TENNESSEE VALLEY AUTHORITY
ENGINEERING LABORATORY

RESULTS OF ANALYSIS OF THE

WATTS BAR NUCLEAR PLANT HEAT REJECTION SYSTEM

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EXECUTIVE SUMMARY

An as-designed analysis has been performed to quantify the impact of design parameters, expected cooling tower performance, and meteorology on the capacity of Watts Bar Nuclear Plant (WBN). These analyses include modeling the performance of the towers as expected in their current condition as well as several alternatives for increasing their performance. The steam turbo-generator performance was based on TVA heat balances and the condenser performance was based on the HEI method. Forty-two years of historical hourly meteorology from the National Weather Service (NWS) was used to estimate the average expected performance and the incremental changes in generation which can be expected. One additional year of historical hourly meteorological data from the WBN met station was used to quantify the impacts of thermal inversions as the NWS data did not include inversion measurements.

The analysis indicates that the performance of the towers is expected to be 10 to 15 percent less than the original design. The presence of thermal inversions, can be expected to further reduce the performance of the towers by as much as 20 percent under adverse conditions. These adverse conditions have been observed at WBN and, in fact, are quantified in the FSAR. This shortfall in tower performance can be expected to result in a reduction in capacity and generation.

The results of the current analysis differ significantly from those of previous analyses because of changes in several key parameters and calculations. The most significant of these is the limiting backpressure. Previous analyses were based on a limit of 4.5 inches Hga (the operating limit at SQN); whereas the present analysis is based on 5.5 (the operating limit at WBN). The turbines at WBN and SQN are identical. When the current assumptions are used for all other key parameters, the difference between a maximum backpressure of 4.5 and 5.5 inches Hga results in a backpressure limited capacity of 888 vs. 1094 MW respectively for 0.1 percent of the average year. The parameters and procedures used in the current analysis are non-conservative; whereas conservative parameters have been used in the past.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

RESULTS OF ANALYSIS OF THE WATTS BAR NUCLEAR PLANT HEAT REJECTION SYSTEM

ASSUMPTIONS

The assumptions and calculations used in this study were prescribed by WBN Engineering and are described in detail in the subsequent sections.

Steam Turbo-Generator Performance

The steam turbo-generator performance was taken from TVA heat balances 47K-1110-1, -2, -3-R0, and -4 labeled "Maximum Guaranteed Throttle Flow with 2 MFPT's," "Maximum Calculated...," "75% of Max Guaranteed...," and "50% of Max...," respectively. These span a range of reactor power input from 3604 to 1863 MWt. All are computed based on condenser zone backpressures of 1.63, 2.38, and 3.4 inches Hga. Information on these heat balances were used to quantify reactor power input, generator output, and condenser heat load.

The effect of condenser backpressure on heat rate and generator output was based on the Westinghouse correction curves AV983-0133 and -0134, respectively. These curves were used to correct the heat balances to their equivalent at 2 inches Hga (which is the zero base for these correction curves). The backpressure correction curves were applied to the three zones by taking the straight arithmetic average of the adjusted heat rate and load as if the entire unit were operating at each of the three backpressures. Because the heat balances were first adjusted accordingly, an exact match was obtained for the conditions corresponding to the four heat balances.

This was the method used to perform the calculations during the design phase [R. E. Taylor (RET) to Files 8/1/72]. The corrections were applied in this manner because a rigorous heat balance for each condition over a range of inlet water temperature, flow, condenser cleanliness, and reactor power input was not feasible in 1972. A rigorous analysis is feasible with currently available computer hardware and software. The difference between applying the correction curves in this manner as compared to a rigorous analysis is uncertain.

Limiting Backpressure

The limiting backpressure has a pronounced effect on the magnitude of the computed impact on generation and capacity. W. S. Bain (WSB) listed the average number of hours where the backpressure would reach or exceed 4.5, 5.0, and 5.5 inches Hga as 2900, 1475, and 460 respectively; and the accompanying average lost generation as 420000, 140000, and 24000 MWhr/yr, respectively [WSB to S. E. Gibson 8/14/84]. A limiting backpressure of 5.5 inches Hga was used in the present analyses.

Operating instructions at Sequoyah Nuclear Plant (SQN) require that the backpressure not exceed 4.5 inches Hga. WSB considered a range of backpressures of 4.5 to 6.0 inches Hga and found that 4.5 inches Hga would be exceeded for an average of 2900 hours per year with a range of 1800 to 4000 hours per year. D. J. Benton (DJB) reported in January of 1992 that the backpressure could be expected to exceed 4.5 inches Hga for 3600 hours per year on the average. Considering the magnitude of potential impact on generation, it is essential that the best available instrumentation be installed and maintained at WBN so as to enable operation as close as practical to this limit.

Condenser Performance Calculations

The performance of the condenser was computed based on the Heat Exchanger Institute (HEI) Standards for Steam Surface Condensers (1988 Edition). The calculations for the present analyses were performed in the same manner as the original design [RET to Files 8/1/72]. The HEI method was applied as if the condenser were actually three separate units each having one-third of the overall tube length and receiving approximately one-third of the heat load (the exact split in heat load was determined from the backpressure curves applied as described previously).

This procedure of treating the condenser as if it were three separate units in series has not been field verified. Furthermore, the HEI calculations are based on the NTU (Number of Transfer Units) method, a discussion of which can be found in any standard heat transfer textbook or handbook. The NTU method is developed theoretically for co-current heat exchangers; whereas, a steam condenser is a crossflow heat exchanger. Many textbooks give theoretical corrections to be used with the NTU method when applied to crossflow heat exchangers; however others caution against the use of this method in such cases [e.g., Heat Transfer, 2nd. Ed., L. C. Thomas, Prentice-Hall, 1991].

The HEI has provided empirical adjustment factors which when applied with the NTU method to steam condensers of the size and design typically found in large electric power plants obtain reasonable accuracy. Applying the same empirical adjustments to a condenser having tubes which are three times as long as most introduces an additional uncertainty. More rigorous methods of analyzing heat exchangers are available and computational capabilities have increased dramatically since 1972.

Condenser Cleanliness

A condenser cleanliness of 95 percent was used in the present analysis. A cleanliness of 95 percent has been reported by SQN. However, there are many other plants in the Southeast which do not achieve a cleanliness of 95 percent on a continuous basis. WSB used a range of condenser cleanliness of 85 to 95 percent in 1984. A more conservative value of 90 percent could have been used in the present analysis in order to allow for some margin in this as well as the simplistic HEI method. Consistent achievement of 95 percent condenser cleanliness at WBN will require proper operation and maintenance of the tube cleaning system.

Cooling Tower Performance

The performance of the cooling towers has been computed based on the manufacturer's curves and the FACTS (Fast Analyzer Cooling Tower Simulator) model [DJB and W. R. Waldrop, "Computer Simulation of Transport in Evaporative Cooling Towers," Journal of Engineering for Gas Turbines and Power, 110:190-196, 1988].

The FACTS model has been extensively verified by third parties including Arkansas Power and Light, Environmental Systems, Houston Lighting and Power, Pacific Gas and Electric, and Southern Company Services. The FACTS model has been validated with field data for a wide range of towers, including several of the same design, vintage, and vendor as the WBN towers. However, there are always some differences between towers even from the same vendor and in the same time period. The FACTS model requires several performance parameters for the tower besides the physical dimensions. Among these parameters is the performance of the fill.

The fill in each of the WBN towers is approximately 1.3 million flat asbestos fiber reinforced cement boards (ACB). No laboratory data is available for this exact type of fill. It has therefore been necessary to extrapolate based on the performance of similar fill. Differences in extrapolation result in changes in expected tower capability on the order of 5 percent. Rigorous calculations for the WBN fill have been proposed and rejected in past years. Because the fill contains asbestos fibers, it is likely that laboratory testing would have to be done in Germany or South Africa.

CCW Water Flow

A CCW flow rate of 420,000 gal/min was used based on TVA Engineering Issued Calculation EPM-JLG-030689.

Makeup Water Temperature

The makeup water was assumed to be at the tower exit temperature.

Capacity Factor

All of the results contained herein are based on 100 percent plant availability.

METEOROLOGY

The effect of thermal inversion (or lapse rate in general) on tower performance has been computed using the FACTS model. The lapse rate is the change in ambient air temperature with elevation. Results using the FACTS model have been compared to field data. As will be detailed subsequently, time did not permit a complete analysis of the impact of thermal inversions based on all available data.

TABLE 1
Results of WBN Simulations for 1949 through 1990

		<----------- 100% design							----------->	gen	<-------------- FACTS							------------->
year	gmax	genr	tlos	blos	lmax	lmin	lth	lbp	hrs	dif	genr	tlos	blos	lmax	lmin	lth	lbp	hrs
1949	10766	10523	242	1	1226	1099	66	64	43	45	10478	284	4	1223	1068	69	92	186
1950	10766	10535	231	0	1228	1144	62	23	5	42	10493	272	1	1227	1110	65	53	42
1951	10766	10532	233	1	1228	1121	64	44	42	44	10488	274	4	1227	1089	67	73	162
1952	10796	10560	235	1	1227	1112	65	52	50	44	10516	276	4	1224	1081	68	80	192
1953	10766	10530	236	0	1228	1116	64	48	30	43	10487	277	3	1225	1085	68	76	122
1954	10766	10530	235	0	1228	1116	64	48	32	42	10488	275	3	1225	1085	68	76	128
1955	10766	10532	234	0	1228	1125	64	40	18	42	10489	275	2	1226	1093	67	69	115
1956	10796	10561	235	0	1227	1150	62	18	7	42	10519	276	1	1224	1115	65	49	46
1957	10766	10524	241	0	1228	1144	62	23	7	42	10482	283	1	1226	1110	65	53	54
1958	10766	10543	223	0	1229	1169	60	0	0	40	10502	263	0	1227	1133	63	33	30
1959	10766	10528	238	0	1228	1139	62	27	19	43	10485	279	2	1226	1106	66	57	115
1960	10796	10571	224	0	1228	1161	60	8	2	41	10531	264	0	1226	1126	64	39	44
1961	10766	10550	216	0	1228	1170	59	0	0	42	10509	257	0	1226	1143	62	24	12
1962	10766	10539	227	0	1229	1151	61	16	5	41	10499	267	1	1227	1115	65	49	38
1963	10766	10554	212	0	1229	1171	58	0	0	41	10514	252	0	1228	1151	61	16	7
1964	10796	10577	218	0	1228	1169	60	0	0	41	10536	260	0	1225	1133	63	33	11
1965	10766	10527	239	0	1228	1144	62	23	14	42	10485	280	2	1226	1110	65	53	70
1966	10766	10542	223	1	1229	1114	65	50	22	43	10500	264	2	1228	1081	68	80	86
1967	10766	10547	219	0	1229	1172	57	0	0	42	10505	261	0	1227	1156	61	12	2
1968	10796	10578	217	0	1228	1150	62	18	15	42	10536	258	2	1226	1115	65	49	89
1969	10766	10549	217	0	1228	1157	61	11	11	42	10508	257	2	1226	1120	64	45	89
1970	10766	10533	233	0	1229	1135	63	32	20	42	10490	274	2	1227	1102	66	61	108
1971	10766	10535	231	0	1228	1169	60	0	0	41	10494	272	0	1226	1133	63	33	15
1972	10796	10572	223	0	1228	1155	61	13	7	42	10530	265	1	1227	1119	64	45	39
1973	10766	10531	235	0	1227	1160	61	8	2	42	10489	276	1	1225	1124	64	41	39
1974	10766	10536	230	0	1227	1172	57	0	0	41	10494	272	0	1224	1156	61	12	5
1975	10766	10529	237	0	1228	1169	60	0	0	43	10486	279	1	1225	1133	63	33	73
1976	10796	10577	219	0	1228	1144	62	23	16	43	10534	260	2	1226	1110	65	53	77
1977	10766	10520	245	1	1229	1124	64	41	65	46	10474	286	6	1227	1091	67	71	270
1978	10766	10530	235	1	1228	1109	65	55	38	43	10487	275	4	1226	1077	69	84	151
1979	10766	10536	230	0	1228	1150	62	18	6	42	10494	271	1	1226	1115	65	49	71
1980	10796	10554	237	5	1228	1067	69	93	189	49	10504	277	14	1227	1037	72	120	385
1981	10766	10531	233	1	1228	1114	65	50	78	46	10486	274	6	1227	1083	68	79	238
1982	10766	10526	240	0	1229	1151	61	16	5	42	10484	282	1	1228	1115	65	49	68
1983	10766	10540	224	3	1229	1056	70	103	86	45	10494	264	7	1227	1028	73	128	209
1984	10796	10573	223	0	1228	1155	61	13	1	42	10531	264	0	1226	1119	64	45	32
1985	10766	10537	229	0	1229	1146	62	21	13	43	10494	270	2	1229	1110	65	54	115
1986	10766	10527	238	0	1229	1130	63	36	37	44	10483	279	4	1227	1097	66	65	189
1987	10766	10536	229	0	1228	1125	64	40	30	44	10492	271	3	1225	1093	67	69	179
1988	10796	10571	223	2	1228	1061	70	98	88	46	10525	263	7	1226	1032	73	124	250
1989	10766	10536	230	0	1229	1140	62	26	25	44	10491	271	3	1227	1105	66	58	172
1990	10766	10525	241	0	1227	1139	62	27	21	43	10481	283	2	1224	1106	66	57	98
minimum		10520	212	0	1226	1056	57	0	0	40	10474	252	0	1223	1028	61	12	2
average		10543	230	0	1228	1137	62	29	25	43	10500	271	2	1226	1105	66	58	105
maximum		10578	245	5	1229	1172	70	103	189	49	10536	286	14	1229	1156	73	128	385

LEGEND

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gmax = maximum (name plate) total generation for year in GWHR
genr = total generation for year in GWHR
tlos = total lost generation due to thermal inefficiency for year in GWHR
blos = total lost generation due to backpressure for year in GWHR
lmax = maximum generator output in MW
lmin = minimum generator output in MW
lth = maximum lost generator output due to thermal inefficiency
lbp = maximum lost generator output due to backpressure
dif = design generation - FACTS generation in GWHR
hrs = number of hours backpressure limited
GWHR = 1000 MWHR (1000 megawatt-hours)

The National Weather Service (NWS) hourly record of dry-bulb and dew-point at the Knoxville Airport (TYS) from 1949 through 1990 was used in all of the present analyses except for the impact of thermal inversions and the variation of lost generation with respect to tower capability. The NWS data does not include vertical temperature variation and thus cannot be used to compute the lapse rate (variation of ambient temperature with elevation). The lapse rate has a pronounced impact on the performance of natural draft cooling towers, as will be detailed in a subsequent section.

The TVA weather station near WBN does record the dew-point at 10 meters as well as the dry-bulb at 10, 45, and 91 meters above ground level on an hourly basis. This record is available, but does not cover the long period of the TYS data. The WBN data contains some missing and erroneous data. Past experience with similar data from SQN and BFN has indicated that detecting and replacing bad data is not a trivial task. The NWS has already done this for their data. It would have reduced the uncertainty in the present analysis to have obtained and verified all of the available WBN data and used this along with the extended TYS data to quantify the impact of meteorology on plant capacity and generation; but resources and schedule did not permit this.

METHODOLOGY AND RESULTS

The methodology and results of the analyses are described herein and the corresponding tables and figures are included.

Cooling Tower Performance

The cooling tower performance curves supplied by the manufacturer, Research-Cottrell, as well as the results of the FACTS model were curve-fitted using standard least-squares regression in order to provide code modules which would return tower exit water temperature as a function of range (the difference between tower inlet and exit water temperatures), wet-bulb, relative humidity, and water flow rate.

Extended Backpressure Correction Curves

The backpressure correction curves provided by Westinghouse are not in a directly useful form. They come as percent correction to heat rate or load as a function of condenser steam flow for various backpressures. In order to apply these corrections, it is necessary to transform them into percent correction to heat rate or load as a function of backpressure for various reactor power levels (which, for instance, is the form of the correction curves supplied by General Electric). In addition to transforming the independent variables, it is necessary to generate a curve fit so that the corrections can be built into the various computer codes.

Individual points were lifted from the correction curves for SQN as well as WBN, as these are identical except that the SQN curves cover from 1.0 to 3.5 inches Hga in steps of

0.5; whereas, the WBN curves cover from 1.0 to 5.0 inches Hga in steps of 1.0. A comparison of the points lifted from the Westinghouse curves and the curve fit are shown in Figure 1.

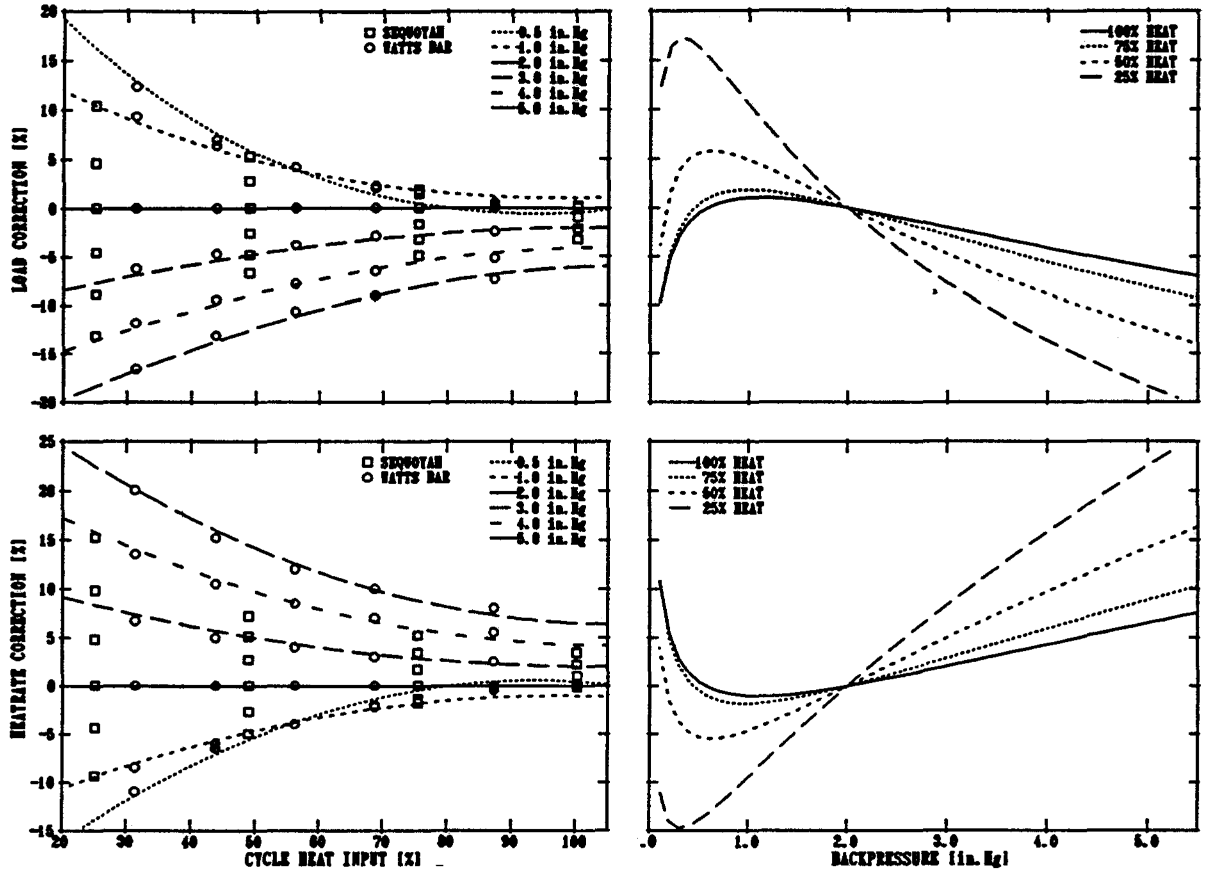

Figure 1. Transformed Backpressure Correction Curves

Generator Output and 3rd-Zone Backpressure vs. CCW Inlet Temperature

A code module was developed which would return generator output and 3rd-zone backpressure as functions of reactor power input, CCW flow, CCW inlet temperature, and condenser cleanliness. Parameters from the four TVA heat balances were curve-fitted and combined with the HEI calculations as detailed in the section on Assumptions and the extended backpressure correction curves to arrive at the necessary code modules. The results of these modules for a heat input of 3425 MWt are illustrated in Figures 2 and 3.

Generator Output and 3rd-Zone Backpressure vs. Wet-Bulb

A code module was developed which would return generator output and zone backpressures as functions of reactor power input, CCW flow, CCW inlet temperature, condenser cleanliness, wet-bulb, relative humidity, and tower capability. The code modules

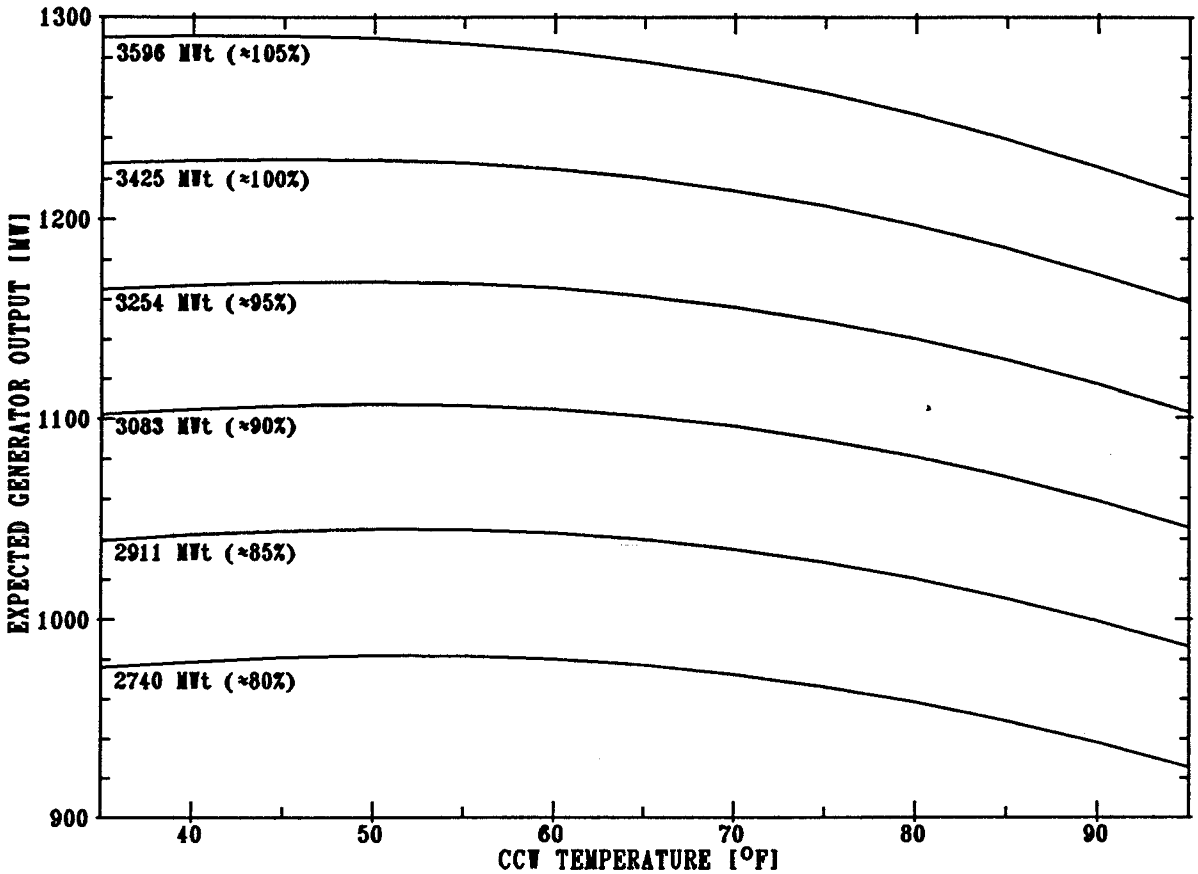

Figure 2. Generator Output vs. CCW Inlet Temperature

returning cooling tower performance, generator output, and 3rd-zone backpressure were combined in order to provide these functions. The results of these modules for a heat input of 3425 MWt are illustrated in Figures 4 and 5.

Figure 4 shows the results without any restriction on 3rd-zone backpressure and Figure 5 shows the results with a limiting backpressure of 5.5 inches Hga. Both correspond to a reactor power input of 3425 MWt, which is the amount shown on the TVA heat balance labeled "Maximum Guaranteed Throttle Flow with 2 MFPT's." Both of the figures show the generation and 3rd-zone backpressures for 80, 90, and 100 percent tower capability as well as the results of the FACTS model.

Lost Generation and Maximum Load Reduction

The code modules were then used to simulate plant operation based on the TYS data set which included 368,160 hourly values of dry-bulb and dew-point. Due to the contracted schedule, only two cases were run for the entire period of record: 100 percent design tower capability and the performance indicated by the FACTS model. The results for 1949 through 1990 are given in Table 1. A summary is given in Table 2.

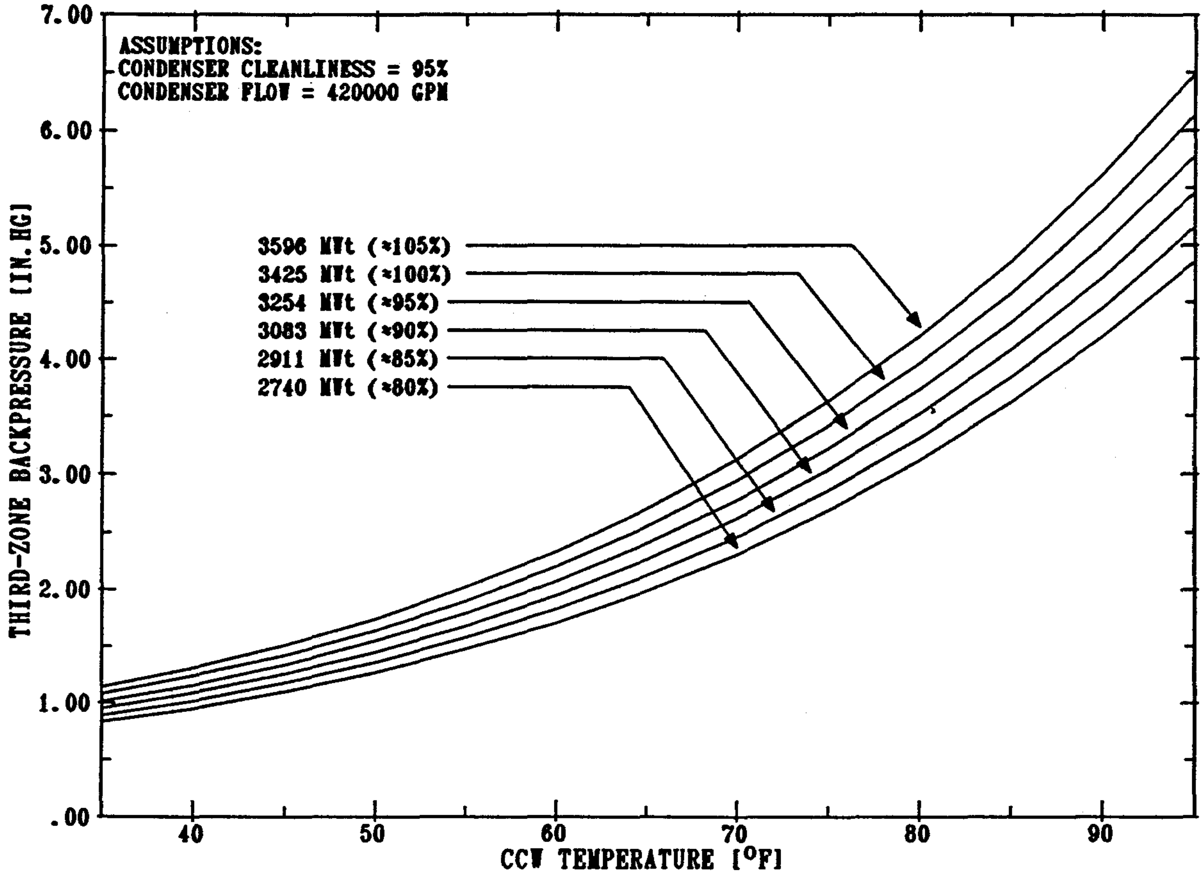

Figure 3. 3rd-Zone Backpressure vs. CCW Inlet Temperature

The Impact of Thermal Inversions on Tower Performance

The impact of thermal inversions on tower performance was computed using the FACTS computer model for a range of lapse rates (variation of ambient air temperature with elevation). These results are shown in Figure 6 which also shows field data and a curve-fit which was obtained by Ben Sherlock of EBASCO from a cooling tower manufacturer. The computer model results compare well with the field data and are well within the range of scatter in the data.

Norris Nielsen, meteorologist with the Atmospheric Sciences Department, supplied a data set for quantifying the temperature inversions at WBN. This data set includes the hourly record for 1988 of the dew-point at 10 meters and the dry-bulb at 10, 45, and 91 meters above ground level at the WBN met station. While this record covers only a single year, it is thought to be more or less typical. Analysis of a larger record could not be completed within the time frame of the current project.

The 1988 met data was used with this performance correction to quantify the expected

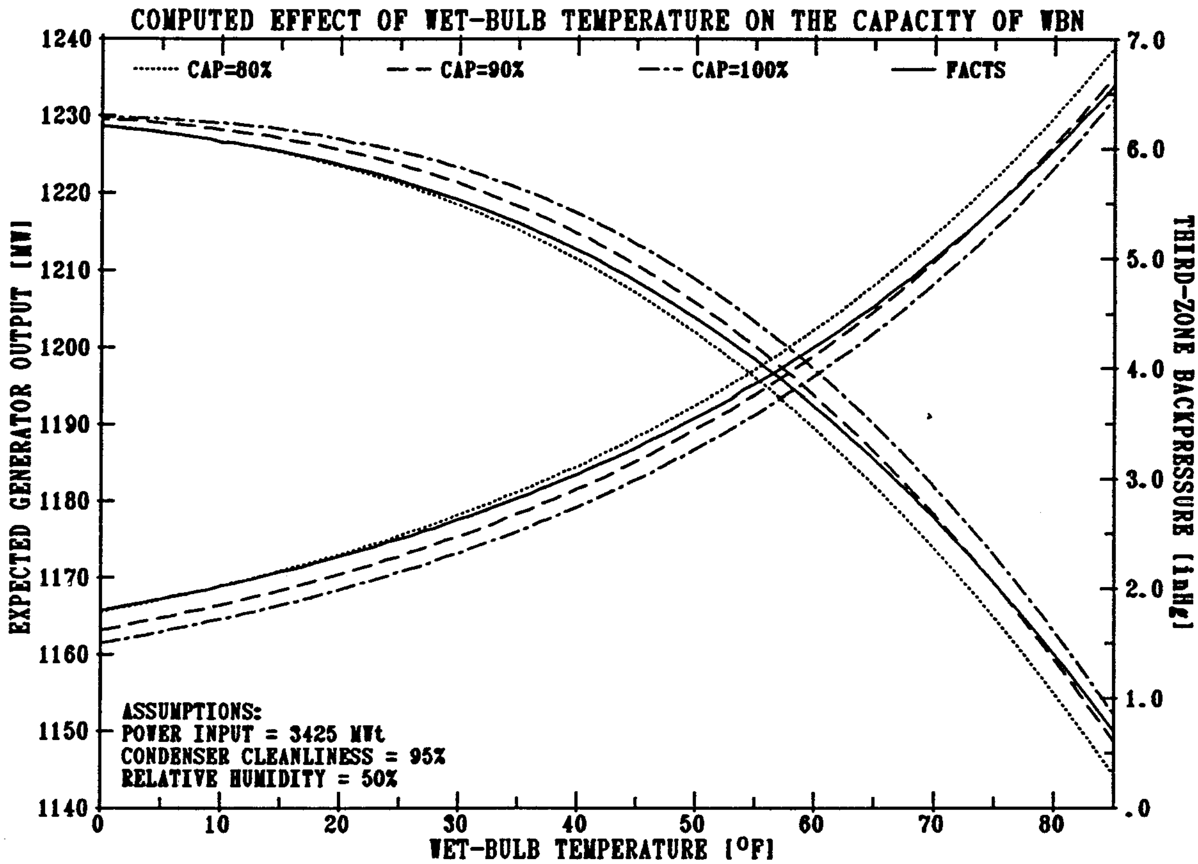

Figure 4. Generator Output and 3rd-Zone BP vs. Wet-Bulb w/o Limited BP

impact of thermal inversion on the performance of the WBN towers. The maximum degradation (due to adverse conditions) was found to be -20 percent. The maximum enhancement (due to favorable conditions) was found to be +5 percent. The arithmetic average effect was found to be -3 percent, while the root-mean-square average was -7 percent. Figure 7 is a scatter plot which reveals that the impact of thermal inversions on tower performance occurs over the entire range of wet-bulbs, and therefore cannot be classified as a seasonal phenomenon.

In order to contain 95 percent of the impact on tower performance due to thermal inversions (based on the 1988 data), it is necessary to consider the tower capability to be short by 12 percent. This 12 percent must be considered in addition to any shortfall due to undersizing by Research-Cottrell as well as, and any other, effects such as wind or physical condition of the fill, spray nozzles, or distribution system.

Estimated Performance of Cooling Towers with Additional PVC Fill

The FACTS cooling tower model was used to estimate the potential increase in tower performance which could be expected by adding PVC film fill above the existing ACB fill. It was found that between 5 and 9 percent increase in performance could be expected

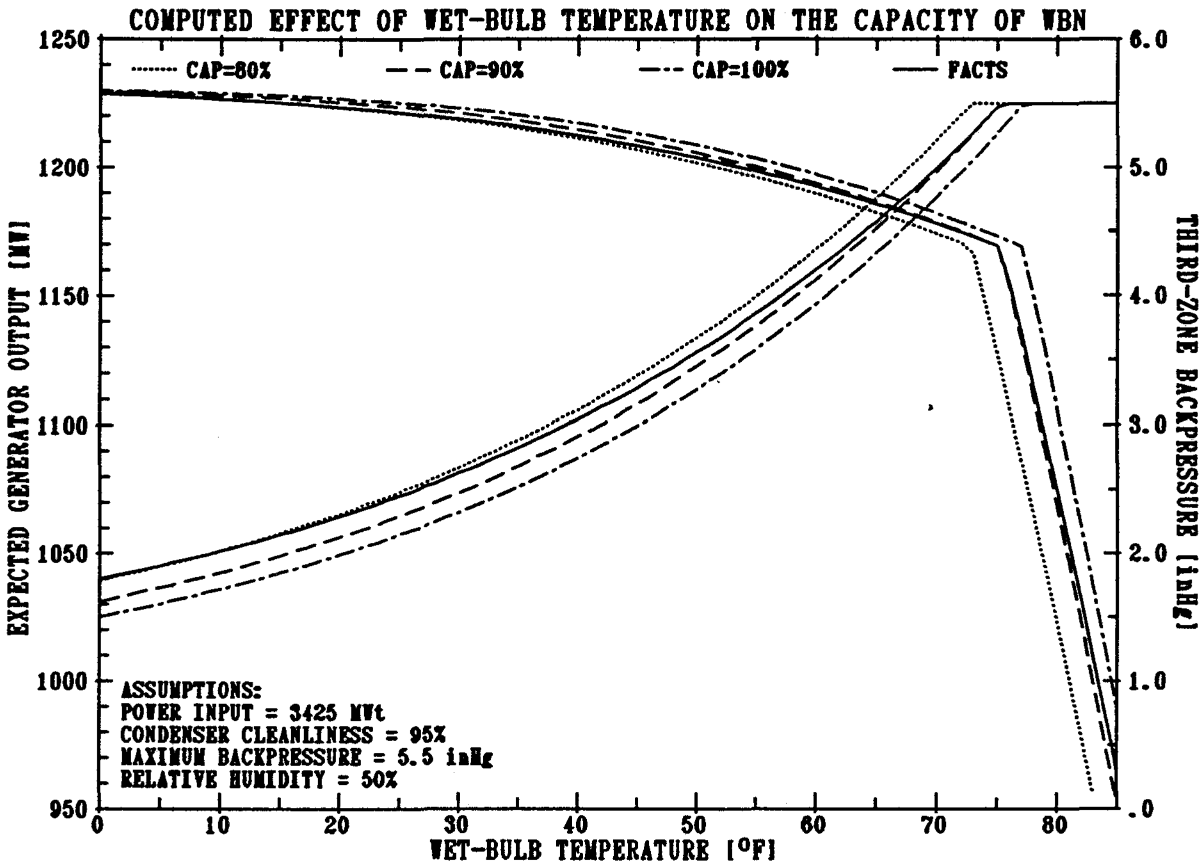

Figure 5. Generator Output and 3rd-Zone BP vs. Wet-Bulb with Limited BP

depending on whether the PVC fill were added around the periphery on Tier 6 or filling in all of Tier 5 up to the level of Tier 6. Some problems do exist with this type of installation including potential plugging of the PVC fill and degradation of spray coverage due to a reduced spray zone. Neither of these effects have been considered in these calculations.

Estimated Performance of Cooling Towers with Added Spray Trees

The performance of the cooling towers with added spray trees was computed as part of this study. The performance of the spray trees was computed by Jerry Hubble and Tom Eldredge using the THERMAL2 computer code which was developed by TVA Nuclear Engineering in 1983. The THERMAL2 code was validated using field and model test data. The THERMAL2 code provided exit wet-bulb, water droplet temperatures, and induced draft based on inlet water temperature and meteorology. Chuck Bowman determined the practical size of the spray trees based on available head and nozzle characteristics.

The FACTS cooling tower code was modified to allow the exit conditions from the sprays (which was output from the THERMAL2 code) to be prescribed as inlet boundary conditions to the tower, thus linking the two models together. The combined performance was computed to be approximately 7 percent greater than the tower without the spray trees.

TABLE 2
Summary Results of WBN Simulations

	best year	ave. year	worst year
DESIGN (100%) tower performance			
generation lost due to thermal [GWHR]	212	230	245
generation lost due to backpressure [GWHR]	0	(0.4)	5
total lost generation [GWHR]	212	230	249
largest load reduction due to thermal [MW]	57	62	70
largest load reduction due to backpressure [MW]	0	29	103
largest total load reduction [MW]	57	91	173
number of hours of backpressure-limited operation	0	25	189
FACTS tower performance			
generation lost due to thermal [GWHR]	252	271	265
generation lost due to backpressure [GWHR]	0	2	14
total lost generation [GWHR]	252	273	279
largest load reduction due to thermal [MW]	61	66	73
largest load reduction due to backpressure [MW]	12	58	128
largest total load reduction [MW]	73	124	201
number of hours of backpressure-limited operation	2	105	385
INCREMENT: 100% design - FACTS tower performance			
generation lost due to thermal [GWHR]	40	41	20
generation lost due to backpressure [GWHR]	0	2	9
total lost generation [GWHR]	40	43	30
largest load reduction due to thermal [MW]	4	4	3
largest load reduction due to backpressure [MW]	12	29	25
largest total load reduction [MW]	16	33	28
number of hours of backpressure-limited operation	2	80	196

Note: GWHR = 1000 megawatt hours

The thermodynamic maximum gain in performance which could be achieved is 11 percent. The computed performance with and without spray trees is shown in Figure 8 along with 80, 90, and 100 percent tower capability.

Estimated Value of Cooling Tower Capability

The capability of a cooling tower is defined as the ratio of the actual water flow to that indicated by the manufacturer's performance curves which the tower should be able to cool the same amount under the same meteorological conditions. A tower which is found to cool the same water flow to a lower temperature or a greater water flow to the same temperature than expected is said to have a capability in excess of 100 percent. The reverse is said of a tower having a capability less than 100 percent. While this definition may not seem to be useful, it is widely used in the industry and under certain restrictions, multiple towers can be added in a manner analogous to flashlight batteries, where water flow is analogous to current and temperature is analogous to voltage.

The 1988 WBN met data was used to provide an estimate of the value of tower capability in terms of lost generation. The results are listed in Table 3. Only 1988 met data was used because of schedule limitations and its use in the thermal inversion calculations. The WBN met data does vary somewhat from the TYS met data so that the lost generation computed for a tower capability of 100 percent does not match exactly that listed in Table 1 (227 as compared to 225 GWHR/year). It should also be noted that 1988 is within

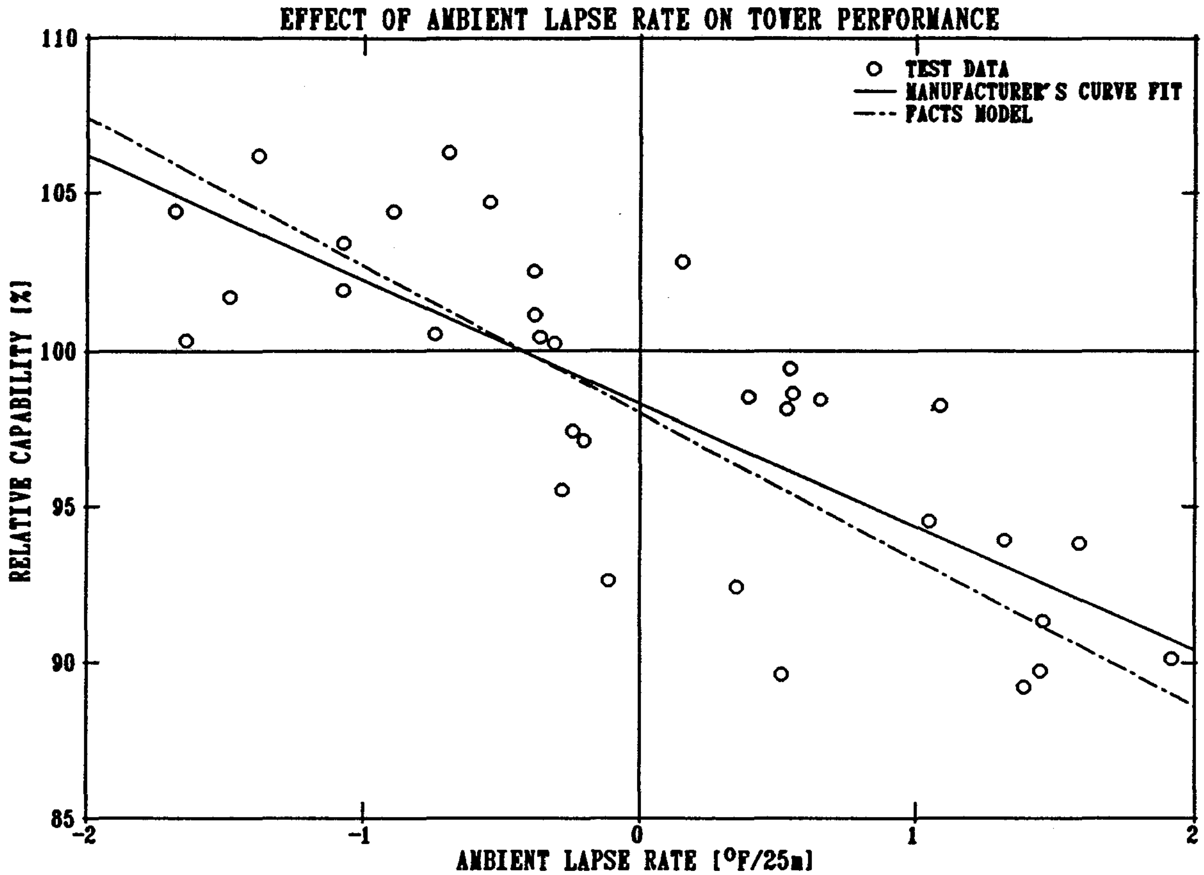

Figure 6. Effect of Ambient Lapse Rate on Cooling Tower Performance

TABLE 3
Estimated Value of Tower Capability

Cap	Ethr	Etot	BPhr	Tval
60	373	488	1849	19.7
70	318	359	769	8.7
80	278	293	377	4.9
90	248	253	160	3.2
100	225	227	57	2.3
110	206	207	19	1.9
120	188	188	8	1.7

Cap is the tower capability relative to the design in percent
Ethr is the total lost generation due to thermal effects in GWHR
Etot is the total lost gener. due to thermal effects plus BP in GWHR
BPhr is the number of hours operation would be limited by 5.5 inch Hg BP
Tval is the value of tower capability in GWHR/year/%

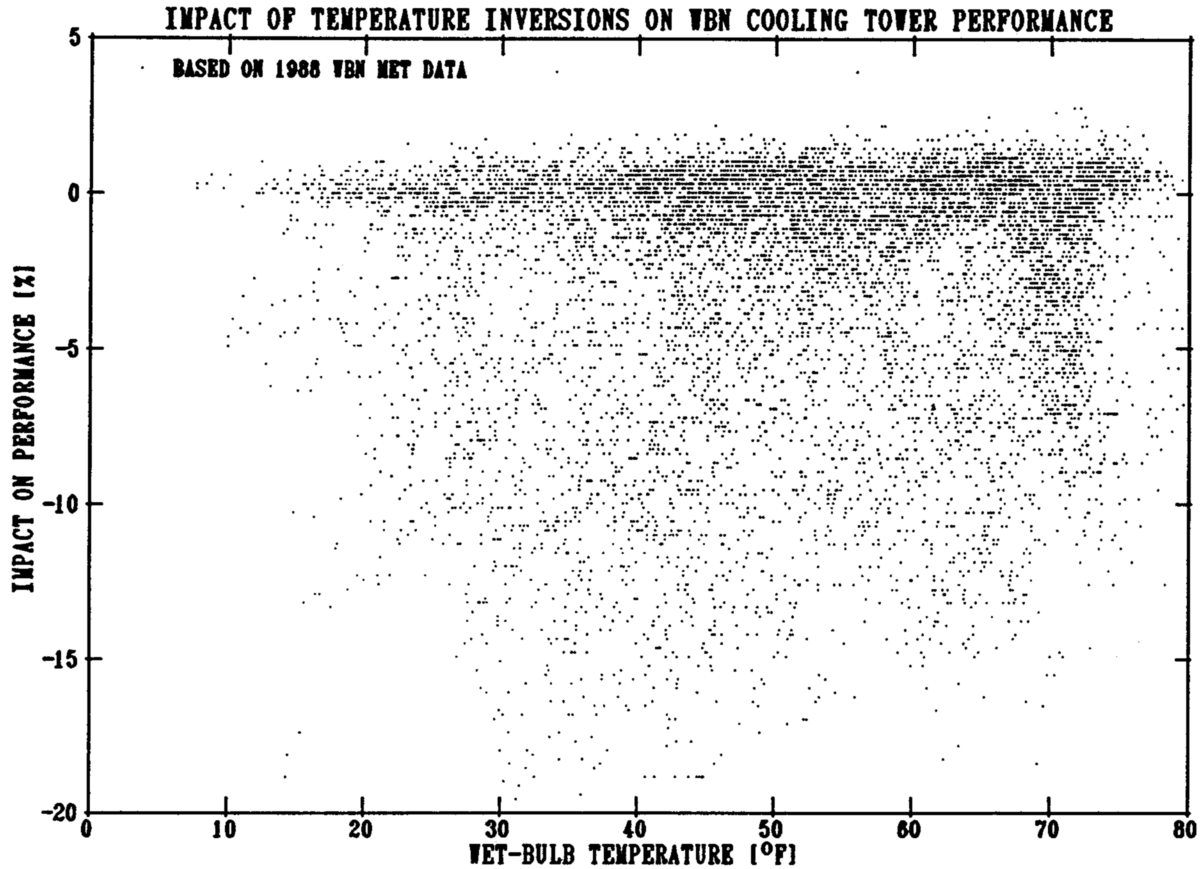

Figure 7. Impact of Temperature Inversions on WBN Cooling Tower Performance

2 percent of the average for the 42 years of record (225 as compared to 230 GWHR/year).

Table 3 shows that a tower capability of 90 percent would result in an average lost generation of 253-227=26 GWHR/year (26000 megawatt-hours/year), 248-225=23 of which would be due to thermal effects and 26-23=3 would be due a backpressure limit of 5.5 inches Hga. Table 2 also shows that each percentage point of capability at 90 percent translates to an average lost generation of 3.2 GWHR/year.

Notice also that there is a diminishing return for each percentage point with increasing tower capability (i.e., a 200 percent tower may provide twice the cooling capacity of a 100 percent tower; but that increase in tower capacity does not double the output of the plant). The information in Table 2 is also shown graphically in Figure 9.

If the towers were found to have a capability of 90 percent under favorable conditions, the average additional impact of thermal inversions would be (3%)*(3.2 GWHR/year/%) = 9.6 GWHR/year (9600 megawatt-hours/year). The maximum impact under adverse (inversion) conditions would be considerably larger as previously indicated by the 20 percent maximum degradation and 12 percent degradation to include the 95 percentile occurrence.

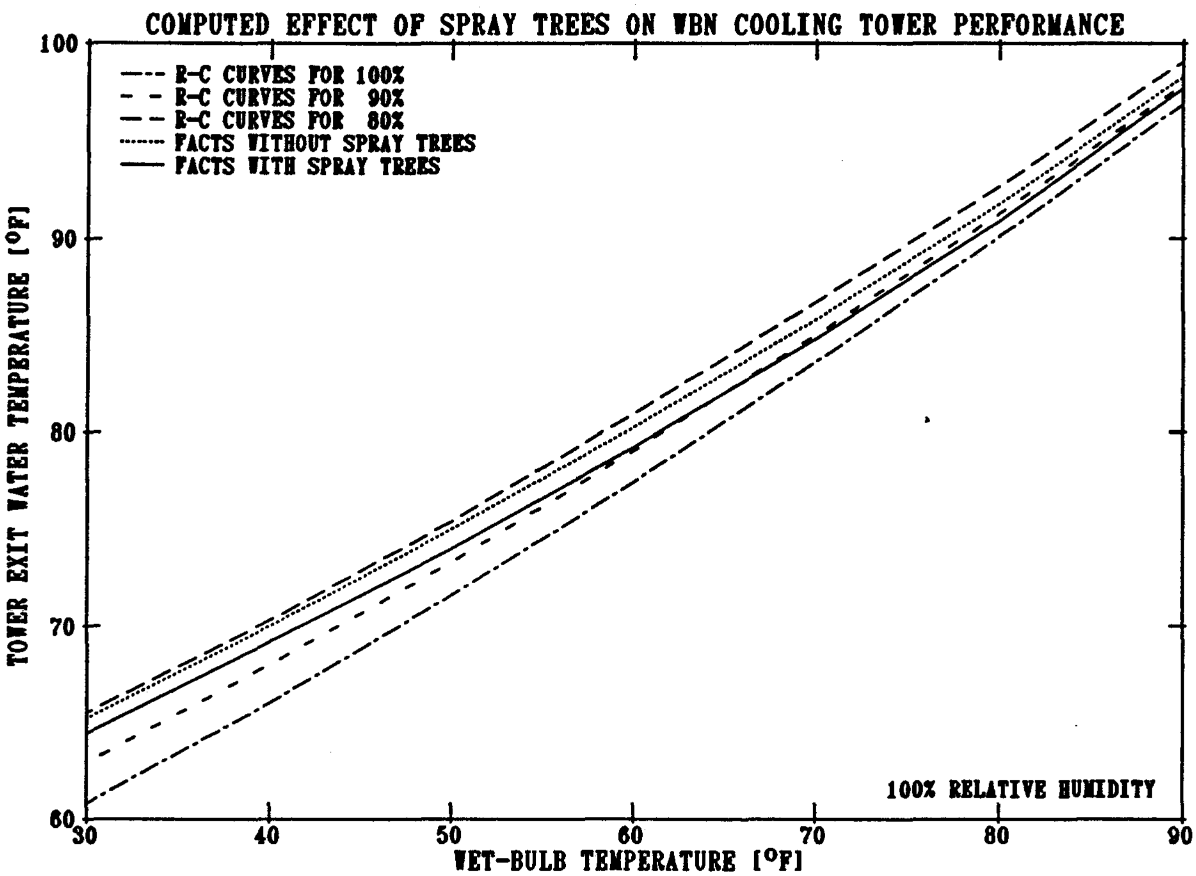

Figure 8. Computed Effect of Spray Trees on WBN Cooling Tower Performance

If the towers were found to have a capability of 90 percent without the spray trees and the increase in performance were 7 percent, then the reduction in lost generation achieved with the spray trees would be (7%)*(3.2 GWHR/year/%)=22.4 GWHR/year (22400 megawatt-hours/year).

Computed Backpressure Resulting in Unit Trip

A concern which raised by M. R. Harding of Nuclear Power Central Staff is that the backpressure alarm point should be sufficiently below the trip point such that the loss of a single CCW pump would not implicitly result in a unit trip. If all of the before-stated assumptions are made, along with a trip point of 7 inches Hga and a 3-pump CCW flow of 370,000 gal/min, the calculations show that the alarm should be no higher than 6 inches Hga. There is, of course, no additional margin in this calculation.

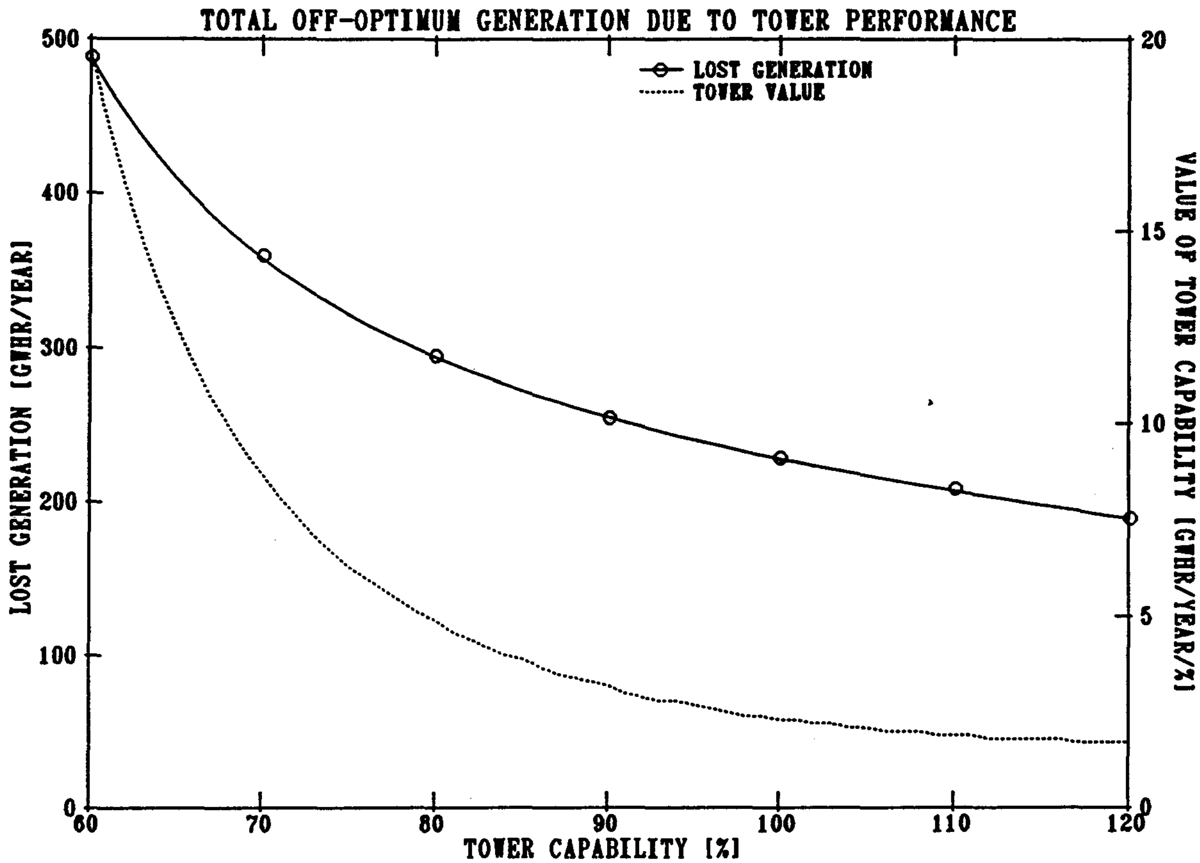

Figure 9. Total Off-Optimum Generation Due to Tower Performance

DIFFERENCES BETWEEN THE PRESENT AND PREVIOUS RESULTS

The previous analyses performed by DJB--and particularly those presented at the January 29 meeting between staff of the Engineering Laboratory and senior management of Nuclear Power--were based on different key parameters than the current analysis. These differences are summarized in Table 4. By far the most significant difference between the present and previous analyses is the limiting backpressure. This difference is illustrated in Figure 10. The parameters used in the present analysis as directed by the Team are non-conservative; whereas analyses in the past were conservative.

TABLE 4
Comparison of Past and Current Assumptions

Assumption	Jan'92	Apr'92	Avg.Impact*
Limiting Backpressure	4.5	5.5	100xMWhr/yr
Condenser Cleanliness	90%	95%	1.5xMWhr/yr
CCW flow	410000	420000	1.05xMWhr/yr
BP correction	consv.	optm.	1.25xMWhr/yr

* 100x means 100 times the number of MWhr/yr

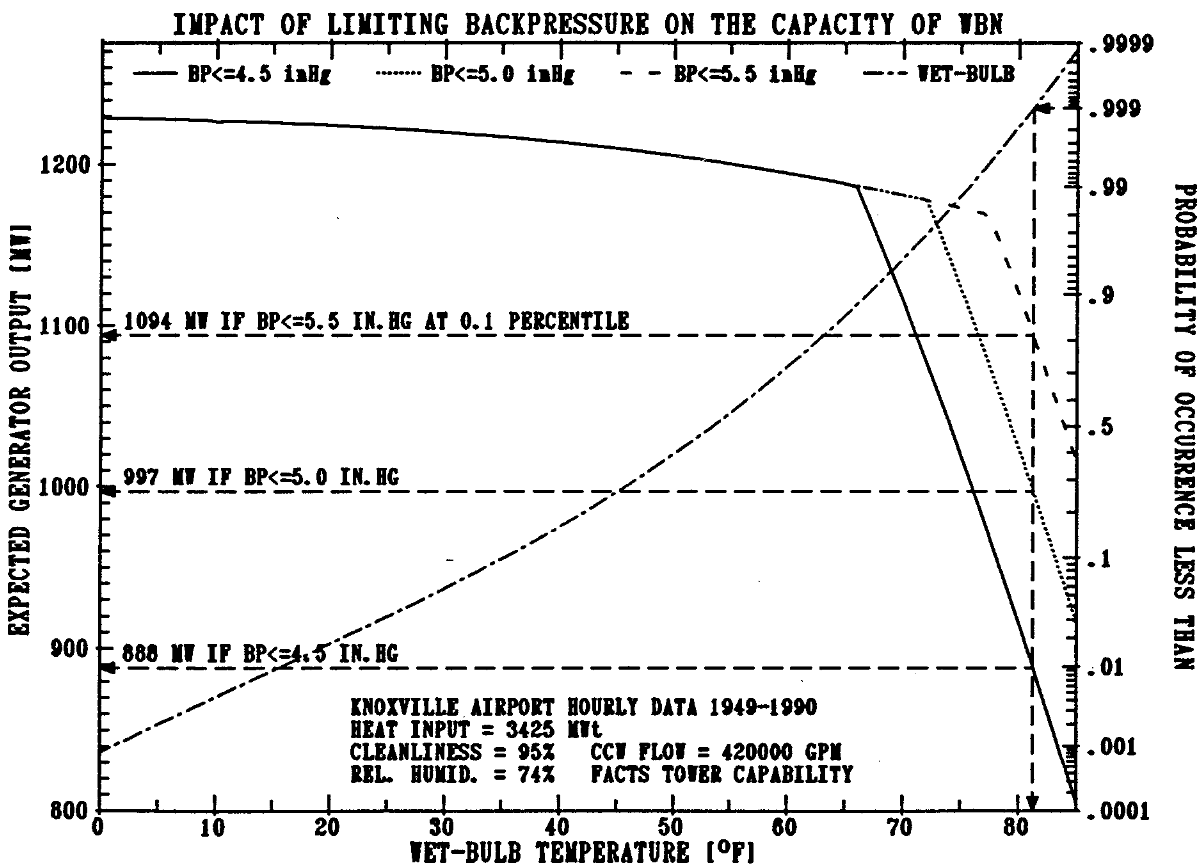

Figure 10. Impact of Limiting Backpressure on the Capacity of WBN