MILLIKEN CLEAN COAL TECHNOLOGY DEMONSTRATION PROJECT

UNIT 2 ELECTROSTATIC PRECIPITATOR PERFORMANCE TEST RESULTS BEFORE AND AFTER MODIFICATION

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EXECUTIVE SUMMARY

As part of NYSEG's Milliken Station Clean Coal Technology Demonstration project, electrostatic precipitators (ESP) on the two 160 MW_e boilers were upgraded to accommodate the wet flue gas desulfurization system. Upgrades of the ESP on each unit consisted of replacement of the internals and retirement of part of the original ESP. A wide plate spacing design with a 16-inch plate spacing was provided by the ESP vendor, Belco Technologies, Inc. The modified unit is smaller and requires less power.

CONSOL Inc., Research & Development, conducted performance tests on the original and modified ESPs. The same coal was fired in the boiler during these tests. The modified ESP with less than one-half of the collection plate area has better removal efficiency than the original unit. The voltage-current product data indicate that the power requirement is 25% less than that of the original ESP. Data collected for the modified ESP was used to evaluate *ESPert,*™ the EPRI ESP computer model. This comparison is reported separately.

INTRODUCTION

NYSEG's Milliken Station was extensively modified to accommodate a wet flue gas desulfurization system. Modifications included upgrading the ESPs on Unit 1 and Unit 2. Design criteria for upgrading the precipitator were based, in part, on the requirements imposed by the flue gas desulfurization system designed by Saarberg-Hölter Umwelttechnik GmbH (S-H-U). This report discusses results of performance testing of the Unit 2 ESP before and after the modification.

Originally, the Unit 2 particulate control system consisted of two ESPs in series, stacked one on top of the other. The ESP for each unit consisted of two independent sections with the gas flow separating upstream of the air heater and rejoining downstream of the final ESP. Each ESP section on Unit 2 consisted of two fields energized by a total of ten transformer-rectifier (TR) sets. During the modifications, the bottom ESP was completely removed while the top ESP was rebuilt. The internals of the top ESP were replaced using a wide plate spacing design by Belco Technologies Corp. An additional third field was added to the ESP. Six new computer controlled TR sets were installed replacing the original ones. The physical characteristics of the old and new ESP systems are shown in the following table.

Precipitator Characteristics

	Original ESP[1]		
	Lower ESP	Upper ESP	New ESP
Date Built	1955-58	1971-74	1993
Plate Spacing, inches	8.75	9	16
Plate Height, feet	20	30	30
Fields	2	2	3
Field Depth, feet, each	9	9	9
Gas Velocity, fps	5.7	3.4	3.7
SCA, ft^2/1,000 acfm gas @ full load	150	242	175

As shown in this table, the plate spacing was increased from approximately nine inches to sixteen inches while the total number of fields decreased from four to three. The SCA at full load decreased from 392 to 175 ft^2 per 1,000 acfm of flue gas. Even with the reduced SCA, the new design was projected to have a higher removal efficiency. This is because the wider plate spacing permits higher applied voltages. The effectiveness increased 80%; that is, the new effectiveness is 1.8 times the original one (16 over 9). Similarly, the operating power was expected to decrease by 262 kW.

The modified Milliken Unit 2 ESP still consists of two separate, parallel sections: a south, or "A," ESP and a north, or "B," ESP. Gas flow is evenly split between these sections. Each side has an additional division wall that runs the length of the ESP box. The south and north sides are identical parallel precipitators with separate TR sets enclosed in a single box. Three fields on each side are individually powered by a total of six TR sets.

Testing of the original and modified ESPs was conducted by CONSOL Inc., Research & Development to document the effect of the modifications. ESP inlet and outlet data were obtained for the following parameters:

- Total Particulate Matter (PM)
- Sulfur Dioxide (SO_2)
- Sulfuric Acid Mist (SO_3)
- Particle Size Distribution
- Flue Gas Composition (O_2, CO_2, N_2 and H_2O)
- Volumetric Flue Gas Flowrate
- Flue Gas Temperature
- Fly Ash Resistivity at the ESP Inlet

Coal and fly ash samples were collected and analyzed. TR set primary voltage, primary current and secondary current data were collected during the original baseline ESP performance evaluation. This information along with additional plant data was collected during the modified ESP performance evaluation. The additional plant and ESP operating data for the modified ESP were required for evaluation[2] of the EPRI ESP predictive model, *ESPert.*™

Baseline performance evaluation was conducted in April 18-20, 1994. The detailed data/evaluation report for the baseline performance test is provided as Appendix 1. On October 17-20, 1995, the performance test of the modified Unit 2 ESP was completed. The test results for the modified ESP are reported in Appendix 2. A medium sulfur (1.8 wt % sulfur), bituminous coal was fired in the boiler during both trials. During the modified ESP field tests, data were collected for each side of the ESP separately. The two sides of the modified ESP were treated as separate, independent units each treating one-half of the Unit 2 boiler flue gas. The baseline performance test was conducted on the total inlet/outlet flows.

DISCUSSION OF THE RESULTS

Performance of the modified ESP exceeded that of the original ESPs at lower power requirement. As the particle size decreases, the performance differences disappear. The performance was calculated from the total particulate concentrations into and out of the ESP. This was used to calculate the penetration. In general, penetration is independent of the absolute concentration for a given size. Penetration is:

$$\text{Penetration} = 100 - \text{Percent Removal}$$

or

$$\text{Penetration} = 100 - \left[\frac{\text{Concentration of Solids in Outlet}}{\text{Concentration of Solids in Inlet}}\right] \cdot 100$$

Penetrations for the <10 Fm and <2.5 Fm fractions were calculated using the daily particle size data. The size test provided the size distribution for the total particulate concentrations conducted on the same day. Thus,

$$\text{Penetration, } <10\,\mu\text{m Frac.} = 100 - \left[\frac{(\text{Outlet Size, } <10\,\mu\text{m Frac.}) \cdot (\text{Conc. of Solids in Outlet})}{(\text{Inlet Size, } <10\,\mu\text{m Frac.}) \cdot (\text{Conc. of Solids in Inlet})}\right] \cdot 100$$

The equation for the <2.5 Fm fraction is similar.

The coal and fly ash properties did not change appreciably between the baseline test and the performance test on the modified ESP as shown in Tables I and II. Inlet fly ash particulate size consists also are similar, as shown in Figure 1. The curves have a similar shape for the finer particulate fractions. Coal sulfur levels, ash concentrations and higher heating values are similar on a dry basis. Fly ash carbon content was slightly higher in the baseline test)) 4.04 wt % versus 2.40 wt %. Fly ash resistivities are also similar. (See Figure 2 and Tables III and IV.) Based on the information shown in these figures and tables, the coal and fly ash properties were identical for both performance tests. Inlet solid concentrations were also similar for both test series. The inlet loading varied between 2.2 and 2.9 gr/dscf.

Results of the performance tests are shown in Figures 3 through 5. These figures show the penetration for the total, the <10 Fm, and <2.5 Fm size fractions. Figure 3 shows that the overall removal improves for the modified ESP, shown on the left portion of the figure. The average penetration before modification is 0.22 % versus 0.12 % after. For the <10 Fm fraction and the <2.5 Fm fraction, shown on Figures 4 and 5, respectively, the differences appear minimal. Penetration of these fractions is dominated by the finest particulate fractions. The very fine particulate is only a small portion of the total inlet sample and thus, small variations dominate the results. For example, the <2.5 Fm fraction is less than 5% of the inlet material. For the particulate fraction >10 Fm, the penetration is the same for both performance tests at 0.02 %.

Shown on Figure 6 are the total V-I (voltage-current product) demands for the original and the modified ESPs. V-I demand is directly related to the power requirement. The modified ESP has 75% of the V-I demand of the original ESPs. The new TR sets show a higher primary voltage, as seen in Tables V and VI. The primary current is about the same; thus, since the modified area is about one-half that of the original ESP, the secondary voltage is about double that for the original ESPs with a 9-inch plate spacing. More than 50% of the V-I requirement is associated with the third field on each side of the modified ESP.

CONCLUSIONS

The modified ESP performs better than the original unit at a lower operating (power) cost. Overall penetration for the modified ESP is about half that of the original ESP. This improvement occurs with a 25% savings in V-I power requirements. The modified ESP has a smaller plant footprint with fewer internals and a smaller SCA. Total internal plate area is less than one-half that of the original ESPs, tending to lower the capital cost.

Data collected for the modified ESP was used to evaluate *ESPert,*™ the EPRI ESP computer model. Results of this comparison are reported separately.

REFERENCES

1. Marker, B. L. and Beckman, E. G. "ESP Modifications at NYSEG's Milliken Station Units 1 and 2," *Joint ASME/IEEE Power Generation Conference*, Kansas City, Kansas, October 17-22, 1993.

2. Maskew, J. T. and Marker, B.*, Comparison of* ESPert™ *Model Predictions with Unit 2 Electrostatic Precipitator Performance*, Milliken Clean Coal Technology Demonstration Project—Interim Report to USDOE, October 1996.

Figure 1

ESP Inlet Size Consist

NYSEG's Milliken Station

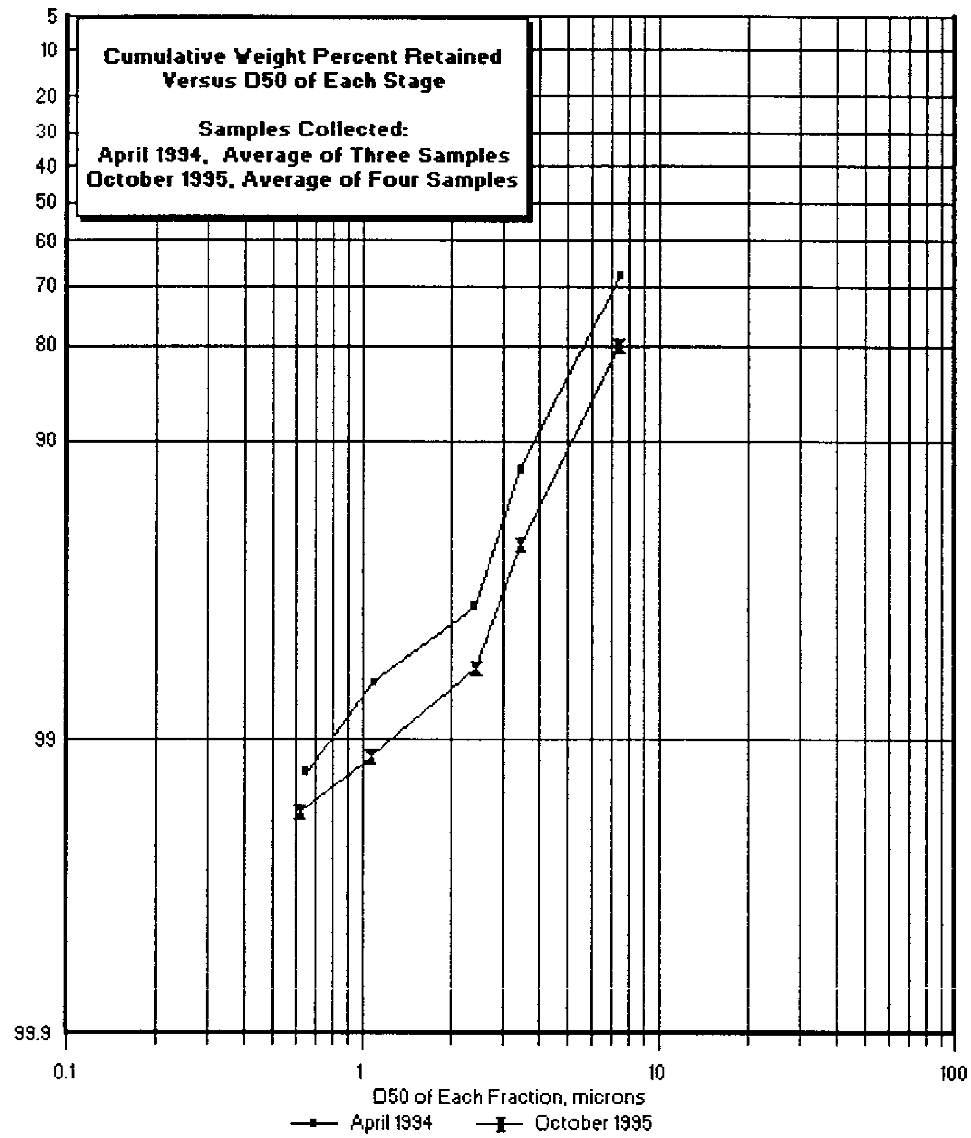

Figure 2

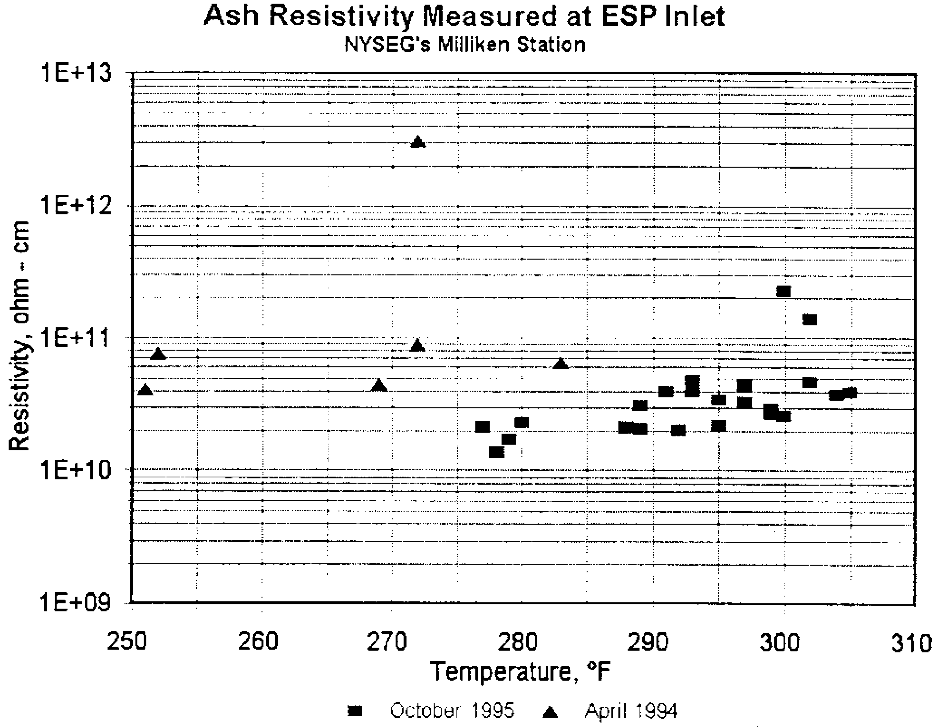

Figure 3

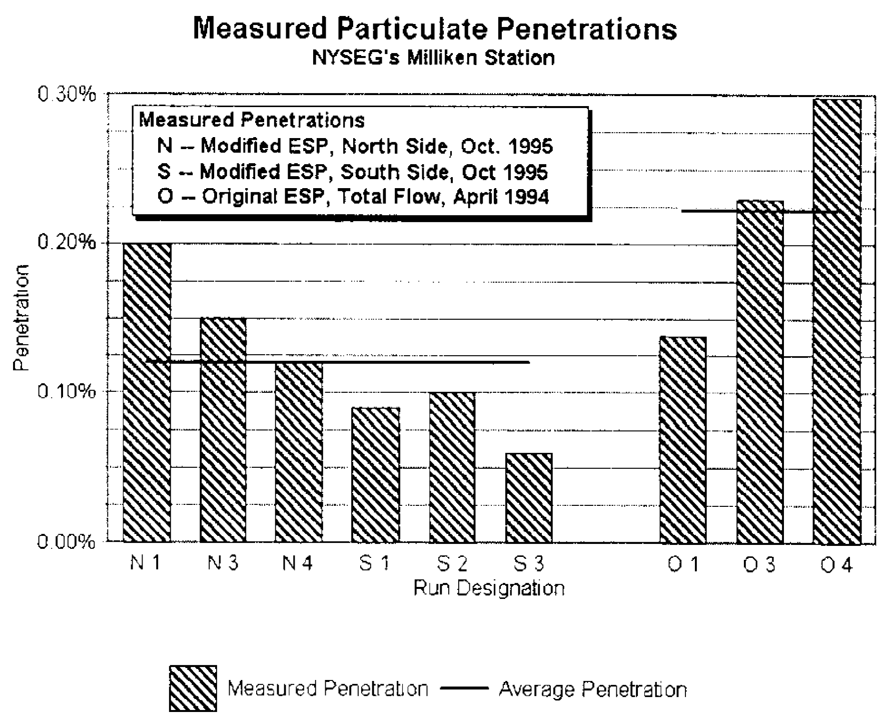

Figure 4

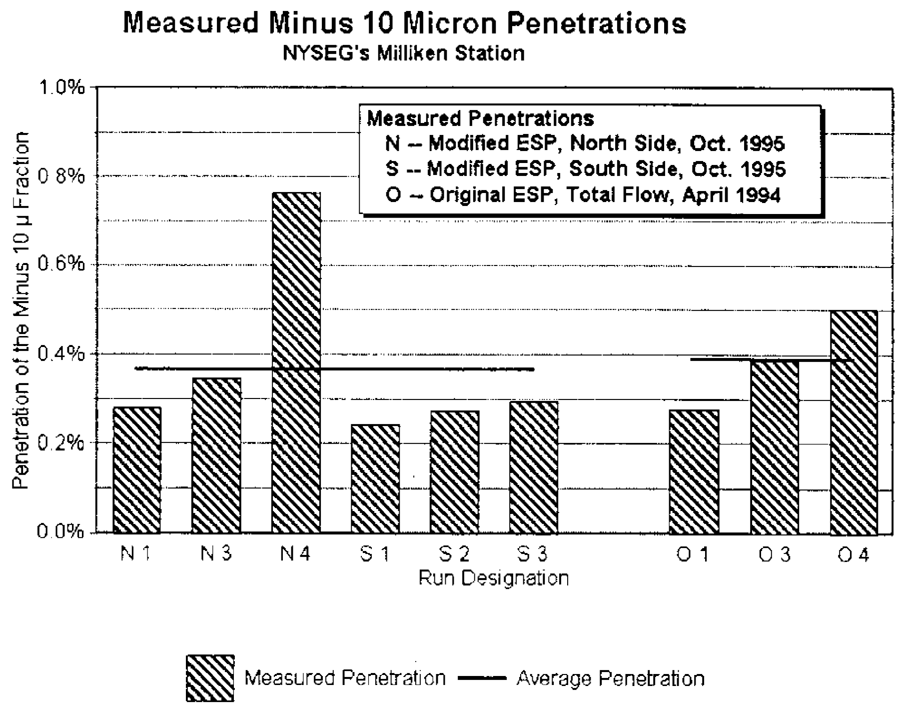

Figure 5

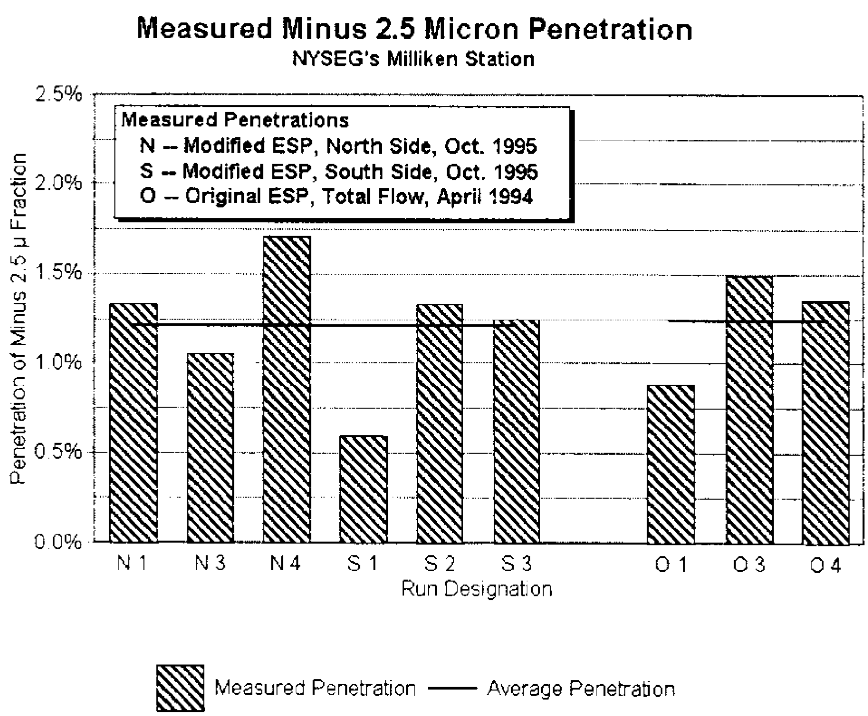

Figure 6

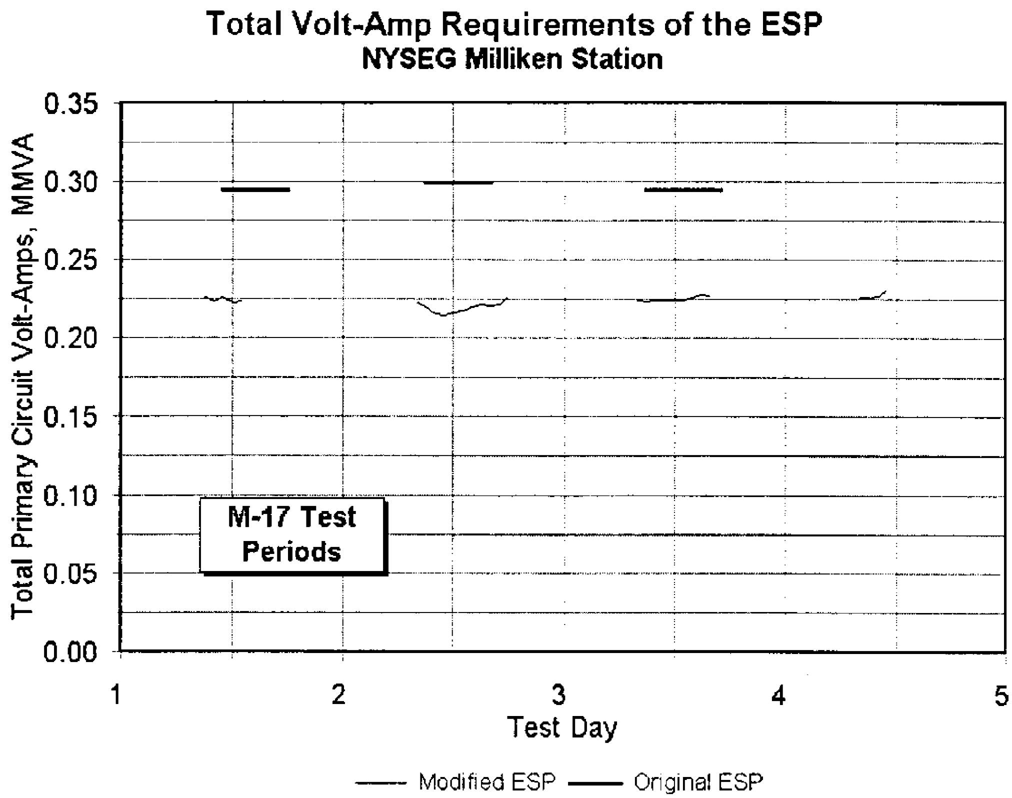
Total Volt-Amp Requirements of the ESP
NYSEG Milliken Station
Total Primary Circuit Volt-Amps, MMVA
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
M-17 Test
Periods
1
2
3
4
5
Test Day
Modified ESP
Original ESP

Table I

AVERAGE COAL ANALYSES

Coal Type: Bituminous

Coal analysis, wt% dry basis	April 1994	October 1995	
Moisture	--	6.46	
Carbon	78.01	78.77	
Hydrogen	5.25	5.10	
Nitrogen	1.51	1.57	
Oxygen (diff)	6.35	5.54	
Sulfur	1.79	1.87	
Ash	7.10	7.15	
HHV	13,950	14,000	Btu / lb
Ash analysis, wt% ash			
Li_2O	--	0.02	
Na_2O	--	0.65	
K_2O	--	1.73	
MgO	--	0.78	
CaO	--	2.83	
Fe_2O_3	--	18.26	
Al_2O_3	--	23.47	
SiO_2	--	47.44	
TiO_2	--	0.96	
P_2O_5	--	0.50	
SO_3	--	2.48	
Unknown	--	0.87	

Average of the analyses of the daily cumulative samples.

Table II

FLY ASH ANALYSES

Ash analysis, wt% as received	April 1994	October 1995
Carbon	4.04	2.40
Nitrogen	0.03	--
Sulfur	0.35	0.45
Moisture	--	0.46
Ash	--	96.87

Average of the analyses of the test samples.

Table III

APRIL 1994 FLY ASH RESISTIVITY

Date	Duct / Port	Temp., °F	Resistivity, Ohms
4/17/94	A / 8	283	6.51×10^{10}
4/18/94	A / 2	251	4.09×10^{10}
4/18/94	A / 2	252	7.67×10^{10}
4/18/94	A / 5	269	4.49×10^{10}
4/18/94	B / 2	272	3.09×10^{12}
4/18/94	B / 5	272	8.90×10^{10}
4/18/94	B / 9	230	5.69×10^{10}

Table IV

OCTOBER 1995 ASH RESISTIVITY

	Samples Collected from North-Side				Samples Collected from South-Side			
	October 17		October 18		October 19		October 20	
Port	Temp., °F	Resistivity, Ohm	Temp., °F	Resistivity, Ohm	Temp., °F	Resistivity, Ohm	Temp., °F	Resistivity, Ohm
B	297	4.49×10^{10}	302	1.39×10^{11}	289	2.02×10^{10}	295	2.20×10^{10}
D	291	3.90×10^{10}	293	4.74×10^{10}	299	2.93×10^{10}	302	4.67×10^{10}
F	288	2.09×10^{10}	297	4.23×10^{10}	293	3.87×10^{10}	292	1.98×10^{10}
H	299	2.68×10^{10}	305	3.86×10^{10}	277	2.07×10^{10}	280	2.29×10^{10}
J	289	3.02×10^{10}	297	3.30×10^{10}	295	3.43×10^{10}	300	2.25×10^{10}
L	278	1.72×10^{10}	278	1.37×10^{10}	304	3.69×10^{10}	300	2.58×10^{10}

Table V

APRIL 1994 ESP TR-SET PRIMARY SIDE CONDITIONS
MILLIKEN UNIT 2 ESP BASELINE TESTS

	17-Apr-94		18-Apr-94		19-Apr-94	
TR-Set Designation	Primary Voltage, Volt	Primary Current, Amp	Primary Voltage, Volt	Primary Current, Amp	Primary Voltage, Volt	Primary Current, Amp
TR-2A3-2S	260	78.0	261	78.5	260	78.5
TR-2A3-1	245	130.0	255	135.0	250	135.0
TR-2A3-2N	235	63.0	240	63.0	235	63.0
TR-2B4-2S	245	63.0	245	62.0	245	62.0
TR-2B4-1	290	140.0	290	140.0	290	140.0
TR-2B4-2N	240	71.0	240	71.0	240	61.0
TR-2A1-2	280	142.0	280	142.0	280	142.0
TR-2B2-2	290	135.0	290	136.0	285	135.0
TR-2B2-1	290	140.0	290	140.0	290	140.0
TR-2A1-1	270	132.0	275	133.0	275	134.0

Table VI

OCTOBER 1995 ESP TR-SET PRIMARY SIDE CONDITIONS
MILLIKEN UNIT 2 MODIFIED ESP TESTS

Averages of Readings Recorded During the Performance Tests

	17-Oct-95		18-Oct-95		19-Oct-95		20-Oct-95	
TR-Set Designation	Primary Voltage, Volt	Primary Current, Amp	Primary Voltage, Volt	Primary Current, Amp	Primary Voltage, Volt	Primary Current, Amp	Primary Voltage, Volt	Primary Current, Amp
TR-1B1	298	38.2	290	34.8	294	36.6	292	35.7
TR-2B2	388	82.9	397	86.5	389	82.8	390	83.3
TR-2B3	440	125.3	421	120.9	442	128.1	441	132.6
TR-2A1	272	36.6	265	33.0	270	35.0	268	34.8
TR-2A2	434	103.1	425	105.0	431	102.8	429	104.1
TR-2A3	471	150.6	468	151.6	473	151.6	473	153.8