CW-WR-79-010

MASTER

COO-4218-2
Distribution Category UC-12

CONCEPTUAL DESIGNS AND COST ESTIMATES OF MECHANICAL DRAFT WET/DRY AND NATURAL DRAFT DRY COOLING SYSTEMS USING CURTISS-WRIGHT INTEGRAL FIN-TUBE HEAT EXCHANGERS

By

R.J. Haberski

J.C. Bentz

APRIL 1979

Prepared For:

The United States Department of Energy
Washington, D.C.

Prepared By:

Curtiss-Wright Corporation
Nuclear Division
Wood-Ridge, New Jersey 07075

DISCLAIMER

LEGAL NOTICE

CONCEPTUAL DESIGNS AND COST ESTIMATES OF MECHANICAL DRAFT WET/DRY AND NATURAL DRAFT DRY COOLING SYSTEMS USING CURTISS-WRIGHT INTEGRAL FIN-TUBE HEAT EXCHANGERS

By

R.J. Haberski

J.C. Bentz

APRIL 1979

Prepared For:

The United States Department of Energy
Washington, D.C.

Prepared By:

Curtiss-Wright Corporation
Nuclear Division
Wood-Ridge, New Jersey 07075

FOREWORD

This study was performed to establish a conceptual design and cost evaluation of an advanced technology mechanical draft wet/dry and natural draft dry cooling systems for large electric power plants using a high performance integral fin-tube heat transfer surface. This study was performed by Curtiss-Wright Corporation and United Engineers & Constructors, Inc., as part of an overall DOE program to develop and demonstrate advanced concept cooling systems for large electric power plants. Results obtained show significant economic advantages compared to results previously published for conventional cooling systems. These advantages are due to the higher heat transfer and lower pressure loss which occur with the use of the selected multi-port integral fin-tubes.

This study reported herein, was a follow-on effort to the previous studies on mechanical draft dry cooling towers which was reported in DOE Report Number COO-4218-1.

ACKNOWLEDGEMENTS

This study was completed under the direction of Mr. I.L. Helms, U.S. Department of Energy, per Contract EN-77-C-02-4218.

Principal contributors included R.J. Haberski and L.R. Cox, Curtiss-Wright Corporation, and G.A. Englesson, M.C. Hu, J.C. Bentz, N.H. Lee, F.R. Eure, J.K. Lin, and A.L. Garrett of United Engineers & Constructors, Inc.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

1.0 INTRODUCTION

Studies performed previously by Curtiss-Wright Corporation (C-W) and United Engineers & Constructors, Inc. (UE&C), References 1 and 2, have indicated that there are substantial cost advantages of dry cooling systems using the integral fin-tube surface developed by C-W as compared to dry cooling systems using the conventional spiral-wound fin-tube surface. The objective of this conceptual design and cost study was to determine the advantages of the C-W integral fin-tube surface compared to the conventional fin-tube surface when these heat transfer surfaces are used in mechanical draft wet/dry tower systems and natural draft all-dry tower systems.

A conceptual design and cost study of dry tower systems previously performed by C-W and UE&C and documented in Reference 2 has demonstrated that cost savings of about 20 percent can be obtained for the C-W dry systems as compared to conventional dry systems. Furthermore, the economic optimization studies (References 3 and 4) of wet/dry and dry tower cooling systems using conventional fin-tubes performed by UE&C have shown that wet/dry tower systems provide major cost savings over all-dry tower systems. Thus, the wet/dry tower system using the Curtiss-Wright high performance integral fin-tube surface should provide additional cost savings over wet/dry cooling systems using conventional fin-tube surfaces. The importance of this task is that a demonstration of additional cost savings, obtained from the use of a high performance heat transfer surface such as the C-W integral fin-tube surface, may enhance the acceptance and adoption of wet/dry cooling by steam-electric utilities at a time when water resources for cooling purposes become increasingly scarce.

In natural draft dry tower systems, a sizable percentage of the cooling tower cost comes from the shell and structure supports. Another objective of this study was to determine whether the improved heat transfer and pressure drop characteristics of C-W heat exchangers would provide a substantial reduction of the natural draft tower size and cost.

The criteria used to design and evaluate the cooling systems are summarized below:

1. The primary evaluations were made for cooling systems sited at Middletown, U.S.A. (Boston, Mass. meteorology) and San Juan, New Mexico (Farmington, N.M. meteorology).

2. Each cooling system was sized at the same design conditions to reject the same quantity of heat.

3. The wet/dry cooling systems were sized to use 10 percent of the make-up cooling water for a comparable wet tower.

4. The natural draft dry tower systems are of hyperbolic concrete shell design.

5. The cooling systems were sized for a 1000 M_{we} nominal size nuclear power plant and were designed to be compatible with a conventional turbine designed to operate with a maximum back-pressure of 5 in. HgA.

   It is recognized that one turbine manufacturer, Reference 5, has proposed to extend the permissible operating range of conventional steam turbines to 8 in. HgA. Such a change would reduce the cost of the cooling system. The use of 5 in. HgA in this study was selected so as to be consistent with the previous studies on dry and wet/dry cooling reported in References 2, 3 and 4.

6. The method of evaluation used herein is based on the assumption of the fixed source - fixed demand approach as described in References 2 and 3. This evaluation is based on total evaluated cost which is the sum of the cooling system total capital cost and its total capitalized operating penalty. These costs are defined in Section 4.0 of this report.

   Although a more comprehensive evaluation of a cooling system may be accomplished by the use of System Lambda, described in the EPRI/DOE Workshop on Power System Economics, Reference 5, the methods of analyses used herein are consistent with earlier studies on mechanical draft dry and dry/wet cooling systems reported in References 2 thru 4. The approach used herein provides a satisfactory and direct means of performing a comparative evaluation of the C-W Integral fin-tube surface vs. the conventional fin-tube surface, in the two cooling systems, such that their economic assessment can be made on a common and direct basis.

In order to avoid ambiguity of terms used in this report, the major components are defined below:

Fin-Tube: These are the basic heat transfer elements exchanging heat between the water and air. The conventional fin-tubes are described in Reference 3 and the unique integral fin-tubes investigated herein are described in Section 3.0 of this report.

Cooling Module: This is essentially a heat exchanger assembly consisting of a number of rows of fin-tubes joined to tubesheets, closures, struts, etc. A description of the selected cooling modules resulting from this study is given in Section 5.0 of this report.

Cooling Cell: This is an assembly of several cooling modules, one or more fans, electric motors, mechanical drives, louvers, water manifolds, vents, etc. Layout drawings of the selected designs are given in Section 6.0 for the mechanical draft wet/dry cooling system.

Cooling Tower: This is an assembly of a number of cooling cells that are joined in a common physical structure, and are supplied with circulating water from a common pipeline. Layouts of the tower arrangement are given in Sections 6.0 and 7.0 for the mechanical draft wet/dry and natural draft dry cooling systems, respectively.

Cooling System: This is the complete assembly of the cooling towers, water distribution system and the condenser. A comparative evaluation of the two systems is given in Section 8.0.

This study was performed by Curtiss-Wright (C-W) and United Engineers & Constructors, Inc. (UE&C) as part of the overall DOE program to develop and demonstrate advanced concept dry cooling systems for large electric power plants. The fin-tube and cooling module parametric design and cost optimizations, and preliminary design selections were performed by C-W as reported in Sections 1.0 through 5.0. The preliminary design and cost investigation of the total cooling system were performed by UE&C and these are reported in Sections 6.0 through 8.0. Requirements and methods of analysis for all of these evaluations are reported in Section 4.0 herein.

2.0 SUMMARY AND CONCLUSIONS

A conceptual design and cost study of power plant cooling systems using the Curtiss-Wright high performance integral fin-tube heat exchangers was performed in two tasks. Task 1 dealt with separate mechanical draft wet/dry cooling tower systems for water conservation, and Task 2 dealt with natural draft dry cooling tower systems. In both tasks, comparable wet/dry and dry cooling tower systems using conventional spiral-wound fin-tube heat exchangers were also evaluated and serve as bases for comparison. These systems are termed conventional or references systems in this report. The purpose of Task 1 was to define the cost advantages that may be obtained for wet/dry cooling tower systems by using C-W integral fin-tube heat exchangers instead of conventional spiral-wound fin-tube heat exchangers in the dry towers. The purpose of Task 2 was to determine if the performance advantages for the C-W systems as demonstrated in previous studies would provide a substantial reduction in the size or number of towers, or the cost for the natural draft all-dry cooling systems.

The cooling systems evaluated were designed for a 1000-MWe (nominal size) light water reactor nuclear plant with a conventional low back-pressure turbine operating at back pressures below 5 in HgA. Two alternate sites were studied; these are: Middletown, U.S.A. (Boston, Mass. meteorology) and San Juan, New Mexico (Farmington, N.M. meteorology). The wet/dry cooling systems were sized to use ten percent of the make-up cooling water required by comparable all-wet cooling systems.

Preliminary installation and piping design layout drawings were made for the mechanical draft wet/dry and natural draft dry cooling systems using both conventional and C-W dry cooling modules. These are shown and described in Sections 6.0 and 7.0 of this report. Comparative design and performance data are shown in Tables 2-1 and 2-2 for the wet/dry and natural draft systems, respectively. Table 2-1 shows that the use of the selected C-W cooling modules will result in a 50% reduction in the number of dry cooling towers, a 47% reduction in the number of dry cooling modules and a 61% reduction in total fan power consumption compared to the use of conventional cooling modules in a mechanical draft wet/dry cooling system.

Similar results were obtained for the natural draft dry cooling system as shown in Table 2-2. These results show that the use of the selected C-W cooling modules results in a reduction in the number of cooling towers of 30% at Middletown and 17% at San Juan, a reduction in the number of cooling modules of 38% at Middletown and 29% at San Juan. Since the evaluation of the natural draft system was made with redesigned conventional dry cooling modules of 81 feet length, the improvement obtained with the use of the C-W dry cooling modules is not as high as was obtained in the mechanical draft wet/dry cooling system, but is still a significant and substantial improvement.

The number of natural draft cooling towers for all of the cases shown in Table 2-2 is acknowledged to be unusually high. This is caused mainly by the severe design conditions imposed by limiting the turbine back pressures to 5 in. HgA. Since the purpose of this evaluation is a comparative evaluation of the merit in using the C-W integral fin-tubes vs. conventional fin-tubes, the selection of the reference data is justified. Therefore, while the number of towers in Table 2-2 is an extreme solution, the percentage difference between the results obtained herein, and the results to be obtained with a full optimization are not expected to be large. This latter evaluation is beyond the scope of this study.

For additional comparison purposes, Table 2-3 is provided herein to show a comparison of the selected C-W dry cooling modules vs. conventional dry cooling modules in an all-dry mechanical draft cooling system. The data of Table 2-3 were abstracted from Reference 2 and show that the C-W cooling module design results in a 50% reduction in the number of cooling towers, a 54% reduction in the number of cooling modules and a 50% reduction in total fan power consumption.

The comparison of capital costs, capitalized operating penalty costs and the total evaluated costs (sum of capital and capitalized operating penalty costs) are given in Tables 2-4 and 2-5 for the separate mechanical draft wet/dry cooling tower systems and the natural draft dry cooling tower systems, respectively.

Table 2-4 shows that the cost advantages for the wet/dry cooling tower systems using the C-W integral fin-tube surface are substantial over those using conventional fin-tube surface. These differences are 12 percent for the Middletown site and 13.4% for the San Juan site in terms of total evaluated cost. These cost advantages are, however, much lower than those (20% for the Middletown site and 21% for the San Juan site) obtained for the mechanical draft all-dry cooling tower systems evaluated on the same basis in a previous study, (Reference 2). The decreases in cost differentials are expected because fewer dry cooling towers are necessary in the wet/dry cooling systems.

Table 2-4 also shows that the savings provided by the C-W wet/dry cooling systems compared to the conventional wet/dry cooling systems make wet/dry systems much more attractive. The cost data for the conventional dry cooling system are taken from Reference 2. The savings in total evaluated cost of the C-W wet/dry cooling systems compared to the conventional dry cooling systems are 50 percent for the Middletown site and 52 percent for the San Juan site. On the other hand, the savings in total evaluated costs of the conventional wet/dry cooling systems over the conventional dry cooling systems are 43 percent for the Middletown site and 44 percent for the San Juan site.

For the natural draft dry cooling tower systems, Table 2-5 shows that the cost advantages in total evaluated cost of the C-W cooling systems over the conventional cooling systems range from 10 percent (San Juan site) to 16 percent (Middletown site). The total costs of the natural draft dry cooling system are higher than the costs of the mechanical draft system, primarily due to the large number of cooling towers in the reference example. These higher tower costs tend to reduce the magnitude of the cost advantage of the C-W dry cooling system in natural draft dry cooling towers.

Results obtained in this study generally corroborate the results obtained in References 1 and 2 in that significant performance and cost advantages would occur in dry cooling applications with the use of the C-W Integral Fin-Tube Cooling Modules compared to the use of conventional cooling modules. Although the results obtained in this study and summarized in Tables 2-4 and 2-5 show significant performance and cost advantages with the use of the selected C-W integral fin-tubing, additional cost advantages are obtainable with further optimization of the cooling module geometries as shown in Sections 5.3 and 5.5 of this study. Additional cost savings of approximately 3% and 1% are obtainable for the mechanical draft wet/dry and the natural draft dry cooling systems, respectively. These further improvements are obtainable with small changes in the selected cooling module geometry.

The substantial improvement predicted by the results of this study, in comparison to the reference dry cooling system, is due primarily to the higher heat transfer and lower pressure loss of the C-W Integral Fin-Tubes compared to round fin-tubes. Figure 2-1 illustrates this improvement. It compares a composite of performance for various C-W Integral Fin-Tube geometries vs. performance data for a composite of round fin-tube geometries. Both sets of data cover a wide range of fin and tube geometries and can be considered to be representive of their levels of performance. This data is presented in terms of J over F ratios, i.e. the Colburn heat transfer coefficient divided by the fin-tube friction factor. This ratio was shown to be inversely proportional to the power consumption at constant heat load and site conditions as described in Reference 2. The integral fin-tube performance data in Figure 2-1 has been adjusted to a common tube geometry in order to include the effect of inlet contraction and outlet expansion pressure losses. This was necessary since the above data was obtained from a wide variety of tube geometries.

It can be seen from Figure 2-1, that the general level of performance for integral fin-tubes is significantly higher than for conventional round fin-tubes. Also, it can be seen on this figure, that the general range of data assumed for this study is conservative compared to the total range of data obtained with these integral fin-tubes during several years of experimental evaluations at Curtiss-Wright. Superimposed on Figure 2-1 are the data which were used for the design of the C-W cooling modules, i.e. the 1-pass cooling module for the wet/dry system and the 2-pass cooling module for the natural draft dry system. For comparison purpose, the estimated performance of the reference conventional cooling module is also shown in Figure 2-1.

The matrix of information provided earlier in Reference 2 and by this report is not complete in that the optimum dry towers could consider extended range or higher back pressure turbines of modified, or high back pressure design. The funds available for the study, herein, did not allow the completion of a full matrix of information. Rather, the objective of these studies was to illustrate the potential benefits of the Curtiss-Wright Integral Fin-Tube surface in selected cases. These cases are extreme in that the maximum benefit of using the Curtiss-Wright design are shown. In those cases where one must use all dry cooling, it has been shown that the C-W approach, would save about 20% compared to conventional dry systems. While this cost reduction is not enough, by itself, to enable the extensive use of all dry systems, this is a significant benefit which can be applied to the dry section of any cooling system. Perhaps with other inputs, such as with the use of extended range turbines, enhanced condenser surfaces, and the use of ammonia as a heat transfer fluid from the condenser to the tower, the cost of an all dry, or nearly all dry cooling system will become economically practical. The latter item is currently being evaluated in other cooling tower studies at EPRI and DOE.

Table 2-1

MECHANICAL DRAFT WET/DRY COOLING SYSTEM COMPARISON

	Middletown, U.S.A.		San Juan, N.M.	
	C-W	Conventional	C-W	Conventional
General Data				
*Plant Capacity, MW_e	1060	1060	1048	1048
Maximum Turbine Back Pressure, in-HgA	4.5	4.5	5.0	5.0
Annual Make-Up Water Required, 10^8 gal.	4.40	4.40	4.57	4.57
*Condenser Heat Load, 10^9 Btu/hr	7.22	7.22	7.25	7.25
Cooling System				
Total No. of Towers, Dry/Wet	3/2	6/2	4/2	8/2
Total No. of Cells, Dry/Wet	72/19	136/19	92/15	170/15
Total No. of Fans, Dry/Wet	144/19	136/19	184/15	170/15
Total No. of Dry Modules	288	544	368	680
Length of Dry Module, Ft.	80	53	80	53
Width of Dry Module, Ft.	12	10.5	12	10.5
Total Fan Power, Bhp, Dry	9878	25,337	11,960	31,093
Total Power (Fan + Water), hp	28,247	41,949	29,000	50,493

* At maximum turbine back pressure

Table 2-2

NATURAL DRAFT DRY COOLING SYSTEM COMPARISON

	Middletown, U.S.A.		San Juan, N.M.	
	C-W	Conventional	C-W	Conventional
General Data				
Plant Capacity, MW_e	1048	1048	1048	1048
Turbine Back Pressure, In-HgA	5.03	5.03	5.03	5.03
Condenser Heat Load, 10^9 Btu/hr	7.26	7.26	7.26	7.26
Cooling System				
Total No. of Towers	7	10	10	12
Total No. of Modules	875	1400	1220	1728
Base Diameter of Tower, Ft	478	461	466	474
Height of Tower, Ft	512	512	535	535
Length of Module, Ft	80	81	80	81
Width of Module, Ft	12	10.3	12	10.3

Table 2-3*

MECHANICAL DRAFT DRY COOLING SYSTEM COMPARISON

	Middletown, U.S.A.		San Juan, N.M.	
	C-W	Conventional	C-W	Conventional
General Data				
Plant Capacity, MW_e	1056	1056	1048	1048
Turbine Back Pre-sure, in-HgA	4.65	4.65	5.0	5.0
Condenser Heat Load, 10^9 Btu/hr	7.23	7.23	7.26	7.26
Cooling System				
Total No. of Towers	7	14	9	18
Total No. of Cells	156	338	200	432
Total No. of Fans	312	338	400	432
Total No. of Modules	624	1352	800	1728
Length of Module, Ft.	80	53	80	53
Width of Module, Ft.	12	10.5	12	10.5
Total Fan Power, b hp	29,578	59,576	37,840	75,133
Total Power, (Fan + Water), b hp	57,706	88,322	71,278	102,139

*Data abstracted from Reference 2.

Table 2-4

SUMMARY COST COMPARISON OF MECHANICAL DRAFT TOWER SYSTEMS, (\$$10^6$, 1977 DOLLARS)

				Percent Savings	
	C-W Wet/Dry	Conventional Wet/Dry	Conventional Dry	C-W Wet/Dry Over Conventional Wet/Dry*	C-W Wet/Dry Over Conventional Dry*
Middletown					
Penalty Cost	41.561	49.287	72.006	16	42
Total Capital Cost	59.492	65.531	130.359	9	54
Total Evaluated Cost	101.053	114.818	202.365	12	50
San Juan					
Penalty Cost	47.003	58.327	81.145	19	42
Total Capital Cost	68.707	75.282	159.618	9	57
Total Evaluated Cost	115.710	133.609	240.763	13.4	52

* Percent Savings of C-W Wet/Dry over Conventional Dry

$$= \frac{\text{(Conventional Wet/Dry)} - \text{(C-W Wet/Dry)}}{\text{(Conventional Wet/Dry)}} \times 100\%$$

** Percent Savings of C-W Wet/Dry over Conventional Dry

$$= \frac{\text{(Conventional Dry)} - \text{(C-W Wet/Dry)}}{\text{(Conventional Dry)}} \times 100\%;$$ data taken from Ref. 2

Table 2-5

SUMMARY COST COMPARISON OF NATURAL DRAFT DRY TOWER SYSTEMS, ($$10^6$, 1977 DOLLARS)

	Conventional	C-W	Percent Savings C-W Over Conventional*
Middletown			
Penalty Cost	54.593	50.992	7
Total Capital Cost	203.639	165.770	19
Total Evaluated Cost	258.232	216.762	16
San Juan			
Penalty Cost	53.306	50.752	5
Total Capital Cost	243.190	214.931	12
Total Evaluated Cost	296.496	265.683	10

$$* \text{ Percent Savings} = \frac{\text{Conventional} - \text{C-W}}{\text{Conventional}} \times 100\%$$

HEAT EXCHANGER PERFORMANCE CHARACTERISTICS

COMPARISON OF CURTISS-WRIGHT INTEGRAL FIN-TUBES VS ROUND FIN-TUBES

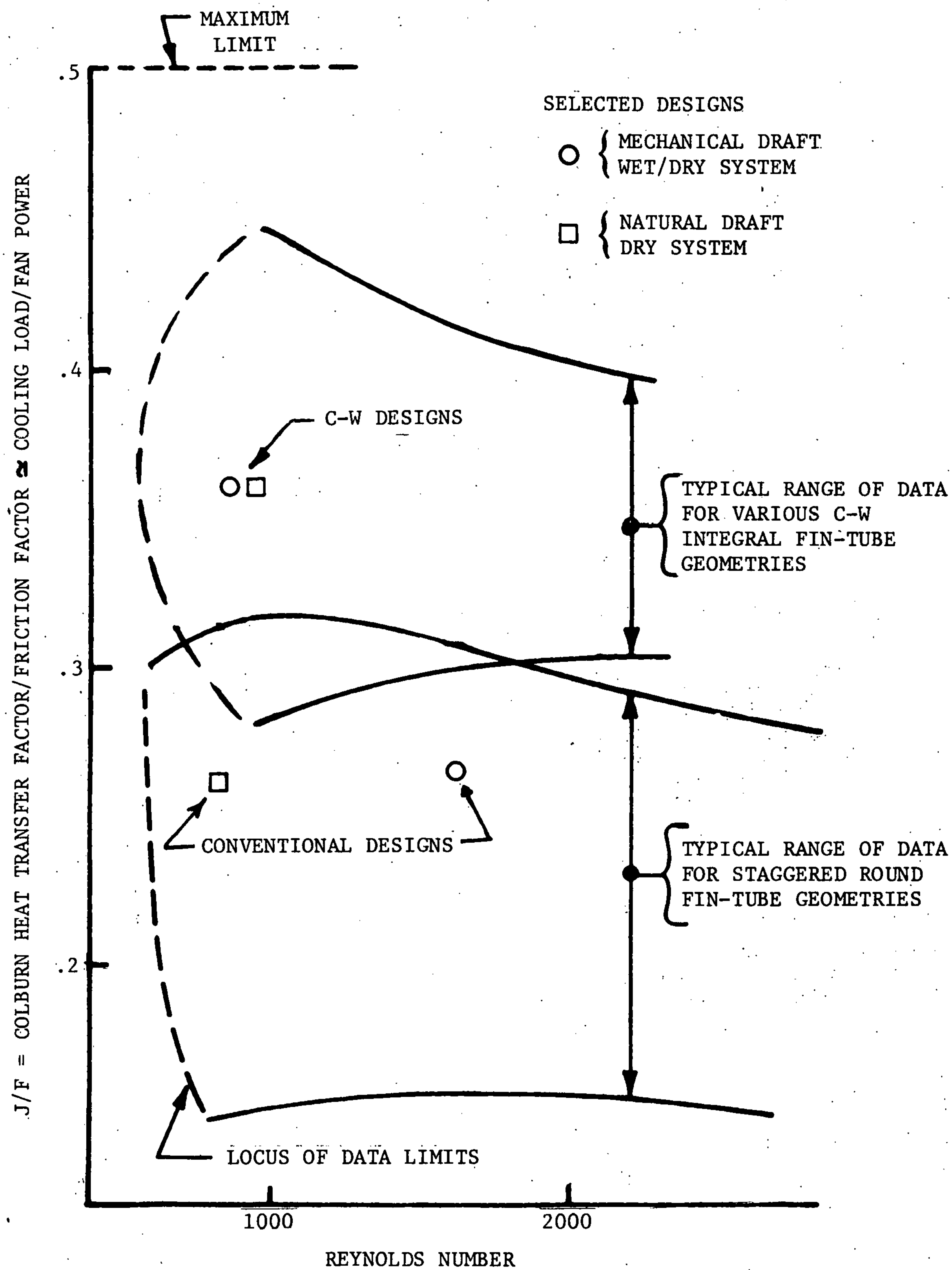


Figure 2-1

3.0 DESCRIPTION OF CURTISS-WRIGHT INTEGRAL FIN-TUBES

During the past several years, Curtiss-Wright has been actively and continuously engaged in the design, development and fabrication of high performance heat exchanger equipment. In particular, this effort has been directed toward the development of high performance and low cost integral fin-tube heat transfer elements for application in high performance and high volume production heat exchanger equipment. These heat transfer elements are fabricated by a unique manufacturing process, namely, by machining the fins, i.e. lifting a chip from the surface of a pre-formed extrusion. The low cost advantages of these integral fin-tubes are achieved by the use of low cost billet material, high speed automated machining, and tube and fin fabrication without any significant scrap material. Figure 3-1 shows a sample of typical multi-port integral fin tube geometries used in various heat exchanger applications. Current production of this type of integral fin-tubing exceeds 15 million feet per year.

Since these integral fin-tubes are machined from a pre-formed extrusion, the fin and tube port geometric variations are almost infinite with the tube size limited only by the capacity of the extrusion press. Therefore, tube designs are possible with various geometry internal fins, various size, number and shape of internal ports or passages, and various shapes and size of the external tube geometry. Although, the minimum tube wall and web thicknesses are limited by extrusion capability, these thicknesses are more often established by allowable wall stresses, tube joint weld requirements and by the design of the tube ports for metal conservation and/or tube side pumping power conservation. For this study, the wall thicknesses were established by consideration of all of the above criteria.

Since the integral fins are machined from a pre-formed tube surface, considerable flexibility exists with respect to fin density, fin shape, fin thickness, fin height and fin width in the flow direction. The fin widths can be made uniform, varied, or sized in almost any manner to obtain optimum performance. Of particular importance, is the fact that the fin size and shape are independent of the tube thickness. Therefore, each of the above fin and tube variables can be independently controlled in this fabrication process such that the resulting integral fin-tube can be fully optimized for performance and cost considerations, as required, for specific application requirements.

During the past several years, numerous and extensive development and experimental performance evaluations have been performed at Curtiss-Wright with these multi-port integral fin tubes. Results have demonstrated superior performance compared to all known and available round fin tube geometries as shown on Figure 2-1. This is considered to be due to the following:

1. The integral fin and tube concept which provides unrestricted heat transfer from the fin to the tube which does not change due to thermal expansion and cycling conditions as may occur with various types of wrapped fins on round tubes.

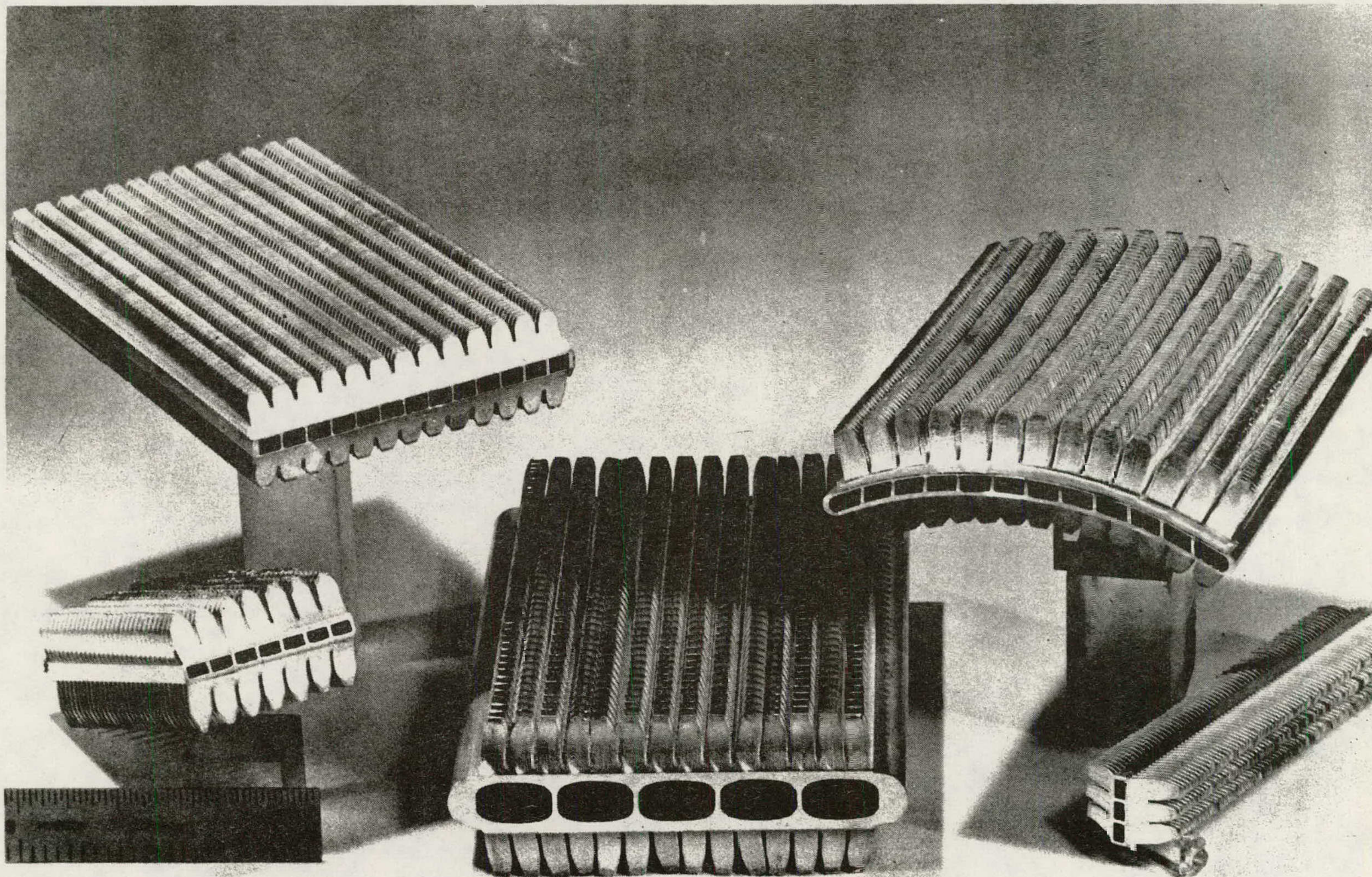
2. The size, number and shape of the fins which can be varied over a wide range and can be optimized to specific requirements for performance and cost.

3. The type, shape and frequency of fin interruptions or serrations which can be varied over a wide range to optimize performance for specific requirements. These fin interruptions inhibit fin boundary layer build-up and increase localized air turbulence resulting in improved performance compared to continuous fins.

4. The type of tube geometry which can be varied over a wide range of configurations which is limited only by extrusion capabilities. The size and shape of the tube ports can be varied to provide optimized coolant pressure loss while the port webs act as integral fins to promote heat transfer.

75-076

Figure 3-1



VARIOUS TYPES OF MULTI-PORT INTEGRAL FIN-TUBE HEAT EXCHANGER ELEMENTS

4.0 REQUIREMENTS, ASSUMPTIONS AND METHODS OF ANALYSES

In order to perform this parametric design and cost optimization study of mechanical draft wet/dry and natural draft dry cooling systems, a number of assumptions were made as to site selection, plant operational requirements, type of steam turbine, fan size and operation characteristics, and cooling cell design, performance, installation and cost analysis procedures. Assumptions, requirements, and methods of analyses, are presented in this section of this report. Evaluations of the parametric sizing, evaluation and selection of the resultant cooling modules are provided in Section 5.0. Comparative evaluations of the results obtained with the selected C-W dry cooling modules vs. the results obtained with conventional dry cooling modules in the mechanical draft wet/dry and natural draft dry cooling systems are given in Sections 6.0, 7.0 and 8.0 of this report.

4.1 Selection of Plant Site and Operating Requirements

The plant site selected for the parametric optimizations of cooling modules and cooling system design selection is Middletown, U.S.A. The Middletown site is the DOE hypothetical site defined as a typical power plant site in the U.S. having meteorological conditions modeled after those of Boston, Massachusetts. In order to extend the usefulness of the results obtained in this study, an evaluation of an alternate site was made. The alternate site chosen for this study was San Juan, New Mexico, with Farmington, New Mexico meteorology. For the wet/dry cooling tower systems, an operating requirement was selected equivalent to 10% make-up water of an all-wet cooling system. The design parameters and the sizes of the major components of the cooling systems at both sites were established in Reference 3. The C-W wet/dry cooling systems at these sites were sized to meet the same design parameters. Tables 4-1 and 4-2 show the performance characteristics of the conventional wet/dry systems.

At both sites, the natural draft dry cooling tower systems were designed for a turbine back pressure of 5 in HgA at the maximum ambient temperature. Tables 4-3 and 4-4 show the performance characteristics of the conventional natural draft dry cooling systems.

The ambient conditions shown in Tables 4-1 and 4-3 for the Middletown site were selected as the design requirements for the parametric optimizations and design selections for the C-W dry cooling module designs established in the investigations herein. The operational performance of the selected cooling system was evaluated at the San Juan site as an off-design operation, i.e. the cooling modules were not re-optimized for the San Juan design condition.

The operating conditions provided in Tables 4-1 thru 4-4 are based on the use of a conventional steam turbine, i.e. one operating with a low back pressure limitation of approximately 5 in. HgA. Although this assumption does not allow for an optimum selection of a dry cooling system, it does provide a means for direct comparison of the C-W dry cooling system with a conventional dry cooling system. The parametric design and economic analyses performed herein are based on total evaluated costs obtained through the fixed source - fixed demand approach. This assumes that the reference plant has a fixed heat source and that there is a fixed demand for the plant output. This method of analysis provides a direct means of performing parametric sizing and performance analyses of cooling modules such that their comparative assessment can be made on a common basis. Although the resulting cooling module selection may vary somewhat from a more comprehensive evaluation in which the cooling module design selection might vary with the power plant load variations, the results presented herein are consistent with results reported in Reference 2 and with earlier UE&C studies conducted for ERDA and EPA, reported in References 3, 4 and 6. Therefore, this approach is considered to be a satisfactory method for illustrating the advantages of C-W improved heat transfer surface.

4.2 Cooling Module and Fan Matching Considerations

The general procedure for matching cooling modules and fans in an induced draft cooling system involves the evaluation and selection of a combination of a large number of variables. These include the number and size of cooling modules, the cooling module face mass velocity, the number of fans, the fan diameter, the fan tip speed, the fan airflow, the number of fan blades, and the blade pitch setting. This combination must result in a total fan airflow that is the same as the total cooling module airflow, and a fan pressure rise which matches the overall system air pressure loss while achieving near maximum fan efficiency.

Fan performance data in terms of pressure rise, horsepower and airflow were extracted from data in Hudson's Catalog, Reference 7, of guaranteed fan performance for the various fan diameters considered in this study. The fan tip speed was maintained at 12,000 feet per minute for all evaluations. Based on the nominal 12 foot by 80 foot modules considered for this application, and previous extensive cooling module and fan matching studies of Reference 2, a cooling cell for this study was considered to consist of four modules and two fans.

4.3 Fin-Tube Design and Performance Analyses

The key item to obtaining good performance, i.e. low power consumption and low capital cost, in any dry cooling system is the use of high performance and low fabrication cost heat transfer elements, such as has been obtained with the Curtiss-Wright Multi-Port Integral Fin-Tubes described in Section 3.0 of this report. The multi-port integral fin-tube used in this study permits a wide selection of tube port geometry for the coolant flow passages. Previous results, Reference 1, have shown that rectangular ports with corner radii will yield significantly less coolant pressure drop and/or significantly less tube metal volume compared to round ports. Therefore, only rectangular ports were evaluated in this study.

The specific port geometry for each tube thickness evaluated in this study was established to yield minimum tube side pressure drop by combining the requirements of internal pressure, allowable stress levels and geometric constraint dictated by extrusion capabilities. Tube side pressure drops were calculated using Moody friction factors for smooth tubes. The water pumping power included a combined pump and drive motor efficiency of 80%. The tube side heat transfer coefficients were calculated using the Colburn correlation for flow inside tubes with an appropriate adjustment for wall viscosity effects. The webs between the ports were treated as equivalent to plane rectangular fins and the fin efficiency was included in the overall resistance calculation.

The parametric performance evaluations performed herein were accomplished using an in-house computer program incorporating the effectiveness/NTU heat transfer and core pressure drop techniques of Kays and London described in Reference 8. The required product of surface area and overall heat transfer coefficient was determined as a function of the heat exchanger effectiveness and the fluid heat capacities for one or two pass cross-counter-flow using an in-house computer which solves the equations of Reference 9 for cross-flow with no mixing within passes and the equations of Reference 8 for the relation between single and multipass configurations.

Air side heat transfer coefficients and pressure drops were calculated using heat transfer and friction factors based on data obtained by Curtiss-Wright from the experimental evaluation of a large number of integral fin-tube geometries of the type used in this study and covering the full range of variables investigated. Using this data, Curtiss-Wright has developed and incorporated into the in-house computer program, correlations for the effect of fin-tube geometry on the level of heat transfer and pressure drop performance factors. The efficiency of the air-side fins were calculated using the relationships for plant rectangular cross-section fins and were included in the overall thermal resistance. The air side pressure loss was calculated using Equation 26a of Reference 8. Thermal conductivity of the aluminum alloy used for the fin tube was 111.3 Btu/(hr-ft^2 - °F/ft).

The range of fin densities in this study were selected from results of References 1 and 2 and were varied from 8 to 14 fins per inch. Similarly, for this study, the fin height was varied from 0.6 to 0.9 inches, the fin thickness was varied from .008 to .020 inches, and the tube overall thickness (blockage) was varied, as required, to satisfy water flow cooling requirements and pumping power conservation. In general, this covered a range of 0.40 to 1.0 inches. These parametric evaluations are described below in Section 4.4 and results obtained are provided in Section 5.0 of this report.

4.4 Cooling Module Parametric Cost Analyses

In order to perform the parametric design evaluations and cost analyses provided herein, a cooling module cost was established in Reference 2 based on the preliminary design layout module shown herein as Figure 5-1. This design layout was used to estimate a fabrication and assembly cost assuming that fabrication was initiated in 1977 and completed in two years. Labor and material cost estimates were made for each component of this cooling module, assuming all fabrication was performed in a fully equipped facility and using average labor rates and markup associated with typical heat exchanger manufacturers. No tooling, facility or hard fixtures cost amortizations were included in this analysis.

The above cost estimates were used to establish cost differentials for various geometric variations such as number and size of fin tubes, number and size of tube joints, finned depth, fin height, fin thickness and fin density. In addition, the cost estimates established in Reference 2 for the fan, motor and mechanical drive assembly were used for the cooling module parametric performance and sizing evaluation described below. It should be noted that these preliminary system cost estimates were used only to establish a "Selected Design" of a cooling module as described in Section 5.0. This selected cooling module design, cost and performance were then used by UE&C to establish a preliminary design and cost estimate of a complete dry cooling system as described in Sections 6.0 and 7.0. The evaluation of this dry cooling system, and the comparison with a conventional dry cooling system, is given in Section 8.0 of this report. After the preliminary design of the entire cooling system was completed, and all component costs were established, a reoptimization was performed to determine the potential for further cost savings. These results are reported in Sections 5.3 and 5.5 of this report.

4.5 Cooling Module Parametric Design and Performance Evaluations

Parametric analyses of the effect of the cooling module geometry and air range on the performance of the cooling modules were directed to determining the optimum configuration for the dry cooling towers. These evaluations were performed using the requirements, assumptions and the results described above. In addition, the following procedures were used in these parametric evaluations.

Middletown site conditions with fixed ITD, water range, air inlet temperature and heat load were used for all parametric evaluations leading to the design selections. Thus, selecting values for the air range establishes the heat exchange effectiveness, the total airflow required to extract the specified heat load and the required product of surface area and overall heat transfer coefficient. For fixed values of the cooling module geometric parameters, such as tube overall thickness, fins per inch, fin thickness, fin height and module face area, an in-house computer program was then used to establish the total number of cooling modules, the depth of the modules, and the fan and pump horsepowers for various or fixed values of airflow per module.

Using these assumptions and procedures, the optimum tube thickness and air range for fixed values of fins per inch and fin height were established using the following techniques. The in-house computer program was used to establish the level of the performance parameter for three values of the air range for each of three selected tube thicknesses. For each tube thickness, a quadratic curve was established for performance versus air range and differentiated to establish the location of the air range corresponding to the minimum value of the performance parameter. A quadratic curve was then established to these minimum performance values versus tube thickness to establish the location of the optimum tube thickness. The in-house computer program was provided with the capability of performing these calculations to yield either minimum power or minimum cost using decreasing increments for air range and tube thickness so that the final optimized values were not influenced significantly by the use of the quadratic curve fits.

Since these computer optimizations can only be conveniently done with all continuous functions, the theoretical optimum designs thus established are permitted to have non-integer values of such things as the number of tubes per module, the number of rows of fins per tube, the number of internal ports per tube and the total number of modules in the dry cooling tower system. In general, therefore, the selected design will be the practical design which comes closest to the theoretical optimum and will not necessarily achieve the theoretical minimum possible power or cost.

4.5.1 Mechanical Draft Wet/Dry Cooling System

Each of the above parametric design evaluations were performed at a constant value of fan airflow. Through the use of a fan exit stack diffuser, a recovery of 70% was assumed. Figure 4-1 shows a visual representation of the mathematical procedure for the optimization of the air range and tube thickness in terms of cost differentials for one set of independent variables of airflow, fins per inch and fin height. Repeating this procedure for other selected combinations of fins per inch and fin heights result in data such as presented on Figure 4-2 from which the combination of these parameters can be established to yield the minimum value of the optimization parameter of interest, which in this case is evaluated cost.

4.5.2 Natural Draft Dry Cooling System

The procedure for the natural draft dry tower studies are similar to the induced draft except that the airflow and pressure drop of the cooling system must be matched to the flow capability and draft of the tower. The tower discharge velocity was established by UE&C at 17 feet per second and the tower pressure loss at 37% of the discharge velocity head. In addition, the entire discharge velocity from both the tower and the cooling modules was assumed to be lost. The effective tower height for the draft calculations was established by UE&C as the overall tower height minus one-half of the cooling module height. The base diameter was established to accommodate the required number of cooling modules around the perimeter, and the upper diameter is sized to pass the total airflow required to extract the specified heat load.

For a given tower height and module geometry, the airflow and, therefore, the air range are established by iterating until the cooling system pressure drop and tower draft are the same. No optimization of the air range is necessary as for the induced draft system where different heads are available at the same airflow. The optimum fin-tube is based on minimum total evaluated cost in the same manner as for the induced draft system.

4.6 Cost Data for Materials and Equipment

The capital cost estimates for all of the cooling tower systems evaluated in this study were based on price levels effective in July, 1977. This cost date was chosen to facilitate cost comparisons with data developed in Reference 2 for the conventional and Curtiss-Wright mechanical draft dry tower systems. The costs for equipment items were obtained previously or currently by UE&C and adjusted to the cost date. For the items which can be estimated on the basis of bulk material (piping and its supports, tower structures, basin and foundations, etc.), the quantities of the bulk material were first determined from the designs and then costed out for the material and labor needed to install these items. The unit costs of materials were taken from UE&C cost data files. The costs of material and equipment were escalated or de-escalated at the rate of 6% annually to July, 1977.

4.7 Cost of Labor

The craft labor rates for the installation of equipment and construction of basins, foundations, structure supports, etc. were estimated using recent productivity experience and various craft labor rates compiled by UE&C for power and chemical processing plants. The labor rates used are composite labor rates. These rates were escalated or de-escalated at the rate of 8% annually to July, 1977.

4.8 Detailed Capital Cost Estimates

The following items were not included in the capital cost estimates: (1) escalation and interest costs during constructions, (2) construction management fees, (3) contingency charges, (4) freight charges, and (5) sales and local taxes.

The detailed capital cost estimates of both the conventional and Curtiss-Wright mechanical draft wet/dry and natural draft dry cooling systems at Middletown, U.S.A. and San Juan, New Mexico are given in Sections 6.0 and 7.0. These cost estimates are organized and presented in accordance with the UE&C uniform system of accounts for steam electric power plants, (Reference 6). The items included in the accounts are explained in Table 4-5.

4.9 Economic Penalty Evaluation

For the analysis described in this study, these economic penalties include the costs incurred to account for: (1) the loss of plant performance relative to the rated capacity (base output) of the power plant (capacity and energy) at elevated ambient temperatures; (2) the power and energy required to operate the cooling system; and (3) the cooling system maintenance requirements.

These penalties are called: (1) capacity penalty, (2) replacement energy penalty, (3) circulating water pumping power penalty, (4) circulating water pumping energy penalty, (5) cooling tower fan power penalty, (6) cooling tower fan energy penalty, and (7) cooling system maintenance penalty.

The equations used for evaluation of the first six penalty costs are as follows:

Capacity Penalty (P_1):

$$P_1 = K \cdot afcr \cdot (\Delta kW)_{max} \tag{1}$$

Replacement Energy Penalty (P_2):

$$P_2 = cap \int_0^{8760} [OAM + F \cdot HR\ (T)]\ \Delta kW(T)\ dt \tag{2}$$

Cooling System Auxiliary (fan or pumping) Power Penalty (P_3):

$$P_3 = K \cdot afcr \cdot (HP)_{aux} \tag{3}$$

Cooling System Auxiliary (fan or pumping) Energy Penalty (P_4):

$$P_4 = cap \int_0^{8760} [OAM + F \cdot HR(T)]\ HP(T)\ dt \tag{4}$$

where:

afcr = annual fixed charge rate, %/100.

cap = average capacity factor of the plant, %/100.

F = fuel cost for the generating unit used to make up the loss of energy, \$/MBtu (\$/GJ).

$(HP)_{aux}$ = cooling system auxiliary power requirement at T_{max}, kW.

HP(T) = cooling system auxiliary power requirement at ambient temperature T, kW.

HR(T) = heat rate as a function of ambient temperature for the generating unit used to make up the loss of energy, Btu/kWh (kJ/kWh).

K = capacity penalty charge rate, \$/kW.

$(\Delta kW)_{max}$ = maximum loss of capacity relative to the plant base output, kW.

$\Delta kW(T)$ = loss of capacity relative to the plant base output at ambient temperature T, kW.

OAM = operation and maintenance cost for the generating unit used, \$/kWh.

T = ambient temperature (T is a function of time), °F (°C).

T_{max} = peak ambient temperature, °F (°C).

t = time, hr.

The capacity penalty, P_1, and auxiliary power penalty, P_3, Equations (1) and (3) are first cost penalties. They represent the capital expenditure of generating equipment needed to supply the extra power.

The replacement energy penalty, P_2, and the cooling system auxiliary energy, P_4, (Equations (2) and (4)) are the energy cost penalties which will accrue over the lifetime of the plant. They are evaluated by capitalizing the respective annual energy costs charged to the cooling system. These annual energy costs are evaluated by integrating the energy costs during an annual temperature cycle as shown in Figures 4-3 and 4-4 for Middletown, U.S.A. and San Juan, New Mexico, respectively.

For this study, the economic factors adjusted from data in Reference 3 and used in the economic penalty evaluation are given in Table 4-6. The factors for the capacity (power) and energy penalties were determined on the assumption that the capacity and energy replacement will come from a base load unit similar to the power plant under consideration. The plant has a rated gross output (base output) of 1094 MWe and its heat rate characteristics as function of turbine back pressure are shown in Figure 4-5. The cooling system maintenance penalty cost is evaluated as a percentage of the direct capital cost of the cooling system.

Table 4-1

CONVENTIONAL WET/DRY COOLING SYSTEM - DRY TOWER PERFORMANCE

MIDDLETOWN, U.S.A.

Percentage Mke-up Requirement to All Wet = 10%

Ambient	Ambient Temperatures DB, °F	WB, °F	Annual Percent of Time	Dry Tower Cold Water Temperature, °F	Dry Tower Range, °F	Dry Tower ITD, °F
1	99.0	75.0	0.0007	115.22	9.54	25.76
2	94.0	74.0	0.0046	113.37	11.40	30.77
3	89.0	69.0	0.0091	111.55	13.22	35.77
4	82.0	65.0	0.0331	108.96	15.80	42.76
5	76.0	62.0	0.0647	106.74	18.02	48.76
6	69.0	59.0	0.1100	104.15	20.61	55.76
7	62.0	55.0	0.1223	101.57	23.20	62.77
8	55.0	49.0	0.1086	99.00	25.77	69.77
9	48.0	43.0	0.1035	92.34	26.07	70.41
10	41.0	37.0	0.1229	84.99	25.93	69.92
11	34.0	29.0	0.1546	77.78	25.86	69.64
12	27.0	22.0	0.0869	70.78	25.83	69.61
13	20.0	15.0	0.0378	63.61	25.82	69.43
14	13.0	8.0	0.0412	56.61	25.82	69.43

Performance at the Maximum Ambient Temperature:

Dry Bulb, °F - 99

Wet Bulb, °F - 75

Turbine Back Pressure, in HgA - 4.5

Flow Rate, GPM - 549,590

Total Cooling Range, °F - 26.25

Dry Tower ITD, °F - 25.76

Dry Tower Cooling Range, °F - 9.34

Table 4-2

CONVENTIONAL WET/DRY COOLING SYSTEM - DRY TOWER PERFORMANCE

SAN JUAN, NEW MEXICO

Percentage Make-up Requirement to All Wet = 10%

Ambient	Ambient Temperatures DB, °F	WB, °F	Annual Percent of Time	Dry Tower Cold Water Temperature, °F	Dry Tower Range, °F	Dry Tower ITD, °F
1	102.0	63.0	0.0029	118.47	10.26	26.73
2	97.9	62.0	0.0171	116.53	12.19	31.72
3	92.0	59.0	0.0399	114.62	14.10	36.72
4	87.0	57.0	0.0571	112.70	16.02	41.72
5	80.0	54.5	0.0856	110.00	18.72	48.72
6	73.0	52.5	0.1056	107.30	21.42	55.72
7	66.0	49.0	0.1084	104.61	24.12	62.73
8	59.0	44.5	0.0999	97.43	24.11	62.54
9	52.0	40.5	0.1170	90.03	23.95	61.98
10	45.0	36.5	0.1027	82.75	23.85	61.60
11	38.0	32.5	0.1113	75.58	23.81	61.39
12	31.0	26.5	0.0913	68.58	23.80	61.38
13	24.0	20.0	0.0514	61.58	23.79	61.37
14	17.0	13.5	0.0098	54.58	23.79	61.37

Performance at the Maximum Ambient Temperature:

Dry Bulb, °F - 102

Wet Bulb, °F - 63

Turbine Back Pressure, in HgA - 5.0

Flow Rate, GPM - 596,320

Total Cooling Range, °F - 24.82

Dry Tower ITD, °F - 26.73

Dry Tower Cooling Range, °F - 10.26

Table 4-3

CONVENTIONAL NATURAL DRAFT DRY COOLING SYSTEM

MIDDLETOWN, U.S.A.

Ambient	Ambient Temperatures DB, °F	WB, °F	Annual Percent of Time	Cold Water Temperature, °F	Range, °F	ITD, °F
1	99.0	75.0	0.0007	118.00	11.00	30.00
2	94.0	74.0	0.0046	112.82	10.92	29.74
3	89.0	69.0	0.0091	107.62	10.86	29.48
4	82.0	65.0	0.0331	100.43	10.81	29.24
5	76.0	62.0	0.0647	94.36	10.78	29.14
6	69.0	59.0	0.1100	87.19	10.76	28.95
7	62.0	55.0	0.1223	80.07	10.76	28.83
8	55.0	49.0	0.1086	72.97	10.76	28.83
9	48.0	43.0	0.1035	65.90	10.76	28.66
10*	41.0	37.0	0.1229	58.90	10.76	28.66
11	34.0	29.0	0.1546	58.90	10.76	35.66
12	27.0	22.0	0.0869	58.90	10.76	42.66
13	20.0	15.0	0.0378	58.90	10.76	49.66
14	13.0	8.0	0.0412	58.90	10.76	56.66

Design:

DB = 99.0°F

CWT = 75.0°F

RA = 11.00°F

Flow Rate = 1,319,174 GPM

ITD = 30.00°F

Tower Size (Diameter x Height) (461' x 512')

No. of Towers = 10

Table 4-4

CONVENTIONAL NATURAL DRAFT DRY COOLING SYSTEM

SAN JUAN, NEW MEXICO

Ambient	Ambient Temperatures DB, °F	WB °F	Annual Percent of Time	Cold Water Temperature, °F	Range, °F	ITD, °F
1	102.0	63.0	0.0029	118.00	11.00	27.00
2	97.0	62.0	0.0171	112.85	10.93	26.78
3	92.0	59.0	0.0399	107.68	10.86	26.54
4	87.0	57.0	0.0571	102.57	10.82	26.39
5	80.0	54.5	0.0856	95.44	10.78	26.22
6	73.0	52.5	0.1056	88.35	10.76	26.11
7	66.0	49.0	0.1084	81.24	10.76	26.00
8	59.0	44.5	0.0999	74.16	10.76	25.92
9	52.0	40.5	0.1170	67.11	10.76	25.87
10*	45.0	36.5	0.1027	60.11	10.76	25.87
11	38.0	32.5	0.1113	60.11	10.76	32.87
12	31.0	26.5	0.0913	60.11	10.76	39.87
13	24.0	20.0	0.0514	60.11	10.76	46.87
14	17.0	13.5	0.0098	60.11	10.76	53.87

Design:

DB = 102.0°F

WB = 63.0°F

CWT = 118.0°F

RA = 11.0°F

Flow Rate = 1,319,174 GPM

ITD = 27.00°F

Tower Size (Diameter x Height) (474' x 535')

No. of Towers = 12

* Ambients 10 through 14 - Reduced Air Flow Rate

Table 4-5

DESCRIPTION OF CODES OF ACCOUNTS FOR CAPITAL COST ELEMENTS

Account Number	Description
233.1	Condensers
24.	Electrical Work: This includes: (1) Station Service - switchgear and controls for circulating water pumps, intake louvers, solenoid operated 3-way valves, freeze protection pumps, and cooling tower fans. (2) Station Service and Start-up Transformers - transformers and foundations. (3) Cable Trays and Supports. (4) Conduit. (5) Station Service Power Wiring.
261.2	Circulating Water Pumphouse: Includes concrete work, excavation and backfill, temporary sheeting, and miscellaneous iron.
262.12	Circulating Water System
262.121	Circulating Water Pumps and Motors
262.122	Freeze Protection Pumps and Motors
262.125	Concrete Pipe: This includes all piping from the condensers to the cooling towers. Placement and connection costs are also included.
262.126	Valves: This includes all valves required for the circulating water system. Installation costs are included in 262.125.
262.1274	Pipe Trenching: This includes all excavation (earth and rock), compacted sandbeds, and backfill required for installing the circulating water lines.
262.12744	Substructure Concrete: This includes formwork, concrete and reinforcing steel required for the construction of the circulating water piping thrust blocks.
262.13	Cooling Towers
262.131	Excavation Work: This includes all earth and rock excavation and backfill required for the cooling towers and storage tanks.
262.133	Substructure Work: This includes the material and labor required for the tower foundations and storage tanks. Items included consist of formwork, reinforcing steel, concrete, embedded steel, floor gratings, and handrails.

Table 4-5 (Cont'd)

Account Number	Description
262.1341	Structural Steel: This includes all fabricated steel required for the tower support structure.
262.1342	Heat Exchangers: Included are the tubes, heads, spacers and frame.
262.1343	Fan System: This includes the fan, motor, fan stack and gearbox.
262.1344	Intake Louvers: This includes the louvers and associated hardware for electric actuation. Electric cable and instrumentation and control required for remote operation are included in account 24.
262.1345	Piping - Carbon Steel: This includes all distribution piping internal to the towers to and from individual heat exchangers.
262.1346	Valves: This includes all valving for isolation of individual heat exchangers. In addition, solenoid operated 3-way valves are included for the filling and dumping of the water in the tower.
262.13471	Hangers and Supports: This includes all pipe supports as required in the cooling towers.
262.1348	Shell Cost: Support columns and hyperbolic shell for natural draft cooling tower.
262.135	Instrumentation and Control: This includes instruments, control panels, and installation of the system.
262.139	Wet Helper Towers (1) Cooling tower basins and foundations, excavation and backfill, forms, reinforcing steel, concrete, concrete finish, anchor bolts, miscellaneous iron, and dewatering. (2) Cooling towers.
262.151	Make-up Water System: This includes: (1) Intake structures including excavation, concrete work, reinforcing steel, miscellaneous iron, cofferdam. (2) Water intake facilities, including travelling screens, trash racks, trash rakes, stop logs, pumps, and drives. (3) Intake lines, including connections from pump discharges to cooling system, steel pipeline, excavation and backfill, coating and wrapping pipe, welding. (4) Water treatment facilities including clarifier-softeners and chemical feeders.

Table 4-5 (Cont'd)

Account Number	Description
262.152	Blowdown System: This includes:
	(1) Discharge structures, including excavation, concrete work, reinforcing steel, miscellaneous iron, coffer cofferdam.
	(2) Discharge lines, including connections from pump discharges to cooling system, steel pipeline, excavation and backfill, coating and wrapping pipe, welding.

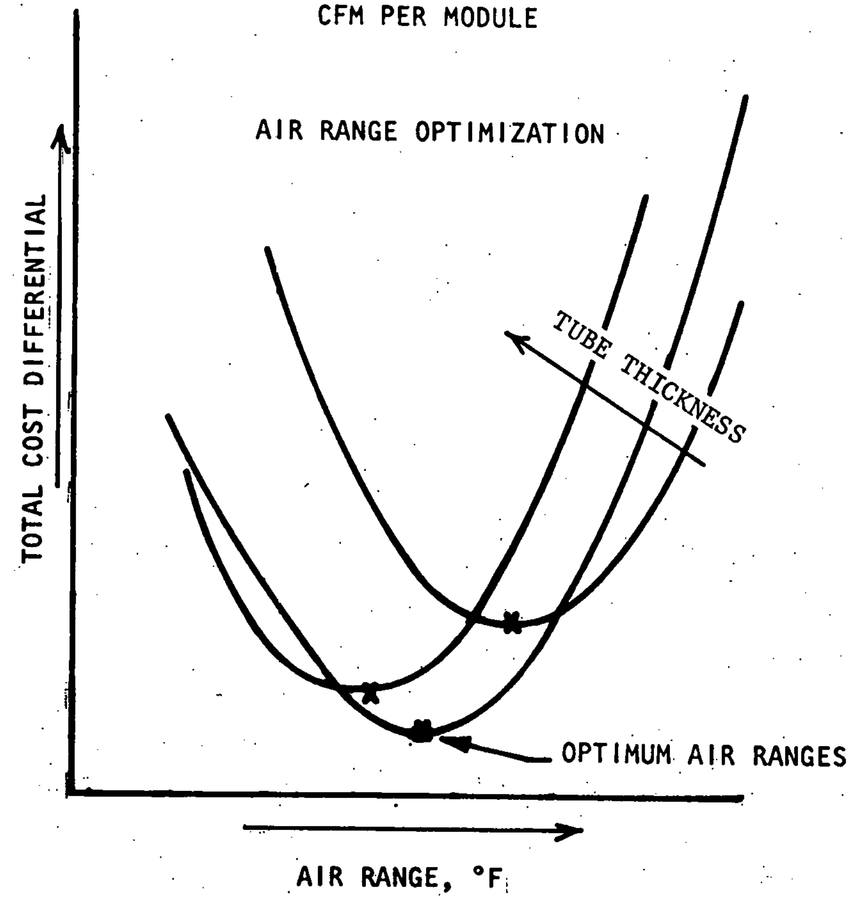
Table 4-6

BASIC ECONOMIC FACTORS

Plant Start-up Date	1977
Average Plant Capacity Factor	0.75
Annual Fixed Charge Rate	18%
Plant Life	40 Years
Capacity Penalty Charge Rate (Incremental Base Load Plant Cost)	\$360/kW
Fuel Cost (For Base Load Plant)	85¢/MBtu
Operation and Maintenance Cost (For Incremental Base Load Plant)	0.443 mills/kWhr
Escalation on Cooling System Equipment and Material . .	6% Per Year
Escalation on Cooling System Labor	8% Per Year

TYPICAL COOLING MODULE AIR RANGE AND TUBE SIZE OPTIMIZATION

DESIGN CONSTANTS:
FIN HEIGHT
FINS PER INCH
CFM PER MODULE



SITE CONSTANTS:
INLET AIR TEMPERATURE
WATER RANGE
I.T.D.
HEAT DUTY

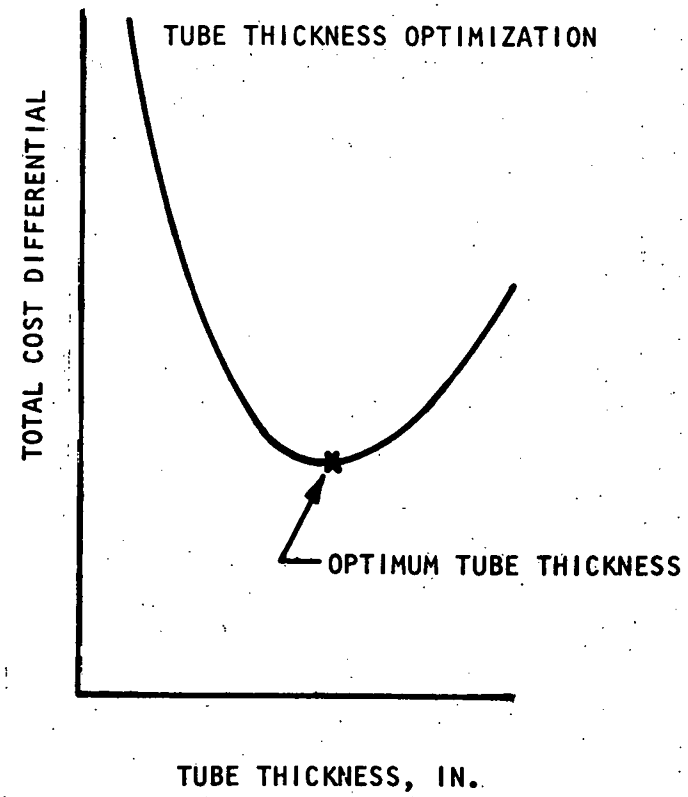


Figure 4-1

COOLING MODULE PARAMETRIC STUDY

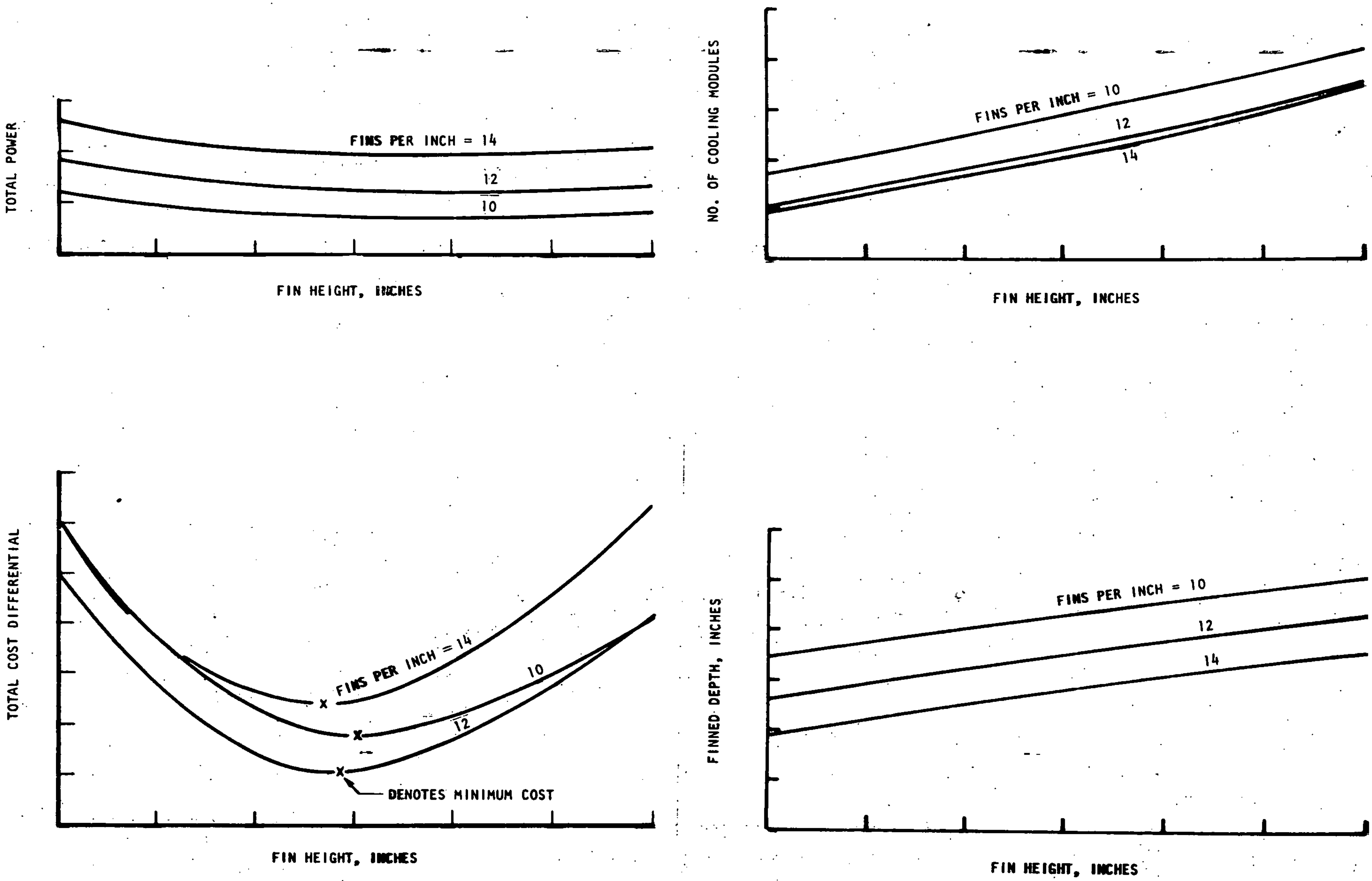


Figure 4-2

TEMPERATURE DURATION CURVE: MIDDLETOWN, U.S.A.

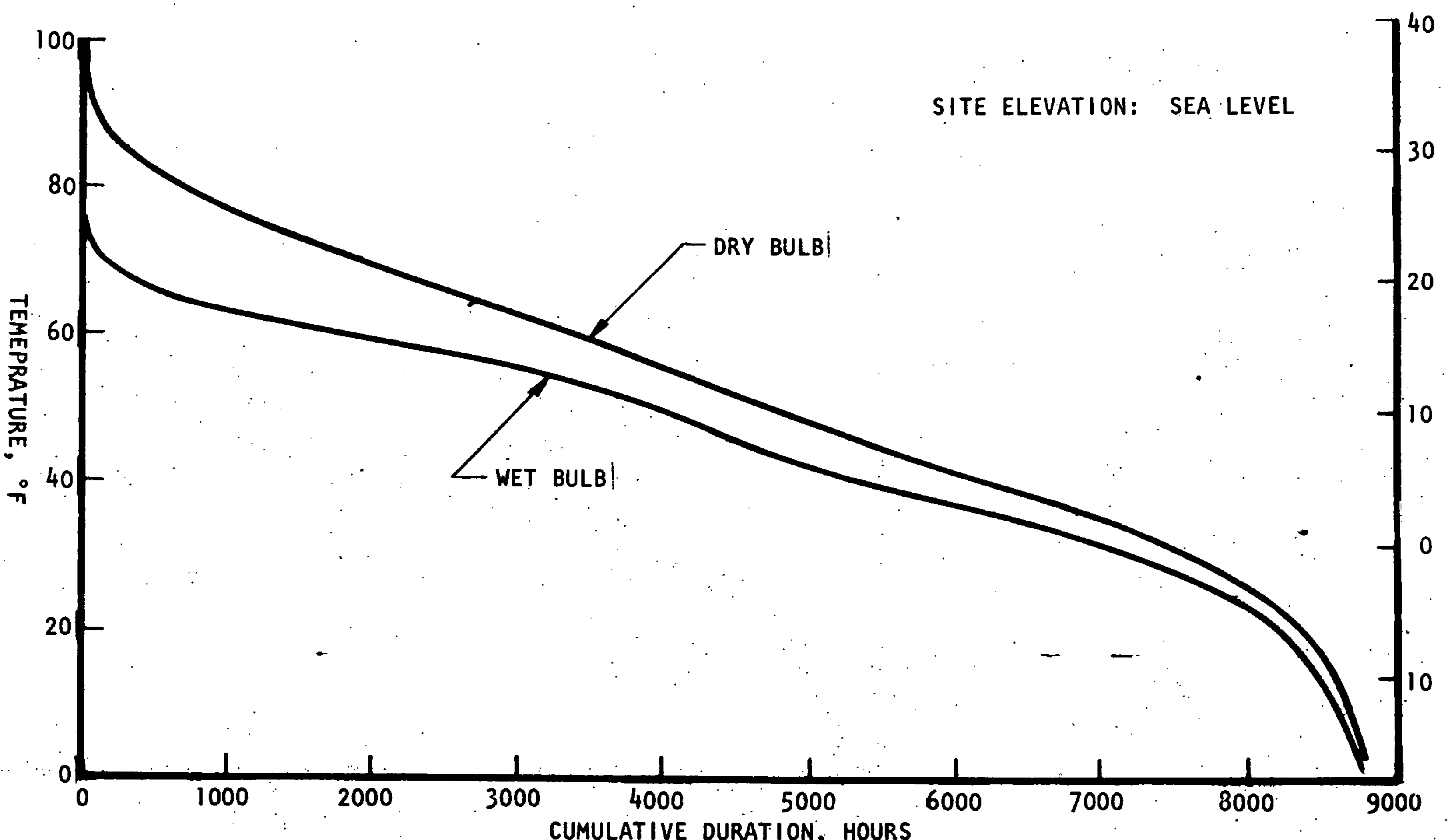


Figure 4-3

TEMPERATURE DURATION CURVE: SAN JUAN, NEW MEXICO

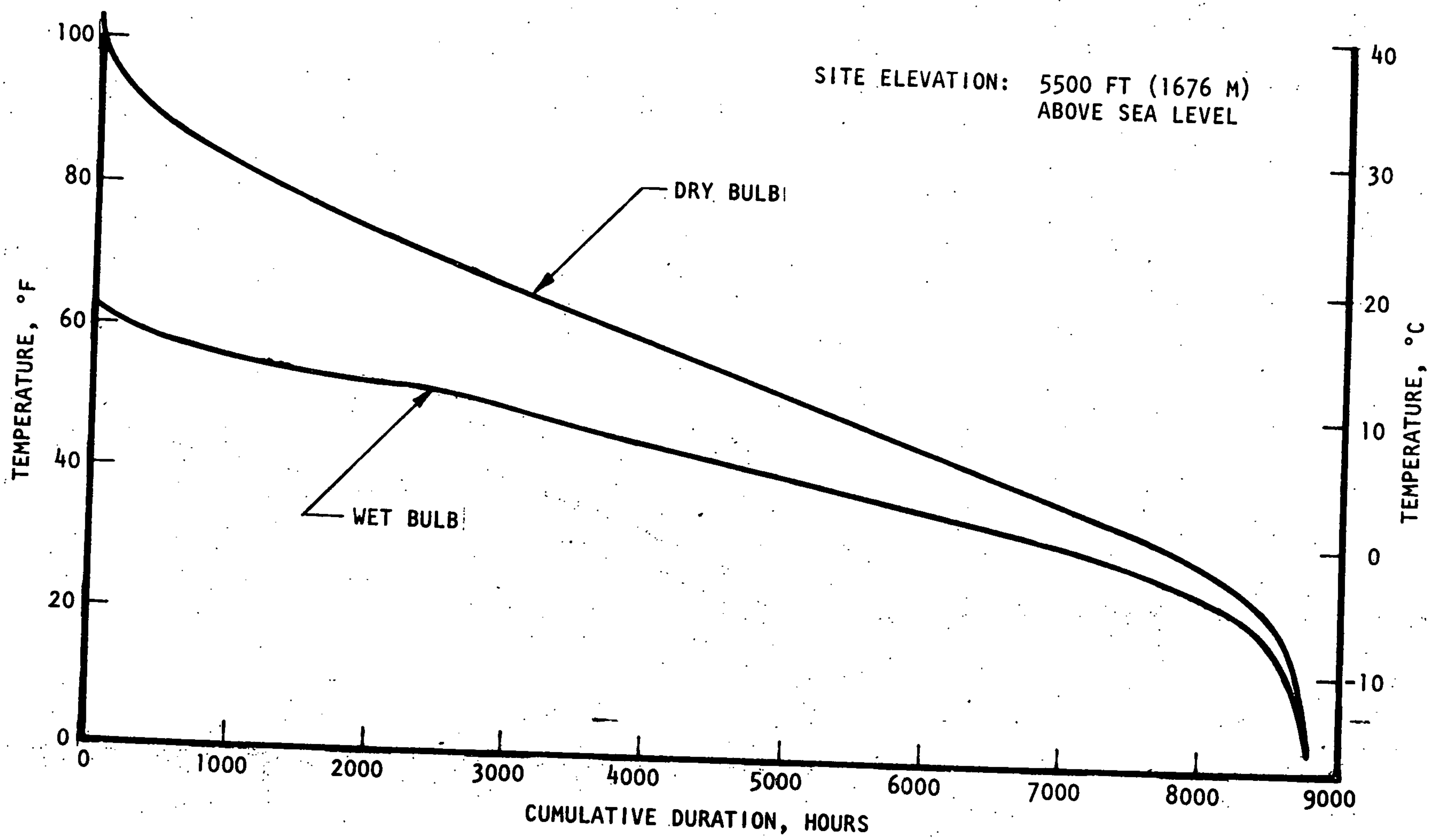


Figure 4-4

HEAT RATE CORRECTION CURVE FOR A PLANT
WITH A CONVENTIONAL TURBINE

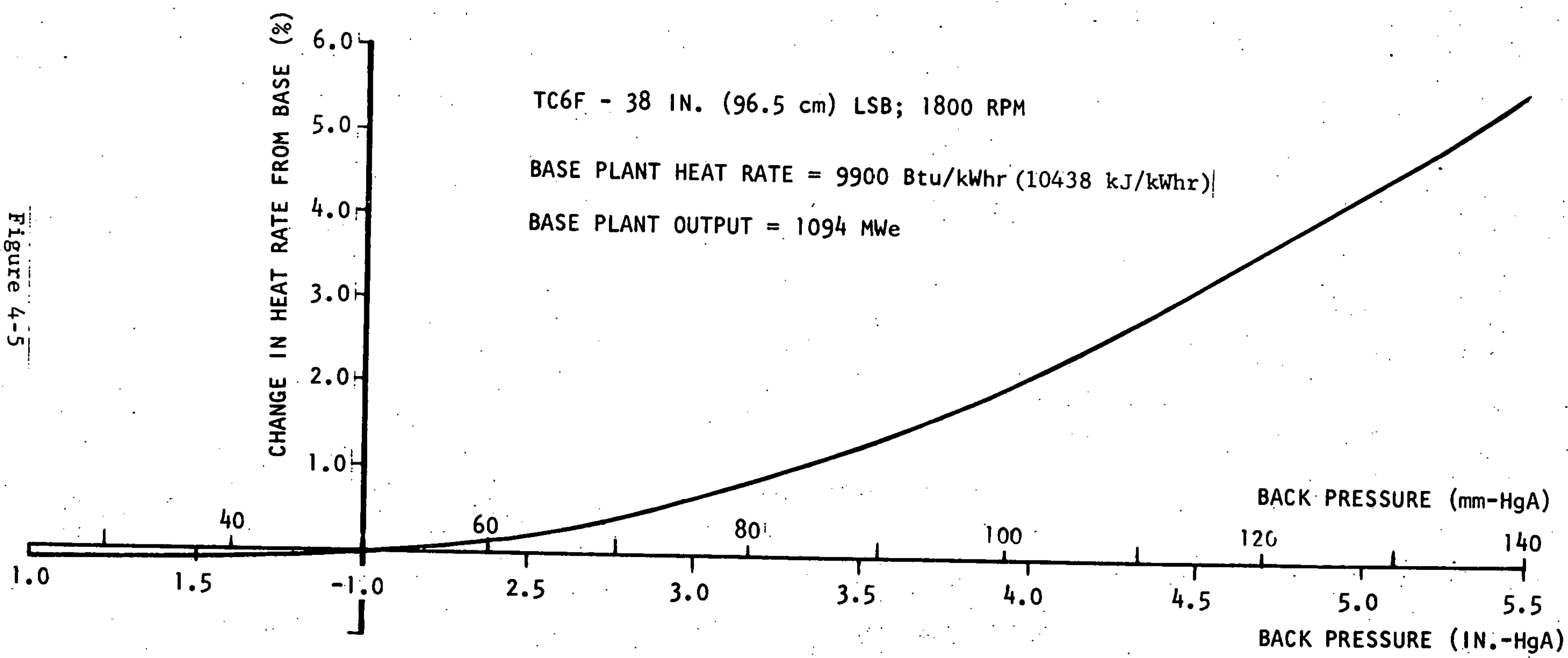


Figure 4-5

5.0 COOLING MODULE DESIGN AND SELECTION

5.1 Cooling Module Description

A dry cooling module design using the C-W Integral Fin-tubes was established in Reference 2 and its design layout is reproduced herein as Figure 5-1. This cooling module has a length of 80 feet, a width of 12 feet and a depth of approximately 1 foot. A 2-pass water side geometry was selected for the mechanical draft wet/dry cooling module and a 1-pass geometry was selected for the natural draft dry cooling module. This selection best satisfies the horizontal module installation of the wet/dry system and the vertical module installation of the natural draft dry system. These two cooling module designs are completely similar, with the major difference being in the fin-tube geometry and provision for either one or two water passes. The 2-pass system is readily accomplished by the use of two multi-port tubes per tube row, and the use of a divider plate in the inlet manifold closure.

The outlet manifold closure then acts as a 180 degree return bend for the 2-pass design. In the 1-pass design, the separator plate is omitted, and the inlet and outlet water nozzles are located on separate manifold closures, i.e. at opposite ends of the cooling module.

In the 1-pass cooling module, only one multi-port integral fin tube is required for the total finned depth. This design has cost advantages compared to the 2-pass cooling module due to a reduced number of tubesheet slots, reduced amount of welding of tubes to tubesheets, reduced handling of fin-tubes, reduced numbers of tube support struts, and reduced complexity in filling and draining the tubes. Since the coolant path is 80 ft vs. 160 ft for the 2-pass system, the tube thickness was reduced for minimum total power consumption.

The two side air seals are essentially commercial steel channel sections and along with the tube cross-members, form the main support structure of the module. These side channels are made in two sections which are joined together in a slip joint at one end. The slip joints are necessary to accommodate the thermal expansion of the tubes. The ends of the channel sections are bolted to the closure heads at each end of the cooling module. The tube support cross-members are bolted to the flanges on the side seal members, and besides being structural, act to reduce the span of the tubes to acceptable limits from a tube vibration point of view. The side seals and closure heads are made of steel.

A comparison of the cooling module geometries selected for the wet/dry and natural draft dry cooling systems, resulting from the design evaluations described below, is given in Table 5-1. For comparison, a description of the conventional cooling module geometries which was used in this study is also given in this table.

Table 5-1

DESCRIPTION OF SELECTED DRY COOLING MODULES

	Curtiss-Wright		Conventional	
Configuration	Mechanical Draft Dry/Wet	Natural Draft Dry	Mechanical Draft Wet/Dry	Natural Draft Dry
No. of Water Passes	1	2	2	1
Module Length, Ft	80	80	53	81
Module Width, Ft	12	12	10.5	10.3
No. of Fin-Tube Rows	78	60	48/49	44
Finned Depth, In.	6.7	4.5	8.6	8.6
No. of Tubes/Row	1	2	4	4
Fins Per Inch	11.5	11.5	10	10

5.2 Evaluation and Selection of Mechanical Draft Wet/Dry Cooling Modules

Using the analytical procedures and requirements delineated in Section 4.0, comprehensive parametric design evaluations were performed to establish the cooling module fin-tube geometry based on minimum cooling system costs. These preliminary costs included the cost of the cooling modules, the fan system and the fuel for providing the auxiliary power. They did not include the other capital and installation costs which were identified and established by UE&C for the cooling tower. Since these other costs are essentially constant or can be related to the required number of cooling modules, it was felt that this was a reasonable procedure for optimizing and selecting the cooling module fin-tube geometry. From results obtained in Reference 2, a 30 foot diameter fan was selected for these optimizations. The parametric evaluations included the optimum combination of fin height, fin density, tube thickness, fan flow, air range, and the number of cooling modules to yield minimum system cost.

The results of this parametric evaluation are shown in Figures 5-2 and 5-3. Results given in Figure 5-2 are presented in terms of percent cost difference based on an assumed total cooling system cost. This procedure was adopted so that the actual cooling system costs due to changes in the cooling module geometry would be more clearly delineated, and those constant costs associated with installation considerations would have a minimum impact on the cooling module design selection. Results provided in Figure 5-2 and 5-3 show that minimum cooling system costs occur at a module airflow of approximately 2.5 (10^6) PPH, a fin height of .67 inches and a fin density of 12.5 fins per inch.

Having thus established the minimum cost configuration based on this preliminary costing analysis, an evaluation of the fin-tube geometry selected for the previous 1-pass dry cooling system, from Reference 2, was conducted over the same range of airflows. These data are also shown on Figures 5-2 and 5-3 for ease of comparison to the optimized designs. Based on using three cooling towers for the wet/dry system, and four cooling modules per cell, the possible cooling tower design selections are denoted on Figure 5-2. It can be seen that 24 cells per tower is near optimum for the previously selected fin-tube geometry from Reference 2, and that 22 cells per tower could be achieved by selecting a new fin-tube geometry. However, the small savings in total system cost of approximately 1.2%, shown in Figure 5-2 did not warrant changing the cooling module fin-tube geometry for this initial selection. In addition, selecting the same geometry as the previous all dry cooling system from Reference 2, would allow a more direct and meaningful comparison of the differences in the type of cooling systems, rather than the cooling module design. Therefore, the 1-pass cooling module geometry established in Reference 2, and summarized in Table 5-1, was used for the detailed cooling system design and cost evaluation reported in Section 6.0 of this report.

5.3 Re-optimization Evaluation of Mechanical Draft Wet/Dry Cooling Modules

Using the selected cooling module design and performance data described above, UE&C performed a comprehensive conceptual design and cost analysis of the mechanical draft wet/dry cooling system as reported in Section 6.0 herein. This evaluation provided detailed capital cost for all components of this cooling system. Using this detail cost data, a reevaluation was performed to determine the potential for further system cost reduction by a re-optimization of the cooling module fin-tube geometry.

These re-optimization investigations covered a range of fin densities from 10 to 14 per inch, fin heights from .6 to .8 inches and fan diameters from 26 to 30 feet. They also included all other capital costs which were not used in the initial parametric evaluation and selection, and were considered to be a function of the number of modules required. Results from this part of this study are presented on Figure 5-4 in terms of percent cost differentials from the C-W selected design versus module airflow. These results show that the conventional cooling system is approximately 13.8% higher cost than the selected C-W system. It can also be seen that a potential for a further reduction of approximately 3% in the total evaluated cost of the C-W cooling system might be realized through the use of a 28 foot diameter fan in conjunction with a different fin-tube geometry selection. Figure 5-5 shows the variation in optimum fin density and fin height for the 28 foot diameter fan with the initially selected design values shown for comparison. The best values occur at 12.0 fins per inch and .65 inch fin height compared to 11.5 fins per inch and .69 fin height for the initial selected design. Although this is a small change in fin-tube geometry, and a small percentage change in total evaluated cost, it does represent a significant further reduction in actual costs of approximately $3 million dollars compared to the selected C-W design. For this study, however, a second iteration of the system design and costs was not justified.

5.4 Parametric Evaluation and Selection of Natural Draft Dry Cooling Modules

In the natural draft dry tower application, the basic cooling module is installed with the 80 foot dimension in a vertical orientation. For this reason, a 2-pass water system was felt to be more appropriate for the C-W selection in this application than a 1-pass system. The former system allows the water to enter and exit the cooling module at near ground level and thus eliminates the necessity for extensive manifolding at the upper end of the cooling modules, and does not require additional vertical feeder pipes.

In order to expedite the design and cost evaluation of the natural draft dry cooling system, the initial cooling module was selected as the 2-pass dry tower module from Reference 2, which incorporated fin-tubes with 10 fins per inch and 0.8 inch fin height. To minimize the effect of cooling tower configuration on the evaluated cost it was decided to select a system design using the initial C-W tube geometry which utilized tower shells which were as close to the conventional system as possible. Results of parametric evaluations pertaining to the effect of number of towers on the required tower configuration for a fixed tower height of 512 feet are shown on Figure 5-6. Since the natural draft dry cooling tower with conventional cooling system incorporated 10 towers of 512 feet height, this height dimension was chosen for this parametric sizing study. The values of upper and lower diameters of the conventional cooling system are shown for comparison.

Selecting seven towers with C-W dry cooling modules results in a tower size having approximately the same dimensions as the towers with conventional cooling modules. Since the tower cost is primarily a function of the tower base diameter and height, selecting a tower size of similar dimensions provides a direct way of comparing the total costs of the two cooling systems. This evaluation was performed by UE&C and is reported in Section 7.0 of this report. Similar results using approximately the same tower dimensions were also performed for the San Juan site, resulting in a selection of 10 towers with C-W cooling modules vs. 12 towers with conventional cooling modules. These results are also shown on Figure 5-6.

5.5 Re-Optimization Evaluations of Natural Draft Dry Cooling Modules

Using the cooling module and tower geometry established above, UE&C performed a comprehensive conceptual design and cost study as reported in Section 7.0. Using the detail cost data provided in this study, a parametric evaluation of the effect of the number of towers and tower height on the overall evaluated cost was undertaken using the above selected 2-pass cooling module geometry. The results of this evaluation are shown in terms of percent cost differentials versus tower height and number of towers on Figure 5-7. Here it can be seen that both the required base diameter and the cost are much more sensitive to the number of towers than to the tower height and that for a range of five to nine towers, the optimum height occurs between 500 and 550 feet. The selected preliminary design is shown for comparison and is seen to be at very nearly the optimum height for seven towers. Although use of five towers would result in a 1.7% reduction in the total evaluated cost, the base diameter is well over 600 feet and may be considered excessive. The selection of seven towers with a 512 foot tower height was, therefore, determined to represent a reasonable choice for further analysis of other fin-tube geometries since the particular cooling module fin-tube configuration would not be expected to significantly change the relationship between number of towers, tower height and total evaluated cost.

Using the costs established for the preliminary design selection as a base, an evaluation was made to determine the potential for reduced cost available through the use of fin-tube geometries which are optimized for this specific natural draft dry cooling module application. Total evaluated costs for various fin densities and fin heights with the optimum fin-tube thickness for each combination were established for seven 512 foot high cooling towers using the same 12' x 80' cooler modules and the Middletown site conditions.

The results of this evaluation are presented on Figure 5-8 for 8, 10 and 12 fins per inch with .6 to .9 fin heights. This range of parameters is seen to encompass the optimum value. The base cost for these data is the total evaluated cost of the C-W design selection and is so denoted on the curve as the base for comparison. It is apparent that the selection of 10 fins per inch with 0.8 fin height was nearly optimum for this application. The cost differences between the optimized fin-tube geometries and the selected design are the result of a reduced number of modules per tower and thus a reduced tower base diameter. The minimum total evaluated cost is less than 1% lower than the selected design. Although this is a low percentage value, it does represent a significant additional cost savings of approximately $2 million compared to the use of the selected C-W cooling system. For this study, however, this further detail design evaluation was not justified.

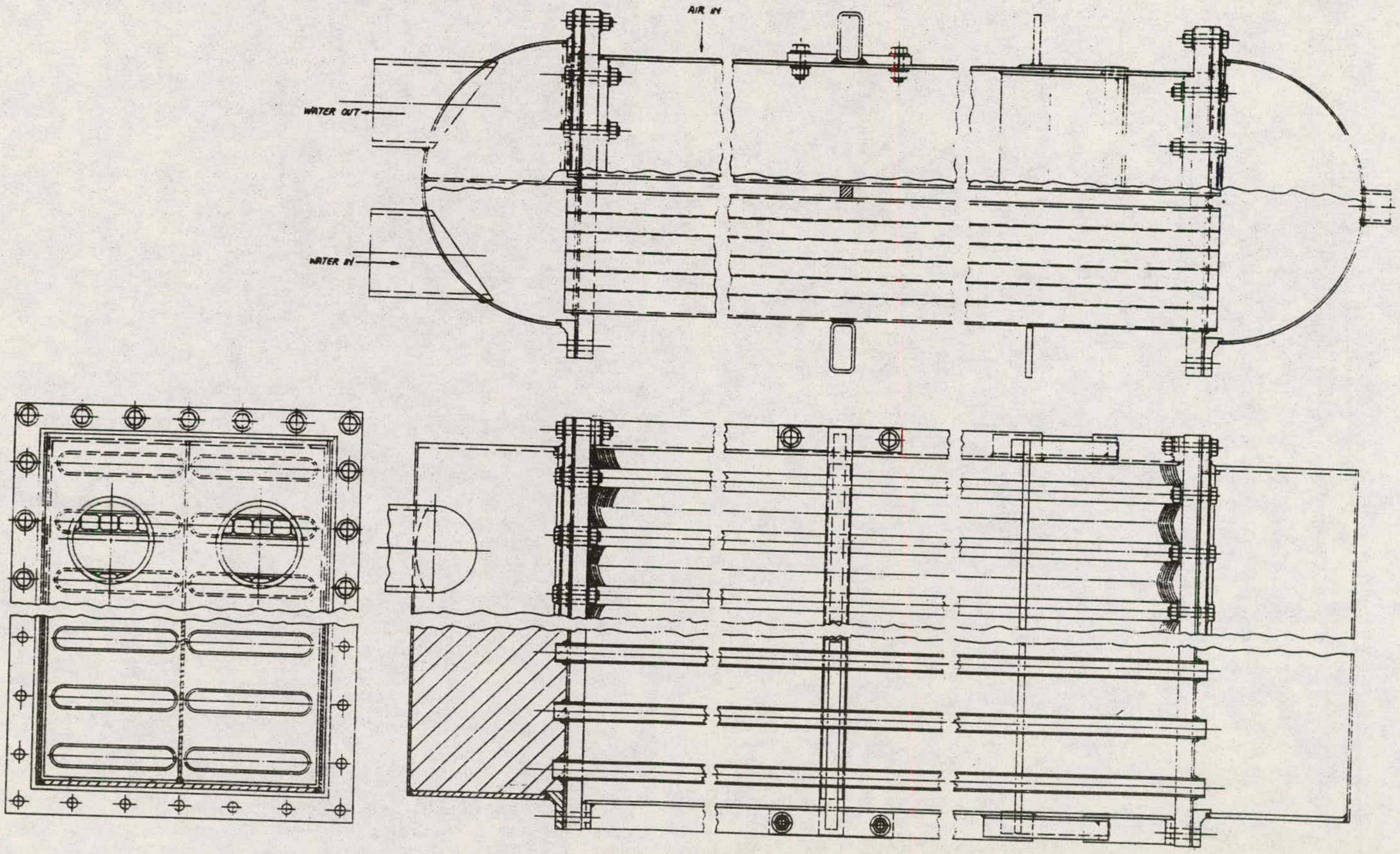


Figure 5-1 CONCEPTUAL DESIGN OF C-W COOLING MODULES

COOLING MODULE EVALUATION AND SELECTION
FOR MECHANICAL DRAFT WET/DRY COOLING SYSTEM

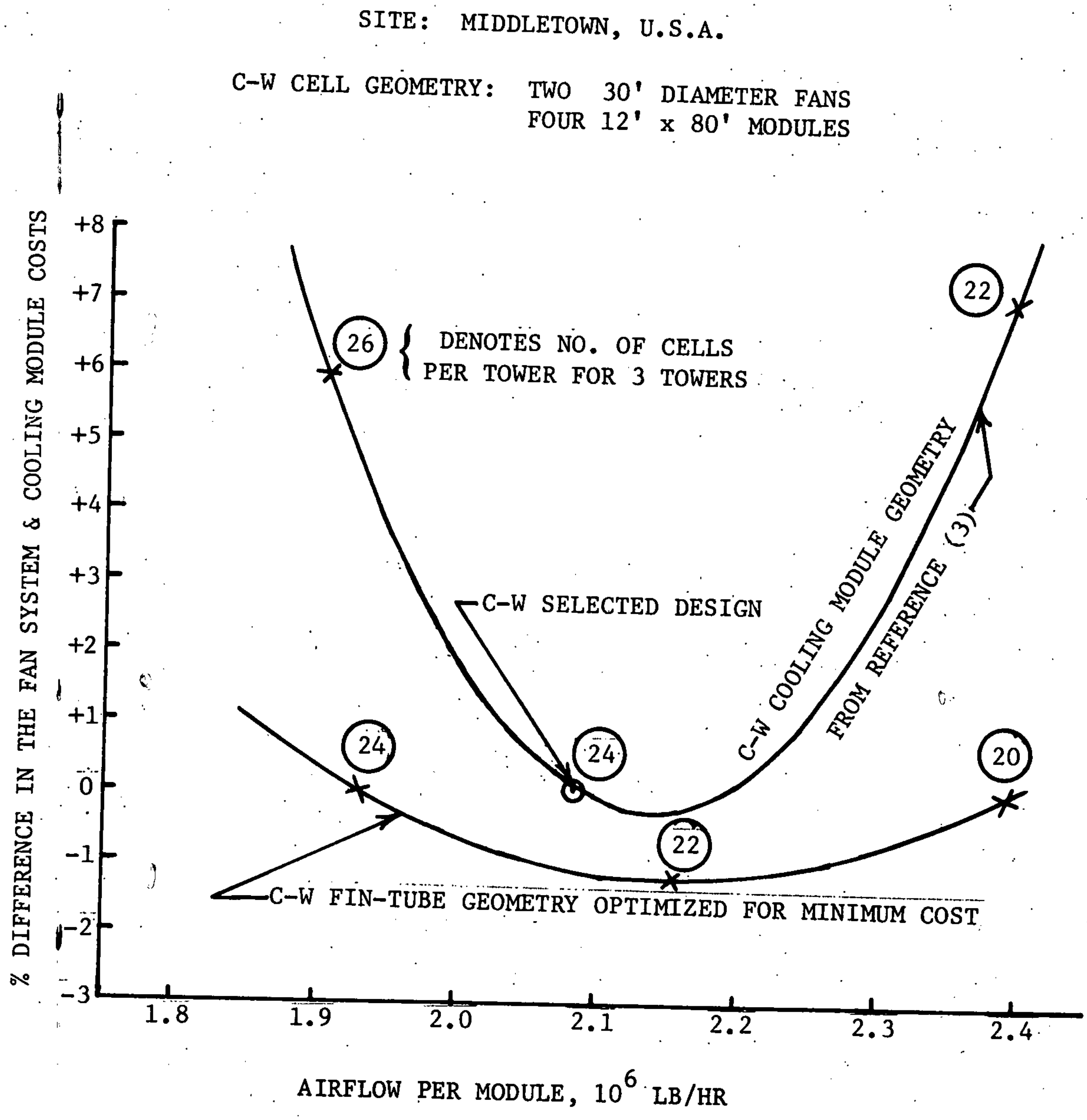


Figure 5-2

OPTIMIZED AND SELECTED INTEGRAL FIN-TUBE GEOMETRY
FOR MECHANICAL DRAFT WET/DRY COOLING SYSTEM

SITE: MIDDLETOWN, U.S.A.

C-W CELL GEOMETRY: TWO 30' DIAMETER FANS
FOUR 12' x 80' MODULES

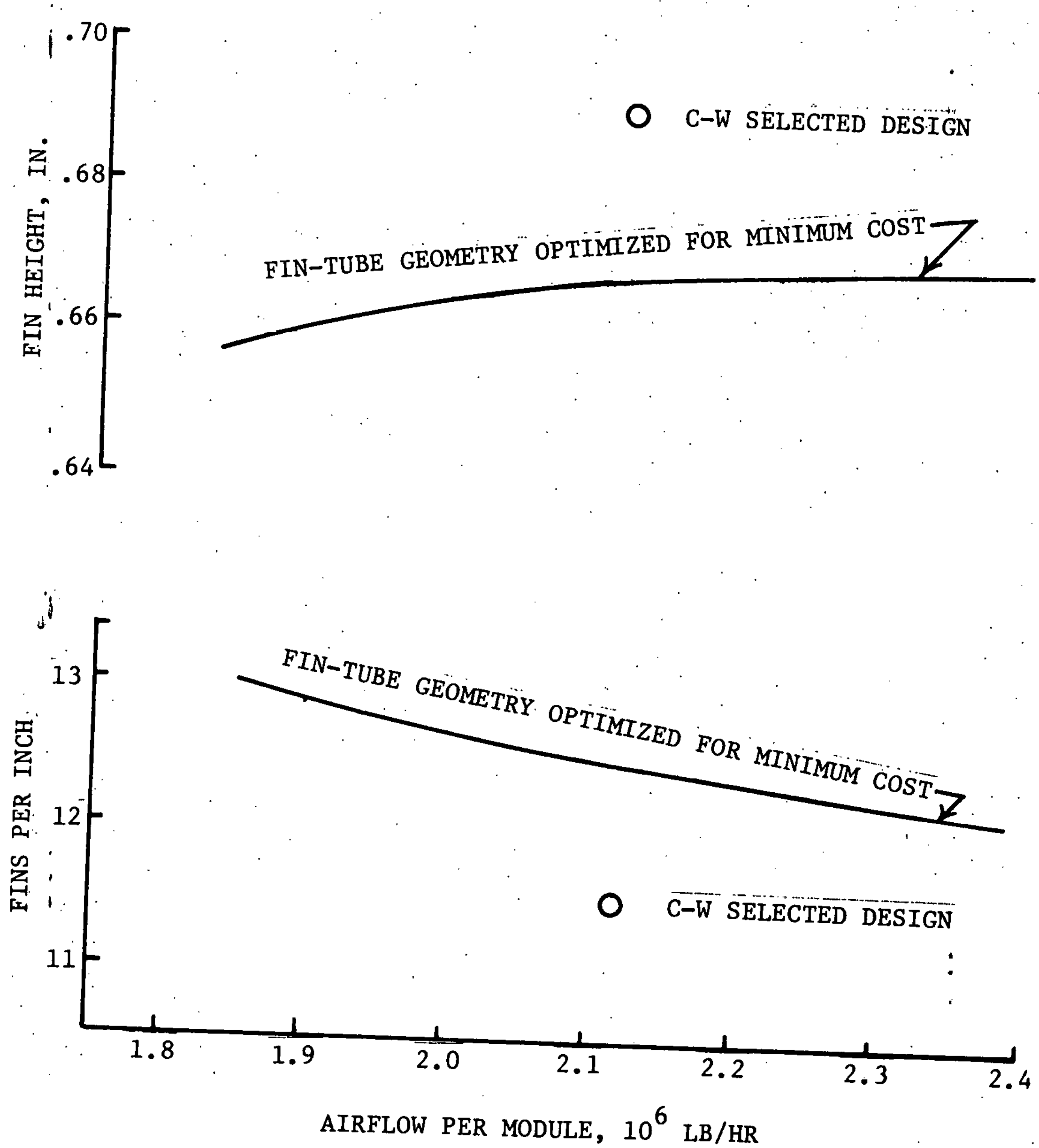


Figure 5-3

FINAL COOLING SYSTEM COST EVALUATIONS FOR
MECHANICAL DRAFT WET/DRY COOLING SYSTEM

SITE: MIDDLETOWN, U.S.A.

C-W CELL GEOMETRY: TWO FANS
FOUR 12' x 80' MODULES

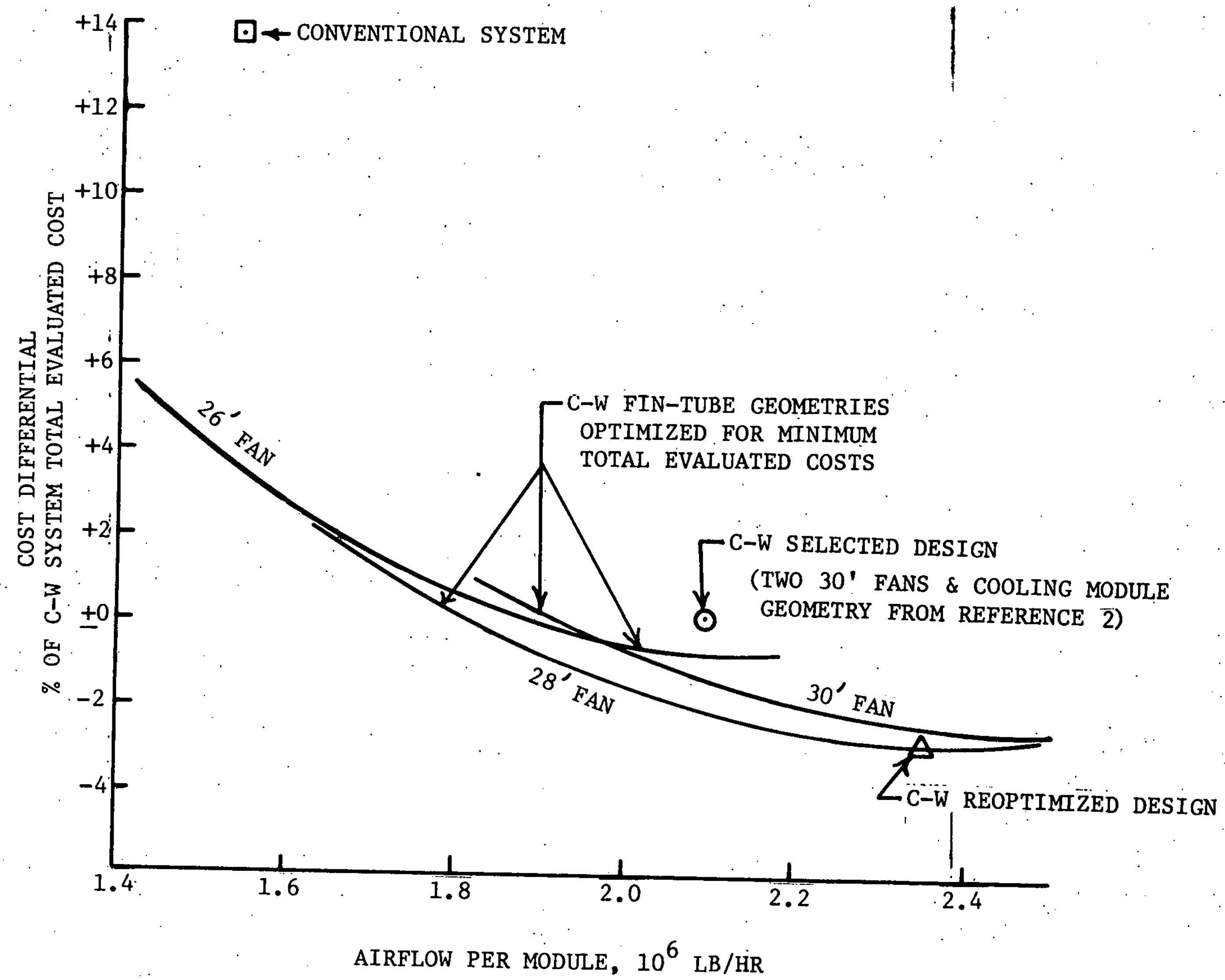


Figure 5-4

OPTIMIZED FIN-TUBE GEOMETRIES BASED
ON TOTAL EVALUATED COST FOR
MECHANICAL DRAFT WET/DRY COOLING MODULES

SITE: MIDDLETOWN, U.S.A.

C-W CELL GEOMETRY: TWO 28' DIAMETER FANS
FOUR 12' x 80' MODULES

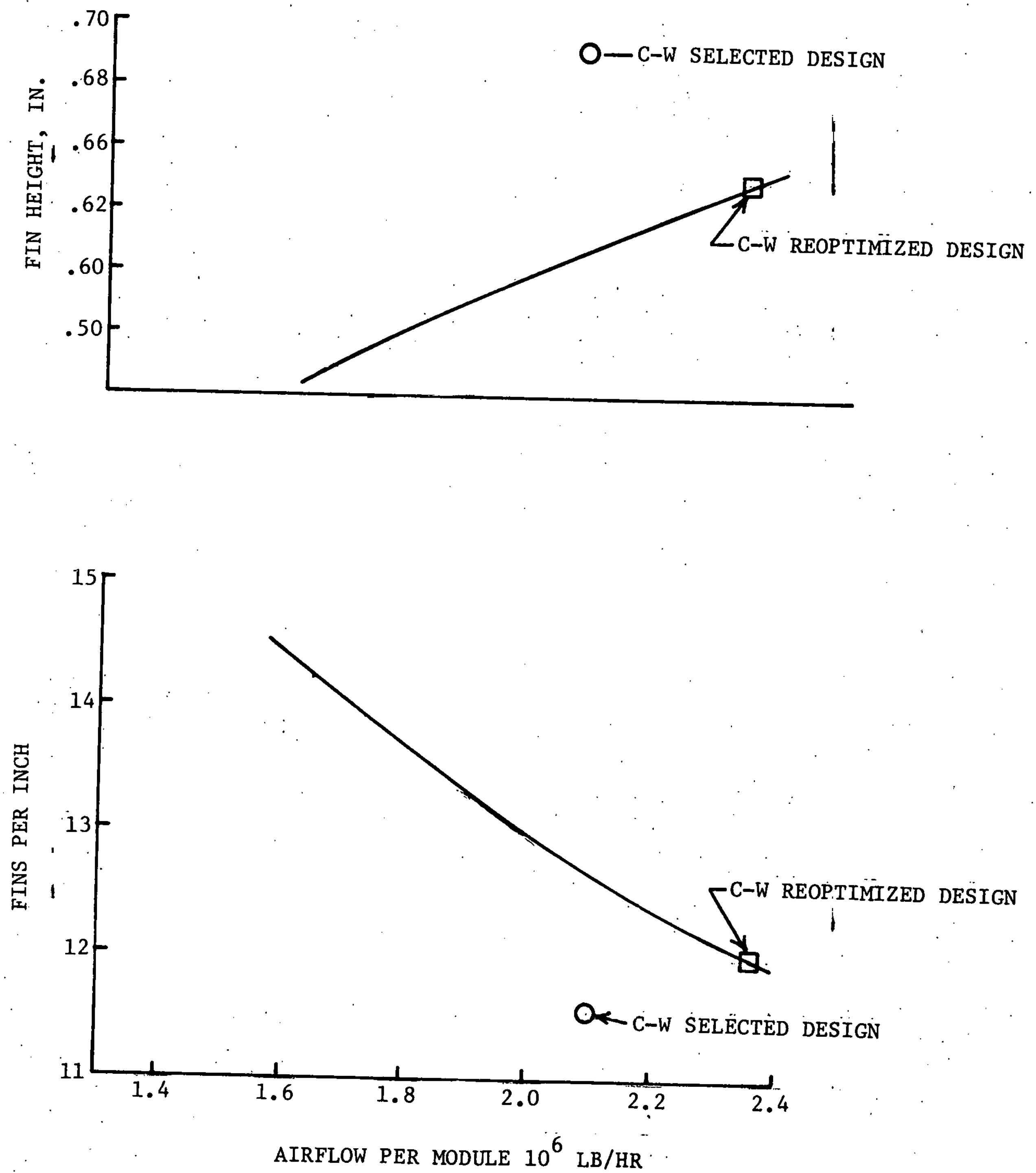


Figure 5-5

COOLING MODULE AND TOWER EVALUATION AND SELECTION
FOR NATURAL DRAFT DRY COOLING SYSTEMS

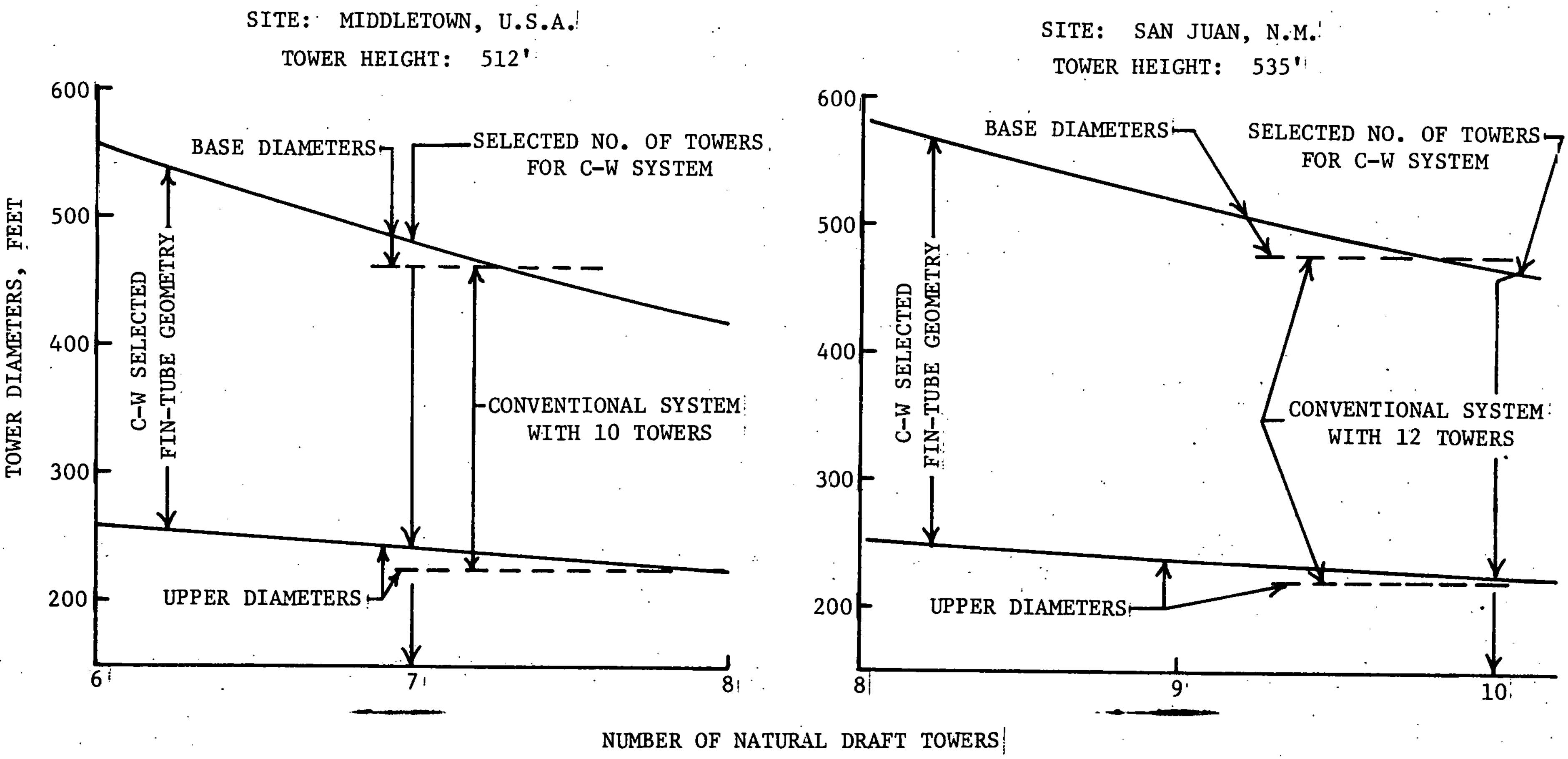


Figure 5-6

PARAMETRIC EVALUATION OF NATURAL DRAFT TOWERS
FOR DRY COOLING SYSTEMS

SITE: MIDDLETOWN, U.S.A.

C-W SELECTED TUBE DESIGN

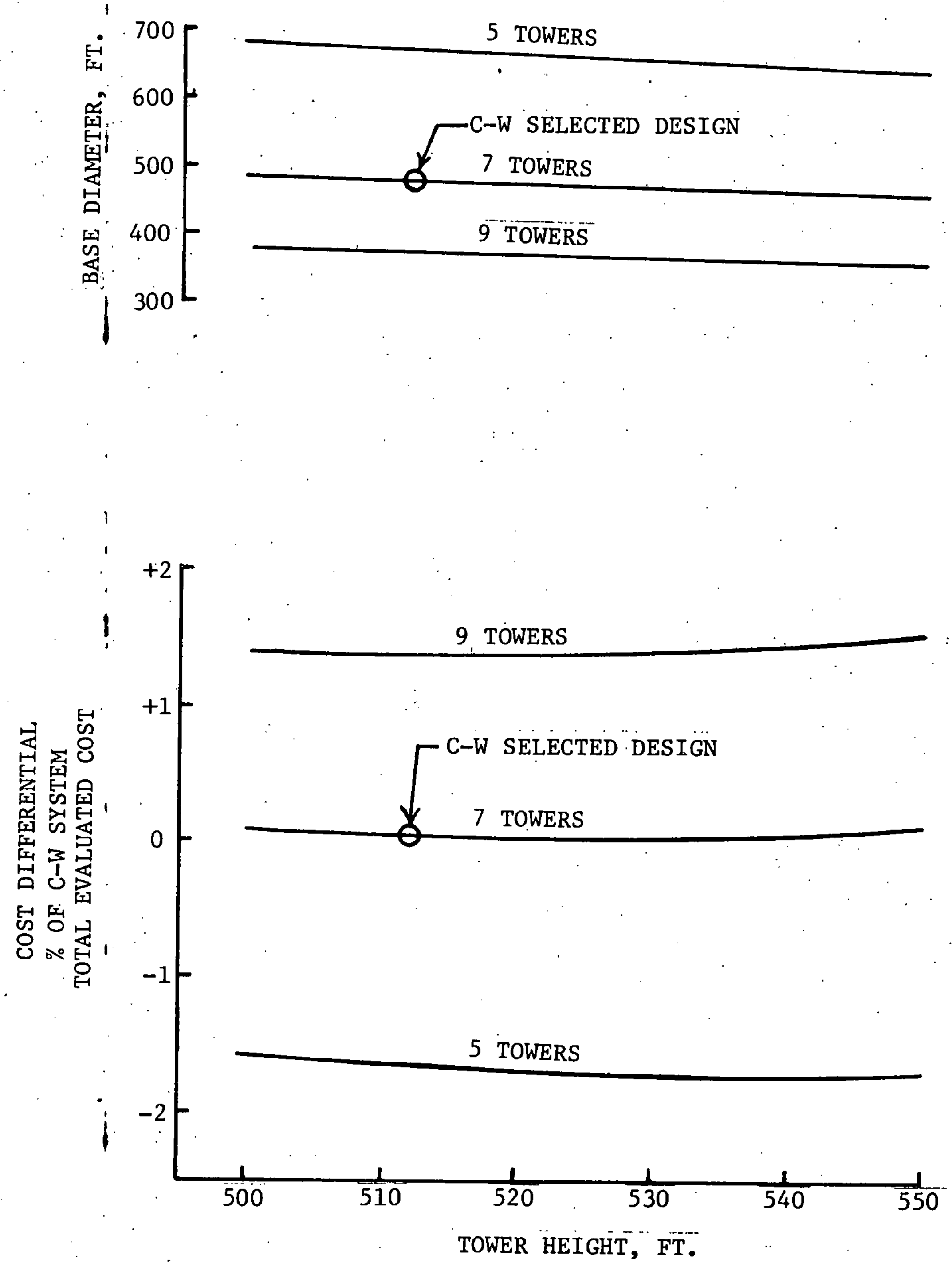


Figure 5-7

PARAMETRIC REOPTIMIZATION OF COOLING MODULES
FOR NATURAL DRAFT COOLING SYSTEM

SITE: MIDDLETOWN, U.S.A.

C-W TOWER GEOMETRY: 7 TOWERS
512' HEIGHT
240' UPPER DIAMETER

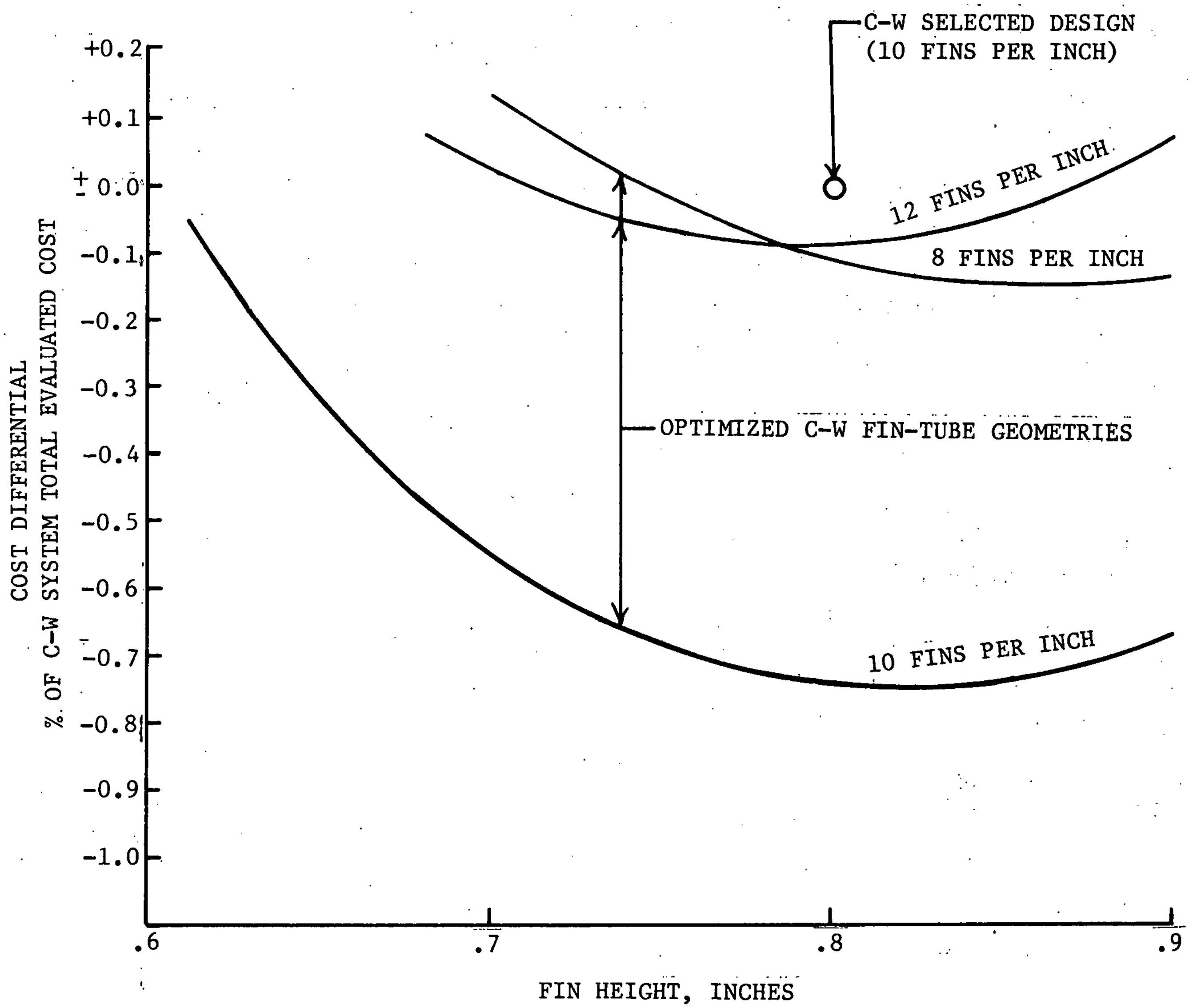


Figure 5-8

6.0 CONCEPTUAL DESIGN AND CAPITAL COST ESTIMATE OF MECHANICAL DRAFT WET/DRY COOLING TOWER SYSTEMS

6.1 Description of Wet/Dry Tower Systems for Water Conservation

Conceptual designs were prepared for the wet/dry tower cooling systems using both C-W integral fin-tube modules and conventional spiral-wound fin-tube modules. The tower system arrangement is one which combines the physically separated mechanical draft wet towers and dry towers into an operational system as analyzed and described in Reference 3. Also, the conceptual design bases of the wet/dry systems in this study were taken from Reference 3 and were developed through computer economic optimization analysis.

Figure 6-1 shows the schematic arrangement of the wet/dry cooling system. Mechanical draft dry tower and wet tower are connected in series on the cooling water side whereas the airflows through the dry and wet towers are in parallel. Exhaust steam from the last stage of the low back-pressure turbine is condensed in the surface condenser. Heat is transferred from the condensing steam to the cooling water inside the condenser tubes. The cooling water from the condenser then passes first through the dry tower and next to the wet tower before circulating back to the condenser.

The wet/dry tower systems were designed to operate in the mode of operation illustrated schematically in Figure 6-2 which shows the turbine back-pressure characteristic of a wet/dry system operated in this mode. During the peak summer ambient temperature, both the wet and dry towers are operating at full capacity as indicated by point 1. As the ambient temperature falls, the wet cells are turned off in succession to maintain the turbine back-pressure essentially constant at the wet tower design value. When point 2 is reached, all of the wet cells have been shut down, and the dry tower handles the entire heat load. The back-pressure curve between points 1 and 2 is of a saw-tooth nature, which results from the intermittent operations of the wet tower's cells as the ambient temperature falls. This operational mode requires continuous feedback controls for the operation of the wet towers.

6.2 Conceptual Design Evaluation

The wet/dry tower systems were designed to serve a 1000 MWe nuclear power plant with a conventional low back-pressure turbine and to use ten percent of the make-up cooling water of comparable wet tower systems. Two alternate sites were evaluated. These are Middletown, U.S.A. (Boston, Massachusetts meteorology) and San Juan, New Mexico (Farmington, New Mexico meteorology). For the conventional wet/dry tower systems at both sites, the design parameters, the sizes of the condenser and the component dry and wet towers were taken directly from Reference 3. From these design bases, the piping layout, the tower structure designs, the sizing of pipes, pumps and motors, tanks and vessels, and instrumentation and controls were performed. For the Curtiss-Wright wet/dry tower systems at the two sites, the same design bases and procedures were used. The component dry towers were sized by Curtiss-Wright to match the heat load requirements for the dry towers of the conventional wet/dry systems at the maximum ambient temperature conditions.

Based on the performance information provided by Curtiss-Wright, the Curtiss-Wright dry towers, once sized to match the same heat load of the conventional dry towers, perform very closely to the conventional dry towers. Therefore, neither the wet tower sizes nor the make-up water requirements were changed.

The system design drawing for the conventional wet/dry tower system at the Middletown site is shown in Figure 6-3. The conventional wet/dry tower design for Middletown has 136 dry cells and 19 wet cells. Each dry cell contains four heat exchanger modules and one fan. Each wet cell has one module and one fan. The dry cells are divided into six cooling towers: five towers of 24 cells and one tower of 16 cells. The wet cells are divided into a ten-cell tower and a nine-cell tower. The towers are spaced approximately one-half a tower length apart and require an area of approximately 1,100 feet by 1,300 feet. In addition, the plan of a typical 24-cell tower shows the major water distribution pipelines, and a schematic diagram exhibits the water circuit for wet/dry operation.

The circulating water lines leading from the condenser to the cooling towers are two 8-foot diameter pipes. Each line supplies half the cooling towers. The number of towers was determined by dividing the total number of cells into even increments, such that the approximate tower length and branch pipeline velocity requirements were met.

The respective drawing for the Curtiss-Wright wet/dry tower system at the Middletown site is shown in Figure 6-4. The C-W wet/dry cooling system design for Middletown uses 72 dry cells and 19 wet cells. Each dry cell contains four heat exchanger modules and two fans. The dry cells are divided into three cooling towers of 24 cells each. The wet cells are divided into a 10-cell tower and a 9-cell tower.

The towers are spaced approximately one-half a tower length apart, and require an area of approximately 800 feet by 1400 feet. Figure 6-4 contains a system and piping layout for the C-W wet/dry cooling system. In addition, the drawing also shows a typical 24-cell dry tower with the major water distribution pipelines, and a schematic diagram exhibits the water circuit for wet/dry operation.

The process flow diagram for both the conventional and Curtiss-Wright systems is shown in Figure 6-5. System design drawings for both conventional and C-W systems sited at San Juan, N.M. were not prepared because these systems were similar to those for the Middletown site except for sizes.

Table 6-1 presents the design parameters, the sizes of steam condensers, circulating water pumps and motors, towers, heat exchangers, for conventional and Curtiss-Wright wet/dry cooling tower systems at the Middletown site and San Juan sites.

6.3 Description of Major Components for the Mechanical Draft Wet/Dry Tower Systems

In this section, a description of essential features of the major components of the mechanical wet/dry cooling systems using the conventional and Curtiss-Wright fin-tube surfaces is described. Each cooling system is composed of four major components: (1) steam condenser, (2) pumps with motors and structures, (3) pipelines, and (4) cooling towers. The size of these components have been given in Table 6-1.

6.3.1 Steam Condensers

At each site, the design of the condenser is common to all wet/dry systems. Each wet/dry system has three field-tubed main surface condensers with fabricated carbon steel water boxes and carbon steel shell. The condenser tubes are 1-inch outside diameter, 20 BWG gauge, 304 stainless steel tubes. The condensers are 2-pass design.

6.3.2 Pumps and Motors

The main circulating water pumps and the booster pumps for the wet tower are of the vertical, wet-pit type with 4160 volts, 3-phase, 60 Hz motors. The pumps have carbon steel casing with chrome steel shaft and bronze impeller.

6.3.3 Pipelines

The main circulating pipes are concrete and buried underground. The above ground distributor pipelines in the dry and wet towers are carbon steel pipes.

6.3.4 Cooling Towers

The wet/dry towers are composed of separate wet and dry towers connected by pipelines in series. The basic designs of the dry towers using both the conventional fin-tube and Curtiss-Wright fin-tube surfaces were the same as those developed in Reference 2. The wet towers are composed of a fixed design module used in Reference 3. All the cooling towers are of mechanical draft design.

6.4 Conventional Dry Cooling Tower Design

The conceptual design of a conventional dry cooling tower is given in Figure 6-6. This figure also shows the water distribution pipelines to and in the tower, the internal design of the tower, and the water storage system.

TABLE 6-1 DESIGN DATA FOR THE WET/DRY COOLING SYSTEMS

VARIABLE	MIDDLETOWN, N.M. CURTISS-WRIGHT	MIDDLETOWN, N.M. CONVENTIONAL	SAN JUAN, N.M. CURTISS-WRIGHT	SAN JUAN, N.M. CONVENTIONAL
General Design Data				
Design Parameters for Dry Towers				
Dry Bulb/Wet Bulb Temperatures, °F	45/40	45/40	55/42	55/42
Cold Water Temperature, °F	89	89	93	93
Cooling Range, °F	26	26	24	24
Tower ITD, °F	70	70	62	62
Turbine Back-pressure, in-HgA	3.45	3.45	3.64	3.64
Condenser Head Load, 10^9 Btu/hr	7.14	7.14	7.16	7.16
Plant Capacity, MWe	1080	1080	1076.7	1076.7
Design Parameters for Wet Helper Towers				
Dry Bulb/Wet Bulb Temperatures, °F	99/75	99/75	102/63	102/63
Tower Approach Temperature, °F	20	20	26	26
Design and Maximum Operating Back-pressure (P_{max}), in-HgA	4.5	4.5	5.0	5.0
Condenser Heat Load at P_{max}, 10^9 Btu/hr	7.22	7.22	7.25	7.25
Heat Load Distribution at P_{max}, Wet Tower/Dry Tower, %	63.7/36.3	63.7/36.3	57.8/42.2	57.8/42.2
Plant Capacity at P_{max}, MWe	1059.5	1059.5	1048.4	1048.4
Annual Make-up Water Requirement, 10^8 gal	4.40	4.40	4.57	4.57
Condenser				
Surface Area, 10^3 ft^2	1049	1049	1088	1088
Number of Tubes	74,000	74,000	80,300	80,300
Tube Length, ft	54.2	54.2	51.8	51.8
Circulating Water Flow and Pump				
Circulating Water Flow Rate, 10^3 gpm	550	550	596	596
Percentage of Circulating Water to Wet Helper Tower	83	83	48	48
Number of Pumps, Dry/Wet	3/3	4/3	4/3	4/3
Pumping Head, ft of Water, Dry/Wet	109.80/61.18	99.28/66.95	99.55/64.4	108.60/64.4
Motor Rating, hp per Pump, Dry/Wet	6500/3000	4500/3500	4500/1500	5000/1500
Motor Brake Horsepower, hp per Pump, Dry/Wet	6123/2832	4153/3066	4260/1470	4850/1470
Cooling System				
Total Number of Towers, Dry/Wet	3/2	6/2	4/2	8/2
Number of Towers - Cells per Tower, Dry/Wet	3-24/1-10 1-9	5-24/1-10 1-16/1-9	2-24/1-8 2-22/1-7	5-22/1-8 3-20/1-7
Total Number of Cells, Dry/Wet	72/19	136/19	92/15	170/15
Total Number of Fans, Dry/Wet	144/19	136/19	184/15	170/15
Number of Fans per Cell, Dry/Wet	2/1	1/1	2/1	1/1
Fan Diameter, ft, Dry/Wet	30/28	28/28	30/28	28/28
Dry Cell				
Total Number of Modules	288	544	368	680
Number of Modules per Cell	4	4	4	4
Length of Module, ft	80	53	80	53
Width of Module, ft	12	10.5	12	10.5
Number of Fin-Tube Rows per Module	78	48 & 49	78	48 & 49
Face Length of Module, ft	79.25	52	79.25	52
Face Width of Module, ft	11.75	10.15	11.75	10.15
Finned Depth of Fin-Tube, in	6.70	8.61	6.70	8.61
Tube Pitch, in	1.81	2.44	1.81	2.44
Number of Fin-Tubes Deep	1	4	1	4
Number of Fins per Inch	11.5	10	11.5	10
Number of Water Passes	1	2	1	2
Design Air Flow per Module, lb/hr	2.09×10^6	1.54×10^6	2.03×10^6	1.48×10^6
Design Water Flow per Module, lb/hr	0.95×10^6	0.5×10^6	0.80×10^6	0.44×10^6
Design Fan Power Requirement per Fan bhp, Dry/Wet	68.6/195.5	186.28/195.5	65.04/191.12	182.9/191.12

* Dry/Wet = Dry Tower Section/Wet Tower Section

The heat exchanger modules of the conventional design are arranged at a 45° angle with respect to the horizontal, and are supported by a triangular framework. This framework is tied together in such a way that four heat exchangers are supported by a common frame called a cell support structure. This structure is supported on concrete piers approximately nine feet high. Three isosceles triangles are used in the cell support structure, and their long sides are jointed together by three I beams. The heat exchanger modules rest on these I beams with the module fixed to the lowest I beam. The heat exchanger module is allowed to move relative to the two upper I beams to accommodate thermal expansions. The fan deck, the area between the fan deck and the louvers, and the ends of the tower are covered by steel sheets. Detail capital cost breakdown for the conventional wet/dry cooling system is given in Tables 6-2 and 6-3 for the Middletown and San Juan sites, respectively.

6.5 Curtiss-Wright Dry Cooling Tower Design

These heat exchanger modules are arranged in a chevron pattern (Figure 6-7) with a slight pitch toward the center of the tower to facilitate draining of the modules. The heat exchanger modules are elevated an average of approximately 40 feet above the ground, and are supported by a truss framework. The individual trusses are tied together by a framework which forms the supporting structure for the fans and fan deck. The fan deck is covered by a thin steel plate. The sides of the tower above the louvers are enclosed by sheet metal, as are the ends of the tower. Louvers are installed on the sides of the towers to help control the airflow.

The heat exchanger modules are supported on an angle iron which runs the length of the truss. At eight locations, the module is bound together by circumferential brackets. At the lower edge of the heat exchanger, the bracket has a foot which rests on the angle iron. The upper edge of the heat exchangers are connected by pin joints. Thermal expansions of the heat exchanger are handled by linear movement of the heat exchanger along the angle iron and angular movement at the pin.

TABLE 6-2 | CAPITAL COST BREAKDOWN FOR MECHANICAL WET/DRY COOLING SYSTEM ($$10^6$)

SITE: Middletown, U.S.A.

SYSTEM: Conventional - 10% Wet/Dry COST YEAR: 1977

Acct. No.	Item	Equipment	Material	Labor	Total
233.1	Condensers	5.805	.029	2.618	8.452
24	Electrical Equipment	5.440	.132	3.263	8.835
261.2	Circulating Water Pumphouse, Wet	.133	-	.177	
	Circulating Water Pumphouse, Dry	.173	-	.205	.688
262.12	Circulating Water System	**	**	**	**
.121	Circulating Water Pump & Motor	4.945	.028	.283	5.256
.122	Freeze Protection Pump & Motor	.299	.004	.037	.340
.125	Concrete Pipe	2.210	.027	.265	2.502
.126	Valves	1.314	-	-	1.314
.1274	Pipe Trenching	-	.372	.817	1.189
.12744	Substructure Concrete	-	.078	.081	.159
262.12	SUBTOTAL	8.768	.509	1.483	10.760
262.13	Dry Cooling Towers	**	**	**	**
.131	Excavation Work	-	.056	.142	.198
.133	Substructure Work	-	.551	.958	1.509
.134	Superstructure	*	*	*	*
.1341	Structural Steel	-	2.350	.633	2.983
.1342	Heat Exchangers	13.946	-	.837	14.783
.1343	Fan System	3.958	-	.356	4.314
.1344	Intake Louvers	1.917	-	-	1.917
.1345	Carbon Steel Piping	1.089	.141	1.412	2.642
.1346	Valves (3 Way & 6-Inch)	.220	-	-	.220
.13471	Hangers & Supports	.218	-	-	.218
.135	Instrumentation & Control	.351	.004	.035	.390
262.13	SUBTOTAL	21.699	3.102	4.373	29.174
262.139	Wet Helper Towers	4.082	-	3.126	7.208
262.151	Make-up Water System	.323	.011	.044	.378
.152	Blowdown System	.033	0	.003	.036
	TOTAL	46.456	3.783	15.292	65.531

TABLE 6-3 CAPITAL COST BREAKDOWN FOR MECHANICAL WET/DRY COOLING SYSTEM ($\$10^6$)

SITE: San Juan, N. M.

SYSTEM: Conventional - 10% Wet/Dry COST YEAR: 1977

Acct. No.	Item	Equipment	Material	Labor	Total
233.1	Condensers	6.039	.030	2.696	8.765
24	Electrical Equipment	6.800	.165	4.079	11.044
261.2	Circulating Water Pumphouse, Wet	.133	-	.177	.688
	Circulating Water Pumphouse, Dry	.173	-	.205	
262.12	Circulating Water System	**	**	**	**
.121	Circulating Water Pump & Motor	5.055	.028	.283	5.366
.122	Freeze Protection Pump & Motor	.373	.005	.046	.424
.125	Concrete Pipe	1.782	.021	.214	2.017
.126	Valves	1.440	-	-	1.440
.1274	Pipe Trenching	-	.900	1.933	2.833
.12744	Substructure Concrete	-	.085	.088	.173
262.12	SUBTOTAL	8.650	1.039	2.564	12.253
262.13	Dry Cooling Towers	**	**	**	**
.131	Excavation Work	-	.069	.177	.246
.133	Substructure Work	-	.689	1.198	1.887
.134	Superstructure	*	*	*	*
.1341	Structural Steel	-	2.937	.791	3.728
.1342	Heat Exchangers	17.433	-	1.046	18.479
.1343	Fan System	4.947	-	.446	5.393
.1344	Intake Louvers	2.396	-	-	2.396
.1345	Carbon Steel Piping	1.362	.177	1.764	3.303
.1346	Valves (3-way & 6-inch)	.275	-	-	.275
.13471	Hangers & Supports	.272	-	-	.272
.135	Instrumentation & Control	.440	.004	.044	.488
262.13	SUBTOTAL	27.125	3.876	5.466	36.467
262.139	Wet Helper Towers	3.223	-	2.468	5.691
262.151	Make-up Water System	.291	.010	.040	.341
.152	Blowdown System	.030	0	.003	.033
	TOTAL	52.464	5.120	17.698	75.282

The water from each module drains into a 10-inch diameter pipe. Two 10-inch diameter pipes merge into a 14-inch diameter pipe which feeds the water into the return pipeline. The return pipeline is supported on the side of the central support columns of the tower. To facilitate draining of the water during shutdown of the power plant, the distribution and return pipelines have a slight slope toward the center of the building. A water storage tank is provided for each cooling tower. This tank is used to store the circulating water from the tower when the system is shut down during the cold weather. Provisions are made for measuring the pressure and temperature of the water at the inlet and discharge of each module. The flow rate is measured for two modules in the tower.

Each heat exchanger module is supplied with isolation valves, which permit removing the module from the water flow circuit to allow for servicing or repairs. A heat exchanger module can be replaced by removing a piece of the sheet metal covering from the side of the tower and taking the module out the side.

The air flow is induced by 28-foot diameter, 6-blade fans which are driven by single speed motors. The tower airflow is controlled by shutting down fans and/or changing the position of louvers. Velocity recovery stacks, constructed from glass reinforced polyester, are used with the fans. Detail capital cost breakdown for the C-W wet/dry cooling system is given in Tables 6-4 and 6-5 for the Middletown and San Juan sites, respectively.

6.6 Wet Tower Cell Design

The mechanical draft wet tower cells are the induced draft, cross-flow type of concrete construction with 41 foot fill height. Each cell has a separate fan; the fan has a diameter of 28 feet, and is driven by a 200 hp motor. The cell dimensions are 71 feet wide, 36 feet long, and 57 feet high.

TABLE 6-4 CAPITAL COST BREAKDOWN FOR MECHANICAL WET/DRY COOLING SYSTEM ($\$10^6$)

SITE: Middletown, U. S. A.

SYSTEM: Curtiss-Wright - 10% Wet/Dry COST YEAR: 1977

Acct. No.	Item	Equipment	Material	Labor	Total
233.1	Condensers	5.805	.029	2.618	8.452
24	Electrical Equipment	4.034	.097	2.420	6.551
261.2	Circulating Water Pumphouse, Wet	.133	-	.177	
	Circulating Water Pumphouse, Dry	.133	-	.177	.620
262.12	Circulating Water System	**	**	**	**
.121	Circulating Water Pump & Motor	4.638	.023	.228	4.889
.122	Freeze Protection Pump & Motor	.734	.007	.075	.816
.125	Concrete Pipe	2.345	.028	.282	2.655
.126	Valves	1.366	-	-	1.366
.1274	Pipe Trenching	-	.324	.715	1.039
.12744	Substructure Concrete	-	.057	.057	.114
262.12	SUBTOTAL	9.083	.439	1.357	10.879
262.13	Dry Cooling Towers				
.131	Excavation Work	-	.083	.206	.289
.133	Substructure Work	-	.376	.481	.857
.134	Superstructure	*	*	*	*
.1341	Structural Steel	-	2.515	.678	3.193
.1342	Heat Exchangers	12.737	-	.764	13.501
.1343	Fan System	4.123	-	.371	4.494
.1344	Intake Louvers	.867	-	-	.867
.1345	Carbon Steel Piping	.750	.097	.972	1.819
.1346	Valves (3-Way & 10-Inch)	.170	-	-	.170
.13471	Hangers & Supports	.157	-	-	.157
.135	Instrumentation & Control	.156	.001	.016	.173
262.13	SUBTOTAL	18.960	3.072	3.488	25.520
262.139	Wet Helper Towers	4.082	-	3.126	7.208
262.151	Make-up Water System	.323	.011	.044	.378
.152	Blowdown System	.033	0	.003	.036
	TOTAL	42.586	3.648	13.258	59.492

TABLE 6-5 | CAPITAL COST BREAKDOWN FOR MECHANICAL WET/DRY COOLING SYSTEM ($$10^6$)

SITE: San Juan, N. M.

SYSTEM: Curtiss-Wright - 10% Wet/Dry COST YEAR: 1977

Acct. No.	Item	Equipment	Material	Labor	Total
233.1	Condensers	6.039	.030	2.696	8.765
24	Electrical Equipment	5.155	.124	3.092	8.371
261.2	Circulating Water Pumphouse, Wet	.133	-	.177	.688
	Circulating Water Pumphouse, Dry	.173	-	.205	
262.12	Circulating Water System	**	**	**	**
.121	Circulating Water Pump & Motor	4.947	.028	.283	5.258
.122	Freeze Protection Pump & Motor	.938	.011	.096	1.045
.125	Concrete Pipe	2.840	.034	.341	3.215
.126	Valves	1.742	-	-	1.742
.1274	Pipe Trenching	-	.244	.534	.778
.12744	Substructure Concrete	-	.057	.059	.116
262.12	SUBTOTAL	10.467	.374	1.313	12.514
262.13	Dry Cooling Towers	**	**	**	**
.131	Excavation Work	-	.106	.264	.370
.133	Substructure Work	-	.480	.615	1.095
.134	Superstructure	*	*	*	*
.1341	Structural Steel	-	3.214	.866	4.080
.1342	Heat Exchangers	16.275	-	.977	17.252
.1343	Fan System	5.268	-	.474	5.742
.1344	Intake Louvers	1.108	-	-	1.108
.1345	Carbon Steel Piping	.958	.124	1.241	2.323
.1346	Valves (3 way & 10 inch)	.217	-	-	.217
.13471	Hangers & Supports	.201	-	-	.201
.135	Instrumentation & Control	.249	.002	.025	.276
262.13	SUBTOTAL	24.276	3.926	4.462	32.664
262.139	Wet Helper Towers	3.223	-	2.468	5.691
262.151	Make-up Water System	.291	.010	.040	.341
.152	Blowdown System	.030	0	.003	.033
	TOTAL	49.787	4.464	14.456	68.707

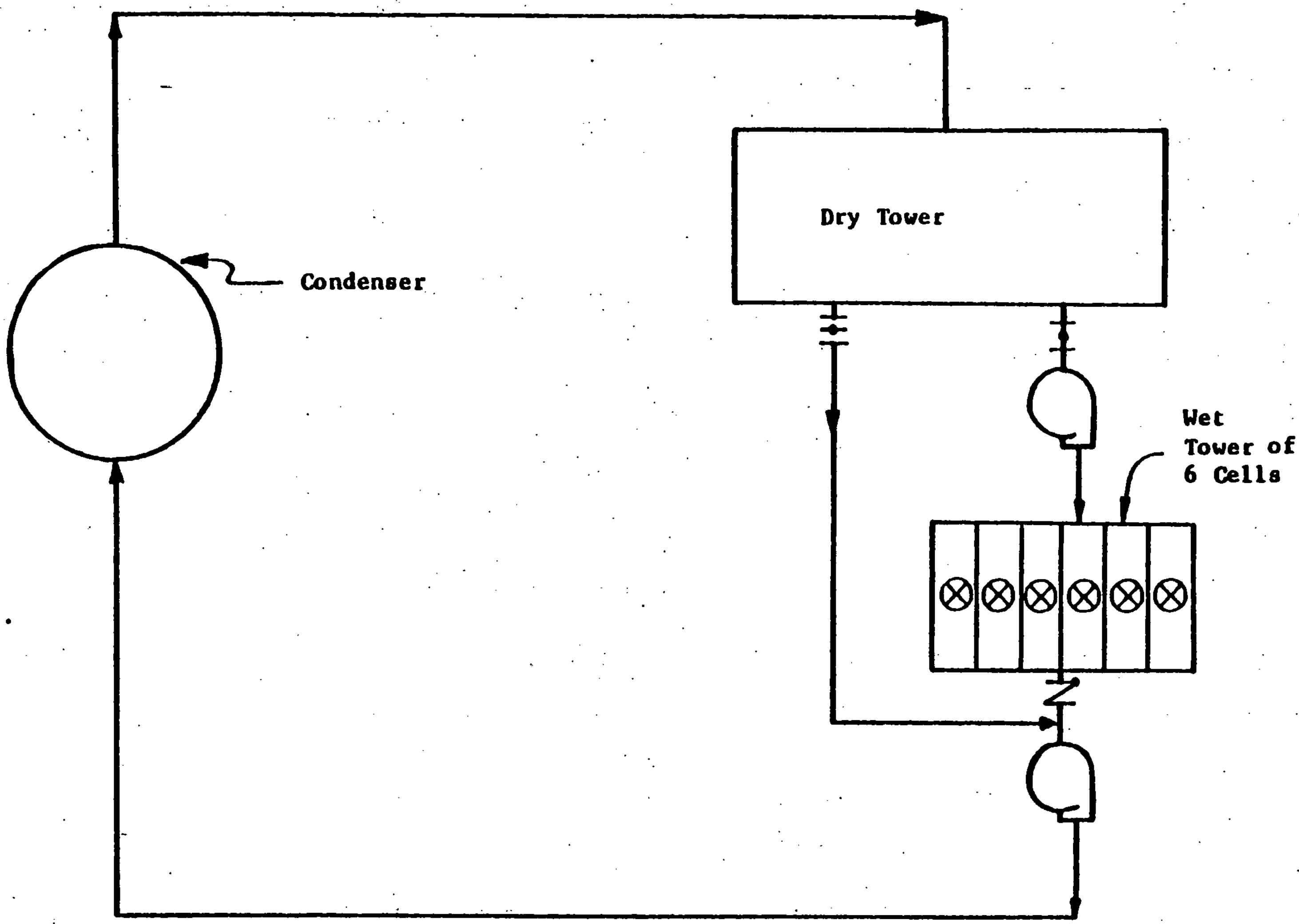


Figure 6-1 **Series-Water Flow Wet/Dry Tower**

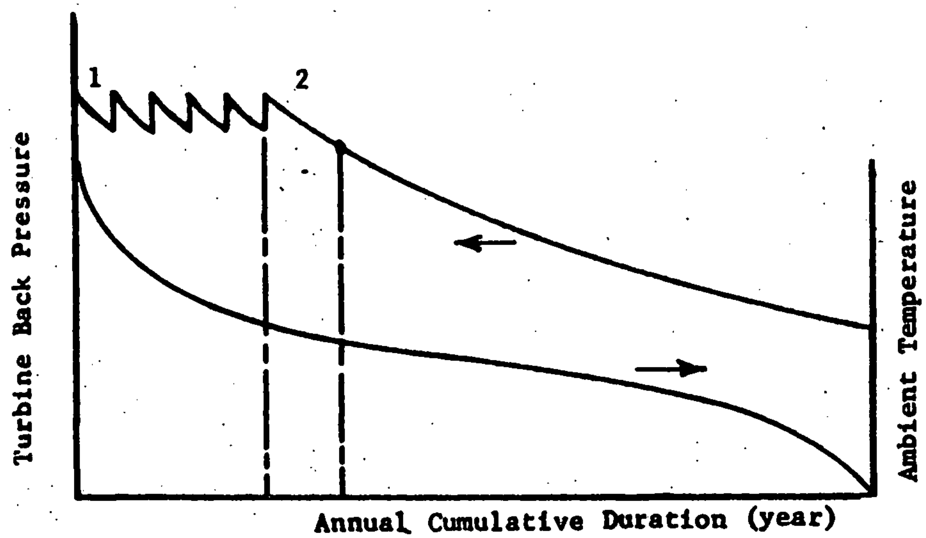


Figure 6-2 **Typical Turbine Back-Pressure Variation of a Wet/Dry Tower System Operating in the S1 Mode**

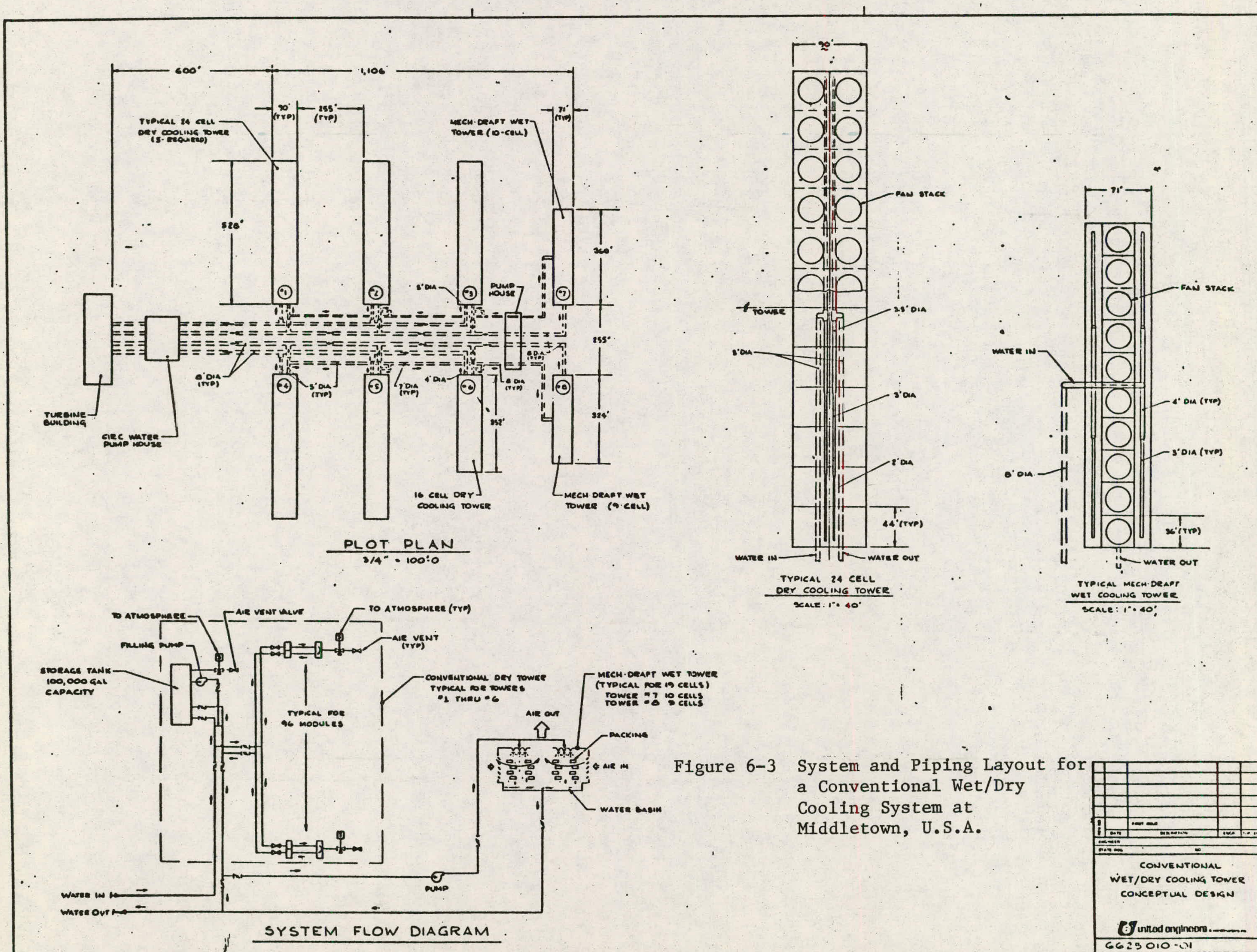


Figure 6-3 System and Piping Layout for a Conventional Wet/Dry Cooling System at Middletown, U.S.A.

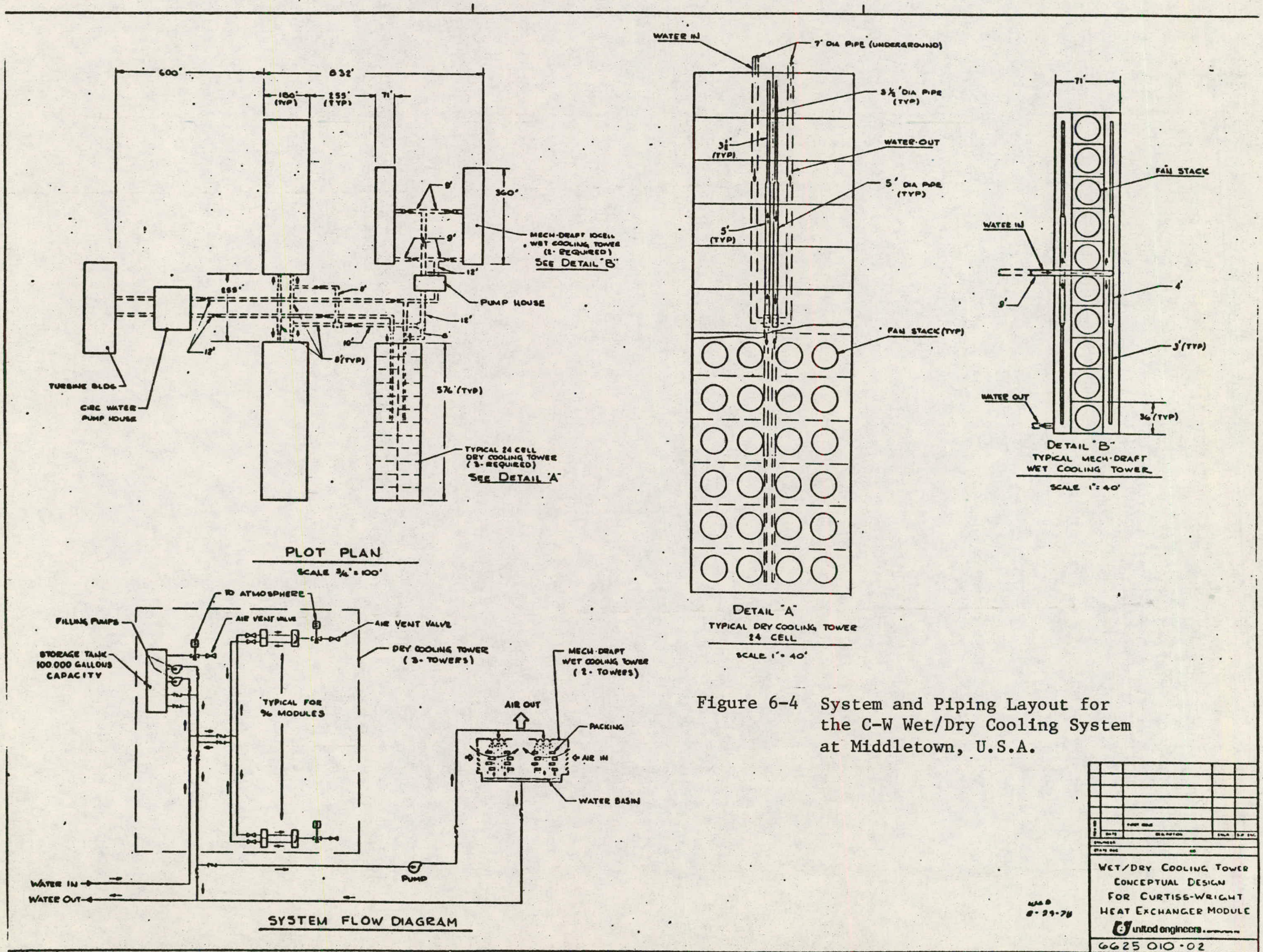


Figure 6-4 System and Piping Layout for the C-W Wet/Dry Cooling System at Middletown, U.S.A.

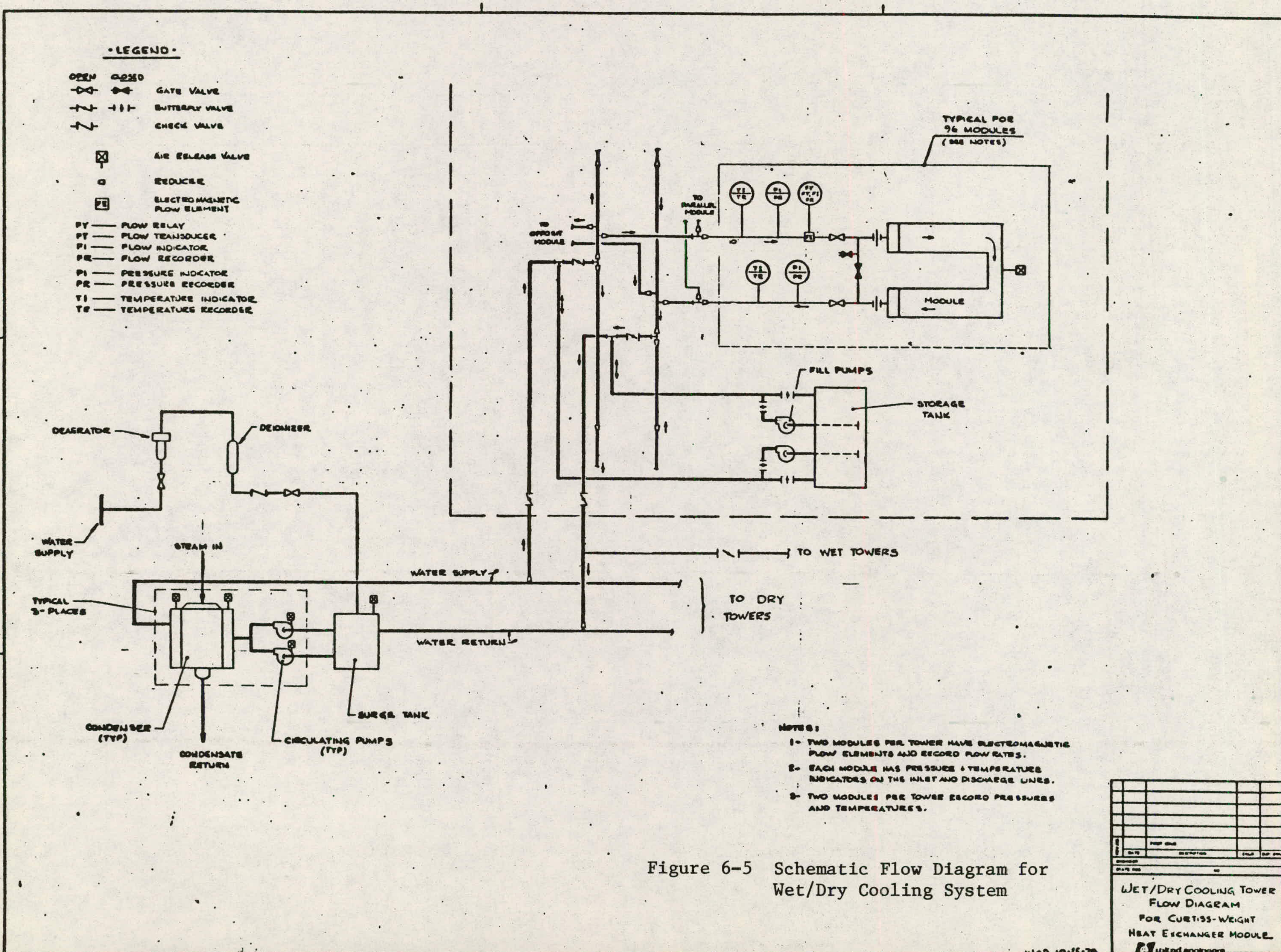


Figure 6-5 Schematic Flow Diagram for Wet/Dry Cooling System

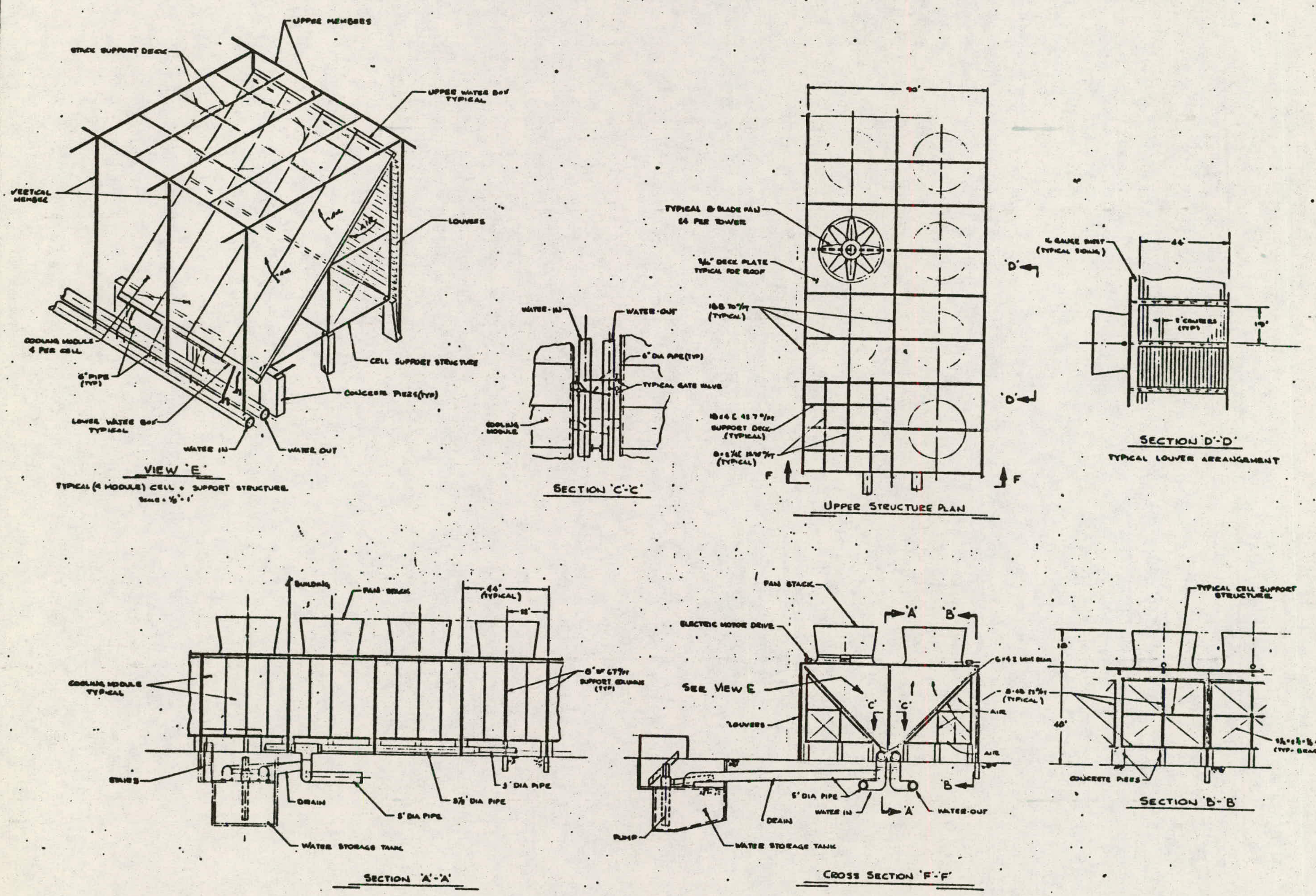


Figure 6-6 Conceptual Design of a Conventional Dry Tower

CONVENTIONAL
DRY COOLING TOWER
CONCEPTUAL DESIGN

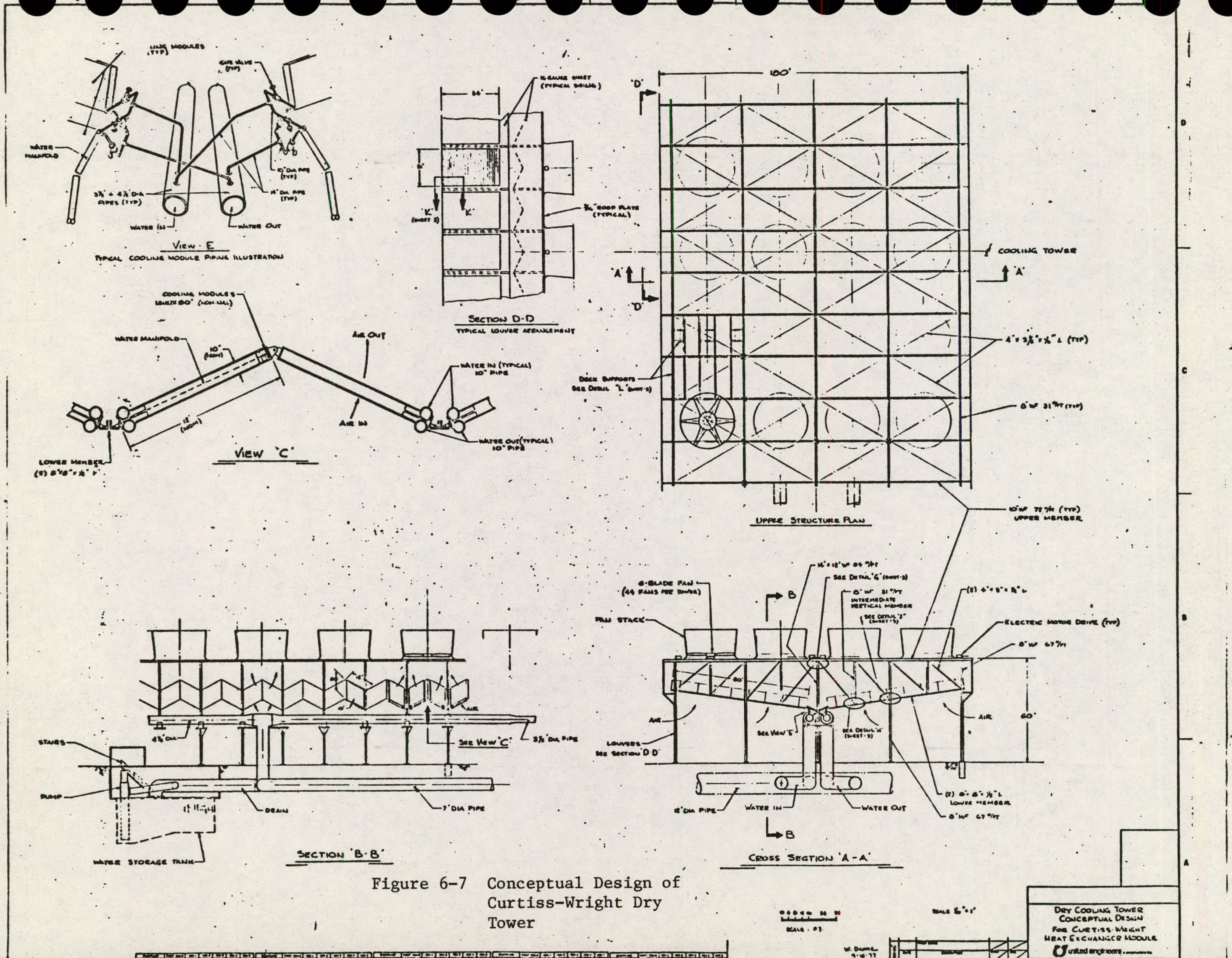


Figure 6-7 Conceptual Design of Curtiss-Wright Dry Tower

7.0 CONCEPTUAL DESIGN AND COST ESTIMATE OF NATURAL DRAFT DRY COOLING SYSTEMS

7.1 Description of Natural Draft Dry Tower Systems

The tower structure is similar to that of the natural draft wet cooling tower, i.e., a hyperbolic concrete structure. The heat exchanger modules are located at the base of the tower. These modules are spaced vertically around the tower's circumference inside the inlet louvers. In this study, two base conceptual designs were developed: (1) a cooling system using two-pass Curtiss-Wright heat exchanger modules, and (2) a cooling system using one-pass conventional heat exchanger modules. A detailed capital cost estimate was made for each design.

The conventional and Curtiss-Wright natural draft dry cooling systems designed for Middletown, U.S.A., are tabulated in Table 7-1. The number of dry modules in substantially less for the Curtiss-Wright design. The Curtiss-Wright dry system has 875 modules in 7 natural draft towers, and the conventional dry design has 1400 modules in 10 natural draft towers. The design data for the San Juan site are also given in Table 7-1.

7.2 Conceptual Design Evaluation

Each dry system is designed to reject the same heat load. Design conditions are identical to those described for the wet/dry systems (see Section 4.0). The system design drawing for the conventional natural draft dry tower system at the Middletown site is shown in Figure 7-1. The conventional dry tower design for Middletown has 10 hyperbolic natural draft cooling towers each having 140 heat exchanger modules. The towers are spaced approximately one half of a tower diameter apart and require a total area of approximately 1900 feet by 2800 feet. The solutions embodied in this report are the result of using a reference case for which UE&C had detail cost figures from previous work which used a peripheral heat exchanger arrangement around the base of the tower.

Figure 7-1 also shows the piping layout for the conventional natural draft dry tower systems, the profile of a natural draft dry tower, and a schematic diagram for the cooling water flow system around the heat exchanger modules. The piping distance from the condenser to the circulating pump house was assumed to be the same for all the tower systems evaluated in this study.

TABLE 7-1

DESIGN DATA FOR THE NATURAL DRAFT DRY COOLING SYSTEMS

VARIABLE	MIDDLETOWN, U.S.A. CURTISS-WRIGHT	MIDDLETOWN, U.S.A. CONVENTIONAL	SAN JUAN, N.M. CURTISS-WRIGHT	SAN JUAN, N.M. CONVENTIONAL
General Design Data				
Design Parameters for Dry Towers				
Dry Bulb/Wet Bulb Temperatures, °F	99/75	99/75	102/63	102/63
Cold Water Temperature, °F	118	118	118	118
Cooling Range, °F	11	11	11	11
Tower ITD, °F	30	30	27	27
Turbine Back-pressure, in-HgA	5.03	5.03	5.03	5.03
Condenser Head Load, 10^9 Btu/hr	7.26	7.26	7.26	7.26
Plant Capacity, MWe	1047.5	1047.5	1047.5	1047.5
Condenser				
Surface Area, 10^3 ft^2	1585	1585	1585	1585
Number of Tubes	177,600	177,600	177,600	177,600
Tube Length, ft	34.1	34.1	34.1	34.1
Circulating Water Flow and Pump				
Circulating Water Flow Rate, 10^3 gpm	1319	1319	1319	1319
Number of Pumps	8	8	8	8
Pumping Head, ft of water	104.63	109.70	87.74	89.35
Motor Rating, hp per Pump	7000	7000	6000	6000
Motor Brake Horsepower, hp per Pump	6354	6662	5328	5426
Cooling System				
Total Number of Towers	7	10	10	12
Number of Modules per Tower	125	140	122	144
Total Number of Modules	875	1400	1220	1728
Base Diameter of Tower, ft	478	461	466	474
Upper Diameter of Tower, ft	240	226	226	220
Height of Tower, ft	512	512	535	535
Length of Module, ft	80	81	80	81
Width of Module, ft	12	10.3	12	10.3
Number of Fin-Tube Rows per Module	60	44	60	44
Number of Fin-Tubes per Module	120	176	120	176
Face Length of Module, ft	79.25	80	79.25	80
Face Width of Module, ft	11.75	10.15	11.75	10.15
Finned Depth of Fin-Tube, in	4.45	8.61	4.45	8.61
Tube Pitch, in	2.35	2.44	2.35	2.44
Number of Fin-Tubes Deep	2	4	2	4
Number of Fins per Inch	10	10	10	10
Number of Water Passes	2	1	2	1
Design Air Flow per Module, lb/hr, $(10)^{-6}$	1.56	1.20	1.30	1.02
Design Water Flow per Module, lb/hr $(10)^{-6}$	0.75	0.47	0.53	0.38

Figure 7-2 shows the design drawing for the C-W natural draft dry tower system. The C-W dry tower system for the Middletown site has 7 hyperbolic natural draft dry towers, each having 125 heat exchanger modules. The towers are spaced approximately one half a tower diameter apart, and occupy the area covered by a circle with a radius of approximately 1000 feet.

The number of natural draft cooling towers in the above examples is acknowledged to be unusually high. This is caused mainly by the severe design conditions imposed by limiting the turbine back pressures to 5 in. Hg A. Since the purpose of this evaluation is a comparative evaluation of the merit in using the C-W integral fin-tubes vs conventional fin-tubes, the selection of the reference data is justified. Therefore, while the number of towers is an extreme solution, the percentage difference between the results obtained herein, and the results to be obtained with a full optimization are not expected to be large. This latter evaluation is beyond the scope of this study.

7.3 Description of Major Components

The cooling system is composed of four major components: (1) condenser, (2) pumps and pump house structure, (3) pipelines, and (4) cooling towers. Identical condensers are used in each design.

7.3.1 Steam Condensers

At each site the design of the condenser is common to all natural draft dry systems. Each dry system has three field-tubed main surface condensers with fabricated carbon steel water boxes and carbon steel shell. The condenser tubes are 1-inch outside diameter, 20 BWG gauge, 304 stainless steel tubes. The condensers are two-pass design.

7.3.2 Pumps and Motors

The main circulating water pumps are of the vertical, wet-pit type with 4160 volts, 3-phase, 60 Hz motors. The pumps have carbon steel casing with chrome steel shaft and bronze impeller.

7.3.3 Pipelines

The main circulating pipes are concrete and are buried underground. The above ground distribution pipelines in the dry towers are carbon steel pipes.

7.3.4 Natural Draft Dry Cooling Towers

Two detailed base designs were made. The first dry design is for the C-W integral fin-tube heat exchanger module, which is 80 feet long and 12 feet wide. The second dry design is for the conventional fin-tube heat exchanger module, which is 81 feet long and 10.3 feet wide. The conceptual design of the dry tower and the piping layout provided sufficient details for capital cost estimation of the major components of the system.

For both the C-W and the conventional dry systems, the piping layout of the tower system was done similarly. The sizing of the dry cooling system determined the number of cooling modules required to reject the waste heat while limiting the maximum turbine back pressure to approximately 5 in-HgA. The criteria used to determine the number of cooling towers and the size of the distribution pipeline to the cooling towers was: (1) the average water velocity in the distribution piping was taken as about 10 ft/sec; (2) the maximum cooling tower height desired was about 550 feet; and (3) the maximum diameter of the distribution pipeline within the tower was 3 feet.

7.4 Conventional Natural Draft Dry Tower Design

The conceptual design of a conventional dry cooling tower is given in Figures 7-3 and 7-4. These figures show the water distribution pipelines to and in the tower, the internal design of the tower, and the water storage system.

The heat exchanger modules of the conventional design are arranged vertically around the circumference of the tower's base. The heat exchanger modules, which are one pass, are approximately 81 feet long, 10.3 feet wide, and hung from the steel framework as shown in Figure 7-3.

The branch pipeline into the tower from the circulating water pipeline is six feet in diameter. This pipeline is below grade. At the tower, the pipeline bifurcates into 4-1/2 foot diameter distribution pipes. Each of these pipes sends a 2-1/2 foot diameter pipe into a tower sector. The distribution pipeline is then reduced to 3-1/2 foot diameter pipe. Again, a 2-1/2 foot diameter pipe comes from each distribution pipeline and feeds a tower sector. Each distribution pipeline is reduced to 2-1/2 foot diameter pipe to feed the remaining sectors. These pipelines are shown on Figures 7-3 and 7-4.

Once inside the tower, the 2-1/2 foot diameter vertical pipes bifurcate into 22 inch diameter pipes which feed 3 modules. The pipe is then reduced to a 20 inch diameter pipe which feeds 3 modules. It is further reduced to 16 inch diameter pipe which feeds 3 modules, and is finally reduced to 10 inch pipe which feeds 3 modules. Figure 7-4 shows the detail distribution to the modules. The return pipeline is at ground level and is similar in size to the distribution system. Both the distribution and return lines between the cooling tower and the storage tank are used simultaneously during the draining and filling processes.

Isolation valves are used on each heat exchanger module to permit servicing the module. Instrumentation is supplied for measurement of the pressure and temperature of each module at both the inlet and discharge. Provisions are made for flow rate measurements of two modules in each tower. Detailed capital cost estimates for the conventional natural draft cooling systems are given in Tables 7-2 and 7-3.

7.5 Curtiss-Wright Natural Draft Dry Tower Design

As shown in Figure 7-2, there are two circulating water lines leading from the condenser to the cooling towers. One is 14 feet in diameter and supplies 4 towers. The other is 12 feet in diameter and supplies the remaining 3 towers.

The branch pipeline into the tower from the circulating water pipeline is 6-1/2 feet in diameter. This pipeline is below grade. As shown in Figure 7-5, when it reaches the tower, it bifurcates into two 5' diameter distribution pipes. These pipes, also below grade, ring the inside of the tower. They each send a 3' diameter pipe into a sector of the tower which contains 22 heat exchanger

TABLE 7-2

CAPITAL COST BREAKDOWN FOR NATURAL DRAFT DRY COOLING SYSTEM ($$10^6$)

SITE: Middletown, U.S.A. PLANT START-UP DATE: 1977

SYSTEM: Conventional COST BASIS: 1977

Acct. No.	Item	Equipment	Material	Labor	Total
233.1	Condensers	9.408	0.047	3.695	13.150
24	Electrical Equipment	4.357	2.244	6.602	13.203
261.2	Circulating Water Pumphouse	-	0.563	0.793	1.356
262.12	Circulating Water System	**	**	**	**
.121	Circulating Water Pump & Motor	8.407	0.039	0.387	8.833
.122	Freeze Protection Pump & Motor	1.321	0.014	0.141	1.476
.125	Concrete Pipe	8.719	0.128	1.284	10.131
.126	Valves	3.398	-	-	3.398
.1274	Pipe Trenching	-	1.213	2.833	4.046
.12744	Substructure Concrete	-	0.325	0.346	0.671
262.12	SUBTOTAL	21.845	1.719	4.991	28.555
262.13	Cooling Towers	**	**	**	**
.131	Excavation Work	-	0.476	1.183	1.659
.133	Substructure Work	-	3.726	5.193	8.919
.134	Superstructure	**	**	**	**
.1341	Structural Steel	-	10.607	2.857	13.464
.1342	Heat Exchangers	42.566	-	2.554	45.120
.1344	Intake Louvers	10.741	-	-	10.741
.1345	Carbon Steel Piping	6.849	0.888	8.876	16.613
.1346	Valves (3-Way & 6-Inch)	1.632	-	-	1.632
.13471	Hangers & Supports	1.370	-	-	1.370
.1348	Tower Shell	-	18.804	28.206	47.010
.135	Instrumentation & Control	0.763	0.008	0.076	0.847
262.13	SUBTOTAL	63.921	34.509	48.945	147.375
	TOTAL	99.531	39.082	65.026	203.639

TABLE 7-3

CAPITAL COST BREAKDOWN FOR NATURAL DRAFT DRY COOLING SYSTEM ($$10^6$)

SITE: San Juan, N. M. PLANT START-UP DATE: 1977

SYSTEM: Conventional COST BASIS: 1977

Acct. No.	Item	Equipment	Material	Labor	Total
233.1	Condensers	9.408	0.047	3.695	13.150
24	Electrical Equipment	4.659	3.106	7.765	15.530
261.2	Circulating Water Pumphouse	-	0.563	0.793	1.356
262.12	Circulating Water System	**	**	**	**
.121	Circulating Water Pump & Motor	7.767	0.038	0.379	8.184
.122	Freeze Protection Pump & Motor	1.630	0.017	0.174	1.821
.125	Concrete Pipe	8.841	0.134	1.344	10.319
.126	Valves	4.032	-	-	4.032
.1274	Pipe Trenching	-	1.372	3.211	4.583
.12744	Substructure Concrete	-	0.435	0.471	0.906
262.12	SUBTOTAL	22.270	1.996	5.579	29.845
262.13	Cooling Towers	**	**	**	**
.131	Excavation Work	-	0.588	1.460	2.048
.133	Substructure Work	-	4.599	6.410	11.009
.134	Superstructure	**	**	**	**
.1341	Structural Steel	-	13.092	3.526	16.618
.1342	Heat Exchangers	52.539	-	3.152	55.691
.1344	Intake Louvers	13.257	-	-	13.257
.1345	Carbon Steel Piping	8.454	1.096	10.956	20.506
.1346	Valves (3 way & 6 inch)	2.015	-	-	2.015
.13471	Hangers & Supports	1.691	-	-	1.691
.1348	Tower Shell	-	23.766	35.663	59.429
.135	Instrumentation & Control	0.942	0.009	0.094	1.045
262.13	SUBTOTAL	78.898	43.150	61.261	183.309
	TOTAL	115.235	48.862	79.093	243.190

TABLE 7-4

CAPITAL COST BREAKDOWN FOR NATURAL DRAFT DRY COOLING SYSTEM ($$10^6$)

SITE: Middletown, U.S.A. PLANT START-UP DATE: 1977

SYSTEM: Curtiss-Wright COST BASIS: 1977

Acct. No.	Item	Equipment	Material	Labor	Total
233.1	Condensers	9.408	0.047	3.695	13.150
24	Electrical Equipment	4.020	1.269	5.289	10.578
261.2	Circulating Water Pumphouse	-	0.563	0.793	1.356
262.12	Circulating Water System	**	**	**	**
.121	Circulating Water Pump & Motor	8.087	0.038	0.383	8.508
.122	Freeze Protection Pump & Motor	0.848	0.009	0.092	0.949
.125	Concrete Pipe	7.068	0.089	0.888	8.045
.126	Valves	2.990	-	-	2.990
.1274	Pipe Trenching	-	1.980	4.359	6.339
.12744	Substructure Concrete	-	0.103	0.151	0.254
	SUBTOTAL	18.993	2.219	5.873	27.085
262.13	Cooling Towers	**	**	**	**
.131	Excavation Work	-	0.301	0.750	1.051
.133	Substructure Work	-	2.391	3.333	5.724
.134	Superstructure	*	*	*	*
.1341	Structural Steel	-	6.502	1.752	8.254
.1342	Heat Exchangers	43.356	-	2.601	45.957
.1344	Intake Louvers	7.081	-	-	7.081
.1345	Carbon Steel Piping	3.974	0.515	5.150	9.639
.1346	Valves (3-Way & 8-Inch)	0.416	-	-	0.416
.13471	Hangers & Supports	0.795	-	-	0.795
.1348	Shell Cost	-	13.661	20.493	34.154
.135	Instrumentation & Control	0.477	0.005	0.048	0.530
	SUBTOTAL	56.099	23.375	34.127	113.601
	TOTAL	88.520	27.473	49.777	165.770

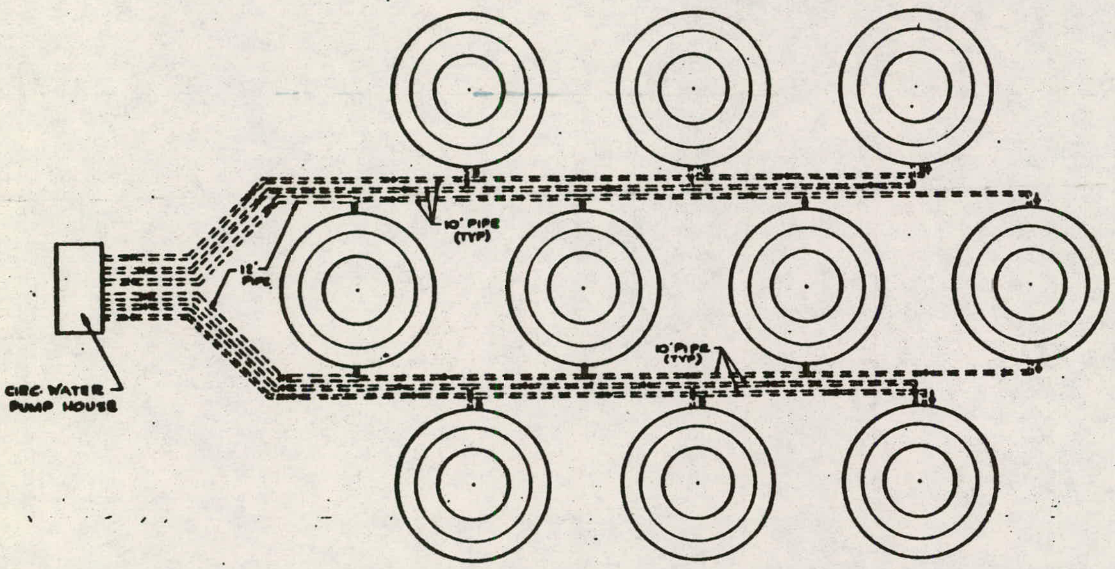
TABLE 7-5

CAPITAL COST BREAKDOWN FOR NATURAL DRAFT DRY COOLING SYSTEM ($$10^6$)

SITE: San Juan, N. M. PLANT START-UP DATE: 1977

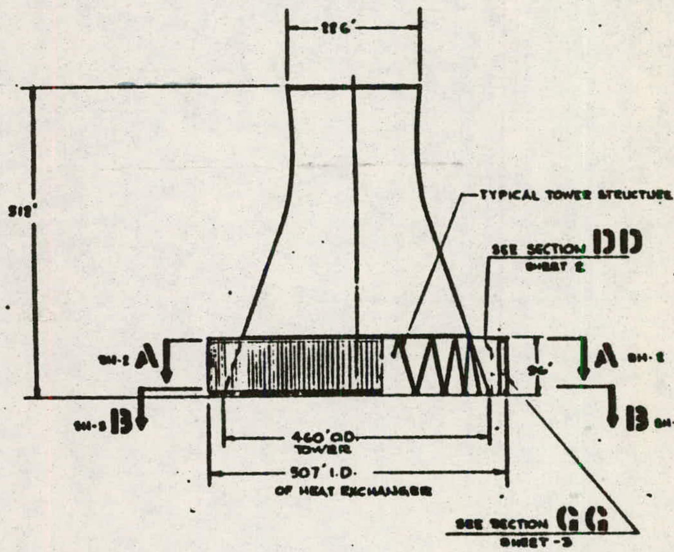
SYSTEM: Curtiss-Wright COST BASIS: 1977

Acct. No.	Item	Equipment	Material	Labor	Total
233.1	Condensers	9.408	0.047	3.695	13.150
24	Electrical Equipment	4.357	2.244	6.602	13.203
261.2	Circulating Water Pumphouse	-	0.563	0.793	1.356
262.12	Circulating Water System	**	**	**	**
.121	Circulating Water Pump & Motor	7.767	0.038	0.379	8.184
.122	Freeze Protection Pump & Motor	1.182	0.013	0.128	1.323
.125	Concrete Pipe	8.719	0.128	1.284	10.131
.126	Valves	3.398	-	-	3.398
.1273	Pipe Trenching	-	1.213	2.833	4.046
.12744	Substructure Concrete	-	0.325	0.346	0.671
262.12	SUBTOTAL	21.066	1.717	4.970	27.753
262.13	Cooling Towers	**	**	**	**
.131	Excavation Work	-	0.420	1.045	1.465
.133	Substructure Work	-	3.334	4.647	7.981
.134	Superstructure	**	**	*	*
.1341	Structural Steel	-	9.066	2.443	11.509
.1342	Heat Exchangers	60.451	-	3.627	64.078
.1344	Intake Louvers	9.873	-	-	9.873
.1345	Carbon Steel Piping	5.541	0.718	7.181	13.440
.1346	Valves (3-way & 8-inch)	0.580	-	-	0.580
.13471	Hangers & Supports	1.108	-	-	1.108
.1348	Shell Cost	-	19.476	29.220	48.696
.135	Instrumentation & Control	0.665	0.007	0.067	0.739
262.13	SUBTOTAL	78.218	33.021	48.230	159.469
	TOTAL	113.049	35.592	64.290	214.931



PLOT PLAN

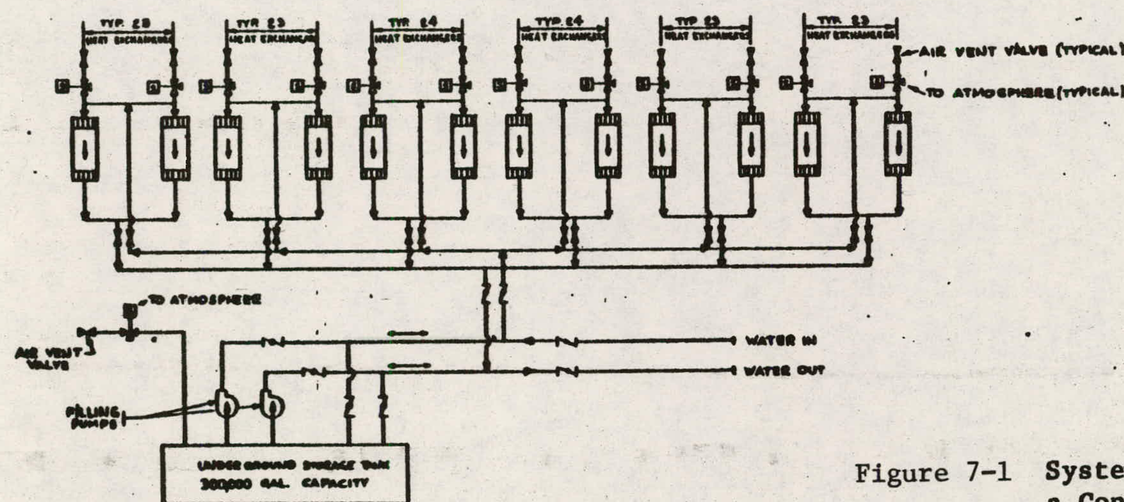
SCALE 1"=200'



DRY TOWER PROFILE

SCALE 1"=100'

(See Figures 4.3 and 4.4 for Details)



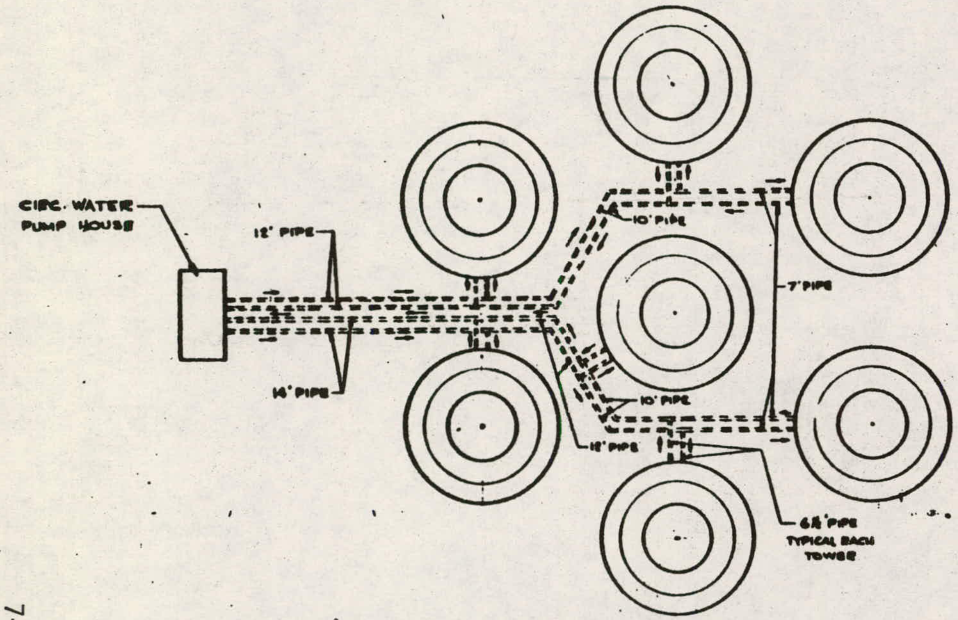
DRY COOLING TOWER
WATER SYSTEM FLOW DIAGRAM

Figure 7-1 System and Piping Layout for a Conventional Natural Draft Dry Cooling System

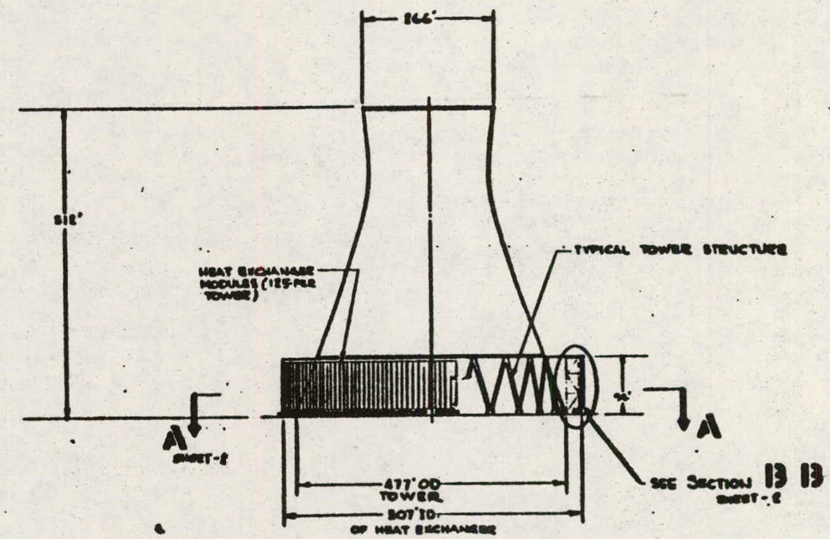
CONVENTIONAL
NATURAL DRAFT
DRY COOLING TOWERS
CONCEPTIONAL DESIGN

united engineers

6625.010-04 SHEET 1 OF 3

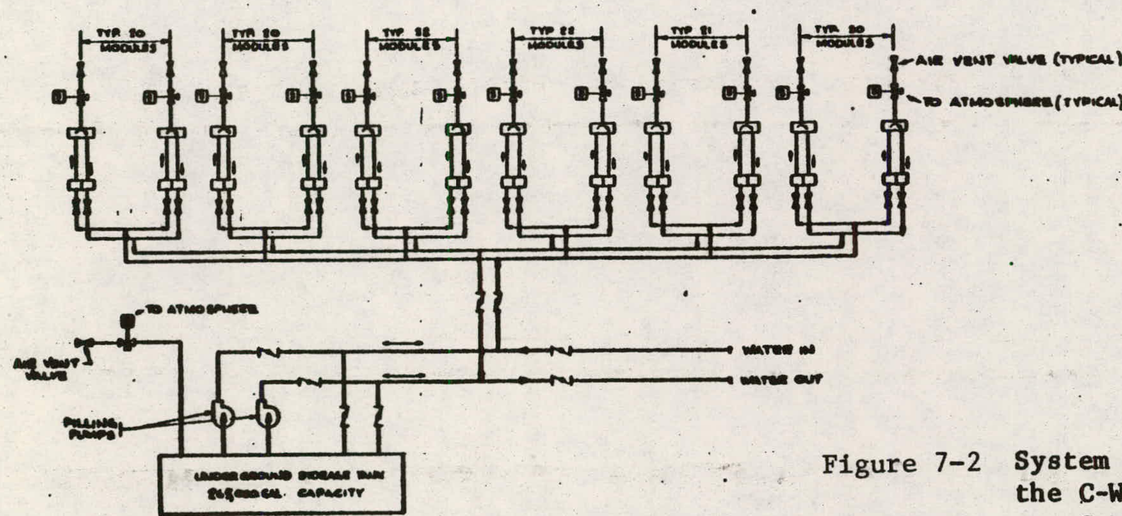


DRY TOWER PLOT PLAN
SCALE: 1" = 200'



DRY TOWER PROFILE
SCALE: 1" = 100'

(See Figure 4.5 for Details)



DRY COOLING TOWER
WATER SYSTEM FLOW DIAGRAM

Figure 7-2 System and Piping Layout for the C-W Natural Draft Dry Cooling System

NATURAL DRAFT
DRY COOLING TOWERS
CONCEPTUAL DESIGN
FOR CURTISS WRIGHT
HEAT EXCHANGER MODULE
united engineers
6625.010-05 SHEET 1 of 2

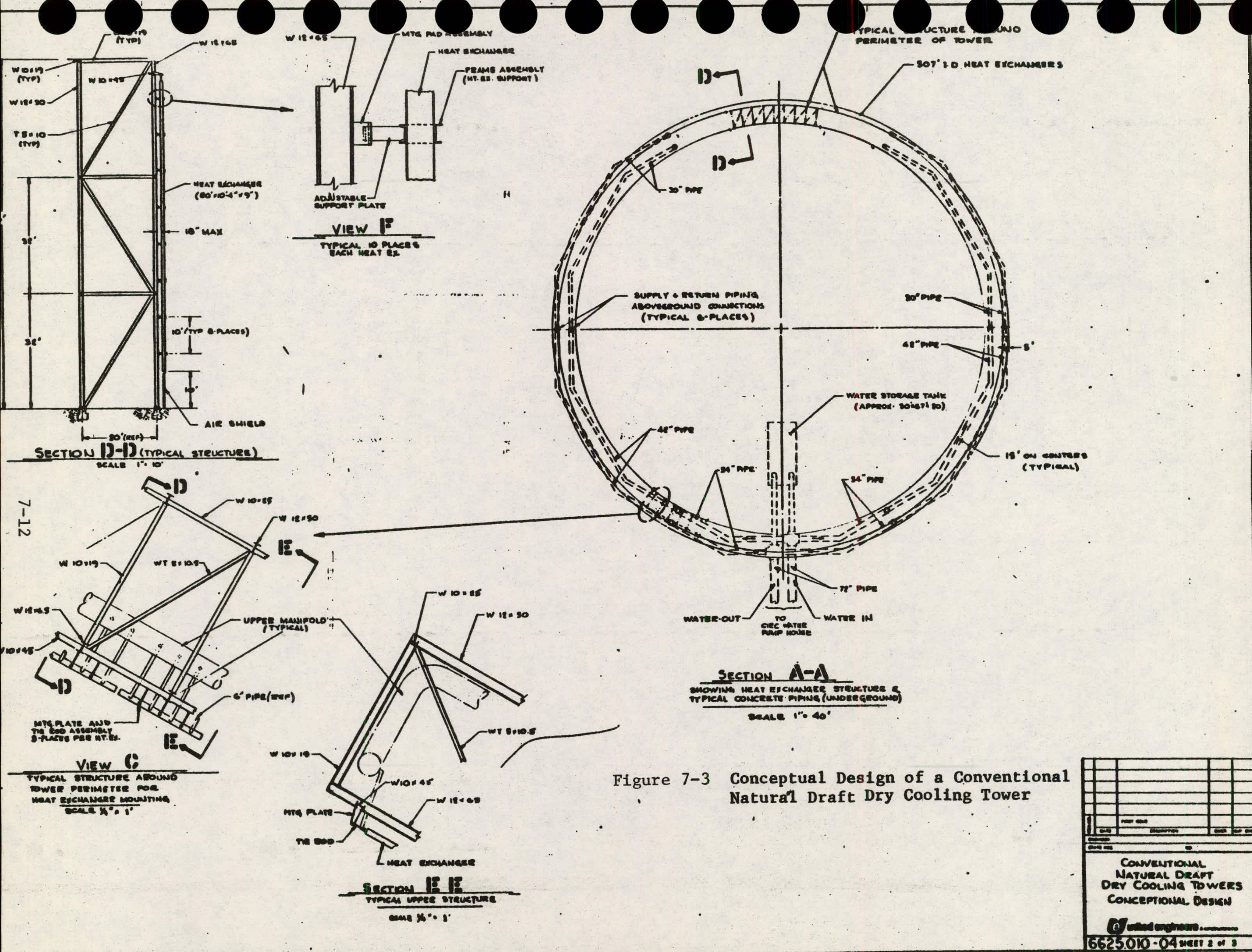
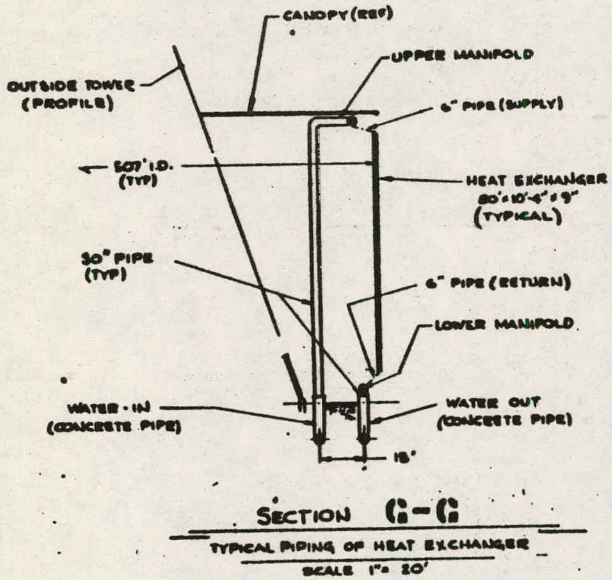
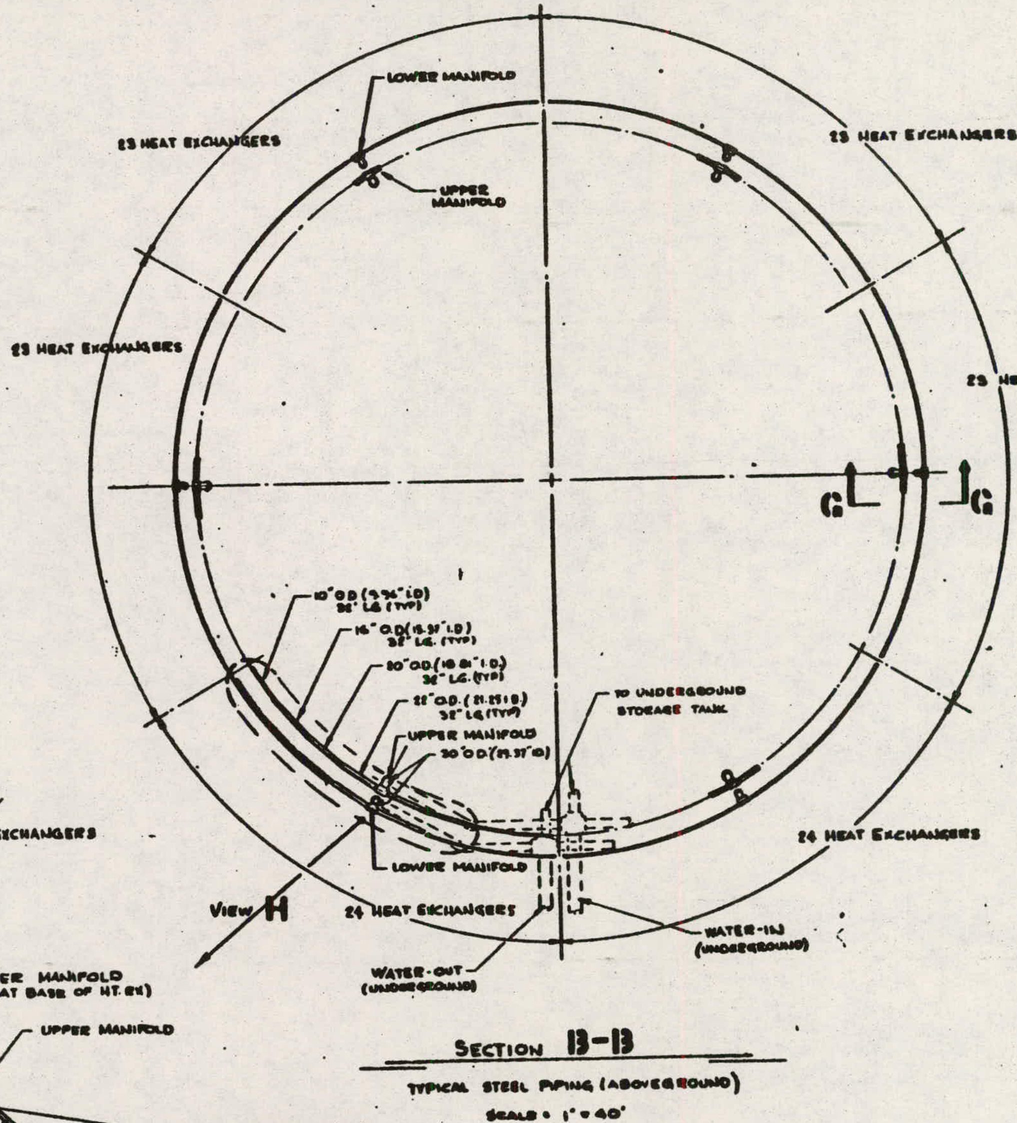
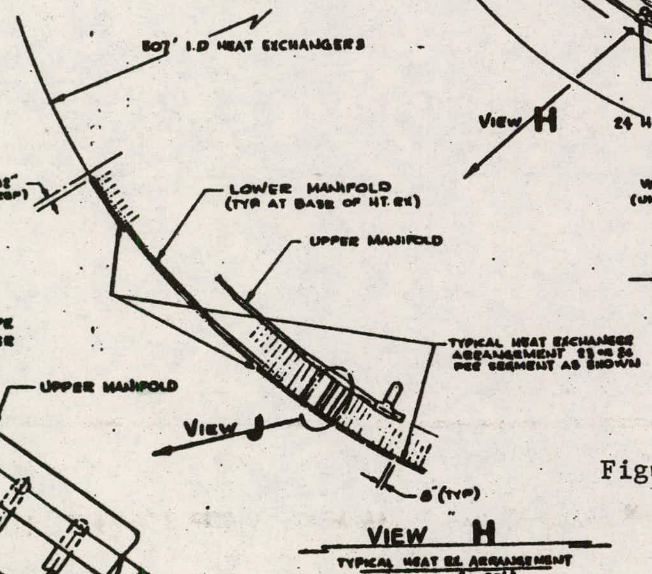
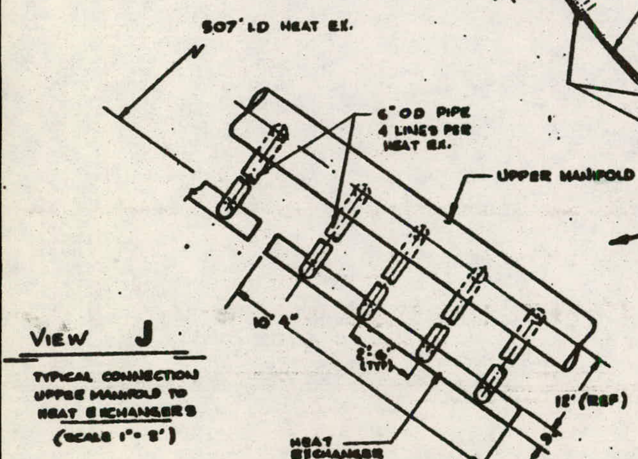


Figure 7-3 Conceptual Design of a Conventional Natural Draft Dry Cooling Tower









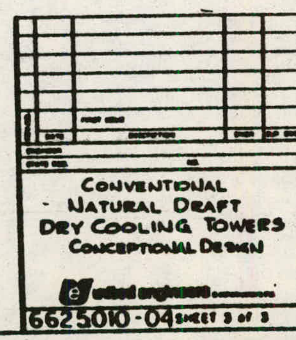


Figure 7-4 Conceptual Design of a Conventional Natural Draft Dry Cooling Tower Showing Piping to Heat Exchangers

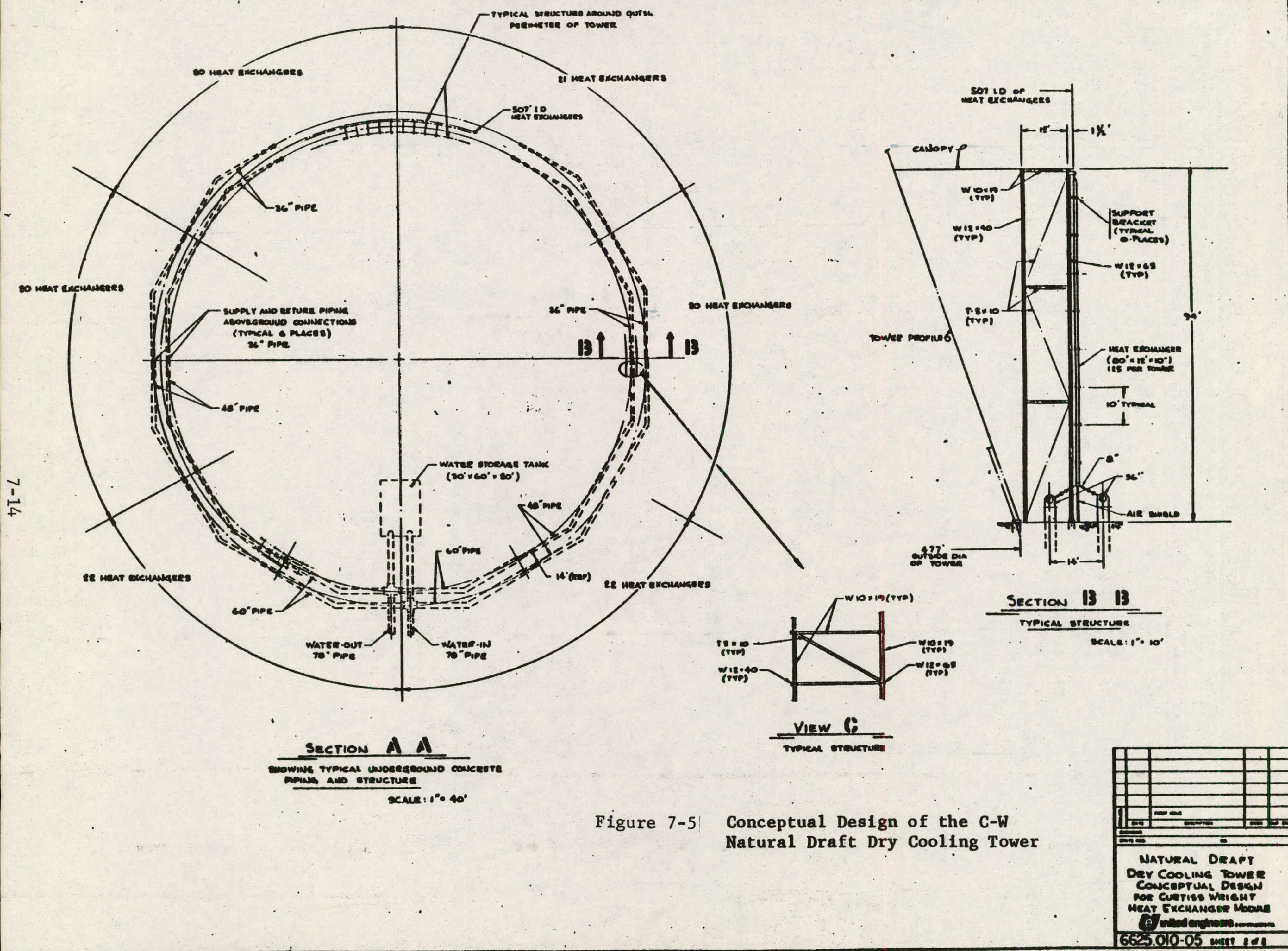


Figure 7-5 Conceptual Design of the C-W Natural Draft Dry Cooling Tower

8.0 COMPARISON OF CONVENTIONAL AND CURTISS-WRIGHT COOLING SYSTEMS

In the comparison of the mechanical draft wet/dry or the natural draft dry cooling tower systems using the Curtiss-Wright (integral finned-tube) surface and the conventional (spiral-wound finned-tube) surface, total evaluated costs are used so that the costs of these cooling systems can be compared on a common basis. The total evaluated cost of a cooling system is the sum of its total capital cost and its total capitalized operating penalty cost. The capital costs and economic penalties have been presented in Section 4.0 of this report.

8.1 Comparison of Curtiss-Wright and Conventional Wet/Dry Tower Systems

The comparisons of detailed penalty costs, total capital and penalty cost, and total evaluated costs of the Curtiss-Wright and conventional wet/dry systems requiring 10% make-up water are given in Tables 8-1 and 8-2 for the Middletown site and the San Juan site, respectively. These data indicate that the conventional wet/dry system has both higher total capital and penalty costs at both sites. In terms of total evaluated cost, the cost savings for the C-W wet/dry systems range from 12% at Middletown to 13% at San Juan.

The data given in Tables 8-1 and 8-2 have been rearranged and presented in Table 8-3 which shows the site comparison of the Curtiss-Wright and the conventional wet/dry systems. This comparison shows that the C-W wet/dry design has greater savings in total evaluated cost at San Juan than at Middletown but the range of potential savings available at alternate sites is small.

8.2 Comparison of Curtiss-Wright and Conventional Natural Draft Dry Tower Systems

The penalty costs, total capital costs and total evaluated costs of the Curtiss-Wright and conventional natural draft dry systems are given in Tables 8-4 and 8-5, for Middletown and San Juan, respectively. These tables show that the conventional natural draft dry system has both higher total capital costs and penalty costs at both sites. The cost savings of the total evaluated costs of the Curtiss-Wright natural draft dry system over the conventional natural draft dry system is 16% at Middletown and 10% at San Juan. Table 8-6 compares these costs for both sites and shows that the C-W design has more cost advantage at Middletown than at San Juan.

TABLE 8-1

COST COMPARISON OF CURTISS-WRIGHT AND CONVENTIONAL WET/DRY COOLING SYSTEMS (10% MAKEUP) AT MIDDLETOWN, U.S.A. SITE ($\$10^6$, 1977 DOLLARS)

Item	Curtiss-Wright	Conventional
Penalty Breakdown:		
Capacity	12.434	12.434
Replacement Energy	6.087	6.351
Circulating Water Pumping Power Requirement	7.215	6.931
Circulating Water Pumping Energy Requirement	4.802	4.560
Cooling Tower Fan Power Requirement	3.651	7.418
Cooling Tower Fan Energy Requirement	2.377	6.341
Make-up Water Purchase and Treatment Penalty	.244	.244
Cooling System Maintenance	4.751	5.008
Cost Summary:		
Total Penalty Cost	41.561	49.287
Total Capital Cost	59.492	65.531
Total Evaluated Cost	101.053	114.818

TABLE 8-2

COST COMPARISON OF CURTISS-WRIGHT AND CONVENTIONAL WET/DRY COOLING SYSTEMS (10% MAKEUP) AT SAN JUAN, N.M. SITE ($$10^6$, 1977 DOLLARS)

Item	Curtiss-Wright	Conventional
Penalty Breakdown:		
Capacity	16.418	16.418
Replacement Energy	7.908	7.908
Circulating Water Pumping Power Requirement	6.164	6.799
Circulating Water Pumping Energy Requirement	4.474	5.006
Cooling Tower Fan Power Requirement	3.360	8.698
Cooling Tower Fan Energy Requirement	2.980	7.772
Make-up Water Purchase and Treatment Penalty	.261	.261
Cooling System Maintenance	5.438	5.465
Cost Summary:		
Total Penalty Cost	47.003	58.327
Total Capital Cost	68.707	75.282
Total Evaluated Cost	115.710	133.609

TABLE 8-3

SITE COMPARISON OF CURTISS-WRIGHT AND CONVENTIONAL WET/DRY SYSTEMS ($\$10^6$, 1977 DOLLARS)

Item	Curtiss-Wright		Conventional	
	Middletown	San Juan	Middletown	San Juan
Penalty Breakdown:				
Capacity	12.434	16.418	12.434	16.418
Replacement Energy	6.087	7.908	6.351	7.908
Circulating Water Pumping Power Requirement	7.215	6.164	6.931	6.799
Circulating Water Pumping Energy Requirement	4.802	4.474	4.560	5.006
Cooling Tower Fan Power Requirement	3.651	3.360	7.418	8.698
Cooling Tower Fan Energy Requirement	2.377	2.980	6.341	7.772
Make-up Water Purchase and Treatment	.244	.261	.244	.261
Cooling System Maintenance	4.751	5.438	5.008	5.465
Cost Summary:				
Total Penalty Cost	41.561	47.003	49.287	58.327
Total Capital Cost	59.492	68.707	65.531	75.282
Total Evaluated Cost	101.053	115.710	114.818	133.609

TABLE 8-4

COST COMPARISON OF CURTISS-WRIGHT AND CONVENTIONAL NATURAL DRAFT DRY COOLING SYSTEMS AT MIDDLETOWN, U.S.A. SITE ($\$10^6$, 1977 DOLLARS)

Item	Curtiss-Wright	Conventional
Penalty Breakdown:		
Capacity	16.738	16.738
Replacement Energy	.150	.150
Circulating Water Pumping Power Requirement	11.686	12.253
Circulating Water Pumping Energy Requirement	10.676	11.193
Cooling System Maintenance	11.742	14.259
Cost Summary:		
Total Penalty Cost	50.992	54.593
Total Capital Cost	165.770	203.639
Total Evaluated Cost	216.762	258.232

TABLE 8-5

COST COMPARISON OF CURTISS-WRIGHT AND CONVENTIONAL NATURAL DRAFT DRY COOLING SYSTEMS AT SAN JUAN, N.M. SITE ($$10^6$, 1977 DOLLARS)

Item	Curtiss-Wright	Conventional
Penalty Breakdown:		
Capacity	16.738	16.738
Replacement Energy	.810	.810
Circulating Water Pumping Power Requirement	9.800	9.980
Circulating Water Pumping Energy Requirement	8.773	8.934
Cooling System Maintenance	14.631	16.844
Cost Summary:		
Total Penalty Cost	50.752	53.306
Total Capital Cost	214.931	243.190
Total Evaluated Cost	265.683	296.496

TABLE 8-6

SITE COMPARISON OF CURTISS-WRIGHT AND CONVENTIONAL NATURAL DRAFT DRY COOLING SYSTEMS ($\$10^6$, 1977 DOLLARS)

Item	Curtiss-Wright		Conventional	
	Middletown	San Juan	Middletown	San Juan
Penalty Breakdown:				
Capacity	16.738	16.738	16.738	16.738
Replacement Energy	.150	.810	.150	.810
Circulating Water Pumping Power Requirement	11.686	9.800	12.253	9.980
Circulating Water Pumping Energy Requirement	10.676	8.773	11.193	8.934
Cooling System Maintenance	11.742	14.631	14.259	16.844
Cost Summary:				
Total Penalty Cost	50.992	50.752	54.593	53.306
Total Capital Cost	165.770	214.931	203.639	243.190
Total Evaluated Cost	216.762	265.683	258.232	296.496

9.0 REFERENCES

1. Haberski, R. J. and R. J. Raco. Engineering Analysis and Development of an Advanced Technology Low Cost Dry Cooling Tower Heat Transfer Surface. Curtiss-Wright Corporation, Wood-Ridge, New Jersey, ERDA Report No. COO-2774-1, 1976.

2. Haberski, R. J. and J. C. Bentz. Conceptual Design and Cost Evaluation of a High Performance Dry Cooling System. Wood-Ridge, New Jersey, (U.S. Energy Research and Development Administration) Report No. COO-4218-1, 1978.

3. Hu, M. C. Engineering and Economic Evaluation of Wet/Dry Cooling Towers for Water Conservation. United Engineers & Constructors Inc., Philadelphia, Pennsylvania, UE&C-ERDA-761130, 1976. (Available from National Technical Information Service, Springfield, Virginia, COO-2442-1.)

4. Hu, M. C. and G. A. Englesson. Wet/Dry Cooling Systems for Fossil-Fueled Power Plants: Water Conservation and Plume Abatement. United Engineers & Constructors Inc., Philadelphia, Pennsylvania, UE&C-EPA-771130, 1977. (Available from National Technical Information Service, Springfield, Virginia, EPA-600/7-77-137.)

5. Bartz, J. A, Proceedings on Power System Economics sponsored by EPRI and DOE, and held in Palo Alto, California, November 1 and 2, 1978.

6. United Engineers & Constructors Inc. Capital Cost: Pressurized Water Reactor Plant. Philadelphia, Pa., Report No. UE&C-ERDA-770501, 2 Volumes, 1977. (Available from National Technical Information Service, Springfield, Virginia, NUREG-0241, COO-2477-5, 2 Volumes.)

7. Hudson Products Catalog of Fan Performance

8. Kays, W. M. and A. L. Londen. Compact Head Exchangers. McGraw Hill Book Company, New York, 1964.

9. Mason, J. L. Heat Transfer in Crossflow. Proceedings of Applied Mechanics, 1954.