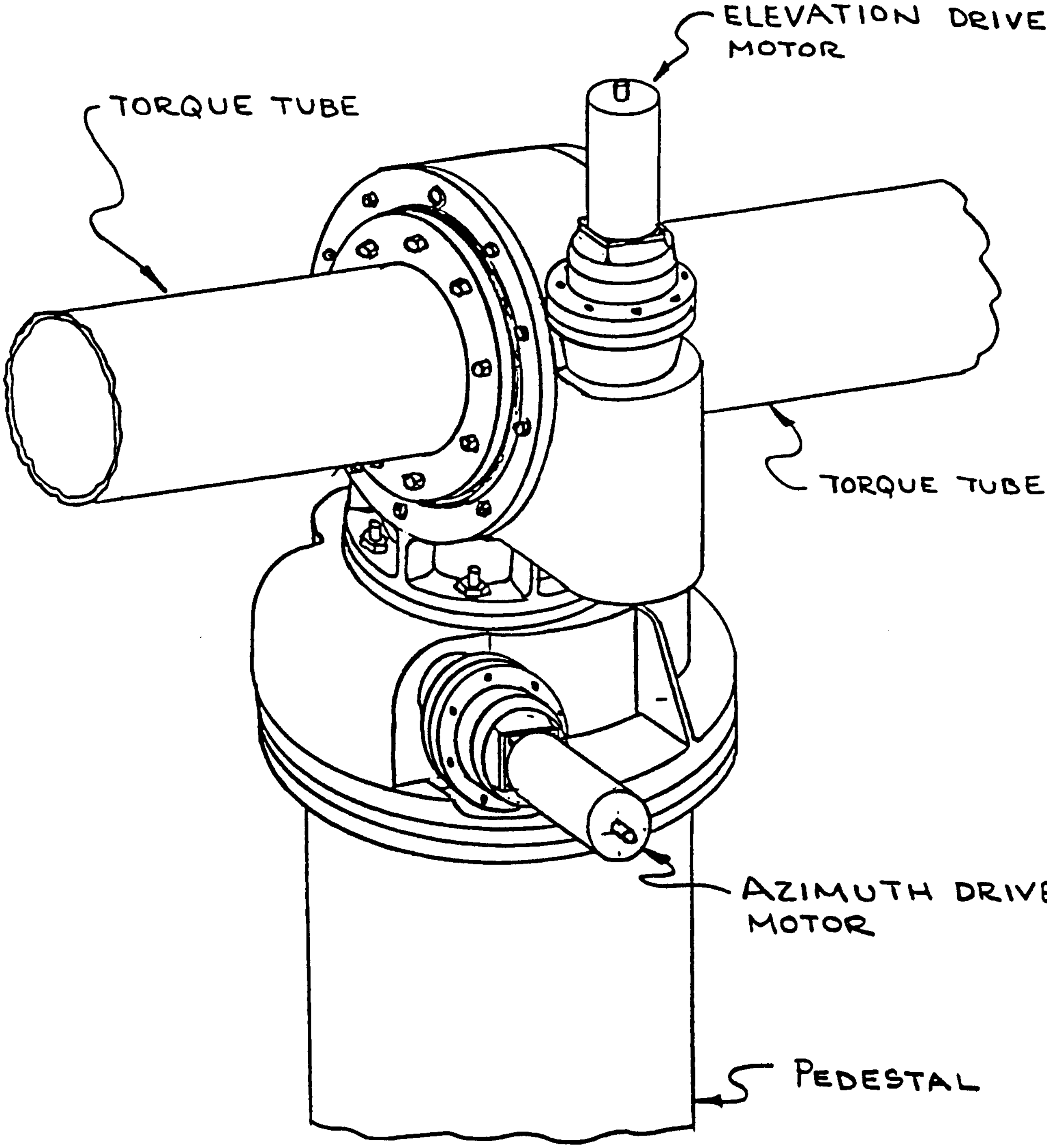


Figure 5.1-10

Perspective View of Winsmith Drive For Northrup II Heliostat

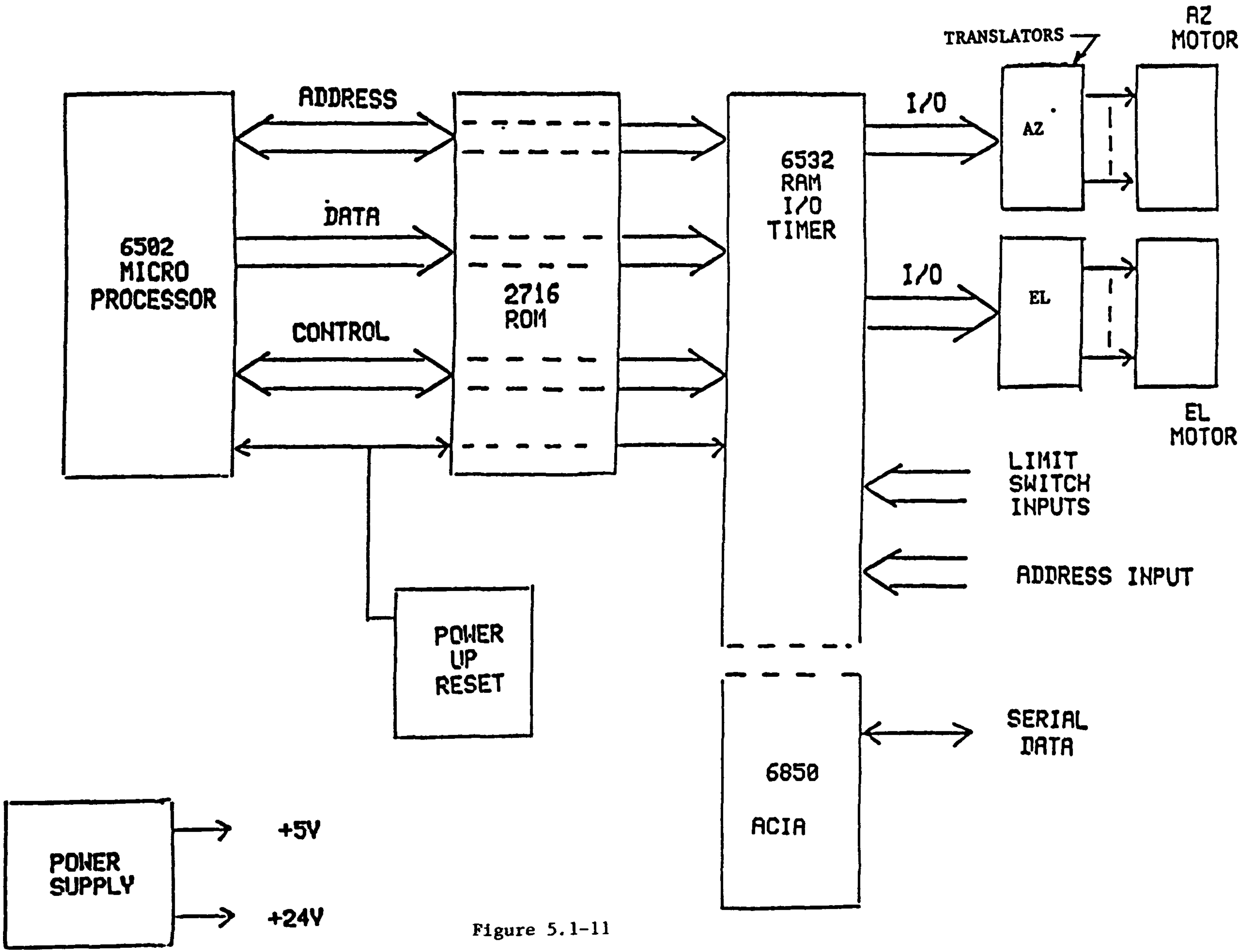


Figure 5.1-11

BREAD BOARD CONTROL ELECTRONICS

timer with interrupt, capable of timing in various intervals from 1 to 263,144 clock periods. One 8 bit data port interfaces with the translators (4 bits total), and limit switches (4 bits total). The other bit port is reserved for the heliostat address input. The timer gives the appropriate delays for acceleration, deceleration and stepping the motors. A 555 timer provides about 20 ms power-up reset to the processor.

The translator used in our design is a Superior Electric TBM 105-1230. Two translators are required, one for azimuth and one for elevation. The translator receiver either cw or ccw pulses from the microprocessor support chip (6532). The pulses are converted to four logic levels by the translator and applied to the motor windings per table below.

STEPPER MOTOR WINDING EXITATION

STEP	SW1	SW2	SW3	SW4
1	on	off	on	off
2	on	off	off	on
3	off	on	off	on
4	off	on	on	off

To reverse motor direction the windings are sequenced in reverse order, i.e., steps 4,3,2,1. The block diagram of the translator is shown in figure 5.1-12.

The actual circuits in the translator consist of logic translation, power switches to apply current to the motor windings and a current source. The logic translation is accomplished by three of four chips consisting of a counter, gates, and a ROM. The counter keeps track of the input pulses from the processor, the gates steer the counter output to the ROM, and the ROM converts the counter states to the logic shown in the above table. The power switching is accomplished by NPN silicon power transistors. The current source is the most complex part of the translator, it consists of a power switching inverter that converts a DC supply to stored energy in an inductor which is applied to the motor windings when a step signal is received from the logic.

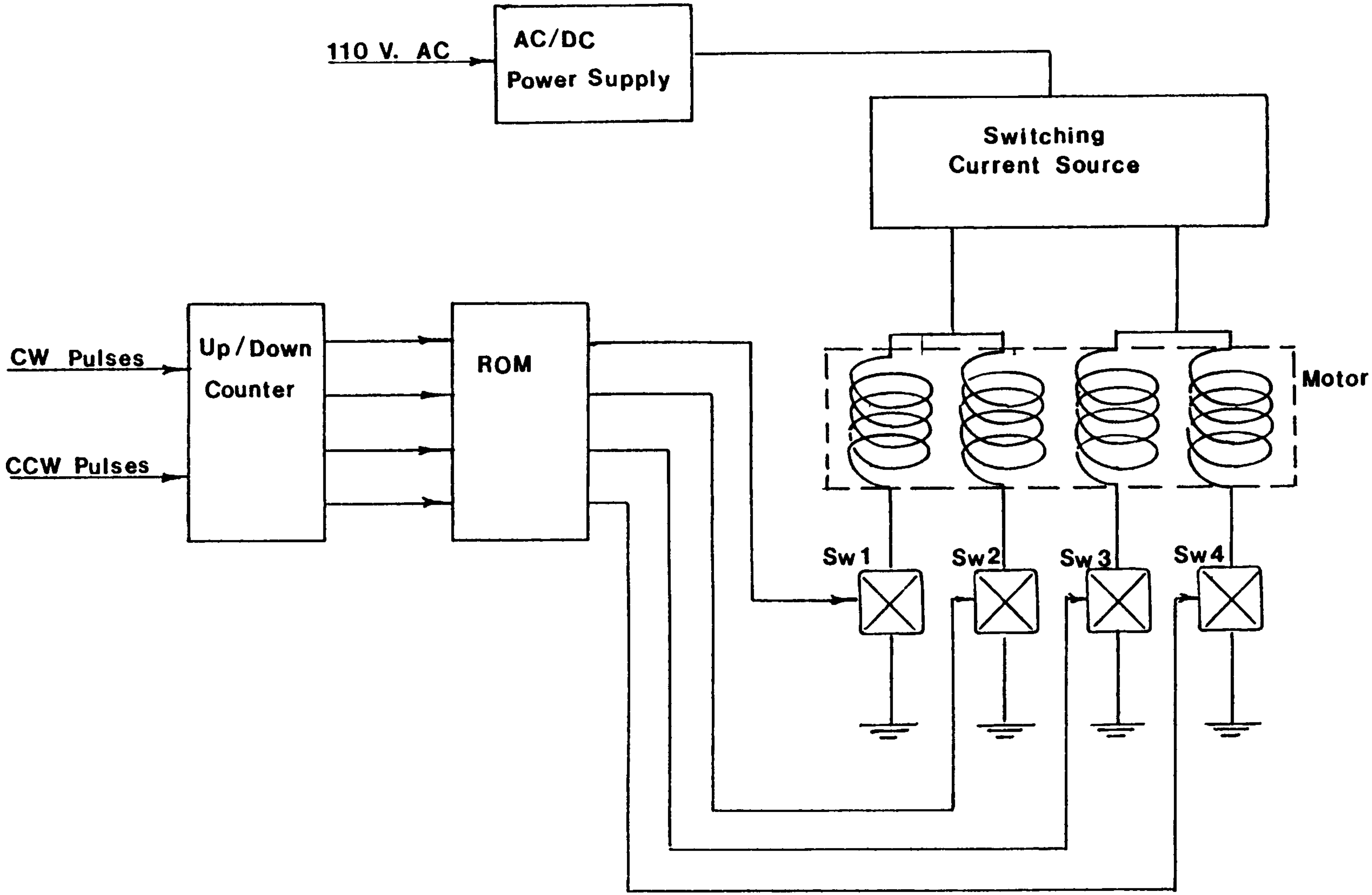


Figure 5.1-12 **Translator Block Diagram**

Pedestal

Design of the combination foundation and support pedestal is being performed under subcontract by Bechtel National Inc.

The heliostat support pedestal concept has evolved from poured concrete and steel to the current approach which uses a straight, pipe-like, pile. The pedestal (pipe) unit is a spiral-welded hollow cylinder 0.61 m (24 inches) outside diameter having a wall thickness of 6.35 mm (0.25 inch). The total length (excluding the flange) is 8.32 m (27.5 ft), of which 3.24 m (10.63 ft) is above grade.

The steel pile is driven in place using a vibratory hammer. No augering or concrete is required with this approach. It is estimated that a 6-man crew can drive approximately 40 piles per day.

The pile can be driven with an angular plumbness of 1.1 angular degrees and a depth tolerance of ± .05 m (± 2 inches). To adjust for the out-of-plumb condition, a pair of tapered, gasketlike, shims are installed on top of the pile flange. These can be rotated relative to each other to achieve a true-horizontal interface for the drive unit. The pile flange is factory-welded to the pile prior to shipment to the site. The pile flange is 0.72 m (28.50 inches) in diameter x 12.7 mm (0.5 inch) thick, and has a 12-hole pattern which accepts the .625 - 11 UNC studs which protrude from the drive unit bottom flange (the drive unit studs being preinstalled during the heliostat assembly in the field assembly building).

Figure 5.1-13 illustrates the Bechtel pedestal-pile concept for the Northrup II heliostat.

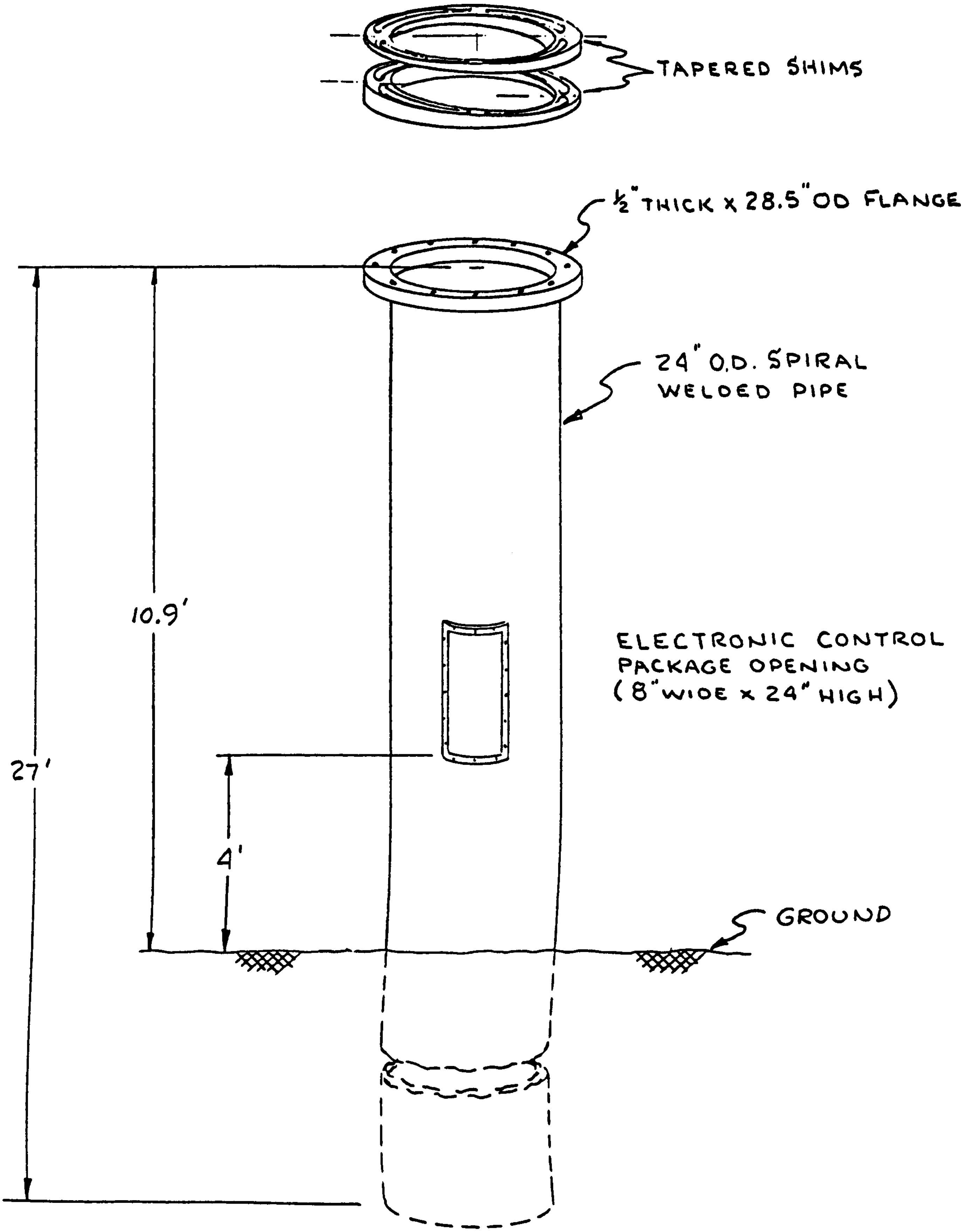


Figure 5.1-13 Bechtel Pile-Pedestal Concept for Northrup II Heliostat

Coles Levee Controls

A block diagram of the controls for 320 heliostats is shown in Figure 5.1-14. Heliostats are partitioned in groups of upto 64 on one data bus. Each data bus is connected to a serial interface at the master controller. This interface is connected in parallel to the Hewlett Packard 9825 i/o bus. There are six serial interfaces connected to the 9825, each interface serving up to 64 heliostats.

The master controller consists of a HP 9825 computer. This computer calculates the heliostat step commands and stores the commands in memory. The memory is interogated sequentially during the I/O operation to the heliostats. The computer is calculating heliostat commands at the same time it is doing I/O to the heliostats. The only time the processor is busy with an I/O operation is during the switchover between groups of heliostats. The switchover time is negligible compared with the total calculation cycle for the 320 heliostats.

The serial interface to the 9825 outputs and inputs RS232 voltage levels. These levels are converted and isolated by a custom interface. This interface converts the RS232 levels to differential current levels. It also provides isolation between the master controller and the heliostat field. A block diagram of this interface is shown in Figure 5.1-15.

The return data containing status of the heliostats is received by the same interface that sends the commands. Six heliostats (one per group) are interogated each calculation cycle. The current heliostat status is available to the operator. The status of any ten heliostats may be displayed on operators console CRT. A malfunction in any heliostat is automatically displayed on the operator's console.

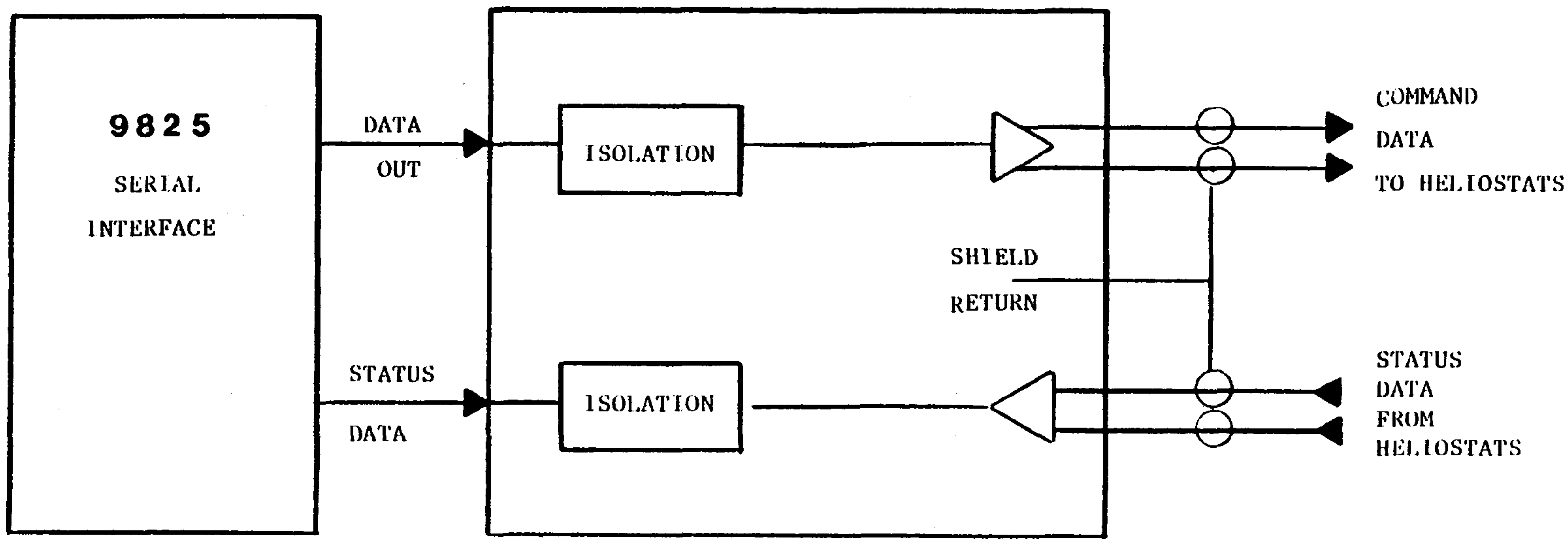


Figure 5.1-14 ISOLATION INTERFACE

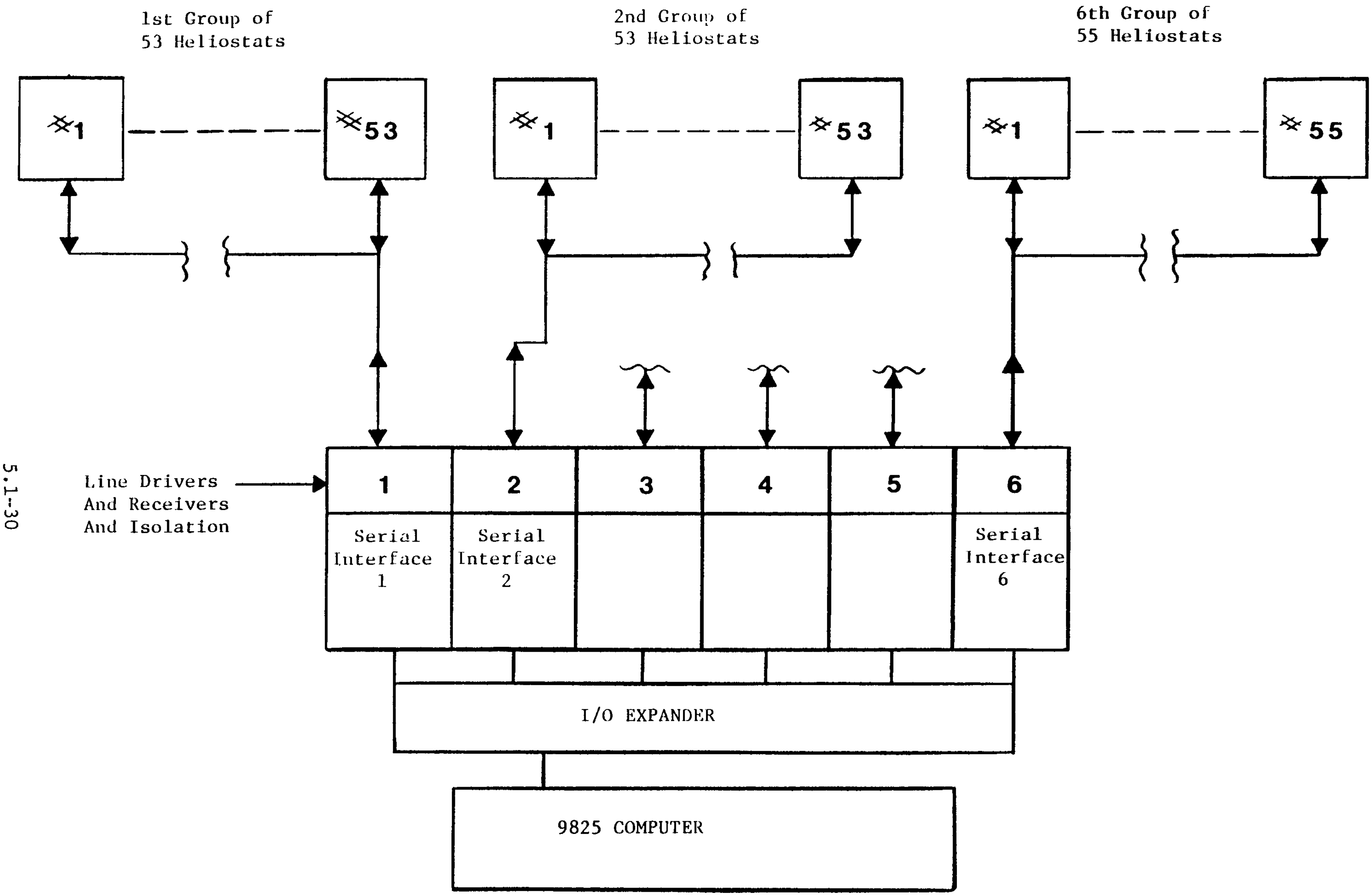


Figure 5.1-15 BLOCK DIAGRAM OF 320 HELIOSTAT CONTROL

5.1.2 Collector Functional Requirements

In accordance with Par 3. Requirements, of the Subsystem Requirements specification (NA 8001) the following items apply to the central receiver type solar collector.

1. Rating of Collector

   Rating = 11.5 MW_t (39.25×10^6 btu/hr) radiant solar energy to the receiver cavity.

2. Rated Operating Conditions

   Insolation = 0.95 kw/m^2 minimum

   Solar Angle = Noon of Summer Solstice and all angles resulting in average field cosine above 0.84

   Environmental Conditions = 0 to 12 m/s (27 mph) wind
   0 to 50°C (32 to 122°F) temp

3. Control Modes

   a. Master Control Modes =
      - tracking
      - "safe course" wake up traverse
      - "safe course" stow traverse
      - emergency defocus to Stand by
      - Stand by
      - Partial Field Track-Partial Field Stand by
      - Vertical Stow
      - Horizontal Stow

   b. Manual Mode = Slew to any position

4. Heliostat

   The heliostat will be "second generation heliostats" being developed under separate contracts to meet the physical and performance requirements of Sandia Specification A 10772 "Collector Subsystem Requirements." Key design driving provisions of A10772 include:

par 3.2.1a Maximum beam pointing error shall be limited to 1.5 mrad standard deviation for each gimbal axis (in "no wind condition).

par 3.2.1b Beam quality shall be such that a minimum of 90% of the reflected energy at the target range whall fall within the area defined by the theoretical beam shape plus a 1.4 mrad fringe width (in "no wind condition").

par 3.2.1c Overall structural support shall limit reflective surface static deflections to an effective 1.7 mrad standard deviation for a field of heliostats in a 12 m/s (27 mph) wind.

par 3.2.1d The allowable tilt of a heliostat foundation shall not exceed $\pm$ 1.5 mrad total angular deflection per axis when the heliostat is subjected to a 12 m/s (27 mph) wind load.

par 3.2.2a The collector subsystem shall function as appropriate for all steady state modes of plant operation. This shall include the capability of controlling the number of heliostats in the tracking mode so as to vary the reflected flux from zero to maximum with step changes no larger than 10 percent of the total field output.

par 3.2.2b Drive systems must be capable of positioning a heliostat to stowage, cleaning, or maintenance orientation from any operational orientation in 15 minutes.

par 3.2.2c Elevation and Azimuth drives shall not drift from last commanded positions due to environmental conditions.

par 3.2.2d Drive systems must be capable of resolving south field control singularity within 15 minutes.

par 3.2.2e Heliostat orientation must be available to master control at all times.

par 3.2.2f Heliostat shall be computer controlled.

par 3.2.3a	Collector Subsystem shall be capable of emergency defocusing radiation on receiver to less than 3% of initial value in 120 seconds.
par 3.2.3c	Beam control strategy will protect personnel and property within and without the plant facility including air space.
par 3.2.5b	Local override of heliostat controller and ability to stow without use of heliostat drive motors.
par 3.2.6 ref to Appendix 1	Survival Wind = 40 m/s (90 mph)
par 3.2.6.1	Wind Direction = $\pm 10^{\circ}$ from Horizontal
par 3.2.6.2	Operational Wind = 12 m/s (27 mph) Meeting Performance
par 3.2.6.3	Maximum Operating Wind = 16 m/s (35 mph)
	Maximum "Any attitude" Wind = 22 m/s (50 mph)
par 3.2.6.4	Hail - Survive 19 mm (.75 inch) diam, .9 spec gravity hail at 20 m/s (65 ft/s).
par 3.2.6.5	Lightning - Controllers adjacent to a heliostat receiving direct strike must be protected.

5.1.3 Collector Design

The conceptual design collector layout started with the single tower optimum collector configuration of the system trade off analysis, updated the sizing in accordance with the finalized process heat load evaluation, and made appropriate adjustments for existing features of the site. Figure 5.1-16 is a plan view of the heliostat layout for the conceptual design. The layout shows positions for 337 heliostats, providing a margin of 17 above the 320 heliostats of the collector. Use of the margin for either additional heliostats, or additional clearances around the major pieces of equipment in the field will be established during "Detail Design". The basic layout pattern of the heliostats is interupted for the three oil wells on the site, for the ARCO Products Pipeline which crosses the site, and for an existing road section which provides access to the well 67 work over area.

The widened space for the outer take up row is used to minimize the impact of access to and work over space for well 57.

Basic geometry of the collector is a 120° circular segment with an inner row radius of 50.7 m (166.5 ft) and an outer row radius of 293.5 m (963 ft). Packing density is 0.196, slightly reduced from that potentially available by the in-field clearance zones.

Data on the row radius, number of heliostats per row, and impacting field features for each row are presented in Table 5.1-1.

The basic north sector arrangement was selected to maximize performance with the relatively small field and to allow use of a single cavity high performance receiver. The radial stagger layout of the heliostat positions was used to maximize packing density and minimize tower height.

Control of the collector is by a central computer (Hewlett Packard 9825) which communicates to six subdivided groups of heliostats on independent data busses as shown in the block

Fig. 5.1-16 Plan View, Conceptual Design Collector

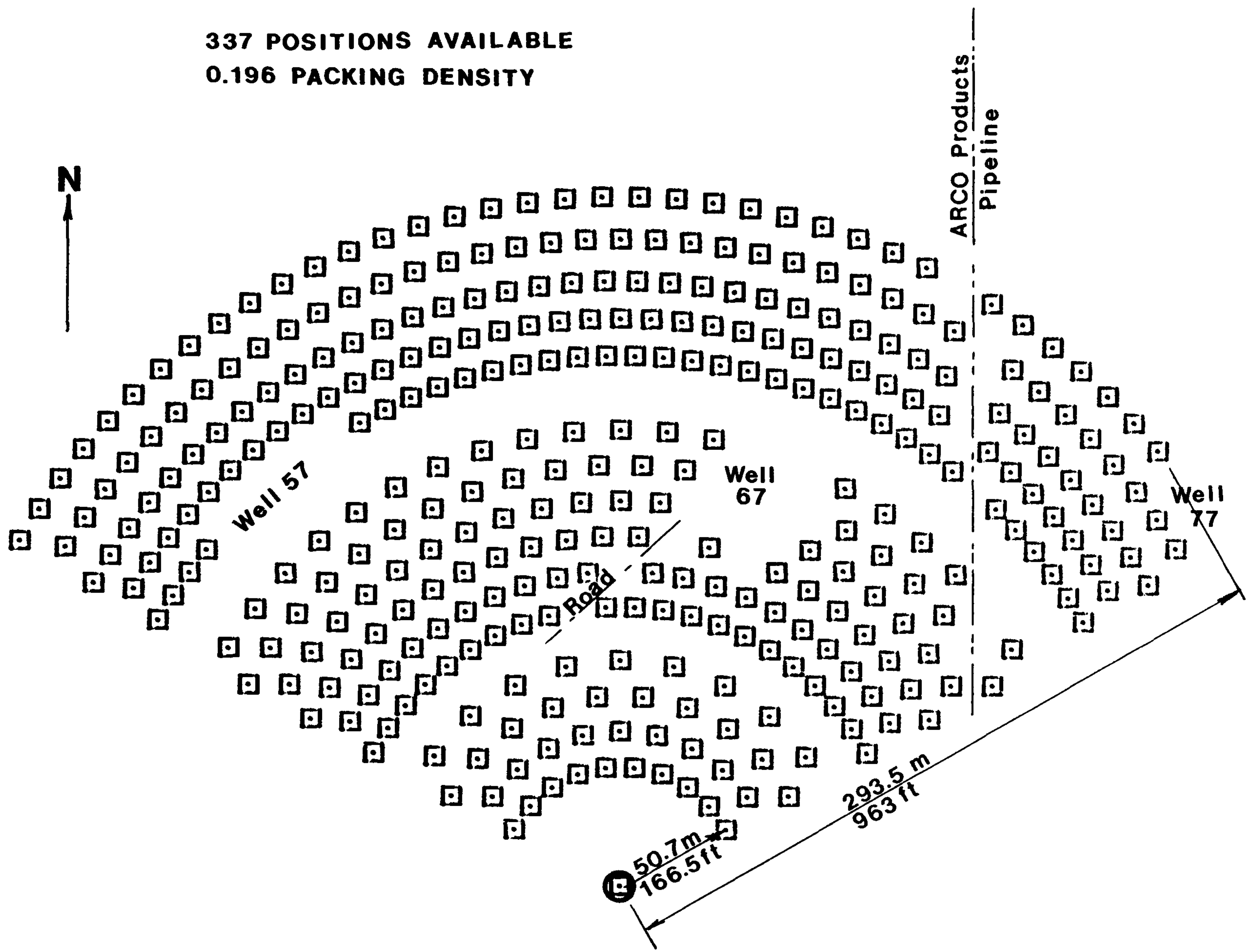


Table 5.1-1

Collector Layout Features

Row	Radius Meters (ft)	Heliostats Potential No. In Row	No. Omitted	Reason Omitted	Number In Row	Cumulative Count
1.	50.7 (166.5)	10	0	-	10	10
2.	65.8 (216.0)	9	0	-	9	19
3.	80.9 (265.5)	10	0	-	10	29
4.	96.0 (315.0)	9	0	-	9	38
5.	118.7 (389.5)	22	1	Road to 67	21	59
6.	133.8 (439.0)	21	1	Road to 67	20	79
7.	148.9 (488.5)	22	2	Road to 67	20	99
8.	163.9 (538.0)	21	3	Well 67	18	117
9.	179.1 (587.5)	22	3 1	Well 67 Prod. Pipeline	18	135
10.	194.1 (637.0)	21	2 1	Well 67 Prod. Pipeline	18	153
11.	225.8 (741.0)	40	6 1	Well 57 Prod. Pipeline	33	186
12.	241.7 (793.0)	39	1	Prod. Pipeline	38	224
13.	257.5 (845.0)	40	1	Prod. Pipeline	39	263
14.	275.5 (904.0)	39	1	Prod. Pipeline	38	301
15.	293.5 (963.0)	40	1 3	Prod. Pipeline Well 77	36	337

diagram of 5.1-15. Each data bus services 53 or 55 heliostats and has the capability to handle 64, providing a margin of design flexibility. The software functional flow diagram for the collector controller is shown in Figures 5.1-17 and 5.1-18. The control software consists of two major sections, an initializing section and an operating section. Functional elements of the initializing section, shown on Fig. 5.1-17 include the basic control mode selection, and the subroutines to read a peripheral equipment clock, compute the solar vector, and provide target data for the operating mode in effect. Computation is cycled through this segment every command cycle.

The operating segment completes the steering algorithm for each heliostat based on the common data supplied by the initializing segment and heliostat unique data (physical X,Y,Z location, azimuth axis position, and elevation axis position). The operating segment then performs the Input/Output (I/O) to the serial data communication bosses, communicates requested status to control room peripheral devices (CRT, Printer, Disc) and returns control of the computation to the initializing segment for another cycle. Data to enable real time observation of axis position and daily history of axis positions such as illustrated in the selected calculation samples of Figures 5.1-19 and 5.1-20 will be read out and recorded by the control room peripheral devices.

Fig 5.1-17 MINI HAC SOFTWARE SCHEMATIC-INITIALIZING SEGMENT

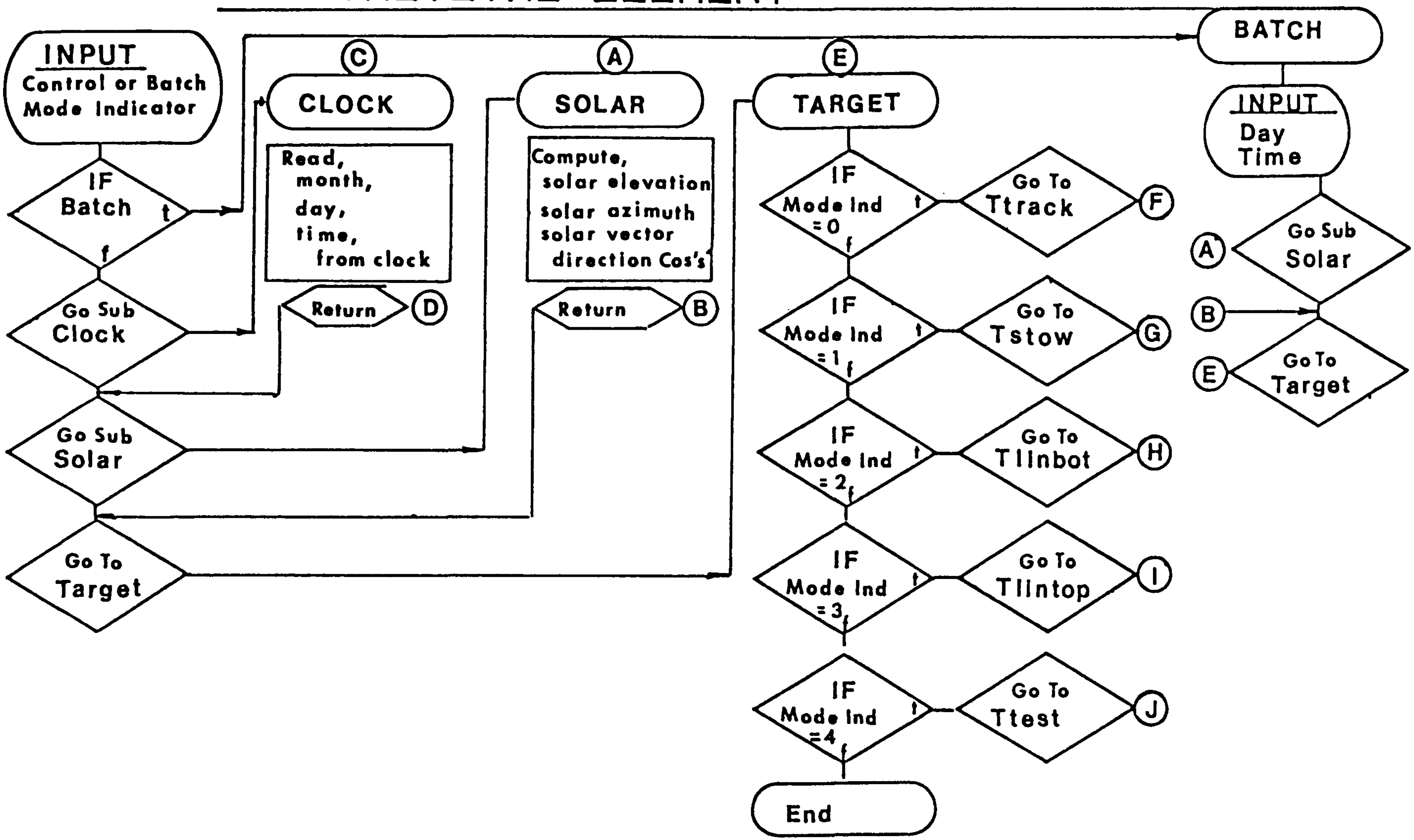


Fig 5.1-18 MINI HAC SOFTWARE SCHEMATIC-OPERATING SEGMENT

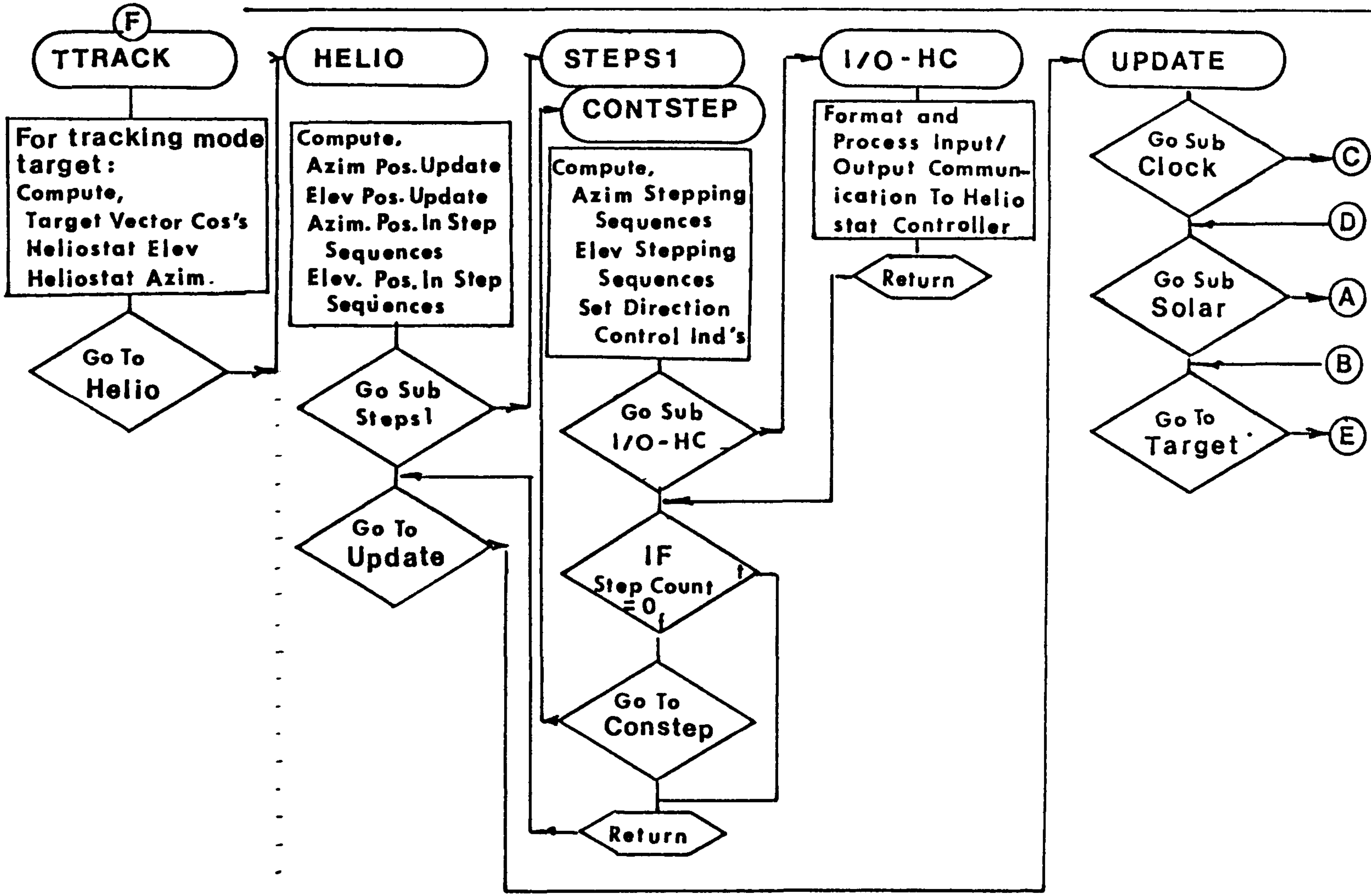


Fig. 5.1-19 Axis Position vs Time Of Day - Sample Heliostat No.12

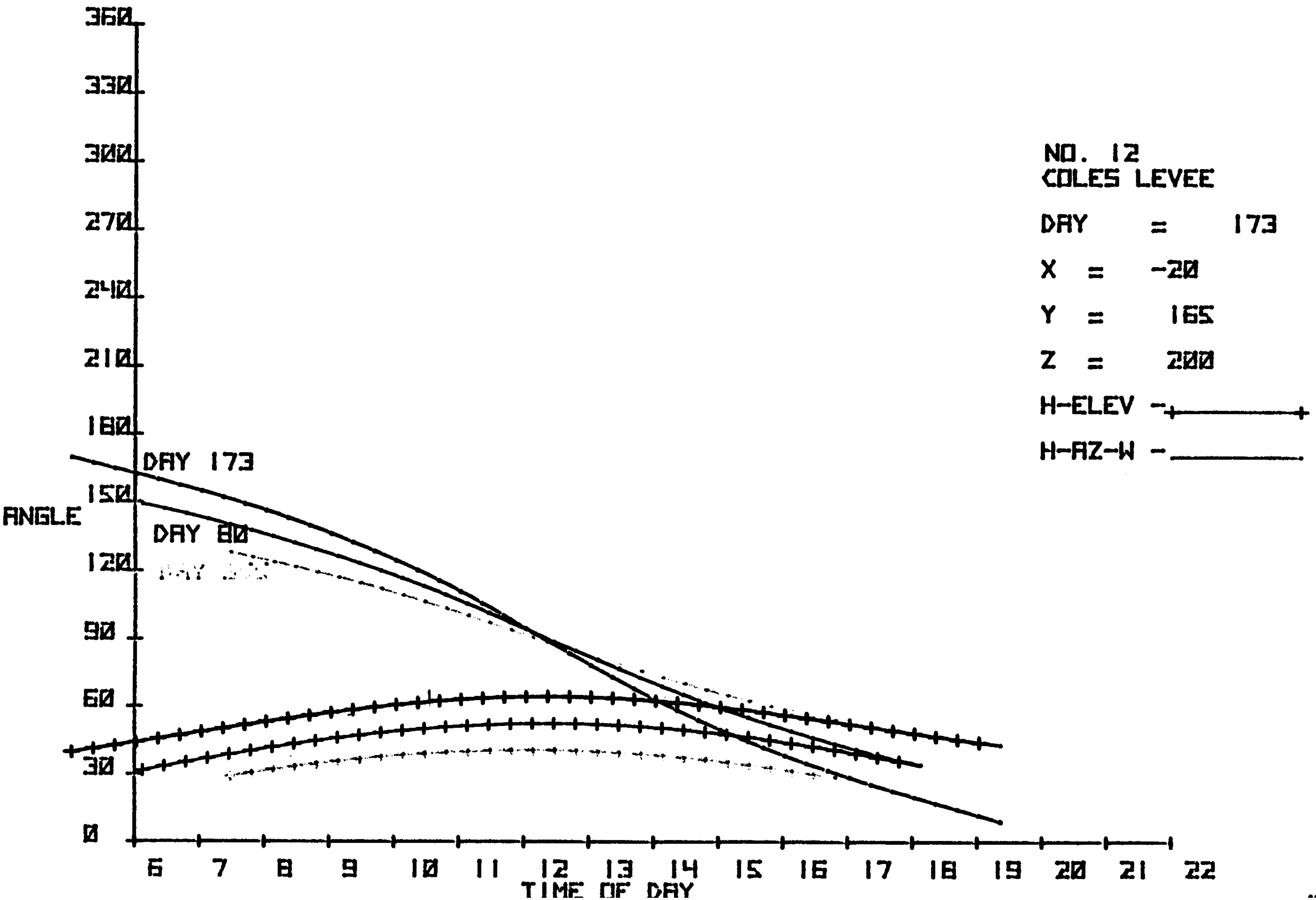
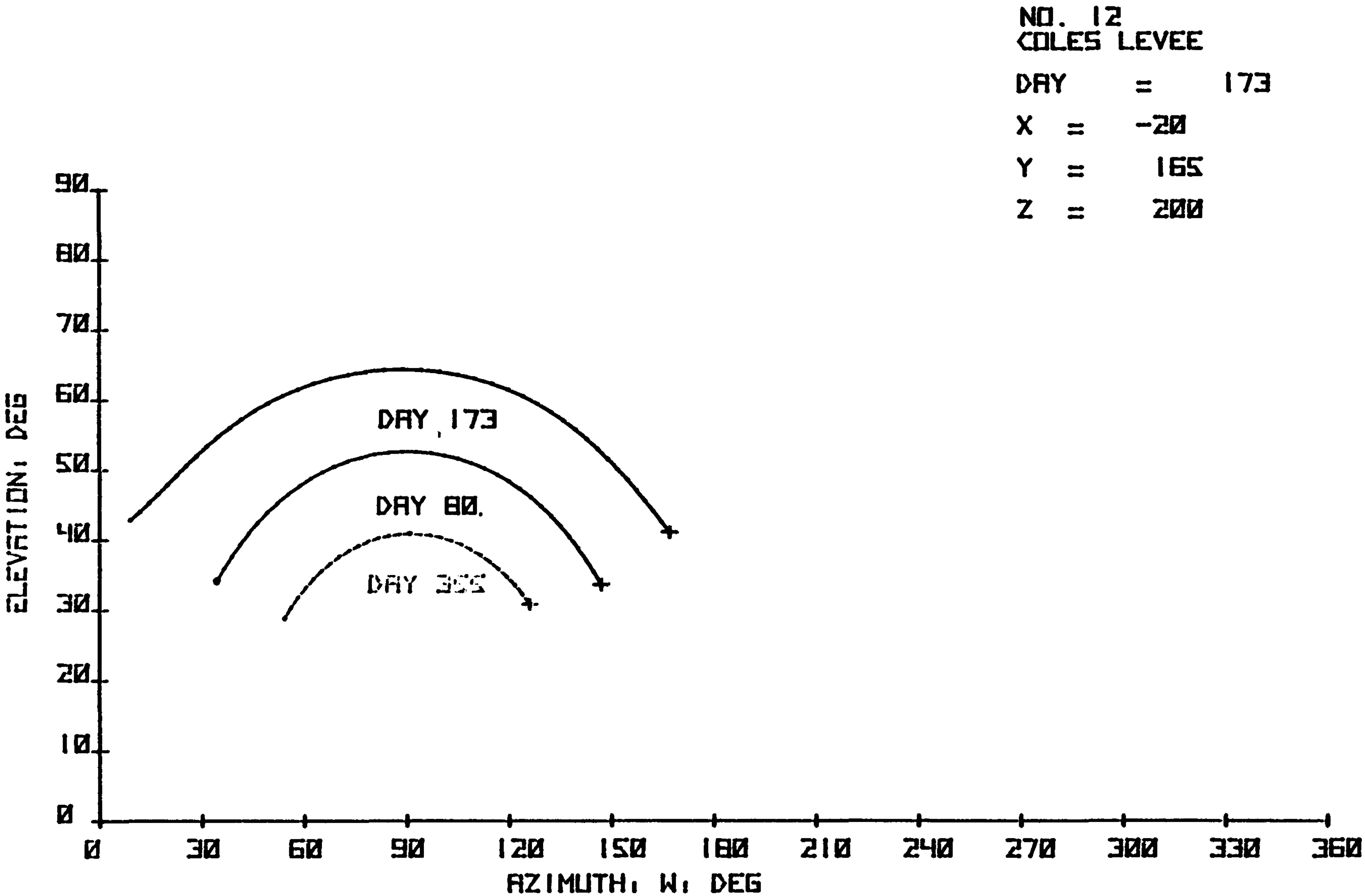


Fig. 5.1-20 Elevation Angle vs Azimuth Angle

Sample Heliostat No. 12



5.1.4 Collector Operating Characteristics

Collector operating characteristics on a daily basis consist of a sequence of operating modes activated by the solar system operator. These consist of the normal modes which collect the maximum available solar energy without interruption and the irregularity modes which are entered to accomodate a system irregularity requiring the normal mode to be over-ridden.

The normal day sequence would consist of 1) the "safe course" wake up traverse, 2) partial track-partial standby heat up, 3) tracking, and 4) "safe course" stow traverse. Stow position for the Coles Levee north field collector is normally with the heliostats vertical and facing 30^{o} north of East.

"Safe Course" Wake Up Mode

The initial operation during morning start up is the "safe course" wake up traverse. For this traverse the initializing segment of the collector control software contains the target position of a location near the ground to the side of the tower given the name "line bottom". All heliostats being activated for the upcoming operation focus the reflected solar beam to this "software target".

The second stage of the wake up traverse moves the heliostats such that all reflected beams intersect an imaginary wire between "line bottom" and "line top", a position in airspace beside the aperture. "Line top" is used as the "Standby" position for operating heliostats not being targeted into the receiver. The "wake up" traverse is complete when all activated heliostats reach and track the "line top" software target.

Partial Track-Partial Stand By Heat Up

Groups of 25-30 heliostats are moved to reflect into the receiver cavity under operator control, based on the temperature of the heat medium oil in the receiver and transport loop, during the partial track-partial stand by heat up sequence. The sequence is complete when all active heliostats are tracking the receiver.

Tracking

The operating mode for the vast majority of operating time is the tracking mode, where all active heliostats are targeted to reflect their concentrated beam into the receiver aperture. The "T track" mode indicator of the initializing segment of the collector controller software is in effect establishing the center of the receiver aperture as the aim point for all heliostats.

"Safe Course" stow Traverse

At the end of the operating day heliostat beams are moved from the tracking target to "line top", and "line bottom" positions. From line bottom the heliostats are "slewed" to the stow position of elevation = 0^o, azimuth = 210^o (referenced from west through south).

Irregularity Modes

At the operator's discretion partial or full "stand by" tracking can override normal tracking. Typical irregularities which would initiate a partial standby would be over temperature or low flow indicator alarms. For a large portion of the year partial standby is likely to be necessary near midday due to the "over capacity" of the Collector resulting from insolation above 950 KW/m^2 or geometric performance above the design point value or both.

Horizontal stow, elevation angle = 90^o, will be used whenever windy conditions above 35 mph are present or forecast.

Operating speed of the heliostats in the fast motor speed mode is 12^o per minute. This will enable 180 degrees of azimuth rotation in 15 minutes and 90^o of elevation rotation in 7.5 minutes. Simultanious operation of the two axes is a normal operating condition. A half speed mode is used by the motors during normal tracking sequences.

5.1.5 Collector Performance Estimates

Performance parameters necessarily determined during the conceptual design program phase included the envelopes of cosine, shading, blocking and tower shadowing which combined to generate the geometric efficiency envelope and specific energy, focal plane flux, and receiver cavity flux data needed for receiver design.

Geometric Performance

Data tables spanning the range of solar elevation angles of 5°, 15°, 25°, 45°, 65°, and 89.5° at solar azimuth angles of 0°, 30°, 60°, 75°, 90° and 110° were generated for collector cosine efficiency, collector shading efficiency, collector blocking efficiency, and tower shading efficiency. Collector geometric efficiency, an overall measure of the collector optical performance obtained by the combination of these four factors is shown for the thirty-six point table in Figure 5.1-21. This table is the principal input to the Northrup computer program "DISBAR" which contains the 1976 Barstow direct insolation data. Annual performance of the collector of 25.428 x 10^6 kW_t-hrs delivered to the cavity is based on the "DISBAR" result discounted ten percent for the "Bakersfield/ Barstow" direct insolation factor. The annual geometric efficiency factor of .8298 is also an output of "DISBAR". The cosine, Shadowing, Blocking, and Tower Shadowing parametric data tables used to generate the geometric efficiency table are included as Figures 5.1-22, 5.1-23, 5.1-24 and 5.1-25 respectively.

Specific Power, Focal Plane Flux, and Cavity Flux

Specific extreme points of the annual performance envelope were analyzed for thermal power, focal plane flux pattern, and receiver panel flux pattern. The points evaluated were winter solstice, equinox, and summer solstice. Summary data for the 8:00, 10:00, and 12:00 times for the three days of the year is presented in Table 5.1-2. Summer solstice noon was established as the design point for sizing of the collector to deliver the 9.52 MW_t power needed to meet the process heat load requirement. Winter solstice noon was established as the receiver design point due to its maximum energy and flux level on the receiver panels.

Fig. 5.1-21 GEOMETRIC PERFORMANCE EFFICIENCY
COLES LEVEE SINGLE MOD, 61M [200FT] TWR

AZIMUTH ANGLE, DEGREES

SOLAR ELEVATION, DEGREES	0	30	60	75	90	110
89.5	0.8005	0.8001	0.7993	0.7988	0.7983	0.7975
65	0.8904	0.8770	0.8399	0.8148	0.7872	0.7498
45	0.9363	0.9147	0.8537	0.8111	0.7635	0.6970
25	0.9510	0.9231	0.8494	0.7932	0.7286	0.6363
15	0.9194	0.8904	0.8082	0.7493	0.6848	0.5877
5	0.7704	0.7383	0.6934	0.6545	0.6187	0.5085

AVE. ANNUAL EFF. = 0.8298   ENERGY = 25.428 $X10^6$ KWT-HRS

TO CAVITY [320 HELIOSTATS]

Fig 5.1-22 COSINE PERFORMANCE EFFICIENCY
COLES LEVEE SINGLE MOD, 61M [200FT] TWR

AZIMUTH ANGLE, DEGREES

SOLAR ELEVATION, DEGREES	0	30	60	75	90	110
89.5	0.8005	0.8001	0.7993	0.7983	0.7983	0.7975
65	0.8904	0.8770	0.8399	0.8148	0.7872	0.7498
45	0.9372	0.9156	0.8537	0.8111	0.7635	0.6970
25	0.9581	0.9304	0.8505	0.7941	0.7295	0.6370
15	0.9586	0.9291	0.8428	0.7812	0.7098	0.6057
5	0.9524	0.9213	0.8310	0.7660	0.6899	0.5758

Fig 5.1-23 SHADOWING PERFORMANCE EFFICIENCY
COLES LEVEE SINGLE MOD, 61M [200FT] TWR

AZIMUTH ANGLE, DEGREES

SOLAR ELEVATION, DEGREES	0	30	60	75	90	110
89.5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
65	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
45	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
25	1.0000	0.9995	0.9988	0.9989	0.9988	0.9989
15	0.9751	0.9743	0.9589	0.9592	0.9648	0.9703
5	0.8326	0.8249	0.8345	0.8545	0.8968	0.8832

Fig 5.1-24 BLOCKING PERFORMANCE EFFICIENCY COLES LEVEE SINGLE MOD, 61M [200FT] TWR

AZIMUTH ANGLE, DEGREES

SOLAR ELEVATION, DEGREES	0	30	60	75	90	110
89.5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
65	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
45	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
25	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
15	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Fig 5.1-25 TOWER SHADOW PERFORMANCE EFFICIENCY
(COLES LEVEE SINGLE MOD, 61M [200FT] TWR

AZIMUTH ANGLE, DEGREES

SOLAR ELEVATION, DEGREES	0	30	60	75	90	110
89.5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
65	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
45	0.9991	0.9991	1.0000	1.0000	1.0000	1.0000
25	0.9926	0.9926	1.0000	1.0000	1.0000	1.0000
15	0.9836	0.9836	1.0000	1.0000	1.0000	1.0000
5	0.9715	0.9715	1.0000	1.0000	1.0000	1.0000

Table 5.1-2 Specific Energy, Focal Plane Flux, Receiver Flux Summary

		Focal Plane		24 ft Rad Receiver	
Day	Time	Energy KW	Peak Flux KW/m^2	Energy KW	Peak Flux KW/m^2
355	12	13021	1707	12193	263
	10	12669	1587	11855	224
	8	10262	1116	9574	213
80	12	12511	1505	11673	236
	10	12195	1394	11299	230
	8	11014	1089	10164	205
173	12	11509	1145	10662	195
	10	11212	1061	10291	196
	8	10067	836	9208	192

The seasonal variation in focal plane flux is illustrated in the graphic plots for the winter day 355 (Fig 5.1-26), the equinox day 80 (Fig 5.1-27) and the summer day 173 (Fig 5.1-28). The focal plane flux patterns were reduced to establish energy vs aperture size characteristics for the equinox and solstice days. These data were used as input to the receiver design and performance analysis programs.

The seasonal variation in receiver flux patterns for the selected 7.3 m (24 ft) radius receiver are shown in the graphic plots for the winter day 355 (Fig 5.1-29), equinox day 80 (Fig 5.1-30), and summer day 173 (Fig 5.1-31). These patterns were the basic thermal input for the receiver design and analysis program.

Fig 5.1-26

NORTHRUP TARGET PLANE FLUX

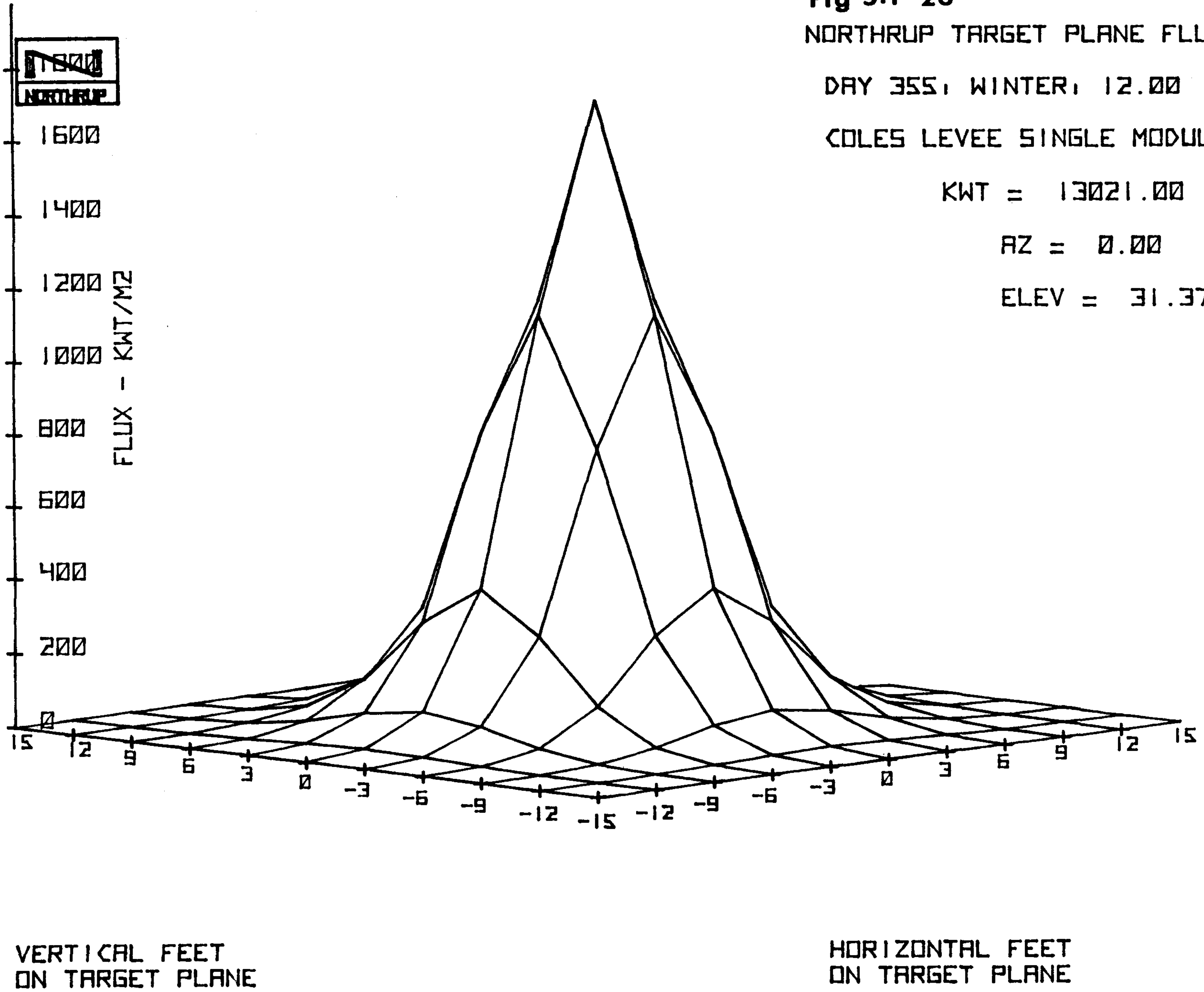
DAY 355, WINTER, 12.00

COLES LEVEE SINGLE MODULE

KWT = 13021.00

AZ = 0.00

ELEV = 31.37



EJB/J 2

Fig 5.1-27
NORTHRUP TARGET PLANE FLUX

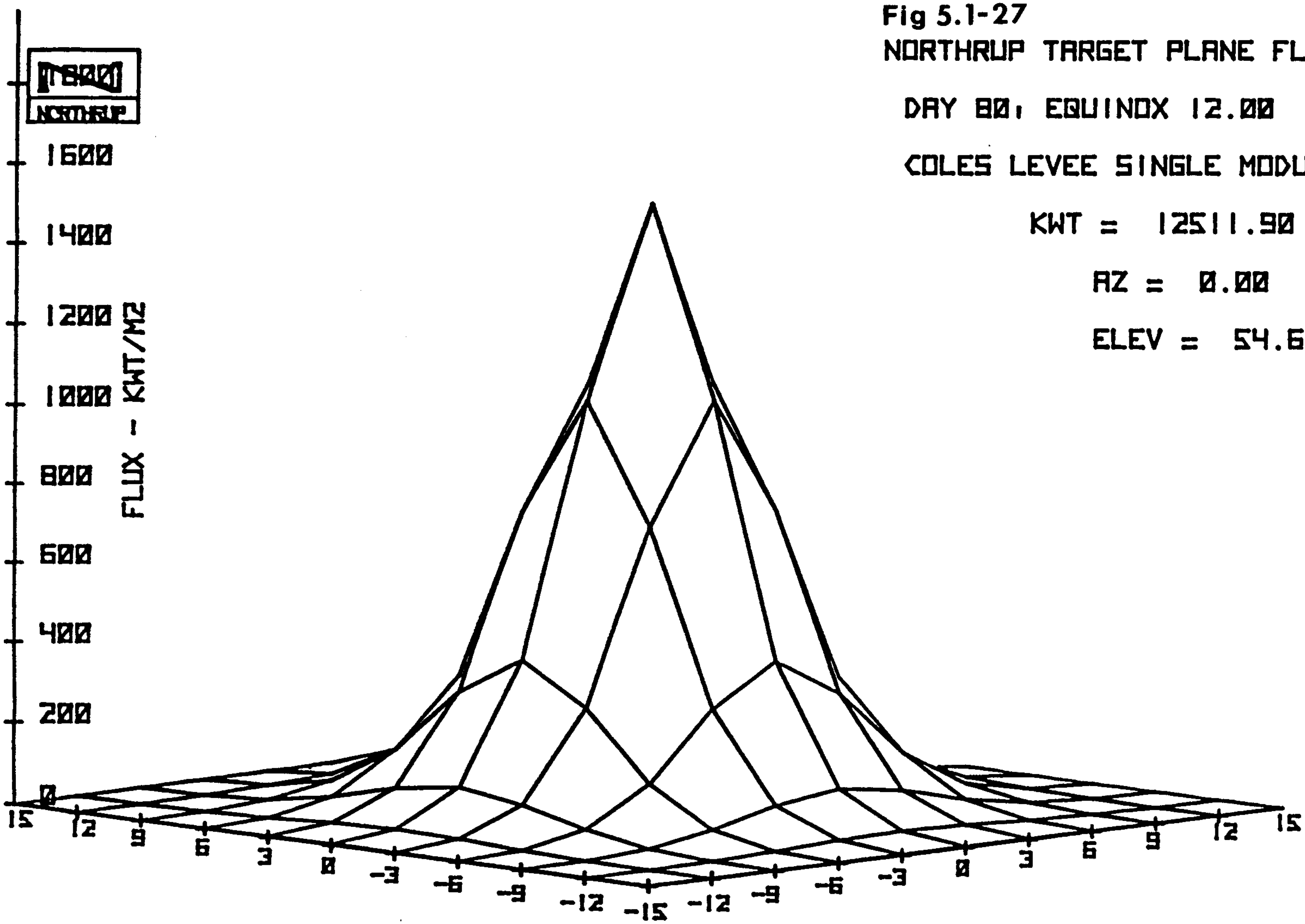
DAY 80, EQUINOX 12.00

COLES LEVEE SINGLE MODULE

KWT = 12511.90

AZ = 0.00

ELEV = 54.68



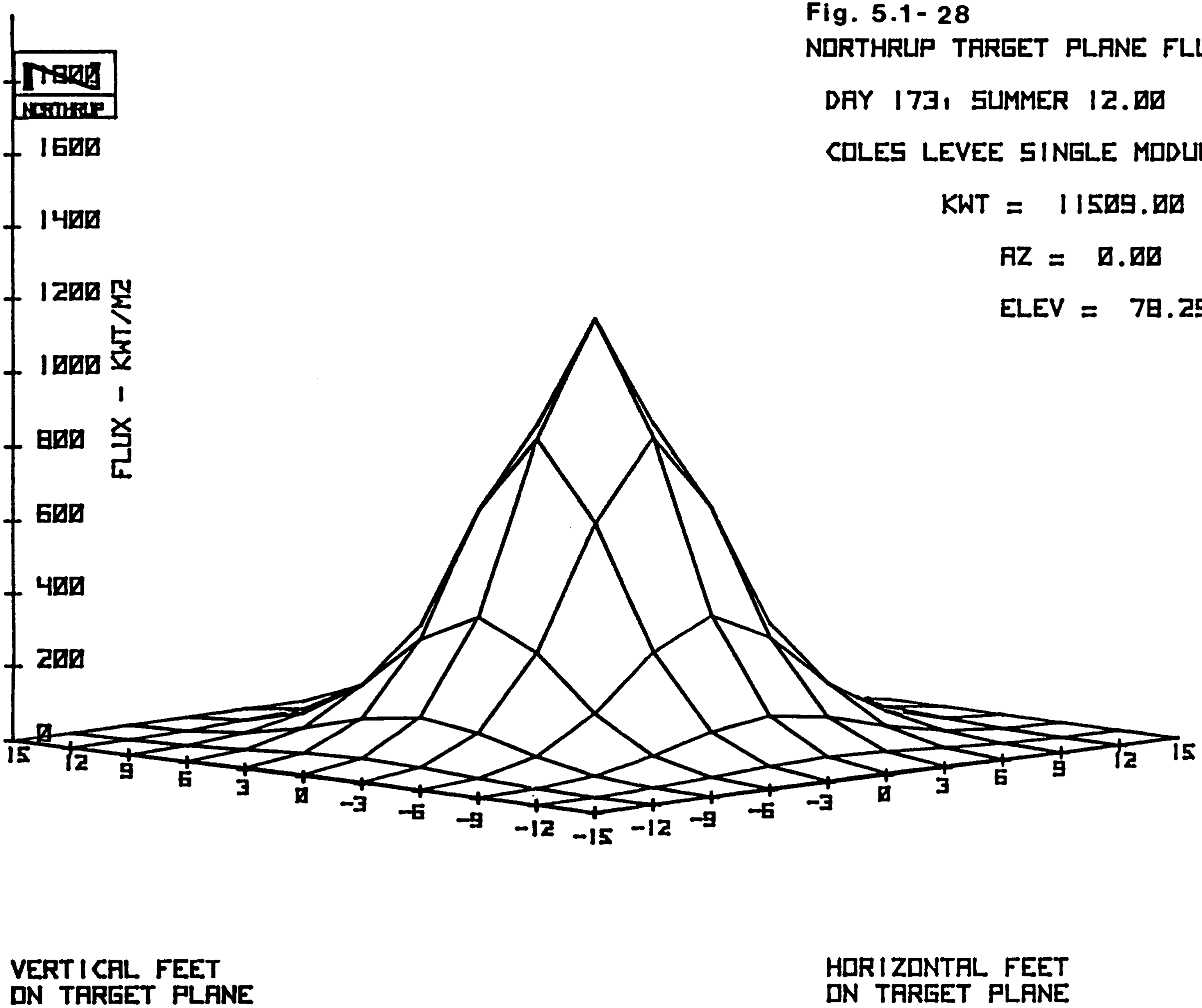


Fig. 5.1- 28
NORTHRUP TARGET PLANE FLUX

DAY 173: SUMMER 12.00

COLES LEVEE SINGLE MODULE

KWT = 11509.00

AZ = 0.00

ELEV = 78.25

EWB/JB 2-4A3

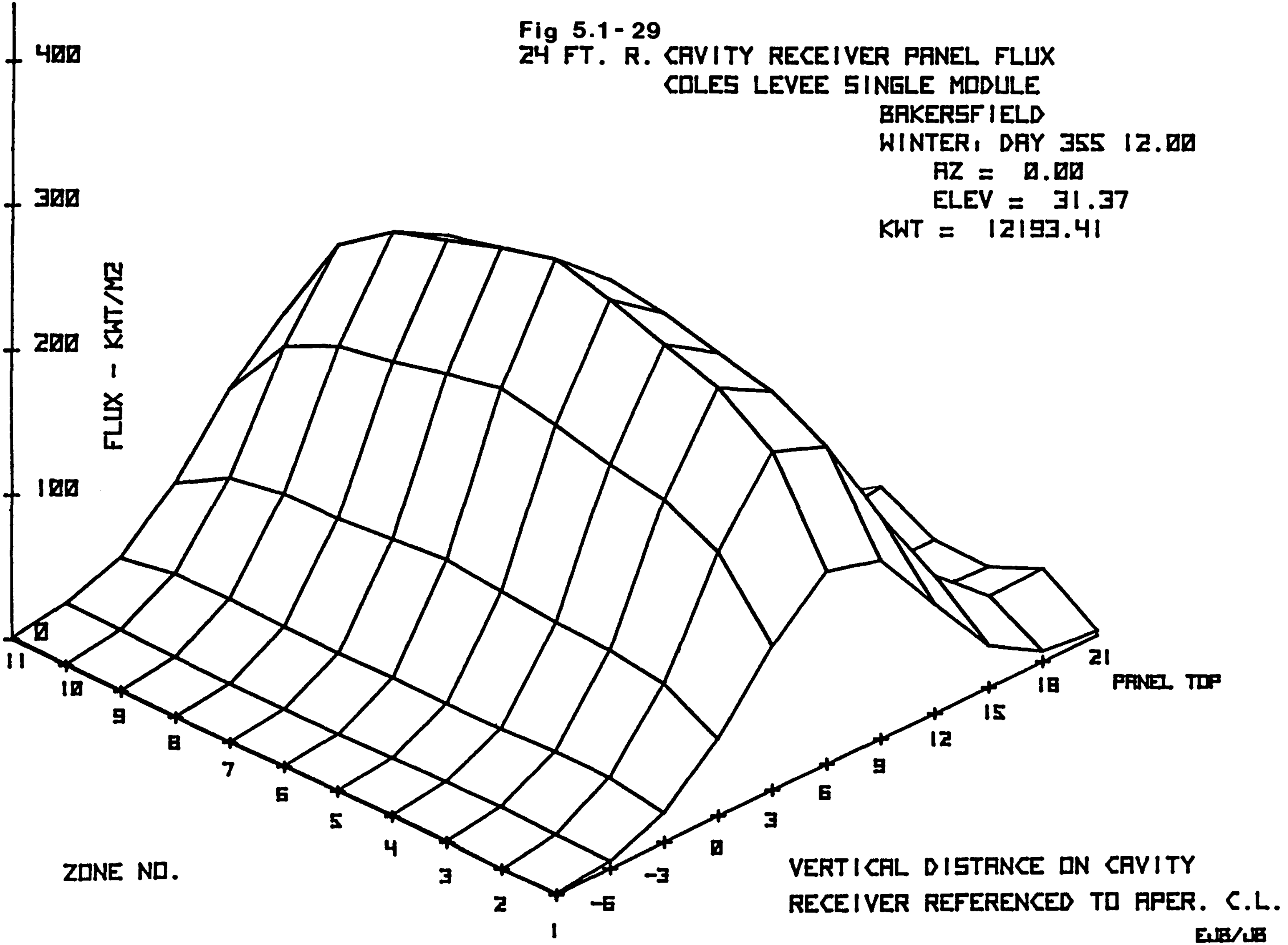
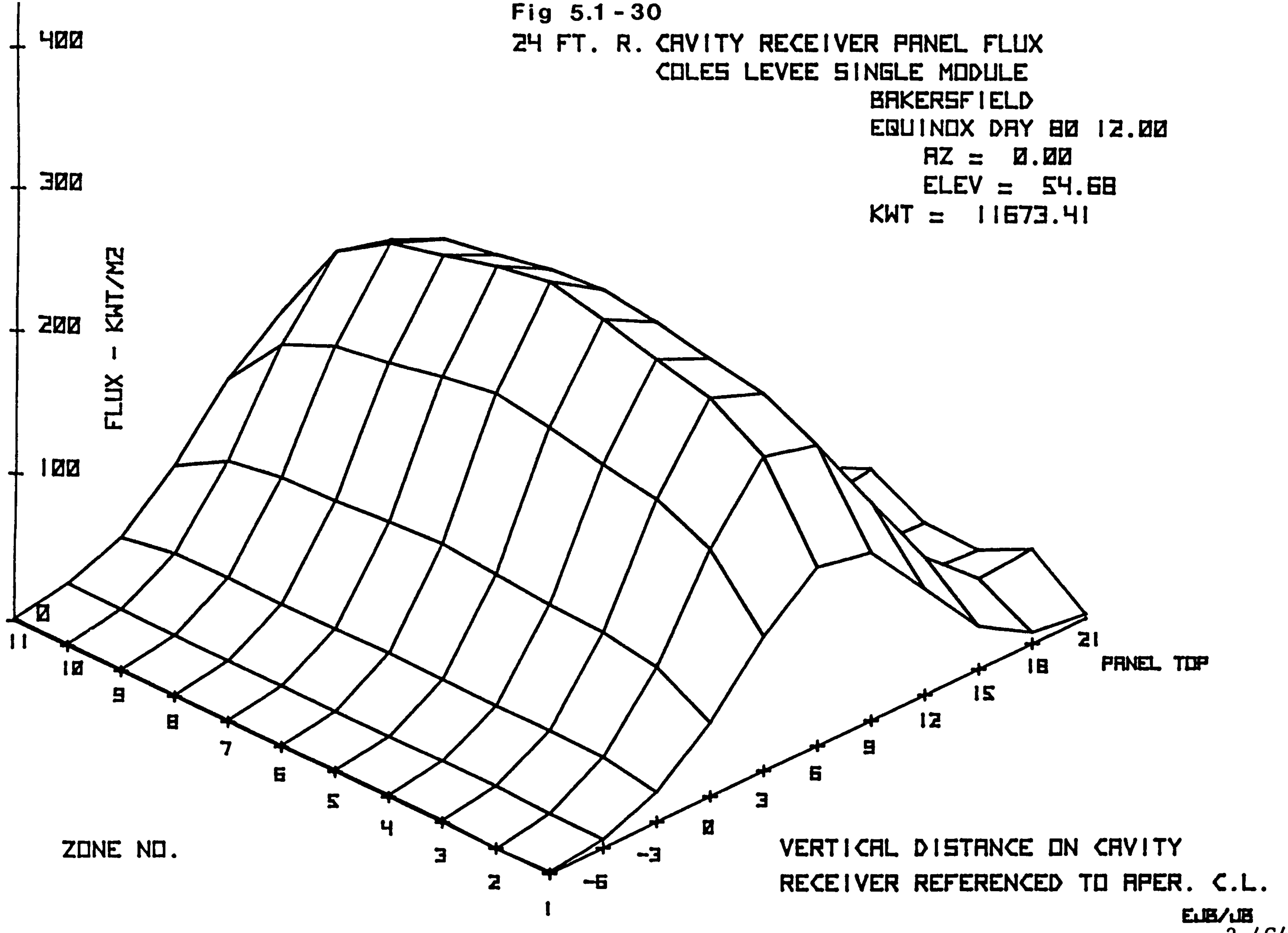


Fig 5.1-29
24 FT. R. CAVITY RECEIVER PANEL FLUX
COLES LEVEE SINGLE MODULE
BAKERSFIELD
WINTER: DAY 355 12.00
AZ = 0.00
ELEV = 31.37
KWT = 12193.41
FLUX - KWT/M2
400
300
200
100
0
ZONE NO.
11
10
9
8
7
6
5
4
3
2
1
-6
-3
0
3
6
9
12
15
18
21
PANEL TOP
VERTICAL DISTANCE ON CAVITY
RECEIVER REFERENCED TO APER. C.L.
EJB/JB

Fig 5.1 - 30


24 FT. R. CAVITY RECEIVER PANEL FLUX
COLES LEVEE SINGLE MODULE
BAKERSFIELD
EQUINOX DAY 80 12.00
AZ = 0.00
ELEV = 54.68
KWT = 11673.41
FLUX - KWT/M2
400
300
200
100
0
ZONE NO.
11
10
9
8
7
6
5
4
3
2
1
-6
-3
0
3
6
9
12
15
18
21
PANEL TOP
VERTICAL DISTANCE ON CAVITY
RECEIVER REFERENCED TO APER. C.L.
EJB/JB
2-4G4

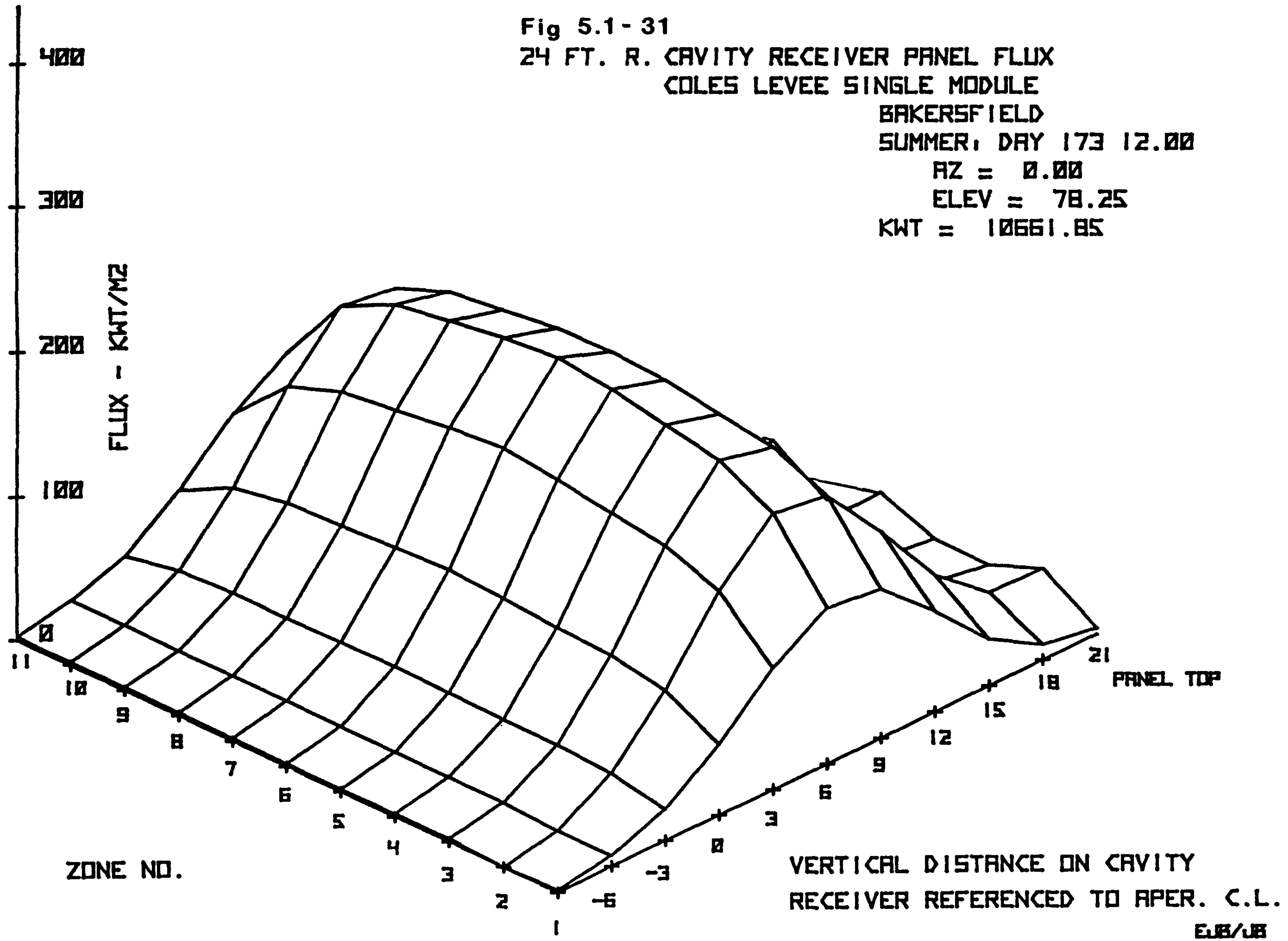


Fig 5.1 - 31
24 FT. R. CAVITY RECEIVER PANEL FLUX
COLES LEVEE SINGLE MODULE
BAKERSFIELD
SUMMER, DAY 173 12.00
AZ = 0.00
ELEV = 78.25
KWT = 10661.85
FLUX - KWT/M2
400
300
200
100
0
ZONE NO.
11
10
9
8
7
6
5
4
3
2
1
-6
-3
0
3
6
9
12
15
18
21
PANEL TOP
VERTICAL DISTANCE ON CAVITY
RECEIVER REFERENCED TO APER. C.L.
EJB/JB

5.1.6 Collector Cost/Performance Trade Offs

Initial collector trade off studies were performed at the subsystem level and provided data for the system level trade which selected the collector design configuration. Small performance advantages of the quad tower and double tower configurations favored them over the single tower at the subsystem level, but this was reversed when the system impacts on cost were considered.

Trade off analysis within the towerless design concept evaluated the relative characteristics of straight row layout vs staggered radial layout for the two row, 19 heliostat modules.

Within the central tower-receiver concept varied module sizes were evaluated ranging from a single module with full capacity, to two modules with 1/2 capacity, to four modules with 1/4 capacity.

The physical arrangement of the two flat field towerless modules is shown in Fig. 5.1-32. Comparative data on major physical features and on key performance parameters are shown on Table 5.1-3. Performance for each of layouts was so close that it dropped out as a decision influence. The land usage was substantially lower for the radial stagger layout raising the effective packing density substantially and enabling greater flexibility of siting on a site where co-existing with existing equipment is necessary. The radial stagger was selected as the winning flat field configuration to be evaluated against the tower concept.

Performance variations between the three tower module configurations were very narrow, as shown in Table 5.1-4, with only 1/2 percent between the highest and lowest. The performance level howeyer, was approximately 7 percent above that for the flat field collectors and in the system level trade off this became the tie breaker justifying the single module selection. The geometric efficiency envelopes for the Quad, Double and Single module layouts are included as Figures 5.1-33, 5.1-34, and 5.1-35.

TABLE 5.1-3

TOWERLESS MODULE EVALUATION

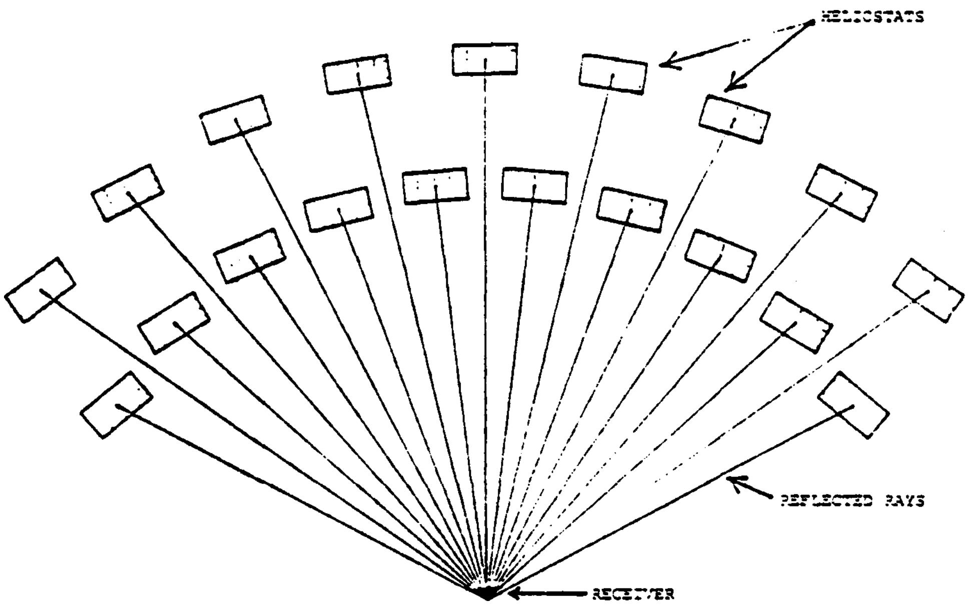
Straight Rows vs. Radial Stagger Rows

PARAMETER	STRAIGHT ROW - TRIANGULAR	RADIAL STAGGER ROW - SECTOR
I. PHYSICAL COMPARISON		
1.1 No. of Heliostats per Module	19	19
1.2 Mirror Area	53.51 m^2 (576 ft^2)	53.51m^2 (576 ft^2)
1.3 Module Size		
1.3.1 Width, E-W	143m (469 ft)	108m (353 ft)
1.3.2 Depth, N-S	68m (225 ft)	66m (216 ft)
1.3.3 Area	9803m^2 (105,512 ft^2)	7094m^2 (76,356 ft^2)
1.4 Packing Density	.0873	.1207
II. PERFORMANCE COMPARISON		
2.1 Peak Geometric Efficiency	.9084	.9239
2.2 Annual Geometric Efficiency	.7672	.7639
2.3 Annual Energy (19 Heliostats)	3.468×10^7	3.457×10^7
2.4 Peak Energy	734 MW	740 MW
2.5 Peak Flux	230 KW/m^2	240 Kw/m^2

RADIAL STAGGER FLAT FIELD LAYOUT

216 FT OUTER. ROW, 166.5 FT INNER ROW

RADIAL LAYOUT NO. 3 FOR 19 - 53.51 M² HELICSTATS



TRIANGULAR FLAT FIELD LAYOUT

224.8 FT OUTER ROW, 175.3 FT INNER ROW

LAYOUT NO. 8 FOR 19 - 53.51 M² HELIOSTATS

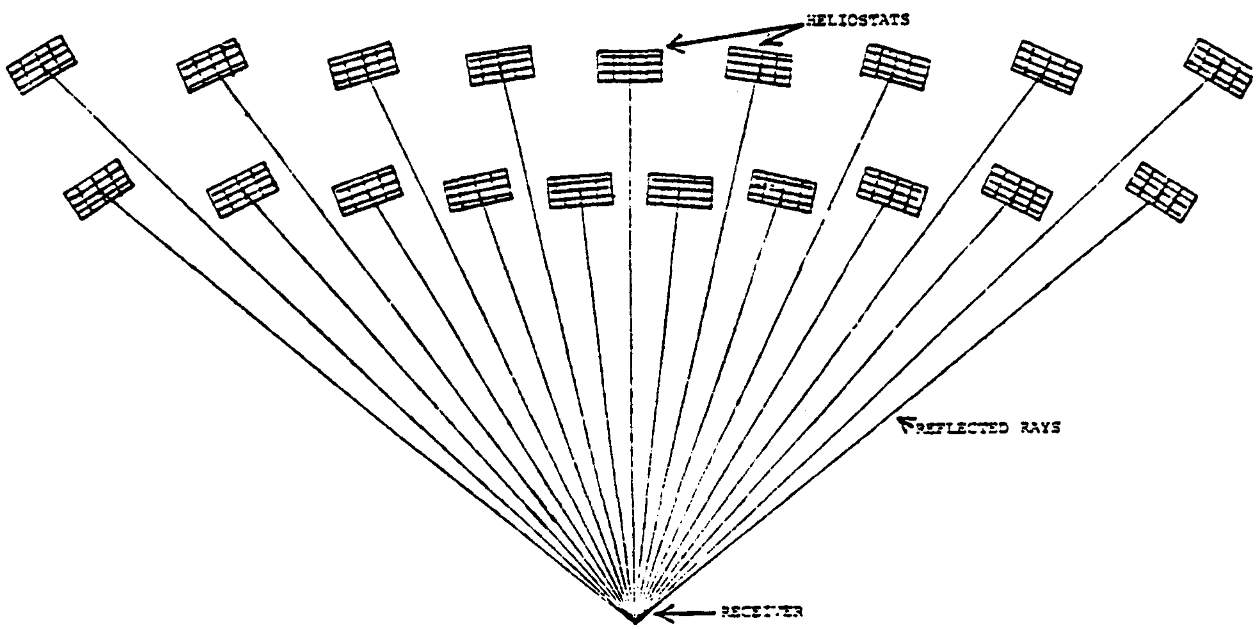


Fig 5.1-32

PLAN VIEW OF THE RADIAL STAGGER AND TRIANGULAR MODULE CONFIGURATIONS

Table 5.1-4 - Performance Trade Off

For Single, Double, and Quad Central

Tower-Receiver Modules - 437 Heliostats

Parameter	Quad Modules	Double Modules	Single Module
Tower Height - Meters - (Feet)	41 (135)	53 (174	61 (200)
Potential Heliostat Positions Per Module	124	246	483
Annual Average Geometric Eff.	.8331	.8314	.8298
Normalized Annual Energy for 437 Heliostats-Mn_t-Hrs	3.762×10^7	3.754×10^7	3.742×10^7
Ranking at Collector Subsystem Level	1	2	3
Performance Factor Referenced to Best Performer	1.0	.9979	.9947

Fig 5.1 - 33
GEOMETRIC PERFORMANCE EFFICIENCY
COLES LEVEE QUAD MOD: 41M [135FT] TWR

AZIMUTH ANGLE, DEGREES

SOLAR ELEVATION, DEGREES	0	30	60	75	90	110
89.5	0.8152	0.8148	0.8141	0.8136	0.8131	0.8123
65	0.9020	0.8890	0.8526	0.8281	0.8011	0.7645
45	0.9455	0.9244	0.8636	0.8219	0.7754	0.7104
25	0.9454	0.9187	0.8560	0.8006	0.7376	0.6468
15	0.8695	0.8572	0.8037	0.7480	0.6879	0.5973
5	0.7299	0.7315	0.6798	0.6417	0.6177	0.5019

AVE. ANNUAL EFF. = 0.8331 ENERGY = 3.7622 X10^7 KWT-HRS

[437 HELIOSTATS]

Fig 5.1-34

GEOMETRIC PERFORMANCE EFFICIENCY
COLES LEVEE DOUBLE MOD, 53M [174FT] TWR

AZIMUTH ANGLE, DEGREES

SOLAR ELEVATION, DEGREES	0	30	60	75	90	110
89.5	0.8120	0.8116	0.8109	0.8104	0.8099	0.8092
65	0.8991	0.8861	0.8496	0.8251	0.7981	0.7615
45	0.9426	0.9215	0.8611	0.8194	0.7727	0.7077
25	0.9482	0.9208	0.8531	0.7978	0.7346	0.6442
15	0.8904	0.8690	0.8015	0.7452	0.6871	0.5931
5	0.7467	0.7384	0.6815	0.6494	0.6211	0.5034

AVE. ANNUAL EFF. = 0.8314

ENERGY = 3.7544×10^7 KWT-HRS
[437 HELIOSTATS]

Fig 5.1-35

GEOMETRIC PERFORMANCE EFFICIENCY
COLES LEVEE SINGLE MOD, 61M [200FT] TWR

NORTHRUP

AZIMUTH ANGLE, DEGREES

SOLAR ELEVATION, DEGREES	0	30	60	75	90	110
89.5	0.8005	0.8001	0.7993	0.7988	0.7983	0.7975
65	0.8904	0.8770	0.8399	0.8148	0.7872	0.7498
45	0.9363	0.9147	0.8537	0.8111	0.7635	0.6970
25	0.9510	0.9231	0.8494	0.7932	0.7286	0.6363
15	0.9194	0.8904	0.8082	0.7493	0.6848	0.5877
5	0.7704	0.7383	0.6934	0.6545	0.6187	0.5085

AVE. ANNUAL EFF. = 0.8298 ENERGY = 3.7422×10^{7} KWT-HRS
[437 HELIOSTATS]

5.1.7 Collector Cost Estimate

The collector cost estimate was performed for three different levels of annual production. The following summarizes the heliostat cost and the resulting collector subsystem cost for these annual production rates:

a. Limited Production Rate (320 Heliostats) - Most of the fabrication work would be sub-contracted. A small assembly line would be set up to assemble mirror modules. All of the tooling costs for the drive unit and mirror modules would be amortized over the 320 units. The resulting installed unit cost would be \$20,235 per heliostat, or \$383/m^2 (\$35.63/ft^2). The total collector subsystem cost would be:

Heliostat Cost	=	\$5,212,480	
Site Related Cost	=	1,020,830	
Construction Cost	=	\$6,233,310	(Cost Code 5300)
Design Cost	=	241,926	
Total Cost	=	\$6,475,236	

b. Moderate Production Rate (2000 heliostats/year) - With this production rate, it was assumed that the drive unit (Winsmith) and trusses (Butler) would be sub-contracts, but all other items would be fabricated in-house. The first 19 heliostats installed would be built on a limited production rate basis (see above), and the remaining 301 would be fabricated in a 2000 heliostat/year production facility. The resulting installed unit cost would be \$15,883 per heliostat (average), or \$301/m^2 (\$27.96/ft^2). The total collector subsystem cost would be:

Heliostat Cost	=	\$3,819,772
Site Related Cost	=	1,020,830
Construction Cost	=	\$4,840,602
Design Cost	=	241,926
Total Cost	=	\$5,082,528

c. High Production Rate (25,000 heliostats/year) - With this production rate, it was assumed that virtually all of the piece parts would be fabricated in a highly automated factory specifically designed to manufacture heliostats. The resulting installed unit cost would be \$9340 per heliostat, or \$177/m^2 (\$16.44/ft^2).

The total collector subsystem cost would be:

Heliostat Cost	=	$1,723,953	
Site Related Cost	=	1,020,830	
Collector Subsystem	=	$2,746,783	(Cost Code 5300)
Design Cost	=	241,926	
Total Cost	=	$2,988,709	

It should be noted that the heliostat unit price is based on the total collector subsystem cost which includes design costs, field wiring, central computation equipment, and non-mechanized field assembly. For a small heliostat field such as the 320 heliostat North Coles Levee project, the cost/m^2 is relatively high compared to the price goal of $230/$m^2$ near term and $100/$m^2$ long term. For a large installation with 5,000 - 10,000 heliostats, the cost/m^2 for this same heliostat would be considerably lower.

The cost basis selected for this study is assumed to be the Moderate Production Rate case, wherein the first 19 heliostats are essentially hand-built, and the remaining 301 units are fabricated in a moderate-sized production facility capable of producing 8 heliostats/day or 2000/year. This appears to be the most likely situation for the timing and phasing of the North Coles Levee project.

5.2 RECEIVER SUBSYSTEM

In this section, the receiver key hardware elements, design, operating characteristics, performance, and costs are presented.

The receiver design for this application is a cavity-type unit with an active absorbing surface which is assembled from standard embossed heat transfer panels. Unlike water-steam receivers which operate at high pressure, the heat transfer oil receiver will operate under 0.93 mPa (135 psig). This lower operating pressure enables the low-cost embossed panel concept to be used. However, the heat transfer characteristics of oil are considerably lower than a water-steam boiler, so the peak flux must be limited to a lower value by de-focusing the incident beam. Hence, an oil receiver will have a larger surface area then a comparable MW-rated water-steam boiler.

The receiver will be fabricated in accordance with Section VIII, Division I of the ASME Unfired Pressure Vessel Code. The Section I ASME Power Boiler Code is limited to water-steam boilers, and as such is not applicable for a heat transfer oil receiver.

5.2.1 Major Receiver Components

The receiver design goal was to utilize low cost materials and commercially available components and piece parts to the maximum extent possible. This goal lead to the decision to use standard embossed metal panels manufactured by Tranter Inc. (Wichita Falls, Texas) for the receiver absorbing surface. Based on June 1980 price quotes from Tranter, the total panel cost for the 151 m^2 (1627 ft^2) absorbing area would be $64,630 or on a unit area basis $428/$m^2$ ($40/$ft^2$). The delivery time for the panels is only 10-12 weeks for the 56 panels required for the receiver.

The receiver absorbing panels are plumbed to the main supply and return lines by means of 6 main headers, each of which is fabricated from 8-inch, Schedule 40 pipe. Feeder pipes between the panels and main headers are all 1.52 m (5.0 ft) long, 1½-inch Schedule 40 pipe, the feeder pipe length being dictated by flexibility considerations to accommodate differential thermal expansion between the panels and main headers. All of the headers and feeder pipes are located in an insulated compartment behind the absorbing panels, so insulation of the individual pipe sections is not required.

The receiver contains no control valves, pumps or other active components. The only valves employed are a pressure relief valve, a gas inlet valve, and 2 drain valves (one each on the supply and return lines). A drain plug is also provided on the outlet pipe at the bottom of each panel. The 2 drain valves enable gravity draining of all headers, feeder pipes, and horizonal panels. The vertical panels have an up and down serpentine flow path which prevents gravity draining. To empty a given panel for servicing or replacement, a compressed air line is connected to the gas inlet valve, the drain plug is removed from the panel outlet, and the oil is blown out of the panel. Since such an occurrence is considered rare, there is no plan to install any permanent pneumatic system on the tower. The air purge would be accomplished with a portable compressor or bottled gas.

Although the multi-panel receiver approach offers many advantages in terms of shipping size, installation ease, low cost, easy replacement of damaged sections, and flow rate tailoring to match flux intensities, there is a major disadvantage with this concept. The flow rate of oil through each panel must be pre-calibrated based on the maximum heat flux and/or the maximum oil temperature which that panel might experience during the year. As will be shown later, this panel-by-panel flow calibration has been analytically determined with acceptable temperatures and thermal stress levels confirmed for the complete year. Physically, however, this means that the inlet line to each panel must contain a flow resistance device (such as an orifice), and a means for measuring the resultant flow rate to each panel during the calibration phase. Even though this calibration would theoretically be a one-time operation which would be performed with a cold system prior to any heat application, in actual practice, it will probably be an iterative process in which the initial calibration would be made based on predicted flux levels, and subsequently modified based on actual flux distributions (as determined by panel temperature measurements). Commercially available units such as Bell and Gossett Circuit Setters or Griswall Controllers are available which provide both adjustable flow resistance and flow measurement, but none could be found with welded fittings and a high temperature rating. Hence, the approach selected is to use orifice flanges and orifice plates in each of the panel inlet feeder lines. It follows logically, then to also use a flange (non-orifice) in the panel outlet line to permit easy panel installation and removal. These flanges and orifices are included in the material cost estimate, and a labor estimate of 360 man-hours is included to cover the initial calibration and two subsequent iterations. It is a design goal for the next (design) phase to eliminate the flanges and orifice plates, and replace them with a welded, variable resistance, flow indicating device.

Another major element of the receiver is the aperture door. This door serves the primary function of insulating the aperture during overnight shutdowns, but also provides several important secondary functions. It provides environmental protection during non-operating periods, provides a human safety function for personnel working in the cavity and could serve as a rapid flux terminator in the event of a power outage or pump failure which causes oil flow stoppage while the heliostats are on-target. Implicit in this last function is the requirement that the door close in the event of power failure or low flow indication. Since the peak flux occurs at the aperture plane, these doors must, therefore, be capable of withstanding high temperatures for 3-5 minutes. Hence, either a ceramic outer layer or a sacrificial (ablative) outer skin in required. The peak temperature at maximum flux for a white material would be approximately 1600 C (2900 F), and for a dark material approximately 2300 C (4200 F). A white ceramic would likely darken considerably from continuous environmental exposure, and a ceramic slab capable of surviving the high temperature and thermal shock would be very expensive. Therefore, the concept of using the main aperture doors as a "flux-stopper" was discarded. The new concept is to deploy a falling curtain in the event a rapid emergency shutdown is needed. The material selected is Nextel 312 ceramic fiber cloth manufactured by the Ceramic Fiber Productis Division of 3M. It is a close-woven, ceramic-fiber cloth 0.3 mm (.012 inch) thick, and is capable of withstanding 1426 C (2600 F) continuously, and 1649 C (3000 F) short term. Since it is normally stowed and only used for emergencies, it should retain its low absorptivity for the life of the receiver. Being thin, it will provide 2 surfaces for heat rejection. For an 1800 kw/m^2 (571,000 BTU/ft^2-hr) peak flux, it is estimated that the curtain temperature would not exceed 1315 C (2400 F). The material cost for a 9.14 x 9.14 m (30 x 30 ft) curtain would be $2800.

The remaining major items comprising the receiver are the main structure, the insulation, and the protective outer skin. The insulation selected is the "I-T" style manufactured by Forty-Eight Insulations Inc. (Aurora, Illinois). It is a light weight insulation having a density of 96 kg/m^3 (6.0 lb/ft^3) and is available in 0.61 x 1.22 x 0.08 m (24 x 48 x 3 inch) slabs. The insulation is water repellent, incombustible, and rated to 454 C (850 F). Application is economical and fast. Dagger-studs or pins are welded to the structure with a stud gun, and the insulation impaled on these studs or pins and fastened with speed clips.

The structural design is based on 0.305 m (12 inch - S12 x 31.8) I-beams as the primary structure, and 1.27 mm (.050 inch) sheet metal stringers as the secondary supports for attaching insulation and the outer protective skin. This same approach is used for all surfaces; top, bottom, back, and sides. A steel decking plate is installed over the floor insulation to provide a durable working surface. The receiver external skin is a standard 22 gage corrugated steel with a baked-on white finish.

5.2.2 Receiver Functional Requirements

The primary receiver functional requirement is to provide an absorbing surface capable of being irradiated with a solar power level up to 13 megawatts, and to convert this power to a safe and efficient useful heating of a heat transfer oil which flows through the absorbing surface. Implicit in the words "safe and efficient" are a series of secondary functional requirements:

A. The receiver panel temperatures must be monitored in perhaps as many as 40-50 (possibly 150-200 places during the initial start-up and check-out) places to assure satisfactory flow rates relative to the flux level. Hence, the receiver instrumentation sub-system has the functional requirement of providing temperature information to the control room.

B. In the event of a power failure or pump stoppage with the heliostats on-target, the flux to the receiver panels must be quickly terminated. Therefore, the receiver contains a flux-curtain at the aperture plane which can be deployed to protect the panels.

C. Since the heat transfer oil receiver is flux-limited and, hence, has a relatively large area, efficient operation requires a heat-trap design; i.e., a well insulated cavity receiver is required.

D. The receiver design must limit heat losses during off-periods as well as during operating periods since the stored energy lost during shutdown must be replaced on re-start. This functional requirement dictates an insulated cavity door to minimize aperture losses after shutdown.

E. Since the working fluid is a combustible oil, a leak in the receiver (where local hot spots on insulation or inactive metal surfaces exist) could result in a fire. This possibility lead to the requirement that non-combustible insulation be employed, and that a Halon fire extinguishing system be installed as a receiver sub-system.

F. The thermal stress levels and resulting fatigue life are governed by the panel design, the flux level, and the panel flow rate. A functional requirement of major importance is that the thermal stress levels be maintained under 172.4 mPa (25,000 psi). Meeting this requirement assures essentially infinite cycle life for panel metal temperatures up to 371 C (700 F).

The receiver contains no control valves, pumps, or other active devices. On start-up, the ground based piping and control system "close-loop" flows the receiver for a short time to bring the receiver and piping up to 216 C (420 F) at which time the solar loop is switched into the plant. Thereafter, the receiver is provided with the full plant flow of 0.067 m^3/s (1064 gpm) and gathers whatever energy is available. Short cloud passages do not affect the operation; i.e., the heliostats remain on-track and the receiver flow continues without interuption or reduction in rate. The control simplicity of the loop system greatly reduces the receiver functional requirements.

5.2.3 Receiver Design

The receiver for the proposed North Coles Levee facility is a cavity type of unit with an insulated door which closes the aperture during extended shutdown periods. Table 5.2.3-1 presents a tabulation of the key physical features of the receiver. Since the annual average clear day power output of the receiver is 10.3 MW_{th} (10300 KW) and the cost is $ 613,000 some interesting unitized parameters are:

Table 5.2.3-1

Receiver Physical Characteristics

Aperture Size, m (ft)	8.23 x 8.23 (27 x 27)
Aperture Area, m^2 (ft^2)	67.73 (729)
Cavity Depth, m (ft)	7.32 (24)
Absorber Width, m (ft)	18.85 (61.84)
Absorber Height, m (ft)	9.14 (30.00)
Absorber Area, m^2 (ft^2)	151.2 (1627.2)
Absorber Type	Embossed and Welded Panels
Absorber Material	AISI 1008 Carbon Steel
Absorber Sheet Thickness (each), mm (in)	3.4 (.1345)
Absorber Weight, kg/m^2 (lb/ft^2)	54.94 (11.25)
Insulation Type	Semi-rigid; fiberglass, mineral wool, binder
Insulation Thickness, m (ft)	0.15 (0.50)
Receiver Weight Breakdown:	
Absorber Panels, kg (lb)	9276 (20444)
Insulation, kg (lb)	10835 (23880)
Piping, kg (lb)	8576 (18902)
Hangers and Misc., kg (lb)	3316 (7309)
Structure, kg (lb)	23807 (52470)
Aperture Door, kg (lb)	6806 (15000)
Flooring, kg (lb)	2348 (5175)
Miscellaneous	1361 (3000)
Total Dry Weight, kg (lb)	66,325 (146,180)
Heat Transfer Oil, kg (lb)	4576 (10,086)
Total Wet Weight, kg (lb)	70,901 (156,266)

Absorber Thermal Output = 68.14 kw/m^2 (21605 Btu/hr-ft^2)
Receiver Cost/Weight = \$8.65/kg (\$3.92/lb)
Receiver Cost/kw = \$59.51/kw

The heart of the receiver is the absorber panels. In keeping with the design goal of using commercially available components to the maximum extent possible, a standard design heat transfer panel manufactured by Tranter, Inc. (Wichita Falls, Texas) was selected for the receiver. These panels, called Platecoils, are available in a wide range of sizes, materials, gage thicknesses, passage flow areas, series and/or parallel flow patterns, and various shapes (rectangular, circular, flat, curved, etc). Figure 5.2.3-1 through 5.2.3-4 provide some general interest information on a few of the Platecoil options which are available. Specifically, Figure 5.2.3-1 illustrates the serpentine flow pattern, the left or right hand inlet/outlet options, the capability to bend panels, and the length and width standards. Figure 5.2.3-2 illustrates the 3 flow pattern options; series, parallel, or combined series parallel. Figure 5.2.3-3 shows the six embossed flow passage sizes available. The double embossed patterns are usually fabricated with sheets of the same thickness, whereas the single embossed sheets are commonly fabricated with thicker backing plates. Figure 5.2.3-4 illustrates some of the accessories and inlet/outlet fitting options. These few illustrations show the design flexibility offered for the design of low pressure receivers using standard panel options. Non-standard options include very long panels of 10 m (33 ft) or greater, portholes, round pancake shapes, complete cylinders, and special flow passage embossments. Materials available include carbon steel; 302, 304, and 316 stainless; Monel; Inconel; Hastelloy "B", "C", and "G"; Carpenter 20-Cb-3; and titanium. The Platecoils may be purchased with an ASME Section VIII "U" stamp and code certification.

Figure 5.2.3-5 presents the selected Platecoil configurations for the North Coles Levee receiver. The Model 60 style, series flow

Figure 5.2.3-1

RECEIVER PANEL CONCEPT - PLATECOILS - (TRANTER MFG. CO.)

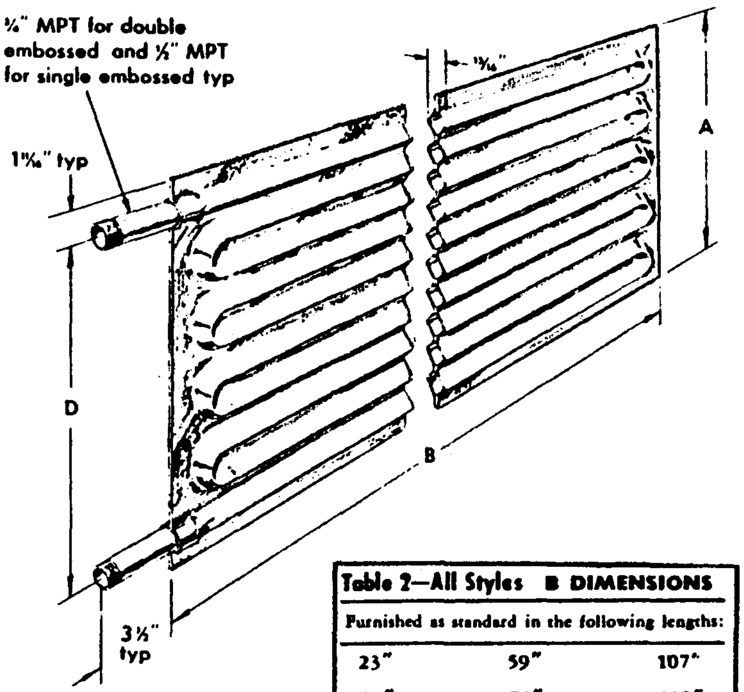
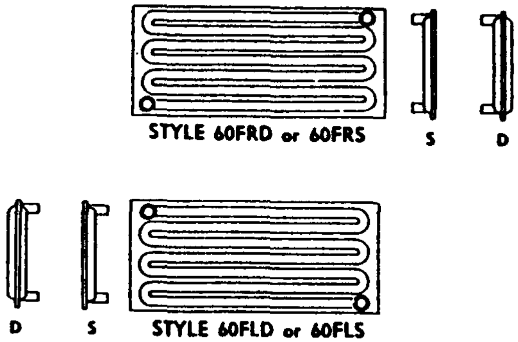


Table 2—All Styles B DIMENSIONS		
Furnished as standard in the following lengths:		
23"	59"	107"
29"	71"	119"
35"	83"	131"
47"	95"	143"



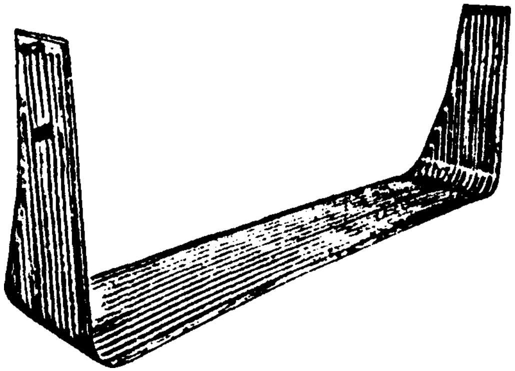
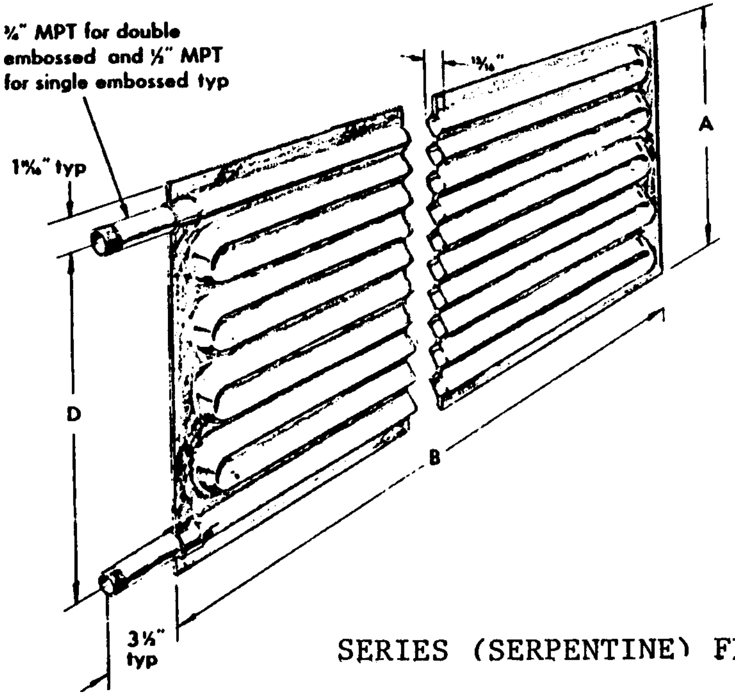


Fig. 15-3 — **Width vs Number of Passes**

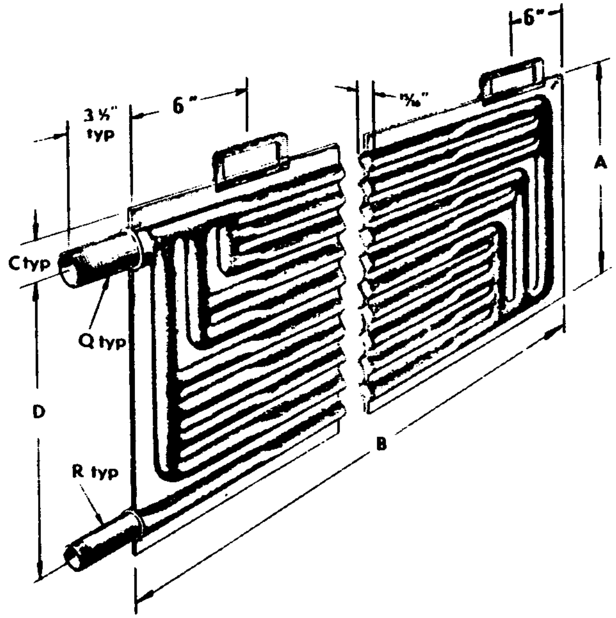
No. of Passes	1	2	3	4	5	6	7	8	9	10	11
Actual Width "	5 3/8	9 3/16	13	16 7/8	20 3/4	24 9/16	28 3/8	32 1/4	36 1/8	39 15/16	43 3/4

Figure 5.2.3-2

SERIES VS PARALLEL FLOW OPTION



SERIES (SERPENTINE) FLOW



PARALLEL FLOW

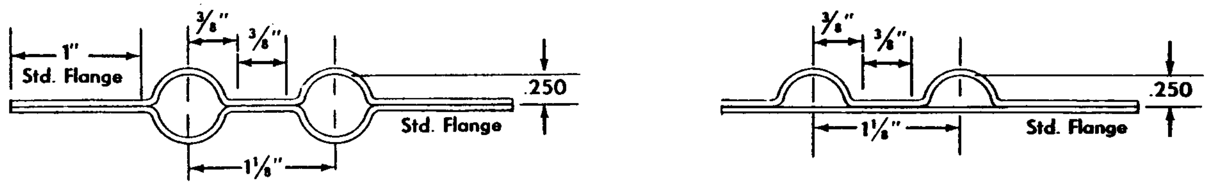
SERIES-PARALLEL FLOW

5.2-10

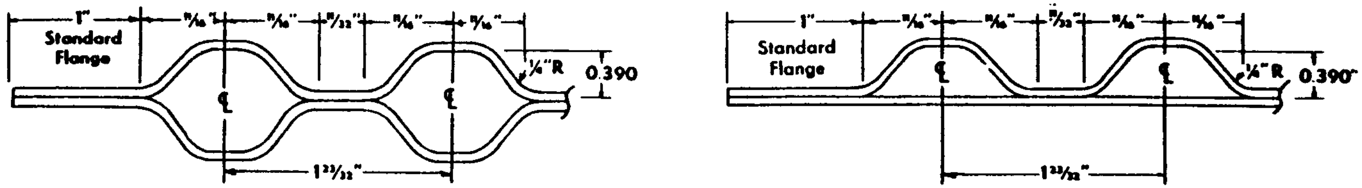
Figure 5.2.3-3

PLATECOIL PASS SIZE

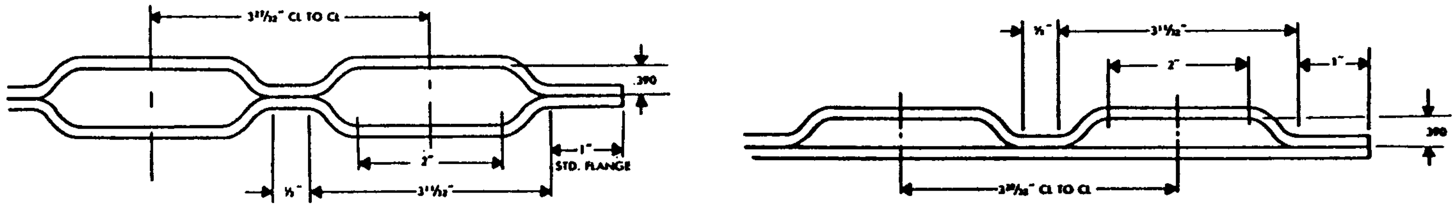
Internal Cross Sectional Area Equivalent to 3/8" Steel Pipe



Standard PLATECOIL Pass (3/4")



Internal Cross Sectional Area Equivalent to 1½" Steel Pipe



PLATECOIL ACCESSORIES & OPTIONAL FEATURES

Handles

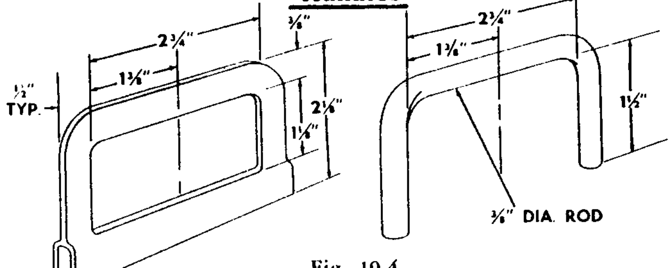


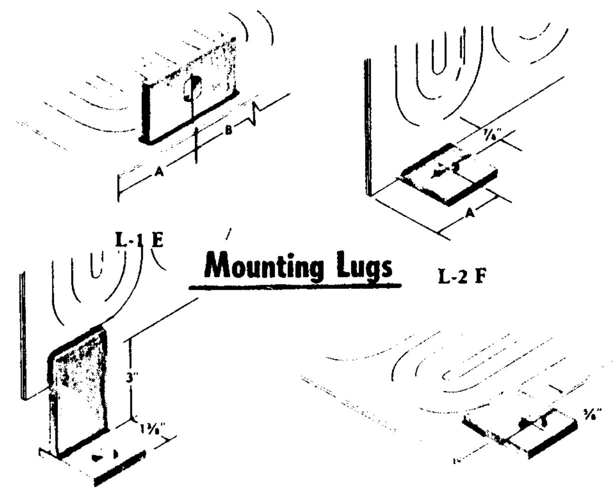
Fig. 19-4

Standard Type* Rod Type

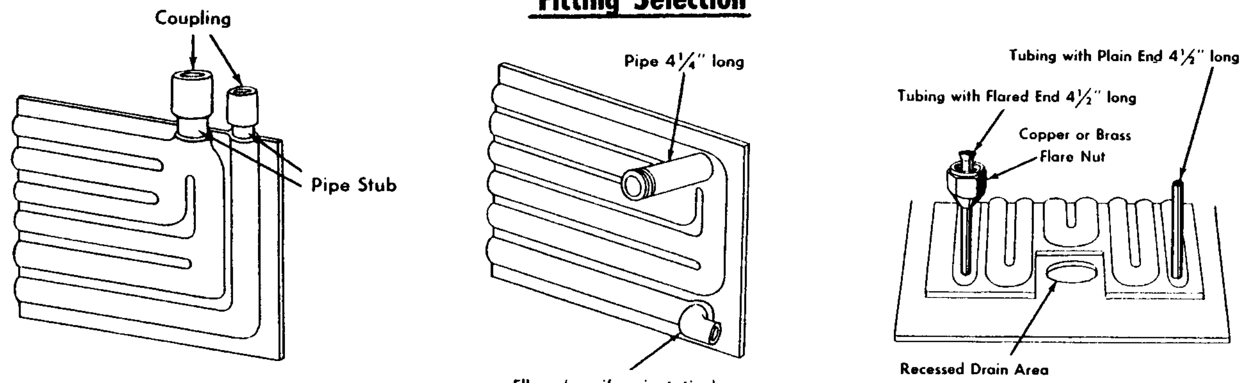
See pages 7 through 11 for locations on PLATECOIL.

* Normally furnished; however ROD TYPE may be specified at no extra cost. ROD TYPE are recommended where a protective coating is applied to the PLATECOIL surface or where food service finish is required.

Mounting Lugs



Fitting Selection

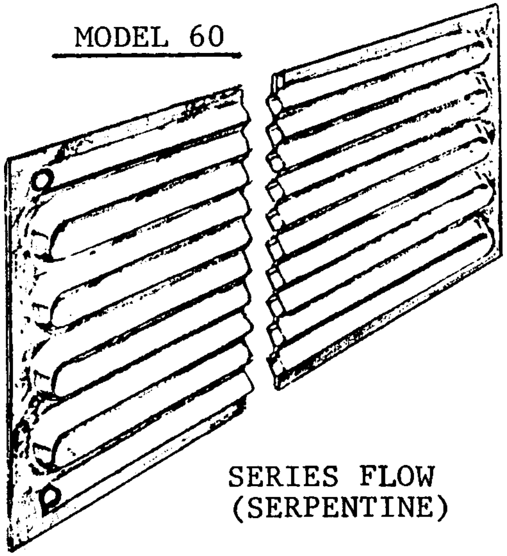


1. Fittings available (any combination).
   a. Pipes — NPT or NPT with 4" long locknut thread or weld end, 2" IPS maximum size of any available schedule pipe.
   b. Couplings — Full half or socket, 2" IPS 6000# class maximum size.
   c. Elbows — Internally threaded, street or weld end, 2" IPS maximum size.
   d. Tubes — Plain end or flared with nut attached, 1" maximum size.
   e. Flange Fittings (not shown) — any type, 2" IPS 2500# class maximum size.
   f. Extra Long Pipe Lengths (not shown) — as in a. and up to approx. 6 feet long with necessary bracing.

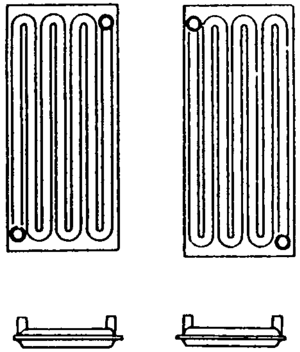
Figure 5.2.3-5

SELECTED PLATECOIL CONFIGURATION

MODEL 60



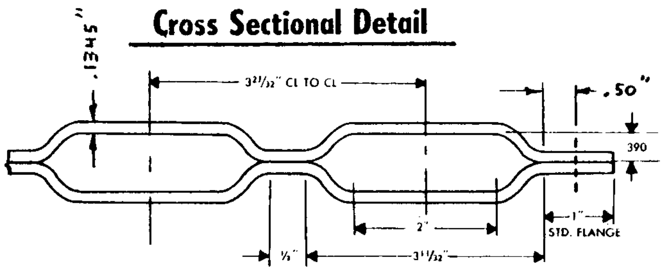
SERIES FLOW (SERPENTINE)



LEFT HAND   RIGHT HAND

DOUBLE EMBOSSED

Cross Sectional Detail



Internal Cross Sectional Area: Double embossed 2.1 sq. in.

Width vs Number of Passes

No. of Passes	1	2	3	4	5	6	7	8	9	10	11
Actual Width	$5\frac{3}{8}$	$9\frac{3}{16}$	13	$16\frac{7}{8}$	$20\frac{3}{4}$	$24\frac{9}{16}$	$28\frac{3}{8}$	$32\frac{1}{4}$	$36\frac{1}{8}$	$39\frac{15}{16}$	$43\frac{3}{4}$

Furnished as standard in the following lengths:

23"	59"	107"
29"	71"	119"
35"	83"	131"
47"	95"	143"

OPERATING PRESSURES CARBON AND 300 SERIES STAINLESS STEEL AND MONEL ASME AND STANDARD

GA.	DOUBLE EMBOSSED	SINGLE EMBOSSED COMPANION PLATE (GA.)										
		16	14	12	11	10	9	8	3/16	1/4	5/16	3/8
16	25	10	20	30	40	50	60	65	70	70	70	70
14	30		20	30	40	50	60	70	90	90	90	90
12	60			40	50	70	70	80	110	110	110	110
11	80				50	80	80	90	120	120	120	120
10	120					90	90	100	130	130	130	130

QTY	SIZE	PASS	FITTING
7	43"x143"	11	L.H.
7	43"x143"	11	R.H.
7	43"x119"	11	L.H.
7	43"x119"	11	R.H.
7	43"x107"	11	L.H.
7	43"x107"	11	R.H.
2	13"x107"	3	L.H.
8	13"x143"	3	R.H.
4	36" x 143"	9	R.H.

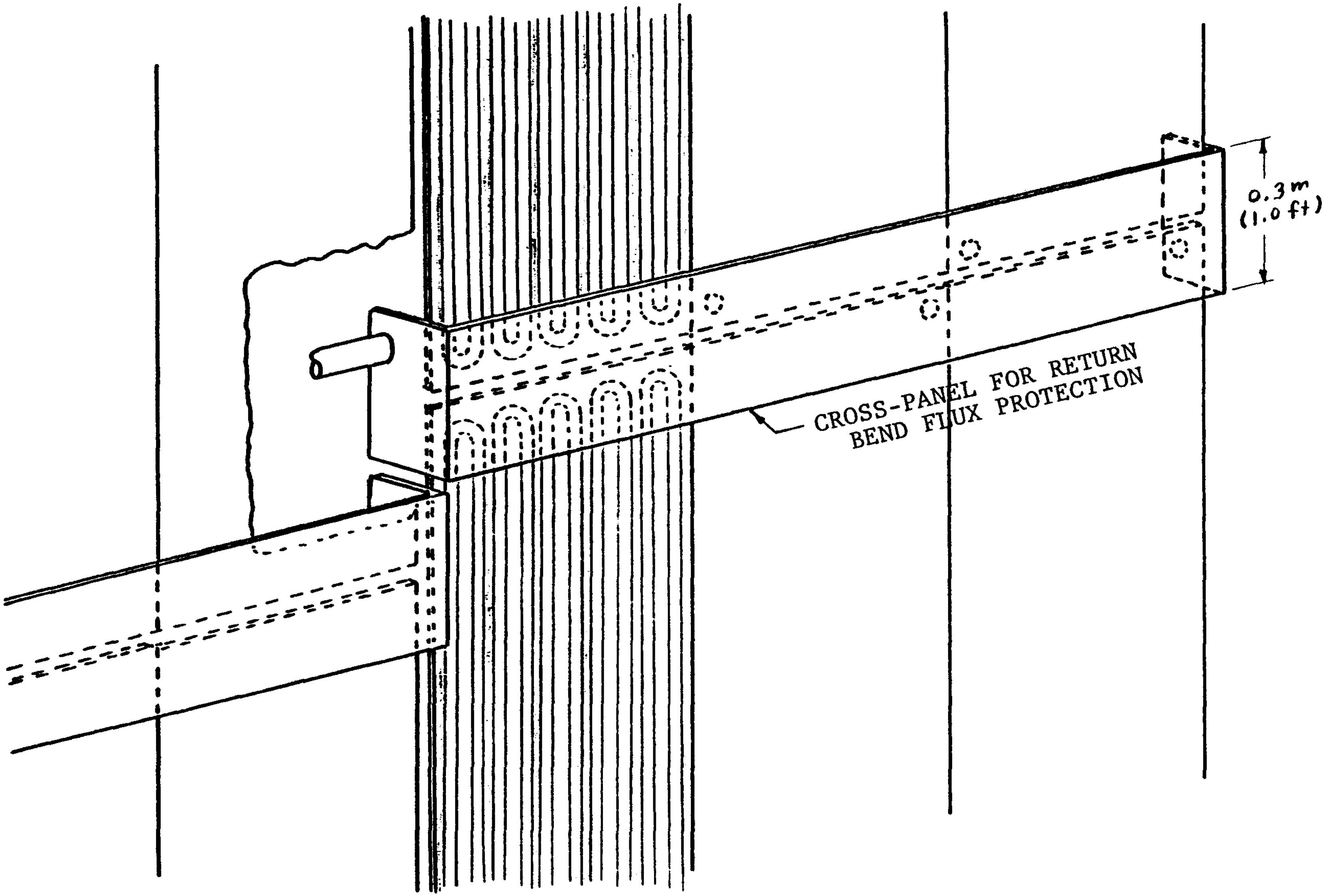
(serpentine) pattern was selected to achieve high flow velocities and high heat transfer coeffients. Since most of the main panels hang vertically, both right and left hand inlets were selected to enable the cool inlet oil to flow through the high flux region first, and as the fluid is progressively heated in each succeeding pass, to then flow through progressively lower flux regions. The largest flow area embossment of 13.55 cm^2 (2.1 in^2) was selected as the best heat transfer-pressure loss compromise. The single embossed version of this shape would provide a doubling of the flow velocity and a 75% higher heat transfer coefficient, but the pressure loss would be 7 times higher. This large passage configuration also features a relatively narrow between-passage fin. This is an important factor because the fin conduction distance dictates the maximum thermal stress and fatigue life to a great extent. Likewise, the material thickness is an equal contributor. The 3.4 mm (.1345 inch) thickness was selected to minimize thermal stress, and also to maximize the pressure rating. Carbon steel was selected for all of the panels to minimize cost.

The major problem in using the Platecoil panel concept for a high flux solar application lies in the return bend region at both ends of the panels. In these regions, there are relatively large areas of metal which are poorly coupled to the oil, and overheating of these uncooled areas would likely occur. This problem was solved by the use of overlapping cross-panels which "hide" the return bend zones of the vertical panels. Figure 5.2.3-6 illustrates the use of these cross-panels for return bend flux protection. The cross-panels are bent at both ends, so their return bend zones will lie behind the panel plane. Adjacent cross-panels are vertically displaced from each other to avoid interference with the inlet/outlet piping.

All of the panels are hung from end supports (hangers) which attach to primary overhead beams in the top of the receiver.

Figure 5.2.3-6

VERTICAL PANEL INTERFACE WITH CROSS-PANELS



A three-panel-high assembly of Platecoils would be loosely pinned together at the mating ends, and would hang as a unit from the overhead beam. This permits the Platecoil panels to freely expand or contract longitudinally. The pinned joints between vertically-adjacent panels are made through horizontally-slotted holes in the panel end flanges to permit differential thermal expansion or contraction in the width direction. Figure 5.2.3-7 shows the hanging technique for the heat transfer panels. Also shown is the similarly hung pipe rack which supports the main supply and return headers. The feeder pipes which connect the headers and panels are all 1½-inch schedule 40 pipe, and are each 1.52 m (5.0 ft) long. This length provides suffient flexibility to accomodate the differential thermal expansion between the piping, rack and panels. Hence, no bellows-type or slip joint type of piping connection is required. Figures 5.2.3-8 and 5.2.3-9 provide a side and plan view of the panel and pipe arrangement.

The conceptual structural design of the outer cavity walls is illustrated on Figure 5.2.3-10. The primary structural elements are 0.304 m (12 inch - 12 I 31.8) I-beams spaced 4.57 m (15.0 ft) apart. A steel studding system using 1.27 x 38.1 x 152.4 mm (.050 x 1.5 x 6.0 inch) studs is installed between I-beams to provide a secondary support structure for attaching the slab insulation and the outer skin. The insulation is manufactured by Forty-Eight Insulations Inc. (Aurora, Illinois), and is a Type "I-T" semi-rigid slab form made from resilient refractory fibers, laminated and felted. The slab size to be used is a standard .08 x 0.61 x 1.22 m (3 x 24 x 48 inch) installed in 2 layers with staggered joints to give a total thickness of 0.15 m (6 inches). The installation is very rapid with dagger-pins first being welded to the stud-members using a standard stud welding gun. The insulation slabs are impaled on these pins and secured with sheet metal speed clips. In areas where direct flux can impinge on the insulation, a layer of Babcock and Wilcox "Kaowool"

Figure 5.2.3-7
Panel and Pipe Rack Hanger Technique

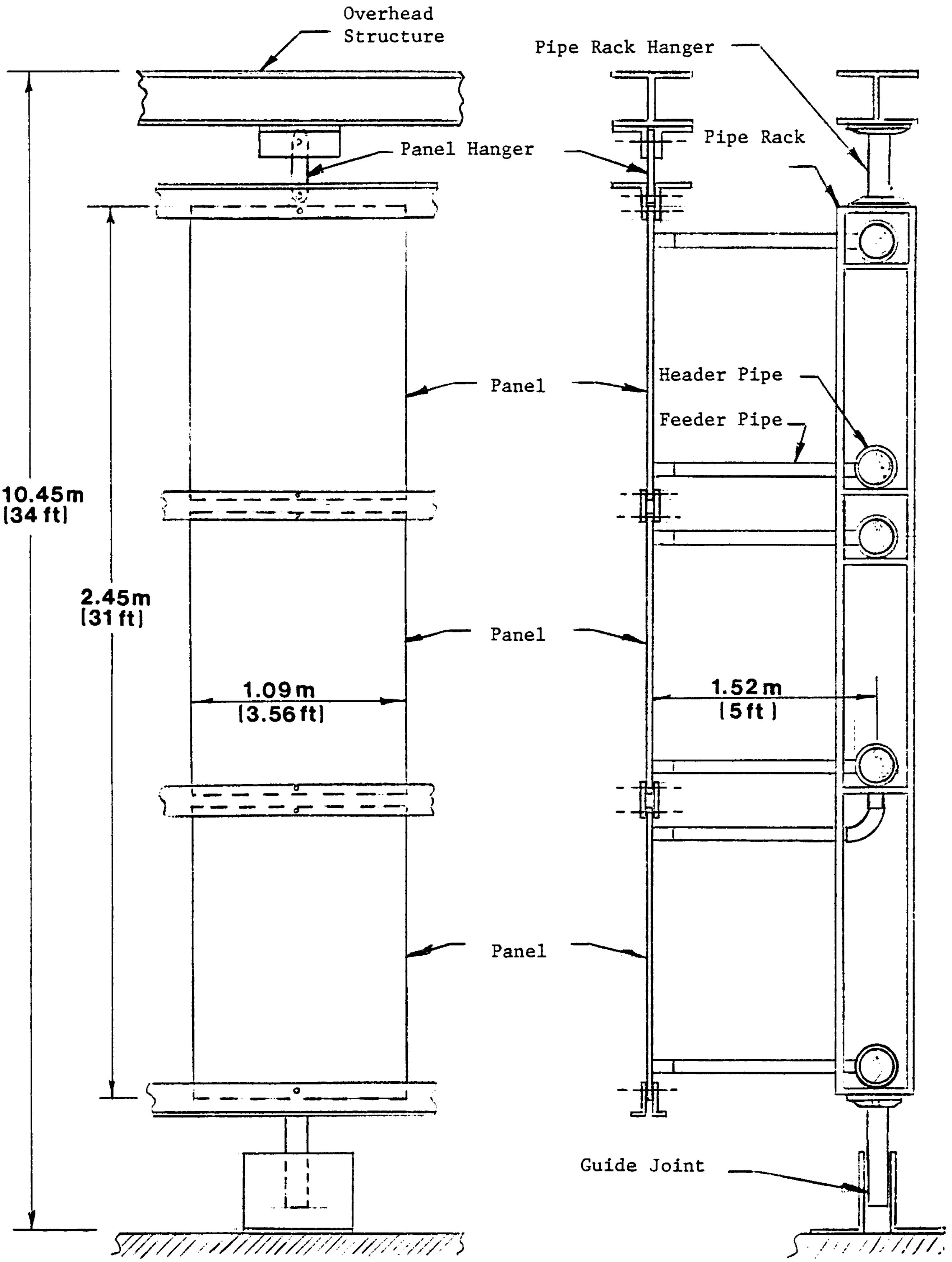


Figure 5.2.3-8
Side View - Panel and Pipe Hangers

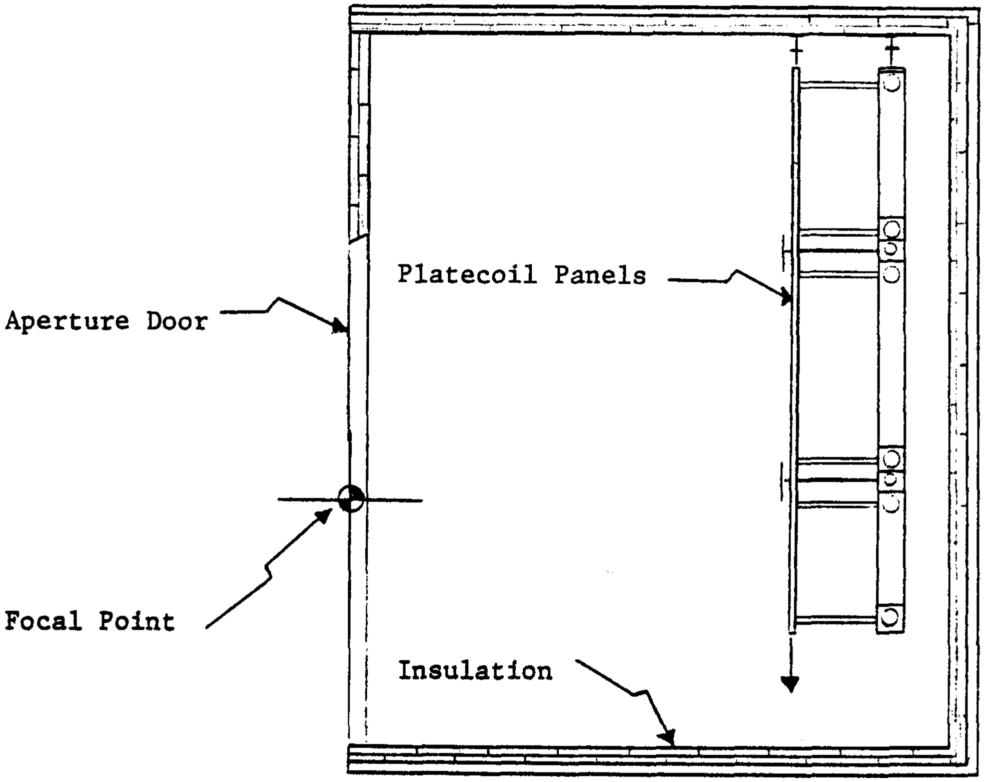


Figure 5.2.3-9
Plan View - Panel and Pipe Arrangement

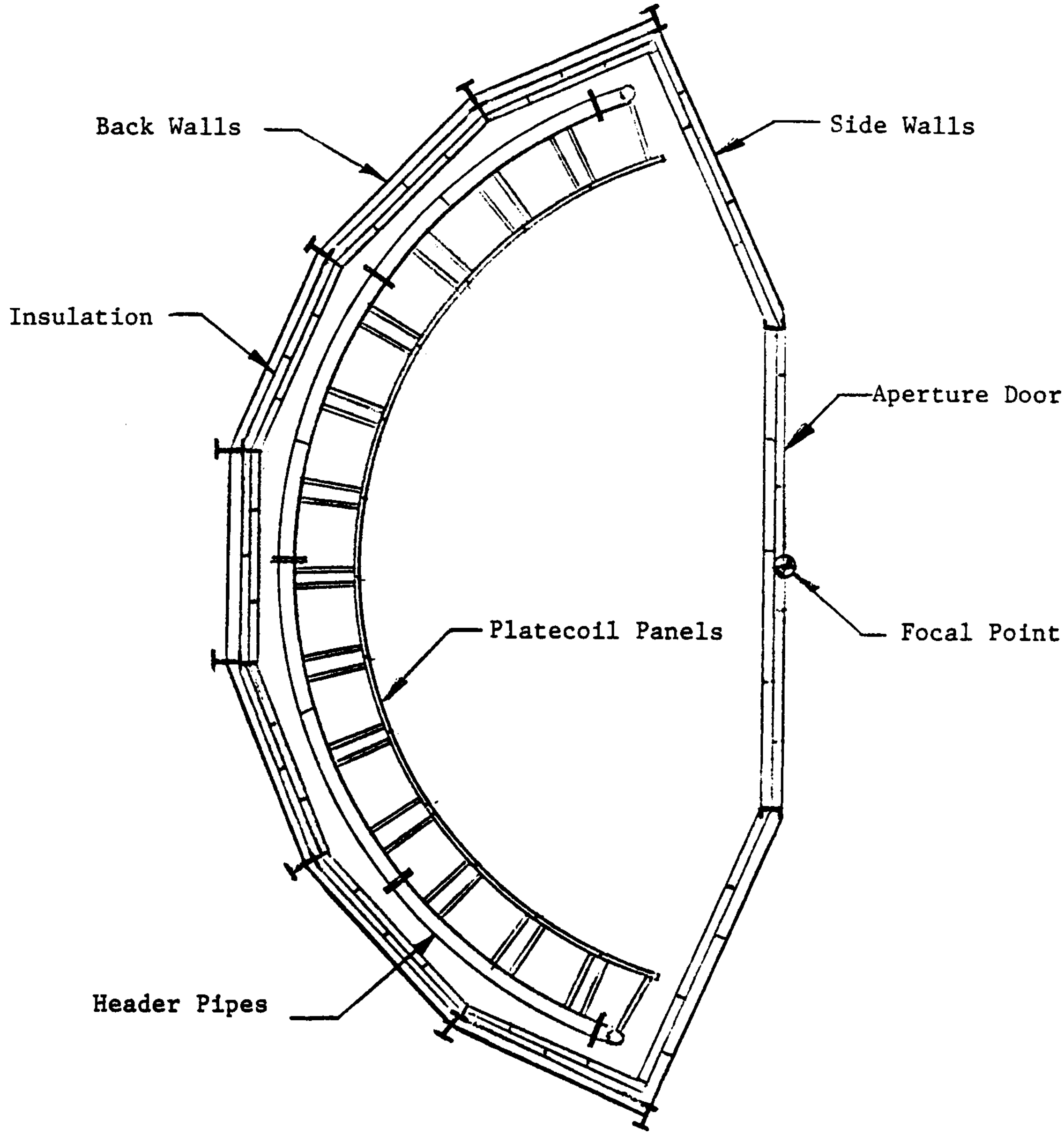
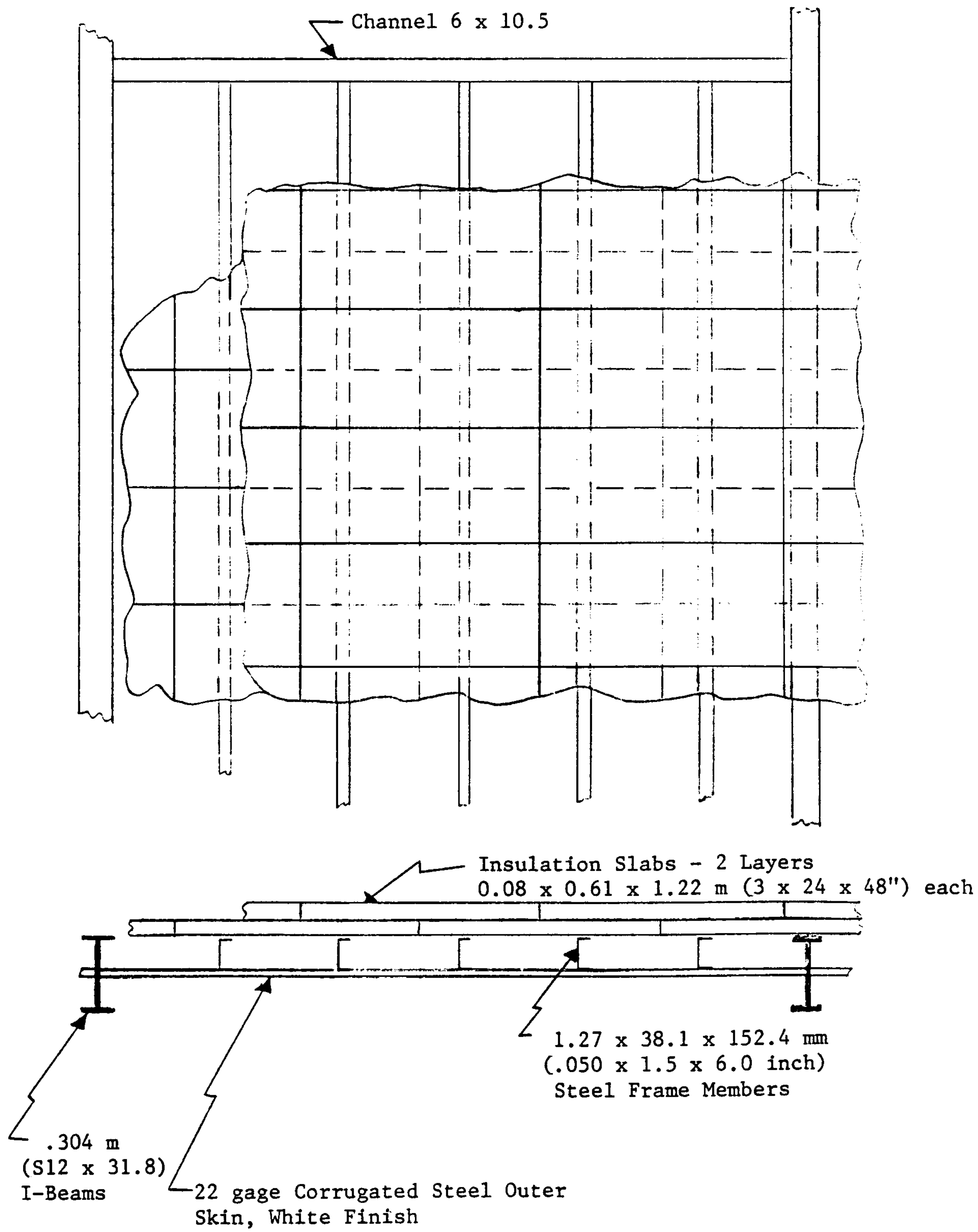


Figure 5.2.3-10
Structure, Insulation and Skin Design



ceramic blanket is also installed. Figure 5.2.3-11 and 5.2.3-12 illustrate the insulation installation technique using both mineral wool block and ceramic blanket materials. In regions where no direct flux impingement occurs, the installation technique will be the same, but no ceramic blanket will be used; i.e., the maximum expected temperature in these areas is only 288 C (550 F), and the "I-T" slab insulation is rated at 454 C (850 F). There is no inner cavity wall skin, and no attempt is made to employ re-reflecting (white) walls due to the rapid discoloration and dirtying of these surfaces from the combined effects of convection and airborne dust and dirt.

The current aperture door design is a single unit approximately 9.14 x 9.14 m (30 x 30 ft) which is raised vertically with a motor and winch system and latched. Due to the high weight of the door, 6800 kg (15,000 lb), a planned future change is to split the door horizontally, and to mechanize the opening operation such that the top half opens upward and the lower half downward. The top section would be somewhat heavier than the bottom section, and would close by gravity force with the bottom section serving as a counterweight for the top section. The door will be insulated with a 0.15 m (6 inch) thickness of "I-T" insulation to minimize the overnight cooldown. Both sides of the door will be sheathed with 22 gage, pre-painted sheet steel for environmental protection and durability.

Initially, it was planned to use the aperture door as a flux-terminator in the event of a power failure or other anomoly which caused the loss of oil flow while the heliostats were on-target. However, due to the high cost of ceramic-type, high temperature insulation, and the likely degradation of the reflectivity of this insulation due to the continuous environmental exposure, the concept was abandoned. The current emergency flux-terminator concept is to employ a curtain fabricated from Nextel 312 (3M Co) which would be stowed in a rolled-up position above the aperture opening and inside of the aperture door plane. The

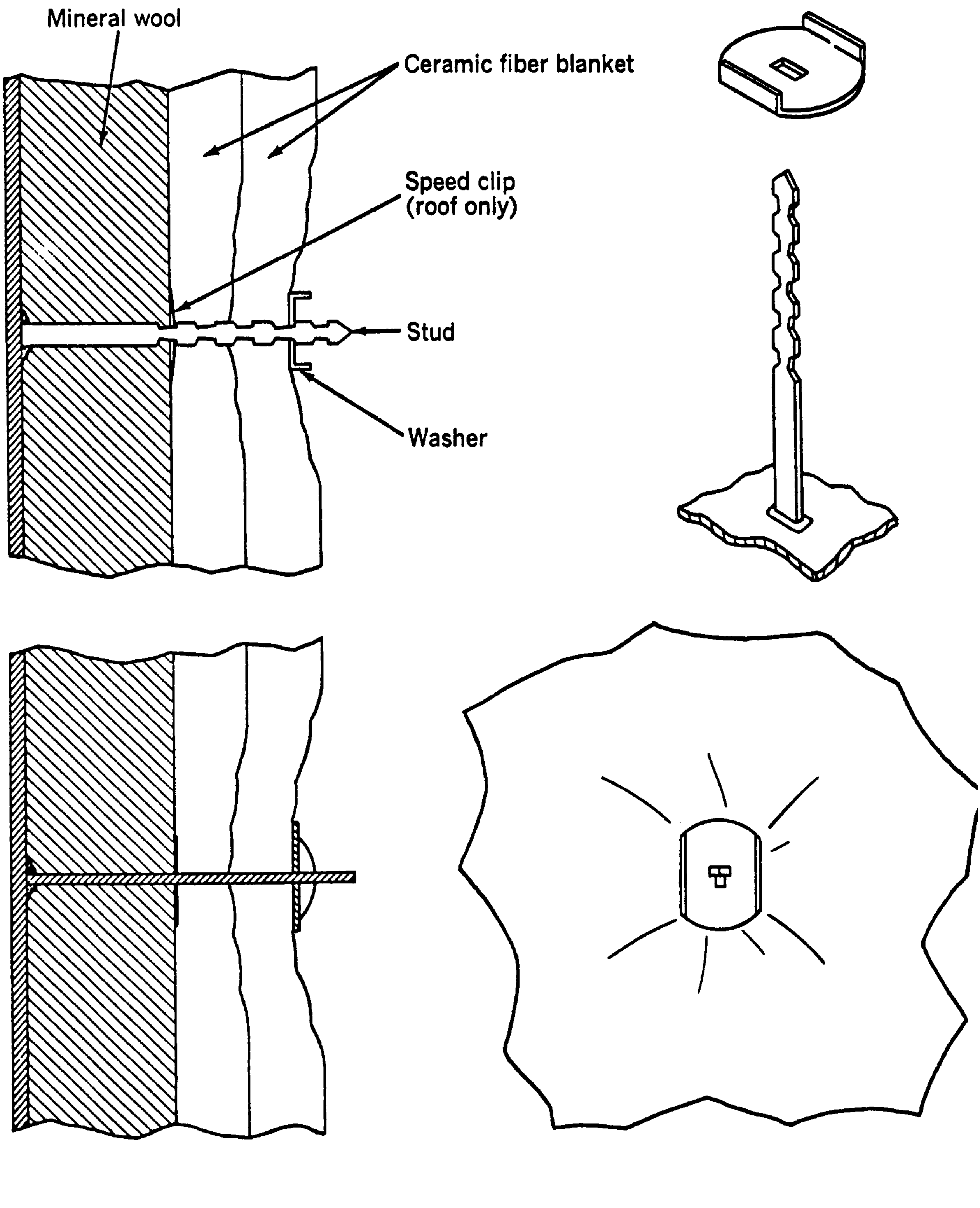


Figure 5.2.3-11
Kao-Lok stud system

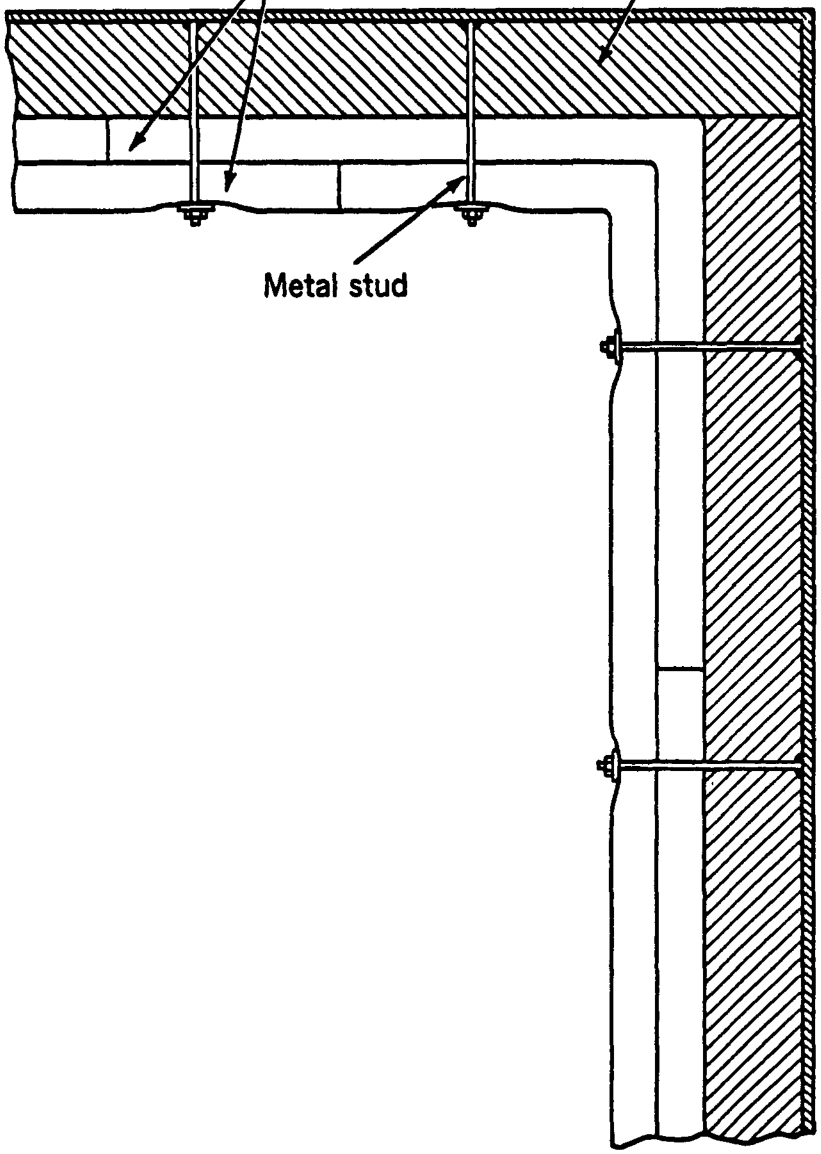


Figure 5.2.3-12

Blanket extending around a corner

rolled-up unit would be held in-place by solenoid latches normally energized "on". The loss of electrical power, or the opening of a relay triggered by low flow (or panel over-temperature) would deploy the curtain by a gravity-drop. The Nextel 312 material is rated at 1426 C (2600 F) continuous and 1649 C (3000 F) short term. For an 1800 kw/m^2 (571,000 BTU/ft^2-hr) peak flux, it is estimated that the curtain temperature would not exceed 1315 C (2400 F). The material cost for a 9.14 x 9.14 m (30 x 30 ft) curtain would be $2800. Since the use of this curtain would be rare, there is no plan to mechanize the raising and restowing; this would be performed manually.

The other safety feature provided in the receiver is a fire extinguishing system. Since the oil is combustible (similar to kerosene), the possibility exists that a leak could result in a fire if the leak impinged on a local hot spot. The system selected is a Halon 1301 type manufactured by Kidde, Inc., and consists of 2 - 136 kg (300 lb) bottles of a fluorinated hydrocarbon liquid (i.e., Freon-type). The presence of a fire would be detected by 538 C (1000 F) sensors located in the receiver ceiling above the panels. These sensors would trigger a solenoid valve which would enable the liquid Halon to be injected into the cavity where it would vaporize and "flood" the volume with an extinguishing vapor. The system is clean and would cause no damage or thermal shock like a water-deluge or foam type of system. The total installed cost of this system including sensors, controls, and piping is approximately $21,000.

Figure 5.2.3-13 illustrates the general appearance of the North Coles Levee receiver in a cutaway-perspective.

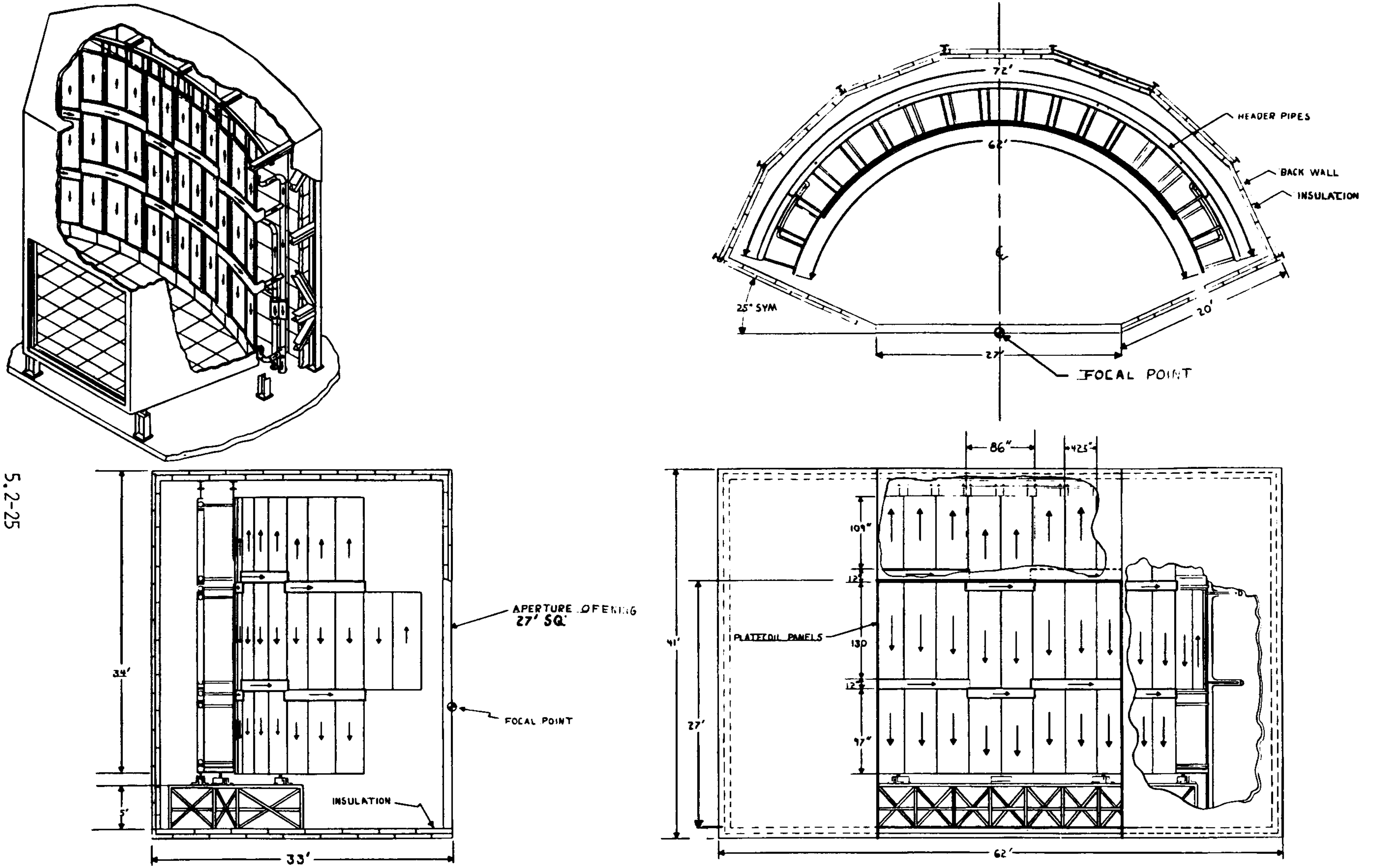


Figure 5.2.3-13

NORTHROP INC
BLAKE LABORATORY
SUITE 306, 7861 S. UNIVERSITY, LITTLETON, CO. 80122

$9.5\ MW_T$ RECEIVER
DIRECT SOLAR ENERGY ON HEAT MEDIUM OIL PANELS

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES

TOLERANCES	
X	= ± .125
X.X	= ± .031
X.XX	= ± .015

SCALE
DRAWN BY Jim Blake
DATE 6/16/80
APPROVED BY

5.2.4 Receiver Operating Characteristics

The receiver is supplied with heat transfer oil from the plant at 216 C (420 F) maximum, a volumetric flow rate of 0.067 m^3/s (1064 gpm), and a supply pressure of 0.93 mPa (135 psig). Figure 5.2.4-1 presents the flow distribution and flow routing between the 56 receiver panels. It will be noted that the receiver panels are arranged to give a 2-pass flow pattern; i.e.; a given fluid element will always flow through 2 panels. The full flow of the 0.067 m^3/s (1064 gpm) cool inlet fluid is first routed to the middle row, and divided among the middle 14 panels in this row. The flow distribution is achieved by a pre-calibration (orifice balancing), and does not vary through-out the year. The criteria used to determine the flow distribution between panels in this first pass are three-fold:

1. Limit the peak between-passage metal fin temperature to 357 C (675 F),
2. Limit the peak passage frontside metal temperature to 343 C (650 F),
3. Limit the maximum thermal stress to 172.4 mPa (25,000 psi).

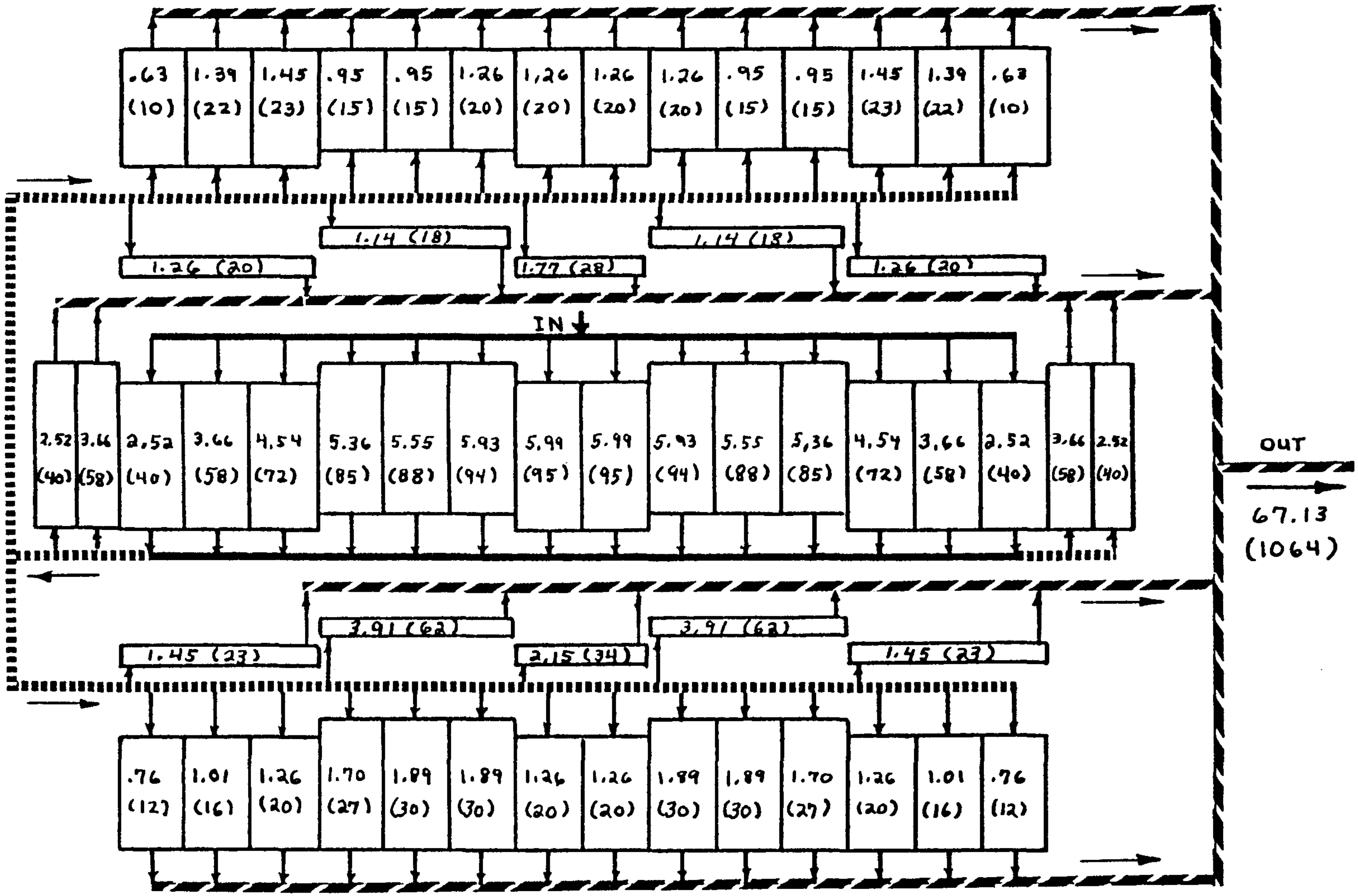
With the receiver inlet fluid temperature at 216 C (420 F), the fluid leaving the first pass will be between 262-281 C (503-537 F). The remaining 42 panels are also all arranged in a parallel flow pattern. The criteria for determining the flow distribution between the 42 panels in the second pass are the same as in the first pass plus the additional requirement that the fluid temperature in any panel must not exceed 315.6 C (600 F). In the next section of this report, it will be shown that all of these criteria have been met for all flux conditions anticipated for the complete operating year.

The pressure loss of the receiver is also provided in the next section of this report. Based on the manufacturer's panel

Figure 5.2.4-1

RECEIVER FLOW PATH & FLOW DISTRIBUTION

$m^3/s \times 10^3$ (gpm)



data, it was found that the pass #1 pressure loss will be 0.28 mPa (40.8 psi), and the pass #2 pressure loss 0.09 mPa (13.3 psi). Assuming a 70% pump and motor efficiency, this total pressure loss of 0.37 mPa (54.1 psi) corresponds to an input power of 35.4 kw which is only 0.34% of the average thermal output power.

The receiver operation is extremely simple. It is either on or off. On start-up, the ground pipe loop is valved to exclude the plant, and flow circulates closed-loop for the purpose of bringing the system minimum temperature up to 216 C (420 F). When this temperature is acheived, the valving is automatically switched to route the outlet flow to the plant. In either case, the receiver operation is the same; there are no valving or control functions performed within the receiver except for the opening and closing of the aperture door. For cloud passages, the operation is very similar. If the passage time is short, the heliostats stay on-track, the pump flow continues, and the aperture door remains open. For long cloudy periods (greater than 30 minutes), the heliostats would be placed in a stand-by mode, the aperture door would be closed, and the pump could either be turned off or maintained on with closed-loop flow.

During operation, the expected conditions within the receiver would be in the following range depending on time of day and year.

1. Oil inlet temperature = 193-216 C (380-420 F).
2. Pass #1 outlet temperature = 239-281 C (463-537 F).
3. Pass #2 outlet temperature = 262-306 C (504-584 F).
4. Maximum local oil temperature = 312 C (594 F).
5. Maximum local frontside fluid passage metal temperature = 335 C (635 F)
6. Maximum local between-passage (fin) metal temperature = 359 C (679 F).
7. Maximum local thermal stress = 151.7 mPa (22,000 psi).
8. Receiver efficiency = 88.2-90.8%

These conditions will be discussed in detail in the next section of this report.

5.2.5 Receiver Performance Estimates

In this section the results of the receiver thermal analyses are presented. The analysis method, assumptions, flow distribution, energy losses, and temperatures are discussed. In addition to the basic thermal evaluations, sensitivity studies are provided which show the receiver performance as a function of wind speed, ambient temperature, and surface optical properties.

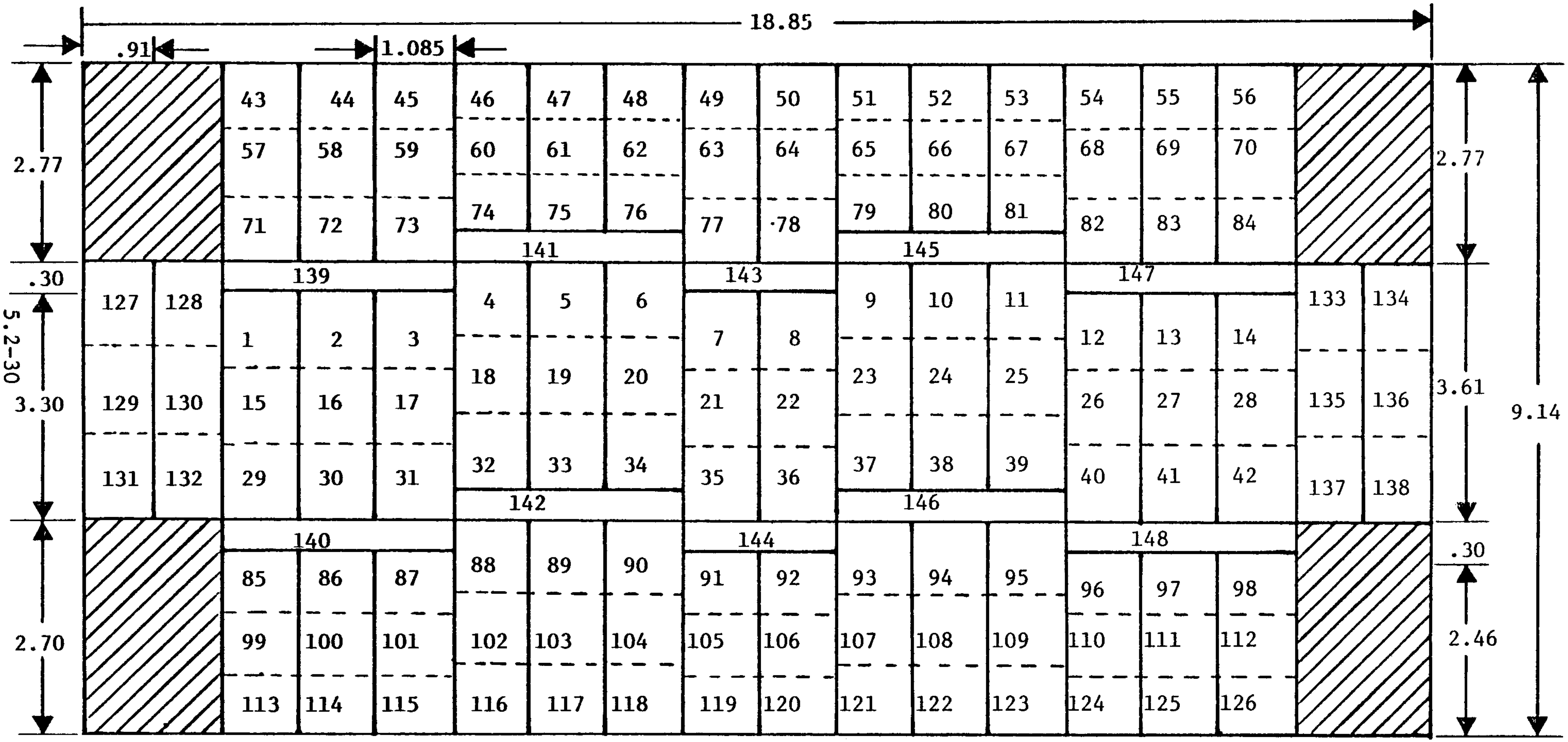
5.2.5.1 Analysis Method

A computer code designated as "ARCOTHERM" was developed for evaluating the thermal performance of the North Coles Levee receiver. The thermal network contains 150 node elements, 148 of which are active receiver panel nodes, and one each are used for the inactive cavity walls and the aperture. Figure 5.2.5-1 provides the receiver panel node numbers, location on the receiver, and dimensional information. It will be noted that the corner zones do not contain active panels due to the low flux level in these regions. Physically, these areas would be insulated with a high temperature insulation such as Babcock and Wilcox refractory known as Kaowool.

Each of the receiver node zones is analyzed by an iterative energy balance technique in which the energy losses and energy gain of the heat transfer oil flowing through the panels are balanced with the incident energy on that zone. The energy losses include convection, conduction through the cavity wall insulation, radiant losses to the inactive walls and aperture, and reflected losses to the inactive walls and aperture. Simultaneously, a detailed conduction and fluid convection analysis is performed for the panel metal temperatures to determine the temperatures of the wetted wall (frontside and backside), and of the between-passage fin region. These temperatures are used in the energy balance computations, and also for determining the thermal stresses resulting from the temperature gradients. Figure 5.2.5-2 illustrates the flow passage configuration and the thermal network used to evaluate the metal temperatures.

Figure 5.2.5-1

THERMAL NETWORK NODE BREAKDOWN



Note: Dimensions shown are in meters. Multiply by 3.2808 to obtain feet.

Figure 5.2.5-2

DETAILED FIN & WET-WALL NETWORK ANALYSIS

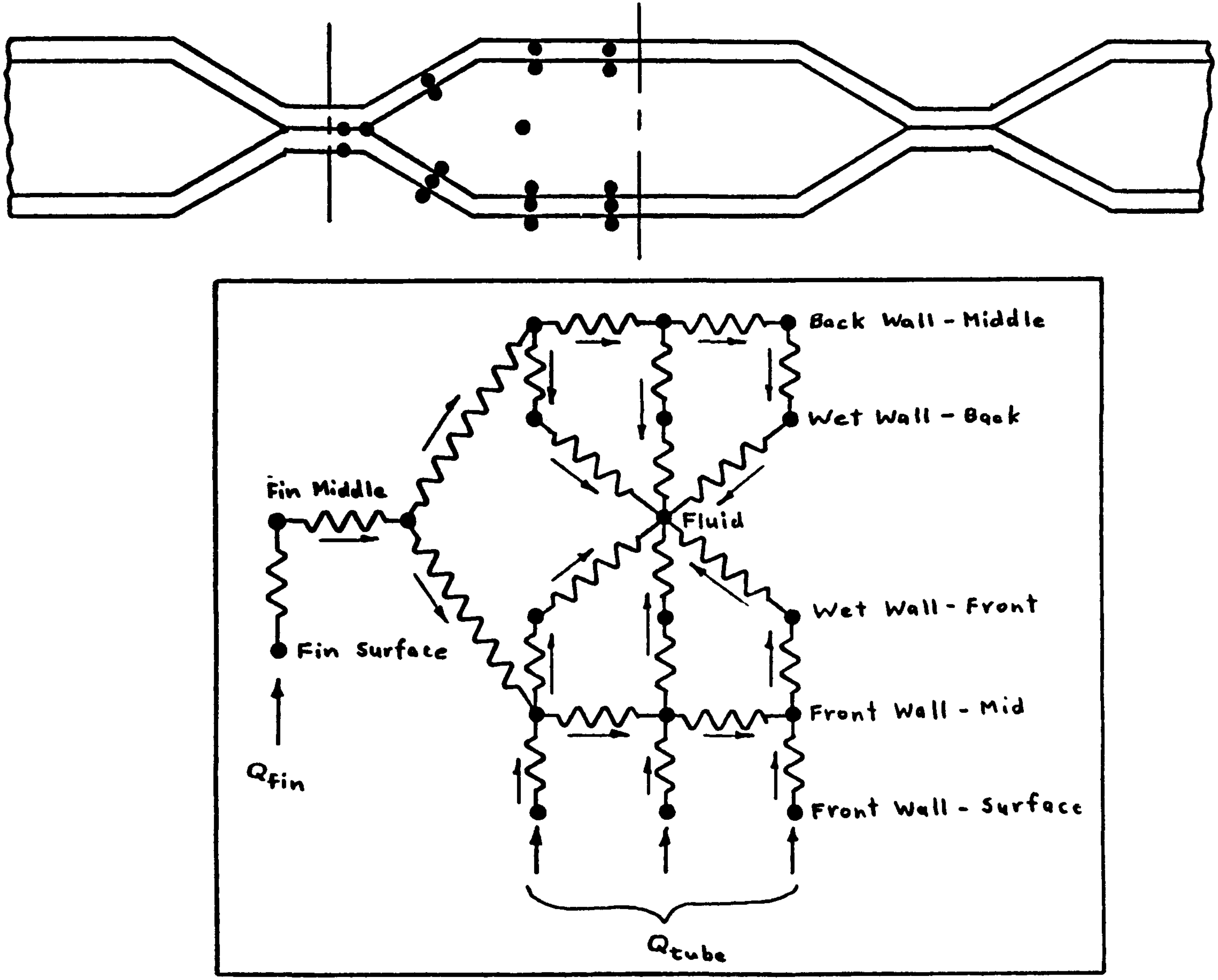


Figure 5.2.5-3 (a-c) illustrates the input; energy, temperature, and stress output (for 42 of the 148 nodes); and a sample run summary from an "ARCOTHERM" computer analysis. It will be noted that the energy losses from a given node contain an allocated portion of the energy loss from the inactive wall. This feature was added to enable a better evaluation of the true energy-gathering effectiveness of each zone. Those zones which showed high losses relative to the energy gain of the oil were deleted; i.e., no panels were installed in these regions. The inactive wall losses were allocated to the panel zone via the view factor between that zone and the inactive wall.

Figure 5.2.5-3a

"ARCOTHERM" Computer Code - Sample Printout

```
ARCO NORTH COLES LEVEE RECEIVER DESIGN - 24FT CAVITY RADIUS
-----------------------------------------------------------



TOTAL PANEL AREA SQ-FT= 1627.17
TOTAL FLOW RATE TO PANELS (GPM AT 420 DEG-F) = 1064
FLOW AREA PER PASSAGE, SQ-IN = 2.1
NUMBER OF PARALLEL FLOW PATHS/PANEL = 1
TOTAL FLOW AREA PER PANEL, SQ-IN = 2.1
TOTAL FLOW AREA, PANEL ARRAY, SQ-IN = 29.4
FLOW PASSAGE HYDRAULIC DIAM., FT = .095
FLOW PASSAGE WETTED WIDTH, IN = 3.34375
BETWEEN-PASSAGE FIN WIDTH, IN = .5
FRONT SHEET GAGE THICKNESS, IN = .1345
BACK SHEET GAGE THICKNESS, IN = .1345
RECEIVER ABSORPTIVITY = .95
RECEIVER EMISSIVITY = .95
CAVITY WALL ABSORPTIVITY = .9
CAVITY WALL EMISSIVITY = .9
OIL INLET TEMPERATURE, DEG-F = 420
AMBIENT TEMPERATURE, DEG-F = 50
TOWER HEIGHT, FT = 200
APERTURE SIZE (SQUARE), FT = 27
APERTURE DEPTH (RADIUS), FT = 24
WINDSPEED AT 30' ELEVATION, MPH = 8
WINDSPEED AT APERTURE ELEVATION, MPH = 10.6335015
```

Figure 5.2.5-3b

"ARCOTHERM" Computer Code Sheet - Sample Printout

DAY 355 TIME=12:00 NOON

.......ENERGY BALANCE, KW............. ...SYSTEM TEMPERATURES, DEG-F...

NODE	INCID Q	LOSS* Q-ABSP	LOSS* Q-CONV	LOSS* Q-COND	LOSS* Q-RAD	NET Q-OIL	METAL TEMPS. FIN	FRT	BCK	OIL OUT	FLOW GPM	THERML STRESS
***************************MIDDLE 14 PANELS******************************												
1	115.1	.60	3.88	.42	2.06	108.1	531	501	449	462	40	10234
15	151.4	.85	4.12	.43	2.25	143.7	604	563	498	515	40	13237
29	122.3	.74	4.22	.44	2.37	114.5	626	591	543	556	40	10313
2	161.8	1.04	3.84	.42	2.16	154.4	556	507	448	461	58	13361
16	209.1	1.46	4.06	.43	2.42	200.8	633	568	496	513	58	16994
30	167.3	1.25	4.13	.43	2.56	158.9	645	593	539	552	58	13205
3	187.4	1.45	3.74	.41	2.26	179.5	566	506	447	459	72	14859
17	246.7	2.11	3.96	.41	2.58	237.6	648	566	493	508	72	19319
31	196.7	1.80	4.00	.41	2.74	187.8	654	589	534	546	72	15031
4	161.8	1.43	3.58	.39	2.25	154.1	539	486	440	448	85	12396
18	257.0	2.54	3.80	.40	2.63	247.6	637	549	479	492	85	19644
32	236.8	2.53	3.87	.40	2.88	227.1	662	580	519	531	85	17763
5	165.6	1.67	3.50	.38	2.32	157.8	541	486	440	448	88	12605
19	266.7	3.01	3.71	.39	2.76	256.9	641	550	479	492	88	20260
33	246.3	3.00	3.78	.39	3.05	236.0	666	581	519	531	88	18359
6	173.1	1.90	3.44	.38	2.37	165.0	544	485	439	447	94	13037
20	276.4	3.40	3.63	.38	2.85	266.1	644	548	477	490	94	20770
34	256.4	3.42	3.69	.38	3.16	245.8	669	579	517	528	94	18932
7	209.4	2.48	3.44	.38	2.51	200.6	570	499	443	453	95	15808
21	293.8	3.88	3.62	.38	3.01	282.9	661	559	484	498	95	22000
35	235.9	3.33	3.63	.38	3.23	225.3	660	578	521	532	95	17301
8	209.4	2.48	3.44	.38	2.51	200.6	570	499	443	453	95	15808
22	293.8	3.88	3.62	.38	3.01	282.9	661	559	484	498	95	22001
36	235.9	3.33	3.63	.38	3.23	225.3	660	578	521	532	95	17301
9	173.1	1.90	3.44	.38	2.37	165.0	544	485	439	447	94	13035
23	276.4	3.40	3.63	.38	2.85	266.1	644	548	477	490	94	20771
37	256.4	3.42	3.69	.38	3.16	245.8	669	579	517	528	94	18932
10	165.6	1.67	3.50	.38	2.32	157.8	541	486	440	448	88	12601
24	266.7	3.01	3.71	.39	2.76	256.9	641	550	479	492	88	20260
38	246.3	3.00	3.78	.39	3.05	236.0	666	581	519	531	88	18359
11	161.8	1.43	3.58	.39	2.25	154.1	539	486	440	448	85	12388
25	257.0	2.54	3.80	.40	2.63	247.6	637	549	479	492	85	19645
39	236.8	2.53	3.87	.40	2.88	227.1	662	580	519	531	85	17764
12	187.4	1.45	3.74	.41	2.26	179.5	566	506	447	459	72	14832
26	246.7	2.11	3.96	.41	2.58	237.6	648	566	493	508	72	19321
40	196.7	1.80	4.00	.41	2.74	187.8	654	589	534	546	72	15033
13	161.8	1.04	3.84	.42	2.16	154.4	556	507	448	461	58	13419
27	209.1	1.46	4.06	.43	2.42	200.8	633	568	496	513	58	17000
41	167.3	1.25	4.13	.43	2.56	158.9	645	593	539	552	58	13211
14	115.1	.60	3.88	.42	2.06	108.1	531	501	449	462	40	10259
28	151.4	.85	4.12	.43	2.25	143.7	604	563	498	515	40	13242
42	122.3	.74	4.22	.44	2.37	114.5	625	591	543	556	40	10283

* NODE LOSSES SHOWN INCLUDE AN ALLOCATED PORTION OF THE WALL LOSS

Figure 5.2.5-3c

"ARCOTHERM" Computer Code - Sample Run Summary

```
RUN SUMMARY,DAY 355  TIME=12:00 NOON
--------------------------------------

APERTURE PLANE ENERGY, KW= 13021
ENERGY ON RECEIVER, KW= 12828.477
ENERGY APERTURE CUT-OFF, KW= 88.5428012
ENERGY MISSING PANELS, KW= 103.98
ABSORPTIVITY LOSS, KW= 125.972
CONVECTION LOSS, KW= 503.275
CONDUCTION LOSS, KW= 52.603
RADIATION LOSS, KW= 329.262
ENERGY TO FLUID, KW= 11817.371

RECEIVER SURFACE AREA = 1627.17
VIEW FACTOR TO APERTURE = .165
RECEIVER EFFICIENCY, %= 90.76

MAX OIL TEMPERATURE, DEG-F= 594.1
MAX FIN TEMPERATURE, DEG-F= 669.5
MAX FRONT TEMPERATURE, DEG-F= 632.2
MAX BACK TEMPERATURE, DEG-F= 593.8

MAXIMUM THERMAL STRESS, PSI= 22001

AVERAGE TUBE SURFACE TEMP = 576
AVERAGE FIN SURFACE TEMP = 606
AVERAGE SURFACE TEMP (CONVECTION) = 580
AVERAGE SURFACE TEMP (RADIATION) = 582
AVERAGE CAVITY WALL TEMP = 543

FLUID INLET TEMP = 420
PASS #1 OUTLET TEMP = 537.1
PASS #2 OUTLET TEMP = 583.5
FLUID AVERAGE TEMP = 501.8

TOTAL PANEL SET FLOW RATE, GPM = 1064

AVERAGE SPECIFIC HEAT, BTU/LB-DEG-F = .621
AVERAGE VISCOSITY, LB/FT-HR = .557
AVERAGE DENSITY, LB/CU-FT = 43.83
AVERAGE CONDUCTIVITY, BTU/FT-HR-DEG-F = .06843

****************************************************************
```

Table 5.2.5-1 provides the primary transport properties of the heat transfer oil as a function of oil temperature. The "ARCOTHERM" thermal analyzer accounts for the variability of these properties based on the average fluid temperature within a given panel zone. Table 5.2.5-2 presents the oil film heat transfer coefficient as a function of oil temperature and passage flow velocity. It will be noted that these film coefficients are considerably lower than those found in conventional water-steam boilers. These lower film coefficients dictate lower allowable receiver flux levels, a deeper cavity to de-focus the peak aperture flux, and a larger receiver area to intercept this de-focused flux. However, these disadvantages are offset by a lower operating pressure than conventional water-steam boilers which enables the low cost Platecoil embossed panels to be employed.

The receiver panels are assumed to be painted with a black coating having an absorptivity and emissivity of 0.95. The inactive cavity walls are assumed to have an absorptivity and emissivity of 0.90. This latter assumption is somewhat unusual in that inactive cavity walls are generally painted with a white paint or clothed with a white insulation (either of which would provide an absorptivity of approximately 0.20 and an emissivity of 0.8-0.9). The theory of using white inactive walls is to reflect the majority of any solar flux incident on these walls back onto the receiver panels. However, experience has shown that white finishes darken very quickly due to airborne dust and dirt. Hence, the conservative assumption was made that the inactive cavity walls are dark and essentially non-reflective.

The energy losses due to convection are not well established for cavity-type receivers, and as such must be estimated. The assumption used in the "ARCOTHERM" computer model is as follows:

A. The air temperature within the cavity is the average between the mean panel temperature and the outside ambient air temperature.

B. Natural convection is always present within the cavity, and the natural convection coefficient is 4.54 W/m^2K (0.8 BTU/ft^2-hr-^oF).

Table 5.2.5-1

Heat Medium Oil Properties

Oil Temperature C (F)	Oil Density	Oil Viscosity	Oil Thermal Conductivity	Oil Specific Heat
204.4 (400)	756.6 (47.22)	1.225 (.823)	.1230 (.8532)	2386 (.570)
232.2 (450)	729.8 (45.55)	1.011 (.629)	.1207 (.8376)	2490 (.595)
260.0 (500)	703.2 (43.89)	.835 (.561)	.1185 (.8220)	2595 (.620)
287.8 (550)	676.5 (42.42)	.689 (.463)	.1162 (.8064)	2700 (.645)
315.6 (600)	649.9 (40.56)	.573 (.385)	.1140 (.7908)	2804 (.670)
343.3 (650)	623.3 (38.90)	.508 (.341)	.1117 (.7752)	2909 (.695)

Note: Oil density units: kg/m^3 (lb/ft^3)

Oil viscosity units: kg/m-hr (lb/ft-hr)

Oil thermal conductivity units: W/mK (BTU-in/ft^2hr-F)

Oil specific heat: J/kg-C (BTU/lb-F)

Table 5.2.5-2

Heat Medium Oil Film Coefficient

Oil Temperature C (F)	.61 m/s (2 ft/s)	1.22 m/s (4 ft/s)	1.83 m/s (6 ft/s	2.44 m/s (8 ft/s)	3.05 m/s (10 ft/s)	3.66 m/s (12 ft/s)
204.4 (400)	982 (173)	1709 (301)	2368 (417)	2981 (525)	3566 (628)	4122 (726)
232.2 (450)	1039 (183)	1806 (318)	2498 (440)	3146 (554)	3759 (662)	4350 (766)
260.0 (500)	1096 (193)	1902 (335)	2635 (464)	3316 (584)	3963 (698)	4588 (808)
287.8 (550)	1153 (203)	2004 (353)	2771 (488)	3487 (614)	4168 (734)	4827 (850)
315.6 (600)	1204 (212)	2095 (369)	2896 (510)	3646 (642)	4355 (767)	5042 (888)

Note: Units for film coefficient: w/m^2k (BTU/ft^2-hr-^oF)

C. Forced convection from wind acts on the aperture plane and is computed from the following relationship (reference: "Forced Convection Heat Transfer at an Inclined and Yawed Square Plate--Application to Solar Collectors", by E. M. Sparrow and K. K. Tien, Journal of Heat Transfer, Nov. 1977, Vol. 99).

$$h = (0.931 \times \rho \times Cp \times V) \,/\, (Pr^{2/3} \times Re^{1/2})$$

where h = heat transfer coefficient, BTU/ft^2-hr-F

ρ = air density, lb/ft^3

Cp = air specific heat, BTU/lb-F

V = wind velocity, ft/hr

Pr = Prandtl number

Re = Reynolds number (based on aperture size)

D. The forced convection heat transfer coefficient at the receiver panels is equal to the aperture coefficient reduced by the ratio of aperture area to receiver panel area. The natural convection effect and forced convection effect are treated as being additive.

The resultant heat transfer coefficient versus wind velocity for an 8.23 x 8.23 m (27 x 27 ft) aperture and a 151 m^2 (1627 ft^2) receiver are tabulated on Table 5.2.5-3. While the validity of the convection coefficients shown cannot be confirmed, the qualitative interpretation appears proper; the convective losses should increase with increasing wind speed (and with increasing aperture area), but the effect should be significantly attenuated by the 7.3 m (24 ft) cavity depth.

The key variable in achieving a satisfactory receiver design for the North Coles Levee facility is the oil flow routing and distribution to the Platecoil panels. The basic problem was to find a flow pattern which accomplishes the following:

A. Limits the peak oil temperature within any panel to 316 C (600°F) to prevent oil breakdown and carburizing of the flow passages.

B. Limits the peak flow passage metal temperature to 343 C (650°F) to stay within the existing Platecoil ASME rating for carbon steel. Higher temperature Platecoil materials are available, but at a considerably higher cost.

Table 5.2.5-3

Combined Forced and Natural Convection

Coefficent Vs. Wind Speed At Aperture

Wind Speed		Convection Coefficient	
m/s	(ft/s)	W/m^2 K	(BTU/ft^2-hr-F)
0	(0)	4.54	(0.8)
2	(6.56)	5.74	(1.01)
4	(13.12)	6.25	(1.10)
6	(19.68)	6.64	(1.17)
8	(26.25)	6.93	(1.22)
10	(32.81)	7.21	(1.27)
12	(39.37)	7.50	(1.32)
14	(45.93)	7.72	(1.36)
16	(52.49)	7.95	(1.40)
18	(59.05)	8.12	(1.43)
20	(65.62)	8.35	(1.47)

C. Limits the maximum thermal stress caused by local temperature differences between the fin, flow passage frontside, and flow passage backside to 172.4 x 10^6 Pa (25,000 psi) to maximize fatigue life.

D. Limits the total receiver pressure loss to 0.41 x 10^6 Pa (60 psi) to minimize pumping power.

Since it is a design goal that no control valves be employed in the receiver, the flow distribution must be such that these criteria are met through-out the complete year with a pre-calibrated, fixed orifice system. Figure 5.2.5-4 presents the flow distribution which satisfies these requirements. Figure 5.2.5-5 presents the panel pressure losses which accompany these flow rates. A discussion of the temperatures and stress levels which accompany these flow rates will be provided in a later section of this report.

Figure 5.2.5-4

RECEIVER FLOW PATH & FLOW DISTRIBUTION

$m^3/s \times 10^3$ (gpm)

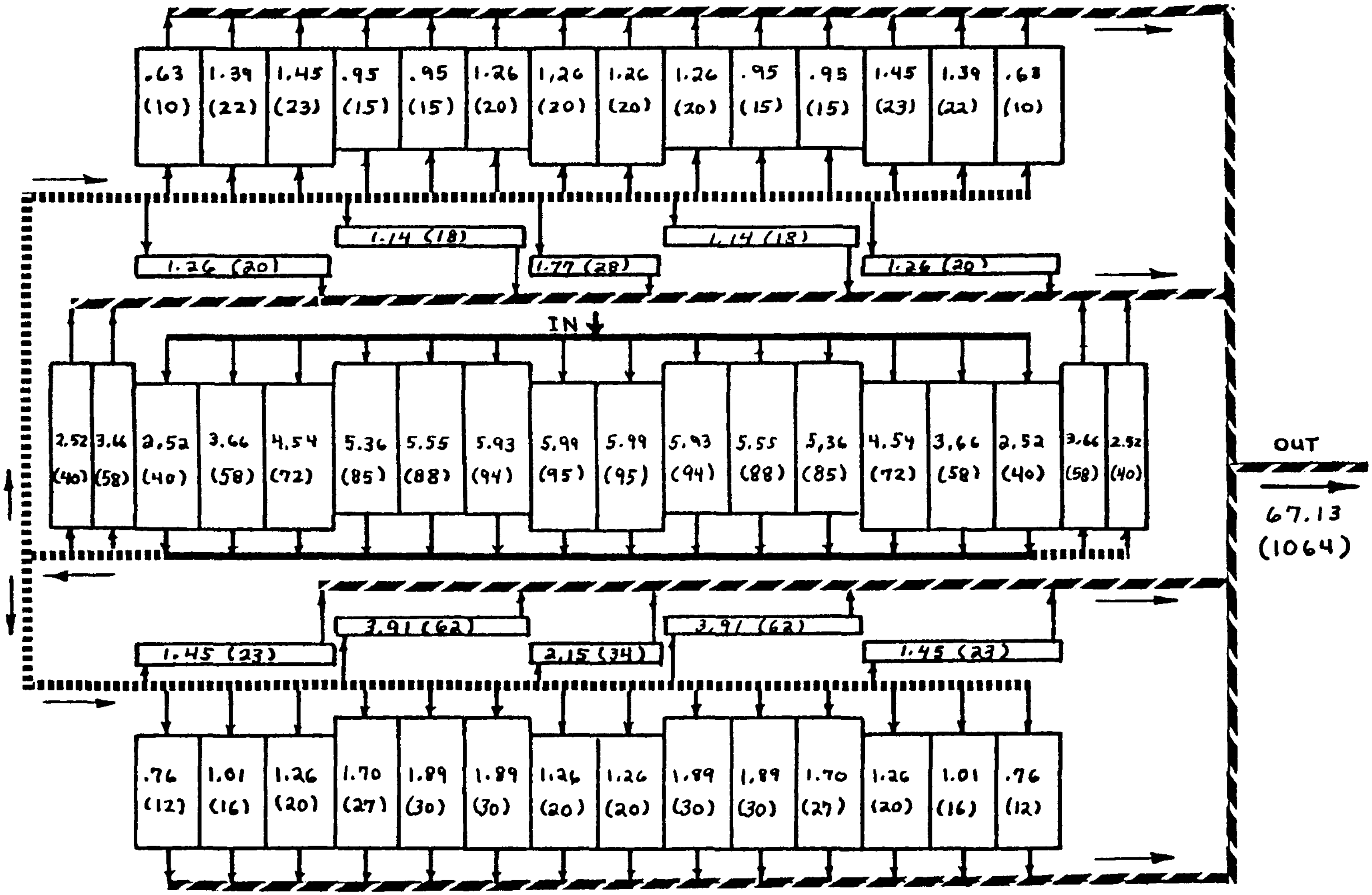
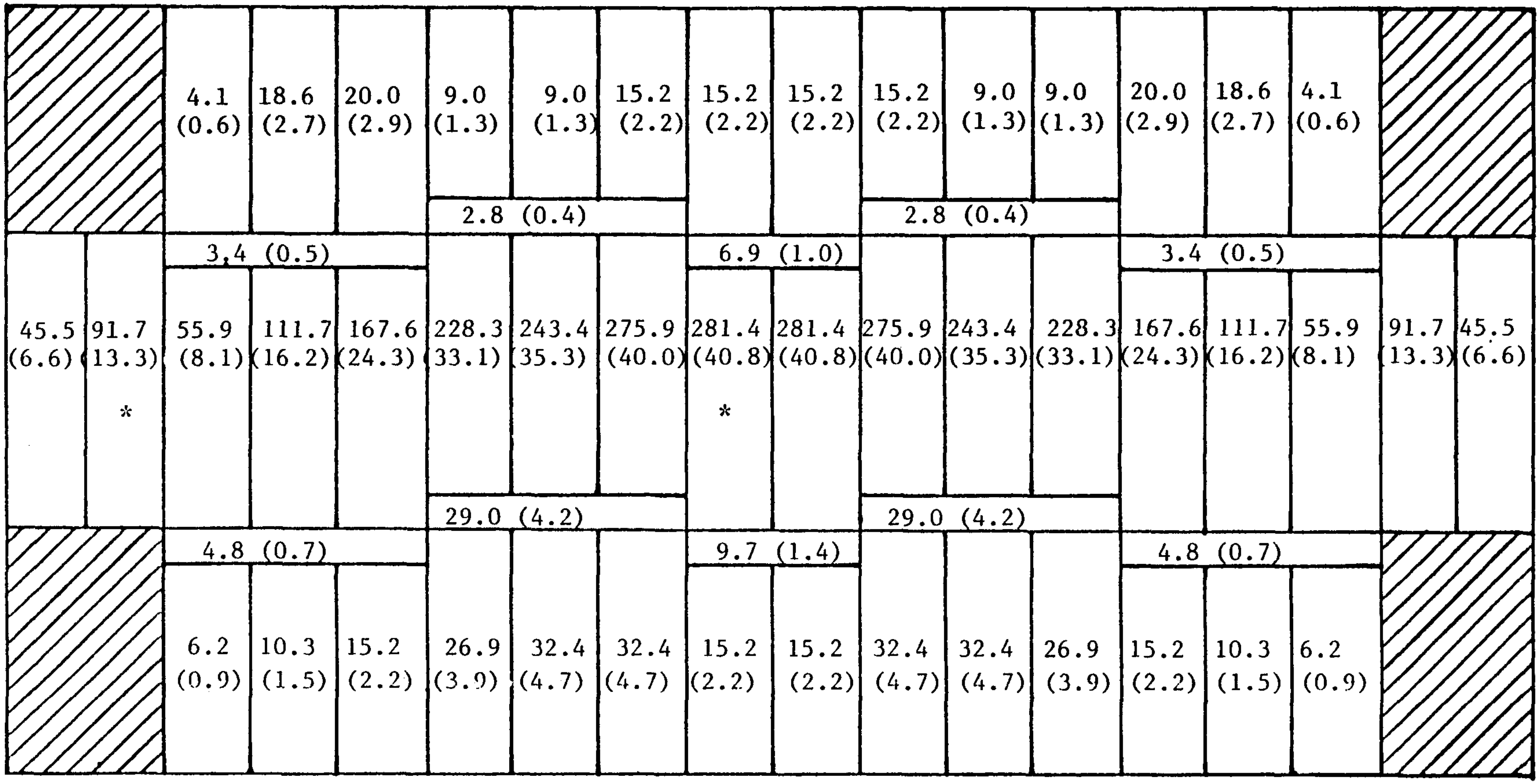


Figure 5.2.5-5
Receiver Panel Pressure Losses, Pa x 10^{-3} (psi)



* These series panels dictate a total receiver pressure loss of 0.37 x 10^6 Pa (54.1 psi)

5.2.5.2 Aperture Optimization

A series of 81 computer runs were performed using the "ARCOTHERM" computer code to determine the optimum aperture size. With a small aperture the convective and radiative losses from the aperature are reduced, but the energy entering the cavity is also reduced due to the cut-off of energy which is incident outside of the cavity zone (i.e., spillage). As the cavity size is increased, the spillage is reduced, but the losses increase. Hence, the aperture size must be optimized. From a practical standpoint, the aperture should be as large as possible to provide maximum accomodation of heliostat tracking variations. Wind induced deflections of the heliostat structure, facet alignment errors, thermal defocusing, and tracking errors will all tend to defocus and enlarge the reflected image.

The computer study encompassed nine different aperture sizes from 2.74 x 2.74 m (9 x 9 ft) to 10.06 x 10.06 m (33 x 33 ft) in 0.91 m (3.0 ft) increments. Three different days of the year were analyzed; day 355 (winter solstice), day 80 (spring equinox), and day 173 (summer solstice). For each day, three different "solar-times" were also evaluated; 8:00 a.m., 10:00 a.m., and 12:00 noon. These series of days and times bracket the extreme conditions of flux pattern and aberration which would be encountered in a complete year.

Table 5.2.5-4 presents the receiver efficiency (energy into the fluid/energy available at the aperture plane) versus aperture size for the nine days and times discussed above. It will be noted that the efficiency does not vary significantly for aperture sizes from about 6.40 x 6.40 m (21 x 21 ft) to 10.06 x 10.06 m (33 x 33 ft). The aperture size selected was 8.23 x 8.23 m (27 x 27 ft). This size is optimum, it provides an ample-sized target for the Northrup heliostat, and it does provide some margin for error in the convection heat loss assumption (i.e., higher convective losses than assumed would favor an 8.23 x 8.23 m size versus a 10.06 x 10.06 m aperture).

Table 5.2.5-4

Receiver Efficiency Vs. Aperture Size

Aperture Size, m (ft)	Day 355 8:00	Day 355 10:00	Day 355 12:00	Day 80 8:00	Day 80 10:00	Day 80 12:00	Day 173 8:00	Day 173 10:00	Day 173 12:00
10.06 x 10.06 (33 x 33)	87.88%	89.21%	89.50%	88.42%	89.07%	89.30%	88.24% *	88.32 %	88.52%
9.14 x 9.14 (30 x 30)	88.28	89.77	90.13	88.98	89.57	89.85	88.23	88.64	88.93
8.23 x 8.23 (27 x 27)	88.69*	90.33*	90.76*	89.54*	90.08*	90.41*	88.21	88.95*	89.36*
7.32 x 7.32 (24 x 24)	87.99	90.12	90.71	88.38	89.54	90.12	86.37	87.77	88.41
6.40 x 6.40 (21 x 21)	87.30	89.91	90.67	87.22	89.00	89.82	84.52	86.59	87.47
5.49 x 5.49 (18 x 18)	82.59	86.15	87.26	81.72	84.48	85.66	77.82	80.75	81.78
4.57 x 4.57 (15 x 15)	77.84	82.35	83.81	76.17	79.91	81.46	71.04	74.85	76.03
3.66 x 3.66 (12 x 12)	63.38	68.43	70.09	61.40	65.65	67.18	55.71	59.72	61.09
2.74 x 2.74 (9 x 9)	48.80	54.42	56.27	46.50	51.27	52.78	40.27	44.47	46.04

* Optimum aperture size for day and time.

The North Coles Levee receiver was analyzed using the "ARCOTHERM" computer code for the winter and summer solstice days and the equinox day at solar times of 8:00 am, 10:00 am, and 12:00 noon. The key assumptions used in this analysis were those discussed in sections 5.2.5.1 and 5.2.5.2 above. In addition to the heat losses and resultant receiver efficiency, the main parameters of importance which were analyzed included the oil temperature in each panel, the maximum between-passage (fin) temperature, the maximum flow passage frontside temperature, and the maximum local thermal stress in each panel.

Since a considerable quantity of data was obtained in this analysis, a run summary of each of the nine "day and time" cases is first provided to give a complete over-view. Then a detailed set of node maps is provided for the peak flux time (winter solstice-noon) which show an itemized node-by-node accounting of the type and magnitude of the heat losses, and a panel-by-panel accounting of the maximum oil temperature, fin temperature, flow passage frontside temperature, and thermal stress. Detailed node maps for the eight other day and time cases are presented in Appendix E.

Table 5.2.5-5 summarized the results from the nine day and time cases analyzed. By virtue of the morning and afternoon symmetry (i.e., receiver efficiency at 10:00 am = receiver efficiency at 2:00 pm), and the equality of the spring and fall equinox conditions, these nine cases can be extrapolated to produce twenty day and time efficiency points. The average of these twenty points resulted in the determination of the annual average receiver efficiency of 89.59%.

Figures 5.2.5-6 through 5.2.5-14 present the summary output results from the "ARCOTHERM" computer code for the nine day and time cases analyzed. The key temperature and thermal stress results from these runs are:

Outlet Maximum Oil Temperature = 306.4 C (583.5° F)
Local Maximum Oil Temperature = 312.3 C (594.1° F)
Local Maximum Passage Temperature = 335.0 C (635.0° F)
Local Maximum Fin Temperature = 359.9 C (679.9° F)
Local Maximum Thermal Stress = 151.7 x 10^6 Pa (22001 psi)

Table 5.2.5-5

North Coles Levee Receiver Performance

Parameter	Day 355 12:00	Day 355 10:00	Day 355 8:00	Day 80 12:00	Day 80 10:00	Day 80 8:00	Day 173 12:00	Day 173 10:00	Day 173 8:00
1. Energy Available, Kw	13021	12669	10256	12512	12119	10925	11509	11118	9971
2. Aperture Cutoff, Kw	89	118	168	116	142	135	171	195	257
3. Panel Miss, Kw	104	108	80	92	83	72	101	93	18
4. Reflected Loss, Kw	126	123	99	120	117	106	110	106	96
5. Convection Loss, Kw	503	499	473	498	493	480	487	482	470
6. Conduction Loss, Kw	53	52	50	52	52	50	51	51	49
7. Radiation Loss, Kw	329	324	290	322	316	300	307	302	286
8. Energy to Oil, Kw	11817	11444	9096	11312	10917	9782	10282	9890	8796
9. Receiver Efficiency, %	90.76	90.33	88.69	90.41	90.08	89.54	89.34	88.95	88.21
10. Oil Outlet Temp. C	306.4	303.7	286.5	302.7	299.9	291.6	295.2	292.4	284.3
(F)	(583.5)	(578.7)	(547.7)	(576.7)	(571.8)	(556.8)	(563.4)	(558.3)	(543.7)

Annual Average Receiver Efficiency = 89.59%

Figure 5.2.5-6

RUN SUMMARY,DAY 355 TIME=12:00 NOON

APERTURE PLANE ENERGY, KW= 13021
ENERGY ON RECEIVER, KW= 12828.477
ENERGY APERTURE CUT-OFF, KW= 88.5428012
ENERGY MISSING PANELS, KW= 103.98
ABSORPTIVITY LOSS, KW= 125.972
CONVECTION LOSS, KW= 503.275
CONDUCTION LOSS, KW= 52.603
RADIATION LOSS, KW= 329.262
ENERGY TO FLUID, KW= 11817.371

RECEIVER SURFACE AREA = 1627.17
VIEW FACTOR TO APERTURE = .165
RECEIVER EFFICIENCY, %= 90.76

MAX OIL TEMPERATURE, DEG-F= 594.1
MAX FIN TEMPERATURE, DEG-F= 669.5
MAX FRONT TEMPERATURE, DEG-F= 632.2
MAX BACK TEMPERATURE, DEG-F= 593.8

MAXIMUM THERMAL STRESS, PSI= 22001

AVERAGE TUBE SURFACE TEMP = 576
AVERAGE FIN SURFACE TEMP = 606
AVERAGE SURFACE TEMP (CONVECTION) = 580
AVERAGE SURFACE TEMP (RADIATION) = 582
AVERAGE CAVITY WALL TEMP = 543

FLUID INLET TEMP = 420
PASS #1 OUTLET TEMP = 537.1
PASS #2 OUTLET TEMP = 583.5
FLUID AVERAGE TEMP = 501.8

TOTAL PANEL SET FLOW RATE, GPM = 1064

AVERAGE SPECIFIC HEAT, BTU/LB-DEG-F = .621
AVERAGE VISCOSITY, LB/FT-HR = .557
AVERAGE DENSITY, LB/CU-FT = 43.83
AVERAGE CONDUCTIVITY, BTU/FT-HR-DEG-F = .06843

****

Figure 5.2.5-7

RUN SUMMARY,DAY 355 TIME=10:00

APERTURE PLANE ENERGY, KW= 12669
ENERGY ON RECEIVER, KW= 12442.853
ENERGY APERTURE CUT-OFF, KW= 117.821703
ENERGY MISSING PANELS, KW= 108.325
ABSORPTIVITY LOSS, KW= 122.545
CONVECTION LOSS, KW= 499.393
CONDUCTION LOSS, KW= 52.217
RADIATION LOSS, KW= 324.248
ENERGY TO FLUID, KW= 11444.449

RECEIVER SURFACE AREA = 1627.17
VIEW FACTOR TO APERTURE = .165
RECEIVER EFFICIENCY, %= 90.33

MAX OIL TEMPERATURE, DEG-F= 591.4
MAX FIN TEMPERATURE, DEG-F= 679.9
MAX FRONT TEMPERATURE, DEG-F= 635
MAX BACK TEMPERATURE, DEG-F= 591.1

MAXIMUM THERMAL STRESS, PSI= 21703

AVERAGE TUBE SURFACE TEMP = 572
AVERAGE FIN SURFACE TEMP = 600
AVERAGE SURFACE TEMP (CONVECTION) = 575
AVERAGE SURFACE TEMP (RADIATION) = 578
AVERAGE CAVITY WALL TEMP = 539

FLUID INLET TEMP = 420
PASS #1 OUTLET TEMP = 533.3
PASS #2 OUTLET TEMP = 578.7
FLUID AVERAGE TEMP = 499.3

TOTAL PANEL SET FLOW RATE, GPM = 1064

AVERAGE SPECIFIC HEAT, BTU/LB-DEG-F = .62
AVERAGE VISCOSITY, LB/FT-HR = .563
AVERAGE DENSITY, LB/CU-FT = 43.91
AVERAGE CONDUCTIVITY, BTU/FT-HR-DEG-F = .0685

****

Figure 5.2.5-8

RUN SUMMARY,DAY 355 TIME=8:00 A.M.

```
APERTURE PLANE ENERGY, KW= 10256
ENERGY ON RECEIVER, KW= 10007.516
ENERGY APERTURE CUT-OFF, KW= 168.198401
ENERGY MISSING PANELS, KW= 80.286
ABSORPTIVITY LOSS, KW= 99.275
CONVECTION LOSS, KW= 472.732
CONDUCTION LOSS, KW= 49.543
RADIATION LOSS, KW= 289.627
ENERGY TO FLUID, KW= 9096.341

RECEIVER SURFACE AREA = 1627.17
VIEW FACTOR TO APERTURE = .165
RECEIVER EFFICIENCY, %= 88.69

MAX OIL TEMPERATURE, DEG-F= 569.1
MAX FIN TEMPERATURE, DEG-F= 657.6
MAX FRONT TEMPERATURE, DEG-F= 606.9
MAX BACK TEMPERATURE, DEG-F= 563.7

MAXIMUM THERMAL STRESS, PSI= 19202

AVERAGE TUBE SURFACE TEMP = 543
AVERAGE FIN SURFACE TEMP = 565
AVERAGE SURFACE TEMP (CONVECTION) = 545
AVERAGE SURFACE TEMP (RADIATION) = 547
AVERAGE CAVITY WALL TEMP = 516

FLUID INLET TEMP = 420
PASS #1 OUTLET TEMP = 510.2
PASS #2 OUTLET TEMP = 547.7
FLUID AVERAGE TEMP = 483.9

TOTAL PANEL SET FLOW RATE, GPM = 1064

AVERAGE SPECIFIC HEAT, BTU/LB-DEG-F = .612
AVERAGE VISCOSITY, LB/FT-HR = .598
AVERAGE DENSITY, LB/CU-FT = 44.43
AVERAGE CONDUCTIVITY, BTU/FT-HR-DEG-F = .0689

*************************************************************
```

Figure 5.2.5-9

RUN SUMMARY,DAY 80 TIME=12:00 NOON

APERTURE PLANE ENERGY, KW= 12512
ENERGY ON RECEIVER, KW= 12295.381
ENERGY APERTURE CUT-OFF, KW= 116.361603
ENERGY MISSING PANELS, KW= 100.258
ABSORPTIVITY LOSS, KW= 120.438
CONVECTION LOSS, KW= 497.684
CONDUCTION LOSS, KW= 52.045
RADIATION LOSS, KW= 321.603
ENERGY TO FLUID, KW= 11303.617

RECEIVER SURFACE AREA = 1627.17
VIEW FACTOR TO APERTURE = .165
RECEIVER EFFICIENCY, %= 90.34

MAX OIL TEMPERATURE, DEG-F= 588.4
MAX FIN TEMPERATURE, DEG-F= 655.4
MAX FRONT TEMPERATURE, DEG-F= 628
MAX BACK TEMPERATURE, DEG-F= 588

MAXIMUM THERMAL STRESS, PSI= 20131

AVERAGE TUBE SURFACE TEMP = 570
AVERAGE FIN SURFACE TEMP = 598
AVERAGE SURFACE TEMP (CONVECTION) = 573
AVERAGE SURFACE TEMP (RADIATION) = 575
AVERAGE CAVITY WALL TEMP = 538

FLUID INLET TEMP = 420
PASS #1 OUTLET TEMP = 530.1
PASS #2 OUTLET TEMP = 576.8
FLUID AVERAGE TEMP = 498.4

TOTAL PANEL SET FLOW RATE, GPM = 1064

AVERAGE SPECIFIC HEAT, BTU/LB-DEG-F = .619
AVERAGE VISCOSITY, LB/FT-HR = .565
AVERAGE DENSITY, LB/CU-FT = 43.94
AVERAGE CONDUCTIVITY, BTU/FT-HR-DEG-F = .06852

****

Figure 5.2.5-10

RUN SUMMARY,DAY 80 TIME=10:00 A.M.

APERTURE PLANE ENERGY, KW= 12119
ENERGY ON RECEIVER, KW= 11894.504
ENERGY APERTURE CUT-OFF, KW= 141.792302
ENERGY MISSING PANELS, KW= 82.704
ABSORPTIVITY LOSS, KW= 116.76
CONVECTION LOSS, KW= 493.414
CONDUCTION LOSS, KW= 51.619
RADIATION LOSS, KW= 316.114
ENERGY TO FLUID, KW= 10916.596

RECEIVER SURFACE AREA = 1627.17
VIEW FACTOR TO APERTURE = .165
RECEIVER EFFICIENCY, %= 90.08

MAX OIL TEMPERATURE, DEG-F= 587
MAX FIN TEMPERATURE, DEG-F= 670.5
MAX FRONT TEMPERATURE, DEG-F= 627.6
MAX BACK TEMPERATURE, DEG-F= 586.3

MAXIMUM THERMAL STRESS, PSI= 20557

AVERAGE TUBE SURFACE TEMP = 565
AVERAGE FIN SURFACE TEMP = 592
AVERAGE SURFACE TEMP (CONVECTION) = 569
AVERAGE SURFACE TEMP (RADIATION) = 571
AVERAGE CAVITY WALL TEMP = 534

FLUID INLET TEMP = 420
PASS #1 OUTLET TEMP = 526
PASS #2 OUTLET TEMP = 571.8
FLUID AVERAGE TEMP = 495.9

TOTAL PANEL SET FLOW RATE, GPM = 1064

AVERAGE SPECIFIC HEAT, BTU/LB-DEG-F = .618
AVERAGE VISCOSITY, LB/FT-HR = .57
AVERAGE DENSITY, LB/CU-FT = 44.02
AVERAGE CONDUCTIVITY, BTU/FT-HR-DEG-F = .06859

****

Figure 5.2.5-11

RUN SUMMARY,DAY 80 TIME=8:00 A.M.

APERTURE PLANE ENERGY, KW= 10925
ENERGY ON RECEIVER, KW= 10717.716
ENERGY APERTURE CUT-OFF, KW= 135.470001
ENERGY MISSING PANELS, KW= 71.814
ABSORPTIVITY LOSS, KW= 105.653
CONVECTION LOSS, KW= 480.447
CONDUCTION LOSS, KW= 50.31
RADIATION LOSS, KW= 299.536
ENERGY TO FLUID, KW= 9781.775

RECEIVER SURFACE AREA = 1627.17
VIEW FACTOR TO APERTURE = .165
RECEIVER EFFICIENCY, %= 89.54

MAX OIL TEMPERATURE, DEG-F= 585.7
MAX FIN TEMPERATURE, DEG-F= 679.9
MAX FRONT TEMPERATURE, DEG-F= 626.7
MAX BACK TEMPERATURE, DEG-F= 576.2

MAXIMUM THERMAL STRESS, PSI= 20645

AVERAGE TUBE SURFACE TEMP = 551
AVERAGE FIN SURFACE TEMP = 575
AVERAGE SURFACE TEMP (CONVECTION) = 554
AVERAGE SURFACE TEMP (RADIATION) = 557
AVERAGE CAVITY WALL TEMP = 522

FLUID INLET TEMP = 420
PASS #1 OUTLET TEMP = 514
PASS #2 OUTLET TEMP = 556.8
FLUID AVERAGE TEMP = 488.4

TOTAL PANEL SET FLOW RATE, GPM = 1064

AVERAGE SPECIFIC HEAT, BTU/LB-DEG-F = .614
AVERAGE VISCOSITY, LB/FT-HR = .588
AVERAGE DENSITY, LB/CU-FT = 44.27
AVERAGE CONDUCTIVITY, BTU/FT-HR-DEG-F = .06878

****

Figure 5.2.5-12

RUN SUMMARY, DAY 173 TIME=12:00 NOON

APERTURE PLANE ENERGY, KW= 11509
ENERGY ON RECEIVER, KW= 11236.338
ENERGY APERTURE CUT-OFF, KW= 171.484101
ENERGY MISSING PANELS, KW= 101.178
ABSORPTIVITY LOSS, KW= 110.102
CONVECTION LOSS, KW= 486.525
CONDUCTION LOSS, KW= 50.937
RADIATION LOSS, KW= 306.938
ENERGY TO FLUID, KW= 10281.832

RECEIVER SURFACE AREA = 1627.17
VIEW FACTOR TO APERTURE = .165
RECEIVER EFFICIENCY, %= 89.34

MAX OIL TEMPERATURE, DEG-F= 580
MAX FIN TEMPERATURE, DEG-F= 634.6
MAX FRONT TEMPERATURE, DEG-F= 618.5
MAX BACK TEMPERATURE, DEG-F= 579

MAXIMUM THERMAL STRESS, PSI= 17125

AVERAGE TUBE SURFACE TEMP = 557
AVERAGE FIN SURFACE TEMP = 582
AVERAGE SURFACE TEMP (CONVECTION) = 561
AVERAGE SURFACE TEMP (RADIATION) = 563
AVERAGE CAVITY WALL TEMP = 528

FLUID INLET TEMP = 420
PASS #1 OUTLET TEMP = 517.5
PASS #2 OUTLET TEMP = 563.4
FLUID AVERAGE TEMP = 491.7

TOTAL PANEL SET FLOW RATE, GPM = 1064

AVERAGE SPECIFIC HEAT, BTU/LB-DEG-F = .616
AVERAGE VISCOSITY, LB/FT-HR = .58
AVERAGE DENSITY, LB/CU-FT = 44.16
AVERAGE CONDUCTIVITY, BTU/FT-HR-DEG-F = .0687

Figure 5.2.5.13

RUN SUMMARY,DAY 173 TIME=10:00 A.M.

APERTURE PLANE ENERGY, KW= 11118
ENERGY ON RECEIVER, KW= 10830.293
ENERGY APERTURE CUT-OFF, KW= 194.565001
ENERGY MISSING PANELS, KW= 93.142
ABSORPTIVITY LOSS, KW= 106.428
CONVECTION LOSS, KW= 482.192
CONDUCTION LOSS, KW= 50.505
RADIATION LOSS, KW= 301.527
ENERGY TO FLUID, KW= 9889.641

RECEIVER SURFACE AREA = 1627.17
VIEW FACTOR TO APERTURE = .165
RECEIVER EFFICIENCY, %= 88.95

MAX OIL TEMPERATURE, DEG-F= 577.7
MAX FIN TEMPERATURE, DEG-F= 644
MAX FRONT TEMPERATURE, DEG-F= 615.4
MAX BACK TEMPERATURE, DEG-F= 576.2

MAXIMUM THERMAL STRESS, PSI= 17956

AVERAGE TUBE SURFACE TEMP = 553
AVERAGE FIN SURFACE TEMP = 577
AVERAGE SURFACE TEMP (CONVECTION) = 556
AVERAGE SURFACE TEMP (RADIATION) = 558
AVERAGE CAVITY WALL TEMP = 524

FLUID INLET TEMP = 420
PASS #1 OUTLET TEMP = 513.7
PASS #2 OUTLET TEMP = 558.3
FLUID AVERAGE TEMP = 489.1

TOTAL PANEL SET FLOW RATE, GPM = 1064

AVERAGE SPECIFIC HEAT, BTU/LB-DEG-F = .615
AVERAGE VISCOSITY, LB/FT-HR = .586
AVERAGE DENSITY, LB/CU-FT = 44.25
AVERAGE CONDUCTIVITY, BTU/FT-HR-DEG-F = .06876

****

Figure 5.2.5-14

RUN SUMMARY,DAY 173 TIME=8:00 A.M.

APERTURE PLANE ENERGY, KW= 9971
ENERGY ON RECEIVER, KW= 9695.801
ENERGY APERTURE CUT-OFF, KW= 257.251797
ENERGY MISSING PANELS, KW= 17.948
ABSORPTIVITY LOSS, KW= 95.624
CONVECTION LOSS, KW= 469.531
CONDUCTION LOSS, KW= 49.222
RADIATION LOSS, KW= 285.731
ENERGY TO FLUID, KW= 8795.696

RECEIVER SURFACE AREA = 1627.17
VIEW FACTOR TO APERTURE = .165
RECEIVER EFFICIENCY, %= 88.21

MAX OIL TEMPERATURE, DEG-F= 569.9
MAX FIN TEMPERATURE, DEG-F= 653.4
MAX FRONT TEMPERATURE, DEG-F= 605.2
MAX BACK TEMPERATURE, DEG-F= 567

MAXIMUM THERMAL STRESS, PSI= 18120

AVERAGE TUBE SURFACE TEMP = 539
AVERAGE FIN SURFACE TEMP = 560
AVERAGE SURFACE TEMP (CONVECTION) = 542
AVERAGE SURFACE TEMP (RADIATION) = 544
AVERAGE CAVITY WALL TEMP = 513

FLUID INLET TEMP = 420
PASS #1 OUTLET TEMP = 502.5
PASS #2 OUTLET TEMP = 543.7
FLUID AVERAGE TEMP = 481.8

TOTAL PANEL SET FLOW RATE, GPM = 1064

AVERAGE SPECIFIC HEAT, BTU/LB-DEG-F = .611
AVERAGE VISCOSITY, LB/FT-HR = .603
AVERAGE DENSITY, LB/CU-FT = 44.49
AVERAGE CONDUCTIVITY, BTU/FT-HR-DEG-F = .06895

****

Figures 5.2.5-15 through 5.2.5-20 provide a detailed accounting of the energy in and out for each of the 148 panel nodes for the peak flux time (winter solstice, 12:00 noon). As noted earlier, the energy losses from each node include an allocated portion of the loss from the inactive cavity wall. This allocation was made in accordance with the view factor x node area of each node/total receiver view factor x total receiver area ratio. The view factors are those between the receiver and the inactive wall. Similar energy node maps for the other eight day and time cases are provided in Appendix E.

Figures 5.2.5-21 through 5.2.5-24 provide a panel-by-panel accounting of the local maximum: oil temperature, flow passage frontside temperature, between-passage fin temperature, and thermal stress for each of the 56 panels which together comprise the receiver. Similar panel maps for the other eight day and time cases are provided in Appendix E.

Figure 5.2.5-15
Incident Power, kw
Day 355 Time 12:00

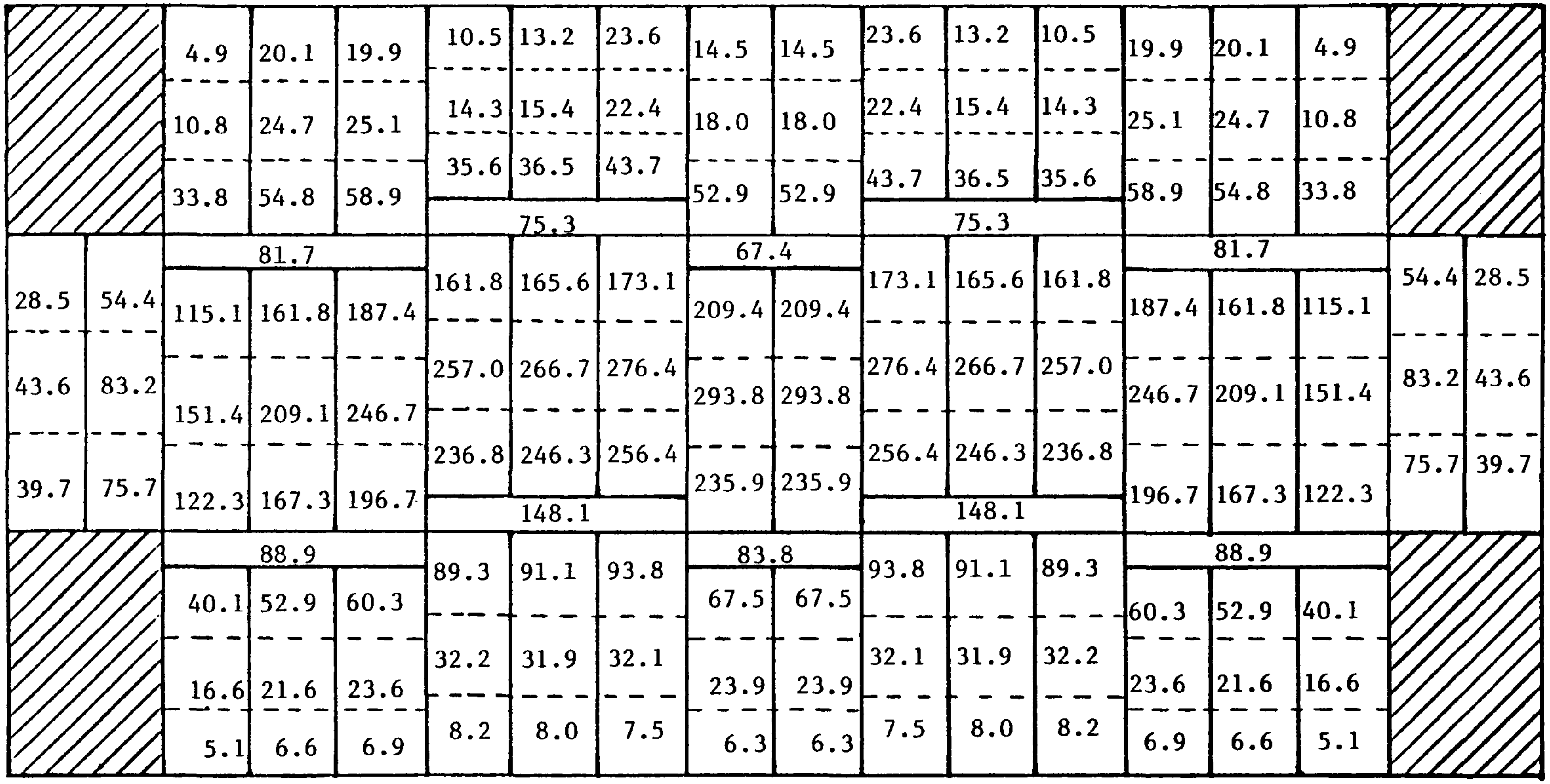
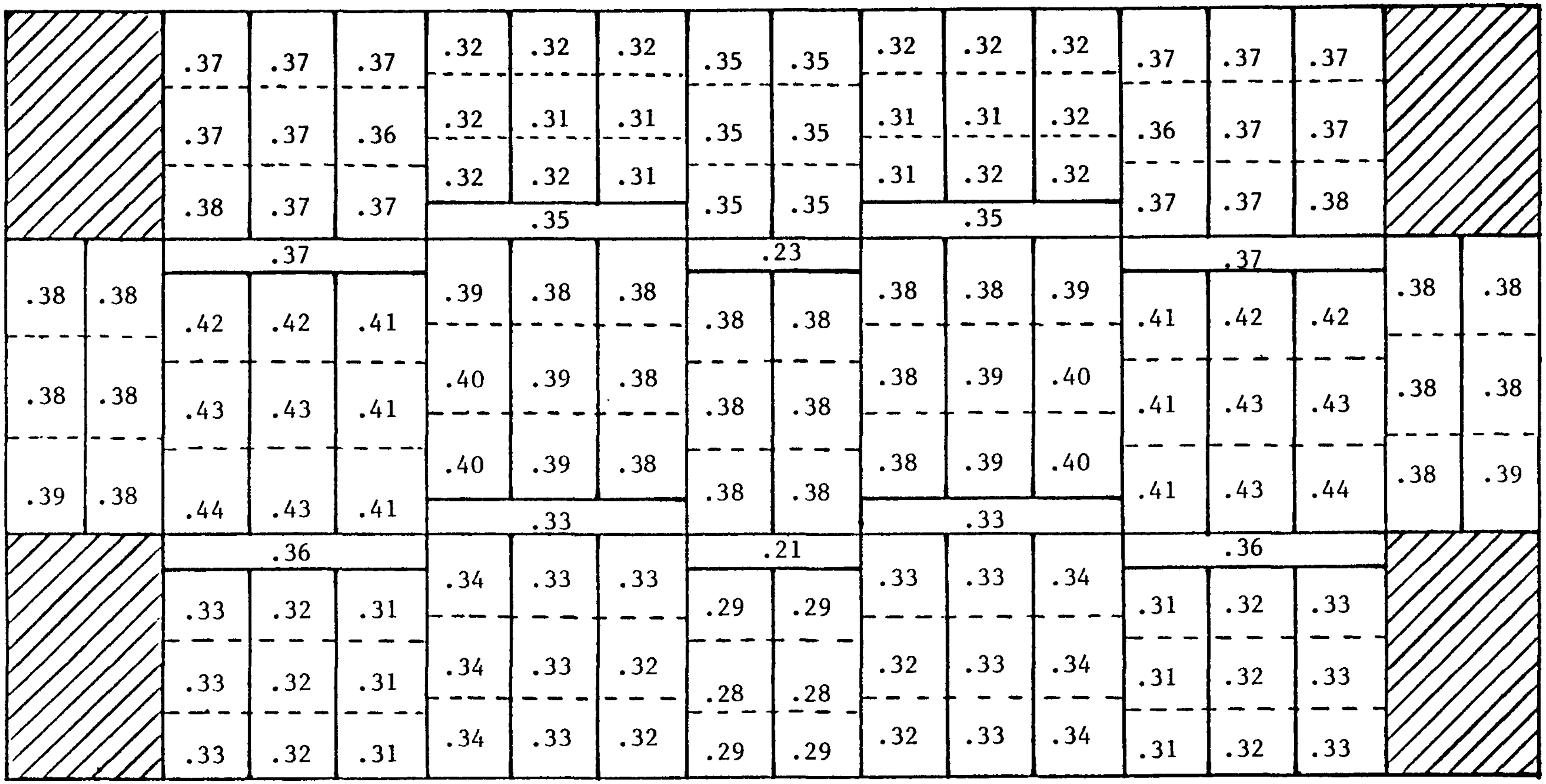
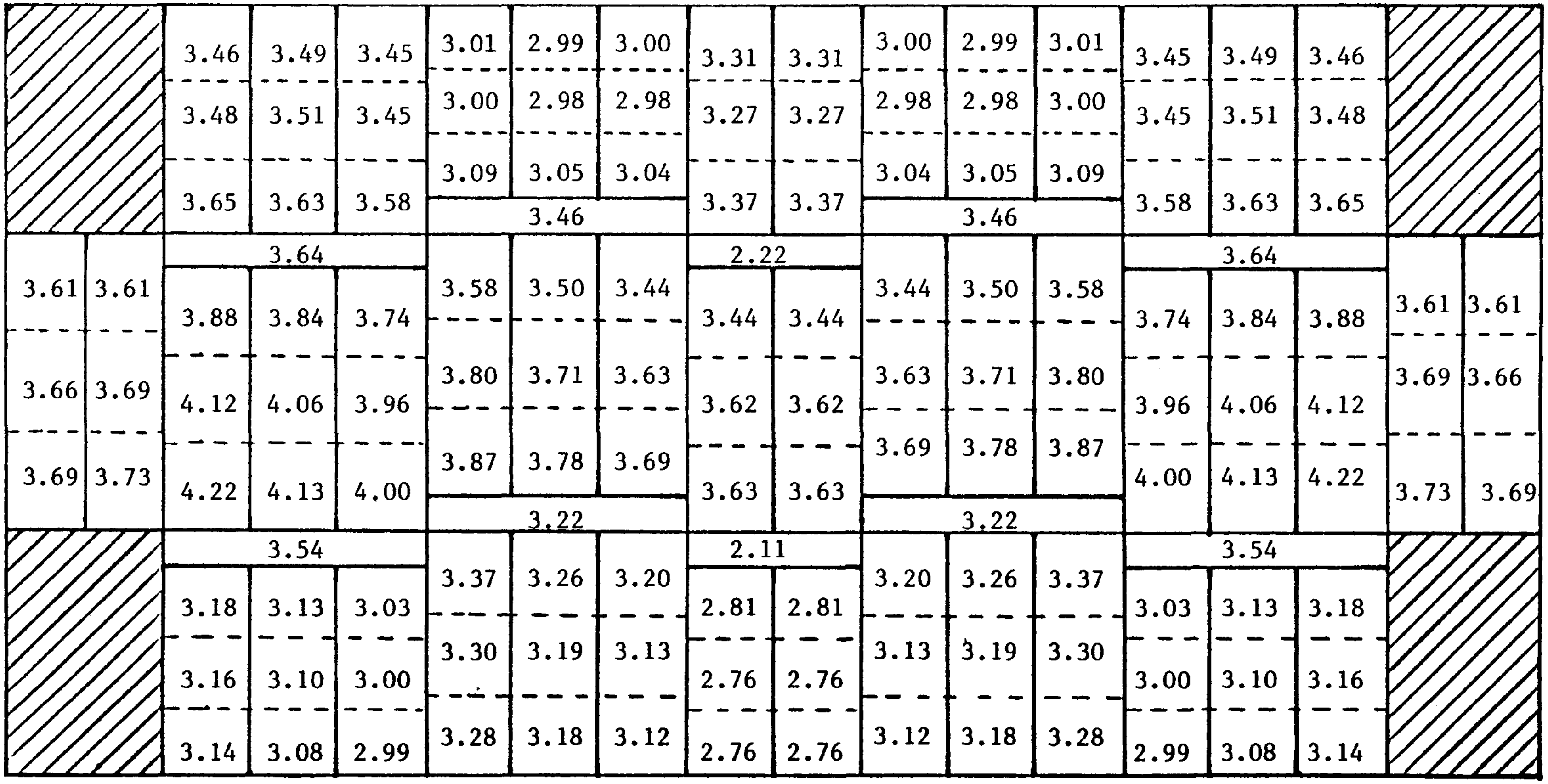


Figure 5.2.5-16
Conduction Loss, kw
Day 355 Time 12:00



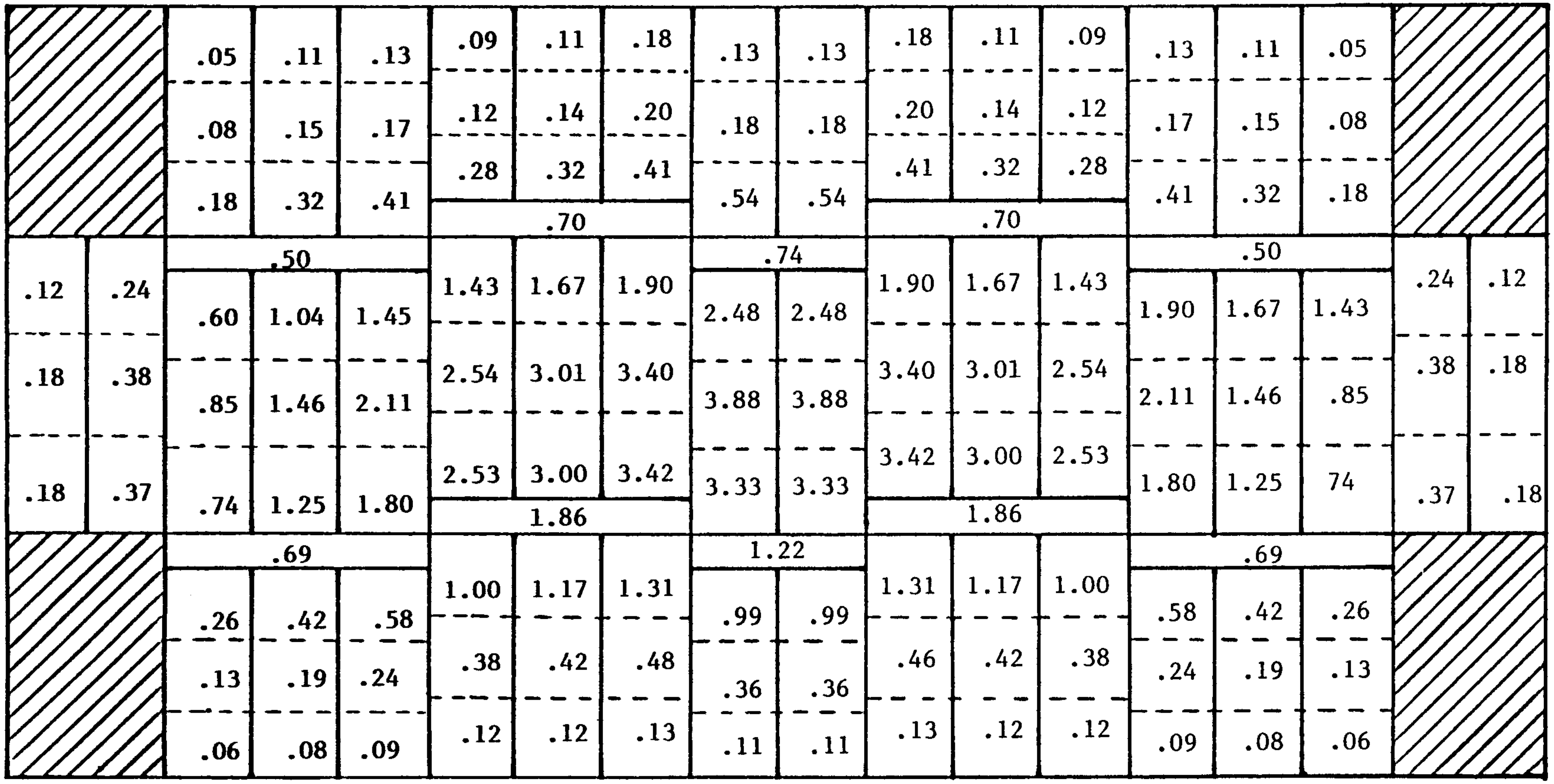
*Node losses shown include an allocated portion of the inactive cavity wall loss

Figure 5.2.5-17
Convective Loss, kw
Day 355 Time 12:00



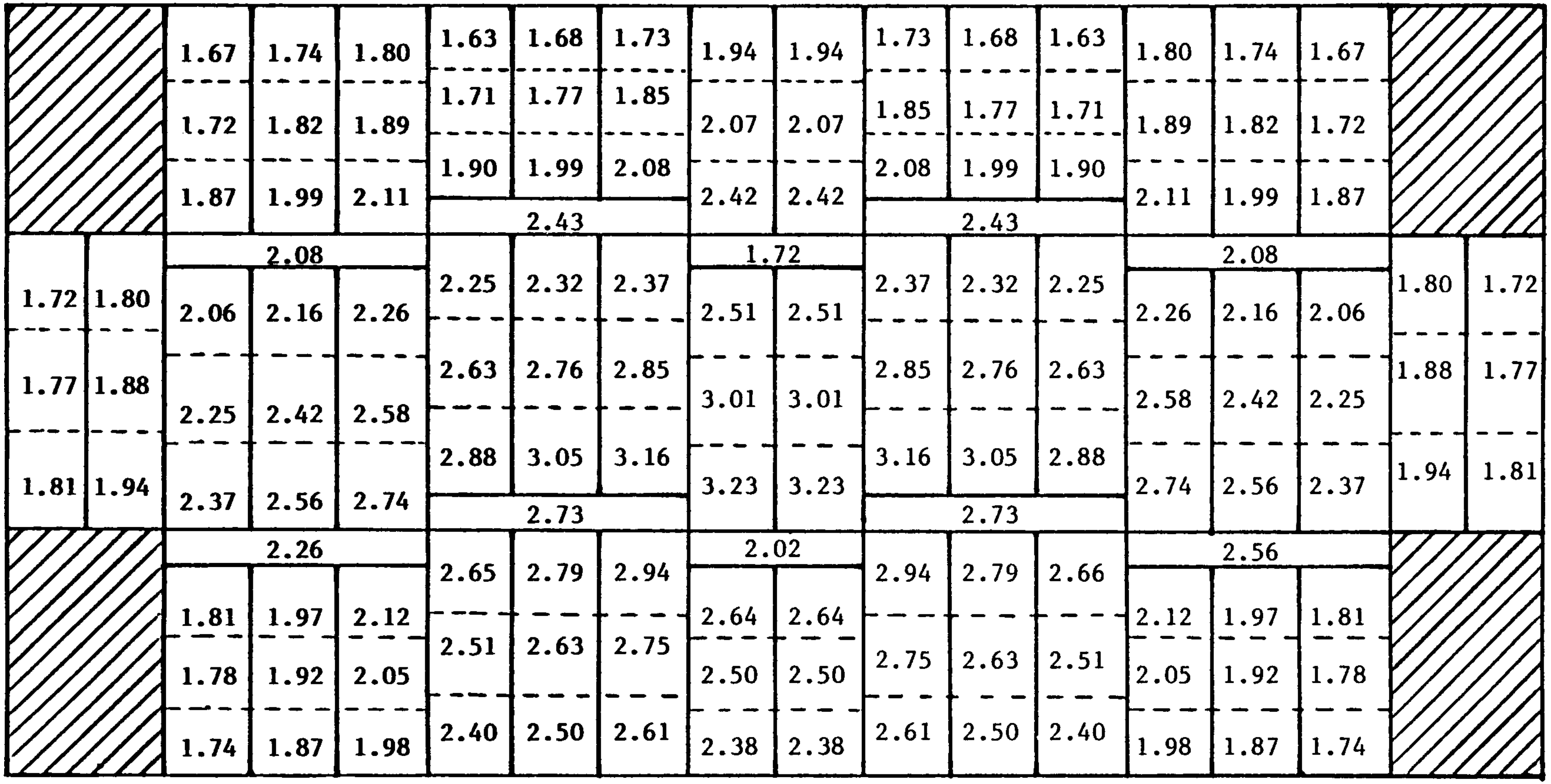
*Node losses shown include an allocated portion of the inactive cavity wall loss

Figure 5.2.5-18
Reflective Loss, kw
Day 355 Time 12:00



*Node losses shown include an allocated portion of the inactive cavity wall loss

Figure 5.2.5-19
Radiation Loss, kw
Day 355 Time 12:00



***Node losses shown include an allocated portion of the inactive cavity wall loss**

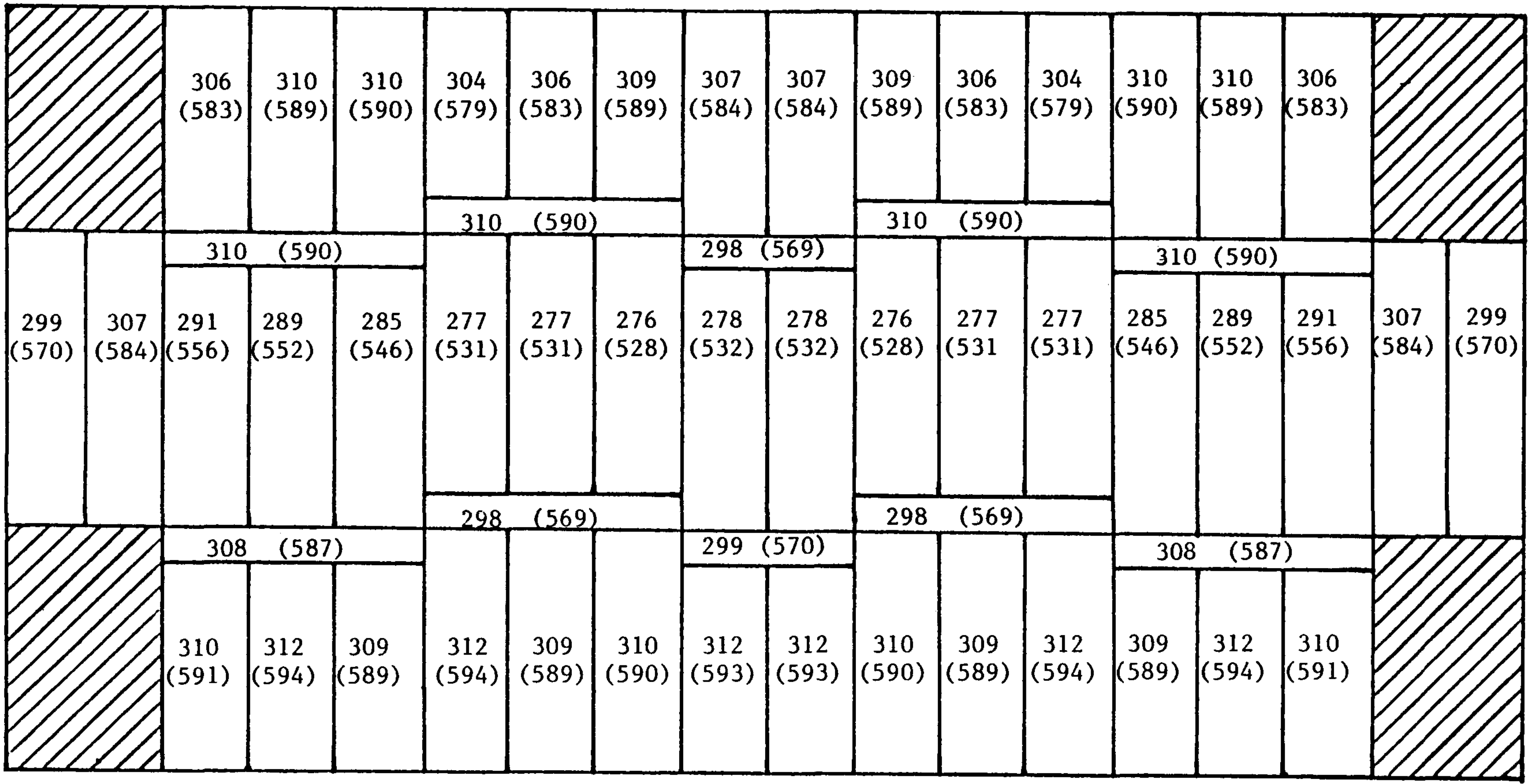
Figure 5.2.5-20
Net Power Into Oil, kw
Day 355 Time 12:00

		-.6	14.4	14.2	5.5	8.1	18.4	8.8	8.8	18.4	8.1	5.5	14.2	14.4	-.6		
		5.2	18.8	19.3	9.2	10.2	17.1	12.1	12.1	17.1	10.2	9.2	19.3	18.8	5.2		
		27.7	48.4	52.5	30.0	30.8	37.8	46.2	46.2	37.8	30.8	30.0	52.5	48.4	27.7		
					68.4					68.4							
		75.1						62.5					75.1				
22.7	48.4	108.1	154.4	179.5	154.1	157.8	165.0	200.6	200.6	165.0	157.8	154.1	179.5	154.4	108.1	48.4	22.7
37.6	76.9	143.7	200.8	237.6	247.6	256.9	266.1	282.9	282.9	266.1	256.9	247.6	237.6	200.8	143.7	76.9	37.6
33.6	69.2	114.5	158.9	187.8	227.1	236.0	245.8	225.3	225.3	245.8	236.0	227.1	187.8	158.9	114.5	69.2	33.6
					140.0					140.0							
		82.0						78.2					82.0				
		34.5	47.1	54.3	81.9	83.5	86.0	60.7	60.7	86.0	83.5	81.9	54.3	47.1	34.5		
		11.2	16.0	18.0	25.7	25.3	25.5	18.0	18.0	25.5	25.3	25.7	18.0	16.0	11.2		
		-.1	1.3	1.6	2.0	1.8	1.3	.8	.8	1.3	1.8	2.0	1.6	1.3	-.1		

FIGURE 5.2.5-21

OIL OUTLET TEMPERATURE, C (°F)

DAY 355 TIME 12:00

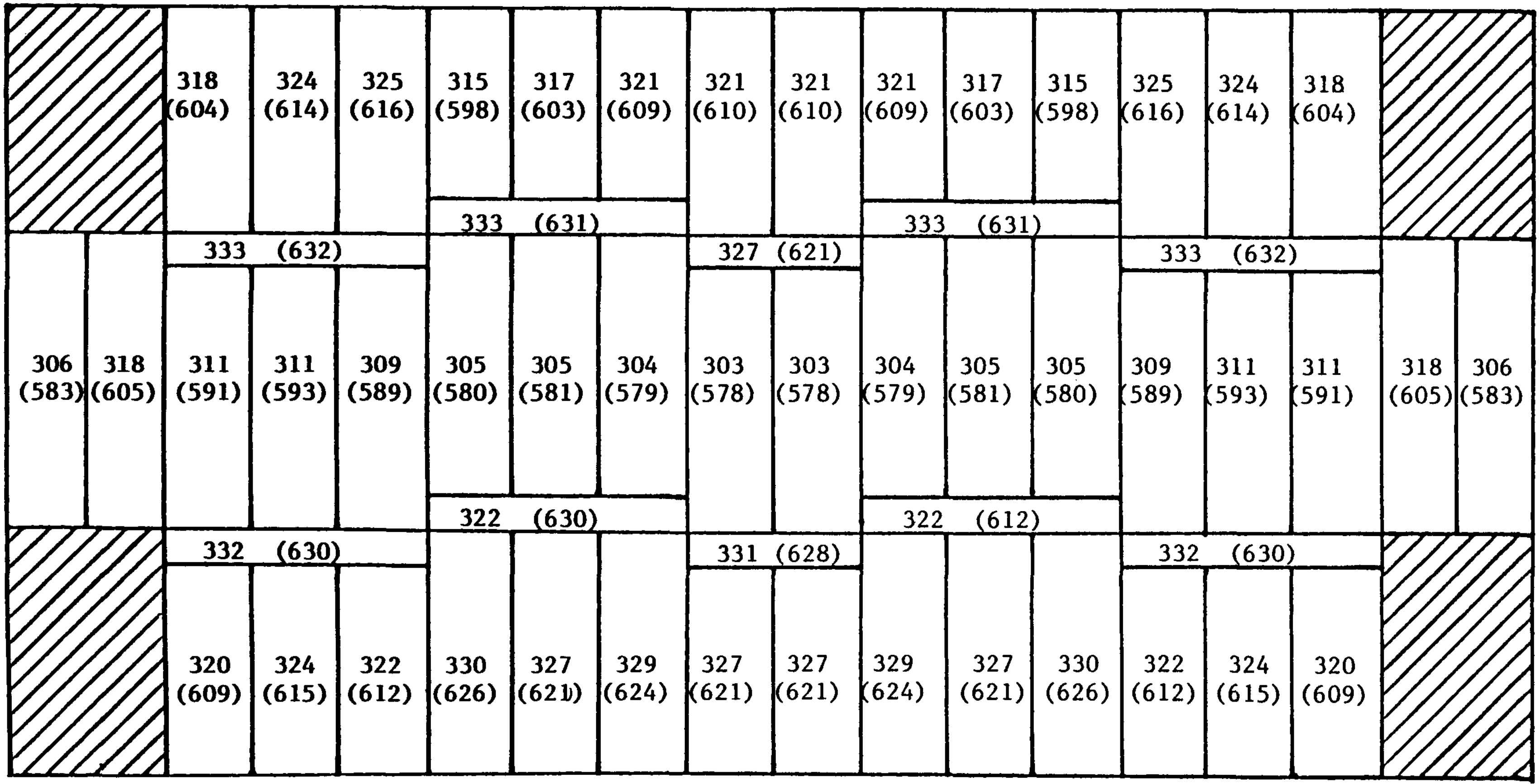


Note: The design goal was to limit the maximum oil outlet temperature to 316 C (600° F).
The actual maximum for this day and time is 312 C (594° F).

FIGURE 5.2.5-22

MAXIMUM FLOW PASSAGE FRONT SIDE TEMPERATURE, C (°F)

DAY 355 TIME 12:00

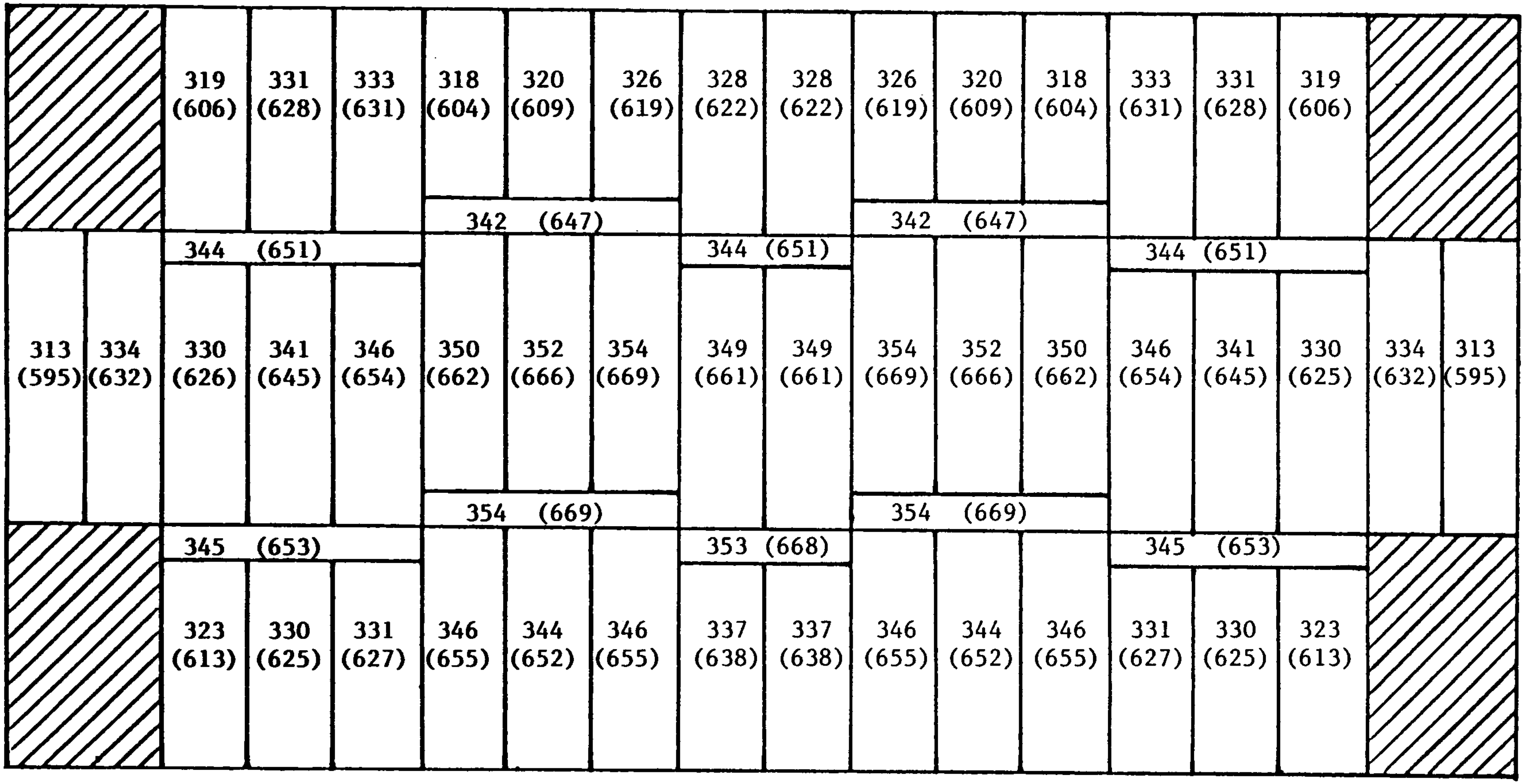


Note: The design goal was to limit the maximum passage front side temperature to 343 C (650° F). The actual maximum for this day and time is 333 C (632° F).

FIGURE 5.2.5-23

MAXIMUM BETWEEN-PASSAGE (FIN) TEMPERATURE, C (°F)

DAY 355 **TIME** 12:00

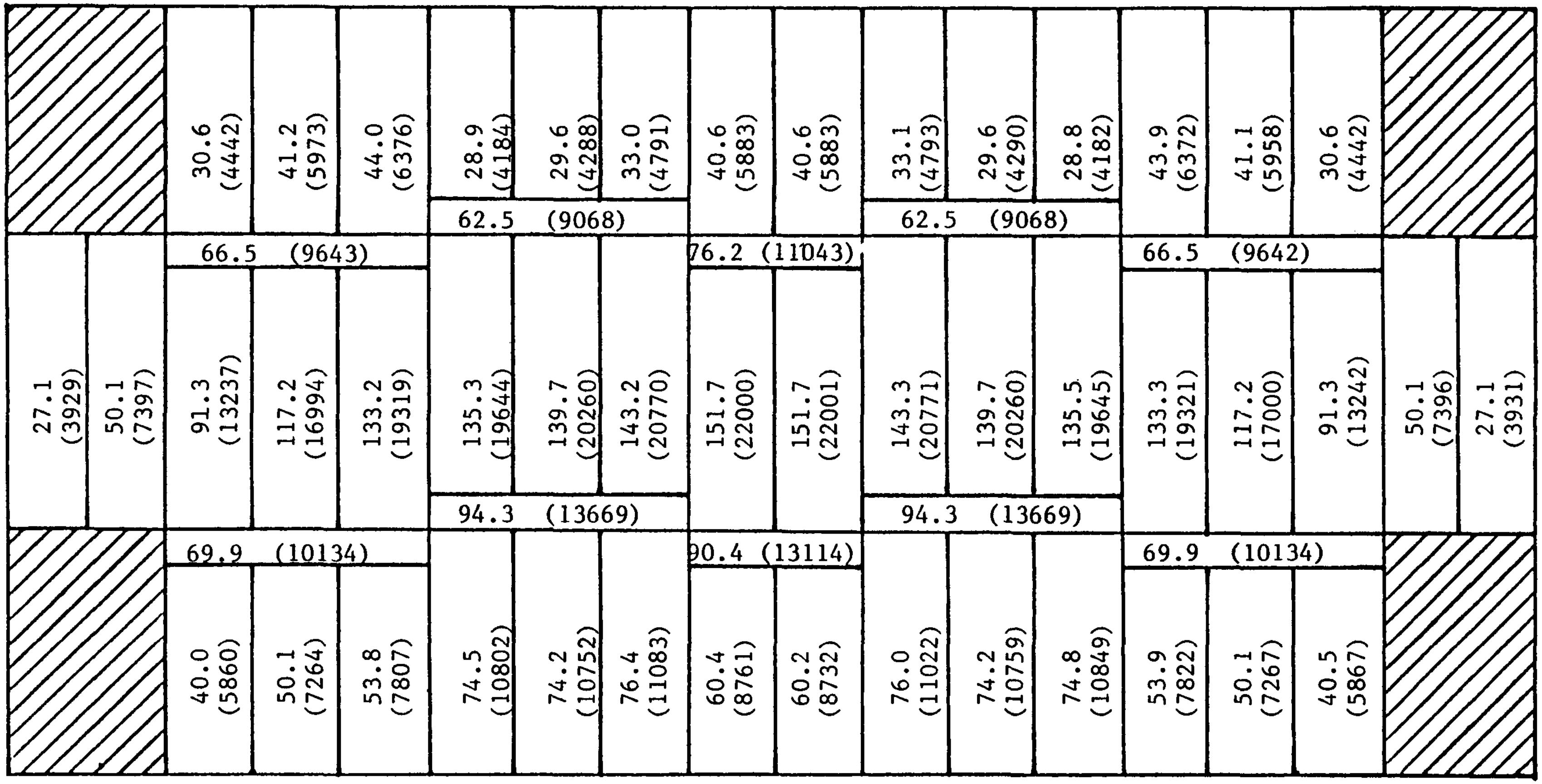


Note: **The design goal was to limit the maximum between-passage (fin) temperature to 357 C (675° F). The actual maximum for this day and time is 354 C (669° F).**

FIGURE 5.2.5-24

MAXIMUM THERMAL STRESS, PASCALS X 10^{-6} (psi)

DAY 355 TIME 12:00



Note: The design goal was to limit the maximum thermal stress to 172.4 x 10^6 Pa (25,000 psi). The actual maximum for this date and time is 151.7 x 10^6 Pa (22,001 psi).

5.2.5.4 Receiver Thermal Performance - Sensitivity

In the previous section, the receiver thermal performance was presented for the baseline assumptions of ambient conditions and surface properties. In this section, the receiver performance is examined as these conditions are varied. The specific variables examined in this study versus the baseline assumptions were:

A. Wind speed at the aperture plane: vary from 0 m/s (0 mph) to 17.88 m/s (40 mph) - baseline windspeed = 4.75 m/s (10.63 mph).

B. Ambient temperature: vary from -17.8 C (0^o F) to 37.8 C (100^o F) - baseline ambient temperature = 10 C (50^o F).

C. Receiver emissivity: vary from 0.2 to 0.95 - baseline emissivity = 0.95.

D. Receiver absorptivity: vary from 0.8 to 0.95 - baseline absorptivity = 0.95.

E. Cavity wall absorptivity: vary from 0.2 to 0.9 - baseline absorptivity = 0.90.

F. Cavity wall emissivity: vary from 0.2 to 0.9 - baseline emissivity = 0.90.

G. Convection coefficient: vary from 4.54 Kw/m^2k (0.8 BTU/ft^2-hr-^oF) to 8.34 Kw/m^2K (1.47 BTU/ft^2-hr-^oF) - baseline value = 6.41 Kw/m^2K (1.13 BTU/ft^2-hr-^oF).

All of the sensitivity variations were evaluated for the peak flux day and time only (12:00 noon, winter solstice). The results are presented on Figures 5.2.5-25 through 5.2.5-31. The important conclusion from this study is that the receiver efficiency for the North Coles Levee cavity receiver is relatively insensitive to a wide range of ambient and surface property conditions. Specifically, the following results were obtained:

A. As windspeed is varied from 0 m/s (0 mph) to 17.88 m/s (40 mph), the receiver efficiency is reduced from 91.62 to 89.97.

B. As ambient temperature is increased from -17.8 C to 37.8 C (0^o to 100^o F), the receiver efficiency is increased from 90.40% to 91.13%.

C. As the receiver emissivity is increased from 0.2 (i.e., highly selective) to 0.95 (non-selective), the receiver efficiency is decreased from 91.95% to 90.76%.

D. As the receiver absorptivity is varied from 0.85 (i.e., dusty surface) to 0.95 (clean black paint), the receiver efficiency is increased from 86.51 % to 90.76%.

E. As the cavity wall absorptivity is varied from 0.2 (white coating) to 0.9 (black or dirty coating), the receiver efficiency is decreased from 91.72% to 90.76%.

F. As the cavity wall emissivity is varied from 0.2 (highly selective) to 0.9 (non-selective), the receiver efficiency is decreased from 91.57 % to 90.76%.

G. As the convection coefficient is varied ± 30% from the baseline assumption, the receiver efficiency varies from 89.88% to 91.62%.

Figure 5.2.5-25
Receiver Efficiency vs. Windspeed

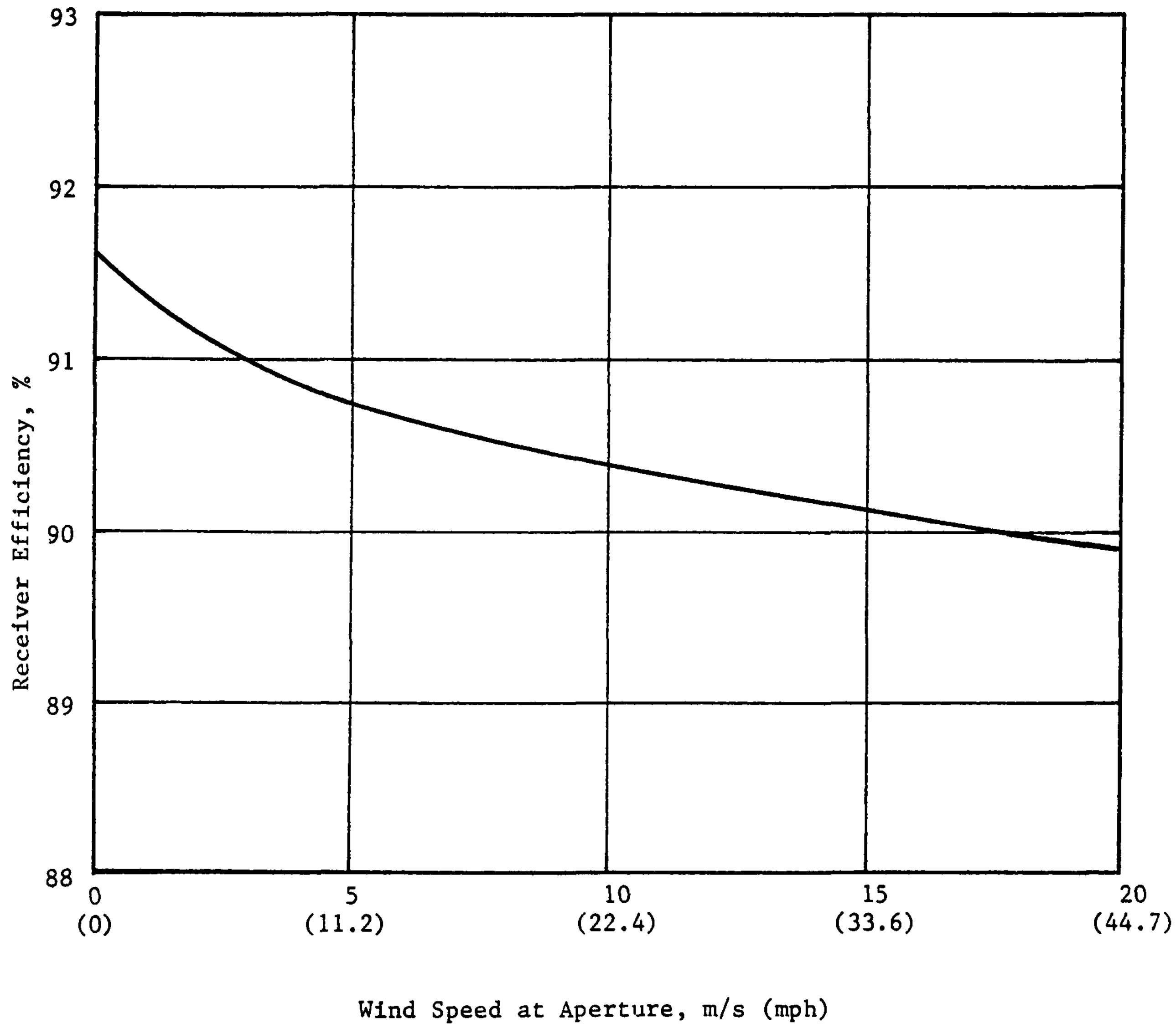


Figure 5.2.5-26
Receiver Efficiency vs. Ambient Temperature

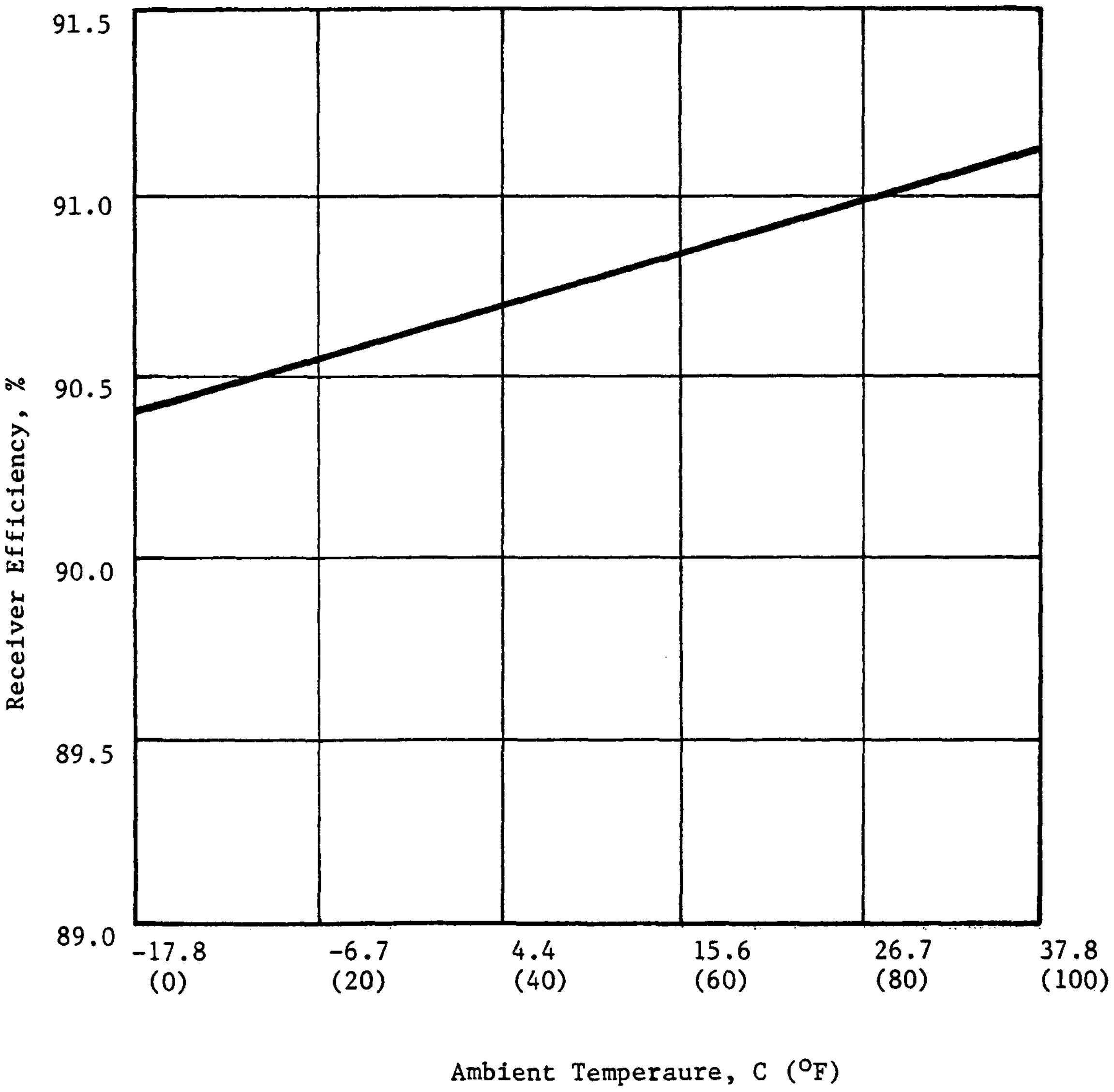


Figure 5.2.5-27
Receiver Efficiency vs. Receiver Emissivity

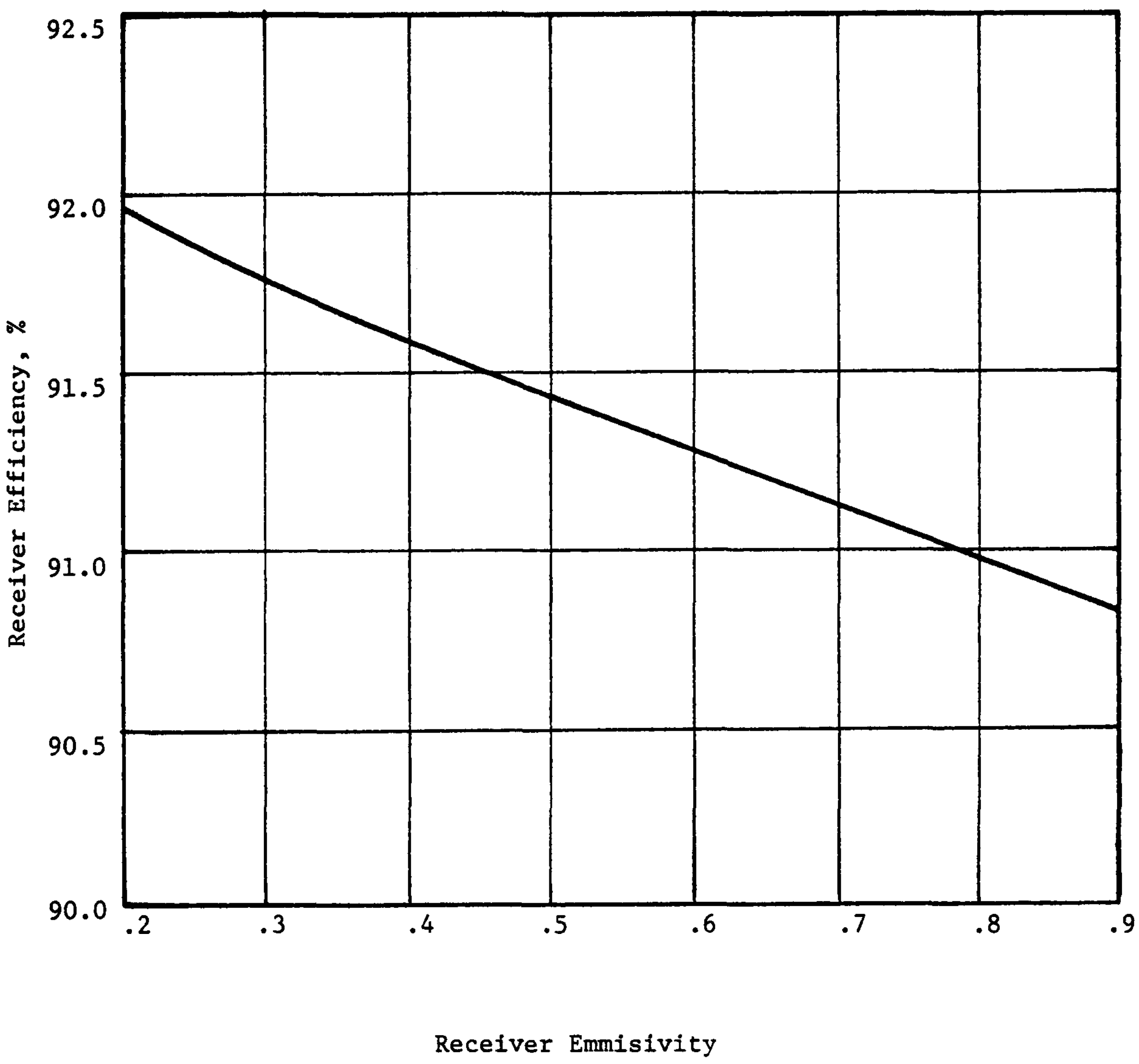


Figure 5.2.5-28
Receiver Efficiency vs. Receiver Absorptivity

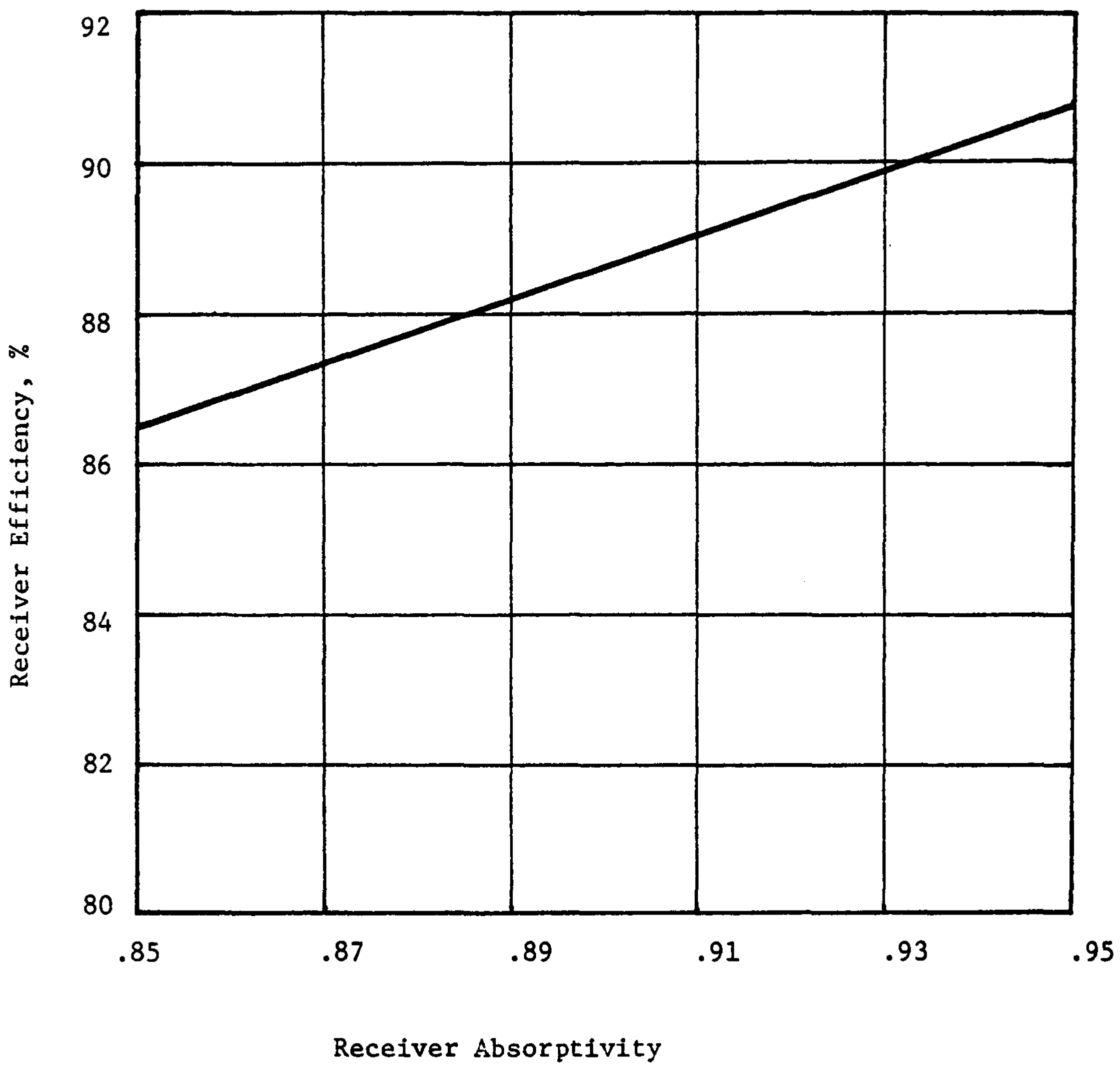


Figure 5.2.5-29
Receiver Efficiency vs. Insulated Cavity Wall Absorptivity

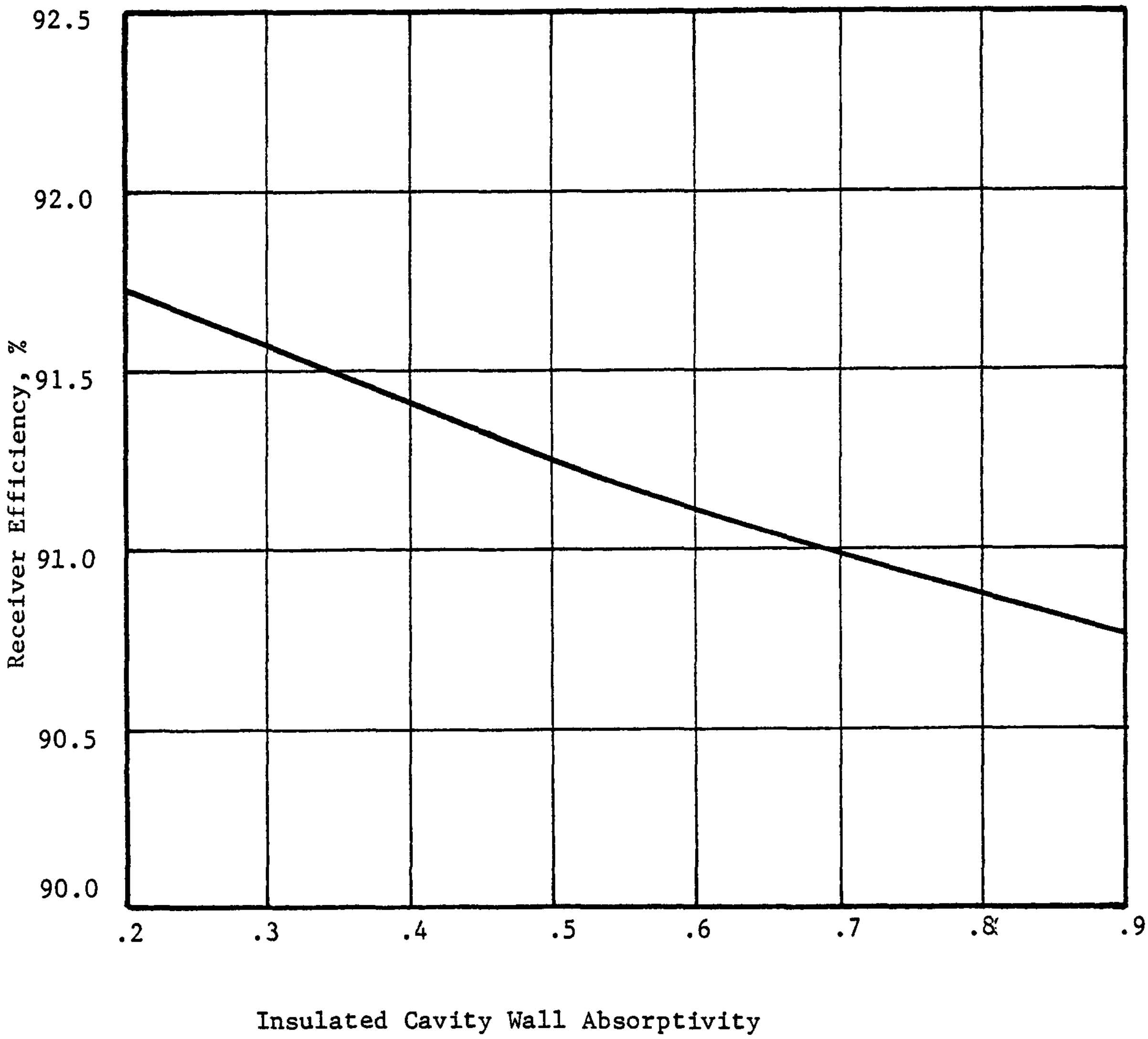


Figure 5.2.5-30
Receiver Efficiency vs. Cavity Wall Emissivity

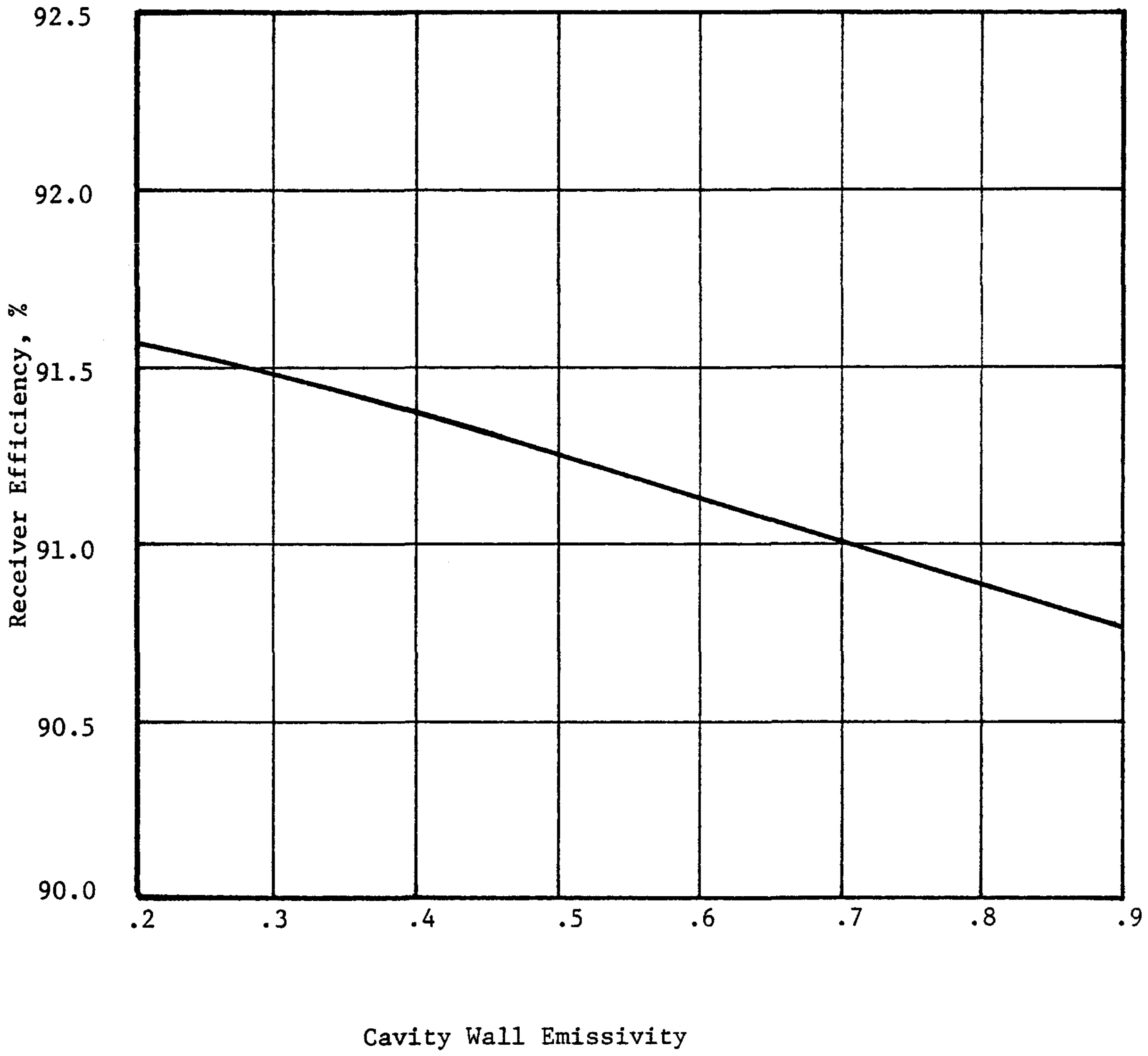
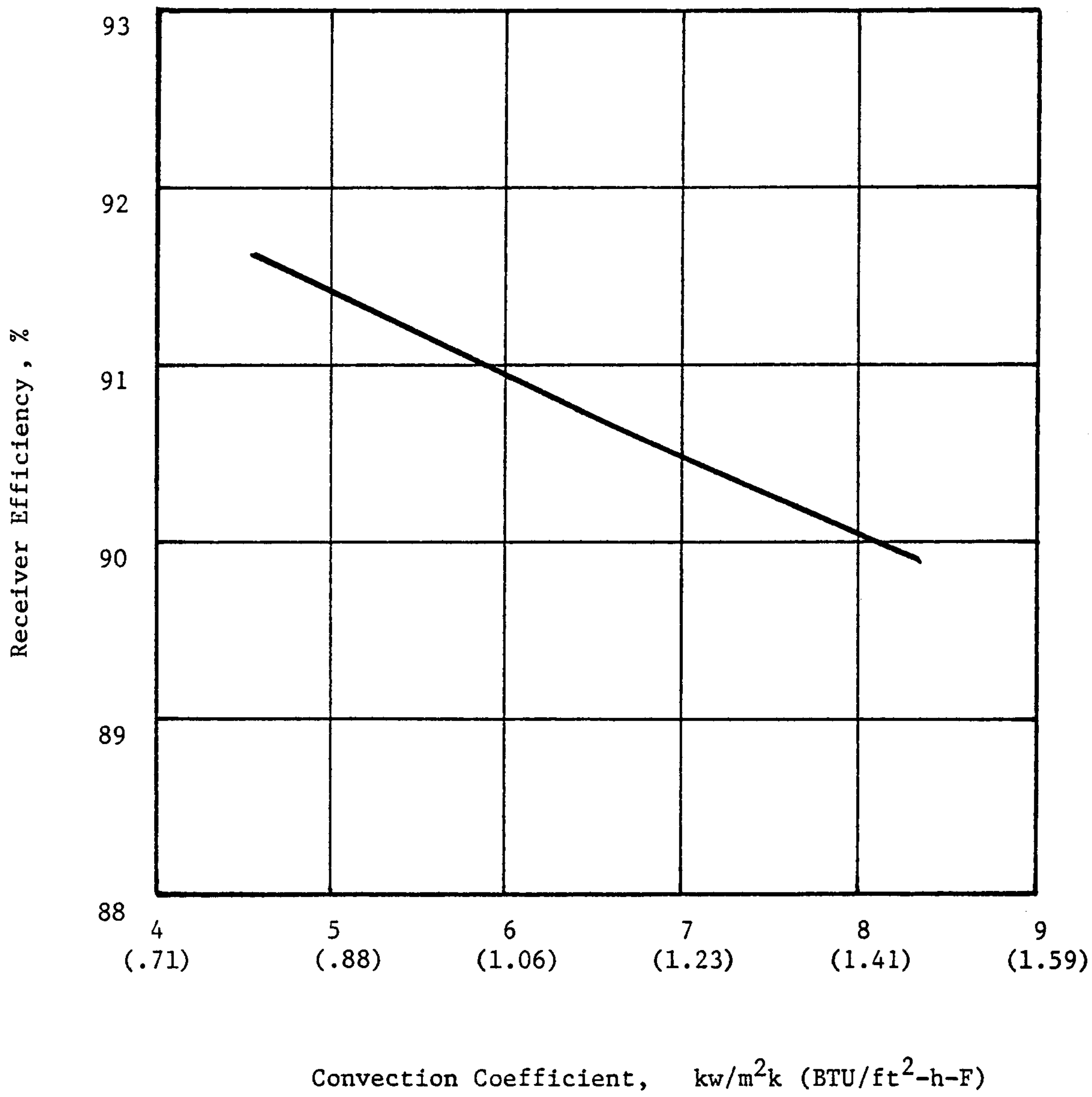


Figure 5.2.5-31
Receiver Efficiency vs. Convection Coefficient



5.2.5.5 Receiver Cooldown Losses

In addition to receiver heat loss during operation, another important loss occurs during shutdown periods such as normal overnight shutdown, rainy days, or extended cloudy periods of several hours duration. The transient cooldown characteristic for the receiver is presented on Figure 5.2.5-32. Heat is lost from the receiver during these off-periods via conduction through the insulation and by air infiltration through the receiver. The receiver loss rate due to air infiltration is assumed to be 50% of the insulation conduction rate.

It will be noted that the cooldown transient begins from a temperature of 215.6 C (420° F) even though the receiver and manifold fluid are normally at 282-304 C (540-580 °F) at the time of heliostat shutdown. The reason for this is that the control system will be configured to maintain the receiver pump "on" until the returning oil temperature falls below 215.6 C (420° F). In this way, a portion of the energy stored in the system is returned to the process rather than being lost in the shutdown cooldown.

Figure 5.2.5-32
Receiver Cooldown Characteristic

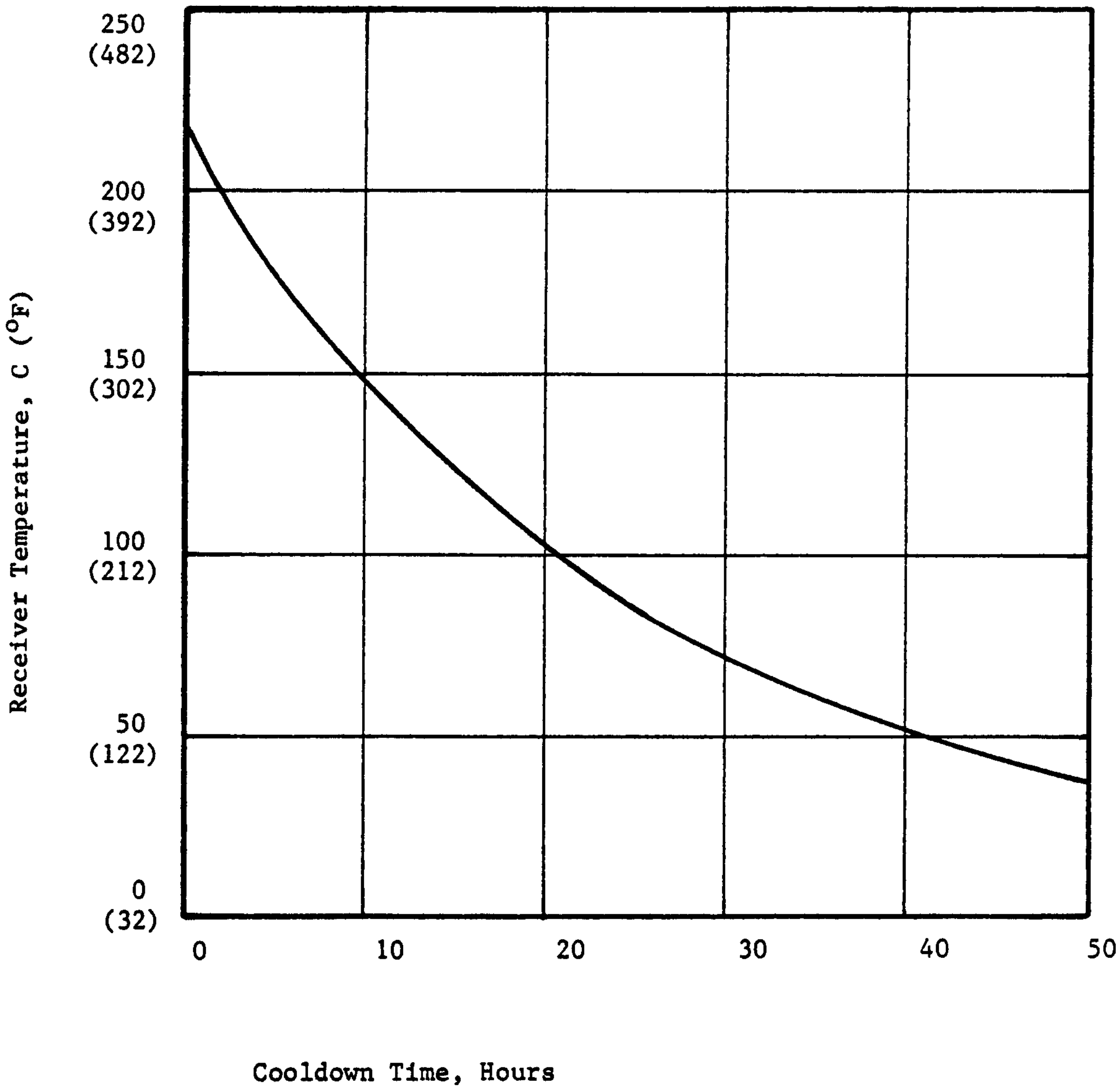


Table 5.2.5-6 presents the receiver cooldown energy loss as a function of the shutdown duration. The difficulty is using these data to predict the annual energy loss is that an estimate must be made of the frequency and duration of the anticipated shutdowns for a complete year. Table 5.2.5-7 presents the cooldown frequency-time estimates used and the corresponding energy loss for the year. It should be noted that these are only estimates, and are not based on an actual weather year analysis. The long duration shutdown times (12 - 48 hours) were estimated with some pertinant Bakersfield weather data (i.e., 202 clear days, 78 partial cloudy days, 12 days with some sunny periods, and 73 generally cloudy or foggy days). Also, the total daylight period down-time is consistent with the average annual percent sunshine of 78% for Fresno.

Since the total annual energy absorbed by the receiver is on the order of 22.9×10^6 kwh annual, this cooldown loss of 235,094 kwh corresponds to a percentage loss of 1.03%. Even though this is a non-operating period loss, it can be assessed against the receiver operating efficiency. This would lower the annual average receiver efficiency from 89.59% to 88.56%.

Table 5.2.5-6
Receiver Energy Loss Following System Shutdown

Shutdown Duration	Receiver Energy Loss
0 hours	0 kw-hr
1	58.2
2	112.5
3	166.8
4	217.2
6	310.3
8	399.6
10	481.0
12	554.7
15	655.6
18	744.8
21	826.3
24	896.1
30	1012.0
36	1103.7
42	1175.6
48	1231.9
∞	1435.3

Table 5.2.5-7
Shutdown Frequency-Time-Energy Loss Estimate
North Coles Levee Receiver System

Frequency	Duration	Energy Loss
19	1 hour	1106 Kwh
16	2	1800
13	3	2168
9	4	1955
6	5	1583
5	6	1552
4	7	1420
3	8	1199
1	9	440
1	10	481
1	11	518
105*	12	58,244
97*	14	60.475
78*	16	53,580
9	24	8,066
12	36	13,244
13	48	16,015
8	96	11,248
Annual Total		235,094 Kwh

*Normal overnight shutdown periods

5.2.6 Receiver Trade-Offs

An early trade-off study was made when the receiver consisted of 23 mini-receivers located at ground level, and was concerned with the use of a selective surface versus a non-selective black paint. The conclusion reached was that progress was being made in the development of a high temperature selective surface (probably black chrome), and that it should be used if available. The primary reason for this conclusion was that if the selective surface degraded or proved unacceptable, it would be an easy and inexpensive process to paint over the surface with a black paint. A detailed discussion of this study is provided in Appendix F.

Since the single receiver evolved as the most economic option, the decision was made to employ a cavity type of receiver, primarily to minimize convection losses (which are somewhat uncertain at high Reynolds Numbers). With a cavity type of receiver, the radiative heat loss is low, even with a non-selective black paint. The sensitivity analysis discussed in the previous section showed that the receiver efficiency would be improved from 90.76% to 91.95% if the absorber emissivity were lowered from 0.95 to 0.20. Even though such an emissivity reduction is possible with a selective surface, this benefit is likely negated by the fact that the absorptivity of selective surfaces is usually lower than black paint. Therefore, a selective surface was not considered for the cavity design.

The primary trade-off study for the cavity receiver was to optimize the aperture size (i.e., optimize the receiver efficiency). The results were discussed in Section 5.2.5, and are summarized again on Table 5.2.6-1. For the nine different day and and time situations, the 8.23 x 8.23 m (27 x 27 feet) clearly optimizes the receiver efficiency.

Table 5.2.6-1

Receiver Efficiency Vs. Aperture Size

Aperture Size, m (ft)	Day 355 8:00	Day 355 10:00	Day 355 12:00	Day 80 8:00	Day 80 10:00	Day 80 12:00	Day 173 8:00	Day 173 10:00	Day 173 12:00
10.06 x 10.06 (33 x 33)	87.88%	89.21%	89.50%	88.42%	89.07%	89.30%	88.24 *	88.32 %	88.52% *
9.14 x 9.14 (30 x 30)	88.28	89.77	90.13	88.98	89.57	89.85	88.23	88.64	88.93
8.23 x 8.23 (27 x 27)	88.69*	90.33*	90.76*	89.54*	90.08*	90.41*	88.21	88.95*	89.36*
7.32 x 7.32 (24 x 24)	87.99	90.12	90.71	88.38	89.54	90.12	86.37	87.77	88.41
6.40 x 6.40 (21 x 21)	87.30	89.91	90.67	87.22	89.00	89.82	84.52	86.59	87.47
5.49 x 5.49 (18 x 18)	82.59	86.15	87.26	81.72	84.48	85.66	77.82	80.75	81.78
4.57 x 4.57 (15 x 15)	77.84	82.35	83.81	76.17	79.91	81.46	71.04	74.85	76.03
3.66 x 3.66 (12 x 12)	63.38	68.43	70.09	61.40	65.65	67.18	55.71	59.72	61.09
2.74 x 2.74 (9 x 9)	48.80	54.42	56.27	46.50	51.27	52.78	40.27	44.47	46.04

* Optimum aperture size for day and time.

5.2.7 Receiver Cost Estimate

The detailed receiver cost estimate is presented in Appendix A. The summary of these costs by major piece part or work task is as follows:

1.	Materials	($ 197,985)
	a. Absorber Panels	64,630
	b. Pipe, fittings, valves, etc	31,172
	c. Insulation	21,784
	d. Structure & Access doors	39,015
	e. Safety Curtain	3,500
	f. Instrumentation	35,564
	g. Painting	2,320
2.	Sub-Contracts	($ 44,900)
	a. Fire Extinguishing System	21,000
	b. Cavity Door	23,900
3.	Direct Labor	($ 114,603)
	a. Absorber Panels	7,194
	b. Pipe, fittings, valves, etc	27,844
	c. Insulation	47,670
	d. Structure & Access doors	12,995
	e. Safety Curtain	800
	f. Instrumentation	15,000
	g. Painting	3,100
4.	Total Direct Costs	$ 357,488
5.	Indirect Field Cost	($ 75,072)
6.	Total Field Cost	$ 432,560
7.	Office Costs	($ 76,998)
	a. Field Engineering	46,473
	b. Major Material Procurement	19,800
	c. Construction Management	10,725
8.	Total Field & Office Costs	$ 509,558
9.	Labor Productivity	$ 17,325
10.	Contingency	$ 50,956
11.	Fee	$ 34,650
12.	Total Construction Cost	$ 612,489 (cost code 5400)

5.2.7 Receiver Cost Estimate, continued

12.	Total Construction Cost	$ 612,489
13.	Design Cost	372,965
14.	Total Receiver Cost	$ 985,454

5.3 TOWER

Section 3.1 presented a summary of the trade studies performed to select the collector field configuration which included tower costs as one of the considerations. These costs were computed using the SNLL tower cost model. These trade studies were conducted early in the contract period before some of the tower specifications were established. The costs were subsequently recomputed using the updated specifications and as a result will appear somewhat different from those in section 3.1.

5.3.1 Major Tower Components

The word tower as used here might more accurately be termed a tower system because of the variety of components directly associated with the tower function. For the purpose of evaluating the cost and performance of the tower the following components and accessories have been identified.

Tower - A 56.4 m (185 ft) free-standing cantilever steel structure consisting of three vertical "K" braced legs.

Platform - A 14.63 m x 9.14 m (48 ft x 30 ft) steel deck mounted atop the tower. The platform will support the receiver directly and provide a catwalk type area completely around the outside of the receiver. A safety banaster will be installed around the outside edge of the deck.

Foundation - The foundation will consist of three steel reinforced concrete piers. Each pier rests on, and is integral with, a 4.27. m x 4.27 m x .91 m (14 ft x 14 ft x 3 ft) steel reinforced concrete pad.

Elevator - A 408.23 kg (900 lb) capacity personnel and equipment elevator.

Emergency Ladder - A steel cage enclosed step ladder mounted on one of the tower legs.

Obstruction Lighting - FAA approved flashing red lights.

Lighting - Lights on one leg for climbing and on the receiver platform.

Lightning Protection - Four air terminals grounded to the tower which is in turn connected to a ground rod that extends to the water table.

5.3.2 Tower Functional Requirements

The principal functional requirement of the tower is to provide a stable platform that will support the receiver the required distance above the ground plane. As stated earlier this requires a tower of sufficient height to position the horizontal midplane of the receiver aperture 60.96 m (200 ft) above grade.

The tower must also provide safe personnel access to the receiver and receiver enclosure for purposes of inspection and maintenance. To accomplish this requirement, a platform, platform railing, elevator and emergency step ladder will be required.

Other important tower requirements are included in the following list.

The tower must support a receiver, receiver housing and fluid total weight of 74,389 Kg (164 Kips).

The tower will be sufficiently rigid to maintain the receiver within allowable lateral movement limits under the most severe operating conditions i.e. $\pm$ 0.15 m (6 in) under 12.07 m/s (27 mph) wind conditions.

Support brackets shall be provided for two 0.2 m (8 in) schedule 40, insulated carbon steel pipes.

The tower system will include metal protective covering around each load bearing member.

The tower shall resist the over turning moment caused by a seismic disturbance with an average lateral ground acceleration of .1524 m/s^2 (.5g) without permanent deformation.

The tower shall resist the overturning moment caused by an 40.2 m/s (90 mph) fastest wind velocity (9.14 m (30 ft height) without permanent deformation.

The tower system shall provide aircraft obstruction lighting and shall be painted red and white as required by appropriate FAA Rules and Regulations.

The tower system will provide for protection of the receiver in the event of a lightning discharge.

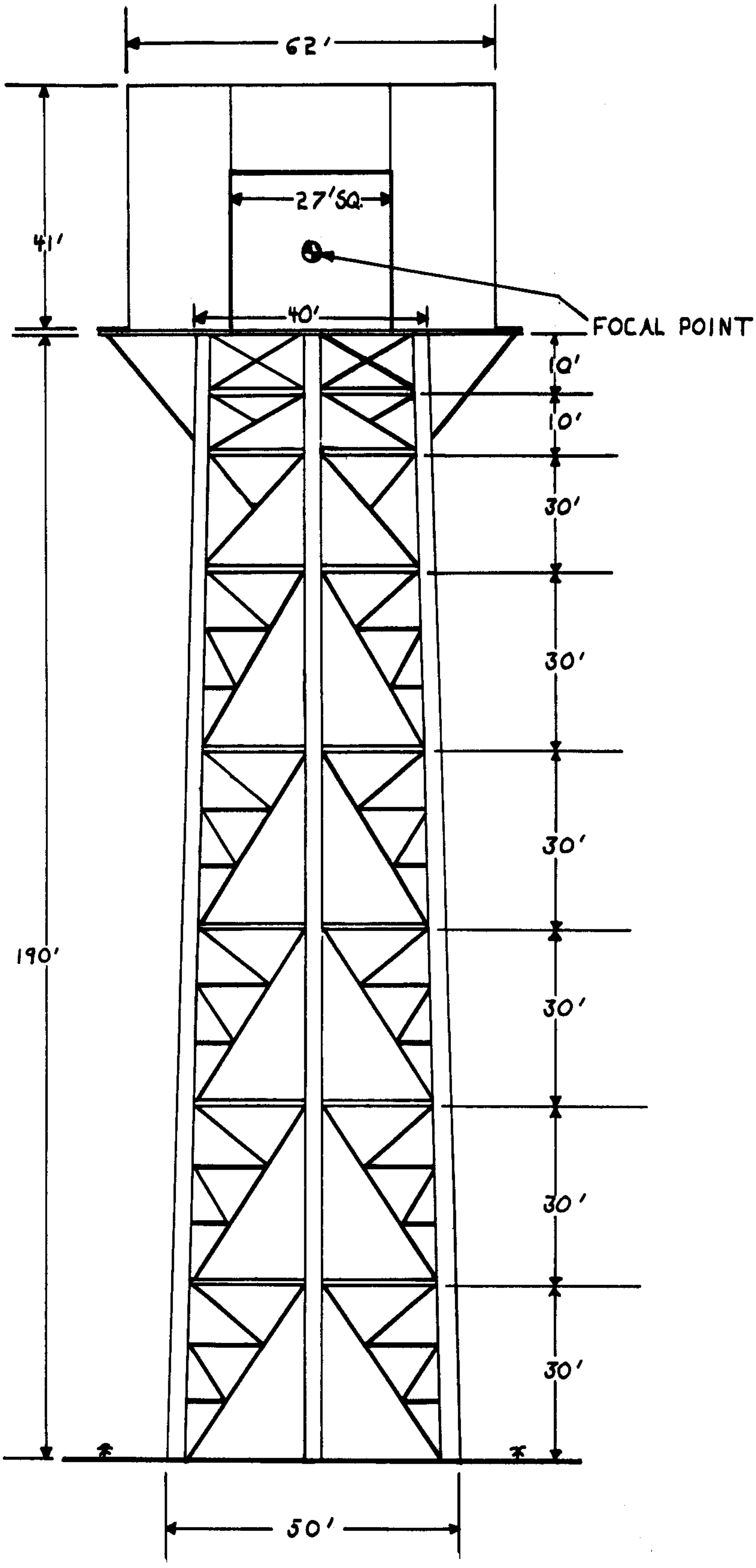
5.3.3 Tower Design

The tower selected for the project is a commercial product manufactured and installed by Unarco-Rohn of Peoria, Illinois. It is a self-supporting structure of the Rohn SSMW series and is used in a variety of applications particularly in the microwave transmission and antenna support areas. Minor modifications to the standard structure will be required to accomodate the receiver and inspection and maintenance requirements. This occurs at the top mounted platform and the supports within the structure for the riser, downcomer, and elevator.

The tower design exhibits three tubular steel legs in an equilateral triangle arrangement and canted from a 15.24 m (50 ft) spacing at ground level 9.14 m (30 ft) spacing at the 54.86 m (180 ft) level and then extend vertically to the platform level. The structural integrity of the tower is maintained with "K" braces. Figure 5.3-1. shows both plan and elevation views of the tower and platform.

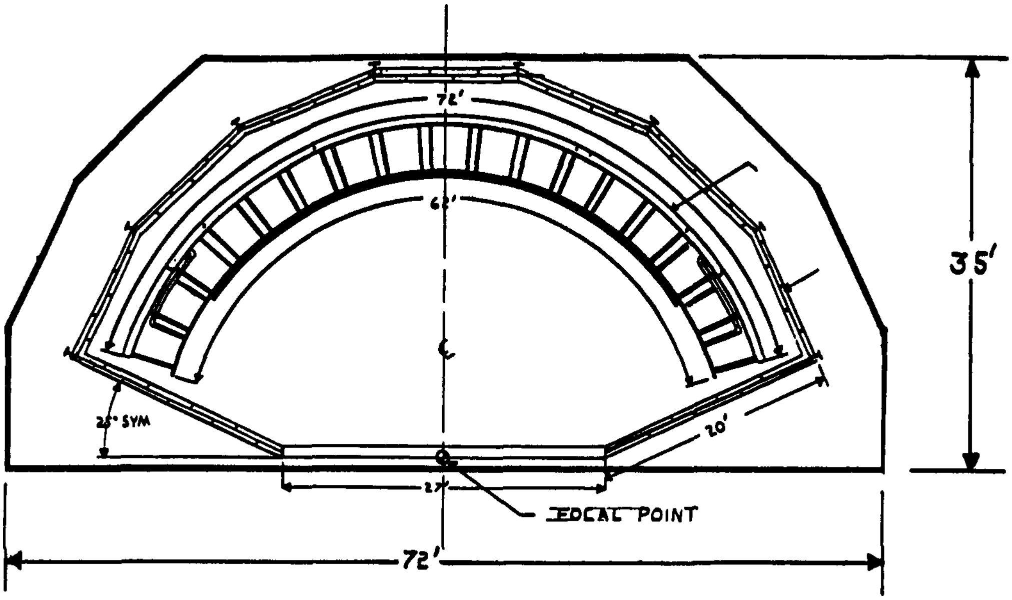
The legs are 0.25 m (10 in) diameter steel pipe that extend from grade to the 18.29 m (60 ft) level. Two tenths meter (8 in) pipe is used from this level to the top. The "K" braces are constructed of .089 m (3.5 in) diameter pipe.

The platform is constructed of steel I beam joists joined and braced with C beams. Expanded metal decking will be used for the surface material. The platform is 21.9 x 10.7m (72 x 35 ft) and permits personnel access to all outside surfaces of the receiver. A 0.10 m (4 ft) guard rail constructed of steel angle material will be installed around the perimeter of the platform.



9.5 MW_T RECEIVER-TOWER

Fig 5.3-1a



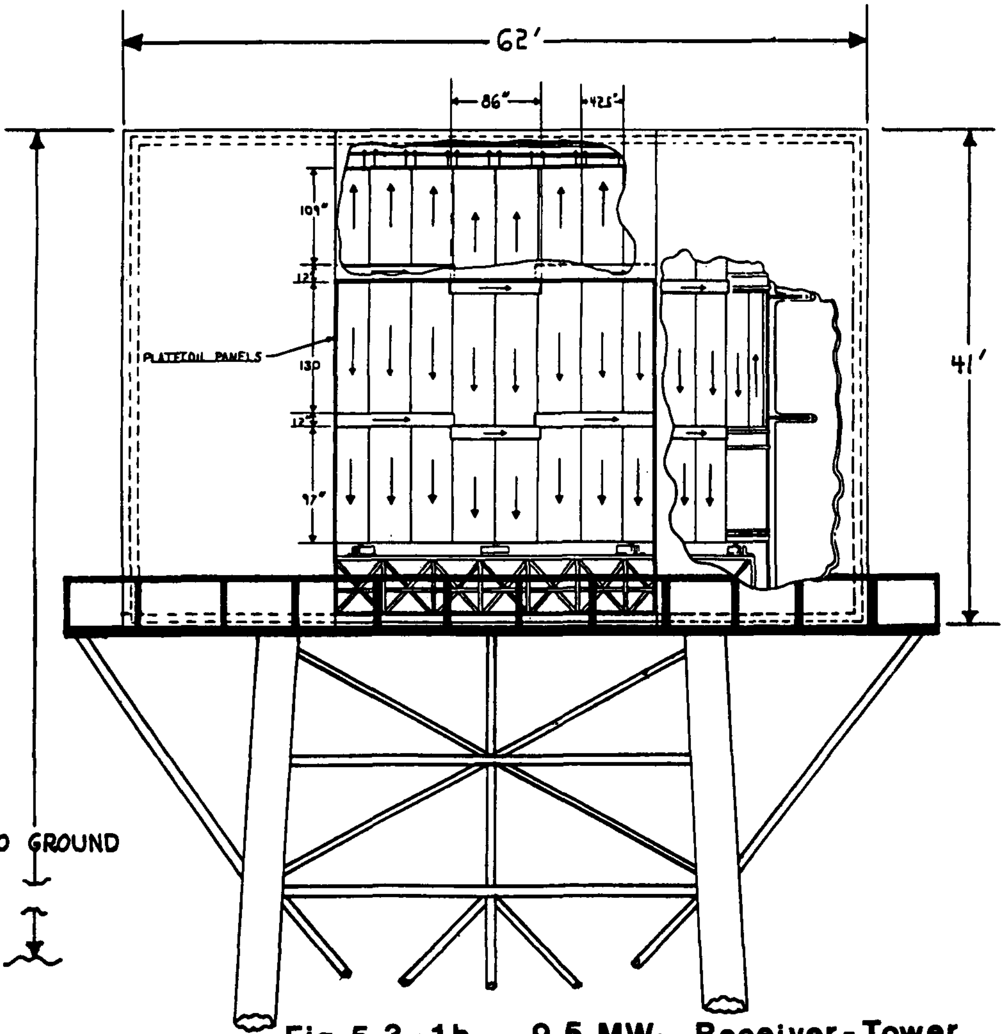


Fig 5.3-1b 9.5 MW_t Receiver-Tower

The foundation is composed of three reinforced concrete piers. Each pier is 1.2 m (4 ft) square by 4.05 m (10 ft) deep and is an integral part of a 4.27 m x 4.27 m (14 ft x 14 ft) concrete pad that is .91 m (3 ft) thick. A concrete grade beam, .61 m x .61 m (2 x 2 ft) spans the distances between the piers at the surface of the ground.

The tower legs will be protected from accidental impingement of large quantities of solar insolation by steel cladding supported by brackets that will provide spacing between the cladding and the leg.

Since the tower-receiver structure extends above 61 m (200 ft), it will be painted red and white in accordance with FAA Rules and Regulations.

The tower is designed to be in compliance with the Electronic Industries Association Standards.

5.3.4 Tower Cost Trade Offs

The extensive tower cost studies conducted by Stearns-Roger and others have clearly shown that, for tower heights of 61 m (200 ft) and below, the steel towers have a significant economic advantage over the concrete type. As a result a concrete tower was not considered for this application.

The initial system costs used in the collector field configuration selection were calculated by means of the SNLL tower cost model. For this purpose, four-legged steel towers of 41.14 m, 53.04 m and 60.96 m (135 ft, 174 ft and 200 ft) heights supporting receiver weights of 5.443.1 kg, 10,668.5 kg and 21,772.4 kg (12 Kips, 23.5 Kips and 38 Kips) were evaluated. The selection of the single module field configuration that incorporates the 60.96 m (200 ft) tower required that a more detailed analysis of tower configuration and design be conducted.

Here again the SNLL tower cost model was used as a basis for the evaluation. These calculations included an update of several input parameters, i.e. the receiver weight was increased to 74,389 kg (164 Kips) and the earthquake accelerations were increased to be consistant with UBC zone 4 rather than 3.

For the purpose of this analysis a four-legged steel tower 56.38 m (185 ft) in height was chosen. This places it well within the envelope of permissable parameters associated with the utilization of the tower cost model. The algorithms incorporated into the cost model are available from SNLL and will not be included in this report. The input parameters used for the calculations are summarized in Table 5.4.1, along with results of the moment calculations. These results show that the wind overturning moment is the dominant moment and was, therefore, used for the cost equation moments.

At this point the decision was made to obtain a quote from a commercial tower manufacturer. An estimate was received based on the same structural specifications and receiver configuration used in the tower cost model. This design, described in the previous section, is available as a complete installed tower system at a cost considerably less than that calculated with the cost model. Table 5.4.3 presents a comparison of the costs associated with the major system components.

5.3.5 Tower Cost Estimate

Table 5.4.2 presents a comparison between the costs from each source. It is interesting to note that the commercial estimate for the tower structure is a factor of 2 more than the cost calculated with the model and that the significant savings accrue from the other system components and cost categories. The engineering and fee quote could be lower because the design configuration is an adaptation of the one used for microwave and transmission towers. The accessory costs could differ significantly based on the cost of two components; the elevator and the obstruction lighting. Strobe type obstruction lighting is very expensive and is not required for the tower at North Coles Levee. The price of the elevator systems can also vary significantly based on size, type, speed and enclosure. If comparable costs were used for all components it is possible that the accessory costs would begin to approach agreement. The most surprising and difficult to explain difference is in the foundation costs. It is probably due to basic differences in the design configuration.

Based on the above considerations, the cost quote for the three-legged tower have been used in both complete system costing and economic analyses.

Table 5.4-3 presents the costs for the complete tower system.

Table 5.3-1 TOWER DESIGN CRITERIA
FOR COST ESTIMATES
SNLL MODEL

I. PARAMETERS INPUT		
TOWER HEIGHT	H_t	57.9 m (185 ft.) (Nominal)
RECEIVER VERTICAL DIMENSION	H_r	10 m (33 ft)
RECEIVER DIAMETER (CHORD)	D_r	19.5 m (64 ft.)
RECEIVER WEIGHT	W_r	74,389 kg (164 kips)
WIND VELOCITY	V_w	40.2 m/s (90 mph) (100 yr. recurrence)
PRESSURE COEFFICIENT	C_f	1.3 (Sq. Face - Normal - h/d=1)
EARTHQUAKE GROUND ACCELERATION	X_g	4.9 m/s^2 (0.5g) (Average - UBC Zone 4)
GUST FACTOR	G_f	1.12 (ANSI A58.1 - 1972)
NUMBER OF LEGS	N	4
II. PARAMETERS CALCULATED USING TOWER COST MODEL		
GUST FACTOR	G_f	1.15
LATERAL FREQUENCY	f_L	0.7455 Hz
WIND MOMENT	M_w	6.81 (3) kg-m (4.9241 (4) ft-kips)
EARTHQUAKE MOMENT	M_e	5.14 (3) kg-m (3.7193 (4) ft.-kips)
COST EQUATION MOMENT	M_d	6.81 (3) kg-m (4.9241 (4) ft.-kips)
COST EQUATION MOMENT	M_d	8.85 (3) kg-m (6.4013 (4) ft.-kips)

Table 5.3-2 TOWER COSTS

	COMPONENT	TOWER COST MODEL	THREE-LEGGED TOWER
I.	TOWER	$ 96,850	$181,370
II.	FOUNDATION	$286,000	$ 30,690
III.	ACCESSORIES	$216,800	$ 89,962
IV.	OVERHEAD, PRODUCTIVITY & CONTINGENCY	-	$138,160
V.	ENGINEERING & FEE	$149,910	$123,740
	TOTAL	$749,560	$563,922

Table 5.3-3 - THREE-LEGGED STEEL TOWER

I.	TOWER (190 ft. Nominal)		
	1. Materials	$ 159,870	
	2. Shipping	12,000	
	3. Installation $50/ft.	9,500	
			$ 181,370
II.	FOUNDATION		
	(3 - 14 x 14 ft. reinforced concrete pads 3 ft. thick, 13 ft deep $250/cu yd.)		$ 30,690
III.	ACCESSORY		
	1. 900 lb. elevator (Seede International)	69,562	
	2. 1000 ft.^{2} service platform	10,000	
	3. Obstruction lighting	1,200	
	4. Safety ladder (cage)	2,000	
	5. Lightning protection	5,000	
	6. Lighting	1,200	
			$ 89,962
IV.	OVERHEAD, PRODUCTIVITY AND CONTINGENCY		138,160
V.	ENGINEERING + FEE		123,740
		TOTAL COST CODE 5420	$ 563,922

(All costs include fee)

5.4 RECEIVER LOOP

The purpose of the receiver loop is to transport the HMO between the existing plant and the receiver when insolation conditions permit solar operation. For reference, it begins at the points of plant interface and terminates at the receiver manifolds. The piping follows the most direct route between these two interfaces. The loop contains all HMO system control and maintenance valves, control and monitoring instrumentation and HMO. Also included, is the receiver fire control system.

5.4.1 Loop Major Components

The loop is composed of four inter-related subsystems, (1) the HMO transport subsystem which includes the piping, booster pump, pipe supports, insulation, and HMO, (2) the HMO flow control and maintenance valves, (3) the control and monitoring instrumentation, and (4) the receiver fire control system.

(1) HMO Transport - This portion of the loop consists of the following major components.

- 914.4 M (3000 ft) of .2 m (8 in) schedule 40 carbon steel pipe and includes the riser and downcomer. Pipe supports, hangers and insulation are also included.
- 34.1 m^3 (9,000 gal.) of ARCO Hydrotreated light cycle oil.
- Two 112 KW (150 horsepower) centrifugal pumps (one is a back up) to boost the HMO to the receiver.

(2) Flow control - the principal function of this system is to establish the operational modes (Solar/Fossil or Fossil only). The bypass valves for maintenance and system drain valves.

- Two 0.1 m (4 in) three-way automatic valves. These valves direct the flow of the HMO either, from the plant system to the receiver, or through the existing system.
- One 0.15 m (6 in) three way automatic valve. This valve directs the return HMO flow from the receiver. The HMO is either directed to the fired heaters or it bypasses the plant and recirculates within the loop.

- Various size hand operated valves for bypassing control valves and pumps to facilitate maintenance and repair.
- Hand operated HMO drain valves.
- One 37.9 m^3 (10,000 gal.) loop drain tank.

(3) Instrumentation - sufficient instrumentation is included to provide for automatic and manual flow control, system performance evaluation and safety.

- Temperature sensors on the loop inlet and outlet with recorders and/or gages in both the solar and plant control rooms.
- A differential temperature analyzer and signal conditioner to activate the automatic flow control valves.
- HMO flow indication and recorder.
- Annunciator panels in both control rooms (receiver high temperature, low flow and fire).
- Manual remote control for automatic valves.
- Pump controls

(4) Receiver Fire Control- This portion of the system provides the capability of detecting a fire within the receiver cavity,

- automatically terminate HMO flow, activate the Halon gas fire extinguisher, and alert the operator.
- 271.16 kg (600 lbs) of Halon gas in two steel bottles located on the platform external to the receiver cavity.
- Temperature activated sensors located inside the receiver cavity.
- Signal conditioning and wiring to isolate solar system at the automatic control valves, shut down the pump, close cavity door, intiate heliostat defocus, and alert the operator.

5.4.2 Loop Functional Requirements

The functional requirements of the receiver loop can be divided into three categories. These are: (1) provide HMO transport between the tower and the receiver, (2) provide control for HMO flow at the solar/non-solar plant interface, and (3) provide instrumentation for both automatic and manual system operations.

(1) HMO Transport - The loop will provide a piping system between the receiver and the existing plant that is designed to transport all the HMO, that normally flows to the fired heaters, to and from the solar receiver. The pipes and valves will be selected and sized to optimize the booster pump requirement relative to flow rates and pressure drops. The system will be insulated to minimize heat loss.

(2) Flow Control - The loop will contain the valves that interface the solar system with the existing plant HMO system. These valves permit the automatic (based on system temperature considerations) or manual control of the HMO flow. These valves control only direction of flow, as flow rate control is not a requirement. The loop will contain sufficient manual valves to permit maintenance of the control valves and pump without requiring system drain down. Separate drain down valves will be provided for the riser and downcomer.

(3) Instrumentation - Instrumentation will provide system status information at both plant and solar system control rooms. It will also provide signals for automatic valve control. Information required will be inlet and outlet temperatures and flow rate at the plant interface, sufficient receiver temperature and pressure data to evaluate receiver performance and safety, annunciations to alert operators of abnormal conditions, and cavity fire detection.

5.4.3 Loop Design

The design of the receiver loop system was based on evaluation of costs, interference with normal plant operations, control simplicity, maintenance, reliability, and plant practices and procedures. A description of the existing HMO system was presented in Section 2.6 and included a simplified flow diagram. The heat augmentation temperature and interface selection trade-off analysis will be discussed in Section 5.4.6. This section is limited to a description of the conceptual design of the solar HMO transport and control system. The interface point at the plant pump discharge will be used as a starting point. As shown in the flow diagram, Figure 5.4.1, the solar inlet interface point is located down stream from the point where the Heat Recovery Unit interfaces with the plant system. The receiver loop will not interfere with the operation of HRU portion of the HMO system.

At the loop to plant system interface, there are actually two three-way valves for each leg of the loop. This is to accommodate the separate pipes for each fired heater.
Figure 5.4-2 presents a detailed illustration of the actual interface. These interface control valves are designated SCV-1 and SCV-2. Each valve is a 0.1 m (4 in) automatic three-way temperature controlled valve operated by compressed air actuated by a preset temperature differential between the temperature at pump discharge and the temperature at valve BPV.

The valves discharge the HMO into a .2 m (8 in) pipe and transport it to the receiver.

The plant piping is elevated 4.67 m (15 ft) above grade at the interface point. In order to maintain this clearance, the loop piping interfaces from above the existing pipe. The loop remains at this elevation, 5.49 m (18 ft), for the 23.16 m (76 ft) run out of the plant and an additional 16.5 m (54 ft) to cross the paved road adjacent to the plant. At this point the elevation is

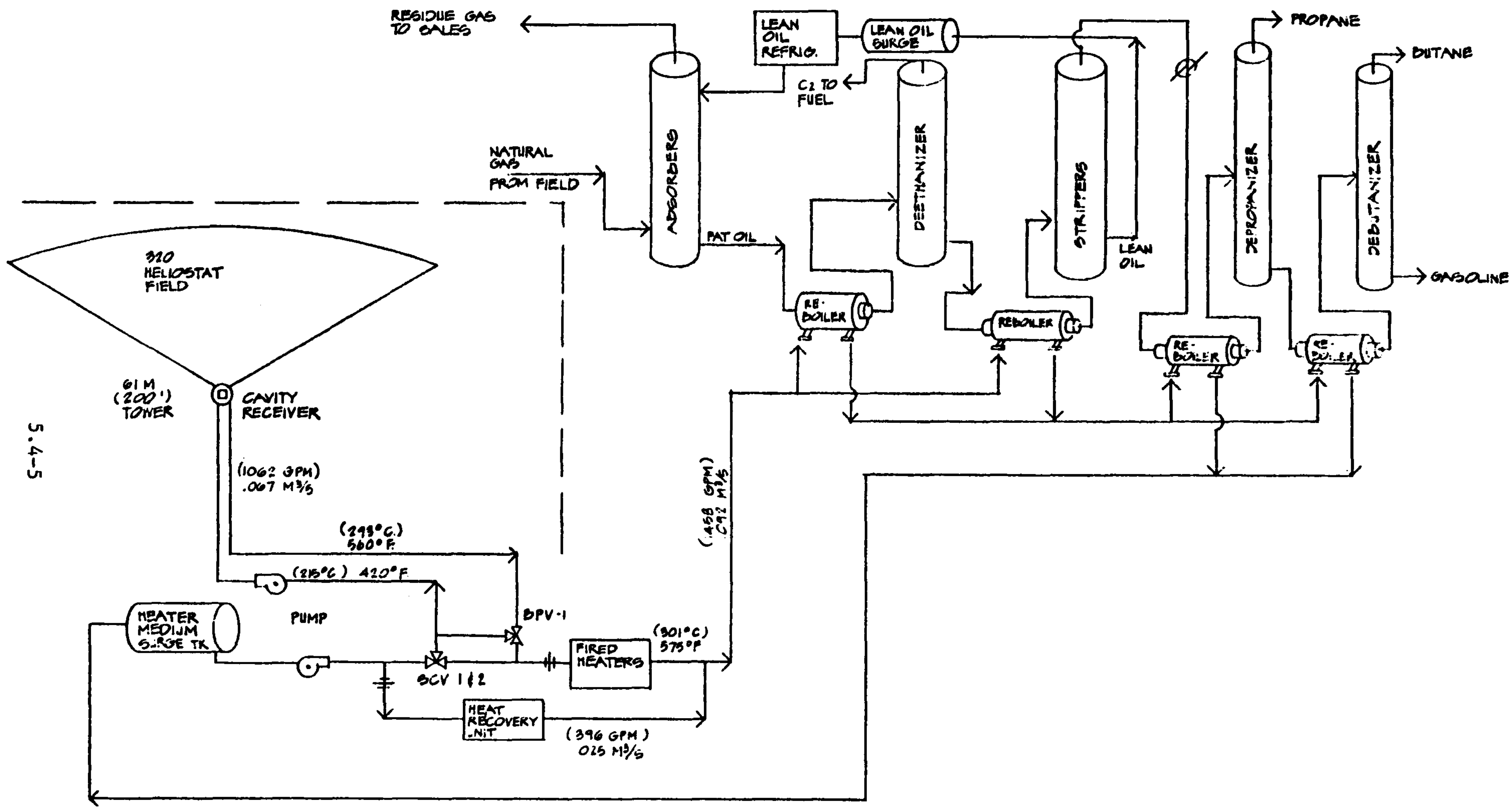


Figure 5.4-1

BPV = BYPASS VALVE
SCV = SYSTEM CONTROL VALVE

System Flow Diagram

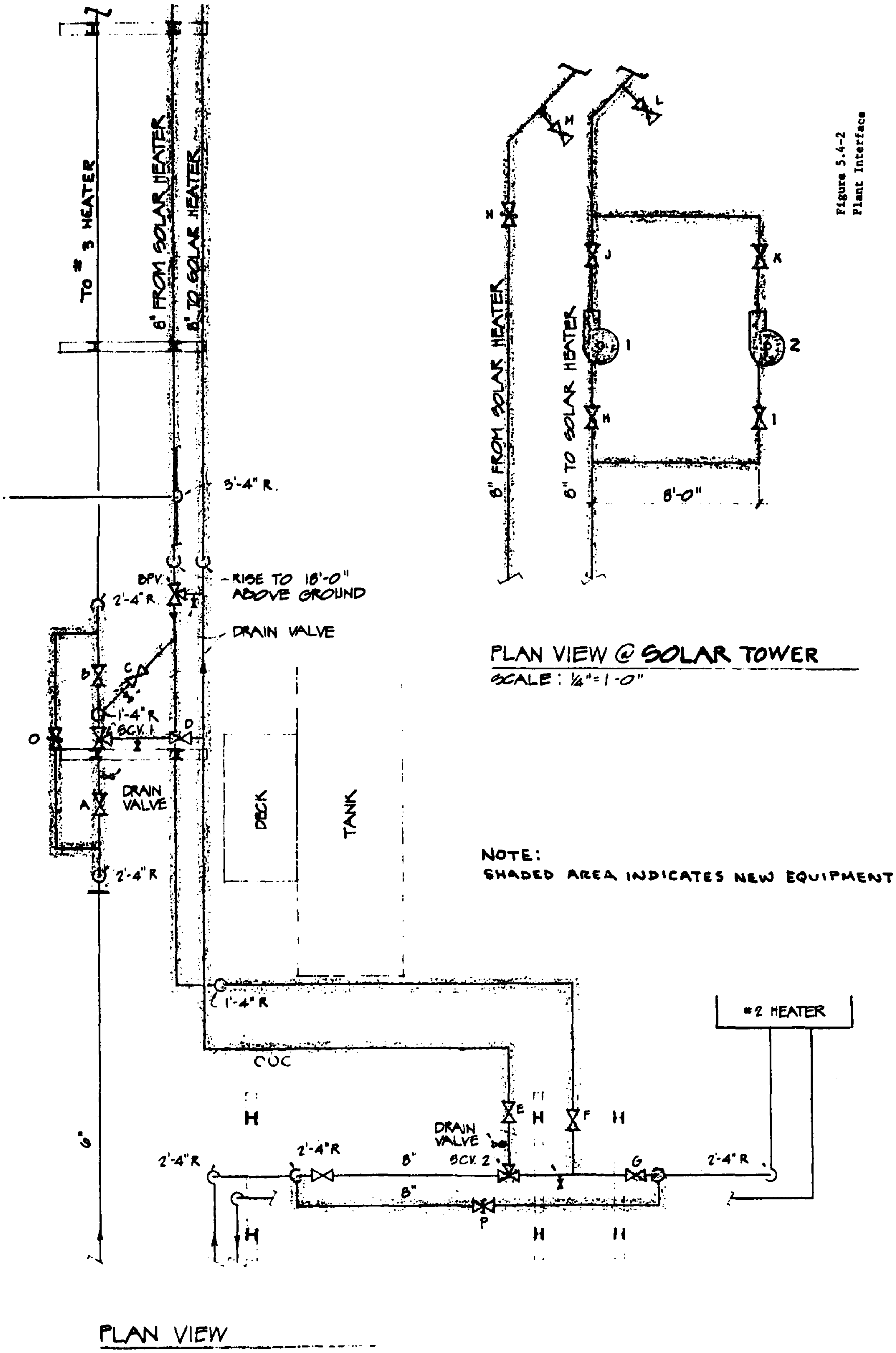


Figure 5.4-2
Plant Interface

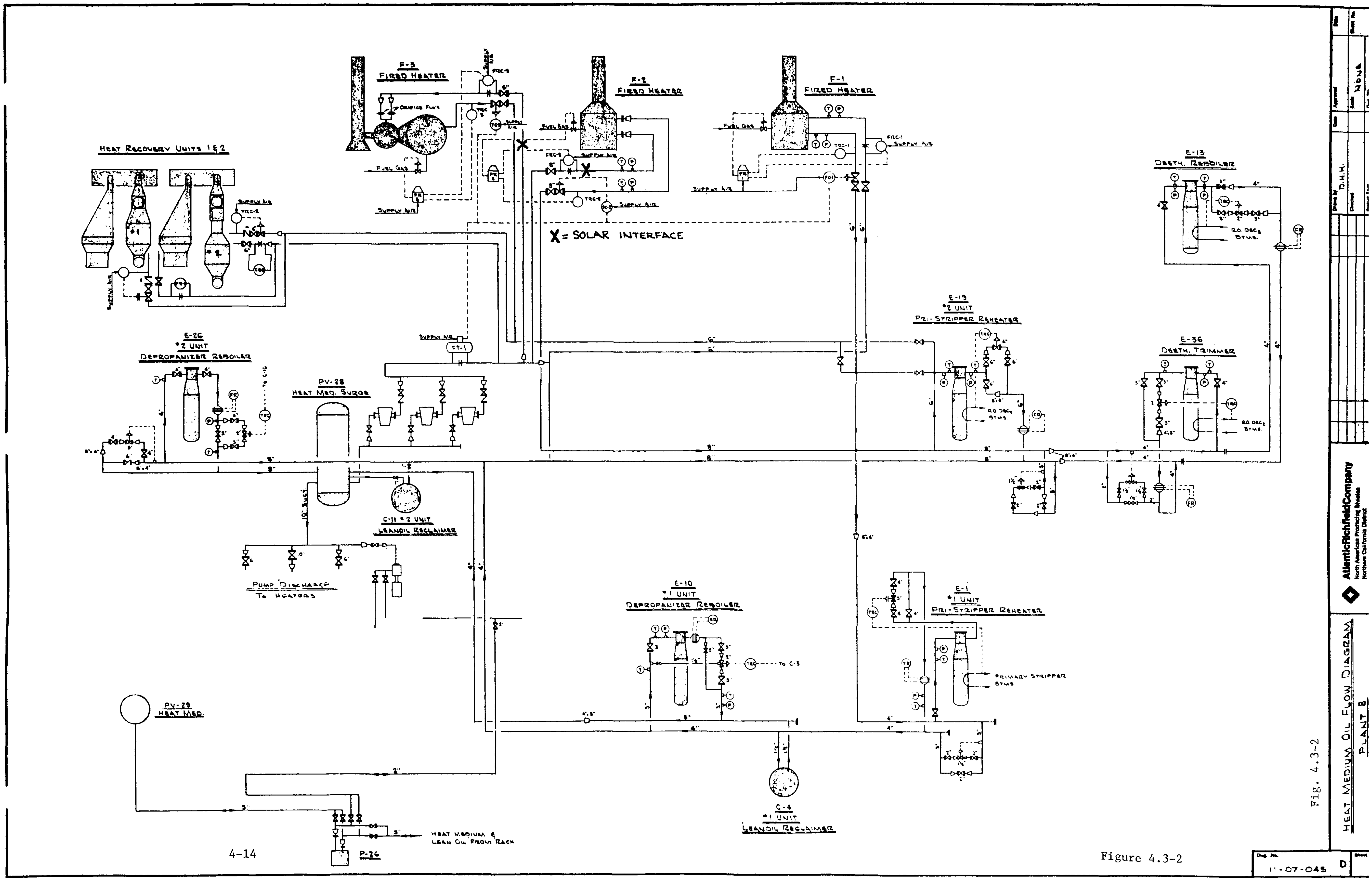


Fig. 4.3-2

4-14

Figure 4.3-2

reduced to approximately .15 m (15 ft) elevation for the remainder of the 356 m (1168 ft) run to the base of the tower. Figure 5.4.-3 shows a plan view of the piping layout.

At the base of the tower, there is located a 112 kW (150 hp) booster pump. This pump is required because of 827.6 kPa (120 psi) pressure will be insufficient to overcome pipe and valve friction loss, vertical head loss and receiver friction loss.

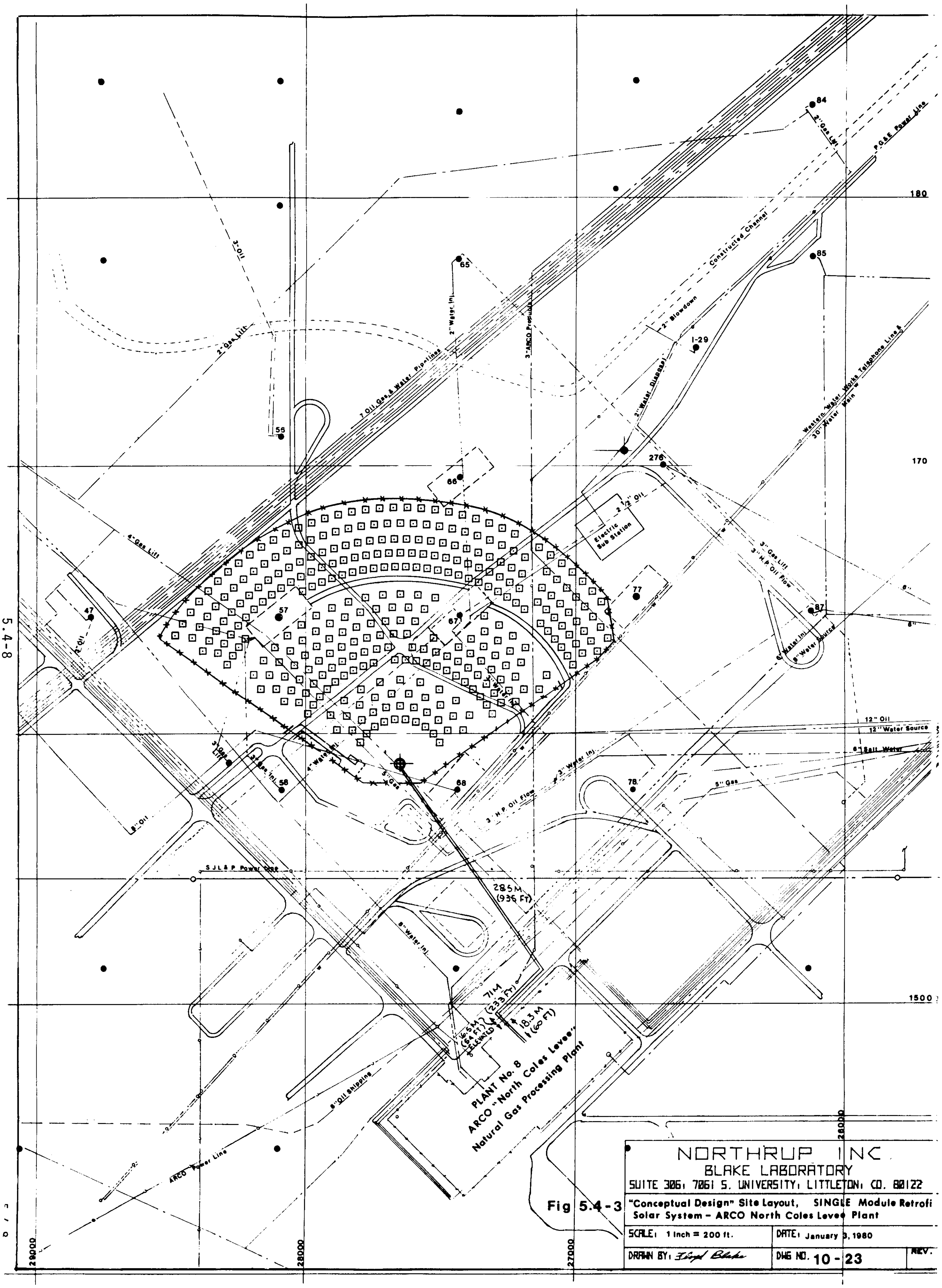
The pump discharges into the riser which is made up of the same size material and insulation as the piping run. The riser contains a manual drain valve located above the horizontal piping elevation. The riser interfaces with the receiver manifold near the bottom of the receiver.

The HMO flows through the receiver and enters the loop via manifolds into the downcomer. The downcomer is of the same construction as the riser. At the .15 m (.5 ft) level it turns horizontal and proceeds parallel with the low temperature pipe to the plant interface. It also contains a drain valve at the same level as the riser.

The plant interface with the existing system can be accomplished with a single three-way valve. Since the blocking or opening of the two individual plant lines from pump discharge to the fired heaters is accomplished by the inlet valves SCV-1 and SCV-2, the valve on the return leg can be placed in the pipe prior to the point where it is divided and interfaced with individual pipes to the heaters.

Valve BPV-1 opens the loop bypass and closes the return line during periods on non-solar operation. When conditions permit solar operation, this valve closes the loop bypass and opens the return loop to the fired heaters.

All the automatic valves in the system are of the pneumatic type. The three main automatic control valves will be operated off the existing plant air system.


NORTHRUP INC
BLAKE LABORATORY
SUITE 306, 7061 S. UNIVERSITY, LITTLETON, CO. 80122
"Conceptual Design" Site Layout, SINGLE Module Retrofi
Solar System - ARCO North Coles Levee Plant
SCALE: 1 inch = 200 ft.
DATE: January 3, 1980
DRAWN BY:
DWG NO. 10-23
REV.
PLANT No. 8
ARCO "North Coles Levee" Natural Gas Processing Plant
Electric Sub Station
285 M (935 FT)
71 M (233 FT)
18.3 M (60 FT)
S J L & P Power Line
ARCO Power Line
PG&E Power Line
Constructed Channel
7 Oil Gas & Water Pipelines
Western Water Works Telephone Line & 30" Water Main
12" Oil
12" Water Source
8" Salt Water
6" Oil Shipping
180
170
1500
29000
28000
27000
Fig 5.4-3

The loop control instrumentation consists of temperature sensors located at the plant pump discharge and the solar loop bypass valve. A differential analyzer compares these signals and, upon detection of a preset 2.78^{o} C (5^{o} F) temperature differential, actuates the automatic valves that control the direction of the HMO flow. These temperatures will be monitored at plant control room. Also included is instrumentation to monitor the HMO flow through the solar system.

5.4.4 Loop Operating Characteristics

The receiver loop operating characteristics were established to provide for efficient HMO system control during the two modes of plant operation; solar/fossil and fossil only. It also provides for safe plant operation during the mode transitions; startup, shutdown and emergency conditions.

Fossil Operation - During periods of insufficient insolation, the control valves SCV-1, SCV-2 and BPV isolate the loop from the plant HMO system. The loop pump is turned off and there is no HMO flow within the receiver loop. The plant HMO system operates in its present configuration. (Figure 5.4-4).

Solar/Fossil Operation - When conditions permit operation in this mode, the control valves SCV-1 and SCV-2 block the HMO flow to the fired heaters and divert it through the loop. The loop pump is on and provides sufficient increase in HMO pressure to overcome piping, head, and receiver losses, Figure 5.4-5. The HMO is heated in the receiver and returned to the plant. Valve BPV at the return interface blocks the loop bypass and allows the HMO to enter the fired heaters.

The mode of operation is determined by the detection of a preset ΔT of 2.78^{o} C (5^{o} F) between the plant surge tank and the loop return (BPV). When the temperature at the BPV exceeds the preset ΔT, the control valves automatically switch the system operating mode to solar/fossil. When the BPV temperature drops

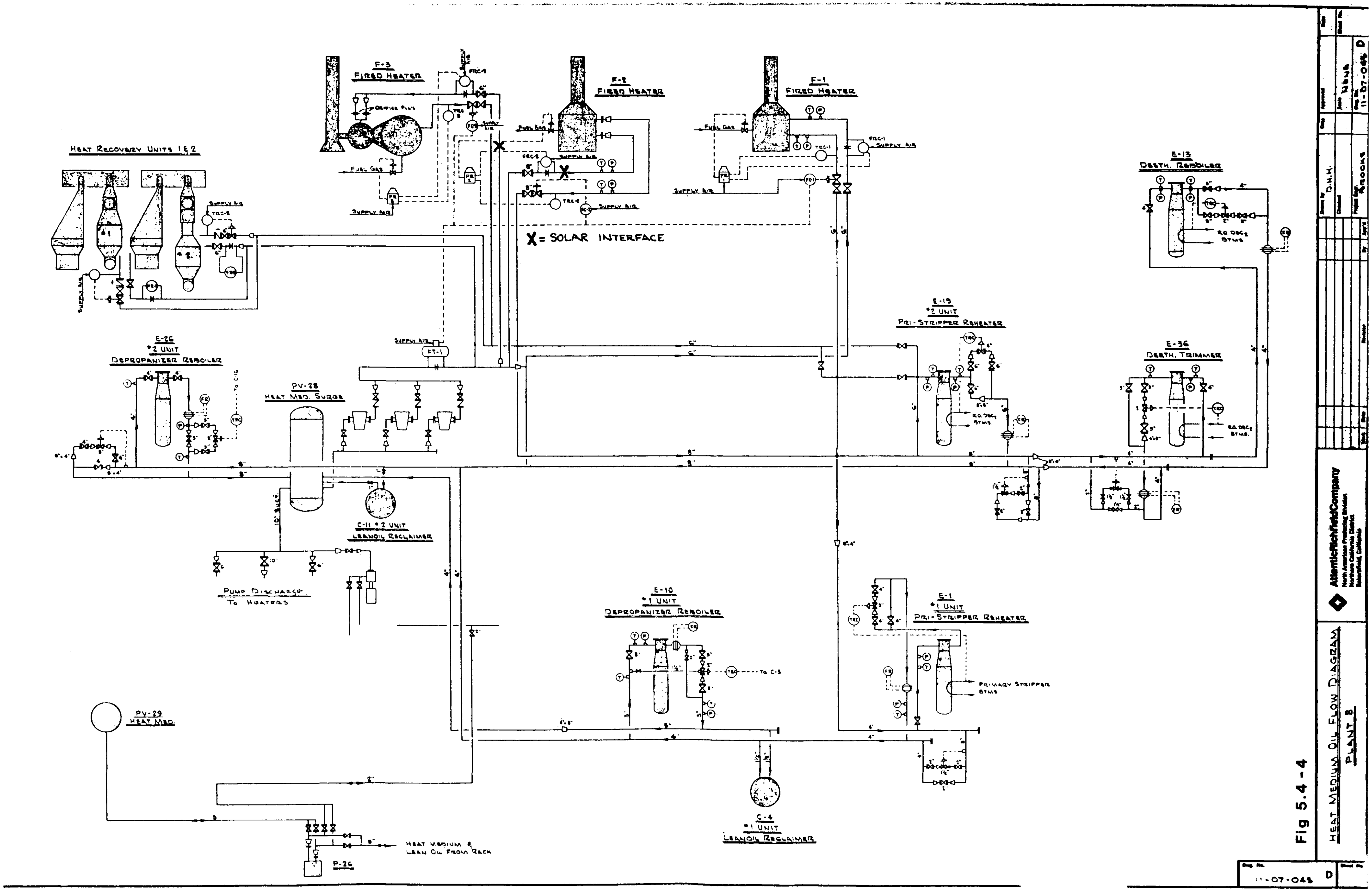
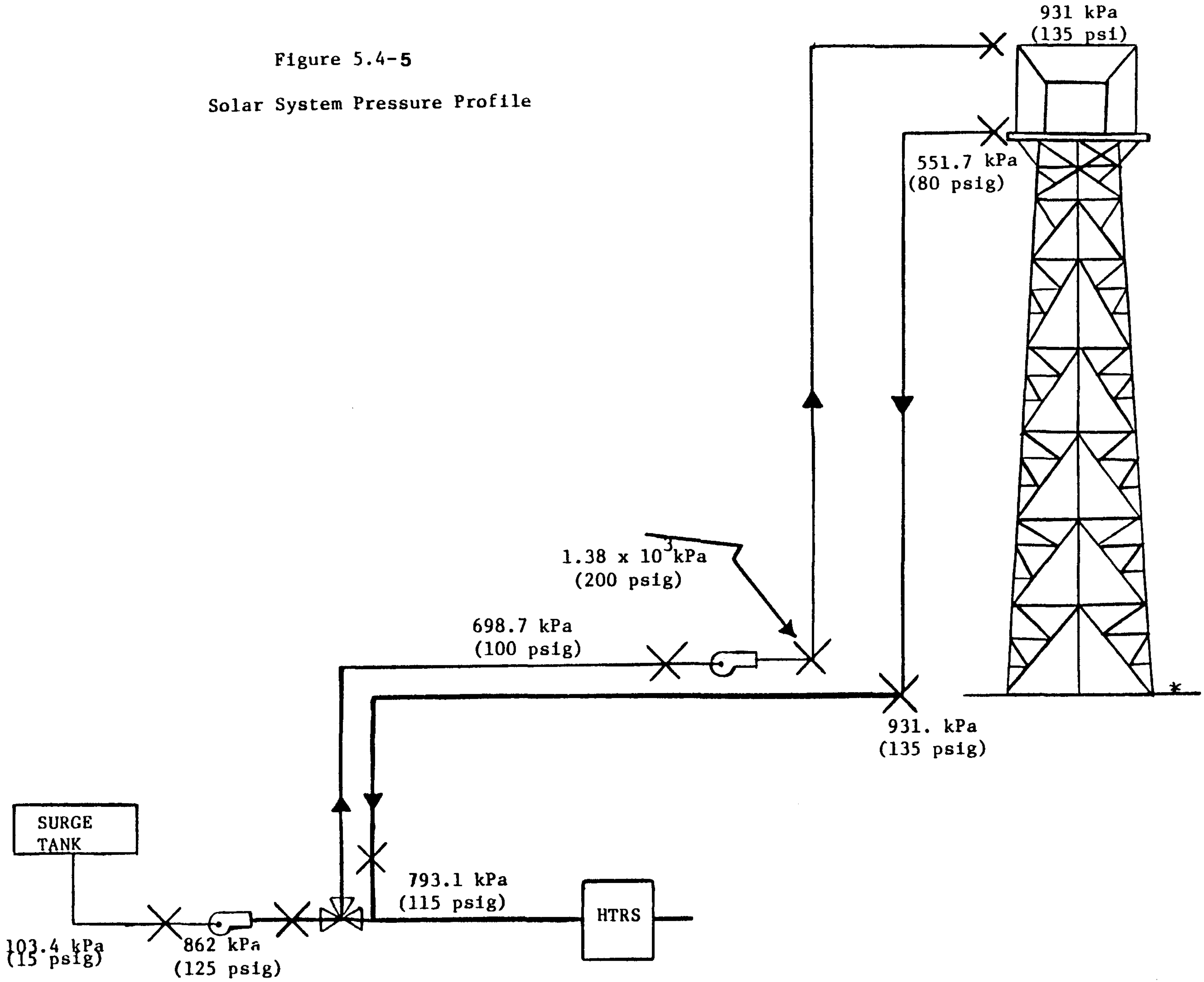

HEAT RECOVERY UNITS 1 & 2
F-3
FIRED HEATER
F-2
FIRED HEATER
F-1
FIRED HEATER
FUEL GAS
SUPPLY AIR
X = SOLAR INTERFACE
E-13
DEETH. REBOILER
E-19
#2 UNIT
PRI-STRIPPER REHEATER
E-36
DEETH. TRIMMER
E-26
#2 UNIT
DEPROPANIZER REBOILER
PV-28
HEAT MED. SURGE
FT-1
C-11 #2 UNIT
LEANOIL RECLAIMER
PUMP DISCHARGE
TO HEATERS
E-10
#1 UNIT
DEPROPANIZER REBOILER
E-1
#1 UNIT
PRI-STRIPPER REHEATER
PRIMARY STRIPPER BTMS
PV-29
HEAT MED.
C-4
#1 UNIT
LEANOIL RECLAIMER
HEAT MEDIUM & LEAN OIL FROM RACK
P-26
AtlanticRichfieldCompany
HEAT MEDIUM OIL FLOW DIAGRAM
PLANT B
11-07-045 D

Fig 5.4-4

Figure 5.4-5

Solar System Pressure Profile



below the preset ΔT, the control valves automatically return the system operating mode to fossil only.

During long periods of fossil operation (overnight, extended cloudiness), the temperature of the HMO receiver and loop will fall below that of the surge tank. This will require that the loop temperature be brought up to surge tank temperature before entering the solar/fossil operating mode. When solar energy is focused on the receiver, the loop pump (1 or 2; Figure 5.4-2) will be turned on. The cold HMO in the loop will be circulated within the receiver and loop and heated until the temperature exceeds the HMO surge tank temperature by 2.78^{o} C (5^{o} F). At that point, the control for the three 3-way valves (SCV-1, SCV-2 and BPV; Figure 5.4-2) will be actuated. The HMO flow will be diverted to the solar loop by SCV-1 and SCV-2, and BPV will allow the HMO from the solar receiver to return to the fired heaters.

The solar/fossil operation will continue until the temperature at the BPV no longer exceeds the preset ΔT. At this point, the control for the three 3-way valves will again be actuated. SCV-1 and SCV-2 will route the HMO flow straight to the fired heaters instead of through the solar receiver, and BPV will be in the "open" position for circulating the HMO through the receiver during the next startup period. The pump will be shut off by the operator. This permits all the usable energy within the receiver and loop to be returned to the plant after the insolation becomes insufficient to contribute energy to the system.

The variations in the HMO loop return temperature caused by cloud transients are compensated for in two ways, depending upon the length of the time of cloud passage. During periods when the cloud passage time is short or field coverage is partial and the loop return temperature remains above the preset ΔT, the temperature control at the fired heaters will provide the compensation required to meet the process requirements. During periods when cloud coverage is of extended duration and drops the HMO temperature out of the receiver below the 2.78^{o} C (5^{o} F) differential, the control for the 3-way valves will be actuated, causing SCV-1, SCV-2 and BPV to return the loop to fossil operations. There are three emergency conditions which will cause the 3-way valves (SCV-1, SCV-2 and BPV) to automatically switch from solar/fossil to fossil operation. These are fire, low flow, and loss of instrument air. Only the fire alarm will shut off the loop pump. A high receiver temperature alarm will not automatically return the loop to fossil operation, but will defocus the heliostats and alert the operator. Operator action is required to place the system in the proper operating mode.

5.4.5 Loop Performance

The loop piping is insulated with a 127 mm (5.0 inch) thickness of high temperature fiberglass insulation covered with a 0.4 mm (.016 inch) thick aluminum lock-on jacket. Since the pipe outside diameter is 0.22 m (8.625 inches), the insulated assembly will have an outside diameter of 0.47 m (18.67 inches). Although this insulation thickness might appear excessive, the energy saving justifies the added cost:

	Standard Insulation Thickness 76.2 mm (3.0 inch)	Heavy Insulation Thickness 127 mm (5.0 inch)
Annual Energy Loss	1,067,400 kwh	731,400 kwh
Average Energy Cost (20 yr)	2.32¢/kwh	2.32¢/kwh
Energy Loss Cost	$24,764/yr	$16,968/yr.
Insulation Cost	$28,650	$55,900

The added insulation cost of $27,250 will yield an average return of $7,796 per year for the 20 year period.

Figure 5.4-6 presents the piping cooldown characteristic for the 884m (2900 ft) of piping. It will be noted that the cooldown transient begins from a temperature of 215.6°C (420° F) even though the return pipe and fluid are normally at 282-304°C (540-580°F) at the time of heliostat shutdown. The reason for this is that the control system will be configured to maintain the loop pump "on" until the oil temperature returning to the plant falls below 215.6°C (420°F). In this way, a portion of the energy stored in the system is returned to the process rather than being lost in the post-operation cooldown.

Table 5.4.5-1 presents the cooldown energy loss of the loop system as a function of cooldown time. The difficulty in using

Figure 5.4 - 6

Piping Cooldown Rate

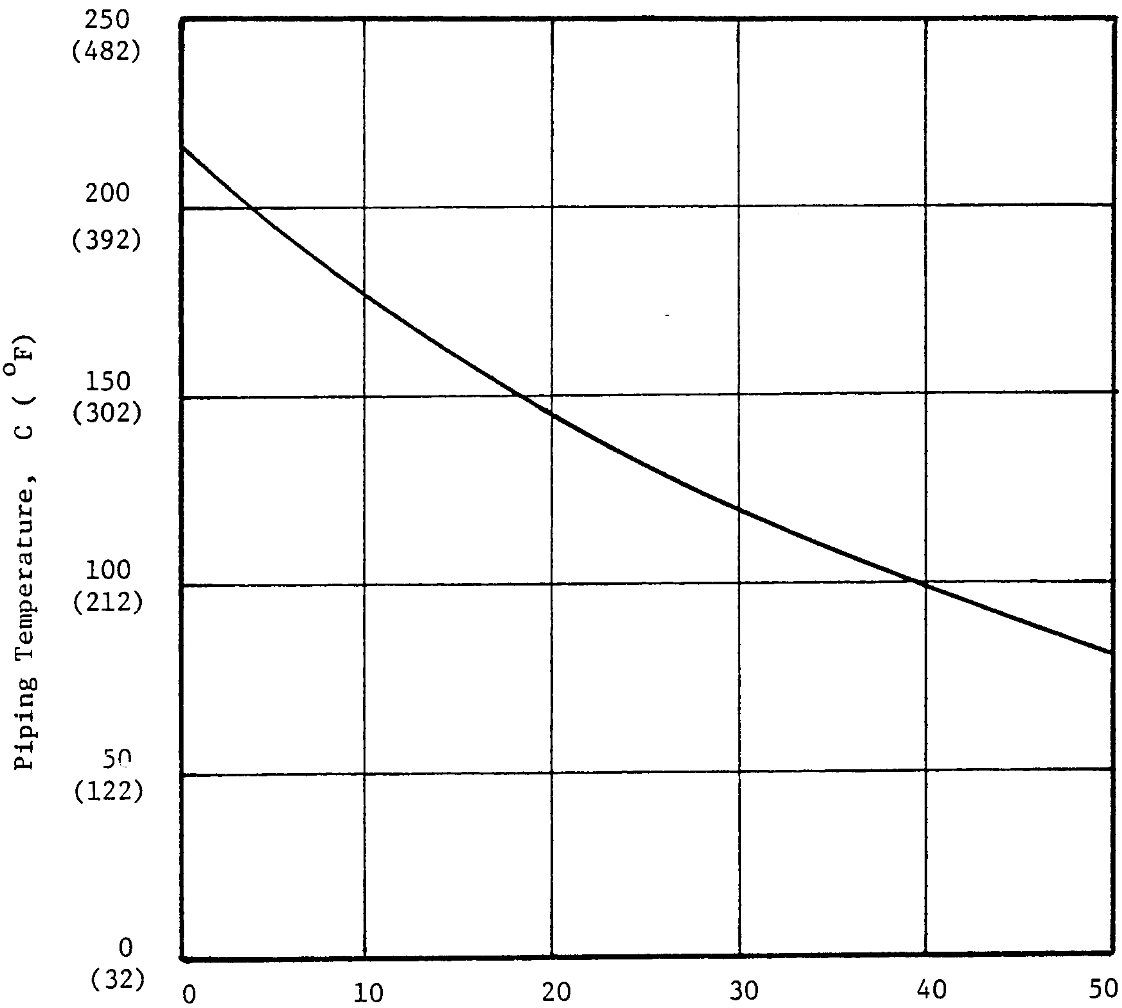


Table 5.4.5-1

Piping Energy Loss Following System Shutdown

Shutdown Duration	Pipe Loop Energy Loss
0	0
1	82.5
2	163.2
3	242.2
4	319.5
6	469.3
8	609.0
10	750.2
12	881.9
15	1069.1
18	1244.7
21	1409.3
24	1563.6
30	1894.0
36	2090.6
42	2307.3
48	2497.9
	3884.9

these data to predict the annual energy loss is that an estimate must be made of the frequency and duration of the shutdown times. Table 5.4.5-2 presents the cooldown frequency-time estimates used, and the corresponding energy loss for a complete year.

Since the total annual energy absorbed by the receiver is on the order of 22.9×10^6 kwh, this annual cooldown loss of 398,334 kwh corresponds to a percentage loss of 1.74%. In addition to this non-operating loss, there is a heat loss from the pipe loop during normal operation. The supply line heat loss is 41.7 kw, and the return line heat loss is 69.1 kw. This total of 110.8 kw represents a percentage loss of 1.08% of the annual average receiver output power. Hence, the total piping loop loss for both operating and non-operating periods is 2.82%.

In order for the plant HMO system to function normally within the process loop, it is necessary for the HMO to enter the fired heaters at approximately 689.5 kPa (100 psig). It is therefore, necessary for the solar system pressure to be boosted sufficiently to return the HMO to the fired heater inlet, compatable with normal system requirements. The results of the analysis of the receiver and receiver loop, showed that a 112 kW (150 hp) booster pump would be required to account for the transport, head, and receiver losses.

Table 5.4.5-2

Shutdown Frequency-Time-Energy Loss Estimate

North Coles Levee Receiver Loop Piping

Frequency	Duration	Energy Loss
19	1 hour	1568 kwh
16	2	2611
13	3	3149
9	4	2876
6	5	2366
5	6	2347
4	7	2157
3	8	1827
1	9	680
1	10	750
1	11	816
105*	12	92,600
97*	14	97,793
78*	16	88,065
9	24	14,073
12	36	25,087
13	48	32,473
8	96	27,096
ANNUAL TOTAL		398,334 kwh

5.4.6 Loop Trade Offs

5.4.6.1 Plant Interface Selection

Initially, three different solar unit tie-ins were chosen for analysis. These are shown in Figure 5.4-7. In each case, the HMO would flow through the fired heaters in the usual manner.

The flow shown in schematic C was considered because the oil temperature from the debutanizer reboiler is the lowest in the system. This would have allowed the greatest temperature differential across the solar unit. Unfortunately, the flow rate through this unit is very small and would not have been adequate for a solar system of sufficient size to meet program requirements. As a result, the flow from the debutanizer reboiler would have to be supplemented with flow from another unit. To achieve this mixing of flows without disturbing the normal plant operations and to allow for the flucuation of flow through the units would have required a complex control system. Due to the complexity involved and the impact on routine plant operations, this tie-in was not chosen.

The flow of schematic B required the simplest piping arrangement of the three. It would provide an adequate flow rate, and could be installed without having to shut down the system. The problem encountered with this tie-in was that the heat from the solar unit would be returned directly to the heat medium surge tank. This would raise the temperature of the surge tank. The feed temperature to the heaters would therefore be raised and less fuel would be required, but at the same time, the feed temperature to the solar unit and the HRU would increase. This would drive down the efficiency of the solar unit, and since the heat from the HRU is constant, the oil from the HRU would be above its degradation temperature. Also to be considered was the effect of the increased temperature on the HMO system pumps. As a result of these considerations, another alternate interface point was evaluated.

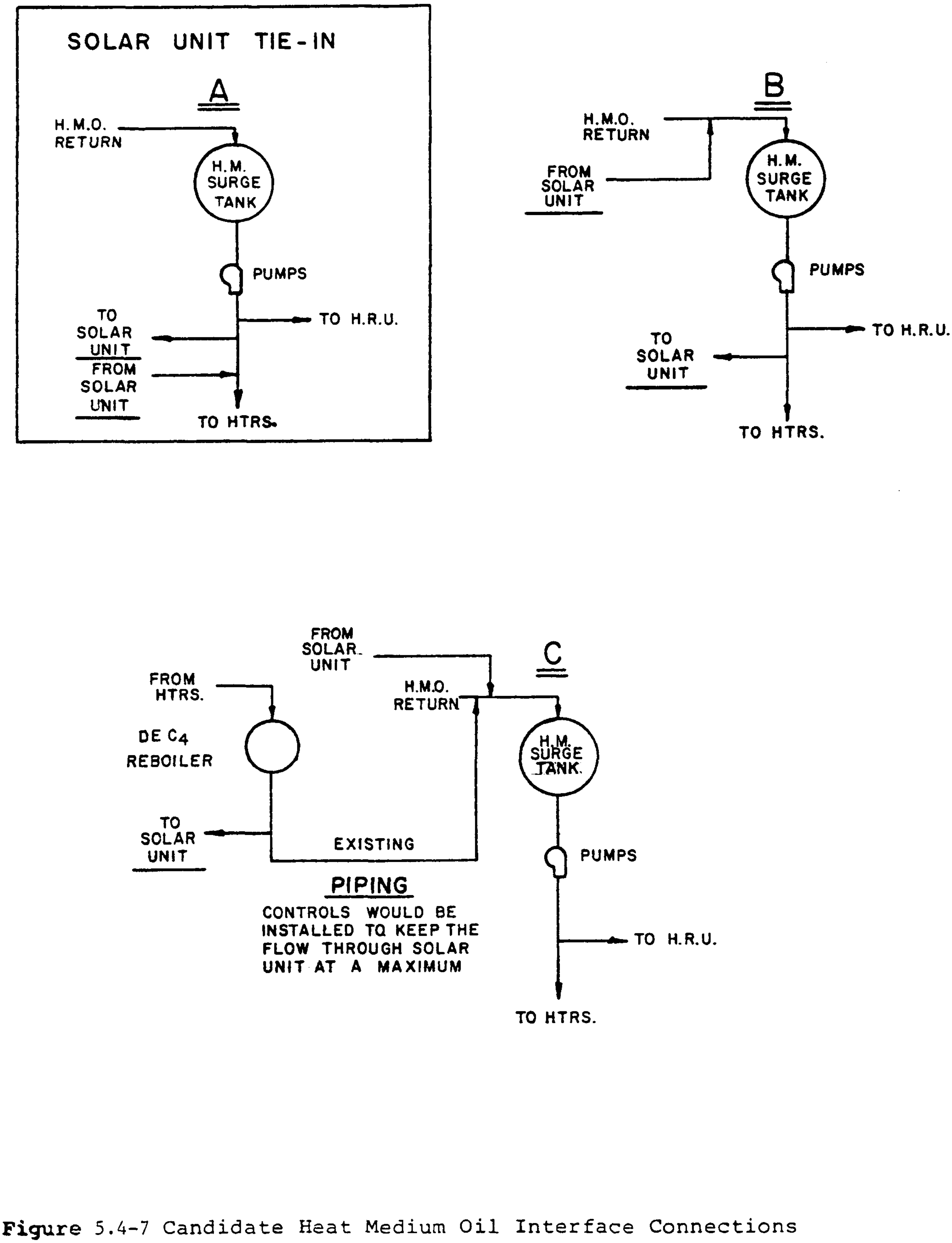


Figure 5.4-7 Candidate Heat Medium Oil Interface Connections

The interface point selected is shown in Schematic A. There are several advantages associated with the arrangement. First, the interface is downstream of the point where that portion of the HMO that flows through the HRU is extracted. Therefore, the operation of this portion of the system is unaffected by the operation of the solar system. Second, this interface point permits all the HMO that flows through the fired heaters to be diverted through the receiver, heated to the extent possible, and returned to the fired heaters to be brought up to the final required temperature and delivered to the process in the usual manner. Having the flow from the solar unit return immediately to the heaters allows greater freedom and simplicity in operating the solar unit. Variations in the HMO return temperature due to system start up and cloud transients can be automatically compensated for by the existing heater controls. As long as the solar unit temperature is higher than the surge tank temperature, all collected solar energy is used. This flow scheme also keeps the heaters up to temperature all day and has them ready for service at night. This means no expansion and contraction stress from repeated shutdowns and startups. Interfacing at this point does have one disadvantage in that the plant will have to be shut down in order to make the tie-in.

Again schematic A offers several advantages:

1. All solar energy collected is used. (Except for line loss and overnight cooldown).

2. All heat supplied by the heat recovery units is still used.

3. Fired heaters are maintained at operating temperature to alleviate thermal stresses.

4. Fired heaters can respond rapidly to transient conditions, so the normal cloud movements will not cause operating problems.

5. The system control is extremely simple.

6. The existing plant operations will have minimum interruption.

5.4.6.2 HMO Transport Line Expansion Analysis

To determine the best way to handle the line expansion, two methods were evaluated. One was the use of expansion loops and the other was the use of expansion joints.

The desired number of loops (12) was chosen and sized to accommodate the thermal stress. From the size and number, a material list was generated so that the cost of loops could be determined. After arriving at that cost, the price for the required number of expansion joints was established. Other factors which were considered were the increased probability of leaks using the joints, and the increased pressure drop caused by the loops.

The expansion joints were selected because the analysis showed that the expansion loops were $18,000 higher in cost (182%) and increased the pressure drop between the plant and receiver by approximately 55.17 KPa (8 psi) which impacted the size pump required.

5.4.6.3 Piping Sizing Analysis

Initially, .254 m (10 in) pipe was selected to be used for the loop to achieve a very small pressure drop through the solar unit. Later, a cost and efficiency comparison was made between this size pipe and .203 m (8 in) pipe. The cost of pipe and insulation, and the pressure drop through the system was determined for both sizes of pipe. The additional power required to overcome the increased pressure drop caused by the .203 m (8 in) pipe was calculated. This was converted to dollars by using the present power costs. The payout time was then obtained by dividing the differential cost of the .254 m (10 in) pipe by the differential power cost of the .203 m (8 in) pipe. This was in excess of twenty years.

Another payout was then calculated by subtracting the increased cost of a pump needed by the .203 m (8 in) system from the differential cost of the .254 m (10 in) system.

This figure was then divided by the power cost and gave a payout of eighteen years.

Based upon the above calculation, it was decided to use .203 m (8 in) pipe for the loop system.

5.4.7 Loop Cost Estimates

The detailed loop cost estimate is presented in Appendix A. The summary of these costs by major component or grouping is as follows.

MATERIALS		$325,872
a. Pipe, Fittings, Valves	$166,700	
b. Pumps	46,000	
c. Drain & Storage Tank	15,950	
d. Instruments & Controls	22,222	
e. Insulation	75,000	
SUBCONTRACTS		18,000
a. Pipe Supports	18,000	
DIRECT LABOR		107,570
a. Pipe, Fittings Valves	65,275	
b. Pumps	7,700	
c. Drain & Storage Tank	2,135	
d. Instruments & Controls	4,260	
e. Insulation	28,200	
TOTAL DIRECT COSTS		451,442
INDIRECT FIELD COST		94,800
TOTAL FIELD COST		546,242
OFFICE COSTS (INCL ENGG. PROCUR, CONSTR. MGMT)		106,211
TOTAL FIELD & OFFICE COST		652,453
LABOR PRODUCTIVITY		22,180
CONTINGENCY		67,460
FEE		50,460
TOTAL CONSTRUCTION COST (CC 5900)		$792,553
DESIGN COST		253,838
TOTAL LOOP COST		$ 1,046,391

SECTION 6.0

ECONOMICS

6.1 METHOD

The objective of this economic evaluation is to determine the financial effectiveness of installing a solar powered heating system to augment the existing gas fired heating system at the North Coles Levee plant. The only way a venture of this type can be feasible, is that (a) by making this investment, the cost of producing energy can be reduced or (b) income from gas sales can be increased. These two items are essentially the same in the case of the North Coles Levee project, in that by producing energy from solar, the gas that would normally be burned may be put into the pipeline and sold right along with the normal gas sales. This effectively raises the profitability of the plant. In order for the project to be feasible, the profitability of the plant must be raised sufficiently to pay for all of the costs of the project for its entire life cycle, including initial investment and yearly operating costs, and then yield a return which would be competitive with alternate investments.

One of the best means of assessing the economic feasibility of the project is to determine the profit contribution from solar and consequently the rate of return on the investment.

Our economic evaluation determined the rate of return on investment by computing the in and out and net cash flow on a year-by-year basis. The yearly net cash flows were then used to determine the rate of return on investment over the life of the venture. Along with the rate of return calculation, other economic indicaters were computed such as payback time, profit/investment ratio, and present worth.

In addition to the normal approaches to economic evaluation, this project was looked at from the standpoint of "cost of producing energy." The cost of producing energy from solar was compared to the cost of producing energy from natural gas.

Figures 6.1-1 through 6.1-4 present a sample print-out from Northrup's "ECON" computer code which illustrates the evaluation technique.

Figure 6.1-1

Sample Print-Out, "ECON" Computer Code

```
                    NORTH COLES LEVEE ECONOMIC ANALYSIS
                    -----------------------------------


 TOTAL SOLAR SYSTEM COST (HELIOSTATS-RECEIVER-TOWER-ETC) =      $ 8336034
   LESS FEDERAL INVESTMENT TAX CREDIT, NORMAL            =   - $  833603
   LESS FEDERAL INVESTMENT TAX CREDIT, SPECIAL SOLAR     =   - $ 1250405
   LESS STATE INVESTMENT TAX CREDIT, SPECIAL SOLAR       =   - $  833603
---------------------------------------------------------------------------
THEREFORE, NET AMOUNT OF SYSTEM COST                     =      $ 5418423

ENTER USEFUL SOLAR ENERGY INPUT TO PROCESS, MILLIONS BTU'S = 76981
ENTER CONVENTIONAL BURNER EFFICIENCY, % = 62.5
ANNUAL GAS USAGE REDUCTION, MCF = 123170 (1000'S OF CUBIC FEET)
ENTER ANNUAL SOLAR SYSTEM OPERATING & MAINTENANCE EXPENSE, = $ 218044
ENTER ANNUAL OPERATING & MAINTENANCE EXPENSE ESCALATION, % = 8
ENTER SYSTEM LIFE, YEARS = 20 (SINKING FUND DEPRECIATION METHOD)
ENTER FEDERAL DEPRECIATION PERIOD, YEARS (3YR-DDB + BAL-SYD) = 11
ENTER STATE DEPRECIATION PERIOD, YEARS (STRAIGHT-LINE) = 3
ENTER FEDERAL CORPORATE TAX RATE, % = 46
ENTER STATE CORPORATE TAX RATE, % = 3.5
ENTER INTEREST RATE, % = 11.5
ENTER CASHFLOW DISCOUNT RATE, % = 11.5
ARCO AVERAGE CASE GAS SCHEDULE
```

Figure 6.1-2

Sample Print-Out, "ECON" Computer Code

YEARLY CASHFLOW ($1000'S)

YR	REVENUE	OPERATING COSTS	TOTAL COSTS	CASH FLOW BFIT	* TAX BENEFITS	CASH FLOW AFIT	** DISCOUNTED CASHFLOW
0	0	0	8336	8336-	2918	5418-	5418-
1	310	218	218	92	716	808	725
2	352	235	235	117	582	699	562
3	399	254	254	145	469	613	442
4	454	275	275	180	364	544	352
5	509	297	297	212	293	505	293
6	649	320	320	329	180	509	265
7	787	346	346	441	70	511	239
8	925	374	374	551	39-	512	215
9	1062	404	404	658	146-	512	192
10	1198	436	436	763	253-	510	172
11	1336	471	471	866	358-	507	153
12	1430	508	508	922	441-	480	130
13	1529	549	549	979	469-	510	124
14	1630	593	593	1037	496-	540	118
15	1738	640	640	1097	526-	572	112
16	1849	692	692	1157	554-	603	106
17	1968	747	747	1221	585-	636	100
18	2218	807	807	1412	676-	736	104
19	2612	871	871	1741	834-	907	115
20	2994	941	941	2053	983-	1070	121
--	25951	9978	18314	24309	769-	6868	780-

* TAX CREDITS & REFUNDS FROM O&M & DEPRECIATION LESS FUEL COST TAX LOSS

** DISCOUNTED AT A COMPOUNDING RATE OF 11.5 % ANNUALLY. NOTE THAT THE COLUMN TOTAL EQUALS THE PRESENT WORTH AT 11.5 %

INTERNAL RATE OF RETURN = 9.17 %

PAYBACK TIME = 9.4 YEARS

PROFIT/INVESTMENT RATIO = 1.27

Figure 6.1-3

Sample Print-Out, "ECON" Computer Code

SOLAR ENERGY PRODUCTION COSTS ($1000'S)

YR	O&M	INTEREST ON INVESTMENT	DEPREC. SINKING FUND	TOTAL EXPENSE	* TAX BENEFITS	NET ANNUAL COST
1	218	623	80	921	1163	242-
2	235	623	80	938	1049	111-
3	254	623	80	957	958	1-
4	275	623	80	977	880	97
5	297	623	80	999	835	165
6	320	623	80	1023	790	234
7	346	623	80	1049	746	303
8	374	623	80	1076	703	374
9	404	623	80	1106	661	446
10	436	623	80	1139	620	519
11	471	623	80	1174	580	593
12	508	623	80	1211	542	669
13	549	623	80	1252	561	690
14	593	623	80	1296	582	713
15	640	623	80	1343	605	738
16	692	623	80	1394	630	765
17	747	623	80	1450	656	794
18	807	623	80	1510	685	825
19	871	623	80	1574	716	858
20	941	623	80	1644	749	895
	9978	12462	1594	24034	14710	9324

* TAX REFUNDS FROM O&M, INTEREST, AND DEPRECIATION

Figure 6.1-4

Sample Print-Out, "ECON" Computer Code

ALTERNATE ENERGY FUEL COST COMPARISON

YR	GAS PRICE (AT-METER) $/MCF OR $/MMBTU	GAS PRICE (TO-PROCESS) $/MCF OR $/MMBTU	GAS PRICE (AFTER-TAX) $/MCF OR $/MMBTU	NET SOLAR FUEL COST $/MMBTU
1	2.52	4.03	2.10	3.15-
2	2.86	4.58	2.38	1.44-
3	3.24	5.18	2.70	.01-
4	3.69	5.90	3.08	1.26
5	4.13	6.61	3.44	2.14
6	5.27	8.43	4.39	3.03
7	6.39	10.22	5.33	3.94
8	7.51	12.02	6.26	4.86
9	8.62	13.79	7.19	5.79
10	9.73	15.57	8.11	6.74
11	10.85	17.36	9.05	7.71
12	11.61	18.58	9.68	8.69
13	12.41	19.86	10.35	8.97
14	13.23	21.17	11.03	9.27
15	14.11	22.58	11.76	9.59
16	15.01	24.02	12.51	9.94
17	15.98	25.57	13.32	10.31
18	18.01	28.82	15.02	10.71
19	21.21	33.94	17.68	11.15
20	24.31	38.90	20.27	11.62
--	10.53	16.86	8.78	6.06

6.2 ASSUMPTIONS WITH RATIONALE

In order to determine profitability, and energy cost from the solar contribution, the components of income and cost were estimated as described in the following paragraphs.

6.2.2 Income Items

1. Gas Sales

The gas that is saved by using the solar system will be sold at the well-head at the prevailing market rate. That rate for 1980 is estimated to be $.0085 per kw hour ($2.49 per million BTU) and is predicted to escalate in future years. Two rates of escalation were used in this evaluation and results are shown for both. One set is based on the value specified in the contract Statement of Work which is 3% above inflation of 8%, for a total of 11%, annually. The second set is a Long Range Planning Integrated Scenario developed by Atlantic Richfield Co., Oil and Gas Division, which averages 12.67%increase in a 20 year period. The ARCO schedule was developed for the National Gas Policy Act Section 102 Category, which applies to the North Coles Levee facility. This schedule assumes that deregulation starts at the end of 1984 and proceeds in a straight line through 1990 at which time it approaches the alternate fuel price level. The two schedules are presented in Table 6.2-1.

The income realized from the sale of natural gas further assumes that, had it been burned instead, it would have been burned by the 62.5% efficient burner currently used at the facility, and that the net cost of the gas would have been decreased by the income tax deduction.

The amount of gas energy saved to be sold annually is that amount which the solar system will annually put into process. The 320 heliostat system will in an average year, in Bakersfield receive a solar radiant energy input of 2488.5 kw hrs/m^2. Since good Bakersfield insolation data is not available this figure was arrived at by using Barstow data and estimating Bakersfield average energy to be 90% of Barstow average energy. Since the yearly efficiency of the solar system is 53.8% the annual system output of 320 heliostats having an area of 52.58 m^2 is 22.55 x 10^6 kw-hrs., or 7.7 x 10^{10} BTU's per average year.

TABLE 6.2-1

GAS PRICE ESCALATION TABLES

Year	SNLL SCHEDULE (11%) $/kw-hr	SNLL SCHEDULE (11%) $/$10^6$BTU	ARCO AVG. SCHEDULE $/kw-hr	ARCO AVG. SCHEDULE $/$10^6$BTU
1980	.0085	2.49	.0086	2.52
1981	.0094	2.76	.0098	2.86
1982	.0105	3.07	.0111	3.24
1983	.0116	3.41	.0126	3.69
1984	.0129	3.78	.0141	4.13
1985	.0143	4.20	.0180	5.27
1986	.0159	4.66	.0218	6.39
1987	.0176	5.17	.0256	7.50
1988	.0196	5.74	.0294	8.62
1989	.0217	6.37	.0332	9.73
1990	.0241	7.07	.0370	10.85
1991	.0268	7.85	.0396	11.60
1992	.0297	8.71	.0423	12.40
1993	.0330	9.67	.0452	13.23
1994	.0366	10.73	.0481	14.10
1995	.0407	11.91	.0512	15.00
1996	.0451	13.22	.0546	15.98
1997	.0501	14.68	.0615	18.00
1998	.0556	16.29	.0724	21.20
1999	.0617	18.09	.0830	24.30
2000	.0685	20.08	.0935	27.38
2001	.0761	22.28	.0998	29.24
2002	.0844	24.73	.1066	31.23
2003	.0937	27.46	.1139	33.37
2004	.1041	30.48	.1217	35.65
2005	.1155	33.83	.1301	38.10
2006	.1282	37.55	.1390	40.71
2007	.1423	41.68	.1485	43.51
2008	.1579	46.26	.1588	46.51
2009	.1753	51.35	.1697	49.71
2010	.1946	57.00	.1815	53.15

2. Tax Credits

The availability of tax credits allows a total of 35% of the total system cost to be paid for by the government at the project inception. The tax credits are:

10% Federal investment tax credit

15% Federal special solar tax credit

10% California state special solar tax credit*

(*The California solar credit is actually 25%, but is reduced by the amount of any federal credit taken.)

3. Income Tax Deductions

Income tax deductions are taken on (a) Operation and Maintenance expenses, (b) Interest on money and (c) depreciation. The federal corporate rate is 46% and the California corporate rate is 3.5% effectively for Atlantic Richfield, due to world operations.

Operation and Maintenance is, or course, a deductible expense for any type of economic analysis.

The interest expense is not used and therefore not deductible when computing rate of return on investment, since the purpose of the analysis is to determine what rate of return (or interest rate) one would realize from an investment of capital. However, when computing the cost of producing solar energy, the cost of money use must be included as an expense and therefore is an income tax deduction.

A very significant income tax deduction is the rapid write-off permitted for depreciation in the early years of the project. The depreciation used in the analyses is as follows:

(a) Federal - ARCO uses an 11 year schedule for production facilities such as the North Coles Levee gas plant. The schedule consists of Double Declining Balance (DDB) for the first 3 years and then switches to Sum of the Years Digits (SYD) for the remaining 8 years. The entire initial cost of the project is depreciated even though tax credits were taken.

(b) State - ARCO anticipates passage in the near future of a new solar energy law which will enable the total installed cost less any California tax credits to be written-off over three years. This was assumed in the analysis with a simple straight line depreciation method employed.

6.2.3 Cost Items

1. System Cost

The initial cost of installing the solar system is detailed in section 4.6. The costs are computed at 1980 material and labor rates adjusted to the job location. The total system cost is:

Design Phase	$ 1,658,762
Owner's Cost	118,973
Construction Cost	6,558,299
TOTAL SYSTEM COST	8,336,034

The Design Phase is based on a considerable amount of engineering and planning effort associated with a "one-of-a-kind" plant. It also includes constructing a receiver/19-heliostat development module and operating it for a 12 month period to validate major hardware functions and system performance. The largest single cost item contributing to the system cost is the cost of the heliostat field, which amounts to approximately 60% of the total cost. The cost of the 19 heliostats purchased during the design phase is based on $21,823 per unit installed. This is the cost of fabrication done with soft tooling and subcontracting most of the hardware to outside venders. The cost of the 301 remaining heliostats procured during the construction phase is based on the heliostats being produced in a small production facility equiped to produce about 2000 units per year. This is the production rate anticipated to be in existance during the 1982-83 time period by a single facility. The production methods would still involve subcontracting major items such as drive units and trusses for which moderate production capability already exists. The principal activities in this plant would be mirror module construction and assembly work. The resulting cost would be $15,508 per unit installed for 301 remaining units.

2. Operation and Maintenance

The operation and maintenance costs are detailed in section 4.7, along with the strategy for integrating the solar system into the existing plant operation. These costs are computed at current material and labor rates and are summarized on an annual cost basis to be:

Operations	$154,082
Maintenance Materials	27,852
Maintenance Labor	36,110
Total	$218,044

The total annual expense is escalated in the economic analysis at an annual rate of 8% per year to account for normal inflation of labor and materials.

3. Cost of Money Use - Interest

The use of money for the initial capital outlay must be included as part of the cost of producing the solar energy. The prevailing interest rate at the time of constructing the system is arbitrarily selected at 11.5% for this type of project. This is 3.5% above the predicted inflation rate of 8%. The interest expense is used when computing the cost of solar energy, but it does not apply when computing the rate of return on investment.

4. Depreciation Due to Deterioration and Obsolescence

The major equipment items of the solar system are designed for a 30 year life. However, the economic evaluation is based on 20 year life of the system for purposes of computing depreciation due to deterioration and obsolescence. This conservatism is used because of the unknowns involved in forecasting the future of the current solar technology and when it might become obsolete, as well as the future of the aging North Coles Levee oil field.

The sinking fund method is the fundamental method of computing depreciation costs for economic studies and therefore is used in this analysis. This method is based on the concept that the annual uniform deduction from income for depreciation will, when invested at a given interest rate, accumulate to the capital value of the enterprise at the termination of the venture.

The depreciation expense is used when computing the cost of solar energy, but it does not apply when computing the rate of return on investment.

5. Leases, Insurance, and Property Taxes

The property on which the North Coles Levee solar installation will be situated is owned by Tenneco West, Inc., and surface lease payments will be required. The amount to be paid has not been negotiated, but a range has been established from preliminary discussions. The range is $3000.00 to 12,000.00, so an average value of 7,500.00 has been selected for this evaluation.

The cost of insurance has been estimated by using the ratio of property and casualty insurance to net assets currently existing in the ARCO Oil and Gas Division, under whose ownership this facility would fall. This ratio was applied to an increased asset value of $8.5 million, to obtain an estimate of annual insurance premiums.

Property taxes are assumed to not apply for the purposes of this estimate. At the present time a property tax is levied on capital assets at the rate of 1.0% to 1.25% of the asset value, by the state of California. However a senate bill, S.B 1306 is currently under consideration, which if passed, will relieve owners of this tax requirement for solar installations. The probability of passage is believed to be good enough that the assumption of no tax is used in this estimate.

6.3 PLANT AND SYSTEM ECONOMIC SIMULATION MODEL

A computer program was developed to generate the economic analyses. The program produces two basic analyses for economic evaluation. The first and most important is year-by-year analysis of cash flow and ultimately the rate of return on the investment. The second is an analysis to compute the unit cost of solar produced energy and a comparison to gas produced energy.

The input parameters for these analyses are:

- Initial System Cost
- Cost of Money Use - Interest Rate
- System Life
- 1st year Operation and Maintenance (O & M)
- O & M Escalation Rate
- Federal Depreciation Period
- Federal Depreciation Formula*
- California Depreciation Period
- California Depreciation Formula*
- Federal Income Tax Rate
- California Income Tax Rate
- Solar Energy into Process
- Burner Efficiency
- Gas Price (at meter) Escalation Schedule
- Federal and California Tax Credits*

(*Semi-built-into program)

A block diagram of the "Cash Flow/Rate of Return" model is shown in Figure 6.3-1.. A block diagram of the "Cost Comparison of Solar vs. Gas Energy" model is shown in Figure 6.3-2.

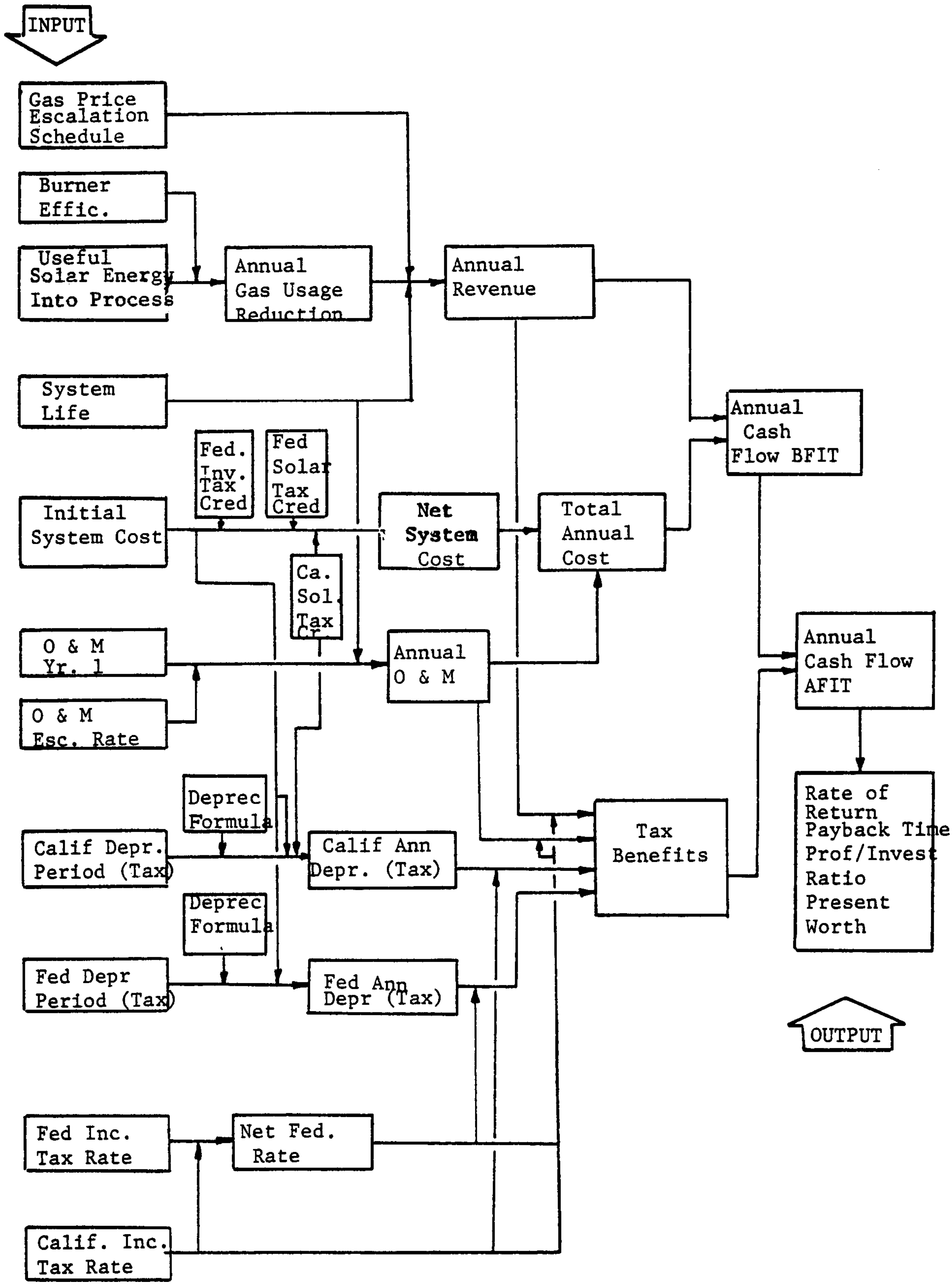


Fig 6.3-1 "Cash Flow/Rate of Return" Model Block Diagram

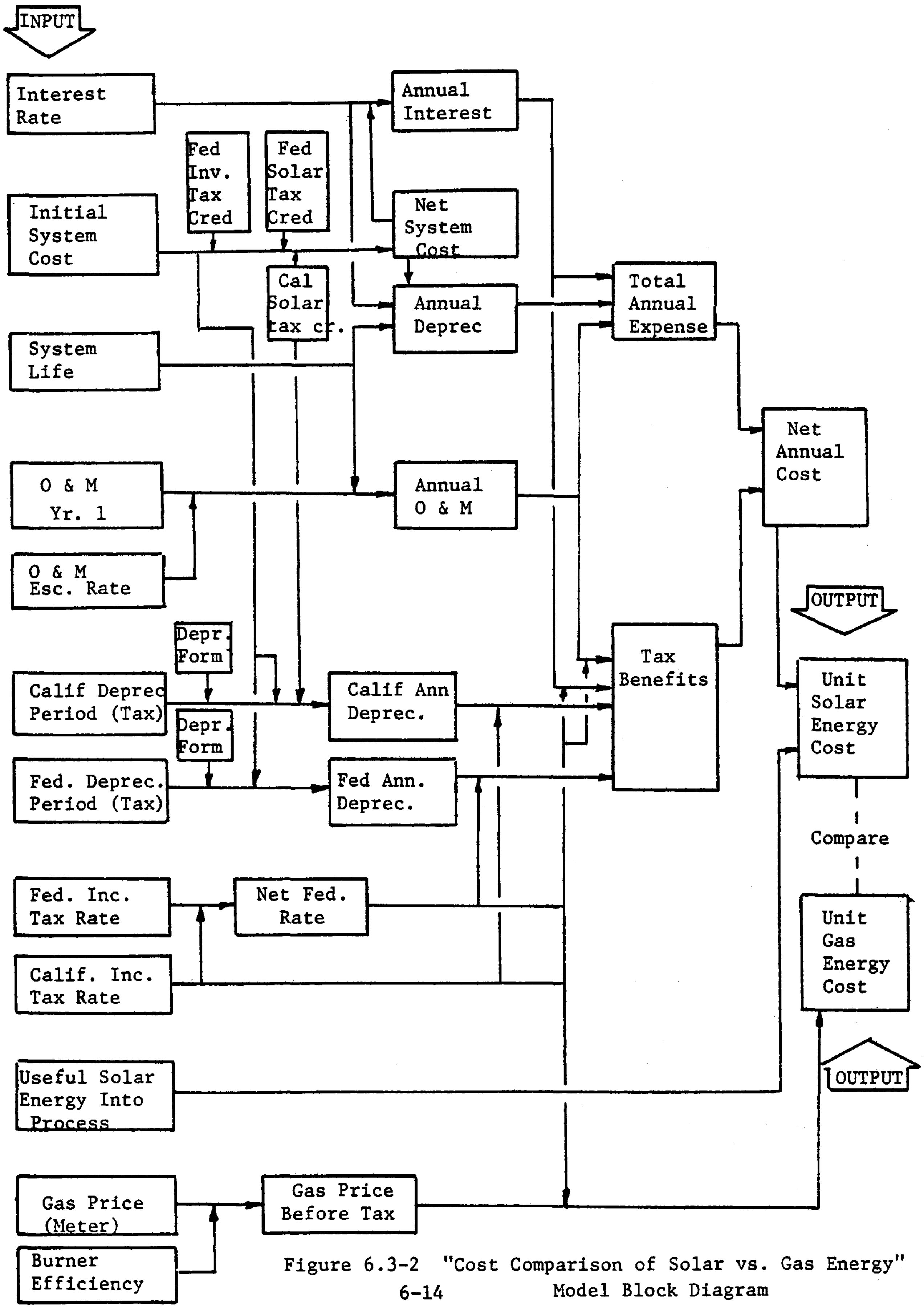


Figure 6.3-2 "Cost Comparison of Solar vs. Gas Energy" Model Block Diagram

6.4 RESULTS AND CONCLUSIONS

The evaluation of the economic feasibility of this project involves the use of several variables and assumptions, each of which can affect the answer significantly. The final decision to construct this project is a matter of judgement relative to the set of assumptions and forecasts into the future, and the goals which the participants wish to accomplish.

If viewed strictly from the standpoint of economic returns, in competition with wholesale natural gas the project is marginal, in that the rate of return on the investment is in the neighborhood of 6% to 10%, coupled with moderate risk. For risks of this nature, an investor normally would demand about 15% return.

However this project should be viewed at least partially from the standpoint of it being part of the early stages of development of a new energy source to offset the rapidly escalating price of fossil fuels. Therefore, an expenditure with a lower rate of return is justifiable, in that, as these systems are installed, operated, and improved, learning should increase, costs should decrease, and rates of return should increase. This project can accomplish a significant step in this process while returning a small to moderate rate of return on investment, which is a desirable situation. Our conclusion is that the project should be undertaken.

In order to evaluate the project economically, a set of values was assigned to each input parameter. These values were selected to be what we believe the real situation will be at the time of installing and operating the North Coles Levee project. These values are specified in Table 6.4-1.

Table 6.4-1

ECONOMIC ASSUMPTIONS

Initial System Cost	$8.34 million
Cost of Money Use - Interest Rate	11.5%
System Life	20 years
1st Year Operation & Maintenance (O & M)	$218,044
O & M Escalation Rate	8% per year
Federal Depreciation Period	11 years
Federal Depreciation Formula	DDB + SYD
California Depreciation Period	3 years
California Depreciation Formula	S.L.
Federal Income Tax Rate	46%
California Income Tax Rate	3.5%
Solar Energy Into Process	76,981 mil. Btu
Burner Efficiency	62.5%
Gas Price (at meter) Escalation Schedule	11% SNLL ARCO AVG.
Federal & California Tax Credits	10%, 15%, 10%

Using this set of assumptions, the following results are obtained:

	GAS ESCALATION SCHEDULE	
	11% SNLL	ARCO AVG.
Rate of Return	6.0%	9.2%
Energy Cost (20 yr. avg)		
. Solar	2.07 ¢/kWh_t	2.07 ¢/kWh_t
. Gas	2.27 ¢/kWh_t	3.00 ¢/kWh_t

Figure 6.4-1 and 6.4-2 illustrate the yearly trends and comparison of solar vs. gas energy cost.

Fig. 6.4-1 ECON CASE C, COLES, PILOT PROD HELIOSTAT DOE GAS ESCALATION SCHEDULE

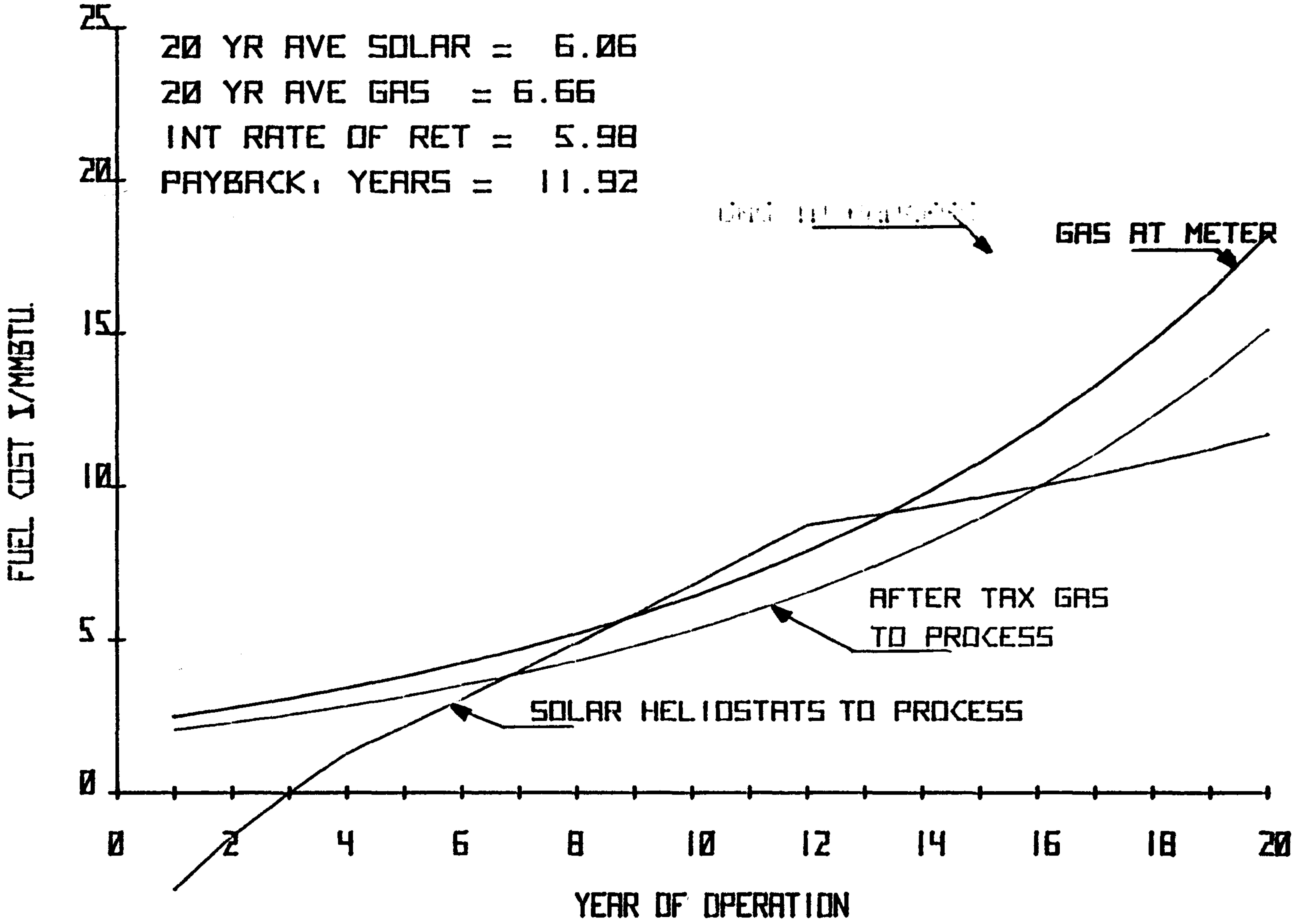
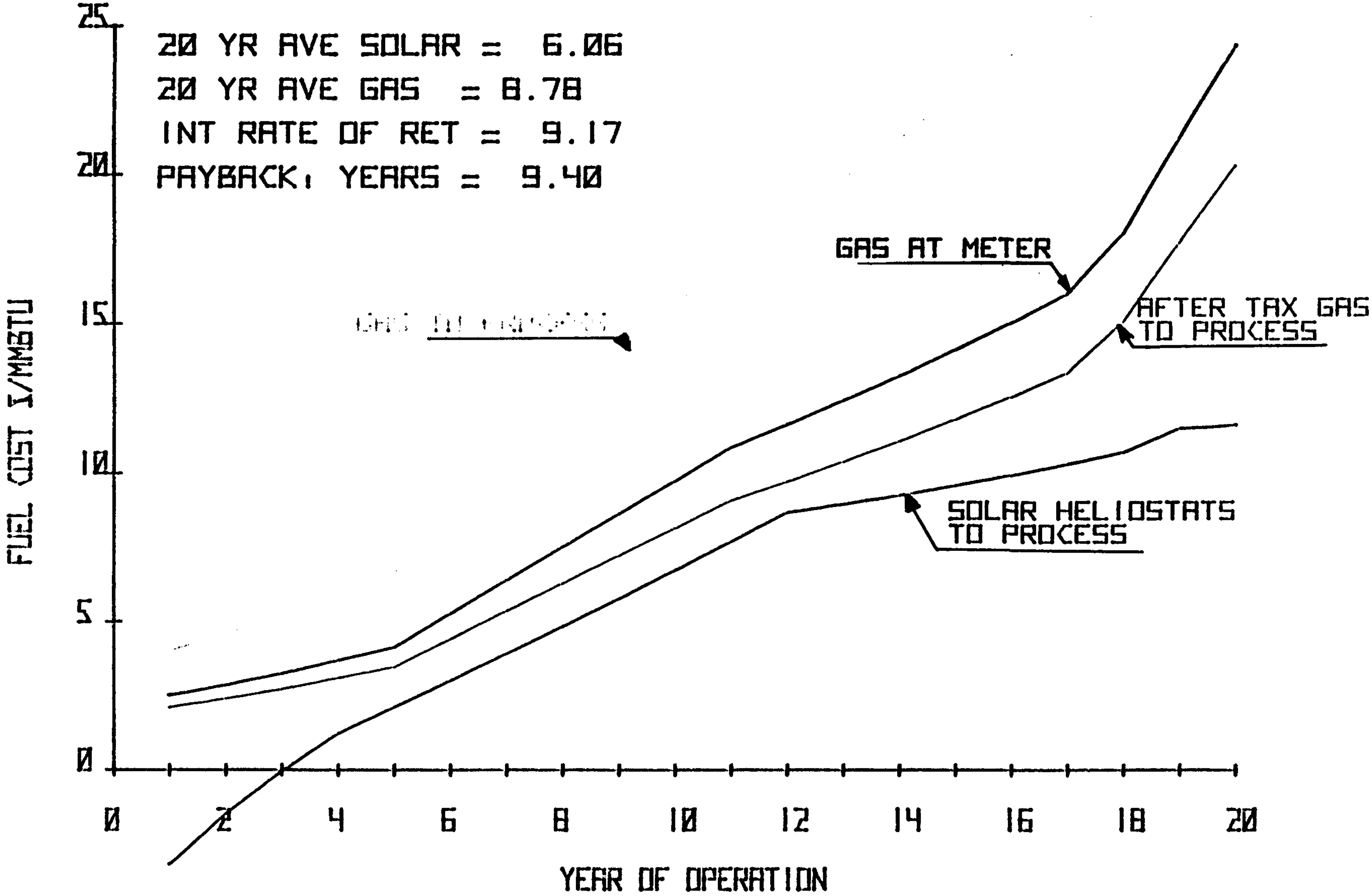


Fig. 6.4-2 ECON CASE D, COLES, PILOT PROD HELIOSTAT
ARCO BASE CASE GAS ESCALATION SCHEDULE



Parametric Analyses - Since the economic analysis is somewhat theoretical in nature, due to the lack of tried and proven cost figures and use of predictions into the future, it is desirable to understand the sensitivity of major elements on the key indicators. Therefore, parametric sensitivity analyses were performed. A description of the analyses and the corresponding figures which present the data are as follows:

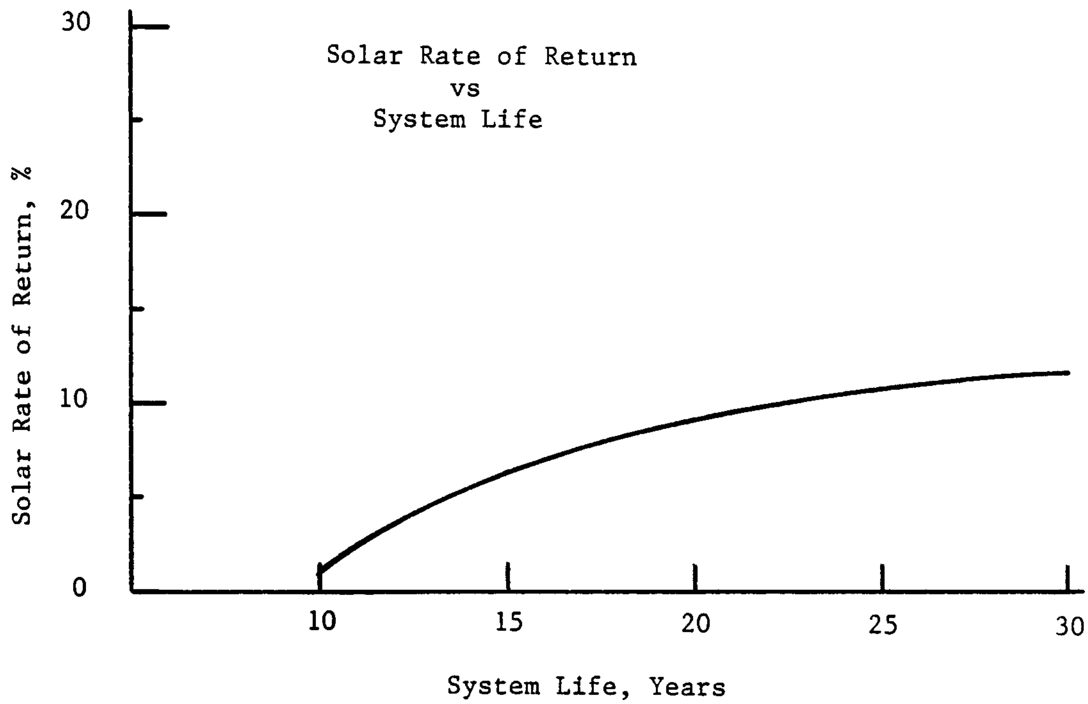
Analysis	Figure
. Varied System Life (10 to 30 years)	6.4-3
. Varied Gas Price Escalation Rate (10 to 25% per year)	6.4-4
. Varied System Cost ($4 to 10 million)	6.4-5
. Varied Discount (Interest) Rate (8% to 16%)	6.4-6
. Varied O & M Escalation Rate (4% to 12%)	6.4-7

The sensitivity plots reveal an interesting conclusion. The rate of return on investment and the solar fuel cost are relatively insensitive to system cost, system life, discount (interest) rate, and O & M escalation rate. The one very sensitive parameter is the gas cost escalation rate. It was found that a 1% increment in gas price escalation rate results in approximately 1% increment in the rate of return on investment. This is highly significant because the latest U. S. Department of Labor, Bureau of Labor Statistics reports the following average annual producer gas price escalation rates between May 1977 and May 1980:

Inter-State Gas Escalation Rate = 53.26%

Intra-State Gas Escalation Rate = 18.78%

Figure 6.4- 3


Solar Rate of Return
vs
System Life
Solar Rate of Return, %
30
20
10
0
10
15
20
25
30
System Life, Years

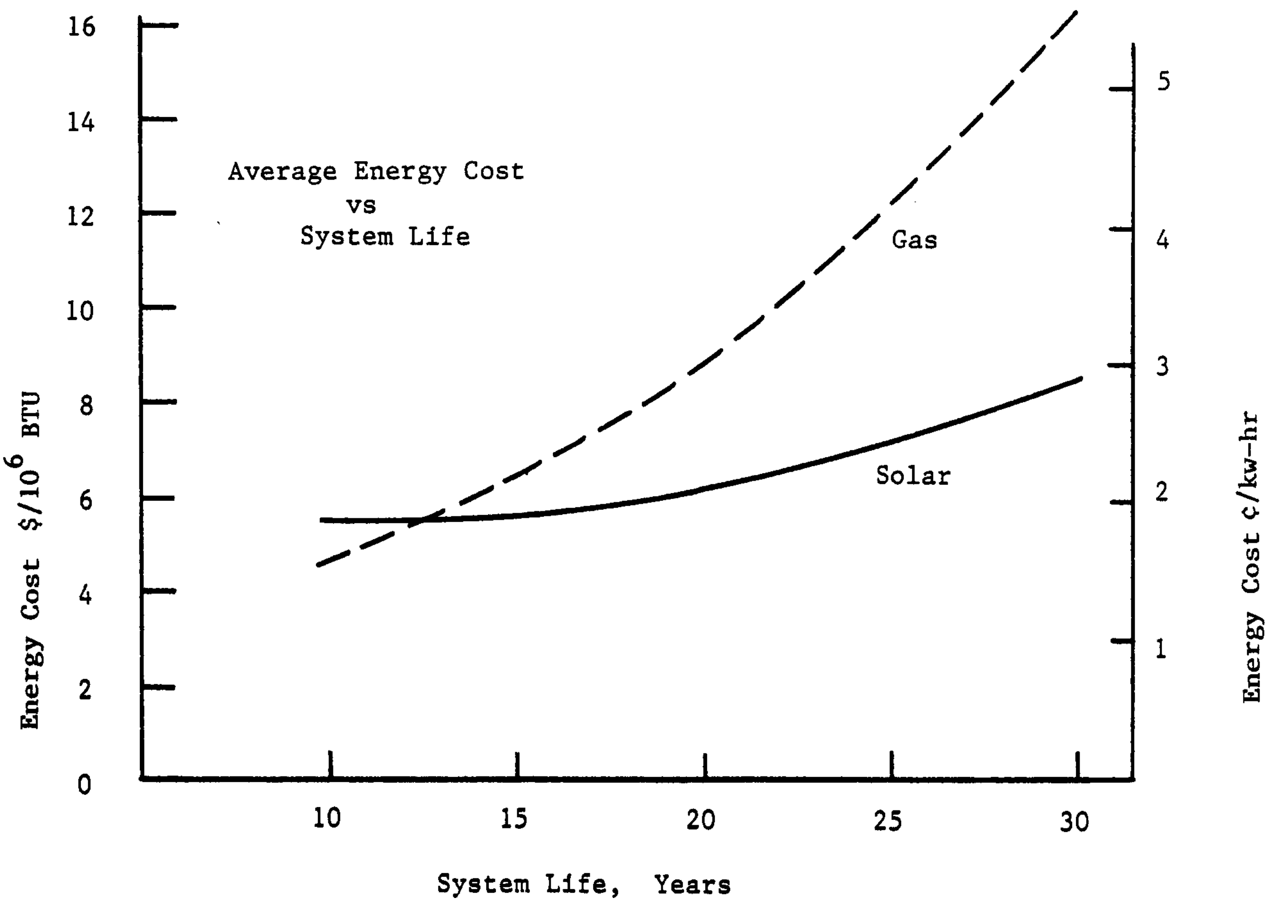
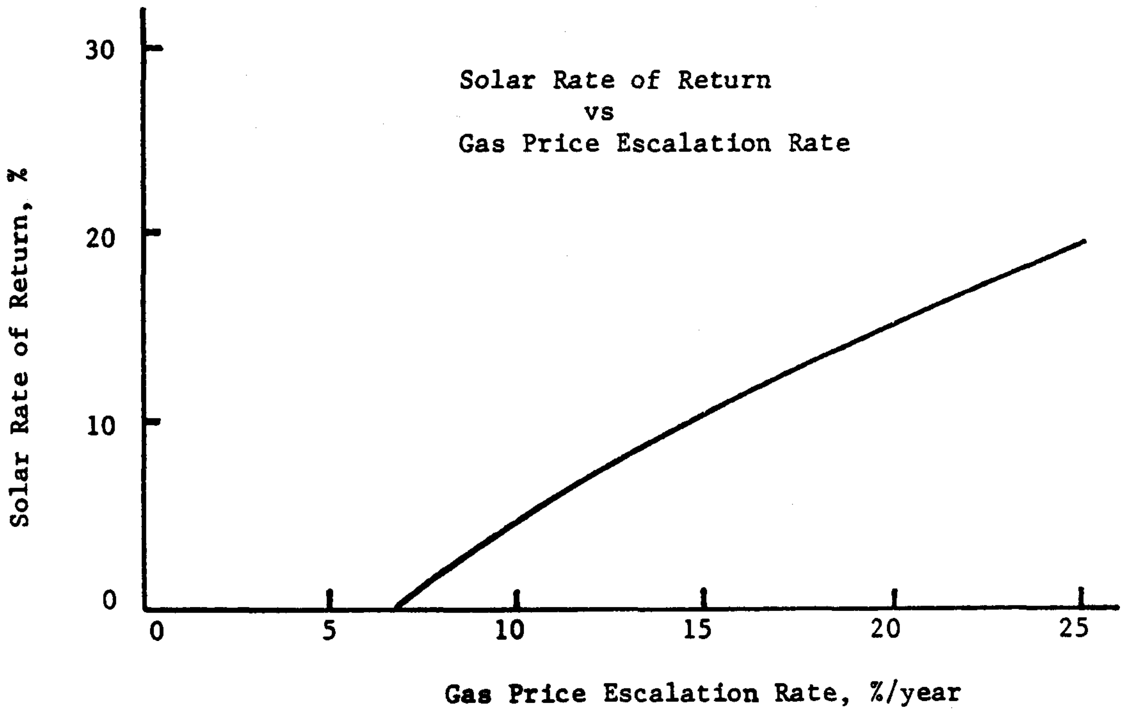

Average Energy Cost
vs
System Life
Gas
Solar
Energy Cost $/10^6 BTU
16
14
12
10
8
6
4
2
0
Energy Cost ¢/kw-hr
5
4
3
2
1
10
15
20
25
30
System Life, Years

Figure 6.4-4


Solar Rate of Return
vs
Gas Price Escalation Rate
Solar Rate of Return, %
30
20
10
0
0
5
10
15
20
25
Gas Price Escalation Rate, %/year

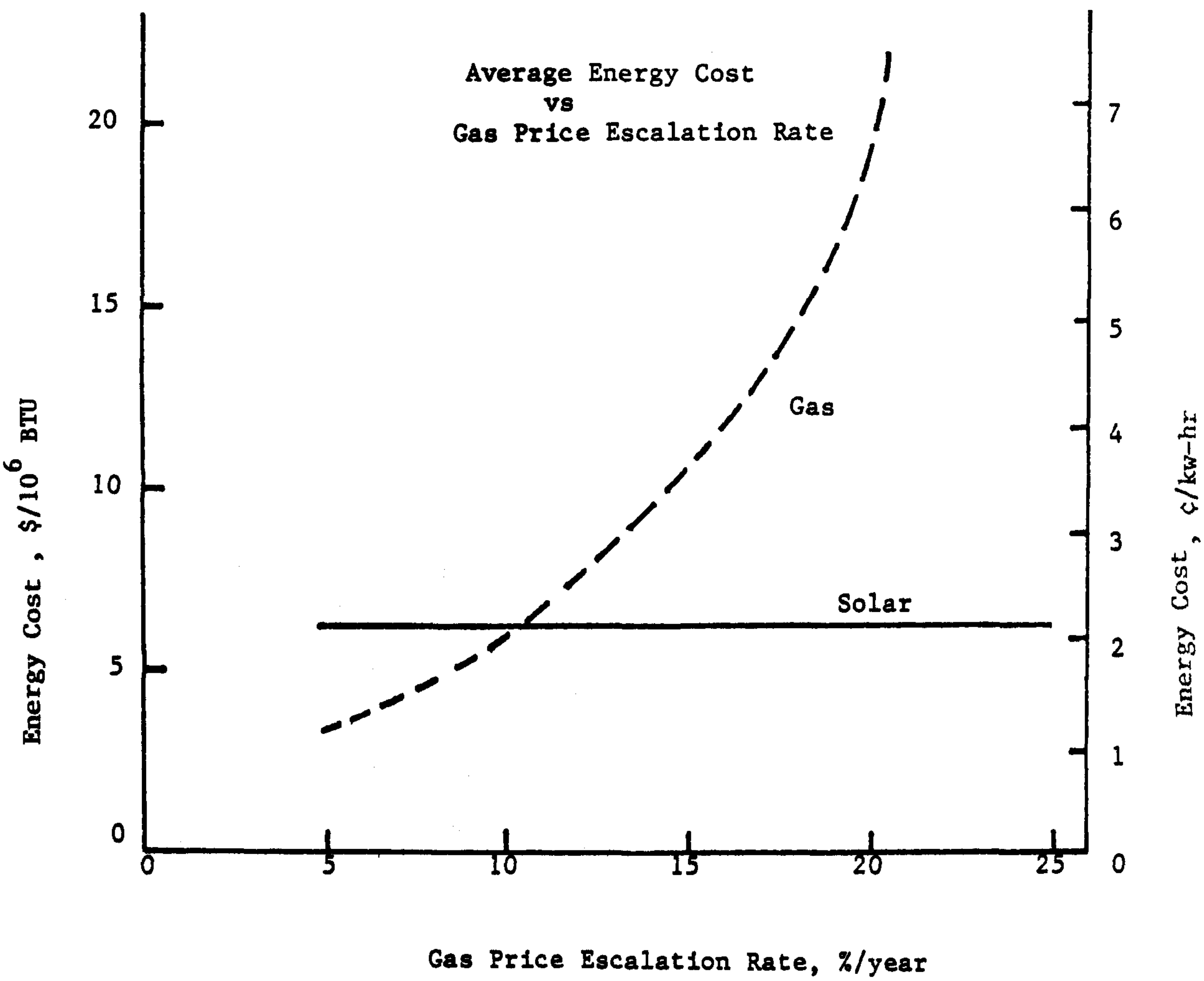
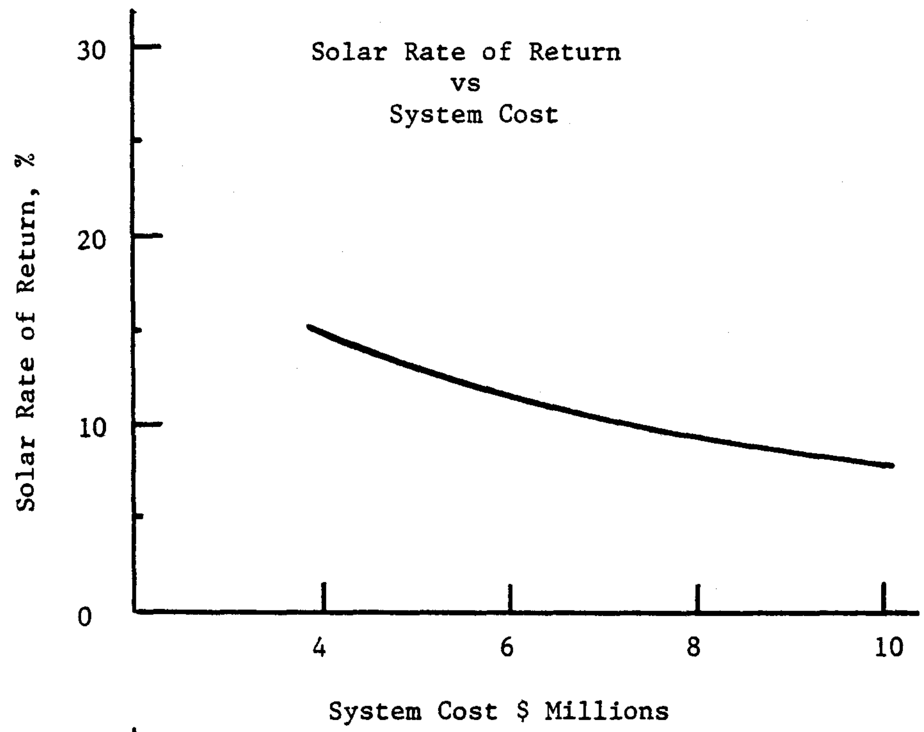
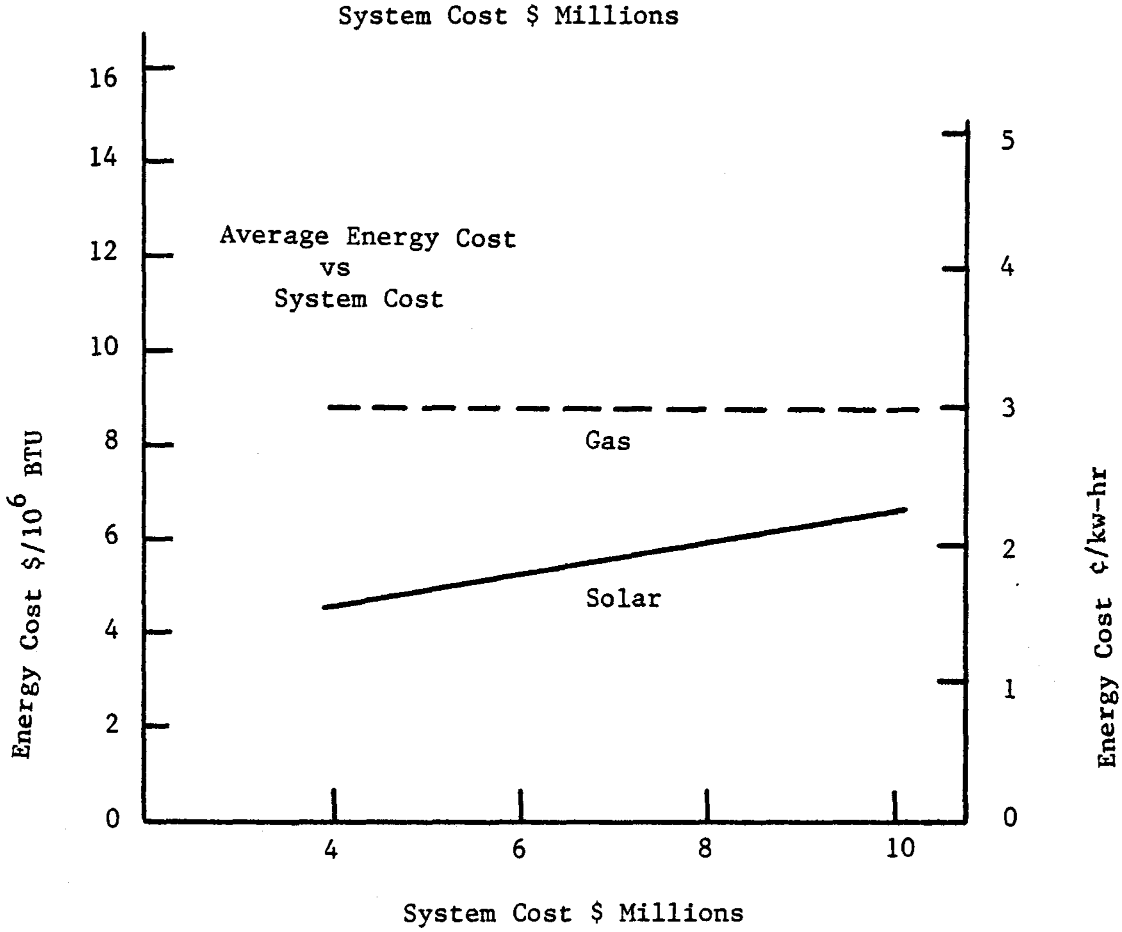

Average Energy Cost
vs
Gas Price Escalation Rate
Energy Cost , $/10^6 BTU
20
15
10
5
0
Gas
Solar
Energy Cost , ¢/kw-hr
7
6
5
4
3
2
1
0
0
5
10
15
20
25
Gas Price Escalation Rate, %/year

Figure 6.4-5

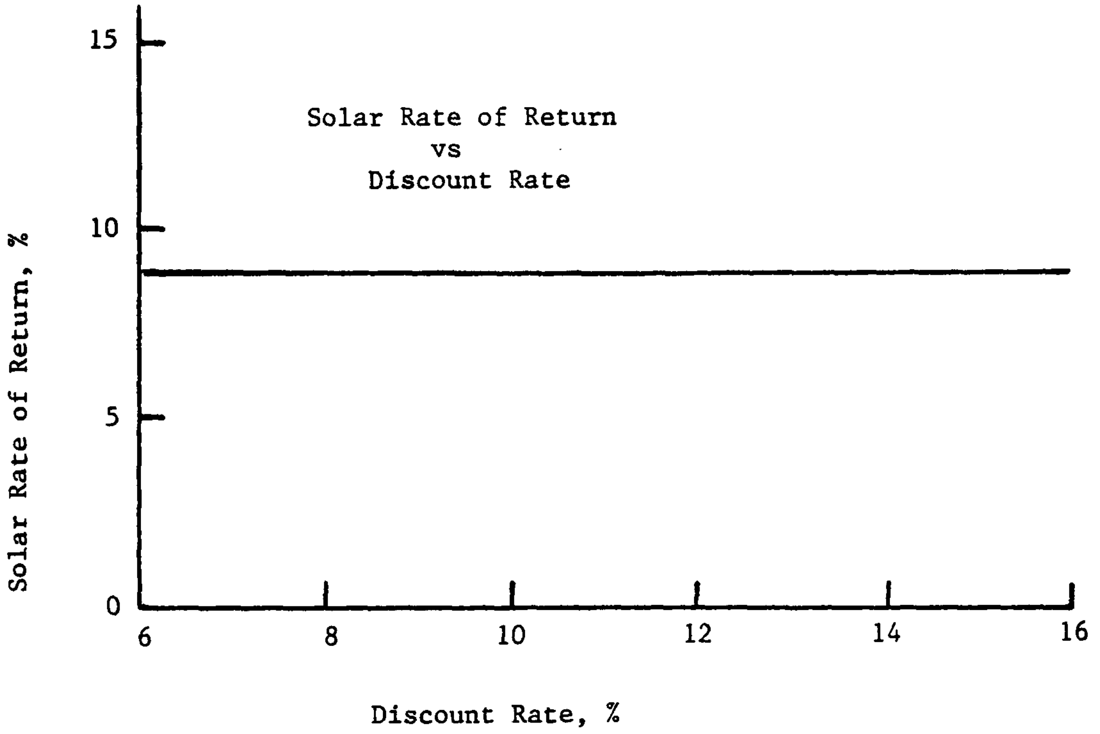


Solar Rate of Return
vs
System Cost
Solar Rate of Return, %
30
20
10
0
4
6
8
10
System Cost $ Millions

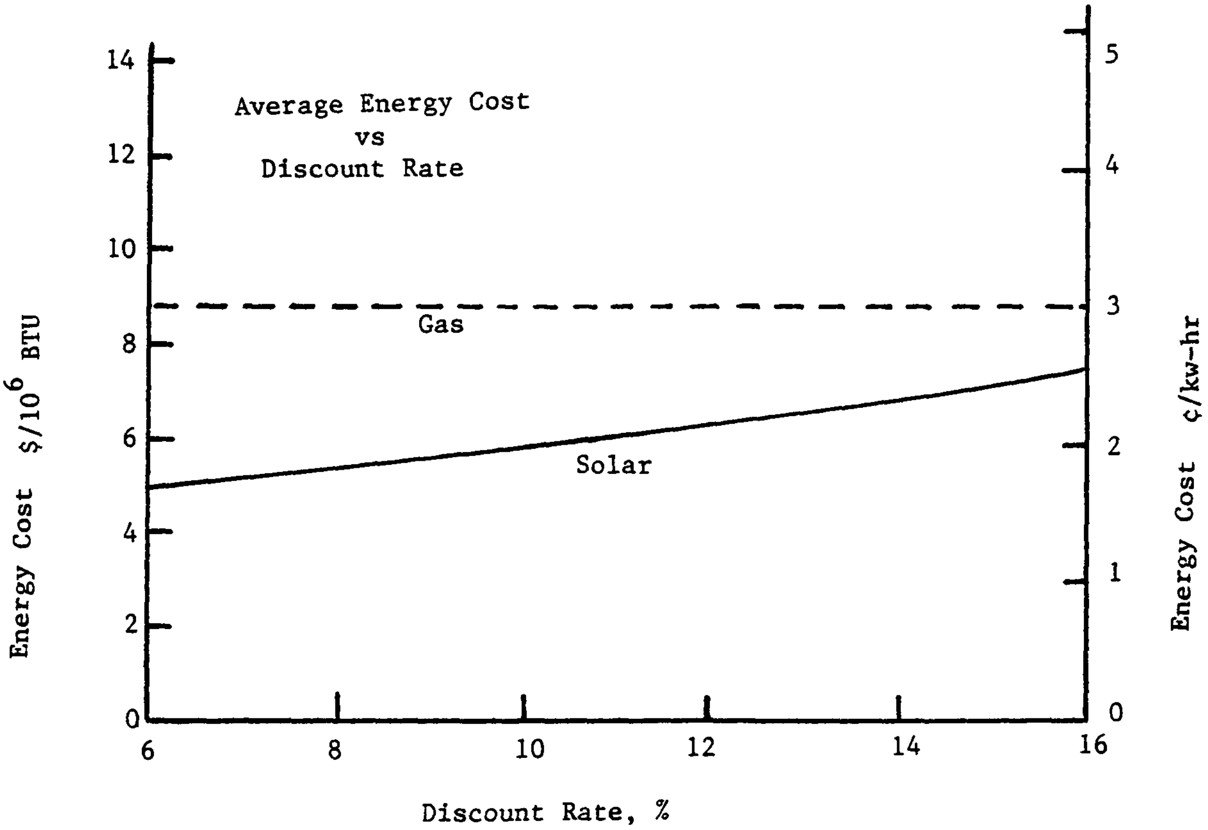


Average Energy Cost
vs
System Cost
Energy Cost $/10^6 BTU
16
14
12
10
8
6
4
2
0
Gas
Solar
5
4
3
2
1
0
Energy Cost ¢/kw-hr
4
6
8
10
System Cost $ Millions

Figure 6.4- 6

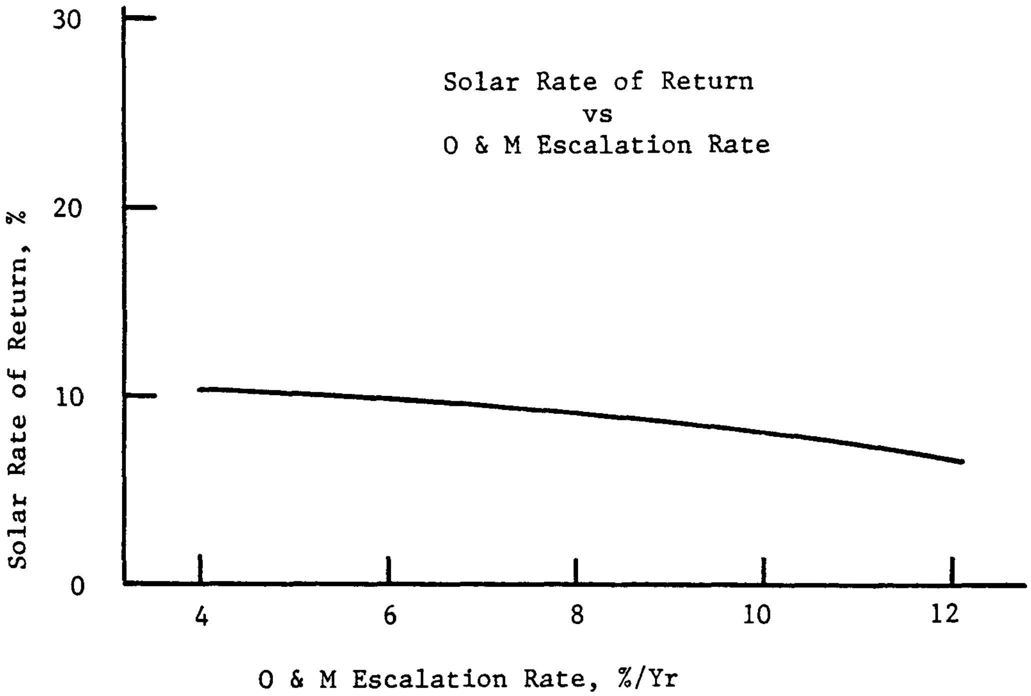


Solar Rate of Return
vs
Discount Rate
Solar Rate of Return, %
15
10
5
0
6
8
10
12
14
16
Discount Rate, %

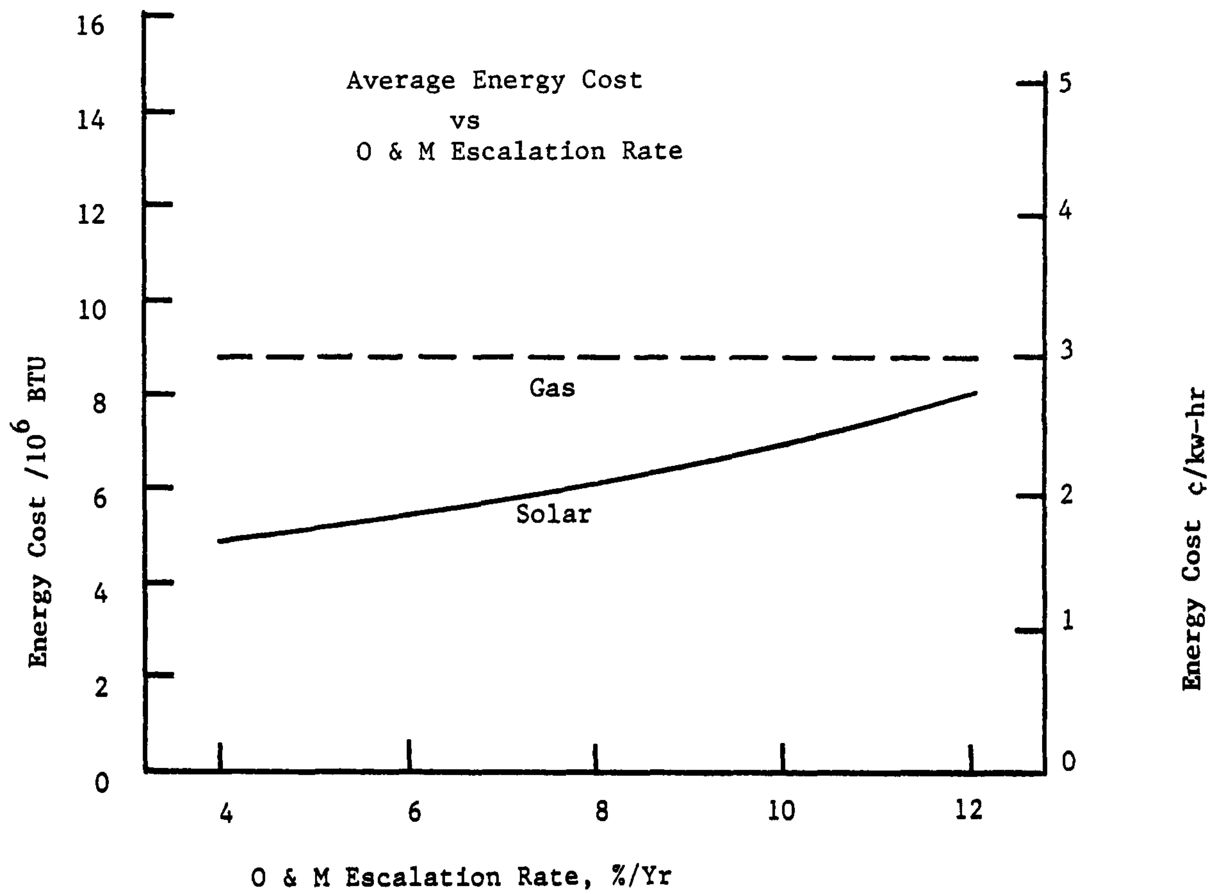


Average Energy Cost
vs
Discount Rate
Energy Cost $/10^6 BTU
14
12
10
8
6
4
2
0
Gas
Solar
5
4
3
2
1
0
Energy Cost ¢/kw-hr
6
8
10
12
14
16
Discount Rate, %

Figure 6.4-7



Solar Rate of Return
vs
O & M Escalation Rate
Solar Rate of Return, %
30
20
10
0
4
6
8
10
12
O & M Escalation Rate, %/Yr



Average Energy Cost
vs
O & M Escalation Rate
Energy Cost /10^6 BTU
16
14
12
10
8
6
4
2
0
Gas
Solar
5
4
3
2
1
0
Energy Cost ¢/kw-hr
4
6
8
10
12
O & M Escalation Rate, %/Yr

Section 7.0

DEVELOPMENT PLAN

This report documents the conceptual design of the solar powered industrial process heat system being developed for installation at North Coles Levee Natural Gas Processing Plant. The work has demonstrated the technical feasibility of contructing a facility of this design. Also demonstrated, was the favorable economic return over a 20 year period of system operation. These facts, coupled with the urgency to apply central receiver technology in energy production, make it extremely important that a well defined development plan be prepared which will provide for a smooth transition into the final design and construction phases. The plan presented here demonstrates that this can be accomplished and the fully operational system can be brought on line 2.5 years after authorization to proceed.

The plan provides for a four phase program beginning with the design phase and terminating at end or a five year operational phase. At this point, the emphasis is placed on the first two phases, i.e., a 12 month design phase and an 18 month construction phase.

The philosophy driving the development of this conceptual design has been to utilize existing technology to the extent possible, thus eliminating the need for subsystem research experiments. The technology advancement associated with the North Coles Levee projects is primarily at the system level. The integration of the major subsystems into a reliable energy producing system operating routinely on a daily basis presents the most significant challenge. As a result, the design team is recommending that a Development Module composed of 19 heliostats and a ground level receiver be installed and operated during the latter part of the design phase and continue into the construction phase. The purpose being to validate design calculations, operational procedures and control strategies. The Developmental Module is discussed in Section 7.1.2.

7.1 DESIGN PHASE

The Program Element Plan presents a Design Phase composed of two subphases; Preliminary Design (9 months) and Detailed Design (12 months). The design team proposes that these two subphases be combined into a single Detailed Design Phase of 12 months duration. The feasibility of this approach is based on several factors.

(1) No thermal storage system.

(2) Small heliostat field.

(3) Single cavity receiver.

(4) Second generation heliostats available.

(5) Simple control system.

(6) Maximum use of existing technology.

7.1.1 Task Outline

The design phase is divided into 6 tasks and 24 related subtasks. Table 7.1-1 presents an outline of this task breakdown.

Task 1 provides for the final design of all subsystems, subsystem integration and engineering analysis. The task deliverables will include drawings and specifications in sufficient detail to solicit bids for all subsystems and/or components. Included also, will be the results of both a performance and economic analysis based on the final design.

Task 2 provides for a complete site development plan that includes grading and filling specifications, utility requirements, control room design and a field wiring plan.

Task 3 requires the development of a subsystem and component procurement plan. This plan will include provisions for identification and procurement of any long-lead items. Also included, will be schedules for all procurement activity.

TABLE 7.1-1

DESIGN PHASE TASK OUTLINE

TASK 1 SYSTEM DESIGN

1.1 Solar Collector
1.2 Receiver
1.3 Receiver Loop
1.4 Tower Evaluation
1.5 System Integration
1.6 System Performance Analysis
1.7 Economic Update

TASK 2 SITE PREPARATION PLAN

2.1 Grade and Fill
2.2 Control Room and Visitor-center design
2.3 Utility service
2.4 Field Wiring

TASK 3 PROCUREMENT PLAN

3.1 Long Lead Item Identification and Procurement
3.2 Subsystem Bid Packages

TASK 4 OPERATION AND MAINTENANCE

4.1 Define Operating procedures
4.2 Prepare Maintenance Plan
4.3 Prepare Safety Plan

TASK 5 DEVELOPMENT MODULE

5.1 Engineering Analysis
5.2 System Final Design
5.3 Construction
5.4 Alignment and Checkout
5.5 Operation

TASK 6 PROJECT MANAGEMENT

6.1 Project Direction

6.2 Reports

6.3 Project Reviews

6.4 Detailed Construction phase plan

Subcontractor and vendor selection criteria will be defined. In addition, this task provides for the preparation of the procurement bid packages.

Under Task 4, a comprehensive operation and maintenance plan will be prepared. This will include definition of system operating procedures. Maintenance requirements will be analyzed to establish procedures and schedules. Lists of equipment and supplies will be developed. A comprehensive safety plan will also be prepared.

Task 5 provides for the design, construction and operation of a 19 heliostat Development Module (see Section 7.1.2).

Task 6 provides for overall project management. Customer visibility is maintained by the preparation and presentation of appropriately scheduled reports and program reviews. A detailed construction phase plan will also be prepared.

The principle deliverables produced by the work under the above tasks will be: (1) bid packages for all systems and components; (2) a comprehensive Construction Phase Plan; and (3) a technical report of the results on the design effort.

The manpower requirements and estimated costs are presented in Section 7.1.3.

The schedule and milestone plan are presented in Section 7.6, Figure 7.6-1.

7.1.2 Development Module

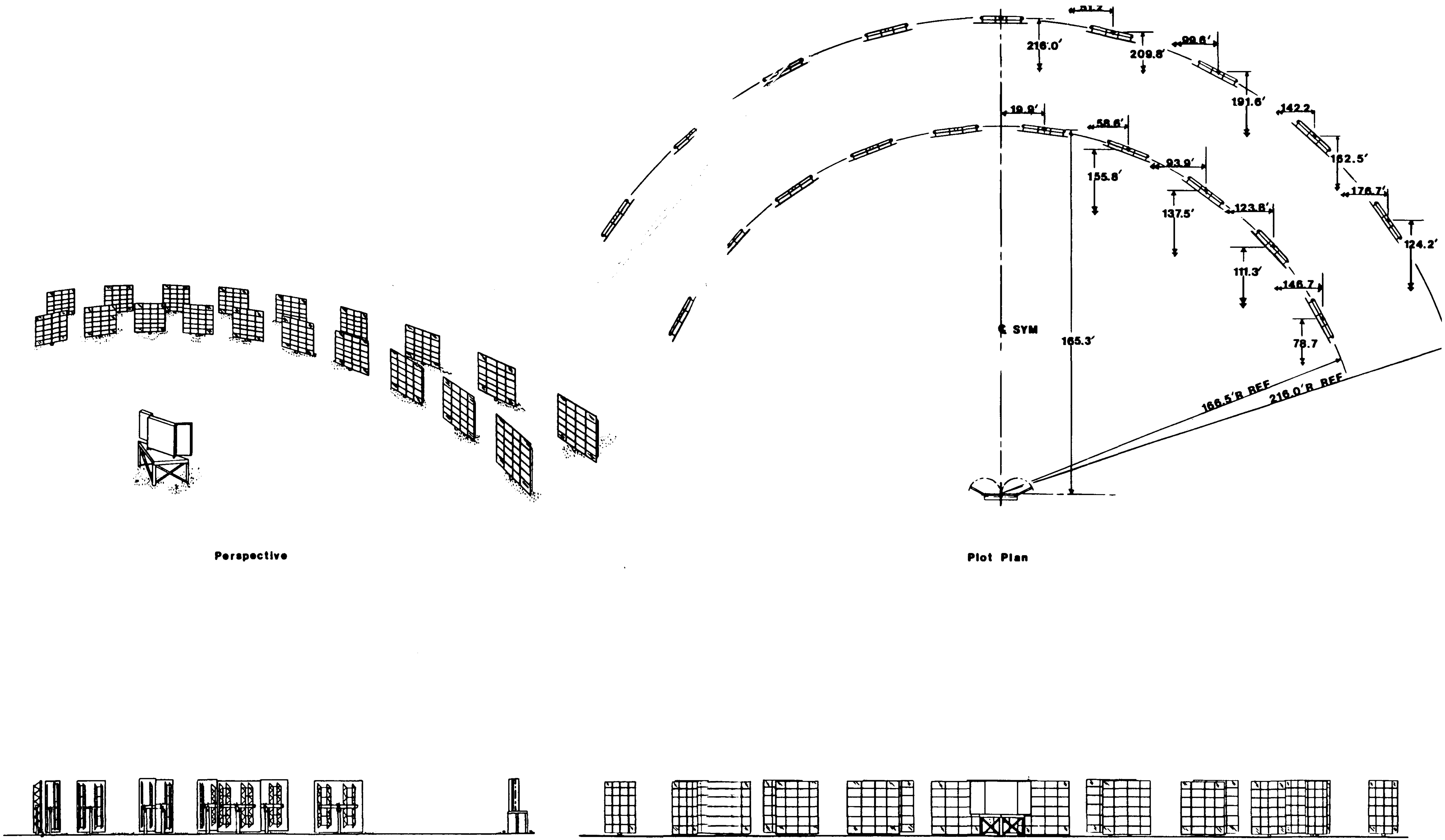
The construction, installation and operation of a Development Module is proposed for the Design Phase. The design of the Module is to be representative of the North Coles Levee solar process heat system and is to be installed at the site.

The collector field will be composed of 19 heliostats arranged in a two-row radial stagger configuration. The spacing between the 10 heliostats on the front row is sufficient to allow the reflected energy from the 9 heliostats on the back row to converge on a ground level receiver located at the center of curvature. Figure 7.1-1 presents both plan and elevation views of the collector field. The heliostats will, in fact, be the first two rows of the full size field. The heliostats are the Northrup II design described in Section 5.2. Table 7.1-2 presents physical parameters and performance characteristic of the module field configuration.

Table 7.1-2

I Physical Parameters	
Mirror Area	999.4 m^2 (10792 ft^2)
Module Size	4539 m^2 (48,858 ft)
Packing Density	.221
II Performance Characteristics	
Peak Geometric Efficiency	.9239
Annual Geometric Efficiency	.7639
Annual Energy	1.503 kW-hr
Peak Energy	740 kW
Peak Flux	241 kW/m^2

The receiver is assembled from commercially available multi-zone embossed and welded heat exchanger plates. The design is based on the use of 5 panels with series flow. The panels are sized to provide a high velocity and high heat transfer rate in the high flux region, and progressively lower velocity and lower pressure losses in the lower flux regions. The panel arrangement and support structure are shown in Figure 7.1-2. The initial calculations for this type receiver yielded an efficiency of 82% (Noon, Dec. 21) using a surface coating of black paint. This can be increased to 87% if a selective surface is used.



Perspective

Plot Plan

Looking East

Looking North

Figure 7.1-1

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES

TOLERANCES

X = ± .125

BLAKE LABORATORY

SUITE 306, 7061 S UNIVERSITY, LITTLETON, CO

NINETEEN HELIOSTAT DEVELOPMENT MODULE

SCALE

DRAWN BY

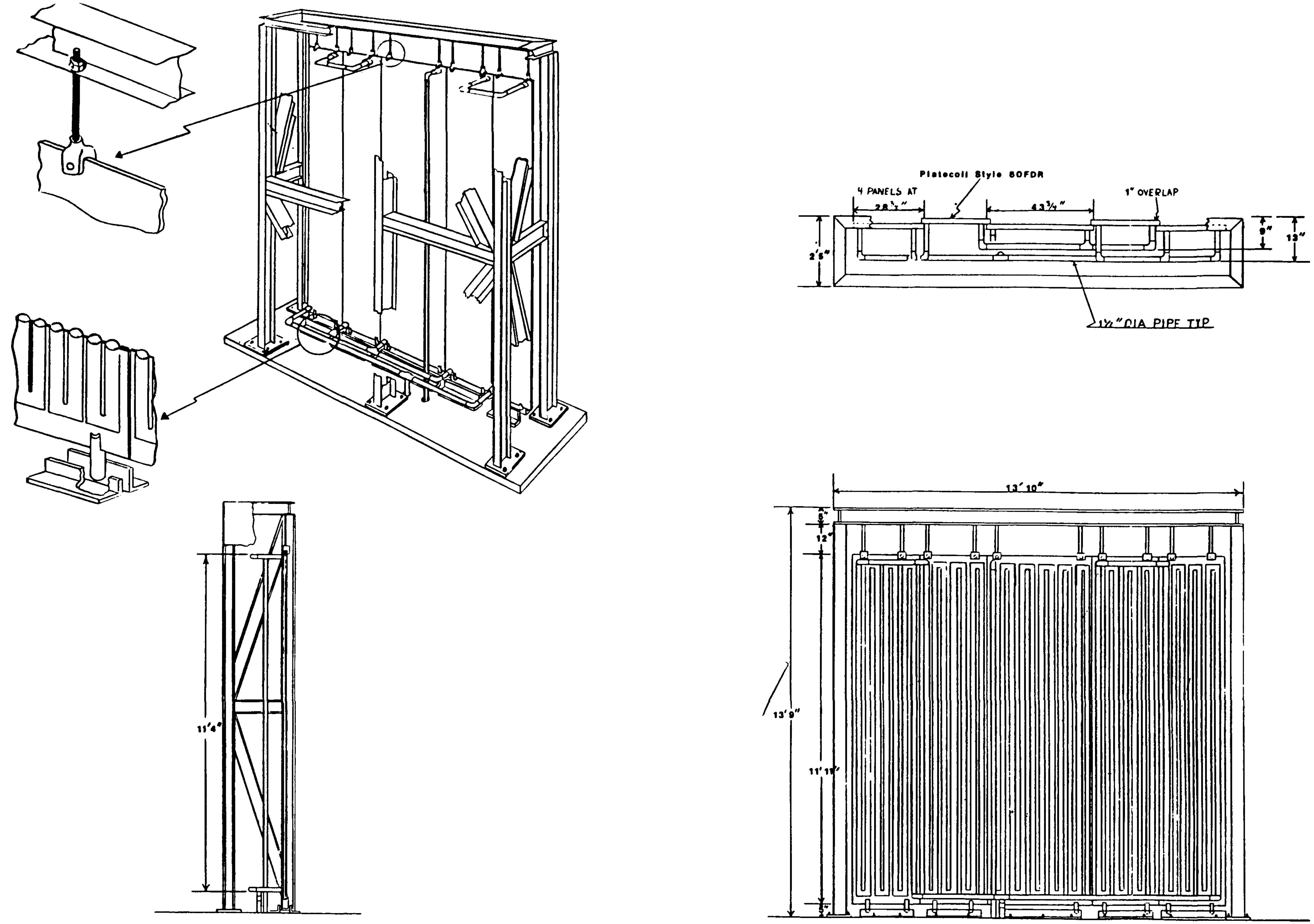


Figure 7.1-2

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES	NORTHRUP INC. BLAKE LABORATORY SUITE 306, 7861 S. UNIVERSITY, LITTLETON, CO. 80122
TOLERANCES	Reciever for Flat Field Collector
X = ± .125 X.X = ± .031	SCALE 1" = 20" DRAWN BY

A receiver support structure is composed of structural steel and is 3.05 m (10 ft) in height. This allows for a ground level safety zone relative to the reflected beam.

The receiver loop will be the same as the loop described in Section 5.4 except that smaller size pipe (.076m-3in) and insulation thickness (0.05 m-2 in) will be required. The loop will require a 7.45 kW (10 hp) booster pump. Two .1 m (4 in) three-way valves will be used for loop control. This size will permit their use in the full field configuration.

The basis for the loop design is the simulation of the "extreme case" conditions encountered in the operation of the full size system receiver. The preliminary analysis shows that this can be achieved with a $6.05 \times 10^{-3}\ m^3/s$ (96 gpm) HMO flow through the loop.

The plant/loop interface will be in the HMO line to fired heater No. 3 at the points planned for the full size system interfaces. The automatic 3-way control valves will be installed at the interface points and will function to control the operation of the Development Module in the same manner as the full size loop is controlled.

The instrumentation requirements will be similar to those of the retrofit system. The principal difference being a reduction in the number of temperature sensors and recorders due to the smaller size of the receiver.

The operation of the Development Module in the configuration described in the previous paragraphs will accomplish the following objectives:

(1) Validate system performance calculations.
(2) Establish operational procedures.
(3) Verify control stratagies.
(4) Verify receiver design and construction.
(5) Provide economic data.
(6) Provide construction experience.

The construction costs associated with the installation of the Development Module are presented in Table 7.1-3. Land costs are not included because the land owner, Tenneco West Inc., has agreed to permit the surface use of the site for the Development Module operational period at no cost. Operation and maintenance costs will be included as a part of the engineering effort during the Design Phase.

7.1.3 Design Phase Costs

Table 7.1-4 presents a summary of the manpower and associated engineering costs for the design phase. These costs include the direct charges, overhead, general and administrative expense, and fee.

The total cost for this phase is estimated to be:

Engineering	$ 964,924
Development Module Construction	693,838
TOTAL	$1,658,762

Table 7.1-3

DEVELOPMENT MODULE CONSTRUCTION COSTS

COMPONENT		COST
Site Preparation		$ 22,822
Receiver & Platform		24,905
Receiver Loop		140,314
Pipe, Insulation, Joints, etc.	84,514	
Valves	30,800	
Pump	5,000	
Instrumentation & Control	19,800	
Fire Est.	200	
Control Room (Trailer Rental)		3,130
Fence		13,000
Total Direct Field Costs		$204,171
Overhead (10%)		20,417
Total Field Costs		$224,588
Construction Management (3%)		6,738
Productivity (Bakersfield 3.4%)		7,636
Contingency (10%)		22,459
Total Field plus Burden		$261,421
Fee (6.8%)		17,777
Total Construction Cost		279,198
*Heliostats (19)		414,640
TOTAL CAPITAL COST		$693,838

*Heliostat costs are total installed costs including Fee.

Table 7.1-4

TASK	MANPOWER (Manmonths)		COSTS
TASK 1 - SYSTEM DESIGN		87	$ 518,200
1.1 Collector	18		
1.2 Receiver	40		
1.3 Receiver Loop	20		
1.4 System Integration	4		
1.5 Performance Analysis	3		
1.6 Economic Update	2		
TASK 2 - SITE PREPARATION PLAN		12	71,476
2.1 Grade & Fill	1		
2.2 Control Room Design	6		
2.3 Utility Service	2		
2.4 Field Wiring	3		
TASK 3 - PROCUREMENT PLAN		7	41,694
3.1 Long Lead Item	2		
3.2 Bid Packages	5		
TASK 4 - OPERATION AND MAINTENANCE		6	35,738
4.1 Define Operating Procedures	2		
4.2 Prepare Maintenance Plan	2		
4.3 Prepare Safety Plan	2		
TASK 5 - DEVELOPMENT MODULE		38	226,340
5.1 Engineering Analysis	12		
5.2 System Final Design	6		
5.3 Construction	6		
5.4 Alignment & Checkout	6		
5.5 Operation	8		
TASK 6 - PROJECT MANAGEMENT & REPORTS		12	71,476
6.1 Project Direction	3		
6.2 Reports	4		
6.3 Reviews	1		
6.4 Construction Plan	4		
TOTAL		162	$ 964,924

7.2 CONSTRUCTION PHASE

The construction phase is planned to begin immediately upon completion of the detailed design phase. The 18 month construction period proposed in the Program Element Plan has been adopted for the North Coles Levee Project.

The construction phase plan is developed on the premise that ARCO Oil and Gas Co. will provide the construction management and act as the prime contractor. All major subsystems will be obtained on a subcontract basis. System start up and check out will be done by the ARCO system design team.

The Program Plan shows the construction phase beginning in February 1983. The design phase proposed in this plan is for a period of 12 months which would permit the construction phase of this project to begin in May 1982 and be ready for acceptance testing in December 1983. A schedule of construction activity is presented in Section 7.6. A detailed construction phase plan is to be prepared under Task 6 of the detailed design phase.

7.3 SYSTEM CHECKOUT AND STARTUP PHASE

This is a 3 month period devoted to establishing the operational capabilities for all components and subsystems.

All wiring and construction work will be checked relative to system specifications. The system will be charged with HMO and tested for leaks or other problems that might have occured during construction. Control valve operation will be evaluated to assure non interference in plant processing during operation in the solar/fossil mode or during mode transitions. Also, the heliostats will be checked for proper operation and response to control stratagies. System startup, operation and shutdown will be conducted using special procedures appropriate for personnel and equipment safety under these initial conditions.

It is recommended that this phase be combined with the System Performance Validation Phase described below in which the final acceptance testing is performed.

7.4 SYSTEM PERFORMANCE VALIDATION PHASE

This is a 3 month phase during which special testing is performed on all major subsystems and components. The early portion of the period will be devoted to special runs under a variety of operating conditions to allow the special tests to be conducted, as opposed to striving to achieve daily operations on a routine basis.

After the tests are completed and adjustments made to components and subsystems to achieve rated performance, the operation and control procedures and strategies will be evaluated. Safety and emergency procedures will also be tested for effectiveness.

During the latter portion of the period the effort will be to bring the system on to a routine operating basis. The emphasis throughout these phases will be placed on data acquisition of sufficient types and quantities, to validate all system, subsystem and component selections and related analyses. A detailed plan for this phase will be finalized during the construction phase.

7.5 JOINT USER/DOE OPERATIONS PHASE

This is a 5 year system operating phase devoted primarily to the acquisition of data related to system performance. During this period the retrofit system will be operated on a routine basis. Special data acquisition instrumentation will be operated to obtain the data necessary to evaluate the performance at the system level, the subsystems and in some cases the component level. A data plan for this phase will be prepared during the construction phase.

7.6 SCHEDULE AND MILESTONE CHART

In order to demonstrate the feasibility of completing the design and construction phases in a 30 month period, detailed schedules have been developed for these phases. Figure 7.6-1 presents the schedule for the design phase. The accomplishment of the 24 subtasks within the time periods shown is reasonable considering the current availability of the required technology.

Another fact that simplifies the scheduling, is that, there appears to be little or no requirement for long lead items. There is time allocated to analyze these requirements in detail, however it is not expected that any component will require a sufficient lead time that procurement will need to be initiated during the design phase.

Figure 7.6-2 presents the construction phase schedule. The activities are grouped under the major subsystems. Procurement activity is scheduled for the first three months of the period. This length of time allows for bid advertising, receipt of quotes, contractor selection and award.

This schedule will be revaluated and developed in more detail during the design phase. Also CPM networks will be prepared if required.

7.7 ROLES OF SITE OWNER, GOVERNMENT AND INDUSTRY.

The roles of the project participants should be related to their individual objectives and the proportionate share of costs and risks assumed by each. The role of Government should be to encourage the development, by the site owner, of a solar powered industrial process heat system that will demonstrate the technical and economic feasability of this alternate energy source. This can be accomplished by providing the results of related R & D and by sharing the risks through cost sharing and incentive programs. The role of the site owner is to design and install a system that is adapted to his specific needs that will demonstrate to manangement the favorable relability and economics of the system.

The roles of the site owner and the Government for this program

FIGURE 7.6-1

DESIGN PHASE SCHEDULE

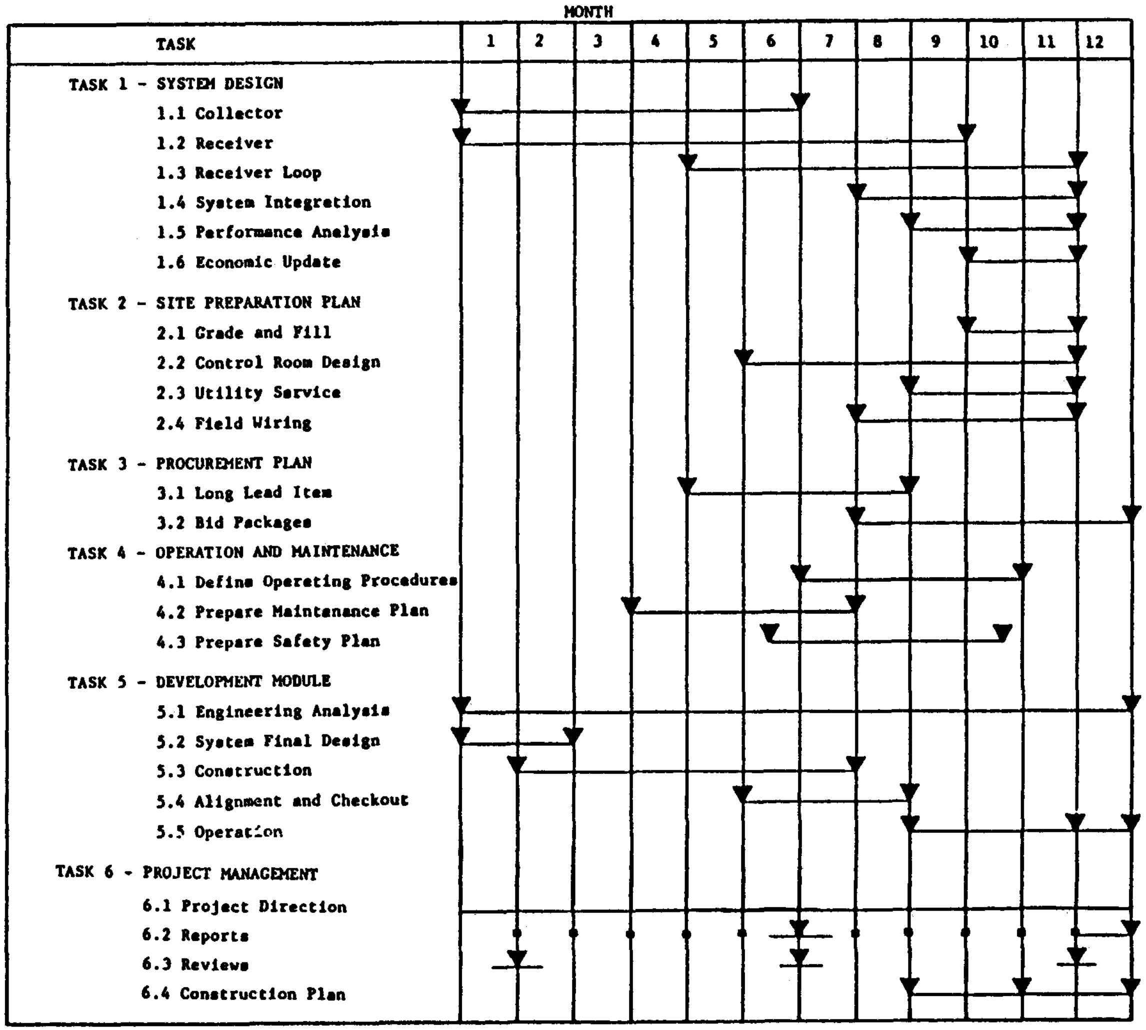
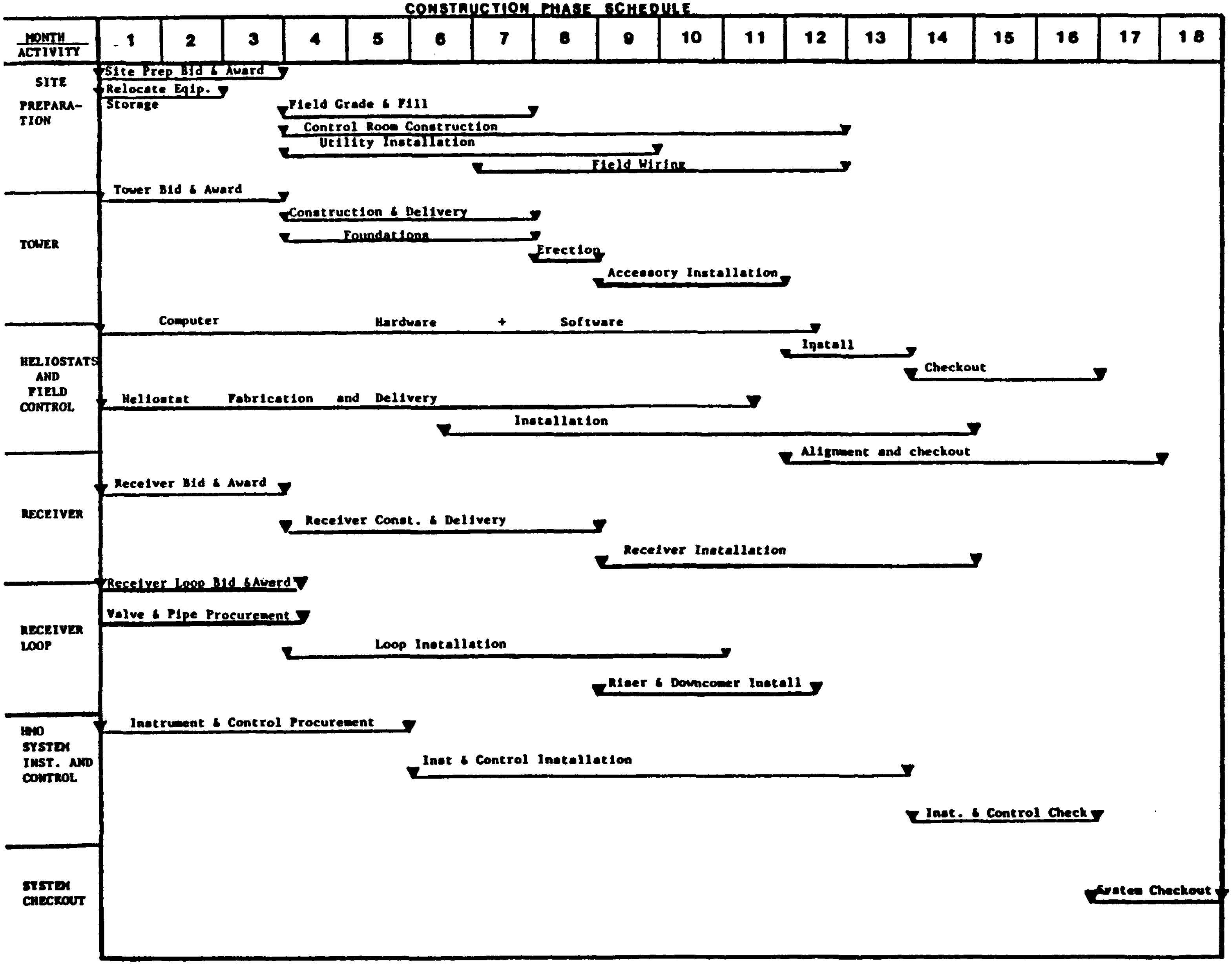


FIGURE 7.6-2
CONSTRUCTION PHASE SCHEDULE



have been further defined in the Solar Repowering/Industrial Retrofit Program Element Plan; Section 6, Management Plan. This plan achieves the appropriate level of authority and responsibility for the participants and should provide a sound basis for accomplishing the program objectives.

The degree of cost sharing can only be finalized on the basis of a specific proposal and after management has had the opportunity to analyze all aspects of the conceptual design. At this point the estimated cost sharing ratios presented in the draft DOE Program Element Plan appear to be a reasonable first approach.

☆U.S. GOVERNMENT PRINTING OFFICE: 1980-740-145/686