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SOLAR THERMAL ENHANCED OIL RECOVERY (STEOR). VOLUME 2 (APPENDICES)

Final Report for Period October 1, 1979—June 30, 1980

By
Eugene Elzinga
David Allen
Patrick Joy
Henry Shaw
Charles Arnold
Robert Garman
Paul Mitchell

November 1980

Work Performed Under Contract No. AC03-79CS30307

Exxon Research and Engineering Company
Linden, New Jersey

and

Foster Wheeler Development Corporation
Livingston, New Jersey

and

Honeywell Incorporated
Minneapolis, Minnesota

U.S. Department of Energy

Solar Energy

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VOLUME II — FINAL REPORT (APPENDICES)

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PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
UNDER CONTRACT DE-AC03-79CS30307

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APPENDIX A

DETAILED SITE DESCRIPTION

CONVERSIONS FOR APPENDIX A

Section A.1

303525 M^2	(75 acres)
213 M	(700 ft)
152 M	(500 ft)
18.3^{o}C	(65^{o}F)
9^{o}C	(48^{o}F)
28.9^{o}C	(84^{o}F)
14.7 cm	(5.8")
3.8 cm	(1.5")
26.8 M/Sec	(60 MPH)
33.5 M/Sec	(75 MPH)
	(6 + 7 KWH/m^2 Day) ?

Section A.2

27.4 M	(90 ft)

Section A.3

90,718 Kg	(100 Tons)
3.7 M	(12 ft)
30.5 M	(100 ft)
8.05 Km	(5 miles)
305 M	(1,000 ft)
9.5 l/sec	(150 gpm)
683.6 Kl/D	(4300 B/D)
795 Kl/D	(5,000 B/D)
1590 Kl	(10,000 Barrels)
190.8 Kl/s	(1200 B/D)
651.8 Kl/D	(4100 B/D)

Section A.3 (Continued)

6.4 M	(21 ft)
6.1 M	(20 ft
11 M	(36 ft)
5.8 M	(19 ft)
17 to 53 Kl/D	(107 to 334 Bs PD)
14.8 Kl	(93 Barrels)
6.2 Kl	(39 Barrels)
2.2 Kl	(14 Barrels)

Section A.4.2.2

160.9 Km	(100 miles)
48.3 Km	(30 miles)

Section A.4.2.3

48.3 Km	(30 miles)

Section A.4.3

Table A-2

23.2 MJ	22 MBTU/hr
26.4 GJ	25 M MBTU/hr
17,217 KPa	2500.0 psig
10,331 KPa	1500 psig
354 ^{o}C	670^{o}F
314 ^{o}C	598^{o}F
16.7 Kl/D	105 BOPD
18.3 Kl/D	115 BOPD
14.3 KL/D	90 BOPD

CONVERSIONS FOR APPENDIX A (Continued)

Section A.4.3 (Continued)

39.8 GJ/Kl	6 M MBTU/BL
2.65 l/sec	42 g PM
3.15 l/sec	50 g PM

Section A.5

317.9 Kl/D	(2000 BOPD)

Section A.6

Table A-3

48.3 KM	30 miles
32.2 KM	20 miles
11.3 KM	7 miles
24.1 KM	15 miles
12.9 KM	8 miles

APPENDIX A

DETAILED SITE DESCRIPTION

The potential sites for Exxon's solar thermal enhanced oil recovery project are located on Exxon's properties in California's Edison field. The Edison operation is the only Exxon field where steam stimulation has been established for a sufficient period of time to show the long term benefits to production. Furthermore, the field is a possible future candidate for a steam drive operation to recover additional oil. Thus, it offers the opportunity to study both types of steaming operations.

The Edison field has other advantages for the STEOR project. It is in one of the zones of highest direct normal insolation (local agricultural activities may reduce this below reported values). The terrain is flat, free from rock and is well drained. There is little chance of structures being erected which could block exposure to the sun since the limits of the field are to the south of Exxon's holdings and are in production by other operators.

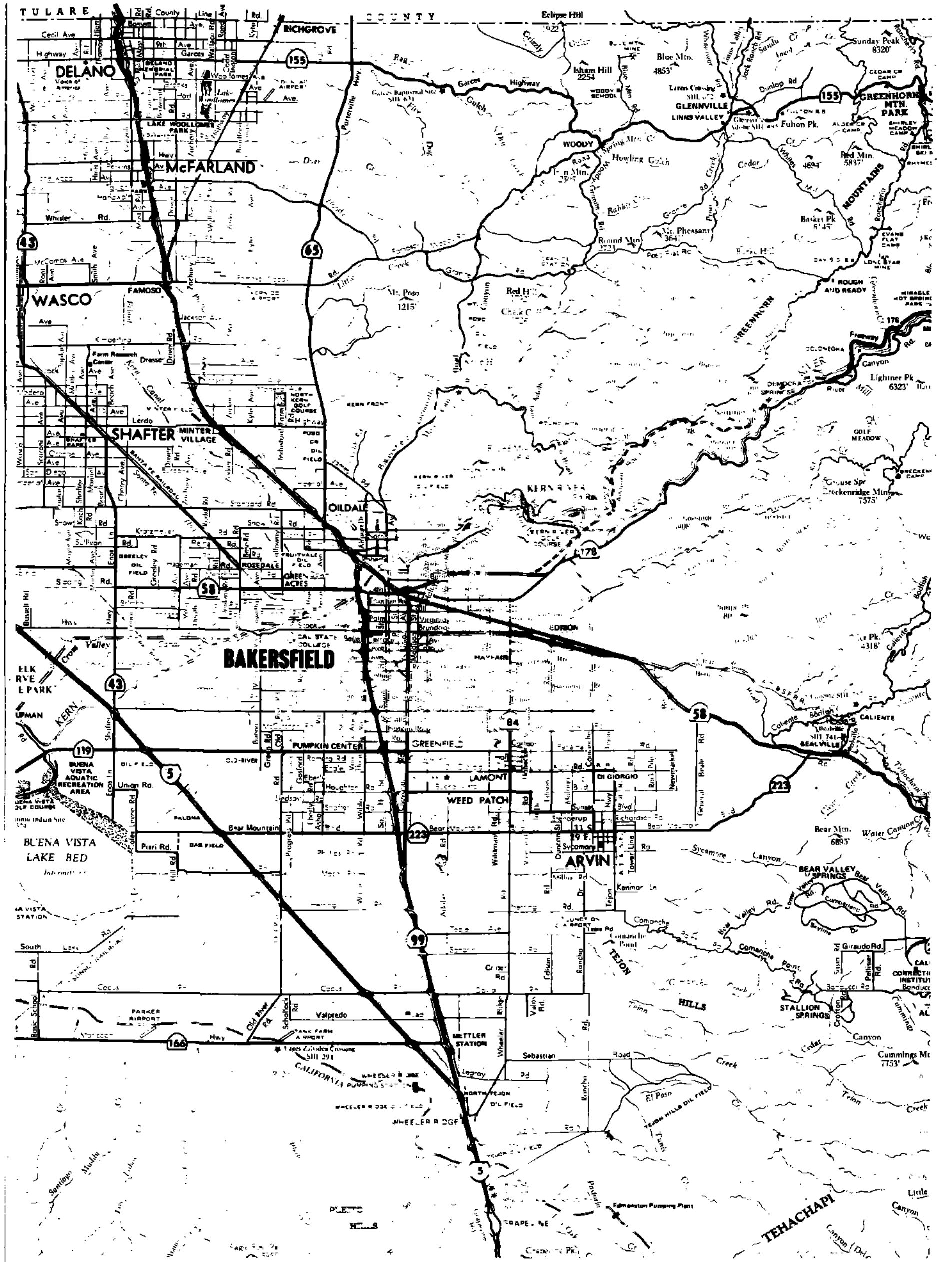
There are a number of potential disadvantages for solar collection systems at this location. Primary among these is the extensive agricultural operations on the field and the surrounding area. This is a year-round activity since the area has a mild climate, is flat and is irrigated. The cost of taking land out of production to install solar collectors will be significant. In addition, the particulates resulting from agricultural activities cause; a year long haze which could significantly reduce the direct beam below that obtained from available solar insolation maps and dust which will add to yearly operating expense for removal from reflecting surfaces. Other factors which must be allowed for are infrequent wind storms and high seismic activity.

A.1 Site Geography

Exxon's Edison field is in parts of sections 13, 14, 15, 18, 19, 22, 23 and 24 of Kern County, California. The field is located on the east side of the San Joaquin Valley, seven miles southeast of Bakersfield. Principal access is by California Highways 58 and 99 (Figure A-1).

Figure A-2 is a plot plan showing the Exxon leases at Edison and the tentative location of the STEOR test sites. The sites considered are located in Exxon lease 808794, 808796 and 808797.

The site area in lease 808794 is approximately 75 acres and encompasses 25 operating wells. Access to the wells is from the west off of Tejon Highway. A service corridor around each well is required for steaming equipment and for well service rigs. The locations in leases 808796 and 808797 do not involve any operating wells.



MAJOR HIGHWAY ACCESS TO BAKERSFIELD AREA
FIGURE A-1

The terrain at Edison is a flat alluvial plain ranging in elevation from about 700 feet in the northeast to 500 feet in the southwest, Figure A-3. The area is free of standing water and is not subject to flooding. After heavy rains of 1 to 2 days duration, it is sometimes necessary to wait 1 to 5 days before heavy equipment can be moved on the field. Since there are no steep slopes in the area, the possibility of slides is non-existant.

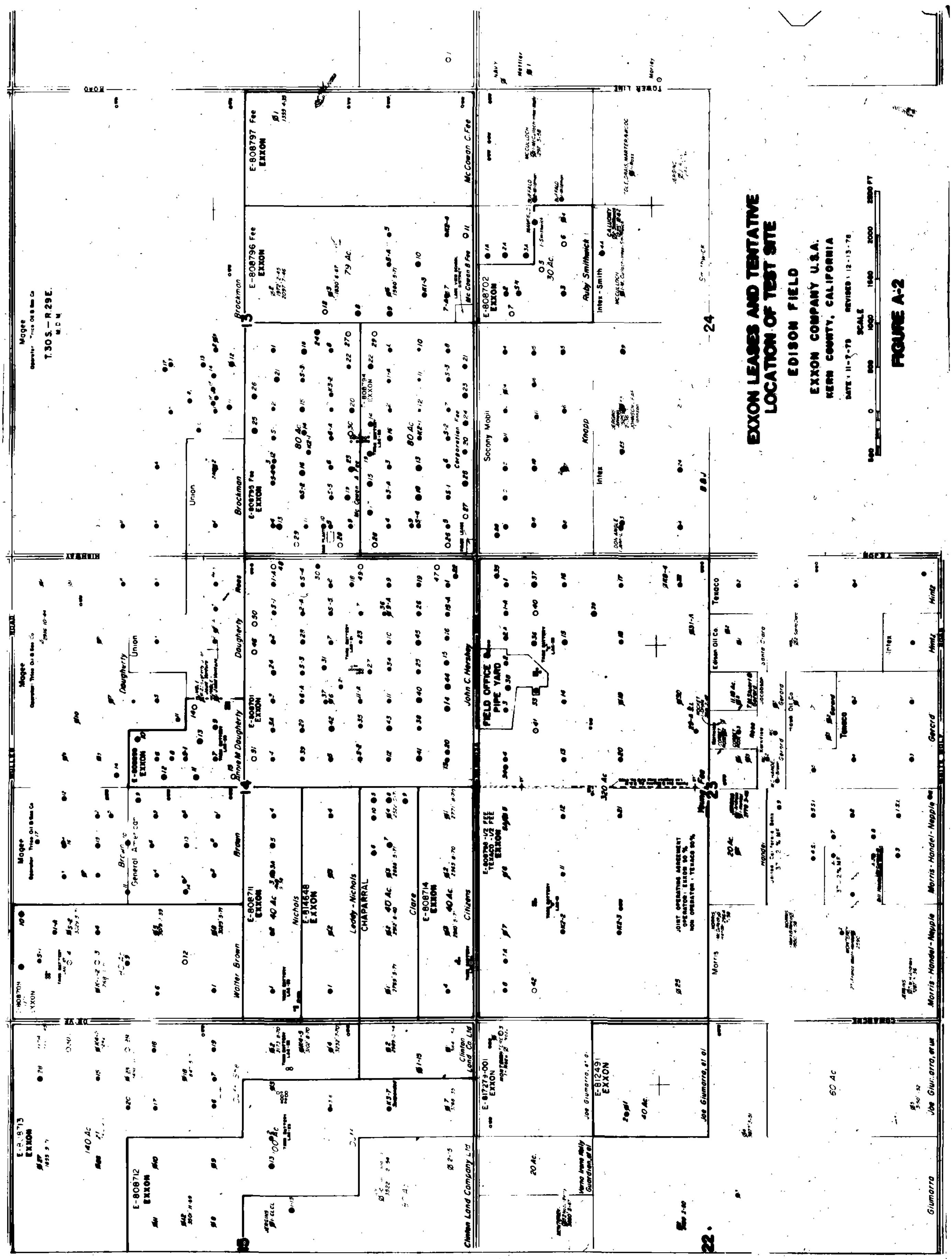
Bakersfield is considered a high earthquake risk area. It is classified Zone 4 in the Uniform Building Code and structures must be designed to appropriate specifications. The Uniform Building Code has four classifications for seismic activity where 4 is the most severe. The soil of the Edison field is in Class 4 (SC), sand and clay. The last major quake was in 1952 and measured 7.5 to 7.7 on the Richter scale (A-1).

The overall climate at Bakersfield is warm and semi arid. Average temperature is 65°F and varies from 48°F in winter to 84°F in summer. Annual precipitation averages 5.8 inches. Snow is rare and no accumulations of greater than 1.5 inches have been recorded. Southeasterly winds, originating in the Tehachapi Mountains can, at times, reach velocities of 60 mph. The most recent severe wind storm occurred in December, 1977 with gusts to 75 mph (A-1). A complete summary of local climatic conditions is contained in Reference A-3.

Annual average direct normal solar insolation read from available solar radiation charts lies between 6 and 7 kWh/m^2 day[2]. However, the degree to which local conditions influence this value are unknown. Local factors include the intensive agricultural operations in the San Jonquin Valley and winter fogs which can be trapped in the area bound by the cost ranges to the west, the Tehachapi Mountains to the south and the Sierra Nevades to the northeast. Because of the importance of this parameter, a study at California State College in Bakersfield to measure the direct normal radiation for approximately one year started during January 1980. Examination of records from Bakersfield Airport (A-3) indicates that local cloud cover is similar to that in Fresno (A-4).

A.2 Legal Consideration

The proposed STEOR test sites are within leases 808794, 808796, 808797 where both the surface and mineral rights are owned by Exxon. There are no zoning or other use restrictions on this and surrounding land. Furthermore, it is five miles to the outskirts of Bakersfield and no extensive residential or commercial activities are anticipated during the period while oil is being produced. Present day residential and commercial activities in the Bakersfield area are expanding to the southwest of the city, away from the intensive oil producing activities in Kern County. Access to the sites is by publicly owned roads adjacent to the test site.


EXXON LEASES AND TENTATIVE LOCATION OF TEST SITE
EDISON FIELD
EXXON COMPANY U.S.A.
KERN COUNTY, CALIFORNIA
DATE: 11-7-78 REVISED: 12-13-78
SCALE
T.30S.–R.29E.
M.D.M.
FIELD OFFICE & PIPE YARD
E-808797 Fee EXXON
E-808796 Fee EXXON
E-808795 Fee EXXON
E-808702 EXXON
E-808711 EXXON
E-814648 EXXON
E-808714 EXXON
E-808712 EXXON
E-812491 EXXON
Socony Mobil
Texaco
John C. Hershey
Clinton Land Company Ltd
Giumarra
Morris-Hendel-Nepple
13
14
22
23
24
FIGURE A-2

The closest non-Exxon lease to the south is owned by Mobil and is in active oil production. Mobil would have to erect a structure 90 feet high to subtend an angle of 10° above the horizon with the southern most boundary of the test site on lease 808794.

Figures A-4, A-5 and A-6 are photographs from a central point in lease 808794 showing the surface features as viewed to the southeast, south and southwest, respectively. Figure A-7 is an aerial view from 1000 feet showing the lack of prominent natural and man-made structures on the field and surrounding land.

Kern County Airport is located approximately 20 miles to the northwest of the test site. The test site is outside the airport control zone.

Land surface in the test site area is currently used for raising potatoes. One crop per year is normally harvested. Potatoes are valued at $1850 per acre per year. Since the test site is an Exxon lease, the permit can be terminated within 60 days.

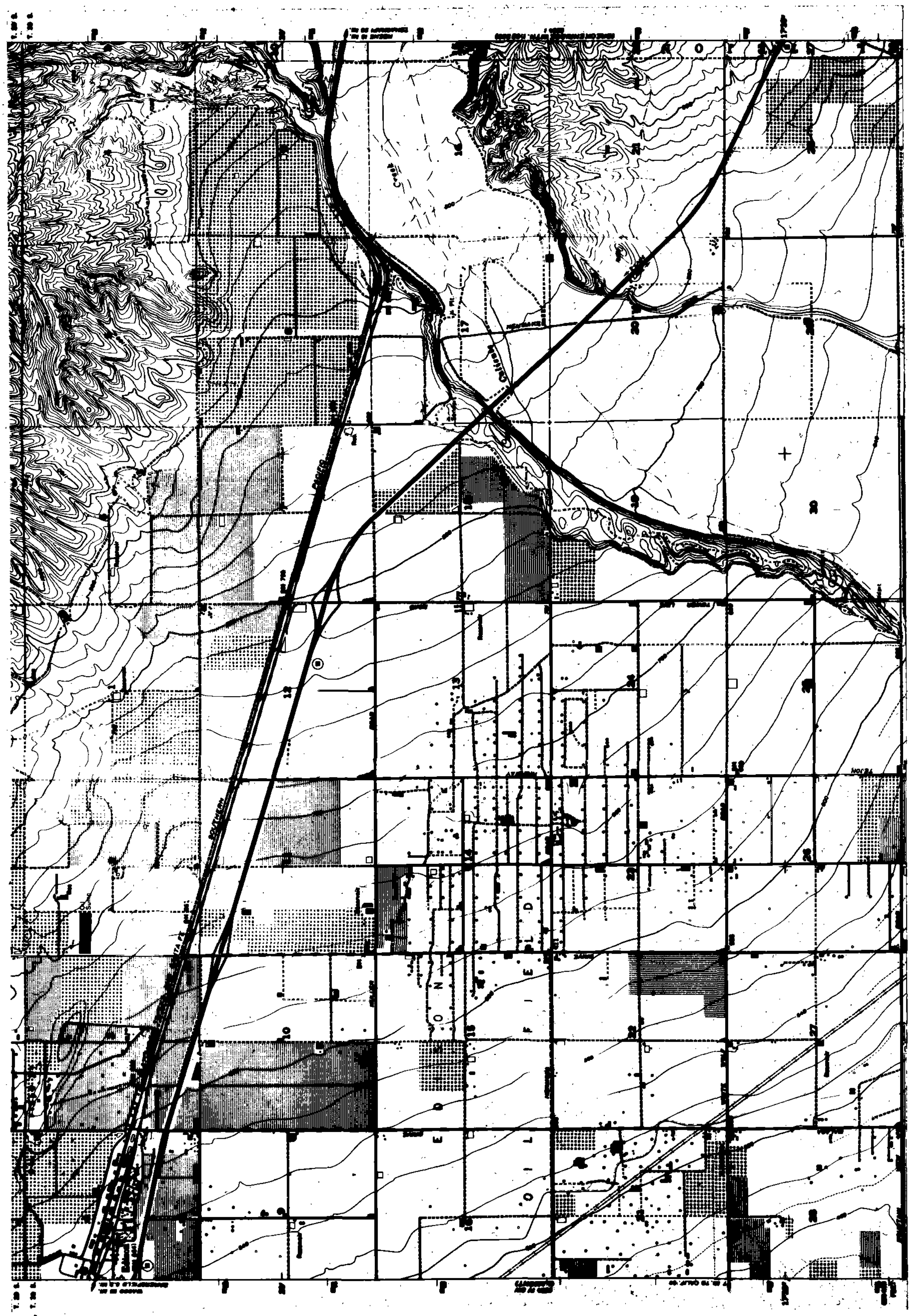
Consultations have been held with California State College personnel at Bakersfield regarding agricultural or related use of the land in the presence of solar collectors. It is anticipated that a cover crop can be found which will at least reduce the dust and errosion problems in the immediate area of the test site.

A.3 Existing Facilities and Services

Shipments to the Edison field area can be made by truck, plane or railroad. Weight limitation on California Routes 58 and 99 and on local roads is 100 tons. Items measuring 12 feet by 100 feet or larger can be shipped by truck but must be escorted. Heavy and bulky equipment is usually shipped by rail (Southern Pacific Railroad) to the freight depot at Edison which is 5 miles northwest of the field. There are no overpasses on the roads between the depot and the field.

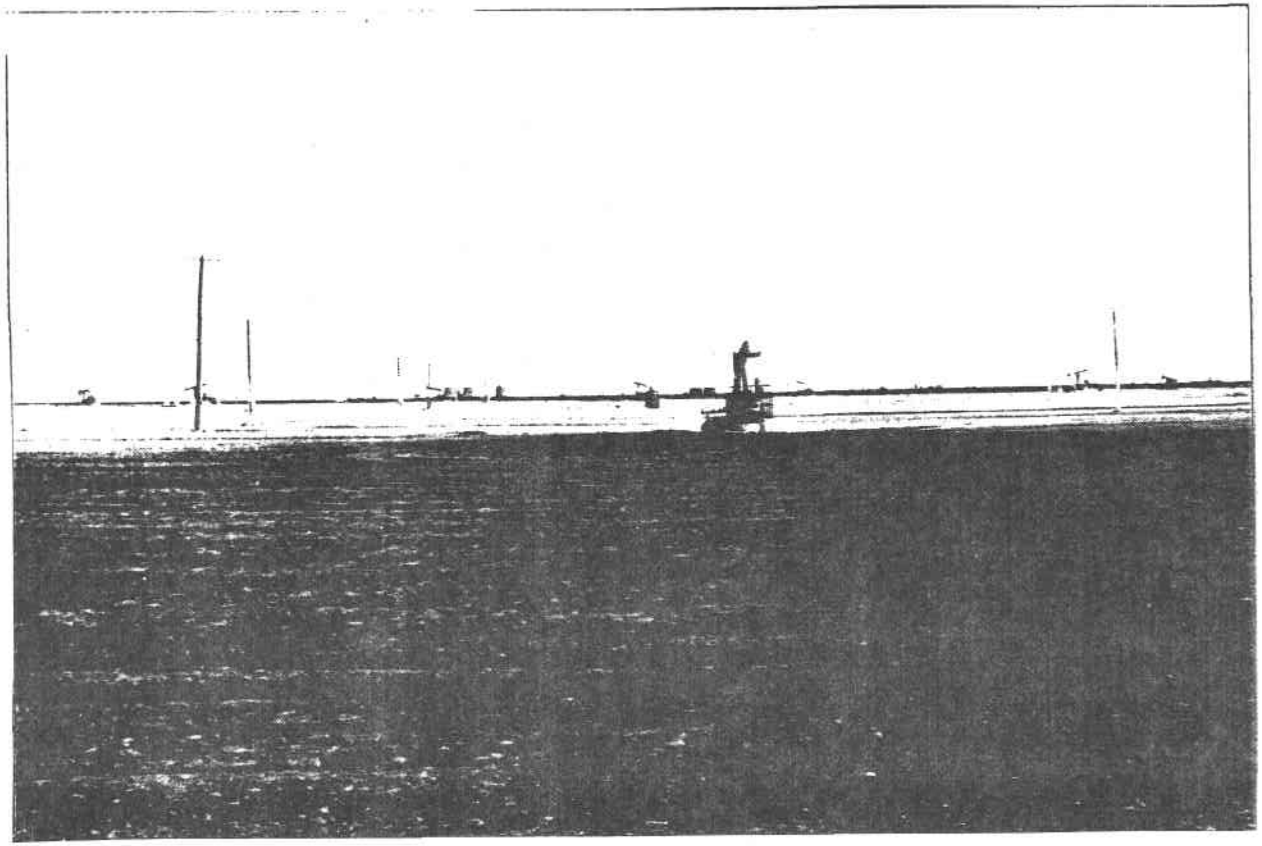
Water supply for steam generation is provided from an Exxon owned and operated well. This well draws water from a depth of 1000 feet at a rate of 150 gpm. Water is distributed to the stimulation site by portable lines. Water is treated in portable units containing ion exchange beds. Table A-1 contains water quality information before and after treatment. No problems are anticipated with the quantity of incremental water required for the solar derived steam.

Produced water is separated from oil in the separator tanks distributed throughout the field and indicated in Figure A-2. This water along with the waste water from the water treating plants is reinjected into the Schist zone through well numbers 5A, 6, 7, 34 on the Young Fee, Figure A-2. The reinjected water averages 4300 B/D. This will increase to about 5000 B/D with the STEOR system in operation.



GEOLOGICAL SURVEY MAP OF EDISON FIELD
FIGURE A-3

VIEW TO SOUTHEAST
OF LEASE 808794
FIGURE A-4



VIEW TO SOUTH OF
LEASE 808794
FIGURE A-5

**VIEW TO SOUTHWEST
OF LEASE 808794
FIGURE A-6**

EDISON FIELD AND SURROUNDINGS
AERIAL VIEW FROM 1,000 FEET
FIGURE A-7

TABLE A-1

WATER QUALITY DATA - IMPURITIES IN PPM

Impurities	As Produced From Well	After Treatment
Calcium	54.4	<0.5
Magnesium	12.6	<0.5
Sodium	50.6	210
Bicarbonates	298.9	
Chlorides	36.1	
Sulphates	2.2	
Nitrates	0.44	
Total Hardness as $CaCO_3$	187.66	<0.5
pH	7.4	9.0

Other wastes are handled as follows. Sanitary water is treated in the privately maintained septic system. Solid wastes, i.e. sludge from the gas scrubbing and oily waste is trucked to a landfill operated by the town of Bakersfield.

The only other utility servicing the field is electric power produced by Pacific Gas & Electric. An existing substation shown in Figure A-2 at the southeast corner of section 13 is rated for 1900 KW. Currently the maximum load is 500 KW. Incremental requirements for STEOR will be easily accommodated. Electric power is brought to the site by overhead cable on utility poles along Hermosa Road.

Two portable boilers will be in use by Exxon for steam stimulation. Table A-2 gives a description of these boilers. A well stimulation is carried out by moving a boiler, a portable water treating unit and portable water, boiler fuel and diesel fuel tanks to the well site. A diesel driven generator is used to supply power for pumping and other auxiliaries on the boiler. A steaming cycle consists of injecting 10,000 barrels of water as 75% quality steam over a period of 7 or 8 days. This is followed by a soaking period of 4 days after which a temperature survey is made of the well and it is returned to production. Each boiler will steam 30 to 40 wells per year and wells with a high potential are steamed about every 18 months.

Wells are pumped by means of electrically driven rod pumps. A buried piping system brings the produced fluids to central storage areas (Figure A-2). The small amount of gas produced is burned to supply heat for the water oil separators. Current production averages about 1200 B/D of oil and 4100 B/D of water. No new storage facilities will be required for the STEOR tests, since adequate tankage already exists.

From the geological description and core analyses data, four correlatable zones were found. As depth increases in the well, these zones were designated as Zones A, B, C, D. The core analyses data indicate the following thickness, permeability, porosity, and oil-saturation data, respectively, for these zones: 21 feet, 170 md, 24.3 percent BV, and 26.5 percent PV oil saturation for the A; 20 feet, 116 md, 24.4 percent BV, and 26.4 percent PV oil saturation for the B; 36 feet, 149 md, 24 percent BV, and 24.3 percent PV oil saturation for the C; and 19 feet, 213 md, 25.5 percent BV, and 13.5 percent PV oil saturation for the D.

The thickness-weighted average oil saturation for all the above zones calculates to be about 23 percent PV. This value is substantially lower than the almost 49-percent-PV oil saturation based on generalized information and on which preliminary simulations were run. The core-analyzed-based oil saturation data are consistent with log-derived oil saturations which, in general, are only several percentage points PV higher than the core analysis data. Such saturations are also consistent with revised material-balance calculations in which fluid production was allocated in a more realistic manner in which sand quality was considered.

Noteworthy also are the lower absolute permeabilities measured for the core plugs. These permeability data average less than 20 percent of the permeability data used in the preliminary simulations. Part of the reason for lower permeability values is likely associated with the use of overburden pressures in the core analysis work. Although these lower permeabilities might restrict productivities and extend depletion times, it is unlikely these permeability levels, by themselves, would curtail prospective steam flooding.

Relative permeability data obtained from the laboratory flood tests were of questionable value largely because of complications associated with suspected clay-particle redistributions during the flood tests. This caused sharp reductions in absolute permeabilities in cores under flood. As a result, core-plug permeabilities measured at connate water saturations were found to be one-tenth or less of nitrogen-measured permeabilities. Accordingly, published relative permeability information for Kern River sands was accepted but was adjusted for a residual oil saturation of 10 percent PV by waterflooding and 5 percent PV by steam flooding.

Data collected were used to update the preliminary steamflood performance calculations for the Edison field. The new evaluations were based on reservoir simulations on cross-section models to obtain relatively quick appraisals of several parameters and on three-dimensional models to establish volumetric sweep efficiencies. Overall, steam-flood performance appears to be marginal to unacceptable at the proposed pilot site largely because of apparently low oil saturations at this location.

Five cross-section cases were run in which four parameters were varied. The following observations were derived from results. First, a 6.4 degree dip in a model had very little effect on results when compared with results from a model with no dip. Second, by excluding the lowermost zone in which the oil saturation is only about 14 percent PV (core analyses disclose that the upper three zones have an average oil saturation of about 26 percent PV), the overall performance of the flood improved only modestly. After about one pore volume of steam injection, the cumulative OSR (oil-steam ratio) increased from 0.071 for the four-zone case to 0.087 for the three-zone case. After about 2.5 pore volumes of cumulative injection of steam and follow-up cold water, the cumulative OSR rose from 0.107 for the four-zone case to 0.133 for the three-zone case. Third, an increase in the steam injection rate from about 107 to 334 BSPD/well accelerated depletion and provided about six percent more oil when taken to the same cumulative injection. And fourth, an increase in the flood-start oil saturation from 26 to 35 percent PV in the upper three zones improved the cumulative OSR for the project from 0.144 to 0.210 for the higher injection-rate case. Flood-start oil saturations above 35 percent PV would provide even better incremental performance.

In an effort to establish areal and volumetric sweep efficiencies for Edison cases, three-dimensional models of a one-eighth element of a repeated five-spot pattern were prepared. These models used both rectilinear and curvilinear grids in the areal plane. Recoveries predicted for the curvilinear models sometimes were as much as ten percent greater than recoveries for the rectilinear model. This difference was believed to be due, at least in part, to grid-orientation effects with the rectilinear model. Overall, however, when the three-dimensional results were compared with cross-section results, it was concluded that an areal sweep efficiency of at least 85 percent should be applied to cross-section results. Also, it appeared that cross-section results themselves provided a reasonable basis for evaluating the relative performance of steam floods.

Corporation Fee 30 Well was steam stimulated late in 1979 and placed on production shortly afterwards. Production tests run on December 24, 1979, indicated that the well produced 93 barrels of fluid per day at a water cut of 15 percent. By January 4, 1980, the fluid rate had declined to 39 barrels per day at a water cut of 23 percent. Additional tests were run in mid-May 1980. By this time, fluid rates had declined to 14 barrels per day and water cuts had risen to about 90 percent. Such test results indicate that (1) reservoir pressures within the drainage volume of

Corporation Fee 30 Well are low, and (2) oil saturations and relative permeability relationships used in the simulation are reasonable because calculations involving these data, confirm the high water cuts measured on this well.

Additional wells are being drilled and cored at Edison to determine if the discouraging data obtained from Corporation Fee 30 are representative. The final decision to begin a pilot steam drive test will depend on the data obtained from these new wells.

A.4 Edison Site Solar Data

A.4.1 Introduction

In order to quantify the solar resource at the Exxon Edison field, a program of measurement and analysis was initiated in the fall of 1979. The program consisted of 1) a preliminary analysis of solar radiation data for the Bakersfield, California area, 2) initiation of total and direct normal insolation measurements in the Edison field and 3) assessment of the measured data for the period January to June 1980. The preliminary analysis of available radiation data resulted in the decision to use the Fresno Typical Metrological Year (TMY) data[A-1] and the direct normal insolation values from TMY data tape as the environmental basis for all performance estimates of candidate solar energy system for the STEOR project at Edison. This decision was supported by the Aerospace Corporation (A-2) who served as the technical program manager for the STEOR project.

Beginning in January 1980, a solar radiation measurement station was installed in the Edison field. In this report, the solar data from the Edison field is presented and compared to the solar measurements made at Fresno, CA during the same time period in an attempt to quantify any real time differences between the two stations. In addition, comparisons are drawn between Edison measured data and Fresno TMY data; also between Edison and nearby solar radiation stations in the San Joaquin Valley.

A.4.2 Discussion

A.4.2.1 Solar Data Station

In January 1980, a solar radiation measurement facility was erected in the Exxon Edison field, approximately fifty yards south of the field office. The facility consisted of two solar radiation sensors including an Eppley Precision Spectral Pyranometer to measure total (or global) radiation on a horizontal surface and an Epply Normal Incidence Pyrheliometer (NIP) to measure direct normal (or beam) radiation. The NIP field of view is 5.7° and the solar disc field of view is 0.5°. The NIP, therefore measures the direct beam radiation from the sun plus a small area surrounding the sun, which is known as circumsolar radiation. Both solar sensors were wired into a two channel millivolt recorder inside the field office. Both sensors are classified as Class I devices by the World Meteorological Organization. The rms error associated with the sensors and recording devices is estimated to be 2%.

The station was maintained by personnel from California State College of Bakersfield who made four to five site visits per week to clean the sensors, adjust the elevation of the NIP and maintain the chart recorder. All records from both sensors were reduced by using a mechanical planimeter. California State College students performed the data reduction which was checked by Dr. Daniel Detwiler of the College and by Exxon personnel. The data reduction is estimated to have an rms error of 2% which leads to an overall rms error of measuring, recording and reducing the data of 2.8%.

The data station became operational on January 19, 1980 and for the period January through June 1980, 118 days of total horizontal (TH) data and 107 days of direct normal (DN) data were recorded. Missing days were due primarily to recorder problems including clogged pens and torn paper. The chart recorder is being replaced by an inkless recorder.

A.4.2.2 1980 Measured Data & Comparisons

For the period January to June 1980 the mean daily total horizontal insolation measured at Edison is 4.82 Kwh/m^2-day. This compares to 5.79 for the Fresno weather station, 5.69 for the Wasco station and 5.60 for the Fresno TMY data. Fresno is about 100 miles North of Edison and Wasco is about 30 miles Northwest of Edison. Adjusting the Edison data by assuming all missing days will be equivalent to the mean daily value for that month results in an adjusted TH of 4.86. Figure A-7 presents the data by month graphically and compares Edison, Fresno, and Wasco TH for the January-June period and also shows the Fresno TMY data which is based on 23 years of data and can be considered a long term average for the Fresno station. As A-7 shows, the six month average TH for

Fresno, Wasco and Fresno TMY are within 2% of each other and Fresno is 20% higher than Edison for the period. All TH daily data for the three locations is given in figures A-8 through A-13.

Of greater significance to the STEOR project is the measured direct normal (DN) insolation at Edison, since STEOR will employ line focus concentrating collectors which convert only direct solar radiation to thermal energy. The mean daily DN measured at Edison for the six month period is 5.41 Kwh/m^2-day. This cannot yet be compared to Fresno for the same period because the Fresno DN data is taken directly on magnetic tape and sent to the National Climatic Center for processing which takes about six months. However, the Fresno TMY DN for the same period is 5.99 Kwh/m^2-day. If the Edison data is adjusted to account for missing days, the mean daily average remains unchanged. Figure A-14 displays the monthly mean daily DN data for Edison and Fresno TMY. Long term DN measurements have not been made at Fresno or Edison and no long term TH measurements have been taken at Edison. The DN data that is used on the TMY tape is not measured data, but derived from a correlation developed by Aerospace Corp (A-3) based on DN and TH measurement at four locations in the U.S. The correlation has not been tested with the Edison data or Fresno data to derive DN from TH measurements. However figure A-15 shows the monthly mean daily ratio of DN/TH for the measured Edison data and the DN/TH for the Fresno TMY data in which DN is derived from TH. As figure A-15 shows, the mean ratio of DN/TH for the period at Edison is 1.12 which compares to 1.07 for the Fresno TMY. In general the ratio DN/TH increases with increasing TH. Thus the Aerospace correlation may not precisely describe Fresno or Edison data but it does appear to more closely fit Edison data than other widely used correlations which would have predicted much higher levels of DN. For example, on an annual basis the ratio of DN/TH for Fresno is predicted to be 1.14 by Aerospace (A-3), 1.27 by Liu and Jordan (A-4) and 1.28 by Boes (A-5).

A.4.2.3 Historical Data For California

- Solar Radiation in Bakersfield Area

No long term solar radiation data exists for Bakersfield. However, reference A-6 summarizes all solar data for a number of California stations including a single year at Bakersfield and various years at locations within a 30 mile radius. This data is summarized in Table A-4 which show the location, insolation values and corresponding Fresno TH values for the same time period. All the stations with the exception of the single year at Bakersfield, are within 5% of the Fresno TH data for the same time period. In particular the five year data at Wasco and Shafter compare closely with Fresno, leading one to conclude that those two stations have similar insolation characteristics to Fresno and to each other. The single year at Bakersfield (70-71) resulted in 17% lower TH than Fresno for the same year. This data would seem to support the tentative conclusion drawn from the 1980 measurements that Bakersfield may have somewhat lower insolation than Fresno. Additional solar data for Bakersfield is needed to form any definitive conclusions.

o Cloudiness Data

An indirect insolation comparison between Fresno and Bakersfield may be made by comparing the National Weather Service records for both stations for mean sky cover or cloudiness. This parameter is a visual observation, made each hour from sunrise to sunset, of the fraction of the total sky dome which is obscured by clouds of any type. It does not give any information on the location of the clouds with respect to the sun.

The historical comparison of mean sky cover for the two stations is given in reference A-6 and for Bakersfield is 36% and Fresno 38% on an annual basis. One estimation of insolation from historical cloud cover data has been made for Bakersfield and is known as the "Ersatz Solmet Data Base" (A-3). Using the 1952-75 period for Bakersfield, the Ersatz data shows an estimated mean daily TH of 5.51 Kwh/m^2 which is 1% higher than the corresponding Fresno data.

An attempt to correlate Edison TH for 1980 with Bakersfield cloud cover data for the same period was not conclusive. Data for a single month (March) is given in Figure A-16. The cloud cover index is 0=clear, 10=overcast. Linearly decreasing values of measured insolation with increasing cloud cover number was expected, but not observed from Figure A-16. Additional solar radiation data from Bakersfield/Edison is required to establish any correlation.

A.4.2.4 Clear Day Comparisons

One method of determining effects of local pollutants or haze on ground-measured insolation data is to compare clear day data. The width, shape and peak insolation values of two clear days from locations of the same latitude and altitude measured within a few days of each other, should be very similar and any differences would be attributed to very local phenomena such as fog, dust or haze. One clear day per month was selected from the Edison data and the Fresno TMY data and plotted together. These plots are shown in figures A-17 through A-21.

Figure A-17 and A-18 compare two clear days in January and February and show very good agreement between Edison and Fresno TMY. The peak values and daily integrated values for DN and TH are very similar for both locations. Figures A-19 through A-21 depict clear days in March, April and May and shows the Fresno location to have higher daily integrated values of both TH and DN and, higher daily peaks for both DN and TH. The difference for these days may be due to haze, dust or both at Edison, but no firm conclusions can be stated until a larger body of data, such as all clear days in one year, is analyzed. In addition, when Fresno measured DN data becomes available, it should be used for clear day comparisons to Edison.

A.4.3 Summary and Recommendations

The results of the Edison solar radiation measurement and analysis program may be summarized as follows:

1. The measured total horizontal insolation values at Edison are significantly (17%) lower than Fresno for the same six month period. This could indicate that the long term Bakersfield/Edison insolation is lower than Fresno, possibly due to agricultural activity or local fog at the Edison field.

2. The direct normal measured insolation at Edison is 10% lower than the Fresno TMY for the same period.

3. Five years of insolation data at stations near Edison (Wasco, Shafter) indicate that they have very similar insolation characteristics compared to Fresno.

4. Twenty-three years of cloud cover data at Bakersfield and Fresno agree to within 1%.

The following activities are recommended:

1. Additional direct and total insolation data is needed for Edison. Exxon is planning to continue operation of the solar data station through 1980.

2. The analysis of data should be repeated after one full year of operation. Six months of data cannot support definitive conclusions.

3. The one year data analysis should include the development of a direct normal insolation prediction for Edison, a comparison of Edison to Fresno direct normal and a Bakersfield/Edison cloud cover/insolation correlation.

TABLE A-2

STEAM BOILERS

	Steamer #1	Steamer #2
Manufacturer	Struthers Thermoflood	Struthers Thermoflood
Heat Output	22M BTU/Hr	25MM BTU/Hr
Pressure Rating	2500 psig	1500 psig
Temperature at Rated Pressure	670°F	598°F
Steam Quality (Design)	80%	80%
(Actual)	75%	--
Fuel Consumption (Max)	105 BOPD	115 BOPD
(Normal)	90 BOPD	--
BTU Rating Fuel	6MM BTU/BBL	6MM BTU/BBL
Efficiency (Estimated)	84%	87%
Flow Rate (Water/Steam)	42 gpm (1440 BWPD)	50 gpm (1700 BWPD)

The total field now consisting of about 165 producing wells is operated by a crew having a field superintendent, lease operators and maintenance specialists. In addition to Exxon personnel, well servicing, well drilling and other non-routine maintenance work is contracted to local concerns.

A.5 Production History

The Main area was discovered in 1931. During the 1930's, initial production rates from wells in the Kern River zone were as high as several hundred barrels of oil per day (BOPD). In 1945 Schist zone production was established. Initial production rates at some wells in excess of 2,000 BOPD were reported.

A.6 Model Studies of Steam Drive at Edison

A significant program effort was devoted to simulating steam drive operations at Edison and measuring pertinent reservoir parameters. Initial simulations based on estimated parameters were quite promising. However, subsequent measurements based on a single field core have raised questions regarding these estimated values. Simulations using measured values for the parameters are much less encouraging than the initial simulation was.

Table A-3

Solar Radiation in Bakersfield Area

Station	Location From Edison	Mean Daily Annual TH (Kwh/m^2-day)	Fresno TH	Years
Wasco	30 miles NW	4.90	5.03	75-79
Shafter	20 miles NW	5.20	5.03	75-79
Bakersfield	7 miles W.	4.40	5.28	70-71
Old River	15 miles SW	4.98	4.80	66-67
Arvin Frick	8 miles S.	5.43	5.23	60-61

References To Appendix A

A-1. I. Hall et.al "Generation of Typical Meterological Years for 26 SOLMET Stations" Report SAND78-1601 August 1978, Sandia Labs, Albuquerque.

A-2. "Direct Normal Insolation Values for Bakersfield" Aerospace Corp. Memo, 28 November 1979, Transmitted by E.J. Rattin, Energy Systems Program Manager.

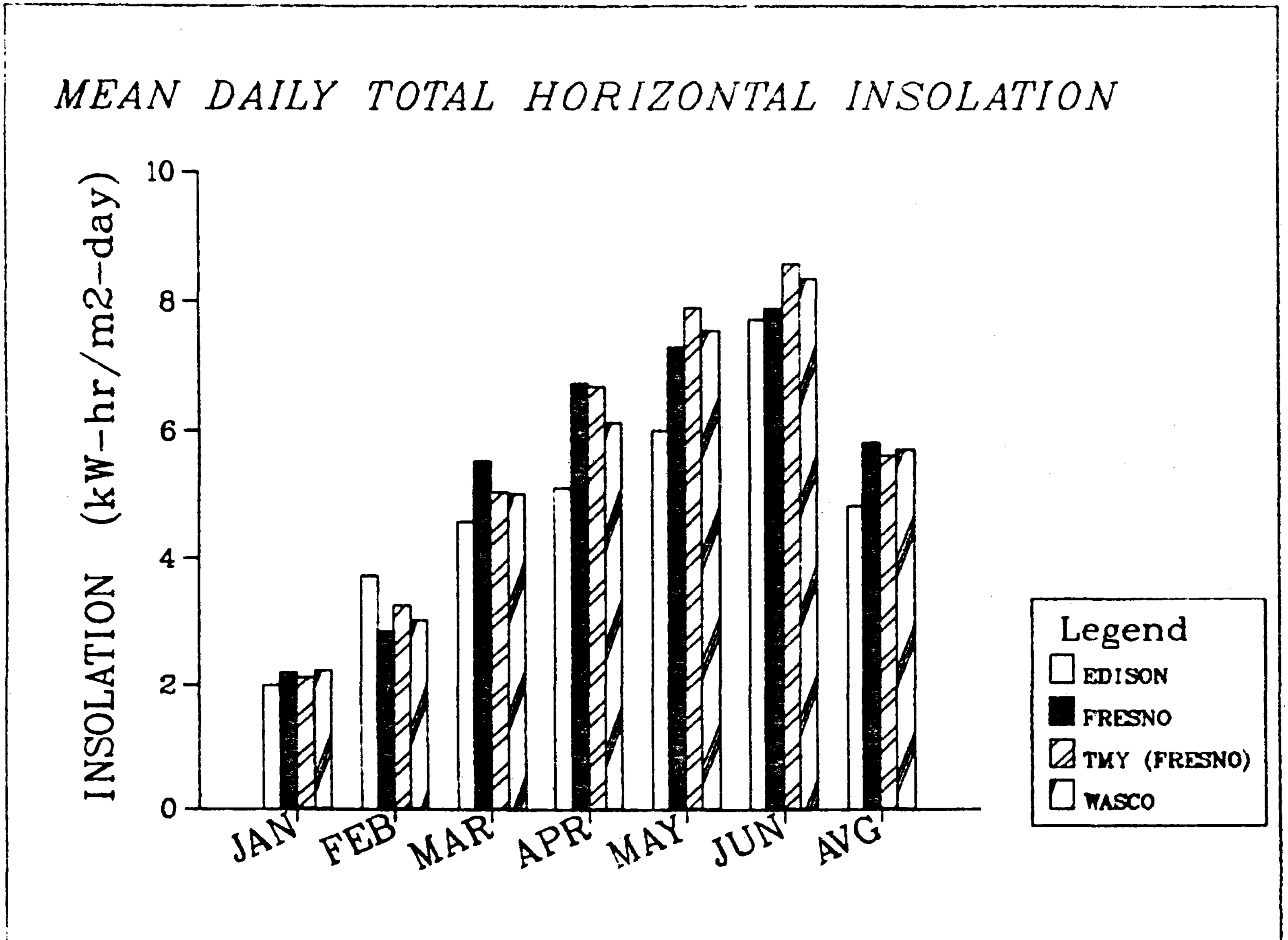
A-3. C. Randall and M. Whitson "Final Report Hourly Insolation and Meteorological Data Bases Including Improved Direct Insolation Estimates" Aerospace Corp. Report ATR-781(7592)-1, December 1977, El Segundo, California.

A-4. Liu, B.Y.H. and Jordan, R.C., "The Interrelationship and Characteristic Distribution of Direct, Diffuse and Total Solar Radiation," Solar Energy, Vol. IV, July, 1960, pp. 1-19.

A-5. Boes, E.C. et. al., "Distribution of Direct and Total Solar Radiation Availabilities for the U.S.A., "Sandia Report SAND76-0411, August, 1976.

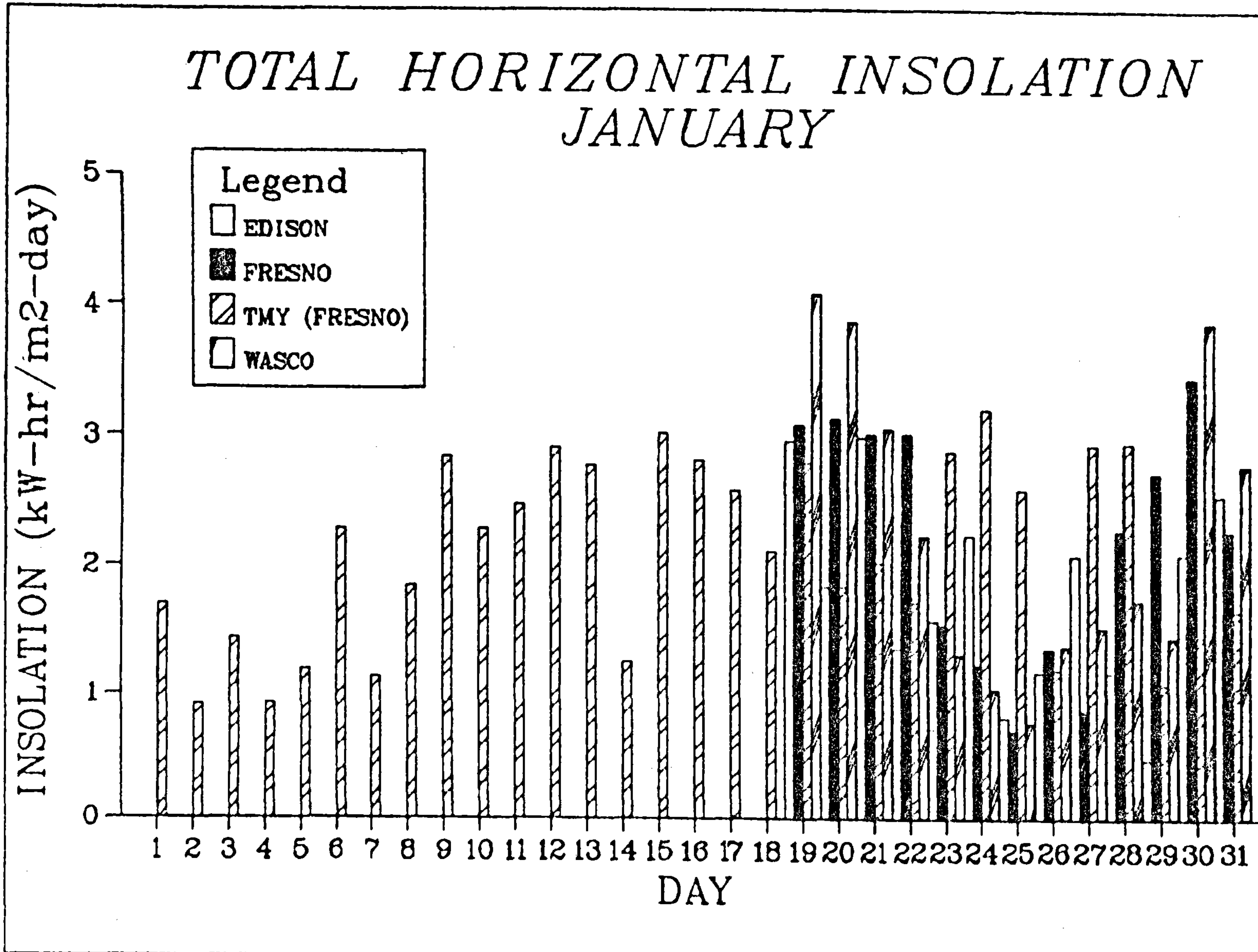
A-6. "California Sunshine-Solar Radiation Data" Bulletin 187, State of California, Dept. of Water Resources, August 1978, Sacramento, California.

FIGURE A-7



MEAN DAILY TOTAL HORIZONTAL INSOLATION
INSOLATION (kW-hr/m2-day)
10
8
6
4
2
0
JAN
FEB
MAR
APR
MAY
JUN
AVG
Legend
EDISON
FRESNO
TMY (FRESNO)
WASCO

FIGURE A-8



TOTAL HORIZONTAL INSOLATION
JANUARY
Legend
EDISON
FRESNO
TMY (FRESNO)
WASCO
INSOLATION (kW-hr/m2-day)
0
1
2
3
4
5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
DAY

FIGURE A-9

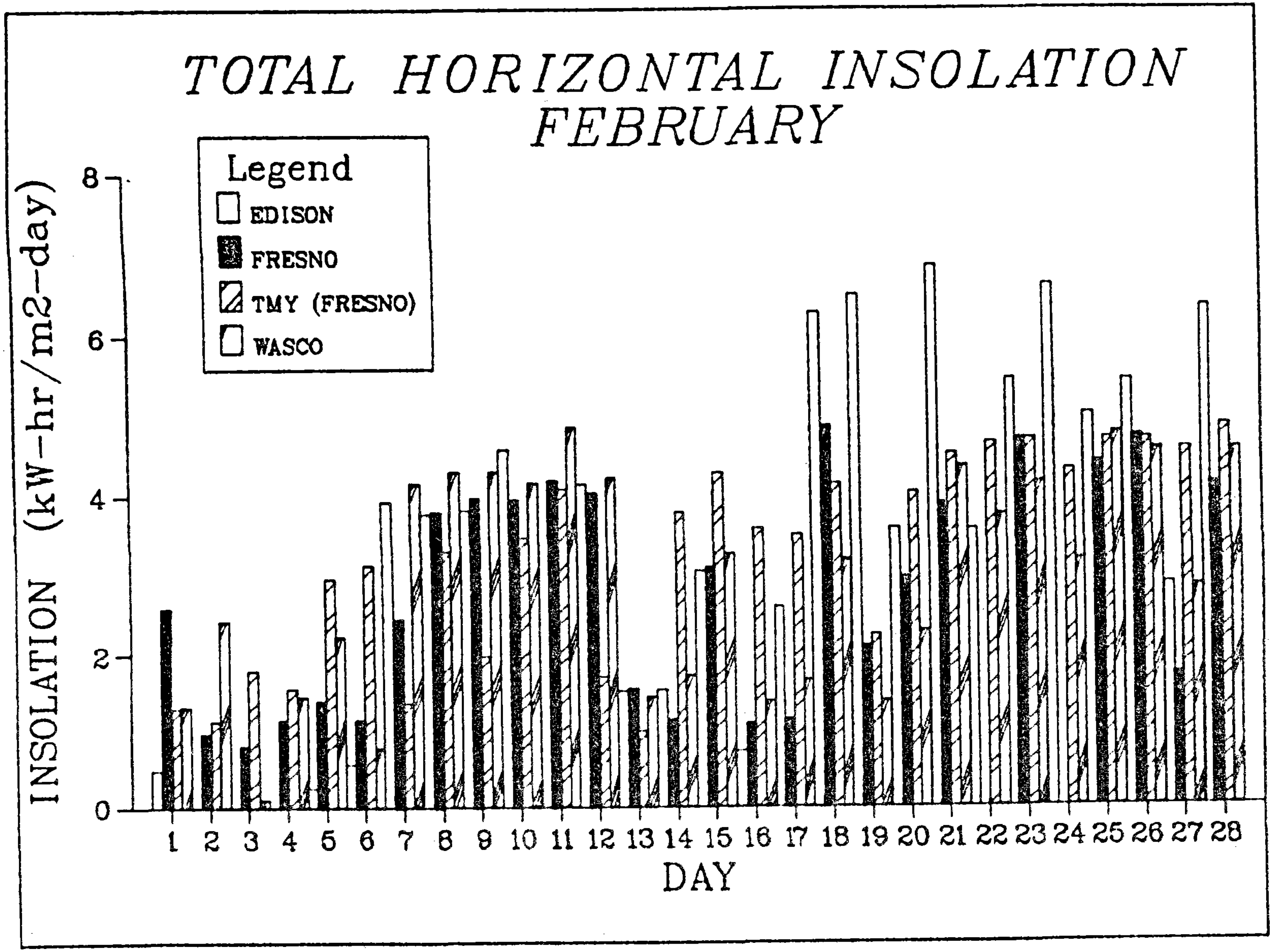
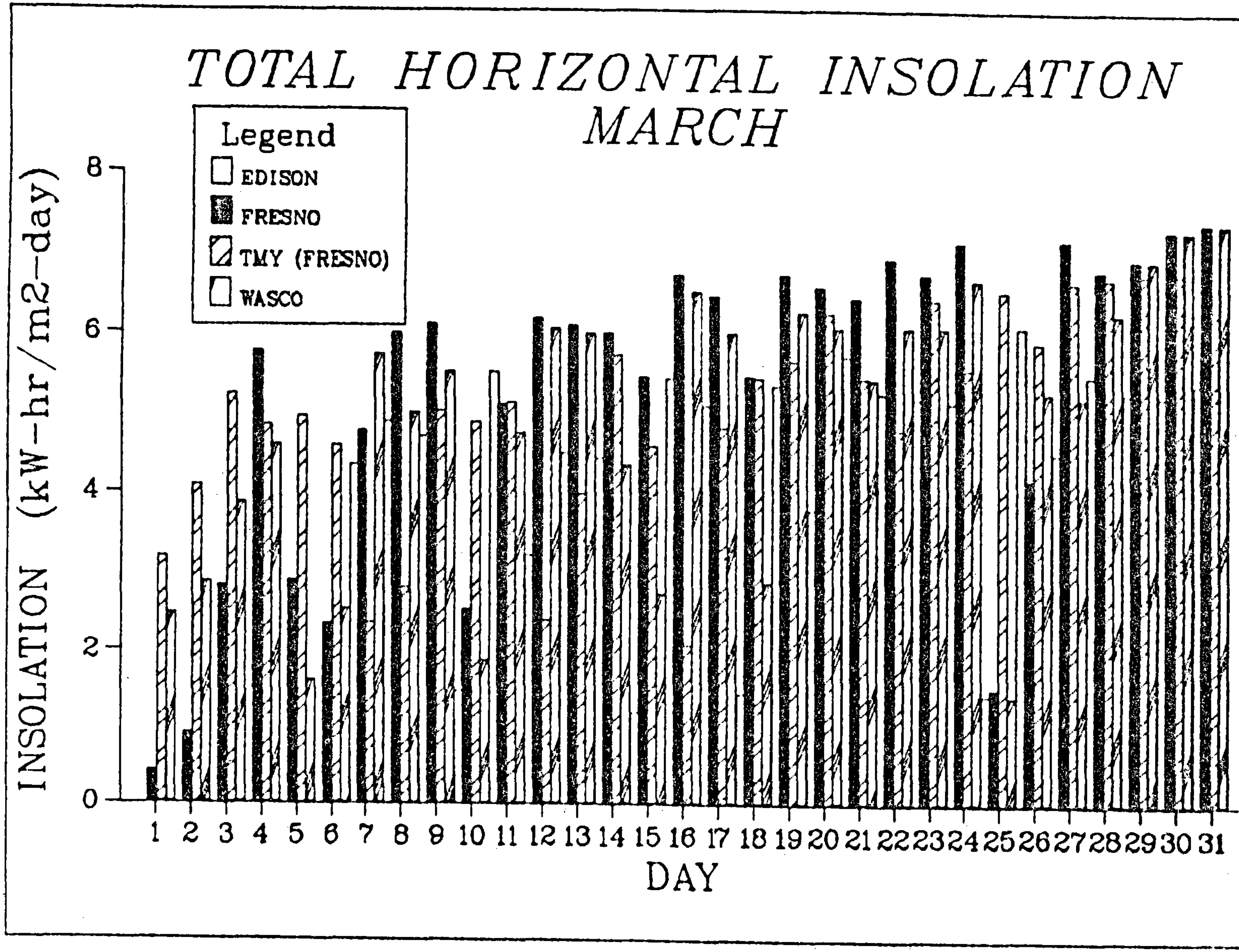

TOTAL HORIZONTAL INSOLATION
FEBRUARY
Legend
EDISON
FRESNO
TMY (FRESNO)
WASCO
INSOLATION (kW-hr/m2-day)
0
2
4
6
8
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
DAY

FIGURE A- 10



TOTAL HORIZONTAL INSOLATION
MARCH
Legend
EDISON
FRESNO
TMY (FRESNO)
WASCO
INSOLATION (kW-hr/m2-day)
0
2
4
6
8
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
DAY

FIGURE A-11

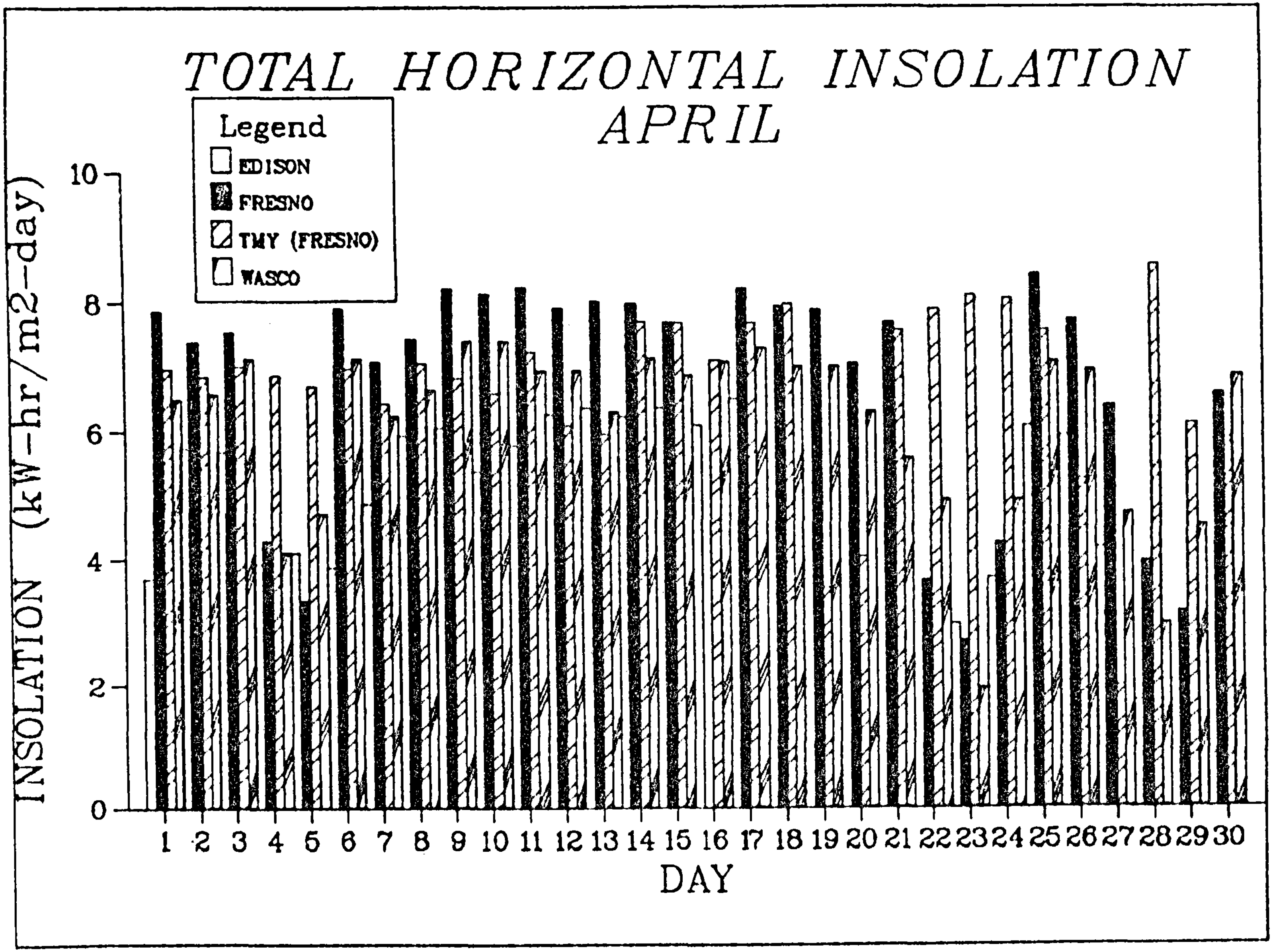

TOTAL HORIZONTAL INSOLATION
APRIL
Legend
EDISON
FRESNO
TMY (FRESNO)
WASCO
INSOLATION (kW-hr/m2-day)
0
2
4
6
8
10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
DAY

FIGURE A-12

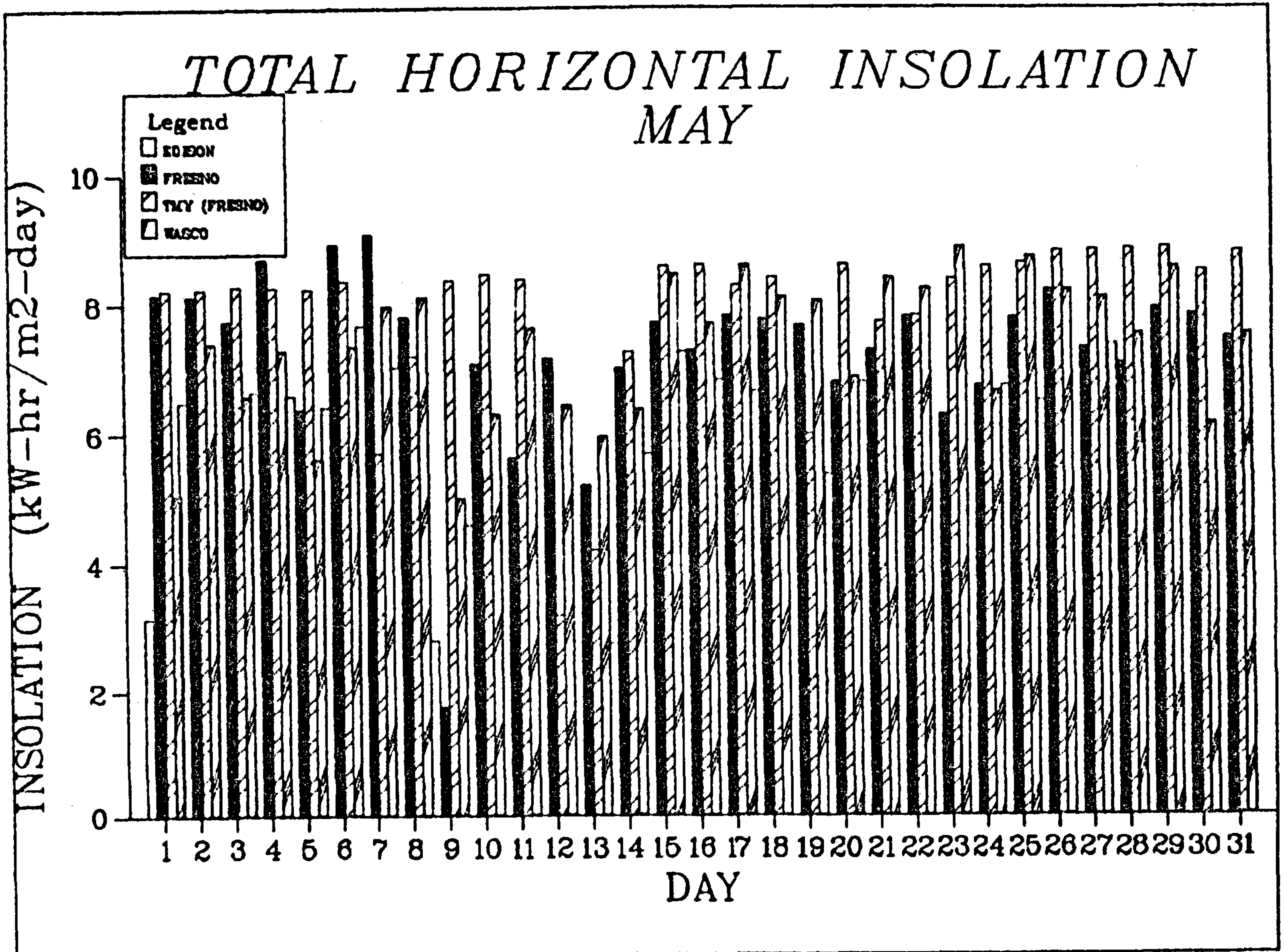

TOTAL HORIZONTAL INSOLATION
MAY
Legend
EDISON
FRESNO
TMY (FRESNO)
WASCO
INSOLATION (kW-hr/m2-day)
0
2
4
6
8
10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
DAY

FIGURE A-13

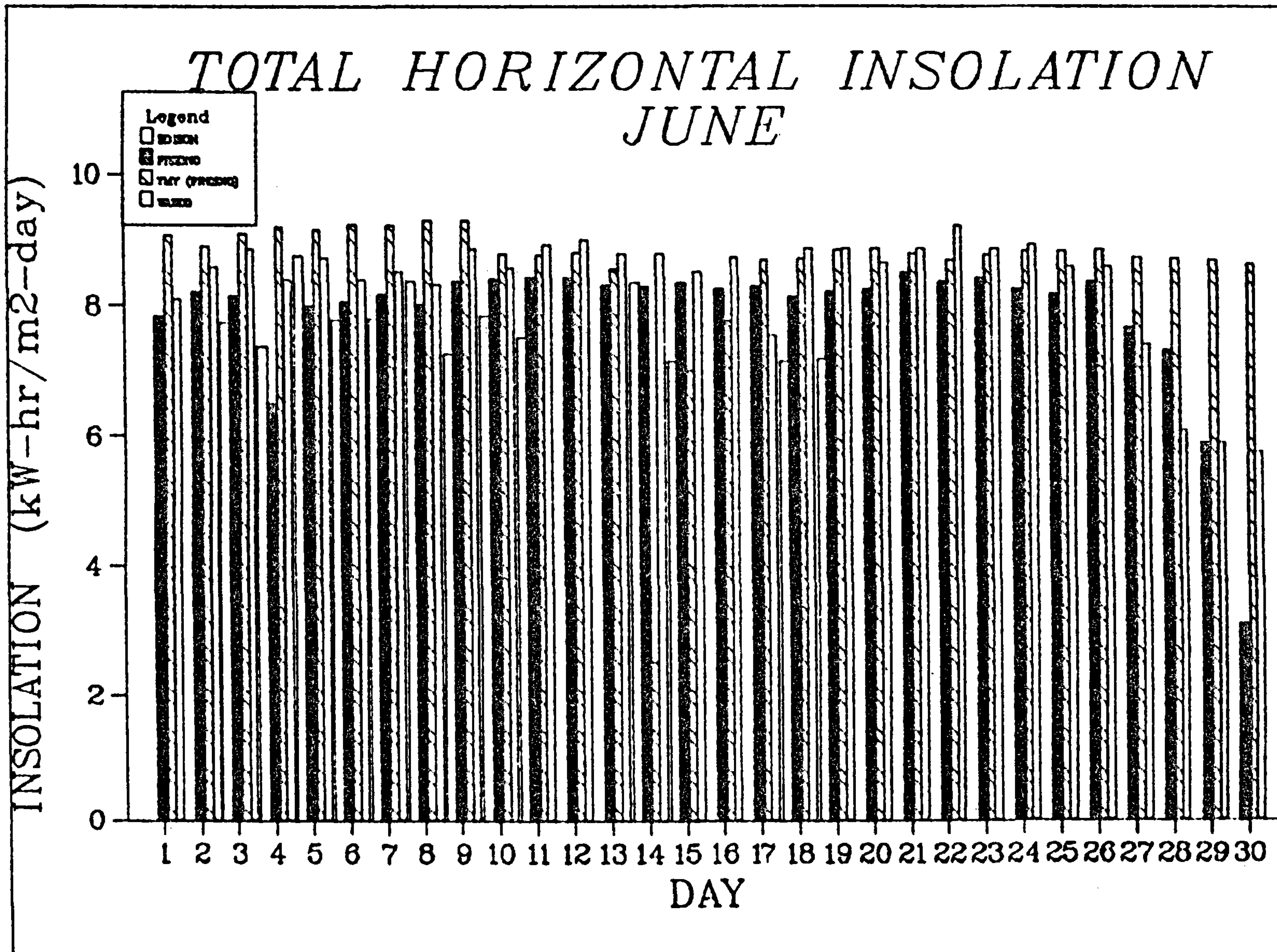
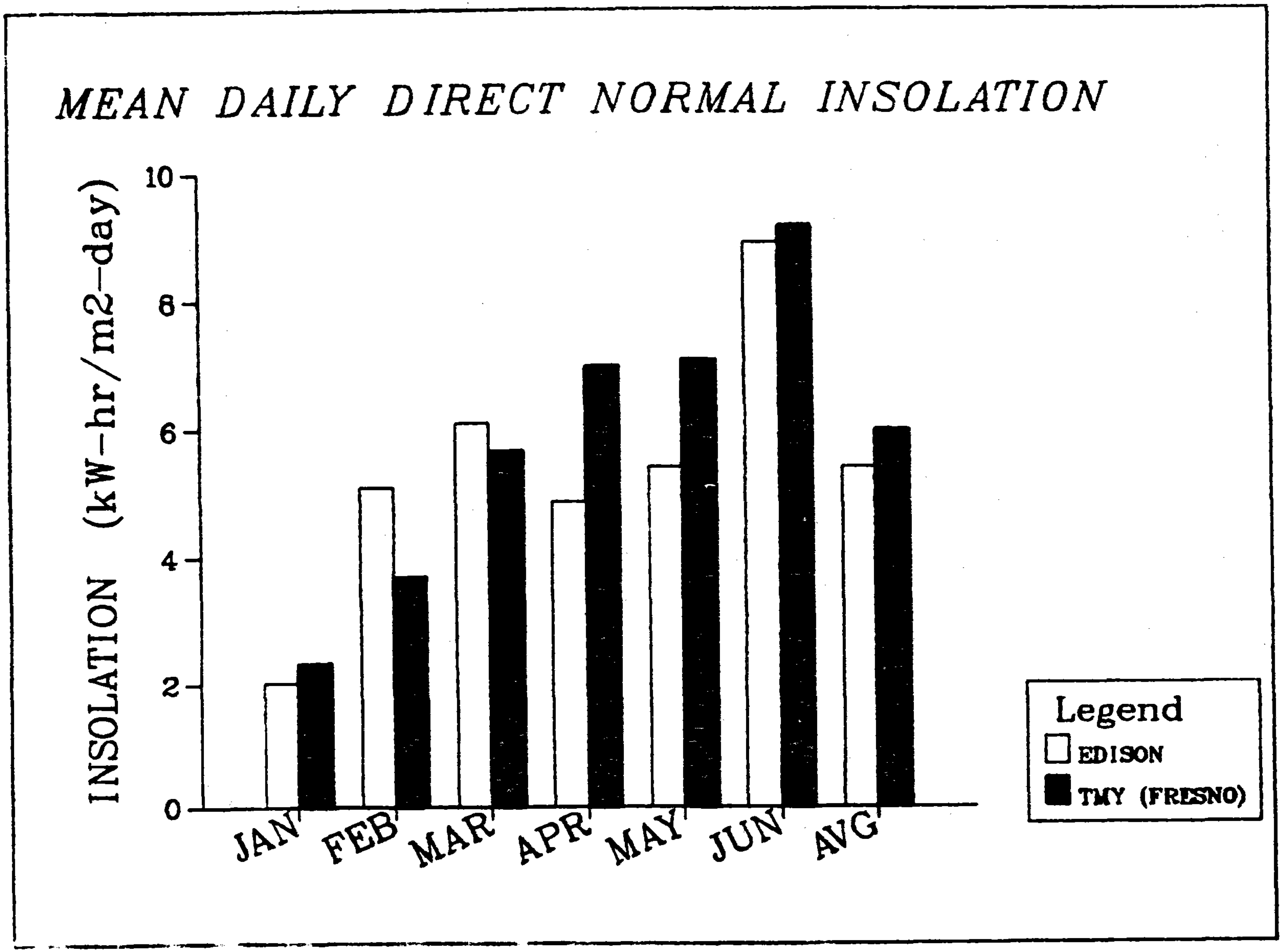

TOTAL HORIZONTAL INSOLATION
JUNE
Legend
INSOLATION (kW-hr/m2-day)
0
2
4
6
8
10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
DAY

FIGURE A-14



MEAN DAILY DIRECT NORMAL INSOLATION
INSOLATION (kW-hr/m2-day)
10
8
6
4
2
0
JAN
FEB
MAR
APR
MAY
JUN
AVG
Legend
EDISON
TMY (FRESNO)

FIGURE A-15

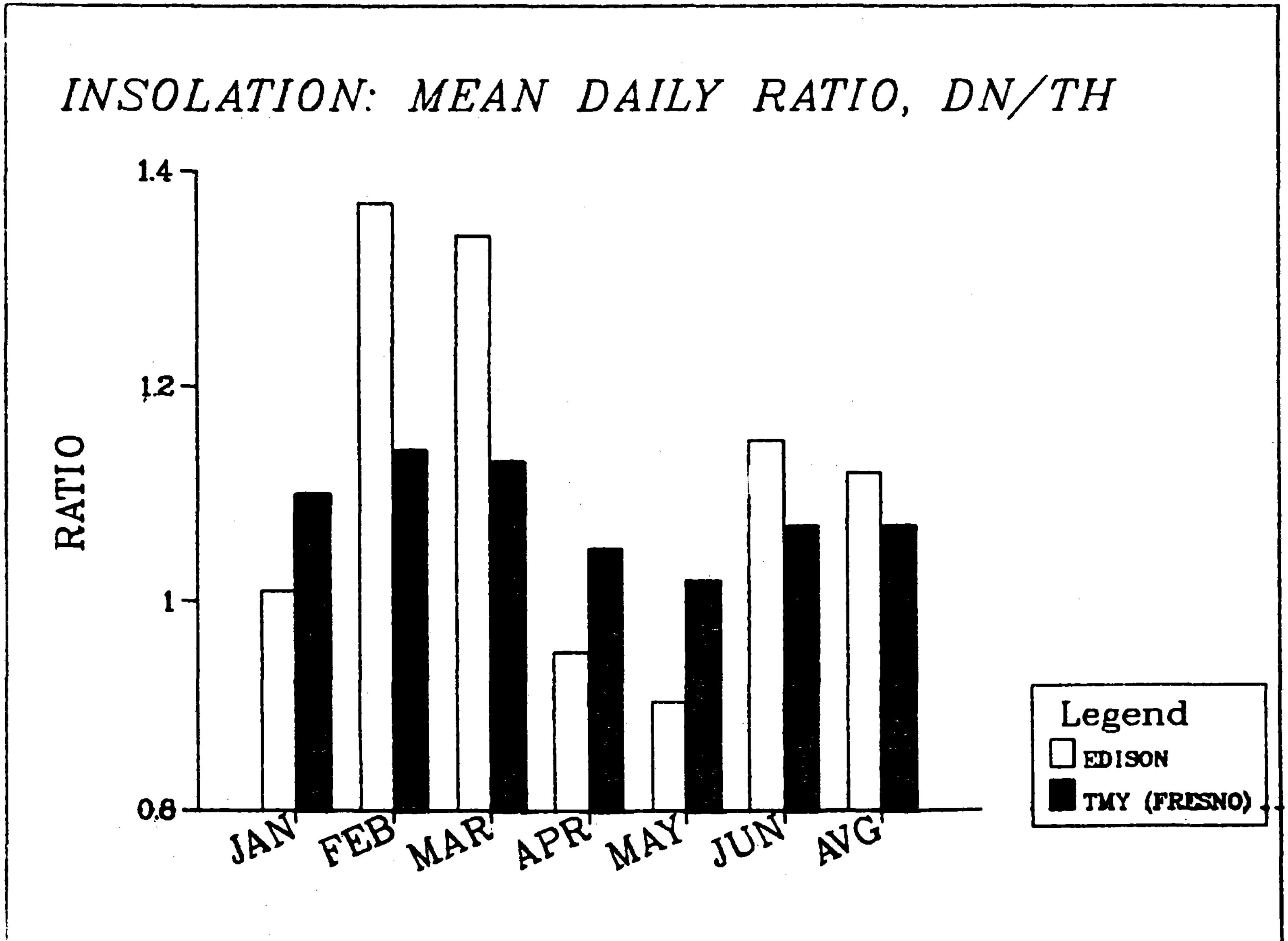
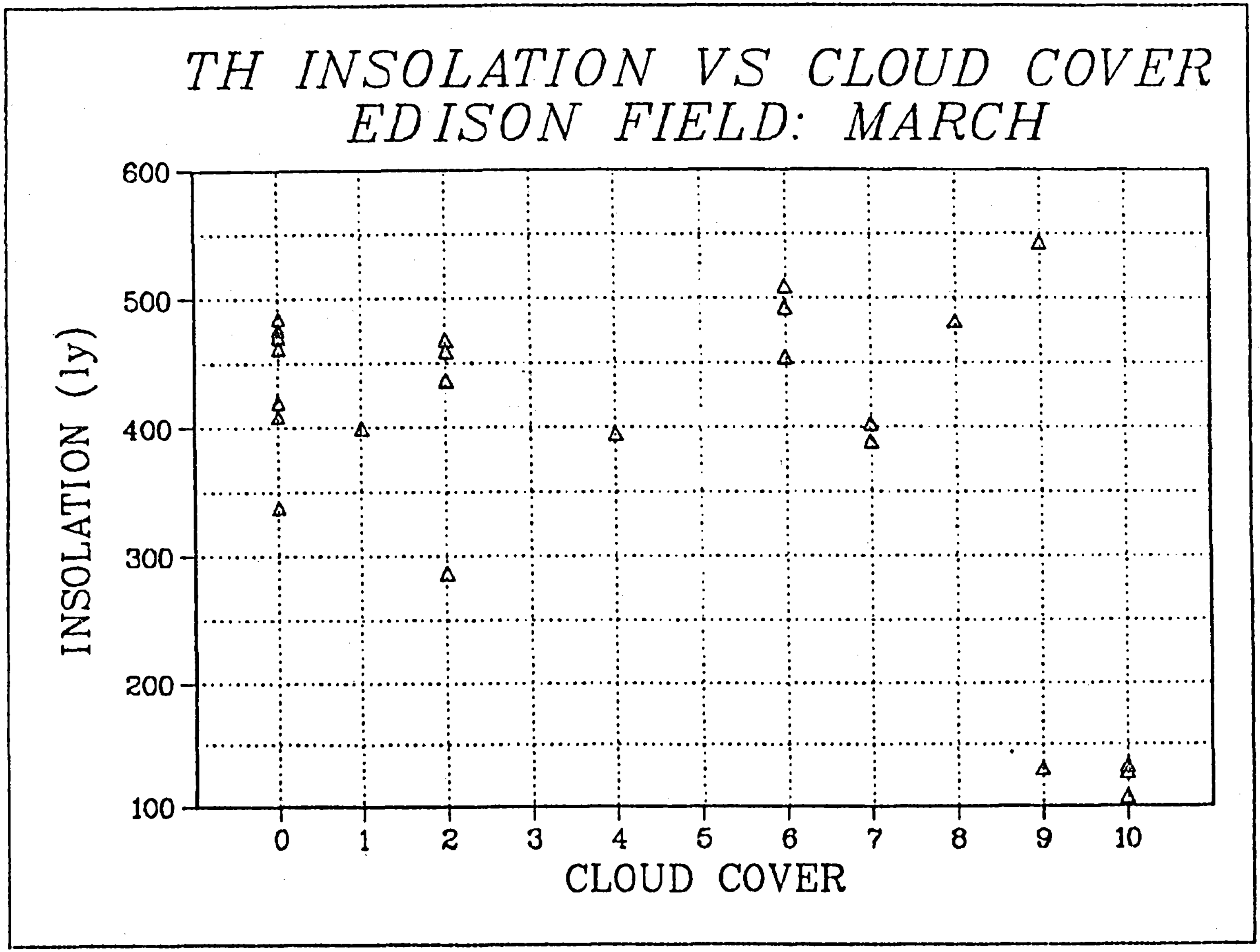
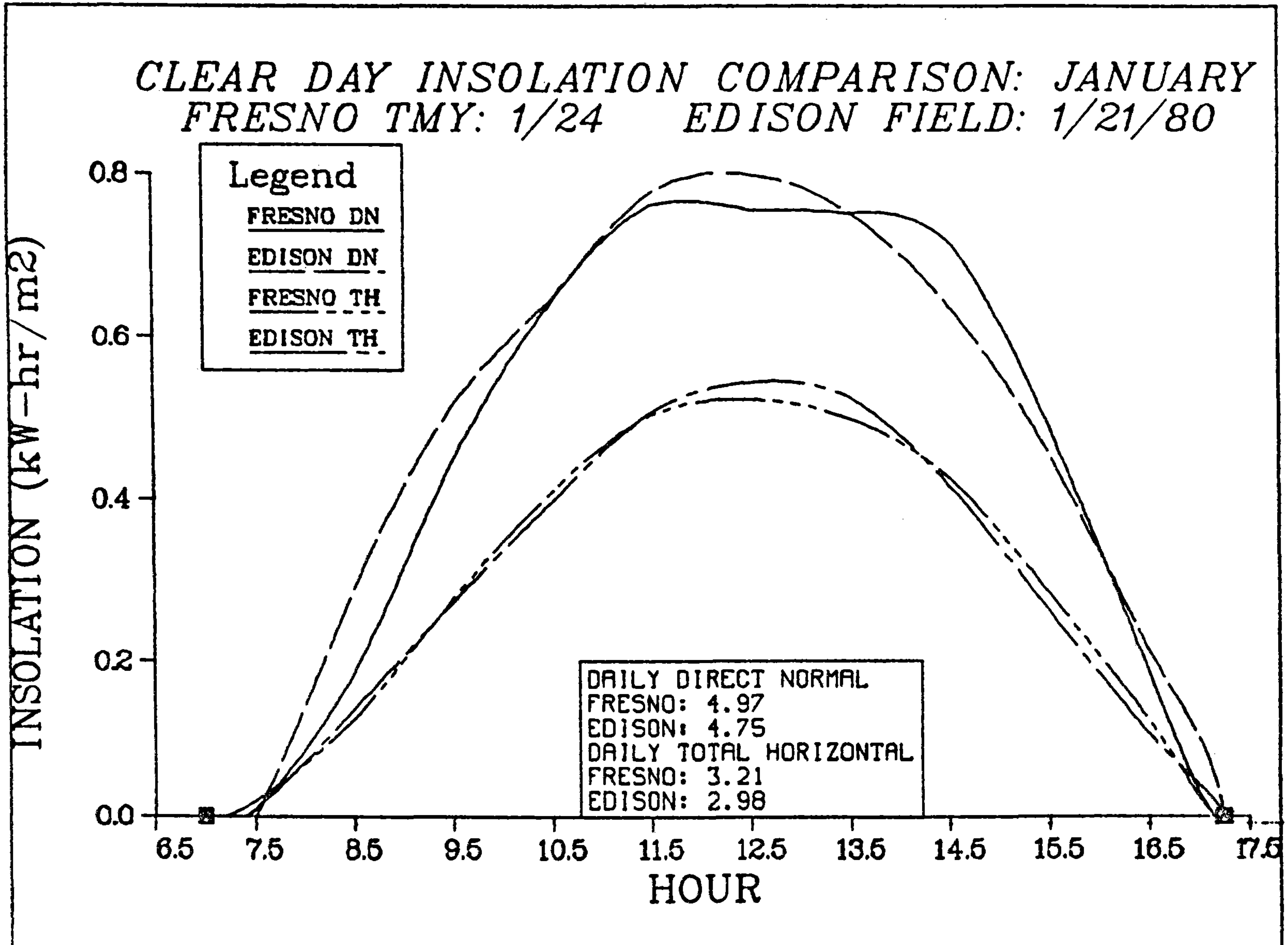

INSOLATION: MEAN DAILY RATIO, DN/TH
RATIO
1.4
1.2
1
0.8
JAN
FEB
MAR
APR
MAY
JUN
AVG
Legend
EDISON
TMY (FRESNO)

FIGURE A-16



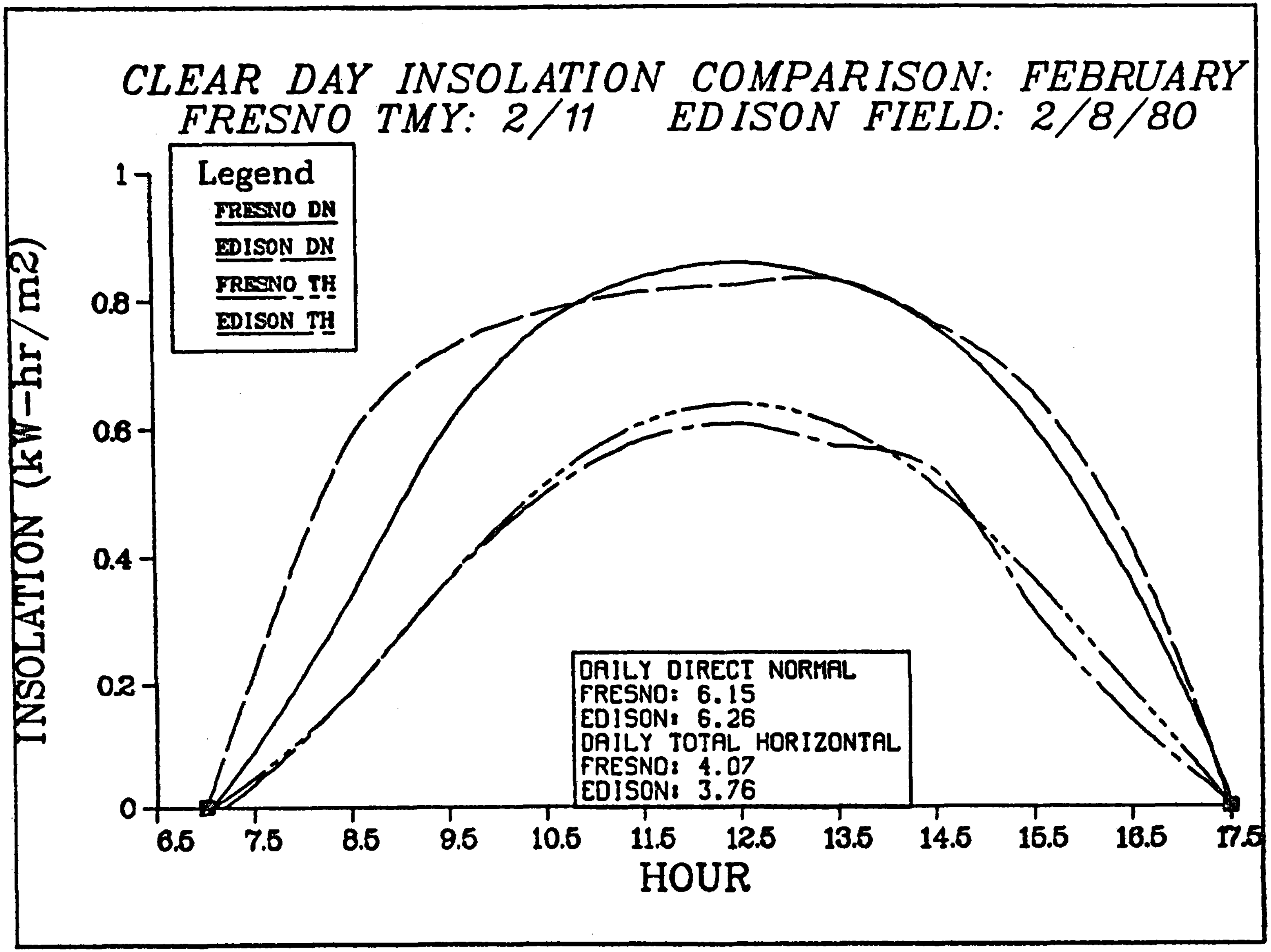
TH INSOLATION VS CLOUD COVER
EDISON FIELD: MARCH
INSOLATION (ly)
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
9
10
CLOUD COVER

FIGURE A-17



CLEAR DAY INSOLATION COMPARISON: JANUARY
FRESNO TMY: 1/24 EDISON FIELD: 1/21/80
Legend
FRESNO DN
EDISON DN
FRESNO TH
EDISON TH
INSOLATION (kW-hr/m2)
0.8
0.6
0.4
0.2
0.0
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
15.5
16.5
17.5
HOUR
DAILY DIRECT NORMAL
FRESNO: 4.97
EDISON: 4.75
DAILY TOTAL HORIZONTAL
FRESNO: 3.21
EDISON: 2.98

FIGURE A-18



CLEAR DAY INSOLATION COMPARISON: FEBRUARY
FRESNO TMY: 2/11 EDISON FIELD: 2/8/80
Legend
FRESNO DN
EDISON DN
FRESNO TH
EDISON TH
INSOLATION (kW-hr/m2)
1
0.8
0.6
0.4
0.2
0
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
15.5
16.5
17.5
HOUR
DAILY DIRECT NORMAL
FRESNO: 6.15
EDISON: 6.26
DAILY TOTAL HORIZONTAL
FRESNO: 4.07
EDISON: 3.76

FIGURE A-19

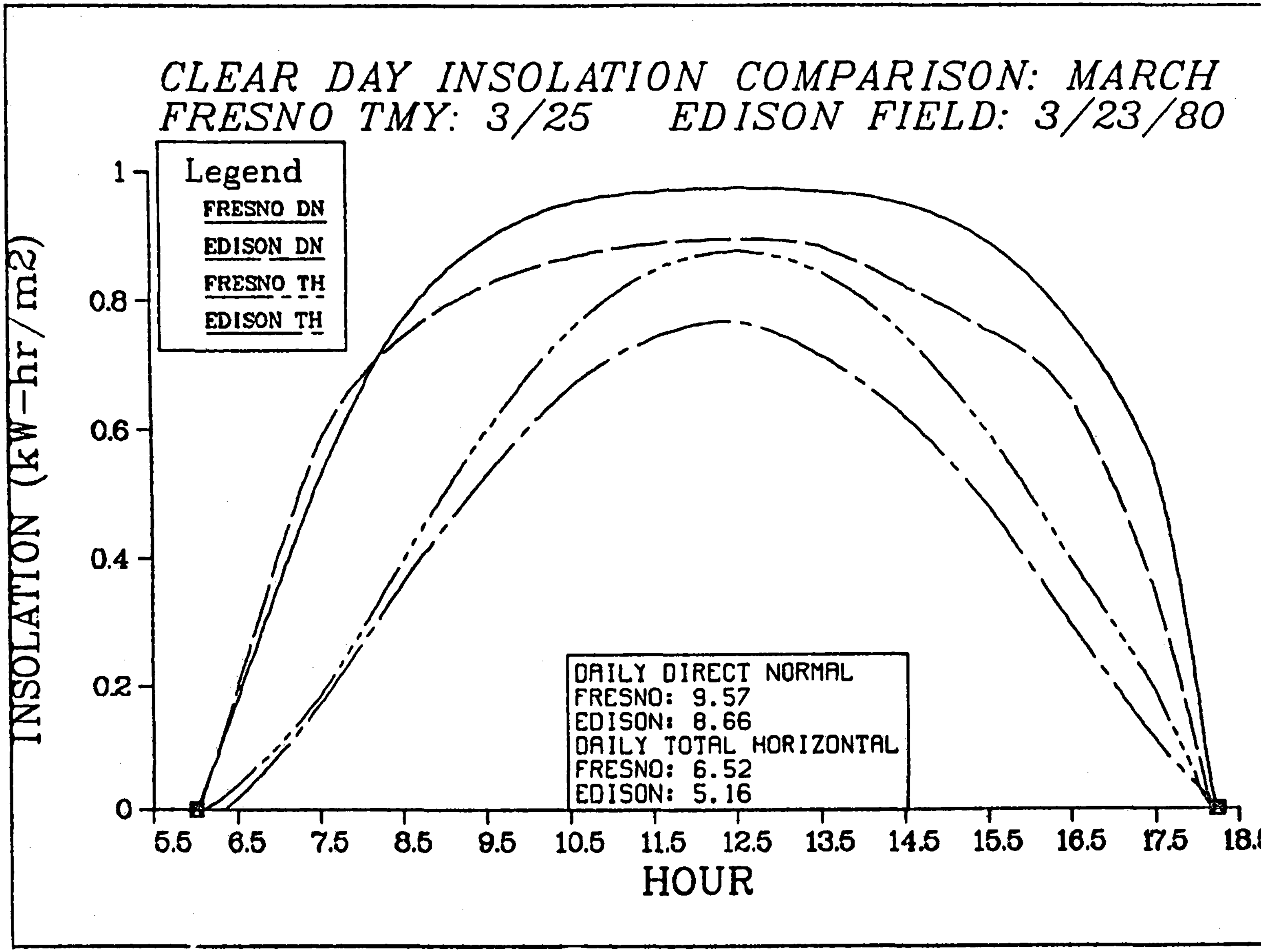
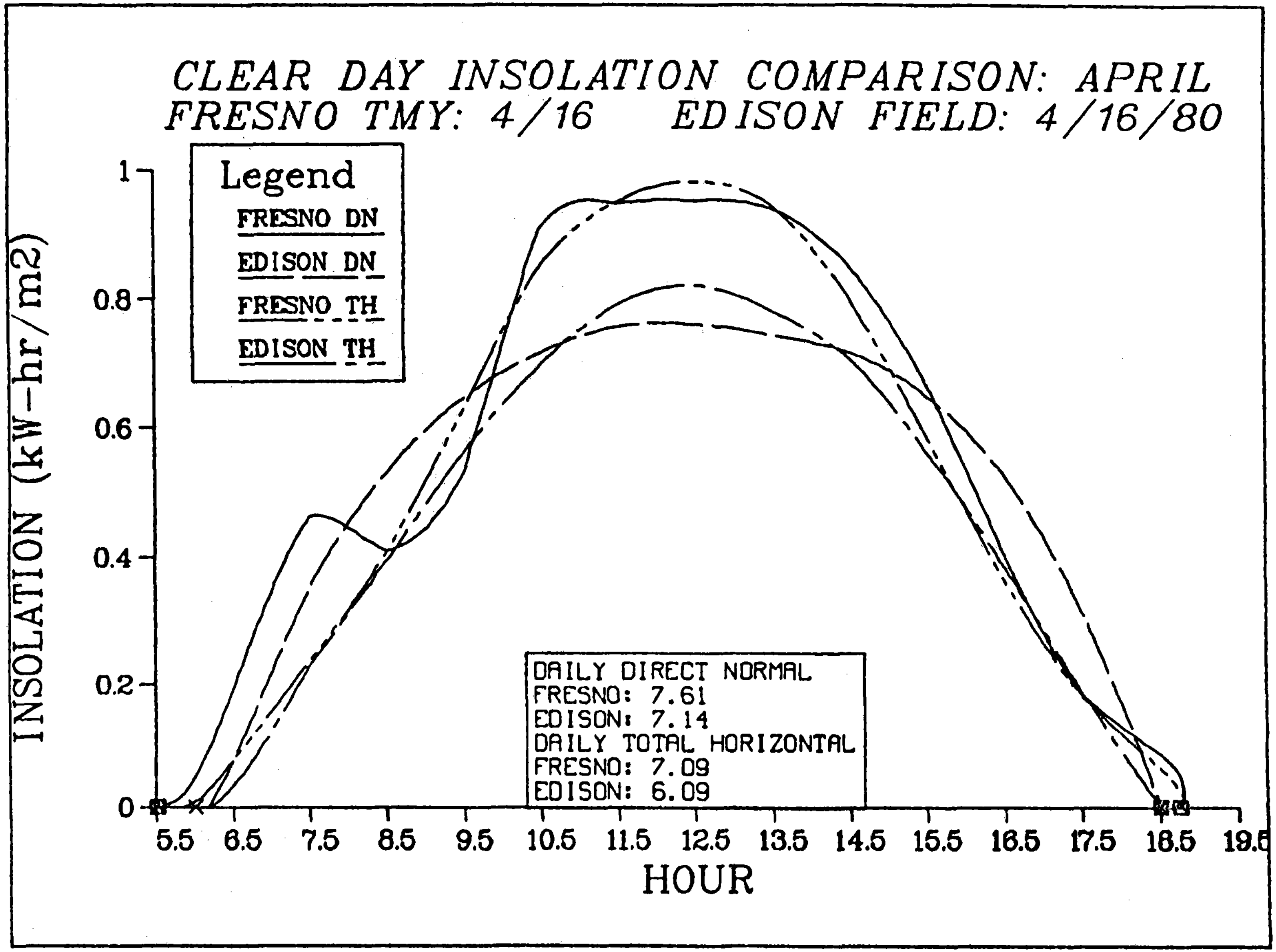
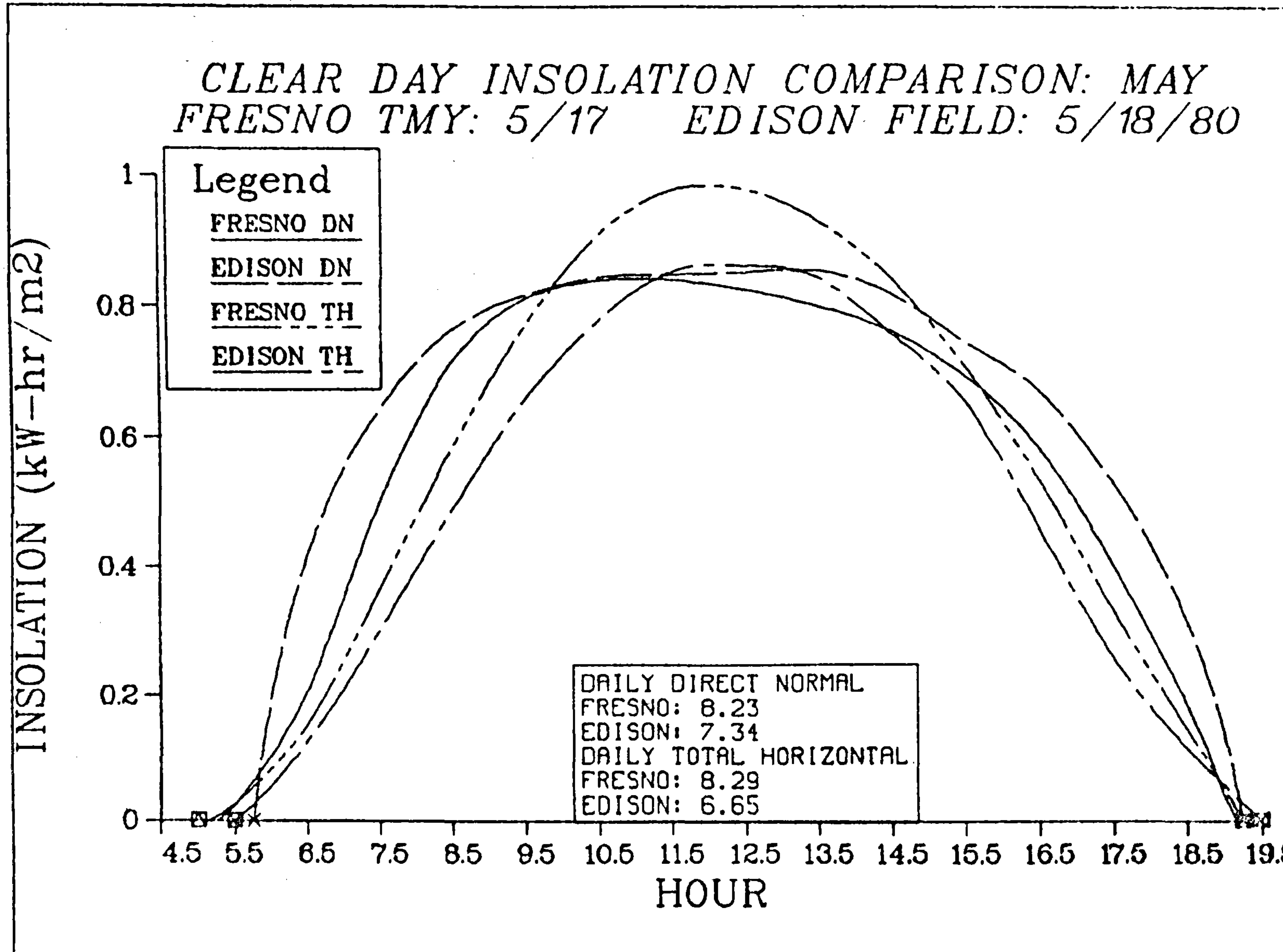

CLEAR DAY INSOLATION COMPARISON: MARCH
FRESNO TMY: 3/25 EDISON FIELD: 3/23/80
Legend
FRESNO DN
EDISON DN
FRESNO TH
EDISON TH
INSOLATION (kW-hr/m2)
1
0.8
0.6
0.4
0.2
0
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
15.5
16.5
17.5
18.5
HOUR
DAILY DIRECT NORMAL
FRESNO: 9.57
EDISON: 8.66
DAILY TOTAL HORIZONTAL
FRESNO: 6.52
EDISON: 5.16

FIGURE A-20



CLEAR DAY INSOLATION COMPARISON: APRIL
FRESNO TMY: 4/16 EDISON FIELD: 4/16/80
Legend
FRESNO DN
EDISON DN
FRESNO TH
EDISON TH
DAILY DIRECT NORMAL
FRESNO: 7.61
EDISON: 7.14
DAILY TOTAL HORIZONTAL
FRESNO: 7.09
EDISON: 6.09
INSOLATION (kW-hr/m2)
HOUR
0
0.2
0.4
0.6
0.8
1
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
15.5
16.5
17.5
18.5
19.5

FIGURE A- 21


CLEAR DAY INSOLATION COMPARISON: MAY
FRESNO TMY: 5/17 EDISON FIELD: 5/18/80
Legend
FRESNO DN
EDISON DN
FRESNO TH
EDISON TH
INSOLATION (kW-hr/m2)
1
0.8
0.6
0.4
0.2
0
4.5
5.5
6.5
7.5
8.5
9.5
10.5
11.5
12.5
13.5
14.5
15.5
16.5
17.5
18.5
19.5
HOUR
DAILY DIRECT NORMAL
FRESNO: 8.23
EDISON: 7.34
DAILY TOTAL HORIZONTAL
FRESNO: 8.29
EDISON: 6.65

APPENDIX B

ADDITIONAL DETAILS OF CONCEPTUAL DESIGNS

CONVERSIONS FOR APPENDIX B

Table B.1

5957 KPa	865 psia
275°C	527°F
198°C	388°F
121°C	250°F
17,645 Kg/hr	38,900 Lb/hr
16,833 Kg/hr	37,220 lb/hr
17,329 Kg/hr	38,205 lb/hr
12,944 Kg/hr	28,538 lb/hr
55,469 Kg/hr	122,288 lb/hr
290°C	555°F
299°C	570°F
198°C	388°F
282°C	540°F
121°C	250°F
264°C	507°F
286°C	547°F
21°C	70°F
271°C	520°F
275°C	527°F
286°C	547°F
28.9 l/sec	458 gpm
123 l/sec	1950 gpm
5.1 l/sec	81 gpm
203 l/sec	3224 gpm
15.4 l/sec	244 gpm
7652 KPa	1111.1 psia
206.6 KPa	30 psia

Table B.1 (Continued)

6543 KPa	950 psia
6776 KPa	984 psia
771 KPa	112 psia
5957 KPa	865 psia
34.4 KPa	5 psia
1343 KPa	195 psia
5992 KPa	870 psia
344 KPa	50 psia
111.9 KW	150 hp
37.3 KW	50 hp
56.7 KW	75 hp
194.6 KW	261 hp
11.2 KW	15 hp
77.7×10^9 KJ	73.6×10^9 BTU/yr
76.9×10^9 KJ	72.9×10^9
79.5×10^9 KJ	75.4×10^9
84.4×10^9 KJ	80×10^9
9.6×10^9 KJ	9.15×10^9
10.1×10^9 KJ	9.61×10^9
8.9×10^9 KJ	8.42×10^9
13.7×10^9 KJ	13.0×10^9
67.5×10^9 KJ	64.0×10^9
66.8×10^9 KJ	63.3×10^9
70.7×10^9 KJ	67×10^9

CONVERSIONS FOR APPENDIX B (Continued)

Explanation B.3

$343^{o}C$	$650^{o}F$

Appendix B

ADDITIONAL DETAILS OF CONCEPTUAL DESIGNS

Additional details of the circulation rates, parasitic power requirements and solar thermal energy delivered and lost are provided in Table B.1 for all but one of the conceptual designs evaluated. As no energy balance calculations were provided or estimates prepared for the natural circulation direct steam generation concept, no details are presented for this concept.

Table B.1

Detailed Description of Conceptual Design

Detail	Flash Separator	Unfired Boiler	Unfired Boiler/Preheat Hybrid		Flash Separator/Feedwater Preheat With Storage Hybrid	
			Unfired Boiler	Preheat	Flash Separator	Preheat
Product	865 lb/in²a steam at 527°F	865 lb/in²a steam at 527°F	865 lb/in²a steam at 527°F	Water preheated to 388°F	865 lb/in²a steam at 527°F	Water preheated to 250°F
Product Rate (lb/h)	38,900	37,220	38,205	---	28,538	122,288
Fluid Circulation (lb/h)	735,360, water	815,000/quad x 4 quads, oil	815,000/quad x 3 quads, oil	40,568, water	1,221,260, water	122,288, water
Collector outlet temperature (°F)	555	570	570	388	540	250
Collector inlet temperature (°F)	507	547	547	70	520	70
Boiler/separator outlet temperature (°F)	527	547	547	---	527	---
Pump rates (gal/min)	458/quad	1950/quad	1950/quad	81	3224	244
Pump discharge pressure (lb/in²a)	1111.1	30	30	950	984	112
Pump Suction pressure (lb/in²)	865	5	5	195	870	50
Motor hp	150	50	50	75	261	15
Thermal energy collected (Btu/yr)	73.6 x 10^9	72.9 x 10^9	75.4 x 10^9		80 x 10^9	
Heat losses (Btu/yr)	9.15 x 10^9	9.61 x 10^9	8.42 x 10^9		13 x 10^9	
Heat delivered (Btu/yr)	64.0 x 10^9	63.3 x 10^9	67.0 x 10^9		67.0 x 10^9	

Table B.2

ASSUMPTIONS MADE IN ECONOMIC ANALYSIS FOR CONCEPTUAL DESIGNS FOR SOLAR THERMAL ENHANCED OIL RECOVERY

A discounted cash flow analysis was performed to determine the cost (in $\$/10^6$ Btu) of the energy produced by the solar thermal system such that a 15 percent/yr rate of return on equity was achieved. The following were the assumptions made in this analysis:

Item	Assumption
1. Costs	Given in December 1979 dollars
2. Capital Costs	Capital costs are those incurred in Phases II and III of this project
3. Federal Income Tax	Rate is 46% Negative taxes are permitted. It is assumed that the parent corporation (Exxon) has other tax liabilities against which such losses can be charged
4. State Income Tax	Rate is 9%
5 Local Taxes	Not charged
6. Investment Tax Credit	28.1% effective rate
7. Funding	100% equity funding
8. Insurance Costs	0.1% per year
9. Salvage Value	Zero
10. Depreciation Method	Sum of Years Digit
11. Depreciation Period	11 yr
12. Project Life	15 yr
13. Investment Schedule	Investment made at end of 1981
14. Extraordinary Charges	An overhead charge of 3% of the capital cost occurs at beginning of the first year.
15. Annual Operations and Maintenance Costs	
Electricity	4¢/kWh
Chemicals and water	$515
Heat-transfer fluids	Replacement costs (if incurred)
Operating manpower	$23,000/yr

Item		Assumption
	Maintenence:	
	Collectors	4%/yr of capital cost
	Remainder of system	2%/yr of capital cost
	Overhead charge on expenses	7%
16.	Inflation or Cost-Escalation Rates	10%/yr for electricity, 7% all others.

The cost of solar thermal energy is quoted as a levelized cost in constant December 1979 dollars.

Explanation B.1

RELIABILITY OF FOUR PUMPS AND SEPARATORS VS. ONE PUMP AND SEPARATOR

Assuming that p is the unavailability of a single collector block because of a noncommon mode failure in its associated pump and separator, the probability of i of n equally sized collector blocks being unavailable at any time due to such failures is

$$\frac{n!}{i!(n-i)!}(1-p)^{n-i}p^{i}$$

and the availability of the whole system A is therefore:

$$A = \sum_{i=0}^{n}\left(1-\frac{i}{n}\right)\left(\frac{n!}{i!(n-i)!}\right)(1-p)^{n-i}p^{i}$$

$$= 1-p$$

This availability is of course identical to the availability of a single collector block. Hence it can be stated that a system with four pumps and separators has a greater availability than a system with only a single large pump and separator only if the availability of the small pumps and separators exceeds that of the large pump and separator. In Foster Wheeler's experience this is not the case providing the sparing policy is adequate, indeed larger pumps, being of heavier construction, tend to be more reliable.

Explanation B.2

RELATIONSHIP BETWEEN PRESSURE DROPS IN LINES AND HEAT-TRANSFER COEFFICIENTS AND THE PROPERTIES OF THE HEAT-TRANSFER FLUIDS

The Nusselt number is defined by the equation:

$$Nu = \frac{h \cdot d}{k} \qquad (1)$$

where h is the heat-transfer coefficient, D is the pipe diameter and k the thermal conductivity in the turbulent flow region.

$$Nu = 0.023\ Re^{0.8}\ Pr^{0.4}$$

where Re is the Reynolds number, $\frac{\rho u D}{\mu}$

and Pr the Prandtl number $\frac{\mu Cp}{k}$, where μ is the fluid viscosity, ρ, its

density, Cp its specific heat, and u the fluid's mean velocity.

Substituting the definitions for the Reynolds and Prandtl numbers in equation (1), we have

$$h = 0.023\ \rho^{0.8}\ D^{-0.2}\ k^{0.6}\ \mu^{-0.4}\ Cp^{0.4}\ u^{0.8} \qquad (2)$$

Similarly, using the Blasius law, we can state that the pressure drop down a pipe is such that

$$\Delta p = 0.158\ \rho^{3/4}\ \mu^{1/4}\ d^{-5/4}\ u^{7/4} \qquad (3)$$

For a given system (i.e., tubes of given diameters and lengths), these equations can be simplified so that they contain only those variables that vary with the fluid and operation of the system.

Thus

$$H \propto 0.8\ k^{0.6}\ -0.4\ Cp^{04}\ u^{0.8} \qquad (4)$$

$$\Delta p \propto \rho^{3/4}\ \mu^{1/4}\ u^{7/4} \qquad (5)$$

Substitution of the values for the heat-transfer fluids in these equations allows us to compare each of the fluids. Redefining (4) and (5) as

$$H = Au^{0.8},\ \Delta p = Bu^{7/4}$$

we can calculate relative values for A and B at 570°F. These are tabulated below.

Fluid	A	B
Dowtherm G	1.58	1.85
LF	1.73	1.53
J	1.88	1.00
Caloria HT-43	1.00	1.58
Therminol 55	1.14	1.63
60	1.43	1.69
66	1.27	1.82
Dow-Corning X2-1162	1.09	1.65
Mobiltherm 600	1.05	1.99

Desirable properties are to combine a high value of A with a low value of B.

Calculations analagous to those performed by General Electric[3] for the design included in the Solar Thermal Enhanced Oil Recovery Project proposal using the Suntec-Hexcel parabolic trough receiver indicate that all fluids have acceptable heat-transfer properties.

Explanation B.3

THE DEGRADATION RATES OF HEAT-TRANSFER FLUIDS

The thermal degradation of heat-transfer fluids is important in so far as it affects the performance of the fluid as reported by Seifert, Jackson, and Sech[4]

> "decomposition is manifested by the appearence of low boiling components and/or high boiling materials (including polymeric tars). Low-boiling materials in fluid may cause excessive venting and high make-up rates may be encountered. In contrast, high boiling materials and polymers in the fluid will result in higher viscosities. (This) will accelerate the degradation process due to less efficient heat transfer and higher film temperature"

In addition, the formation of polymeric tars may lead to the fouling of the receiver tubes, which in turn would lead to a diminished heat transfer coefficient and higher receiver coating temperatures. The latter might result in degradation of the receiver coating. It is evident then that particular attention should be taken to avoid the fouling of the receiver tubes.

Two types of study have been performed to determine the degradation rates of heat-transfer fluids. These are the static tests performed by Seifert et al.[5] and dynamic tests performed by Monsanto. The latter are particularly relevant in that they are more representative of the service conditions to which the fluids are exposed and readily allow for the detection of fouling. In addition, Sandia Laboratories has examined the weight losses that occur when heat-transfer fluids are used as mediums for heat storage.

The results of these tests are often contradictory, Seifert et al. showed a degradation rate for Dowtherm G at 650°F of 0.075%/week. In the flowing system, however, Monsanto reported a degradation rate of 0.31%/week at 650°F for Dowtherm G. In evaluating the fluids we have paid particular attention to results observed in flowing systems on the grounds that these provide a more realistic representation of our systems.

APPENDIX C

FOUNDATION DESIGN FOR SOLAR COLLECTORS

CONVERSIONS FOR APPENDIX C

Section I

30.48 cm	(12 in)
2.13 M	7 ft
1.22 M	4 ft
$17.65/M^2	$1.64/ft^2
6.3 M	20'8"
2.06 M	81"
1020 Kg	2250 lbs
1.35 M	53"

Section II

40.6 cm	16 in
30.48 cm	12 in
40.6 cm	16 in
45.7 x 35.6 cm	18 in x 14 in
40.6 cm	16 in
27,550 KPa	4000 psi
26.8 m/s	60 MPH
22.4 m/s	50 MPH
13.4 m/s	30 MPH
.72 KPa	15 lbs/SQ FT
71.7 KPa	1500 lbs/SQ FT
7.17 KPa	150 lbs/SQ FT
1.68 M	5'6"
1.07 M	3'6"
$1.74 \times 10^6 Kg/m^3$	$63\ lb/in^3$
$8.3 \times 10^6 Kg/m^3$	$300\ lb/in^3$

CONVERSIONS FOR APPENDIX C (Continued)

Section IV

30.5 cm	12 in
2.13 M	7 ft
1.22 M	4 ft
$17.65/M^2	$1.64/ft^2

Table C-1

11,610 N	2,610 lbs f
9296 N	2090 lbs f
4626 N	1040 lbs f
6183 N	1390 lbs f

Table C-2

4817 N	1083 lbs f
4564 N	1026 lbs f
2936 N	660 lbs f
1112 N	250 lbs f
8230 N.M	6070 ft. lbs
8677 N.M	6400 ft. lbs
6142 N.M	4530 ft lbs
1492 N.M	1100 ft lbs

APPENDIX C

Foundation Design for Solar Collectors

I. SUMMARY

The objective of this study was to develop the most economical foundations for supporting single-axis-tracking solar collectors to be installed at Exxon's Edison field near Bakersfield, California. At present, there are no design criteria in the codes and standards available for solar collector foundations. Therefore, in this study, various methods of computing applied loads, were considered for various soil parameters, factors of safety and types of foundations.

The collector foundations proposed for this solar thermal energy project have double concrete piers under each support point: two 12 in. piers, each 7 ft. deep and located 4 ft. apart are recommended. The estimated installed cost of foundations for 504 collectors requiring 2520 support point is $404,500. This amounts to approximately $1.64 per square ft. of collector area.

The solar collector array used in this study consists of 504 collectors. Each collector contains four 20 ft. 8 in. modules, has an aperature of 81 inches and weighs about 2250 lbs. The collector's center of rotation is located 53 inches above ground level.

Based on the results of the study of this array, recommendations are made. These are consistent with standard industrial practices while accounting for the special features of solar collectors.

II. FOUNDATION DESIGN CRITERIA

1. Types of Foundation

The following types of foundation are evaluated -

1. 16 in. diameter drilled single concrete pier (Figure C-1)

2. 12 in. diameter drilled double concrete piers connected by structural steel beams (Figure C-2)

3. Rectangular spread footing with 16 in. diameter pier (Figure C-3)

4. 18 in. wide x 14 in. deep grade beam with 16 in. diameter pier
   (a) Continuous grade beam running normal to solar collector with tie beams as required (Figure C-4).

   (b) Grade beam connecting only two solar collector modules with tie beams as required (Figure C-5).

In all types of foundations, 4000 psi concrete and ASTM A615 grade 600 rebars are assumed.

2. <u>Applied Loads</u>

Even though the Edison field is located in a very severe earthquake zone, (zone 4), seismic loading does not govern the design as the solar collectors are comparitively light. Rather wind loading governs the design.

According to ANSI A58.1 (C-1) the design wind speed at Bakersfield, California should be 60 m.p.h. This was used for evaluating the collectors when in their stowed position. Under operating conditions, a design wind speed of 50 m.p.h. was used. This is justified by the fact that the collectors are normally stowed if the wind speed exceeds 30 m.p.h.

The following three methods of computing wind loadings were considered:

A. <u>Full Wind for Uniform Building Code (C-2)</u>

The horizontal pressure of 15 lbs/sq. ft. given in the Uniform Building Code (2, Section 2311) was used without any modifications or shape factors. The upward wind pressure equals 1.25 times the horizontal pressure. The forces obtained are shown in Table C-1.

B. <u>Reduced Wind per Uniform Building Code for Miscellaneous Structures (C-2, Section 2311h)</u>

The horizontal pressure for the reduced wind loading equals 2/3 of 15 lbs/sq.ft and the uplift pressure equals 3/4 of the horizontal pressure. The corresponding loadings are given in Table C-1.

C. <u>Wind Loadings per Wind Tunnel Tests C-3</u>

Wind tunnel tests performed by Sandia Laboratories at Colorado State University (C-3)developed wind load coefficients for single-axis-tracking solar collectors. These coefficients were used to determine the wind loads on the collector foundations. The resulting loads for the drive and non-drive support points are shown in Table C-2.It should be noted that there is only one drive-support and four non-drive supports for each collector.

3. <u>Soil Parameters</u>

The soil at the Edison site is described as generally sandy with moderate to good bearing strength and is classified to be class 4, type SC (C-4) "SC" type soil is coarse grained and can be classified as granular soil (C-5) The specific soil parameter used in the analyses depends on the foundation type. For example, the internal fiction angle of soil, ϕ, is the relevant soil parameter for foundation types 1 and 2. Since the value of ϕ is not available for the Edison field site, values of ϕ ranging from 25 to 45 deg. were used in this study. This range of ϕ generally covers all granular soils from "very loose" to "very dense" (C-6, page 85)

The design of foundation types 3 and 4 require the following soil parameters. Values for these were obtained from the Uniform Building Code (C-2, Table 29-B]:

Allowable soil pressure	1500 lbs/sq.ft
Allowable lateral bearing	150 lbs/sq.ft/ft. of depth below grade.
Coefficient of friction	0.25

4. Factor of Safety

The choice of safety factor is a matter of engineering judgement which is based on the accuracy of information provided. With good quality information on design loadings and soil parameters, a safety factor of 1.5 to 2 is recommended.

For foundation types 1 and 2, results are tabulated with a factor of safety of 1.5. For foundation types 3 and 4, the following safety factors are used:

Overturning	≥ 1.8
Uplift	≥ 1.5
Sliding	≥ 1.5

5. Design Procedure

To compute the embedment length (Fig. C-6) of drilled pier for foundation types 1and 2, the "flag pole" formula (C-6, p. 421) was used:

$$D^4 - D^2\left(\frac{8Pu}{C}\right) - D\left(\frac{12Pu\ Y}{C}\right) - \left(\frac{2Pu}{C}\right)^2 = 0$$

where

D = embedment length of the pier (ft.)

Pu = lateral force (lbs)

$C = \gamma (K_p - K_a) d$

γ = soil density (100 lb/ft^3 assumed)

K_a = active earth-pressure coefficient $= \tan^2 (45° - \frac{\emptyset}{2})$

d = diameter of pier (ft)

y = eccentricity of P_u above grade (ft)

ϕ = angle of internal friction of soil.

The results are calculated with a factor of safety of 1.5 applied to the loading rather than to the soil properties or to the final results.

The uplift capacity of drilled piers, foundation types 1 and 2, is computed by the following relationship (C-7, p. 262).

$$S_f = 0.7 \, \gamma \, d \, D^2 \tan \phi$$

where

S_f = ultimate uplift resistance to soil friction (lbs).

In foundation types 1 and 2, the minimum length of drilled pier is restricted to 5 ft. for practical reasons. The maximum and minimum spacing between two drilled piers of foundation type 2 are assumed to be 5 ft. 6 in. and 3 ft. 6 in. respectively.

In the design of spread footings, foundation type 3, overturning governs the size of footing. A safety factor of 1.8 was used in the calculation.

For the design of grade beams, foundation type 4, the "beam on elastic foundation" approach was used. The value of the coefficient of subgrade reaction varies from 63 lb/in^3 for "loose" granular soil to 300 lb/in^3 for medium dense granular soil (C-7, p. 188). The grade beams are designed such that in this range of values for the coefficient of subgrade reactions, the foundation is adequate for all three sets of loadings.

III Results of the Foundation Design Study

The general layout of the solar collectors used in the design is shown in Figure C-7. The design of foundation types 1 to 4 are shown in Figures C-1 to C-5. The results for the type 1 foundation design scheme for a factor of 1.5 are shown in Table C-3. Similar results for foundation type 2 are presented in Table C-4. The results shown in Tables C-3 and C-4 are for values of the internal friction of soil, ϕ , ranging from 25 to 45 degrees. They show that as ϕ increases, indicating denser soil, the required foundation size decreased. Details of the foundation designs for the type 3 foundation are presented in Table C-5. No parametric studies were performed for grade beam foundation designs (types 4 (a) and (b).

A comparison of the quantites of concrete required for each support for various loading conditions and foundation types is presented in Table C-6.

IV COST ESTIMATES AND FOUNDATION CONCEPT EVALUATION

The results presented in Table C-6 indicate that the full wind loads determined according to the Uniform Building Code lead to a significantly more conservative foundation designs than do the alternative methods of determining wind loads. In contrast, the reduced wind loads obtained assuming the solar collectors to be in the Uniform Building Code's miscellaneous category give only slightly heavier foundations than do the wind loads derived from the wind tunnel data. Accordingly it is recommended that the reduced wind loads calculated assuming that collectors fall into the Uniform Building Code's miscellaneous category be adopted for foundation design. This method represents a more established methodology of determining wind loads; its use rather than the method that assumes full wind loads in justified in that the collectors are not hazardous to personnel.

Since the value of the internal friction of soil, ϕ, is not available for the Edison field site, a relatively conservative value of $\phi = 30$ degrees was selected. Thus for the reduced wind loadings from the Uniform Building Code and $\phi = 30$ degrees, the estimated installed cost of the various foundation types is presented in Table C-7.

The double-pier foundation scheme is found to be the most cost-effective. It is also intrinsically a more stable design than the single-pier concept. Therefore, the double-pier design shown in Figure C-2
In this design, each of the two piers are 12 inches in diameter, 7 ft. deep and are located 4 ft. apart from the other. The total installed cost of 2510 foundations (504 collectors) of this design would be $404,500 or approximately $1.64 per square foot of collector area. This estimate has an accuracy of $\pm$ 20 percent.

The recommendation that a double-pier type foundation be adopted is expected to hold for wider aperture collectors.

It is recommended that the internal friction of soil (ϕ) be determined by soil tests at the Edison site. If ϕ is found to be larger than 30 degrees, the foundation design can be modified and the total cost reduced.

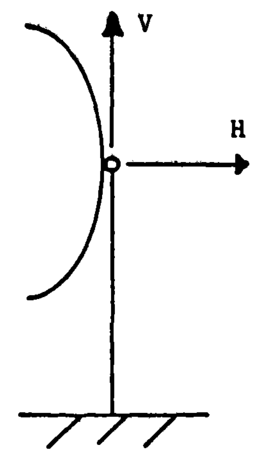


Table C-1 Wind Loads Per U. B. C.

LOADING	V (lbs)	H (lbs)
LOADING TYPE A	2610	2090
LOADING TYPE B	1040	1390

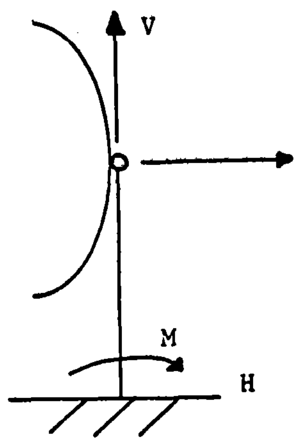


Table C-2 Wind Loads Using Wind Tunnel Data

LOADING	OPERATION			STOW		
	V (lbs)	H (lbs)	M (ft. lbs.)	V (lbs)	H (lbs)	M (ft. lbs.)
DRIVE - SUPPORT	1083	1026	6070	660	250	-6400
NON - DRIVE SUPPORT	1083	1026	4530	660	250	1100

Table C-3 FOUNDATION TYPE 1

LOADING TYPE	LOADING CONDITIONS	ϕ =25° "L"	Anch. Bolts	ϕ =30° "L"	Anchor Bolts	ϕ =36° "L"	Anchor Bolts	ϕ =40° "L"	Anchor Bolts	ϕ =45° "L"	Anchor Bolts
A	FULL WIND PER U.B.C.	13" - 0"	4-1 1/8"ϕ	11' - 10"	4-1 1/8"	1C'-6"	4-1 1/8" ϕ	9'-9"	4-1 1/8"	9'-0"	4-1 1/8"ϕ
B	REDUCED WIND PER U.B.C.	11'-2"	4-1"ϕ	10'-2"	4-1"	9-0"	4-1"ϕ	8-6	4-1"ϕ	7'-8"	4-1"ϕ
C	DRIVE SUPPORT	10' - 6"	4-1" ϕ	9'-6"	4-1" ϕ	8'-6"	4-1" ϕ	8'-0"	4-1 ϕ	7'-3"	4-1" ϕ
	NON-DRIVE SUPPORT	10' - 0"	4-7/8" ϕ	9'-0"	4-7/8" ϕ	8"-1"	4-7/8" ϕ	7'-6"	4-7/8 ϕ	7"-0"	4-7/8" ϕ

Table C-4 FOUNDATION TYPE 2

LOADING TYPE	LOADING CONDITIONS	φ = 25°			φ = 30°			φ = 36°			φ = 40°			φ=4[illegible]°		
		L	B	Anchor Bolts	L	B	Anchor Bolts	L	B	Anchor Bolts	L	B	Anchor Bolts	L	B	Anchor Bolts
A	FULL WIND PER U.B.C.	9'-3"	4'-6"	2-1" φ	8'-3"	4'-6"	2-1" φ	7'-3"	5'-0"	2-1" φ	6'-9"	5'-0"	2-1" φ	6'-0"	5'-6"	2-1" φ
B	REDUCED WIND PER U.B.C.	7'9"	4'-0"	2-3/4"φ	7'-0"	4'-0"	2-3/4"φ	6'-3"	4'-0"	2-3/4φ	5'-9"	4'-6"	2-3/4φ	5'-3"	4'-6"	2-3/4"φ
C	DRIVE SUPPORT	7' -4"	5'-6"	2-3/4" φ	6'-10"	5'-6"	2-3/4" φ	6'-3"	5" - 6"	2-3/4"φ	6'-0"	5'-6"	2-3/4" φ	5'-8"	5'-6"	2-3/4" φ
	NON-DRIVE SUPPORT	6'-10"	5'-0"	2-3/4" φ	6'-2"	5'-6"	2-3/4" φ	5' -8"	5'-6"	2-3/4"φ	5'-4"	5'-6"	2-3/4" φ	5'-0"	5'-6"	2-3/4" φ

Table C-5 Design of Foundation Type 3 for Various Loading Conditions

LOADING TYPE	LOADING CONDITIONS	L	B	Anch. Bolts	"X"	"Y"
A	FULL WIND PER U.B.C. (1979)	7'-0"	3'-6"	4-1 1/8" Φ	8-#4	5-#4
B	REDUCED WIND PER U.B.C. (1979)	6'-4"	3'-2"	4-1"φ	7-#4	5-#4
C	DRIVE SUPPORT	6'-4"	3'-2"	4-1"φ	7-#4	5-#4
	NON-DRIVE SUPPORT	6'-0"	3'-0"	4-7/8"	6-#4	4-#4

Table C-6

Concrete Volume Per Solar Collector Support (Ft.^{3})

FDN. TYPE / LOADING CONDITION	ONE PIER* (TYPE 1)					TWO PIER* (TYPE 2)					RECT. FTG. (TYPE 3)	GRADE BM (TYPE 4)	
	ϕ=25°	ϕ=30°	ϕ=36°	ϕ=40°	ϕ=45°	ϕ=25°	ϕ=30°	ϕ=36°	ϕ=40°	ϕ=45°		(a)	(b)
FULL WIND PER U.B.C. (1979) (TYPE A)	18.1	16.4	14.6	13.5	12.5	14.5	13.0	11.4	10.6	9.4	30.9	35.6	25.3
REDUCED WIND PER U.B.C (1979) (TYPE B)	15.5	14.1	12.5	11.8	10.7	12.2	11.0	9.8	9.0	8.2	25.7	35.6	25.3
DRIVE SUPPORT (TYPE C)	14.6	13.2	11.8	11.1	10.1	11.5	10.7	9.8	9.4	8.9	25.7	35.6	25.3
NON - DRIVE SUPPORT (TYPE C)	13.9	12.5	11.2	10.4	9.7	10.7	9.7	8.9	8.4	7.9	23.3	35.6	25.3

* For Factor of Safety = 1.5

Table C-7 COST ESTIMATES FOR VARIOUS FOUNDATION COSTS

Foundation type	Installed cost per cubic yard of concrete* ($)	Cost of foundation per square ft. of collector area ($)	Total installed cost for 504 collectors ($)
1. Single pier	394	2.11	518,500
2. Double pier	394	1.64	404,500
3. Spread Footing	355	3.46	851,650
4. a. Continuous grade beam	348	4.70	1,156,400
b. Grade beam connecting two modules	348	3.34	821,740

*Assuming 2520 foundations installed

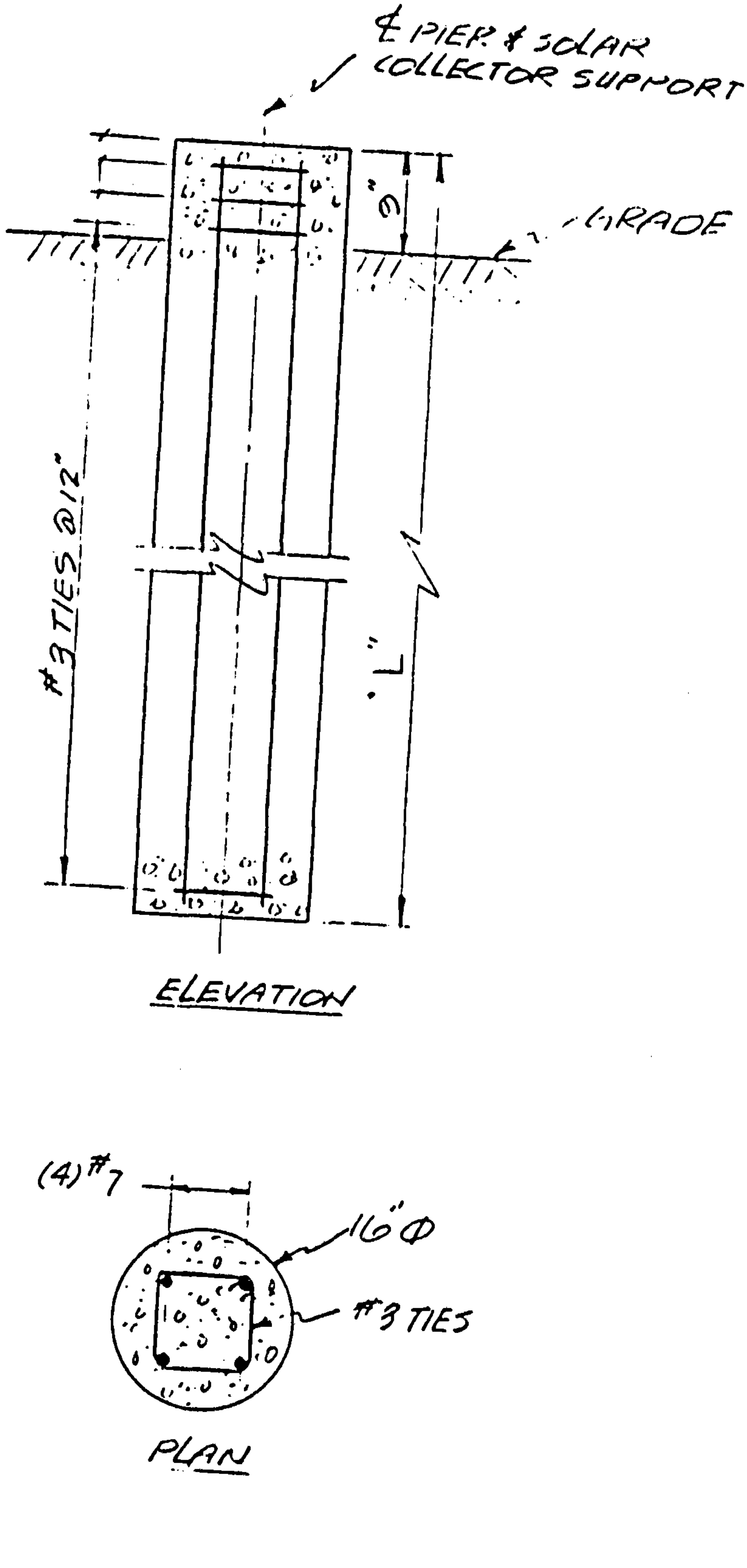


Figure C-1

Single Pier Foundation Design (Type 1)

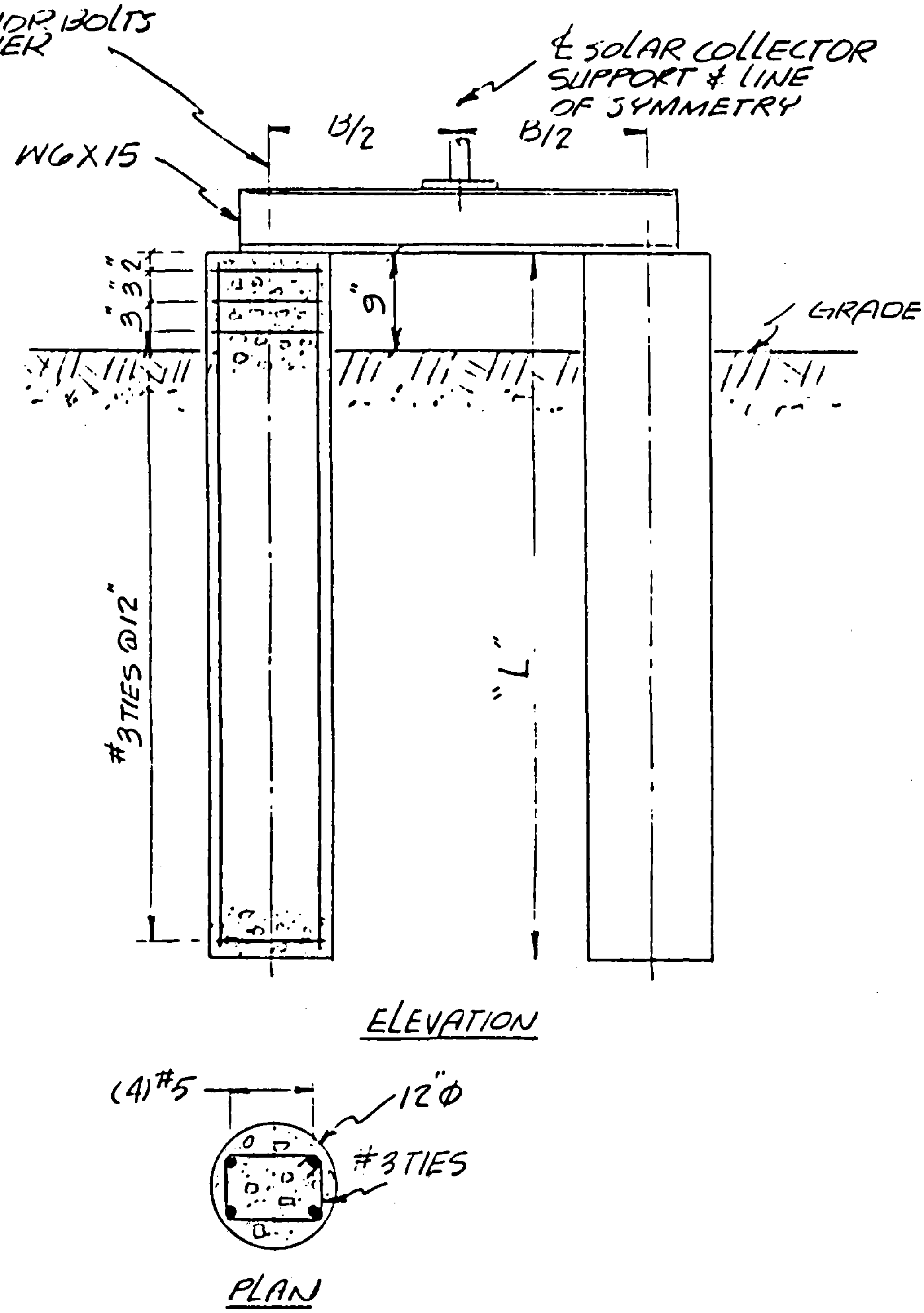


Figure C-2

Double Pier Foundation Design (Type 2)

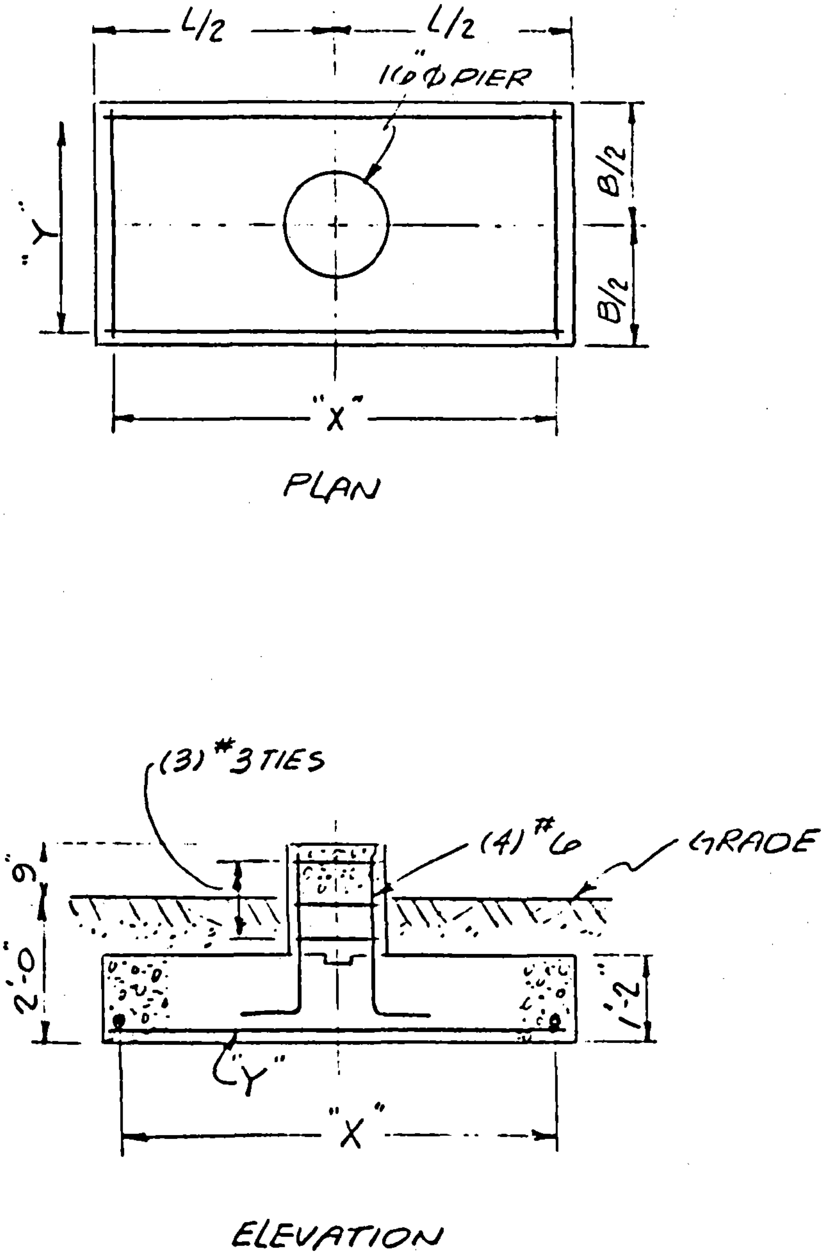


Figure C-3

Spread Footing Foundation Design (Type 3)

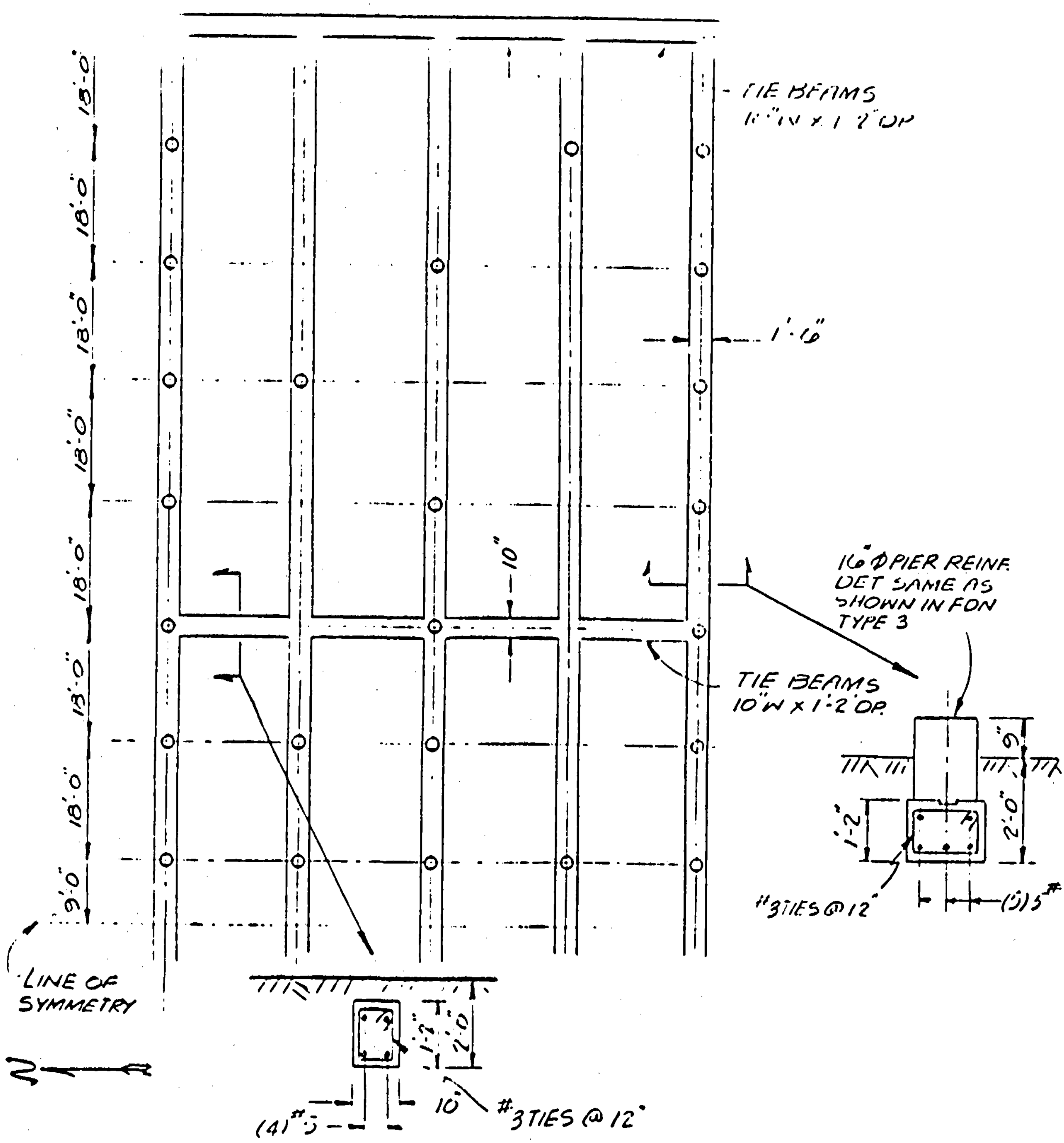


Figure C-4
Continuous Grade Beam Design (Type 4 (a))

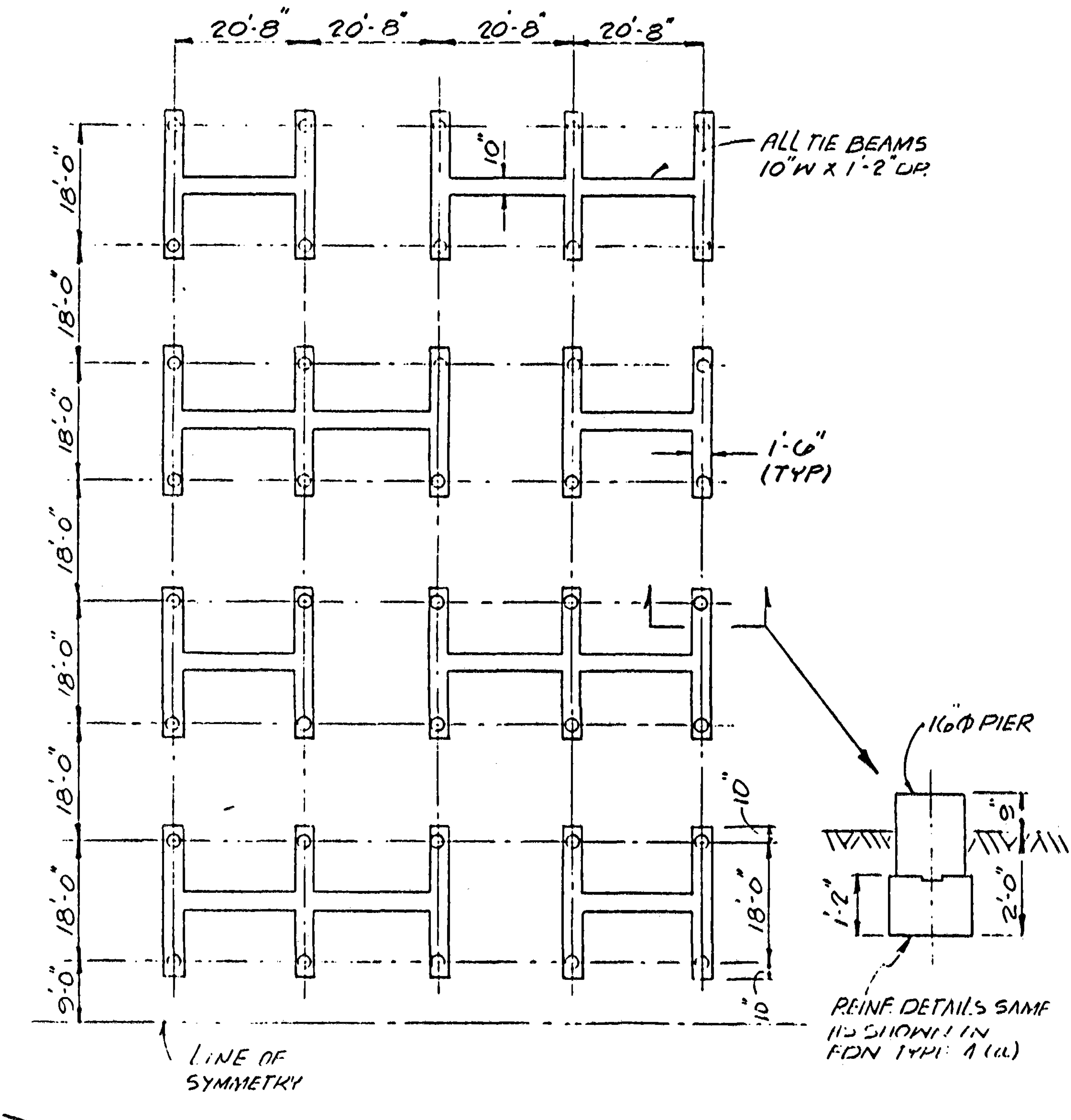


Figure C-5

Design of Grade Beams Connecting Two Modules(Type 4 (b))

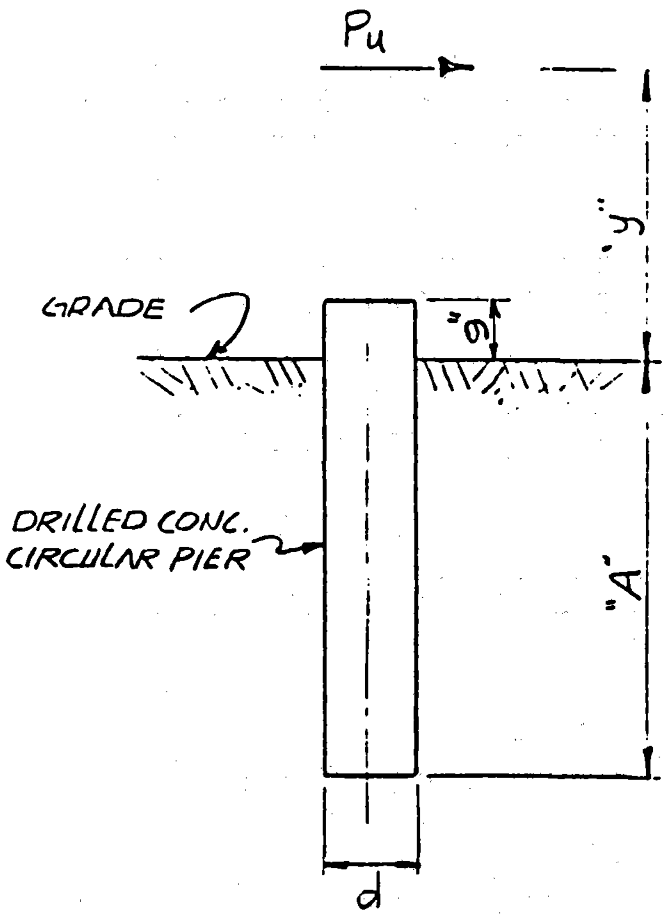


Figure C-6

Drilled Pier - Foundation Types 1 and 2

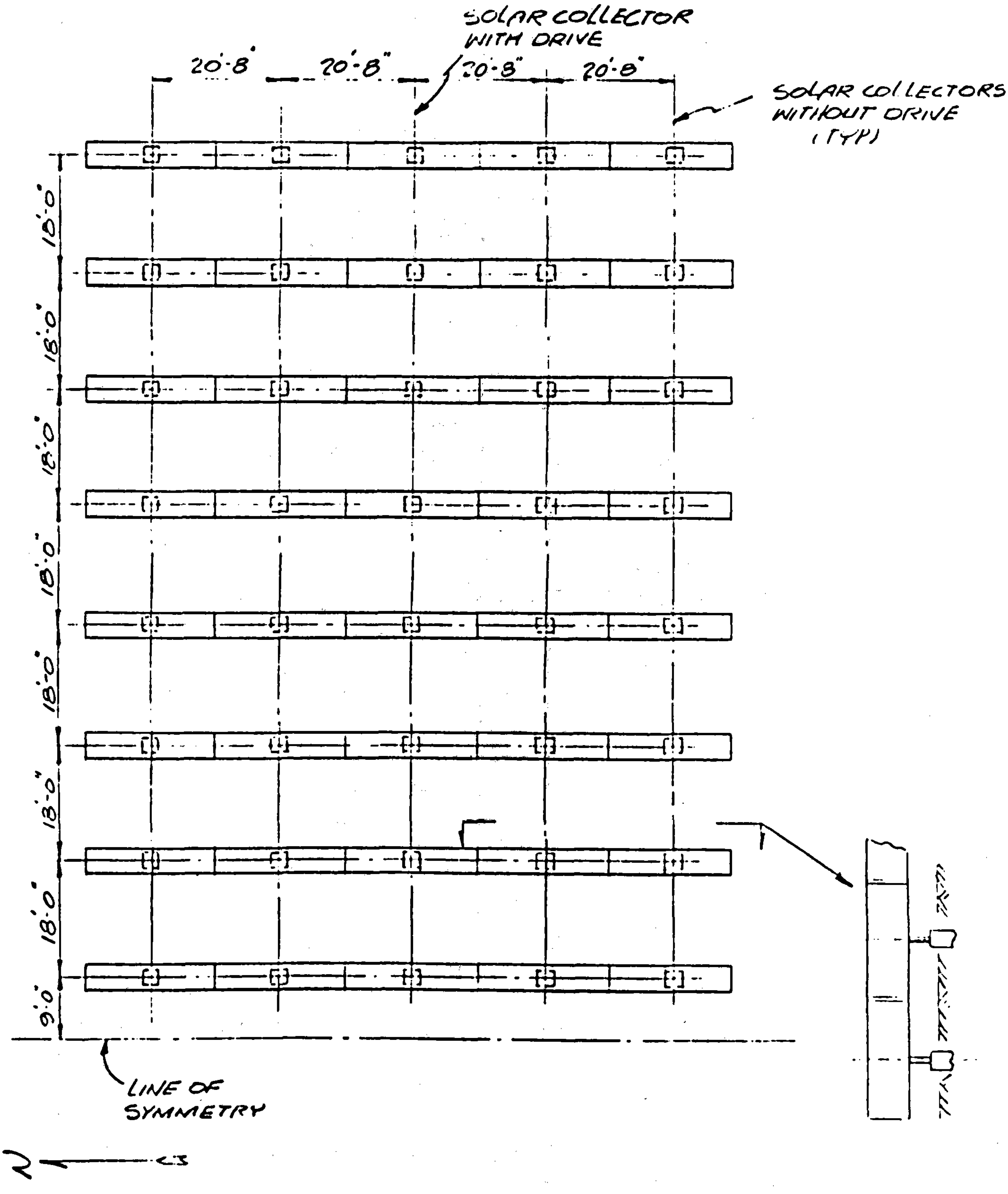


Figure C-7

General Layout

APPENDIX D

FATIGUE TESTING OF FLEXIBLE HOSES

CONVERSIONS FOR APPENDIX D

61 cm	24"
3.25 M	128"
3.81 M	150"
6887 KPa	1000 psi
$282^{o}C$	$540^{o}F$
$427^{o}C$	$800^{o}F$

APPENDIX D

Fatigue Testing of Flexible Hoses

OBJECTIVE:

To determine the fatigue life of flexible metal hoses subjected to thermal and mechanical load cycles representative of those experienced in service with parabolic trough collectors.

BACKGROUND:

An uncertainty in the design of the solar steam generation portion of the Solar Thermal Enhanced Oil Recovery project is the fatigue life of the flexible metal hoses that connect inlet and outlet pipes to the solar receiver pipe. These metal hoses are made of thin steel plates formed into bellows. One or two stainless steel braids are wrapped around these bellows to form the flexible hose. The hoses are subjected to hoop streses (due to pressure) and bending stresses. Because of the diurnal startup and shutdown, hoop and bending stresses are cyclic in nature; at least one cycle is induced every day. Determining the fatigue life of these hoses by stress analysis and the use of fatigue curves is not considered practical because of the complexity of the analysis and consequent uncertainty about its accuracy. Hence, testing to determine the fatigue life of the hose is necessary.

The following is a description of a test plan that we recommend.

FLEXIBLE HOSE ARRANGEMENT:

Two types of flexible hose connections are considered in this test plan. The first type is shown in Figures D-1 and D-2. This arrangement utilizes a 24" diameter drum. One end of the flexible hose is connected to the distribution piping through an elbow. The other end is connected to the receiver pipe, also through an elbow such that the flexible hose is always in a plane perpendicular to the receiver. This arrangement avoids any significant torsion in the flexible hose.* It is expected that any tendency to squirm under pressure will be prevented by the drum. One disadvantage of this arrangement is that the drum will partially shade the collector. Another is that the length of the hose is increased considerably; a hose length of 128" is required for uninsulated hose and 150" for insulated hose.

* The thermal expansion of the receiver tube will cause some torsion in the hose, but this will be negligibly small.

The second type of connection considered is shown in Figure D-3. In this arrangement the drum is eliminated and consequently the length of the hose is reduced by about 50%. However, there is concern that the hose may squirm under pressure, which may lead to premature failure.

TEST DESCRIPTION:

The test fixture is shown in Fig. D-4. This fixture will accomodate two short hoses (without drum) and two long hoses (with drum). One end of each hose will be fixed and the other end will be rotated through an angle of 270°. The rotation will be accomplished by using a 270° actuator (Ohio oscillator). The test will be accelerated : rotation will occur at 1 cycle per minute. As the design life of the flexible hose is 15,000 cycles, with a factor of safety of 4, a satisfactory test life will be 60,000 cycles. At the rate of 1 cycle per minute, a 60,000 cycle-test can be completed in 42 days.

The test will be conducted at room temperature. A pressure of 1000 psi will be applied to each tube using water at room temperature. Tests at the operating temperature of 540°F would be inordinately expensive. Moreover, at 540°F, temperature effects on fatigue would not be significant in flexible hoses made of stainless steel.*

The hoses will be tested until 60,000 cycles have been completed or until a full penetration crack occurs. When such a crack occurs, a pressure drop will actuate a pressure switch shutting down the system for hose removal. All hoses which survive 60,000 cycles will be tested with a dye penetrant. Questionable areas will be cut out and checked for cracks in the metallurgical laboratory; hardness, grain structure and corrosion will be examined.

COST ESTIMATE

The following is an estimated cost of the recommended test.

	Man-Hours	Estimated Cost ($)
Engineering and Drafting	280	11,300
Technician	500	11,200
Test Fixture		2,000
Instrumentation		500
4 Hoses		2,000
TOTAL COST		27,000

In a detailed proposal contingencies and fees would be added to this estimate.

For every additional 4 hoses tested, the cost would be $10,000.

*It may be noted that the ASME Boiler and Pressure Vessel Code, Section VIII, Div. 2 recommends the same fatigue curves for high alloy steels for all temperatures up to 800°F

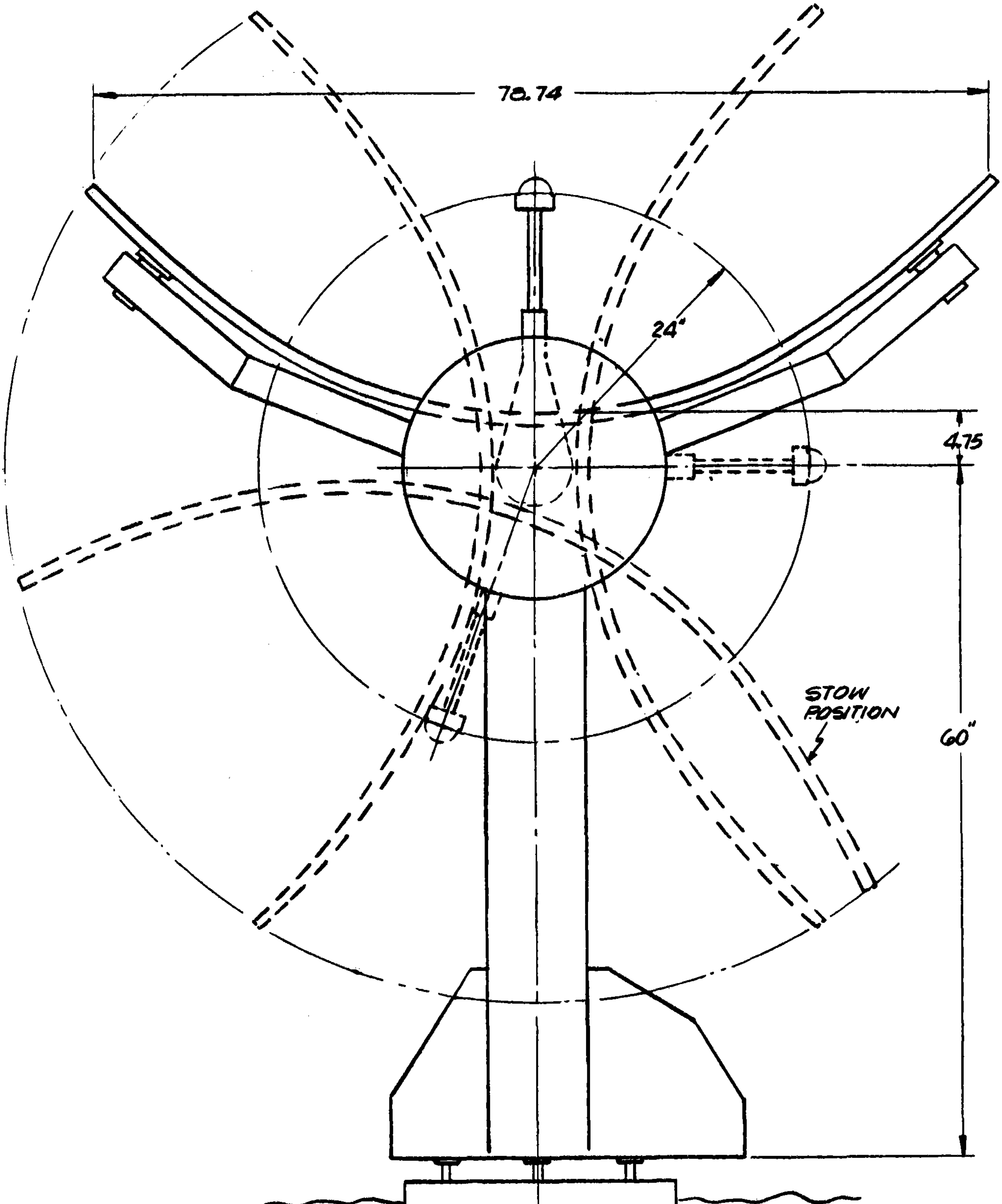


FIGURE D-1 PARABOLIC TROUGH COLLECTOR WITH DRUM

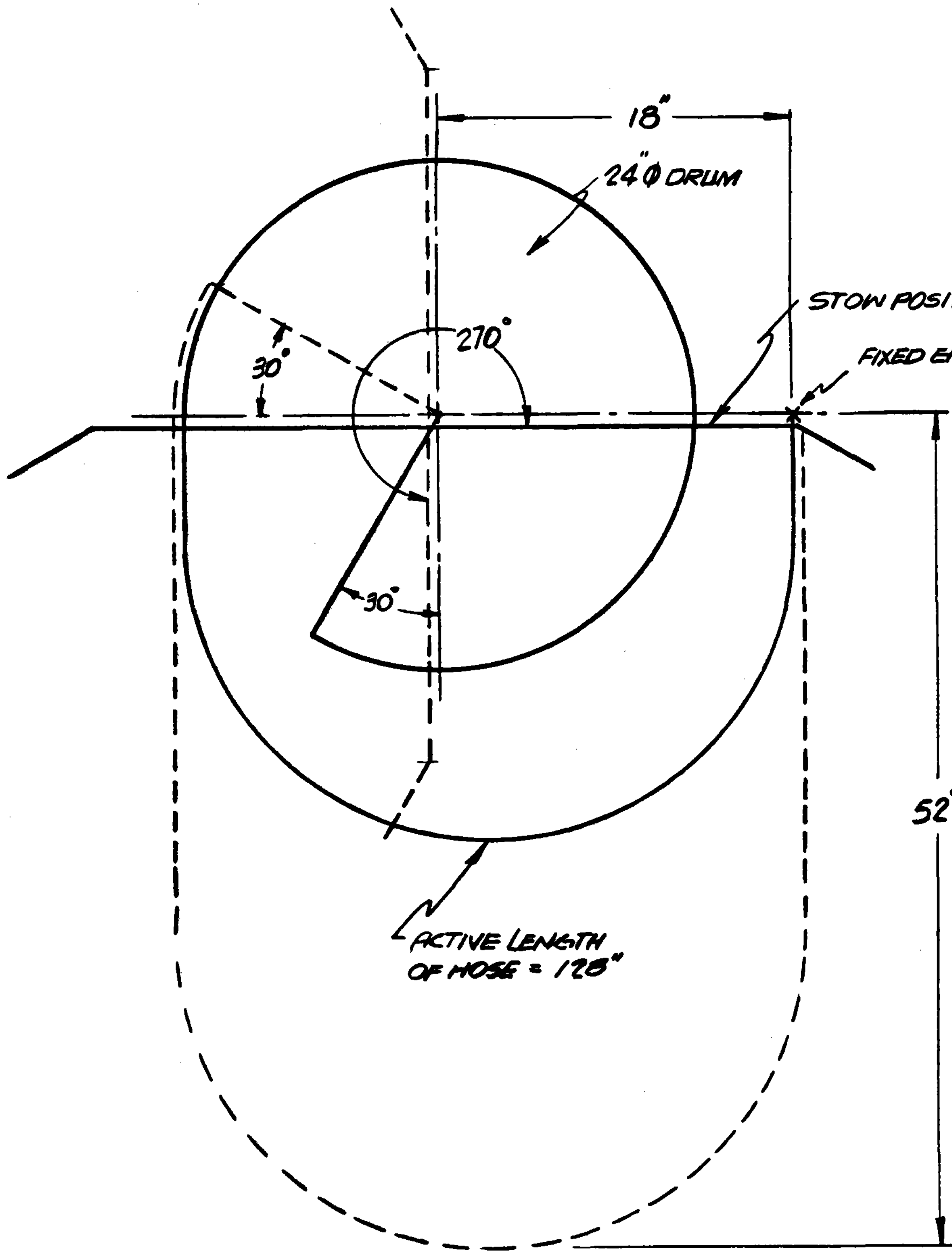
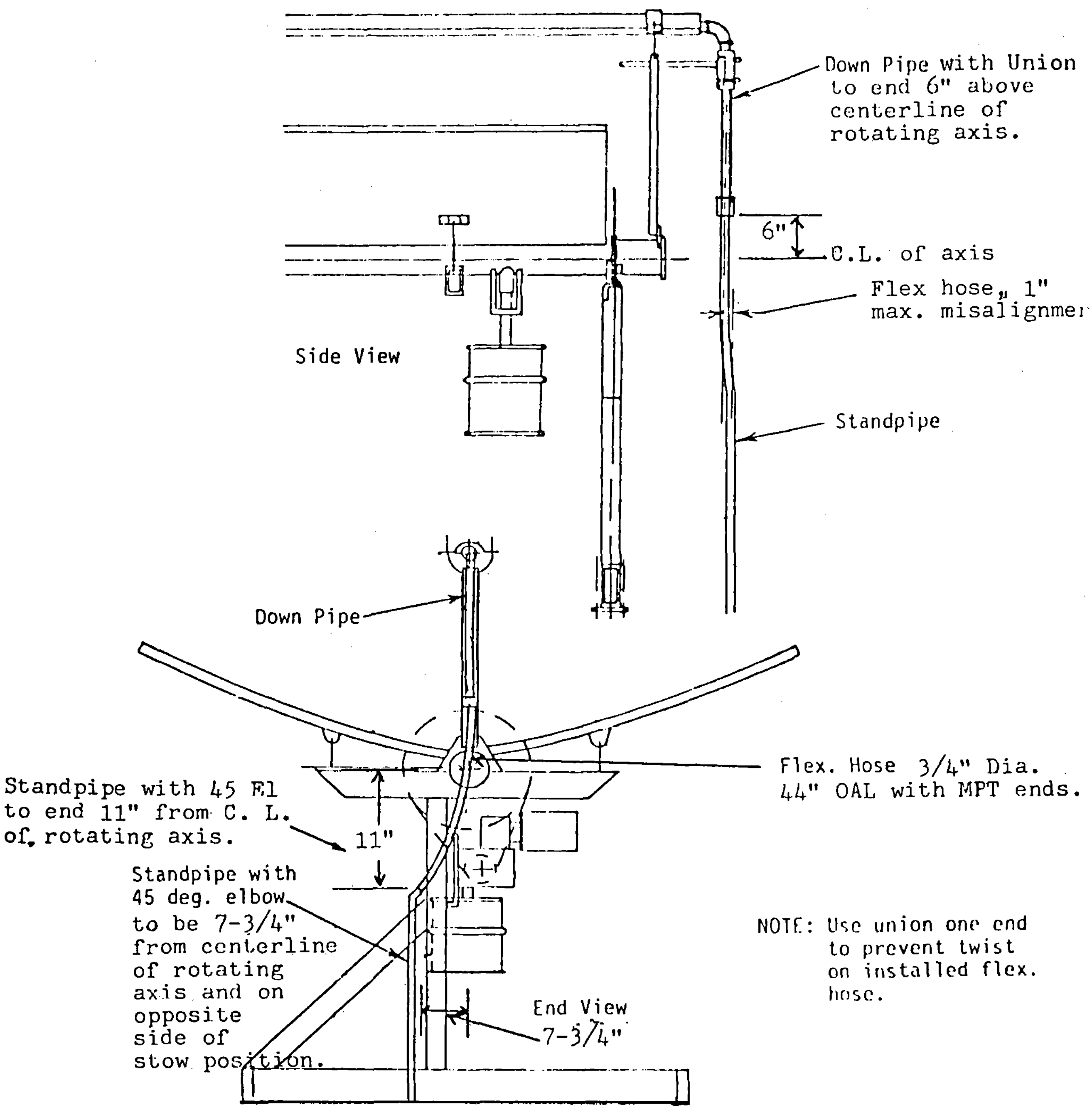


FIGURE D-2 SCHEMATIC OF HOSE MOVEMENT WITH A DRUM

FIGURE D-3 HOSE ARRANGEMENT WITHOUT DRUM

(Suntec Collector, dimensions shown appropriate for 3/4" diameter hose only)



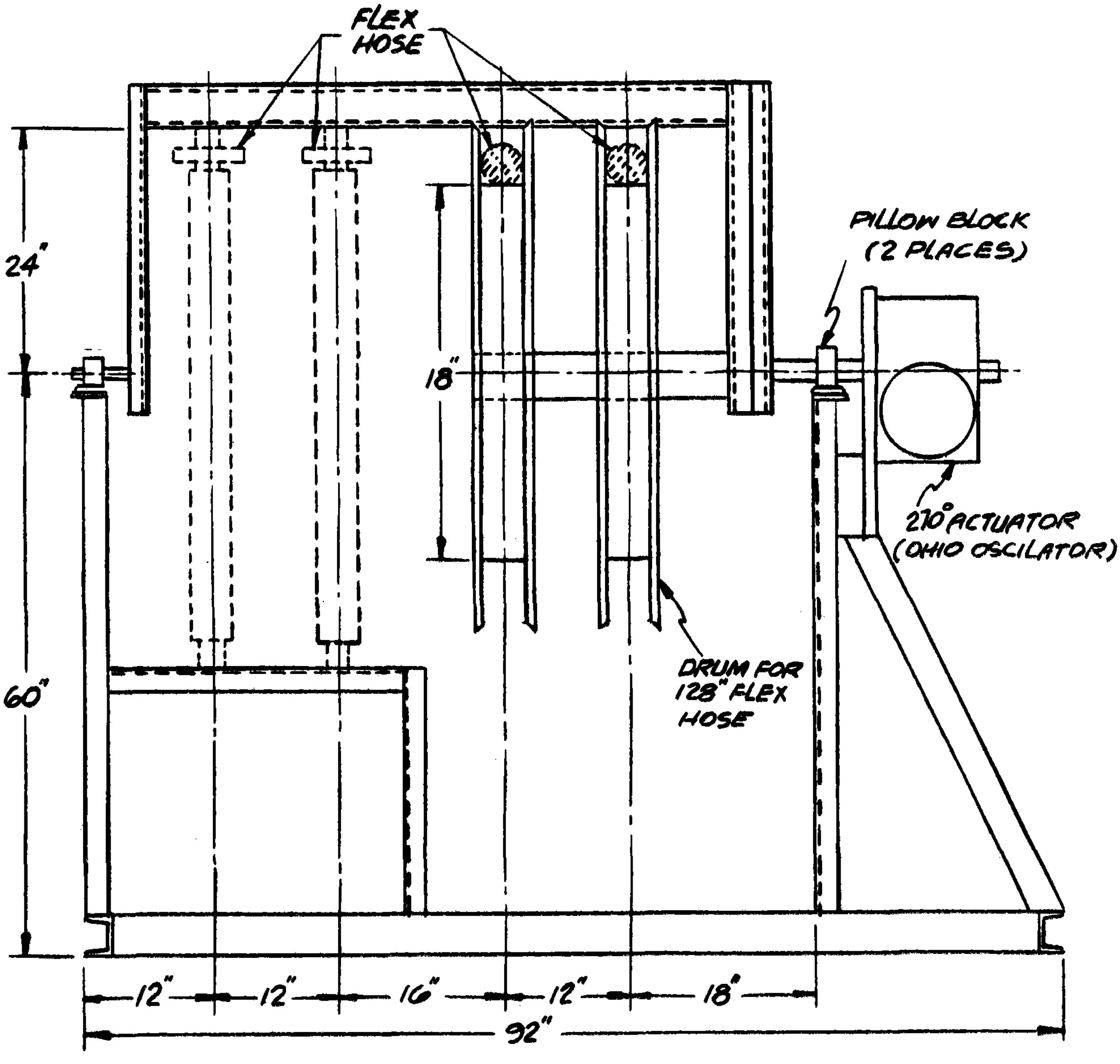


FIGURE D-4 FLEXIBLE METAL HOSE TEST FIXTURE

APPENDIX E

DESIGN BASIS

CONVERSIONS FOR APPENDIX E

Section A1

21°C	70°F
121°C	250°F
33,522 Kg/hr	73,905 lb/hr
121°C	250°F
12,710 Kg/hr	28,000 lb/hr
5957 KPa	865 psia
275°C	527.3°F

Section A2

21°C	70°F
344 KPa	50 psig
305 M	1000 ft

Section A3

121°C	250°F
137.7 KPa	20 psig
275°C	527.3°F
5957 KPa	865 psia

Section A4

14,070,000 KJ/hr	13,336,000 BTU/hr
45.3 M^2	487.41 ft^2
6520 M^2	70,187 ft^2
200 KJ/hr	190 BTU/hr

Section A4 (Continued)

28,870,000 KJ/hr	27,363,000 BTU/hr
45.3 M^2	487.41 ft^2
16,300 M^2	175,468 ft^2
165 KJ/hr	156 BTU/hr
385,100 Kg	849,000 lbs
146,050 Kg	322,000
156,500 Kg	345,000
82,960 Kg	182,900
121,560 Kg	268,000
204,520 Kg	450,900
27,220 Kg	60,000
177,300 Kg	390,900

Section A5

21^{o}C	70^{o}F
344 KPa	50 psig
63,500 Kg/hr	140,000 lb/hr
275^{o}C	527.3^{o}F
5854 KPa	850 psig
12,700 Kg/hr	28,000 lb/hr
121^{o}C	250^{o}F
137.7 KPa	20 psig
13,608 Kg/hr	30,000 lb/hr

APPENDIX E

DESIGN BASIS

A. BASIS OF DESIGN

A1 Capacity

a. Preheat Field

At peak insolation the solar collector preheat (SCP) field is designed to preheat water as follows:

Water temperature in	70°F
Water temperature out	250°F
Water flow rate	73,905 LB/HR

b. Boiler Field

At peak insolation, the solar collector boiler (SCB) field is designed to generate steam as follows:

Feed water temperature in	250°F
Steam generated:	
Flow rate	28,000 LB/HR
Pressure	865 psia
Temperature, saturated	527.3°F

A. BASIS OF DESIGN

A2 Feed condition and Composition

Feedwater

Temperature	70°F
Pressure (assumed)	50 psig

Composition

Dissolved O_2 content	less than .005 cc/litre
pH value	9.0
Total hardness as $CaCO_3$	less than 0.5 ppm
Sodium	210 ppm
Calcium	less than 0.5 ppm
Magnesium	less than 0.5 ppm

Water supply for steam generation is drawn from an onsite well with a depth of 1000 feet. The water is treated in portable units containing ion exchange beds and then the dissolved oxygen content is reduced by the direct injection of hydrazine solution.

A. BASIS OF DESIGN

A3 Product Condition and Composition

a. Preheated water

Temperature	250°F
Pressure (at grade)	20 PSIG
Composition (estimated)	
Total hardness as $CaCO_3$	less than .76 ppm
Sodium	321 ppm
Calcium	less than .76 ppm
Magnesium	less than .76 ppm

b. Steam

Temperature (saturated)	527.3°F
Pressure	865 psia

A. BASIS OF DESIGN

A4 Design Basis

a. Solar Collector Preheat Field

Gross Heat Input	13,336,000 BTU/hr
Number of collectors	144
Area of each collector	487.41 SQ. FT.
Total collector area	70,187 SQ. FT.
Peak insolation rate (June 21)	190 BTU/HR (SF)

b. Solar Collector Boiler Field

Gross Heat Input	27,363,000 BTU/hr
Number of collectors	360
Area of each collector	487.41 SQ. FT.
Total collector area	175,468 SQ. FT.
Peak insolation rate (June 21)	156 BTU/HR (SF)

c. Boiler Feed Water Storage

Capacity of the tanks will be based on net storage requirements for one 11½-hour solar day as follows:

			Pounds
SCP in flow	73,905 x 11.5h	=	849,000
less			
Flow to SCB	28,000 x 11.5h	=	322,000
Flow to SW Thermoflood	30,000 x 11.5h	=	345,000
Sub total			182,900
plus "heat recovery" inflow of			
SCP and SCB	134,000 x 2h		268,000
Sub total			450,900
less flow to Thermoflood	30,000 x 2h		60,000
	Total		390,900

A. BASIS OF DESIGN

A5 Battery Limit Conditions

The design battery limit conditions for feed and products are as follows:

	Temp. (°F)	Pressure (PSIG)	Flowrate (LB/HR)
FEED			
Boiler feedwater from OSBL	70	50	140,000 (max)
PRODUCT			
Steam from SCB field system to OBSL	527.3	850	28,000
Preheated water from TK-101 A/B to OBSL	250	20 (at grade)	30,000

A. BASIS OF DESIGN

A6 Summary of Estimated Utility Requirements

Presented below are the estimated utility requirements for the solar thermal enhanced oil recovery (STEOR) Plant.

Item No.	Service	Connected Load, KW	Simultaneous Peak Peak, KWH/HR
SCP 101/244 SCB 401/760	Trickle Charger for SCP 101/244 and SCB 401/760	69.1	69.1
P-101	Preheat Feedwater Pump	4.9	4.9
P-102	Solar Feedwater Pump	52.7	52.7
P-103	Solar Circulation Pump	348.0	348.0
P-104	Freeze Protection Pump	.06	0
P-105	SCB Preheat Circulation Pump	13.3	13.3
PG-102	Instrument Air Package	3.1	3.1

A. BASIS OF DESIGN

A7 Operating Philosophy

A system of controls and interlocks is afforded in the design for completely untended operation of the solar boiler feedwater preheat and steam generation unit. The control loops are simple and direct but the logic is sufficiently complete to provide for no operator intervention when all equipment systems are functioning properly.

The primary function of the operator personnel is related to optimization of performance and to identify items of equipment that require maintenance and cleaning. To facilitate these activities a central control house is provided to permit operator personnel to monitor the unit in its operating modes.

In addition, the set points of key operating variables may be adjusted within limits to maximize recovery of solar energy during changes of seasons and to meet weather patterns.

PROCESS EQUIPMENT SPECIFICATIONS

FORM NO. 135-904

FOSTER WHEELER ENERGY CORP.
PROCESS PLANTS DIVISION

CONTRACT: 11-60035
SECTION:

EQUIPMENT LIST

NAME OF UNIT: Solar Thermal Enhanced Oil Rec.

PAGE 1 OF 1

CLIENT: EXXON/DEPARTMENT OF ENERGY
LOCATION: BAKERSFIELD, CALIFORNIA

REVISION	ORIGINAL	1	2	3	4	5
DATE	2/26/80	3/28/80				

CLASS	ITEM NO.	DESCRIPTION	EFD	REQ'N. NO	P. O. NO.		REV.
SOLAR COLLECTORS	SCP-101 Thru 244	Preheat Solar Collector Modules					
	SCB-401 Thru 760	Boiler Solar Collector Modules					
TANKS	TK-101A	Boiler Feedwater Storage Tanks					
	TK-101B						
DRUMS	D-101	Flash Separator Drum					
PUMPS	P-101	Preheat Feedwater Pump					
	P-102	Solar Feedwater Pump					
	P-103	Circulation Pump					
	P-104	Freeze Protection Circulator					
	P-105	SCB Preheat Circulation Pump					
MISCELL-ANEOUS	M-101	Line Mixer					
PACKAGE	PG-102	Instrument Air Supply Package System					

B. PROCESS EQUIPMENT SPECIFICATIONS

B2 Vessels

a. Drums

Process Specifications for the following drum is included in this section:

D-101	Flash Separator

b. Tanks

TK-101A/B	Boiler Feedwater Tanks

B. PROCESS EQUIPMENT SPECIFICATIONS

B3 Solar Collectors

Process Specifications for the solar collectors for preheat and boiler fields are included in this section:

SCP-101 Through 244	Preheat Solar Collector Modules
SCB-401 through 760	Boiler Solar Collector Modules

MATERIAL REQUISITION

FOSTER WHEELER

FOR EXXON/DOE F.W. REF. 11-600[illegible]	REQUISITION NUMBER		DATE
SITE BAKERSFIELD, CALIFORNIA			3/[illegible]/80
MATERIAL	SUPERSEDED BY CHANGE NO.:		
SERVICE OF UNIT: BOILER SOLAR COLLECTOR MODULE	C1 3/28/80	C4	
ITEM NO. SCB-401 THRU SCB-760	C2	C5	
	C3	C6	

FORM 135-20A

NO. REQUIRED: 360 MODULES

SIZE: MODULE LENGTH 80 FT.

SQ.FT. SURFACE/MODULE: 487.41 SQ.FT

PERFORMANCE OF ONE UNIT

FLUID CIRCULATED: WATER

TOTAL FLUID ENTERING 3,170 LBS/HR

GRAVITY IN/OUT .767/.747

VISCOSITY IN/OUT (CP) .1/.1

TEMP. IN/OUT (°F) 520/540

OPERATING PRESS. 1020 PSIG

PRESSURE DROP (CALCULATED) .5 PSIG (2)

SOLAR ENERGY ABSORBED: 76035 BTU/HR (1)

CONSTRUCTION OF ONE MODULE

RECEIVER IS 1¼" IPS SCH. 80 STEEL PIPE

△1 EACH COLLECTOR IS DRIVEN BY ⅓ h.p D.C Motor

REMARKS: (1) CORRESPONDS TO PEAK INSOLATION OF 156 BTU/HR.SF

(2) ONLY FOR RECEIVER PIPE

BY: FTS	P.O.NO.	SUPPLIER: [illegible]

MATERIAL REQUISITION

FOSTER WHEELER

FORM 135-20A

FOR EXXON/DOE F.W.REF. 11-60035	REQUISITION NUMBER		DATE	
SITE BAKERSFIELD, CALIFORNIA			3/6/1990	
MATERIAL	SUPERSEDED BY CHANGE NO.:			
SERVICE OF UNIT: PREHEAT SOLAR COLLECTOR MODULE	C1	3/28/80	C4	
ITEM NO. SCP-101 THRU SCP-244	C2		C5	
	C3		C6	

NO. REQUIRED: 144 MODULES.

SIZE: MODULE LENGTH 80 FT.

SQ.FT. SURFACE/MODULE: 487.41 SQ.FT.

PERFORMANCE OF ONE UNIT

FLUID CIRCULATED: WATER

TOTAL FLUID ENTERING: 515. LB/HR

GRAVITY IN/OUT 1./.944

VISCOSITY IN/OUT (CP) 1./.24

TEMP. IN/OUT (°F) 70/250

OPERATING PRESS. 90 PSIG

PRESSURE DROP (CALCULATED) .9 PSI (2)

SOLAR ENERGY ABSORBED: 92610 BTU/HR (1)

CONSTRUCTION OF ONE MODULE

RECEIVER IS 1¼" IPS SCH. 40 STEEL PIPE

△1 EACH COLLECTOR IS DRIVEN BY ⅓ h.p size D.C motor.

REMARKS: (1) CORRESPONDS TO PEAK INSOLATION OF 190 BTU/HR.SF.

(2) ONLY FOR RECEIVER PIPE.

BY: FTS	P.O.NO.	SUPPLIER: SANDIA EPT

B. PROCESS EQUIPMENT SPECIFICATIONS

B4 Pumps

Process Specifications for the following pumps have been included in this section:

Item No.	Service
P-101	Preheat Feedwater Pump
P-102	Solar Feedwater Pump
P-103	Solar Circulation Pump
P-104	Freeze Protection Circulation Pump
P-105	SCB Preheat Circulation Pump

FORM 110 29

FOSTER WHEELER ENERGY CORPORATION — FW — PUMP PROCESS DATA

CUSTOMER EXXON DOE — JOB NO. 11-60035
LOCATION BAKERFIELD, CA — SHEET 1 OF 1
ITEM NO. P-101
SERVICE PREHEAT FEEDWATER PUMP
SPARE ALSO COMMON TO ITEM

REV.	0	1	2	3
DATE	1/2/80	2/26/80		
MADE BY	KAB	KAB		

PUMP TYPE: ☒ CENTRIF. ☐ RECIP. POWER ☐ RECIP. STEAM ☐ ROTARY ☐ METERING ☐

NUMBER OF PUMPS REQUIRED: ONE — OPERATING ONE — SPARE

TYPE OF DRIVER: MOTOR — OPERATING — SPARE

DUTY: ☐ CONTIN. ☒ INTERMITT. ? APPROX. 3000 HRS/YR.

PROCESS REQUIREMENTS PER PUMP

OPERATING CASE		DESIGN			MINIMUM FLOW CASE	MAXIMUM SP. GR. CASE
LIQUID		BOILER FEEDWATER			TO BE DETERMINED	
PUMPING TEMP.: NORMAL	°F	70				
EXPECTED MAX.	°F					
SP.GR. @ P.T.: RATED (MIN.)		1.0				1.0
EXPECTED MIN.						
VAPOR PRESS. @ P.T.	PSIA	.3628				
VISCOSITY @ P.T.	CKS	.875				
C1 CAPACITY @ P.T.: REQUIRED U.S.	GPM	160				
NORM. U.S.	GPM	147.8				
C1 DISCH. PRESS.: REQUIRED	PSIG	89.1				
SUCT. PRESS.: REQUIRED	PSIG	50				
(MAX. POSSIBLE)	PSIG	( )	( )	( )	( )	( )
DIFFERENTIAL PRESS.	PSI	62.4				62.4
DIFF. HEAD (CENTRIF. PUMPS ONLY)	FT	144				144
NPSH AVAILABLE	FT	148				
CORROSION/EROSION FROM						
SPECIAL DETAILS						

FLOW CONTROLLED BY ☐ LC ☒ TC ☐ PC ☐ FC ☐ OTHER

METHOD OF STARTING SPARE PUMP: ☐ MANUAL ☐ AUTOMATIC

DRIVER STEAM: INLET
EXHAUST

NOTES:

MATERIALS RECOMMENDED — CASING — INTERNALS

FOSTER WHEELER ENERGY CORPORATION FW PUMP PROCESS DATA

CUSTOMER EXXON/DOE JOB NO. 11-60035
LOCATION BAKERFIELD, CA SHEET 1 OF 1
ITEM NO. P-102
SERVICE SOLAR FEEDWATER PUMP
SPARE ALSO COMMON TO ITEM

REV.	0	1	2	3
DATE	1/2/80	2/26/80		
MADE BY	RAB	RAB		

FORM ...-29

PUMP TYPE: ☒ CENTRIF. ☐ RECIP. POWER ☐ RECIP. STEAM ☐ ROTARY ☐ METERING ☐

NUMBER OF PUMPS REQUIRED: ONE OPERATING ONE SPARE

TYPE OF DRIVER: MOTOR OPERATING SPARE

DUTY: ☐ CONTIN. ☒ INTERMITT @ APPROX. 3000 HRS/YR.

PROCESS REQUIREMENTS PER PUMP

	OPERATING CASE	DESIGN			MINIMUM FLOW CASE	MAXIMUM SP.GR.CASE
	LIQUID	BOILER FEED WATER				
	PUMPING TEMP.: NORMAL °F	250				70
	EXPECTED MAX. °F					
	SP.GR. @ P.T.: RATED (MIN.)	0.944				1.00
	EXPECTED MIN.					
	VAPOR PRESS. @ P.T. PSIA	29.82				.3628
	VISCOSITY @ P.T. CKS	0.2165				.975
C-1	CAPACITY @ P.T.: REQUIRED U.S. GPM	67				200
C-1	NORM. U.S. GPM	60.46				VARIES
C-1	DISCH. PRESS.: REQUIRED PSIG	1021				72.47
	SUCT. PRESS.: REQUIRED PSIG	22.9				50.00
	(MAX. POSSIBLE) PSIG	( )	( )	( )	( )	( )
C-1	DIFFERENTIAL PRESS. PSI	998.15				22.47
C-1	DIFF. HEAD (CENTRIF. PUMPS ONLY) FT	2442.5				51.97
C-	NPSH AVAILABLE FT	17.9				148
	CORROSION/EROSION FROM					
	SPECIAL DETAILS					

FLOW CONTROLLED BY ☒ LC ☐ TC ☐ PC ☐ FC ☐ OTHER

METHOD OF STARTING SPARE PUMP: ☐ MANUAL ☐ AUTOMATIC

DRIVER STEAM: INLET
EXHAUST

NOTES:

MATERIALS RECOMMENDED CASING INTERNALS

FOSTER WHEELER ENERGY CORPORATION FW PUMP PROCESS DATA

CUSTOMER EXXON/DOE JOB NO. 11-60035
LOCATION BAKERSFIELD, CA SHEET 1 OF 1
ITEM NO. P-103
SERVICE SOLAR CIRCULATION PUMP
SPARE ALSO COMMON TO ITEM

REV.	0	1	2	3
DATE	1/2/80	2/26/80		
MADE BY	LAB	SAD		

PUMP TYPE: ☒ CENTRIF. ☐ RECIP. POWER ☐ RECIP. STEAM ☐ ROTARY ☐ METERING ☐

NUMBER OF PUMPS REQUIRED: ONE OPERATING ONE SPARE

TYPE OF DRIVER: MOTOR OPERATING SPARE

DUTY: ☐ CONTIN. ☒ INTERMITT. APPROX. 3000 HRS/YR.

PROCESS REQUIREMENTS PER PUMP

OPERATING CASE		DESIGN			MINIMUM FLOW CASE	MAXIMUM SP. GR. CASE
LIQUID		BOILER WATER				DAILY WINTER START
PUMPING TEMP.: NORMAL	°F	527				70
EXPECTED MAX.	°F	540				1.0
SP.GR. @ P.T.: RATED (MIN.)		0.757				
EXPECTED MIN.		0.750				
VAPOR PRESS. @ P.T.	PSIA	879.5				
VISCOSITY @ P.T.	CKS	0.1				
CAPACITY @ P.T.: REQUIRED U.S. GPM		3550				3550
NORM. U.S. GPM		3224				
DISCH. PRESS.: REQUIRED	PSIG	984				156.6
SUCT. PRESS.: REQUIRED	PSIG	870				4.6
(MAX. POSSIBLE)	PSIG	( )	( )	( )	( )	( )
DIFFERENTIAL PRESS.	PSI	114				152
DIFF. HEAD (CENTRIF. PUMPS ONLY)	FT	350				350
NPSH AVAILABLE	FT	12				
CORROSION/EROSION FROM						
SPECIAL DETAILS						

FLOW CONTROLLED BY ☐ LC ☐ TC ☐ PC ☒ FC ☐ OTHER

METHOD OF STARTING SPARE PUMP: ☐ MANUAL ☐ AUTOMATIC

DRIVER STEAM: INLET
EXHAUST

NOTES: MOTOR NON OVERLOADING

MATERIALS RECOMMENDED CASING INTERNALS

FORM ...-29

FORM 110-29

FOSTER WHEELER ENERGY CORPORATION — PUMP PROCESS DATA

CUSTOMER: EXXON/DoE
LOCATION: BAKERSFIELD, CA
ITEM NO.: P-104
SERVICE: FREEZE PROTECTION CIRCULATOR
SPARE ALSO COMMON TO ITEM:

JOB NO. 11-60035
SHEET 1 OF 1

REV.	0	1	2	3
DATE	2/20/80			
MADE BY	[illegible]			

PUMP TYPE: ☒ CENTRIF. ☐ RECIP. POWER ☐ RECIP. STEAM ☐ ROTARY ☐ METERING ☐ ______

NUMBER OF PUMPS REQUIRED: OPERATING ONE SPARE NONE

TYPE OF DRIVER: OPERATING ONE SPARE NONE

DUTY: ☐ CONTIN. ☒ INTERMITT. APPROX. 40 HRS/YR.

PROCESS REQUIREMENTS PER PUMP

OPERATING CASE		DESIGN			MINIMUM FLOW CASE	MAXIMUM SP. GR. CASE
LIQUID		BOILER FEED WATER				
PUMPING TEMP.: NORMAL	°F	250				
EXPECTED MAX.	°F					
SP.GR. @ P.T.: RATED (MIN.)		0.944				
EXPECTED MIN.						
VAPOR PRESS. @ P.T.	PSIA	29.82				
VISCOSITY @ P.T.	CKS	0.265				
CAPACITY @ P.T.: REQUIRED U.S. GPM		15				
NORM. U.S. GPM						
DISCH. PRESS.: REQUIRED	PSIG	29.4				
SUCT. PRESS.: REQUIRED	PSIG	28.2				
(MAX. POSSIBLE)	PSIG	( )	( )	( )	( )	( )
DIFFERENTIAL PRESS.	PSI	1.2				
DIFF. HEAD (CENTRIF. PUMPS ONLY)	FT	3				
NPSH AVAILABLE	FT	16.4				
CORROSION/EROSION FROM						
SPECIAL DETAILS						

FLOW CONTROLLED BY ☐ LC ☐ TC ☐ PC ☐ FC ☐ OTHER
NONE

METHOD OF STARTING SPARE PUMP: ☐ MANUAL ☒ AUTOMATIC

DRIVER STEAM: INLET
EXHAUST

NOTES: PUMP MOTOR WILL BE NON-OVERLOADING

MATERIALS RECOMMENDED — CASING — INTERNALS

FORM 110-29

FOSTER WHEELER ENERGY CORPORATION

PUMP PROCESS DATA

CUSTOMER EXXON / DOE
LOCATION BAKERFIELD CA
ITEM NO. P-123
SERVICE SCB PREHEAT CIRCULATION PUMP
SPARE ALSO COMMON TO ITEM ______

JOB NO. 11-60035
SHEET 1 OF 1

REV.	0	1	2	3
DATE	2/26/80	[illegible]		
MADE BY	JAB	RAB		

PUMP TYPE: ☒ CENTRIF. ☐ RECIP. POWER ☐ RECIP. STEAM ☐ ROTARY ☐ METERING ☐ ______

NUMBER OF PUMPS REQUIRED: OPERATING ONE SPARE —

TYPE OF DRIVER: MOTOR OPERATING ONE SPARE ______

DUTY: ☐ CONTIN. ☐ INTERMITT .@ APPROX.______HRS/YR.

PROCESS REQUIREMENTS PER PUMP

OPERATING CASE	SCB PREHEAT			MINIMUM FLOW CASE	MAXIMUM SP.GR.CASE
LIQUID					
PUMPING TEMP.: NORMAL °F	250			50	
EXPECTED MAX. °F					
SR.GR. @ P.T.: RATED (MIN.)					
EXPECTED MIN.					
VAPOR PRESS. @ P.T. PSIA	29.82				
VISCOSITY @ P.T. CKS	.265				
CAPACITY @ P.T.: REQUIRED U.S. GPM	900			PER RPM	
NORM. U.S. GPM	800				
DISCH. PRESS.: REQUIRED PSIG	43			MANUAL	
SUCT. PRESS.: REQUIRED PSIG	21.8			20	
(MAX. POSSIBLE) PSIG	(865)	( )	( )	( )	( )
DIFFERENTIAL PRESS. PSI	21.2				
DIFF. HEAD (CENTRIF. PUMPS ONLY) FT	50				
NPSH AVAILABLE FT	14.9				
CORROSION/EROSION FROM					
SPECIAL DETAILS					

FLOW CONTROLLED BY ☐ LC ☒ TC ☐ PC ☐ FC ☐ OTHER

METHOD OF STARTING SPARE PUMP: ☐ MANUAL ☐ AUTOMATIC

DRIVER STEAM: INLET
EXHAUST

NOTES:

(1) MOTOR NON-OVERLOADING

MATERIALS RECOMMENDED CASING INTERNALS

B. PROCESS EQUIPMENT SPECIFICATIONS

B5 Instrument Schedule

A schedule of process instruments is included in this section (3 pages).

B. PROCESS EQUIPMENT SPECIFICATIONS

B6 Miscellaneous Equipment

a. Line Mixer

The Process Specification for the following static on-line mixer is included in this section:

M-101	Line Mixer

b. Package Unit

The Process Specification for the following package unit is included in this section:

PG-102	Instrument Air Supply Package System

B. PROCESS EQUIPMENT SPECIFICATIONS

B7 Control and Interlock Description

The control and interlocks of the solar boiler feedwater preheat and steam generation unit is shown diagramatically on the Engineering Flow Diagram (60035-1-50-1) and the Interlock Diagram (60035-2-60-1).

MATERIAL REQUISITION

FOSTER WHEELER

FORM 135-20A

FOR EXXON/DOE	F.W. REF. 11-60035	REQUISITION NUMBER	DATE
SITE BAKERSFIELD, CALIFORNIA			3/20/80
MATERIAL		SUPERSEDED BY CHANGE NO.:	
SERVICE OF UNIT: MIXER		C1	C4
ITEM NO. M-101		C2	C5
		C3	C6

PROCESS REQUIREMENTS

Provide one (1) in-line (Static) Mixer for the following hot water blending service:

1. COLD WATER FEED

Line 4" (Nominal): 95.0 GPM (Max)
42.0 GPM (Min)

	Normal	Maximum
Operating Temperatures	70°F	250°F
Specific Gravity	1.0	0.94

2. HOT WATER FEED (FLASHING)

Line 6" (Nominal)· 240 GPM

	Control Range		Maximum
Operating Temperatures	280	510	527
Specific Gravity	0.94	.757	.75

Temperature varies continuously starting at 527°F dropping to 245°F.

3. MIXED FLOW

Line Size: 8" (Vendor to confirm)

Control Range - Hot water Temperature	280°F	510°F
Flow thru Mixer	220 GPM	470 GPM

4. OPERATING PRESSURES

Downstream	16 psig.
Upstream	25 psig. (Vendor to confirm)
Maximum Downstream	50 psig.

BY:	P.O.NO.	SUPPLIER:

FOSTER WHEELER ENERGY CORPORATION				PACKAGE ITEM **PROCESS DATA**
CUSTOMER EXXON/DOE	JOB NO. 11-60035			
LOCATION BAKERSFIELD, CA	SHEET 1 OF 1			
ITEM NO. PG-102	REV. 0	1	2	3
SERVICE Instrument Air Supply Package System	DATE 3/28/80			
DATE 3/28/80	MADE BY FTS			

PROCESS REQUIREMENTS

At Inlet : Ambient Air

Outlet:

Temperature : Ambient

Pressure : 90 PSIG

SCFM : 18.0

Estimated Utilities

Compressor : 3.8 bhp

Inter-Stage Air Coolers : .5 bhp

Dessicant Dryer : 1.8 kw

MAJOR ITEMS IN THE PACKAGE

1. 2-STAGE RECIPROCATING AIR-COMPRESSOR.
2. AIR-COOLER FOR INTERSTAGE AIR COOLING.
3. DESSICANT DRYER.
4. RECEIVER (8 hour capacity)
5. INSTRUMENTATION FOR COMPLETE AUTOMATION.

A. Warm-up

1. When the sun comes up in the morning, the solar intensity detector output increases to XSH-1 which (if wind speed is not high NSH-1 and demand switch HS-16 is on) starts:

   a. timer KC-1A
   b. pump P101
   c. pump P103 (if D101 level is not very low, LSLL-15)

2. Flow switchs FSL-4 and FSL-7 detect flow and send signals to master controller UC-300 and field controllers UC-100 and UC-400 which send tracking signals to local controllers at each collector.

B. Normal Operation: Steam Generation

As preheat zone warms up, TRC-2 starts throttling. As boiler field warms up, steam pressure in flash separator rises until PDSL is 10 psi, which starts pump P102.

If FSL-14 detects loss of steam flow for more than 20 minutes start heat recovery mode (see D.).

C. Normal Operation: Steam Generation Collector Field in Preheat Mode

If boiler field does not reach pressure before KC-1A times out:

a. Start pump P102
b. Start SCB Field Preheat mode:

   Valve HV-10 closes, valve HV-11 opens, valve TV-38 opens and starts throttling, stop P103 pump and start pump P105.

D. Normal Non-winter Heat Recovery Mode

As the sun goes down (or clouds), solar intensity detector output decreases to below XSH which after 30 minutes time delay starts the heat recovery mode:

Valve HV-10 closes, valve HV-11 opens valve FV-6 opens which starts TIC-5 throttling, also valve TV-38 closes if it was open.

E. Shutdown Mode

During the heat recovery mode, ambient temperature water flows through the SCB field and the hot water (which is tempered by preheated water from valve TV-5) flows to TK-101. When the temperature of this water decreases to TSL-5:

Stop pumps P101, P102, and P105, open valve HV-10, close valve HV-11 close valves FV-6 and TV-38.

F. Night-time Operation

At night, if ambient temperature drops to TSL-12, start pumps P-104 and P-105 to keep water from freezing. Flow of water from TK-101 A/B to the Thermoflood boiler continues.

G. Other Miscellaneous Conditions

1. If TK-101 level is high LSH-3, close feed valve LV-3.
2. If TK-101 level is very low LSLL-3, open valve LV-39A, close valve LV-39B, close valve HV-10, and open valve HV-11.
3. Switch HS-36 enables operator to manually put system in "shutdown" mode.
4. If D-101 level goes very low LSLL-15, stop master controllers UC-100 and UC-400 from tracking, and after time delay of 20 minutes stop pump P-103.
5. Also high wind speed NSH-1 or demand HS-16 off causes master controllers UC-100 and UC-400 to stop tracking.

C. DRAWINGS

C1 Plot Plan and Major Piping Layout

The Plot Plan and Major Piping Layout for the STEOR plant in this section is preliminary. It indicates the proposed layout of process equipment but will be subject to review during detailed engineering of the plant.

Drawing No.	Description
60035-1-51-1	Piping Layout Solar Boiler Feedwater Preheating and Steam generation for Enhanced Oil Recovery
60035-1-01-1	Plot Plan Solar Boiler Feedwater Preheating and Steam generation for Enhanced Oil Recovery

C. PROCESS EQUIPMENT SPECIFICATIONS

C2 Engineering Flow Diagram

The following engineering flow diagram is included in this section:

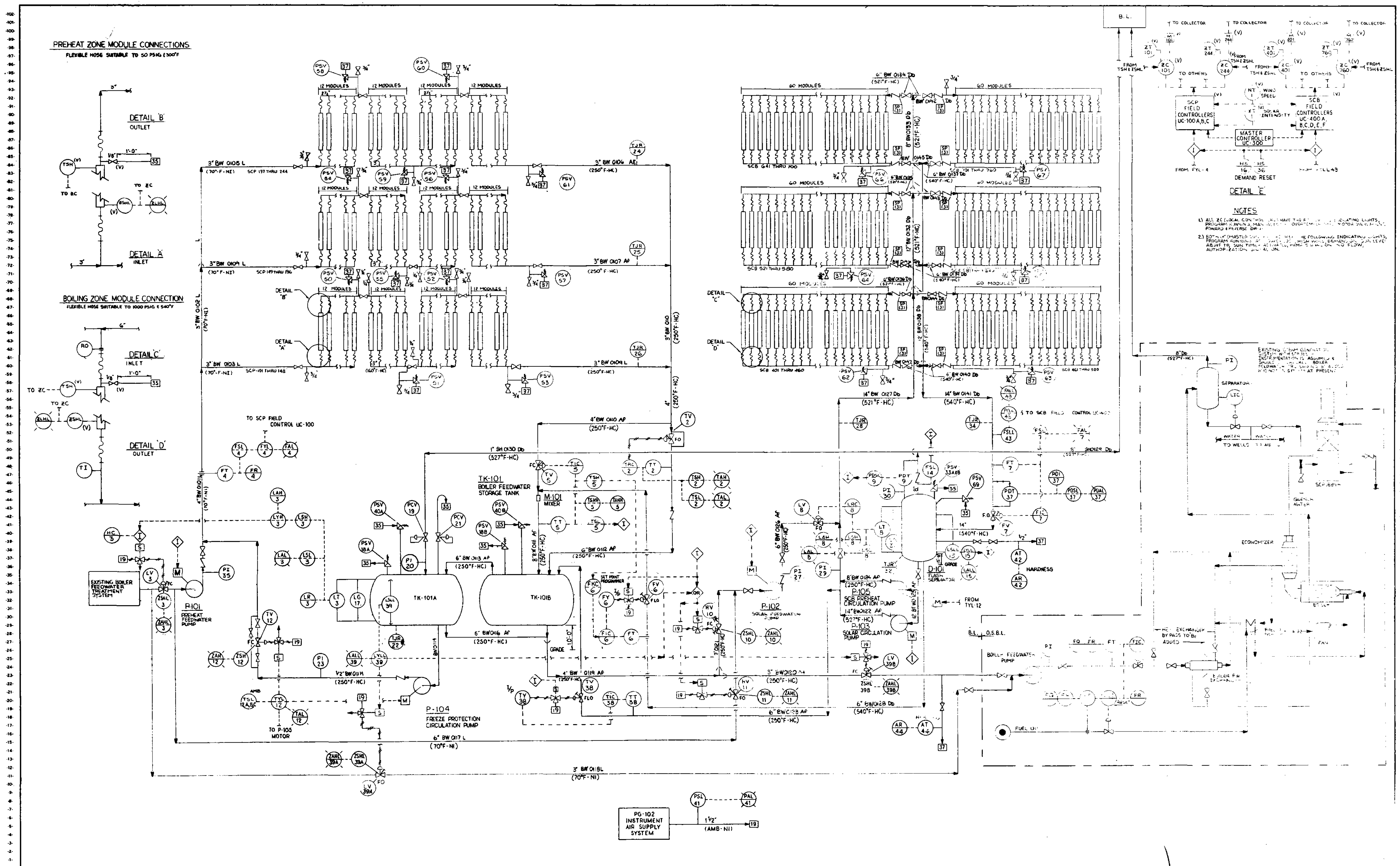
Drawing No.	Description
60035-1-50-1	Solar Boiler Feedwater Preheating and Steam Generation for Enhanced Oil Recovery

C. DRAWINGS

C3 Design Temperature and Pressure Diagram

The Design Temperature and Pressure Diagram is included in this section:

Drawing No.	Description
60035-2-50-301	Design Pressure and Temperature Diagram Solar BFW Preheating and Steam Generation



L E G E N D						
11 COOLING WATER SUPPLY	16 # EXHAUST STEAM	21 CONDENSATE	26 OILY OR DIRTY WATER SEWER	31 PUMPOUT	36 INERT GAS	41
12 COOLING WATER RETURN	17 POTABLE WATER	22 TREATED WATER	27 PROCESS SEWER	32 PURGE GAS	37 PIPE TO 6" ABOVE GROUND	42
13 # H.P. STEAM	18 PLANT AIR	23 FUEL OIL	28 SANITARY SEWER	33 BLOWDOWN	38	43
14 # STEAM (INTERMEDIATE PRESS.)	19 INSTRUMENT AIR	24 FUEL GAS	29 FIRE WATER	34 FLARE	39	44
15 # L.P. STEAM	20 H.P. CONDENSATE	25 CLEAN WATER SEWER	30 FLUSHING OIL	35 TO ATMOSPHERE	40	45

NOTES
1. CELL IS SANDIA EPT. TYPE
2. REFER TO INTERLOCK LOGIC DWG. TO SEE DETAILS AS SHOWN BY ⟨I⟩
3. EXCESS FLOW VALVES.

ITEM NO.	SCP-101 THRU 244	SCB-401 THRU 760
SERVICE	PREHEAT SOLAR COLLECTOR MODULES	BOILER SOLAR COLLECTOR MODULES
SIZE		
DES. PRESS-TEMP.		
OPER. PRESS-TEMP.		
MATERIAL		
INSULATION		

ITEM NOS. THIS DWG.

This Drawing is the Property of the FOSTER WHEELER ENERGY CORPORATION 110 SOUTH ORANGE AVENUE, LIVINGSTON, N.J.

ENGINEERING FLOW DIAGRAM
SOLAR BOILER FEEDWATER
PREHEATING & STEAM GENERATION
FOR ENHANCED OIL RECOVERY

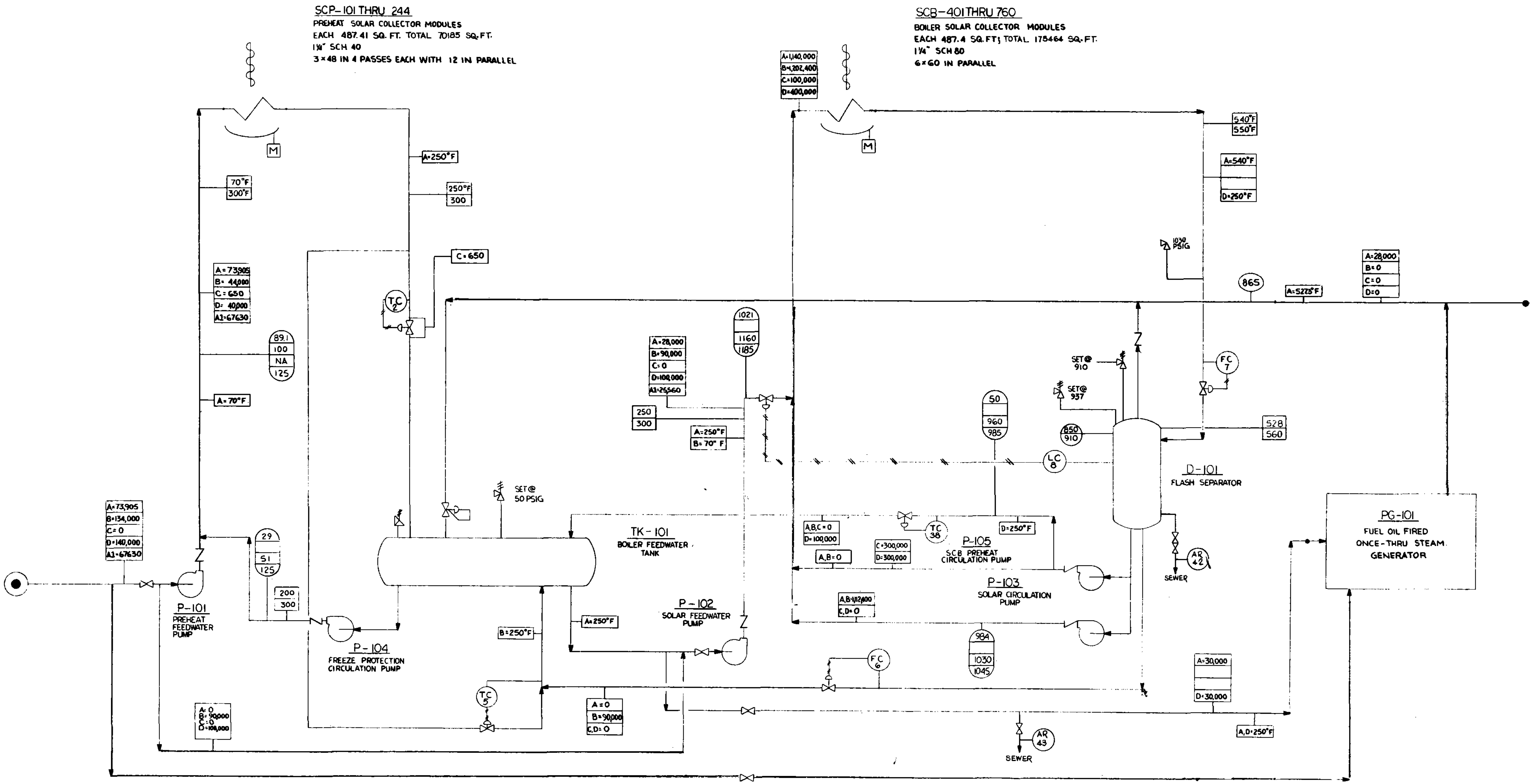
EXXON DOE CALIFORNIA

EST NO | DRAWN BY S.G.S. 3-3-80 | SH. 1 OF

CONTRACT NUMBER 11-60035 | DWG. NO. - 60035-1-50-1

THIS DRAWING SUPERSEDES

REVISIONS



PRESSURE PSIA

FLOW LBS./HRS.

A= PEAK INSOLATION (SCP-101/244-190 BTU/HR,SF; SCB 401/750-156 BTU/HR,SF)
B= POST SUNDOWN HEAT RECLAIM
C= FREEZE PROTECTION CIRCULATION
D= WINTER SCB-401/760 ON PREHEAT SERVICE, PEAK INSOLATION 102.8 BTU/HR-SF
A1= AVG. INSOLATION FOR 11.5 HR D 21 JUNE (SCP 101/244-173.5 BTU/HR.SF, SCB 401/760-142.4 BTU/HR.SF)
NA= NOT AVAILABLE

OPERATING PRESSURE PSI (GAUGE)
DESIGN PRESSURE PSI (GAUGE)

OPERATING TEMPERATURE °F
DESIGN PRESSURE °F

NORMAL DISCHARGE PRESS PSI (GAUGE)
SHUT-OFF PRESS @ NORMALL SUCTION PRESS
SHUT-OFF PRESS @ MAX SUCTION PRESS

NORMAL SUCTION PRESSURE PSI (GAUGE)
MAXIMUM SUCTION PRESSURE PSI (GAUGE)

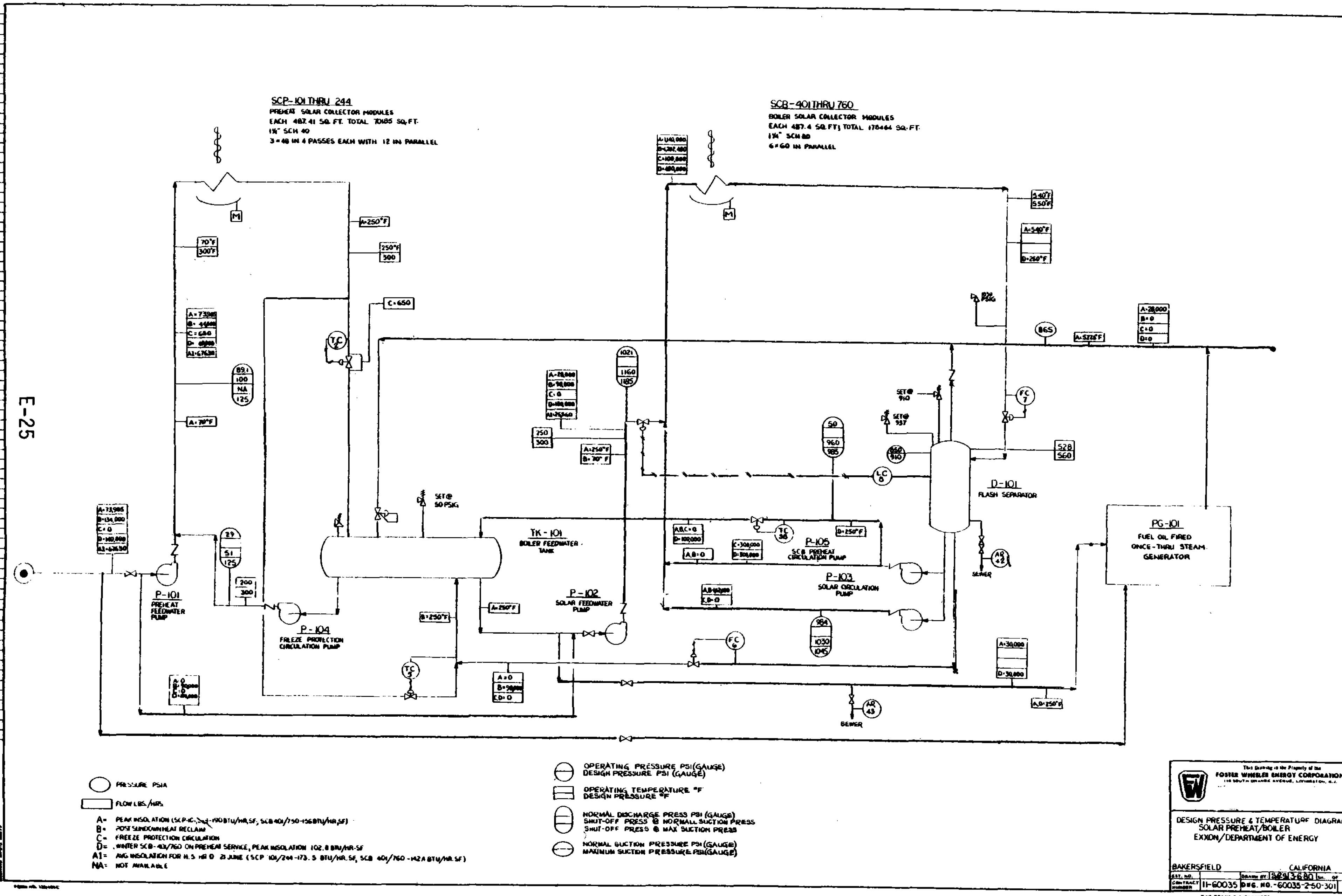
DESIGN PRESSURE & TEMPERATURE DIAGRAM
SOLAR PREHEAT/BOILER
EXXON/DEPARTMENT OF ENERGY

BAKERSFIELD CALIFORNIA

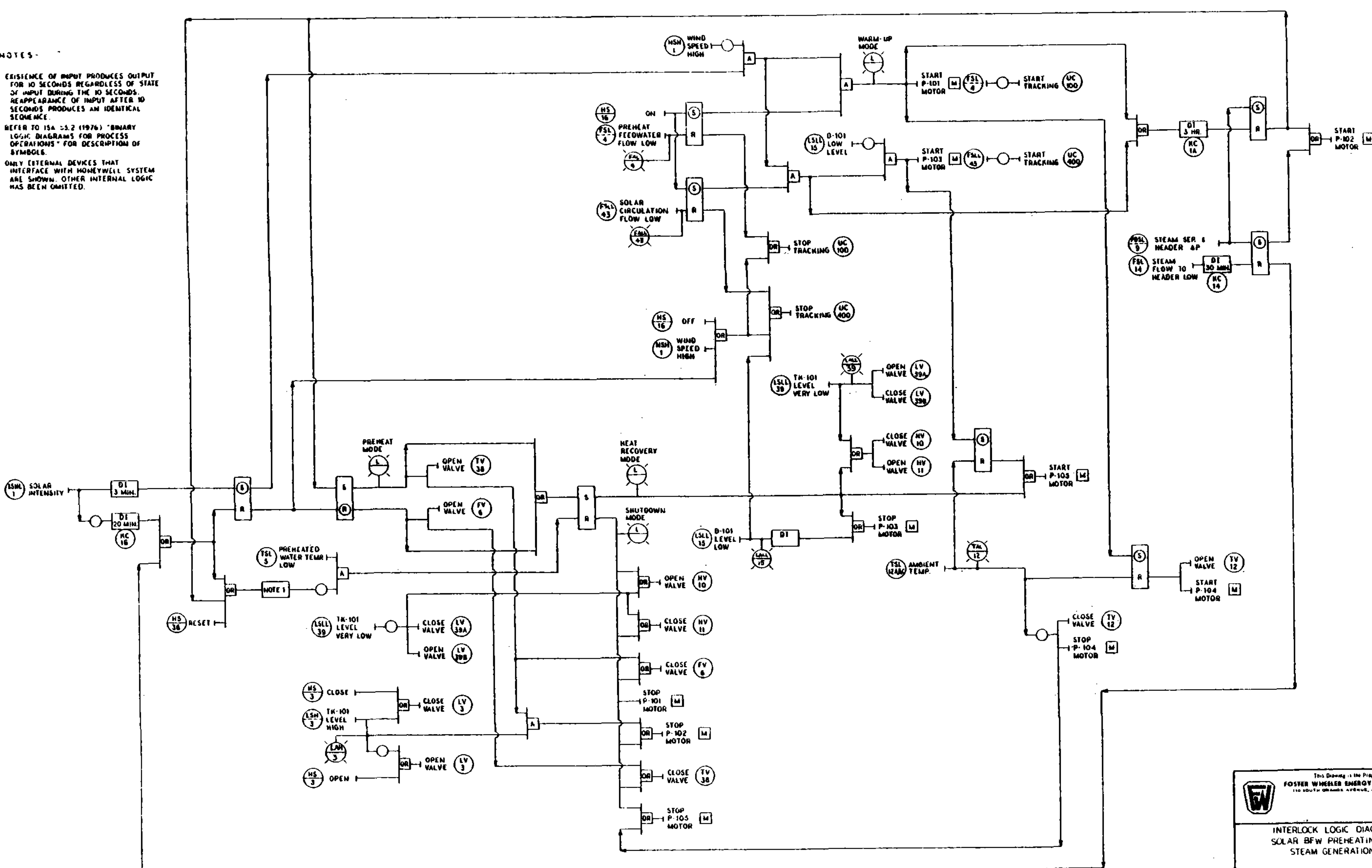
EST. NO.		DRAWN BY: S.G.S. 3-6-80	SH. OF
CONTRACT NUMBER	11-60035	DWG. NO.-60035-2-50-301	

THIS DRAWING SUPERSEDES

FORM NO. 130-104C



SCP-101 THRU 244
PREHEAT SOLAR COLLECTOR MODULES
EACH 487.41 SQ.FT. TOTAL 70185 SQ.FT.
SCB-401 THRU 760
BOILER SOLAR COLLECTOR MODULES
P-101
PREHEAT FEEDWATER PUMP
P-104
FREEZE PROTECTION CIRCULATION PUMP
TK-101
BOILER FEEDWATER TANK
P-102
SOLAR FEEDWATER PUMP
P-105
SCB PREHEAT CIRCULATION PUMP
P-103
SOLAR CIRCULATION PUMP
D-101
FLASH SEPARATOR
PG-101
FUEL OIL FIRED ONCE-THRU STEAM GENERATOR
SET@ 50 PSIG
SEWER
PRESSURE PSIA
FLOW LBS/HRS
C= FREEZE PROTECTION CIRCULATION
NA= NOT AVAILABLE
OPERATING PRESSURE PSI (GAUGE)
DESIGN PRESSURE PSI (GAUGE)
OPERATING TEMPERATURE °F
DESIGN PRESSURE °F
NORMAL DISCHARGE PRESS PSI (GAUGE)
SHUT-OFF PRESS @ NORMAL SUCTION PRESS
SHUT-OFF PRESS @ MAX SUCTION PRESS
NORMAL SUCTION PRESSURE PSI (GAUGE)
MAXIMUM SUCTION PRESSURE PSI (GAUGE)
FOSTER WHEELER ENERGY CORPORATION
DESIGN PRESSURE & TEMPERATURE DIAGRAM
SOLAR PREHEAT/BOILER
EXXON/DEPARTMENT OF ENERGY
BAKERSFIELD
CALIFORNIA
11-60035
DWG. NO.-60035-2-50-301



· NOTES ·

1. EXISTENCE OF INPUT PRODUCES OUTPUT FOR 10 SECONDS REGARDLESS OF STATE OF INPUT DURING THE 10 SECONDS. REAPPEARANCE OF INPUT AFTER 10 SECONDS PRODUCES AN IDENTICAL SEQUENCE.
2. REFER TO ISA S5.2 (1976) "BINARY LOGIC DIAGRAMS FOR PROCESS OPERATIONS" FOR DESCRIPTION OF SYMBOLS.
3. ONLY EXTERNAL DEVICES THAT INTERFACE WITH HONEYWELL SYSTEM ARE SHOWN. OTHER INTERNAL LOGIC HAS BEEN OMITTED.

This Drawing is the Property of the FOSTER WHEELER ENERGY CORPORATION

INTERLOCK LOGIC DIAGRAM
SOLAR BFW PREHEATING &
STEAM GENERATION

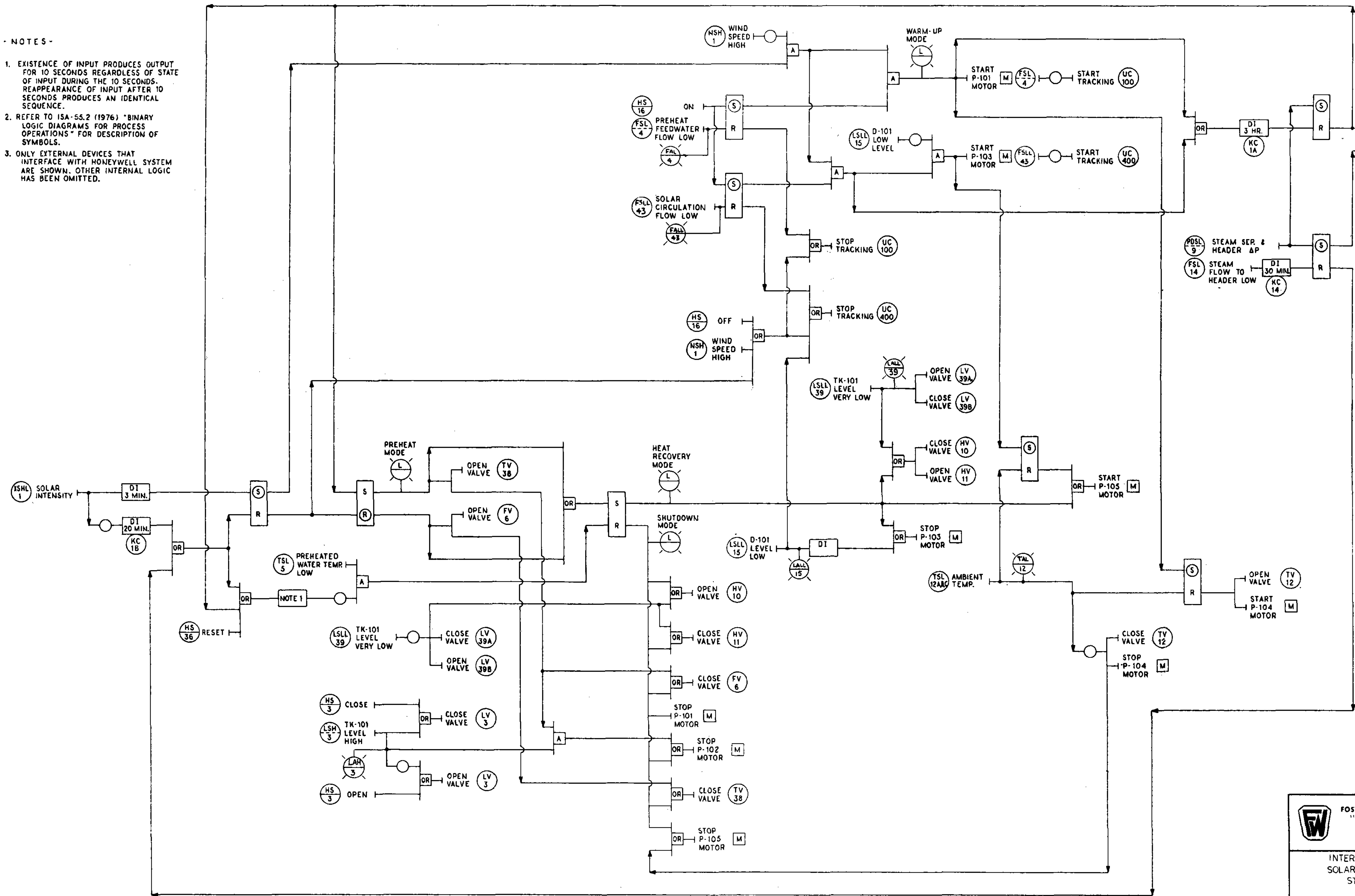
EXXON / DOE CALIFORNIA

CONTRACT NUMBER 11-60035 DWG. NO. 60035-2-60-1

THIS DRAWING SUPERSEDES

- NOTES -

1. EXISTENCE OF INPUT PRODUCES OUTPUT FOR 10 SECONDS REGARDLESS OF STATE OF INPUT DURING THE 10 SECONDS. REAPPEARANCE OF INPUT AFTER 10 SECONDS PRODUCES AN IDENTICAL SEQUENCE.
2. REFER TO ISA-55.2 (1976) "BINARY LOGIC DIAGRAMS FOR PROCESS OPERATIONS" FOR DESCRIPTION OF SYMBOLS.
3. ONLY EXTERNAL DEVICES THAT INTERFACE WITH HONEYWELL SYSTEM ARE SHOWN. OTHER INTERNAL LOGIC HAS BEEN OMITTED.



This Drawing is the Property of the
FOSTER WHEELER ENERGY CORPORATION
110 SOUTH ORANGE AVENUE, LIVINGSTON, N.J.

INTERLOCK LOGIC DIAGRAM
SOLAR BFW PREHEATING &
STEAM GENERATION

EXXON / DOE — CALIFORNIA

EST. NO.		DRAWN BY:	3-19-80	SH. OF
CONTRACT NUMBER	11-60035	DWG. NO.-60035-2-60-1		

THIS DRAWING SUPERSEDES

FORM NO. 136-104C

C. DRAWINGS

C4 Interlock Diagram

The Interlock Diagram for the STEOR plant is included in this section.

Drawing No.	Description
60035-2-60-1	Interlock Logic Diagram Solar BFW Preheating and Steam generation

FORM NO. 135-905

FOSTER WHEELER ENERGY CORP.
PROCESS PLANTS DIVISION

CONTRACT: 11-60035
SECTION:

LINE CLASSIFICATION LIST

FLOW SHEET NUMBER & REVISION: 60035-1-50-1-A

REVISION	ORIGINAL	1	2	3	4	5	6	7	8	9	10	11
DATE	3-20-80											

LINE NUMBER			LINE EXTREMITIES		OPERATING		DESIGN		INSULATION		PLAN OR ISOMETRIC DRAWING NO.	PIPE WALL THK	FLU. CAT.	REMARKS
SIZE	SERIAL	SPEC	FROM	TO	TEMP °F.	PRESS PSIG	TEMP °F.	PRESS PSIG	TYPE	THK				
4	BN 0101	L	P101	3" BW 0102	70				NI	—				
3	BN 0103	L	3" 0102	SCP 101/148	70				NI	—				
3	BW 0104	L	3" 0102	SCP 149/196	70				NI	—				
3	BN 0105	L	3" 0102	SCP 197/244	70				NI	—				
3	BW 0106	L	SCP 197/244	3" 0108	70				NI	—				
3	BW 0107	Af	SCP 149/196	3" 0108	250				HC	2½				
3	BW 0109	Af	SCP 101/148	3" 0108	250				HC	2½				
4	BW 0110	Af	3" 0108	8" 0111	250				HC	2½				
4"	BW 0110	Af	4" 0110	6" 0112	250				HC	2½				
6	BW 0113	Af	TK 101A	TK 101B	250				HC	2½				
1	BW 0114	Af	TK 101A	SUCTION P104	250				HC	2½				
½	BW 0115	Af	P104	4" BW1001	250				HC	2½				
6	BW 0116	Af	TK 101A	TK 101B	250				HC	2½				
6	BW 0117	L	P101 SUCTION	P102	70				NI	—				
3"	BW 0118	L	EXISTING BOILER FEEDWATER TO EXISTING EXXON BFW PUMP		70				NI	—				
4	BW 0119	Af	TK 101B	3 BW0120	250				HC	2½				
3	BW 0120	Af	4 BW0119	EXISTING EXXON BFW PUMP	250				HC	2½				
3	BW 0121	Af	4 0119	SUCTION P102	250				HC	2½				
14	BW 0122	Af	DISCH P-103	6" 0123	527				HC	5				
6	BW 0123	Af	14 BW 0122	TK 101B	250				HC	5				
8	BW 0124	Af	P105	14" 0122	250				HC	5				
12	BW 0125	Af	D-101	P-105/103	250		540		HC	5				
6	BW 0126	Af	P102	14" 0127	250		540		HC	5				
6	BW 0128	Db	D101	EV6	540				HC	4				
8	SH 0129	Db	D101	BATTERY LIMITS	527				HC	5				
1	SH 0130	Db	SH 0129	TK 101A	527				HC	5				
14	BW 0131	Db	P103	SCB 401/460	527				HC	4				
12	BW 0132	Db	14 0127	SCB 521/580	527				HC	5				
8	BW 0133	Db	12 0132	SCB 611/700	527				HC	5				
6	BW 0134	Db	8 0133	SCB 701/760	527				HC	4				
6	BW 0135	Db	12 0132	SCB 581/640	527				HC	4				
6	BW 0136	Db	14 0127	SCB 461/520	527				HC	4				
(5) ← SEE NOTES – LINE CLASSIFICATION LIST INDEX →					(1)	(1)	(1)	(1)		(2)		(3)		(4)

FORM NO. 135-905

FW FOSTER WHEELER ENERGY CORP. PROCESS PLANTS DIVISION	CONTRACT: 11-60035 SECTION:	LINE CLASSIFICATION LIST	FLOW SHEET NUMBER & REVISION 60035-1-50-1-A	PAGE 2 OF 2

REVISION	ORIGINAL	1	2	3	4	5	6	7	8	9	10	11
DATE	3-20-80											

LINE NUMBER			LINE EXTREMITIES		OPERATING		DESIGN		INSULATION		PLAN OR ISOMETRIC DRAWING NO.	PIPE WALL THK	FLU CAT.	REMARKS
SIZE	SERIAL	SPEC	FROM	TO	TEMP °F.	PRESS PSIG	TEMP °F.	PRESS PSIG	TYPE	THK				
6	BW0137	Db	SCB 701/760	12 0138	540				HC	4				
6	BW0139	Db	SCB 581-640	12 0138	540				HC	4				
6	BW0140	Db	SCB 461-520	12 0138	540				HC	4				
12	BW0138	Db	SCB'S	14" 0141	540				HC	5				
14	BO0141	Db	12" 0138	D-101	540				HC	5				
8	BW0128		EV 6	M101	250				HC	5				
6"	BW0142		8" BW 0133	SCB 701-760	520				HC	4				
6	BW0143		12" BW 0132	SCB 581-640	520				HC	4				
6	BW0144		14 BW 0138	SCB 461-520	520				HC	4				
6	BW0145		SCB 641/700	12 0138	540				HC	4				
6	BW0146		SCB 521/580	12 0138	540				HC	4				
6	BW0147		SCB 401/460	14 0141	540				HC	4				

(5) ← SEE NOTES - LINE CLASSIFICATION LIST INDEX → (1) (1) (1) (1) (2) (3) (4)

E-30

APPENDIX F

PRELIMINARY DESIGN - SOLAR CONTROL

CONVERSIONS FOR APPENDIX F

Section 1

24.4 M	80 ft
23,225 M^2	250,000 ft^2
121^oC	250^oF
275^oC	527^oF

Section 2

260^oC	500^oF
23,225 M^2	250,000 ft^2
282^oC	540^oF
316^oC	600^oF
343^oC	650^oF

Section 3

-28.9^oC	-20^oF
65.6^oC	150^oF

Appendix F

Preliminary Design-Solar Control

FOREWORD

This Appendix, prepared by Honeywell, Inc., documents a preliminary design of the solar controls. The design addresses a system comprised of 504 Sandia EPT sized collectors (80 feet long) in a 250,000 square foot field that both preheats water to 250^{o}F and generates 527^{o}F steam. Figure 1 illustrates the STEOR baseline design used as the basis for the control requirements.

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1. Control Philosophy
2. Local Control (Suntracker) Requirement
3. Local Controller Preliminary Specification Summary
4. Discussion of Local Controller Methods
5. Local Controller Preliminary Specification
6. Field Controller Preliminary Specification Summary
7. Field Controller Preliminary Specification
8. Master Controller Concept
9. Process Control Concept
10. Sequence of Operation

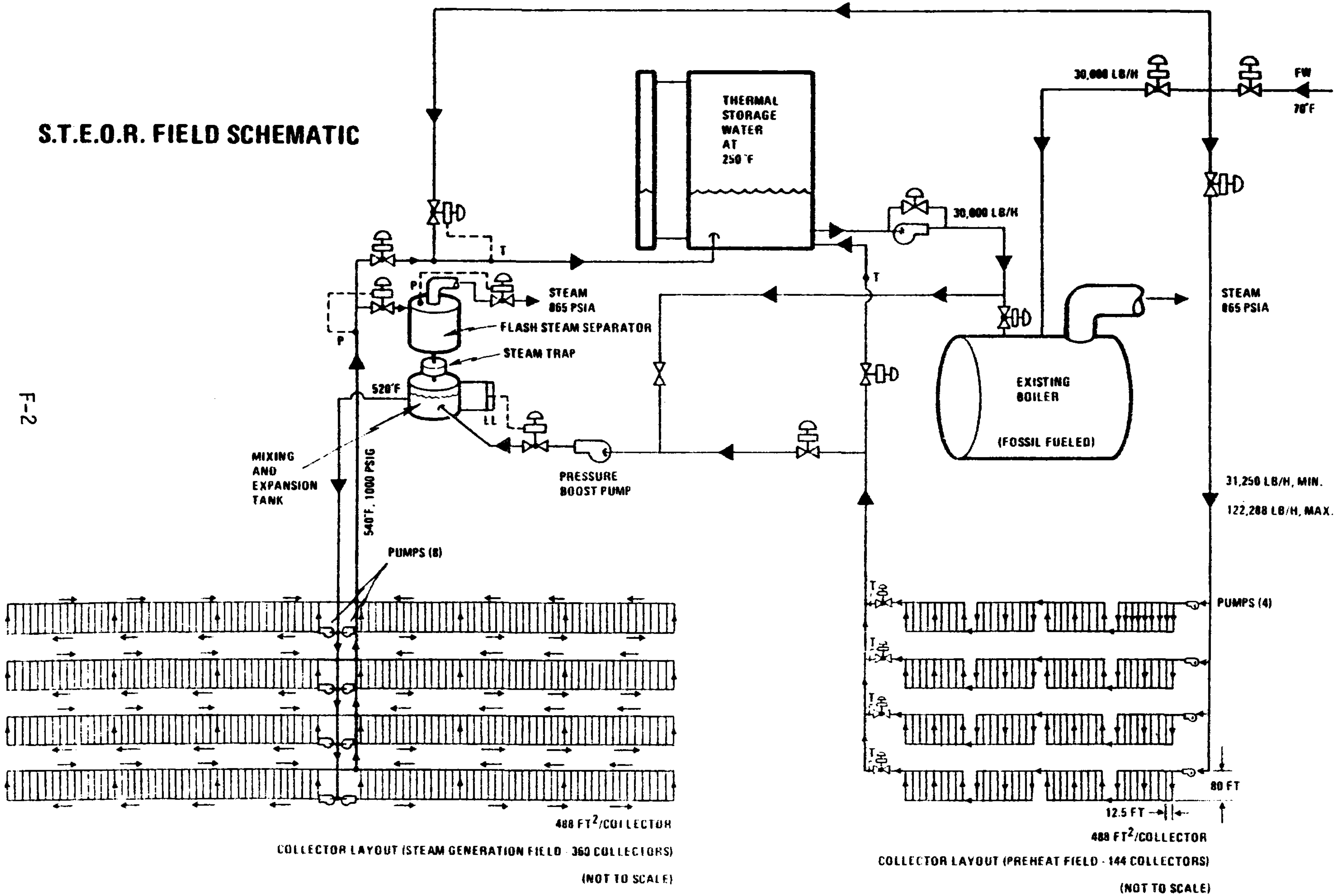

FIGURE 1. STEOR Baseline Field Schematic (Feb., 1980)

1.0 CONTROL PHILOSOPHY

A highly distributed control philosophy was developed to respond to the following STEOR characteristics:

- large collector field (area and distance)
- large number of collectors (504)
- Exxon concern for high reliability
- Exxon concern for minimized maintenance
- high temperature operation (with respect to black chrome durability)

This control philosophy puts a high level of control and computation capability at the collector itself, to allow nearly autonomous operation of the collectors and hereby a highly reliable and redundant collector system, that can continue to operate effectively in spite of individual collector problems.

Furthermore, system operation, maintenance, and control is facilitated through serial communications from and to the local collector controller. These communications include collector status for reasons of operation and maintenance, and collector alarms. Alarms are initiated by the control system, status is accessed by the operator. In addition, communication to the local controller can modify setpoints and operational strategy, either automatically or under operator control.

Figure 2 is a schematic of the distributed control philosophy selected by Honeywell. The 504 local collector controllers (suntrackers) are represented by the boxes on the left. The proposed design utilizes a single microprocessor chip.

The field controller represents a second level of control. Each field controller can handle up to 60 local controllers. Thus the collector

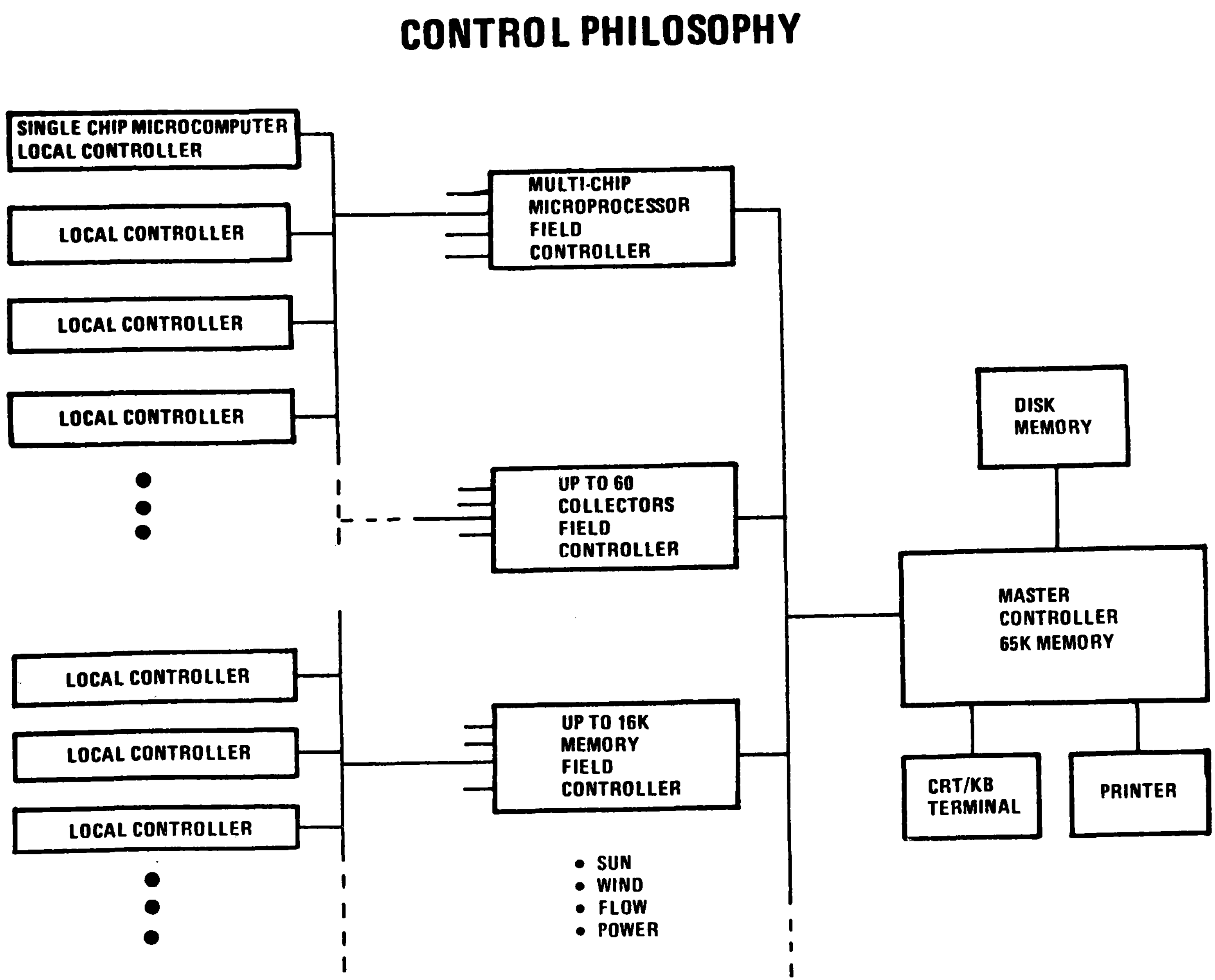

Figure 2. Control Philosophy

fields are made up of modules of 60 collector under independent and autonomous control. The field controllers operate independent of one another providing another level of system redundancy.

Whereas, each local controller provides the self protection features for its collector, the field controller provides the self protection features for its collector field module. It performs morning wakeup and evening shutdown of its collectors and can control flows, temperatures, and pressures in its collector field module. The field controllers can operate independent of the master controller.

For the baseline STEOR field with 504 collectors, nine field controllers are defined, three for the preheat field (48 collectors each), and six for the steamer field (60 collectors each). The field controllers communicate to the local controllers serially and by broadcast.

The master controller conceptualized provides primarily supervisory functions. It allows a man-machine interface with the collector field for alarms and status. Control is mainly by exception - response to alarms and response to operator inputs (setpoint variation or actual control). In general, the system operaties without intervention by the master controller.

The master controller also monitors the process controller (non-solar functions) and can be utilized in data acquisition.

2.0 LOCAL CONTROL (SUNTRACKER) REQUIREMENTS

For clarity, the local controller requirements are divided into two listings:

- Standard suntracker requirements - based on operating experience with current systems (low pressure, less than $500^{o}F$)

- Special STEOR suntracker requirements - consistent with STEOR characteristics

2.1 STANDARD SUNTRACKER REQUIREMENTS

The usual requirements for a single axis tracking solar collector follow:

- Automatic search sequence to lock onto the sun upon receipt at the local controller of a track authorization command.

- Maintenance of an accurate collector-sun relationship with respect to collector rotation in elevation in the presence of adequate direct normal insolation (DNI). The specific tracking accuracy must be compatible with the structural rigidity of the collector to avoid hunting. A tracking accuracy of $\pm$ .25 degree, 1σ is within reason.

- Maintenance of a relatively stable collector attitude in the presence of intermittent interruptions of DNI or during gusty winds with wind speed less than the stow wind speed.

- Return of the collector to the stowed position when the system is not authorized to operate.

- Monitoring conditions for protection of the individual collectors from unsafe conditions, such as too high receiver temperature, and returning of the collector to the stowed position after occurrence. Stow after a too high receiver temperature should be permanent, i.e., stow should last until the operator resets the local unit.

- Transmission of collector stow status to the master controller for interpretation.

- Provision for a means of manual control of each individual collector for maintenance purposes.

- Bypassing all other electrical circuits and stopping the collector rotation should the collector exceed normal travel limits.

- Capability of driving the collector at full speed over the range of elevation used for tracking and stow. In particular, the capability should exist to drive the collector to the stow position at full speed.

- Maintenance of a collector relationship to the sun of $\pm 5^{o}$ during brief periods of insufficient DNI. (This feature is regarded as desirable, but it is not an absolute requirement.)

2.2 SPECIAL STEOR SUNTRACKER REQUIREMENTS

The STEOR field is large with 504 collectors totalling 250,000 square feet of collector aperture. Due to the large size of this field, to meet schedules, and to reduce operating costs, special suntracker requirements exist as presented below. They are arranged in order of proirity, i.e., No. 1 is the most important feature.

1. Schedule. The fabrication and delivery of the collector controllers must meet the STEOR schedule.

2. Protection. Overtemperature protection requirements are included in the standard list. However, in the case of STEOR particular attention must be placed on the temperature sensor and its location. Hardware such as an RTD to monitor the temperature of the receiver is required. This is a high temperature application ($540^{o}F$) and if the temperature of the receiver exceeds $\sim 600^{o}F$, the black chrome on the reciever may fail. The failure point of the black chrome is $\sim 650^{o}F$.

   The system should be protected also from lightning. This may be at the expense of damage to a single collector per lightning strike.

3. Communications. The individual collectors should be capable of receiving a command input to permit the operator to modify the operational sequences of the collector. The collector should transmit status to the field controller and to the master controller to permit operator interpretation of status. Included in communications should be the ability to position any collector or series of collectors from the master controller for purposes of cleaning reflectors or system repair, to change deadbands, to permit tracking tolerance to be varied with the time of day, to stow collectors individually, etc.

4. Reliability. Collector positional feedback, such as could be obtained with a shaft encoder or a potentiometer, is highly desirable. Reliable limit control such as with a shaft encoder or with mercury switches is required.

3.0 LOCAL CONTROLLER PRELIMINARY SPECIFICATION SUMMARY

CHARACTERISTIC	SPECIFICATION
Electronics Power Requirements	24 VDC ± 5V 200 mA (Nominal)
Operating Temperature	-20°F to 150°F Ambient
Interface Signal (Inputs)	
Communications	RS 422 110 Baud
Temperature	Analog - RTD
Maximum Forward Limit	Normally Closed Switch
Stow Limit	Normally Closed Switch
Overtravel	Normally Closed Switch
Cabinet Door	Normally Open Switch
Position Feedback (optional)	Precision Pot. Shaft Encoder Resolver } (Optional)
Indicator Signal (Outputs)	
Program Running	Green LED
Manual Mode	Green LED
Overtemperature/Manual Mode	Red LED
Overtemperature/Auto Mode	Red LED
Motor Overcurrent	Red LED
Forward and Reverse Drive	Green LEDs
Drive Output	± 24 VDC 19 Amps (Current limited to 21 Amps for approximately 2 seconds)
Manual Controls	
Program Reset	Push Button Switch
Mode Select	3-Position Toggle Switch: Manual/Auto/Not Used
Manual Motor Drive	3-Position Toggle Switch: Reverse/Off/Forward (Spring loaded to the off position)
Local Authorization	2-Position Toggle Switch: Remote/Local
Tracking Error	.125 Degree RMS
Physical	10 3/4 x 12 3/4 x 2 1/2 inches with pre-drilled holes to directly mount in a standard Nema 4 (12 x 14 x 6 inches) enclosure with weld nut spacing of 10 1/4 x 12 1/4 inches

4.0 DISCUSSION OF LOCAL CONTROLLER METHODS

4.1 Current Tracker

The present Fairchild based Flux-Line Suntracker System incorporates an algorithm that uses the stow position and maximum forward position of the collector as feedback points on which to base a logical means of locating the sun with the collector. This is done by driving the collector forward (out of stow) when the local control module is authorized to track and it detects a stow position, or in reverse when the local control module is authorized to track and it detects a maximum forward position. While the collector is being driven in either direction, the local control module monitors the flux-line sensor outputs in order to detect the presence of concentrated light. During the time that concentrated light is on at least one of the sensors in sufficient quantity, the control module moves the collector in the proper direction to accurately point the collector to the sun. The concentrated light at the sensors will always be great enough for proper tracking if the collector position is within ± 5 degrees rotation of the true tracking angle and if there is at least 100 W/m^2 (0.1 sun) of direct sunlight (DNI) available.

Once the tracker has "locked-on" the concentrated flux-line, it tracks very accurately in increments on the order of 0.1 degrees under wide range of sky conditions and sun angles. If the direct sunlight is interrupted by a cloud (and the master controller does not stow the collector field) the collector will remain stationary. If the sun come out after a long period of cloudiness (and the field controller has not stowed the collector field), the suns position with respect to the collector may result in the flux line reflecting outside the sensors 5 degree capture angle. In this case, logic is employed to overcome this condition by causing the local controller to attempt to find the sun again. The controller waits until 30 minutes after the last collector correction is made and then drives the collector in the forward direction to search for the condition of concentrated light on the flux-line sensors. The collector is driven forward until the flux line is found or the maximum forward limit is reached at which time the collector is driven toward the stow position searching for the flux line in the vicinity of the sensors. If there is no flux line and the stow limit is reached, the system delays ten minutes and then repeats the search sequence.

Thus, through a set of logic defining a search and acquire technique (shown in Figure 3) and the proper definition of timing delays in the local controller and the field controller (also sensing sunlight and providing an authorize signal) the collectors can search, acquire, and track the sun under a wide variety of conditions with the minimum of extraneous motions during partly cloudy conditions. This design provides a compromise in the trade-off between searching aimlessly when insignificant energy is present, and pointing incorrectly.

4.2 Further Developments

To track the position of the sun regardless of sky conditions would be a great improvement. This could be done by calculating the position of the sun relative to the collector elevation position and then placing the collector at that position. In order to do this it is necessary to use some type of collector position encoder. The problem with the usual application of encoders is that the encoder resolution must be in the neighbor-

STEOR LOCAL CONTROLLER LOGIC FLOW DIAGRAM

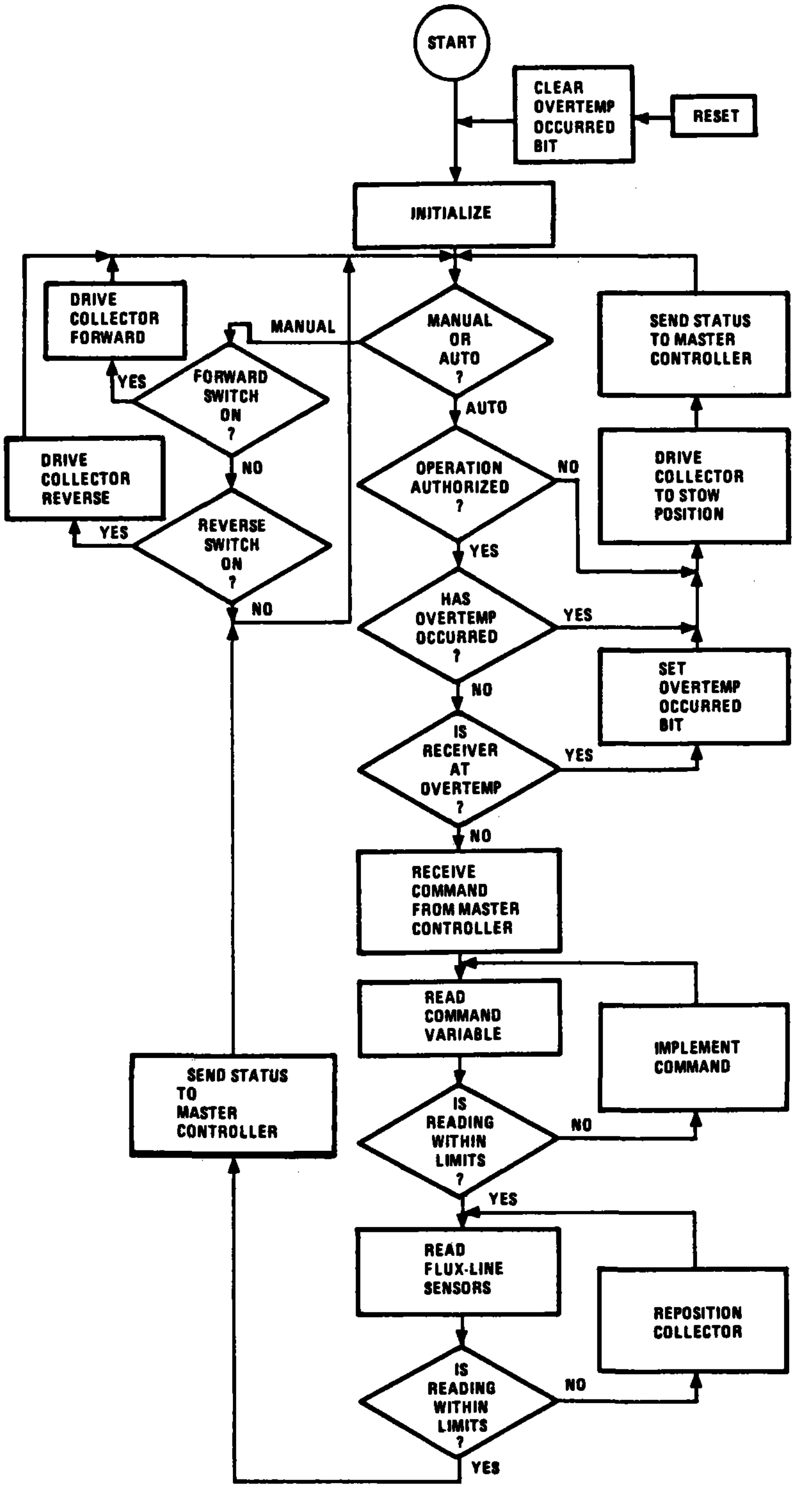

Figure 3. Local Controller Logic

hood of 1 part in 1500 to achieve a tracking accuracy of $\pm$ 0.25 degrees (1σ) of collector rotation. One encoder would be needed for each collector in a solar field of collectors.

The cost of the above type of high resolution encoder is high and could be the major cost item in a tracking system. But by using the flux line sensors in conjunction with an encoder the resolution of a collector position encoder needs to be only approximately 1.5 degrees (1 part in 240). This would be well within the capture angle of the flux line sensors. Therefore, an economical shaft encoder could be used in association with the flux line sensors.

Presently there is no collector position feedback to the Honeywell local control module other than the forward and reverse limits, and the position of the collector is not known during the collector operating time.

It would be very beneficial to be able to calculate every few minutes the correct position at which the collector would be pointing directly at the sun and then to position the collector within $\pm$ five degrees of this position. The flux line sensors would always have concentrated light on them whenever there is sufficient direct normal sunlight available since the capture angle of the flux line sensors is at least $\pm$ five degrees and since these sensors directly couple the flux line to the collector through the control module and drive mechanism. Tracking accuracies of 0.1 to 0.25 degrees (1σ) of collector rotation are possible. In fact the tracking accuracy of an individual collector is more dependent on the drive mechanism resolution than on the error detection system.

The required collector position for any specific time can be calculated, coded as a commmand collector position point, and transmitted via a serial communication link to the local control module(s) by the master controller. The local control module would then read its associated collector position indicator such as a shaft encoder, compare this reading with the master command point, and, if the collector is greater than five degrees away from the command point, move the collector to the command point location.

The addition to the present tracker design of these two features - position feedback and serial communications - would open up the avenues to local control modification by sending commands from the master controller to the local control module via the serial communication link. With the collector position always known, the collector would always be closely aligned with the sun even if direct sunlight were absent because of cloud cover. As an added bonus the communications link could be used by the master controller to interrogate the local control module to obtain a status report from the local control module. This would enable an operator at a console (CRT, TTY, etc.) to obtain information such as the temperature of a collector receiver, the present position of a collector, or almost any other condition of a collector that the local control module has the means to measure.

Figure 4 illustrates an implementation of the collector controller with revisions discussed above as they may be used for the STEOR system. Note that communications capability is included. Also note that the collector position feedback is optional.

EXXON SOLAR THERMAL ENHANCED OIL RECOVERY (STEOR) CONCEPTUAL COLLECTOR DESIGN

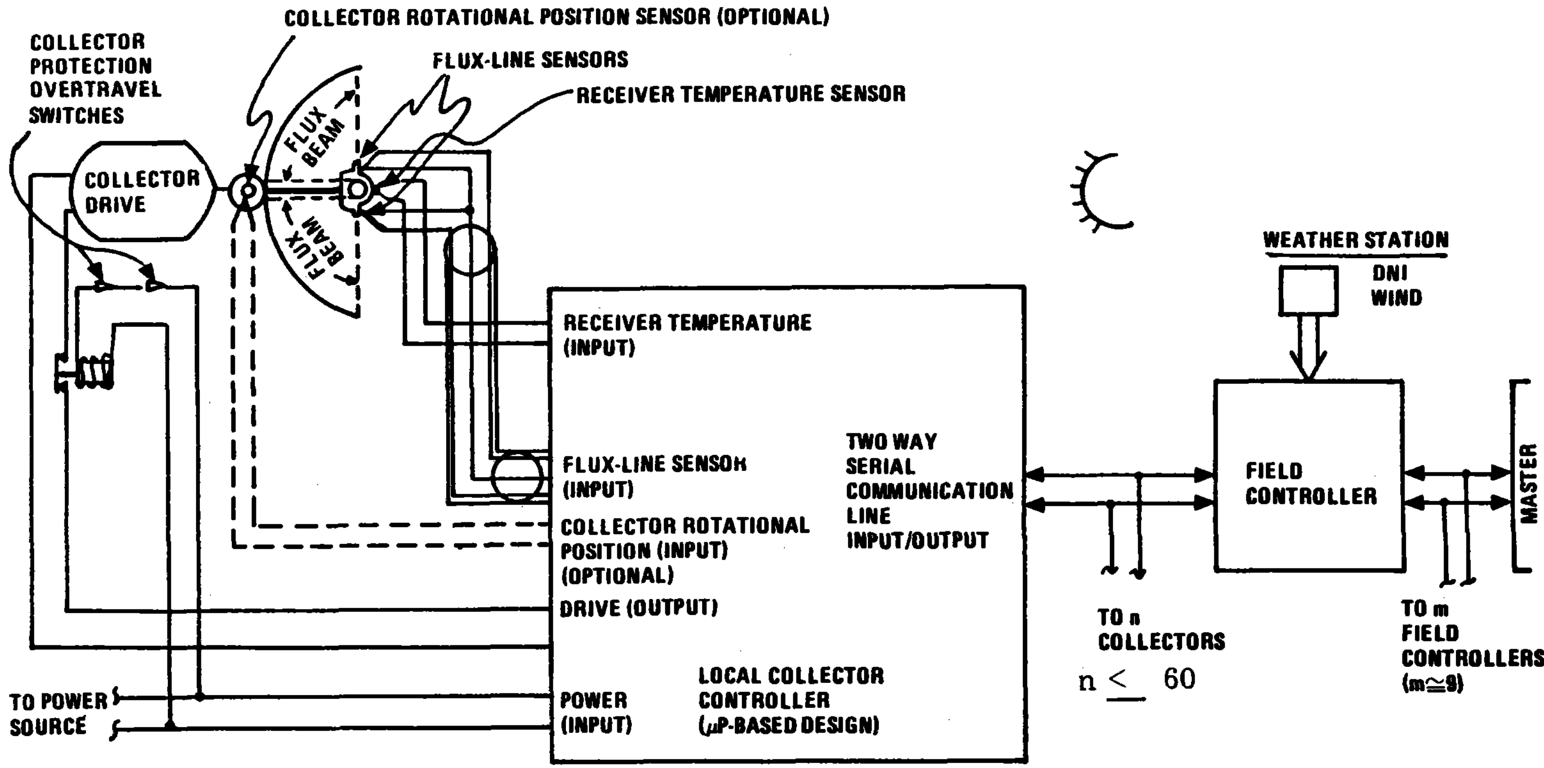

Figure 4. Local Controller Schematic

5.0 LOCAL CONTROLLER PRELIMINARY SPECIFICATION

The following ten (10) pages contain the local controller preliminary specification in the standard Honeywell specification format .

Honeywell PRELIMINARY

ENERGY RESOURCES CENTER CODE IDENTIFICATION NO. 55513

HONEYWELL REQUIREMENTS SPECIFICATION NO. ES1031-01

THIS HONEYWELL REQUIREMENTS SPECIFICATION IS FOR:

S.T.E.O.R. Local Controller Hardware and Software Design Specification

SIGNATURES	DATE
PREPARED BY W.E. Anderson, R.J. Schnell, M.R. Schwochert	02-27-80
APPROVED BY PROJECT ENGINEER Paul D. Mitchell	

REVISIONS

LTR	DESCRIPTION	DATE	APPROVAL	LTR	DESCRIPTION	DATE	APPROVAL

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1.0 SCOPE

(TBD)

2.0 APPLICABLE DOCUMENTS

2.1 Specifications (TBD)

2.2 Standards (TBD)

2.3 Drawings

2.3.1 Honeywell Drawing No. 23000693 - (TBD) Honeywell Inc., Technology Strategy Center, (date).

2.4 Bulletins (TBD)

2.5 Other Publications (TBD)

3.0 REQUIREMENTS

The usual requirements for a single axis sun tracking solar collector follow:

3.1 Automatic search sequence to lock onto the sun upon receipt at the local controller of a track authorization command.

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3.2 Maintenance of a correct relationship to the sun of TBD ($\sim \pm .25^{\circ}$, 1σ) of collector rotation in elevation in the presence of adequate direct normal insolation (DNI). Tracking accuracy can be tightened easily, but the specification must be compatible with the structural rigidity of the collector to avoid hunting.

3.3 (Maintenance of a collector relationship to the sun of $\pm 5^{\circ}$ during brief periods of insufficient DNI. This feature is regarded as desirable, but it is not an absolute requirement.)

3.4 Maintenance of a relatively stable collector attitude in the presence of intermittent interruptions of DNI or during gusty winds with wind speed less than the stow wind speed.

3.5 Return of the collector to the stowed position when the system is not authorized to operate.

3.6 Monitoring of conditions for protection of the individual collectors from unsafe conditions, such as too high receiver temperature, and returning of the collector to the stowed position after occurrence. Stow after a too high receiver temperature should be permanent, i.e., stow should last until the operator resets the system.

3.7 Transmission of collector stow status to the master controller for interpretation.

3.8 Provision for a means for individual manual control of each collector for maintenance purposes.

3.9 Bypassing of all other electrical circuits and stopping of the collector rotation should the collector exceed normal travel limits. Reliable switches such as mercury switches shall be considered.

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3.10 Capability of driving the collector at full speed over the range of elevation used for tracking and stow. In particular, the capability shall exist to drive the collector to the stow position at full speed.

Due to the large size of the STEOR field, special sun-tracker requirements exist as presented below. They are arranged in order of priority, i.e., No. 1 is the most important feature.

3.11 Protection. Hardware such as a clamp-on RTD to monitor the temperature of the receiver is required. STEOR is a high temperature application. If the temperature of the receiver exceeds $\sim 600^{\circ}F$, the black chrome on the receiver may fail. The failure point of the black chrome is $\sim 650^{\circ}F$.

The system shall also be protected from lightning. This may be at the expense of damage to a single collector per lightning strike.

3.12 Communications. The individual collectors shall be capable of receiving a command input to permit the operator to modify the operational sequences of the collector. The collector shall transmit status every five minutes (as an estimate) to the field controller and to the master controller to permit operator interpretation of status. Included in communications shall be the ability to position any collector or series of collectors from the master controller for purposes of cleaning reflectors or system repair, to change deadbands, to permit tracking tolerance to be varied with the time of day, to stow collectors individually, ...

3.13 Reliability. The system shall be reliable. Collector positional feedback is optionally required such as could be obtained with a shaft encoder or a potentiometer. Reliable limit control such as with a shaft encoder or with mercury

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LTR	DESCRIPTION	DATE	APPROVAL

switches is required.

4.0 HARDWARE SPECIFICATIONS

Figure 1 depicts the local controller in the STEOR control system.

The implementation of the requirements in 3.0 shall be accomplished with a local controller meeting the specifications in Table 1.

5.0 SOFTWARE SPECIFICATIONS

Figure 2 presents the required STEOR local controller logic flow diagram.

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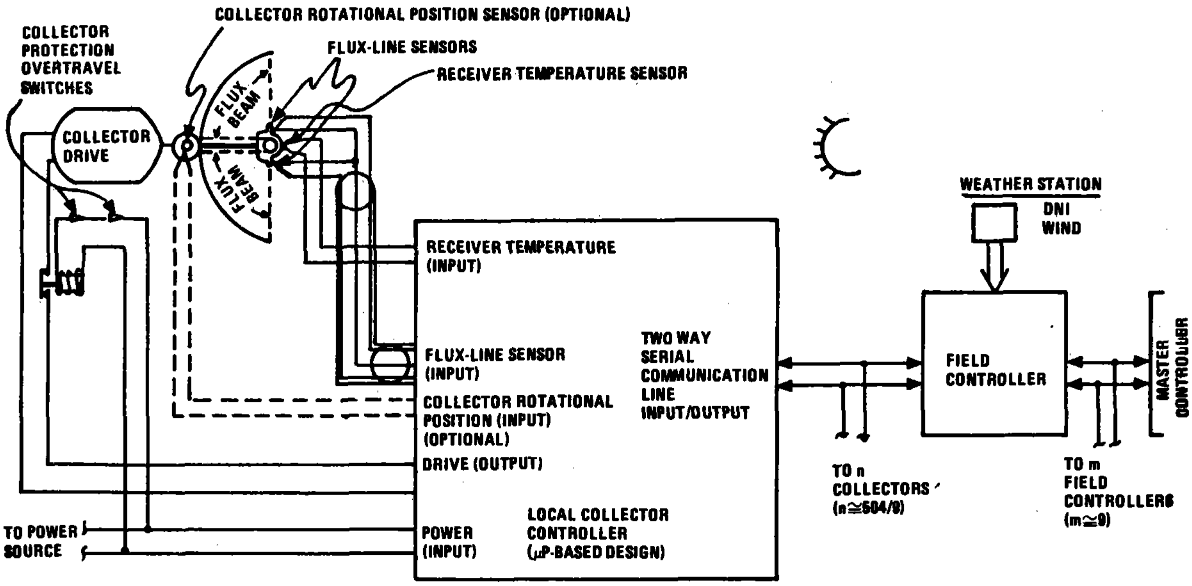

Figure 1. Solar Thermal Enhanced Oil Recovery (STEOR) Collector Control Systems.

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Table 1. STEOR Local Controller (DC) Specifications

CHARACTERISTIC	SPECIFICATION
Electronics Power Requirements	24 VDC ± 5V 200 mA (Nominal)
Operating Temperature	-20°F to 150°F Ambient
Interface Signal (Inputs)	
Communications	RS 422 110 Baud
Temperature	Analog - RTD
Maximum Forward Limit	Normally Closed Switch
Stow Limit	Normally Closed Switch
Overtravel	Normally Closed Switch
Cabinet Door	Normally Open Switch
Position Feedback (optional)	Precision Pot. / Shaft Encoder / Resolver (Optional)
Indicator Signal (Outputs)	
Program Running	Green LED
Manual Mode	Green LED
Overtemperature/Manual Mode	Red LED
Overtemperature/Auto Mode	Red LED
Motor Overcurrent	Red LED
Forward and Reverse Drive	Green LEDs
Drive Output	± 24 VDC 19 Amps (Current limited to 21 Amps for approximately 2 seconds)
Manual Controls	
Program Reset	Push Button Switch
Mode Select	3-Position Toggle Switch: Manual/Auto/Not Used
Manual Motor Drive	3-Position Toggle Switch: Reverse/Off/Forward (Spring loaded to the off position)
Local Authorization	2-Position Toggle Switch: Remote/Local
Tracking Error	.125 Degree RMS
Physical	10 3/4 x 12 3/4 x 2 1/2 inches with pre-drilled holes to directly mount in a standard Nema 4 (12 x 14 x 6 inches) enclosure with weld nut spacing of 10 1/4 x 12 1/4 inches

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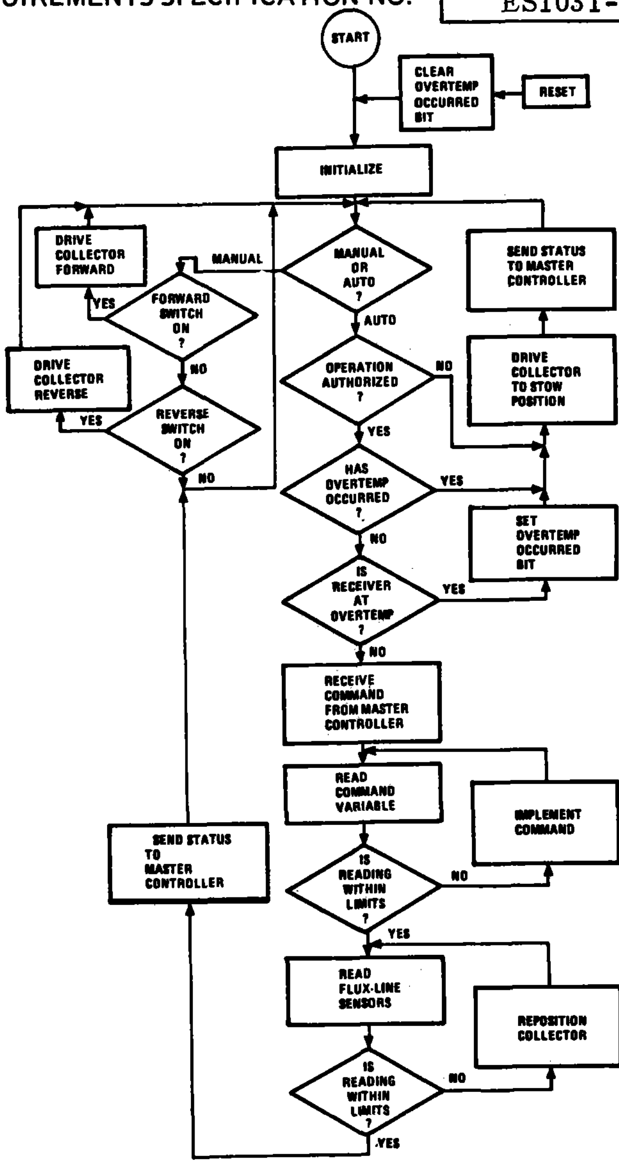

Figure 2. STEOR Local Controller Logic Flow Diagram.

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6.0 QUALITY ASSURANCE (TBD)

7.0 PREPARATION FOR DELIVERY (TBD)

8.0 NOTES (Not requirements)

8.1 Introduction to STEOR (TBD)

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7.0 FIELD CONTROLLER PRELIMINARY SPECIFICATIONS

The following fifteen (15) pages contain the field controller preliminary specification in the standard Honeywell specification format.

Honeywell

PRELIMINARY

ENERGY RESOURCES CENTER CODE IDENTIFICATION NO. 55513

HONEYWELL REQUIREMENTS SPECIFICATION NO. ES1030-01

THIS HONEYWELL REQUIREMENTS SPECIFICATION IS FOR:

S.T.E.O.R. Field Controller Hardware and Software Design Specification

SIGNATURES	DATE
PREPARED BY W.E.Anderson, R.J. Schnell, M.R. Schwochert	Feb. 27, 1980
APPROVED BY PROJECT ENGINEER Paul D. Mitchell	

REVISIONS

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1.0 SCOPE (TBD)

2.0 APPLICABLE DOCUMENTS

2.1 Specifications (TBD)
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2.3 Drawings (TBD)

2.3.1 Honeywell Drawing No. 23000TBD-(TBD), Honeywell Inc., Technology Strategy Center, (date).

2.4 Bulletins (TBD)
2.5 Other Publications (TBD)

3.0 REQUIREMENTS

The requirements for the field controller follow:

3.1 The field controller shall be able to communicate with its associated local controllers at the collectors at 110 baud.

3.2 The field controller shall be able to communicate with the master (i.e., supervisory) controller at 9600 baud.

3.3 The field controller shall be able to communicate with the portable field controller display box (which is used for diagnostics) at 9600 baud.

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3.4 The field controller shall be designed to transmit signals in series pairs for transmission error detection and to repeat the signals when requested to do so by a receiver.

3.5 The field controller shall communicate with the local controllers as follows:

3.5.1 Send track authorization.

3.5.2 Send stow commands.

3.5.3 Send collector elevation angle commands (optional).

3.5.4 Send commands to an individual local controller.

3.5.5 Send broadcast commands to all of its associated local controllers.

3.5.6 Send modifications to parameters in algorithms in its associated local controllers.

3.5.7 Send addresses.

3.5.8 Receive status bits (on/off, good/bad, true/false, go/no go, high/low, overcurrent, auto./manual, temperature limits, flow limits, elevation tracking travel limits, DNI limits, pressure limits, expansion limits, stow status).

3.5.9 Receive status words (temperature in ^{o}F, flow in gpm, collector position in degrees of rotation in elevation (optional), pressure in psig, DNI in W/m^2).

3.5.10 Receive address.

3.5.11 Receive warnings, faults, and emergency situations.

3.6 The field controller shall communicate with the master controller as follows:

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3.6.1 Send address.

3.6.2 Send field status bits (DNI, wind, flow, valves, pumps, temperatures, pressures, voltages).

3.6.3 Send field status words (DNI, wind, flow, valves, pumps, temperatures, pressures, voltages).

3.6.4 Send individual collector status (bits and words).

3.6.5 Send all collector status (bits and words).

3.6.6 Send warnings, faults, and emergency situations.

3.6.7 Receive individual commands at its address.

3.6.8 Receive broadcasted commands.

3.6.9 Receive modifications to parameters in its algorithms.

3.6.10 Receive authorization to operate the field.

3.6.11 Receive commands to open/close valves.

3.6.12 Receive commands to turn pumps on/off.

3.6.13 Receive discrete collector elevation limit position commands.

3.6.14 Receive collector angular orientation commands (optional).

3.6.15 Receive commands to stow the field.

3.7 The field controller shall be designed to accept environmental data of the following types and quantities (n):

3.7.1	Direct normal insolation (DNI)	(1)
3.7.2	Wind speed	(1)
3.7.3	Ambient temperature	(3)
3.7.4	Rain, hail, snow	(1)
3.7.5	Ice (optional-use feature)	(1)

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3.8 The field controller shall be designed to activate or control the following types of devices and quantities (n):

3.8.1	Pumps	(3)
3.8.2	Valves - open/close	(3)
3.8.3	Valves - modulating	(3)
3.8.4	Alarms	(1)
3.8.5	Field freeze protection	(1)

3.9 The field controller shall be designed to monitor analog parameters of the following types and quantities (n):

3.9.1	Temperatures	(1)
3.9.2	Flow rates	(1)
3.9.3	Pressures	(2)
3.9.4	Valve positions	(1)
3.9.5	Collector orientations (optional)	(TBD)

3.10 The field controller shall be designed to monitor discrete signals of the following types and quantities (n):

3.10.1	No flow	(1)
3.10.2	Low voltage	(8)
3.10.3	Power loss	(8)
3.10.4	Miscellaneous faults	(TBD)
3.10.5	Hydraulic problems	
	3.10.5.1 Loss of power	(TBD)
	3.10.5.2 Loss of pressure	(TBD)
	3.10.5.3 Loss of hydraulic fluid	(TBD)
3.10.6	Liquid levels	(1)

3.11 The field controller shall be designed to permit at the field controller manually overriding controls of the following types:

3.11.1 Track authorization

3.11.2 Pumps

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3.11.3 Valves - open/close
3.11.4 Valves - modulate
3.11.5 Freeze protection

3.12 The field controller shall be designed with start and stop software timers (for delays) relating to:

3.12.1 DNI
3.12.2 Wind speed
2.12.3 Power loss
2.12.4 Others (TBD)

3.13 The field controller shall be designed with an accurate algorithm and accurate clock capable of calculating the elevation and azimuth angles of the sun for any time of the day, for any day of the year, and at any latitude and longitude where solar systems may be used. (optional)

3.14 The field controller shall be designed to operate on 24 VDC ± 5 VDC.

3.15 The field controller shall have a 24 VDC battery back-up system.

3.16 The field controller shall be designed to protect the field based on data it receives for the following types of problems or situations:

3.16.1 No flow
3.16.2 High temperatures
3.16.3 High pressures
3.16.4 Boiling
3.16.5 Low liquid levels
3.16.6 High winds
3.16.7 Loss of power
3.16.8 Low voltage
3.16.9 Hydraulic problems

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

3.16.9.1 Loss of power
3.16.9.2 Loss of pressure
3.16.9.3 Loss of hydraulic fluid

3.16.10 Low temperatures requiring freeze protection

3.16.11 Failure of some or all collectors to stow

3.16.12 Manual field authorization or a collector manually out of stow. The response shall be to turn on the pump(s) and to activate the valve(s) properly.

4.0 HARDWARE SPECIFICATIONS

Figure 1 is a functional chart of the STEOR field controller.

The implementation of the requirements in 3.0 shall be accomplished with a field controller meeting the specifications in Table 1.

The sensors which shall be used in conjunction with the field controller are listed in Table 2.

5.0 SOFTWARE SPECIFICATIONS

Figure 2 presents the required STEOR field controller logic flow diagram.

6.0 QUALITY ASSURANCE (TBD)

7.0 PREPARATION FOR DELIVERY (TBD)

8.0 NOTES (Not requirements)

8.1 Introduction to STEOR (TBD)

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

Honeywell

ENERGY RESOURCES CENTER CODE IDENTIFICATION NO. 55513

HONEYWELL REQUIREMENTS SPECIFICATION NO. ES1030-01

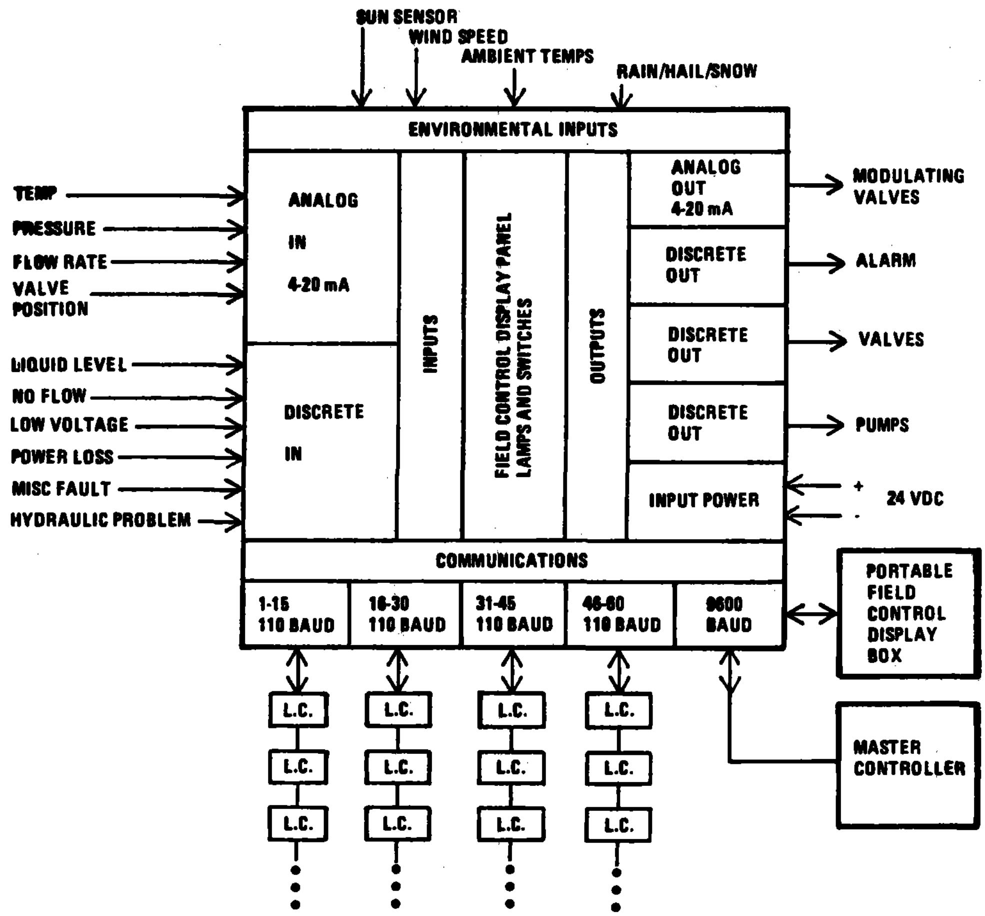

Figure 1. Functional Diagram of the STEOR Field Controller Showing Inputs and Outputs.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

Table 1. STEOR Field Controller Specifications

CHARACTERISTIC	SPECIFICATION
Power Requirements	
Field Controller	24 VDC ± 5 V @ 1 Amp (Nominal)
Ice Detector (Optional)	Powered from the field controller
Sun Sensor (Elevation and DNI)	Powered from the field controller
Wind Sensor	Powered from the field controller
Operating Temperature	$-20^{o}F$ to $+150^{o}F$ ambient
Four (4) Communication Channels	RS-422-A, 110 baud Up to 15 receivers per channel
One (1) Communication Channel	RS-422-A, 9600 baud To master controller and to portable field controller display box when plugged into field controller
Input Signals	
Analog Inputs	
Ambient Temperature	Analog RTD measurement
Wind Speed	0-7.6 VAC, corresponds to 0-100 mph
Solar Intensity, DNI	0-10 VDC, corresponds to 0-1000 W/m^2
Ice Buildup (Optional)	+24 VDC = no ice 0 VDC = more than 0.10 inch of ice
Temperatures, Pressures, Flow Rates, Valve Positions	Analog, 4-20 mA input

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

Table 1. STEOR Field Controller Specifications (Continued)

CHARACTERISTIC	SPECIFICATION
Discrete Inputs	
AC Power Loss	Contacts open = AC power off Contacts closed = AC power on
Liquid Levels Low Voltage Miscellaneous Fault Rain/Hail/Snow Hydraulic Problem	Contacts open = fault condition Contacts closed = no fault condition
No Flow	Contacts open = no flow Contacts closed = flow
Output Signals	
Analog Outputs	
Modulating Valve Control	4-20 mA output signal
Discrete Outputs	
Pump Control Signal Alarm Valve Control	+ 24 VDC turns on 0 VDC turns off
Trip Points and Time Delays	All are manually adjustable by commands from CRT/KB
AC Power Loss	30-second delay
AC Power Recovery	3-minute delay
Wind Speed Above Trip Point	30-second delay

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

Table 1. STEOR Field Controller Specifications (Continued)

CHARACTERISTIC	SPECIFICATION
Wind Speed Below Trip Point	2-minute delay Wind speed trip point is manually adjustable; it is factory set at 25 mph
Solar Intensity Above Trip Point	3-minute delay
Solar Intensity Below Trip Point	20-minute delay Solar intensity level trip point is manually adjustable; it is factory set at 315 W/m^2 DNI
Front Panel Status Lamps	28 VDC incandescent GE #387
Program Running	Green
Power Loss (Low Voltage or AC Power Loss)	Red
Environmental Fault	Red
Discrete Input Fault	Red
Demand On	Green
Alarm Condition	Flashing red
Pump Signal On	Green
No-Flow	Red
Track Authorization Signal On	Green
Analog Input Fault	Red
Front Panel Switches	
Valve Control	3-position toggle: open-close-auto
Program Reset	Momentary push button
Lamp Test	Momentary push button

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

Table 1. STEOR Field Controller Specifications (Continued)

CHARACTERISTIC	SPECIFICATION
Power Switch	2-position toggle: on-off
Pump Switch	2-position toggle: on-auto
Track Authorization Switch	3-position toggle: on-off-auto
Alarm Acknowledge	Momentary push button
Circuit Board Switches	
Sun Simulation	2-position toggle: on-off
Cabinet	Type NEMA 4
Hoffman A-1412 CHNF	14 x 12 x 6 inches Mounting holes 5/16-inch diameter, 10 x 14 3/4 inches on center

REVISIONS			
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Table 2. STEOR Field Controller Sensor List

SENSOR	QUANTITY
Solar Wake-up Sensor (Honeywell Inc.)	1
Wind Speed Sensor (Weather Measure W200SA)	1
Ambient Temperature Sensor (RTD's)	3
Rain/Hail/Snow Detector	1
Ice Detector (Optional)	1
Liquid Level Detector	1
Low Voltage Relays, 1 per Battery Pack	8
Power Loss Relays, 1 per Battery Pack	8
Flow Switches	1
Hydraulic Sensors	(TBD)
Temperature Sensors, 4-20 mA	1
Temperature Sensors, RTD's	(TBD)
Pressure Sensors, 4-20 mA	2
Flow Rate Sensors, 4-20 mA	1
Modulating Valves	3
Valves, On-Off	3
Pumps	3
Alarms	1

REVISIONS			
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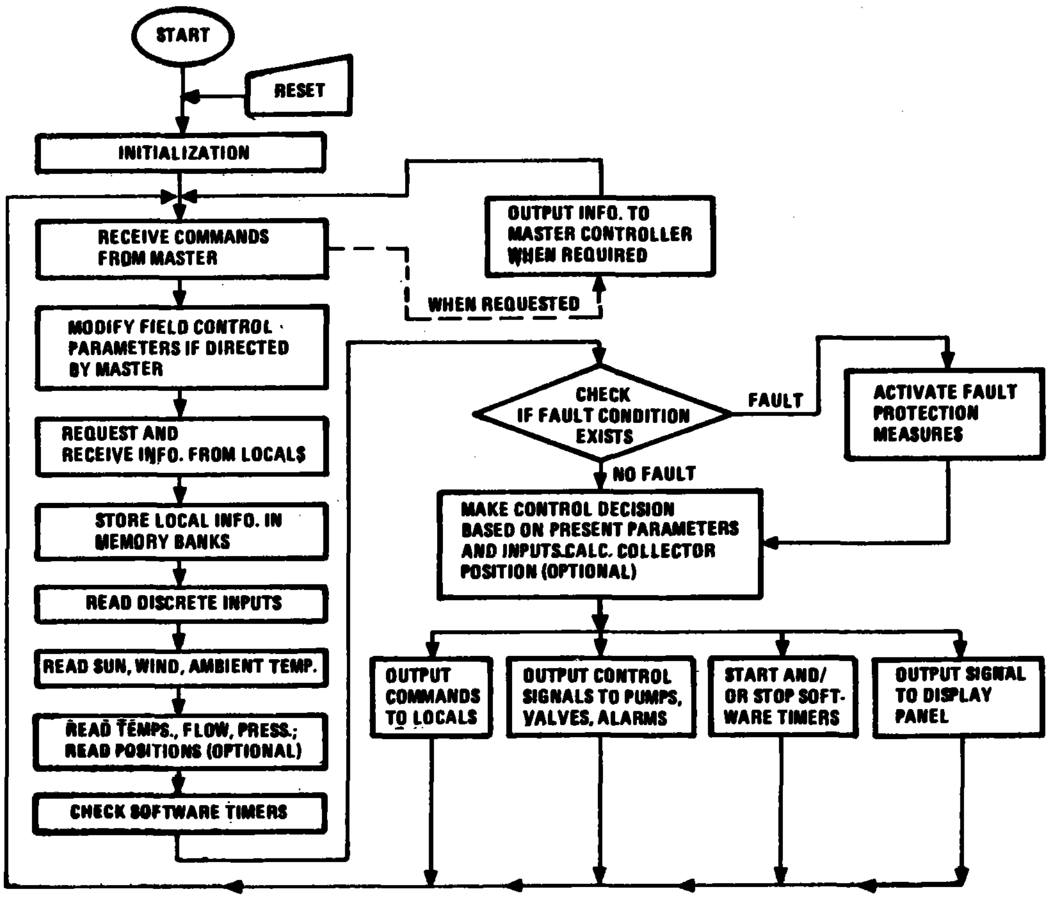

Figure 2. STEOR Field Controller Logic Flow Diagram.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

8.0 MASTER CONTROL CONCEPT

8.1 Control Philosophy

The control system is a distributed system where particular control functions are performed by specific microprocessor controllers. These controllers are all integrated to operate as a system by a supervisor master controller.

The major control functions provided by the system are:

- temperature control for the solar preheat field (250°F, local loop)
- process steam temperature control for the steam generating field (865 psig @ 540°F max).
- make-up water control for the steam generating field
- auxiliary boiler demand control
- Thermal Flush Control
- Coarse tracking (synthetic track) of 504 collector systems (optional)
- Fine tracking (flux line tracking) of 504 collector systems

The STEOR integrated system control is separated into two areas:

- Generation of Process Steam and Hot Water, ie:
  - Collector Control:
    - Closed Loop Sun Tracking
    - Synthetic Track (optional)
  - Thermal Loop Flow Control (local loop)
  - Auxiliary Boiler Control
- Use of Process Steam and Hot Water, ie:
  - Process Steam Loop
    - Valves
    - Pumps
  - Make-Up Water
    - Valves

The STEOR can be thought of as operating in two basic "modes":

"On-Line Mode"

- Solar Tracking Control
- Process Steam Control
- Man-Machine Interface To:
  - Change System Mode
  - Access Process Variable Data
- Archive System Performance Analysis Data (optional)
- Print Reports

"Off-Line Mode"

- Support Data Reduction for System Performance Analysis
- Print Reports

These major functions and modes are distributed in four major control subsystems:

- Master Controller subsystem
- Process Controller subsystem
- Field Controller subsystem
- Local Controller subsystem

Overall system control is maintained by the master controller (MC). The MC continuously requests status information from the process controller (PC) and the nine field controllers (FC). At present sample rates, it is envisioned that the MC will have a complete "snapshot" of all the system process variables once every 30 seconds. The master controller uses this snapshot to subsequently order mode change (if required) to the PC and FC.

The following list is typical of the data inputted to the MC from the PC and FC subsystems:

- collector temperatures
- collector flow discretes
- mechanical limit discretes
- collector position values
- solar preheat loop manifold temp
- total solar preheat loop manifold temps
- process steam loop manifold temps
- wind speed measurements
- DNI insolation measurements
- battery status
- process heat loop bypass value status
- field electrical power available
- discrete flow switches

The remaining paragraphs describe in detail the master controller in terms of a functional description, hardware, and software.

Figure 5 is an illustration of the STEOR Control and Instrumentation showing the relationship of the Master Controller to the field controllers, process controller, and data acquisition controller.

STEOR CONTROL AND INSTRUMENTATION BLOCK DIAGRAM

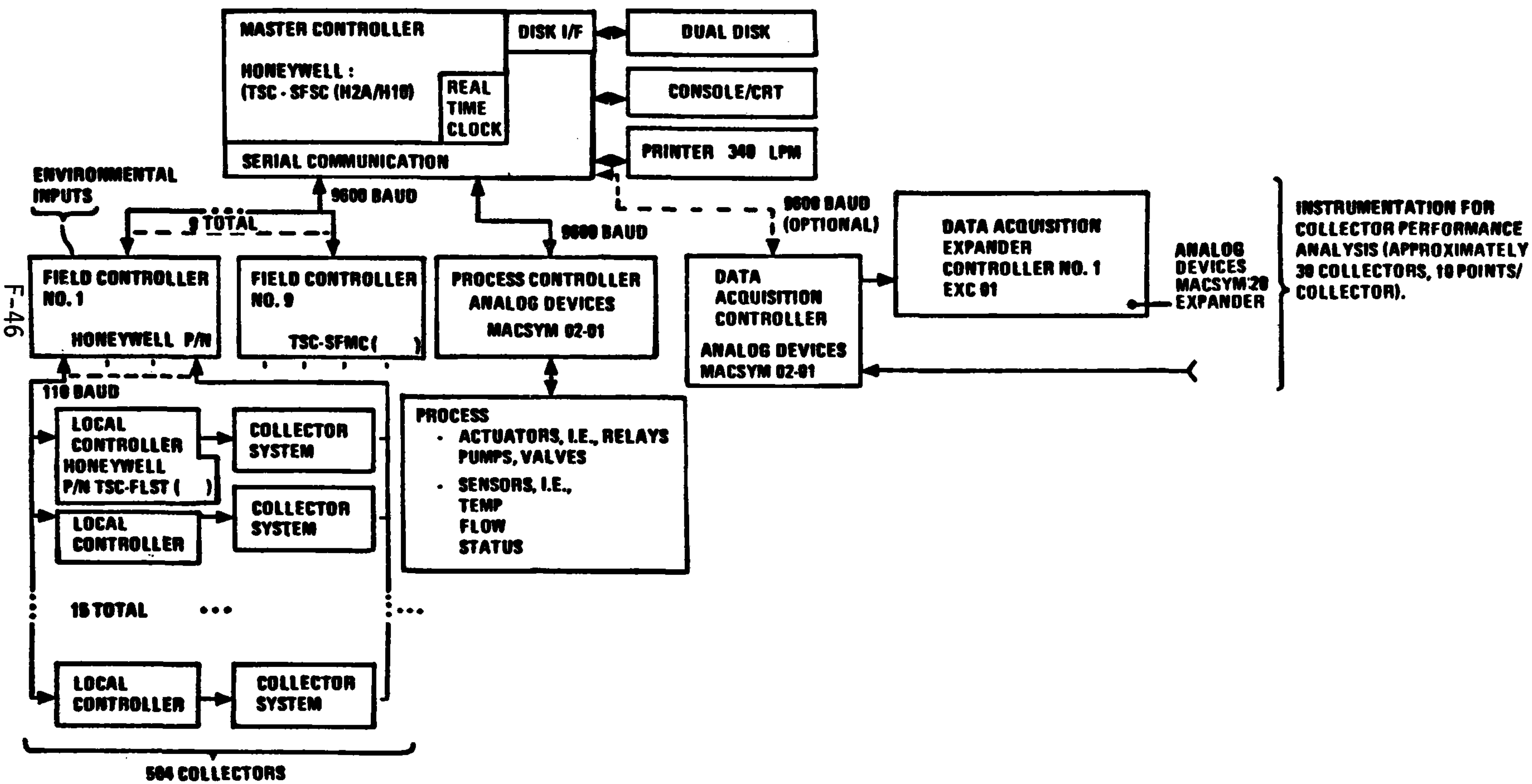

Figure 5. STEOR Control and Instrumentation Block Diagram

8.2 Master Controller (MC)

8.2.1 MC Functional Description

The MC provides the following major functions:

- Overall supervisory control to process controller and nine field controllers
  - allows (enables) automatic wakeup
  - transfers manually entered set-point data to the particular controllers
  - places system controllers to the required mode to facilitate overall control
- A Man-Machine Interface
  - To enter set point data for process controller
  - To allow automatic collector wake-up
  - To allow system status review
- System Status Display
  - Receiver temperatures
  - Collector operational status
  - Collector position (Optional)
  - Process steam status
  - Valve status
  - Pump status
  - Mass flow rates
- Process variables monitor to sound alarms, and display operator prompts signalling required operator interactions
- 2-way, high speed, serial communication to the process controller and the 9 field controllers

8.2.2 MC Hardware Description

The MC is a specially tailored micro computer system. Figure 6 illustrates the components utilized. The serial I/O (FC & PC interface) functions are all mechanized by a dedicated microprocessor system (H10). Classical disk control, CRT/KB control, and the serial line printer are mechanized by another microprocessor system (H2A). The system includes a floppy disk to support application program development as well as storage of system status data.

The H2 system consists of:
- H2 CPU circuit card (includes 8K PROM memory) Memory and 4K RAM memory
- 64K (8 bit words) dynamic ram memory circuit card
- Disk controller circuit card
- Parallel interface adapter circuit card
- Boschert power supply
- Motherboard chassis

The H10 system consists of:
- H10 CPU circuit card (includes 8K PROM)
- RAM memory circuit card (4K or 48K-8 bit words)
- (4) serial data links circuit card
- Power supply
- Motherboard chassis

The system peripherals are:
- (2) Schugart floppy disks (200K bytes/disks)
- (1) CRT/KB unit
- (1) GE terminet line printer, (340 LPM)

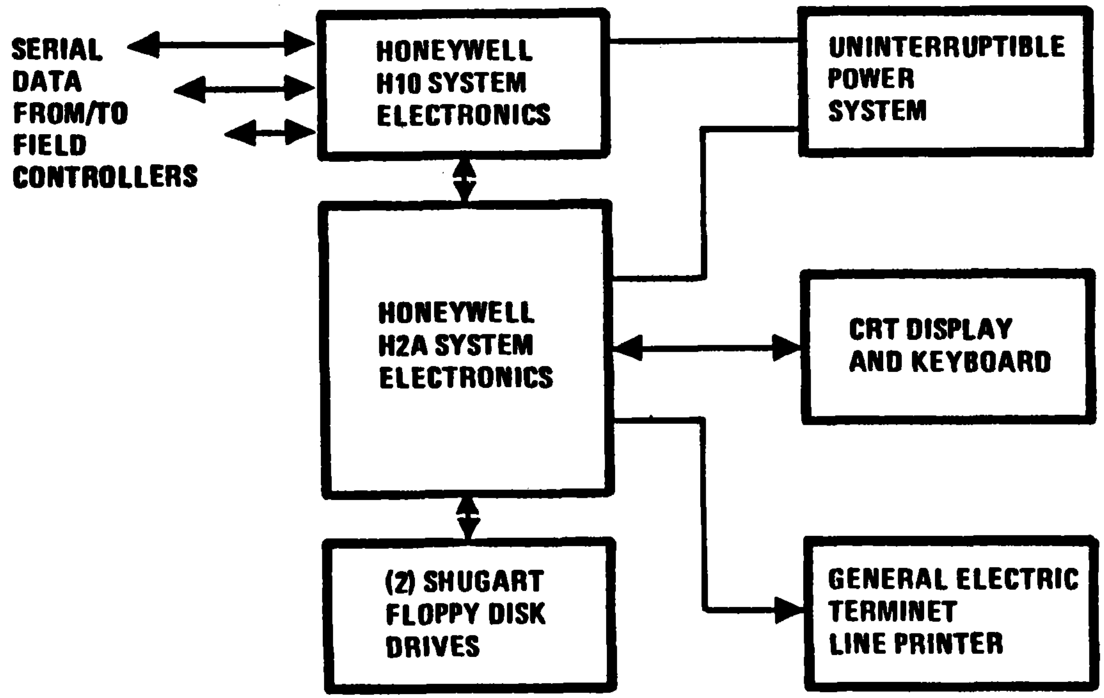

Figure 6. Master Controller.

8.2.3 Software

8.2.3.1 System Software

The H2A operating system is the M6800 MDOS system designed to support 6800 type microprocessor systems. This MDOS system supports MPL and FORTRAN higher order languages as well as the M6800 assembly level language for application software development. Editor and utility routines are all part of the MDOS operating system.

8.2.3.2 Applications software:

Special purpose software developed for a particular application is referred to as " applications software". Based on the execution speed required of the application, this software is either implemented in "assembly language" or a higher order language, i.e. "FORTRAN".

Since time is of the essence in supporting the serial communication requirements, this software will be written in the M6800 Motorola assembly language. Other functions, such as organizaing system responses for overall control, developing mode logic, accessing data from memory for display on the CRT, formatting of data for subsequent printout, etc., will be written using the FORTRAN language.

9.0 PROCESS CONTROL CONCEPT

The Process Controller (PC) is a microprocessor based control and data acquisition system capable of operating under supervisory control of the MC or under its own keyboard entered control inputs.

9.1 Functional Description

The main purpose of the PC is to control the dispensation of the hot water and process steam once these two energy flows have been supplied by the collector field. The PC measures process variables and executes control algorithms to implement closed loop control of the following valves and actuators:

- 70^{O}F feedwater to existing boiler pump on/off
- pre-heat pump on/off
- thermal storage to steam field and existing boiler
- thermal flush pump
- steam water recirculating pump on/off
- hot water flow control
- feedwater input valve control
- bypass valve control
- make-up water valve control

The following process variables are measured.

- valve position status
- solar preheat field outlet temperature
- steam generating field outlet temperature
- steam generating field outlet pressure
- system set-point requests
- operator demand (manual mode)

The PC software uses the above process variables to calculate the following control algorithms:

- hot water loop
- steam loop
- flush loop

Finally, the PC sends PC mode status along with process variàble, actuator command, and point status information to the MC.

9.2 Hardware description

The PC hardware selected is an Analog Devices Macsym 2 system.

MACSYM 2 is a complete stand alone system designed specifically for measurement and control applications. Both system hardware and software are human engineered to enable the simple and cost effective application of computer intelligence to measurement and control tasks. From system architecture and packaging, to software and documentation, MACSYM 2 is specifically designed to minimize the time, effort, and experience required for system configuration, hook-up and operation. No signal conditioning expertise is required. To configure MACSYM to signal conditioning requirements, appropriat I/O cards are plugged into any of the 16 card slots provided in the macsym mainframe. The cards are then connected directly to the application or to the optional externally mounted screw termination boards. Operating the system is equally easy. You need no prior software experience or a separate development system. Write your application programs immediately in MACBASIC, an easy to learn, easy to use, high level language.

The ADIO (Analog/Digital Input/Output) Controller, a key element of MACSYM provides an intelligent interface between real world signals and the environment of the high speed computer. It contains the elements necessary to implement all measurement and control functions by way of the unique ADIO bus structure.

Signal conditioning is accomplished by a wide variety of specialized plug-in cards, up to 16 of which can be accommodated in the MACSYM 2. Applications may be connected directly to the cards, or through optional screw terminal boards. Extension chasses are available to increase the card capacity to 256.

The ADIO Controller contains a single-shared analog to digital conversion system which eliminates the redundancy of data acquisition components on each card, thus reducing system costs and enhancing signal conditioning.

The 16-bit, high performance Central Processor Unit (CPU) is built on microprogrammed, Schottky 4-bit slice elements. It is capable of addressing 128K bytes of memory, and performs all functions traditionally associated with processors in the minicomputer class.

MACSYM 2 incorporates a microprocessor controlled data terminal which features a full ASCII keyboard and a five-inch CRT display, allowing MACSYM to be an interactive stand-alone unit,

Mass storage in the standard MACSYM 2 is provided by a reliable data cartridge system which features a microprogrammed controller and a 105K byte capacity. This integral system provides for storage of programs and data without the need for additional hardware.

Other components integral to MACSYM 2 include: a real-time clock for accurate system timing and control of real-time events, battery back-up protection for memory, serial communications ports, and an IEEE-488 communications interface.

Among the peripherals available to extend MACSYM's system capability are: mass storage systems (single or dual floppy disc), printers, terminals, a teletypewriter, an interactive graphics plotter, and a desk cabinet.

9.3 Software Description

Control output and process variable input functions are implemented using a specially designed BASIC interpreter, MACBASIC (trademark of Analog Devices, Corp).

MACBASIC is a high level, interactive programming language that is a highly enhanced version of standard Dartmouth BASIC and is optimized for measurements and control applications.

BASIC is a language intended to provide the casual computer user with a simple, but effective means of implementing a wide variety of data processing algorithms. Because it uses brief English language statements that are self explanatory, BASIC programs can be written in a short time even though the user has had no prior programming experience.

A BASIC statement is composed of an English language "keyword" such as PRINT IF, FOR, followed by the necessary expressions of variables and constants. With just a few simple BASIC statements, the user can perform calculations, from strings address the MACSYM II ADIO cards, and manipulate data to and from them.

One requirement in many measurement and control applications is the ability to perform several operations or "tasks", independently of each other, in the same program. Some examples might include the monitoring of several analog signals in the laboratory, or control of several process loops. In order to provide for this requirement, MACBASIC is structured as a "multitasking" language and contains the necessary keywords for implementation. Tasks are simply groups of MACBASIC language statements that are defined as a task, and are executed each time that task is activated either unconditionally, or by the satisfaction of a condition such as an external event, or on a periodic basis. Up to 18 tasks may be defined at a given time, and if more than one task is active at a given moment, the active tasks will share resources and run simultaneously unless a higher priority is assigned to a particular task. If a task completes its defined operation, it can "DISMISS" itself and return its resources to the system until the task is activated again.

10.0 SEQUENCE OF OPERATION

There are several different modes in which the STEOR field operates: some involve normal operation around the clock and others involve emergency operations such as emergency shut-down and freeze protection. Normal around-the-clock operations for a 24-hour day with sun and negligible daytime cloudiness are presented below. This presentation is followed by actions which are taken during departures from a typical and sunny day.

1.0 NIGHTTIME SEQUENCE

Sufficiently far into the night the system status is as follows:

1.1 All collectors of the preheat and steam generation fields are stowed.

1.2 All field controllers are monitoring the following:

- 1.2.1 Collector stow status
- 1.2.2 Ambient temperature for system freeze protection
- 1.2.3 Wind speed
- 1.2.4 Rain, snow, and hail
- 1.2.5 Direct normal insolation (DNI) and sun angle for the morning wake-up command

1.3 Preheat and steam generation field loops are at or near ambient temperature (because of the flush mode which was activated by the control system earlier, near sunset).

1.4 Preheat and steam generation field valves are in their field shutdown status. (Preheat field circulation pump outlet valves never close completely.)

1.5 Preheat field and steam generation field pumps are turned off.

1.6 The fossil-fueled boiler controls are active to protect the boiler and to produce steam.

1.7 The 250°F feedwater (FW) from the thermal storage tank is supplied to the fossil-fueled boiler until the tank is emptied.

1.8 Valves and pumps are controlled to transfer from thermal storage to 70°F FW for the fossil-fueled boiler.

1.9 All field controllers are authorized by the master controller to bring up both fields when the sun angle and DNI are above the threshold setting.

2.0 MORNING WAKE-UP

After receiving the wake-up authorization command from the master controller, each field controller of both fields does the following:

2.1 Starts the wake-up time delay (~ 3 minutes). (This prevents bringing the field up with only a small opening in clouds.)

2.2 Resets the wake-up timer if the DNI goes below the threshold value.

After the field controller timer times out, each field controller does the following:

2.3 Opens valves to supply 70°F FW to the preheat field

2.4 Turns on the circulation pumps for the preheat field

2.5 Operates valves and turns on the pressure boost pump to supply preheat feedwater to the steam generation field to fill the mixing chamber to the proper level.

2.6 Sends commands to all of its associated local controllers at the collectors to track the sun when liquid levels and flows are established.

The master controller and process controller supervise the system to control valves, pumps, and processes as required.

Both fields are now up and tracking the sun.

Other system conditions are these:

- The thermal storage tank is empty.
- The fossil-fueled boiler is still producing steam using 70°F FW.

3.0 PREHEAT FIELD OPERATION SEQUENCE

The operations during a sunny day are these:

3.1 The local controllers keep the collectors tracking the sun.

3.2 The control subsystem controls valves and the pressure boost pumps to continue to fill the thermal storage tank with 250°F preheat water. The circulation pump outlet valves are locally modulated using a signal from an adjacent temperature sensor to provide the 250°F outlet water.

3.3 The field controllers monitor pressures, temperatures, and flows to protect the field from high temperatures, high pressures, no flow, and boiling conditions. (Each field controller is programmed with the boiling point/pressure curve of the liquid.)

3.4 Valves and pumps are controlled to supply the fossil-fueled boiler with 250°F FW from the storage tank.

3.5 These operations (3.1-3.4) continue until close to sunset.

4.0 STEAM GENERATION FIELD OPERATION SEQUENCE

The operations during a sunny day are these:

4.1 The local controllers keep the collectors tracking the sun.

4.2 The liquid is continuously circulated in the steam generation field loop. When the loop temperature and pressure reach $540^{\circ}F$ and 948 psig, the steam valve on the flash separator is opened and controlled to produce and deliver steam at $527^{\circ}F$ and 865 psig.

4.3 The control subsystem continues to control valves and pumps to supply preheat water to the steam generation field to compensate for the mass of water departing the loop as steam.

4.4 The field controller monitor pressures, temperatures, and flows to protect the field from high temperatures, high pressures, no flow, and boiling conditions. (Each field controller is programmed with the boiling point/pressure curve of the liquid.)

4.5 These operations (4.1-4.4) continue until close to sunset.

5.0 COMPLETE SYSTEM OPERATION

The system operates during a sunny day as summarized below:

5.1 $70^{\circ}F$ FW is supplied to the preheat field.

5.2 The preheat field supplies its water to be used for filling the thermal storage tank, for feedwater to the steam generation field, and for feedwater for the fossil-fueled boiler. Alternate sources of feedwater are available if needed.

5.3 The pressure boost pump of the steam generation field and associated valves are controlled to maintain the liquid level in the mixing chamber of the steam generation field by using the preheat water.

5.4 The steam generation loop continuously circulates high temperature water and flashes some to produce steam at the flash separator.

5.5 The fossil-fueled boiler is producing steam at the temperature and pressure of that from the flash separator of the steam generation field.

5.6 The local controllers control the solar tracking of the collectors, protect the collectors and thereby the system from hazards, and communicate continually with the field controllers.

5.7 The field controllers control the field to operate within established limits as determined through continual communications with the master controller and the local controllers. New set points and other instructions arrive from the master controller; data arrives from the local controllers.

5.8 The process controller controls critical processes as supervised by the master controller.

5.9 The master controller continuously does the following:

5.9.1 Collects data on system operation from the field controllers.

5.9.2 Analyzes and updates system operating parameters as needed to control the entire system processes efficiently.

5.9.3 Supervises and directs the entire process control.

5.9.4 Outputs messages and alarms to the CRT and printer.

5.9.5 Allows operator interrogation and intervention via the CRT/keyboard.

5.9.6 Protects the system from hazards.

6.0 SUNSET SEQUENCE

When the sun angle and the DNI fall below the threshold setting:

6.1 The field controllers on both the preheat and steam generation fields:

6.1.1 Command each of their associated local controllers to stow its collector

6.1.2 Monitor inlet and outlet temperatures

6.2 70°F feedwater continues to flow into the preheat field.

6.3 The preheat field continues to deliver water but at minimum flow.

6.4 The flash separator no longer delivers steam.

6.5 The steam generation field continues to circulate water in its loop.

6.6 Feedwater for the fossil-fueled boiler is supplied from the thermal storage tank.

6.7 The fossil-fueled boiler continues to deliver steam.

6.8 The master controller continues to supervise and control the systems.

7.0 COOL DOWN FLUSH SEQUENCE

The two fields are hot. This thermal energy is saved to be used during the nighttime as feedwater for the fossil-fueled boiler by flushing both fields into the thermal storage tank. The cool down process proceeds in the following manner:

7.1 Control pumps and valves to supply 250°F feedwater from the thermal storage tank to the fossil-fueled boiler.

7.2 The fossil-fueled boiler continues to produce steam.

7.3 Control pumps and valves to supply 70°F feedwater to the preheat field.

7.4 Control pumps and valves to direct preheat field water into the mixing chamber of the steam generation field.

7.5 Control pumps and valves to direct the steam generation field water to the point where it mixes with 70°F feedwater.

7.6 Control valves to mix 70°F feedwater with the steam generation field water to produce water at 250°F.

7.7 Control valves to direct the 250°F field water to the thermal storage tank.

7.8 Monitor the outlet temperature of the steam generating field water until it reaches 250°F.

7.9 Close the 70°F feedwater valve to the preheat field.

7.10 Shut off the preheat field and steam generation field circulation and pressure boost pumps.

7.11 Close the 70°F feedwater valve to the steam generator water cool-down mixing point.

7.12 Set all valves to the nighttime shutdown position.

7.13 The field controllers, with the rest of the control system, continue to monitor the system to protect it from hazards; they provide freeze protection by starting up the flush mode using 70°F feedwater.

8.0 EVENING SEQUENCE

During the evening the following events occur:

8.1 The fossil-fueled boiler continues to produce steam using 250°F feedwater from the thermal storage tank until it becomes empty.

8.2 Pumps and valves are controlled to transfer to 70°F feedwater for the fossil-fueled boiler.

8.3 The system enters the nighttime sequence.

9.0 DEPARTURES FROM TYPICAL; LOCAL CONTROLLERS

The local controllers control or are controlled in the following manner should problems arise or should special control be required:

9.1 Fault detection and protection

9.1.1 Receiver overtemperature

9.1.1.1 Stows collector

9.1.1.2 Lights LED

9.1.1.3 Sets fault bit. Manual reset is required to clear the fault. This may be accomplished through the CRT/keyboard at the master controller or at the local controller.

9.1.1.4 Sends the fault status to the field controller.

9.1.2 Motor overcurrent

9.1.2.1 Stops the collector drive motor

9.1.2.2 Waits for the time delay to expire

9.1.2.3 Starts the collector drive motor

9.1.2.4 Lights the LED

9.1.2.5 Sends the fault status to the field controller.

9.1.3 Dead communication line

9.1.3.1 Waits for time delay to expire

9.1.3.2 Stows the collector

9.1.4 Collector overtravel

9.1.4.1 Collector drive motor leads are physically disconnected.

9.1.4.2 Local controller may have malfunctioned.

9.1.4.3 Sends alarm to field controller and on to master controller.

9.1.5 No flow, overexpansion, no pressure

9.1.5.1 Stows collector

9.1.5.2 Sends fault status to field controller

9.2 Manual control

In manual control the operator in the field and the controller perform as follows:

9.2.1 The operator sets the auto/manual switch to manual

9.2.2 The operator actuates forward or reverse switches to manually drive the collector toward zenith or toward nadir (stow).

9.2.3 The controller sends its status to the field controller.

10.0 DEPARTURES FROM TYPICAL; FIELD CONTROLLERS

10.1 Any of the following conditions cause the entire collector field to stow and cause the field controller to send an alarm to the master controller:

10.1.1 No flow

10.1.2 Loop overtemperature

10.1.3 Loop overpressure

10.1.4 Loop boiling condition

10.1.5 High wind speed

10.1.6 Rain, hail, snow

10.1.7 Lack of authorization from the master controller

10.1.8 A dead communication line to the master controller

10.2 The loss of AC power to the battery charger or a low DC voltage on the battery pack causes the collectors on that voltage bus to stow. The field controller sends an alarm to the master controller.

10.3 When the DNI is below threshold on a cloudy day:

10.3.1 The field controller activates a 20 minute timer.

10.3.2 The collector field remains up

10.3.3 The timer is reset if the DNI exceeds the threshold value before the timer times out.

10.3.4 If the timer times out, stow collectors and initiate the flush sequence.

10.3.5 If the DNI exceeds the threshold value, reinitiate the wake-up sequence.

10.4 The system is freeze protected as follows:

10.4.1 Ambient temperature is sensed with RTDs. The set point is 35°F.

10.4.2 Freeze protection is initiated at 35°F.

10.4.3 Control valves.

10.4.4 Turn on pumps.

10.4.5 Circulate 70°F feedwater through the preheat and steam generation fields and through any other pipes that could freeze.

10.4.6 Use freeze protection water as feedwater to the fossil-fueled boiler generating steam.

11.0 DEPARTURES FROM TYPICAL; MASTER CONTROLLER

11.1 Individual rows, groups, sections, or fields may be stowed from the master controller by:

11.1.1 Operator-entered commands on the CRT/keyboard.

11.1.2 The process control algorithms in the master controller for control or protection of the entire process and system.

11.1.3 Use of the all-stow panic button.

APPENDIX G

FAILURE MODES AND EFFECTS ANALYSIS

OF SOLAR THERMAL SYSTEM

APPENDIX G

FAILURE MODES AND EFFECTS ANALYSIS OF SOLAR THERMAL SYSTEM

This appendix details the results of a failure modes and effects analysis upon the solar thermal system described in Appendices A, B, and C. A failure modes and effects analysis is an extensive survey of the failure behavior of the system. "What if?" questions are asked about components, operators and process conditions to identify possible failure modes and their consequences together with the likelihood and severity. All modes of operation are considered. Where problems exist, the remedy is usually obvious and corrective action can be proposed. All the recommendations made in the course of this analysis have been incorporated into the preliminary design.

The failure modes and effects analysis is able to address both reliability and safety problems. The severity and probability of each failure mode are ranked qualitatively on the following ordinal scales.

Rank	Severity	Probability
1	Negligible, no shutdown	Highly unlikely
2	System shutdown	Low in lifetime of system
3	Damage to equipment, injury	Likely in system
4	Catastrophic damage, serious injury	Almost certain in system lifetime

The severity assigned to each failure mode is assigned without regard for the other protective features incorporated in the design.

Much attention has been paid to the ranking of the failure modes according to their "criticality"--this term generally being defined as the product of the assigned failure mode probability and severity. The concept of criticality is however misleading(as the product of two ordinal scales does not necessarily have meaning) and is generally unnecessary (as problem areas are usually conspicuous and need no further identification). Accordingly we make no attempt to define criticalities.

The failure modes and effects analysis follows.

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LEVEL #2 INSTRUMENTATION

LEVEL #3

LEVEL #4

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

DRAWING: 60035-1-50-1

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
SOLAR INTENSITY DETECTOR XSH/L-1	1.10	FAILS TO DETECT HIGH INTENSITY	DEFECTIVE INSTRUMENT IMPROPER CALIBRATION MALFUNCTION	FAILURE OF COLLECTORS TO UNSTOW	PUMPS P-101 AND P-103 FAIL TO TURN ON	COLLECTORS STOWED EVEN THOUGH ADEQUATE INSOLATION AVAILABLE SYSTEM EFFICIENCY DROPS	VISUAL SYSTEM STATUS MONITORED VIA COMPUTER	2	2	
	1.11	FAILS TO DETECT LOW INTENSITY	AS 1.10	VISUAL FAILURE OF COLLECTORS TO STOW	FAILURE TO SWITCH TO FLUSH MODE EXPOSURE SURFACE	LESS EFFICIENT OPERATION	MANUAL	2	1	
INTENSITY TRANSMITTER XT	1.12	FAILS TRANSMITTING FALSE HIGH INTENSITY	INTERNAL DEFECT	VISUAL MONITORING OF SYSTEM STATUS	PREMATURE START UP FAILURE TO STOW		MANUAL SHUT DOWN FIELD CONTROLLERS	2	1	
	1.13	FAILS TRANSMITTING FALSE LOW INTENSITY	AS 1.12	AS 1.12	PREMATURE SWITCH TO FLUSH MODE	POSSIBLE OVER-FILLING OF STORAGE TANK	FIELD CONTROLLERS	2	1	
INTENSITY RECORDER XR	1.14	FAILS RECORDING FALSE HIGH INTENSITY	INTERNAL DEFECT		ERRONEOUS DATA RECORDED			2	1	
	1.15	FAILS RECORDING FALSE LOW INTENSITY	AS 1.14	AS 1.14	AS 1.14			2	1	

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LEVEL #1 SOLAR THERMAL SYSTEM

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PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
WIND SPEED DETECTOR NSH-1	1.20	FAILS TO DETECT HIGH WIND SPEED	DEFECTIVE INSTRUMENT JAMMED IMPROPER CALIBRATION MALFUNCTION	COLLECTORS UNSTOWED	COLLECTORS UNSTOW IN HIGH WIND CONDITION	POSSIBLE DAMAGE TO COLLECTORS	MANUAL	2	3	
	1.21	FAILS ON (FALSE INDICATION OF HIGH WIND SPEED)	AS 1.20		PUMPS P-101 AND P-103 FAIL TO START	FAILURE OF SYSTEM TO START		2	2	
MASTER/FIELD CONTROLLER UC-100	1.30	FAILS TO SEND TRACK SIGNAL TO LOCAL CONTROLLERS	POWER FAILURE INTERNAL DEFECT MALFUNCTION	TRACKING DOES NOT COMMENCE ON HIGH SOLAR INTENSITY		NO PREHEATING OF WATER		2	1	
	1.31	FAILS TO SEND STOW SIGNAL	AS 1.30	MONITORING SYSTEM STATUS	FAILS TO STOW ON LOSS OF POWER OR HIGH WIND ETC.	POSSIBLE DAMAGE TO COLLECTORS NO STEAM GENERATION	COLLECTOR OVER-TEMPERATURE PROTECTION	2	4	
MASTER/FIELD CONTROLLER UC-400	1.32	FAILS TO SEND TRACK SIGNAL TO LOCAL CONTROLLERS	AS 1.30	AS 1.30				2	1	
	1.33	FAILS TO SEND STOW SIGNAL	AS 1.31		AS 1.31	AS 1.31	AS 1.31	2	4	
COLLECTOR TRACKING CONTROL	1.35	FAILS	MALFUNCTION DEFECTIVE INSTRUMENT	COLLECTORS HUNT	INABILITY TO FOCUS COLLECTORS	LESS EFFICIENT OPERATION		2	1	

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LEVEL #1 SOLAR THERMAL SYSTEM

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
DEMAND SWITCH HS-16	1.40	FAILS OFF	MALFUNCTION	FAILURE OF SYSTEM TO START	COLLECTORS FAIL TO TRACK SUN NO WATER CIRCULATION IN SYSTEM	NO STEAM GENERATION	MASTER CONTROLLERS AND PUMPS TURNED ON MANUALLY	2	2	
	1.41	FAILS ON	AS 1.40		SYSTEM STARTS IF INSOLATION ADEQUATE	POSSIBLE DAMAGE TO SYSTEM OR INJURY	MANUAL SHUT DOWN	2	3	
RESET SWITCH HS-36	1.42	FAILS OFF	DEFECT	MONITORING OF SYSTEM STATUS	SYSTEM CAN-NOT BE SHUT DOWN MANUALLY	POSSIBLE DAMAGE	SHUT DOWN OF EQUIPMENT INDIVIDUALLY	2	3	
	1.43	FAILS ON	MALFUNCTION	AS 1.42	SYSTEM SHUT DOWN	INTERRUP-TION		2	2	
HAND SWITCH HS-3	1.44	FAILS ON	DEFECT		LV-3 OPENED	POSSIBLE UNDESIR-ABLE FLOW OF WATER INTO PREHEAT FIELD		2	2	
	1.45	FAILS CLOSED	DEFECT		LV-3 CLOSED	NO FLOW THROUGH PREHEAT FIELD	LOW FLOW SHUT DOWN	2	4	
TIMER K[illegible]-1A	1.50	FAILS OFF	DEFECTIVE SWITCH TIME SETTING TOO LONG	MONITORING SYSTEM STATUS	FAILS TO SWITCH OPERATION OF STEAM GENERATOR FIELD TO	LOWER EFFICIENCY OF OPERATION	MANUAL SWITCH	2	1	

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LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 INSTRUMENTATION

LEVEL #3

LEVEL #4

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
					PREHEATING WATER					
	1.51	FAILS ON	DEFECT TIME SETTING TOO SHORT	MONITORING SYSTEM STATUS	SWITCH OPERATION OF STEAM GENERATOR TO PREHEAT MODE	EXCESSIVE HOT WATER PREHEATED	MANUAL SWITCH FLOW OF WATER TO COLLECTOR FIELD STOPPED WHEN TANK IS FULL	2	2	
TIMER KC-1B	1.52	FAILS OFF	AS 1.50	AS 1.50	FAILS TO SWITCH TO FLUSH MODE ON LOW INSOLATION	LESS EFFICIENT OPERATION	SWITCH TO FLUSH MODE FOLLOWING STEAM GENERATION	2	1	
	1.53	FAILS ON	DEFECTIVE SWITCH TOO SHORT A TIME SET	AS 1.50	FLUSH MODE INITIATED	AS 1.52		2	1	
TIMER KC-14	1.60	FAILS OFF	DEFECTIVE TIMER MALFUNCTION	FAILURE TO REACH STEAM GENERATION TEMPERATURE	FAILURE TO SWITCH TO PREHEAT MODE	LESS EFFICIENT OPERATION	MANUAL	2	1	
	1.61	FAILS ON	AS 1.60		PREMATURE SWITCH TO PREHEAT MODE	POSSIBLE FILLING OF WATER STORAGE TANK		2	2	

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LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 COLLECTOR FIELD

LEVEL #3

LEVEL #4

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
SOLAR COLLECTOR/ RECEIVER	2.10	ABSORBER PIPE RUPTURES	IMPACT OVERPRESSURE CLOGGING FLUID INSIDE THE PIPE FREEZES		DAMAGE TO RECEIVER	WATER/ STEAM ESCAPES FLOW MALDISTRI- BUTION COLLECTOR OVERHEAT- HEATED	FREEZE PROTECTION PROVIDED EXCESS FLOW VALVE PLACED UPSTREAM OF COLLECTORS AND CHECK VALVE DOWNSTREAM	2	4	
	2.11	EXCESSIVE TEMPERATURE IN COLLECTORS	LOW/NO FLOW THROUGH COLLECTOR		POSSIBLE OVER PRESSURE DEGRADATION OF RECEIVER COATING		OVERTEMPER- ATURE STOWAGE OF COLLECTORS PSV INSTALLED TO RELIEVE PRESSURE	2	4	
	2.12	LEAKS	DEFECTS IN MANUFACTURE AND INSTALLATION	VISUAL	LOSS OF FLUID			2	3	
	2.13	ENTRY OF COOL LIQUID INTO HOT TUBE	MISHAP, LATE OPENING OF ISOLATION VALVES		THERMAL SHOCK	LEAKS DEVELOP		3	4	
	2.14	PERCOLATION OF FLUID IN EMPTY TUBE	VALVES LEAKS		THERMAL STRESSES EXPOSURE OF WORKERS TO HOT WATER/ STEAM			2	3	

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 COLLECTOR FIELD

LEVEL #3

LEVEL #4

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	2.15	STRESS	HIGH WIND	VISUAL WIND TRANS-MITTER NSH-1	FOUNDATION AND COLLECTOR DAMAGE		COLLECTORS STOW IN HIGH WIND CONDITION	2	3	
	2.16	DAMAGE TO COLLECTOR SURFACE	HAIL PAINT SPILL FLUID LEAKAGE FROM PIPES/ SEALS DIRT/DUST ACCUMU-LATION	VISUAL	DAMAGE TO COLLECTOR SURFACE		COLLECTORS STOW ON DETECTION OF LOW INSOLATION/ WIND (BOTH INDICATIONS OF HAIL)	2	3	
	2.17	FAILS TO STOW	POWER FAILURE DRIVE MOTOR FAILS GEAR/DRIVE PULLEY JAMS OR BREAKS	OBSERVATION OF SYSTEM STATUS	DAMAGE TO COLLECTOR SURFACE/ RECEIVER		STORAGE BATTERIES DRIVE COLLECTOR MOTORS	4	4	
	2.18	BOILING OF RESIDUAL LIQUID IN EMPTY TUBE	FAILURE TO STOW COLLECTORS INSUFFICIENT FLUID IN THE SYSTEM		OVERTEMPER-ATURE OF COLLECTORS	THERMAL STRESS DEGRADA-TION OF RECEIVER COATING	COLLECTORS STOW ON OVER-TEMPERATURE	2	4	

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LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 COLLECTOR FIELD

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE: LOCAL EFFECT	EFFECT OF FAILURE: END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	2.19	VISUAL HAZARDS	PERSONNEL CLOSE TO COLLECTOR EXPOSED TO CONCENTRATED RADIATION		EXPOSURE OF PEOPLE TO STRONG RADIATION	EYE DAMAGE	PERIMETER FENCE AND TRIP WIRE 5 FEET FROM COLLECTOR	3	4	OPERATING PROCEDURES NOT TO ALLOW MAINTEN-ANCE WHEN COLLECTORS UNSTOWED NEARBY
	2.20	RECEIVER ISOLATED AND EXPOSED TO CONCENTRATED SOLAR RADIATION	UNDER REPAIR		OVERHEATING PRESSURE RISE	RUPTURE	PSV STOW IF RECEIVER TEMPERATURE TOO HIGH	2	4	ENSURE HAVE LOCAL MANUAL SWITCH TO KEEP COLLECTOR STOWED
	2.21	PARABOLIC TROUGH REFLECTIVITY DIMINISHED	DUST, DIRT, SNOW ETC. ACCUMULATION	VISUAL	DROP IN WATER TEMPERATURE		SPRAY WASH	4	1	ENSURE THAT THE TREES OR BUILDINGS DO NOT CAST SHADOW ON THE COLLECTORS

LEVEL #1 SOLAR THERMAL SYSTEM

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LEVEL #2 COLLECTOR FIELD

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

LEVEL #3

DRAWING: 60035-1-50-1

LEVEL #4

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	2.22	TROUGH BREAKS/ FRACTURES/ DISTORTS	HIGH WIND	VISUAL		COLLECTOR EFFICIENCY DROPS	CLEAN, STOW ON DETECTION OF HIGH WIND	3	2	ENSURE SPARE COLLECTORS FOR IMMEDIATE REPLACE-MENT
	2.23	SAND ENTERS GLASS TUBES	STORM	VISUAL		EFFICIENCY DROPS	EMPTY AND CLEAN	3	1	ENSURE TIGHT FIT ACHIEVED INITIALLY
HAIL	2.24	FAILS TO STOW IN HAIL STORM		VISUAL	COLLECTOR SURFACE COULD BE DAMAGED		MANUAL STOWAGE OF COLLECTORS SEEING HAIL CONDITIONS HAIL USUALLY ACCOMPANIED BY CLOUDS AND HIGH WINDS	2	3	
SAND STORM	2.25	FAILS TO STOW COLLECTORS		VISUAL	DAMAGE TO COLLECTOR SURFACE		COLLECTORS STOW ON OCCURENCE OF WINDS ACCOMPANYING SAND STORM	2	3	

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 COLLECTOR FIELD

LEVEL #3

LEVEL #4

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
WATER FLOW THROUGH RECEIVER (PREHEAT ZONE)	2.30	MALDISTRIBU-TION	PLUGGING	STOWING OF COLLECTORS ON DETECTION OF HIGH TEMPERATURE	HIGH TEMPERATURE IN RECEIVER	DAMAGE TO RECEIVER COATING	OVER TEMPERATURE SHUT DOWN	2	4	
	2.31	TOO SLOW/ NO FLOW	LV-3 CLOSED TOO FAR PLUGGING	AS 2.30	BOILING, HIGH RECEIVER TEMPERATURE	AS 2.30	STOWING. TJR-26, LOW FLOW ALARM FR-4 AND SHUT DOWN,	2	4	
	2.32	FLOW TOO FAST	TV-2 OPENED TOO FAR		FLOW TOO HIGH	EXIT TEMPERA-TURE TOO LOW	HIGH FLOW RECORDED ON FR-4	2	1	
FLEXIBLE HOSE	2.40	LEAKS/BREAKS	OVER STRESSED OVER PRESSURE EROSION	VISUAL	LOSS OF PRESSURE, COLLECTOR SAFETY HAZARD	OVER TEMPERA-TURE IN RECEIVER	SHUT DOWN	2	4	CONSERVA-TIVE DESIGN USED
	2.41	CLOGGED DOWNSTREAM	INSTALLATION DEBRIS		OVER PRESSURE	OVER HEATING IN PREHEAT ZONE AND OVER TEMPERA-TURE SHUT DOWN	SAFETY RELIEF VALVE. OVER TEMPERATURE STOWING	2	4	

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 COLLECTOR FIELD

LEVEL #3

LEVEL #4

PROGRAM: YES

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
VALVES ISOLATING COLLECTORS	2.42	VALVE CLOSED	ACCIDENTAL CLOSING OF WRONG VALVE		EXCESSIVE TEMPERATURE IN COLLECTOR	DAMAGE TO COLLECTOR	OVER TEMPERATURE PROTECTION ON COLLECTORS	2	4	
	2.43	CLOSURE OF BOTH ISOLATION VALVES	AS 2.42		AS 2.42	OVER PRESSURE IN COLLECTORS	STOWAGE OF COLLECTORS PSV	2	4	
	2.44	OPENING OF SUPPOSEDLY CLOSED VALVES/ LEAKS	ACCIDENT ON REMOVAL OF COLLECTOR FROM SERVICE OR PUTTING COLLECTOR INTO SERVICE		POSSIBLE EXPOSURE OF PERSONNEL TO STEAM		LINES WILL BE BLANKED OFF	2	4	ENSURE LINES BLANKED OFF MAINTEN-ANCE PERFORMED AT NIGHT WHERE POSSIBLE
COLLECTOR DRAIN VALVE	2.45	ACCIDENTLY OPENED/FAILS OPEN	ERROR	VISUAL LOW LEVEL ALARM LAL-3	WATER/STEAM SPRAY	FLOW MALDISTRI-BUTION	EXCESS FLOW VALVES AND CHECK VALVES	2	4	

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 COLLECTOR FIELD

LEVEL #3

LEVEL #4

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
PRESSURE SAFETY VALVES PROTECTING COLLECTORS	2.46	STICKS	JAMMED IMPACT		OVERPRESSURE IF NO FLOW AND EXPOSED TO INSOLATION	TUBE RUPTURES COATING FAILS	OVERTEMPER-ATURE STOWAGE OF COLLECTORS	2	4	ROUTINE CHECKS
	2.47	DISCHARGE LINE BLOCKED	DEBRIS ICE		AS 2.46		AS 2.46	2	4	
	2.48	FAILS OPEN	JAMMED	VISUAL		MALDISTRI-BUTION OF FLOW		2	3	
VENT VALVES	2.49	FAIL OPEN	LEFT OPEN AFTER USE FAIL	VISUAL	LOSS OF WATER	POSSIBLE PERSONNEL HAZARD	FLOW THROUGH VALVES SLOW	2	4	VENT IS DIRECTED UPWARDS
ELECTRICAL POWER TO BATTERIES DRIVING COLLECTOR MOTORS	2.50	PERSONNEL CONTACT WITH LIVE CIRCUIT	ERRONEOUS CONNECTION INADEQUATE INSTALLATION DEFECTIVE ELECTRICAL EQUIPMENT		HAZARD TO OPERATORS			1	4	ENSURE ELECTRICAL CONNECT-IONS CONFIRM WITH ACCEPTABLE CODES

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 COLLECTOR FIELD

LEVEL #3

LEVEL #4

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	2.51	SHORT CIRCUIT	LIVE WIRES TOUCHING MOISTURE FAULTY CONNECTOR INADEQUATE OR DETERIORATED INSULATION	POWER CUT OFF	INSTRUMENTS AND CONTROLS DO NOT RESPOND	SYSTEM SHUT OFF	AUTOMATIC SHUT DOWN OF COLLECTOR	3	2	
	2.52	POWER SOURCE FAILS	SHORT CIRCUIT FAILURE OF BASIC ENERGY CONVERTER LACK OF BACKUP EQUIPMENT LACK OF FAIL SAFE DESIGN	SYSTEM DOES NOT START		SYSTEM SHUT DOWN	STORAGE BATTERIES FOR COLLECTORS	2	3	STANDBY DIESEL/ GASOLINE GENERATOR
BATTERIES DRIVING COLLECTOR MOTORS	2.53	FAILS	OVER HEATING EXCESSIVE CURRENT DRAIN HIGH INTERNAL RESISTANCE BURSTS LEAKAGE OR LACK OF ELECTROLYTE	VISUAL	COLLECTORS NOT STOWED ON DEMAND DAMAGE TO SURROUNDING SURFACES FROM ACID SLUGGISH OR NO DRIVE POWER FOR MOTORS	POSSIBLE OVER HEATING OF RECEIVERS INABILITY TO STOW COLLECTORS	ALARM TURNS ON IF COLLECTOR FAILS TO STOW ROUTINE CHECK OF VOLTAGE ACCROSS BATTERIES REGULAR MAINTENANCE CEASE OPERATION IF	3	4	TEMPERA-TURE RISE BEYOND 400F IS NOT ANT-ICIPATED IN PREHEAT FIELD ENSURE SUFFICIENT NUMBER OF BATTERIES

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LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 COLLECTOR FIELD

LEVEL #3

LEVEL #4

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
			TERMINAL CONNECTION FAILURE LOSS OF VOLTAGE EXCESSIVE DRAIN		POSSIBLE SHORT ACCROSS BATTERIES		EXCESSIVE STOWING IS REQUIRED			IN STOCK SMALL DEFLECTION OF COLLECTOR ADEQUATE TO REMOVE OVER TEMPERA- TURE HAZARD
MOTORS TO STOW COLLECTORS	2.54	MOTOR/DRIVE FAILS	ELECTRICAL/ MECHANICAL FAULT	VISUAL, COLLECTORS OUT OF POSITION	INABILITY TO TRACK ON OR STOW COLLECTORS	OVER HEATING OF COLLECTORS IF NO/LOW FLUID FLOW	ROUTINE CHECKS	3	4	INSTALL MANUAL CRANK
	2.55	ELECTRICAL POWER FAILURE		LOW FLOW ALARM	PUMPS SHUT DOWN	OVER HEATING OF COLLECTORS	COLLECTORS STOW USING BATTERY POWER	3	4	
ELECTRICAL POWER TO SOLAR THERMAL SYSTEM	2.60	FAILS OFF	LINES DOWN		PUMPS STOP	POSSIBLE OVERTEMP- ERATURE IN COLLECTORS	SHUT DOWN OF SYSTEM COLLECTORS STOW BACK-UP GENERATOR FOR FREEZE PROTECTION	3	4	

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LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 FEEDWATER PREHEAT

LEVEL #3 WARM UP MODE

LEVEL #4

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DRAWING: 60035-1-50-1

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
MOTOR FOR PUMP P101	3.10	FAILS	HIGH LOAD MECHANICAL BLOCKAGE OR BEARING FREEZE-UP BROKEN BELT SHAFT OR COUPLING BLOWN FUSE, LOOSE CONNECTION HIGH SOURCE VOLTAGE	P-101 DOES NOT TURN ON	NO WATER CIRCULATION THROUGH THE PREHEAT ZONE	OVER TEMPERATURE IN PREHEAT ZONE	FSL-4 CAUSES PREHEAT COLLECTOR FIELD TO STOW OVER TEMPERATURE PROTECTION IN EACH COLLECTOR PRESSURE RELIEF VALVES	2	4	ENSURE SPARE MOTOR IN STOCK FOR IMMEDIATE REPLACEMENT
	3.11	WIRING INSULATION DETERIORATES	DAMAGE AT INSTALLATION OR OVER CURRENT CONDITION		AS 3.10		ROUTINE CHECKS	2	4	ENSURE SPARE MOTOR PARTS IN STOCK
	3.12	MOTOR INSULATION FAILS	OVER CURRENT	MOTOR HEATS UP	AS 3.10		AS 3.11	2	4	
	3.13	BEARING FAILS	IMPROPER LUBRICATION, VIBRATION	NOISE	PUMP SHUT DOWN		REPLACE BEARINGS	2	2	AS 3.11
	3.14	MOTOR CASE RUPTURES	POOR WORKMANSHIP DEFECTIVE MATERIAL DAMAGED IN TRANSIT	VISUAL	PUMP SHUT DOWN		REPLACE MOTOR CASE	1	1	AS 3.11

LEVEL #1 SOLAR THERMAL SYSTEM

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LEVEL #2 FEEDWATER PREHEAT

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

LEVEL #3 WARM UP MODE

DRAWING: 60035-1-50-1

LEVEL #4

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
PREHEAT FEEDWATER PUMP P-101	3.15	FAILS TO START	PUMP OR MOTOR MALFUNCTION CORROSION/ EROSION OF INTERNAL PUMP PARTS JAMMED OR CLOGGED	NO CIRCULATION OF WATER	AS 3.10	AS 3.10	AS 3.10	2	2	ENSURE SPARE PUMP IN STOCK FOR IMMEDIATE REPLACE- MENT
	3.16	STOPS	POWER FAILURE MOTOR FAILURE FAILURE OF PUMP PARTS DEADHEADING JAMMED OR CLOGGED	WATER CIRCULATION STOPS	AS 3.10		AS 3.10	2	4	
	3.17	LEAKS	WORN OUT SEALS AND GASKETS CASING CRACKED CONTACT SURFACES INADEQUATELY FINISHED POORLY DESIGNED CONNECTION FITTINGS LOOSENED BY VIBRATION	VISUAL WATER LEAK	WATER ESCAPES		ROUTINE CHECKS SHUT DOWN PUMP	2	1	

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LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 FEEDWATER PREHEAT

LEVEL #3 WARM UP MODE

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DRAWING: 60035-1-50-1

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
			ERRONEOUSLY OPENED DRAIN OR CONNECTION							
			DIRT OR OTHER SOLID CONTAMINANTS BETWEEN MATING PARTS							
	3.18	VIBRATION AND NOISE	LOOSE OR UNDERSIZED MOUNTINGS		LOSS IN PUMP EFFICIENCY	SHUT DOWN OF P-101	ROUTINE CHECKS	2	2	AS 3.15
			MISALIGNED PARTS IN MOTION							
			CAVITATION							

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 FEEDWATER PREHEAT

LEVEL #3 WARM UP MODE

LEVEL #4

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

DRAWING: 60035-1-50-1

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
LEVEL CONTROL VALVE LV-3	3.19	FAILS OPEN	CLOGGED WITH BUILD-UP OR DEBRIS EROSION/ CORROSION IMPROPER INSTALLATION		WATER CAN CONTINUE TO ENTER PREHEAT FIELD	POSSIBLE OVER FILLING OF TANK	LAH-3 ON TANKS TK-101A/B PUMP P-101 SHUTS OFF ON HIGH LEVEL LIMIT SWITCH ON LV-3	2	2	
	3.20	FAILS/STICKS CLOSED	AS 3.19 LOSS INSTRUMENT AIR		LOSS OF FLOW	POSSIBLE OVER TEMPERA- TURE IN PREHEAT FIELD	FSL-4 OVER TEMPERATURE PROTECTION ON COLLECTORS, TJR-26 LIMIT SWITCH ON LV-3 LOW FLOW SHUT DOWN	2	4	COLLECTORS SET TO STOW AT 300F
	3.21	LEAKS	SEALS FAIL POOR SEATING OF SEALS EXCESSIVE CLEARANCE FATIGUE OF MATERIALS FRACTURE RUPTURE		LOSS OF FLOW	DECREASED FLOW RATE		2	1	
	3.22	NOISE	CAVITATION AND TURBULANCE OF FLOW		DAMAGE TO THE PIPING		ROUTINE MAINTENANCE	1	1	

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LEVEL #3 WARM UP MODE

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
LEVEL CONTROL VALVE LV-39A	3.23	FAILS OPEN	CLOGGED WITH BUILD-UP OR DEBRIS; EROSION/ CORROSION; IMPROPER INSTALLATION; LOSS OF INSTRUMENT AIR	MONITORING OF SYSTEM STATUS	BOILER FEED WATER COOLER THAN DESIRED	LESS EFFICIENT OPERATION OF SYSTEM	LIMIT SWITCH ON LV-39A	2	2	
	3.24	FAILS CLOSED	AS 3.23	AS 3.23	LOSS OF BOILER FEED WATER IF TK-101A/B EMPTY	POSSIBLE BURN OUT IN FIRED BOILER	LIMIT SWITCH ON LV-39A	2	4	ENSURE FIRED BOILER SHUTDOWN ON LOSS OF WATER FLOW
	3.25	LEAKS	AS 3.21	VISUAL	LOSS OF FLOW		ROUTINE CHECKS	2	1	
	3.26	NOISE	AS 3.22	SOUND	VALVE FAILS		AS 3.25	2	2	
TWO WAY VALVE BETWEEN LV-39A AND BOILER FEED WATER PUMP	3.27	MANUALLY CLOSED	ERROR		LOSS OF FEED WATER FLOW TO BOILER ONCE TK-101 A/B EMPTY	TUBES BURN OUT		1	4	AS 3.24
PRESSURE INDICATOR PI-35	3.28	NO READING ON GAGE	DEFECTIVE GAGE	VISUAL	LOSS OF RUDUNDANCY IN PRESSURE MEASUREMENT		PI-20	2	1	
	3.29	WRONG READING	IMPROPER		AS 3.28		PSV-18	3	1	

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	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
		ON GAGE	CALIBRATION OF GAGE				PCV-21			
			MALFUNCTIONING OF GAGE							
	3.30	SEALS OR GASKETS FAIL	VISUAL, SOUND	WATER ESCAPES	DROP IN SYSTEM	ROUTINE MAINTENANCE		3	1	

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TWOWAY VALVE IN BETWEEN PI-35 AND FT-4	3.31	CLOSED	ERROR		LOSS OF FLOW THROUGH PREHEAT FIELD	POSSIBLE OVER TEMPERA-TURE IN COLLECTORS	FSL-4 OVER TEMPERATURE PROTECTION ON COLLECTORS	1	4	
	3.32	LEAKS	AS 3.25		LOSS OF WATER		ROUTINE MAINTENANCE	2	1	
FLOW TRANSMITTER FT-4	3.33	FAILS TRANSMITTING FALSE HIGH FLOW	SENSOR FAILS PROBE FAILS ELECTRICAL/ MECHANICAL FAULT IMPROPER CALIBRATION DEFECTIVE INSTRUMENT	ABNORMAL FLOW RATE INDICATED	FAILS TO DETECT LOW FLOW	LOSS OF LOW FLOW PROTECTION IN PREHEAT FIELD	OVER TEMPERATURE PROTECTION IN COLLECTORS TJR-26	2	4	
	3.34	FAILS TRANSMITTING FALSE LOW FLOW	AS 3.33	AS 3.33	FSL-4 ON	ERRONEOUS SHUT DOWN	FLOW RECORDER	2	2	
	3.35	NO SIGNAL TO FLOW SWITCH FSL-4	INTERNAL DEFECT	FLOW RECORDER FR-4 IS NOT ACTIVATED	FSL-4 ON		TJR-26	1	1	

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FLOW RECORDER FR-4	3.36	FAILS RECORDING FALSE HIGH FLOW	ELECTRICAL/ MECHANICAL FAULT FLOW TRANSMITTER FAILS TO TRANSMIT SIGNAL DEFECTIVE INSTRUMENT IMPROPER CALIBRATION	ABNORMAL FLOW RATE	ABNORMAL FLOW RATE RECORDED	POSSIBLE ERRONEOUS SHUT DOWN OF SYSTEM	TJR-26	2	1	
	3.37	FAILS RECORDING FALSE LOW FLOW	AS 3.36	AS 3.36	ABNORMAL FLOW RATE RECORDED	POSSIBLE ERRONEOUS SHUT DOWN OF SYSTEM	TJR-26	2	2	
LOW FLOW SWITCH FSL-4	3.38	FAILS OFF	DEFECTIVE SWITCH ELECTRIC SHORT /MALFUNCTION	NO ALARM ON FAL-4 WHEN LOW FLOW IS INDICATED	NO SIGNAL TO THE MASTER CONTROLLER UC-100 WHICH SENDS STOW SIGNAL TO THE LOCAL CONTROLLERS AT EACH COLLECTOR	OVER HEATING IN PREHEAT ZONE	TJR-26 FR-4	2	4	
	3.39	FAILS ON	AS 3.38 IMPROPER CALIBRATION	ALARM BUT NO LOW FLOW INDICATED	ALARM AND SHUT DOWN	POSSIBLE ERRONEOUS SHUT DOWN OF SYSTEM		2	1	

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
LOW FLOW RELAY SWITCH FYL-4	3.40	FAILS OFF	ELECTRIC SHORT /MALFUNCTION	AS 3.38	AS 3.38	AS 3.38	FR-4 OVERTEMPERATURE PROTECTION	2	4	
	3.41	FAILS ON	DEFECTIVE INSTRUMENT SWITCH NOT PROPERLY CALIBRATED	AS 3.39	AS 3.39	AS 3.39	FR-4	2	2	
LOW FLOW ALARM FAL-4	3.42	FAILS ON	ELECTRICAL/ MECHANICAL FAULT	SOUND	REDUNDANCY IN LOW FLOW PROTECTION LOST	ERRONEOUS POSSIBLE SHUT DOWN	FR-4	2	2	
	3.43	FYL-4 FAILS TO RELAY SIGNAL	FYL-4 FAILS TO RELAY SIGNAL IMPROPER CALIBRATION DEFECTIVE INSTRUMENT		AS 3.42	POSSIBLE OVERTEMPERATURE CONDITION IN PREHEAT ZONE	OVERTEMPERATURE SHUT DOWN	2	4	

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	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
THERMOCOUPLE CONNECTED TO RECORDER (AT COLLECTOR OUTLET) TJR-26	3.44	FAILS RECORDING FALSE LOW TEMPERATURE	ELECTRICAL SHORT/ MALFUNCTION INTERNAL DEFECT		LOSS OF REDUNDANCY IN TEMPER- ATURE MEASUREMENT		TRC-2	2	1	
	3.45	FAILS RECORDING FALSE HIGH TEMPERATURE	AS 3.44			OPERATER MAY ERRONEOUS- LY SHUT DOWN SYSTEM	AS 3.44	2	2	
	3.46	THERMOCOUPLE PROBE FAILS		CONTINUOUS RECORDING			REPAIR/REPLACE	2	1	
TEMPERATURE CONTROL VALVE TV-2	3.47	FAILS OPEN	AS 3.19 LOSS OF INSTRUMENT AIR DEFECTIVE VALVE	LOW EXIT WATER TEMPERATURE INDICATED	LOW WATER TEMPERATURE			2	1	
	3.48	FAILS CLOSED	AS 3.19	HIGH WATER EXIT TEMPERATURE INDICATED	HIGH WATER TEMPERATURE	OVER TEMPERA- TURE IN STORAGE TANK	TJR-26, TRC AND TAH BYPASS ALWAYS OPEN OVER TEMPERATURE PROTECTION ON COLLECTORS PSV AND PCV'S ON TK-101	2	3	
	3.49	LEAKS	AS 3.21		LOSS OF HEATED WATER		REGULAR MAINTENANCE	2	2	

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	3.50	NOISE	AS 3.22		DAMAGE TO FLANGED CONNECTIONS		MAINTENANCE CHECKS	1	1	
TEMPERATURE TRANSMITTER TT-2	3.55	FAILS TRANSMITTING FALSE HIGH TEMPERATURE	AS 3.33		OPENS TV-2	WATER IN TK-101A/B COOLER THAN DESIRED	TJR-26	2	2	
	3.56	FAILS TRANSMITTING FALSE LOW TEMPERATURE	AS 3.55		THROTTLING AT TRC-2 DOES NOT COMMENCE	WATER IN TK-101A/B TOO HOT	TJR-26 PSV AND PCV'S ON TANKS	2	3	
TEMPERATURE RECORDING CONTROLLER TRC-2	3.57	FAILS CONTROLLING FALSE LOW TEMPERATURE	AS 3.44		AS 3.56	AS 3.56	TJR-26	2	1	
	3.58	FAILS CONTROLLING FALSE HIGH TEMPERATURE	AS 3.57		AS 3.55	AS 3.55		2	2	

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	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
ONE WAY VALVE BETWEEN TV-2 AND TANK TK-101	3.59	FAILS CLOSED	EROSION/ CORROSION IMPROPER INSTALLATION		AS 3.48	AS 3.48	TJR-26 TRC-2 TAH	2	4	
	3.60	LEAKS	AS 3.21	VISUAL		LOSS OF FLOW	ROUTINE CHECK	2	1	
TEMPERATURE CONTROL VALVE TV-5	3.61	FAILS OPEN	AS 3.19 ERRONEOUS COMMAND		LOSS OF CONTROL OVER PREHEAT FIELD WATER TEMPERATURE WATER TEMPERATURE TOO LOW			2	1	
	3.62	LEAKS	AS 3.21	VISUAL SOUND	LOSS OF HOT WATER		ROUTINE MAINTENANCE	2	1	

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BOILER FEEDWATER TANK TK-101A/B	3.65	LEAKS	POROSITY OR WELD DEFECT INADEQUATELY FITTED OR TIGHTENED PARTS MATING FACES INADEQUATELY FINISHED WORN OUT SEALS/ GASKETS ERRONEOUSLY OPENED DRAIN	VISUAL	HOT WATER/ STEAM LEAKS AND FLASHES	DROP IN TANK LEVEL LOW LEVEL OF FLUID IN THE SYSTEM	LAL-3 LSLL-39	2	3	
	3.66	RUPTURES	IMPACT FAILURE ,CORROSION AND OVERPRESSURE	VISUAL		POTENTIAL HAZARD TO OPERATORS		1	4	
	3.67	FAILS	IMPACT AND SHOCK		RELEASE AND FLASHING OF WATER	POSSIBLE SHUTDOWN		1	4	
	3.68	OVERPRESSURE	PCV-21 FAILS CLOSED TANKS FILLING	PI-20	RUPTURE OF TANK		PSV-18 A/B	2	4	TANKS TK-101 A/B ARE CONNECTED
	3.69	VACUUM	PCV-19 FAILS CLOSED	PI-20		TANKS COLLAPSE	PSV-40A/B	2	4	

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	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
		TANKS EMPTYING								
	3.70	OVERFILLING	FIRED BOILER UNAVAILABLE		POSSIBLE RUPTURE IF EXIT LINES INADEQUATE		LAH-3 PCV-21 PSV-18A/B LG-17	2	4	
	3.71	EMPTYING	INSUFFICIENT SUPPLY OF PREHEATED WATER		STOP IN FLOW TO STEAM GENERATOR FIELD AND FIRED BOILER	TUBE FAILURE IN FIRED BOILER	LSLL-39 LAL-3 LG-17	2	4	

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PRESSURE REGULATING VALVE PCV-19	3.75	FAILS GIVING HIGH PRESSURE	MISSET/ MALFUNCTION	PI-20	OVERPRESSURE IN TANK	PRESSURE IN THE TK-101A/B HIGHER THAN ANTICIPAT-ED	PSV-18 PCV-21 PI-20	2	4	
	3.76	FAILS GIVING LOW PRESSURE	AS 3.75	PI-20	PRESSURE IN TK-101A/B LOWER THAN ANTICIPATED		PI-20	2	1	
PRESSURE INDICATOR PI-20	3.77	NO READING ON GAGE	AS 3.28	VISUAL	LOSS OF REDUNDANCY IN PRESSURE MEASUREMENT		PSV PCV-21	2	1	
	3.78	WRONG READING ON GAGE	AS 3.29		AS 3.74		AS 3.77	3	1	
	3.79	LEAKS	SEALS AND GASKETS FAIL	VISUAL SOUND	WATER ESCAPES AND FLASHES	FALL IN SYSTEM PRESSURE POSSIBLE BOILING	ROUTINE CHECK	3	1	
PRESSURE CONTROL VALVE PCV-21	3.80	FAILS OPEN	AS 3.19 MALFUNCTION		LOW PRESSURE	BOILING IN TANKS	PI-20	2	2	
	3.81	FAILS CLOSED	AS 3.20	INCREASE IN LINE PRESSURE	GRADUAL PRESSURE RISE WHEN FILLING TANK	OVER PRESSURE IN SYSTEM	PSV-18A/B ROUTINE MAINTENANCE	2	4	
	3.83	LEAKS	AS 3.21	VISUAL, SOUND	GRADUAL PRE-SSURE LOSS			2	1	

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	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
PRESSURE RELIEF VALVE PSV-18A/B	3.83	FAILS TO OPEN ON OVER PRESSURE	INTERNAL DEFECT	GAGES	PROTECTION AGAINST OVERPRESSURE LOST	POSSIBLE RUPTURE OF TK-101A/B	PCV-21	2	4	
	3.84	PREMATURE OPENING	AS 3.83	SOUND VISUAL	PRESSURE LOSS IN THE SYSTEM	BOILING IN TANKS TK-101A/B		2	1	
VACUUM BREAKER PSV-40A/B	3.85	FAILS OPEN	INTERNAL DEFECT MALFUNCTION		PRESSURE DROP IN THE SYSTEM		PI-20	2	2	
	3.86	FAILS CLOSED	CLOGGING DEFECT			POSSIBLE COLLAP-SING OF TANK DUE TO VACUUM CREATION	PCV-19	2	4	
	3.87	LEAKS	SEALS/GASKETS FAIL	VISUAL, SOUND	PRESSURE DROP		ROUTINE CHECKS	2	1	
LEVEL GAGE LG-17	3.88	FAILS INDICATING FALSE HIGH LEVEL	MALFUNCTION BLOCKAGE IN LOWER LOAD	VISUAL	POSSIBLE EMPTYING/ INSUFFICIENT FILLING OF TANK TK-101A/B REDUNDANCY IN TANK LEVEL MEASUREMENT LOST	LOW FLUID LEVEL IN THE SYSTEM	LAL-3 LSLL-3	2	2	
	3.89	FAILS	MALFUNCTION	AS 3.88	POSSIBLE		LAH-3	2	2	

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		INDICATING FALSE LOW LEVEL	BLOCKAGE IN UPPER LOAD		OVERFILLING OF TANK REDUNDANCY IN TANK LEVEL MEASUREMENT LOST		SIGNAL TO CLOSE LV-39A AND PUMP P-101 TO CUT OFF FLOW			
	3.90	BREAKS	IMPACT	AS 3.88	WATER FLASHES	POSSIBLE PERSONAL HAZARD	VALVE OFF LINE TO THE LEVEL GAGE	2	4	ENSURE LEVEL GAGE IS ADEQUA-TELY PROTECTED AGAINST BREAKAGE
LEVEL TRANSMITTER LT-3	3.91	FAILS INDICATING FALSE LOW LEVEL	MALFUNCTION			POSSIBLE TANK FLOODING	LG-17	2	2	

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	3.92	FAILS INDICATING FALSE VERY LOW LEVEL	AS 3.91	ABNORMAL LEVEL RECORDED ON LR-3	OPENING OF LV-39A FOR BOILER FEED WATER	AS 3.91	LG-17	2	2	
	3.93	FAILS INDICATING FALSE HIGH FLOW	AS 3.91	LR-3	WATER FEED TO PREHEAT FIELD CUT	POSSIBLE EMPTYING OF STORAGE TANK	LG-17	2	2	
LEVEL RECORDER LR-3	3.94	RECORDS FALSE HIGH FLOW	MALFUNCTION	COMPARISON WITH LG-17	REDUNDANCY TO LG-17 COST			2	1	
	3.95	RECORDS FALSE LOW LEVEL	AS 3.94	AS 3.94				2	1	
LOW LEVEL SWITCH LSL-3	3.96	FAILS ON	AS 3.38		LOW LEVEL ALARM GIVEN	POSSIBLE SHUTDOWN OF PREHEAT SYSTEM	LG-17 LR-3	2	2	
	3.97	FAILS OFF	AS 3.96 SWITCH NOT PROPERLY CALIBRATED		REDUNDANCY IN LOW LEVEL ALARM COST		LG-17 LR-3 LSLL-3	2	1	

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LOW LEVEL ALARM LAL-3	3.98	FAILS ON	MALFNCTION	SOUND		POSSIBLE SHUTDOWN OF PREHEAT SYSTEM	LG-17 LR-3	2	1	
	3.99	FAILS OFF	IMPROPER CALIBRATION		REDUNDANCY IN LOW LEVEL ALARM LOST		AS 3.98	2	2	
HIGH LEVEL SWITCH LSH-3	4.10	FAILS OFF	AS 3.96		NO ALARM ON HIGH LEVEL	POSSIBLE OVERFLOW-ING	PUMP TO BE STOPPED MANUALLY	2	1	
	4.11	LEVEL SWITCH TRIGGERS WHEN TANK IS NOT OVERFILLED	SWITCH NOT PROPERLY CALIBRATED		FALSE HIGH LEVEL ALARM PREHEAT FIELD SHUTDOWN			2	2	
HIGH LEVEL RELAY LYH-3	4.12	FAILS OFF	SOLENOID FAILS	NO ALARM AT HIGH LEVEL	AS 4.10	POSSIBLE FLOODING OF TK-101 A/B	LG-17 LR-3	2	2	
	4.13	FAILS ON	AS 4.12	CONTINUOUS ALARM	AS 4.11	P-101 STOPS		2	2	
HIGH LEVEL ALARM LAH-3	4.14	FAILS ON	AS 3.98	SOUND	HIGH LEVEL ALARM	POSSIBLE SHUTDOWN OF SYSTEM	LG-17 LR-3	2	2	
	4.15	FAILS OFF	AS 3.99		NO ALARM ON HIGH LEVEL	OVER FLOWING	AS 4.14	2	3	

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	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
LOW LOW LEVEL SWITCH LSLL-39	4.16	FAILS OFF	AS 3.96		POSSIBLE EMPTYING OF TK-101A/B CAVITATION OF PUMPS LOSS OF FEEDWATER FLOW TO BOILER	NO/LOW FLOW IN STEAM GENERATOR BOILER TUBE FAILURE	AS 3.98	2	4	
	4.17	FAILS ON	AS 4.16 SET POINT TOO HIGH	EMPTYING OF TK-101A/B STOPS	LOWER EFFICIENCY OF SYSTEM	AS 4.16		2	1	
LOW LOW LEVEL RELAY LYLL-39	4.18	FAILS CLOSED	AS 4.12 MALFUNCTION		NO ALARM ON LOW LOW LEVEL	POSSIBLE EMPTYING OF TK-101A/B	SYSTEM SHUTDOWN	2	4	
	4.19	FAILS OPEN	AS 4.18		CONTINUOUS ALARM	REDUNDANCY IN LOW LOW ALARM LOST	LOW LOW ALARM	2	1	
THEMOCOUPLE CONNECTED TO RECORDER (ON TK-101A/B) TJR-22	4.20	FAILS RECORDING FALSE LOW FLOW	AS 3.44		LOSS OF REDUNDANCY IN TEMPERATURE MEASUREMENT			2	1	
	4.21	FAILS RECORDING FALSE LOW FLOW	AS 4.20		POSSIBLE OPERATOR INITIATION OF PURGE			2	1	

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 STEAM GENERATOR

LEVEL #3 WARM UP MODE

LEVEL #4

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

DRAWING: 60035-1-50-1

DATE 3 17 1980

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
WATER FLOW THROUGH RECEIVER (STEAM GENERATOR FIELD)	4.30	MALDISTRIBUTION	PLUGGING	STOWING OF COLLECTORS ON HIGH TEMPERATURE	HIGH TEMPERATURE IN RECEIVER	DAMAGE TO RECEIVER COATING BOILING	STOWING	2	4	
	4.31	TOO SLOW/ NO FLOW	FV-7 CLOSED TOO FAR PLUGGING	AS 4.30	HIGH RECEIVER TEMPERATURE BOILING	OVER PRESSURE	STOWING TJR-34 LOW FLOW ALARM AND SHUT DOWN	2	4	
	4.32	FLOW TOO FAST	FV-7 VALVE OPENED TOO FAR		TEMPERATURE TOO LOW		TJR-34 HIGH FLOW INDICATOR FIC-7	2	1	
	4.33	TOO HOT	STEAM OFF TAKE HALTED		RISE IN PRESSURE HIGHER RECEIVER TEMPERATURES	OVER PRESSURE DAMAGE TO RECEIVER	PSV-33	2	4	
TJR-34 AT COLLECTOR OUTLET	4.35	FAILS INDICATING FALSE LOW TEMPERATURE	PROBE FAILS MALFUNCTION		LOSS OF REDUNDANCY IN TEMPERATURE MEASUREMENT		TJR-28 TJR-32	2	1	
	4.36	FAILS INDICATING FALSE HIGH TEMPERATURE	AS 4.35		AS 4.35	OPERATOR MAY SHUT DOWN SYSTEM IN ERROR	AS 4.35	2	2	

LEVEL #1 SOLAR THERMAL SYSTEM
LEVEL #2 STEAM GENERATOR
LEVEL #3 WARM UP MODE
LEVEL #4

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY
DRAWING: 60035-1-50-1

DATE 3 17 1980

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
FLOW TRANSMITTER FT-7	4.40	FAILS TRANSMITTING FALSE HIGH FLOW	PROBE FAILS SENSOR FAILS		FV-7 CLOSED	OVER TEMPERA-TURE IN BOILING ZONE	OVER TEMPERATURE STOWING OF COLLECTORS LOW FLOW SHUT DOWN FSL-43	2	4	
	4.41	FAILS TRANSMITTING FALSE LOW FLOW	IMPROPER CALIBRATION		FV-7 OPENED	TEMPERA-TURE TOO LOW		2	1	
FLOW INDICATING CONTROLLER FIC-7	4.45	FAILS INDICATING FALSE LOW FLOW	ELECTRIC SHORT MALFUNCTION		INFORMATION LOST	SHUT DOWN OF STEAM GENERATOR IN ERROR		2	2	
	4.46	FAILS INDICATING FALSE HIGH FLOW	AS 4.45		INFORMATION LOST			2	1	
	4.47	FAILS DEMANDING LOW FLOW	AS 4.45 SET POINT TOO LOW		FV-7 CLOSES	FLOW THROUGH FIELD REDUCED OVER TEMPERA-TURE	LOW FLOW SHUT DOWN OVER TEMPERATURE PROTECTION ON COLLECTORS	2	4	
	4.48	FAILS DEMANDING HIGH FLOW	AS 4.45 SET POINT TOO HIGH		FV-7 OPENS	TEMPERA-TURE OF WATER EXITING FROM FIELD FALLS		2	1	

LEVEL #1 SOLAR THERMAL SYSTEM

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LEVEL #2 STEAM GENERATOR

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

LEVEL #3 WARM UP MODE

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LEVEL #4

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
LOW FLOW SWITCH FSL-43	4.50	FAILS ON TRIGGERS AT TOO HIGH A FLOW	DEFECTIVE SWITCH IMPROPER CALIBRATION OF SWITCH ELECTRIC SHORT /MALFUNCTION		SHUT DOWN			2	2	
	4.51	FAILS OFF TRIGGERS AT TOO LOW A FLOW	AS 4.50	LOW FLOW LOST	REDUNDANCY IN LOW FLOW PROTECTION LOST	OVER TEMPERA-TURE	FIC-7	2	4	
LOW FLOW SWITCH RELAY FYL-43	4.55	SOLENOID INOPERATIVE	FORIEGN MATERIAL ACCUMULATION		NO SIGNAL TO FAL-7	NO ALARM ON LOW FLOW NO SHUT DOWN	FIC-7 OVER TEMERATURE PROTECTION ON COLLECTORS	2	4	
	4.56	FAILS OPERATING	MALFUNCTION SHORT		LOW FLOW SHUT DOWN AND ALARM	FIC-7	FIC-7	2	2	
LOW FLOW ALARM FAL-43	4.60	FAILS ON	ELECTRICAL FAULT DEFECTIVE ALARM		ALARM GIVEN	POSSIBLE SHUT DOWN OF FIELD IN ERROR		2	2	
	4.61	FAILS OFF	FYL-43 FAILS TO RELAY SIGNAL IMPROPER CALIBRATION	LOW INDICATION ON FIC-7	ALARM ON LOW FLOW LOST		LOW FLOW SHUT DOWN	2	4	

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 STEAM GENERATOR

LEVEL #3 WARM UP MODE

LEVEL #4

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
FLOW CONTROL VALVE FV-7	4.62	FAILS OPEN	AS 3.19 HANDWHEEL USED IN ERROR	FIC-7	LOW TEMPERATURE IN COLLECTOR FLOW THROUGH FIELD INCREASES	STEAM GENERATION DIMINISHES		2	1	
	4.63	FAILS CLOSED	AS 4.62	FIC-7	NO/LOW FLOW	HIGH TEMPERA-TURE IN BOILING ZONE	TJR-34 LOW FLOW ALARM SHUT DOWN	2	4	A STOP IS PLACED ON FV-7 TO PREVENT FULL CLOSING
	4.64	LEAKS	AS 3.21	VISUAL SOUND	WATER ESCAPES AND FLASHES		FIC-7 LAL-8	2	3	
FLASH TANK SEPARATOR D-101	4.65	PRESSURE TOO HIGH	STEAM NOT REMOVED CV'S OR CONTROL VALVE FAIL CLOSED	PR TR	TEMPERATURE INCREASES	HIGH TEMPERA-TURE /PRESSURE RELATED DAMAGE	PSV-33 TJR-32	2	4	

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 STEAM GENERATOR

LEVEL #3 WARM UP MODE

LEVEL #4

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PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
FLASH SEPARATOR D-101	4.67	LEAKS	AS 3.65	VISUAL	STEAM ESCAPES AND FLASHES	POTENTIAL HAZARD TO OPERATOR AND SYSTEM		2	4	ALARMS SHOULD BE USED TO ALERT THE PERSONNEL
	4.68	RUPTURES	AS 3.66	VISUAL	LOSS OF STEAM HIGH PRESSURE STEAM EXPLOSION			1	4	AS 4.67
	4.70	CORROSION	INCOMPATIBILI-TY OF MATERIALS DAMAGED PROTECTIVE SURFACES					1	4	
	4.71	IMPACT AND SHOCK	HANDLING AND TRANSPORTATION DAMAGE QUICK ACTING PNEUMATICALLY OR HYDRAULICALLY ACTIVATED DEVICES DURING TRANSIT		AS 4.67			1	4	

LEVEL #1 SOLAR THERMAL SYSTEM
LEVEL #2 STEAM GENERATOR
LEVEL #3 WARM UP MODE
LEVEL #4

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY
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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	4.72	STRUCTURAL DAMAGE OR FAILURE	SHOCK BY IMPACT INADEQUATE DESIGN ROUGH HANDLING REDUCTION OF STRENGTH BY CORROSION INTERNAL OVERPRESSURE THERMAL EXPANSION	VISUAL		SYSTEM SHUTDOWN	ROUTINE CHECKS	1	4	
	4.73	VIBRATION AND NOISE	LOOSE OR UNDERSIZED MOUNTINGS	SOUND	DAMAGE		AS 4.72	1	3	
	4.74	OVERFILLS	FAILURE IN LEVEL CONTROL		ESCAPE OF WATER	POSSIBLE RUPTURE IF PSV-33 CANNOT HANDLE FLOW	LAH-8	2	3	
	4.75	EMPTIES	AS 4.74 PUMP P-102 FAILS		FLOW TO FIELD CEASES CAVITATION IN PUMP		LALL-15 LAL-8	2	2	
MOTOR FOR PUMP P-103	4.80	FAILS	AS 3.10	P-103 FAILS TO START	WATER CIRCULATION STOPS	HIGH TEMPERA-TURE IN BOILING ZONE	OVER TEMPERATURE SHUT DOWN OR LOW FLOW	2	4	AS 3.10

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LEVEL #1 SOLAR THERMAL SYSTEM

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LEVEL #3 WARM UP MODE

LEVEL #4

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
	4.81	WIRING INSULATION DETERIORATES	AS 3.11		POSSIBLE ELECTRIC SHORT		ROUTINE CHECKS	2	1	AS 3.11
	4.82	MOTOR INSULATION FAILURE	AS 3.12	MOTOR WARMS UP	INEFFICIENT OPERATION		AS ABOVE	2	3	
	4.83	BEARING FAILURE	AS 3.13	NOISE	PUMP SHUTDOWN		REPLACE BEARINGS	2	2	ROUTINE CHECKS
	4.84	MOTOR CASE RUPTURES	AS 3.14	VISUAL	AS 4.83		REPLACE MOTOR/ MOTOR CASE	1	3	AS 3.11
SOLAR CIRCULATION PUMP P-103	4.85	STOPS	AS 3.15	NO CIRCULATION	LOSS OF FLOW	OVER TEMPERA- TURE IN COLLECTORS	COLLECTORS STOW ON OVER- TEMPERATURE/ LOW FLOW	2	4	
	4.86	FAILS TO START	AS 3.16		NO CIRCULATION THROUGH COLLECTORS IN BOILER ZONE	SYSTEM DOWN	AS 4.85	2	2	
	4.87	LEAKS	AS 3.17	WATER ESCAPES AND FLASHES	AS 4.85	FLOW RATE DROPS	REPLACE OR REPAIR LEAKS	2	1	

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 STEAM GENERATOR

LEVEL #3 WARM UP MODE

LEVEL #4

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
CHECK VALVE BETWEEN P-103 AND PI-29	4.90	ALLOWS REVERSE FLOW	AS 3.19		REDUCTION IN FLOW TO COLLECTORS	POSSIBLE OVER-TEMPER-ATURE IN COLLECTOR FIELD	OVER TEMPERATURE SHUTDOWN	1	4	
	4.91	LEAKS	AS 3.21	WATER ESCAPES AND FLASHES	WATER SPILLS		ROUTINE CHECKS	2	2	
LOW LOW LEVEL SWITCH LSLL-15	4.92	FAILS OFF	AS 3.96		POSSIBLE EMPTYING OF D-101	THERMAL STRESSES OVERTEMP-ERATURE IN BOILING ZONE	OVERTEMPERA-TURE PROTECTION LOW FLOW SHUTDOWN	2	4	
	4.93	LEVEL SWITCH TRIGGERS WHEN D-101 IS NOT BELOW SET LIMIT/ FAILS ON	AS 4.92		LOW LEVEL SHUTDOWN		AS 4.92	2	2	
LOW LOW LEVEL ALARM LALL-15	4.94	FAILS OFF	AS 3.98	HIGH TEMPER-ATURE ON TJR-32	NO ALARM ON LOW LOW FLOW	OVER-TEMPERA-TURE SHUTDOWN	LG-31	2	1	
	4.95	FAILS ON	AS 3.99			POSSIBLE SHUTDOWN OF SYSTEM IN ERROR	AS 4.94	2	2	
PRESSURE INDICATOR PI-30	4.96	FALSE LOW INDICATION	AS 3.28	CHECK AGAINST PRESSURE RECORDER	LOSS OF REDUNDANCY IN PRESSURE MEASUREMENT		PDSL-9	2	1	

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LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 STEAM GENERATOR

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

LEVEL #3 WARM UP MODE

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LEVEL #4

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
	4.97	FALSE HIGH INDICATION	AS 4.96	AS 4.96	AS 4.96		PDI-37 PDSL-9	2	1	
	4.98	LEAKS	AS 3.97	STEAM/HOT WATER ESCAPES	STEAM/HOT WATER ESCAPES	DROP IN SYSTEM PRESSURE	ROUTINE CHECKS	2	1	
FV-6	5.00	FAILS OPEN	LOSS INSTRUMENT AIR CLOGGED EROSION/ CORROSION IMPROPER INSTALLATION		D-101 EMPTIES	LOSS OF FLOW THROUGH COLLECTOR FIELD	LSLL-15 LAL-8 FSL-43	2	4	
TV-38	5.01	FAILS OPEN	AS 5.00		AS 5.00	AS 5.00	AS 5.00	2	4	

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 STEAM GENERATOR

LEVEL #3 WARM UP MODE

LEVEL #4

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
THERMOCOUPLE CONNECTED TO RECORDER (ON D-101) TJR-32	5.10	FAILS INDICATING FALSE LOW TEMPERATURE	AS 3.44		LOSS OF REDUNDANCY IN TEMPERATURE MEASUREMENT			2	1	
	5.11	FAILS INDICATING FALSE HIGH TEMPERATURE	AS 5.10		AS 5.10	POSSIBLE ERRONEOUS SHUTDOWN OF STEAM GENERATOR FIELD	LSLL-15	2	1	
CHECK VALVE BETWEEN P-103 AND TJR-28	5.15	CLOSED	ERROR		LOSS OF FLOW IN BOILING ZONE	POSSIBLE OVER-TEMPERA-TURE IN RECEIVERS	FAL-43	2	4	
	5.16	LEAKS	AS 3.21	VISUAL	LOSS OF WATER/STEAM		ROUTINE MAINTENANCE	2	1	
THERMOCOUPLE CONNECTED TO RECORDER (AT COLLECTOR FIELD INLET) TJR-28	5.17	FAILS RECORDING FALSE LOW TEMPERATURE	AS 5.10		BOILING IN RECEIVER	OVER-TEMPERA-TURE IN BOILING ZONE		2	2	
	5.18	FAILS RECORDING FALSE HIGH TEMPERATURE	AS 5.10		AS 5.17		ROUTINE CHECKS	3	1	

LEVEL #1 SOALR THERMAL SYSTEM

LEVEL #2 STEAM GENERATOR

LEVEL #3 WARMUP MODE

LEVEL #4

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
LEVEL CONTROL VALVE LV-39B	5.20	FAILS OPEN	IMPROPER INSTALLATION EROSION/ CORROSION SOLENOID FAILS LOSS OF INSTRUMENT AIR		POSSIBLE EMPTYING OF TK-101A/B	CAVITATION IN BOILER FEEDWATER PUMP REDUCED FLOW TO FIRED BOILER	LSLL-3 LG-17 LR-3	2	4	
PIPING	5.21	LEAKAGE THROUGH PIPE CRACK	PIPE MATERIAL OR WELD DEFECT	PI-35 PI-23 PI-27 PI-30	DROP IN SYSTEM PRESSURE	POSSIBLE SHUTDOWN	FIC-6 FIC-7 FR-4	2	4	

LEVEL #1 SOLAR THERMAL SYSTEM
LEVEL #2 STEAM GENERATION
LEVEL #3
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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
LOW FLOW SWITCH FSL-14	6.10	FAILS ON	SWITCH NOT PROPERLY CALIBRATED		HEAT RECOVERY MODE INITIATED	LOSS OF STEAM PRODUCTION IN D-101		2	1	
	6.11	FAILS OFF	DEFECTIVE SWITCH MALFUNCTION		FAILURE TO SWITCH TO HEAT RECOVERY MODE UNTIL INSOLATION LOW	STEAM GENERATION STOPS	COLLECTORS STOW ON DETECTION OF CLOUDS OR LOW INTENSITY	2	1	
PRESSURE DIFFERENTIAL TRANSMITTER PDT-9	6.12	FAILS TRANSMITTING FALSE LOW DIFFERENTIAL PRESSURE	INTERNAL DEFECT		PREMATURE START UP OF P-102			2	1	
	6.13	FAILS TRANSMITTING FALSE HIGH DIFFERENTIAL PRESSURE	MALFUNCTION		FAILURE OF P-102 TO START	LEVEL IN D-101 FALLS AS STEAM GENERATED	LAL-8 LSLL-15 LG-31	2	4	
LOW PRESSURE DIFFERENTIAL SWITCH PDSL-9	6.20	FAILS OFF	ELECTRICAL SHORT/ MALFUNCTION DEFECTIVE SWITCH IMPROPER	PDI-37	AS 6.13	AS 6.13	HIGH TEMPERATURE SHUT DOWN TJR-34	2	4	

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LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 STEAM GENERATION

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LEVEL #4

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
			CALIBRATION							
	6.21	FAILS ON	AS 6.20		AS 6.12		TJR-28 PDI-37	2	1	
MOTOR FOR P-102	6.22	FAILS	AS 3.10	P-102 DOES NOT TURN ON	NO FEED WATER TO COLLECTOR IN BOILING ZONE	HIGH TEMPERATURE IN COLLECTOR D-101 EMPTIES	OVER TEMPERATURE SHUT DOWN OF COLLECTORS LAL-8 LSLL-15 LG-31	2	4	
	6.23	DETERIORATES	AS 3.11				ROUTINE CHECKS	2	1	
	6.24	MOTOR INSULATION FAILURE	OVERCURRENT	MOTOR WARMS UP			AS 6.23	2	1	
	6.25	BEARING FAILURE	AS 3.13	NOISE			REPLACE BEARINGS	2	1	
	6.26	MOTOR CASE RUPTURES	AS 3.14	VISUAL			REPLACE MOTOR CASE	1	1	
	6.27	STOPS	AS 3.16	MOTOR FAILS TO START	AS 6.22	AS 6.22	AS 6.22	2	3	
	6.28	LEAKS	AS 3.17	WATER ESCAPES AND FLASHES	FLOW STOPS	DECREASE IN FLOW RATE	REPAIR/REPLACE PUMP	2	3	

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 STEAM GENERATION

LEVEL #3

LEVEL #4

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FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE: LOCAL EFFECT	EFFECT OF FAILURE: END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
VALVE HV-10	6.30	FAILS OPEN	AS 3.19	LIMIT SWITCH	POSSIBLE BACK FLOW OF 70F FEED WATER INTO TK-101A/B IF EMPTY	POSSIBLE CAVITATION IN P-102	LIMIT SWITCHES	2	1	
	6.31	FAILS CLOSED/ FAILS TO OPEN	AS 6.30	LIMIT SWITCHES	NO FEED TO P-102	OVER TEMPERA-TURE IN PUMP COLLECTORS D-101 EMPTIES	LIMIT SWITCHES LAL-8 LSLL-15	2	4	
	6.32	LEAKS	AS 3.21	VISUAL	HOT WATER ESCAPES		ROUTINE MAINTENANCE	2	3	
	6.33	LIMIT SWITCH DISPLAYS IMPROPER OPENING				POSSIBLE ERRONEOUS REACTION BY OPERATOR		2	1	
HAND CONTROL VALVE HV-11	6.35	FAILS OPEN	AS 6.30	LIMIT SWITCHES	WATER SUPPLY TO D-101 COOLER THAN DESIRED	POSSIBLE EVENTUAL OVER FILLING OF TK-101A/B	LIMIT SWITCHES	2	1	
	6.36	FAILS CLOSED	AS 6.35	LIMIT SWITCHES	NO WATER SUPPLY TO P-102 IF TK-101A/B EMPTY	D-101 EMPTIES	LIMIT SWITCHES	2	4	
	6.37	LEAKS	AS 6.32	VISUAL	HOT WATER ESCAPES			2	3	

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LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 FEED WATER PREHEAT

LEVEL #3 WARM UP MODE

LEVEL #4

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	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
LEVEL GAGE LG-31	6.40	FAILS INDICATING FALSE HIGH LEVEL	MALFUNCTION		REDUNDANCY IN INDICATION OF LEVEL LOST	POSSIBLE ERONEOUS OPERATOR ACTION	LAL-8 LALL-15 LRC-8	2	1	
	6.41	FAILS INDICATING FALSE LOW LEVEL	IMPROPER CALIBRATION		AS 6.40		LAH-8 LRC-8	2	1	
	6.42	BREAKS	IMPACT		HIGH PRESSURE WATER FLASHES			2	3	ENSURE LEVEL GAGE IS ADEQUATELY PROTECTED AGAINST BREAKAGE OTHER VALVES SHOULD BE LOCATED OFF LINE TO LG-31 RESTRICTION ORIFICIES REDUCE FLOW RATE

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 STEAM GENERATION

LEVEL #3

LEVEL #4

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LEVEL TRANSMITTER LT-8	6.45	FAILS INDICATING FALSE LOW LEVEL (SLIGHTLY BELOW SET LEVEL)	MALFUNCTION	INDICATION ON LG-31	FLOW OF MAKE UP WATER INCREASES	TANK FLOODED NO GENERATION OF STEAM	LG-17	2	3	
	6.46	FAILS INDICATING FALSE VERY LOW LEVEL	AS 6.45	AS 6.45	ALARM LAL-8 GIVEN	OPERATOR SHUTS DOWN	LG-17	2	2	
	6.47	FAILS INDICATING FALSE HIGH LEVEL	AS 6.45	AS 6.45	FLOW OF MAKE UP WATER CEASES	LEVEL FALLS TANK EMPTIES CAVITATION IN PUMP	LSLL-15	2	4	
LEVEL RECORDING CONTROLLER LRC-8	6.50	RECORDS FALSE HIGH LEVEL	MALFUNCTION	COMPARISON WITH LG-31	REDUNDANCY TO LG-31 LOST		LAL-8	2	1	
	6.51	RECORDS FALSE LOW LEVEL	AS 6.50	AS 6.50	AS 6.50		LAH-8	2	1	
	6.52	CALLS FOR LOW LEVEL	AS 6.50		FLASH SEPARATOR LEVEL FALLS	D-101 EMPTIES	LAL-8, LALL-15, AND LG-31	2	4	
	6.53	CALLS FOR HIGH LEVEL	AS 6.50		FLASH SEPARATOR LEVEL RISES	D-101 FLOODS	LAH-8 LG-31	2	3	

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 STEAM GENERATION

LEVEL #3

LEVEL #4

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	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
HIGH LEVEL SWITCH LSH-8 AND ALARM LAH-8	6.55	FAILS OFF	DEFECTIVE SWITCH HORN, BULB FAIL ELECTRIC SHORT /MALFUNCTION IMPROPER CALIBRATION	COMPARISON WITH LG-31	NO ALARM ON HIGH LEVEL	FLASH TANK OVERFILLED	LRC-8 LG-31	2	3	
	6.56	FAILS ON	AS 6.55	AS 6.55	REDUNDANCY IN HIGH LEVEL ALARM LOST	OPERATOR MAY MANUALLY REDUCE FLOW, EMPTYING D-101	AS 6.55	2	2	
LOW LEVEL SWITCH LSL-8 AND ALARM LAL-8	6.60	FAILS OFF	AS 6.55	AS 6.55	REDUNDANCY IN INDICATION OF LOW LEVEL LOST	POSSIBLE EMPTYING OF D-101 UNKNOWN	LSLL-15	2	3	
	6.61	FAILS ON	AS 6.60	AS 6.60	AS 6.60	POSSIBLE SHUT DOWN	AS 6.60	2	2	

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 STEAM GENERATION

LEVEL #3

LEVEL #4

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

DRAWING: 60035-1-50-1

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
PRESSURE SAFETY VALVE PSV-33	6.65	FAILS CLOSED	JAMMED MISSET	PI-30	PROTECTION AGAINST OVER PRESSURE LOST	POSSIBLE TANK RUPTURE IF ISOLATED AND UNDER WATER PRESSURE	SAFETY VALVES IN EACH COLLECTOR PI-30 NORMAL STEAM EXIT	2	4	
	6.66	PREMATURE OPENING	MALFUNCTION SET TO RELIEVE AT TOO LOW A PRESSURE	VISUAL PI-30	PRESSURE DROP IN STEAM GENERATOR SYSTEM	BOILING THROUGH OUT SYSTEM LEADING TO FOULING AND VIBRATION	PI-30 OVER TEMPERATURE PROTECTION IN COLLECTORS	2	3	
LEVEL CONTROL VALVE LV-8	6.70	FAILS OPEN	AS 3.19		EXCESSIVE FLOW TO D-101	LEVEL IN D-101 RISES TEMPERA- TURE FALLS	LAH-8 LG-31	2	3	
	6.71	FAILS CLOSED	AS 6.70	PI-27	BACK PRESSURE DEVELOPED PUMP DEADHEADED	LEVEL IN D-101 FALLS OVERTEMP- ERATURE IN COLECTORS	LAL-8 LSLL-15 LG-31	2	1	
	6.72	LEAKS	AS 3.21	WATER ESCAPES	DROP IN FLOW RATE		ROUTINE MAINTENANCE	2	3	
	6.73	NOISE	AS 3.22				ROUTINE MAINTENANCE	2	1	

G-53

DATE 3 17 1980

FMEA

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 FREEZE PROTECTION

LEVEL #3

LEVEL #4

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

DRAWING: 60035-1-50-1

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
RECEIVER	7.10	ISOLATED	UNDER MAINTENANCE BUT FILLED WITH WATER		FREEZING	SPLITTING OF RECEIVER		2	4	DRAIN AND MAINTAIN N2 PURGE ON ISOLATED RECEIVER
LOW TEMPERATURE SWITCH TSL-12	7.20	FAILS OFF	ELECTRIC SHORT /MALFUNCTION IMPROPER CALIBRATION DEFECTIVE SWITCH	P-104 NOT OPERATING AT FREEZING CONDITIONS	FREEZE PROTECTION LOST	SPLITTING OF PIPE	OPERATOR STARTS THE PUMPS P-104 SEEING FREEZE CONDITION	2	4	
	7.21	FAILS ON	AS 7.20		WATER TEMPERATURE DROPS	SYSTEM EFFICIENCY LOSS	INTERLOCK PREVENTS P-104 SARTING WHEN P-101 ON, LIKEWISE P-105 AND P-103	2	1	
LOW TEMPERATURE RELAY TYL-12	7.25	SOLENOID FAILS	ACCUMULATION OF DIRT AND DEBRIS IF SOLENOID NOT COVERED	AS 7.20	NO FREEZE PROTECTION	PIPES SPLIT ON FREEZING OF WATER	MANUAL OPERATION	2	4	

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 FREEZE PROTECTION

LEVEL #3

LEVEL #4

DATE 3 17 1980

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

DRAWING: 60035-1-50-1

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
TEMPERATURE CONTROL VALVE TV-12	7.30	FAILS OPEN	EROSION/ CORROSION DEFECTIVE VALVE IMPROPER INSTALLATION EXTREME TEMPERATURE/ PRESSURE		BACK FLOW OF FEEDWATER INTO TANK IF CHECK VALVE FAILS	LESS EFFICIENT OPERATION OF SYSTEM OVER FILLING OF TANKS OVER HEATING IN COLLECTORS	ROUTINE CHECK TJR-26 TAH-2	2	2	
	7.31	FAILS CLOSED	AS 7.30		DEADHEADING DAMAGE TO PUMP P-104	FREEZE PROTECTION LOST	USE P-101 TO CIRCULATE WATER	2	3	LOW (FREEZING) TEMPERA- TURE ALARM RECOM- MENDED
	7.32	LEAKS	SEALS FAIL EXCESSIVE CLEARANCE FATIGUE OF MATERIALS FRACTURE/ RUPTURE	WATER ESCAPES	LOW FLOW RATE			2	1	

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 FREEZE PROTECTION

LEVEL #3

LEVEL #4

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

DRAWING: 60035-1-50-1

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
MOTOR FOR P-104	7.40	FAILS	HIGH LOAD MECHANICAL BLOCKAGE OR BEARING FREEZE-UP BROKEN BELT SHAFT OR COUPLING BLOWN FUSE, LOOSE CONNECTION HIGH SOURCE VOLTAGE	P-104 DOES NOT TURN ON	FREEZE PROTECTION LOST	DAMAGE TO THE RECEIVER AND PIPING PIPES SPLIT	USE P-101 TO CIRCULATE WATER	2	4	
	7.41	WIRING INSULATION DETERIORATES	DAMAGE AT INSTALLATION OR OVERCURRENT CONDITION				ROUTINE CHECKS	2	1	
	7.42	MOTOR INSULATION FAILURE	OVERCURRENT	MOTOR WARMS UP			AS 7.41	2	1	
	7.43	BEARING FAILURE	IMPROPER LUBRICATION, VIBRATION	NOISE			REPLACE BEARING	2	1	
	7.44	MOTOR CASE RUPTURES	POOR WORKMANSHIP DEFECTIVE MATERIAL DAMAGED IN TRANSIT	VISUAL			AS 7.43	1	1	

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 FREEZE PROTECTION

LEVEL #3

LEVEL #4

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

DRAWING: 60035-1-50-1

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
CIRCULATION PUMP P-104	7.50	FAILS TO START	PUMP OR MOTOR MALFUNCTION	NO CIRCULATION	POSSIBLE FREEZING OF WATER IN PIPES	POSSIBLE SPLITTING OF PIPES	START P-101 MANUALLY	2	4	
	7.51	STOPS	POWER FAILURE	FR-4	AS 7.50	AS 7.50	USE P-101 TO CIRCULATE WATER	2	4	
			MOTOR FAILURE	TJR-26						
			FAILURE OF PUMP PARTS							
			DEADHEADING							
			JAMMED OR CLOGGED							
	7.52	LEAKS	WORN OUT SEALS AND GASKETS	WATER ESCAPES	WATER CIRCULATION REDUCED		REPAIR LEAKS	2	1	
			CASING CRACKS							
			CONTACT SURFACES INADEQUATELY FINISHED							
			POORLY DESIGNED CONNECTION							
			FITTINGS LOOSENED BY VIBRATION							
			ERRONEOUSLY OPENED DRAIN OR CONNECTION							

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2 FREEZE PROTECTION

LEVEL #3

LEVEL #4

FMEA

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

DRAWING: 60035-1-50-1

DATE 3 17 1980

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
	7.53	VIBRATION	LOOSE OR UNDERSIZED MOUNTINGS MISALIGNED PARTS IN MOTION CAVITATION	NOISE	PUMP EFFICIENCY DROPS		ROUTINE MAINTENANCE	2	1	
PRESSURE INDICATOR PI-23	7.60	NO READING ON GAGE	DEFECTIVE GAGE ELECTRIC SHORT /MALFUNCTION				PI-20	2	1	
	7.61	WRONG READING ON GAGE	IMPROPER CALIBRATION MALFUNCTION-ING OF GAGE		LOSS OF REDUNDANCY IN PRESSURE MEASUREMENT		AS 7.60	2	1	
	7.62	LEAKS	SEALS OR GASKETS FAIL	VISUAL SOUND	WATER ESCAPES AND SPILLS		FREQUENT CHECKS	2	3	OPERATING MANUAL TO INCLUDE ROUTINE CHECKS

LEVEL #1 STEAM GENERATION

DATE 3 17 1980

LEVEL #2

PROGRAM: STEAM GENERATION

LEVEL #3 STEAM GENERATION

DRAWING: 60035-1-50-1

LEVEL #4

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE: LOCAL EFFECT	EFFECT OF FAILURE: END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
MOTOR FOR P-105	7.70	FAILS	AS 7.40	P-105 NOT OPERATING AT FREEZING CONDITIONS	NO FREEZE PROTECTION	POSSIBLE DAMAGE TO RECEIVER	USE P-103 FOR WATER CIRCULATION	2	4	AS 7.40
	7.71	WIRING INSULATION DETERIORATES	AS 7.41				ROUTINE CHECKS	2	1	
	7.72	MOTOR INSULATION FAILS	OVERCURRENT	MOTOR WARMS UP			AS 7.71	2	1	
	7.73	BEARING FAILURE	AS 7.43	NOISE			REPLACE BEARINGS	2	1	
	7.74	MOTOR CASE RUPTURES	AS 7.44	VISUAL			ROUTINE CHECKS	1	1	
CIRCULATION PUMP P-105	7.80	FAILS TO START/STOPS	AS 7.51 MOTOR MALFUNCTION	NO INDICATION ON FIC-7	WATER FREEZES IN PIPES AND RECEIVER	SYSTEM DOWN	USE P-103	2	4	
	7.82	LEAKS	AS 7.52	AS 7.52	LOWER CIRCULATION RATE		REPAIR LEAKS	2	1	
	7.82	VIBRATION	AS 7.53	NOISE	AS 7.53		AS 7.53	2	1	
ONE WAY CHECK VALVE BETWEEN P-103 AND PI-29	7.85	ALLOWS REVERSE FLOW	IMPROPER INSTALLATION CLOGGING		REDUCTION IN FLOW TO COLLECTOR	LOSS OF FREEZE PROTECTION	TJR-28 ROUTINE CHECKS	1	2	
	7.86	LEAKS	SEALS FAIL, EXCESSIVE CLEARANCE POOR SEATING OF SEALS	WATER ESCAPES	WATER SPILLS		AS 7.85	2	1	

LEVEL #1 SOLAR THERMAL SYSTEM

FMEA

DATE 3 17 1980

LEVEL #2

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

LEVEL #3 PREHEAT MODE

DRAWING: 60035-1-50-1

LEVEL #4

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
FLOW CONTROL VALVE FV-6	8.10	FAILS OPEN	IMPROPER CALIBRATION EROSION/ CORROSION LOSS OF INSTRUMENT AIR	FIC-6	EXCESS FLOW FROM D-101	COOLER WATER ENTERING TK-101A/B		2	1	
CONTROL VALVE HV-10	8.12	FAILS OPEN	AS 8.10		WATER AT 250F ENTERS D-101	TV-38 WIDE OPEN. TEMP-ERATURE INCREASE IN TK-101A/B	LIMIT SWITCH	2	3	
CONTROL VALVE HV-11	8.14	FAILS CLOSED	IMPROPER INSTALLATION EROSION/ CORROSION	LALL-15	NO FLOW TO D-101	D-101 EMPTIES	LIMIT SWITCH, LSLL-15, LSL-8, LG-31, ETC.	2	4	

LEVEL #1 SOLAR THERMAL SYSTEM

DATE 3 17 1980

LEVEL #2

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

LEVEL #3 PREHEAT MODE

DRAWING: 60035-1-50-1

LEVEL #4

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
TEMPERATURE TRANSMITTER TT-38	8.16	FAILS TRANSMITTING FALSE HIGH TEMPERATURE	SENSOR FAILS PROBE FAILS ELECTRICAL/ MECHANICAL FAULT DEFECTIVE INSTRUMENT	NO INDICATION ON TIC-36	TV-38 OPENED	WATER AT LESS THAN 250F ENTERS TK-101. TANK OVERFILLS		2	2	
	8.17	FAILS TRANSMITTING FALSE LOW TEMPERATURE	AS 8.16	AS 8.16	TV-38 CLOSED	WATER AT GREATER THAN 250F ENTERS TK-101	TJR-22 PSV-18A/B	2	4	
TEMPERATURE INDICATING CONTROLLER TIC-38	8.20	FAILS DEMANDING FALSE HIGH TEMPERATURE	ELECTRIC SHORT MALFUNCTION		AS 8.16	AS 8.16		2	2	
	8.21	FAILS DEMANDING FALSE LOW TEMPERATURE	AS 8.20		AS 8.17	AS 8.17	TJR-22 AND PSV-18A/B	2	1	
TEMPERATURE SOLENOID VALVE TY-38	8.25	FAILS RELAYING THE SIGNAL	SOLENOID FAILS POWER FAILURE		TV-38 FAILS TO OPEN/ CLOSE ON DEMAND		LAH-3 AND LALL-3	2	4	

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2

LEVEL #3 PREHEAT MODE

LEVEL #4

FMEA

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

DRAWING: 60035-1-50-1

DATE 3 17 1980

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
TEMPERATURE CONTROL VALVE TV-38	8.26	FAILS CLOSED	IMPROPER INSTALLATION EROSION/ CORROSION LOSS OF INSTRUMENT AIR	TIC-36	NO WATER DRAWN OUT OF D-101	TEMPERA-TURE INCREASE IN STEAM GENERATOR FIELD	TJR. OVER TEMPERATURE PROTECTION	2	4	
CIRCULATION PUMP P-105	8.27	STOPS	POWER FAILURE JAMMED EROSION/ CORROSION OF PARTS MOTOR FAILURE	TJR-28 FIC-7	CIRCULATION OF WATER THROUGH COLLECTOR FIELD STOPS	POSSIBLE OVER HEATING IN RECEIVER	TJR-34 FAL-43 OVER TEMPERATURE SHUT DOWN	2	4	
CIRCULATION PUMP P-103	8.28	FAILS TO SWITCH OFF	PUMP/MOTOR MALFUNCTION	TJR-28 TJR-34	EXCESSIVE FLOW THROUGH COLLECTOR FIELD	WASTE OF POWER	FI-7	2	1	

DATE 3 17 1980

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2

LEVEL #3 HEAT RECOVERY MODE

LEVEL #4

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

DRAWING: 60035-1-50-1

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE		POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE		EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
	SN	DESCRIPTION			LOCAL EFFECT	END EFFECT				
TEMPERATURE CONTROL VALVE TV-38	9.10	FAILS OPEN	IMPROPER INSTALLATION CORROSION, EROSION CLOGGED	TIC-38	EXCESS FLOW FROM D-101	TEMPER-ATURE IN TK-101A/B TOO HIGH	PSV-18A/B TJR-22	2	3	
FLOW TRANSMITTER FT-6	9.11	FAILS TRANSMITTING FALSE HIGH FLOW	SENSOR FAILS ELECTRICAL/ MECHANICAL FAULT IMPROPER CALIBRATION	ABNORMAL FLOW INDICATED	CLOSES FV-6	HEAT RECOVERY DOES NOT OCCUR POSSIBLE OVER-TEMPERA-TURE IN STEAM GENERATOR FIELD	TJR-32	2	3	
	9.12	FAILS TRANSMITTING FALSE LOW FLOW	AS 9.11	AS 9.11	OPENS FV-6	POSSIBLE OVERFILL-ING OF TK-101A/B POSSIBLE TEMPERA-TURE RISE IN TK-101A/B *C	TJR-22 LSH-3 LG-17	2	3	
FLOW INDICATING CONTROLLER FIC-6	9.13	FAILS DEMANDING HIGH FLOW	ELECTRICAL SHORT/MAL-FUNCTION		EXCESSIVE FLOW TO TK-101A/B THROUGH FV-6	POSSIBLE OVER-FILLING OF TK-101A/B	LAH-3 LG-17	2	3	
	9.14	FAILS	DEFECT		SLOW HEAT	EXCESSIVE	AS 9.13	2	1	

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2

LEVEL #3 HEAT RECOVERY MODE

LEVEL #4

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

DRAWING: 60035-1-50-1

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
		DEMANDING LOW FLOW			RECOVERY	HEAT LOSSES				
	9.15	FAILS INDICATING LOW FLOW	SET POINT TOO LOW		LOSS OF INFORMATION ABOUT FLOW		AS 9.13	2	1	
	9.16	FAILS INDICATING HIGH FLOW	SET POINT TOO HIGH		AS 9.15		AS 9.13	2	1	
FLOW RELAY FY-6	9.17	FAILS TO RELAY SIGNAL	SOLENOID FAILS POWER FAILURE	NO INDICATION ON FIC-6	FV-6 FAILS TO OPEN /CLOSE ON DEMAND	AS 9.13	FIC-6	2	3	

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2

LEVEL #3 HEAT RECOVERY MODE

LEVEL #4

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

DRAWING: 60035-1-50-1

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
FLOW CONTROL VALVE FV-6	9.20	FAILS CLOSED	LOSS OF INSTRUMENTATION AIR IMPROPER INSTALLATION CORROSION, EROSION CLOGGING		LOSS OF FLOW FROM D-101 TO TK-101A/B	POSSIBLE OVER-TEMPERATURE IN COLLECTORS	OVER-TEMPERATURE SHUTDOWN FIC-6	2	2	
TEMPERATURE TRANSMITTER TT-5	9.21	FAILS TRANSMITTING LOW TEMPERATURE	IMPROPER CALIBRATION DEFECTIVE INSTRUMENT SENSOR FAILS	ABNORMAL FLOW INDICATED ON TIC-5	LOW TEMPERATURE SHUTDOWN	FAILURE TO RECOVER ALL HEAT	TIC-5	2	1	
	9.22	FAILS TRANSMITTING HIGH TEMPERATURE	AS 9.21	AS 9.21	CUTS FLOW FROM FV-6 SYSTEM FAILS TO SHUT-DOWN	AS 9.20	AS 9.21	2	2	
TEMPERATURE INDICATING CONTROLLER TIC-5	9.23	FAILS DEMANDING HIGH TEMPERATURE	ELECTRICAL SHORT/ MALFUNCTION SET POINT TOO HIGH		HOT WATER OVER 250 F ENTERS TANK TK-101B	OVER-TEMPERATURE SHUT-DOWN OF PREHEAT ZONE COLLECTORS	TJR-22	2	3	
	9.24	FAILS DEMANDING LOW TEMPERATURE	SET POINT TOO LOW ELECTRICAL SHORT/		WATER ENTERS TANKS AT TOO LOW A TEMPERATURE		AS 9.23	2	3	

LEVEL #1 SOLAR THERMAL SYSTEM

LEVEL #2

LEVEL #3 HEAT RECOVERY MODE

LEVEL #4

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

DRAWING: 60035-1-50-1

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
			MALFUNCTION		TANKS OVERFILL					
LOW TEMPERATURE SWITCH TSL-5	9.25	FAILS OFF	DEFECTIVE SWITCH ELECTRICAL SHORT/ MALFUNCTION		FAILURE TO SHUTDOWN COOLER WATER ENTERS TANKS		TIC-5	2	2	
	9.26	FAILS ON	IMPROPER CALIBRATION		POSSIBLE OVERFILLING SIGNAL TO INTERLOCK	LOW TEMPERA-TURE SHUTDOWN	TIC-5	2	1	
HIGH TEMPERATURE SWITCH TSH-5	9.27	FAILS OFF	AS 9.25	TIC-5	NO CONTROL ON THE OPENING OF FV-6	HOTTER WATER ENTERS TK-101A/B	FIC-6	2	3	
	9.28	FAILS ON	AS 9.26	AS 9.27	FKC-6 REDUCES FLOW THROUGH FV-6	COOLER WATER ENTERS TK-101A/B	AS 9.27	2	1	

LEVEL #1 SOALR THERMAL SYSTEM

LEVEL #2

LEVEL #3 HEAT RECOVERY MODE

LEVEL #4

PROGRAM: SOLAR THERMAL ENHANCED OIL RECOVERY

DRAWING: 60035-1-50-1

FUNCTIONAL/ COMPONENT DESCRIPTION	FAILURE MODE SN	FAILURE MODE DESCRIPTION	POSSIBLE CAUSES	SYMPTOMS DETECTABILITY	EFFECT OF FAILURE LOCAL EFFECT	EFFECT OF FAILURE END EFFECT	EXISTING COMPENSATING PROVISION	PROB	LEVEL OF SEV	REMARKS
SET POINT PROGRAMMER FKC-6	9.29	FAILS DEMANDING LOW FLOW SETTING	INTERNAL DEFECT POWER FAILURE	FIC-6 LAH-3	WATER COOLER THAN 250 F ENTERS TK-101A/B DUE TO EXCESSIVE FLOW THROUGH FV-6			2	2	
	9.30	FAILS DEMANDING HIGH FLOW SETTING	AS 9.29	AS 9.29	LOW/NO FLOW TO TANKS	POSSIBLE OVER-HEATING	LAL-3 LALL-3	2	2	
TEMPERATURE CONTROL VALVE TV-5	9.31	FAILS OPEN	IMPROPER INSTALLATION ELECTRICAL SHORT/ MALFUNCTION	TIC-5	COOLER WATER ENTERING TK-101A/B POSSIBLE OVERFILLING OF TANKS		TSL-5	2	2	
	9.32	FAILS CLOSED	AS 9.31		LOW FLOW TO TANKS	POSSIBLE OVER-HEATING		2	2	
TEMPERATURE CONTROL VALVE TV-2	9.33	FAILS OPEN	AS 9.31	TRC-2	EXCESSIVE FLOW TO TK-101A/B	POSSIBLE FLOODING IN TANKS	LAH-3 LG-17 LR-3	2	2	

APPENDIX H

BASIS FOR PRELIMINARY COST ESTIMATE

CONVERSIONS FOR APPENDIX H

10,330 KPa	1500 psi
1.22 M	4'
6.1 x 6.1 M	20' x 20'
20.3 cm	8"
884 M	2900'

APPENDIX H

BASIS FOR PRELIMINARY COST ESTIMATE

The following summarizes the input, clarification and exceptions for the cost estimate presented in Section 6 of this report:

I. Scope of Work

1. (a) Engineering flow diagram dwg. #60035-1-50-2 (Appendix E)
   (b) Process flow diagram dwg. #60035-2-50-101 (Appendix E)
2. Plot plan dwg. #60035-1-01-1 (Appendix E)
3. Diagramatic piping layout dwg. #60035-1-51-1 (Appendix E)
4. Equipment list dated 2/26/80 (Appendix E)
5. Equipment sketches and data sheets (Appendix E)
6. Solar collector foundation sketches (Appendix C)
7. All other requirements are based on Foster Wheeler Energy Corp.

II. Basis of Estimate

Civil

1. The site is assumed level, clear and free of above ground and under ground obstructions.
2. No site preparation, paving, roads or access ways are included in the estimate.
3. Equipment foundation design is based on spread footings - 1500 psi - soil at 4'-0" depth.
4. Cost of culverts for pipe lines crossing designated roads and access ways have been included. (Re: As depicted on dwg. no's 60035-1-01-1 & 60035-1-51-1).
5. It has been assumed all excavated material can be dumped within one mile of construction site.
6. Cost for a pre-fab metal control bldg. with HVAC has been included. (Re: 20'x20').
7. A perimeter fence with truck and personnel gates around solar collector field has been included.
8. Costs for grass planting and irrigation system in the solar collector area have been included.
9. Pipe support sleepers have been included where required.
10. No site drainage or underground facilities have been provided.
11. Solar collector supports will be type B as per design sketch.
12. Gravelled area has been included for the area of the solar steam station.

Electrical

1. Source of power to MCC has been taken from the existing sub-station located in the southwest corner of the plot near Hermosa Road and Tejon Highway. Power is assumed to be available at required voltage. Transportation (if required) is assumed to be by others.
2. No area lighting has been provided.
3. Power distribution to users is above ground in conduits.
4. Grounding grid is underground.
5. No convenience outlets or welding receptacles have been provided.
6. MCC is outdoor weather tight type enclosed with perimeter fence.
7. Power supply to solar collectors is based on battery packs and chargers for every eight solar collector modules. (Batteries and chargers by Solar Collector supplier).

Equipment and Pumps

1. Have been provided in accordance with data sheets. (Appendix E)

Piping

1. Underground drainage facilities and fire protection systems have been excluded.
2. Utility stations for plant maintenance have been excluded.
3. Steam distribution to wells from solar steam station has been included as per instructions. (That is, 8" sch.80 insulated steam hdr for distribution to 10 wells approx. 2900 ft. of pipe installed on sleepers).
4. Source of boiler feed water to P101 has been taken from southwest corner of the plot near Hermosa Road and Tejon Highway and is routed above ground on sleepers.
5. Plant air is excluded.
6. Potable water is excluded.
7. Instrument air system has been included.

Instruments

1. No computer cost has been included.
2. No data acquisition costs have been included.
3. Instruments are conventional electronic type.
4. Solar collector control is based on Honeywell distributive type control system. (Appendix F)
5. Control bldg. is located on the west side of the solar steam station.
6. Instrument signal wire has been run above ground in rigid steel conduit.

General

1. Pricing is on a current day basis assuming instant execution; i.e., all costs March 1980.
2. The cost of all construction utilities is assumed to be by others.
3. All costs are through mechanical completion.
4. Sales and use taxes are excluded.
5. Start-up costs are excluded.
6. Permits and licenses are assumed to be by others.
7. The estimate is comprised of three basic sections:

(a)	Preheat Zone	(144 collectors - TK101A&B) (P101, P104, M101)
(b)	Boiling Zone	(360 collectors - D101, P102) (P103, P105)
(c)	Common Users	Control bldg. - fence - Instr. air pkg. - grass plant & irrigation - MCC & feeder - steam header to wells - sleepers - culverts

8. Instr. air supply pkg (PG102) has been located on the south side of the control bldg. Instrument air package is located in a metal sided shelter.
9. Pick-up truck has been excluded.
10. Mobile washing equipment (re: for Solar Collector maintenance) has been excluded.
11. Pricing for Solar Collectors, pumps, grass planting & irrigation and insulation were supplied by project team.
12. Piping required for connecting back-up steam distribution from mobile steam generating station to well distribution system by others.

APPENDIX I

BACKUP FOR SECTION 8 OF FINAL REPORT

CONVERSIONS FOR APPENDIX I

\$.072/liter	\$11.46/BBL
\$9.17/KJ	\$.033/KWH
$\$622.17/M^2$	$\$57.80/ft^2$
26.375 GJ/H	25 MBTU/H
219,493 GJ/yr	208,050 MBTU/yr
23.2 GJ/H	22 MBTU/H
1,590,000 liters	10,000 BBLS
115,094 liters	724 BBLS
97,390 MJ	27,053 KWH

APPENDIX I

These exhibits provide backup to Section 8 of the final report, as noted in the text or references. The sections are:

I. 1 Appendices to Section 8.3

I. 2 Cash Flow Equation

I. 3 Foster Wheeler Economics (P.R.P. Method)

I. 4 Enclosure 4 to DOE San Francisco Operations Office letter dated March 23, 1979, "Summary of Proposal Conference for PON 03-79-CS30051"--slide entitled "States Containing Heavy Oil."

I. 5 Proposal Economic Assumptions & Historical Interest Rates for Debt Instruments

I-1.1 EFFECT OF WELL SPACING ON LAND AVAILABILITY FOR SOLAR COLLECTORS

In determining the effect of well spacing on land availability for solar collectors, a five-spot pattern was assumed. As indicated in Figure I.1, a 150-foot square was reserved around each well for oil production operations. The wells were connected in rows by roads of 30-foot width.

If

S = well spacing in acres/well

$d = \sqrt{(2)(43,650)\,S}$ ft, length of side of one five-spot pattern

For values of S greater than 1.033 acres/well,

$d^2 - [45,000 + 60(d - 150)]$ ft^2 = area available in each five-spot pattern for solar collectors

$$\frac{d^2 - [45,000 + 60(d - 150)]}{d^2} = F_w$$

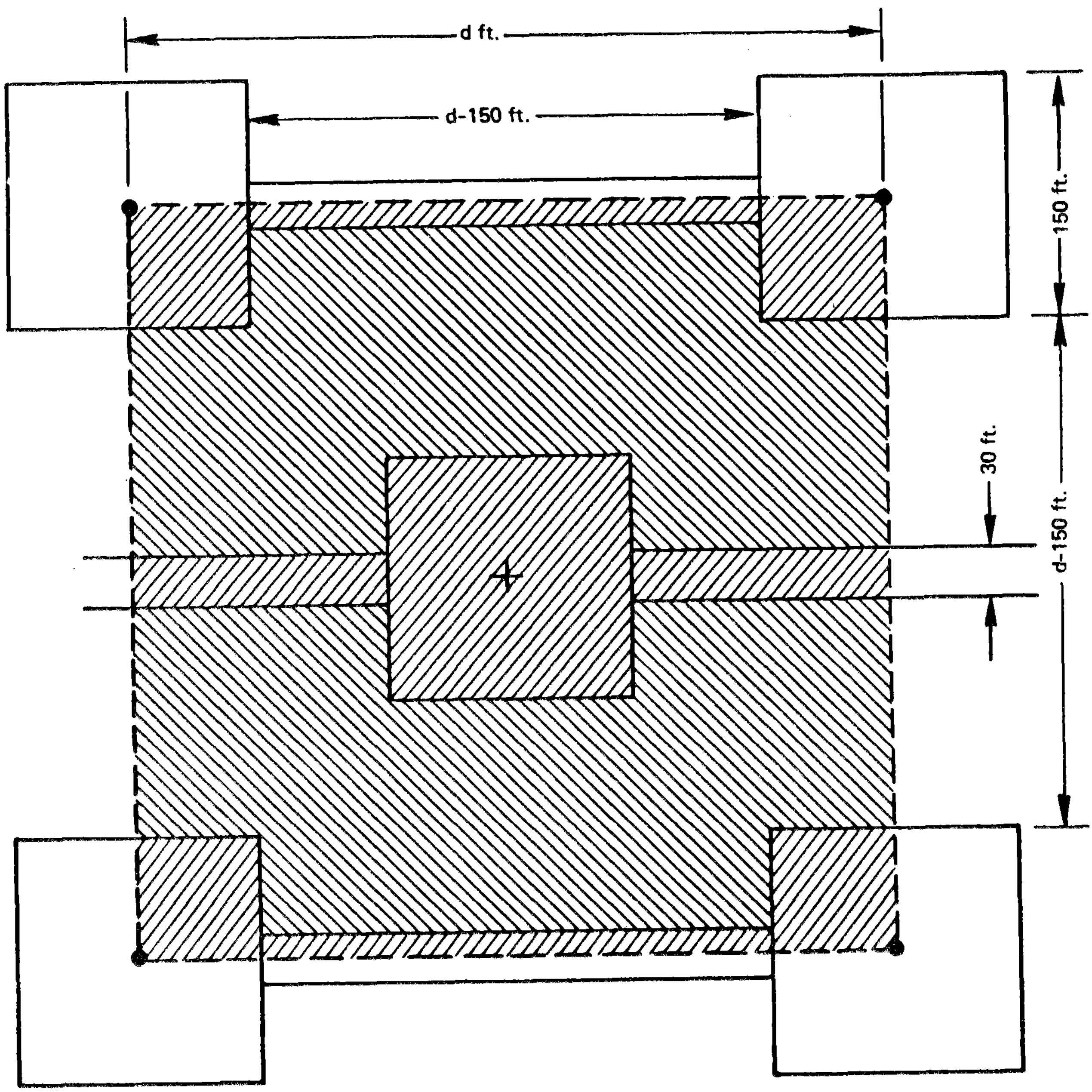
F_w, fraction of area available for solar collectors.

Values for typical well spacings are given in Table I.1 below.

TABLE I.1

VALUES OF F_w AS A FUNCTION OF WELL SPACING

Well Spacing (acres/well)	F_w
1.033	0.4000
1.25	0.4876
2.50	0.7061
5.00	0.8264



$d = \sqrt{(2)\ (43{,}560)\ s}$
WHERE
s = WELL SPACING

LAND AVAILABLE FOR SOLOR COLLECTORS
LAND RESERVED FOR OIL PRODUCTION OPERATIONS

EFFECT OF WELL SPACING ON LAND AVAILABILITY FOR SOLAR COLLECTIONS.

FIGURE I.1

I-1.2 EFFECTS OF STEAM TRANSMISSIBILITY LIMITS ON APPLICABILITY OF SOLAR COLLECTORS

In assessing the technical limits of applicability of parabolic trough solar collectors to steam injection techniques for enhanced oil recovery, it is essential that some consideration be given to probable maximum distances for transmission of solar-generated steam. In the present study, attention was given first to estimating land availability for solar collectors within a one-mile distance around each field of interest. Attention was then paid to the total amount of steam generation capacity anticipated for each of these fields. The question then arises as to whether or not practical distance limits on steam pipelining will add still other restrictions to solar steam use. The following discussion illustrates considerations given to this problem for the special case of a hybrid solar-fossil fuel system and the solar fraction of the total steam equal to one-third.

Assumptions

0.3×10^6 Btu/(ft^2)(year) = net rate of heat generation from parabolic trough solar collector system in the Bakersfield area

0.35 = (solar collector aperture area)/(net land area utilized)

350,000 Btu = energy required to generate one barrel of 80 percent quality steam

A_{gross} = gross land surface considered suitable for distribution of parallel trough solar collectors

F_t = correction factor applied to gross acreage due to surface irregularities and small distributed land usages (roads, oil field tankage, buildings, etc.)

F_w = correction factor applied to gross acreage due to well spacing

$A_{net} = A_{gross} F_t F_w$ = net land surface available for solar collectors

i_s = rate of steam injection, bbl/(acre)(day)

$i_s/3$ = maximum rate of solar steam injection, bbl/(acre)(day)

$$q_s = (43{,}560)(F_t)(F_w)(0.35)(0.3 \times 10^6)(1/365)(1/350{,}000)$$

$$= 35.80\ F_t\ F_w \text{ bbls steam generated/(acre)(day)}$$

d = maximum distance for steam transmission

The General Case for Steam Transmission from One Area to Another

Wherever the distances involved do not exceed steam transmission distance limits, the potential exists for transmission of solar-generated steam from an area of surplus generation capacity ($35.80\ F_t\ F_w > i_s/3$) to one of insufficient generation capacity ($i_s/3 > 35.80\ F_t\ F_w$). Perhaps the most obvious case is that where the area of excess generation capacity is outside the field and the steam generation rate is $35.80\ F_t$ bbls/(acre)(day).

Simple relationships exist between areas accepting steam to their full potential and those supplying steam to their full potential. If the width of the donor zone is indicated by x and the width of the acceptor zone is indicated by y, then the two zone widths are related by:

$$x(35.80\ F_t\ F_w - i_s/3)_x = y(i_s/3 - 35.80\ F_t\ F_w)_y \quad (1)$$

If z is the distance of separation between the two areas, then the following limits apply to the two distances:

$$x + z \leq d \quad (2)$$

$$y + z \leq d \quad (3)$$

Potential for Extending the Size of Zones Accepting Supplemental Solar Steam

A potential exists in some field situations for extending the size of solar steam acceptor zones above that indicated in the previous section. In these situations, the effects of excess steam in one area (Area 1) are transmitted through an area of approximate solar steam sufficiency (Area 2) to an area of steam insufficiency (Area 3). Briefly, solar steam from Area 1 is used to supply Area 2. The displaced steam generated in Area 2 is then used to supply Area 3. In no case is the steam transmitted more than an accepted transmission limit; for example, one mile.

Steps Taken in Applying Steam Transmission Distance Limits

The following steps were taken in applying steam transmission distance limits to the problem of developing the applicability of solar steam to heavy oil recovery.

(1) Mark off areas on maps where different levels of solar steam are being supplied.

(2) Calculate the solar steam excess or deficiency per acre for each area.

(3) Utilize the principles described above to predict the areas of insufficiency that can be supplied from the areas of excess.

(4) From the resulting areas and solar steam supply rates, calculate the maximum solar steam utilization for the field.

(5) Use the maximum solar steam utilization to calculate the corresponding solar collector aperture area.

I.2 CASH FLOW EQUATION

The Basic Cash flow Equation is:

$$NPV = -I + \sum_{M=1}^{K} \left\{ \frac{1}{(1+i)^M} \left[(1-T) \left(X_{CDo} (1+Do)^M + X_{CD_1} (1+D_1)^M + X_{CD_2} (1+D_2)^M \right) + T\, D_M + C_M \right] \right\}$$

The terms in the equation are:

- I - Total cash cost of the investment to the owner at the start of operations (net of direct government funds).
- i - Discount rate.
- Do - The G.N.P. deflator
- X_{CDo} - Cash expenses which inflate by Do (e.g., labor, maintenance, etc.
- D_1 - The total rate of increase in the price of oil sold or burned.
- X_{CD_1} - Cash expenses for oil burned
- D_2 - The total rate of increase in the price of electric power.
- X_{CD_2} - Cash expenses for electric power.
- T_1 - Total Marginal Tax Rate, including federal and state income taxes.
- C_M - Investment Tax Credit, Tertiary Incentive Revenue (after tax), or other credit in year M.
- K - Calculation horizon, physical or useful life of solar hybrid.
- D_M - Depreciation in year M.
- M - Year of cash flow.

I.3 FOSTER WHEELER ECONOMICS (P.R.P. METHOD)

P.R.P. Method (ORNL 5251) MARCH 1977

The P.R.P. approach calculates a series of expressions for year-end capital balances. In a given (non-start-up) year, the year-end capital balance (S_j) is defined as the sum of the year-beginning capital balance ($S_{j-1} < 0$), the return on that balance ($KS_{j-1} < 0$), and the net cash flow for the year (A_j). The cash flow (A_j) is defined as the after tax value of the difference between the "levelized constant dollar energy" cost times the solar energy delivered, less cash expenses and depreciation.

(1) $A_j = (P_0Q - E_0)(1 + i)^j(1-\tau) + \tau D_j$ for > 1

The expression assumes a constant inflation rate for P_0 (and E_0, if desired). The terms are as defined as follows:

A_j = net cash flow

Q = net energy delivered

E_0 = constant dollar expenses

i = inflation rate

τ = tax rate

P_0 = "levelized constant dollar cost of energy"

D_j = depreciation in year j

The P.R.P. method generates a power series in (1+K), where K is the specified rate of return:

(2) $S_1 = A_1 = -I$ = year-end capital

(3) $S_2 = (1+K)\, A_1 + A_2,\ A_2 > 0$

(4) $S_3 = (1+K)^2 A_1 + (1+K)\, A_2 + A_3$

(5) $S_n = (1+K)^{n-1}A_1 + (1+K)^{n-2}A_2 + (1+K)\, A_n-1 + A_n$

The method then solves for a, P_0 (levelized price) such that $S_n=0$:

(6) $0 = S_n = (1+K)^{n-1}A_1 + (1+K)^{n-2}A_2 ++ A_n$

If all other quantities are known, P_0, may be factored out explicitly. First, however, the equation is simplified by dividing both sides by the constant $(1+K)^n$:

(7) $$0 = \frac{A_1}{1+K} + \frac{A_2}{(1+K)^2} ++ \frac{A_n}{(1+K)^n}$$

This is a standard discounted cash flow expression, used to solve for rate of return or levelized costs.

By substituting (1) and (2) into (7), an expression in P_0 can be developed.

$$(8) = \frac{-I}{1+K} + \sum_{j=2}^{n} \frac{\tau D_j + (1-\tau)(1+i)^j (P_0 Q - E_0)}{(1+K)^j}$$

(9) Factoring out $P_0 Q$ and combining expense and investment terms, one has a defintion of total levelized cost:

<u>Total Levelized Costs</u> = <u>Total Investment Plus Expense</u>

$$(10)\ (P_0 Q) \times \sum_{j=2}^{n} \frac{(1-\tau)(1+i)^j}{(1+k)^j} = \frac{I}{(1+k)} + \sum_{j=2}^{n} \frac{E_0 (1-\tau)(1+i)^j - \tau D_j}{(1+K)^j}$$

Then, P_0 is obtained by dividing through by the energy and the financial factor which represents the net present value of 1 dollar after tax inflated at a constant rate. If inflation applied to the levelized cost is defined as zero, i.e., an equal payment annualized cost method (such as Dickinson) is used, then the left hand side becomes:

$$(11)\ (R_0 Q)(1-\tau) \sum_{J=2}^{n} \frac{1}{(1+K)^j} \equiv \text{Investment + Expenses}$$

The summation term is the inverse of the capital recovery factor for a cash flow pattern as defined by P.R.P. By inspection, P_0 will equal R_0, only if $i = o$ in the P.R.P. method, i.e. only if a world of zero inflation exists. Otherwise, if $i > 0$ then P_0 is $< R_0$ from the following:

$$(12)\quad (R_0 Q)(1-\tau) \sum_{j=2}^{n} \frac{1}{1+k^j} = (P_0 Q)(1-\tau) \sum_{j=2}^{n} \frac{(1+i)^j}{(1+K)^j}$$

Dividing out Q and $(1-\tau)$

$$(13)\quad R_0 \sum_{j=2}^{n} \frac{1}{(1+K)^j} = P_0 \sum_{j=L}^{n} \frac{(1+i)^j}{(1+K)^j}$$

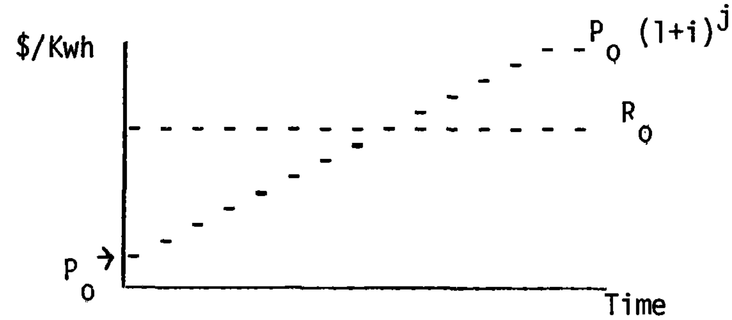
If $i > 0$ the numerator of each term in the right hand sumation is greater than the left, so

$$(14)\quad \sum_{j=2}^{n} \left(\frac{1}{1+K}\right)^j < \sum_{j=2}^{n} \frac{(1+i)^j}{(1+K)^j}$$

dividing (13) by (14) we get

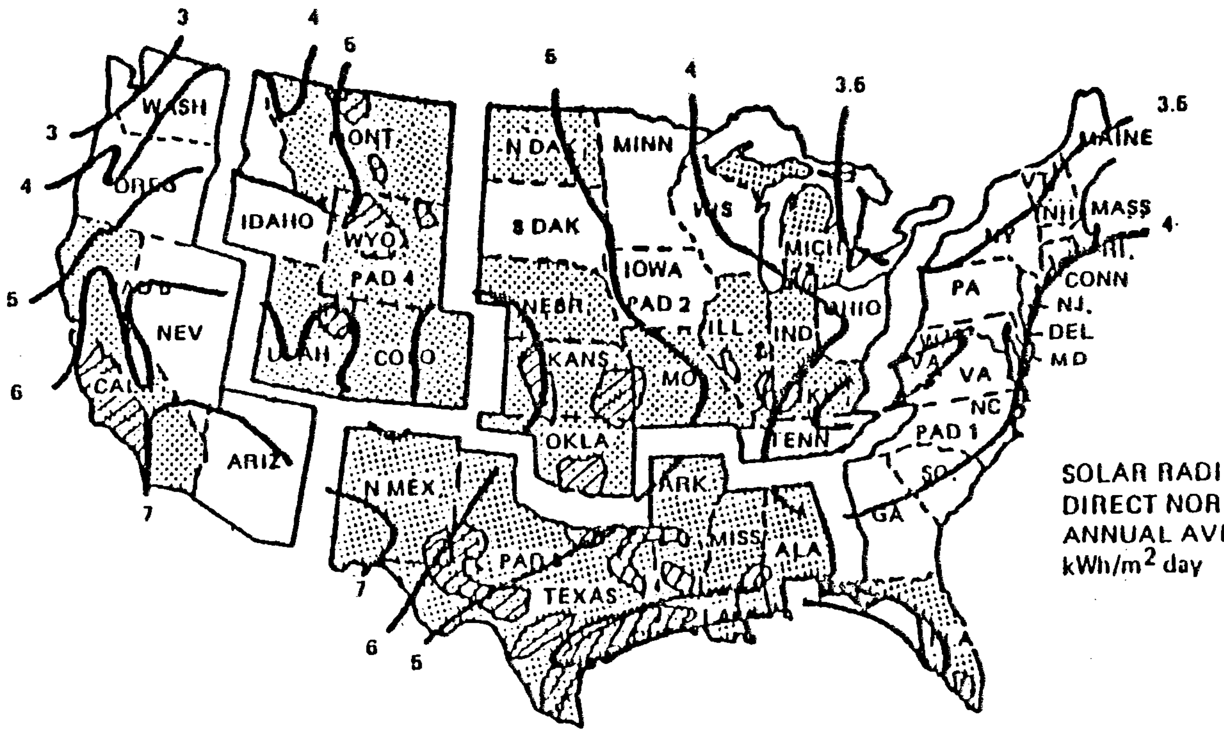
$$(15)\quad R_0 > P_0 \quad , i > 0.$$

Equation 15, suggests the following graphical representation:

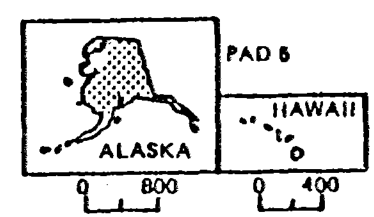


P_o is useful for comparison against a fuel cost with no constant dollar price increase, where it can be matched to a current day price of energy. If differential fuel price escalation occurs, neither measure P_o or R_o, is theoretically superior. R_o, is however the most common measure, and the one adopted in Section 8.

States Containing Heavy Crude Oil



SOLAR RADIATION
DIRECT NORMAL INSOLATION
ANNUAL AVERAGE-DAY VALUES
kWh/m[2] day



KNOWN HEAVY CRUDE OIL RESOURCE BY STATE

STATE	BILLIONS OF STOCK-TANK BARRELS	
	TOTAL	MOST FAVORABLE RESERVOIRS
CALIF	53.6	33.4
TEXAS	30.6	3.4
LOUISIANA	6.4	0.8
WYOMING	5.3	2.7
ARKANSAS	5.0	4.1
TOTAL U.S.	106.8	45.9

LEGEND

PAD PETROLEUM ADMINISTRATION DEFENSE

AREA OF SIGNIFICANT HEAVY-OIL ACCUMULATIONS

STATES CONTAINING HEAVY OIL

I.5 SELECTIONS FROM PROPOSAL ECONOMIC ANALYSIS

PROGRAM OPPORTUNITY NOTICE FOR THE
DESIGN, CONSTRUCTION, OPERATION AND
EVALUATION OF PROTOTYPES OF STEAM
GENERATOR SYSTEMS, WHICH USE SOLAR THERMAL ENERGY
IN LIEU OF OIL OR NATURAL GAS
IN STEAM INJECTION ENHANCED OIL RECOVERY
APPLICATIONS

PON 03-79-CS30051

Exxon Research and Engineering Company
Name of Organization

Linden, New Jersey 07036
Address of Organization

Solar Thermal Enhanced Oil Recovery Project
Title of Proposed Project

Proposed Duration Phase I, 6 Months

Requesting Starting Date October, 1979

Name of Project Manager	E. R. Elzinga, Jr.
Position and Title	Area Manager - Senior Engineering Associate
Telephone (w/area code)	201-474-2502
Department Affiliation	Advanced Energy Systems Laboratory

Authorized Officials

Name	A. Skopp		
Signature			
Title	Director		
Date	May 8, 1979		

2.3 Assumed Values of Key Variables

2.3.1 General Assumptions

These assumptions cover basic prices and escalation rates, the presumed date of operations, system economic lifetime, taxes, and depreciation. A discount rate of 15% is assumed for Exxon equity.

2.3.1.1 Prices and Inflation Rates (Prices are stated in current year dollars)

	Current 1979 Price	Total Annual Inflation	Initial Year
• General Expenses	-	7%	1982
• Crude Oil (Edison)	$11.46/Bbl	10%	1982
• Electricity	$0.033/KWH	9%	1982
• Investments			
+ Base Case	$1,321,000	7%	1981
+ Solar	$57.80/ft^2	7%	1981

The general inflation rate was selected based on an expectation of continued inflation in line with the President's Wage and Price Guidelines. It is significant only in its relation to rate of return expectations of the sources of capital. The oil price escalation rate follows a choice used by Sandia Albuquerque in an economic study of solar EOR. It should be noted that the current market price for Edison heavy crude is $4 per barrel below the OPEC benchmark crude oil price. This reflects the relative competitive price disadvantage of heavy, sour crudes as a refinery feedstock. The electric rate listed is the most recent monthly average rate incurred by Edison Field for power from Pacific Gas and Electric. For simplification, the average electric price is used. The 2% real increase in electric rates is based on a rounding upwards of the 1.6% figure used by a 1978 Office of Technology Assessment (OTA) Study of Solar Potential.

2.3.1.2 Date of Initial Operations

To simplify economic calculations during the conceptual design activity, a convention was selected to fix construction costs (investments) in 1981 and to begin counting operating costs and revenues in 1982. All figures are in current (inflated) dollars.

revenues due to the reduction of its prices elsewhere in the composite. One published estimate indicates that Exxon production accounts for 8% of the dollar value of the composite. Hence, the net TIR incentive will be 75% x (1-.5086) x (1-.08) = 33.9% applied only against the non-fossil boiler expenses in the solar hybrid case.

2.3.2 Fossil Base Case Operations

A Struthers Thermoflood OH-25 unit with Flue Gas Desulpherization is used in both the fossil-base and solar-fossil hybrid cases.

2.3.2.1 Struthers Thermoflood 25 MBTU/H Steamer Specifications

The Specifications are:

- Rated Output — 25 Million BTU/H
- Service Factor — 95%
- Annual Energy Output — 208,050 Million BTU/Y
- Output Steam Quality — 80%
- Crude Oil input in barrels per barrel of steam output — 0.0 724 $\frac{\text{Bbls-in}}{\text{Bbls out}}$
- KW for Auxiliaries — 175 KW
- Allowable cutback level (% of Rated) — 20%
- Baseload efficiency — 87%
- Cutback efficiency — 75% (Est.)
- Scrubber useage of oil -- (included in the total oil-to-steam ratio above) — 0.0058 $\frac{\text{Bbl-in}}{\text{Bbl-out}}$

These data are engineering estimates based on manufacturer's product literature, nameplate ratings, and vendor estimates (cutback efficiency). Service factor is an Exxon Company USA judgment based on experience with a 22 MBTU/H unit.

2.3.2.2 Typical Well Steaming Costs

The following cost figures were estimated assuming continued cyclic steam injection operations to input 10,000 barrels of 80% quality steam per well per injection. If and when a switchover were to occur to steam drive (steam flood), most of these expenses which are variables per unit volume of steam produced would not change.

Certain other costs associated with the disassembly, reassembly, and preparation of each injected well would be less in a steam drive mode. However, these reduced expenses would be offset by increased costs of capital investment in injection lines and increased well maintenance costs. For the development of the conceptual design, these two effects were assumed to be offsetting in their relative impact on the net present value of each case, assuming that a switchover occurs after 1988.

The $ 1979 costs per 10,000 Barrels, including Flue Gas Desulpherization (FGD) are:

• Oil Consumed	724 BBls
• Electricity (equivalent of present diesel output)	27,053 KWH
• Chemicals and Water, etc.	$1,140
• Disposal of FGD Scrubber wastes	$540
• Misc. Rig rentals and steam line connections	$7,600
• Overhead Charge	7% of expenses

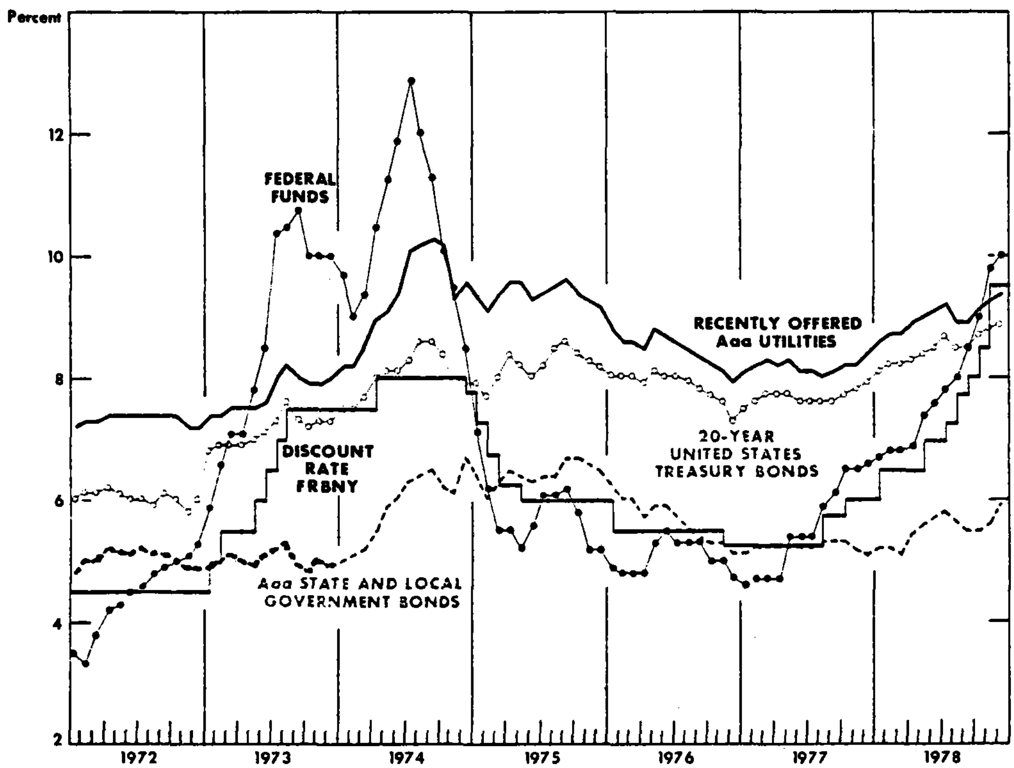
2.3.2.3 Other Annual Costs

The other estimated annual operating costs which are not variable per well injected include:

• Manpower - 1/2-man, 7 days/week	$23,000
• Maintenance (boiler and scrubber)	$20,000
• Overhead Charge	7% expenses 3% capital (a one-time overhead charge is made at 3% of book value cost in the first year of operation (1982).

FIGURE 2-2

HISTORICAL INTEREST RATES FOR DEBT INSTRUMENTS



Source: Annual Report for 1978, Federal Reserve Bank of New York.
Recent Rates: Utility Aaa 9.5%, Local Gov't. 6-7%, Prime 11 1/2 - 11 3/4%, Federal Funds 10 1/8% (offered), US Treasury Bond Yield 9.7%, FRBNY 9 1/2%, as quoted by the Wall Street Journal, April 24, 1979.

APPENDIX J

ENVIRONMENTAL IMPACT ANALYSIS

CONVERSIONS FOR APPENDIX J

Table J.1

Ton/Day: (kg/DAY)	Ton/Day: (kg/DAY)
169 (1.71×10^5)	195 (1.98×10^5)
33 (3.3×10^4)	41 (4.1×10^4)
1 (1.01×10^4)	47 (4.7×10^4)
203 (2.06×10^5)	283 (2.8×10^5)
112 (1.13×10^5)	114 (1.15×10^5)
68 (6.90×10^4)	225 (2.28×10^5)
146 (1.48×10^5)	31 (3.14×10^4)
160 (1.62×10^5)	169 (1.71×10^5)
194 (1.97×10^5)	247 (2.5×10^5)
63 (6.4×10^4)	6.3 (6.4×10^3)
35 (3.5×10^4)	119.9 (1.21×10^5)
48 (4.8×10^4)	71.0 (7.21×10^4)
146 (1.48×10^5)	39.2 (3.98×10^4)
95 (9.6×10^4)	282.5 (c) (2.87×10^5)
38 (3.8×10^4)	518.9 (5.27×10^5)
181 (1.83×10^5)	27.5 (2.79×10^4)
	7.7 (7.82×10^3)

Table J.3

Given: (N) g/M^3 to convert to (M) lbs/ft^3:

Multiply: (N) x (6.243×10^{-11}) = (M) lbs/ft^3

Given: (N)Mg/M^3 to convert to (M) lbs/ft^3

Multiply: (N) x (6.243×10^{-8}) = (M) lbs/ft^3

APPENDIX J

ENVIRONMENTAL IMPACT ANALYSIS

An important part of this analysis is to show to what extent the application of solar technology can mitigate undesirable environmental effects from TEOR, to thereby improve environmental quality or to allow increased oil recovery without a corresponding decrease in quality. The study will begin by defining the present inventory of pollutant emissions, along with projections of future emissions. Emissions will then be related to present ambient air quality and to future air quality including the relative contribution from various sources, and the potential benefits from solar application. Results from dispersion modeling studies are presented elsewhere in this report. Finally, costs of alternative environmental controls will be estimated in order to define the potential market for STEOR and the effect of environmental control costs on future oil production by thermal enhancement.

J.1 EMISSION INVENTORY AND PROJECTIONS

Various estimates are available for the amounts of pollutant emissions in Kern County as shown in Table J.1. Included are estimates allowing for new facilities that received authority to construct by September 12, 1979 on the basis that applicable regulations are complied with. Regulation 424 covers SO_x emissions (see Ref. J-1), while a recent ruling requires 25%. NO_x reduction (see Ref. J-2). Emissions have also been estimated from oil production rate, fuel burned etc., for confirmation. In the case of SO_x, estimates of present emission used by Technology Service Corp. (TSC) (see Ref. J-3) appear to be realistic. As shown, SO_x emissions are projected to decrease in the future as scrubbers are more widely used. Even by 1990, at which time TEOR is expected to peak, SO_x emissions will be slightly less than in the recent past. On NO_x, the TSC estimates look too low for the TEOR contribution and the CARB basis will be used. Some projection of future allowable emissions have been made by Radian (see Ref. J-4), but appear to be low for NO_x and SO_x projections. As noted on Table J.1, CO emission reported for mobile sources looks low by a factor of about two relative to the expected NO_x/CO ratio for automobiles of roughly 0.08 by weight, or 0.05 by gas volume (see Ref.J-5).

As shown in Figure J-1, our estimate of emissions from TEOR for Kern County in 1990 is based on doubling net oil production from the recent level of 237,000 B/D (see Ref. J-1). The increase in TEOR fuel consumption is somewhat greater, 2.5 fold, since the expanded production is mainly by steam drive which uses relatively more fuel than cyclic steam stimulation. These trends are shown in Figures J-2 and J-3. To the extent that STEOR is applied, emissions would decrease proportionally. Thus, supplying 30% of the heat by solar would decrease TEOR emissions of SO_x, NO_x, etc. by a maximum factor of 0.3 regardless of the specific manner in which solar is incorporated in the system. For example, preheating boiler feed water by solar is environmentally just as effective as making steam. Alternatively, oil production could be increased while holding the same emissions level. Parameters for a typical TEOR furnace are given in Figure J-4.

Table J.1

Inventory of Emissions - Kern County

Source of data (a)	1976 TSC	1976 CARB	1982 ERE	1982 Radian	1990 ERE	1990 with LNB
SO_x, tons/day						
TEOR	169	-	112(b)	68	160	
Other stationary	33	-	33	-	33	
Mobile	1	-	1	-	1	
Total	203		146		194	
NO_x, tons/day			(CARB)			
TEOR	63	95	195	114	225	169
Other stationary	35	38	41	-	41	31
Mobile	48	48	47	-	47	47
Total	146	181	283		313	247
CO, tons/day						
TEOR	6.3	-	-	-	-	-
Refinery	119.9	-	-	-	-	-
Carbon Black	71.0	-	-	-	-	-
Other stationary	39.2	-	-	-	-	-
Mobile	282.5(c)	-	-	-	-	-
Total	518.9					
Particulates, tons/day						
TEOR	-	-	-	27.5(allowable)	-	-
Non-methane Hydrocarbons						
TEOR	-	-	-	7.7(allowable)	-	-

Notes:

(a) Sources: Technology Service Corp. (TSC) Ref.J-3. California Air Resources Board (CARB) Ref. 1. Exxon Research and Engineering (ERE) Radian Corp. Ref. J-4.

(b) Estimated from furnace capacities given by CARB.

(c) CO from mobile sources look low by a factor of about two relative to typical automobile NO_x/CO ratio.

FIGURE J-1

KERN COUNTY TEOR

ADAPTED FROM NPC REPORT (7)
AND PROJECTION ADDED

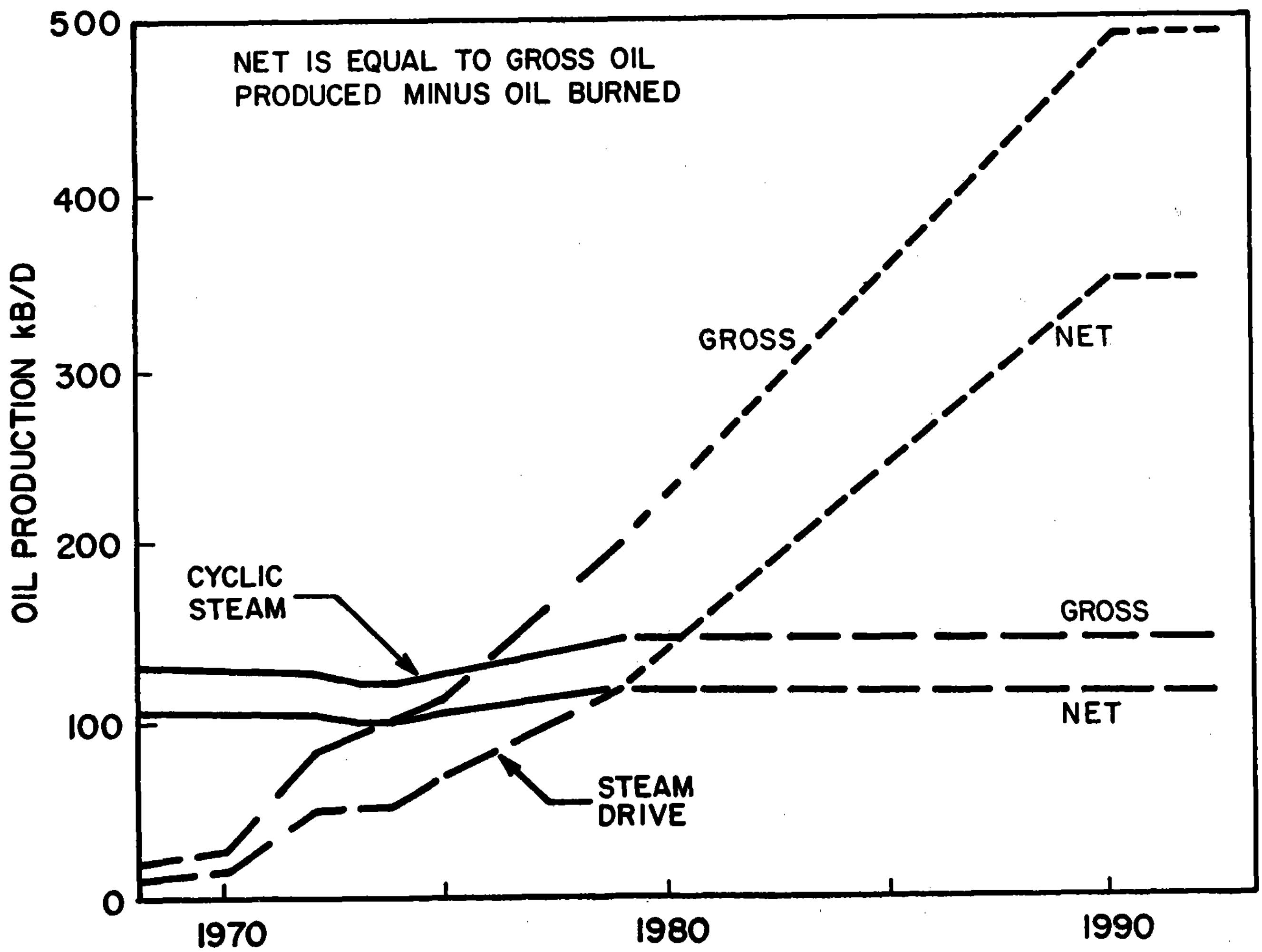


FIGURE J-2

PROPORTION OF STEAM DRIVE RELATIVE TO CYCLIC STEAM

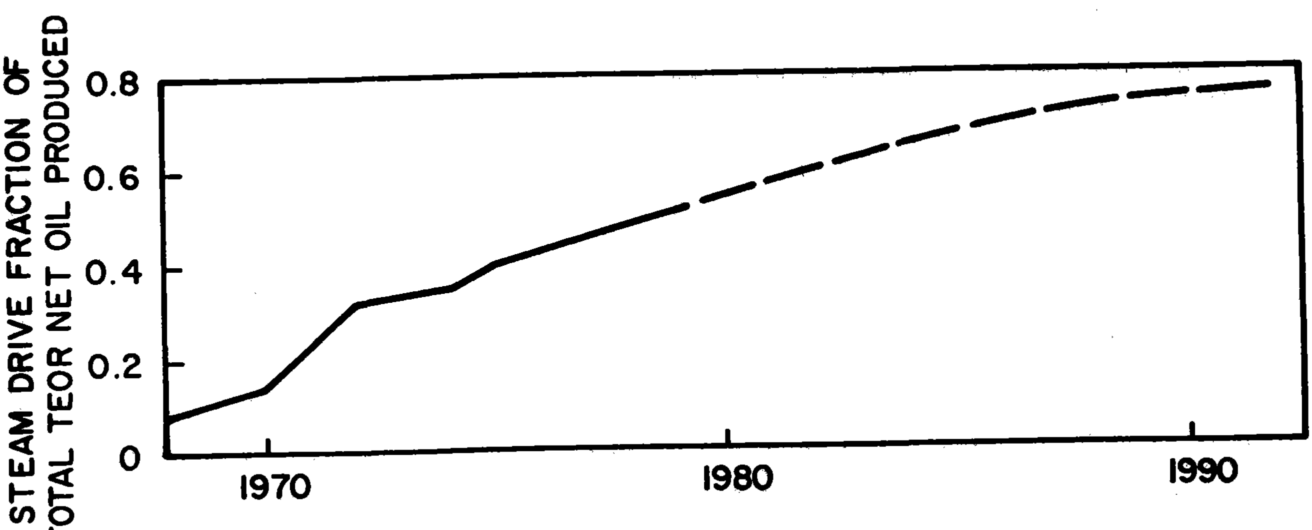


FIGURE J-3

TRENDS IN TEOR FUEL CONSUMPTION

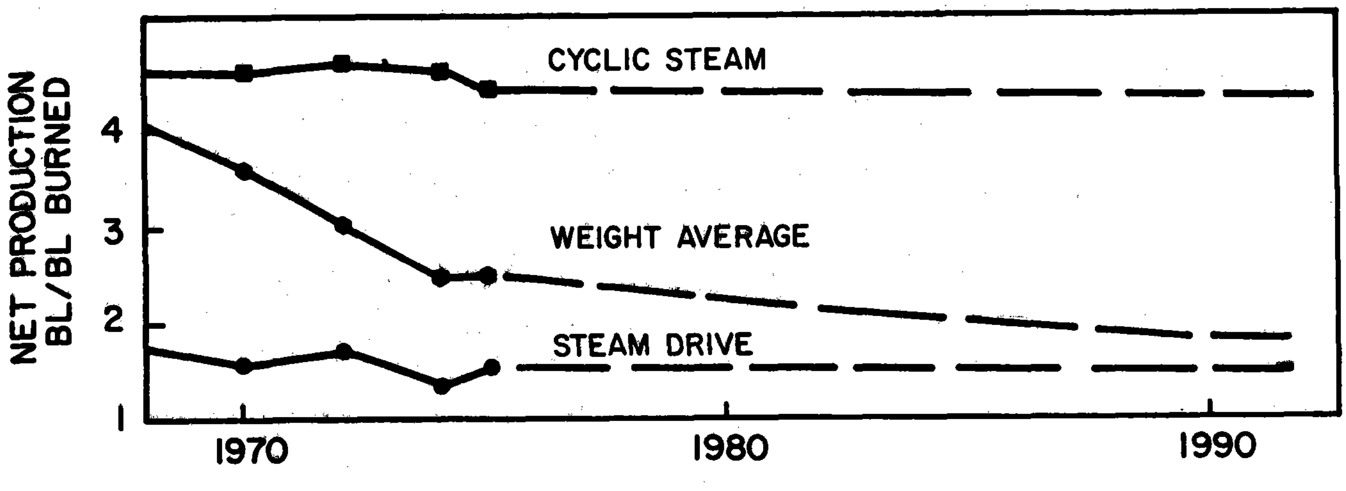
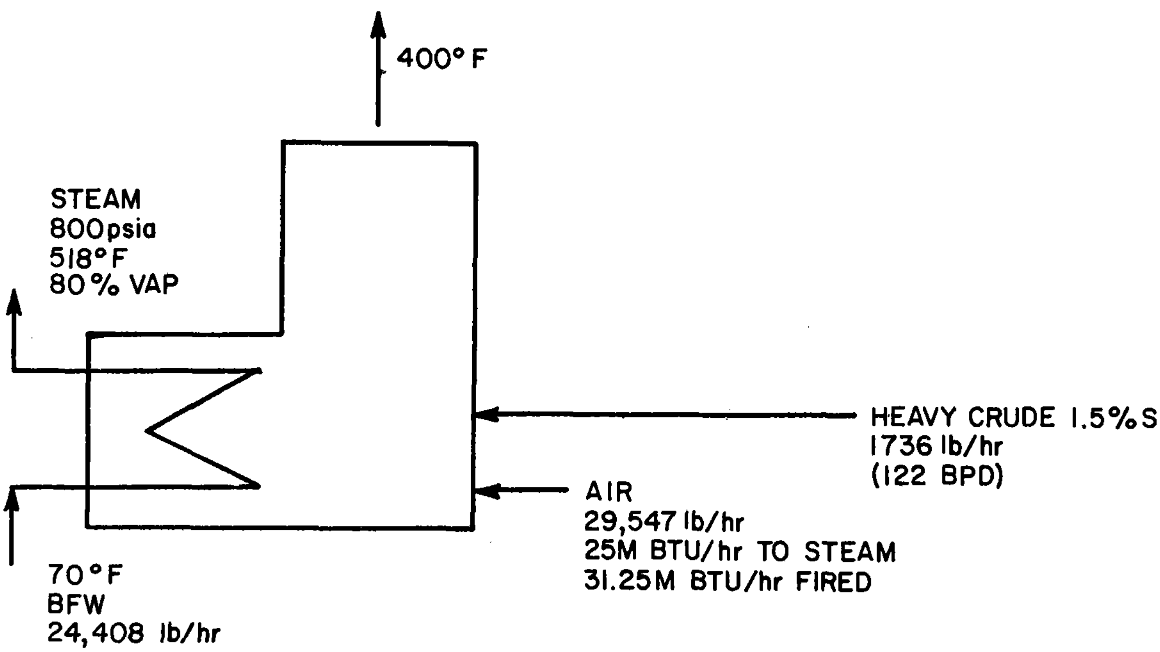


FIGURE J-4
TEOR BASE CASE FURNACE



FLUE GAS

31,235 lb/hr (dry 29,377 lb/hr)

CO_2	11.8v %	NO_x	12.5 lb/hr
H_2O	9.7	SO_x	3.7 lb/hr
O_2	3.3	CO ca	5 lb/hr
N_2	75.2		
	100.0		

FGD 92.8% SO_x REMOVAL

24.1 lb SULFER

to .06 lbS/MBTU

J.2 AMBIENT AIR QUALITY

Many areas of California are in violation of Federal air quality standards. The problem is greatest in Los Angeles, Kern County and San Diego as shown in Table J-2, which lists various areas in the order of decreasing pollution. Kern County does not appear to be much different than other nearby populated areas except that SO_2 is high. In all cases, poor air quality is accompanied by high CO level even in the southeast desert and Lake Tahoe areas implying that automobiles may be a major contributor. CARB has reported a sharp rise in ambient NO_2 level over the period 1974-1978 for Bakersfield and attributes the rise to increased TEOR activity in Kern County. They are taking actions based on this premise.

Ambient NO_2 level as presented by CARB is plotted in Figure J-5 for the Chester Ave. station in Bakersfield showing that The Federal Standard is closely approached, before allowing for new construction already authorized. Federal and California state air quality standards are summarized in Table J-3. The increase in ambient NO_2 of about 50% has been attirbuted to TEOR by CARB; however, the increase in kg./day of NO_2 from TEOR was only about 20% of total Kern County emission. Previous studies have estimated the relative contribution of TEOR to ambient NO_x levels by using SO_2 as a tracer for furnaces, and CO as a tracer for automobiles (see Refs. J-3, J-5). The study by TSC concluded that the TEOR contribution to ambient NO_x was no more than 20%, and that changes in analytical procedures in March 1977 accounted for at least a 15% increase in apparent NO_2 levels (see Ref. J-3). On the contrary, CARB allocated the TEOR contribution in proportion to the kg./day emissions from TEOR relative to the total for Kern County, giving roughly 50% from TEOR. In view of the disagreement on TEOR contribution we have used alternative assumptions for both 20% and 50% TEOR contribution in projecting air quality.

Ambient NO_2 levels projected to 1990 are shown in Figure J-6 based on the assumption of TEOR contributing 50% to the level in 1978. The effects of using Low NO_x Burners (LNB) or thermal $deNO_x$ are also indicated, in one case applied only to new construction (solid lines) and in a second case including retrofit on all existing TEOR furnaces (dashed lines). On the basis assumed, extensive NO_x controls are clearly needed to avoid violating air quality standards in the future. The benefit of solar might be to drop the increase between now and 1990 by a factor of 0.3 for example. The alternative assumed basis of 20% TEOR contribution results in TEOR having only a minor impact on ambient NO_x. Low NO_x burners may be warranted if a substantial decrease in ambient NO_2 level cannot be achieved by TEOR controls (see Figure J-7). Automobiles appear to be the major cause of the NO_x problem throughout California including Kern County as indicated by others in a study of Los Angeles (see Ref. J-5).

Table J.2

Ambient Air Qualities in California

	O_3	NO_2	CO	SO_2	P.M.	HC(1)	Pb(2)	SO_4(3)
Los Angeles	+	+	+	+	+	10	+	+
Kern County	+	o	+	+	+	6	+	+
San Diego	+	+	+	o	o	9	+	+
San Francisco	o	o	+		o	4	+	o
Southeast Desert	+	o	o		+	4	+	
Lake Tahoe	o		+			4		

+ denotes contaminants exceeding Federal air quality standards (3)
o denotes contaminants now close to federal standards (3)

(1) Values given are for total hydrocarbons including methane as ppm by volume and are an average of the worst one hour each day for December 1978. The Federal standard is 0.24 ppm max. of non-methane hydrocarbons for 3 hours from 6:00 a.m. to 9:00 a.m. and although such data are not readily available it appears that the standard may be exceeded at all of the above locations.

(2) California State standard (No Federal standard).

(3) See Table J.3 for summary of Federal and California standards.

FIGURE J-5

HISTORICAL TREND IN NITROGEN DIOXIDE BAKERSFIELD CHESTER AVE. STATION (1)

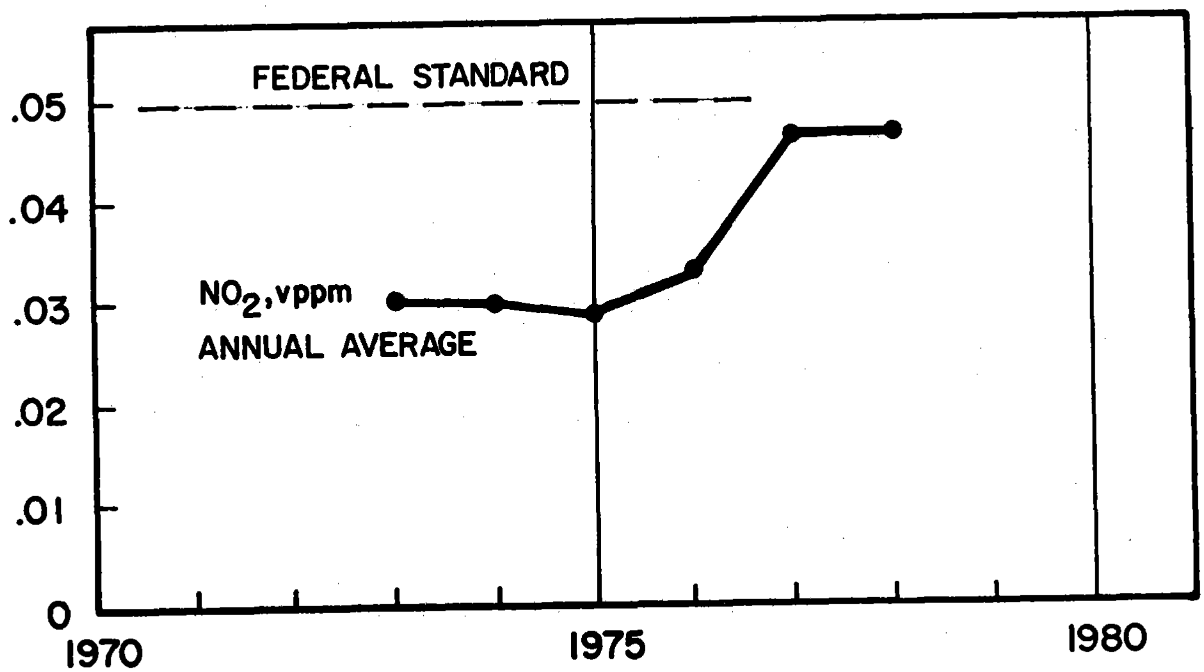


Table J.3

AMBIENT AIR QUALITY STANDARDS (6)

Pollutant	Averaging Time	California Standards[1]		National Standards[2]		
		Concentration[3]	Method[4]	Primary[3,5]	Secondary[3,6]	Method[7]
Oxidant (Ozone)	1 hour ✓	0.10 ppm (200 ug/m^3)	Ultraviolet Photometry	160 ug/m^3 * (0.08 ppm)	Same as Primary Std.	Chemiluminescent Method
Carbon Monoxide	12 hour	10 ppm (11 mg/m^3)	Non-Dispersive Infrared Spectroscopy	—	Same as Primary Standards	Non-Dispersive Infrared Spectroscopy
	8 hour	—		10 mg/m^3 (9 ppm)		
	1 hour	40 ppm (46 mg/m^3)		40 mg/m^3 (35 ppm)		
Nitrogen Dioxide	Annual Average	—	Saltzman Method	100 ug/m^3 (0.05 ppm)	Same as Primary Standards	Proposed: Modified J-H Saltzman (O$_3$ corr) Chemiluminescent
	1 hour	0.25 ppm (470 ug/m^3)		—		
Sulfur Dioxide	Annual Average	—	Conductimetric Method	80 ug/m^3 (0.03 ppm)	—	Pararosaniline Method
	24 hour	0.05 ppm (131 ug/m^3)[9]		365 ug/m^3 (0.14 ppm)	—	
	3 hour	—		—	1300 ug/m^3 (0.5 ppm)	
	1 hour	0.5 ppm (1310 ug/m^3)		—	—	
Suspended Particulate Matter	Annual Geometric Mean	60 ug/m^3	High Volume Sampling	75 ug/m^3	60 ug/m^3	High Vol. Sampling
	24 hour	100 ug/m^3		260 ug/m^3	150 ug/m^3	
Sulfates	24 hour	25 ug/m^3	AIHL Method No. 61	—	—	—
Lead	30 Day Average	1.5 ug/m^3	AIHL Method No. 54	—	—	—
Hydrogen Sulfide	1 hour	0.03 ppm (42 ug/m^3)	Cadmium Hydroxide Stractan Method	—	—	—
Hydrocarbons (Corrected for Methane)	3 hour (6-9 a.m.)	—	—	160 ug/m^3 ** (0.24 ppm)	Same as Primary Standards	Flame Ionization Detection Using Gas Chromatography
Ethylene	8 hour	0.1 ppm	—	—	—	—
	1 hour	0.5 ppm				
Visibility Reducing Particles	1 observation	In sufficient amount to reduce the prevailing visibility to less than 10 miles when the relative humidity is less than 70% (8)		—	—	—
APPLICABLE ONLY IN THE LAKE TAHOE AIR BASIN:						
Carbon Monoxide	8 hour	6 ppm (7 mg/m^3)	NDIR	—	—	—
Visibility Reducing Particles	1 observation	In sufficient amount to reduce the prevailing visibility to less than 30 miles when the relative humidity is less than 70% (8)		—	—	—

* Revised to 0.12 ppm February 1979

** ppm. vol., calculated as CH_4

FIGURE J-6

PROJECTED AIR QUALITY (NO_2) AND IMPACT OF NO_X CONTROLS

CHESTER AVE; BASIS: 50% OF NO_X IN 1979 IS FROM TEOR

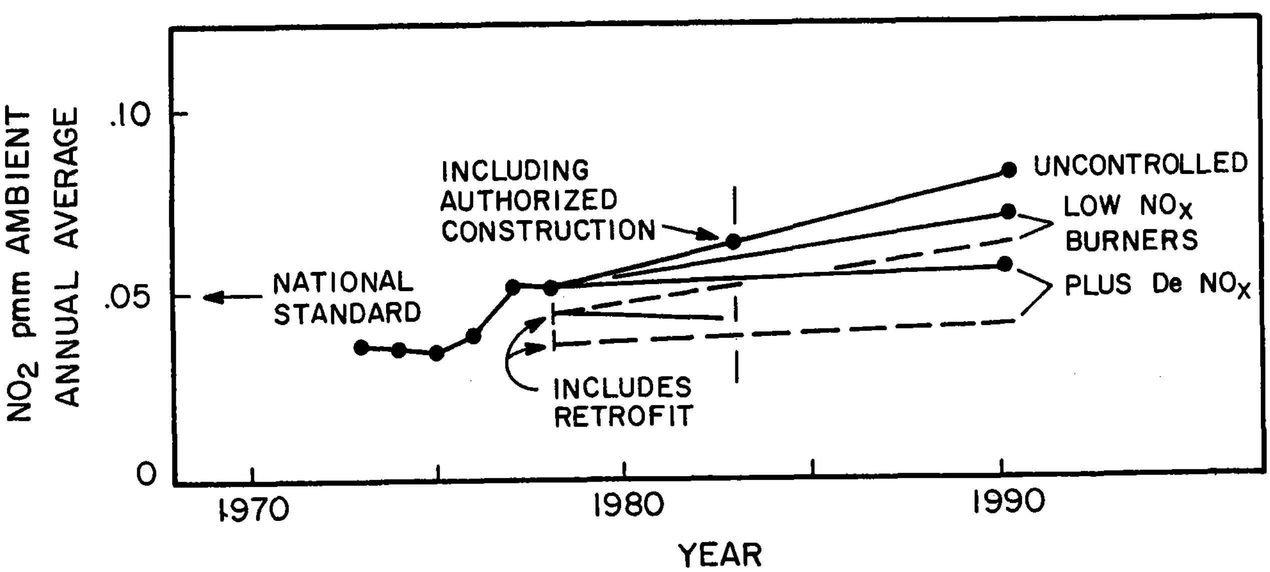
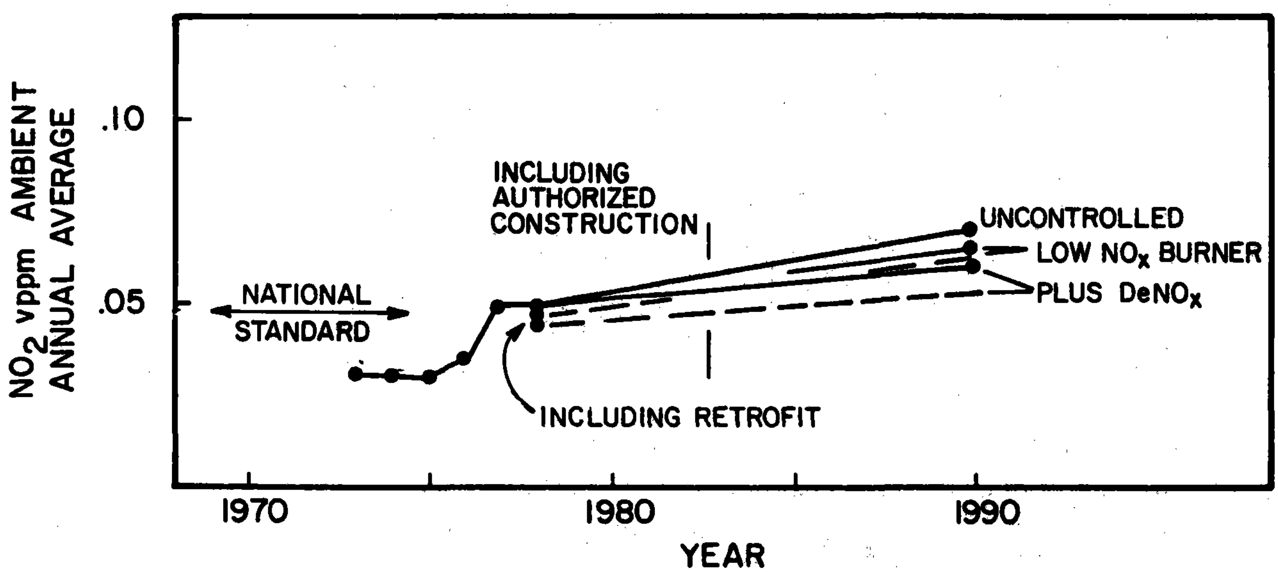


FIGURE J-7

PROJECTED AIR QUALITY AND IMPACT OF NO_x CONTROLS

CHESTER AVE.; BASIS: 20% OF NO_x IN 1979 IS FROM TEOR



High levels of SO_x are also of concern particularly around Bakersfield. The interpretation that oil field operations contribute roughly 90% of the measured ambient SO_x is consistent with available information. Scrubbers for SO_x control are required by Kern County Rule 424 including retrofit controls on existing steam generators. These controls will decrease SO_x emissions as shown in Table J.1, even with authorized new construction. By 1990 the SO_x emissions are projected to return to near the 1978 level, so future reevaluation of the situation will be warranted. Again, solar could substantially decrease the SO_x emission caused by new facilities so as to avoid violating standards.

Other air contaminants of immediate concern include CO and hydrocarbons. Furnaces inherently have a low emission of CO and the TEOR contribution is minor compared to automobiles. No significant impact of TEOR on ambient CO concentrations is discernable from our analysis of the data. The oil fields have had emissions of hydrocarbon vapors in the past but adequate controls and operating procedures have been instituted to adequately protect the environment in line with county and state regulations. Ambient levels of hydrocarbons are high in Kern County; however, the levels are even higher in Los Angeles and are generally high throughout much of California. Even at Lake Tahoe the hydrocarbon level is lower by only a factor of about two. Hydrocarbon levels correlate well with ambient CO level, again pointing to automobiles as the cause. Particulates are also a cause for concern, including lead which reflects automobiles. In the case of sulfates and other particulates, the relative impacts of various sources has not yet been established so projections of future levels can not be made. To the extent that oil field operations are a contributing source, the wide application of SO_x scrubbers should result in some improvement.

J.3 OTHER CONSIDERATIONS

Waste liquid streams will be returned underground as has been satisfactory in the past. The major waste stream is spent liquor from SO_x scrubbing with sodium hydroxide or carbonate. As is established practice suitable precaution must be taken to assure that potable water and irrigation water etc. is not contaminated. Where NO_x reduction systems are used with ammonia addition, compounds of ammonia can be expected in the waste liquor but are not expected to present added environmental problems. With the application of solar, emissions from the fuel fired section will decrease in direct relation to the proportion of solar heat component. Other sections of this report discuss related areas such as the effect of solar on agriculture, ground cover to minimize dust and potential glare from solar collectors.

J.4 ENVIRONMENTAL COSTS AND CREDITS

Solar heating is known to be expensive due to high capital cost; however, the credits for environmental advantages can be substantial. In order to quantify these environmental credits the cost of alternative heating systems were compared and specific costs were determined for removing individual pollutants. Results are summarized in Table J.4 which shows the breakdown of credits into the general areas: fuel value, combustion facilities investment and environmental controls. The total cost of supplying steam amounts to $6.48/$10^9$J ($6.84/MBTU) transferred to steam, of which $0.61/$10^9$J ($0.64/MBTU) is the cost of environmental controls. On the same basis present solar technology costs $49.29/$10^9$J ($52.00/MBTU) and is not economic today without special incentives such as the U.S. and California Solar tax credits or Tertiary Incentive Revenue.

Additional credits for solar were considered but there does not appear to be any reasonable basis for expecting other credits. Items considered included the advantage for solar of eliminating emissions of CO, hydrocarbons, particulates, ammonia from NO_x removal, and effects on visibility. The only potential debits for solar appear to be the impact on land use for a larger area of land, and possible reflected glare from collectors. Also, a solar installation depends on large industrial facilities to manufacture the equipment, with associated environmental impacts such that solar applications may serve mainly to transfer emissions from one location to another rather than actually eliminating them.

Table J.4

Credits for Solar Heating

Credits	$/MBtu to steam	$/B Net Oil(4)
Fuel saved (1)	5.21	13.89
Furnace costs (1)	0.99	2.64
Total ex environmental	6.20	16.53
SO_x removal (2)	.42	1.12
Low NO_x burners (LNB) (3)	.11	.29
LNB plus $DeNO_x$ (3)	.22	.58
Maximum SO_x plus NO_x credit	.64	1.70
Maximum value of solar heat	6.84	18.23

Notes:

(1) Assumptions per section 8.5.2.2.3, assuming 11 year S.O.Y.D. depreciation. Stated as 20 year levelized costs for 1981 investment and 1982 startup.

(2) SO_x removal by sodium scrubbing using Section 8.5.2.2.3 assumptions for 1.5% sulfur fuel. If prorated to 100% "sulfur removal" for solar versus 92.8% on furnace, a 3¢ increase would occur.

(3) Based on costs per pound of NO_x removed as reported by CARB (1). These costs appear reasonably consistent with other available information for Low NO_x Burners (LNB) and Thermal $DeNO_x$.

(4) Based on fuel consumption estimated for 1990 of one barrel burned for each 1.8 barrel net oil production, 80% efficiency and 6 MBTU/BBL. (The last two numbers are approximate values to 82% efficiency and 5.93 MBTU/BBL used in Section 8.5.2.2.3).

REFERENCES TO APPENDIX J

J-1 Harrison, R. Staff Report, California Air Resources Board, presented at CARB Kern County Hearing November 28, 1979, Bakersfield, California.

J-2 Anonymous. "Views Differ on Kern County Air Regulations," Oil Gas Journal, March 17, 1980, pg. 64.

J-3 Eldon, J., Gins, J., Horie, Y., (November 1979) Sources and Concentration of NO_x in Bakersfield. Reported by Technology Service Corp. for Western Oil and Gas Association presented at CARB Kern County hearing November 28, 1979.

J-4 Norton, J.F., Arnold, C.W., Husband, S.N., and Tannahill, G.K., (November 27, 1979) Impact of Proposed NO_x Control Regulations on the Production of Thermally Enhanced Oil in Kern County. Report prepared by Radian Corp. for Gary Peterson of D.O.E., San Francisco.

J-5 Chang, T.Y., Norbeck, J.M., and Weinstock, B., February 1980 No_2 Air Quality -- Precursor Relationship: An Ambient Air Quality Evaluation in the Los Angeles Basin (Ford Motor Co.) Journal of the Air Pollution Control Assoc. Vol. 30, No. 2, pp. 157-162.

J-6 Robinson, E., and Robbins, R.C., (February 1969) Sources, Abundances, and Fate of Gaseous Atmospheric Pollutants, Stanford Research Institute Report to API.

J-7 Series of Reports by California Air Resources Board, "Air Quality Data," Technical Services Division, 1976-1978.

APPENDIX K

AIR QUALITY ANALYSIS

CONVERSIONS FOR APPENDIX K

Section K.1

5.08×10^4 kg	(50 Tons)
25.4×10^4 kg	(250 Tons)
7.32 Megawatts	(25 MBTU/hr)
.03 kg	(.06 lbs)
.91 kg	(2.0 lbs)
68.40 kg	(150 lbs)
90.72 kg	(200 lbs)
1.23×10^{-10} kg/JOULE	(.30 lbs/MBTU)

Section K.2

.16 kg	(.37 lbs)
.03 kg	(.06 lbs)
.291 Megawatt/hrs	(1 million BTU)
7.32 Megawatts	(25 MBTU/hr)
1.70×10^{-10} kg/JOULE	(.40 lbs/MBTU)
130.63 kg/DAY	(288 lbs/DAY)
91.62 kg/DAY	(202 lbs/DAY)
23.58 kg/DAY	(52 lbs/DAY)
7.32 Megawatts	(25 MBTU/hr)
39.0 kg/DAY	(86 lbs/DAY)
6.44 Megawatts	(22 MBTU/hr)
34.02 kg	(75 lbs)
7.32 Megawatts	(25 MBTU)
49.44 kg	(109 lbs)

Section K.2 (Continued)

.12 PPM	(.054 GRAINS/ft^3)
.20 PPM	(.090 GRAINS/ft^3)
.22 PPM	(.10 GRAINS/ft^3)
68.0 kg/day	(150 lb/day)
.09 PPM	(.040 GRAINS/ft^3)
.10 PPM	(.046 GRAINS/ft^3)

SECTION K DISCUSSION OF RESULTS:

5.5 M	(18.04 ft)
3.76 M^3/S	(132.76 ft^3/S)
6.57 g SO_2/S	(.014 lbs SO_2/S)
2 $\mu g/M^3$	(1.24×10^{-10} lbs/ft^3)
2 KM	(1.24 miles)
80 $\mu g/M^3$	(4.9×10^{-9} lbs/ft^3)
5 $\mu g/M^3$	(3.12×10^{-10} lbs/ft^3)
63 $\mu g/M^3$	(3.9×10^{-9} lbs/ft^3)
30 M	(98.43 ft)
1300 $\mu g/M^3$	(8.11×10^{-8} lbs/ft^3)
2.57×10^{-3} lbs/JOULE	(.06 lb/MBTU)
1 KM	(.6214 miles)
1 $\mu g/M^3$	(6.23×10^{-11} lbs/ft^3)
43 $\mu g/M^3$	(2.68×10^{-9} lbs/ft^3)
30 M	(98.43 ft)
7.32 Megawatts	(25 MBTU/hr)

Section K.3

Section K.3

7.32 MEGAWATTS	(25 MBTU/hr)
2.43 MEGAWATTS	(8.3 MBTU/hr)
9.760 MEGAWATTS	(33.3 MBTU/hr) (ALL)
7.32 MEGAWATTS	(25 MBTU/hr) (ALL)
2.58 x 10^{-11} Kg/JOULE	(.06 lb/MBTU)
825 M	(2706.82 ft)
255 M	(836.65 ft)
1600 M	(5249.6 ft)
600 M	(1968 ft)
1400 M	(4593 ft)
400 M	(1312 ft)
19.9^{o}C	(35.82^{o}F)
152.4 M	(500 ft)
213.3 M	(700 ft)
243.8 M	(800 ft)
1 KM	(3281.0 ft)
9.760 MEGAWATTS	(33.3 MBTU/hr)
1 μg/M^3	(6.23 x 10^{-11} lbs/ft^3)
100 μg/M^3	(6.23 x 10^{-9} lbs/ft^3)

APPENDIX K

AIR QUALITY ANALYSIS

K.1 AIR QUALITY REGULATIONS

The requirements for assessment of the environmental impact of systems involving fired and solar energy production are set forth in the 1977 Clean Air Act; Prevention of Significant Deterioration and Emission Offset Interpretive Ruling. The California Air Resources Board is responsible for the State Implementation Plan through which the Clean Air Act is administered. Therefore, the regulations of Kern County Air Pollution Control District set the standards to be met by sources of pollutants in Kern County.

The Environmental Protection Agency is also authorized to approve construction of new facilities which may be a source of air pollution. This authority derives from the Environmental Protection Agency's Prevention of Significant Deterioration Regulations. To obtain EPA approval, it is necessary to demonstrate that the proposed new source (1) will meet emission limits representative of the best available control technology, (2) will not cause any applicable ambient air quality increment to be violated, and (3) will not cause any National Ambient Air Quality Standard to be violated. However, the three determinations for EPA approval are not required when the emission of any criteria pollutant from the source does not exceed 50 tons per year after controls or 250 tons per year before controls. No_x is usually the largest pollutant emission of a steam generator but SO_x can be considerable, if uncontrolled. A 25 million BTU/hr generator with a low NO_x burner emits less than 50 tons per year. For small sources such as this, information regarding emission control methods employed, air quality data, analysis of effect of project on ambient air quality increments, and additional impact analyses are required by EPA if EPA rules aggregate the steamers together as a single source. EPA's potential jurisdiction notwithstanding, the regulations used herein as applicable to the system selected are solely those of the Kern County Air Pollution Control District of the State of California.

<u>Ambient Air Quality Standards</u>. The five criteria pollutants considered in these standards are Volatile Organic Compounds (VOC, also referred to as non methane hydrocarbons, NMHC), Carbon Monoxide (CO), Nitrogen Oxides (NO_x calculated as NO_2), Sulfur Oxides (calculated as sulfur in SO_2 and SO_3), and Particulate Matter (PM).

Table K.1 lists the California and National Ambient air Quality Standards for the criteria pollutants.

<u>Kern County Emission Limits</u>. Kern County's emission standards have been developed as part of the State Implementation Plan required under the Federal Clean Air Act Amendments of August 1977. Emission limits for oil field steam generators have been established for the three pollutants (NO_x, SO_x, PM) released in significant quantities by these generators.

Sulfur content of emissions, regardless whether as SO_2, SO_3, or as sulfate is limited by Kern County Air Pollution Control District Rule 424 as amended September 26, 1979. For new steam generators the maximum permitted emission of sulfur compounds is an average of 0.06 pounds of sulfur per million Btu of heat input to the single (multisteamer) source. To satisfy this requirement without a SO_2 scrubber, would require burning oil that contains no more than 0.11% sulfur. A second less stringent rule (no. 407) prohibits discharge to the

Table K.1 Ambient Air Quality Standards for Criteria Pollutants

Pollutant	Averaging Time	California Std. Concentration	National Standard Primary	National Standard Secondary	Class II PSD Increments
Volatile Organic Compounds (Non Methane Hydrocarbons)	3 hour (6-9 am)	-	160 $\mu g/m^3$ (0.24 ppm)	same as primary	
Carbon Monoxide	12 hour	10 ppm (12 mg/m^3)	-	-	None
	8 hour	-	10 mg/m^3 (9 ppm)	same as primary	
	1 hour	40 ppm 46 mg/m^3	40 mg/m^3 (35 ppm)	same as primary	
Nitrogen Dioxide	Annual Average (arithmetic mean)	-	100 $\mu g/m^3$ (0.05 ppm)	same as primary	None
	1 hour	0.25 ppm (470 $\mu m/m^3$)	-	-	
Sulfur Dioxide	Annual Average (arithmetic mean)	-	80 $\mu g/m^3$ (0.03 ppm)	-	20 $\mu g/m^3$
	24 hour	0.05 ppm (131 $\mu g/m^3$)	365 $\mu g/m^3$ (0.14 ppm)	-	91 $\mu g/m^3$
	3 hour	-	-	1,300 $\mu g/m^3$ (0.5 ppm)	512 $\mu g/m^3$
	1 hour	0.5 ppm (1310 $\mu g/m^3$	-	-	
Suspended Particulate Matter	Annual Average (geometric mean)	60 $\mu g/m^3$	75 $\mu g/m^3$	60 $\mu g/m^3$	19 $\mu g/m^3$
	24 hour	100 $\mu g/m^3$	260 $\mu g/m^3$	150 $\mu g/m^3$	37 $\mu g/m^3$

All values other than annual values are maximum concentrations not to be exceeded more than once per year. Standard conditions are taken to be 25°C and 101.3 kPa. PPM values are approximate concentrations by volume.

NOTE: SEE CONVERSION TABLES FOR EQUIVALENT VALUES.

atmosphere of streams which exceed at the point of discharge 0.2% (by volume) sulfur compounds calculated as sulfur dioxide. Rule 407 would permit 2.0 pounds of sulfur to be emitted per million Btu fuel value. Therefore Rule 424 which is specific to oilfield steam generators controls.

Kern County APCD Rule 210.1 as amended November 27, 1979 sets forth the requirements for a permit to construct a new source or modify an existing emission source. This rule applies to all air contaminants for which there is a national ambient air quality standard (e.g. SO_x, NO_x and PM).

Under the rules, the existing steam generators at Edison Field must be considered a single emission source and installation of a new steam generator is a modification of that source. The rules have many exemptions and qualifications to permit them to apply to a variety of sources but the essential features which apply to the system of this study are:

- The requirements of Rule 210.1 apply only to modifications which result in a net increase in emissions of 150 lbs or more per day in any air contaminant after September 12, 1979.

- If emission increase is more than 150 lbs/day but less than 200 lbs/day best available control technology is required. Best available control technology is generally defined to be the technology which gives the maximum degree of reduction which the Control Officer determines is achievable for such source. BACT for NO_x is uncertain. Low NO_x burners or a combination of low NO_x burners and thermal denox, or other system could be required.

- Emissions over 200 lbs/day require construction with lowest achievable emission rate technology and offsetting reduction of emissions from existing sources.

- Rule No. 425 was promulgated on March 6, 1980, as an addition to the Kern County Air Pollution Control District Regulations. It would require retrofit control of existing steam generators to limit NO_x emission to 0.30 pound per million Btu of heat input by July 1982. Emission reductions could become bankable for use to offset increased emissions due to expansion, if such a rule were promulgated.

K.2 CONTROL OF EMISSIONS

Sulfur Dioxide and Sulfates. Sulfur dioxide and sulfur trioxide, which in the regulation are considered sulfates, will be removed by an efficient scrubber. A spray type scrubber utilizing a sodium sulfite-bisulfite system is planned. In this, sulfur dioxide is reacted with sodium sulfite to form sodium bisulfite. Either sodium hydroxide or soda ash is added to convert bisulfite back to sulfite. The concentration of dissolved salts is regulated at about 14% by continuous removal of a portion of this circulating scrubber liquor.

To reduce uncontrolled emission of 0.37 lb sulfur (present in SO_2 & SO_3) per million Btu heat input to the required 0.06 lb sulfur/million Btu required by Rule 424 requires the scribber to remove 84% of inlet sulfur. However, with a 95% efficient scrubber, the sulfur content of fuel oil could more than double before emissions would approach the permitted amount. The effect of sulfur emission control is shown in Figure K-1.

Nitrogen Oxides. Uncontrolled NO_x emission of the planned 25 million Btu/hour steam generator will be about 0.40 lbs/million Btu input. This would result in net increase in NO_x emission of about 288 lbs/day. However, when equippped with low NO_x burner, the increase is reduced to 202 lbs/day. To reduce the net NO_x increase of the source to 150 lbs requires a reduction of 52 lbs NO_x/day which can be obtained by retrofitting the other steam generators which are a part of the same source with low NO_x burners.

The reduction obtainable at the existing 25 million Btu/hr steam generator is 86 lbs/day, and the 22 million Btu/hr generator's emission can be reduced about 75 lbs/day. The effect of the modification of the system, consisting of an addition of a new 25 million Btu/hr steam generator with low NO_x burner, and retrofitting both existing steam generators with low NO_x burners is to provide about 109 lbs/day of NO_x reduction beyond the required amount. The effect of NO_x emission control is shown in Figure K-1.

Particulate Matter. The ash content of crude from Edison Field was recently found to be 0.18%. However, other measurements indicate that it can be as high as 0.30%. The uncontrolled particulate emission of a steam generator with standard burner using 20% excess air is 0.054 grains per standard cubic foot of flue gas, when the fuel contains 0.18% ash. With 0.30% ash in fuel uncontrolled PM emission will be 0.090 grains per SCF which is within the maximum emission limit of 0.10 grains per SCF.

Assuming increases in PM due to steamers added after December 1979 are less than 150 lbs/day, then no equipment for mitigation of PM is required to meet standards. However, some of the equipment installed to mitigate emission of other pollutants also affects the concentration of PM in flue gases. These effects are shown in Figure K-2. Installation of a scrubber to remove SO_2 also produces a 25% reduction in PM. For fuel with 0.18% ash, the PM concentration in the stack is about 0.040 grains per SCF. It remains the same for a system with a scrubber combined with solar since, unlike SO_2 and NO_x, PM is measured as the concentration in the stack rather than related to the quantity of energy input to the system.

Use of low NO_x burners increases the concentration of PM in the stack by reducing the quantity of flue gas. The standard burner operates with 20% excess air and the low NO_x burner with 5% excess air. This increases PM concentration in the stack to 0.046 grains per SCF.

Figure K-1
SULFUR AND NO_x
COMPARISON OF EMISSION CONTROL METHODS

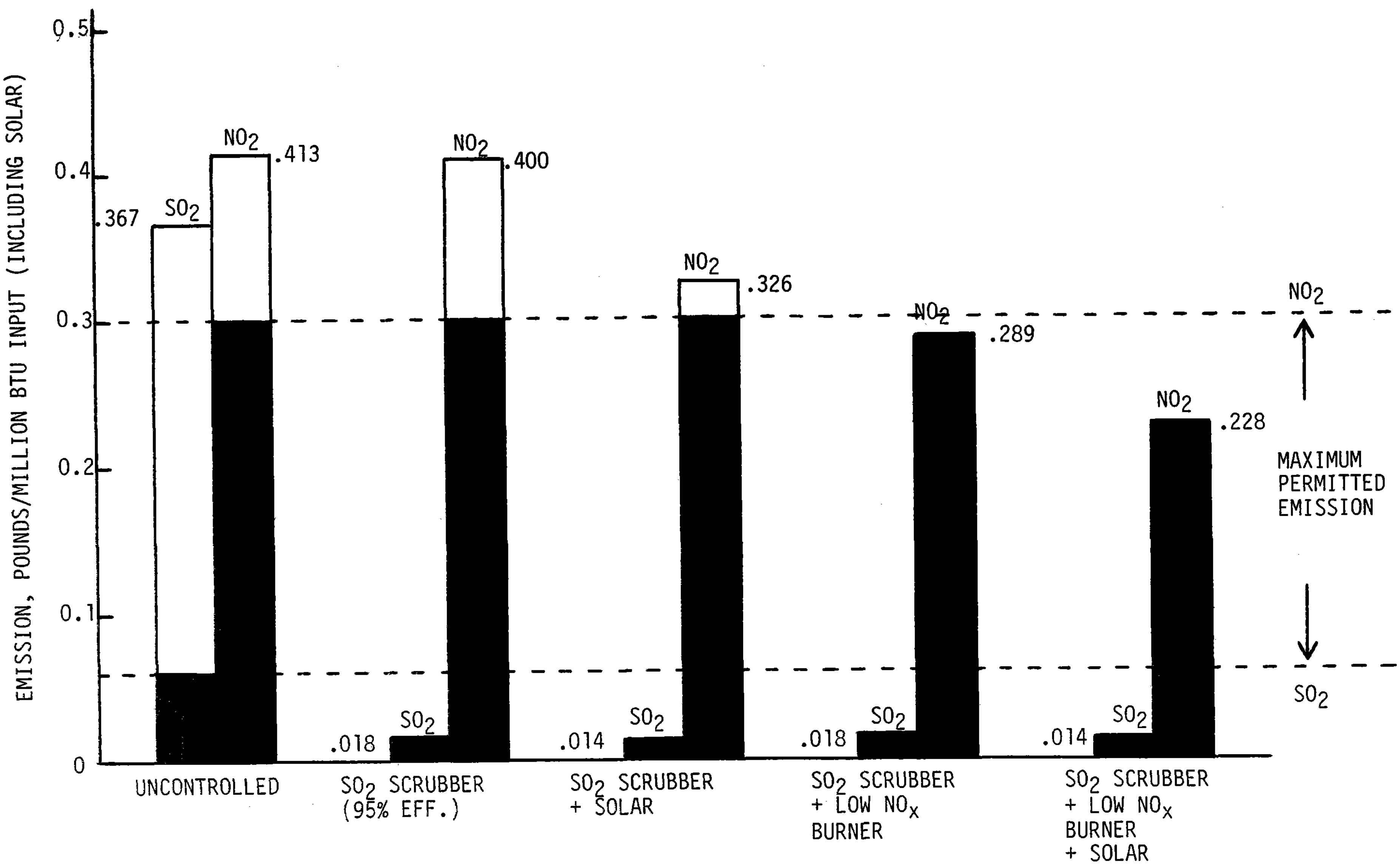
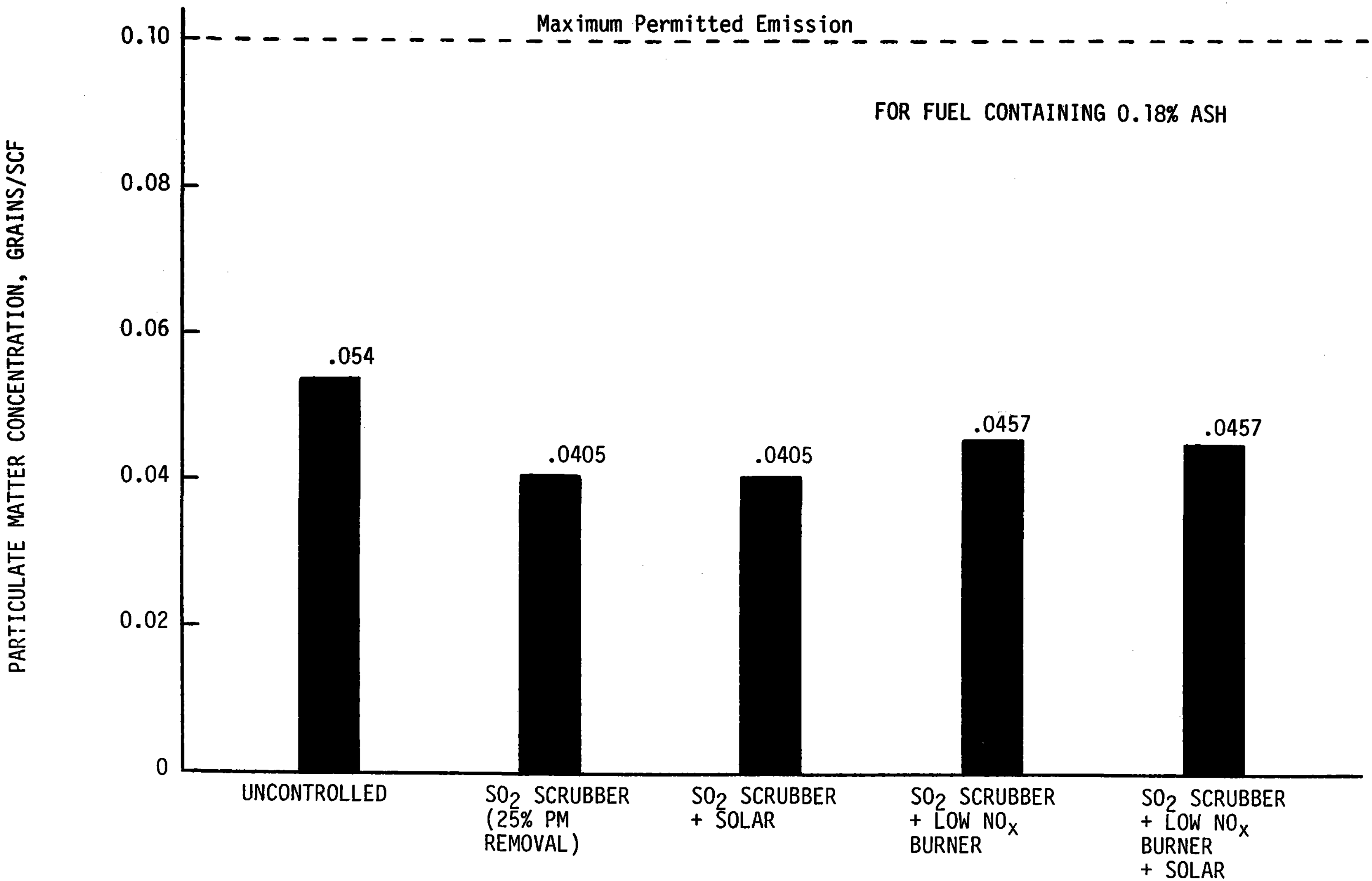


FIGURE K-2
PARTICULATE MATTER
COMPARISON OF EMISSION CONTROL METHODS



K.3 IMPACT ON AMBIENT AIR QUALITY

The STEOR flash separator preheat plus storage preliminary design for the Edison field involves the introduction of a new 25 MBTU/hr steam generator and a solar thermal system with an equivalent generating capacity of 8.3 MBTU/hr (annual average). The preliminary design utilizes the full capacity of the new boiler and thus generates steam at the rate of 33.3 MBTU/hr. The objective of this analysis is to assess the impact of this preliminary design on ambient air quality and determine the extent of beneficiation due to the solar thermal steam generation. In addition, ambient increments due to the combination of existing and proposed steam generating equipment will be examined. Of the pollutants for which ambient standards exist, only SO_2 and NO_x will be treated here. Emissions of particulate matter, hydrocarbons, and carbon monoxide are discussed elsewhere and from these units are sufficiently low that the resulting ambient contributions are small compared to other sources.

Methodology of Impact Assessment. The approach which we have taken is to use dispersion modeling to predict the incremental effect on ambient air quality due to the steam generating system at the Edison field. By ambient increment we mean that portion of the ground level concentration of a pollutant at a given receptor which is attributable to emissions from the sources under consideration. Increments rather than absolute levels of air quality are examined for two reasons. First, our primary interest is in quantifying the effect of the steam generators on ambient levels. Second, no air monitoring station is properly located to allow an accurate assessment of air quality in the vicinity of the Edison Field.

In order to estimate the improvement in air quality due to the solar-thermal generation of steam, the ambient increments due to an oil-fired 25 MBTU/hr steam generator are compared to those due to an oil-fired 33.3 MBTU/hr unit. This comparison provides a reasonable measure of the solar beneficiation of air quality, because, in order to produce oil at the same rate as the solar hybrid system, a 33.3 MBTU/hr conventional generator would be required. This comparison depends, of course, on the pollutant emission rates assumed for the conventional boiler and consequently on the control options employed.

Description of Cases Modeled. The basic task is the estimation of the air quality impact of the 25 versus the 33.3 MBTU/hr steam generators, located at the site proposed for the new unit. It is first necessary to specify control options in use on the "competitive" steam generator before the improvement in air quality due to the solar contribution can be meaningfully assessed. In order to underscore the significant role of Kern County Air Pollution Control District Rule 424 requiring SO_2 emissions not to exceed an average of 0.06 lb sulfur per MBTU heat input, the ambient SO_2 emissions and with scrubbing to the required level have been predicted. Because SO_2 emissions from new generators (and from existing ones by 1984) must be controlled, the comparison between the 25 and 33.3 MBTU/hr units has been made on the basis that both are equipped with scrubbers.

NO_x emissions (as NO_2) for these steam generators have been based on the use of conventional and low NO_x emissions. For consideration of the dispersion of NO_x, the stack gas temperature for these cases has been taken to be that typical of scrubbed flue gas.

Finally, the ambient increments due to the proposed steam generator and the two existing boilers are investigated. The two existing units are a 22 MBTU/hr generator which is not currently equipped with a flue gas scrubber and a newer 25 MBTU/hr unit with a scrubber. Neither of these boilers is now equipped with a low NO_x burner, but it is assumed that both will be so retrofitted. Ambient SO_2 contributions from these three units are examined for the case with scrubbers on the two larger units and the smaller unscrubbed and for the case with scrubbers on all three. The use of low NO_x burners on all three units is assumed.

For the purposes of this analysis, the new generator for the solar hybrid system is assumed to be stationary and located approximately 825 meters east of the center line of Tejon Highway and 255 meters north of the center line of Hermosa Road. The existing units are portable and will be moved throughout the field. For the purposes of modeling ambient increments, we have treated them as located centrally in the field; once, 1600 meters west and 600 meters south of it. This placement is representative of the separation of these units and should provide a reasonable estimate of their air quality impact. A source of conservatism in our treatment is the use of emission rates for the year which are based on firing the units at full capacity. It is possible that the stationary unit will have a very high service factor, but the portable units are likely to have a service factor of approximately 80%. However, no credit for the consequent reduction in emissions from these units has been taken.

All the cases considered are summarized in Table K.2. The details of the dispersion modeling of these cases are discussed on the following page.

Modeling Procedure. The effect on air quality of the oil-fired steam generators has been predicted primarily through the use of the Climatological Dispersion Model, the EPA's gaussian model for the calculation of annual average concentrations for shorter averaging times is more difficult and typically requires more extensive meteorological input data. The use of the EPA single source model CRSTER was investigated, but no source of relevant upper air data could be located. Short-term concentrations have been screened using the EPA PTMAX model. Use here of these idealized models, however, should not be taken as providing a basis for permitting a steamer, since the models can exhibit large predictive variances from actual observed conditions.

Meteorological Inputs. The meteorological joint frequency function used in the CDM was that for Bakersfield from observations for the period 1967 to 1971, obtained from the National Climate Center, Asheville, North Carolina. For later analysis, we present in Figure K-3 the wind rose based on this function, which shows the long-term relative frequency

Table K.2

Cases for the Estimation of Air Quality Impact

Case	Steam Generating Capacity (MBTU/hr)	Pollutant Considered	Sulfur Removal	Low NO_x Burner
I-a	25	SO_2	No	-
I-b		SO_2	Yes	-
I-c		NO_x	Yes	No
I-d		NO_x	Yes	Yes
II-a	33.3	SO_2	Yes	-
II-b		NO_x	Yes	No
II-c		NO_x	Yes	Yes
III-a	1 unit @ 22 2 units @ 25	SO_2	Yes on 25's/ No on 22	-
III-b		SO_2	Yes on all	-
III-c		NO_x	Yes on all	Yes

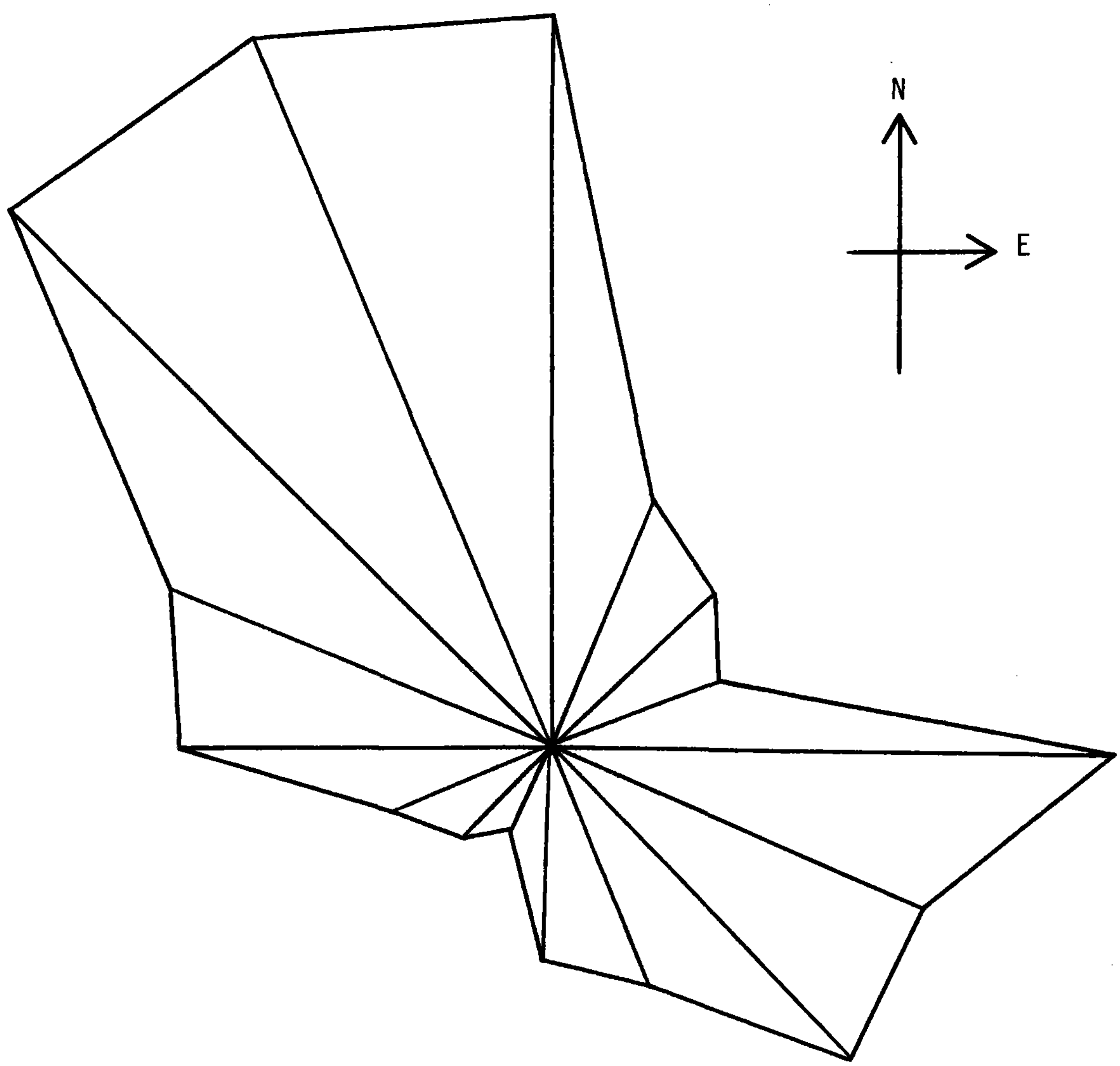


Figure K-3 Wind Rose for Bakersfield, California (Dates of Observations: 1967-1971; Source: National Climate Center, Asheville, North Carolina) of wind direction, i.e., the length of the line segment extending in a given direction is proportional to the frequency with which the wind blows from that direction. The average afternoon and nocturnal mixing heights used were 1400 meters and 400 meters, respectively, with mean atmospheric temperature of 19.9°C.

Source Characteristics. The input variables required to characterize a steam generator as a source for dispersion modeling have been derived from the information presented in section 3. For a 25 MBTU/hr unit, fired with 1.5% sulfur crude oil, these source characteristics are summarized in Table K.3.

Terrain Considerations. Even though the Edison Field is situated within sight of the foothills of the Tehachapi Mountains, the field itself is on a flat alluvial plain which rises gradually from an elevation of 500 feet above sea level in the southwest to about 700 feet in the northeast. A narrow ridge of only slightly higher ground, rising to an average elevation of 800 feet, runs parallel to Caliente Creek in the vicinity of the field in sections 17, 18, 19, and 30. (These features can be seen on the geological survey maps shown in Figures K-4 to K-13) Because the terrain within a few kilometers of the sources being considered is gently sloping, the dispersion of pollutants within this area can be adequately treated by the CDM without recourse to complex terrain considerations.

Limits of the Analysis. The dispersion models employed use the Brigg's formula to calculate plume rise, an important factor in determining the dispersion of the pollutants emitted and consequently in calculating ground level concentrations. Although its form is based on theoretical considerations of entrainment of air into the plume, Brigg's formula has been compared with and fit to numerous observations of plume rise, chiefly for plumes from power plant stacks. The stacks or vents on the steam generators under consideration, especially those equipped with open-top scrubbers, are certainly not typical because of their large diameter combined with low stack gas exit velocity. The extent of applicability of Brigg's formula to these cases is by no means clear and is deserving of further study which is beyond the scope of the present project. Further, because of the low release of the plume, low exit velocity, and proximity of the vent to the unit, the possibility of aerodynamic downwash under conditions of high wind is great, resulting in high ground level concentrations close to the generator during such periods.

In our treatment of the impact of these units on ambient NO_x levels, we have prepared NO_2 isopleths based on a non-reactive assessment. The limits to the assumption that all NO_x is emitted as NO_2 or converted to NO_2 by the time it reaches the ground and the treatment of NO_2 as a nonreactive pollutant are well-known. Nevertheless, such an approach does provide a preliminary conservative assessment of point-source contributions. Also, the non-reactive modeling approach (using EPA models) is essentially precluded by local California regulations and guidelines. It should not be read here as establishing a basis for permitting, rather, it represents a first order estimate of the potential impact of the preliminary design for STEOR.

Table K-3

Source Characteristics for the
25 MBTU/hr Steam Generator
Fired with 1.5% Sulfur Crude Oil

	With Scrubber	Without Scrubber
Stack (Vent) Height	5.5 m	5.5 m
Stack Gas Temperature	66°C	177°C
Volumetric Flowrate	3.76 m^3/s	5.08 m^3/s
Source Strength(g/s)		
SO_2	0.47	6.57
NO_x, Uncontrolled	1.58	1.58
NO_x, Low NO_x Burner	1.10	1.10

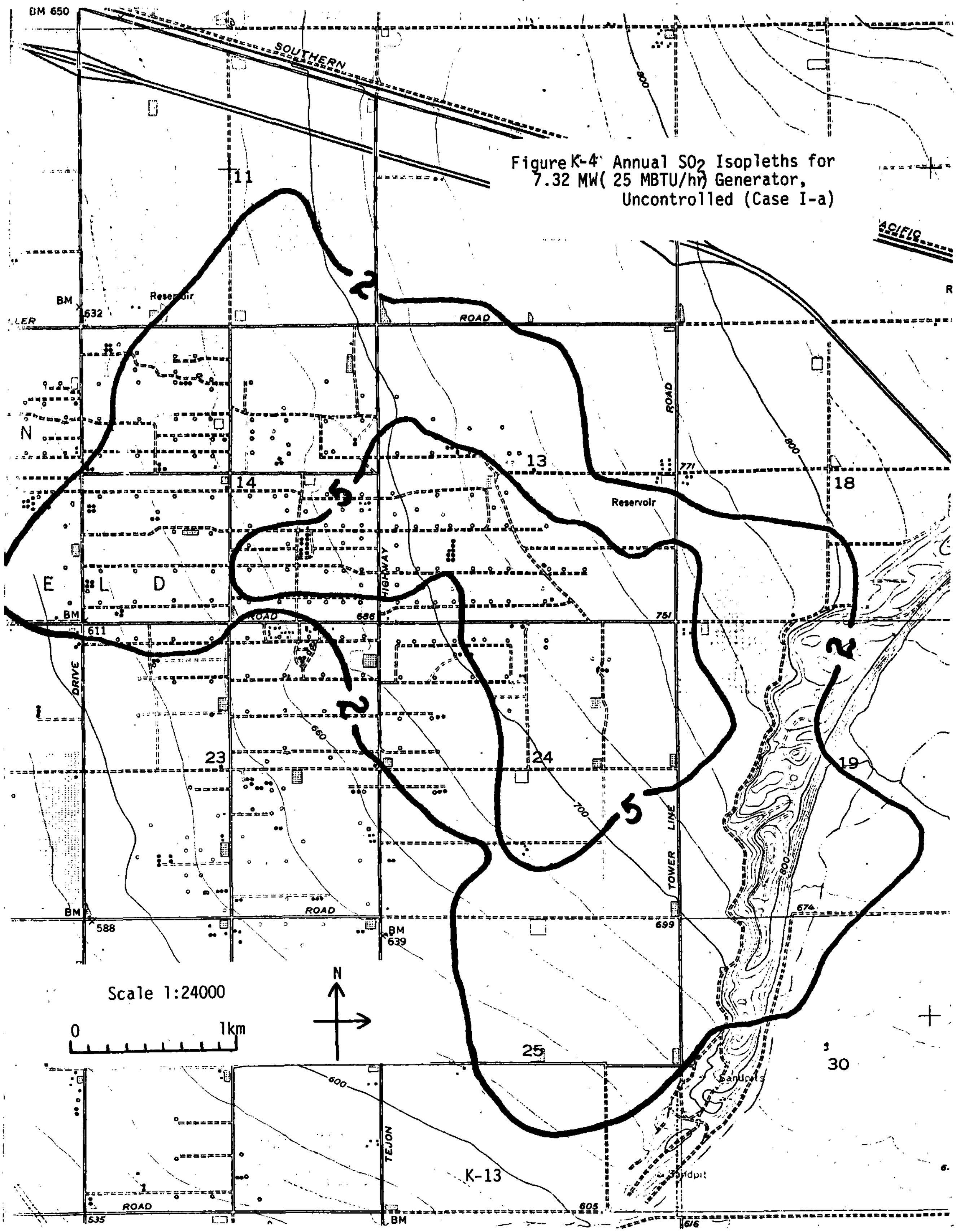
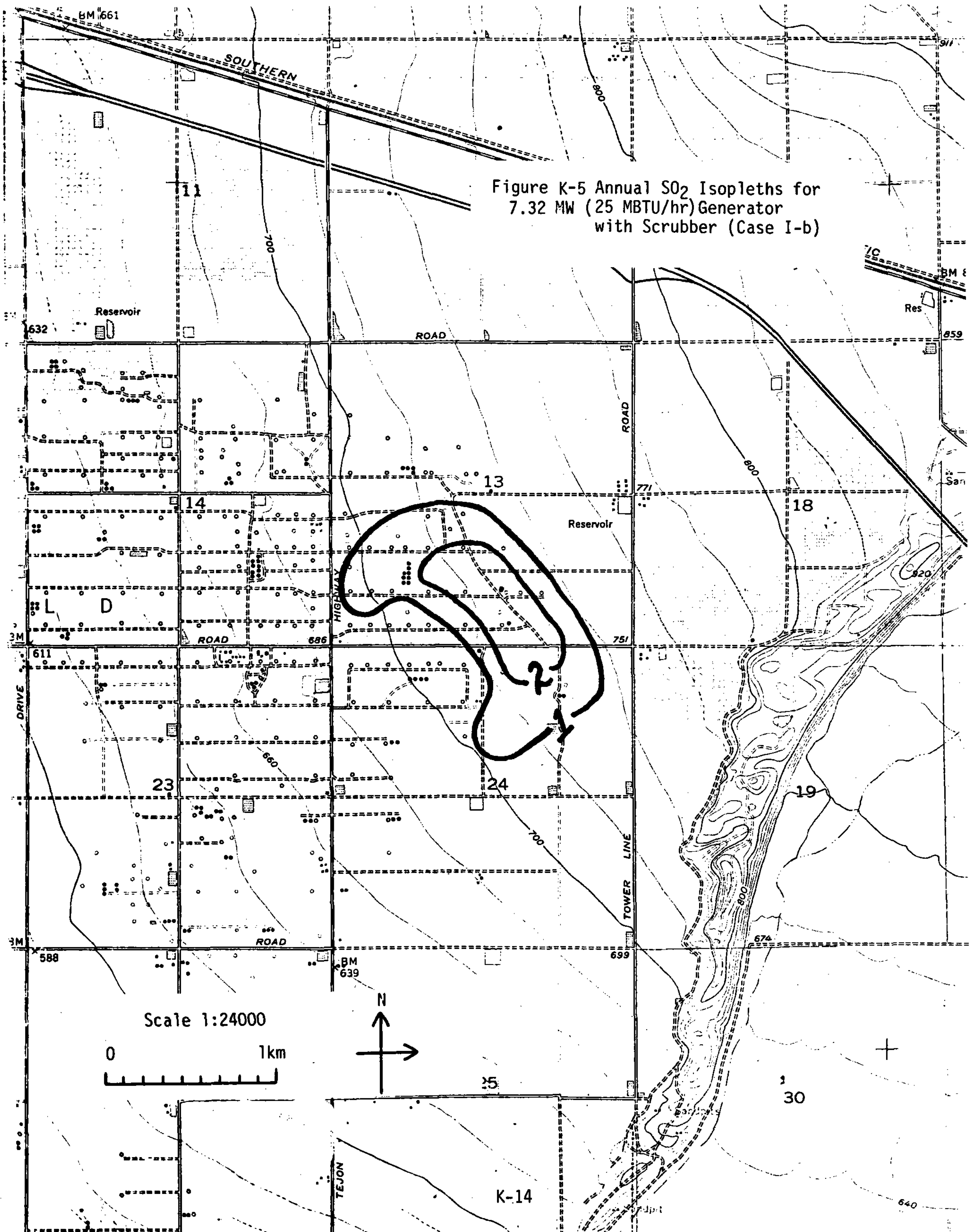


Figure K-4 Annual SO_2 Isopleths for 7.32 MW(25 MBTU/hr) Generator, Uncontrolled (Case I-a)

Figure K-5 Annual SO_2 Isopleths for 7.32 MW (25 MBTU/hr) Generator with Scrubber (Case I-b)



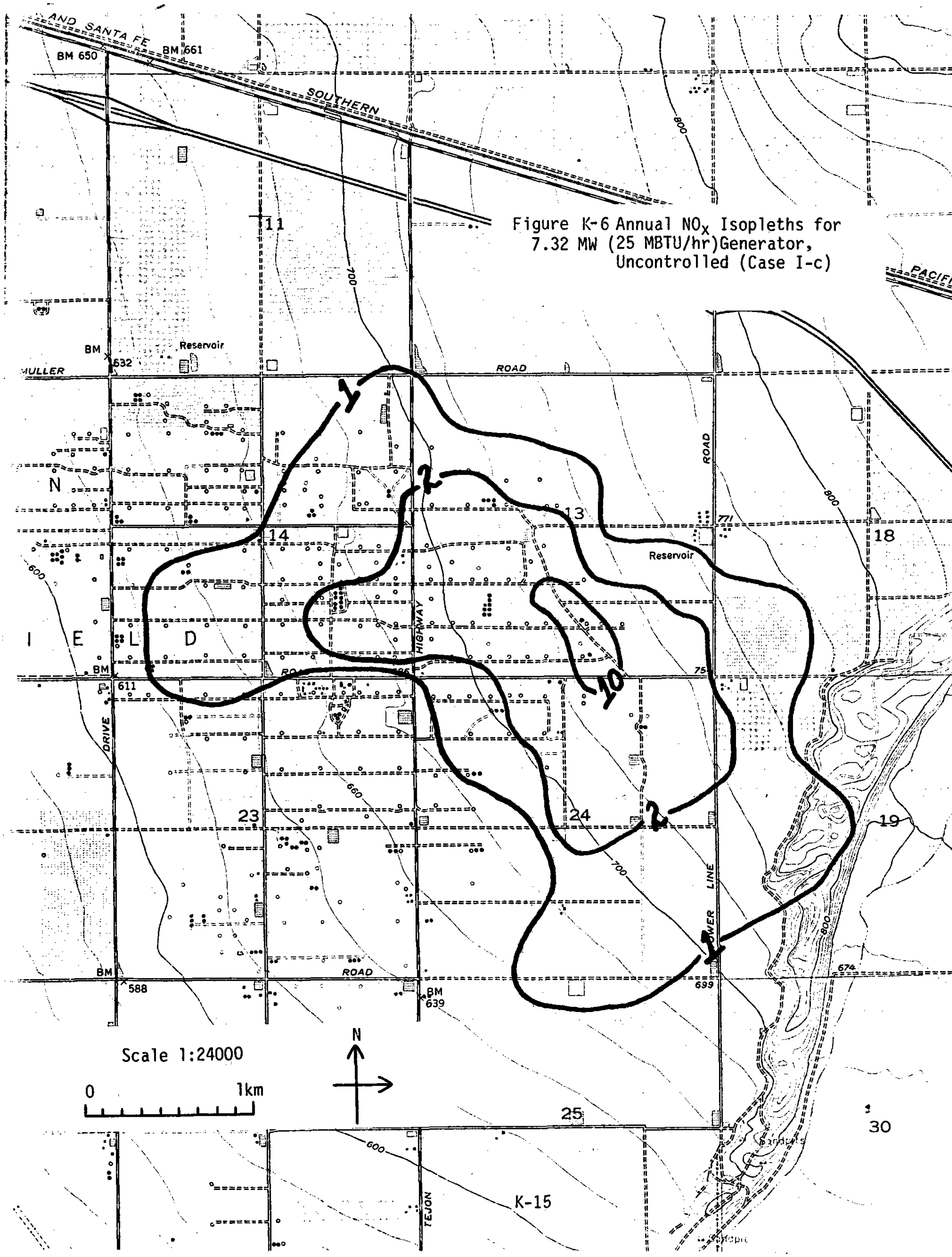


Figure K-6 Annual NO_x Isopleths for 7.32 MW (25 MBTU/hr)Generator, Uncontrolled (Case I-c)

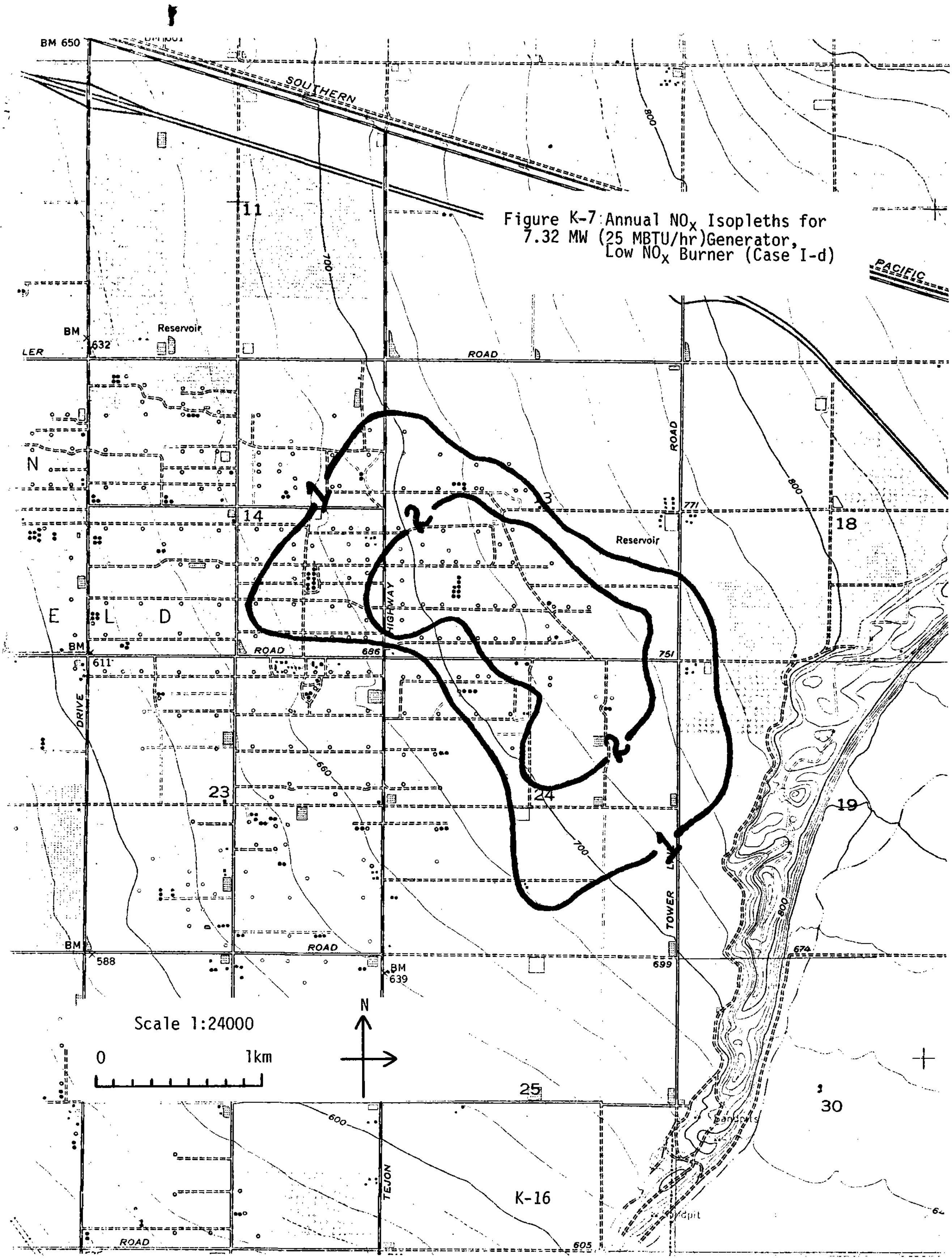


Figure K-7 Annual NO_x Isopleths for
7.32 MW (25 MBTU/hr) Generator,
Low NO_x Burner (Case I-d)
BM 650
SOUTHERN
PACIFIC
800
700
660
600
11
14
18
23
24
19
25
30
K-16
Reservoir
BM
632
611
588
BM 639
771
751
686
699
674
605
LER
ROAD
HIGHWAY
TOWER
TEJON
DRIVE
N
E
L
D
1
2
Scale 1:24000
0
1km
N

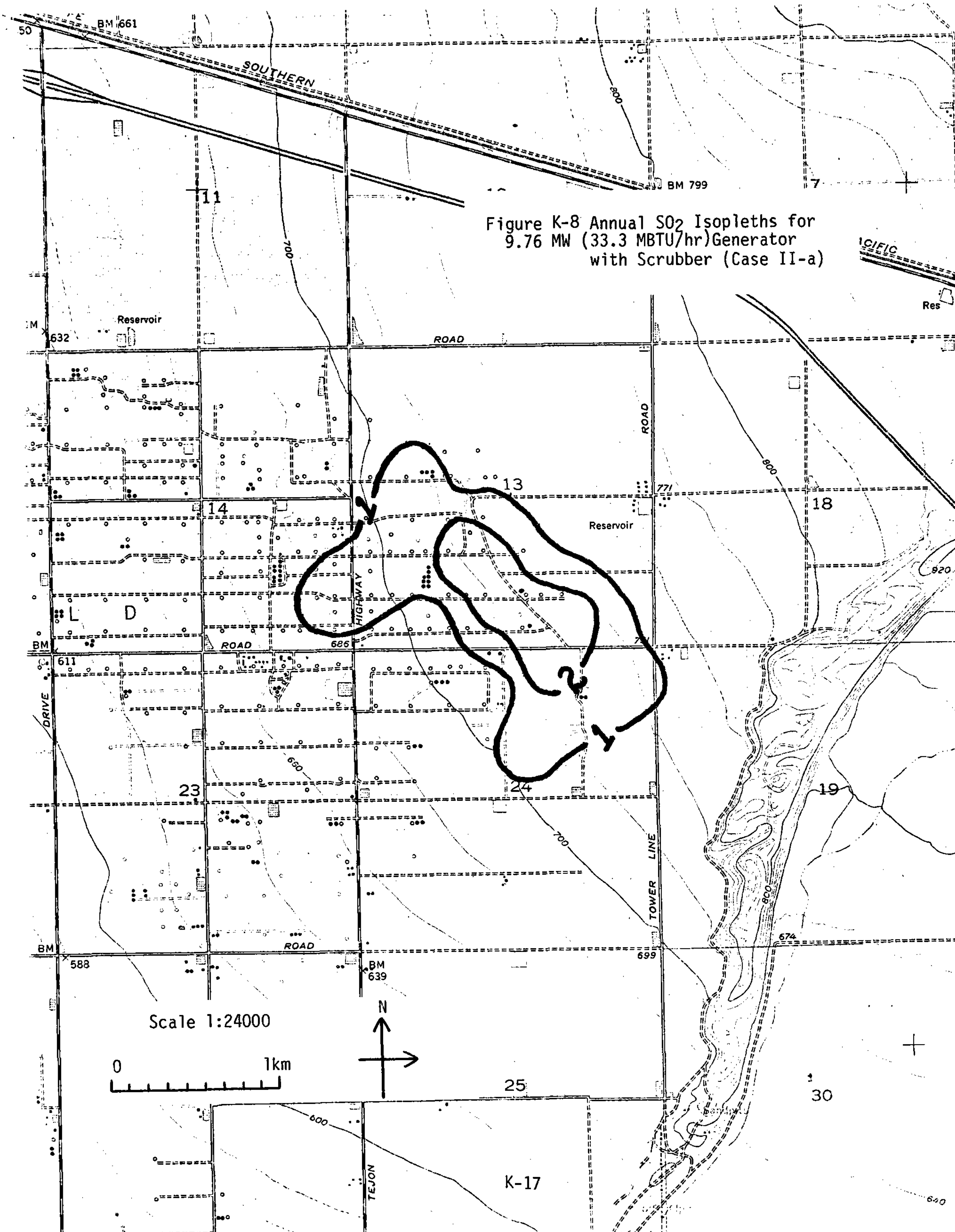


Figure K-8 Annual SO_2 Isopleths for 9.76 MW (33.3 MBTU/hr) Generator with Scrubber (Case II-a)

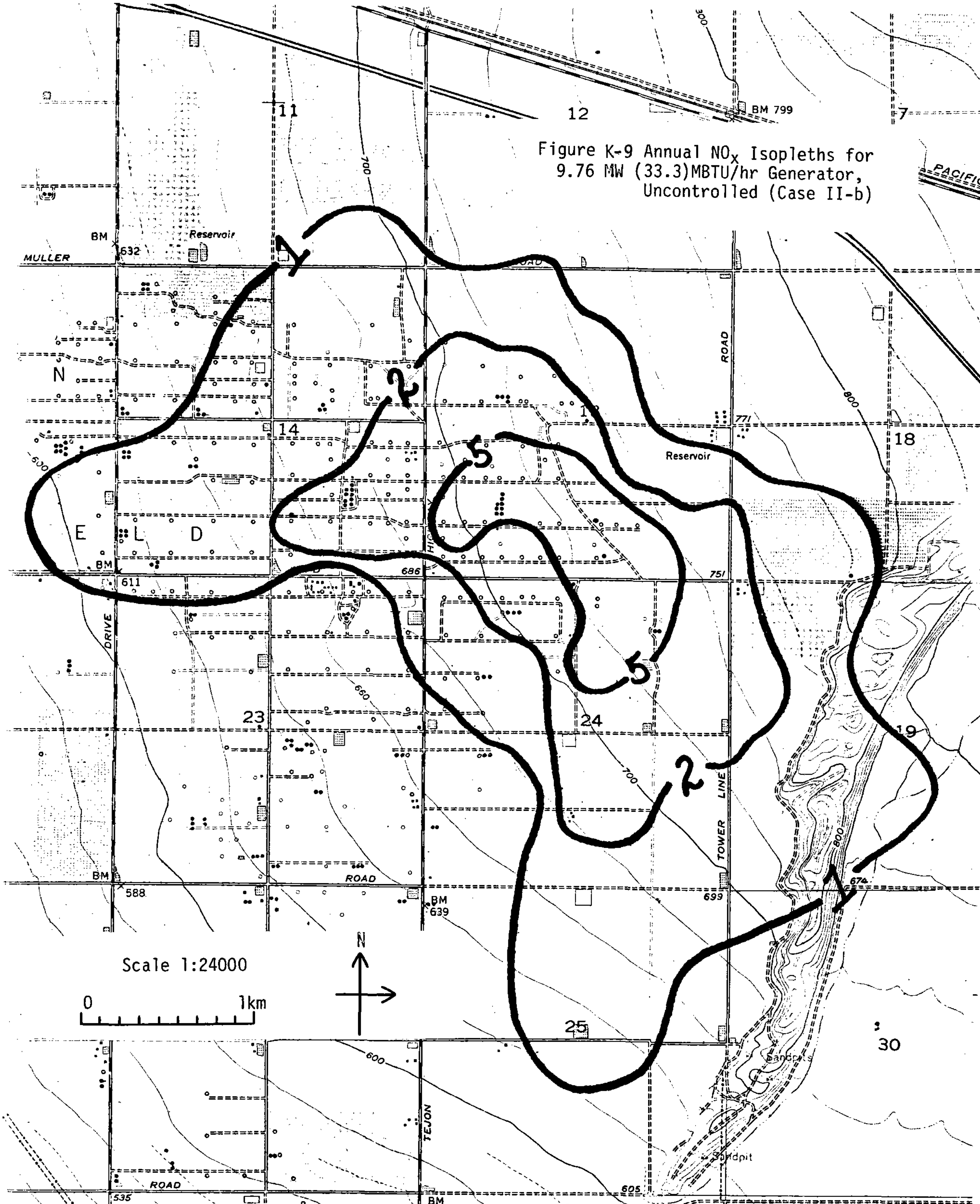


Figure K-9 Annual NO_x Isopleths for 9.76 MW (33.3)MBTU/hr Generator, Uncontrolled (Case II-b)

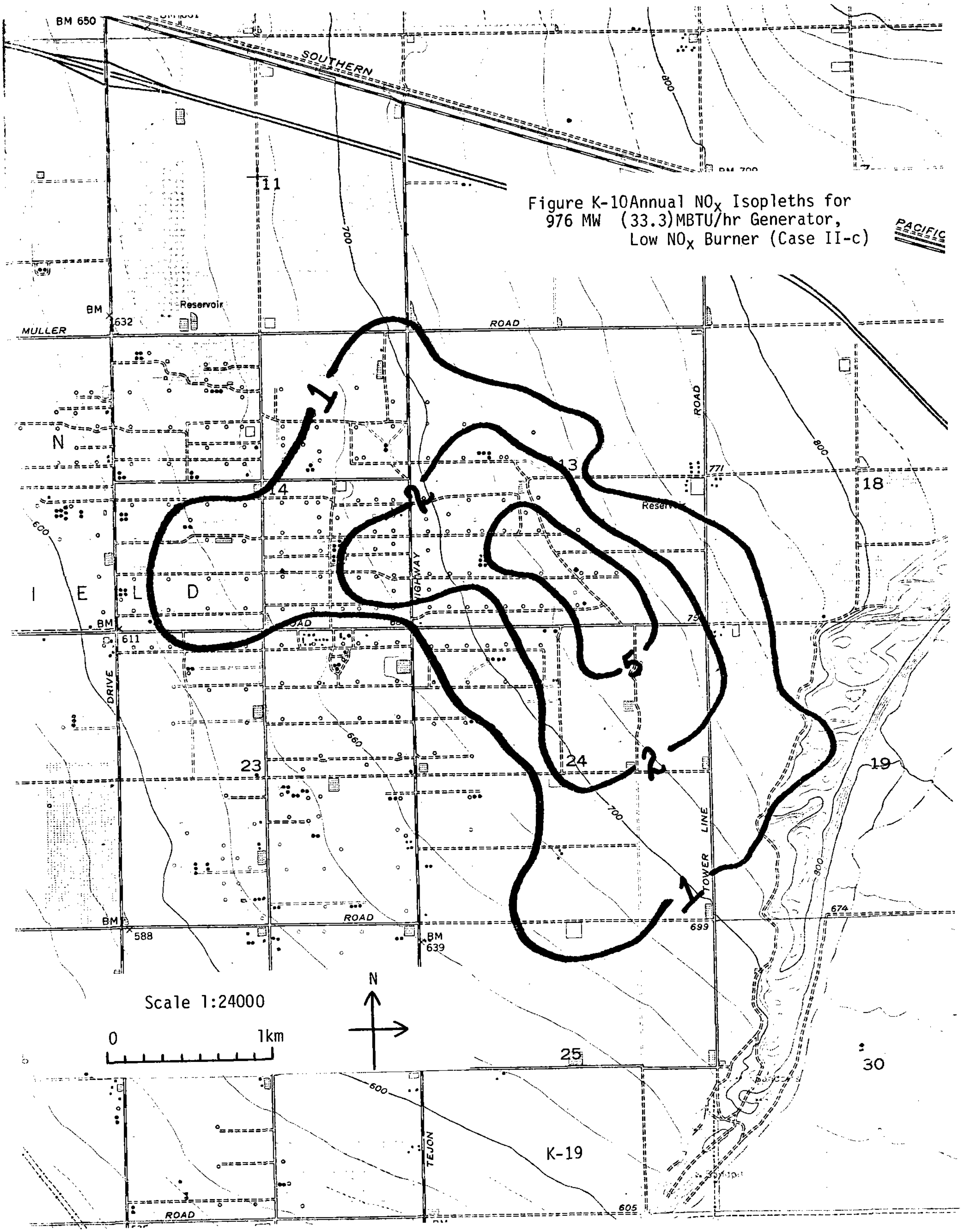


Figure K-10 Annual NO_x Isopleths for 976 MW (33.3)MBTU/hr Generator, Low NO_x Burner (Case II-c)
SOUTHERN
PACIFIC
MULLER
ROAD
Reservoir
HIGHWAY
TOWER LINE
DRIVE
TEJON
N
I E L D
Scale 1:24000
0
1km
N
1
2
5
K-19

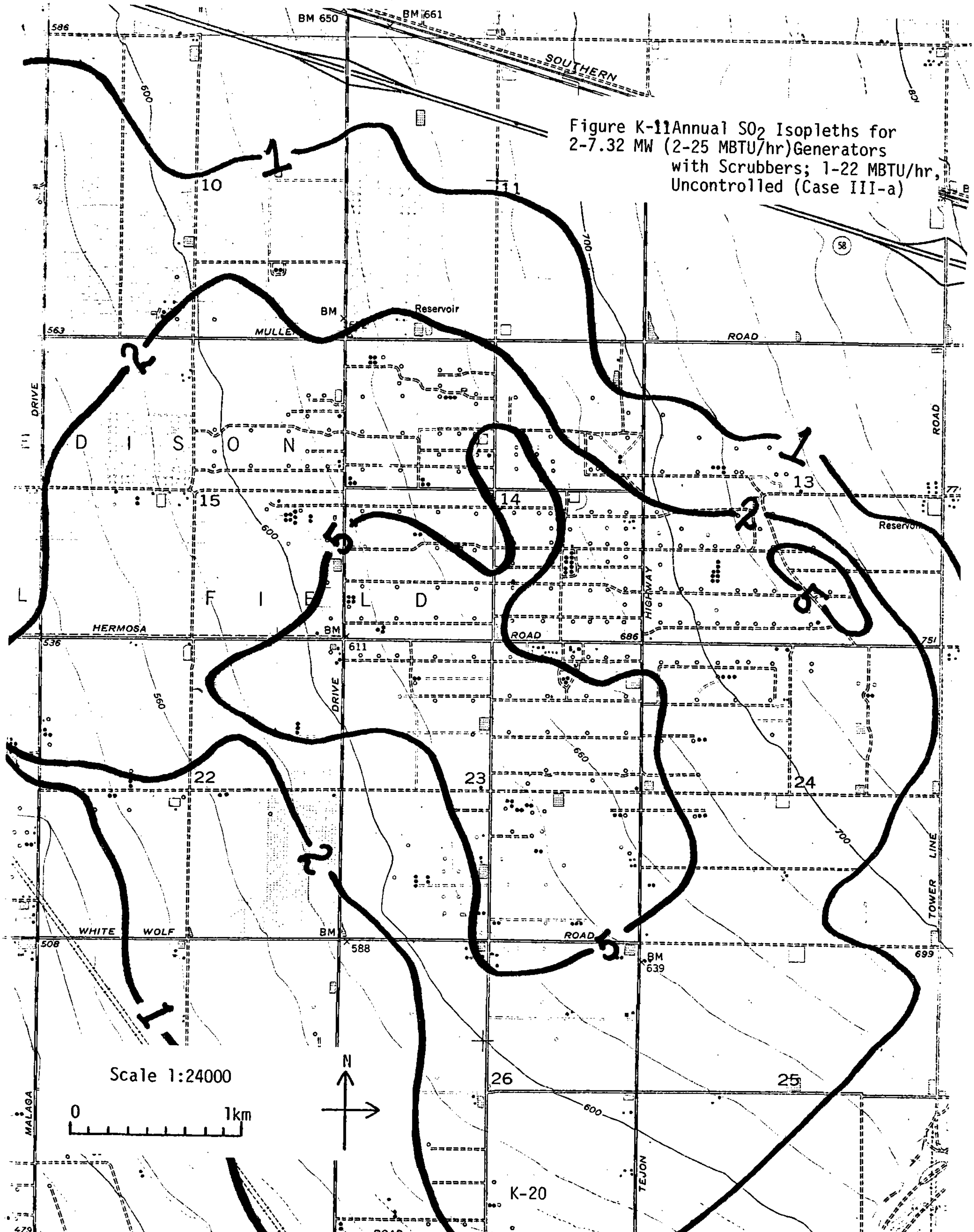


Figure K-11 Annual SO_2 Isopleths for 2-7.32 MW (2-25 MBTU/hr) Generators with Scrubbers; 1-22 MBTU/hr, Uncontrolled (Case III-a)

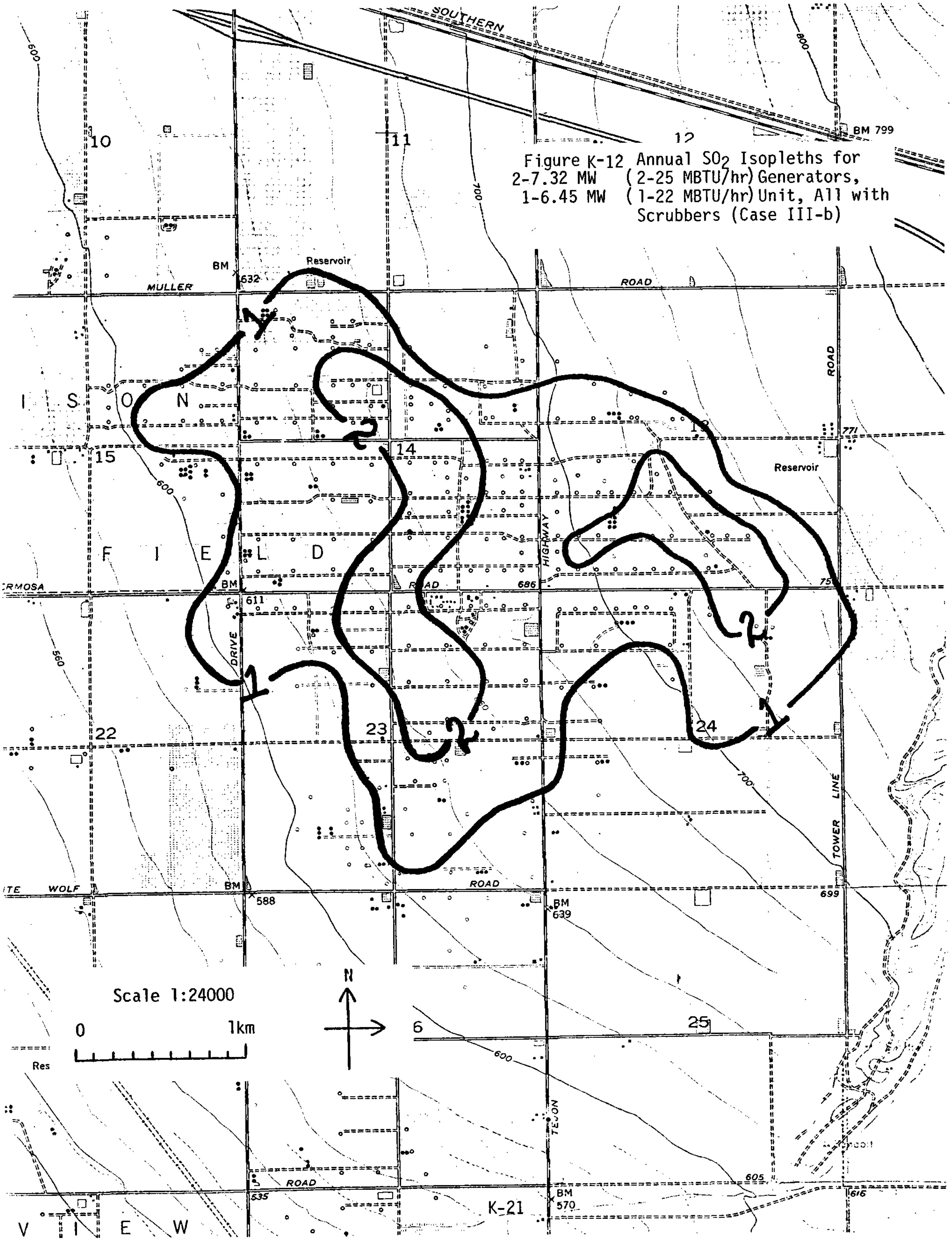


Figure K-12 Annual SO_2 Isopleths for 2-7.32 MW (2-25 MBTU/hr) Generators, 1-6.45 MW (1-22 MBTU/hr) Unit, All with Scrubbers (Case III-b)

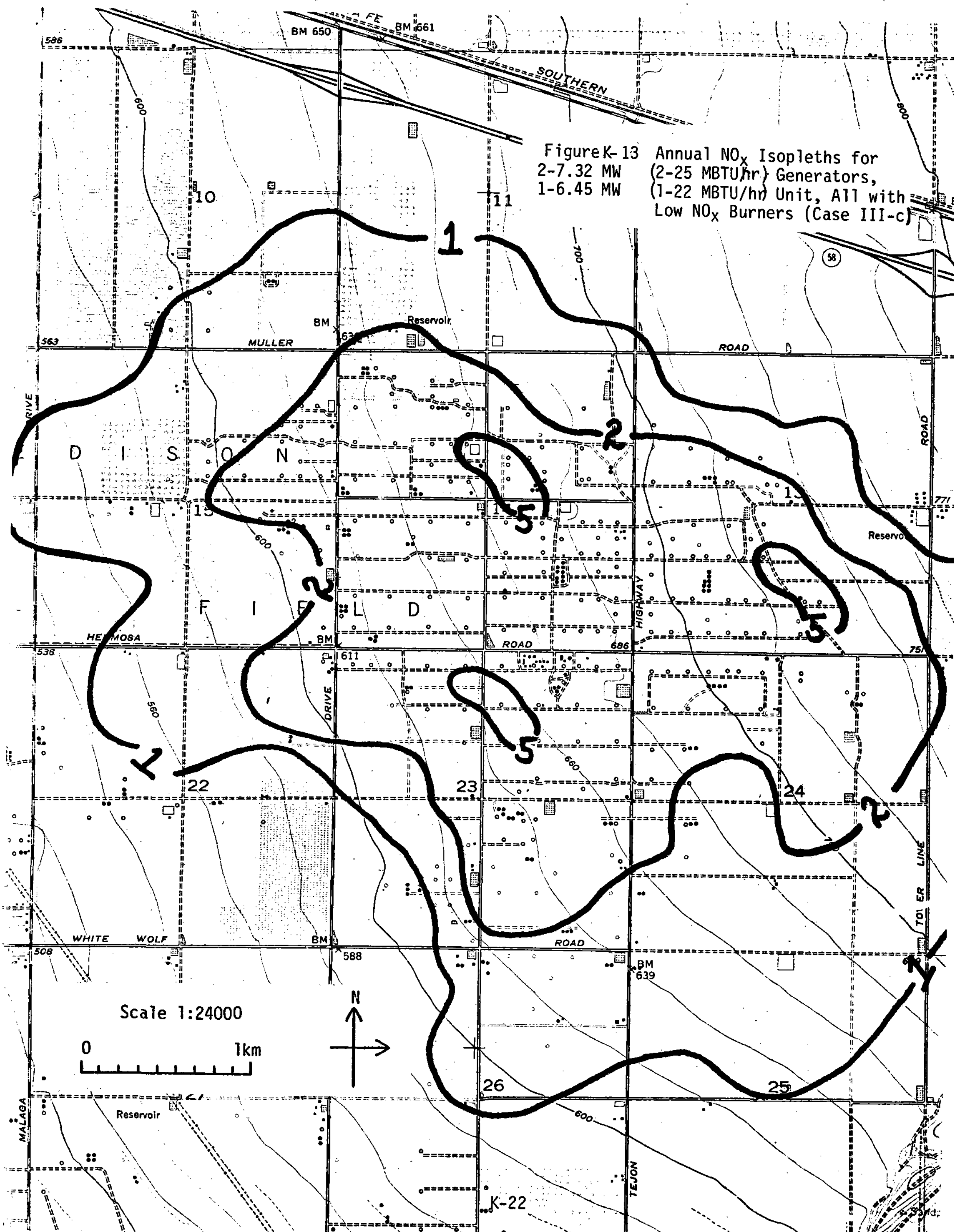


Figure K-13 Annual NO_x Isopleths for 2-7.32 MW (2-25 MBTU/hr) Generators, 1-6.45 MW (1-22 MBTU/hr) Unit, All with Low NO_x Burners (Case III-c)

Discussion of the Results. The results of the dispersion modeling using the CDM have been plotted to show the contour lines of constant ground level concentration. These isopleths have been superimposed on a geological survey map to show their location relative to the Edison Field. The cases enumerated in Table K.2 are presented in Figures K-4 through K-13. We proceed to analyze and compare these results.

The isopleths indicating ambient increments from uncontrolled SO_2 emissions from a 25 MBTU/hr unit are displayed in Figure K-4. The source characteristics which affect the dispersion from this unit are its low stack height (5.5m), low volumetric flow rate (3.76 m^3/s), and relatively weak source strength (6.57 g SO_2/s). The latter two are a reflection of the small size of the unit. These factors result in small ambient SO_2 increments at distances exceeding a few kilometers from the source. Indeed, the $2\mu g/m^3$ isopleth is virtually contained in a circle of 3 km radius and the $5\mu g/m^3$ isopleth, in a circle of 2 km radius. It is instructive to compare these values to the annual average National Ambient Air Quality Standard (NAAQS) for SO_2 of $80\mu g/m^3$.

The kidney shape of these isopleths is due to the prevailing winds in Bakersfield, which are predominantly from the N-NNW-NW and secondarily from the E-ESE-SE. This relationship can be clearly seen by comparison of these isopleth curves with the wind rose presented in Figure K-3 (after rotation of the latter by 180^o).

Due to the low release of the plume, annual averages close to the unit can be much greater. For example, a value of 63μ g/m^3 is predicted approximately 30 meters southwest of the source. The consideration of such a value from a regulatory standpoint depends on whether or not the field is classified as an industrial site. There is public access to the field via the roads which traverse it. However, the field is not used for recreational purposes, no houses have been built on or anywhere near the field, and public exposure from traveling on these secondary roads is clearly minimal. It is clear that these high values close to the unit are not of concern for occupational health and safety when they are compared to the workplace TLV® limit for SO_2 of $1300\mu g/m^3$. In summary for this case, the annual average SO_2 increments due to a small steam generator, even with uncontrolled emissions, can be high close to the unit but decrease rapidly to low levels with increasing distance from the generator.

When the 25 MBTU/hr unit is equipped with a scrubber operated to control emissions to 0.06 lb sulfur per MBTU heat input, the effect on the source characteristics is to weaken the source strength considerably (for 1.5% sulfur crude oil, by 92.8%) and to reduce stack gas temperature. The comments concerning the dispersion characteristics of the uncontrolled unit are also valid for the generator with a scrubber, with the added consideration that the lower stack gas temperature results in less plume rise due to the decreased buoyancy of the plume. This lower plume rise brings maximum ground level concentrations in closer to the stack and generally diminishes dispersion of the emitted pollutants.

For SO_2 emissions, this effect is overshadowed by the greatly lessened source strength of the scrubbed unit. We observe that, if necessary, it is possible to change the dispersion characteristics of these sources by the use of taller stacks, ducting several units to a single stack, or stack gas reheat.

The isopleths produced from the output of the CDM for this case (I-b of Table K-2) are presented in Figure K-5. At distances greater than one kilometer, the ground level SO_2 contribution is uniformly less than 1μ g/m^3. Again, higher values do occur close to the generator, for example, an increment of 43μ g/m^3 is predicted for a receptor located approximately 30 meters southwest of the unit. Finally, comparison of Figures K-4 and K-5 shows the striking effect on ambient air quality of the SO_2 emissions limit imposed by Kern County Rule 424.

We now compare the ambient SO_2 increments for the 25 and 33.3 MBTU/hr units, both scrubbed (Cases I-b and II-a), in order to assess the extent of improvement which can be ascribed to the solar contribution to steam generation. The rationale for this comparison was discussed previously. The SO_2 isopleths for these cases are found in Figures K-5 and K-8 respectively. The same considerations which apply to dispersion from the 25 MBTU/hr unit also apply to the larger unit, with the obvious difference that source strength and flow rate are proportionally greater. The increase in source strength is the dominant effect and produces higher ground level concentrations for the 33.3 MBTU/hr unit. However, because we are comparing cases in which scrubbers are employed on both units, the differences in ambient increments at distances exceeding 0.5 kilometers are less than 1μ g/m^3; considerably less at greater distances. Thus for the case of a small project in which a fraction of controlled SO_2 emissions is displaced by a solar contribution, little improvement in air quality as reflected in ambient SO_2 levels can be expected.

Comparison of annual NO_x isopleths for the 25 MBTU/hr steam generator with conventional burner in Figure K-6 and for the same unit with low NO_x burner in Figure K-7 shows the effect of the 30% reduction assumed for this control option. Because a single generator of this size is not a major source of NO_x, the difference due to this reduction is not great. For the same reasons as discussed for SO_2, comparison of the NO_x increments due to 25 and 33.3 MBTU/hr generators, both with conventional burners as presented in Figures K-6 and K-9 and with low NO_x burners in Figures K-7 and K-10 reveals little beneficiation from the solar contribution.

Ambient increments due to the proposed steam generator and the two existing boilers are displayed in Figures K-11- K-13 (Cases III-a, b, c of Table K-2). The first figure exhibits the annual SO_2 isopleths for the units as they will first be operated, namely, with the two larger units scrubbed and the smaller unscrubbed. For this case, ground level SO_2 concentrations beyond the boundary of the field can be seen to be less then 2μ g/m^3 and to exceed 5μ g/m^3 only within two kilometers of the center of the field. When Figures K-11 and K-12 are compared, the improvement due to control of SO_2 emissions, as required for existing units by 1984, is readily seen. Finally, ambient NO_x increments shown in Figure K-13 are small relative to the annual NO_2 standard of $100 \mu g/m^3$.

The EPA PTMAX model has been used to give a preliminary analysis of ground level increments for shorter averaging times due to the generators under consideration. One cause for high short-term concentrations is the persistence of wind direction, expecially with high wind speeds, for a period of time--a so-called steady wind incident. The PTMAX model calculates the maximum ground level concentration due to the source once the plume has reached steady-state for a given wind direction, wind speed, and stability class (the latter affecting the vertical and lateral plume spread). Thus the maximum concentration calculated using PTMAX gives a very conservative estimate of the maximum ambient increment which can be expected due to the source for an averaging time during which the given meteorological conditions persist. The results obtained for SO_2 emissions from the 25 MBTU/hr generator equipped with a scrubber, having source characteristics as in Table K.3, are given in Table K.4. Again it can be seen that the maximums occur typically within a few hundred meters of the source. Further, the predicted maximum is always less than $100 \mu g/m^3$. This value should be compared to the Federal 3-hour and California 1-hour SO_2 standards, both of which are $1300 \mu g/m^3$. As would be expected, a small source such as this one will not by itself produce a violation of short-term standards during steady wind incidents. More extensive development of a field poses greater potential for infractions during steady wind incidents, although the emissions controls imposed on these generators greatly lessen the probability.

Extensions and Conclusions. A cause of high short-term concentrations which has not been the subject of our modeling effort is the occurrence of inversions, i.e., the condition in which the atmospheric vertical temperature profile does not decrease normally with height. This condition greatly reduces vertical air movement, therby restricting the dispersion of pollutants. Most troublesome for the San Joaquin Valley Air Basin is the occurrence of inversions with elevated bases which prevent the ventilation of the basin, creating severe air stagnation problems. During such episodes, it is possible for some pollutants to persist in the atmosphere and create short-term concentrations which violate ambient standards (e.g., "overnight NO_2").

It is clear that the reduction in emissions due to one or several small STEOR projects would not significantly affect total oil-field generator emissions and would have little effect on high short-term concentrations during periods of stagnation. Were overall oil-field emissions considerably reduced by the widespread use of solar steam generation, then an improvement in air quality during such episodes would be expected. It is, however, quite difficult to assess the relative contributions of mobile and stationary sources, specifically oil-field generators, under such circumstances.

Table K.4 Maximum Ground Level SO_2 Concentrations for 25 MBTU/hr Generator with Scrubber from EPA PTMAX Model (Source Characteristics as in Table K.3)

Stability	Wind Speed (m/s)	Maximum Concentration ($\mu g/m^3$)	Distance Source (km)
1	0.5	33.9	0.316
1	1.0	49.5	0.183
1	2.0	68.0	0.108
1	3.0	78.0	0.080
2	0.5	30.9	0.479
2	1.0	49.1	0.257
2	2.0	71.9	0.142
2	3.0	83.5	0.105
2	4.0	88.8	0.087
2	5.0	90.6	0.076
3	2.0	77.0	0.208
3	3.0	90.1	0.153
3	5.0	98.8	0.110
3	7.0	97.8	0.092
3	10.0	91.0	0.079
3	12.0	85.8	0.074
3	15.0	78.2	0.069
4	0.5	20.8	1.553
4	1.0	41.8	0.700
4	2.0	67.7	0.365
4	3.0	80.9	0.264
4	5.0	90.5	0.188
4	7.0	90.5	0.156
4	10.0	84.9	0.132
4	12.0	80.2	0.123
4	15.0	73.4	0.114
4	20.0	63.6	0.105
5	2.0	24.5	0.952
5	3.0	21.0	0.822
5	4.0	18.6	0.743
5	5.0	16.9	0.688
6	2.0	28.9	1.389
6	3.0	24.8	1.188
6	4.0	22.2	1.066
6	5.0	20.3	0.982

It is certainly not clear that the use of a linear rollback model based on emissions for Kern County alone allows an accurate assessment of the effect of such a reduction.

On the basis of the idealized dispersion modeling presented here, we have seen that the predicted improvement in air quality due to the solar contribution of the proposed preliminary design is small. The reasons that the improvement is minimal are two-fold. First is the size of the system, i.e., only one-fourth of the preliminary design hybrid system steam generating capacity and only 10% of the total capacity currently estimated for the field is due to the solar contribution. Second, the pollution controls required on conventional generators have resulted in greatly reduced emissions from these units, thereby diminishing the emissions displaced by the solar capacity. These comments apply to any project of the same scale. However, under certain circumstances environmental considerations may play a role in the decision to undertake a STEOR project to increase steam generating capacity. Examples are oil fields which are already heavily developed, which are adjacent to or interspersed with residential areas, or for which offsets required for the operation of new conventional generators cannot be obtained.

Air quality in Kern County could apparently improve if a significant fraction of oil-fired steam generator emissions were displaced by the solar thermal generation of steam. However, conventional control technologies for steam generators have the capability to minimize the potential for violations of federal or state air quality standards in which these sources play a significant role. Thus energetic and economic considerations, rather than environmental beneficiation, are likely to be the controlling factors in the introduction of solar steam generating systems into the oil fields.

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