TRI-STATE SYNFUELS COMPANY
Indirect Coal Liquefaction Plant
Western Kentucky

FLUOR ENGINEERS AND CONSTRUCTORS, INC.
Contract 835504

COMPARISON OF MECHANICAL AND NATURAL DRAFT COOLING TOWERS FOR TRI-STATE SYNFUELS COMPANY

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ENGINEERING DEVELOPMENT STUDY NO. 6

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1.0 SCOPE

The purpose of this study is to provide an economic and physical comparison of mechanical and natural draft cooling towers for the Tri-State Synfuels Project. The utility cooling towers and the process cooling towers were evaluated on a separate basis as follows:

1.1 UTILITY PLANT

In order to make a fair comparison between mechanical and natural draft cooling towers for the Utility Plant, the Utility System conditions were optimized by evaluating the costs for the turbines, surface condensers, pumps and heat exchangers, as well as the cooling towers. The primary activities consisted of the following:

A. Optimization of the cooling water temperature approach.

B. Optimization of the cooling water temperature range.

C. Optimization of the turbine back pressure.

D. Economic comparison between mechanical and natural draft cooling towers.

1.2 PROCESS PLANT

The Process Plant was not optimized like the Utility Plant since optimization would require extensive plant redesign. The main activity consisted of ecnomically comparing mechanical and natural draft towers for two sets of cooling water conditions.

2.0 DESIGN CRITERIA

2.1 UTILITY PLANT DATA

The detailed optimization of the Utility Plant involved the cooling towers, turbines, surface condensers, heat exchangers, pumps, connecting piping and operating costs. The following criteria were used.

A. Cooling Towers

Mechanical and natural draft concrete cooling towers were considered for the Utility Plant. For each type of tower, the cooling water approach and range were varied in order to optimize the entire system. Refer to Table I for the definition of the specific cases used in the evaluation.

(1) Approach

In the cooling tower design, the temperature approach is the difference between the cold water temperature leaving the cooling tower and the measured wet bulb temperature at the inlet. Generally, the size and price of cooling towers will decrease with larger temperature approaches for a constant heat load. Using a design wet bulb temperature of 78°F, temperature approaches of 5°F, 7°F, 13°F, and 20°F were evaluated. The 5°F approach was the minimum approach guaranteed by cooling tower vendors. The 20°F approach represented the maximum feasible approach based on a 78°F design wet bulb and the turbine back pressures used in the evaluation.

(2) Cooling Range

The cooling range is the difference between the cooling water inlet and outlet temperatures to the tower. The range is inversely proportional to the cooling water flowrate. Thus, with increasing range, the flowrates will decrease and thus the pumps and pump horsepower required will decrease. The cooling range was varied between 13°F and 30°F. A maximum limit on the cooling water temperature was set at 130°F to avoid corrosion problems.

TABLE I - LISTING OF STUDY CASES
FOR THE UTILITY PLANT

CASE	TYPE OF TOWER	FLOWRATE (GPM)	HWT(°F)	CWT(°F)	DUTY (10^9BTU/HR)	APPROACH (°F)	RANGE (°F)	TURBINE BACK PRESS. (IN. HG)
U2-1M	MDT	355,000	96	83	2.31	5	13	2.5
*U2-2M	MDT	231,000	103	83	2.31	5	20	2.5
U2-3M	MDT	355,000	98	85	2.31	7	13	2.5
U2-4M	MDT	243,000	104	85	2.31	7	19	2.5
U2-5M	MDT	355,000	104	91	2.31	13	13	2.5
U4-1M	MDT	377,000	96	83	2.45	5	13	4.0
U4-2M	MDT	245,000	103	83	2.45	5	20	4.0
U4-3M	MDT	377,000	98	85	2.45	7	13	4.0
U4-4M	MDT	258,000	104	85	2.45	7	19	4.0
U4-5M	MDT	377,000	104	91	2.45	13	13	4.0
U4-6M	MDT	245,000	111	91	2.45	13	20	4.0
U4-7M	MDT	169,000	120	91	2.45	13	29	4.0
U4-8M	MDT	245,000	118	98	2.45	20	20	4.0
U5-1M	MDT	389,000	96	83	2.53	5	13	5.5
U5-2M	MDT	253,000	103	83	2.53	5	20	5.5
U5-3M	MDT	389,000	98	85	2.53	7	13	5.5
U5-4M	MDT	266,000	104	85	2.53	7	19	5.5
U5-5M	MDT	389,000	104	91	2.53	13	13	5.5
U5-6M	MDT	253,000	111	91	2.53	13	20	5.5
U5-7M	MDT	174,000	120	91	2.53	13	29	5.5
U5-8M	MDT	253,000	118	98	2.53	20	20	5.5
U5-9M	MDT	169,000	128	98	2.53	20	30	5.5
U2-5N	NDT	355,000	104	91	2.31	13	13	2.5
U4-5N	NDT	377,000	104	91	2.45	13	13	4.0
U4-6N	NDT	245,000	111	91	2.45	13	20	4.0
**U4-7N	NDT	169,000	120	91	2.45	13	29	4.0
U4-8N	NDT	245,000	118	98	2.45	20	20	4.0
U5-5N	NDT	389,000	104	91	2.53	13	13	5.5
U5-6N	NDT	253,000	111	91	2.53	13	20	5.5
U5-7N	NDT	174,000	120	91	2.53	13	29	5.5
U5-8N	NDT	253,000	118	98	2.53	20	20	5.5
U5-9N	NDT	169,000	128	98	2.53	20	30	5.5

* Optimum Mechanical Draft

** Optimum Natural Draft

MDT = Mechanical Draft Tower

NDT = Natural Draft Tower

2.0 DESIGN CRITERIA

2.1 UTILITY PLANT DATA (continued)

B. Turbines

A total of seven (7) condensing turbines were evaluated in the Utility Plant. One (1) was used to drive a 55-Megawatt generator with 120 psig, 438°F steam. Two (2) were used to drive two 15000 hp oxygen compressors using 600 psig, 750°F steam. Four (4) were used to drive four 45000 hp oxygen compressors using 600 psig, 750°F steam. Three different turbine back pressures were evaluated; they were 2.5" Hg, 4" Hg, and 5.5" Hg. Steam rates were calculated for each size turbine at each back pressure assuming a 75 percent efficiency and a constant power output. Combinations of different turbine back pressures were not considered. Spare turbines were not used in the economic evaluation.

C. Surface Condensers

Each condensing turbine has a steam surface condenser. For each turbine back pressure (2.5" Hg, 4" Hg, and 5.5" Hg), there is a corresponding steam saturation temperature (109°F, 125°F, and 137°F). The approach in the condenser is the difference between the steam saturation temperature and the hot water temperature at the condenser outlet. The approach in the condenser was limited to minimum of 5°F because of the thermal guarantees of vendors. Thus in deciding upon the case to be evaluated, Fluor was limited to a 5°F approach between the hot water temperature and the steam saturation temperature in the condenser and a 5°F approach between the cold water temperature and the design wet bulb temperature in the cooling tower (Refer to Sheet I in Appendix 2). The duties for each condenser were calculated from the turbine steam rates at the various back pressures. The metallurgy was assumed to be carbon steel.

D. Heat Exchangers

Fluor assumed that cooling water was also utilized in four (4) air aftercoolers with duties of 19 X 10^6 Btu/Hr each. These were assumed to be carbon steel shell and tube units.

E. Pumps

Vertical turbine centrifugal pumps were used as a basis for the estimates. A total pumphead of 115 feet was assumed for each case. Fluor assumed a nominal pump efficiency of 85% and a nominal motor efficiency of 94%. One spare pump was included for every four operating pumps.

2.0 DESIGN CRITERIA

2.1 UTILITY PLANT DATA (continued)

F. Connecting Piping

Carbon steel piping was assumed for the estimate. A design study line was chosen to figure the differential piping costs from the main water lines to the cooling towers for each case.

G. Operating Costs

Operating costs used in the evaluation included pumping costs, fan power costs (for mechanical draft only), and steam differential costs. Refer to Sheet II in Appendix 2 for the formulas used to calculate the operating costs. Fluor assumed that the evaporation rates for each tower were equal since the duties were similar, therefore the differential costs for make-up water were not included. The analysis was based on 100 percent operation during summer conditions. An annualized cost factor of 5.0 was used.

2.2 PROCESS PLANT DATA

Mechanical and natural draft towers were evaluated for two sets of conditions in the Process Plant. The first set of conditions (case P-1M and P-1N) represent the base conditions used for the initial plant design. Since the base conditions had such a low temperature approach (7°F), an alternate case with a 13°F approach was studied (cases P-2M and P-2N). Both sets of conditions evaluated for the Process Cooling Towers are listed below.

Case:	P-1M,P-1N	P-2M,P-2N
Design Duty (10^9 Btu/hr):	4.06	4.06
Tower Inlet Temperature (°F):	106	112
Tower Outlet Temperature (°F):	85	91
Cooling Water Flowrate (gpm):	387,000	387,000
Cooling Range (°F):	21	21
Temperature Approach (°F):	7	13

2.3 SITE DATA

Location: Henderson County, Kentucky
Temperature °F
Design Wet Bulb Temperature: 78°F
Design Dry Bulb Temperature: 96°F
Maximum Wind Velocity: 110 MPH
Plant Elevation: 600 feet above sea level

2.4 ECONOMIC EVALUATION DATA

Power Cost: $0.055/KWH
Evaluation Period: 25 years
Steam Cost:

120 psig, 438°F	$2.45/Mlb
600 psig, 750°F	$3.25/Mlb

Annualized cost factor (25 years, 20% minimum return on investment): 5.0

[redacted]

3.0 RESULTS

3.1 UTILITY PLANT

Table II lists the breakdown of the estimated costs obtained for the evaluation of the Utility Plant. The cost figures represent the following:

A. Turbines

Estimates were received from a turbine vendor for the three (3) sizes of turbines at each of the different back pressures. A total of nine (9) estimates were received. As anticipated, the total cost of the turbines was higher for the lower back pressures because an efficient turbine was required.

B. Condensers and Heat Exchangers

Estimates were done in house at Fluor for the surface condensers and heat exchangers. As shown in Table II, the total price of the condensers and heat exchangers increased as the range and approach in the cooling tower was increased. This was due to the small mean temperature difference (MTD) in the condensers and heat exchangers as a result of the larger approaches and cooling ranges in the cooling tower.

C. Pumps

Pump estimates were received from a vendor. As illustrated in Table II, the pump costs increased with larger flowrates and smaller cooling ranges.

D. Cooling Towers

Estimates were received from a cooling tower vendor for concrete mechanical and natural draft towers. The cooling tower vendor optimized each selection using the project's economic evaluation data. The mechanical draft tower estimates were based on octagonal counterflow designs of dimensions shown in Table III. The vendor did not provide estimates for natural draft towers with approaches of 5°F and 7°F because they would be very uneconomical and impractical. As Table II shows, the cost of the towers decreased as the approach and range increased.

E. Piping

Plot layouts were made for selected cooling towers in order to arrive at an estimate of the difference in the costs for the connecting piping. Drawings I and II are for the mechanical draft towers. Drawing III is for the natural draft towers. As shown in Table II, the price increased for larger flowrates. Also, the price was more when two towers were required versus one tower.

TABLE II - BREAKDOWN OF EVALUATED COSTS ($MM)
FOR THE UTILITY PLANT

CASE	TURBINE COST	CONDENSER AND HEAT EXCHANGER COST	PUMP COST	COOLING TOWER COST	TOTAL EQUIP. COST	PIPING COST	PUMP OPERAT. COST	FAN OPERAT. COST	STEAM DIFF. COST	TOTAL EVALUAT. COST
U2-1M	15.100	6.148	2.695	10.730	34.673	1.450	21.591	9.910	(17.935)	49.689
U2-2M	15.100	7.666	1.960	8.664	33.390	1.070	14.049	7.433	(17.935)	38.007*
U2-3M	15.100	6.708	2.695	9.414	33.917	1.450	21.591	8.892	(17.935)	47.915
U2-4M	15.100	8.423	1.960	7.788	33.271	1.100	14.779	7.031	(17.935)	38.246
U2-5M	15.100	9.513	2.695	6.764	34.072	1.150	21.591	4.955	(17.935)	43.833
U4-1M	13.700	4.662	2.940	10.730	32.032	1.510	22.929	9.910	0	66.381
U4-2M	13.700	5.041	1.960	8.664	29.365	1.110	14.901	7.433	0	52.809
U4-3M	13.700	4.893	2.940	9.414	30.947	1.510	22.929	8.892	0	64.278
U4-4M	13.700	5.171	1.960	7.788	28.619	1.150	15.691	7.031	0	52.491
U4-5M	13.700	5.298	2.940	6.764	28.702	1.230	22.929	4.955	0	57.816
U4-6M	13.700	6.280	1.960	5.365	27.305	0.820	14.901	4.955	0	47.981
U4-7M	13.700	8.085	1.225	4.551	27.561	0.580	10.279	3.716	0	42.136
U4-8M	13.700	8.974	1.960	4.479	29.113	0.820	14.901	3.080	0	47.914
U5-1M	13.500	4.238	2.940	10.730	31.408	1.550	23.659	9.910	9.637	76.164
U5-2M	13.500	4.771	1.960	8.664	28.895	1.130	15.387	7.433	9.637	62.482
U5-3M	13.500	4.401	2.940	9.414	30.255	1.550	23.659	8.892	9.637	73.993
U5-4M	13.500	4.487	1.960	7.788	27.735	1.170	16.179	7.031	9.637	61.752
U5-5M	13.500	4.487	2.940	6.764	27.691	1.270	23.659	4.955	9.637	67.212
-6M	13.500	5.729	1.960	5.365	26.554	0.840	15.387	4.955	9.637	57.373
-7M	13.500	5.855	1.225	4.551	25.131	0.600	10.583	3.716	9.637	49.667
U5-8M	13.500	6.807	1.960	4.479	26.752	0.840	15.387	3.080	9.637	55.696
U5-9M	13.500	8.134	1.225	3.638	26.497	0.580	10.279	2.692	9.637	49.685
U2-5N	15.100	9.513	2.695	15.822	43.130	1.150	21.591	-	(17.935)	47.936
U4-5N	13.700	5.298	2.940	15.822	37.760	1.230	22.929	-	0	61.919
U4-6N	13.700	6.280	1.960	12.750	34.690	0.820	14.901	-	0	50.411
U4-7N	13.700	8.085	1.225	10.493	33.503	0.580	10.279	-	0	44.362*
U4-8N	13.700	8.974	1.960	9.927	34.561	0.820	14.901	-	0	50.282
U5-5N	13.500	4.487	2.940	15.822	36.749	1.270	23.659	-	9.637	71.315
U5-6N	13.500	5.729	1.960	12.750	33.939	0.840	15.387	-	9.637	59.803
U5-7N	13.500	5.855	1.225	10.493	31.073	0.600	10.583	-	9.637	51.893
U5-8N	13.500	6.807	1.960	9.927	32.194	0.840	15.387	-	9.637	58.058
U5-9N	13.500	8.134	1.225	8.235	31.094	0.580	10.279	-	9.637	51.590

* Optimum Mechanical Draft

** Optimum Natural Draft

TABLE III - COMPARATIVE TOWER SIZES FOR THE UTILITY PLANT

CASE	TYPE	NO. OF TOWERS	DIAMETER (FT)	HEIGHT (FT)
U2-1M	MDT	2	232	74
*U2-2M	MDT	2	204	70
U2-3M	MDT	2	211	71
U2-4M	MDT	2	189	69
U2-5M	MDT	1	264	72
U4-1M	MDT	2	232	74
U4-2M	MDT	2	204	70
U4-3M	MDT	2	211	71
U4-4M	MDT	2	189	69
U4-5M	MDT	1	264	70
U4-6M	MDT	1	224	72
U4-7M	MDT	1	202	69
U4-8M	MDT	1	208	66
U5-1M	MDT	2	232	74
U5-2M	MDT	2	204	70
U5-3M	MDT	2	211	71
U5-4M	MDT	2	189	69
U5-5M	MDT	1	264	70
U5-6M	MDT	1	224	72
U5-7M	MDT	1	202	69
U5-8M	MDT	1	208	66
U5-9M	MDT	1	184	64
U2-5N	NDT	1	394	550
U4-5N	NDT	1	394	550
U4-6N	NDT	1	333	500
** U4-7N	NDT	1	288	450
U4-8N	NDT	1	278	400
U5-5N	NDT	1	394	550
U5-6N	NDT	1	333	500
U5-7N	NDT	1	288	450
U5-8N	NDT	1	278	400
U5-9N	NDT	1	234	360

* Optimum Mechanical Draft

** Optimum Natural Draft

3.0 RESULTS

3.1 UTILITY PLANT (Continued)

F. Operating Costs

As illustrated in Appendix 2, Sheet II, the pump operating cost is a linear function of the cooling water flow rate since a constant pump head of 115 feet was assumed for all cases. As noted previously, the cooling water flow rate is inversely proportional to the cooling range for constant head loads. Therefore, as illustrated in Table II, the pump operating costs decreased as the cooling range was increased.

Also, as illustrated in Appendix 2, Sheet II, the fan operating cost is a linear function of the fan horsepower required. The fan horsepower required decreased as the approach and the cooling range were increased because the cooling tower could operate more efficiently. Therefore, as illustrated in Table II, the fan operating costs decreased as the approach and cooling range were increased.

Finally, as illustrated in Appendix 2, Sheet II, the steam differential cost is a linear function of the differential steam flow rate. The steam flow rate required increases with higher turbine back pressures. Therefore, as illustrated in Table II, the steam differential cost increased as the turbine back pressures were increased. Two different pressures of steam were required, so they were evaluated separately and added in order to arrive at the total steam differential cost. Also, note that the steam flow rate required for 4.0" Hg turbine back pressure was used for the base in calculating the steam differential costs.

G. Total Evaluated Costs

Each yearly operating cost was multiplied by the Annualized Cost Factor of 5.0 and added to the equipment costs in order to arrive at the total evaluated cost. As illustrated in Table II, the lowest evaluated cost was case U2-2M using two (2) 204 foot diameter, 70 foot high octagonal mechanical draft counterflow cooling towers. The optimum conditions included a 5°F temperature approach, 20°F cooling range, 231,000 gpm flow rate, and a 2.5" Hg turbine back pressure.

3.0 RESULTS

3.2 PROCESS PLANT

Cooling tower estimates were received for mechanical (MDT) and natural draft (NDT) selections for the base and alternate conditions. The results are listed below:

	BASE		ALTERNATE	
Case	P-1M	P-1N	P-2M	P-2N
Tower Type	MDT	NDT	MDT	NDT
Number Required	2	2	2	2
Tower Diameter (ft.)	249	458	200	292
Tower Height (ft.)	61	525	60	500
Tower D&E Cost ($MM)	15.400	38.00	9.200	21.600
Fan Operating Cost ($MM)	7.910	-0-	7.600	-0-
Total Evaluated Cost ($MM)	23.310	38.00	16.800	21.600

The mechanical draft selections (case P-1M and P-2M) are concrete round counterflow cooling towers. The fan operating costs for the mechanical draft selections were calculated per Appendix 2 and added to the delivered and erected (D&E) costs to arrive at evaluated costs to compare with the natural draft selections. The natural draft selection for case P-1N is extremely large due to the small temperature approach (7°F). The cooling tower vendor noted that the natural draft towers selected for case P-1N are larger than they have ever constructed.

In both cases, the mechanical draft towers were more economical than the natural draft selections. Both types of towers had lower costs for the alternate case with the higher temperature approach.

4.0 ANALYSIS

4.1 UTILITY PLANT

A. Optimization of the Cooling Tower Temperature Approach

Graph I is a plot of the temperature approach versus the evaluated cost of the system using mechanical draft towers. Note that there are constant turbine back pressure and cooling range lines. The lowest evaluated cost is for Case U2-2M with a 5°F approach, 20°F range, and 2.5" Hg turbine back pressure. Because of the limiting steam saturation temperature of 109°F, no higher approaches were evaluated at the turbine back pressure of 2.5" Hg and a range of 20°F. For the higher turbine back pressures of 4.0" Hg and 5.5" Hg, the optimum temperature approaches were projected at around 18°F, but the effect of the approach on the evaluated cost is minimal after 12°F. For the larger back pressures, the fan operating cost and the cooling tower cost were the determining factors encouraging larger approaches.

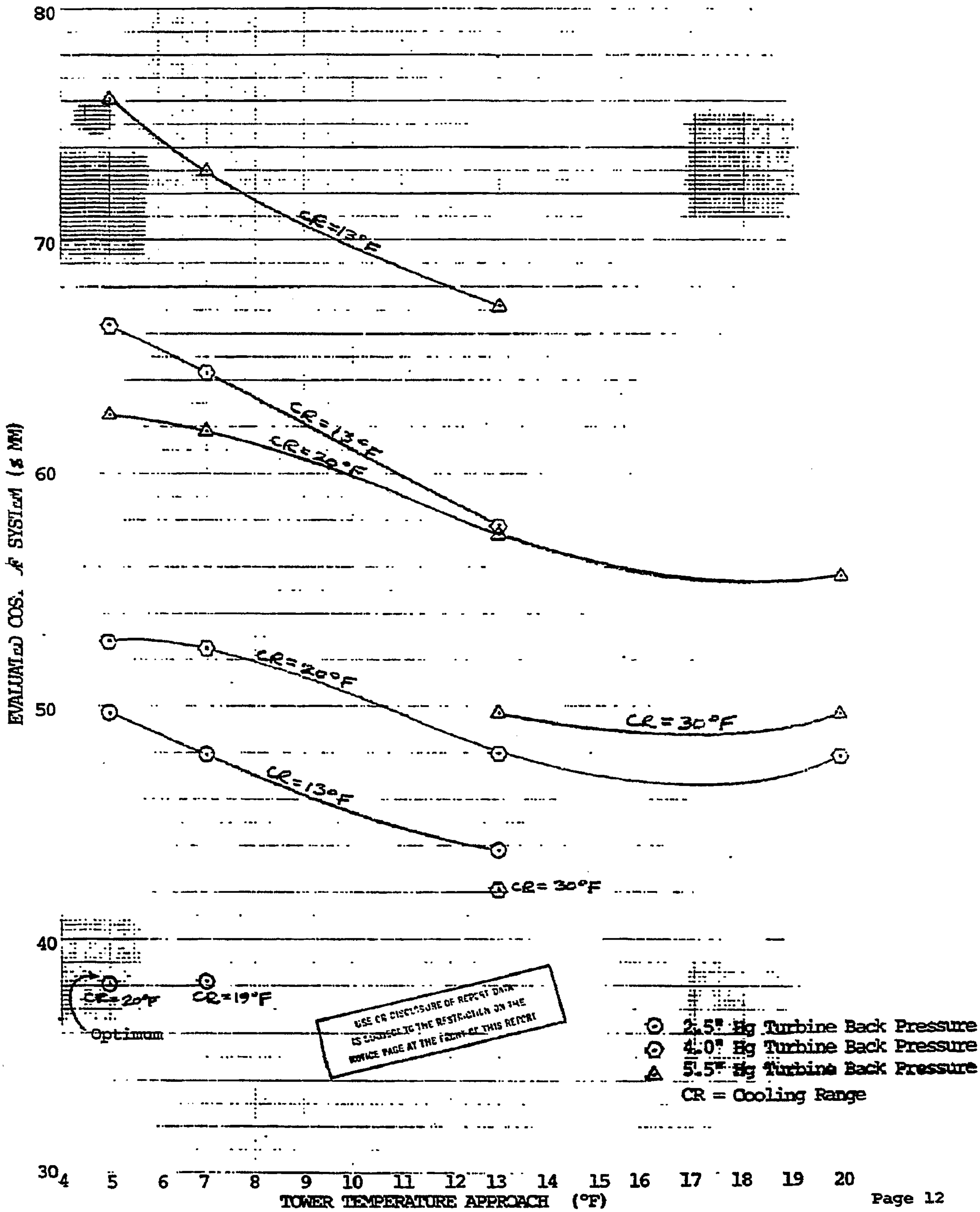
Graph II is a similar plot but it is for natural draft towers. The optimum utility system with natural draft towers is Case U4-7N with an approach of 13°F, range of 29°F, and turbine back pressure of 4" Hg. As Graph II shows, the approach did not have a major effect on the evaluated cost of the system. Also, as noted before, natural draft towers with approaches of 5°F and 7°F were not considered because of their large comparable expense.

B. Optimization of Cooling Water Range

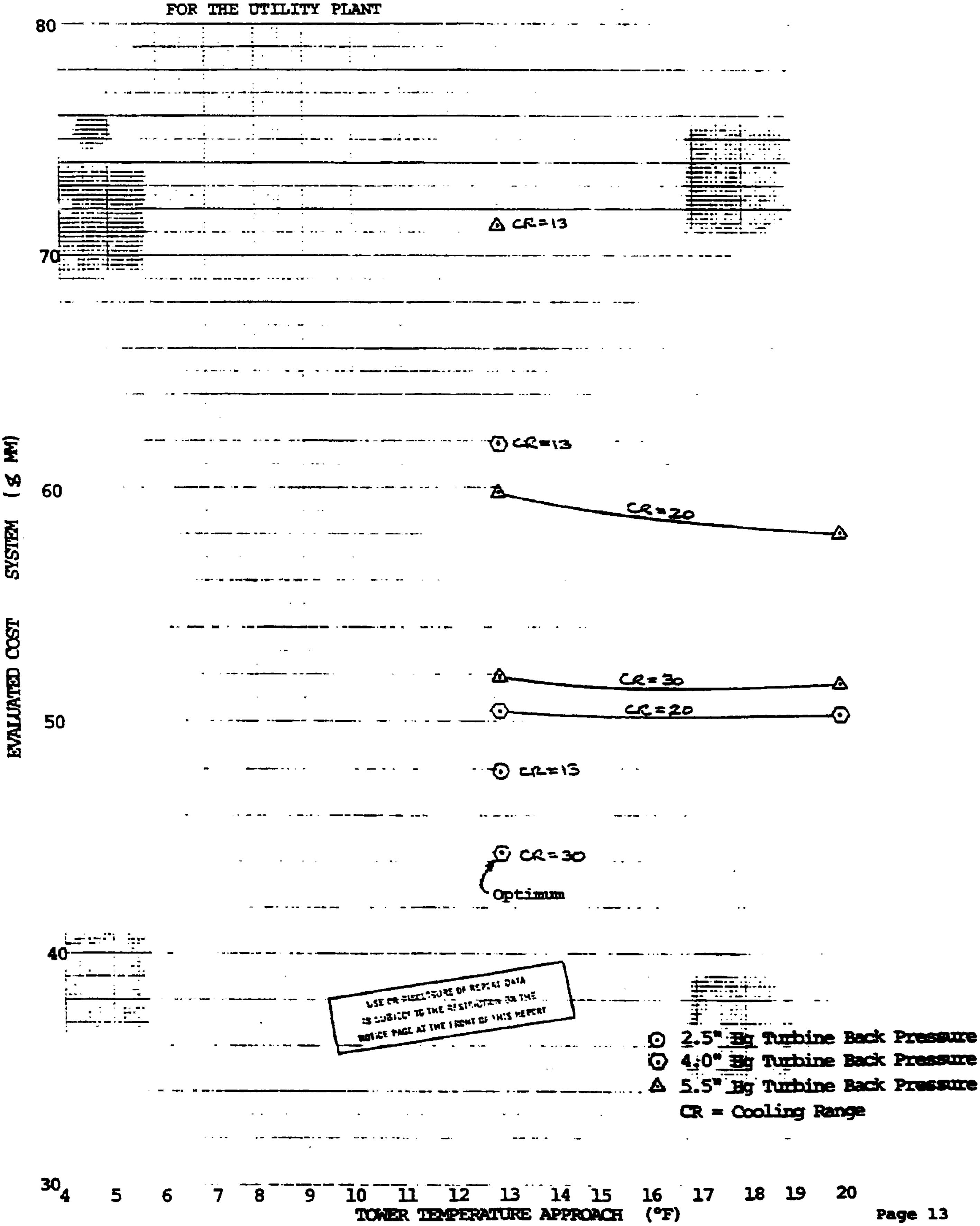
Graph III is a plot of the cooling range versus the evaluated cost of the system using mechanical draft towers. Note that there are constant turbine back pressure and approach lines. As the graph illustrates, the total evaluated cost decreases with increasing cooling ranges. This is primarily due to the lower pump operating costs which are a function of the cooling water flowrates. The optimum (Case U2-2M), as mentioned before, had a cooling range of 20°F; this was the highest range evaluated at 2.5" Hg of turbine back pressure because of the approach limitations. For the higher back pressures of 4.0" Hg and 5.5" Hg, the effect of the cooling range on and evaluated cost is minimal after 28°F.

Graph IV is a similar graph except it is for natural draft towers. The conclusion is quite similar to the mechanical draft towers. The evaluated cost decreases as the range increases. The lowest cost natural draft system (Case U4-7N) utilized a cooling range of 29°F. However, the effect of the cooling range on the evaluated cost is minimal after 27°F.

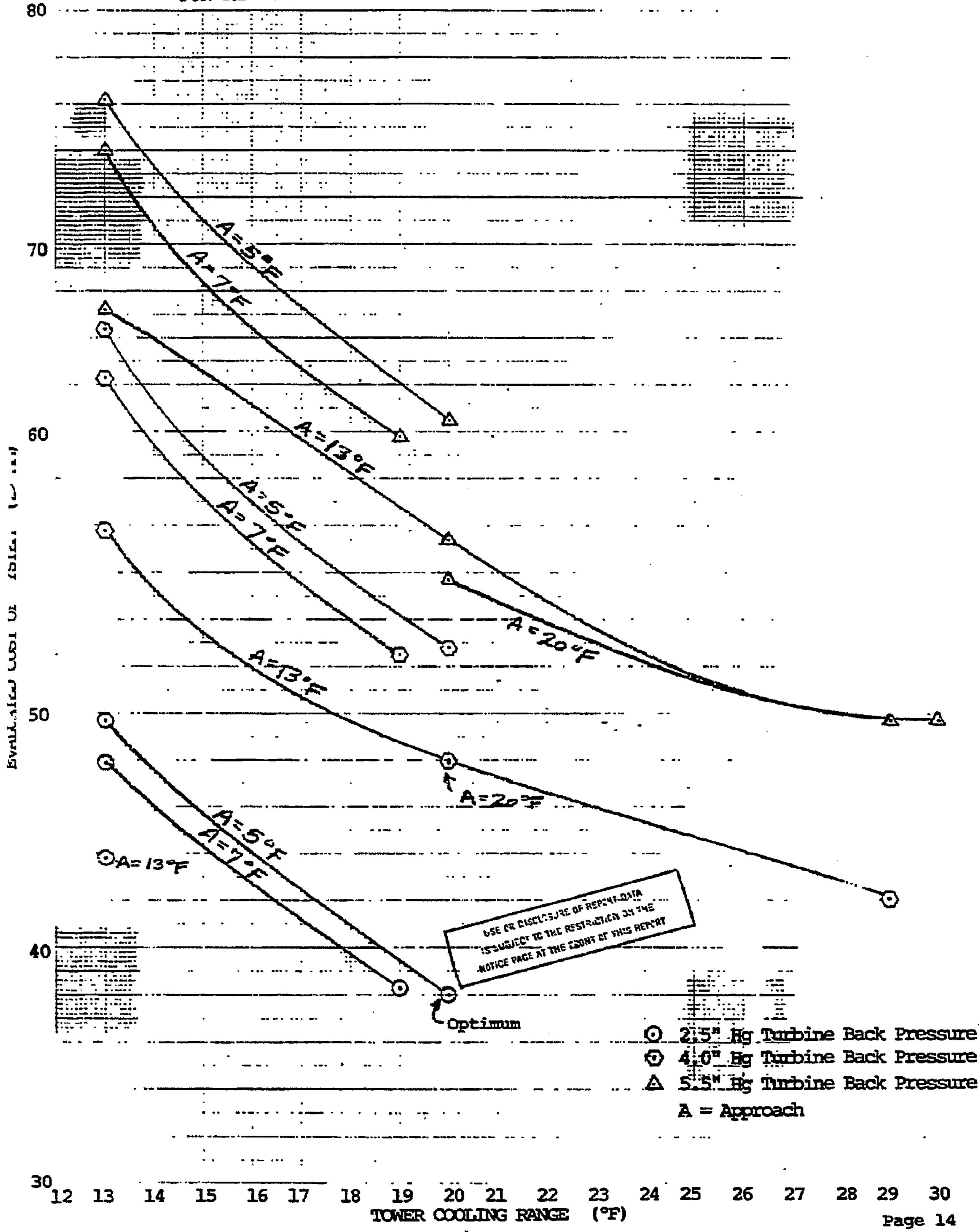
GRAPH I - TOWER TEMPERATURE APPROACH VS EVALUATED COST USING MECHANICAL DRAFT TOWERS FOR THE UTILITY PLANT



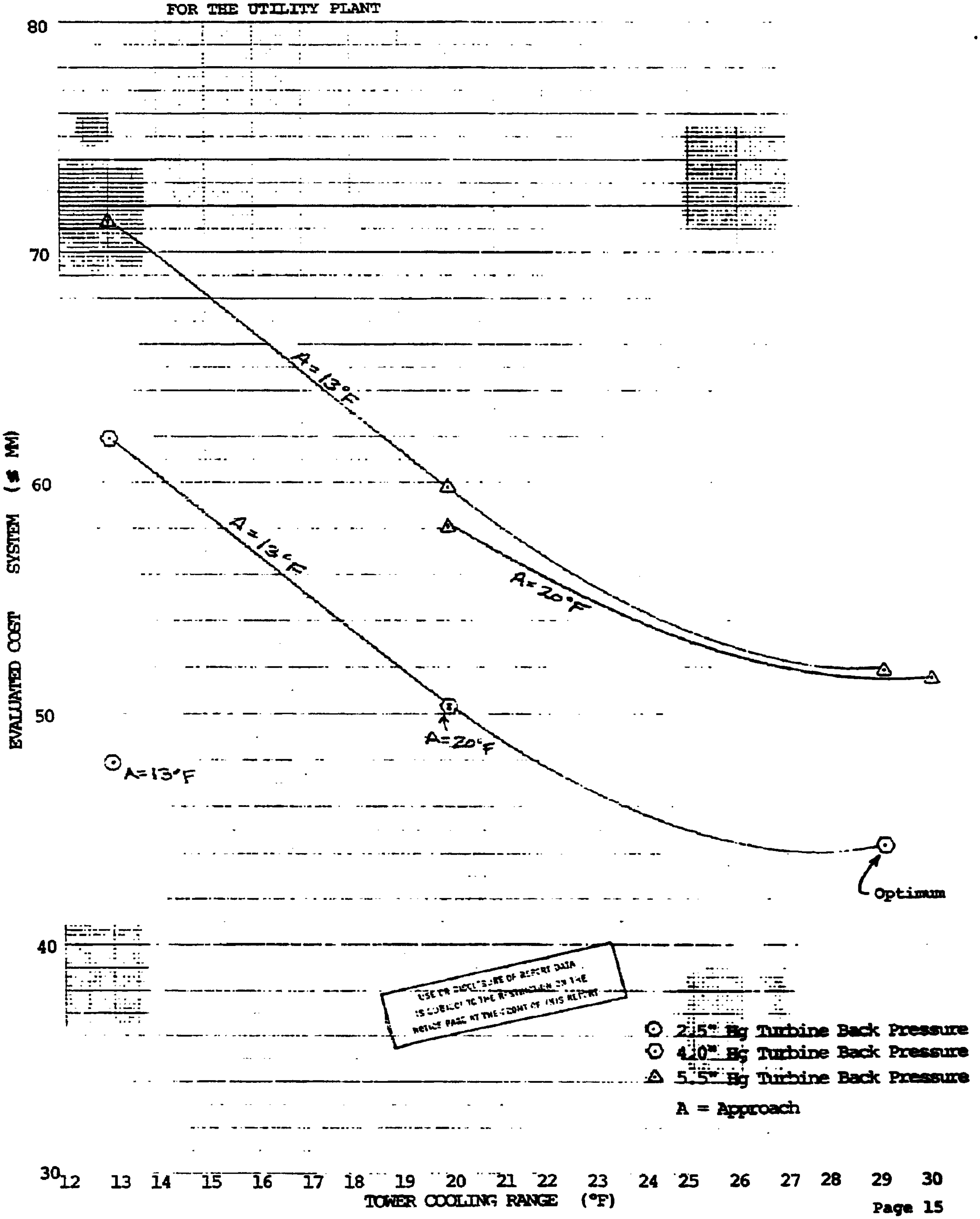
GRAPH II - TOWER TEMPERATURE APPROACH VS EVALUATED COST USING NATURAL DRAFT TOWERS FOR THE UTILITY PLANT



GRAPH III - TOWER COOLING RANGE VS EVALUATED COST USING MECHANICAL DRAFT TOWERS FOR THE UTILITY PLANT



GRAPH IV - TOWER COOLING RANGE VS EVALUATED COST USING NATURAL DRAFT TOWERS FOR THE UTILITY PLANT



4.0 ANALYSIS

4.1 Utility Plant

C. Optimization of the Turbine Back Pressure

Graph V is a plot of the turbine back pressure versus the evaluated cost of the system using mechanical draft towers. Note that there are constant approach and constant range lines. As the graph illustrates, the evaluated cost of the system decreases with the smaller turbine back pressures. This is primarily due to the differential cost of steam. The lowest cost system (Case U2-2M) utilized a turbine with a back pressure of 2.5" Hg.

Graph VI is a similar plot but it is for natural draft towers. The results, however, are the same. The evaluated cost of the system decreases with smaller turbine back pressure.

D. Comparison Between Mechanical and Natural Draft Cooling Towers

As illustrated in this study, mechanical draft towers are economically more attractive. Table IV compares the optimum mechanical draft tower (Case U2-2M) with the optimum natural draft tower (Case U4-7N). The overall evaluated cost of Case U4-7N is 17% more than Case U2-2M. In fact, there are three other mechanical draft cases (U2-4M, U4-7M, and U2-5M) which provided economically more feasible than the optimum natural draft case according to Table II. So, economically, the mechanical draft towers proved to be the clear cut choice.

However, final selection of the cooling tower design also depends upon factors other than economics such as plot size, height, plume, and hydrocarbon emissions.

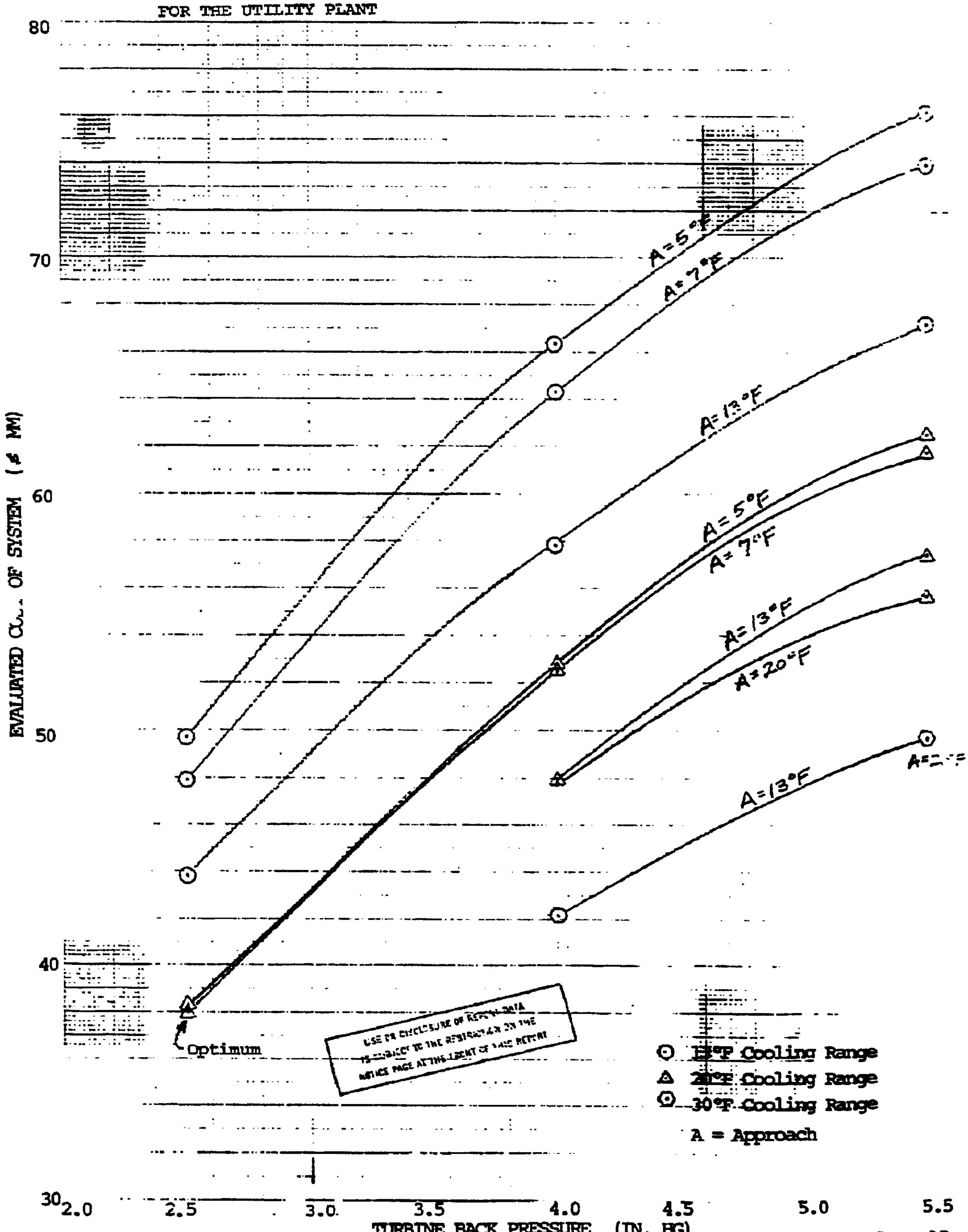
(1) Plot Size

As noted in Table IV, the optimum mechanical draft case employs two (2) 204 foot diameter towers while the optimum natural draft case employs one (1) 288 foot diameter tower. The optimum mechanical draft tower will therefore occupy twice as much plot space as the optimum natural draft tower. However, in Fluor's opinion, plot space will not limit the size of the cooling tower. If plot space becomes a major concern, there are other mechanical draft cases (U4-7M and U2-5M) which occupy less plot space and are more economical than the optimum natural draft case U4-7N.

(2) Height

Height is also a consideration. As Table IV illustrates, the optimum natural draft tower is 450 feet high compared to 70 feet high for the optimum mechanical draft tower. From both a visual and air traffic obstacle standpoint, the lower mechanical draft towers would be preferred over the higher natural draft designs.

GRAPH V – TURBINE BACK PRESSURE VS EVALUATED COST USING MECHANICAL DRAFT TOWERS FOR THE UTILITY PLANT



GRAPH VI - TURBINE BACK PRESSURE VS EVALUATED COST USING NATURAL DRAFT TOWERS FOR THE UTILITY PLANT

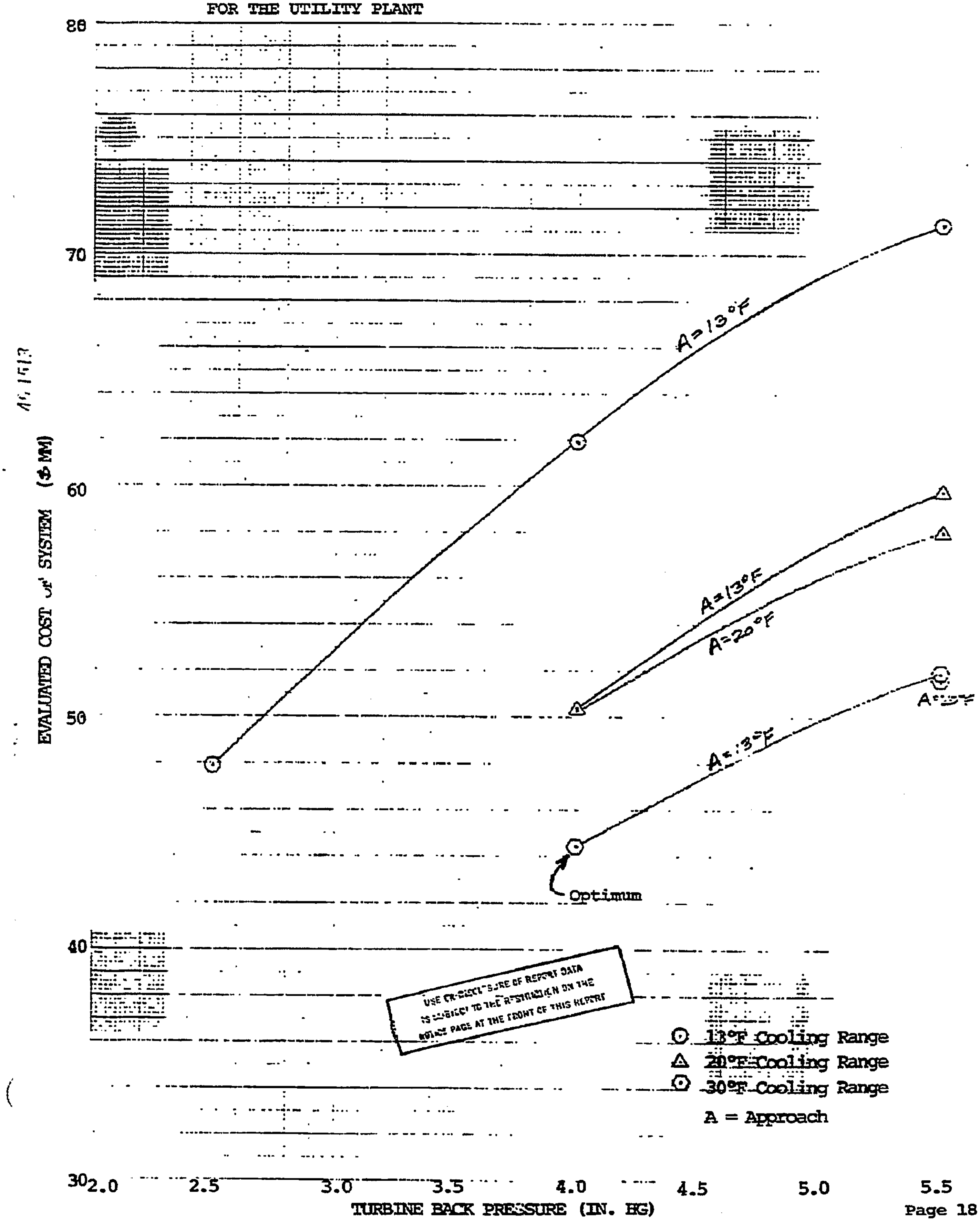


TABLE IV

COMPARISON OF OPTIMUM MECHANICAL AND NATURAL DRAFT COOLING TOWERS FOR THE UTILITY PLANT

	OPTIMUM MECHANICAL DRAFT TOWER	OPTIMUM NATURAL DRAFT TOWER
CASE	U2-2M	U4-7N
FLOWRATE (gpm)	231,000	169,000
HOT WATER TEMPERATURE (°F)	103	120
COLD WATER TEMPERATURE (°F)	83	91
DUTY (10^9 Btu/Hr)	2.31	2.45
APPROACH (°F)	5	13
RANGE (°F)	20	29
TURBINE BACK PRESSURE (IN. Hg)	2.5	4.0
EVALUATED COST OF SYSTEM ($MM)	38.007	44.362
COOLING TOWER COST ($MM)	8.664	10.493
NUMBER OF COOLING TOWERS	2	1
DIAMETER OF EACH TOWER (ft.)	204	288
HEIGHT OF EACH TOWER (ft.)	70	450

4.0 ANALYSIS

D. Comparison Between Mechanical and Natural Draft Cooling Towers

(3) Plume

The visible plume is an important consideration. The exhaust air or plume from the cooling tower will produce a visible fog condition when the ambient air temperature is low and the relative humidity is high such that a supersaturated condition is introduced. Visible plume is more likely to occur during the winter months and in the early morning hours and will usually last a few hours. The path that the fog takes is dependent upon the wind conditions and will rise vertically if no winds are present. Under the same conditions, mechanical and natural draft towers will produce the same amount of visible plume. Natural draft towers have a slight advantage under fogging conditions since the discharge is at a much higher altitude and thus the fog sometimes will spread out more depending on wind conditions and inversion layers. However, the difference would not be substantial enough to justify the cost difference between natural and mechanical draft towers. If fogging became a problem, there are a variety of plume abatement systems which could be used.

As a matter of reference, Fluor Power Services is constructing two power plants in the area of Tri-State Synfuels Plant. In both cases, mechanical draft towers were economically more feasible. However, one of the plants was surrounded by 400 foot bluffs, so natural draft towers were used to ensure that the plume would get over the bluffs. The other plant was on level ground so mechanical draft towers were used. Since the Tri-State Plant is to be constructed on relatively level ground and not subject to restrictions of minimum plume height, the mechanical draft towers are the recommended choice.

(4) Hydrocarbon Emissions
Since make-up to the cooling system will be treated process effluent water, there is a possibility that dissolved hydrocarbons could be released to the atmosphere in the cooling tower plume. To ensure against this, the treatment process includes steam stripping in the ammonia plant followed by biotreatment in large settling ponds. Both mechanical and natural draft towers would be equipped with drift eliminators to further reduce emissions. In this area, both types of towers perform equally well.

4.0 ANALYSIS

4.2 PROCESS PLANT

The mechanical draft towers were more economical than the natural draft towers for both sets of conditions evaluated. For the base case (7°F approach), the natural draft tower cost is $14.7 million or 63% more than the evaluated cost of the mechanical draft towers. For the alternate case (13°F approach), the natural draft tower cost is $4.8 million or 28% more than the evaluated cost of the mechanical draft tower. For both cases, the plot size required for the natural draft towers is substantially more than that required for mechanical draft towers. In regards to height, plume, and hydrocarbon emissions, the general conclusions concerning the utility towers would also be applicable to the process tower. Thus, the mechanical draft towers are the most economical and most feasible selection for the Process Plant.

Also it should be noted that the base case should not be compared to the alternate case without taking into consideration the process heat exchangers. When the temperature approach in the cooling tower is increased, the mean temperature difference in the process - cooling water exchangers decreases and therefore the size and price of these heat exchangers will increase. A redesign of the Process Plant would be necessary in order to project the increased cost of the heat exchangers for the higher approach temperatures. A Process Plant redesign is not within the scope of this study but the information generated is sufficient to compare mechanical and natural draft towers for each set of conditions.

5.0 RECOMMENDATIONS

5.1 Utility Plant

On the basis of the assumptions made in this study, Fluor recommends the use of mechanical draft cooling towers for the Utility Plant. This recommendation is based on a 17% cost difference between the optimum mechanical draft selection and the optimum natural draft selection. Furthermore, this recommendation is based on using the following optimum conditions as used in case U2-2M:

2.5" Hg Turbine Back Pressure
20°F Cooling Range
5°F Temperature Approach

A preliminary cooling tower data sheet for the utility tower is attached in Appendix 2.

5.2 Process Plant

On the basis of the assumptions made and the process conditions used in this study, Fluor recommends the use of mechanical draft cooling towers for the Process Plant. This recommendation is based on a 63% cost difference between the mechanical and natural draft selections for the base case. A preliminary cooling tower data sheet for the process tower is attached in Appendix 2.

APPENDIX 1

MECHANICAL STUDY

Comparison of Mechanical and Natural Draft Cooling Towers.

TRI-STATE SYNFUELS PROJECT

1.0 GENERAL

This study will provide an economic and physical comparison between mechanical and natural draft cooling towers for the Tri-State Synfuels Company project. The study will be divided into the two parts-one for the Process cooling towers and the other for the Utility Cooling towers.

2.0 WORK DEFINITION

2.1 Process Cooling Towers

A. Determine the size and price for mechanical and natural draft cooling towers based on the design conditions.

B. Layout Process towers and connecting piping.

C. Estimate total installed costs.

2.2 Utility Cooling Towers

A. Evaluate the plant design by varying the turbine back pressures, the cooling water temperature and flowrates. Obtain size and price of turbines and surface condensers as well as the cooling towers in order to optimize the plant design. Choose the most economical mechanical and natural draft cooling towers.

B. Layout Utility towers and connecting piping.

C. Estimate total installed costs.

3.0 DELIVERABLE TO TRI-STATE

A formal report that contains the following:

3.1 Preliminary Cooling Tower Data Sheets

3.2 Plot layouts including tower, connecting piping, and structural supports.

3.3 Cost comparisons between the mechanical and natural draft cooling towers for both the process and utility plants including capital costs, operating costs, piping costs, and installation costs.

4.0 SCHEDULE

It is estimated that the above work will be completed in no more than 20 weeks.

APPENDIX 2
STUDY CRITERIA

Sheet I - Temperature - Duty Sketch

Sheet II - Operating Cost Equations (2 pages)

Drawing I -
Drawing II } Plot Layouts for Selected Mechanical Draft Towers

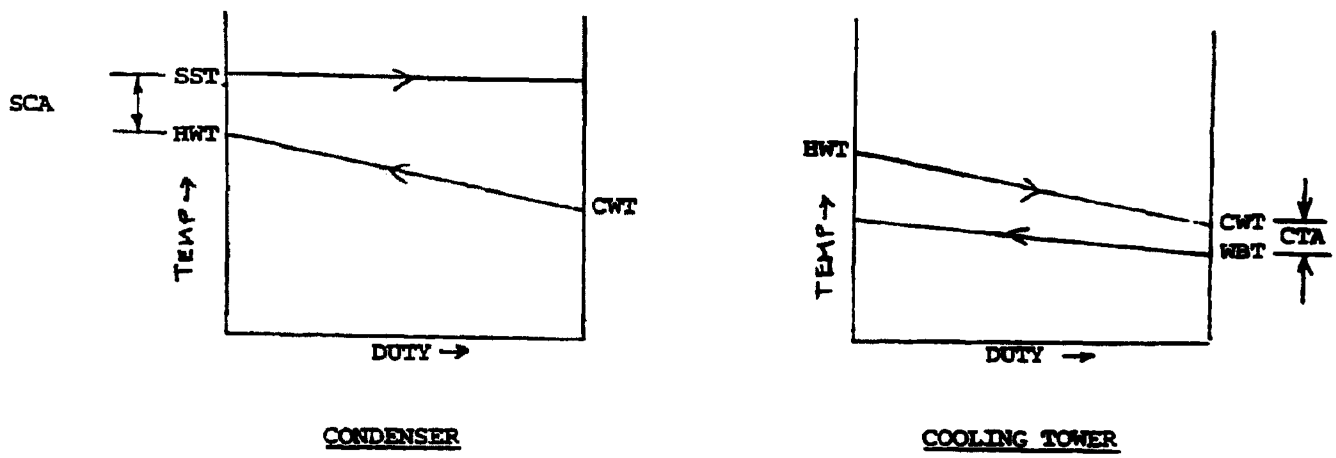
Drawing III - Plot Layouts for Selected Natural Draft Towers

Data Sheet I - Preliminary Data Sheet For Utility Cooling Tower

Data Sheet II - Preliminary Data Sheet For Process Cooling Tower

APPENDIX 2

SHEET I - TEMPERATURE - DUTY SKETCH



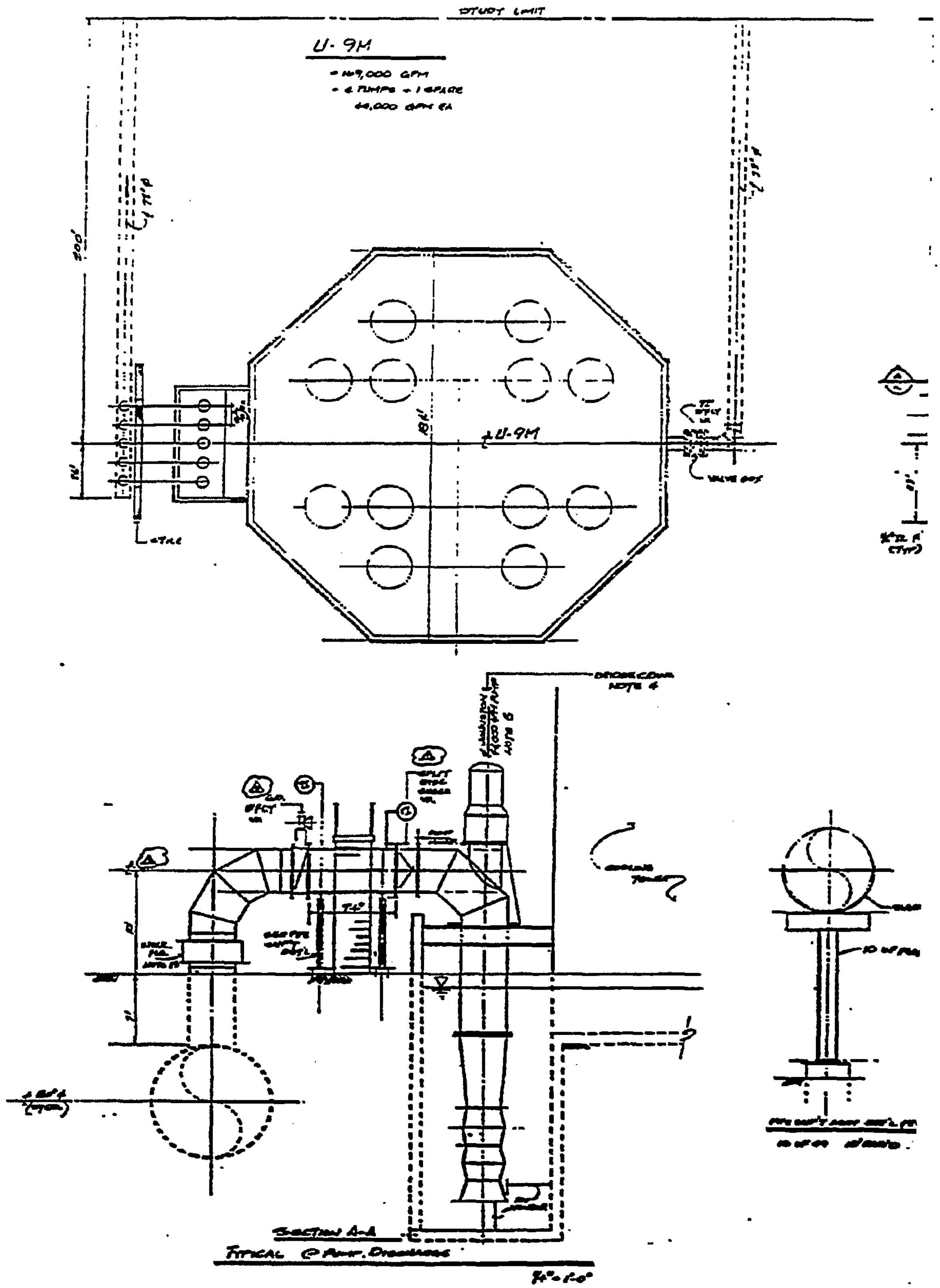
SST = Steam Saturation Temperature

HWT = Hot Water Temperature

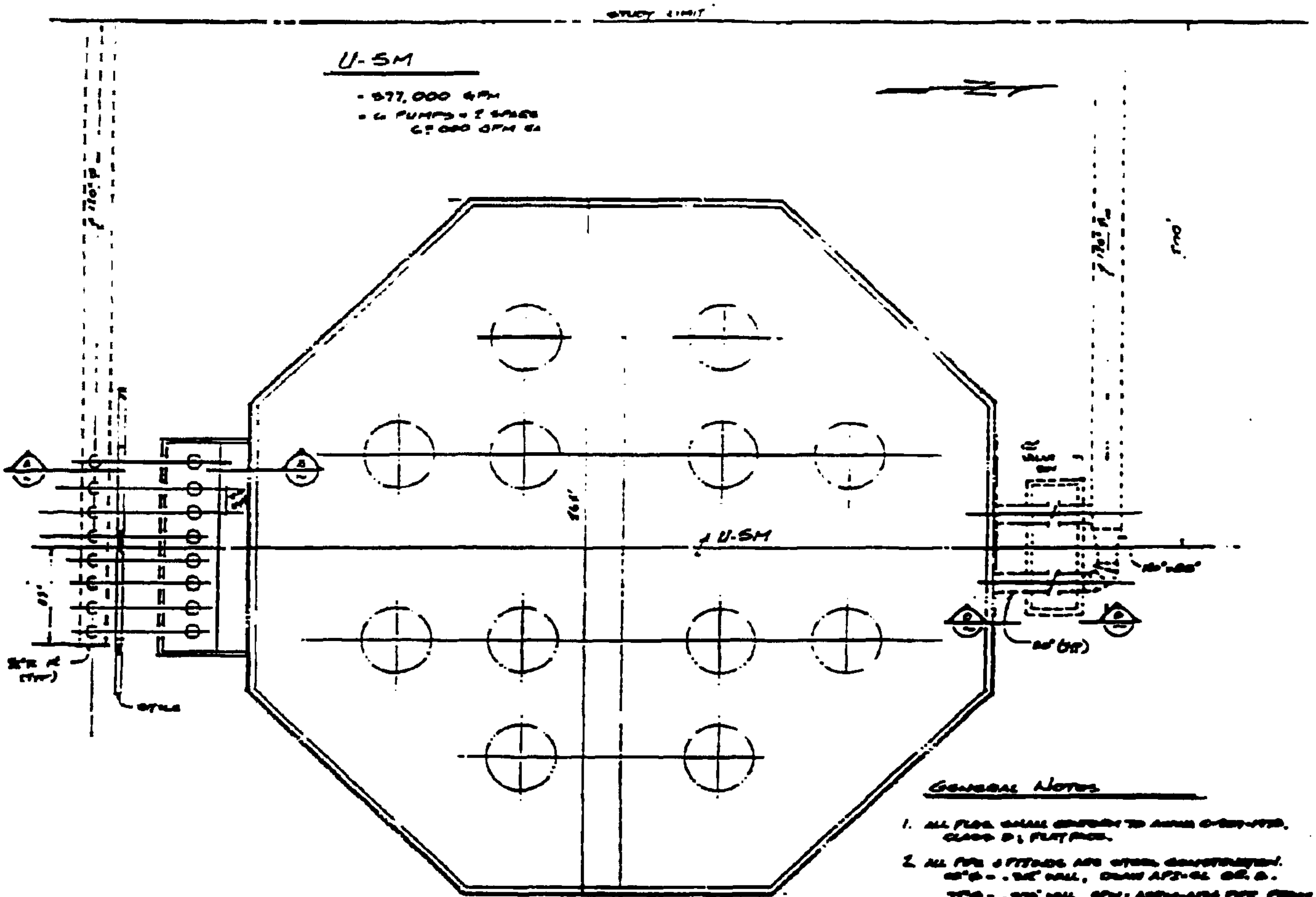
CWT = Cold Water Temperature

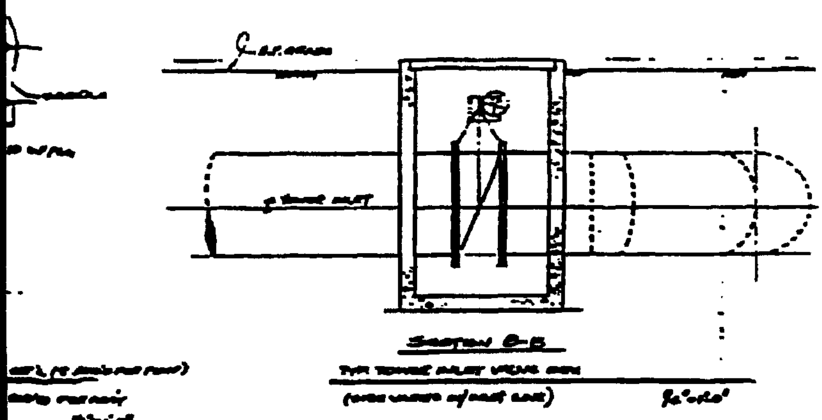
WBT = Wet Bulb Temperature (Inlet)

Min. 5°F { SCA = Surface Condenser Approach = SST-HWT
CTA = Cooling Tower Approach = CWT-WBT



STUDY LIMIT
U-9M
℄ U-9M
VALVE BOX
SECTION A-A
TYPICAL @ PUMP DISCHARGE





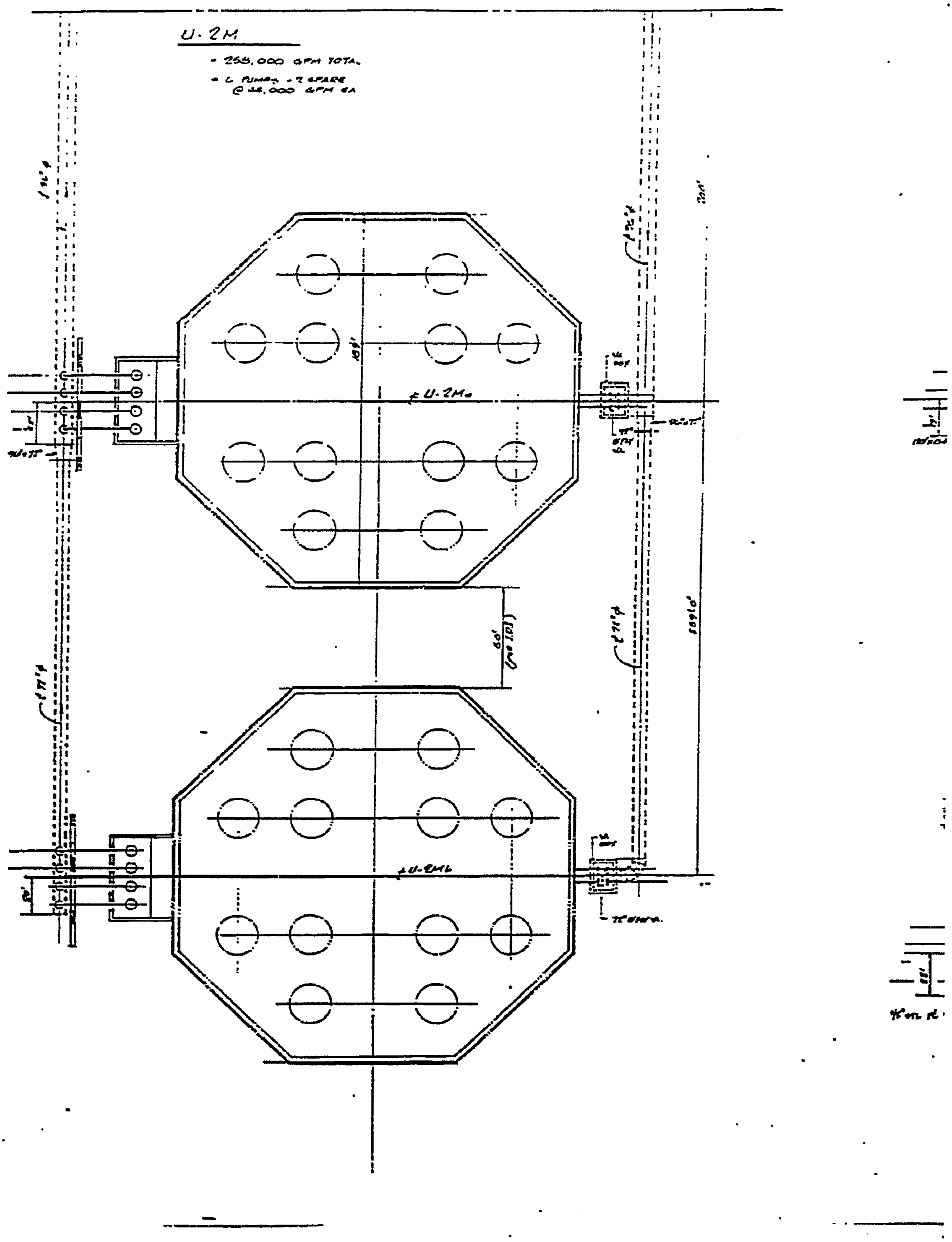
GENERAL NOTES

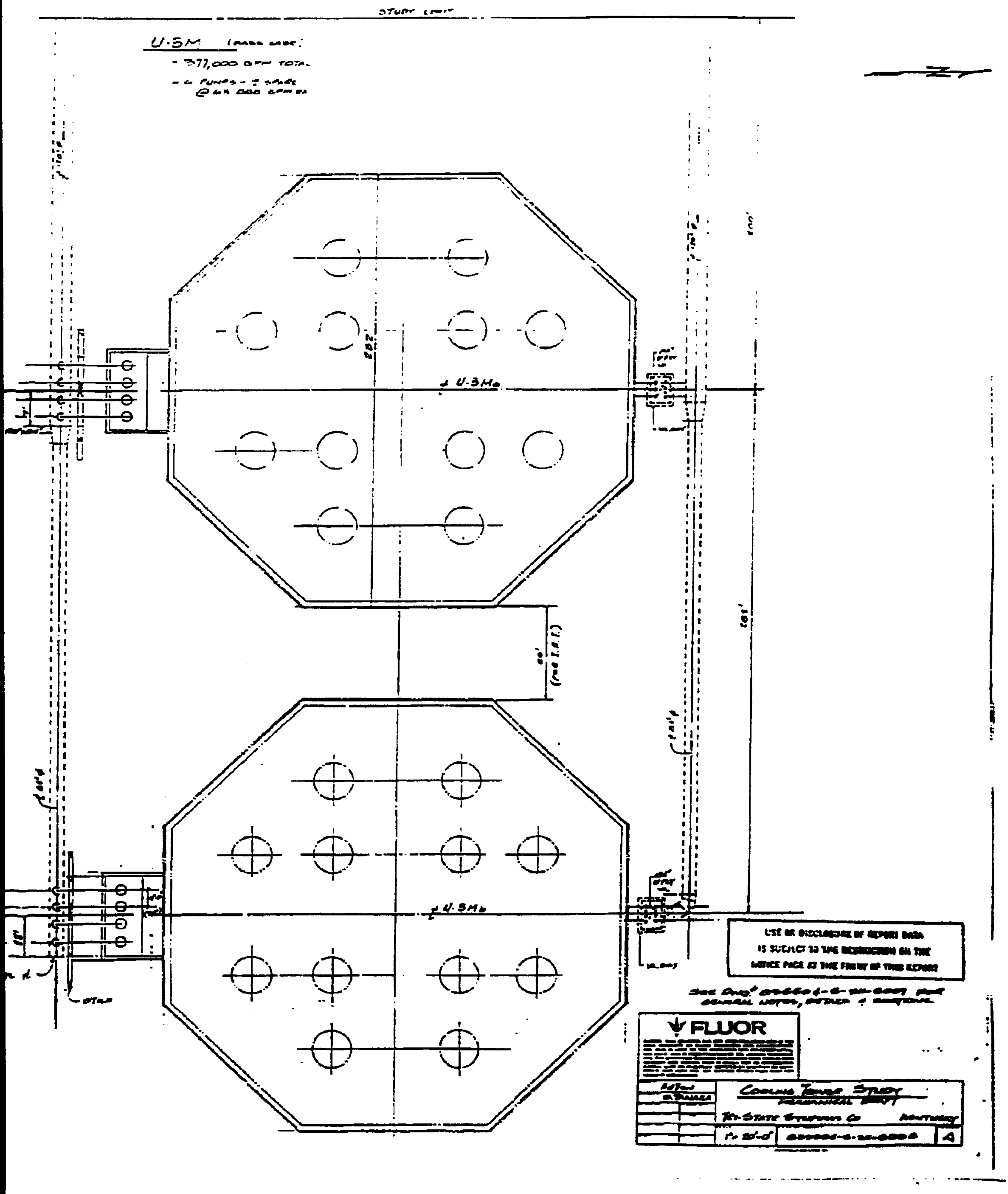
1. ALL FLGS. SHALL CONFORM TO AWWA C-207-[illegible], CLASS D, FLAT FACE.
2. ALL PIPE & FITTINGS ARE STEEL CONSTRUCTION. [illegible]
3. OPTIONAL CONSTRUCTION: a. [illegible] b. F.R.P. [illegible]
4. [illegible]
5. [illegible]
6. ALL VALVES ARE [illegible] TYPE.
7. COOLING TOWER BASIN COSTS ESTIMATED BY MARLEY.
8. [illegible]
9. [illegible]
10. [illegible]
11. [illegible]
12. DELETED
13. [illegible]
14. [illegible]
15. [illegible]
16. [illegible]

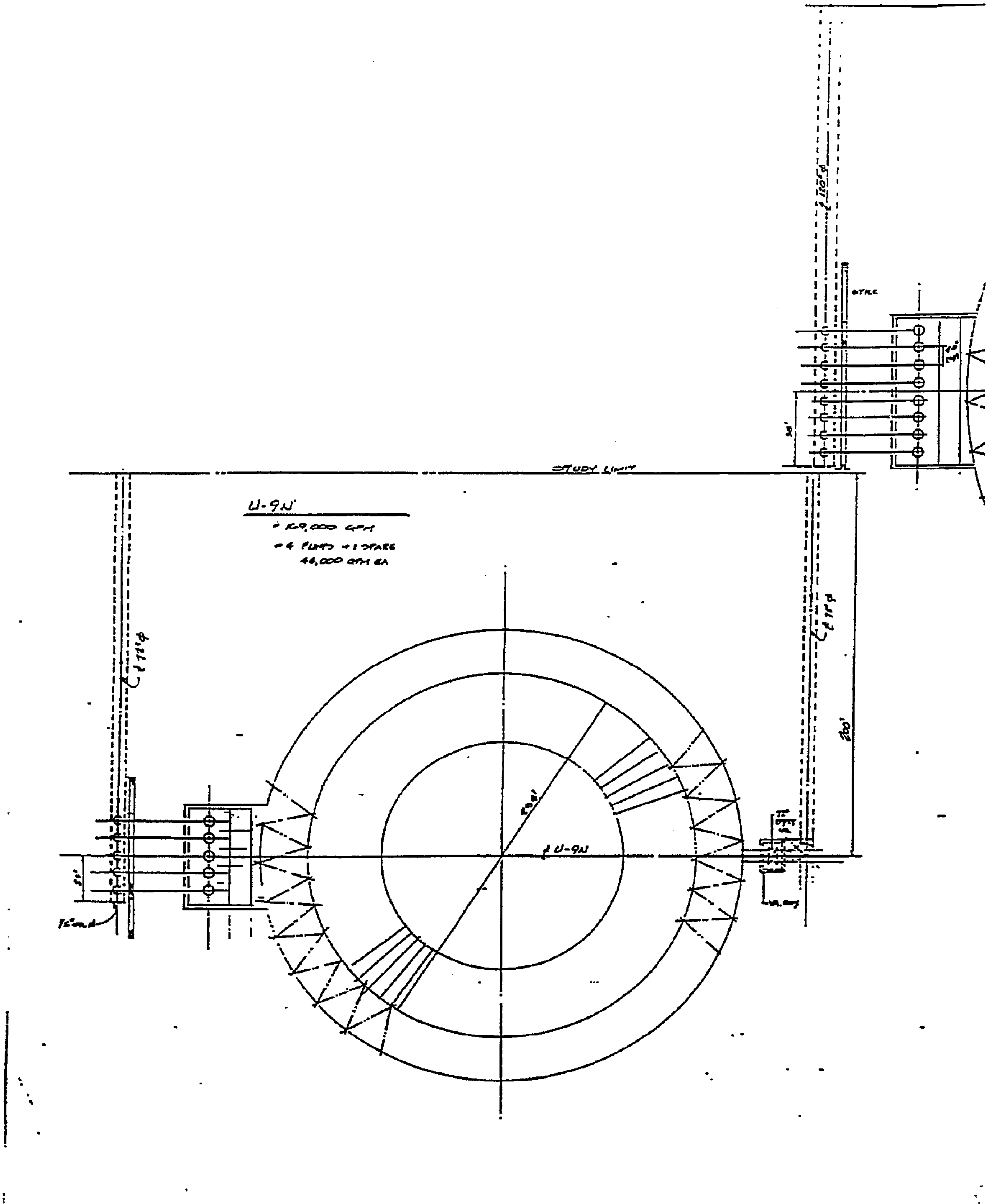
FLUOR

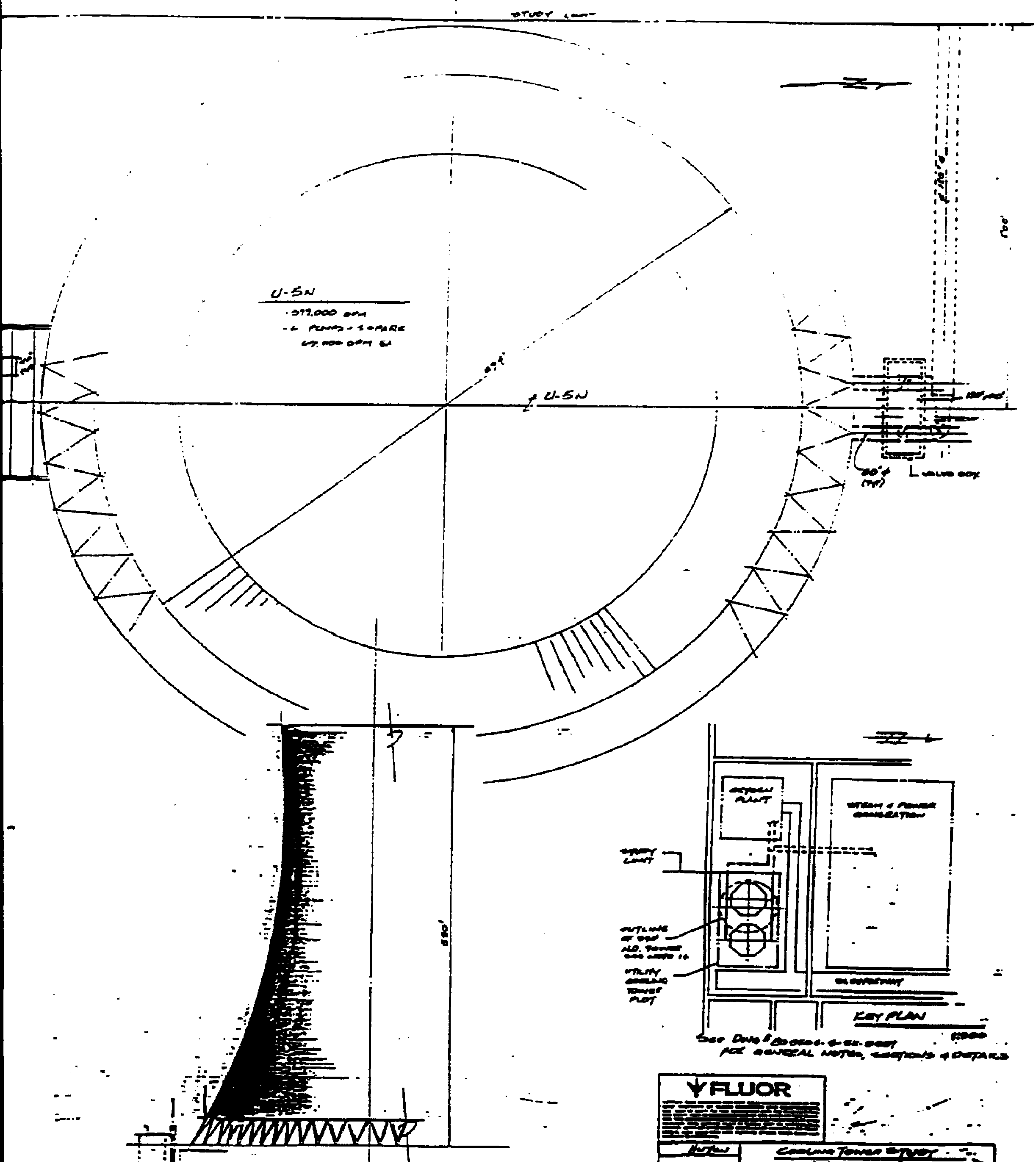
COOLING TOWER STUDY

[illegible] COMPANY


U-2M
255,000 GPM TOTAL


STUDY LIMIT
U-5M (BASE CASE)
377,000 GPM TOTAL
U-5Ma
U-5Mb
USE OR DISCLOSURE OF REPORT DATA
IS SUBJECT TO THE RESTRICTION ON THE
NOTICE PAGE AT THE FRONT OF THIS REPORT
FLUOR
COOLING TOWER STUDY
A


STUDY LIMIT
U-9N
4 PUMPS + 1 SPARE
46,000 GPM EA
℄ U-9N


STUDY LIMIT
U-5N
577,000 GPM
℄ U-5N
VALVE BOX
OXYGEN PLANT
STEAM & POWER GENERATION
STUDY LIMIT
KEY PLAN
FOR GENERAL NOTES, SECTIONS & DETAILS
FLUOR
COOLING TOWER STUDY
NATURAL DRAFT (HYPERBOLIC)
TRI-STATE SYNFUELS CO.
KENTUCKY
U-5N

APPENDIX 2 - DATA SHEET I

FLUOR

SPECIFICATION SHEET

COOLING TOWER

CONTRACT 835504
ITEM NO U-1
REV 0 DATE 8-23-81
HTE CED
PROCESS
SHEET 1 OF 1

			REV
CLIENT TRI-STATE SYNFUELS	VENDOR		△
PLANT UTILITY	MODEL NO	TOWER TYPE MECHANICAL	△

PERFORMANCE OF ONE UNIT		FAN DRIVER		REV
CIRCULATING WATER FLOW GPM	231,000	MOTOR SUPPLIED BY		△
HOT (INLET) WATER TEMP °F	103	ELECTRIC POWER AVAILABLE		△
COLD (OUTLET) WATER TEMP °F	83	RATED HORSEPOWER		△
DESIGN INLET WET BULB TEMP °F	78	ONE SPEED/TWO SPEED		△
DESIGN HEAT DUTY MM BTU/HR	2,310	TYPE MOTOR (OPEN, TEFC, XP)		△
ELEVATION ABOVE SEA LEVEL FT	600	MOTOR MANUFACTURER		△
MINIMUM ATMOSPHERIC TEMP °F	0	NUMBER MOTORS REQUIRED		△
MATERIALS		**FAN DATA**		
~~LUMBER~~ — STRUCTURAL MEMBERS	CONCRETE	NUMBER PER CELL		△
LUMBER — NON-STRUCTURAL MEMBERS		MANUFACTURER		△
DRIFT ELIMINATORS/SPACERS		BLADES PER FAN/DIAMETER	/	△
FILL		MODEL NUMBER		△
FILL SUPPORTS		ONE SPEED/TWO SPEED RPM		△
SIDING		TIP SPEED(S) FPM		△
INLET LOUVERS		ACFM PER FAN ACFM		△
HARDWARE/JOINT CONNECTORS		DESIGN EXIT AIR TEMP °F		△
DRIVE-SHAFT/COUPLING		DESIGN STATIC PRESSURE IN H_2O		△
DISTRIBUTION HEADER/NOZZLES		DESIGN VELOCITY PRESSURE IN H_2O		△
MISCELLANEOUS CASTINGS		HP/FAN INCL GEAR LOSSES BHP		△
ANCHOR CASTINGS		TOTAL HORSEPOWER BHP		△
MOTOR AND GEAR SUPPORT		STATIC EFFICIENCY		△
FAN STACK		TOTAL EFFICIENCY		△
				△
GEAR		**COUPLING**		
TYPE		TYPE		△
MODEL NO		MODEL NO		△
MANUFACTURER		MANUFACTURER		△
SPEED RATIO		RATED HP/RPM		△
AGMA SERVICE FACTOR				△
TOWER DATA		**FILL DATA**		
NO OF CELLS		DESCRIPTION, TYPE		△
OVERALL DIMENSIONS (LxWxH) FT		LENGTH/WIDTH/HEIGHT FT		△
REQ'D BASIN DIMENSIONS (LxW) FT		AIR TRAVEL (CROSSFLOW) FT		△
BASIN DEPTH (CURB TO FLOOR) FT		TOTAL VOLUME FT^3		△
POST EXTENSION BELOW CURB FT		VERTICAL SPACING IN		△
HT OF FAN DECK ABOVE CURB FT		HORIZONTAL SPACING IN		△
HT OF FAN STACK FT		MATERIAL DIMENSIONS		△
STATIC PUMP HD ABOVE CURB FT		LxWxTHICKNESS IN		△
TOTAL DYNAMIC HD ABOVE CURB FT		H_2O/UNIT AREA GPM/FT^2		△
NO AND SIZE OF RETURN CONN		L/G (TOTAL) AT DESIGN		△
DRIFT LOSS, % CIRCULATING GPM				△
				△
SHIPPING WEIGHT/CUBAGE:				△

REVISION LOG

REV	HTE	PROCESS	DESCRIPTION
1			
2			
3			
4			
5			

APPENDIX 2 - DATA SHEET II

FLUOR

SPECIFICATION SHEET

COOLING TOWER

CONTRACT 835564
ITEM NO P-1
REV 0 DATE 3-23-81
HTE CEW
PROCESS
SHEET 1 OF 1

CLIENT TRI-STATE SYNFUELS VENDOR
PLANT FCCCESS MODEL NO TOWER TYPE MECHANICAL

PERFORMANCE OF ONE UNIT		FAN DRIVER	
CIRCULATING WATER FLOW GPM	387,000	MOTOR SUPPLIED BY	
HOT (INLET) WATER TEMP °F	106	ELECTRIC POWER AVAILABLE	
COLD (OUTLET) WATER TEMP °F	85	RATED HORSEPOWER	
DESIGN INLET WET BULB TEMP °F	78	ONE SPEED/TWO SPEED	
DESIGN HEAT DUTY MM BTU/HR	4,060	TYPE MOTOR (OPEN, TEFC, XP)	
ELEVATION ABOVE SEA LEVEL FT	600	MOTOR MANUFACTURER	
MINIMUM ATMOSPHERIC TEMP °F	0	NUMBER MOTORS REQUIRED	
MATERIALS		**FAN DATA**	
~~LUMBER~~ – STRUCTURAL MEMBERS	CONCRETE	NUMBER PER CELL	
LUMBER – NON-STRUCTURAL MEMBERS		MANUFACTURER	
DRIFT ELIMINATORS/SPACERS		BLADES PER FAN/DIAMETER	/
FILL		MODEL NUMBER	
FILL SUPPORTS		ONE SPEED/TWO SPEED RPM	
SIDING		TIP SPEED(S) FPM	
INLET LOUVERS		ACFM PER FAN ACFM	
HARDWARE/JOINT CONNECTORS		DESIGN EXIT AIR TEMP °F	
DRIVE-SHAFT/COUPLING		DESIGN STATIC PRESSURE IN H_2O	
DISTRIBUTION HEADER/NOZZLES		DESIGN VELOCITY PRESSURE IN H_2O	
MISCELLANEOUS CASTINGS		HP/FAN INCL GEAR LOSSES BHP	
ANCHOR CASTINGS		TOTAL HORSEPOWER BHP	
MOTOR AND GEAR SUPPORT		STATIC EFFICIENCY	
FAN STACK		TOTAL EFFICIENCY	
GEAR		**COUPLING**	
TYPE		TYPE	
MODEL NO		MODEL NO	
MANUFACTURER		MANUFACTURER	
SPEED RATIO		RATED HP/RPM	
AGMA SERVICE FACTOR			
TOWER DATA		**FILL DATA**	
NO OF CELLS		DESCRIPTION, TYPE	
OVERALL DIMENSIONS (LxWxH) FT		LENGTH/WIDTH/HEIGHT FT	
REQ'D BASIN DIMENSIONS (LxW) FT		AIR TRAVEL (CROSSFLOW) FT	
BASIN DEPTH (CURB TO FLOOR) FT		TOTAL VOLUME FT^3	
POST EXTENSION BELOW CURB FT		VERTICAL SPACING IN	
HT OF FAN DECK ABOVE CURB FT		HORIZONTAL SPACING IN	
HT OF FAN STACK FT		MATERIAL DIMENSIONS	
STATIC PUMP HD ABOVE CURB FT		LxWxTHICKNESS IN	
TOTAL DYNAMIC HD ABOVE CURB FT		H_2O/UNIT AREA GPM/FT^2	
NO AND SIZE OF RETURN CONN		L/G (TOTAL) AT DESIGN	
DRIFT LOSS, % CIRCULATING GPM			
SHIPPING WEIGHT/CUBAGE:			

REVISION LOG

REV	HTE	PROCESS	DESCRIPTION
1			
2			
3			
4			
5			