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Review of Concurrent Mass Emission and Opacity Measurements for Coal-burning Utility and Industrial Boilers

Interagency Energy/Environment R&D Program Report

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EPA REVIEW NOTICE

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Review of Concurrent Mass Emission and Opacity Measurements for Coal-burning Utility and Industrial Boilers

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ABSTRACT

Concurrent particulate emissions and opacity measurements based upon visual observations and/or in-stack transmissometry are reported for more than 400 compliance, acceptance, or experimental tests on coal-fired utility and industrial boilers. The sampling, which includes a capacity range of a few to several hundred megawatts and typical firing methods (pulverized, stoker and cyclone) in most cases reflects flyash control by electrostatic precipitation although filters or mechanical collectors were used at a few installations. All opacity measurements were standardized to their equivalent values for a 4 meter (13.0 ft) diameter stack before comparisons were made with their corresponding particulate emissions, the latter expressed as actual grams per cubic meter. No discernible correlations applicable to all sources were observed although some modest but apparently significant correlations were noted on an individual source basis. Thus, any useful and definitive relationships between particulate mass emission rates and their corresponding opacity levels appear to be site specific. Furthermore, correlations with transmissometer measurements were far stronger than those derived from visual estimates of opacity. The report findings are considered sufficiently encouraging to warrant further analyses of the existing and new data to determine how effective a monitoring tool in-stack transmissometer measurements might be with skillful application.

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We also wish to acknowledge the assistance of the following GCA personnel; Mr. Michael Jasinski who helped compile and proof the tabular material and Ms. Deborah Stott, Judith Wooding and Ann Marie Tirone who prepared the final graphs and tables.

SECTION 1

SUMMARY AND RECOMMENDATIONS

Particulate emission data based upon more than 400 compliance, acceptance or experimental stack samples and concurrent visibility data based upon in-stack transmissometer measurements and/or visual opacity estimates for the flue gas plumes were collected from Federal, State, and Local pollution control agencies. These data were collated and analyzed to determine the degree of correlation between particulate emissions expressed either as mass concentration (g/m^3) or the emission rate per unit heating value of the fired fuel (ng/J) and flue gas opacity. The outstack (visual) opacity observations were standardized to their equivalent values for a 4 meter (~13 ft) diameter stack by means of Bougeur's Law[1] (see Section 3).

Standardized opacities were then plotted as a function of particulate mass emission rates ng/J ($lb/10^6$ Btu), or particulate mass concentrations as grams per actual cubic meter (g/am^3) or grains per actual cubic foot (gr/aft^3). No discernible correlations applicable to all sources were observed although some modest but apparently significant correlations were noted on an individual source basis. Thus, any useful and definitive relationships between particulate mass emission rates and their corresponding opacity levels appear to be site specific. Furthermore, correlations with transmissometer measurements were far stronger than those derived from visual estimates of opacity. Although the regression lines developed from in-stack opacity estimates could not be used for accurate prediction of mass emission ($\pm$20 percent accuracy at best for a 95 percent confidence interval) it appeared that with an improved and more detailed description of all system operating parameters, considerable data refinement might be obtainable.

The findings presented in this report are considered sufficiently encouraging to warrant further analyses of the existing and new data to determine how effective a monitoring tool in-stack transmissometer measurements might be with skillful application.

It is expected that further review of data collected over a period of years will not have the value of recently performed tests where the sources can be contacted easily for additional information. Thus, it is also recommended that concurrent opacity measurements by both visual and stack transmissometer techniques be performed if possible when compliance tests are conducted. At these times, it is essential that boiler control device and fuel parameters be clearly defined so that variables impacting upon opacity and mass emission can be correlated to the maximum extent.

SECTION 2

INTRODUCTION

CURRENT STATUS, NSPS FOR PARTICULATE MASS EMISSIONS AND OPACITY

Particulate emissions from fossil fuel-fired boilers are presently regulated by two standards, the first describing an allowable emission rate based upon the boiler heat input; i.e., ng/J or lb/10^6 Btu and the second, the light obscuring properties of the exiting flue gas as estimated by visual observations and defined in terms of plume opacity. Prior to promulgation of the Method 9 technique for determining plume opacity, early regulations simply prohibited "dense black smoke" while later Ringelman and more recent opacity regulations placed quantitative limits on the percent of incident light that any colored exhaust plume could obscure.

While a source must comply with both the mass emission and opacity sections of the current legislation, it is recognized that compliance with mass standards does not necessarily assure compliance with opacity standards. Official recognition of this fact is exemplified by EPA's recent ruling exempting Southwestern Public Service (SPS) Company's Harrington Station Unit No. 1 from the present NSPS opacity standard of 20 percent. The SPS electrostatic precipitator and marble bed scrubber control system were able to meet all emission criteria including the NSPS particulate mass emission standard yet could not, without extensive retrofit at a significantly increased cost, meet the 20 percent opacity limit. Thus, while the mass emission standard remained unchanged, the general operating opacity limit was raised by EPA from 20 to 35 percent[2].

The above NSPS modification is based on regulations cited under 40 CFR 60.11(e) that allow any source that complies with all applicable standards except for opacity to request a source specific opacity limit.

PROGRAM OBJECTIVE

The development of a reliable, albeit empirical, correlation between plume opacity by either in-stack transmissometer measurement or by visual observations of the plume and particulate mass emissions would greatly assist those agencies responsible for enforcement of emissions regulations. The basic objective of the present study is to establish whether useful correlations have been demonstrated (or might be) and which measured parameters best describe any such mass emission-opacity relationships.

BACKGROUND DATA

Several empirical and theoretical correlations between stack transmissometer tests and/or visual opacity measurements and mass emissions criteria have been proposed for specific sources. Schneider[3] demonstrated a consistent relationship between in-stack flue gas optical density measurements and effluent particulate concentration for a coal-fired utility boiler (Figure 1), while Hurley and Bailey[4] (Figure 2) and Stoecker[5] (Figure 3) reported similar correlations for small, hand-fired coal boilers. Reisman et al.[6] investigated the relationship between in-stack particulate opacity as computed from transmissometer measurements and mass concentration for six industrial sources that included a large oil-fired utility boiler. Schiff[7] (Figure 4) also noted a good correlation between particulate emission rate and in-stack opacity for three large coal-fired units. The Industrial Gas Cleaning Institute (IGCI) has estimated the maximum outlet particulate concentration for various processes for which there are no discernible visual indications of particle presence. The flue gas parameters are based on actual operating conditions reported by a comprehensive sampling of member companies. The results of this survey are presented in Table 1.

TABLE 1. CLEAR STACK CRITERIA. EMISSION LEVELS PRODUCING CLEAR, OR NEARLY CLEAR PLUMES (EXCEPTING CONDENSED MOISTURE)*

Utility or industrial boiler	ESP and fabric filter outlet concentration g/m^3 at ^oC (gr/ft^3 at ^oF)	Wet scrubber outlet concentration g/m^3 at 21^oC, 101 kPa (gr/ft^3) at 70^oF, 14.7 Psig
Coal		
Pulverized	0.046 at 127-160 (0.020 at 260-320)	0.066-0.071 (0.029-0.031)
Cyclone Boiler	0.023 at 127-160 (0.010 at 260-320)	0.032-0.037 (0.014-0.016)
Stoker-fired	0.114 at 177-232 (0.050 at 350-450)	0.183-0.206 (0.080-0.090)
Oil	0.007 at 149-204 (0.003 at 300-400)	0.0108-0.0121 (0.0047-0.0053)

*From the Industrial Gas Cleaning Institute, Inc., Alexandria, VA

The basic physical laws governing plume opacity are well-documented in the literature. The theoretical computation of aerosol optical properties is usually based on Maxwell's[8] classical relationships defining the interactions between electromagnetic radiation (visible spectrum in the present case) and suspended particulates and the solution of these equations as proposed by von Mie.[9] The theoretical treatment for the special case of particles smaller than the wavelength of the incident light is described by the Rayleigh approach.[10]

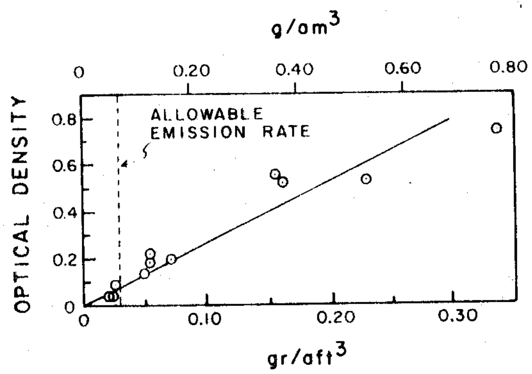

Figure 1. Flue gas in-stack optical density versus outlet particulate concentration for a large coal-fired utility boiler.[3]

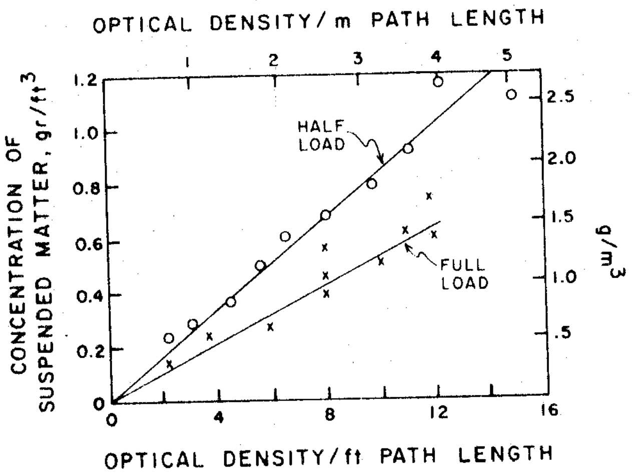

Figure 2. Flue gas in-stack optical density versus outlet particulate concentration and firing rate for a small hand-fired boiler.[4]

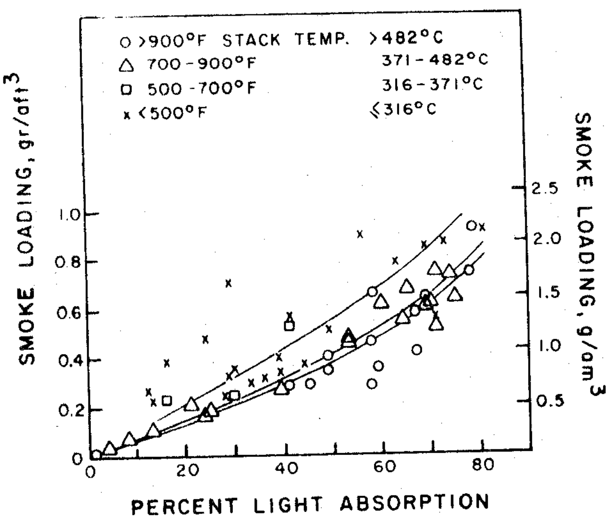

Figure 3. Flue gas light absorption versus particulate concentration for an experimental stoker-fired furnace with a 0.15 m (6 in.) diameter stack.[5]

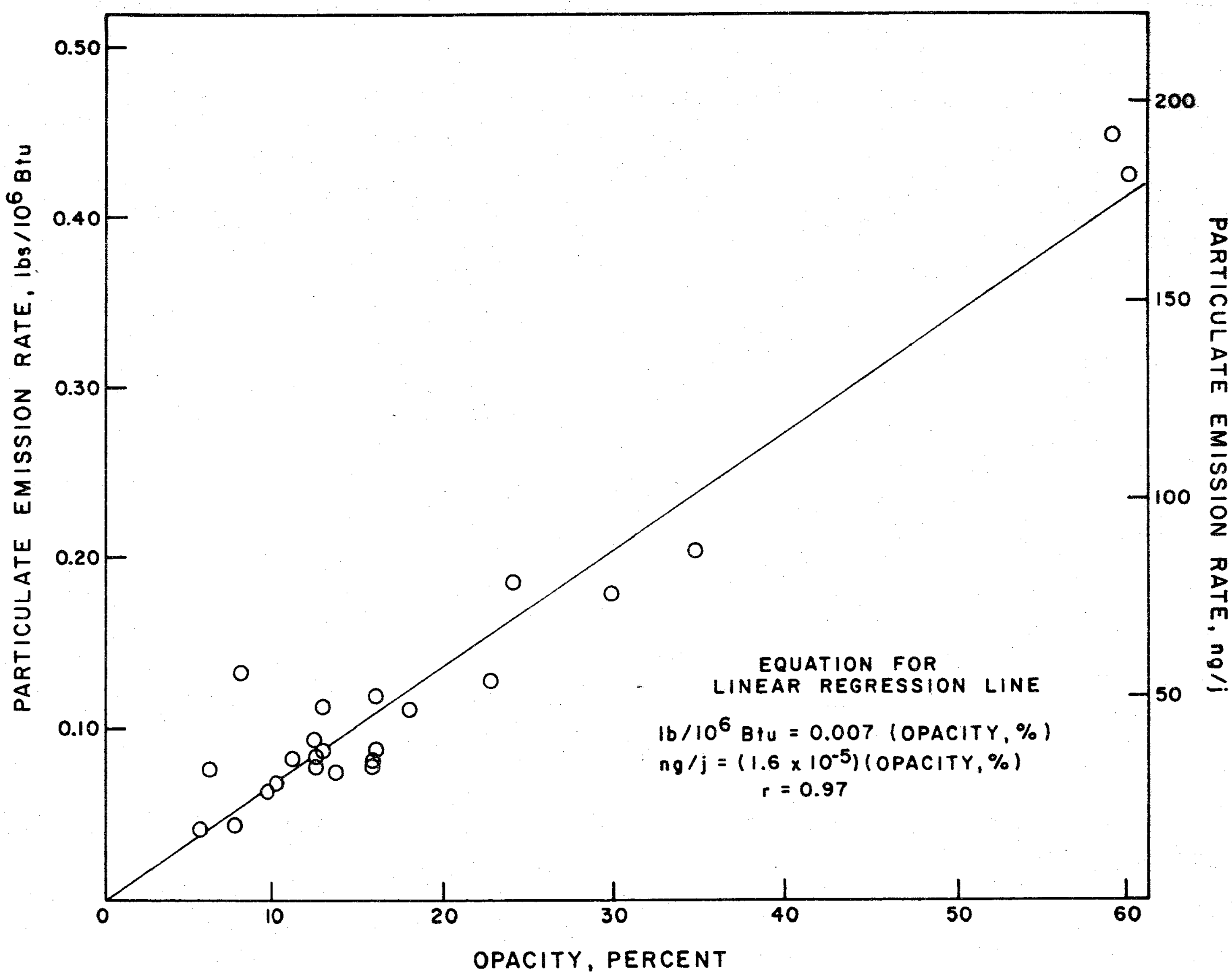

Figure 4. Particulate emission rate versus in-stack opacity for three coal-fired utility boilers and equivalent stack diameter of 4.6 m (15 ft).[7] (Electrostatic precipitator effluents.)

Ensor and Pilat (1971)[11] developed a computer program utilizing the Mie concepts from which the light attenuating properties of a stack plume containing a broad particle size spectrum could be calculated. Using a method similar to that reported by Ensor and Pilat, Severson et al. in a recent EPRI study[12] have calculated the theoretical opacities for several outlet particle size distributions and loadings for correlation with the corresponding mass emission rates,[12] Figure 5. Halow and Zeek[13] utilized particle optical properties and Mie theory in their computer based system to correlate the color contrast between the plume and ambient background with the observed opacity. They have also investigated the effect of viewer orientation or perspective with respect to sun location and observer angle.

Wier et al.[14] pointed out several factors that can affect plume appearance and hence its opacity as determined by visual emissions estimates. A partial listing of external factors influencing an observer's judgment include:

- Color contrast ratio between the plume and ambient background,
- Stack (plume) diameter,
- Position of the sun and observer relative to the stack,
- Elevation of the observer relative to the top of the stack.

These have been discussed by Fennelly and Lilienfeld[15] in the "Opacity Handbook," an EPA sponsored document describing the history and present status of opacity legislation and visible emission observation procedures.

The methodology employed by environmental agencies to assess plume opacity by visual observation does not make any quantitative allowance for the several external factors that may influence the observer's description of plume appearance. However, the official methodology does acknowledge their impact on a qualitative basis. In fact, EPA Method 9[16] is based on estimating procedures by which the observed plume opacity (or more correctly, appearance) tends to be less than the true opacity as determined by in-stack transmissometry.[17]

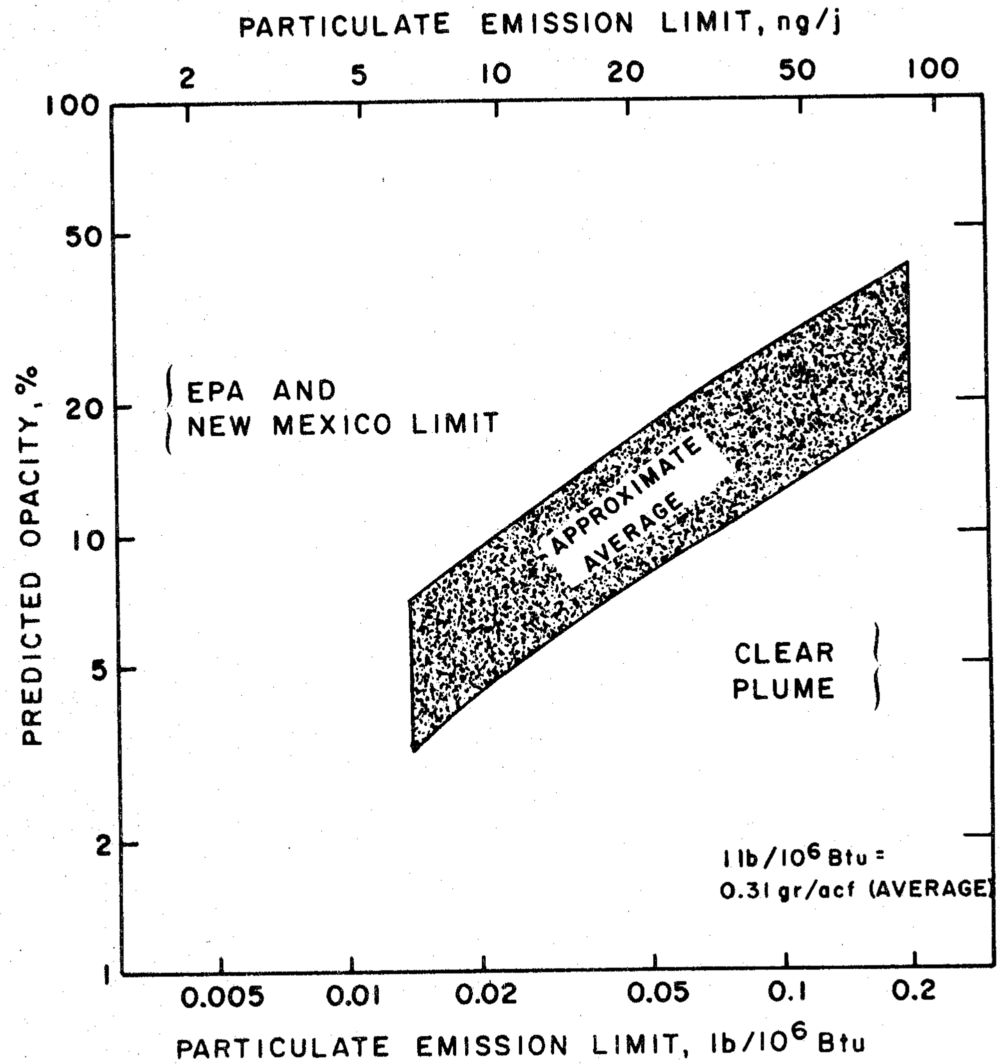

Figure 5. Predicted opacity versus coal flyash outlet loading from electrostatic precipitators for several particle size distributions.[12]

SECTION 3

BASIC OPACITY RELATIONSHIPS

The fundamental relationship between plume opacity and the characterizing aerosol properties responsible for the observed opacity condition is described by Bougeur's Law,[18] viz.

$$\text{Opacity} = 1 - I/I_o = 1 - T = 1 - \exp(-bL) \quad (1)$$

where:

I/I_o = the ratio of the amount of light transmitted through the plume to the amount of light incident upon the plume

$T = I/I_o$ = transmittance = 1 - opacity

b = extinction coefficient for the aerosol (m^{-1})

L = depth of plume or length of obscuring light path as defined approximately by stack exit diameter (m).

The extinction coefficient, b, may be expressed by the following relationship:

$$b = Sp\ W \quad (2)$$

where:

Sp = specific projected particle extinction area, m^2/g (ft^2/gr)

W = particulate mass concentration, g/m^3 (gr/ft^3)

Although the term W is readily measured, the quantity b in Equation 2 can be defined only through the solution of the classical electro-optical equations by complex computer techniques. For example, b is calculated from the relationship:

$$b = \pi \int_{r_1}^{r_2} Q_E\ (\alpha,m) r^2\ n(r)\ dr \qquad (3)$$

α = size parameter, $2\pi r / \lambda$

r = particle radius

λ = wavelength of light

m = refractive index of particle relative to air

$n(r)$ = size frequency distribution, number of particles of radius r per volume of aerosol per Δr

$Q_E(\alpha,m)$ = particle light extinction efficiency factor, the total light flux scattered and absorbed by a particle divided by the light flux incident on the particle.

For highly specialized circumstances where laboratory studies permit rigorous control of particle composition with respect to shape, surface, and refractive index and the intensity and wavelength of the incident light are precisely defined, the validity of Equation 3 may be successfully demonstrated. Conversely, the fact that the composition spectrum of real life aerosols is virtually unknown except for crude estimates of particle dimensions suggests that any detailed theoretical approach is not always justified.

A major obstacle to any simplified solution to Equation 3 is the oscillating, nonunique feature of the particle light extinction factor $Q_E(\alpha,m)$ with respect to α for those particle dimensions and incident light wavelengths almost always associated with significant light obscuration by smoke plumes. The fact that the oscillations in Q_E are significantly damped when light absorbing particles such as carbon consititute a significant fraction of the aerosol further complicates the prediction of plume opacity when the refractive index varies. The effect of variations in both particle radius and refractive index are shown in Figure 6. For many common flyash constituents, Q_E can vary from 2 to 4 for the light obscuring particle sizes encountered in combustion effluents. As particle diameter and α become very large, Q_E will approach a theoretical limiting value of 2.0. Insofar as the number of critical variables are concerned, the computation of particle mass concentration, W, appears to be a relatively simple matter, i.e.,

$$W = \frac{4}{3} \pi p \int_{r_1}^{r_2} r^3\ n(r) dr \qquad (4)$$

where:

ρ = discrete particle density and the terms r and n(r) are defined as in Equation 3. The size frequency distribution n(r) is usually expressed as:

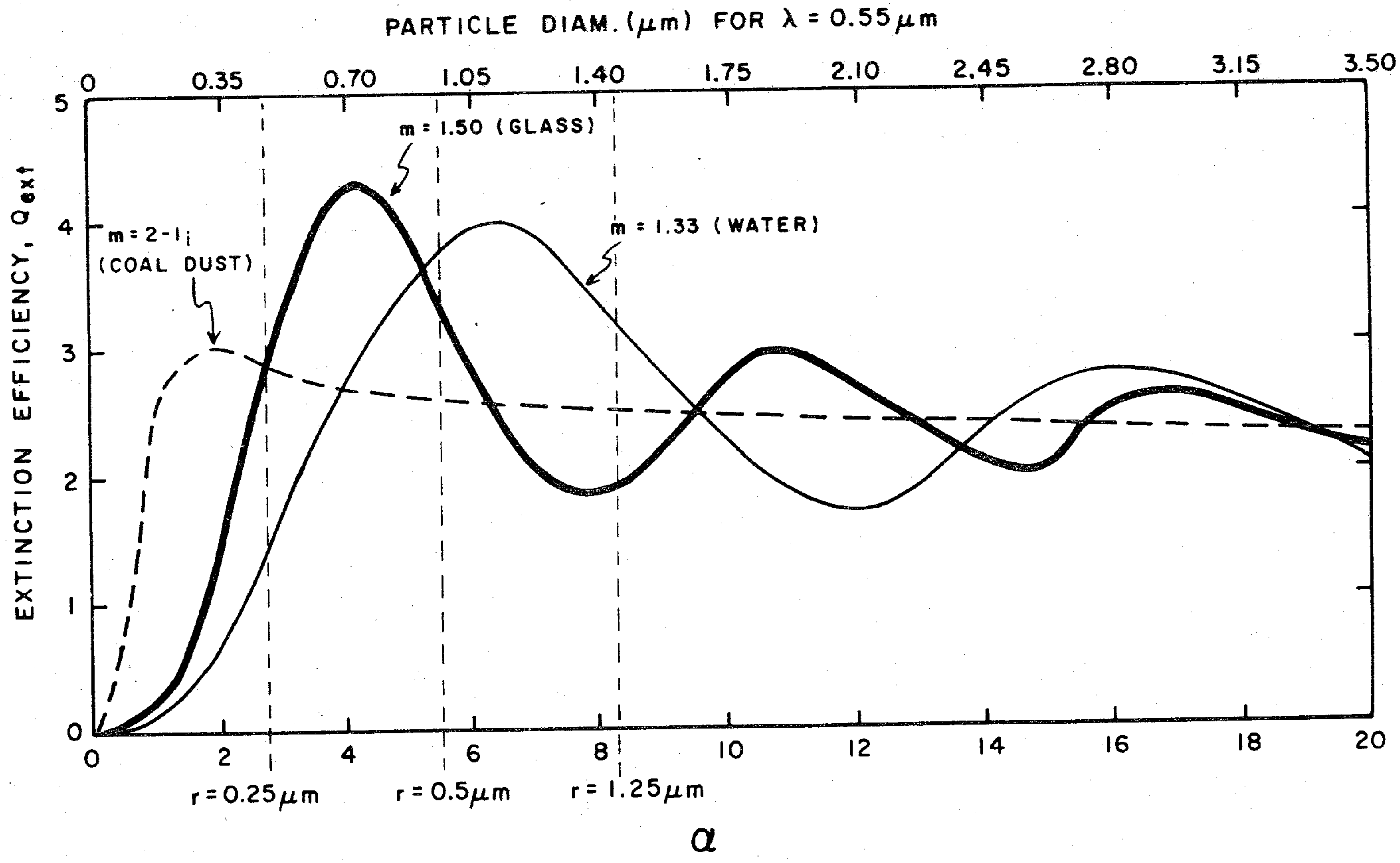

Figure 6. Particle extinction efficiencies for spherical particles as a function of α for m = 1.33, m = 1.5, and m = 2 - 1i (which approximates the value for coal).

$$n(r) = N\ f(r)$$

where:

$f(r)$ = particle number fraction frequency, the fraction of all particles having a radius of r, and

N = total particle number concentration.

The ratio of the particulate mass concentration, W, to the extinction coefficient, b, in conjunction with particle density, ρ, is described by Ensor and Pilat[19] as the "specific particulate volume extinction coefficient," K.

$$K = W/b\rho \qquad (5)$$

By rearranging and solving for b, Bougeur's Law can also be expressed as:

$$I/I_o = \exp\ (-WL/K\rho) \qquad (6)$$

Hence, with the terms L, K, W, and ρ defined, a less complex relationship evolves for predicting the mass concentration, W, associated with a plume opacity, $1- I/I_o$, i.e.,

$$W = -K\rho \ln(I/I_o)/L \qquad (7)$$

Measured K values for several process aerosols have been compiled by Ensor and Pilat[19] from several information sources. Excerpts from the above source are presented in Table 2.

TABLE 2. MEASURED K VALUES FOR PROCESS AEROSOL EMISSIONS[19]

Source	Average K, cm^3/m^2
Orchard heater (black smoke)	0.025
Coal power plant (flyash)	0.64
Coal stoker (black smoke)*	0.084
Coal stoker (black smoke)*	0.11
Oil power plant (black smoke)	0.059
White smoke generator	
$W = 0.22\ g/m^3$	0.46
$W = 0.47\ g/m^3$	0.30
$W = 1.00\ g/m^3$	0.20
Kraft mill recovery furnace	0.6
Veneer dryer	0.36

*Two separate sources

In those cases where K has been measured directly, the several variables affecting K as shown in Equation 3 (r, α, λ, m) need not be considered insofar as their quantitative contributions are concerned. Equation 7 then becomes a more useful tool for correlating the mass concentration and light obscuring properties of a smoke plume.

It must be recognized, however, that the K values cited in Table 2 apply only to the specific aerosols for which they were measured. Because variability in flyash physical and chemical properties is the rule rather than the exception, it should not be assumed that they apply automatically to any similar combustion source(s). Variability may arise due to basic differences in fuel composition, method of fuel preparation, firing method, completeness of combustion, or furnace design features.

Another difficulty is that even when theoretical solutions to light attenuation equations are sought through computer technology, the particle size parameters are usually described by logarithmic-normal distributions. Unfortunately, the latter approach although convenient for data processing may actually lead to incorrect prediction of the "whole cloud" optical properties. Furthermore, the best available instrumentation for size measurements combined with the statistical and logistical problem of securing representative data, make it extremely difficult to obtain accurate sizing (and derived optical) data.

For this reason, one should never assume, without verification, that the size properties of the uncontrolled aerosol describe the effluent from a particulate control device.[20,21] In the special case of certain fabric filters, e.g., woven, surface treated glass, it has been noted that minimal changes in size distribution parameters may occur when the majority of the penetrating dust particles result from temporary or permanent leak points in the filter system.[22]

It is also necessary to consider the possibility of alterations in particle size properties between the point of measurement in a stack and the region immediately outside the stack from which visual opacity estimates are made. Since semiquantitative relationships between sulfur content and ESP collection efficiency have been demonstrated,[23] Figure 7, it is suggested that coal sulfur content should also be considered in relating optical properties to flyash mass concentration.

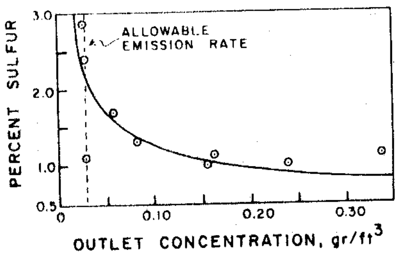

Figure 7. Effect of coal sulfur content on mass emissions from an ESP controlled boiler.[23]

SECTION 4

DISCUSSION OF RESULTS

INTRODUCTION

The results of more than 400 mass emission tests on coal- and oil-fired boilers for which simultaneous visual estimates of plume opacity and/or in-stack transmissometer measurements were available have been collected and analyzed. The analytical effort was centered on the coal-fired systems due to the scarcity of simultaneous mass and optical measurements for oil-fired boilers. The "as received" opacity data reflected several measuring techniques such as EPA Method 9, the Ringelman method, rough personalized estimates, in-stack transmissometry and various combinations of the above. The actual format for the original data varied considerably from agency to agency. Thus, particulate emission rates were reported on a mass per unit energy basis (as-fired) $lb/10^6$ Btu or ng/J, and/or on a particulate mass concentration basis, gr/ft^3 or g/m^3.

DATA SOURCES

A list of the contributing agencies and the types of data submitted appear in Table 3. In Tables A-1 through A-4, Appendix A, both mass emissions and opacity data are presented for numerous coal burning sources. Opacity data range from Method 9 estimates of plume appearance by trained observers (although test conditions sometimes represented less refined versions of the former approach) to in-stack transmissometer measurements with both optical techniques performed in some cases. The results of several carefully controlled in-stack transmissometer measurements are compared to mass emission rates in Table A-4, Appendix A. The above transmissometers were certified as meeting the performance specifications outlined in 40 CFR 60, Appendix B, of the Federal Register.

MASS EMISSIONS VERSUS OPACITY MEASUREMENTS

EPA Regions I and V and State Sources

Concurrent mass emission and opacity tests representing both visual and in-stack opacity estimates are shown in Table A-1 for a miscellaneous collection of coal-fired boilers. The above measurements reflect several variations in boiler capacity, firing methods, and particulate control methods. The latter include ESP, fabric filter and cyclonic devices, as well as some systems without emission controls.

TABLE 3. FEDERAL, STATE, AND COUNTY AGENCIES SUPPLYING SIMULTANEOUS MASS EMISSION AND OPACITY DATA

Contributing organization	Particulate mass emission rate g/m^3	Particulate mass emission rate ng/J	Standardized opacity	Method 9 opacity	In-stack transmissometer
U.S. EPA Region I	C*	C	C	I†	I
U.S. EPA Region IV	C	C	C	I	C
U.S. EPA Region V	I	C	C	C	-
State of Arkansas	I	C	C	C	-
State of Georgia	C	C	C	-	C
State of Indiana	C	C	C	C	-
State of Nebraska	-	C	C	C	-
State of New York	C	C	C	C	-
State of North Dakota	I	C	C	C	-
State of South Carolina	-	C	C	C	-
Hillsborough County, Florida	C	C	C	C	-

*Data complete

†Limited data available

For purposes of identifying possible correlations between opacity (by Method 9 or in-stack transmissometry) and mass emissions it was decided that expressing mass emissions in terms of the actual particulate mass concentration, g/am^3 or gr/aft^3 at the flue gas stack temperature was the preferred approach. This follows from the fact that both descriptors, opacity (surface area) and concentration (mass), are referred to identical gas volumes. Additionally, although mass emission rates on an energy input basis, ng/J or $lb/10^6$ Btu, are directly proportional to mass concentrations, g/m^3 or gr/ft^3, with a constant excess air rate, there are some situations, particularly during boiler turndown, where the excess air might be increased appreciably. Thus, with no change in mass emissions per unit energy input, a significant decrease in opacity might be observed.

Data from Table A-1 have been graphed in Figures 8 and 9 so that the relevant test conditions for each set of data points are indicated. Visual opacity estimates by EPA Method 9, for example are coded with the symbol V9, whereas other visual procedures differing from Method 9 are labeled as VE. A "T" designates an in-stack transmissometer measurement and geometric codings describe the type and/or absence of particulate control devices. To make a clearer presentation, the high level, >45 percent opacity values have been graphed separately, Figure 9. Although opacities relating to cyclone-controlled systems predominate in the high range, it should be noted that three boilers in this group showed relatively low values for both mass emissions (0.1 to 0.2 g/am^3) and opacity (10 percent).

The discouraging aspect of the data point arrays on Figures 8 and 9 is the lack of correlation between mass concentration and opacity. Although one should expect to see at least more precision with stack transmissometer measurements, it appears that little distinction can be made between the results for the visual and in-stack opacity estimates. It is also shown, Figure 10, that the standardization of the in-stack transmissometer results to a 4 m diameter equivalent stack does not show any better mass emission-opacity correlation than that indicated in Figure 8. The poor correlations noted between mass emissions and the PSCNH* in-stack opacities may have resulted from instrument problems. Generally, because a stack transmissometer is influenced by fewer uncontrollable variables, one expects to see a consistent relationship between mass concentration and in-stack opacity provided that boiler load levels and fuel composition remain constant. On the other hand, plume opacities are much more difficult to define due to the numerous external complicating factors discussed in Section 3. Thus, estimation of flue gas opacities by well-trained observers is still more a subjective art than an objective science. It must also be noted that some of the visual evaluations used in this study were made under viewing conditions much less favorable than those considered acceptable for enforcement purposes. For example, viewing a white plume during an increasingly heavy snowstorm would be unacceptable for assessing a source's compliance status. Similarly, to perform visible emission observations while the sun is in front of the observer is an improper procedure. However, where visual observations are performed only to determine fluctuations in boiler operation during a specific stack test and with no intent to use these data for compliance purposes, several variations,

*Public Service Company, New Hampshire

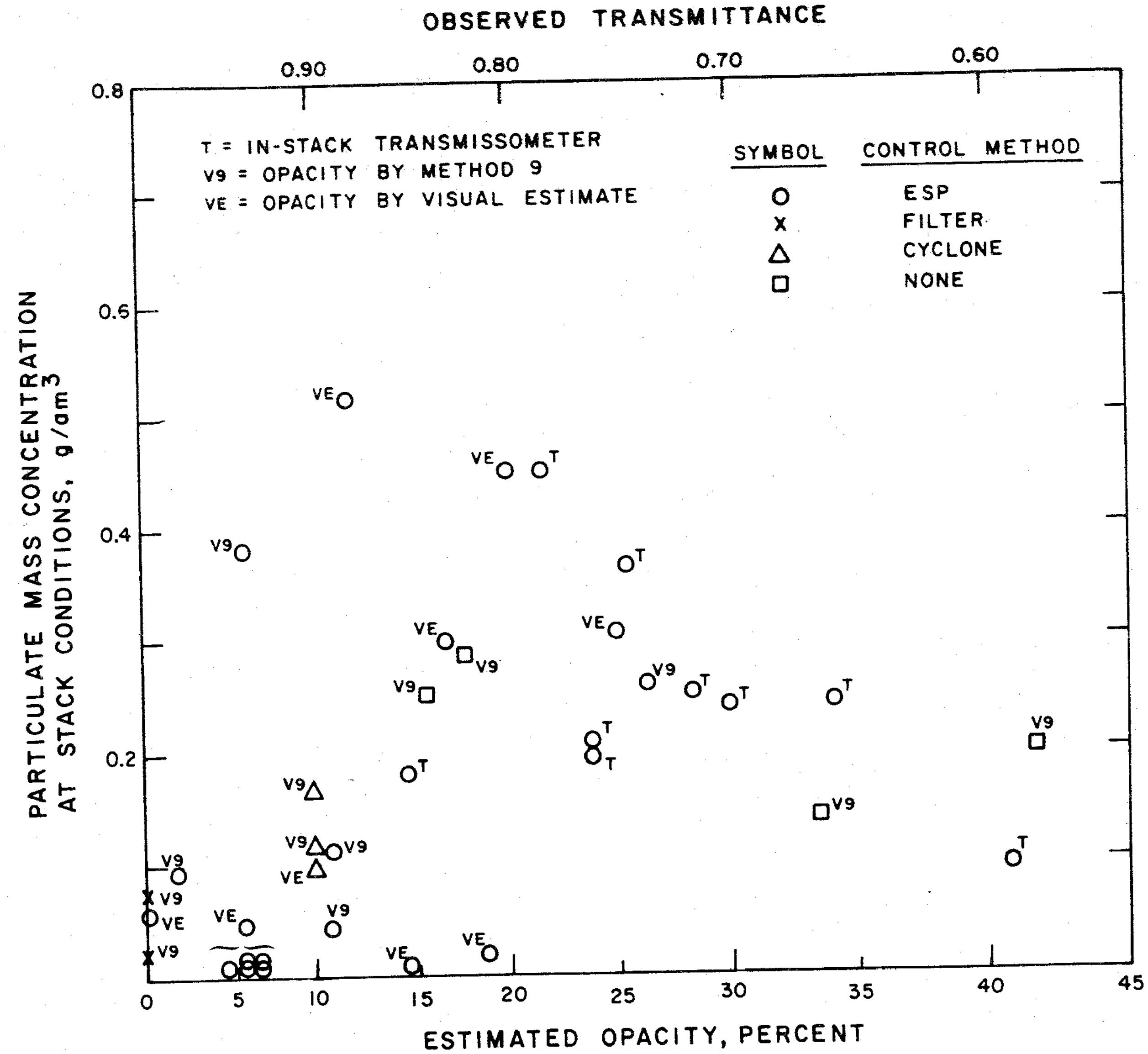

Figure 8. Particulate mass concentration versus estimated opacity by transmissometer and visual methods for various coal firing methods and types of particulate control, 0 to 45 percent opacity.

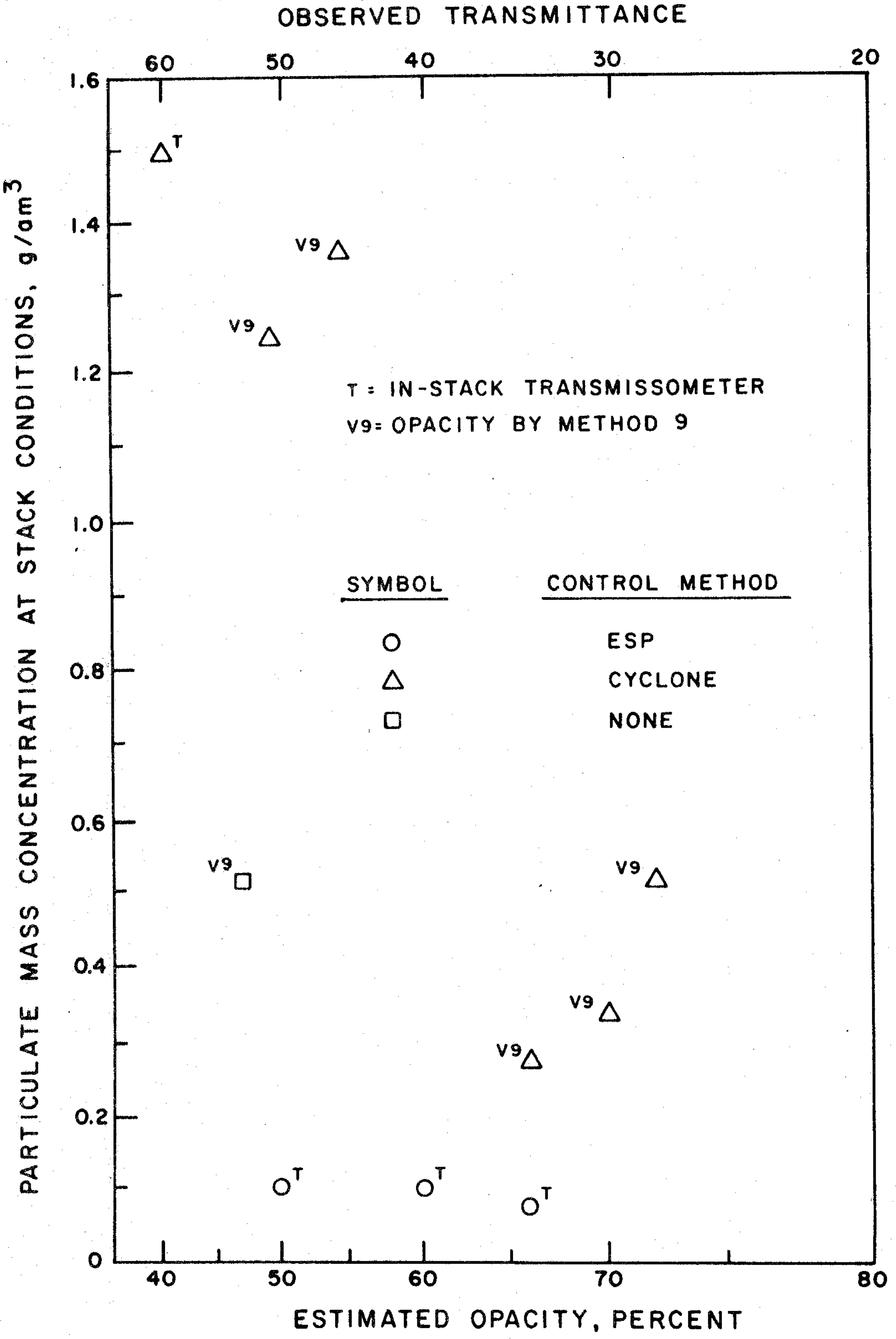

Figure 9. Particulate mass concentration versus estimated opacity by transmissometer and visual methods for various coal firing methods and types of particulate control, 45 to 80 percent opacity.

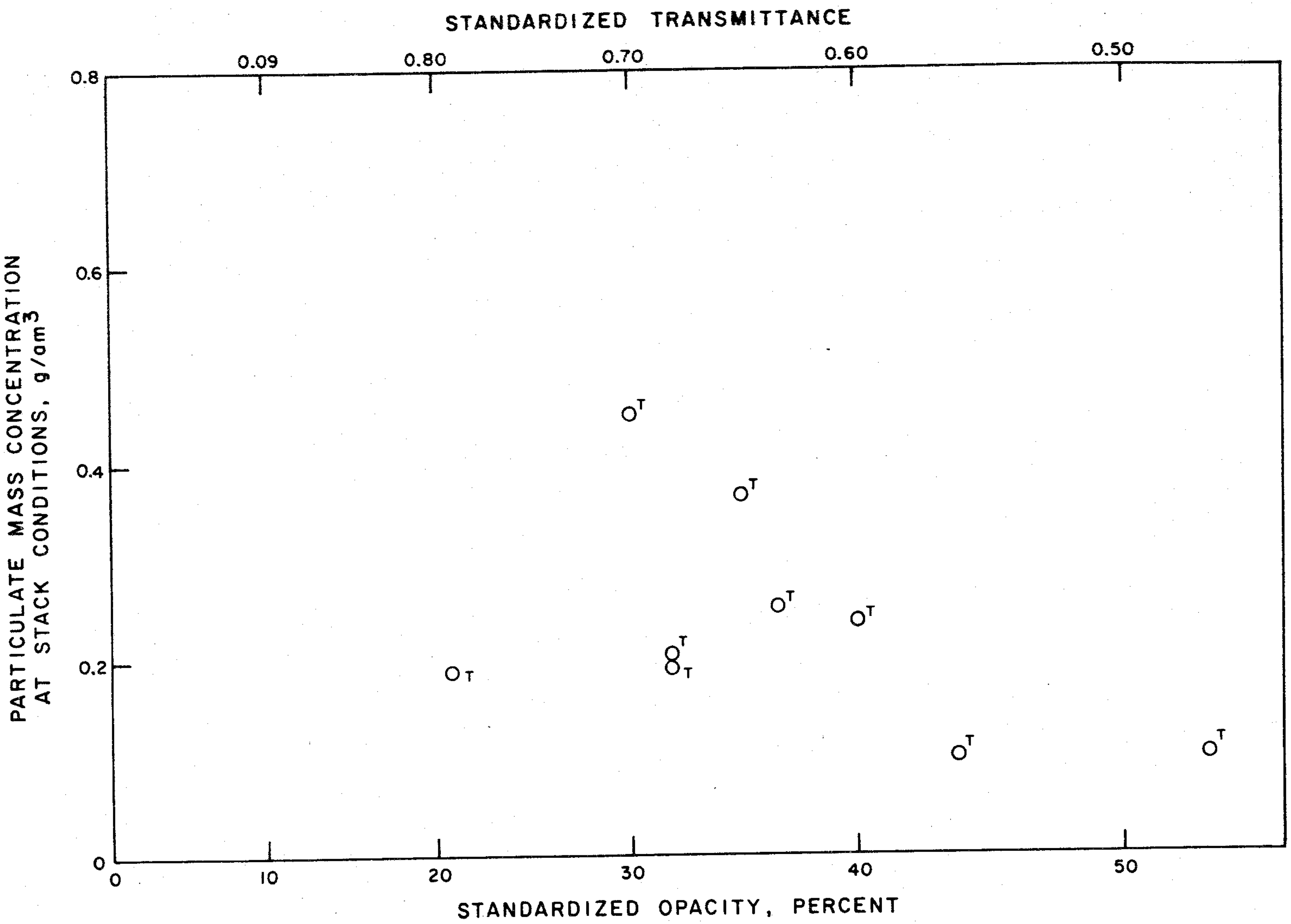

Figure 10. Particulate mass concentration versus standardized opacity based upon in-stack transmissometer measurements on Boilers No. 1 and No. 2, Public Service Co. of New Hampshire.

modifications or short cuts are perfectly reasonable. Thus, whereas several tests performed on one boiler may be internally consistent, they will probably provide no useful correlations when compared with opacity tests on different boilers. The above factor may partially account for the broad spread in data points shown in Figures 8, 9, and 10.

Additional factors influencing the quality of visual opacity measurements are:

- Visual observations are often conducted for a period of time that is less than the time interval required for compliance mass concentration measurements.
- Visual opacity estimates may be biased based on a prior knowledge of statuatory opacity standards.
- Visual evaluation of plume opacity may be performed during periods when the opacity and particulate emission rate vary significantly from the mean values representing the total sampling period.
- Visual opacity estimates by trained observers are often less accurate than measurements made by in-stack transmissometers meeting EPA performance specifications.

The concept of expressing particulate emission rates on the basis of fuel firing rate (Btu/hr) puts all potential emitters on the same basis. With the above approach, deliberate use of high excess air rates cannot be used to conceal poor performance on the part of a control device. However, because of variations in operating protocol (base load or peaking units) or methods of firing, there will be many situations where the actual outlet concentration in g/am^3 can easily vary by a factor of two for the same boiler firing rate or power output. Thus, as stated previously, unless a given set of boilers have utilized identical fuels, firing methods and excess air rates, any correlations between mass emission rates and particulate emissions expressed as either ng/J or $lb/10^6$ Btu are expected to be of limited value.

Opacity must also be based on the same viewing depth if observations from stacks of differing diameters are to be compared. Thus, when sufficient data were available, measured opacity values were standardized to their equivalents had the given particulate-laden stream been discharged from a 4 meter (~ 13 ft) diameter stack. A brief description of the procedure used to calculate standardized opacity is presented in Appendix B.

EPA Region IV — TVA, Georgia, and South Carolina

In Table A-2, visual and in-stack opacity estimates are compared for several TVA boilers located in EPA Region IV. All in-stack transmissometer values were obtained with Lear Siegler instrumentation that has been certified as meeting the Federal performance specifications outlined in 40 CFR 60, Appendix B. TVA mass emissions were based upon EPA Method 5 compliance testing.

The sole purpose of the TVA stack testing, and also that described in Table A-3 for several utility and industrial boilers in South Carolina, was to ascertain boiler compliance status with respect to particulate emission standards. Stack tests described in Table A-4 for the Georgia Power facilities, however, were conducted to determine source compliance with particulate emission standards as well as to establish the correlation between particulate emission rate (as pounds per million Btu) and flue gas opacity via stack transmissometer. Various opacity levels were produced by experimental variation of ESP energizing levels for a broad range of boiler firing rates. Thus, the state of Georgia assigned an "opacity index value" to each source. The opacity index value is defined as that value of the flue gas opacity above which the particulate emission rate will exceed the applicable particulate emission standard. At the present time, the above concept is exemplified by the "site specific" variance for a difficult effluent that permits a plume opacity higher than the present NSPS of 20 percent provided that the mass emission criterion is satisfied. All testing in the Georgia program was by EPA Method 17.

TVA Data--

Following standardization of opacity measurements, the mass emission versus opacity statistics for TVA coal-fired utility boilers were plotted as shown in Figure 11. With the exception of three boilers in this group for which cyclone collectors preceded the electrostatic precipitators, all TVA boilers used ESP systems for particulate control. Despite the crowding of data points it was decided to plot all TVA data on one graph so that the effects, if any, of (a) the method of opacity determination, visual estimate by trained observer versus certified in-stack transmissometer data; (b) the firing method, pulverized coal or cyclonic injection; and (c) the use of mechanical collectors in series with electrostatic precipitators could be compared.

Inspection of Figure 11 shows the dispersion patterns for opacity estimates by both trained observers and in-stack transmissometry to be equally broad and of little value for predictive purposes. Additionally, the data for pulverized-fired and cyclone boilers show similar dispersions. Very limited information for ESP controlled systems with augmentation by mechanical collectors suggest that outlet mass concentrations, per se, exert a negligible effect on plume opacities. The absence of any significant correlations, Figure 11, demonstrates conclusively that use of opacity measurements to predict mass emissions should not be attempted until more sophisticated analytical procedures are developed.

State of South Carolina--

Despite the fact that comparative opacity and mass emission data were available for several industrial and utility boilers located in South Carolina, descriptive information relating to many plant design and operating parameters were missing. Therefore, no effort was made to analyze these data beyond the plots shown in Figure 12 in which the "as received" and standardized opacity measurements have been separated. Generally, the data set shows the same weak correlations exhibited for other visual estimates presented in this report. Failure to demonstrate any strong correlation is again attributed to the inherent limitations of visual opacity estimates plus the fact that plant size, quality of maintenance, coal firing method, particulate control method and coal properties are not taken into account.

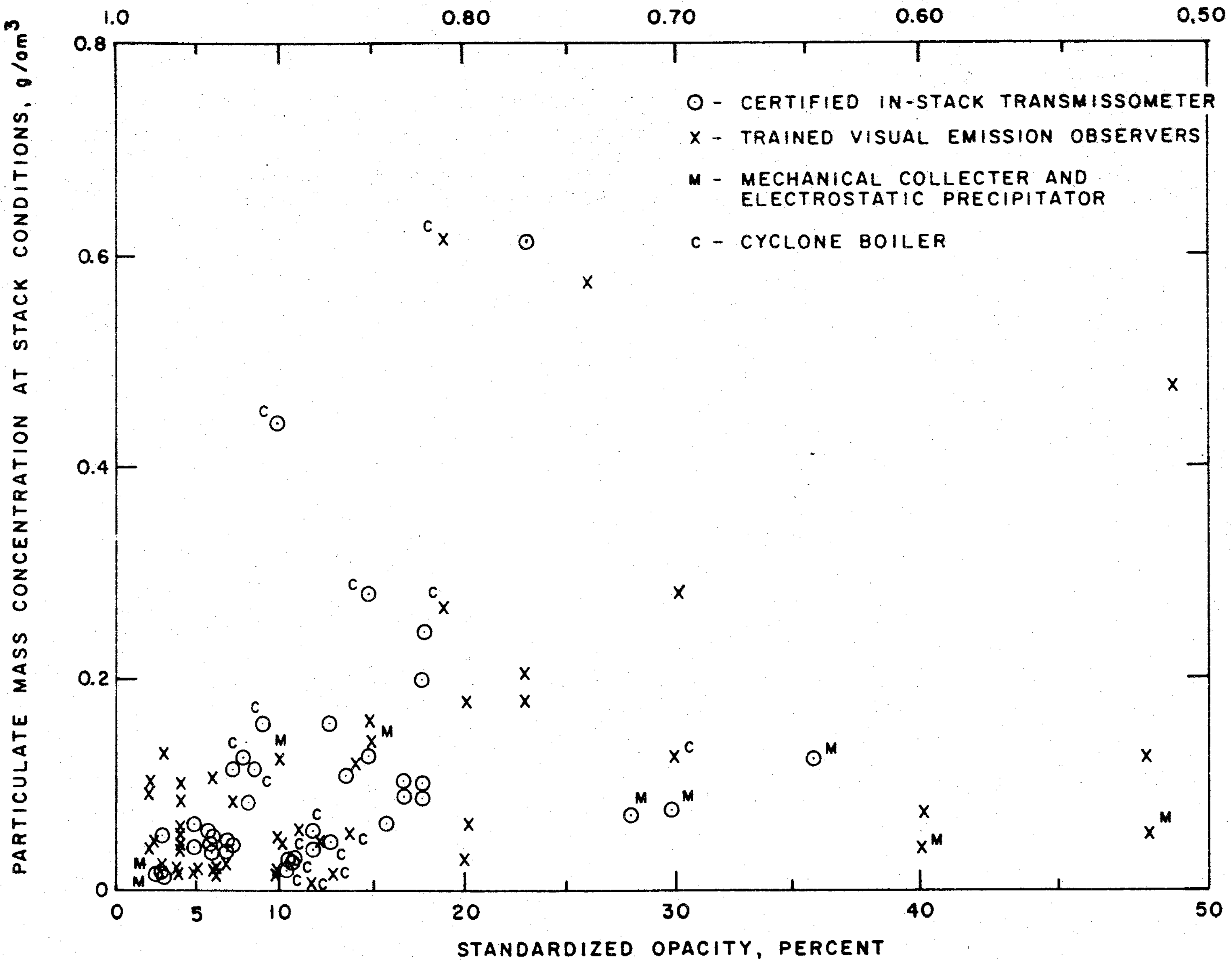

Figure 11. Particulate mass concentration - standardized opacity (in-stack and visual) — TVA coal-fired utility boilers with ESP control and pulverized coal firing.

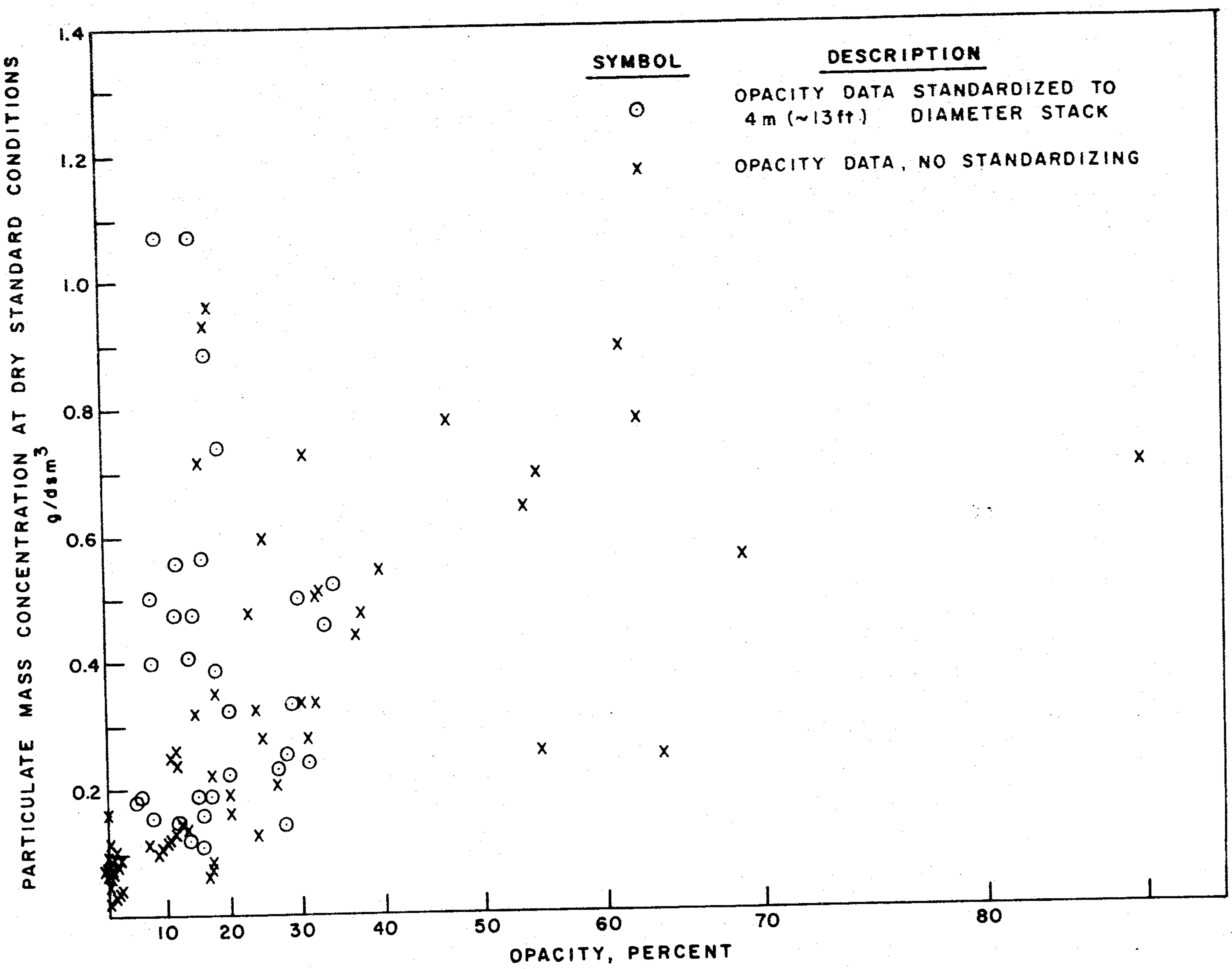

Figure 12. Particulate mass concentration versus measured and standardized opacities for coal-fired utility and industrial boilers. State of South Carolina.

State of Georgia — Georgia Power Co.--

Figure 13 depicts the relationship between particulate mass concentration and standardized opacity for all Georgia Power sources shown in Table A-4. As with the TVA sources cited earlier, (Table A-2) there is no definitive relationship between particulate concentration and opacity that applies to the complete data set. For example, by exclusion of the extreme opacity values corresponding to a mass concentration of 0.29 g/am^3, a simple visual estimate of the point spread suggests a standardized opacity range of roughly 14 to 33 percent. Similarly, a measured opacity estimate of 20 percent appears to bracket a mass concentration range of about 0.1 to 0.35 g/am^3. Although the predictive capabilities in either case are well within an order of magnitude, any working relationship developed from the Figure 13 data set has no value for enforcement purposes and very limited applications for diagnostic situations. Consequently, the following analyses were performed to determine if more definitive mass concentration-opacity relationships might be obtained if the Georgia Power Company data were examined on a site-specific basis.

Figures 14 through 30 show particulate mass concentration versus standardized opacity for several of the Georgia Power sources listed in Table A-4. The emissions refer to single or multiple boiler operation depending upon the number of boilers whose effluents discharge through a common stack. Figures 14 through 18 show the relationship between mass emissions and opacity for pulverized coal boilers with opposite or front firing. Figures 19 through 30 provide similar information for pulverized coal boilers with tangential firing. Linear regression lines and the correlation coefficients, r, were also computed by the method of least squares for the curves of Figures 19 through 30. These equations are given in the form

$$C\ (g/am^3) = A \ln T_s + B$$

where C is the particulate concentration at actual stack conditions, T_s is the standardized transmittance, and A and B are constants. Characterizing opacity parameters (opacity index) for the curves shown in Figures 14 through 30, Table 4, include the plume opacity corresponding to the average mass concentration, for each boiler, equivalent to an emission rate of 43 ng/J (0.1 lb/10^6 Btu) and the 95 percent confidence limits for certain mass emissions at a plume opacity of 20 percent. A modified extinction parameter has also been computed for each curve whose function is to describe the relative obscuration characteristics (and particle size properties) for the aerosols departing each control device.

Opacity ranges--Standardized opacity levels corresponding approximately to the former NSPS of 43 ng/J (about 0.06 to 0.08 g/am^3) indicate that all boilers represented in Table 4 produced effluents satisfying the EPA opacity criterion of 20 percent.

Since the reported values are referred to the same mass loading, one may infer that the higher opacities relate to those effluents containing the larger fraction of fine, light-obscuring particles. Conversely, the lower opacities are associated with those aerosols containing fewer fine particles. The size properties of the particulate emissions, in the simplest analysis, depend upon the size of the uncontrolled aerosol and the efficiency with which the electrostatic precipitator removes the various size fractions. In practice, however, it is recognized that re-entrainment during plate rapping and by-pass leakage through unelectrified areas may appreciably alter the theoretical size properties. Furthermore, in the case of electrostatic precipitators, absolute opacity values can also be expected to vary with the inlet concentration to the ESP since, for fixed aerosol properties, the efficiency is nearly constant when the loading range is not excessive.

Prediction capability of opacity measurements--In the absence of more details, it is difficult to estimate which of the two information bits making up each data pair; i.e., the mass concentration or the in-stack opacity estimate, is the more reliable. However, if the time averaging of recorded opacity values is performed correctly, it is believed that the accuracy of opacity readings for a well-maintained in-stack transmissometer will exceed that of Method 5 particulate measurements. The considerable point scatter displayed by the Georgia Power data is attributed in part to the unavoidable combination of effluents from more than one boiler when the load levels were varied and to the intentional variation of precipitator operation to determine the impact on system performance.

Estimates of the 95 percent confidence intervals for predicted mass concentrations centering about the 20 percent opacity level indicate that the ratios of envelope limits range from 1.2 to 3.0. The procedures used to estimate confidence intervals are indicated in Appendix C. Although this level of accuracy is not satisfactory for any rigid monitoring application, it may be useful for troubleshooting purposes.

Modified extinction parameter--The slopes of the curves showing the mass emission versus opacity relationships in Figures 14 through 30 provide an indirect measure of particle size properties with an increasing slope signifying a reduction in the concentration of fine, light obscuring particles. However, a more definitive way to interpret these curves is to compute a modified extinction parameter, K_m, whose magnitude is directly related to the total surface area per unit mass of particulate material. Here K_m is the product of $(S_p)(L)$ where S_p represents the specific projected particle extinction area, m^2/g, and L the length of the obscuring light path in meters as used in Equations 1 and 2, Section III. Given similar K_m or S_p values with other viewing factors the same, one should expect to observe equal opacity levels. It should also be noted that it is not necessary that characterizing mean or median particle diameters nor distribution parameters such as the geometric standard deviation be identical to furnish similar specific surface values.

Despite the fact that several degrees of electrical energizing are cited in Table A-5, it is not possible to relate these variations in any detailed manner to plume opacity properties without more information. However, it was possible to compare performance for certain boilers where the average energizing levels could be described as either incomplete or nearly complete. Thus, when optimum electrification is reported, the K_m values diminish as shown by comparing the curves of Figures 14 and 15 and Figures 27 through 30. It is inferred here that the ESP capability to remove fine, light-obscuring particles is the greatest with maximum precipitator energization.

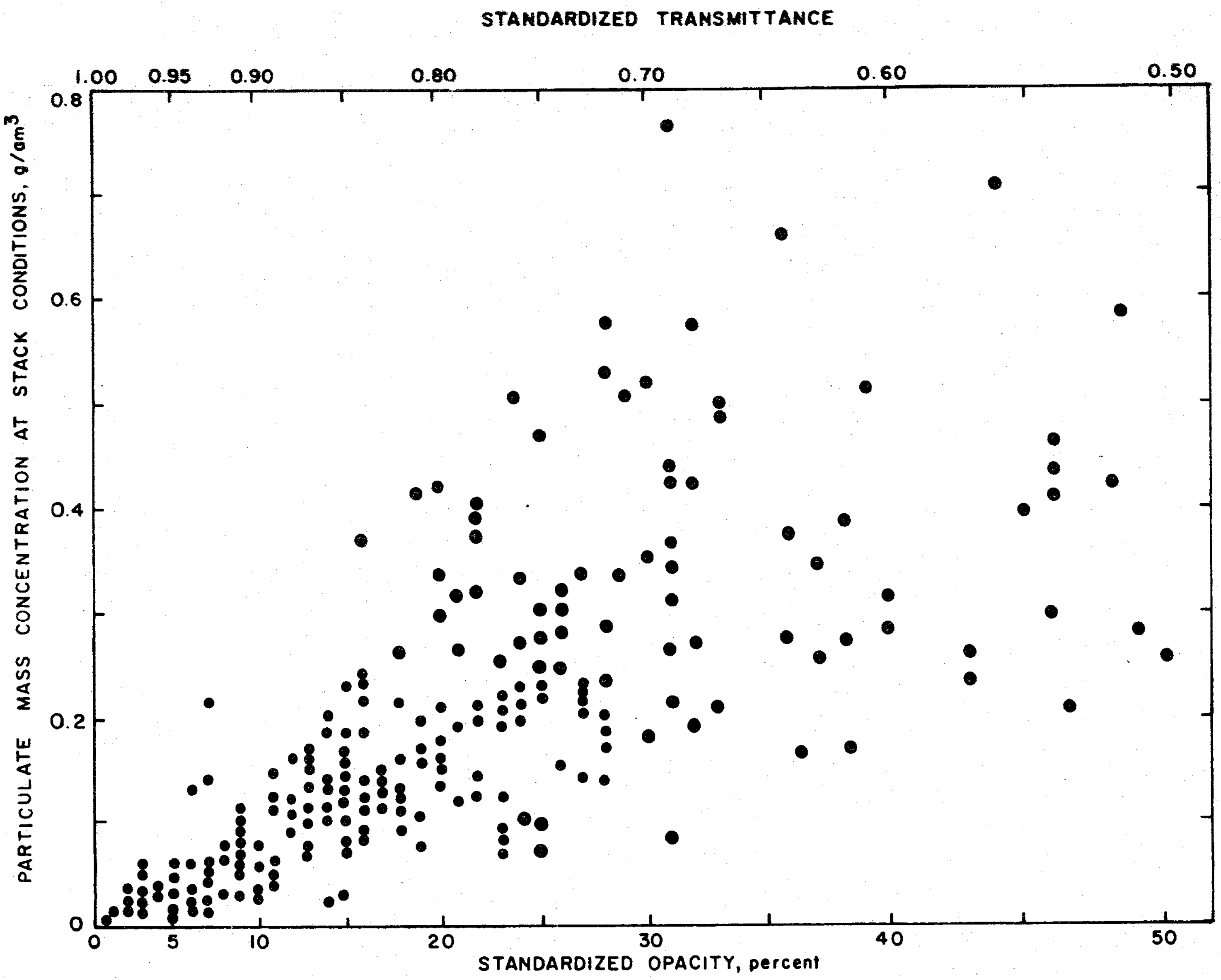

Figure 13. Particulate mass concentration versus standardized opacity for coal-fired utility boilers employing in-stack transmissometers. Georgia Power Co. boilers with ESP particulate controls.

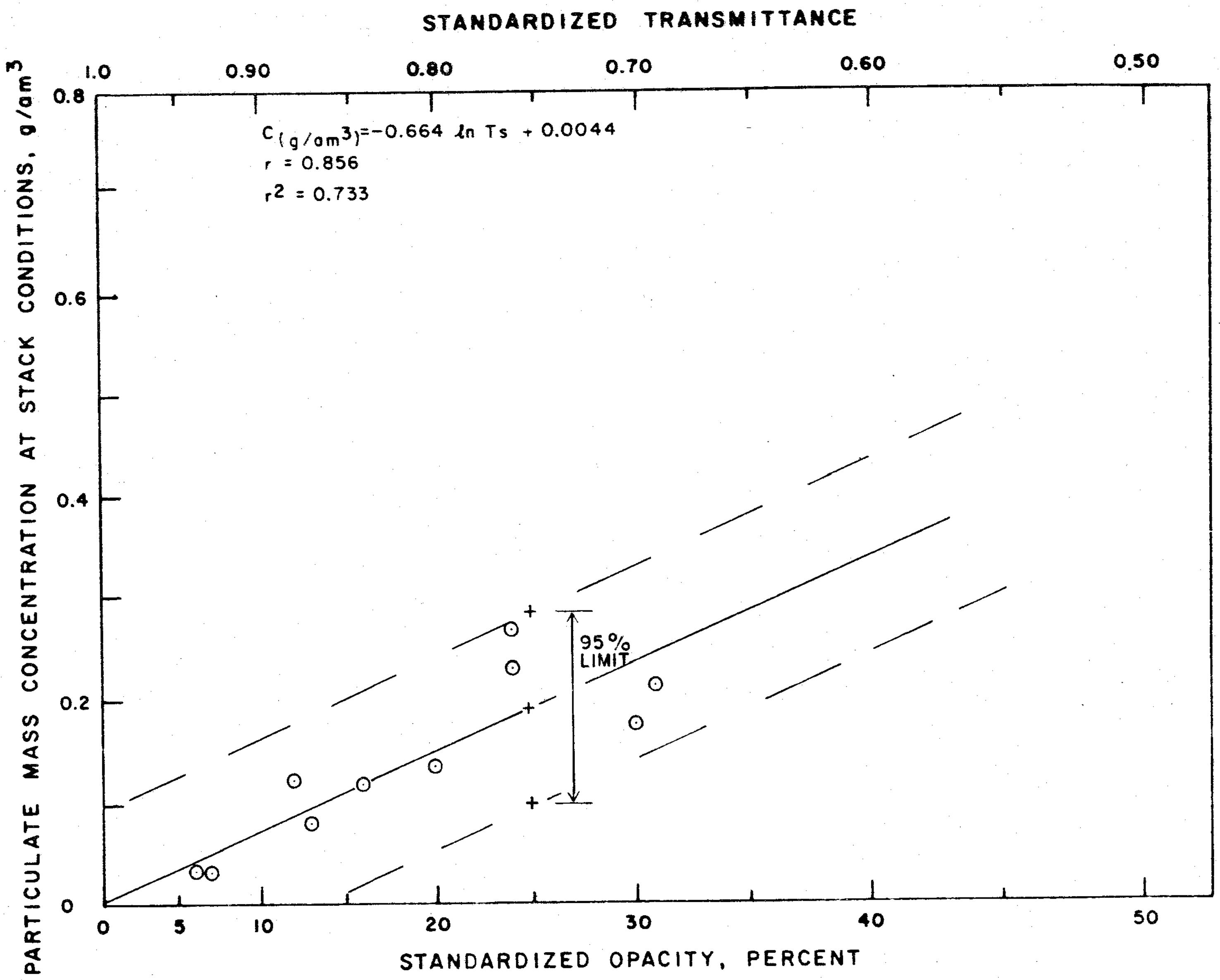

Figure 14. Particulate mass concentration versus standardized opacity for Georgia Power, Branch Units 1 and 2, opposite-fired boilers, incomplete energizing.

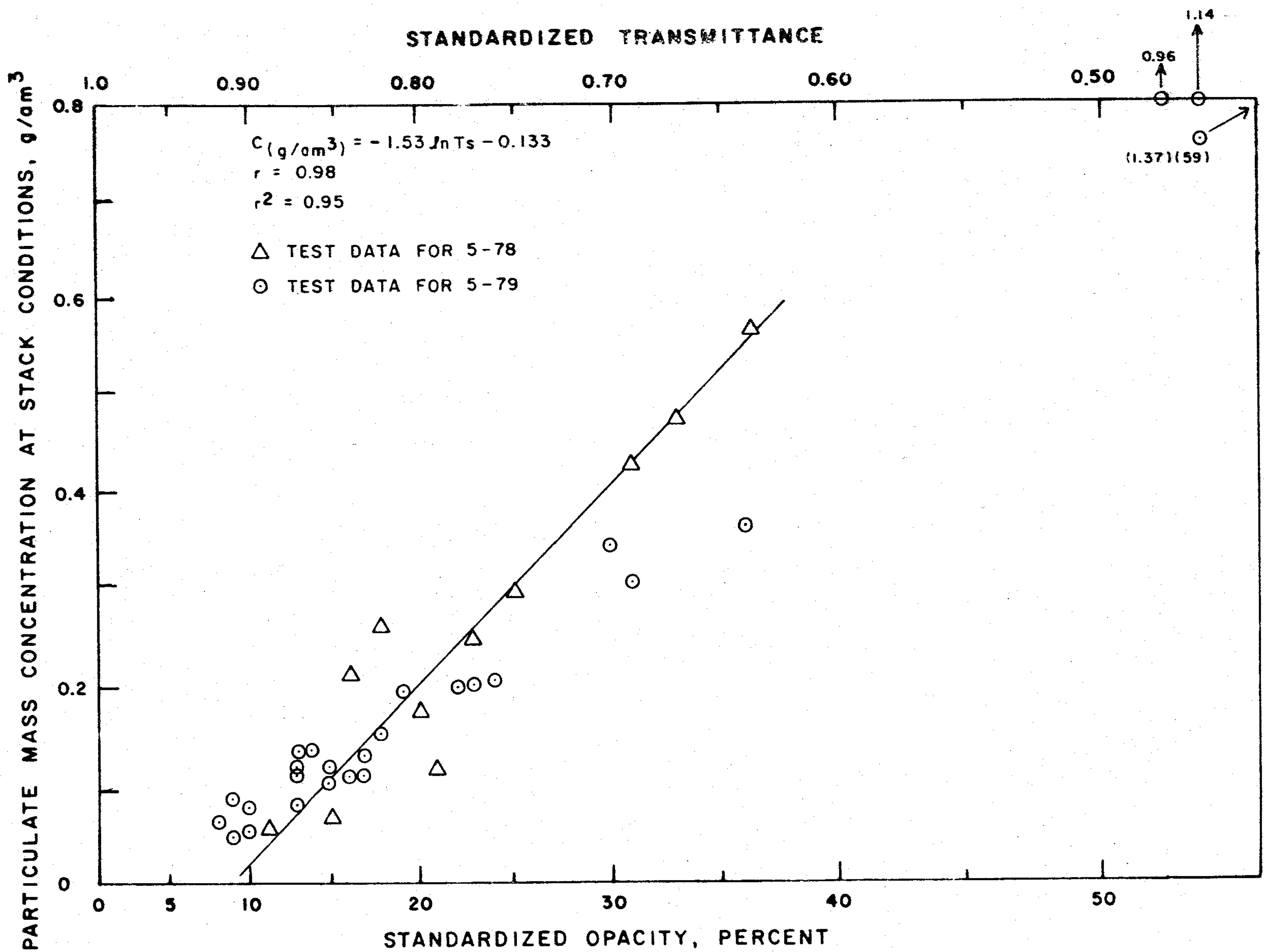

Figure 15. Particulate mass concentration versus standardized opacity for Georgia Power, Branch Units 3 and 4, oppositely-fired boilers, complete energizing.

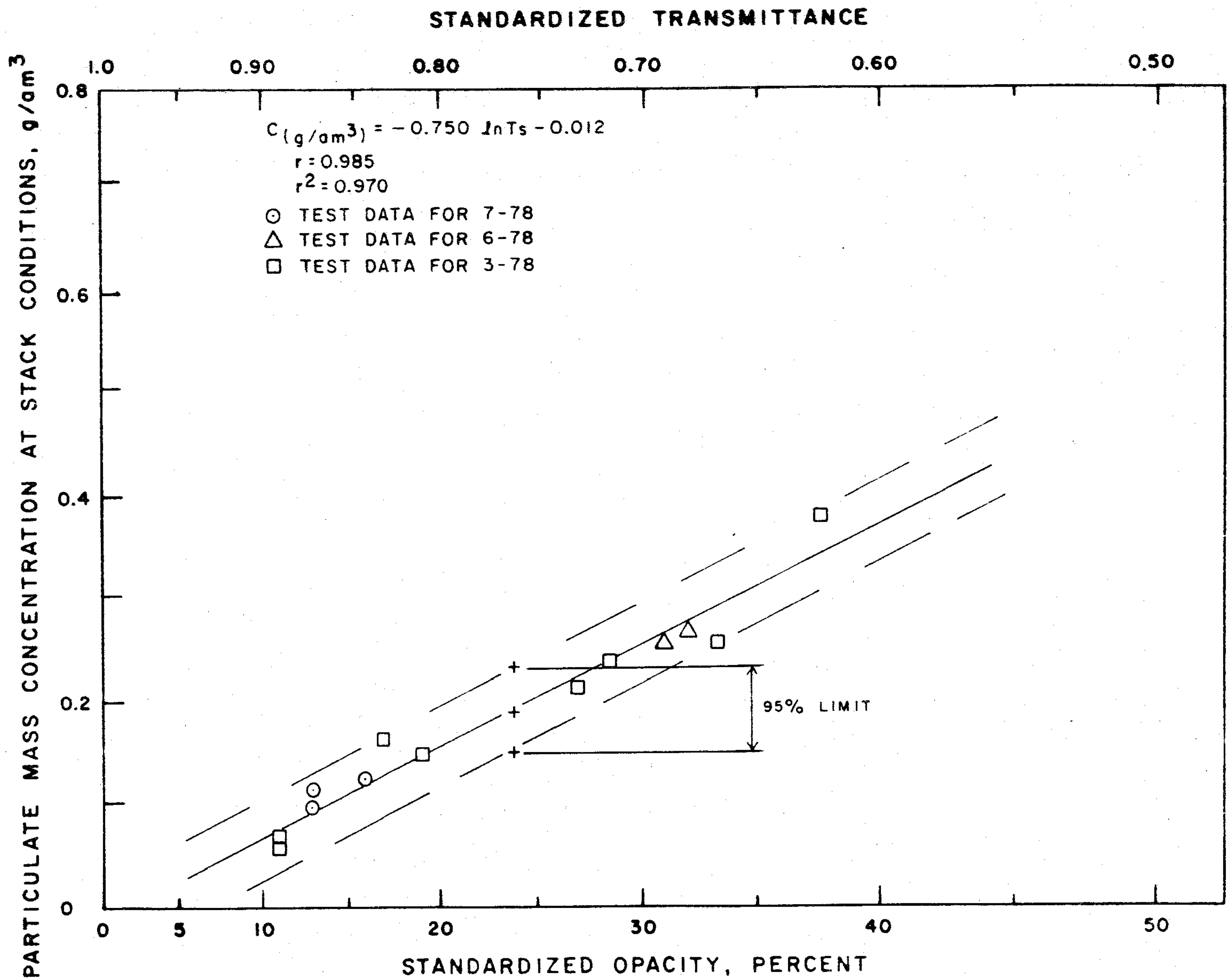

Figure 16. Particulate mass concentration versus standardized opacity for Georgia Power, Hammond Units 1, 2 and 3, front-fired boilers, incomplete energizing.

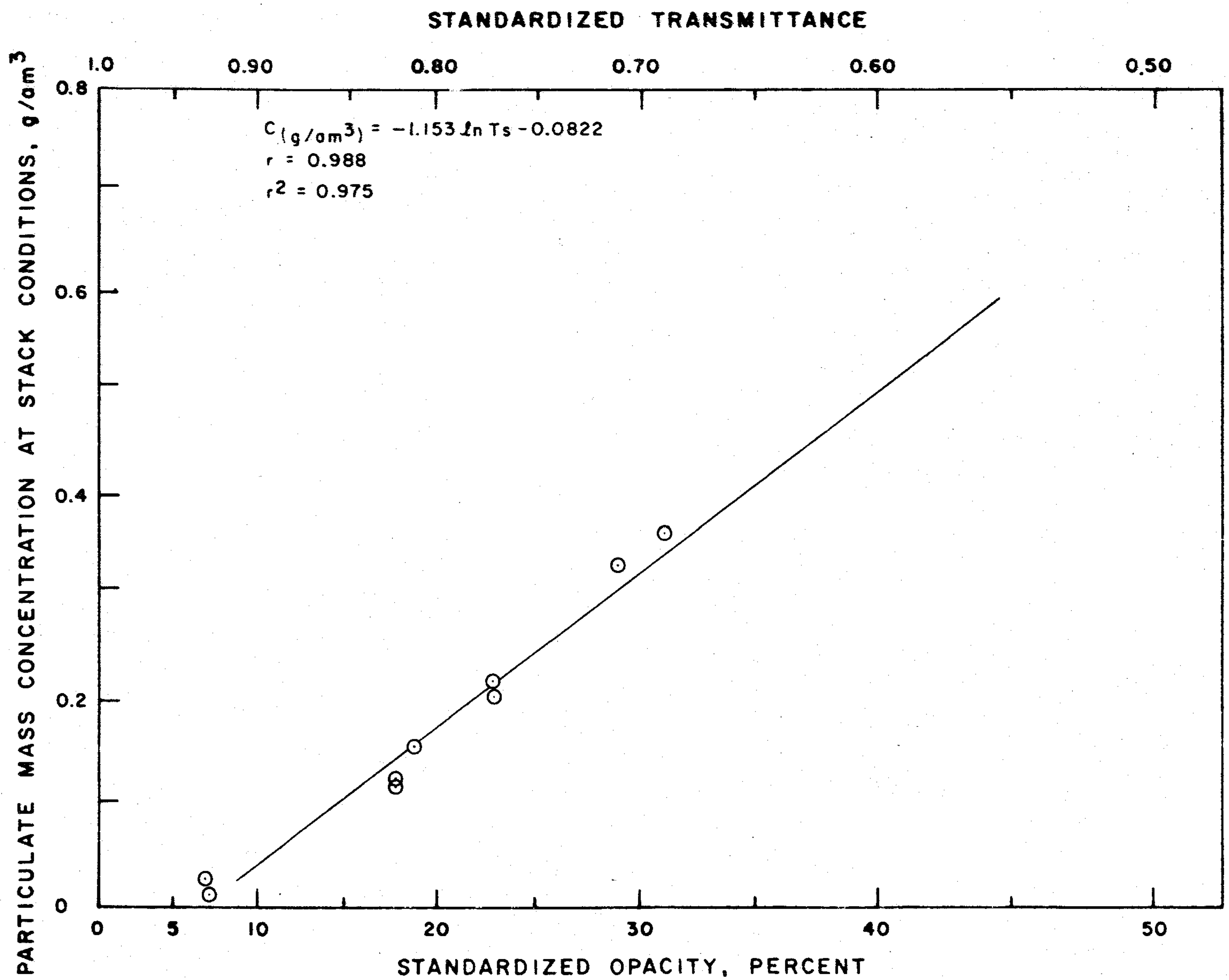

Figure 17. Particulate mass concentration versus standardized opacity for Georgia Power, Hammond Unit 4, opposite-fired boiler, incomplete energizing.

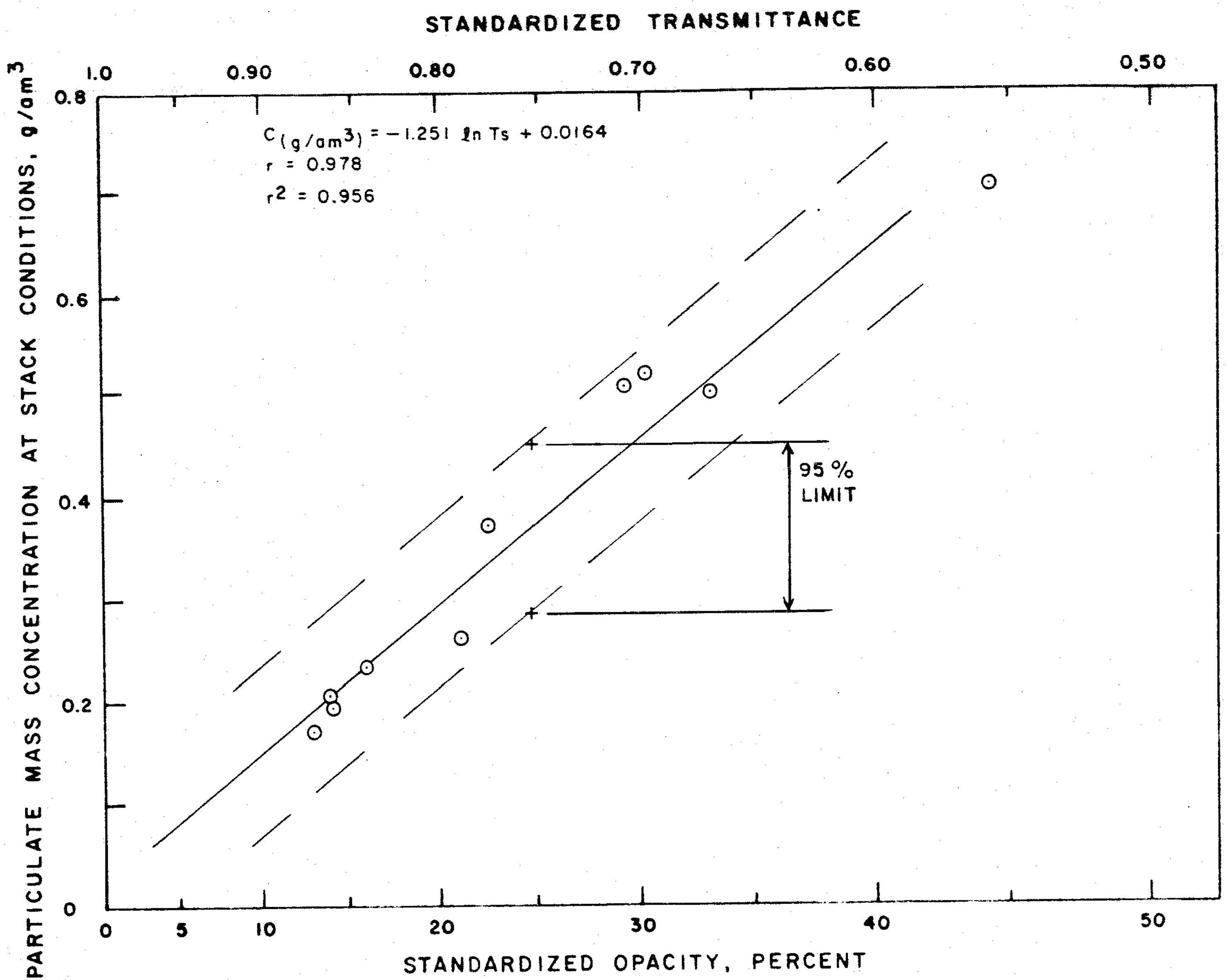

Figure 18. Particulate mass concentration versus standardized opacity for Georgia Power, Mitchell Units 1 and 2, front-fired and Unit 3, opposite-fired boilers, incomplete energizing.

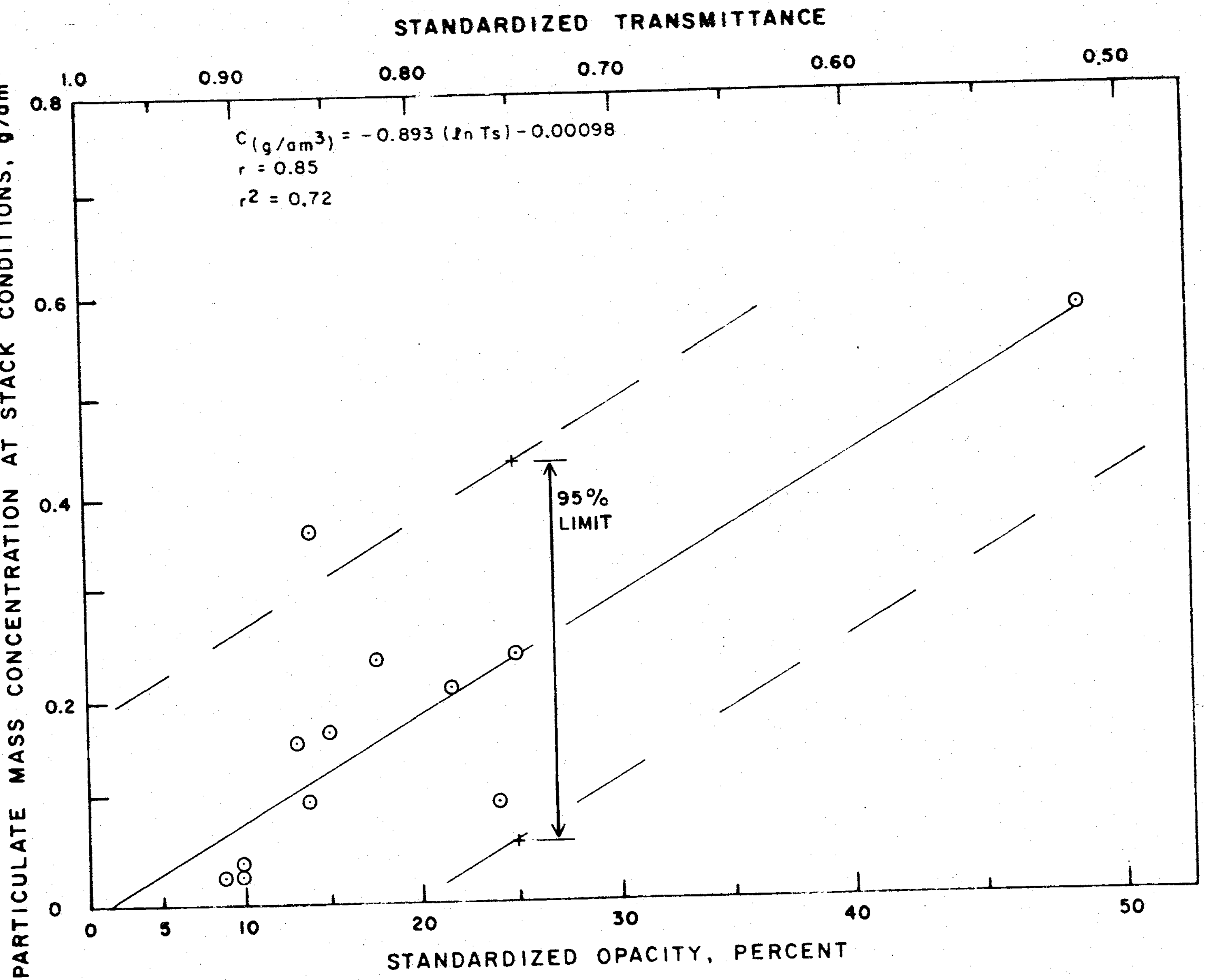

Figure 19. Particulate mass concentration versus standardized opacity for Georgia Power, Arkwright Units 1 through 4, tangentially-fired boilers, incomplete energizing.

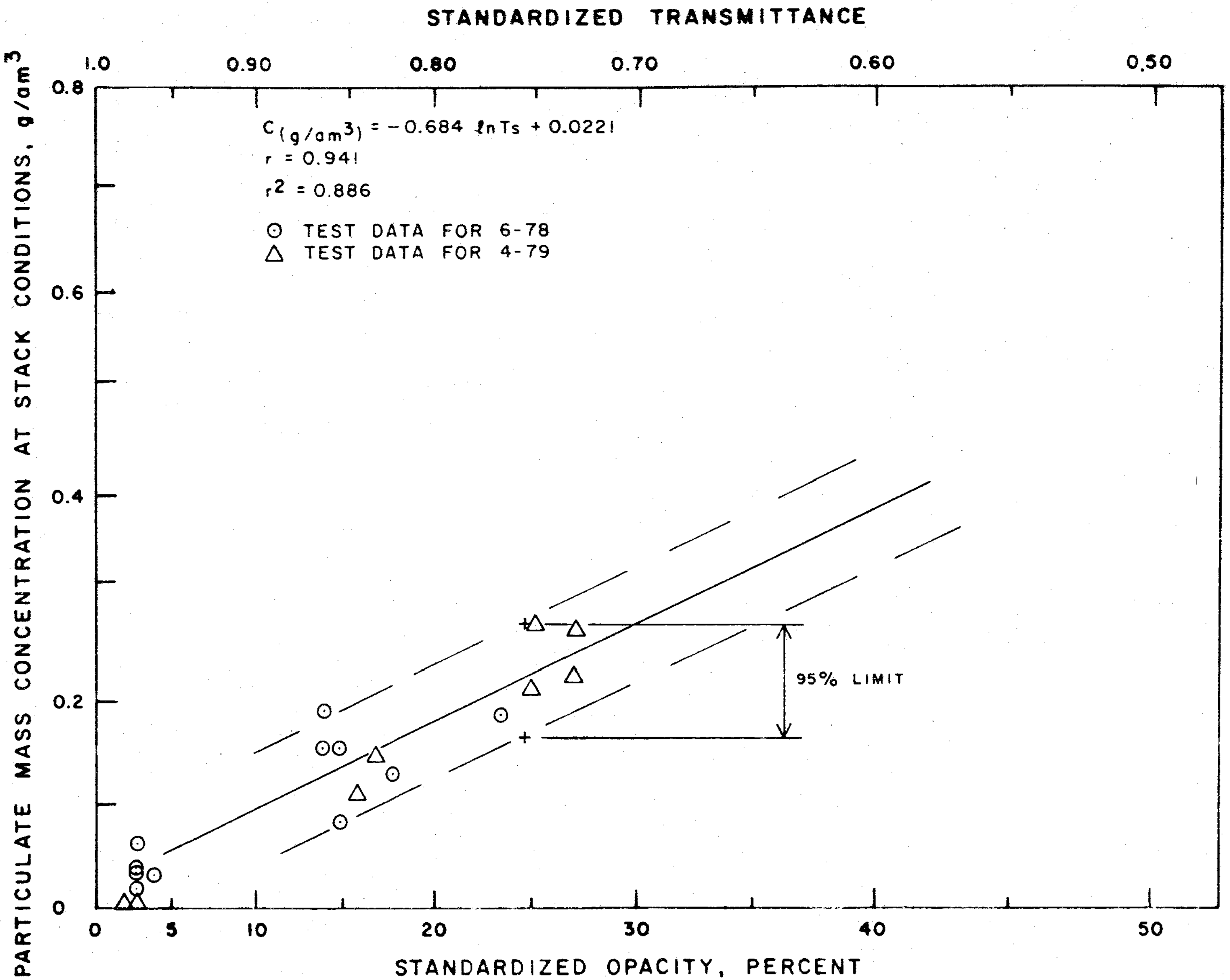

Figure 20. Particulate mass loading versus standardized opacity for Georgia Power, McDonough Units 1 and 2, tangentially-fired boilers, incomplete energizing.

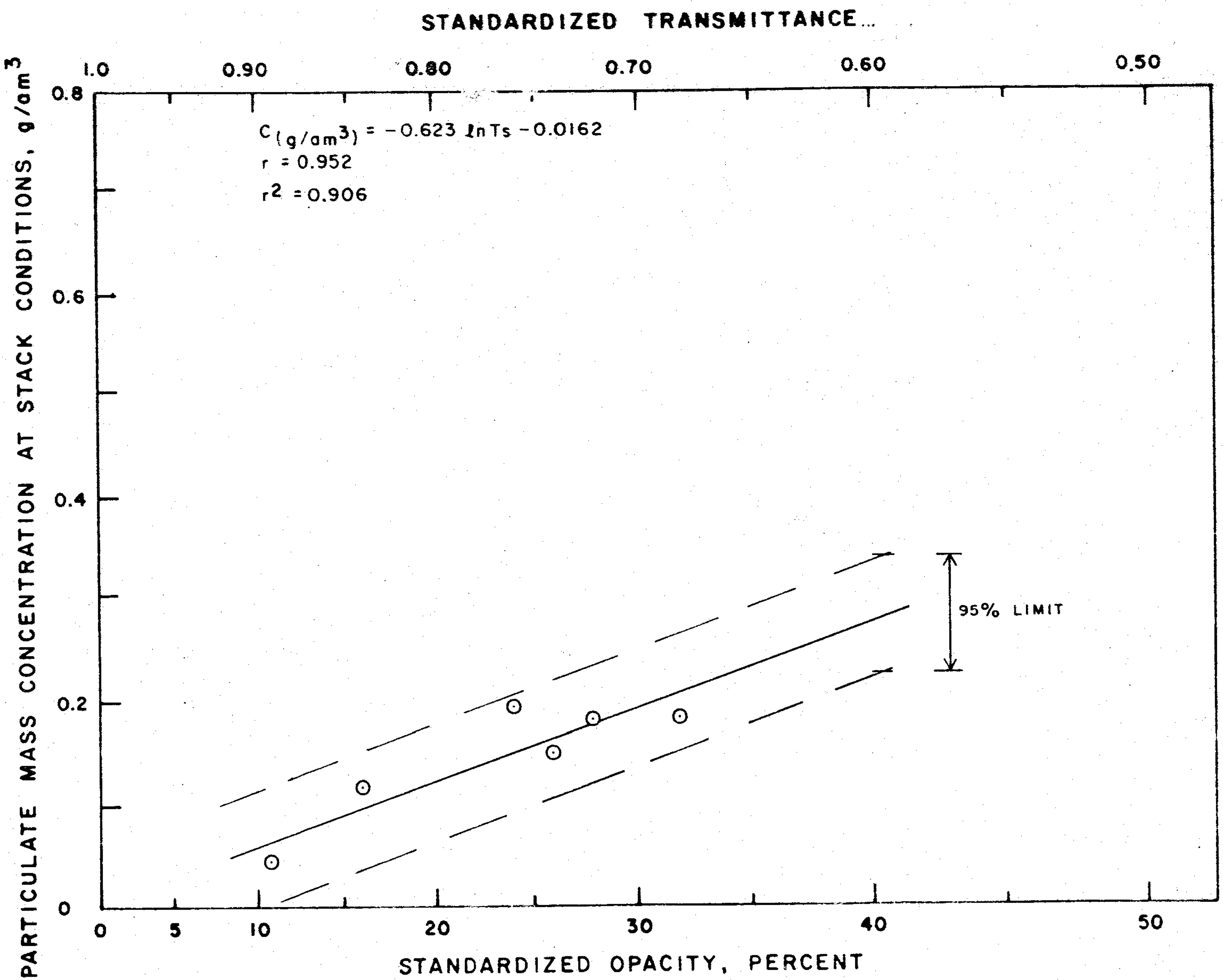

Figure 21. Particulate mass concentration versus standardized opacity for Georgia Power, Wansley Unit 1, tangentially-fired boiler, incomplete energizing.

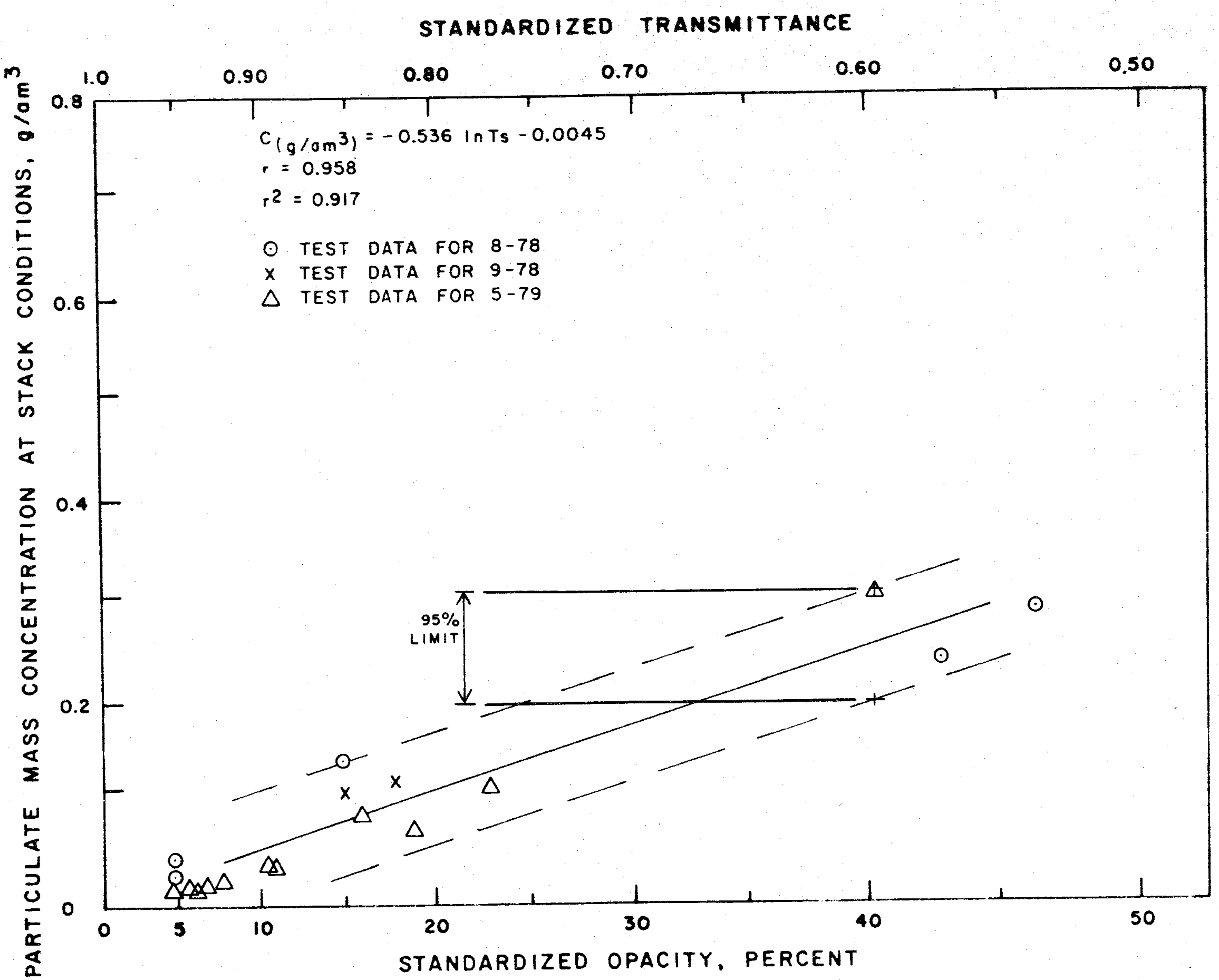

Figure 22. Particulate mass concentration versus standardized opacity for Georgia Power, Wansley Unit 2, tangentially-fired boiler, incomplete energizing.

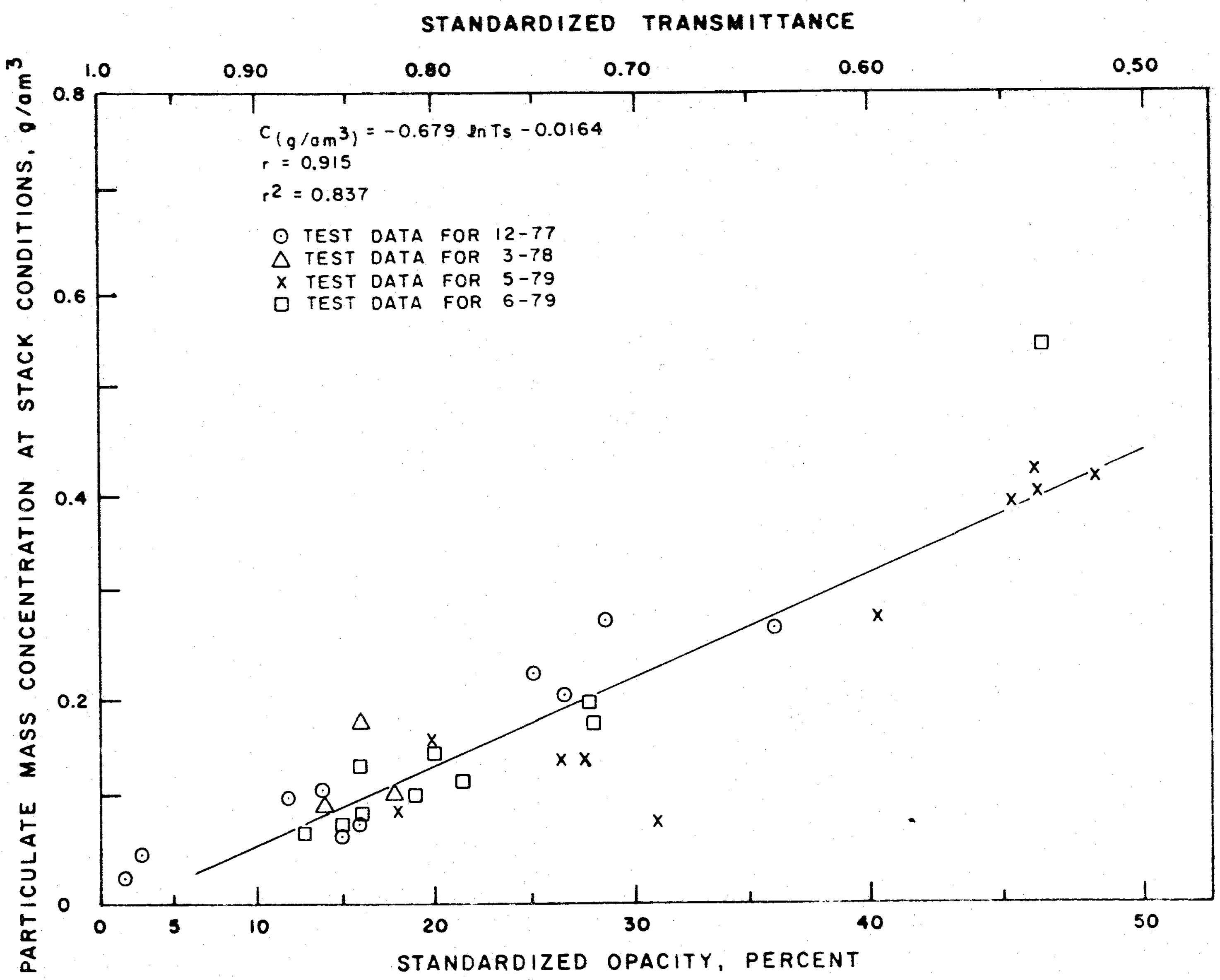

Figure 23. Particulate mass concentration versus standardized opacity for Geogia Power, Yates Units 1, 2 and 3, tangentially-fired boilers, incomplete energizing.

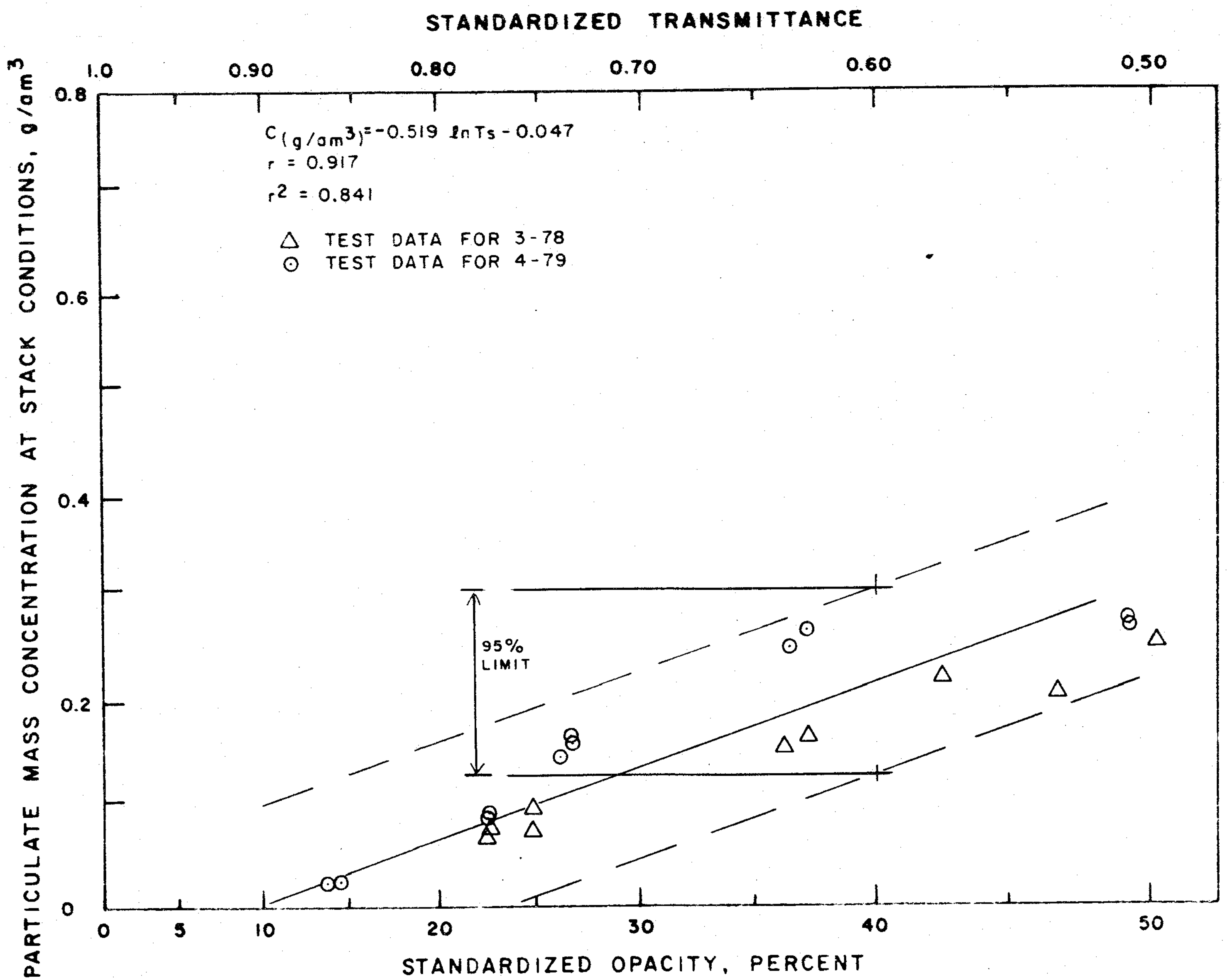

Figure 24. Particulate mass concentration versus standardized opacity for Georgia Power, Yates Units 4 and 5, tangentially-fired boilers, incomplete energizing.

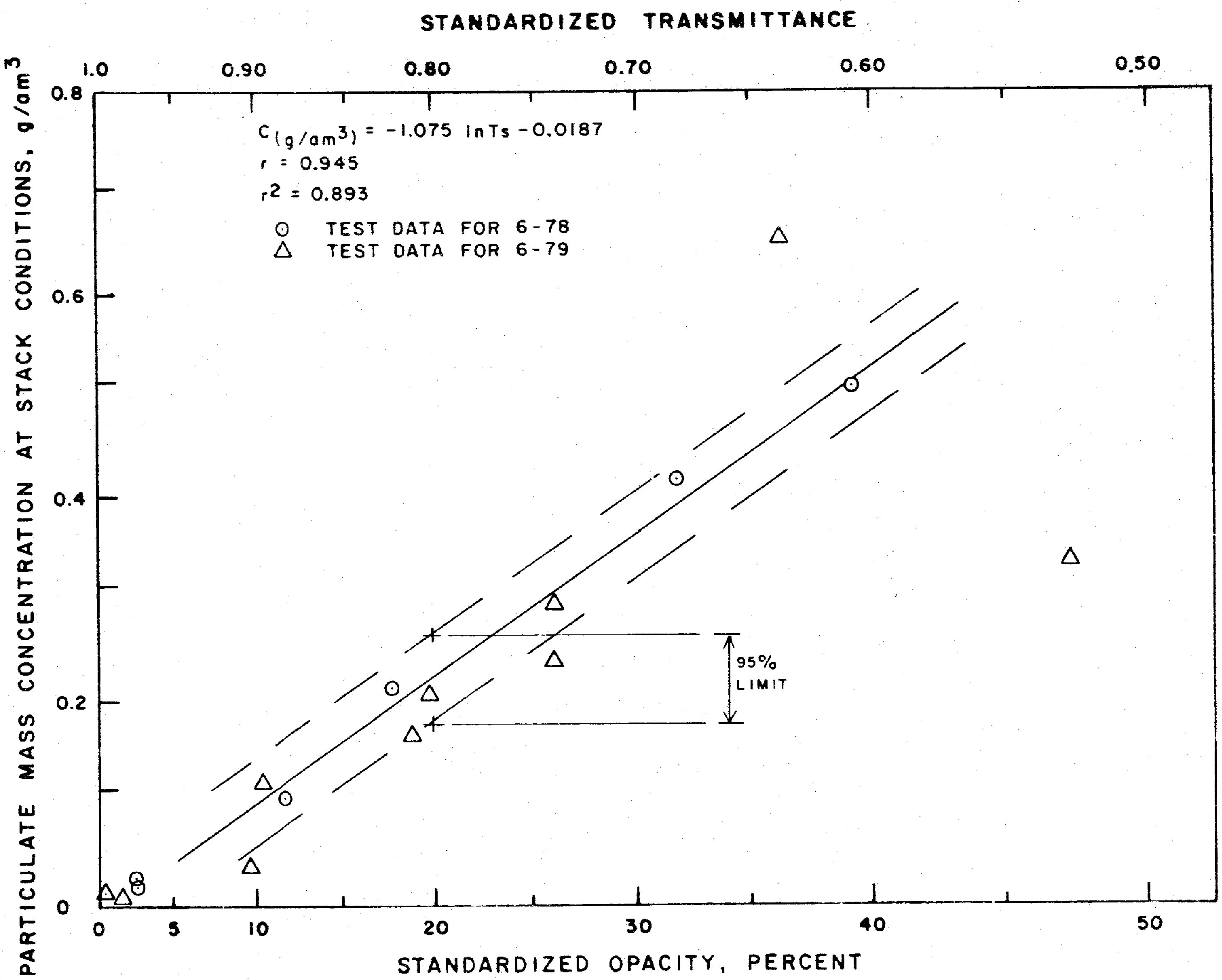

Figure 25. Particulate mass concentration versus standardized opacity for Georgia Power, Yates Unit 6, tangentially-fired boiler, incomplete energizing.

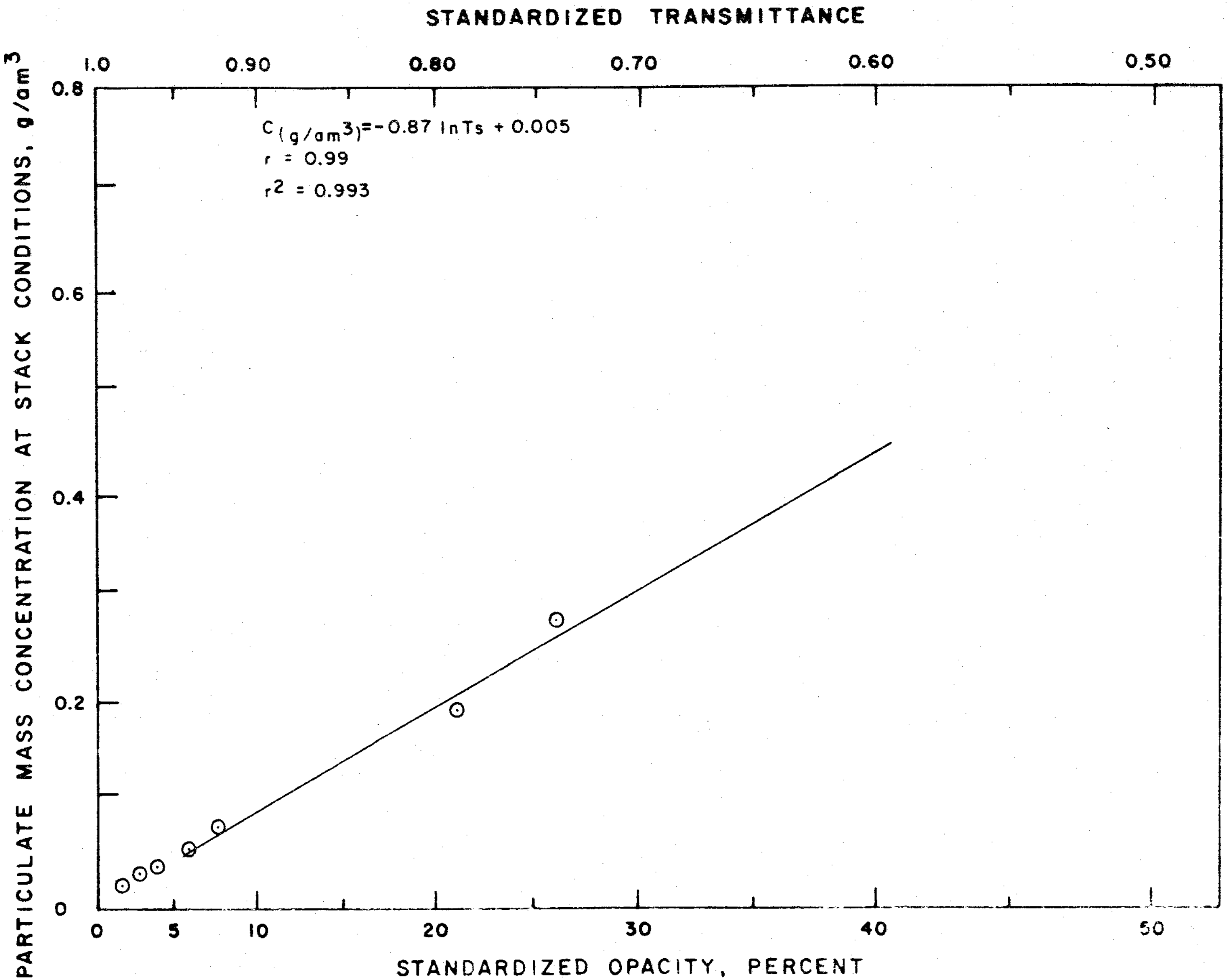

Figure 26. Particulate mass concentration versus standardized opacity for Georgia Power, Yates Unit 7, tangentially-fired boiler, incomplete energizing.

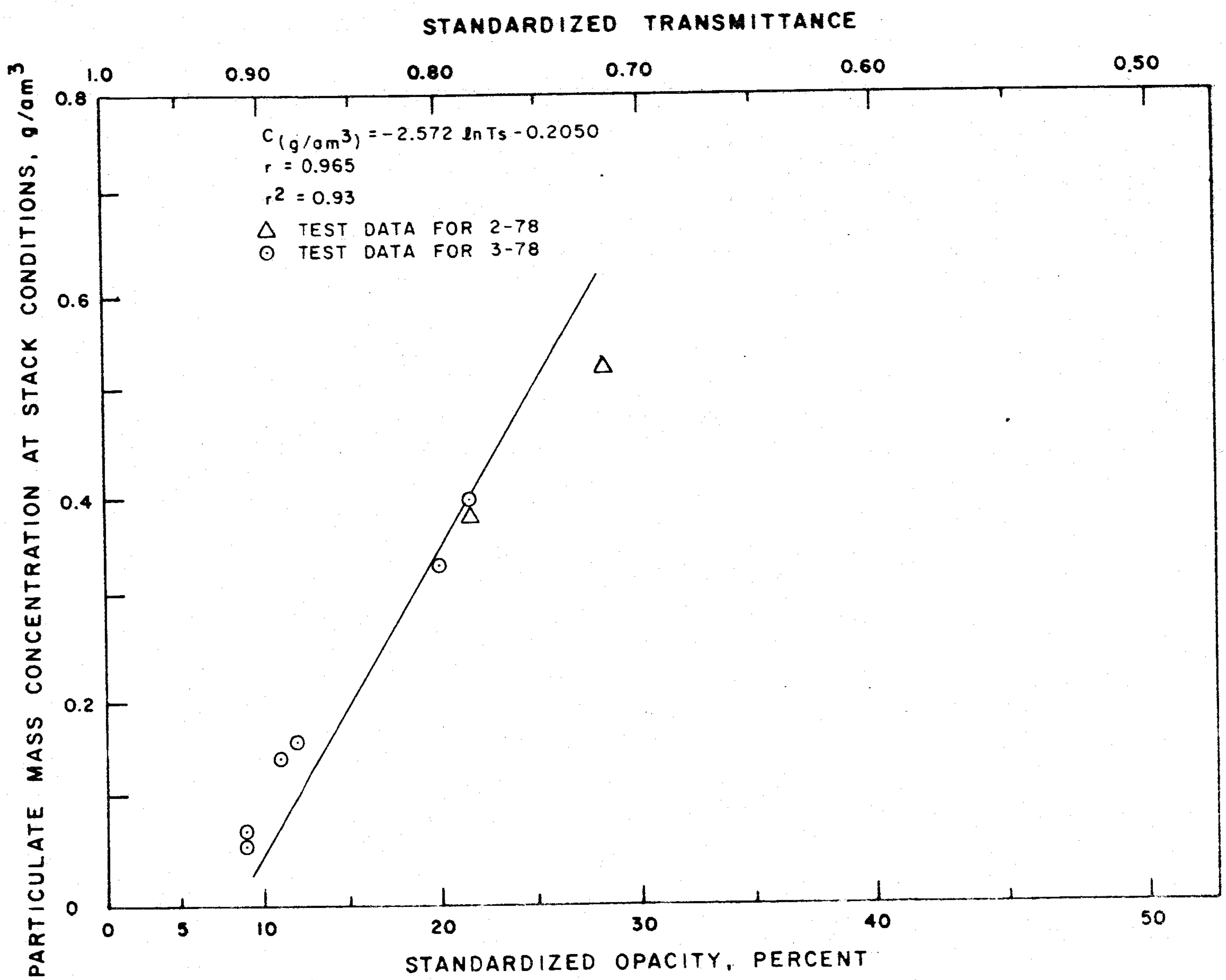

Figure 27. Particulate mass concentration versus standardized opacity for Georgia Power, Bowen Unit 1, tangentially-fired boiler, nearly complete energizing.

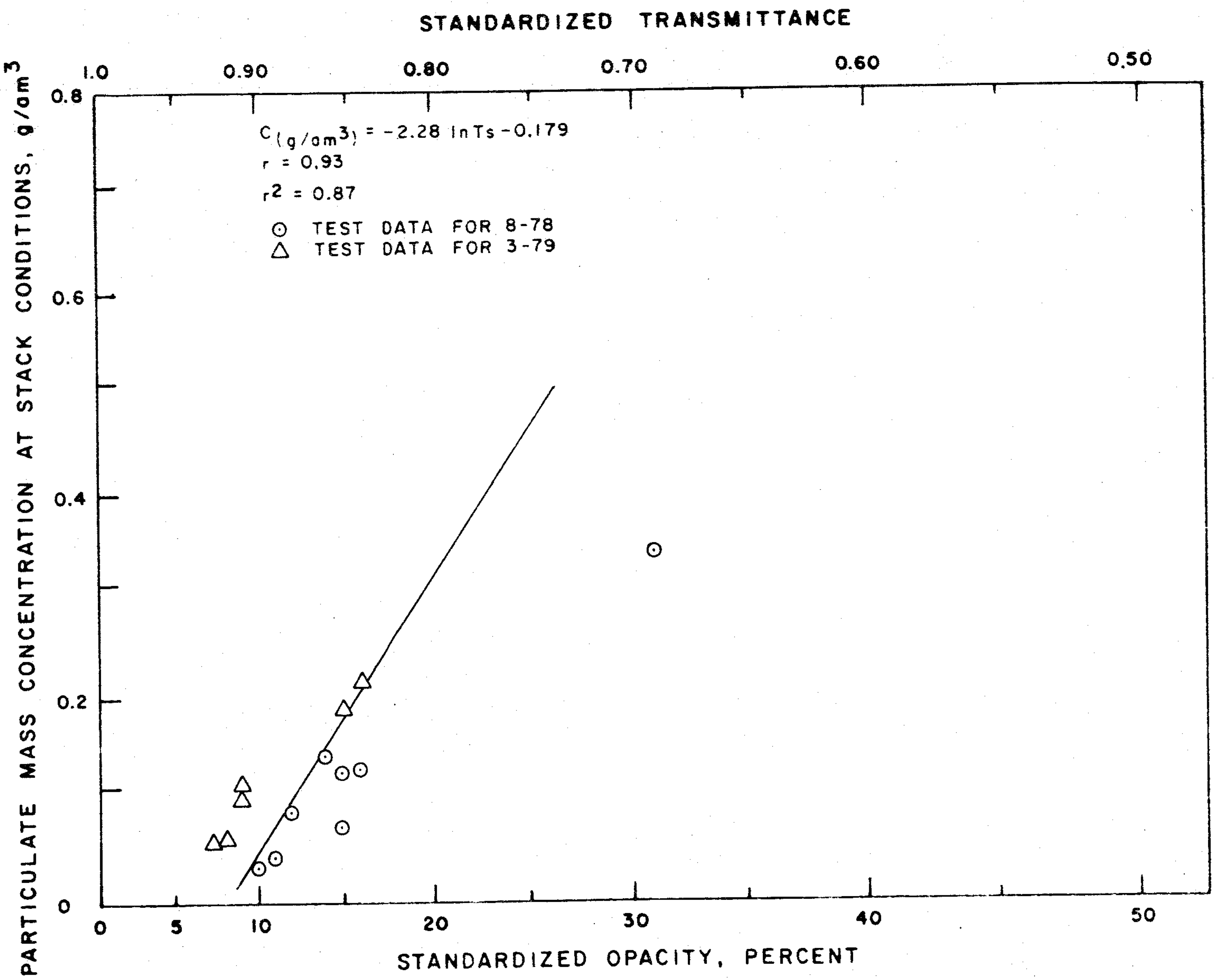

Figure 28. Particulate mass concentration versus standardized opacity for Georgia Power, Bowen Unit 2, tangentially-fired boiler, nearly complete energizing.

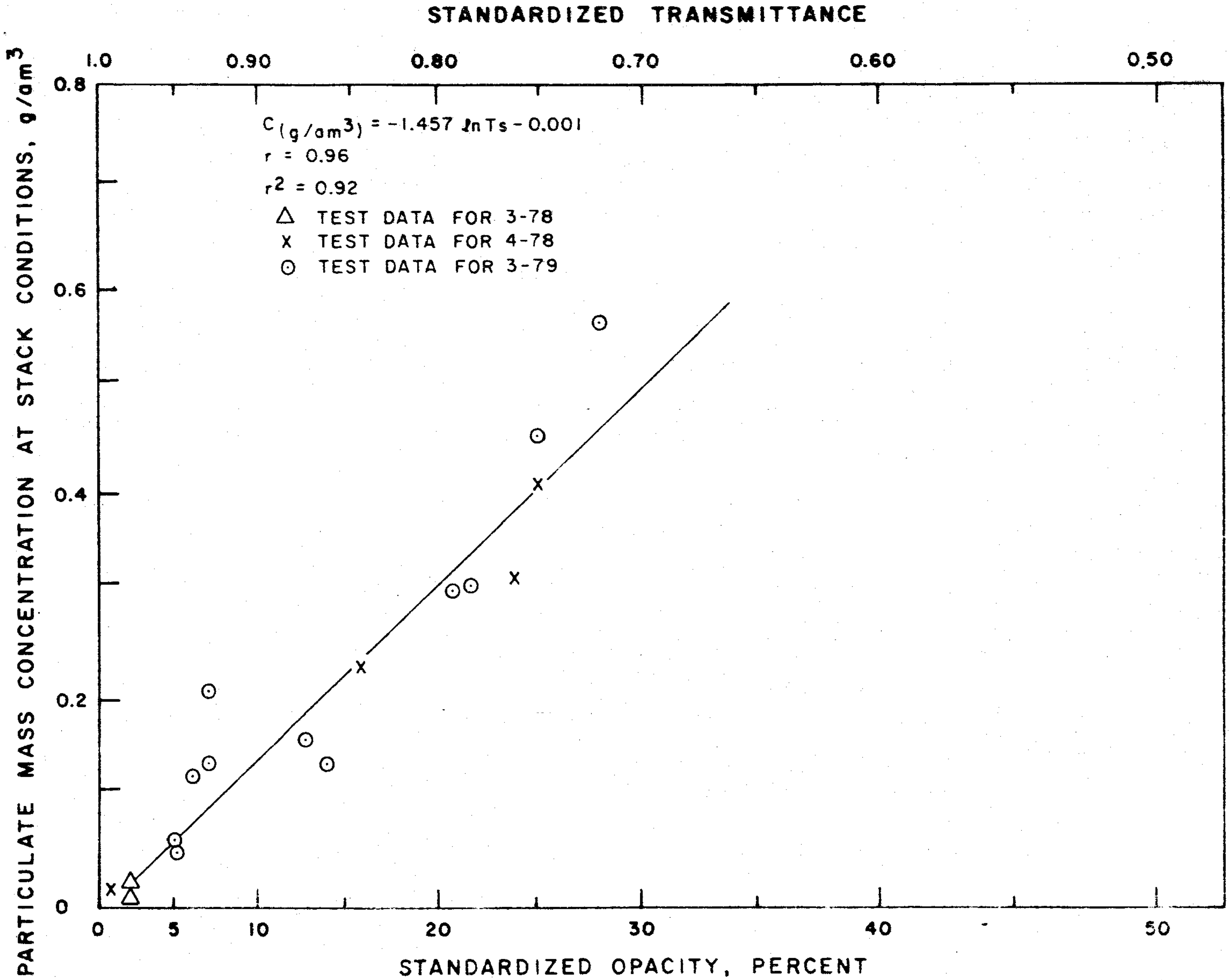

Figure 29. Particulate mass concentration versus standardized opacity for Georgia Power, Bowen Unit 3, tangentially-fired boiler, incomplete energizing.

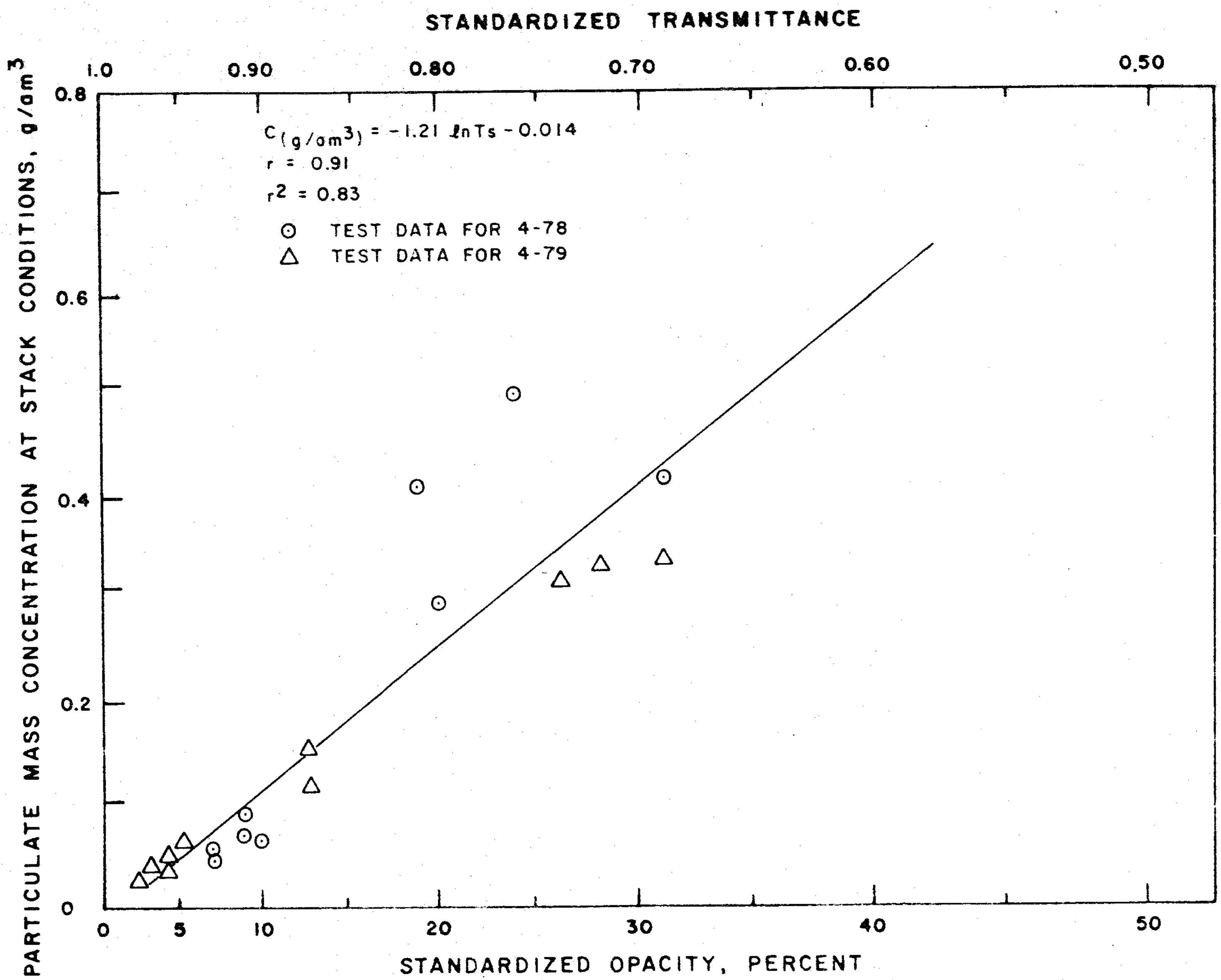

Figure 30. Particulate mass concentration versus standardized opacity for Georgia Power, Bowen Unit 4, tangentially-fired boiler, incomplete energizing.

TABLE 4. SUMMARY OF CHARACTERIZING OPACITY PARAMETERS FOR MASS EMISSION VS. OPACITY RELATIONSHIPS, GEORGIA POWER CO. PULVERIZED COAL BOILERS

Boiler(s)	Figure No.	Estimated* opacity index percent	Mass emission range (95% confidence limit) at 20% opacity g/am^3	Modified† extinction parameter K_m
Opposite or Front-fired				
Branch Units 1 and 2	14	9.5	0.15 - 0.24	-1.5‡
Branch Units 3 and 4	15	13.0	---	-0.60§
Hammond Units 1, 2 and 3	16	10.0	0.12 - 0.19	-1.4
Hammond Unit 4	17	12.5	---	-0.88
Mitchell Units 1, 2 and 3	18	3.5	---	-0.80
Tangentially-fired				
Arkwright Units 1-4	19	8.0	0.21 - 0.38	-1.1
McDonough Units 1 and 2	20	7.5	0.16 - 0.23	-1.4
Wansley Unit 1	21	11.5	0.06 - 0.18	-1.8
Wansley Unit 2	22	14.5	0.06 - 0.16	-2.0
Yates Units 1, 2 and 3	23	11.5	---	-1.8
Yates Units 4 and 5	24	19.5	---	-0.90
Yates Unit 6	25	9.5	0.00 - 0.16	-0.90
Yates Unit 7	26	10.0	0.18 - 0.26	-1.1
Bowen Unit 1	27	11.0	---	-0.40§
Bowen Unit 2	28	11.5	---	-0.50§
Bowen Unit 3	29	6.5	---	-0.70‡
Bowen Unit 4	30	7.0	---	-0.80‡

*Estimated opacity standardized to a 4.0 m (~ 13 ft) stack diameter and adjusted to the average mass emission for each boiler corresponding to 43 ng/J (0.1 $lb/10^6$ Btu)

†$K_m = (S_p)(L)$ from Equations 1 and 2.

‡Incomplete energizing.

§Nearly complete energizing.

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APPENDIX A

DATA TABULATIONS FOR ALL MASS EMISSION
AND OPACITY MEASUREMENTS

TABLE A-1. CONCURRENT MASS EMISSIONS AND OPACITY ESTIMATES FOR COAL-FIRED BOILERS WITH AND WITHOUT PARTICULATE CONTROL. DATA FOR EPA REGIONAL AND STATE SOURCES.

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e $(10^6$ Btu/hr$)_T$	Flow rate am³/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e $(10^6$ Btu/hr$)_T$	Particulate loading[b] at stack conditions ng/J (lb/10⁶ Btu)	g/am³ (gr/acf)	Opacity[c] %	Stack diameter m (ft)	Standardized opacity[d] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
EPA-Region I												
PSC NH BOW 1[e]												
Test 11 (4-77)[f]	Cyclone boiler 120 MW, flyash reinjection	12,023	151	–	274	0.450-E	20 (VE)	2.82	27	2.59	6.96	32,264
		(424,574)	(303)	(1124)	(0.637)	(0.197)		(9.25)				(13,871)
Test 12 (4-77)[f]		11,372	153	–	133	0.230-E	30 (TR)	2.82	40	2.59	6.96	32,264
		(401,591)	(308)	(1118)	(0.309)	(0.100)		(9.25)				(13,871)
Test 3 (7-77)		11,703	154	–	114	0.194-E	24 (TR)	2.82	32	3.00	7.30	32,890
		(413,284)	(310)	(1138)	(0.265)	(0.085)		(9.25)				(14,054)
Test 4 (7-77)		11,646	154	–	119	0.204-E	24 (TR)	2.82	32	3.00	7.30	32,890
		(411,268)	(309)	(1140)	(0.277)	(0.089)		(9.25)				(14,054)
Test 5 (7-77)		10,869	153	–	148	0.254-E	28 (TR)	2.82	37	3.00	7.30	32,890
		(383,850)	(308)	(1060)	(0.344)	(0.111)		(9.25)				(14,054)
PSC NH BOW 2												
Test 1 (8-77)[g]	Cyclone boiler 347 MW (3015)	33,362	166	–	59	0.101-E	60 (TR)	4.85	53	3.9	9.44	31,920
		(1,178,151)	(330)	(3201)	(0.137)	(0.044)		(15.9)				(13,723)
Test 2 (8-77)[g]		33,554	166	–	58	0.098-E	41 (TR)	4.85	35	3.9	9.44	31,920
		(1,184,943)	(331)	(3196)	(0.136)	(0.043)		(15.9)				(13,723)
PSC NH BOW 1												
Test 1 (4-77)[h]	Cyclone boiler 120 MW, flyash reinjection	11,612	153	–	841	1.45-E	41 (TR)	2.82	53	2.86	7.08	32,773
		(410,058)	(308)	(1140)	(1.95)	(0.634)		(9.25)				(14,090)
Test 4 (4-77)[g]		11,520	155	–	107	0.183-E	15 (TR)	2.82	21	2.85	7.07	32,210
		(406,833)	(311)	(1120)	(0.249)	(0.080)		(9.25)				(13,848)
Test 5 (4-77)[g]		11,589	154	–	265	0.450-E	22 (TR)	2.82	30	2.85	7.07	32,210
		(409,252)	(310)	(1119)	(0.617)	(0.197)		(9.25)				(13,848)
Test 6 (4-77)[g]		11,143	152	–	203	0.364-E	26 (TR)	2.82	35	2.72	7.06	32,673
		(393,527)	(305)	(1137)	(0.472)	(0.159)		(9.25)				(14,047)
Test 7 (4-77)[g]		11,349	148	–	313	0.513-E	12 (VE)	2.82	17	2.72	7.06	32,673
		(400,785)	(298)	(1058)	(0.729)	(0.224)		(9.25)				(14,047)
Test 8 (4-77)[g]		11,223	146	–	210	0.303-E	25 (VE)	2.82	34	2.72	7.06	32,673
		(396,349)	(295)	(922)	(0.488)	(0.132)		(9.25)				(14,047)
Test 9 (4-77)[f]		11,235	154	–	140	0.245-E	34 (TR)	2.82	45	2.59	6.96	32,264
		(396,349)	(310)	(1117)	(0.327)	(0.107)		(9.25)				(13,871)
Test 10 (4-77)[f]		10,732	162	–	162	0.299-E	17 (VE)	2.82	23	2.59	6.96	32,264
		(379,012)	(324)	(1125)	(0.378)	(0.131)		(9.25)				(13,871)
PSC NH BOW 2												
Test 3 (8-77)[g]	Cyclone boiler 347 MW (3015)	33,036	163	–	57	0.099-E	50 (TR)	4.85	44	3.9	9.44	31,920
		(1,166,666)	(325)	(3204)	(0.132)	(0.043)		(15.9)				(13,723)
Test 4 (8-77)[f]		32,718	161	–	51	0.087-E	66 (TR)	4.85	59	3.9	9.44	31,920
		(1,155,430)	(322)	(3174)	(0.118)	(0.038)		(15.9)				(13,723)

(continued)

TABLE A-1 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e $(10^6$ Btu/hr$)_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e $(10^6$ Btu/hr$)_T$	Particulate loading[b] at stack conditions: ng/J (lb/10^6 Btu)	Particulate loading[b] at stack conditions: g/am^3 (gr/acf)	Opacity[c] %	Stack diameter m (ft)	Standardized Opacity[d] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
NORTH DAKOTA MINNKOTA POWER COOP. (9-75)	Lignite utility boiler 235 MW	31,000 (1,100,000)	154 (310)	– (2425)	3 (0.007)	0.0039-E (0.0017)	7 (VE)	5.79 (19)	5	– –	– –	– –
SQUARE BUTTE YOUNG 2 (6-78)	Lignite utility boiler 440 MW	53,500 (1,890,000)	78 (172)	442 (5048)	14 (0.033)	0.023-E&S (0.010)	19 (VE)	7.62 (25)	10	– –	– –	– –
HESKETT - UNIT 1 Test 6 (12-75)	Lignite utility boiler 25 MW	5,312 (187,600)	174 (345)	– (340)	8 (0.019)	0.0087-E (0.0038)	5 (VE)	2.13	9	–	–	15,991 (6,875)
HESKETT - UNIT 2 (12-75)	Lignite utility boiler 66 MW	10,200 (360,000)	154 (309)	– (751)	7 (0.016)	0.0087-E (0.0038)						
LELAND OLDS UNIT 1 (5-75)	Lignite fired boiler 216 MW	– –	– –	– (2236)	3 (0.008)	– –	7 (VE)	3.66 (12)	5	– –	– –	16,080 (6,913)
LELAND OLDS UNIT 2 (12-76)	Lignite fired boiler 440 MW	62,300 (2,200,000)	204 (399)	– (4752)	9 (0.022)	0.0127-E (0.0056)	15 (VE)	6.71 (22)	9	– –	– –	– –
MDU-BEULAH UNITS 3,4,5 (4-76)	Lignite boiler	– –	– –	– (159)	72 (0.168)	– –	5 (VE)	2.29 (7.5)	9	– –	– –	– –
MDU-BEULAH UNIT 1 (10-71)	Lignite fired boiler	–	–	– (63)	710 (1.65)	– –	35 (VE)	1.52 (5)	68	– –	– –	– –
BASIN ELEC. VELVA 2 Test 3 (8-78)	Lignite utility boiler 21 MW	4,069	206	18.4 (325)	10 (0.024)	0.014-E (0.0062)	7 (VE)	1.83 (6)	15	– –	– –	– –
BASIN ELEC. VELVA 2 Test 4 (8-78)	Lignite utility boiler 21 MW	3,859 (136,290)	192 (377)	17.7 (294)	7 (0.016)	0.0092-E (0.0040)	6 (VE)	1.83 (6)	13	– –	– –	– –
UPA-STANTON (6-76)	Lignite utility boiler 172 MW	– –	– –	– (1237)	43 (0.101)	– –	10 (VE)	4.57 (15)	9	– –	– –	– –

(continued)

TABLE A-1 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e $(10^6\ Btu/hr)_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e $(10^6\ Btu/hr)_T$	Particulate loading[b] at stack conditions ng/J (lb/10^6 Btu)	g/am^3 (gr/acf)	Opacity[c] %	Stack diameter m (ft)	Standardized opacity[d] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
CATERPILLAR TRACTOR DECATUR (4-77)	Coal-fired steam boiler	≈900 (≈32,000)	163 (326)	–	–	0.064-F (0.028)	0 (VE)	1.37	0	1.6-2.3	9-11	≈29,500 (≈12,700)
PACIFIC PWR & LT CENTRALIA 1 (7-77)	Coal-fired utility boiler 680 MW	– –	– –	– –	– –	– –	10 (VE)	– –	– –	– –	– –	– –
ADOLPH COORS CO. (6-77)	Corner-fired coal boiler	5,100 (180,000)	179 (355)	– (418)	14 (0.032)	est. 0.02-F (est. ≈0.01)	0 (VE)	2.13 × 3.05 (7 × 10)	0	0.53	10	≈26,000 (≈11,000)
EPA-Region V OHIO EDISON SAMMIS-STACK 1 (4-78)	2 front fired pulv. coal 185 MW each	– –	– –	– –	2,073 (4.82)	– –	– –	6.40 (21.0)	– –	– –	– –	– –
OHIO EDISON SAMMIS-STACK 2 (4-78)	2 front fired pulv. coal 185 MW each	– –	– –	– –	1,479 (3.44)	– –	98 (VE)	6.10 (20.0)	92	– –	– –	– –
KAISER ALUM. (3-78)[i]	2 coal-fired boilers, common stack	2,061 (72,775)	221 (429)	– (128)	247 (0.576)	0.289-N (0.126)	18 (VE)	2.22 (9.29)	30	1.74	13.2	25,130 (10,804)
CENTRAL OHIO PSYCH. HOSP. Test 1 (9-78)	60,000 lb/hr steam, chain grate stoker	– –	– –	– –	– –	– –	4 (VE)	– –	– –	– –	– –	– –
ARKANSAS POTLATCH CORP.												
Test 1		2,915 (102,930)	210 (410)	– –	22 (0.05)	0.044 (0.0193)	11 (VE)	2.74 (9)	16	– –	– –	– –
Test 2		4,179 (147,564)	210 (410)	– –	22 (0.05)	0.048 (0.0211)	6 (VE)	2.74 (9)	9	– –	– –	– –
Test 3		4,182 (147,700)	210 (410)	– –	9 (0.02)	0.017 (0.0075)	6 (VE)	2.74 (9)	9	– –	– –	– –
NEBRASKA WRIGHT PWR STA UNIT 8 (10-77)		– –	– –	– –	44 (0.1014)	– –	26 (VE)	2.74 (9)	35	0.42-0.47	6.6-14	27,200-28,000 (11,700-12,400)

(continued)

TABLE A-1 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e $(10^6\ Btu/hr)_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e $(10^6\ Btu/hr)_T$	Particulate loading[b] at stack conditions ng/J ($lb/10^6$ Btu)	g/am³ (gr/acf)	Opacity[c] %	Stack diameter m (ft)	Standardized opacity[d] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
WRIGHT PWR STA UNIT 8 (10-77)		— —	— —	— —	26 (0.0596)	—	15 (VE)	2.74 (9)	21	Same as previous test		
(10-77)		— —	— —	— —	72 (0.1664)	— —	20 (VE)	2.74 (9)	27	Same as previous test		
(10-77)		— —	— —	— —	47 (0.1085)	—	22 (VE)	2.74 (9)	31	Same as previous test		
(10-77)		— —	— —	— —	54 (0.125)	— —	31 (VE)	2.74 (9)	42	Same as previous test		
(10-77)		— —	— —	— —	56 (0.130)	— —	23 (VE)	2.74 (9)	31	Same as previous test		
(10-77)		— —	— —	— —	83 (0.193)	— —	31 (VE)	2.74 (9)	41	Same as previous test		
(10-77)		— —	— —	— —	80 (0.185)	— —	19 (VE)	2.74 (9)	27	Same as previous test		
(10-77)	91 MW (800)	— —	— —	— —	187	— —	32 (VE)	2.74	44	0.42 - 0.47	6.6 - 14	27,200-28,000 (11,700-12,400)
KRAMER POWER STA UNITS 1 & 2		— —	— —	— —	26 (0.060)	— —	5 (VE)	2.57 (8.42)	8	0.73	3.33	29,960 (12,881)
FLORIDA												
TAMPA ELEC. Gannon 5 Test 2 (7-78)	Pulv. coal; opp. 240 MW (2386)	13,600 (481,000)	162 (323)	240 (2386)	5 (0.012)	0.0158-E (0.0069)	0 (VE)	4.45 (14.6)	0	1.1	11	27,600 (11,900)
BIG BEND UNIT 2 Test 2 (10-78)	Pulv. coal; opp. 350 MW (3070)	34,800 (1,230,000)	140 (284)	350 (3070)	77 (0.18)	0.119-E (0.052)	11 (VE)	7.32 (25)	6	3.0	11	27,500 (11,800)
INDIANA												
WASH PWR & LT Boiler 1 Test 1 (4-75)[j]	Chain grate (120)	1,130 (39,900)	311 (592)	— (74.3)	452 (1.05)	0.520-N (0.227)	47 (VE)	3.66 (12.0)	50	—	—	— —
Boiler 2 Test 1 (6-75)[k]	Chain grate (72)	1,260 (44,700)	179 (355)	— (23.0)	813 (1.89)	0.259-N (0.113)	16 (VE)	3.66 (12.0)	17	—	—	— —
Boiler 2 Test 3 (6-75)[k]		1,390 (49,200)	205 (401)	— (42.6)	374 (0.87)	0.200-N (0.088)	42 (VE)	3.66 (12.0)	45	—	—	— —

(continued)

TABLE A-1 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e (10^6 Btu/hr)$_T$	Flow rate am³/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e (10^6 Btu/hr)$_T$	Particulate loading[b] at stack conditions ng/J (lb/10^6 Btu)	Particulate loading[b] at stack conditions g/am³ (gr/acf)	Opacity[c] %	Stack diameter m (ft)	Standardized opacity[d] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
OLIN at Covington Boiler 2												
Test 1 (10-75)[k]	Spreader stoker (≈100)	740 (26,000)	169 (336)	— (57)	619 (1.44)	0.847 (0.370)	58 (VE)	2.13 (7.0)	80	—	—	— —
GMC at Anderson Boiler 2												
Test 1 (6-76)	Coal-fired steam boiler (≈100)	1,270 (45,000)	204 (400)	— (94)	190 (0.44)	0.264-C (0.115)	27 (VE)	1.65 (5.42)	53	—	—	— —
CRAWFORDSVILLE ELEC. Boiler 5												
Test 1 (11-75)[l]	— —	2,030 (71,600)	196 (384)	— (86)	1152 (2.68)	1.26-C (0.550)	49 (VE)	2.03 (6.67)	73	3.69	10.8	30,290 (13,022)
Test 2 (11-75)[l]	— —	2,040 (72,200)	194 (381)	— (95)	1109 (2.58)	1.47-C (0.642)	52 (VE)	2.03 (6.67)	76	3.41	11.7	29,800 (12,811)
Test 3 (11-75)[k]	— —	2,050 (72,400)	196 (385)	— (125)	1015 (2.36)	1.35-C (0.588)	53 (VE)	2.03 (6.67)	77	3.82	12.4	29,680 (12,759)
Boiler 6												
Test 1 (11-75)[k]	— —	1,910 (67,300)	211 (411)	— (170)	175 (0.407)	0.281-C (0.123)	66 (VE)	2.67 (8.75)	80	3.05	11.4	29,720 (12,778)
Test 2 (11-75)[k]		1,910 (67,500)	214 (418)	— (170)	299 (0.695)	0.477-C (0.209)	72 (VE)	2.67 (8.75)	85	3.39	11.1	29,920 (12,862)
Test 3 (11-75)[k]		1,950 (68,800)	216 (421)	— (190)	204 (0.474)	0.344-C (0.151)	70 (VE)	2.67 (8.75)	84	3.42	12.1	29,510 (12,688)
<u>NEW YORK STATE</u> ANACONDA BRASS Buffalo (2-77)[m]	Coal-fired underfeed retort (24)	600 (21,000)	102 (215)	— (25)	215 (0.5)	0.16-C (0.07)	10 (M9)	2.4 (7.8)	16	—	—	— —
CITY OF BUFFALO; Publ. School (--)[n]	Manual stoker (1.5)	110 (3,800)	— —	— (1.5)	542 (1.26)	0.13-N (0.06)	33 (VE)	0.78 × 0.94 (2.6 × 3.1)	87	3.3	—	30,630 (13,167)
CARBORUNDUM Niagara Falls (6-77)[n]	Spreader stoker (85)	760 (27,000)	— —	— (82)	200 (0.46)	0.38 (0.17)	6 (VE)	3.15 (10.3)	8	—	—	— —
MIDDLETOWN STATE HOSPITAL												
Test 2 (2-73)	Coal-fired steam boiler	— —	193 (380)	— (57)	181 (0.42)	—	~20 (VE)	3.35 (11.0)	~23	2.69	7.9	31,615 (13,592)

(continued)

TABLE A-1 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e (10^6 Btu/hr)$_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e (10^6 Btu/hr)$_T$	Particulate loading[b] at stack conditions ng/J (lb/10^6 Btu)	Particulate loading[b] at stack conditions g/am^3 (gr/acf)	Opacity[c] %	Stack diameter m (ft)	Standardized opacity[d] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
MIDDLETOWN STATE HOSPITAL												
Test 3 (2-73)	Coal-fired steam boiler	— —	— —	— (69)	172 (0.40)	—	~20 (VE)	3.35 (11.0)	23	2.69	7.9	31,635 (13,592)
Test 4 (2-73)		— —	— —	— (64)	176 (0.41)	—	~20 (VE)	3.35 (11.0)	23	2.69	7.9	31,615 (13,592)
UNION CARBIDE Niagara Falls												
Test 1 (11-77)	Carbon baking ring. furn. 4	640 (22,660)	52 (126)	— —	— —	0.040 (0.017)	10 (VE)	1.52 (4.98)	24	—	—	— —
Test 2 (11-77)		655 (23,128)	57 (135)	—	—	0.013 (0.006)	0 (VE)	1.52 (4.98)	0	—	—	— —
Test 3 (11-77)		656 (23,179)	— —	— —	— —	0.035 (0.015)	0 (VE)	1.52 (4.98)	0	—	—	— —
PRESTOLITE CO. Niagara Falls												
Test 1 (11-77)	B&W east coal boiler (24)	429 (15,160)	286 (546)	— (17)	151 (0.350)	0.108-C (0.047)	10 (VE)	0.95 (3.12)	36	—	—	— —
Test 2 (11-77)		438 (15,470)	291 (555)	— (18)	134 (0.311)	0.095-C (0.042)	10 (VE)	0.95 (3.12)	36	—	—	— —
Test 3 (11-77)		424 (14,980)	281 (537)	— (23)	145 (0.336)	0.137-C (0.059)	10 (VE)	0.95 (3.12)	36	—	—	— —
GOWANDA PSYCH. CENTER Helmuth, NY												
Test 1 (8-76)[o]	Underfeed stoker	646 (22,800)	168 (334)	— (17)	147 (0.342)	0.0673 (0.0294)	0 (VE)	2.78 × 2.73 (9.12 × 8.96)	0	—	—	30,505 (13,149)
Test 2 (8-76)[p]		799 (28,210)	162 (324)	— (15)	271 (0.631)	0.0920 (0.0402)	2 (VE)	2.78 × 2.73 (9.12 × 8.96)	3	—	—	30,515 (13,149)
Test 3 (8-76)[q]		701 (24,760)	154 (309)	— (18)	151 (0.352)	0.0686 (0.0300)	0 (VE)	2.78 × 2.73 (9.12 × 8.96)	0	—	—	30,505 (13,149)

[a] e = electrical, T = thermal

[b] Control by ESP (E), filter (F), cyclone (C), none (N), or scrubber (S)

[c] VE = Visual observation
TR = In-stack transmissometer
M9 = Method 9

[d] Standardized to 4.0 m (~ 13.0 ft)

[e] PSC NH = Public Service Company of New Hampshire

[f] No additive

[g] With additive

[h] Soot blowing

[i] Particle size data available

[j] White plume, white sky VE 30 min of 96 min test

[k] VE 30 min of 96 min stack test

[l] VE 30 min of 96 stack test

[m] Soot blowing nonconcurrent VE

[n] Average opacity and emission rates

[o] VE for 15 min

[p] VE for 34 min

[q] VE for 10 min

TABLE A-2. CONCURRENT MASS EMISSION AND OPACITY TESTS FOR EPA REGION IV, COAL-FIRED BOILERS WITH ELECTROSTATIC PRECIPITATORS. TVA SYSTEM.

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e $(10^6\ Btu/hr)_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e $(10^6\ Btu/hr)_T$	Particulate loading at stack conditions ng/J $(lb/10^6\ Btu)$	Particulate loading at stack conditions g/am^3 (gr/acf)	Opacity[b] %	Stack diameter m (ft)	Standardized opacity[c] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
TVA-ALLEN 1	B&W Cyclone 280 MW (2931)											
Test 1 (7-78)[d]		25,440 (898,500)	144 (292)	— (2428)	9 (0.020)	0.0146 (0.0064)	5 (VE)	3.90 (12.8)	5	3.0	12.1	27,524 (11,833)
Test 2 (7-78)[e]		25,000 (882,900)	144 (292)	— (2439)	9 (0.021)	0.0156 (0.0068)	<6 (VE)	3.90 (12.8)	6	3.0	12.1	27,524 (11,833)
TVA-ALLEN 2												
Test 1 (7-78)		28,710 (1,013,800)	148 (299)	278 (2460)	20 (0.046)	0.0300 (0.0131)	11 (TR)	3.90 (12.8)	11	2.8	12.1	26,737 (11,495)
Test 2 (7-78)		29,490 (1,041,300)	148 (298)	279 (2469)	22 (0.050)	0.0318 (0.0139)	11 (TR)	3.90 (12.8)	11	2.8	12.1	26,737 (11,495)
Test 3 (7-78)		28,590 (1,009,800)	146 (295)	275 (2463)	21 (0.048)	0.0311 (0.0136)	11 (TR)	3.90 (12.8)	11	2.8	12.1	26,737 (11,495)
TVA-ALLEN 3												
Test 1 (7-78)		27,400 (968,000)	145 (293)	— (2364)	31 (0.072)	0.0471 (0.0206)	13 (TR) 13 (VE)	3.90 (12.8)	13 13	3.1	12.1	27,956 (12,019)
Test 2 (7-78)		26,950 (951,900)	144 (291)	— (2419)	27 (0.063)	0.0426 (0.0186)	12 (TR) 12 (VE)	3.90 (12.8)	12 12	3.1	12.1	27,956 (12,019)
Test 3 (7-78)		27,640 (976,200)	144 (291)	— (2389)	37 (0.085)	0.0556 (0.0243)	12 (TR) 11 (VE)	3.90 (12.8)	12 11	3.1	12.1	27,956 (12,019)
TVA COLBERT 1	Pulverized, dry bottom 223 MW											
Test 1 (9-78)		24,750 (874,200)	188 (371)	182 (1357)	51 (0.118)	0.0487 (0.0213)	9 (TR) 7 (VE)	5.03 (16.5)	7 6	3.9	14.3	26,650 (11,460)
Test 2 (9-78)		24,400 (862,000)	196 (385)	182 (1580)	41 (0.096)	0.046 (0.0200)	9 (TR) 9 (VE)	5.03 (16.5)	7 7	3.7	12.9	27,590 (11,860)
Test 3 (9-78)		24,410 (862,200)	187 (368)	180 (1586)	35 (0.081)	0.0398 (0.0174)	9 (TR)	5.03 (16.5)	7	2.4	15.5	26,998 (11,607)
TVA-COLBERT 2												
Test 1 (9-78)		19,910 (708,700)	167 (332)	180 (1792)	35 (0.080)	0.0542 (0.0237)	7 (TR) 5 (VE)	5.03 (16.5)	6 4	3.8	14.5	27,417 (11,787)
Test 2 (9-78)		20,900 (744,000)	167 (333)	180 (1700)	30 (0.069)	0.0423 (0.0185)	7 (TR) 12 (VE)	5.03 (16.5)	6 10	3.9	13.5	27,975 (12,027)
Test 3 (9-78)		19,880 (702,100)	168 (334)	180 (1745)	25 (0.058)	0.0384 (0.0168)	8 (TR)	5.03 (16.5)	6	3.8	13.5	27,200 (11,694)

(continued)

TABLE A-2 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e $(10^6$ Btu/hr$)_T$	Flow rate am³/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e $(10^6$ Btu/hr$)_T$	Particulate loading at stack conditions: ng/J (lb/10⁶ Btu)	Particulate loading at stack conditions: g/am³ (gr/acf)	Opacity[b] %	Stack diameter m (ft)	Standardized opacity[c] %	Fuel weight % sulfur	Fuel weight % sulfur	Fuel heat content kJ/kg (Btu/lb)
TVA-COLBERT 3												
Test 1 (9-78)		22,310 (787,920)	177 (350)	— (1993)	38 (0.089)	0.0604 (0.0264)	6 (TR) 5 (VE)	5.03 (16.5)	5 4	3.7	13.8	27,270 (11,724)
Test 2 (9-78)		22,470 (793,600)	182 (360)	— (2175)	34 (0.079)	0.0577 (0.0252)	6 (TR) 6 (VE)	5.03 (16.5)	5 5	3.9	13.9	27,189 (11,689)
Test 3 (9-78)		24,660 (870,700)	180 (356)	— (2085)	28 (0.065)	0.0426 (0.0186)	6 (TR) 5 (VE)	5.03 (16.5)	5 4	3.5	14.6	27,554 (11,846)
TVA-COLBERT 4	Pulverized, dry bottom 223 MW											
Test 1 (11-78)		20,530 (724,900)	167 (332)	(200) (1806)	79 (0.183)	0.122 (0.0532)	9 (TR) 12 (VE)	5.03 (16.5)	7 10	2.08	17.7	26,582 (11,428)
Test 2 (11-78)		20,450 (722,300)	166 (331)	200 (1775)	55 (0.128)	0.0840 (0.0367)	10 (TR) 9 (VE)	5.03 (16.5)	8	1.98	18.3	26,454 (11,373)
Test 3 (11-78)		20,090 (709,400)	165 (329)	200 (1800)	67 (0.155)	0.105 (0.0459)	17 (TR) 7 (VE)	5.03 (16.5)	14 6	2.36	17.0	27,219 (11,702)
TVA-WIDOWS CREEK Boiler 7												
Test 1 (2-79)		49,740 (1,756,700)	144 (292)	— (5000)	217 (0.63)	0.475 (0.2076)	66 (VE)	6.34 (20.8)	49	2.1	13.9	27,640 (11,883)
Test 3 (3-79)		50,980 (1,800,400)	148 (298)	— (4900)	340 (0.79)	0.576 (0.2517)	38 (VE)	6.34 (20.8)	26	2.8	14.2	26,970 (11,594)
Test 4 (3-79)	C.E. pulverized, dry bottom 500 MW	46,490 (1,641,700)	144 (292)	— (4700)	348 (0.81)	0.614 (0.2683)	34 (TR) 29 (VE)	6.34 (20.8)	23 19	3.0	14.6	27,500 (11,822)
Test 1 (10-78)		49,610 (1,751,900)	154 (310)	— (4460)	133 (0.262)	0.178 (0.0778)	34 (VE)	6.34 (20.8)	23	3.7	14.7	26,368 (11,336)
Test 2 (10-78)		49,590 (1,751,400)	153 (307)	— (4490)	111 (0.258)	0.177 (0.0772)	30 (VE)	6.34 (20.8)	20	3.8	15.3	25,998 (11,177)
Test 3 (10-78)		50,060 (1,768,000)	154 (310)	— (4430)	127 (0.296)	0.198 (0.0867)	27 (VE)	6.34 (20.8)	18	3.8	14.4	25,364 (11,084)
TVA-CUMBERLAND Boiler 1												
Test 1 (10-78)		135,500 (4,786,000)	149 (300)	1300 (10,975)	95 (0.23)	0.140[f] (0.061)	31 (VE)	9.45 (31.0)	15	3.6	15.4	25,050 (10,770)
Test 2 (10-78)	B&W pulverized 1300 MW	131,600 (4,648,000)	148 (298)	1300 (11,045)	84 (0.20)	0.124[f] (0.054)	22 (VE)	9.45 (31.0)	10	3.5	14.6	25,240 (10,850)
Boiler 2												
Test 4 (4-79)		88,120 (3,155,100)	141 (285)	700 —	— —	0.0169[f] (0.0069)	8 (TR)	9.45 (31.0)	3	—	—	— —

(continued)

TABLE A-2 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e $(10^6\ Btu/hr)_T$	Flow rate am³/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e $(10^6\ Btu/hr)_T$	Particulate loading at stack conditions ng/J (lb/10⁶ Btu)	Particulate loading at stack conditions g/am³ (gr/acf)	Opacity[b] %	Stack diameter m (ft)	Standardized opacity[c] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
TVA-CUMBERLAND Boiler 2												
Test 5 (4-79)	B&W pulverized 1300 MW	89,340 (3,155,100)	141 (285)	700 —	— —	0.0158[f] (0.0069)	8 (TR)	9.45 (31.0)	3	—	—	— —
Test 6 (4-79)		88,850 (3,137,700)	142 (288)	700	—	0.0158[f] (0.0069)	8 (TR)	9.45 (31.0)	3	—	—	— —
TVA-JOHNSONVILLE Boilers 9 & 10												
Test 1 (10-78)	Pulv. coal; front fired 135 MW each	30,950 (1,092,900)	158 (316)	143/133 (2480)	85 (0.20)	0.120[f] (0.0526)	38 (TR) 50 (VE)	4.27 (14.0)	36 48	3.3	15.3	25,980 (11,170)
Test 2 (10-78)		30,000 (1,059,400)	153 (307)	135/135 (2430)	50 (0.12)	0.0712 (0.0311)	32 (TR) 42 (VE)	4.27 (14.0)	30 40	3.3	16.0	(10,790)
Test 3 (10-78)		30,680 (1,083,400)	156 (313)	145/140 (2560)	47 (0.11)	0.0684 (0.0299)	30 (TR)	4.27 (14.0)	28	3.8	16.4	25,610 (11,010)
TVA-PARADISE Boiler 1												
Test 1 (10-78)	Cyclone boiler 700 MW	54,050 (1,908,600)	144 (291)	610 —	— —	0.124 (0.0542)	15 (TR)	7.92 (26.0)	8	3.7	13.7	25,519 (10,971)
Test 2 (10-78)		54,330 (1,918,800)	144 (292)	602 —	— —	0.118 (0.0517)	17 (TR) 26 (VE)	7.92 (26.0)	9 14	3.5	12.9	25,926 (11,146)
Test 3 (10-78)		54,290 (1,917,300)	144 (292)	600 —	— —	0.159 (0.0695)	17 (TR)	7.92 (26.0)	9	3.5	12.9	25,926 (11,146)
Boiler 2												
Test 1 (10-78)[g]		61,990 (2,189,100)	141 (286)	650 (7150)	305 (0.71)	0.619 (0.2707)	35 (TR) 34 (VE)	7.92 (26.0)	20 19	4.3	16.0	24,607 (10,579)
Test 2 (10-78)		60,630 (2,141,200)	138 (281)	650 (6450)	236 (0.55)	0.443 (0.1936)	18 (TR)	7.92 (26.0)	10	3.9	13.4	25,551 (10,985)
Test 3 (10-78)		59,730 (2,109,200)	141 (286)	643 (6700)	142 (0.33)	0.280 (0.1222)	27 (TR) 51 (VE)	7.92 (26.0)	15 30	3.9	13.4	25,551 (10,985)
TVA-WATTS BAR Units A & B												
Test 1 (10-78)	Pulv. coal; wet & dry bottom 60 MW each	15,130 (534,400)	173 (343)	58/58 (1190)	95 (0.22)	0.130 (0.0570)	18 (TR) 4 (VE)	4.88 (16.0)	15 3	2.2	14.8	28,170 (12,110)
Test 2 (10-78)		17,180 (606,800)	174 (346)	58/58 (1210)	82 (0.19)	0.100 (0.0439)	20 (TR) 3 (VE)	4.88 (16.0)	17 2	2.4	19.0	26,400 (11,350)
Test 3 (10-78)		19,960 (563,500)	169 (336)	58/58 (1310)	64 (0.15)	0.0931 (0.0407)	20 (TR) 3 (VE)	4.88 (16.0)	17 2	2.5	16.2	27,700 (11,910)

(continued)

TABLE A-2 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e (10^6 Btu/hr)$_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e (10^6 Btu/hr)$_T$	Particulate loading at stack conditions ng/J (lb/10^6 Btu)	Particulate loading at stack conditions g/am^3 (gr/acf)	Opacity[b] %	Stack diameter m (ft)	Standardized opacity[c] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
TVA-WATTS BAR Units A & B												
Test 4 (10-78)[h]	Pulv. coal; wet & dry bottom 60 MW each	17,080 (613,300)	172 (341)	58/58 (1190)	52 (0.12)	0.0611 (0.0267)	19 (TR) 24 (VE)	4.88 (16.0)	16 20	2.5	15.7	27,470 (11,810)
Unit C												
Test 1 (10-78)		8,100 (286,100)	163 (326)	56 (580)	69 (0.16)	0.0863 (0.0377)	21 (TR) 5 (VE)	4.88 (16.0)	18 4	2.8	17.1	27,470 (11,810)
Test 2 (10-78)		9,760 (344,800)	162 (323)	54 (600)	95 (0.22)	0.100 (0.0438)	22 (TR) 5 (VE)	4.88 (16.0)	18 4	2.1	15.3	28,450 (12,230)
Test 3 (10-78)		8,250 (291,200)	158 (316)	56 (660)	60 (0.14)	0.0854 (0.0373)	22 (TR)	4.88 (16.0)	18	2.4	12.6	29,350 (12,620)

[a]E = electrical, T = thermal

[b]VE = visual emissions
TR = In-stack transmissometer

[c]**Standardized to 4.0 m (~ 13.0 ft)**

[d]**VE for only 6 min**

[e]**VE for 12 min**

[f]**Systems with ESP and mechanical collector (cyclone)**

[g]**VE and trans. from previous day**

[h]**Soot blowing during VE**

TABLE A-3. CONCURRENT MASS EMISSIONS AND VISUAL OPACITY ESTIMATES FOR UTILITY AND COAL-FIRED BOILERS FROM SOUTH CAROLINA, INCOMPLETE DATA

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e (10^6 Btu/hr)$_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e (10^6 Btu/hr)$_T$	Particulate loading at dry standard conditions: ng/J (lb/10^6 Btu)	Particulate loading at dry standard conditions: g/dsm^3 (gr/$dsft^3$)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
DUKE POWER												
LEE 1												
Test 1 (8-74)		—	—	—	52	0.171	10	2.44	16	—	—	—
		—	—	(969)	(0.1215)	(0.0746)		(8)				—
Test 2 (8-74)		—	—	—	34	0.108	10	2.44	16	—	—	—
		—	—	(961)	(0.0780)	(0.0472)		(8)				—
Test 3 (8-74)		—	—	—	73	0.194	11	2.44	17	—	—	—
		—	—	(987)	(0.0848)	(0.0848)		(8)				—
Test 1 (5-77)		—	—	—	42	0.121	9	2.44	14	—	—	—
		—	—	(942)	(0.098)	(0.053)		(8)				—
LEE 3												
Test 3 (5-77)		—	—	—	51	0.147	18	2.44	28	—	—	—
		—	—	(1642)	(0.118)	(0.064)		(8)				—
SONOCO												
UNIT 4												
Test 1 (4-77)	Coal > 250 Btu/hr	—	—	—	202	0.517	31	—	—	—	—	—
		—	—	(358)	(0.47)	(0.226)		—				—
Test 2 (4-77)		—	—	—	163	0.423	34	—	—	—	—	—
		—	—	(356)	(0.38)	(0.185)		—				—
Test 3 (4-77)		—	—	—	198	0.549	32	—	—	—	—	—
		—	—	(375)	(0.46)	(0.24)		—				—
S.C. ELEC. & GAS												
McMEEKIN 1												
Test 1 (3-76)	Pulv. coal; tang. fired, 147 MW (1113)	—	—	—	82	0.226	26	5.27	20	—	—	—
		—	—	(1142)	(0.19)	(0.0985)		(17.3)				—
Test 2 (3-76)		—	—	—	129	0.333	25	5.27	20	—	—	—
		—	—	(1128)	(0.30)	(0.1455)		(17.3)				—
Test 3 (3-76)		—	—	—	73	0.189	6	5.27	5	—	—	—
				(1103)	(0.17)	(0.0825)		(17.3)				
McMEEKIN 2												
Test 1 (3-76)	Pulv. coal; tang. fired, 147 MW (1113)	—	—	—	310	0.743	24	5.27	19	—	—	—
		—	—	(1111)	(0.72)	(0.3245)		(17.3)				—
Test 2 (3-76)		—	—	—	198	0.478	16	5.27	12	—	—	—
		—	—	(1077)	(0.46)	(0.2095)		(17.3)				—
Test 3 (3-76)		—	—	—	228	0.480	18	5.27	14	—	—	—
		—	—	(1067)	(0.53)	(0.2510)		(17.3)				—
Test 1 (?-77)		—	—	—	120	0.317	19	5.27	15	—	—	—
		—	—	(1088)	(0.28)	(0.1384)		(17.3)				—

(continued)

TABLE A-3 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e (10^6 Btu/hr)$_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e (10^6 Btu/hr)$_T$	Particulate loading at dry standard conditions ng/J (lb/10^6 Btu)	Particulate loading at dry standard conditions g/dsm³ (gr/dsft³)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
McMEEKIN 2												
Test 2 (?-77)	Pulv. coal; tang. fired, 147 MW (1113)	— —	— —	— (1088)	129 (0.30)	0.327 (0.1429)	15	5.27 (17.3)	12	—	—	— —
Test 3 (?-77)		— —	— —	— (1095)	163 (0.38)	0.400 (0.1749)	11	5.27 (17.3)	8	—	—	— —
URQUHART 1												
Test 1 (9-75)	Pulv. coal; tang. (763)	— —	— —	— (736)	232 (0.54)	0.565 (0.247)	17	4.27 (14.0)	16	—	—	— —
Test 2 (9-75)		— —	— —	— (764)	206 (0.48)	0.522 (0.228)	36	4.27 (14.0)	34	—	—	— —
Test 3 (9-75)		— —	— —	— (764)	189 (0.44)	0.506 (0.221)	32	4.27 (14.0)	30	—	—	— —
Test 1 (9-77)		— —	— —	— (775)	108 (0.25)	0.255 (0.116)	30	4.27 (14.0)	28	—	—	— —
Test 2 (9-77)		— —	— —	— (773)	194 (0.45)	0.463 (0.2024)	35	4.27 (14.0)	33	—	—	— —
URQUHART 2												
Test 1 (7-77)	Pulv. coal; tang. fired, 75 MW (763)	— —	— —	— (762)	129 (0.30)	0.336 (0.147)	31	4.27 (14.0)	29	—	—	— —
Test 2 (-)		— —	— —	— (768)	90 (0.21)	0.217 (0.095)	29	4.27 (14.0)	27	—	—	— —
URQUHART 3												
Test 1 (9-75)	Pulv. coal; tang. fired, 100 MW (1040)	— —	— —	— (980)	176 (0.41)	0.391 (0.171)	21	4.72 (15.5)	18	—	—	— —
Test 3 (9-75)		— —	— —	— (994)	103 (0.24)	0.233 (0.102)	35	4.72 (15.5)	31	—	—	— —
Test 1 (?/78)		— —	— —	— (957)	91 (0.211)	0.194 (0.085)	7	4.72 (15.5)	6	—	—	— —
Test 2 (?/78)		— —	— —	— (958)	68 (0.158)	0.146 (0.064)	9	4.72 (15.5)	8	—	—	— —
WATEREE 1												
Test 1 (1-77)	Pulv. coal; opposed fired 386 MW (3450)	— —	— —	— (3414)	142 (0.33)	0.409 (0.179)	20	5.79 (19.0)	14	—	—	— —
Test 2 (1-77)		— —	— —	— (3490)	189 (0.44)	0.568 (0.248)	17	5.79 (19.0)	12	—	—	— —

(continued)

TABLE A-3 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e $(10^6$ Btu/hr$)_T$	Flow rate am³/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e $(10^6$ Btu/hr$)_T$	Particulate loading at dry standard conditions ng/J (lb/10⁶ Btu)	Particulate loading at dry standard conditions g/dsm³ (gr/dsft³)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
WATEREE 1												
Test 3 (1-77)		— —	— —	— (3547)	168 (0.39)	0.504 (0.220)	12	5.79 (19.0)	8	—	—	— —
WATEREE 2												
Test 1 (?-77)		— —	— —	— (4064)	503 (1.17)	1.383 (0.6039)	31	5.79 (19.0)	27	—	—	— —
Test 2 (?-77)		— —	— —	— (3031)	378 (0.88)	1.073 (0.4679)	14	5.79 (19.0)	10	—	—	— —
Test 3 (?-77)		— —	— —	— (3133)	378 (0.88)	1.071 (0.4628)	21	5.79 (19.0)	15	—	—	— —
S.C. PUB. SERV. JEFFRIES 3	Pulv. coal; opposed fired 386 MW (3450)											
Test 1 (5-78)		— —	— —	— (861)	348 (0.81)	0.731 (0.3203)	31	— —	—	—	—	— —
JEFFRIES 4												
Test 1 (5-78)		— —	— —	— (1410)	271 (0.63)	0.896 (0.3913)	63	— —	—	—	—	— —
Test 2 (5-78)		— —	— —	— (1290)	275 (0.64)	0.691 (0.3017)	55	— —	—	—	—	— —
Test 3 (5-78)		— —	— —	— (1260)	400 (0.93)	0.638 (0.2785)		— —	—	—	—	— —
WINYAH 1												
Test 1 (2-76)		— —	— —	— (2649)	22 (0.05)	0.0545 (0.0238)	0	— —	—	—	—	— —
Test 2 (2-76)		— —	— —	— (2659)	30 (0.07)	0.0824 (0.0360)	0	— —	—	—	—	— —
CONE MILLS UNIT 2												
Test 2 (11-75)		— —	— —	— (73)	598 (1.39)	0.891 (0.389)	17	— —	—	—	—	— —
Test 3 (11-75)		— —	— —	— (73)	568 (1.32)	0.0872 (0.381)	18	— —	—	—	—	— —
UNIT 2												
Test 1 (3-77)		— —	— —	—	155 (0.36)	0.245 (0.107)	12	— —	—	—	—	— —

(continued)

TABLE A-3 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e $(10^6\ Btu/hr)_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e $(10^6\ Btu/hr)_T$	Particulate loading at dry standard conditions ng/J (lb/10^6 Btu)	g/dsm^3 (gr/$dsft^3$)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
UNIT 2												
Test 2 (3-77)		— —	— —	— (80)	146 (0.34)	0.258 (0.113)	11	— —	—	—	—	— —
Test 3 (3-77)		— —	— —	— (79)	146 (0.34)	0.263 (0.115)	10	— —	—	—	—	— —
UNIT 3												
Average (3-73)		— —	— —	— (86)	326 (0.757)	0.691 (0.302)	85	— —	—	—	—	— —
Test 1 (11-75)		— —	— —	— (62)	482 (1.12)	0.712 (0.311)	16	— —	—	—	—	— —
Test 2 (11-75)		— —	— —	— (62)	666 (1.55)	0.932 (0.407)	17	— —	—	—	—	— —
Test 3 (11-75)		— —	— —	— (62)	516 (1.20)	0.957 (0.331)	18	— —	—	—	—	— —
<u>GRACE BLEACHERY</u>												
UNIT 1												
Average (7-75)		— —	— —	— (180)	26 (0.06)	0.0776 (0.0339)	0	— —	—	—	—	— —
UNIT 2												
Average (7-75)		— —	— —	— (172)	34 (0.08)	0.0902 (0.0394)	0	— —	—	—	—	— —
UNIT 3												
Average (7-75)		— —	— —	— (179)	17 (0.04)	0.0345 (0.0151)	0	— —	—	—	—	— —
UNIT 4												
Average (7-75)		— —	— —	— (186)	22 (0.05)	0.0496 (0.0217)	0	— —	—	—	—	— —
UNIT 1												
Average (2-77)		— —	— —	— (142)	43 (0.10)	0.0904 (0.0395)		— —	—	—	—	— —
UNIT 2												
Average (1-77)		— —	— —	— (142)	77 (0.18)	0.168 (0.0735)	0	— —	—	—	—	— —

(continued)

TABLE A-3 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e (10^6 Btu/hr)$_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e (10^6 Btu/hr)$_T$	Particulate loading at dry standard conditions ng/J (lb/10^6 Btu)	Particulate loading at dry standard conditions g/dsm^3 ($gr/dsft^3$)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
UNIT 3												
Average (11-77)		– –	– –	– (170)	69 (0.16)	0.131 (0.0574)	0	– –	–	–	–	– –
KENDALL UNIT 1												
Test 2 (5-74)		– –	– –	– (48)	133 (0.31)	0.239 (0.1045)	64	– –	–	–	–	– –
Test 3 (5-74)		– –	– –	– (53)	133 (0.31)	0.248 (0.1084)	55	– –	–	–	–	– –
Test 1 (7-76)		– –	– –	– (70)	280 (0.65)	0.536 (0.2340)	40	– –	–	–	–	– –
Test 2 (7-76)		– –	– –	– (69)	284 (0.66)	0.513 (0.224)	32	– –	–	–	–	– –
Test 3 (7-76)		– –	– –	– (75)	297 (0.69)	0.513 (0.224)	32	– –	–	–	–	– –
UNIT 2												
Test 1 (5-74)		– –	– –	– (74)	120 (0.28)	0.275 (0.1203)	39	– –	–	–	–	– –
Test 2 (5-74)		– –	– –	– (56)	159 (0.37)	0.286 (0.1248)	31	– –	–	–	–	– –
Test 3 (5-74)		– –	– –	– (76)	116 (0.27)	0.288 (0.1258)	25	– –	–	–	–	– –
Test 1 (7-76)		– –	– –	– (70)	275 (0.64)	0.476 (0.208)	38	– –	–	–	–	– –
Test 2 (7-76)		– –	– –	– (62)	284 (0.66)	0.428 (0.187)	37	– –	–	–	–	– –
KLOPMAN UNIT 1												
Test 1 (5-76)		– –	– –	– (177)	116 (0.27)	0.348 (0.1520)	32	– –	–	–	–	– –
Test 2 (5-76)		– –	– –	– (176)	125 (0.29)	0.327 (0.143)	30	– –	–	–	–	– –
UNIT 2												
Test 1 (5-76)		– –	– –	– (184)	133 (0.31)	0.350 (0.153)	18	– –	–	–	–	– –

(continued)

TABLE A-3 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e $(10^6$ Btu/hr$)_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e $(10^6$ Btu/hr$)_T$	Particulate loading at dry standard conditions ng/J (lb/10^6 Btu)	g/dsm^3 (gr/$dsft^3$)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
UNIT 2												
Test 2 (5-76)		— —	— —	— (181)	129 (0.30)	0.327 (0.143)	24	— —	—	—	—	— —
Test 3 (5-76)		— —	— —	— (171)	133 (0.31)	0.318 (0.139)	15	— —	—	—	—	— —
MANETTA MILLS												
Test 1 (6-74)		— —	— —	— (8.4)	1449 (3.37)	0.780 (0.3407)	62	— —	—	—	—	— —
Test 2 (6-74)		— —	— —	— (8.2)	1462 (3.40)	0.786 (0.3433)	47	— —	—	—	—	— —
Test 2 (6-74)		— —	— —	— (8.3)	972 (2.26)	0.550 (0.2401)	69	— —	—	—	—	— —
REEVES BROS. UNIT 1												
Test 1 (9-75)		— —	— —	— (44)	194 (0.45)	0.169 (0.074)	20	— —	—	—	—	— —
Test 3 (9-75)		— —	— —	— (40)	236 (0.55)	0.194 (0.087)	20	— —	—	—	—	— —
Test 1 (9-77)		— —	— —	— (35)	155 (0.36)	0.116 (0.051)		— —	—	—	—	— —
Test 2 (9-77)		— —	— —	— (32)	181 (0.42)	0.122 (0.053)	10	— —	—	—	—	— —
Test 3 (9-77)		— —	— —	— (29)	224 (0.52)	0.119 (0.052)	10	— —	—	—	—	— —
UNIT 2												
Test 1 (1975)		— —	— —	— (70)	168 (0.39)	0.204 (0.089)	27	— —	—	—	—	— —
Test 2 (1975)		— —	— —	— (57)	116 (0.27)	0.130 (0.057)	11	— —	—	—	—	— —
Test 3 (1975)		— —	— —	— (51)	138 (0.32)	0.146 (0.064)	14	— —	—	—	—	— —
Test 1 (1977)		— —	— —	— (42)	189 (0.44)	0.167 (0.073)	12	— —	—	—	—	— —
Test 2 (1977)		— —	— —	— (38)	138 (0.32)	0.122 (0.053)	7	— —	—	—	—	— —
Test 3 (1977)		—	—	— (37)	120 (0.28)	0.101 (0.044)	8	— —	—	—	—	— —

(continued)

TABLE A-3 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e $(10^6$ Btu/hr$)_T$	Flow rate am³/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e $(10^6$ Btu/hr$)_T$	Particulate loading at dry standard conditions: ng/J (lb/10⁶ Btu)	Particulate loading at dry standard conditions: g/am³ (gr/dsft³)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
RIEGEL UNIT 7												
Test 1 (9-77)		–	–	–	39	0.069	16	–	–	–	–	–
		–	–	(133)	(0.09)	(0.0302)		–				–
SONOCO UNIT 3												
Test 4 (1976)		–	–	–	13	0.0252	0	–	–	–	–	–
		–	–	(135)	(0.03)	(0.011)		–				–
J.P. STEVENS CLEMSON 5												
Test 1 (1975)		–	–	–	236	0.599	25	–	–	–	–	–
		–	–	(113)	(0.55)	(0.262)		–				–
Test 3 (1975)		–	–	–	150	0.485	23	–	–	–	–	–
		–	–	(142)	(0.35)	(0.212)		–				–
UNIROYAL												
Test 2 (8-75)		–	–	–	181	0.133	24	–	–	–	–	–
		–	–	(14)	(0.42)	(0.058)		–				–
Test 1 (8-75)		–	–	–	236	0.222	17	–	–	–	–	–
		–	–	(16)	(0.55)	(0.097)		–				–

[a]**Subscripts: E = electrical; T = thermal.**

[b]**Standardized to 4.0 m (~ 13.0 ft) diameter stack.**

TABLE A-4. CONCURRENT MASS EMISSIONS AND IN-STACK TRANSMISSOMETER MEASUREMENTS FOR SEVERAL COAL-FIRED BOILERS, DIFFERENT FIRING METHODS, AND EXPERIMENTAL VARIATIONS IN ESP OPERATION. STATE OF GEORGIA, GEORGIA POWER

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e (10^6 Btu/hr)$_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e (10^6 Btu/hr)$_T$	Particulate loading at stack conditions: ng/J (lb/10^6 Btu)	Particulate loading at stack conditions: g/am^3 (gr/acf)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
ARKWRIGHT 1-4												
Test 1 (6-78)		22,440 (792,462)	179 (355)	40; 23; 40; 40 (1787)	113 (0.262)	0.158 (0.0689)	19	6.10 (20.0)	13	1.79	16.1	27,012 (11,613)
Test 2 (6-78)		22,200 (784,064)	178 (352)	40; 23; 40; 40 (1909)	109 (0.254)	0.165 (0.0722)	22	6.10 (20.0)	15	1.38	13.9	27,921 (12,004)
Test 3 (6-78)		19,200 (678,066)	177 (351)	40; 23; 40; 40 (1708)	139 (0.324)	0.244 (0.106)	36	6.10 (20.0)	18	1.16	14.0	28,017 (12,045)
Test 4 (6-78)		22,100 (780,034)	178 (353)	40; 23; 40; 40 (1711)	152 (0.354)	0.207 (0.0905)	32	6.10 (20.0)	22	1.27	13.6	28,200 (12,124)
Test 5 (6-78)		19,740 (697,173)	168 (334)	30; 29; 30 30 (1379)	83 (0.192)	0.101 (0.0442)	34	6.10 (20.0)	24	1.54	14.3	27,856 (11,976)
Test 6 (6-78)	Pulv. coal; tang. fired, 40 MW each	19,460 (687,314)	170 (338)	30; 29; 30; 30 (1436)	79 (0.184)	0.102 (0.0447)	20	6.10 (20.0)	14	1.68	13.9	27,224 (11,704)
Test 7 (6-78)		23,160 (817,916)	178 (352)	40; 31; 40 40 (1719)	24 (0.056)	0.0313 (0.0137)	14	6.10 (20.0)	9	2.07	14.9	27,752 (11,931)
Test 8 (6-78)		22,970 (811,045)	179 (355)	50; 31; 40 40 (1848)	26 (0.060)	0.0365 (0.0159)	15	6.10 (20.0)	10	1.82	14.2	27,984 (12,031)
Test 9 (6-78)		22,970 (811,291)	184 (363)	40; 31; 40; 40 (1719)	25 (0.059)	0.0332 (0.0145)	15	6.10 (20.0)	10	1.77	12.5	28,580 (12,287)
Test 10 (6-78)		23,430 (827,470)	181 (358)	41; 30; 40 40 (1881)	415 (0.965)	0.585 (0.256)	63	6.10 (20.0)	48	1.24	13.0	28,352 (12,189)
Test 11 (6-78)		23,770 (839,472)	182 (360)	40; 30; 40; 40 (1862)	269 (0.625)	0.369 (0.161)	24	6.10 (20.0)	14	1.29	13.9	28,568 (12,282)
BRANCH 1&2												
Test 1 (2-79)		42,840 (1,512,848)	114 (238)	260; 270 (4450)	12 (0.0289)	0.023 (0.0099)	10	6.40 (21.0)	6	0.96	10.3	28,590 (12,290)
Test 2 (2-79)		42,550 (1,502,794)	116 (240)	260; 270 (4380)	14 (0.0330)	0.0256 (0.0112)	11	6.40 (21.0)	7	0.95	9.6	28,966) (12,453)
Test 3 (2-79)	Pulv. coal; opp. fired, 250, 319 MW	36,450 (1,287,174)	116 (240)	150; 270 (3460)	164 (0.3809)	0.273 (0.1194)	36	6.40 (21.0)	24	1.09	9.8	28,938 (12,441)
Test 4 (2-79)		36,580 (1,291,966)	110 (230)	130; 287 (3300)	84 (0.195)	0.133 (0.0580)	30	6.40 (21.0)	20	1.37	12.2	27,247 (11,714)
Test 5 (2-79)		38,180) (1,348,188)	111 (231)	155; 287 (3490)	142 (0.3307)	0.228 (0.0995)	35	6.40 (21.0)	24	1.31	11.3	27,833 (11,966)
Test 6 (2-79)		38,130 (1,346,521)	110 (230)	158; 287 (3430)	125 (0.2905)	0.197 (0.0861)	33	6.40 (21.0)	22	0.91	8.6	28,791 (12,378)

(continued)

TABLE A-4 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e $(10^6\ Btu/hr)_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e $(10^6\ Btu/hr)_T$	Particulate loading at stack conditions: ng/J ($lb/10^6$ Btu)	Particulate loading at stack conditions: g/am^3 (gr/acf)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
BRANCH 1&2												
Test 7 (2-79)		41,400 (1,462,060)	114 (238)	122; 287 (3720)	49 (0.1142)	0.0773 (0.0338)	20	6.40 (21.0)	13	1.01	9.9	28,798 (12,381)
Test 8 (2-79)		41,390 (1,461,599)	118 (245)	220; 275 (3760)	75 (0.1747)	0.120 (0.0524)	19	6.40 (21.0)	12	2.06	10.2	28,868 (12,411)
Test 9 (2-79)	Pulv. coal; opp. fired, 250, 319 MW	44,150 (1,559,096)	119 (246)	260; 287 (4080)	75 (0.1738)	0.121 (0.0529)	25	6.40 (21.0)	16	1.19	10.6	28,619 (12,304)
Test 10 (2-79)		44,620 (1,575,604)	127 (261)	260; 287 (4040)	114 (0.2649)	0.181 (0.0790)	44	6.40 (21.0)	30	1.21	11.7	27,928 (12,007)
Test 11 (2-79)		43,970 (1,552,833)	131 (267)	260; 287 (3970)	134 (0.3121)	0.213 (0.929)	45	6.40 (21.0)	31	1.40	10.4	28,470 (12,240)
BRANCH 3&4												
Test 1 (5-78)		67,190 (2,372,700)	127 (261)	437; 382 (7160)	133 (0.3101)	0.250 (0.1091)	44	8.84 (29.0)	23	~1.5	~14	~29,800 (~12,800)
Test 2 (5-78)		67,820 (2,394,900)	127 (260)	435; 382 (7230)	158 (0.3673)	0.296 (0.1294)	47	8.84 (29.0)	25	~1.5	~14	~29,800 (~12,800)
Test 3 (5-78)		61,770 (2,181,400)	122 (251)	395; 357 (6730)	91 (0.2120)	0.175 (0.0763)	39	8.84 (29.0)	20	~1.5	~14	~29,800 (~12,800)
Test 4 (5-78)		48,840 (1,724,800)	113 (235)	320; 180 (4900)	34 (0.0795)	0.0602 (0.0263)	23	8.84 (29.0)	11	~1.5	~14	~29,800 (~12,800)
Test 6 (5-78)		74,770 (2,640,500)	123 (253)	440; 430 (7300)	282 (0.6548)	0.483 (0.2111)	59	8.84 (29.0)	33	~1.5	~14	~29,800 (~12,800)
Test 7 (5-78)	Pulv. coal; opp. fired, 481, 490 MW	75,670 (2,672,400)	127 (260)	440; 430 (7170)	262 (0.6094)	0.437 (0.1909)	56	8.84 (29.0)	31	~1.5	~14	~29,800 (~12,800)
Test 8 (5-78)		75,390 (2,662,300)	127 (261)	440; 430 (7290)	335 (0.7789)	0.569 (0.2488)	64	8.84 (29.0)	37	~1.5	~14	~29,800 (~12,800)
Test 9 (5-78)		56,400 (1,991,600)	119 (246)	430; 203 (6290)	133 (0.3092)	0.261 (0.1140)	35	8.84 (29.0)	18	~1.5	~14	~29,800 (~12,800)
Test 10 (5-78)		55,280 (1,952,200)	121 (250)	430; 203 (6190)	110 (0.2547)	0.216 (0.0942)	32	8.84 (29.0)	16	~1.5	~14	~29,800 (~12,800)
Test 11 (5-78)		44,700 (1,578,700)	116 (240)	249; 225 (4640)	38 (0.0891)	0.0698 (0.0305)	30	8.84 (29.0)	15	~1.5	~14	~29,800 (~12,800)
Test 12 (5-78)		46,380 (1,637,743)	116 (241)	249; 225 (4830)	64 (0.1488)	0.117 (0.0512)	40	8.84 (29.0)	21	~1.5	~14	~29,800 (~12,800)

(continued)

TABLE A-4 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e (10 Btu/hr)$_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW (10^6 Btu/hr)$_T$	Particulate loading at stack conditions ng/J (lb/10^6 Btu)	Particulate loading at stack conditions g/am^3 (gr/acf)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
BRANCH 3&4												
Test 1′ (5-79)	Pulv. coal; opp. fired, 481, 490 MW	78,000 (2,755,849)	122 (251)	460; 400 (7650)	795 (1.8492)	1.37 (0.599)	86	8.84 (29.0)	59	—	—	— —
Test 2′ (5-79)		78,330 (2,766,041)	124 (256)	460; 400 (7800)	651 (1.514)	1.14 (0.498)	81	8.84 (29.0)	53	—	—	— —
Test 3′ (5-79)		78,880 (2,785,461)	126 (258)	460; 400 (7850)	551 (1.281)	0.963 (0.421)	80	8.84 (29.0)	52	—	—	— —
Test 4′ (5-79)		50,860 (1,796,244)	113 (235)	390; 185 (5200)	44 (0.1014)	0.0783 (0.0342)	26	8.84 (29.0)	13	—	—	— —
Test 1 (5-79)		54,150 (1,912,284)	116 (240)	300; 165 (4700)	71 (0.1661)	0.109 (0.0475)	32	8.84 (29.0)	16	—	—	— —
Test 2 (5-79)		54,380 (1,920,284)	116 (239)	355; 165 (4780)	72 (0.1686)	0.112 (0.0488)	27	8.84 (29.0)	13	—	—	— —
Test 3 (5-79)		48,800 (1,723,327)	111 (231)	230; 165 (4430)	31 (0.0716)	0.0490 (0.0214)	18	8.84 (29.0)	9	—	—	— —
Test 4 (5-79)		60,500 (2,136,445)	120 (248)	430; 220 (5580)	96 (0.2242)	0.156 (0.0682)	36	8.84 (29.0)	18	—	—	— —
Test 5 (5-79)		65,140 (2,300,403)	124 (255)	430; 220 (6210)	118 (0.2741)	0.197 (0.0862)	38	8.84 (29.0)	19	—	—	— —
Test 6 (5-79)[c]		80,330 (2,836,856)	121 (250)	445; 442 (7750)	217 (0.5055)	0.368 (0.1608)	63	8.84 (29.0)	36	—	—	— —
Test 7 (5-79)[c]		81,280 (2,870,356)	127 (261)	445; 442 (7730)	185 (0.4304)	0.309 (0.1349)	56	8.84 (29.0)	31	—	—	— —
Test 8 (5-79)[c]		81,870 (2,891,103)	131 (268)	445; 438 (7430)	221 (0.5128)	0.351 (0.1533)	55	8.84 (29.0)	30	—	—	— —
Test 9 (5-79)[c]		76,260 (2,693,170)	127 (261)	435; 382 (6850)	127 (0.2957)	0.200 (0.0876)	43	8.84 (29.0)	22	—	—	— —
Test 10 (5-79)[c]		74,800 (2,641,680)	127 (260)	430; 370 (6680)	112 (0.2605)	0.176 (0.0767)	39	8.84 (29.0)	20	—	—	— —
Test 11 (5-79)[c]		61,100 (2,157,698)	110 (230)	370; 282 (5750)	30 (0.0687)	0.0487 (0.0213)	19	8.84 (29.0)	9	—	—	— —
Test 12 (5-79)[c]		62,140 (2,194,389)	114 (237)	380; 285 (5820)	47 (0.1099)	0.0778 (1.0340)	21	8.84 (29.0)	10	—	—	— —
Test 13 (5-79)[c]		67,560 (2,385,980)	116 (240)	447; 290 (6490)	80 (0.1859)	0.135 (0.0589)	28	8.84 (29.0)	14	—	—	— —

(continued)

TABLE A-4 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e (10^6 Btu/hr)$_T$	Flow rate am³/min (acfm)	Exhaust temperature °C (°F)	Load during test MW (10^6 Btu/hr)$_T$	Particulate loading at stack conditions: ng/J (lb/10^6 Btu)	Particulate loading at stack conditions: g/am³ (gr/acf)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
BRANCH 3&4												
Test 14 (5-79)[c]	Pulv. coal; opp. fired, 481; 490 MW	71,370 (2,520,433)	119 (247)	405; 290 (6770)	72 (0.1664)	0.119 (0.0520)	30	8.84 (29.0)	15	—	—	— —
Test 15 (5-79)[d]		— —	— —	432; 435 —	125 (0.2902)	— —	40	8.84 (29.0)	20	—	—	— —
Test 16 (5-79)[d]		—	—	432; 435 —	95 (0.2201)	— —	36	8.84 (29.0)	18	— —	— —	— —
Test 17 (5-79)[d]		— —	— —	432; 435	97 (0.2248)	—	40	8.84 (29.0)	20	—	—	— —
Test 18 (5-79)[d]		85,490 (3,019,043)	122 (251)	430; 385 (7610)	76 (0.1758)	0.118 (0.0517)	27	8.84 (29.0)	13	—	—	— —
Test 19 (5-79)[d]		91,260 (3,222,713)	122 (251)	430; 385 (8310)	84 (0.1947)	0.134 (0.0584)	27	8.84 (29.0)	13	—	—	— —
Test 20 (5-79)[d]		63,800 (2,252,942)	104 (220)	400; 380 (8650)	45 (0.1051)	0.0773 (0.0338)	20	8.84 (29.0)	10	—	—	— —
Test 21 (5-79)[d]		92,940 (3,281,984)	107 (225)	400; 390 (8920)	33 (0.0771)	0.0558 (0.0244)	20	8.84 (29.0)	10	—	—	— —
Test 22 (5-79)[e]		98,670 (3,484,508)	120 (248)	431; 437 (10,820)	53 (0.1225)	0.101 (0.0443)	30	8.84 (29.0)	15	—	—	— —
Test 23 (5-79)[e]		101,000 (3,566,694)	118 (245)	432; 442 (10,760)	61 (0.1418)	0.114 (0.0498)	34	8.84 (29.0)	17	—	—	— —
Test 24 (5-79)[e]		102,300 (3,576,865)	121 (250)	432; 442 (10,880)	71 (0.1645)	0.133 (0.0583)	33	8.84 (29.0)	17	—	—	— —
Test 25 (5-79)[e]		89,800 (3,171,223)	110 (230)	390; — (10,200)	47 (0.1082)	0.0927 (0.0405)	18	8.84 (29.0)	9	—	—	— —
Test 26 (5-79)[e]		90,650 (3,201,297)	112 (233)	400; — (10,300)	31 (0.0732)	0.0627 (0.0274)	16	8.84 (29.0)	8	—	—	— —
Test 27 (5-79)[e]		103,200 (3,644,641)	116 (240)	432; — (10,780)	111 (0.2592)	0.204 (0.0892)	44	8.84 (29.0)	23	—	—	— —
Test 28 (5-79)[e]		99,350 (3,508,519)	117 (242)	431; 442 (10,500)	112 (0.2613)	0.208 (0.0911)	45	8.84 (29.0)	24	—	—	— —

(continued)

TABLE A-4 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e (10^6 Btu/hr)$_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW (10^6 Btu/hr)$_T$	Particulate loading at stack conditions ng/J (lb/10^6 Btu)	Particulate loading at stack conditions g/am^3 (gr/acf)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
HAMMOND 1,2,3												
Test 1 (3-78)	3 pulv. coal; front fired, 100 MW each	— —	— —	95; 50; 50 —	46 (0.1068)	0.0684 (0.299)	17	6.55 (21.5)	11	1.3- 1.5	11 -15	26,700 (11,500)
Test 2 (3-78)		— —	— —	95; 50; 50 —	38 (0.0893)	0.0588 (0.0257)	17	6.55 (21.5)	11	1.3- 1.5	11 -15	26,700 (11,500)
Test 3 (3-78)		— —	— —	95; 51; 50 —	239 (0.5560)	0.382 (0.1671)	54	6.55 (21.5)	38	1.3- 1.5	11 -15	26,700 (11,500)
Test 4 (3-78)		— —	— —	95; 50; 50 —	162 (0.3770)	0.257 (0.1123)	48	6.55 (21.5)	33	1.3- 1.5	11 -15	26,700 (11,500)
Test 5 (3-78)		— —	— —	106; 70; 90 —	85 (0.1987)	0.138 (0.0605)	27	6.55 (21.5)	17	1.3- 1.5	11 -15	26,700 (11,500)
Test 6 (3-78)		— —	— —	106; 72; 90 —	90 (0.2092)	0.146 (0.0639)	29	6.55 (21.5)	19	1.3- 1.5	11 -15	26,700 (11,500)
Test 7 (3-78)		— —	— —	106; 102; 101 —	146 (0.3400)	0.233 (0.1018)	41	6.55 (21.5)	28	1.3- 1.5	11 -15	26,700 (11,500)
Test 8 (3-78)		— —	— —	106; 103; 100 —	133 (0.3098)	0.212 (0.0928)	39	6.55 (21.5)	27	1.3- 1.5	11 -15	26,700 (11,500)
Test 1 (6-78)		33,780 (1,193,046)	141 (285)	300 total (3140)	166 (0.385)	0.270 (0.1180)	47	6.55 (21.5)	32	—	—	— —
Test 2 (6-78)		33,940 (1,198,709)	142 (287)	301 total (3130)	163 (0.378)	0.263 (0.1150)	45	6.55 (21.5)	31	—	—	— —
Test 3 (6-78)		34,950 (1,234,273)	143 (289)	301 total (3190)	164 (0.382)	0.263 (0.1151)	46	6.55 (21.5)	31	—	—	— —
Test 1 (7-78)		34,140 (1,205,755)	— —	301 total (3180)	61 (0.141)	0.0993 (0.0434)	21	6.55 (21.5)	13	1.09	9.5	29,159 (12,536)
Test 2 (7-78)		34,020 (1,201,394)	— —	301 total (3140)	69 (0.161)	0.112 (0.0491)	20	6.55 (21.5)	13	1.22	9.3	29,342 (12,615)
Test 3 (7-78)		34,540 (1,219,640)	— —	304 total (3170)	77 (0.179)	0.124 (0.0543)	25	6.55 (21.5)	16	1.12	9.3	29,068 (12,497)
HAMMOND 4												
Test 1 (10-78)	Pulv. coal; opp. fired, 500 MW	55,310 (1,953,333)	158 (316)	467 (4998)	76 (0.177)	0.121 (0.053)	28	6.71 (22.0)	18	—	—	— —
Test 2 (10-78)		56,270 (1,987,043)	160 (320)	467 (5120)	77 (0.178)	0.122 (0.0535)	29	6.71 (22.0)	18	—	—	— —
Test 3 (10-78)		57,600 (2,034,007)	159 (318)	469 (5270)	97 (0.226)	0.156 (0.0682)	30	6.71 (22.0)	19	—	—	— —

(continued)

TABLE A-4 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e (10^6 Btu/hr)$_T$	Flow rate am³/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e (10^6 Btu/hr)$_T$	Particulate loading at stack conditions: ng/J (lb/10^6 Btu)	Particulate loading at stack conditions: g/am³ (gr/acf)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
HAMMOND 4												
Test 4 (10-78)		59,850 (2,113,748)	157 (314)	468 (5650)	122 (0.284)	0.203 (0.0886)	36	6.71 (22.0)	23	—	—	—
Test 5 (10-78)		58,630 (2,070,332)	156 (312)	470 (5500)	133 (0.310)	0.220 (0.096)	36	6.71 (22.0)	23	—	—	—
Test 6 (10-78)	Pulv. coal; opp. fired, 500 MW	30,720 (1,085,014)	128 (262)	217 (2960)	14 (0.033)	0.024 (0.0105)	12	6.71 (22.0)	7	—	—	—
Test 7 (10-78)		32,400 (1,144,389)	131 (267)	219 (3050)	9 (0.021)	0.0150 (0.0065)	12	6.71 (22.0)	7	—	—	—
Test 8 (10-78)		45,370 (1,602,298)	147 (296)	349 (4290)	218 (0.508)	0.363 (0.159)	46	6.71 (22.0)	31	—	—	—
Test 9 (10-78)		46,360 (1,637,345)	148 (298)	350 (4380)	199 (0.463)	0.331 (0.145)	44	6.71 (22.0)	29	—	—	—
MITCHELL 1,2,3												
Test 1 (6-78)		—	—	20; 22; 157 —	57 (0.133)	—	32	6.40 (21.0)	21	—	—	—
Test 2 (6-78)		—	—	20; 22; 159 —	55 (0.127)	—	32	6.40 (21.0)	21	—	—	—
Test 3 (6-78)		—	—	20; 22; 159 —	54 (0.126)	—	32	6.40 (21.0)	21	—	—	—
Test 4 (6-78)		—	—	18; 21; 157 —	113 (0.263)	—	45	6.40 (21.0)	31	—	—	—
Test 5 (6-78)	3 pulv. coal; Unit 1&2 front fired; Unit 3 opp. fired, 22.5; 125 MW	—	—	18; 21; 157 —	80 (0.186)	—	41	6.40 (21.0)	28	—	—	—
Test 6 (6-78)		—	—	18; 21; 158 —	195 (0.454)	—	53	6.40 (21.0)	38	—	—	—
Test 7 (6-78)		—	—	18; 21; 157 —	137 (0.318)	—	46	6.40 (21.0)	32	—	—	—
Test 8 (6-78)		—	—	10; 10; 100 —	7 (0.016)	—	22	6.40 (21.0)	14	—	—	—
Test 9 (6-78)		—	—	10; 10; 100 —	6 (0.014)	—	22	6.40 (21.0)	14	—	—	—
Test 1 (6-79)		22,900 (808,809)	151 (304)	20; 22; 166 (1960 total)	135 (0.314)	0.203 (0.0888)	22	6.40 (21.0)	14	1.10	10.6	29,270 (12,584)
Test 2 (6-79)		22,390 (790,748)	152 (306)	20; 22; 165 (1910 total)	124 (0.289)	0.186 (0.0813)	21	6.40 (21.0)	14	1.15	11.1	28,980 (12,460)

(continued)

TABLE A-4 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e (10^6 Btu/hr)$_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e (10^6 Btu/hr)$_T$	Particulate loading at stack conditions ng/J (lb/10^6 Btu)	Particulate loading at stack conditions g/am^3 (gr/acf)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Feul weight % ash	Fuel heat content kJ/kg (Btu/lb)
MITCHELL 1,2,3												
Test 3 (6-79)		22,950 (810,470)	153 (307)	20; 22; 165 (2040 total)	107 (0.248)	0.166 (0.0727)	20	6.40 (21.0)	13	1.09	9.7	29,908 (12,858)
Test 4 (6-79)		23,080 (815,038)	149 (300)	21; 21; 164 (1960 total)	153 (0.356)	0.229 (0.100)	25	6.40 (21.0)	16	1.21	11.1	28,980 (12,459)
Test 5 (6-79)		22,870 (807,564)	150 (302)	21; 21; 164 (2020 total)	169 (0.393)	0.229 (0.100)	23	6.40 (21.0)	15	1.25	10.9	29,363 (12,624)
Test 6 (6-79)	3 pulv. coal; Unit 1&2 front fired; Unit 3 opp. fired, 22.5; 22.5; 125 MW	22,810 (805,696)	152 (305)	21; 21; 165 (1750 total)	192 (0.447)	0.260 (0.113)	31	6.40 (21.0)	21	1.31	14.0	28,161 (12,107)
Test 7 (6-79)		22,460 (793,032)	152 (306)	21; 21; 165 (2040 total)	231 (0.538)	0.369 (0.161)	33	6.40 (21.0)	22	1.28	14.1	28,330 (12,180)
Test 8 (6-79)		23,085 (815,245)	144 (292)	22; 22; 167 (1890 total)	350 (0.813)	0.505 (0.221)	42	6.40 (21.0)	29	1.36	14.4	27,968 (12,024)
Test 9 (6-79)		22,640 (799,468)	146 (295)	22; 22; 165 (1940 total)	344 (0.799)	0.517 (0.226)	44	6.40 (21.0)	30	1.32	12.5	29,030 (12,480)
Test 10 (6-79)		22,670 (800,506)	147 (297)	22; 22; 165 (1920 total)	334 (0.777)	0.496 (0.217)	47	6.40 (21.0)	33	1.34	13.8	28,356 (12,191)
Test 11 (6-79)		22,350 (789,295)	147 (296)	22; 22; 164 (1900 total)	469 (1.09)	0.702 (0.307)	61	6.40 (21.0)	44	1.20	10.5	29.584 (12,719)
McDONOUGH 1&2												
Test 1 (6-78)		59,710 (2,109,000)	149 (301)	490 (5195 total)	22 (0.050)	0.0329 (0.0144)	7	7.92 (26.0)	4	–	–	– –
Test 2 (6-78)		52,990 (1,871,000)	152 (305)	490 (4785 total)	11 (0.025)	0.0171 (0.0075)	6	7.92 (26.0)	3	–	–	– –
Test 3 (6-78)		52,820 (1,865,000)	152 (305)	490 (4815 total)	23 (0.054)	0.0372 (0.0163)	6	7.92 (26.0)	3	–	–	– –
Test 4 (6-78)	2 pulv. coal; tang. fired; 245 MW each	51,540 (1,820,000)	149 (300)	490 (4635 total)	52 (0.122)	0.0829 (0.0362)	27	7.92 (26.0)	15	–	–	– –
Test 5 (6-78)		51,180 (1,807,000)	153 (308)	490 (4730)	94 (0.218)	0.192 (0.0666)	36	7.92 (26.0)	14	–	–	– –
Test 6 (6-78)		50,950 (1,799,000)	155 (311)	490 (4810)	90 (0.210)	0.189 (0.0655)	41	7.92 (26.0)	23	–	–	– –
Test 7 (6-78)		52,750 (1,863,000)	159 (318)	490 (4940)	64 (0.148)	0.132 (0.0458)	33	7.92 (26.0)	18	–	–	– –

(continued)

TABLE A-4 (continued)

Boiler name, test number, and date	Boiler type and design capacity MWe (10^6 Btu/hr)$_T$	Flow rate am³/min (acfm)	Exhaust temperature °C (°F)	Load during test MWe (10^6 Btu/hr)$_T$	Particulate loading at stack conditions: ng/J (lb/10^6 Btu)	Particulate loading at stack conditions: g/am³ (gr/acf)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
McDONOUGH 1&2												
Test 8 (6-78)	2 pulv. coal, tang. fired; 245 MW each	39,110 (1,381,000)	147 (296)	350 (3490)	37 (0.076)	0.0645 (0.0224)	6	7.92 (26.0)	3	–	–	– –
Test 9 (6-78)		39,240 (1,386,000)	147 (297)	350 (3490)	20 (0.046)	0.390 (0.0135)	5	7.92 (26.0)	3	–	–	– –
Test 10 (6-78)		36,910 (1,302,000)	148 (298)	300 (3100)	70 (0.196)	0.132 (0.0544)	26	7.92 (26.0)	14	–	–	– –
Test 11 (6-78)		36,870 (1,302,000)	148 (298)	300 (3100)	84 (0.196)	0.157 (0.0544)	28	7.92 (26.0)	15	–	–	– –
Test 1 (4-79)		50,160 (1,771,000)	149 (300)	245; 245 (4990)	24 (0.055)	0.0522 (0.0181)	5	7.92 (26.0)	3	1.91	10.2	27,298 (11,738)
Test 2 (4-79)		49,240 (1,739,000)	149 (301)	245; 243 (4680)	30 (0.069)	0.0623 (0.0216)	5	7.92 (26.0)	3	1.97	10.0	27,207 (11,697)
Test 3 (4-79)		48,440 (1,711,000)	149 (301)	240; 244 (4720)	25 (0.059)	0.0548 (0.0190)	5	7.92 (26.0)	3	1.87	10.4	27,026 (11,619)
Test 4 (4-79)		41,640 (1,470,000)	136 (277)	175; 175 (3570)	17 (0.040)	0.0326 (0.0113)	4	7.92 (26.0)	2	1.78	10.2	27,472 (11,811)
Test 5 (4-79)		41,120 (1,452,000)	138 (280)	175; 175 (2830)	16 (0.037)	0.0245 (0.0085)	4	7.92 (26.0)	2	1.82	10.3	27,514 (11,829)
Test 6 (4-79)		41,350 (1,460,000)	140 (284)	175; 175 (2960)	71 (0.164)	0.112 (0.0388)	29	7.92 (26.0)	16	1.84	11.2	27,235 (11,709)
Test 7 (4-79)		42,140 (1,488,000)	139 (282)	175; 175 (2740)	103 (0.239)	0.148 (0.0514)	31	7.92 (26.0)	17	1.99	11.3	27,100 (11,651)
Test 8 (4-79)		48,580 (1,716,000)	141 (286)	245; 245 (3600)	131 (0.304)	0.215 (0.0744)	43	7.92 (26.0)	25	1.80	10.2	27,654 (11,889)
Test 9 (4-79)		48,930 (1,728,000)	141 (285)	245; 245 (4430	111 (0.259)	0.223 (0.0775)	46	7.92 (26.0)	27	1.74	10.7	27,724 (11,919)
Test 10 (4-79)		48,020 (1,696,000)	138 (280)	245; 245 (4260)	176 (0.410)	0.275 (0.120)	44	7.92 (26.0)	25	1.76	10.4	27,828 (11,964)
Test 11 (4-79)		47,400 (1,674,000)	136 (277)	245; 245 (4150)	148 (0.344)	0.227 (0.0994)	46	7.92 (26.0)	27	1.85	10.3	27,677 (11,899)

(continued)

TABLE A-4 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e $(10^6\ Btu/hr)_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e $(10^6\ Btu/hr)_T$	Particulate loading at stack conditions ng/J ($lb/10^6$ Btu)	Particulate loading at stack conditions g/am^3 (gr/acf)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
WANSLEY 1												
Test 1 (8-78)	Pulv. coal; tang. fired; 833 MW	89,680 (3,167,000)	157 (315)	880 (8550)	92 (0.214)	0.154 (0.0674)	43	7.62 (25.0)	26	—	—	— —
Test 2 (8-78)		87,820 (3,101,000)	157 (315)	880 (8170)	119 (0.277)	0.195 (0.0851)	40	7.62 (25.0)	24	—	—	— —
Test 3 (8-78)		87,190 (3,079,000)	159 (319)	880 (8130)	113 (0.262)	0.185 (0.0807)	52	7.62 (25.0)	32	—	—	— —
Test 4 (8-78)		86,910 (3,069,000)	159 (319)	880 (8220)	111 (0.258)	0.184 (0.0806)	46	7.62 (25.0)	28	—	—	— —
Test 5 (8-78)		58,820 (2,113,000)	148 (299)	660 (5550)	13 (0.030)	0.0211 (0.0092)	10	7.62 (25.0)	5	—	—	— —
Test 6 (8-78)		59,860 (2,114,000)	149 (300)	600 (5570)	8 (0.019)	0.0134 (0.0058)	10	7.62 (25.0)	5	—	—	— —
Test 7 (8-78)		58,440 (2,064,000)	149 (300)	600 (5570)	28 (0.065)	0.047 (0.020)	20	7.62 (25.0)	11	—	—	— —
Test 8 (8-78)		58,670 (2,072,000)	149 (300)	600 (5450)	73 (0.170)	0.119 (0.052)	29	7.62 (25.0)	16	—	—	— —
WANSLEY 2												
Test 1 (8-78)	Pulv. coal; **tang. fired; 860 MW**	82,270 (2,905,000)	150 (302)	890 (7730)	19 (0.045)	0.032 (0.014)	10	7.62 (25.0)	5	—	—	— —
Test 2 (8-78)		82,470 (2,913,000)	151 (304)	890 (7970)	28 (0.064)	0.047 (0.020)	10	7.62 (25.0)	5	—	—	— —
Test 3 (8-78)		82,780 (2,923,000)	151 (303)	890 (8090)	170 (0.396)	0.292 (0.128)	69	7.62 (25.0)	46	—	—	— —
Test 4 (8-78)		85,380 (3,105,000)	151 (303)	(7980)	150 (0.348)	0.246 (0.107)	66	7.62 (25.0)	43	—	—	— —
Test 5 (8-78)		52,160 (1,842,000)	132 (269)	(4760)	89 (0.207)	0.143 (0.062)	27	7.62 (25.0)	15	—	—	— —
Test 6 (8-78)		51,530 (1,820,000)	129 (264)	(4980)	84 (0.196)	0.143 (0.063)	37	7.62 (25.0)	22	—	—	— —
Test 7 (8-78)		50,540 (1,785,000)	128 (263)	600 (5020)	63 (0.147)	0.110 (0.048)	24	7.62 (25.0)	15	—	—	— —

(continued)

TABLE A-4 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e (10^6 Btu/hr)$_T$	Flow rate am³/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e (10^6 Btu/hr)$_T$	Particulate loading at stack conditions: ng/J (lb/10^6 Btu)	Particulate loading at stack conditions: g/am³ (gr/acf)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
Test 8 (9-78)		50,870 (1,797,000)	127 (261)	600 (5010)	72 (0.167)	0.124 (0.054)	32	7.62 (25.0)	18	–	–	– –
WANSLEY 1&2												
Test 1 (5-79)		79,370 (2,803,000)	146 (295)	865 –	22 (0.05)	0.0304 (0.0133)	15	7.62 (25.0)	8	1.90	8.9	26,000 (11,180)
Test 2 (5-79)		79,130 (2,794,000)	146 (294)	869 –	17 (0.04)	0.0286 (0.0125)	13	7.62 (25.0)	7	2.05	9.0	26,200 (11,265)
Test 3 (5-79)		80,270 (2,835,000)	149 (300)	873 –	17 (0.04)	0.0359 (0.0157)	11	7.62 (25.0)	6	2.07	8.8	26,212 (11,269)
Test 4 (5-79)		68,940 (2,435,000)	142 (287)	756 –	13 (0.03)	0.0190 (0.0083)	11	7.62 (25.0)	6	2.06	8.9	26,177 (11,254)
Test 5 (5-79)	Pulv. coal; tang. fired;	69,500 (2,454,000)	136 (276)	758 –	13 (0.03)	0.0217 (0.0095)	9	7.62 (25.0)	5	2.14	8.7	26,900 (11,565)
Test 6 (5-79)		83,000 (2,931,000)	157 (314)	862 –	219 (0.51)	0.306 (0.1337)	53	7.62 (25.0)	40	1.81	9.7	25,575 (10,995)
Test 7 (5-79)		85,290 (3,012,000)	154 (310)	869 –	82 (0.19)	0.116 (0.0508)	39	7.62 (25.0)	23	1.72	9.6	24,401 (10,913)
Test 8 (5-79)		84,280 (2,976,000)	157 (315)	868 –	52 (0.12)	0.073 (0.0320)	33	7.62 (25.0)	19	1.70	9.8	24,614 (11,008)
Test 9 (5-79)		79,720 (2,815,000)	157 (315)	873 –	64 (0.15)	0.090 (0.0394)	28	7.62 (25.0)	16	2.03	9.2	25,238 (11,287)
Test 10 (5-79)		79,170 (2,796,000)	157 (315)	870 –	30 (0.07)	0.041 (0.0177)	20	7.62 (25.0)	11	1.97	8.9	25,372 (11,347)
Test 11 (6-79)		81,220 (2,868,000)	157 (315)	868 –	26 (0.06)	0.040 (0.0176)	20	7.62 (25.0)	11	1.90	8.9	25,213 (11,276)
YATES 1,2,3												
Test 1 (12-77)		33,910 (1,197,000)	133 (271)	95; 105; 105 (2680)	76 (0.177)	0.106 (0.0462)	15	5.00 (16.4)	12	–	–	– –
Test 2 (12-77)	3 pulv. coal; tang. fired; 100 MW each	35,810 (1,264,000)	137 (278)	95; 105; 105 (2960)	7 (0.180)	0.112 (0.0491)	17	5.00 (16.4)	14	–	–	– –
Test 3 (12-77)		35,410 (1,251,000)	137 (279)	95; 105; 105 (2750)	207 (0.481)	0.282 (0.123)	34	5.00 (16.4)	28	–	–	– –
Test 4 (12-77)		36,030 (1,272,000)	138 (280)	95; 105; 105 (2950)	159 (0.370)	0.229 (0.100)	30	5.00 (16.4)	25	–	–	– –

(continued)

TABLE A-4 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e $(10^6\ Btu/hr)_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e $(10^6\ Btu/hr)_T$	Particulate loading at stack conditions ng/J ($lb/10^6$ Btu)	Particulate loading at stack conditions g/am^3 (gr/acf)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
YATES 1,2,3												
Test 5 (12-77)	3 pulv. coal; tang. fired; 100 MW each	23,290 (822,500)	126 (258)	95; 50; 50 (1790)	37 (0.086)	0.050 (0.022)	3	5.00 (16.4)	3	—	—	— —
Test 6 (12-77)		23,450 (828,000)	124 (256)	95; 50; 50 (1900)	23 (0.054)	0.033 (0.014)	2	5.00 (16.4)	2	—	—	— —
Test 7 (12-77)		23,380 (825,500)	125 (257)	95; 50; 50 (1990)	181 (0.421)	0.270 (0.118)	43	5.00 (16.4)	36	—	—	— —
Test 8 (12-77)		23,540 (831,300)	126 (258)	95; 50; 50 (2000)	136 (0.316)	0.203 (0.089)	33	5.00 (16.4)	27	—	—	— —
Test 9 (12-77)		29,170 (1,030,000)	136 (276)	50; 90; 90 (2570)	45 (0.105)	0.070 (0.031)	18	5.00 (16.4)	15	—	—	— —
Test 10 (12-77)		26,110 (1,028,000)	136 (276)	50; 90; 90 (2450)	55 (0.127)	0.081 (0.035)	20	5.00 (16.4)	16	—	—	— —
Test 1 (3-78)		35,610 (1,258,000)	133 (272)	87; 97; 96 (3260)	60 (0.140)	0.0970 (0.0424)	17	5.00 (16.4)	14	—	—	— —
Test 2 (3-78)		35,980 (1,271,000)	134 (273)	88; 96; 94 (3270)	75 (0.174)	0.182 (0.0794)	20	5.00 (16.4)	16	—	—	— —
Test 3 (3-78)		35,970 (1,270,000)	134 (273)	89; 97; 94 (3320)	67 (0.156)	0.109 (0.0477)	22	5.00 (16.4)	18	—	—	— —
Test 1 (5-79)		37,200 (1,314,000)	141 (285)	90; 103; 100 (3190)	284 (0.66)	0.394 (0.172)	53	5.00 (16.4)	45	1.18	9.2	29,461 (12,666)
Test 2 (5-79)		37,160 (1,312,000)	144 (291)	90; 103; 101 (3150)	202 (0.47)	0.280 (0.122)	47	5.00 (16.4)	40	1.18	8.6	29,068 (12,497)
Test 3 (5-79)		33,060 (1,168,000)	145 (293)	83; 80; 84 (2740)	99 (0.23)	0.140 (0.061)	33	5.00 (16.4)	27	1.18	8.7	29,552 (12,705)
Test 4 (5-79)		33,870 (1,196,000)	144 (292)	82; 79; 82 (2720)	108 (0.25)	0.138 (0.060)	34	5.00 (16.4)	28	1.19	8.8	29,263 (12,581)
Test 5 (5-79)		33,370 (1,178,000)	141 (286)	59; 60; 65 (2060)	116 (0.27)	0.156 (0.068)	24	5.00 (16.4)	20	1.14	8.6	29,363 (12,624
Test 6 (5-79)		27,750 (979,900)	138 (281)	61; 59; 65 (2080)	64 (0.15)	0.0897 (0.0392)	22	5.00 (16.4)	18	1.14	8.5	29,691 (12,765)
Test 7 (5-79)		27,700 (978,100)	137 (278)	87; 87; 80 (2800)	60 (0.14)	0.080 (0.0351)	37	5.00 (16.4)	31	1.17	8.6	29,645 (12,745)

(continued)

TABLE A-4 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e (10^6 Btu/hr)$_T$	Flow rate am³/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e (10^6 Btu/hr)$_T$	Particulate loading at stack conditions ng/J (lb/10^6 Btu)	Particulate loading at stack conditions g/am³ (gr/acf)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Feul weight % ash	Fuel heat content kJ/kg (Btu/lb)
YATES 1,2,3												
Test 8 (5-79)	3 pulv. coal; tang. fired; 100 MW each	37,960 (1,341,000)	145 (293)	110; 105; 95 (3200)	322 (0.75)	0.427 (0.187)	54	5.00 (16.4)	46	1.61	8.7	29,587 (12,720)
Test 9 (5-79)		37,740 (1,333,000)	144 (292)	99; 105; 95 (3200)	301 (0.70)	0.403 (0.176)	54	5.00 (16.4)	46	1.14	8.6	29,575 (12,715)
Test 10 (5-79)		38,470 (1,358,000)	148 (298)	95; 105; 96 (3180)	314 (0.73)	0.415 (0.181)	56	5.00 (16.4)	48	1.16	8.7	29,349 (12,618)
Test 1 (6-79)		32,810 (1,159,000)	141 (286)	91; 103; 97 (2830)	50 (0.117)	0.076 (0.0332)	18	5.00 (16.4)	15	2.31	9.5	26,870 (11,552)
Test 2 (6-79)		33,240 (1,174,000)	144 (292)	91; 103; 97 (3200)	80 (0.187)	0.136 (0.059)	20	5.00 (16.4)	16	2.43	9.0	26,882 (11,557)
Test 3 (6-79)		33,910 (1,198,000)	144 (291)	90; 104; 96 (2850)	57 (0.133)	0.085 (0.037)	20	5.00 (16.4)	16	2.45	8.9	26,733 (11,493)
Test 4 (6-79)		33,540 (1,184,000)	142 (288)	90; 104; 96 (2980)	94 (0.218)	0.146 (0.064)	24	5.00 (16.4)	20	2.33	9.0	26,656 (11,460)
Test 5 (6-79)	2 pulv. coal; tang. fired; 100 MW each	33,900 (1,197,000)	136 (276)	(2970)	43 (0.101)	0.067 (0.029)	16	5.00 (16.4)	13	2.46	9.0	26,821 (11,531)
Test 6 (6-79)		34,100 (1,204,000)	138 (208)	(2770)	47 (0.110)	0.067 (0.029)	16	5.00 (16.4)	13	2.35	9.2	26,700 (11,479)
Test 7 (6-79)		33,760 (1,192,000)	141 (286)	(3000)	75 (0.174)	0.117 (0.051)	27	5.00 (16.4)	22	2.55	9.0	26,756 (11,503)
Test 8 (6-79)		33,890 (1,197,000)	142 (288)	(2760)	74 (0.171)	0.105 (0.046)	23	5.00 (16.4)	19	2.33	8.9	26,972 (11,596)
Test 9 (6-79)		34,110 (1,205,000)	138 (281)	(3020)	117 (0.271)	0.181 (0.079)	34	5.00 (16.4)	28	2.35	9.6	26,996 (11,606)
Test 10 (6-79)		33,330 (1,212,000)	141 (285)	(2960)	132 (0.306)	0.199 (0.087)	54	5.00 (16.4)	46	2.27	9.2	27,005 (11,610)
Test 11 (6-79)		34,430 (1,216,000)	138 (280)	(2990)	366 (0.852)	0.559 (0.244)	34	5.00 (16.4)	28	2.31	9.0	26,986 (11,602)
YATES 4&5												
Test 1 (3-78)	2 pulv. coal; tang. fired; 125 MW each	25,920 (915,500)	140 (284)	125; 127 (2260	108 (0.250)	0.165 (0.072)	41	4.42 (14.5)	38	–	–	–
Test 2 (3-78)		25,780 (910,400)	141 (285)	125; 126 (2350)	100 (0.233)	0.160 (0.070)	40	4.42 (14.5)	37	–	–	–

(continued)

TABLE A-4 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e (10^6 Btu/hr)$_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e (10^6 Btu/hr)$_T$	Particulate loading at stack conditions ng/J ($lb/10^6$ Btu)	Particulate loading at stack conditions g/am^3 (gr/acf)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
YATES 4&5												
Test 3 (3-78)		25,290 (893,200)	136 (277)	(2460)	148 (0.345)	0.254 (0.111)	54	4.42 (14.5)	50	—	—	— —
Test 4 (3-78)		25,140 (888,000)	138 (280)	(2430)	120 (0.280)	0.204 (0.089)	50	4.42 (14.5)	47	—	—	— —
Test 5 (3-78)		19,080 (673,700)	129 (265)	(1540)	52 (0.120)	0.073 (0.032)	27	4.42 (14.5)	25	—	—	— —
Test 6 (3-78)		19,120 (675,300)	128 (262)	(1510)	49 (0.114)	0.068 (0.030)	25	4.42 (14.5)	23	—	—	— —
Test 7 (3-78)		17,730 (626,000)	126 (259)	(1570)	317 (0.738)	0.495 (0.216)	61	4.42 (14.5)	57	—	—	— —
Test 8 (3-78)		18,710 (660,600)	126 (258)		154 (0.358)	0.226 (0.099)	46	4.42 (14.5)	43	—	—	— —
Test 9 (3-78)		21,160 (747,200)	128 (262)	(1810)	65 (0.152)	0.0986 (0.043)	27	4.42 (14.5)	25	—	—	— —
Test 10 (3-78)	2 pulv. coal; tang. fired; 125 MW each	20,800 (734,600)	124 (256)	100; 100 (1820)	54 (0.126)	0.083 (0.036)	25	4.42 (14.5)	23	—	—	— —
Test 1 (4-79)		29,560 (1,044,000)	146 (295)	132; 129 (1810)	103 (0.24)	0.167 (0.0731)	30	4.42 (14.5)	38	1.74	13.5	27,742 (11,497)
Test 2 (4-79)		29,200 (1,031,000)	148 (298)	132; 132 (2130)	103 (0.24)	0.170 (0.0744)	30	4.42 (14.5)	28	1.86	14.4	26,689 (11,474)
Test 3 (4-79)		29,570 (1,044,000)	149 (300)	132; 130 (1950)	86 (0.20)	0.144 (0.0629)	29	4.42 (14.5)	27	1.85	13.8	26,663 (11,463)
Test 4 (4-79)		28,940 (1,022,000)	146 (295)	129; 128 (2130)	194 (0.45)	0.279 (0.122)	52	4.42 (14.5)	49	1.68	13.2	26,679 (11,470)
Test 5 (4-79)		28,750 (1,015,000)	147 (297)	126; 130 (2190)	202 (0.47)	0.277 (0.121)	52	4.42 (14.5)	49	1.60	12.4	27,275 (11,726)
Test 6 (4-79)		29,330 (1,036,000)	147 (297)	128; 126 (2420)	172 (0.40)	0.252 (0.110)	40	4.42 (14.5)	37	1.49	11.9	27,265 (11,722)
Test 7 (4-79)		29,740 (1,050,000)	148 (298)	130; 125 (2360)	181 (0.42)	0.270 (0.118)	41	4.42 (14.5)	38	1.65	13.1	26,696 (11,477)
Test 8 (4-79)		24,780 (875,100)	140 (284)	10; 103 (1710)	60 (0.14)	0.0888 (0.0388)	25	4.42 (14.5)	23	2.16	15.2	25,509 (10,967)

(continued)

TABLE A-4 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e $(10^6\ Btu/hr)_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e $(10^6\ Btu/hr)_T$	Particulate loading at stack conditions: ng/J ($lb/10^6$ Btu)	Particulate loading at stack conditions: g/am^3 (gr/acf)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
YATES 4&5												
Test 9 (4-79)		24,070 (850,000)	139 (283)	105; 101 (1710)	60 (0.14)	0.0922 (0.0403)	25	4.42 (14.5)	23	2.90	15.6	25,479 (10,954)
Test 10 (4-79)	2 pulv. coal; tang. fired; 125 MW each	15,290 (539,900)	124 (255)	56; 55 (1030)	22 (0.05)	0.0268 (0.0117)	16	4.42 (14.5)	15	1.81	14.7	25,923 11,145)
Test 11 (4-79)		15,300 (540,300)	124 (255)	56; 55 (1060)	22 (0.05)	0.0247 (0.0108)	15	4.42 (14.5)	14	1.84	13.7	26,800 (11,522)
YATES 6												
Test 1 (6-78)		33,930 (1,198,000)	138 (281)	355 (3670)	15 (0.035)	0.029 (0.013)	3.4	4.98 (16.3)	3	—	—	— —
Test 2 (6-78)		33,130 (1,170,000)	138 (280)	345 (3580)	12 (0.029)	0.024 (0.010)	3.4	4.98 (16.3)	3	—	—	— —
Test 3 (6-78)		33,180 (1,172,000)	138 (281)	346 (2570)	13 (0.031)	0.025 (0.011)	3.4	4.98 (16.3)	3	—	—	— —
Test 4 (6-78)		15,620 (551,600)	112 (233)	177 (1770)	42 (0.098)	0.084 (0.037)	11	4.98 (16.3)	9	—	—	— —
Test 5 (6-78)		15,990 (564,600)	112 (234)	178 (1820)	34 (0.079)	0.068 (0.030)	10	4.98 (16.3)	8	—	—	— —
Test 6 (6-78)	Pulv. coal; tang. fired; 350 MW	31,590 (1,116,000)	123 (254)	337 (3670)	104 (0.242)	0.213 (0.093)	22	4.98 (16.3)	18	—	—	— —
Test 7 (6-78)		31,720 (1,120,000)	130 (266)	337 (3610)	53 (0.123)	0.106 (0.046)	15	4.98 (16.3)	12	—	—	— —
Test 8 (6-78)		32,700 (1,155,000)	133 (272)	342 (3680)	258 (0.601)	0.511 (0.223)	46	4.98 (16.3)	39	—	—	— —
Test 9 (6-78)		33,520 (1,184,000)	137 (278)	344 (3750)	212 (0.493)	0.417 (0.182)	38	4.98 (16.3)	32	—	—	— —
Test 1 (6-79)		— —	— —	354 —	9 (0.02)	0.0185 (0.0081)	1	4.98 (16.3)	1	1.79	12.7	27,114 (11,657)
Test 2 (6-79)		— —	— —	356 —	4 (0.01)	0.0110 (0.0048)	2	4.98 (16.3)	2	1.77	12.7	27,158 (11,676)
Test 3 (6-79)		34,490 (1,218,000)	184 (363)	360 —	13 (0.03)	0.0220 (0.0096)	4	4.98 (16.3)	3	1.87	12.8	26,840 (11,539)

(continued)

TABLE A-4 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e $(10^6\ Btu/hr)_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e $(10^6\ Btu/hr)_T$	Particulate loading at stack conditions ng/J $(lb/10^6\ Btu)$	Particulate loading at stack conditions g/am^3 (gr/acf)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
YATES 6												
Test 4 (6-79)		34,510 (1,219,000)	185 (365)	363 —	73 (0.17)	0.124 (0.0542)	14	4.98 (16.3)	11	1.95	12.5	26,991 (11,604)
Test 5 (6-79)		34,970 (1,235,000)	182 (360)	355 —	22 (0.05)	0.0366 (0.0160)	12	4.98 (16.3)	10	2.04	12.5	26,893 (11,562)
Test 6 (6-79)		32,000 (1,130,000)	161 (322)	360 —	95 (0.22)	0.166 (0.0727)	23	4.98 (16.3)	19	2.31	11.5	26,844 (11,541)
Test 7 (6-79)	Pulv. coal; tang. fired; 350 MW	32,820 (1,159,000)	162 (323)	361 —	116 (0.27)	0.209 (0.0914)	24	4.98 (16.3)	20	2.20	11.5	26,682 (11,471)
Test 8 (6-79)		32,040 (1,131,000)	160 (320)	364 —	168 (0.39)	0.298 (0.1302)	31	4.98 (16.3)	26	2.00	11.0	26,984 (11,601)
Test 9 (6-79)		31,170 (1,001,000)	163 (325)	—	138 (0.32)	0.242 (0.1057)	31	4.98 (16.3)	26	1.73	10.0	27,993 (12,035)
Test 10 (6-79)		30,850 (1,090,000)	165 (329)	—	228 (0.53)	0.658 (0.2874)	43	4.98 (16.3)	36	1.64	9.1	28,428 (12,222)
Test 11 (6-79)		31,340 (1,107,000)	166 (331)	—	185 (0.43)	0.343 (0.1498)	44	4.98 (16.3)	47	1.65	11.0	27,782 (11,944)
YATES 7												
Test 1 (6-78)		33,840 (1,195,000)	139 (283)	345 (3290)	12 (0.029)	0.0213 (0.0093)	2.6	4.98 (16.3)	2	—	—	— —
Test 2 (6-78)		33,750 (1,192,000)	139 (283)	341 (3410)	14 (0.032)	0.0245 (0.0107)	2.6	4.98 (16.3)	2	—	—	— —
Test 3 (6-78)		33,870 (1,196,000)	139 (283)	339 (3410)	12 (0.028)	0.0213 (0.0093)	2.5	4.98 (16.3)	2	—	—	— —
Test 4 (6-78)	Pulv. coal; tang. fired; 350 MW	32,620 (1,152,000)	128 (262)	337 (3480)	43 (0.099)	0.080 (0.035)	10	4.98 (16.3)	8	—	—	— —
Test 5 (6-78)		32,720 (1,155,000)	129 (264)	333 (3480)	33 (0.077)	0.062 (0.027)	7	4.98 (16.3)	6	—	—	— —
Test 6 (6-78)		32,700 (1,155,000)	128 (263)	334 (3500)	150 (0.349)	0.282 (0.123)	31	4.98 (16.3)	26	—	—	— —
Test 7 (6-78)		32,640 (1,153,000)	129 (264)	332 (3490)	102 (0.238)	0.193 (0.084)	26	4.98 (16.3)	21	—	—	— —

(continued)

TABLE A-4 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e $(10^6\ Btu/hr)_T$	Flow rate am³/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e $(10^6\ Btu/hr)_T$	Particulate loading at stack conditions: ng/J (lb/10⁶ Btu)	g/am³ (gr/acf)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
YATES 7												
Test 8 (6-78)		25,620 (904,800)	117 (243)	255 (2660)	6 (0.013)	0.0102 (0.0045)	0.7	4.98 (16.3)	0.6	—	—	—
Test 9 (6-78)	Pulv. coal; tang. fired; 350 MW	26,270 (927,600)	120 (248)	254 (2690)	6 (0.013)	0.0101 (0.0044)	0.7	4.98 (16.3)	0.6	—	—	—
Test 10 (6-78)		26,060 (920,400)	119 (247)	254 (2660)	22 (0.052)	0.040 (0.018)	5	4.98 (16.3)	4	—	—	—
Test 11 (6-78)		26,320 (929,600)	121 (249)	257 (2720)	21 (0.048)	0.037 (0.016)	4	4.98 (16.3)	3	—	—	—
BOWEN 1												
Test 2 (2-78)		59,980 (2,118,016)	135 (275)	610 (6050)	299 (0.696)	0.530 (0.2318)	47	7.62 (25.0)	28	1.55	12.5	30,000 (12,900)
Test 3 (2-78)		49,120 (1,734,666)	128 (263)	520 (5020)	215 (0.501)	0.387 (0.1691)	37	7.62 (25.0)	22	1.55	12.5	30,000 (12,900)
Test 6 (2-78)		46,140 (1,629,312)	128 (263)	472 (5390)	296 (1.533)	0.527 (0.2301)	46	7.62 (25.0)	28	1.55	12.5	30,000 (12,900)
Test 7 (3-78)		53,820 (1,900,654)	128 (263)	539 (5390)	659 (1.533)	1.16 (0.5069)	59	7.62 (25.0)	37	1.55	12.5	30,000 (12,900)
Test 8 (3-78)	Pulv. coal; tang. fired, 700 MW (6500)	44,100 (1,557,378)	128 (262)	441 (4400)	228 (0.531)	0.401 (0.1751)	38	7.62 (25.0)	22	1.55	12.5	30,000 (12,900)
Test 9 (3-78)		38,420 (1,356,652)	124 (255)	411 (3930)	188 (0.438)	0.339 (0.1482)	35	7.62 (25.0)	20	1.55	12.5	30,000 (12,900)
Test 10 (3-78)		33,110 (1,169,128)	120 (248)	344 (3250)	85 (0.197)	0.146 (0.0639)	20	7.62 (25.0)	11	1.55	12.5	30,000 (12,900)
Test 11 (3-78)		34,030 (1,201,817)	120 (248)	347 (3360)	93 (0.216)	0.161 (0.0705)	21	7.62 (25.0)	12	1.55	12.5	30,000 (12,900)
Test 12 (3-78)		30,870 (1,090,242)	115 (239)	263 (2920)	43 (0.101)	0.0723 (0.0316)	17	7.62 (25.0)	9	1.55	12.5	30,000 (12,900)
Test 13 (3-78)		30,510 (1,077,514)	113 (236)	265 (2900)	38 (0.088)	0.0632 (0.0276)	16	7.62 (25.0)	9	1.55	12.5	30,000 (12,900)
BOWEN 2												
Test 1 (8-78)		73,690 (2,602,191)	154 (310)	700 (6710)	107 (0.248)	0.171 (0.0746)	26	7.62 (25.0)	15	—	—	—
Test 2 (8-78)		74,550 (2,632,784)	158 (317)	700 (7130)	86 (0.20)	0.145 (0.0632)	25	7.62 (25.0)	14	—	—	—
Test 4 (8-78)	Pulv. coal; tang. fired, 700 MW (6500)	67,790 (2,393,910)	152 (305)	650 (6400)	54 (0.125)	0.089 (0.0390)	22	7.62 (25.0)	12	—	—	—
Test 5 (8-78)		70,600 (2,493,434)	154 (310)	650 (6700)	76 (0.176)	0.126 (0.0551)	27	7.62 (25.0)	15	—	—	—
Test 7 (8-78)		73,600 (2,599,371)	157 (315)	690 (6750)	81 (0.189)	0.131 (0.0572)	28	7.62 (25.0)	16	—	—	—

(continued)

TABLE A-4 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e $(10^6\ Btu/hr)_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e $(10^6\ Btu/hr)_T$	Particulate loading at stack conditions ng/J $(lb/10^6\ Btu)$	Particulate loading at stack conditions g/am^3 (gr/acf)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
BOWEN 2												
Test 8 (8–78)		74,200 (2,620,113)	158 (317)	700 (6960)	207 (0.481)	0.341 (0.149)	41	7.62 (25.0)	31	—	—	— —
Test 10 (8–78)		57,200 (2,019,778)	152 (306)	535 (5600)	26 (0.060)	0.0444 (0.0194)	20	7.62 (25.0)	11	—	—	— —
Test 11 (8–78)		56,720 (2,003,203)	152 (305)	535 (5500)	19 (0.045)	0.0329 (0.0144)	18	7.62 (25.0)	10	—	—	— —
Test 1 (3–79)		72,070 (2,544,957)	143 (290)	695 (7137)	568 (1.321)	0.979 (0.4279)	57	7.62 (25.0)	36	1.46	11.8	28,080 (12,073)
Test 2 (3–79)		69,300 (2,447,061)	142 (287)	696 (7090)	482 (1.122)	0.842 (0.3681)	54	7.62 (25.0)	33	1.52	11.8	28,250 (12,146)
Test 3 (3–79)	Pulv. coal; tang. fired, 700 MW (6500)	67,000 (2,469,364)	141 (285)	685 (7055)	432 (1.005)	0.759 (0.3317)	50	7.62 (25.0)	31	1.34	11.4	28,660 (12,323)
Test 6 (3–79)		57,410 (2,027,421)	132 (270)	563 (5507)	114 (0.265)	0.190 (0.0830)	27	7.62 (25.0)	15	1.36	11.2	28,660 (12,323)
Test 7 (3–79)		56,030 (1,978,520)	129 (264)	562 (5552)	125 (0.291)	0.216 (0.0943)	28	7.62 (25.0)	16	1.40	11.6	28,510 (12,257)
Test 8 (3–79)		48,700 (1,719,480)	124 (256)	487 (4752)	60 (0.140)	0.102 (0.0444)	16	7.62 (25.0)	9	1.44	11.9	28,340 (12,186)
Test 9 (3–79)		48,060 (1,698,091)	122 (252)	485 (4886)	63 (0.147)	0.112 (0.0488)	17	7.62 (25.0)	9	1.42	11.5	28,530 (12,264)
Test 10 (3–79)		42,510 (1,502,074)	122 (252)	418 (4418)	35 (0.081)	0.0632 (0.0276)	14	7.62 (25.0)	8	1.40	11.8	28,310 (12,171)
Test 11 (3–79)		40,750 (1,439,854)	119 (246)	418 (4192)	35 (0.082)	0.0634 (0.0277)	13	7.62 (25.0)	7	1.47	12.2	28,100 (12,079)
BOWEN 3												
Test 1 (3–78)		81,610 (2,883,912)	148 (299)	800 (7652)	12 (0.027)	0.0191 (0.00836)	4	7.62 (25.0)	2	—	—	— —
Test 2 (3–78)		81,710 (2,887,439)	151 (304)	800 (7880)	19 (0.044)	0.0320 (0.0140)	4	7.62 (25.0)	2	—	—	— —
Test 3 (3–78)	Pulv. coal; tang. fired, 880 MW (8200)	84,030 (2,967,624)	149 301	840 (8620)	182 (0.423)	0.327 (0.143)	41	7.62 (25.0)	24	—	—	— —
Test 4 (4–78)		57,160 (2,018,728)	129 (264)	600 (5724)	9 (0.022)	0.0167 (0.00728)	3	7.62 (25.0)	2	—	—	— —
Test 5 (4–78)		58,810 (2,076,776)	130 (266)	600 (5724)	13 (0.031)	0.0228 (0.00997)	3	7.62 (25.0)	2	—	—	— —
Test 6 (4–78)		57,660 (2,036,347)	128 (262)	600 (5896)	133 (0.310)	0.240 (0.105)	29	7.62 (25.0)	16	—	—	— —

(continued)

TABLE A-4 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e (10^6 Btu/hr)$_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e (10^6 Btu/hr)$_T$	Particulate loading at stack conditions ng/J ($lb/10^6$ Btu)	g/am³ (gr/acf)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	Fuel heat content kJ/kg (Btu/lb)
BOWEN 3												
Test 8 (4-78)		58,020 (2,049,133)	128 (262)	600 (6317)	217 (0.505)	0.416 (0.182)	42	7.62 (25.0)	25	—	—	— —
Test 9 (4-78)		57,235 (2,021,237)	121 (249)	500 (5038)	11 (0.025)	0.0160 (0.007)	3	7.62 (25.0)	2	—	—	— —
Test 10 (4-78)		48,470 (1,711,766)	122 (251)	500 (5040)	8 (0.019)	0.0149 (0.00653)	2	7.62 (25.0)	1	—	—	— —
Test 1 (3-79)		86,710 (3,062,148)	140 (284)	846 —	126 (0.293)	0.214 (0.0934)	13	7.62 (25.0)	7	2.09	11.0	27,000 (11,603)
Test 2 (3-79)		86,760 (3,064,030)	141 (286)	846 —	83 (0.192)	0.143 (0.0625)	13	7.62 (25.0)	7	2.24	11.0	27,230 (11,708)
Test 3 (3-79)		87,000 (3,072,342)	142 (288)	846 —	77 (0.178)	0.132 (0.0576)	12	7.62 (25.0)	6	2.00	12.0	27,230 (11,714)
Test 4 (3-79)	Pulv. coal; tang. fired, 880 MW (82,000)	86,590 (3,057,829)	141 (285)	842 —	186 (0.432)	0.317 (0.1386)	37	7.62 (25.0)	22	2.05	11.3	27,360 (11,763)
Test 5 (3-79)		86,880 (3,068,106)	141 (285)	845 —	186 (0.433)	0.313 (0.1367)	36	7.62 (25.0)	21	2.24	10.6	27,330 (11,750)
Test 6 (3-79)		87,670 (3,095,995)	138 (281)	844 —	338 (0.787)	0.576 (0.2517)	46	7.62 (25.0)	28	2.23	10.6	27,120 (11,661)
Test 7 (3-79)		87,400 (3,086,534)	138 (281)	841 —	270 (0.629)	0.465 (0.2031)	42	7.62 (25.0)	25	2.22	10.9	27,380 (11,773)
Test 8 (3-79)		66,340 (2,342,792)	122 (252)	660	37 (0.086)	0.0627 (0.0274)	10	7.62 (25.0)	5	2.34	10.5	27,140 (11,667)
Test 9 (3-79)		66,680 (2,354,680)	122 (252)	661	33 (0.077)	0.0568 (0.0248)	10	7.62 (25.0)	5	2.33	10.2	27,370 (11,765)
Test 10 (3-79)		66,150 (2,336,155)	122 (252)	658	83 (0.193)	0.142 (0.0620)	25	7.62 (25.0)	14	2.42	9.9	27,070 (11,637)
Test 11 (3-79)		65,770 (2,322,601)	122 (252)	660	99 (0.231)	0.168 (0.0735)	24	7.62 (25.0)	13	2.21	10.4	27,080 (11,642)
BOWEN 4												
Test 1 (4-78)		82,870 (2,926,387)	149 (301)	800 (7777)	47 (0.109)	0.0869 (0.038)	17	7.62 (25.0)	9	—	—	— —
Test 2 (4-78)	Pulv. coal; tang. fired, 800 MW (8200)	83,000 (2,931,324)	150 (302)	800 (7914)	40 (0.094)	0.0677 (0.0296)	16	7.62 (25.0)	9	—	—	— —
Test 3 (4-78)		0.0283 (2,943,651)	149 (300)	800 (7682)	310 (0.721)	0.501 (0.219)	41	7.62 (25.0)	24	—	—	— —
Test 4 (4-78)		83,070 (2,933,635)	148 (299)	800 (7778)	257 (0.598)	0.423 (0.185)	50	7.62 (25.0)	31	—	—	— —

(continued)

TABLE A-4 (continued)

Boiler name, test number, and date	Boiler type and design capacity[a] MW_e $(10^6 Btu/hr)_T$	Flow rate am^3/min (acfm)	Exhaust temperature °C (°F)	Load during test MW_e $(10^5 Btu/hr)_T$	Particulate loading at stack conditions ng/J $(lb/10^6 Btu)$	Particulate loading at stack conditions g/am^3 (gr/acf)	Opacity %	Stack diameter m (ft)	Standardized opacity[b] %	Fuel weight % sulfur	Fuel weight % ash	cd. heat kJ/kg (Btu/lb)
BOWEN 4												
Test 5 (4-78)		61,410 (2,168,532)	127 (261)	600 (5866)	37 (0.087)	0.0629 (0.0275)	17	7.62 (25.0)	10	–	–	– –
Test 6 (4-78)		6,230 (220,124)	127 (260)	600 (5938)	43 (0.099)	0.0714 (0.0312)	17	7.62 (25.0)	9	–	–	– –
Test 7 (4-78)		62,040 (2,190,769)	128 (262)	600 (5847)	162 (0.376)	0.413 (0.1804)	33	7.62 (25.0)	19	–	–	– –
Test 8 (4-78)		62,170 (2,195,367)	127 (261)	600 (6008)	174 (0.405)	0.295 (0.129)	34	7.62 (25.0)	20	–	–	– –
Test 9 (4-78)		51,510 (1,818,948)	127 (260)	500 (4986)	26 (0.060)	0.0439 (0.0192)	13	7.62 (25.0)	7	–	–	– –
Test 10 (4-78)		49,560 (1,750,248)	126 (258)	500 (4824)	30 (0.069)	0.0508 (0.0222)	13	7.62 (25.0)	7	–	–	– –
Test 1 (4-79)		88,300 (3,118,404)	149 (301)	877 (8014)	22 (0.051)	0.0350 (0.0153)	8	7.62 (25.0)	4	2.34	10.4	26,540 (11,460)
Test 2 (4-79)		88,400 (3,121,845)	150 (303)	875 (7942)	28 (0.065)	0.0437 (0.0191)	8	7.62 (25.0)	4	2.31	10.7	26,520 (11,452)
Test 3 (4-79)	Pulv. coal; tang. fired, 880 MW (8200)	88,010 (3,107,997)	152 (306)	878 (7974)	40 (0.093)	0.0634 (0.0277)	9	7.62 (25.0)	5	2.43	10.5	26,670 (11,516)
Test 4 (4-79)		81,860 (2,890,769)	148 (298)	830 (7682)	71 (0.164)	0.116 (0.0508)	24	7.62 (25.0)	13	2.31	10.9	26,590 (11,483)
Test 5 (4-79)		82,770 (2,922,887)	146 (295)	830 (7599)	95 (0.220)	0.152 (0.0665)	23	7.62 (25.0)	13	2.31	10.7	26,420 (11,406)
Test 6 (4-79)		8,700 (3,073,734)	154 (310)	813 (8149)	202 (0.474)	0.335 (0.1463)	46	7.62 (25.0)	28	2.30	11.1	27,170 (11,732)
Test 7 (4-79)		86,320 (3,048,470)	156 (312)	822 (7984)	197 (0.458)	0.320 (0.1397)	43	7.62 (25.0)	26	2.22	11.2	2,698 (11,650)
Test 8 (4-79)		65,980 (2,329,937)	146 (294)	642 (6344)	20 (0.047)	0.0343 (0.0150)	5	7.62 (25.0)	3	2.26	10.8	27,130 (11,714)
Test 9 (4-79)		66,530 (2,349,639)	148 (299)	641 (6246)	0.468 (0.033)	0.0231 (0.0101)	4	7.62 (25.0)	2	1.97	11.0	27,650 (11,938)
Test 10 (4-79)		66,750 (2,357,119)	148 (299)	640 (6321)	206 (0.480)	0.343 (0.1499)	50	7.62 (25.0)	31	2.08	10.8	27,410 (11,836)
Test 11 (4-79)		65,800 (2,323,823)	148 (298)	641 (6153)	193 (0.449)	0.317 (0.1384)	43	7.62 (25.0)	26	1.47	10.0	25,250 (10,904)

[a]Subscripts: E = electrical; T = thermal.
[b]Standardized to **4.0 m (~ 13.0 ft) diameter stack.**
[c]Flue gas conditioning, Unit 4
[d]Flue gas conditioning, Unit 3
[e]Flue gas conditioning, Unit 3&4

TABLE A-4 (continued)

Boiler name, test number, and date	Electrification details
ARKWRIGHT 1-4	
Test 1 (6-78)	24 of 48 ESP sections energized
Test 2 (6-78)	24 of 48 ESP sections energized
Test 3 (6-78)	32 of 48 ESP sections energized
Test 4 (6-78)	32 of 48 ESP sections energized
Test 5 (6-78)	39 of 48 ESP sections energized
Test 6 (6-78)	39 of 48 ESP sections energized
Test 7 (6-78)	All ESP sections energized
Test 8 (6-78)	All ESP sections energized
Test 9 (6-78)	All ESP sections energized
Test 10 (6-78)	16 of 48 ESP sections energized
Test 11 (6-78	16 of 48 ESP sections energized
BRANCH 1&2	
Test 1 (2-79)	34 of 34 ESP sections energized
Test 2 (2-79)	34 of 34 ESP sections energized
Test 3 (2-79)	33 of 34 ESP sections energized
Test 4 (2-79)	33 of 34 sections on 3 arcing or low power
Test 5 (2-79)	32 of 34 sections on 3 arcing or low power
Test 6 (2-79)	33 of 34 sections on 3 arcing or low power
Test 7 (2-79)	32 of 34 sections on 2 arcing or low power
Test 8 (2-79)	33 of 34 sections on 1 at low power
Test 9 (2-79)	33 of 34 sections on 1 at low power
Test 10 (2-79)	21 of 34 full power, 11 reduced, 2 off
Test 11 (2-79)	22 of 34 full power, 11 low power, 1 off
BRANCH 3&4	
Test 1 through Test 26 (5-79)	All ESP sections in operation
Test 27 (5-79)	ESP energy levels decreased
Test 28 (5-79)	ESP energy levels decreased
HAMMOND 1, 2, 3	
Test 1 (7-78)	2 sections out on Unit 1
Test 2 (7-78)	2 sections out on Unit 1
Test 3 (7-78)	2 sections out on Unit 1
Test 1 (6-78)	All ESP sections in operation
Test 2 (6-78)	All ESP sections in operation
Test 3 (6-78)	All ESP sections in operation
Test 1 (3-78)	1 ESP section out of service
Test 2 (3-78)	1 ESP section not in operation
Test 3 (3-78)	1 section out; inlet and center of 2 & 3 out
Test 4 (3-78)	1 section out; inlet and center of 2 & 3 out
Test 5 (3-78)	1 section out
Test 6 (3-78)	1 section out
Test 7 (3-78)	1 section out
Test 8 (3-78)	1 section out
HAMMOND 4	
Test 1 (10-78)	All ESP sections in operation
Test 2 (10-78)	All ESP sections in operation
Test 3 (10-78)	All ESP sections in operation
Test 4 (10-78)	28 of 32 sections reduced power
Test 5 (10-78)	28 of 32 sections reduced power
Test 6 (10-78)	All ESP sections in operation
Test 7 (10-78)	All ESP sections in operation
Test 8 (10-78)	22 sections out of 32 inoperative
Test 9 (10-78)	22 sections out of 32 inoperative
MITCHELL 1,2,3	
Test 1 (6-78)	All ESP sections energized
Test 2 (6-78)	All ESP sections energized
Test 3 (6-78)	All ESP sections energized
Test 4 (6-78)	Sections G,H,J,K outlets of Unit 3 out
Test 5 (6-78)	Sections G,H,J,K of Unit 3 out
Test 6 (6-78) and Test 7 (6-78)	Sections G,H,J,K of Unit 3 and outlet of 1&2 sections out
Test 8 (6-78)	All ESP sections out
Test 9 (6-78) through Test 3 (6-79)	All ESP sections energized
Test 4 (6-79) through Test 11 (6-79)	No data
McDONOUGH 1&2	
Test 1 (6-78)	All ESP sections energized
Test 2 (6-78)	All ESP sections energized
Test 3 (6-78)	All ESP sections energized
Test 4 (6-78)	24 of 64 sections energized (as Test 7)
Test 5 (6-78)	20 of 64 ESP sections energized
Test 6 (6-78)	20 of 64 ESP sections energized
Test 7 (6-78)	24 of 64 ESP sections energized
Test 8 (6-78)	All ESP sections energized
Test 9 (6-78)	All ESP sections energized
Test 10 (6-78)	24 of 64 ESP sections energized
Test 11 (6-78)	24 of 64 ESP sections energized
Test 1 (4-79) through Test 5 (4-79)	All ESP sections in operation
Test 6 (4-79) through Test 11 (4-79)	58 of 64 ESP sections in operation
WANSLEY 1	
Test 1 (8-78)	All sections reduced power
Test 2 (8-78)	30 of 32 sections reduced, 2 out
Test 3 (8-78)	28 of 32 sections reduced, 4 out

(continued)

TABLE A-4 (continued)

Boiler name, test number, and date	Electrification details
WANSLEY 1	
Test 4 (8-78)	26 of 32 sections reduced, 6 out
Test 5 (8-78)	All ESP sections in service
Test 6 (8-78)	All ESP sections in service
Test 7 (8-78)	28 of 32 sections in operation
Test 8 (8-78)	28 of 32 sections in operation
WANSLEY 2	
Test 1 (8-78)	30 of 32 sections in operation
Test 2 (8-78)	30 of 32 sections in operation
Test 3 (8-78)	30 of 32 sections at reduced power, 2 out
Test 4 (8-78)	30 of 32 sections at reduced power, 2 out
Test 5 (8-78)	22 of 32 sections in operation, 10 out
Test 6 (9-78)	22 of 32 sections reduced power, 10 out
Test 7 (9-78)	22 sections reduced power; 10 sections out
Test 8 (9-78)	22 sections reduced power; 10 sections out
Test 1 (5-79)	8 ESP fields not operational
Test 2 (5-79)	2 ESP fields not operational
Test 3 (5-79) through Test 8 (5-79)	All sections in operation
YATES 1,2,3	
Test 1 (12-77)	All ESP sections in operation
Test 2 (12-77)	All ESP sections in operation
Test 3 (12-77)	4 ESP sections out; 2 sections reduced power
Test 4 (12-77)	4 ESP sections out; 2 sections reduced power
Test 5 (12-77)	All ESP sections in operation
Test 6 (12-77)	All ESP sections in operation
Test 7 (12-77)	14 ESP sections out of service
Test 8 (12-77)	14 ESP sections out of service
Test 9 (12-77)	2 ESP sections out of service
Test 10 (12-77)	2 ESP sections out of service
Test 1 (3-78) through Test 6 (6-79)	All ESP sections in service
YATES 4&5	
Test 1 (3-78)	All ESP sections energized
Test 2 (3-78)	All ESP sections energized
Test 3 (3-78)	2 of 3 ESP sections energized
Test 4 (3-78)	2 of 3 ESP sections energized
Test 5 (3-78)	All ESP sections energized
Test 6 (3-78)	All ESP sections energized
Test 7 (3-78)	≈ 1½ of 3 ESP sections energized
Test 8 (3-78)	≈ 1½ of 3 ESP sections energized
Test 9 (3-78) through Test 4 (3-79)	All ESP sections energized
Test 4 (4-79)	All ESP sections at 40 percent power
Test 5 (4-79)	All ESP sections at 40 percent power
Test 6 (4-79)	All ESP sections at 50 percent power
Test 7 (4-79)	All ESP sections at 55 percent power
Test 8 (4-79) through Test 11 (4-79)	All ESP sections in operation
YATES 6	
Test 1 (6-78) through Test 3 (6-78)	All ESP sections in operation
Test 4 (6-78 through Test 7 (6-78)	10 ESP sections not energized
Test 8 (6-78)	14 ESP sections not energized
Test 9 (6-78)	14 ESP sections not energized
Test 1 (6-79)	All ESP sections in operation
Test 2 (6-79)	2 ESP sections not in operation
Test 3 (6-79)	2 ESP sections not in operation
Test 4 (6-79)	11 ESP sections not in operation
Test 5 (6-79)	10 ESP sections not in operation
Test 6 (6-79)	13 ESP sections not in operation
Test 7 (6-79)	13 ESP sections not in operation
Test 8 (6-79)	13 ESP sections not in operation
Test 9 (6-79)	15 ESP sections not in operation
Test 10 (6-79)	14 ESP sections not in operation
Test 11 (6-79)	14 ESP sections not in operation
YATES 7	
Test 1 (6-78)	1 ESP section not energized
Test 2 (6-78)	1 ESP section not energized
Test 3 (6-78)	1 ESP section not energized
Test 4 (6-78)	12 ESP sections not energized
Test 5 (6-78)	12 ESP sections not energized
Test 6 (6-78)	16 ESP sections not energized
Test 7 (6-78)	16 ESP sections not energized
Test 8 (6-78)	1 ESP section not energized
Test 9 (6-78)	1 ESP section not energized
Test 10 (6-78)	12 ESP sections not energized
Test 11 (6-78)	12 ESP sections not energized

APPENDIX B

METHOD FOR COMPUTING STANDARDIZED OPACITY

Bougeur's Law states that the optical transmittance of an aerosol is related to the path length of light passing through it, viz.

$$I/I_o = T = \exp(-bL) \qquad (1)$$

I/I_o = ratio of the amount of light transmitted through the plume to the amount of light incident upon the plume

T = transmittance: $T = 1 - \text{Opacity}$

b = extinction coefficient of a volume of aerosol (m^{-1})

L = path length of light passing through the plume (approximated as stack exit diameter for visible emission analysis), (m).

Solving for b, Equation 1 may be rewritten:

$$b = \frac{-\ln T}{L} \qquad (2)$$

The extinction coefficient, b, is a physical constant for a given aerosol at stated conditions. Thus, for a given aerosol with an extinction coefficient of b, a change in the path length, L, will necessarily result in a change in the value of the transmittance such that the ratio of the natural logarithm of the transmittance to the path length is constant:

$$-b = \frac{\ln T_1}{L_1} = \frac{\ln T_2}{L_2} = \frac{\ln T_n}{L_n}$$

If T_o and L_o are the actual observed values for transmittance and path length, respectively, then T_s, the transmittance of this same aerosol as viewed through a new path length of L_s, is

$$T_s = \exp\left(\frac{L_o}{L_s} \ln T_o\right) \qquad (3)$$

For visual opacity estimates the actual path length was assumed to equal the stack exit diameter. Any effects due to plume billowing or observer viewing station in relation to the stack were ignored. The path length for transmissometer measurement was also assumed to equal stack exit diameter in accordance with 40 CFR 60, Appendix B, Section 4.3. In all cases, the standardized path length was set equal to 4.0 meters (~ 13.0 ft).

APPENDIX C

CONFIDENCE LIMITS FOR PREDICTED INDIVIDUAL y VALUES

The following procedures were used to compute the 95 percent confidence limits for any predicted value of the mass emission (g/am^3) in terms of the opacity value indicated by the linear regression line. The general expression for y* is

$$y^* \; 95\% / = y^* \pm t_{n-2,\; 0.05} \sqrt{Sy.x^2 \left[1 + \frac{1}{n} + \frac{(x-\bar{x})^2}{\sum (x-\bar{x})^2)} \right]} \qquad (1)$$

If it is assumed that the number of data pairs, n, is large and that the $(x-\bar{x})^2$ value for the point of interest is small compared to the term $\sum (x-\bar{x})^2$, Equation C-1 reduces to the form

$$y^* \pm t_{n-2,\; 0.05} \; Sy.x \qquad (2)$$

Since Sy.x can be expressed as

$$Sy.x = Sy \sqrt{1-r^2} \qquad (3)$$

and Sy, the sample standard deviation for the y values can be computed as

$$Sy = \sqrt{\frac{\sum (y-\bar{y})^2}{n-1}} = \sqrt{\frac{\sum y^2 - (\sum y^{\,2}/n)}{n-1}} \qquad (4)$$

the parameters derived during the development of the regression line $(y-\bar{y})$, Sy and r are available for rough estimates of confidence limits. In computing the "t" value, 2 degrees of freedom are lost through the use of the mean values and the standard deviations. The "t" function represents the area described by 0.025 of either tail of the t distribution. The statistical development used here is based upon procedures reported by Collins.[24]

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16. ABSTRACT The report gives results of concurrent particulate emissions and opacity measurements based on visual observations and/or in-stack transmissometry for more than 400 compliance, acceptance, or experimental tests on coal-fired utility and industrial boilers. The sampling, which includes a capacity range of a few to several hundred megawatts and typical firing methods (pulverized, stoker, and cyclone), in most cases reflects flyash control by electrostatic precipitation, although filters or mechanical collectors were used at a few installations. All opacity measurements were standardized to their equivalent values for a 4 m (13.0 ft) diameter stack before being compared with their corresponding particulate emissions, the latter expressed as actual grams per cubic meter. No discernible correlations applicable to all sources were observed, although some modest (but apparently significant) correlations were noted on an individual source basis. Thus, any useful and definitive relationships between particulate mass emission rates and their corresponding opacity levels appear to be site specific. Furthermore, correlations with transmissometer measurements were far stronger than those derived from visual estimates of opacity. Report findings were sufficiently encouraging to warrant furthur analyses relating to in-stack transmissometer measurements.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Dust	Pollution Control	13B	11G
Coal	Aerosols	Stationary Sources	21D	07D
Combustion	Boilers	Mass Emissions	21B	13A
Measurements	Transmissometers	Particulate	14B	
Opacity		Particulate Mass Emissions		
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