Development of Startup and Shutdown Permit Limits Based Upon Historical Data from Combustion Sources Monitored by Continuous Emission Monitoring Systems

A&WMA's 102nd Annual Conference & Exhibition
Detroit, Michigan
June 15 - 19, 2009

Manuscript 2009-A-597-AWMA

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ABSTRACT

There has been a growing trend in recent years to establish startup (SU) and shutdown (SD) limits for large stationary combustion units, particularly for pollutants measured by Continuous Emission Monitoring Systems (CEMS), such as NO_x and CO that exceed existing limits intended for steady state operation. Unlike permitting methods used to establish steady state limits, a process for determining SU/SD limit values is generally not well defined by regulating agencies. Rather than determining limits using best available control technologies prior to commencing operation, as is done for steady state limits, facilities often collect and evaluate at least six to twelve months of SU/SD CEMS data to develop limits. There is inherent variability in SU/SD emission profiles specific to each facility, unit and operating scenario. For these reasons, establishing SU/SD limits that both government agencies and the energy industry find satisfactory can be a challenge. This paper discusses the application of linear regression and the upper prediction bound to develop SU/SD duration and mass emission permit limits based upon historical CEMS data. The upper prediction bound uses historical data to predict with a certain level of confidence whether the next observation will be less than the upper prediction bound. The SU/SD duration analysis uses the upper prediction bound for a new observation. Since SU/SD mass emissions are dependent upon duration, the mass emissions analysis utilizes the upper prediction bound for a new observation based on a regression of mass emissions (Y) on duration (X). Results will be presented for NO_x and CO hot, warm and cold startup as well as shutdown emissions from three GE Frame 7FA gas-fired combined cycle combustion turbines, whose steam feeds a common steam turbine generator. These analyses can be applied to any combustion unit equipped with CEMS that accurately monitors emissions of any pollutant during SU/SD events.

INTRODUCTION

As there are a growing number of non-baseload simple cycle and combined cycle combustion turbines (CTs) there has been an increasing importance to better quantify and regulate emissions during transient events such as startups and shutdowns.[1] Emissions during these transient time periods can account for a large portion of total emissions depending upon their frequency. Peaking units and merchant power plants that are mainly comprised of both simple and combined cycle CTs typically operate during periods of high energy demand and commonly startup and shutdown daily. Emissions from large stationary combustion units can depend upon the type of combustion unit, many operational factors as well as ambient temperature and humidity conditions that fluctuate throughout the year so applying general emission standards during startup and shutdown time periods is not an option. For these reasons, developing emission limits based upon traditional permitting techniques is difficult and has in many cases led to facilities needing to revise air permit limits.[2]

Considering emission limits have historically been developed for steady state emissions, there has been a debate regarding how to best regulate combustion units during periods of transient events such as startup, shutdown and malfunctions. In 1999 the Environmental Protection Agency (EPA) provided updated policy guidance regarding excess emissions during startup, shutdown and malfunction events.[3] According to this guidance, in cases which a single source or small group of sources do not have the potential to cause an exceedance of a National Ambient Air Quality Standard (NAAQS) or Prevention of Significant Deterioration (PSD) increments, this policy has allowed states the flexibility to add provisions to air permits limiting the applicability of emission limits to non-startup and non-shutdown periods; otherwise the enforcement discretion approach applies during elevated emission time periods caused by these transient events.

Over the years, regulatory agencies have sought new methods to quantify and regulate startup and shutdown emissions[1] and for this reason have implemented this 1999 EPA guidance non-uniformly. Some states have limited the applicability of emission limits to non-startup and non-shutdown periods, while others have adopted the concept of quantifying startup and shutdown emissions using historical Continuous Emission Monitoring Systems (CEMS) data to develop site specific startup and shutdown emission limits. When historical CEMS data is used for startup and shutdown emission limit development there is no current standard regarding how to analyze and interpret CEMS data for this purpose. Other states have opted to use enforcement discretion and have not altered their historical permitting guidelines. For energy companies that seek more control over possible enforcement actions, proposing startup and shutdown limits for inclusion within their air permit based upon a sound data analysis strategy may allow for added control over the possibility of regulatory agencies implementing their enforcement discretion during startup and shutdown events. At the same time, proposing limits to regulatory agencies that justify the inclusion of site specific startup and shutdown emission limits may alleviate states the burden of continuously evaluating their enforcement discretion with regards to startup and shutdown emissions.

Emission limits are also continuing to develop and the trend has been to restrict combustion sources to lower emission levels over shorter compliance time frames (e.g. 30-day averages to 1-hr averages). For instance, the 2004 updates of 40 CFR 60 Subpart GG now allow for the use of a NO_x CEMS for compliance purposes based upon a 4 hour average and states commonly apply hourly emission standards in new air permits based upon best available control technology standards prior to a combustion unit commencing operation. As the averaging period and emission levels have decreased through the years, separating emission limits between steady state and transient events such as startup and shutdown are becoming more important. During this transition there has been a greater need to utilize CEMS real time pollutant data for the development of site specific startup and shutdown pollutant emission limits.

Considering there is little guidance regarding how to develop transient emission limits from CTs,[1,4] this paper introduces a general data analysis method that utilizes historical CEMS data and the upper prediction bound that can be used by both regulatory agencies and/or the energy industry to help standardize the development of startup and shutdown duration as well as emission limits for air permitting and compliance purposes. Considering the large number of simple and combined cycle CTs that operate during peak demand times, developing a standardized method to evaluate and determine permit limits for transient events may allow more facilities to implement site specific startup and shutdown duration and emission limits based upon historical CEMS data. Although CEMS duration and emissions data from three GE Frame 7FA gas-fired combined cycle CTs are used to exemplify the data analysis method as described below, data from any combustion source can be utilized within this data analysis process.

BACKGROUND

Startup and shutdown duration and mass emissions data are presented herein from three GE Frame 7FA combined cycle CTs with a combined nominal generating capacity of 750 MW. Each CT fires natural gas and minimizes NO_x emissions with the use of dry low NO_x combustors as well as selective catalytic reduction. Each CT is rated at 1949 mmBtu/hr at 0°F and is equipped with a set of natural gas and/or refinery gas fired duct burners that are each rated at 333 mmBtu/hr. The steam generated from each combined cycle unit also feeds a common steam turbine generator. The facility is limited by a state air plan approval and is currently working through the Title V air permit application process.

Each combined cycle CT is equipped with a dry extractive NO_x and CO CEMS. The NO_x CEMS is regulated under 40 CFR 60 and 75 and both NO_x and CO CEMS are regulated by the state agency. CEMS components include NO_x, O_2 and CO gaseous analyzers, fuel metering systems as well as a gas chromatograph. Prior to the preparation of the startup and shutdown duration and mass emissions datasets, minute data was reviewed during startup and shutdown events. This review process identified the need to increase the CO analyzer scale ranges from the original settings of 0 – 200ppm. The scale ranges for each CO analyzer have subsequently been increased to 0 – 2000ppm in accordance with 40 CFR 60 Appendix B, Performance Specification 4A. For this reason, another year and half was required to document startup and shutdown emissions.

The data analysis was performed to satisfy an air permit requirement, which states:

> "The company shall submit a report to the Department, based on at least six months of operational data, that details the actual amount of time required for each startup and each shutdown scenario and the estimated emissions associated with each startup and shutdown scenario."

Described below is a discussion of the data analysis process used to estimate duration and NO_x and CO mass emissions associated with the CTs' startup and shutdown events.

Startup/Shutdown Dataset Description

An evaluation based on minute CEMS data was performed during startup and shutdown time periods from each CT between January 2007 through June 2008. This evaluation included identification and documentation of each CTs hot, warm and cold startup and shutdown durations as well as corresponding NO_x and CO mass emissions. As stated within the facility's air plan approval, definitions of hot, warm and cold startup conditions are as follows:

- Hot Startup – A startup that occurs after the CT has been offline for less than 8 hours.
- Warm Startup – A startup that occurs after the CT has been offline for 8 hours to 48 hours.
- Cold Startup – A startup that occurs after the CT has been offline for at least 48 hours.

The following startup and shutdown duration definitions were used throughout the analyses because the data acquisition and handling system (DAHS) is not equipped with either startup or shutdown signals. The following definitions were used to approximate the duration of the startup and shutdown operational definition.[5] In general, when startup and shutdown operational signals are available in the DAHS and accurately represent the duration of individual startup and shutdown durations they should be used for this purpose of defining startup and shutdown durations. When startup and shutdown operational signals are not available, definitions must be determined and adhered to throughout the analysis process.

- Startup Duration – The period of time between the start of fuel combustion and when the CT of interest satisfies the steady state hourly emission limits for both NO_x and CO emissions on the minute level.
- Shutdown Duration – The shutdown duration is defined as the period of time between when the load (MW) begins to decrease and either NO_x or CO emissions on the minute level exceed the hourly steady state limits until the time fuel combustion is complete.

An evaluation was conducted using startup and shutdown data between January 2007 – September 2007 and although this time frame allowed for a satisfactory amount of hot startup and shutdown conditions, it did not allow for an adequate number of warm or cold startup events. For this reason, the time frame was extended through June 2008 to capture more warm and cold startup events as well as their associated shutdowns.

Startup and shutdown datasets were compiled from minute NO_x and CO mass emissions data during startup/shutdown time periods for each CT (i.e. CT1, CT2 and CT3). Mass emissions are calculated by the DAHS using CEMS data from NO_x, CO and O_2 analyzers, natural gas and refinery gas fuel meters and a gas chromatograph. The DAHS utilizes the following 40 CFR 75 Appendix F formulas. The following formulas represent one method to calculate NO_x and CO mass emissions; however, there are other common sampling and calculation methods (e.g. utilizing a stack flow monitor in lieu of fuel meters).

$$M_{(NOx/CO)} = ER_{(NOx/CO)} \times HI \times t \qquad \text{(Eq. 1)}$$

$M_{(NOx/CO)}$ = NO_x or CO mass emissions in lbs

$ER_{(NOx/CO)}$ = NO_x or CO mass emissions rate in lb/mmBtu, where:

$$ER_{(NOx/CO)} = K \times C \times F \times \frac{20.9}{20.9 - \%O_2} \qquad \text{(Eq. 1a)}$$

K = 1.194 x 10-7 (lb/dscf)/ppm NO_x or 7.27 x 10-8 (lb/dscf)/ppm CO

C = NO_x or CO CEMS concentration during unit operation in ppm

F = A factor representing a ratio of the volume of dry flue gases generated to the caloric value of the fuel combusted in dscf/mmBtu. The refinery gas F-factor is monitored by an on-site gas chromatograph.

$\%O_2$ = Oxygen CEMS volume during unit operation expressed as $\%O_2$

HI = Heat input rate, mmBtu/hr, where:

$$HI = \frac{(Q_{CT,ng} \times GCV_{ng})}{10^6} + \frac{(Q_{DB,ng} \times GCV_{ng})}{10^6} + \frac{(Q_{DB,rg} \times GCV_{rg})}{10^6} \qquad \text{(Eq. 1b)}$$

Q = Metered flow rate of gaseous fuel in hscf/hr. Each CT is equipped with a separate natural gas fuel meter and each set of duct burners (DB) are equipped with separate natural gas (ng) and refinery gas (rg) fuel meters.

GCV = Gross calorific value of gaseous fuel in Btu/hscf. The refinery gas GCV is monitored by an on-site gas chromatograph.

10^6 = Conversion of Btu to mmBtu

t = Monitoring location operating time in hours or fraction of an hour

The startup and shutdown duration and mass emissions data were compiled for 3x1 operational sequences (i.e. sequential startup or shutdown of 3 CTs and 1 steam turbine). Because the 3x1 operational sequences exhibit longer aggregate durations than the 2x1 and 1x1 operational sequences and the 3x1 operational sequences have been more common, only the 3x1 startup and shutdown events are included within the startup and shutdown datasets. In addition, only 3x1 startups were included that contained all three CTs operating in the same startup category (i.e. hot, warm or cold) as it is not uncommon during a 3x1 startup condition that one or more CTs are in a different hot, warm or cold startup category.

The hot, warm and cold startups as well as shutdown datasets were compiled for each "Individual CT" and "Aggregated CTs". Duration and NO_x and CO mass emissions data were compiled for each of the three CTs, while the "Aggregated CTs" data represented the sum of the three CTs durations and mass emissions during either a 3x1 startup or 3x1 shutdown event. Because the 3x1 startup and 3x1 shutdown sequences involve starting up and shutting down each turbine separately, each CT operates for a different amount of time during a 3x1 startup or 3x1 shutdown event. For this reason, the "Individual CT" data and data analyses presented below utilize only the maximum individual CT duration, NO_x and CO mass emissions values from the three CTs during each 3x1 startup or 3x1 shutdown event. In general, the latter units in a multiple unit startup or shutdown take a shorter amount of time to startup or shutdown. Unrepresentative events, such as unit trips or events not entirely monitored due to CEMS downtime (e.g. an infrequent analyzer malfunction or calibration during a startup or shutdown event) were not included within the datasets.

The datasets compiled and described within this section are the basis for the analyses described below and are assumed to approximate normally distributed data. The following specific data results apply only to the three GE Frame 7FA combined cycle CTs described herein; however, the data analysis process can be applied to other combustion units.

Startup and Shutdown Durations

A startup and shutdown duration analysis was conducted, as mentioned above, using only the maximum duration values from each individual CT during a 3x1 startup or 3x1 shutdown event, so as not to underestimate the duration statistics. Figure 1 illustrates the "Individual CT" hot, warm and cold startups as well as shutdown duration datasets. Figure 2 illustrates the same data using individual box plots, which represent the quartiles of each dataset (i.e. the minimum, 25^{th} percentile, median or 50^{th} percentile, 75^{th} percentile and maximum values).

Figure 1 - Individual CTs Hot, Warm & Cold Startups & Shutdown Duration Raw Data

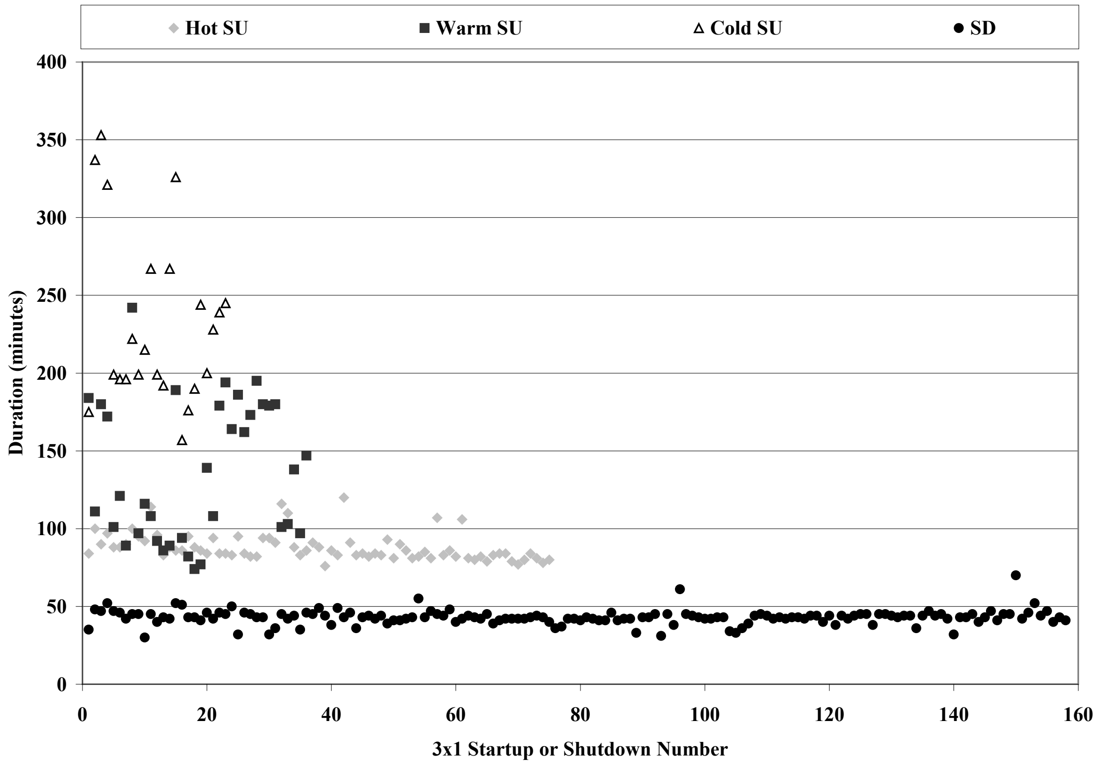
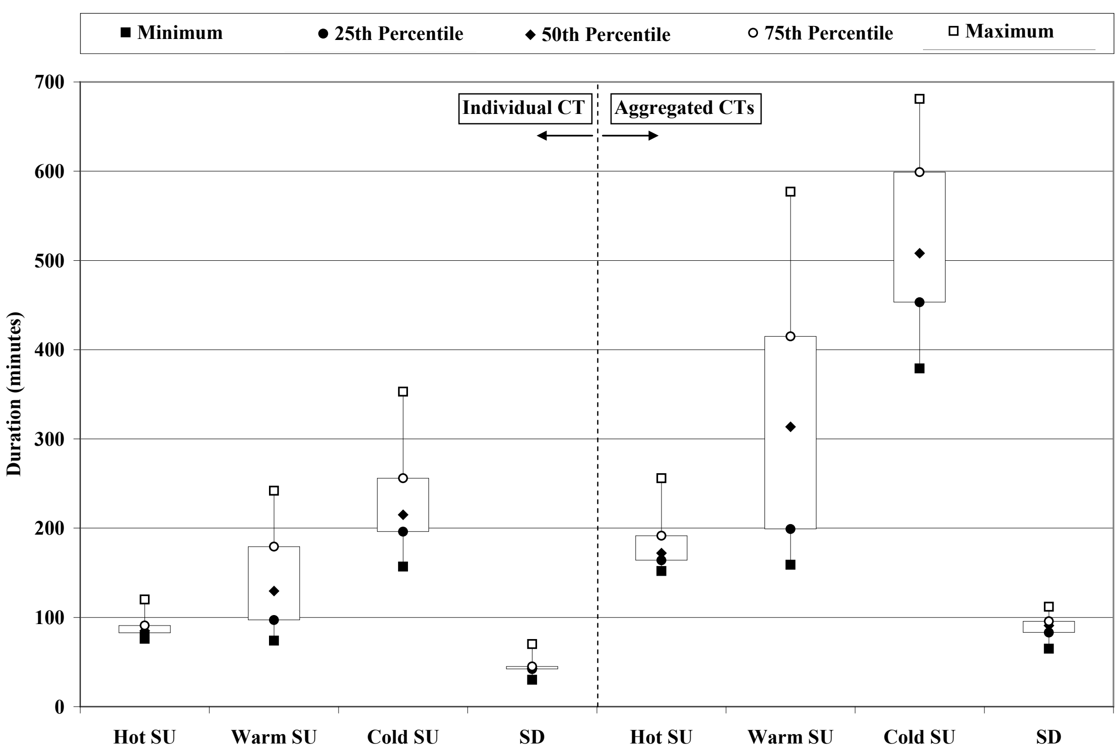


Figure 2 - Duration Box Plots for Individual and Aggregated CTs Hot, Warm and Cold Startups & Shutdowns



The descriptive duration statistics shown in Table 1 summarize the sample size, maximum, mean, 95% confidence interval, standard deviation, 99.9% upper prediction bound, as well as proposed duration limits during startup and shutdown periods for each operational sequence considered.

Table 1 - Startup (SU) & Shutdown (SD) Descriptive Duration Statistics

Statistics	Individual CT				Aggregated CTs			
	Hot SU	Warm SU	Cold SU	SD	Hot SU	Warm SU	Cold SU	SD
Sample Size	75	36	23	158	75	36	23	158
Maximum Duration (minutes)	120	242	353	70	256	577	681	112
Mean (min)	88	137	232	43	181	309	525	89
95% Confidence Interval (min)	(86,90)	(122,152)	(209,255)	(42,44)	(176,186)	(271,347)	(488,562)	(88,90)
Standard Deviation (min)	9	45	56	5	24	115	91	9
99.9% Upper Prediction Bound (min)	115	273	403	57	253	658	803	116
Proposed Duration Limit (min)	120	300	420	60	270	660	810	120
Proposed Duration Limit (hours)	2.0	5.0	7.0	1.0	4.5	11.0	13.5	2.0

Figures 1 and 2 and Table 1 presented above, as well as the "Aggregated CTs" analogous versions, not shown, illustrate:

- The durations associated with "Individual CT" and "Aggregated CTs" datasets for 3x1 hot, warm and cold startup or shutdown operational sequences.
- The distributions of each dataset are different, as shown within the duration box plots. In addition, the datasets' variability increase in the following order (i.e. shutdown < hot startup < cold startup < warm startup). In other words, the shutdown datasets show the least amount of variability, while the warm startup datasets show the most variability.
- As expected, a general upward trend in duration occurs from hot to warm to cold startups as well as a general upward trend in duration occurs when comparing the "Individual CT" datasets to the "Aggregated CTs" datasets.
- The means are statistically different because the 95% confidence intervals for each sample mean do not overlap. Furthermore, the means are statistically different from one another at the 0.0001 level of significance (one-way anova, p-value < 0.0001). The statistical difference between sample means justifies the separate treatment of each dataset (i.e. the hot, warm and cold startup duration datasets are not the same because there is a statistical difference between their sample means).

To develop/propose a duration limit that may be applied to the CTs during startup and shutdown time periods, the 99.9% upper prediction bound based on one sample is determined for each historical startup and shutdown duration dataset that are briefly described above.

The upper prediction bound formula for Y_0, where Y_0 is a new single observation to be predicted, is:[6]

$$\text{UPB} = \bar{Y} + z \cdot s \cdot \sqrt{1 + \frac{1}{n}} \qquad \text{(Eq. 2)}$$

where:

UPB = The upper prediction bound
$\bar{Y}$ = The sample mean of the data Y
s = The sample standard deviation where: $s = \sqrt{\frac{\sum (Y_i - \bar{Y})^2}{n-1}}$
z = The critical value from the standard normal distribution (for a 3 sigma upper bound $z = 3$)
n = The sample size

Importantly, the upper prediction bound equation takes into consideration the sample size n, which can be limited when compiling startup and/or shutdowns from a combustion source as their frequencies may be limited or only a small amount of accurately monitored data may be available.

The upper startup prediction bound and upper shutdown prediction bound, shown in Table 1 above, can be used to predict future startup and shutdown duration values. Future startup and shutdown duration values are expected to be less than or equal to the 99.9% upper prediction bounds with an approximate 99.9% confidence. In other words, the forecasted number of startups or shutdowns that may exceed the 99.9% upper prediction bound will be approximately 1 out of 1,000.

The proposed duration limits, shown in Table 1, round the upper prediction bounds to the next half hour and can be used to either update previously implemented duration limits not based on CEMS data or propose new startup and shutdown duration limits.

Startup and Shutdown NO_x & CO Mass Emissions

As required by the facility's air plan approval, a NO_x and CO mass emissions analysis was conducted using the datasets described above. Figures similar to 1 and 2 and Table 1, above, were prepared for NO_x and CO mass emissions to properly summarize each dataset. Developing these figures and table may allow for the determination of outliers or erroneous data during the dataset preparation process. Throughout the analysis presented herein, the outliers were kept in the dataset because after an operational review none of the outliers were identified as non-representative events. Shown below in Figures 3 and 4 are box plots of each NO_x and CO mass emissions startup and shutdown data set.

Figure 3 - NO_x Mass Emissions Box Plots for Individual and Aggregated CTs Hot, Warm and Cold Startups & Shutdowns

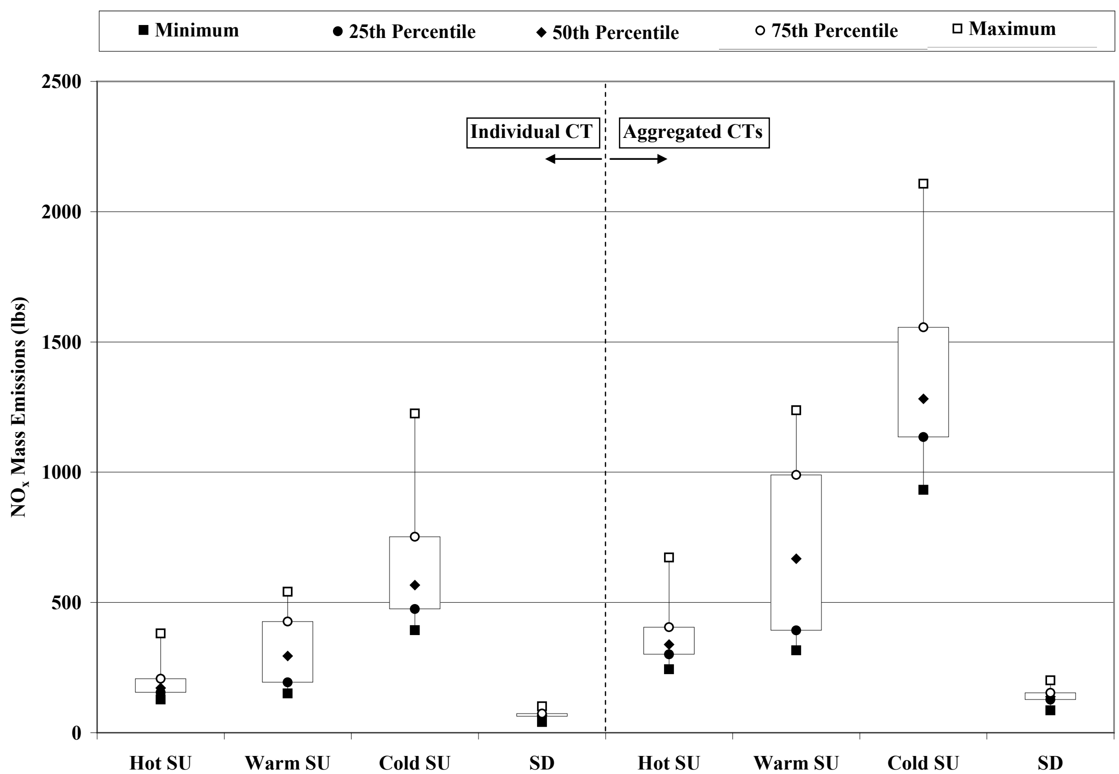
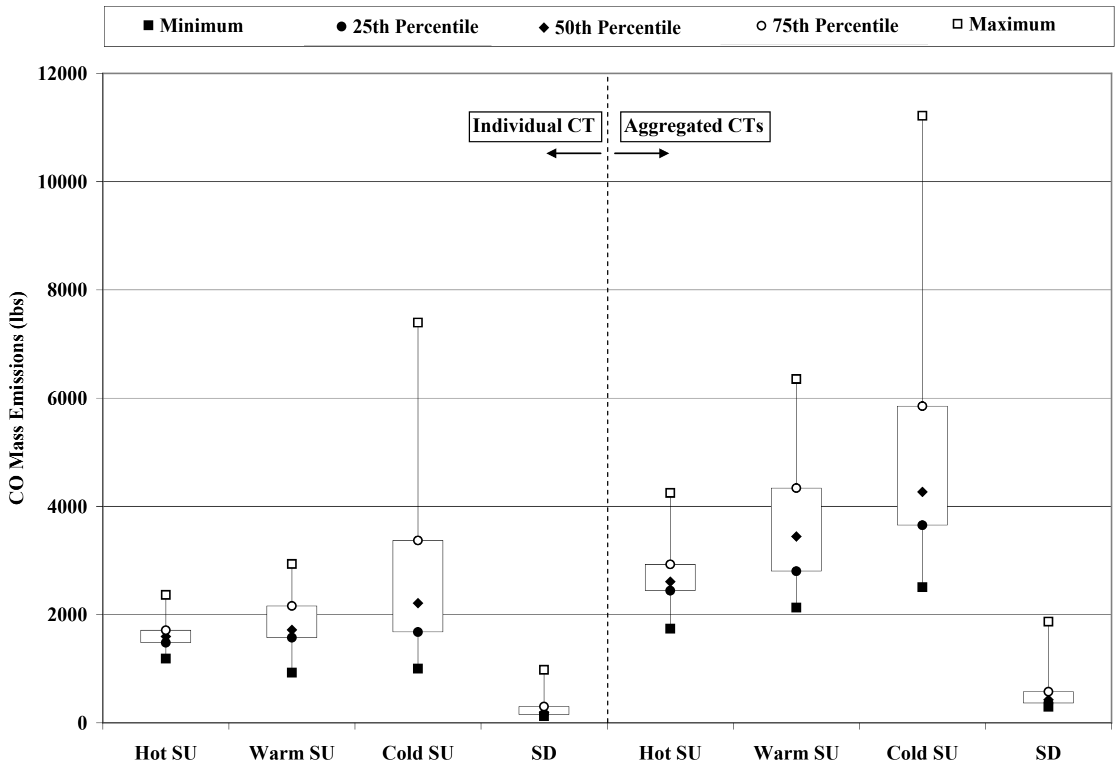


Figure 4 - CO Mass Emissions Box Plots for Individual and Aggregated CTs Hot, Warm and Cold Startups & Shutdowns

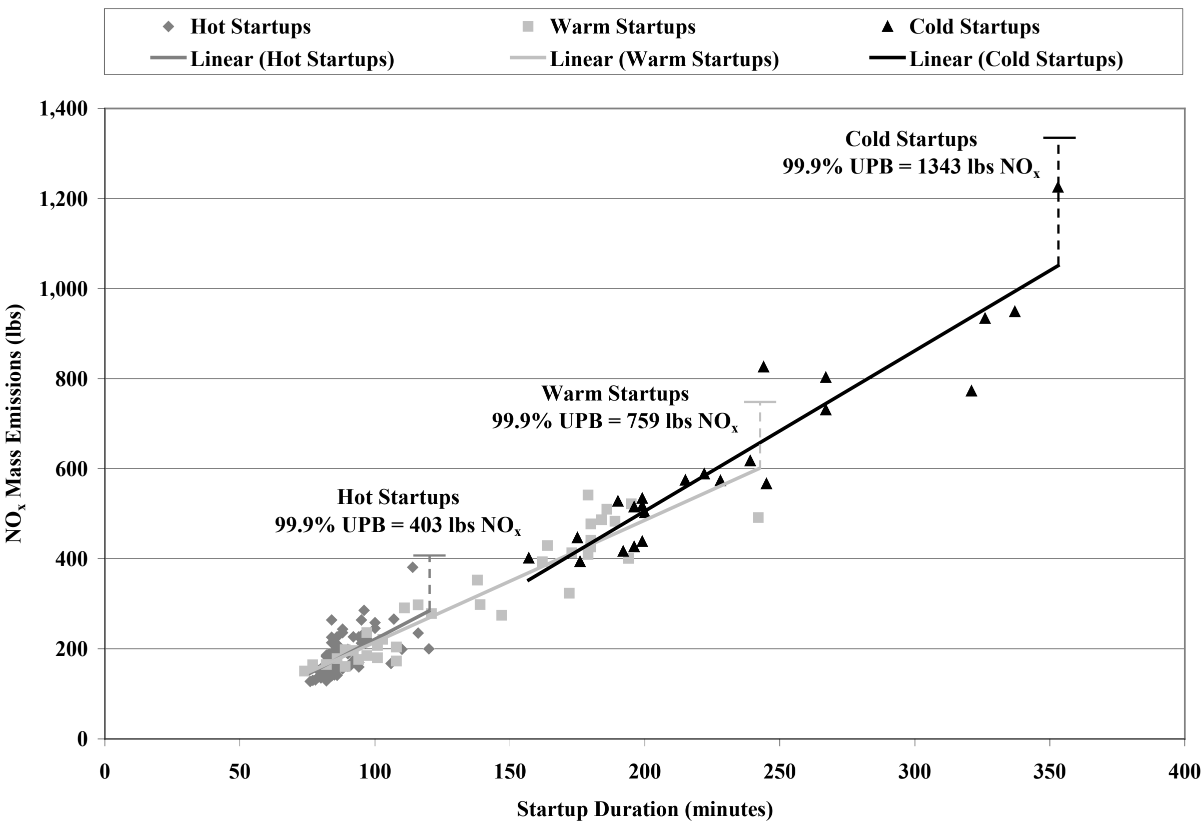


Similar to the duration figures and table presented above, Figures 3 and 4 as well as their associated descriptive statistics, not shown, illustrate:

- The NO_x and CO mass emissions associated with "Individual CT" and "Aggregated CTs" hot, warm and cold startups as well as shutdown events.
- The distributions of each dataset are different, as shown within the NO_x and CO mass emissions box plots. In addition, the datasets' variability increase in the following order (i.e. shutdown < hot startup < warm startup < cold startup). In other words, the shutdown datasets show the least amount of variability, while the cold startup datasets show the most variability.
- As expected, a general upward trend in duration occurs from hot to warm to cold startups as well as a general upward trend in duration occurs when comparing the "Individual CT" datasets to the "Aggregated CTs" datasets.
- The means are statistically different because the 95% confidence intervals for each sample mean do not overlap. Furthermore, the means are statistically different from one another at the 0.0001 level of significance (one-way anova, p-value < 0.0001). The statistical difference between sample means justifies the separate treatment of each dataset (i.e. the hot, warm and cold startup mass emissions datasets are not the same because there is a statistical difference between their sample means).

Since mass emissions from the CTs are dependent upon duration (i.e. the longer a unit operates the more emissions are generated), a regression analysis was performed to calculate the upper prediction bound for NO_x and CO mass emissions at each of the eight startup and shutdown categories. Regression analyses were prepared for NO_x and CO mass emissions versus duration for each startup and shutdown category. As an example, Figure 5 illustrates the NO_x mass emissions dependence upon hot, warm and cold startup durations by plotting NO_x mass emissions versus duration for each startup event. Figure 5 also includes the best fit line through each of the three separately treated datasets (i.e. hot, warm and cold startups). Although the slopes of the three best fit lines are similar, they differ slightly, most likely due to the variability in the available data.

Figure 5 - NO_x Mass Emissions vs. Duration, Best Fit Lines & Upper Predictive Bounds for Hot, Warm and Cold Individual CT Startups



The 99.9% upper prediction bound is calculated assuming a NO_x and CO mass emissions dependence on duration for each historical startup and shutdown dataset. Because mass emissions are dependent upon startup and shutdown durations, the upper prediction bound equation also utilizes the estimated slope from the fitted regression model between mass emissions and duration.

To develop/propose a NO_x and CO mass emissions limit that may be applied to the CTs during both startup and shutdown time periods, the 99.9% upper prediction bound equation for a new observation based on a regression of Y on X is utilized.

The upper prediction bound formula for Y_0, where Y_0 is a new single observation to be predicted from a regression based on *X*, predicted at X_0, is as follows.[6] The linear regression equation is:

$$Y = \beta_0 + \beta_1 X + \varepsilon \qquad \text{(Eq. 3)}$$

where:

β_0 = The y intercept in the regression model
β_1 = The slope in the regression model
ε = The random error

The upper prediction bound for Y_0 at X_0 formula is:

$$\text{UPB} = \overline{Y} + \hat{\beta}_1 (X_0 - \overline{X}) + z \cdot s_{Y|X} \cdot \sqrt{1 + \frac{1}{n} + \frac{(X_0 - \overline{X})^2}{(n-1) s_X{}^2}} \qquad \text{(Eq. 4)}$$

where:

UPB = The upper prediction bound
$\overline{Y}$ = The sample mean of the data *Y*
X_0 = The *X* value where the prediction of *Y* is made
$\overline{X}$ = The sample mean of the data *X*
$\hat{\beta}_1$ = The estimated slope from the fitted regression model
$s_{Y|X}$ = The sample standard deviation of Y at X_0 where: $s_{Y|X} = \sqrt{\frac{\sum (Y_i - \hat{Y}_i)^2}{n-2}}$
$\hat{Y}_i$ = The predicted value of *Y* and X_i where: $\hat{Y}_i = \hat{\beta}_o + \hat{\beta}_i X_i$
$\hat{\beta}_0$ = The estimated y-intercept from the fitted regression model
s_X = The sample standard deviation of the data *X* where: $s_X = \sqrt{\frac{\sum (X_i - \overline{X})^2}{n-1}}$
z = The critical value from the standard normal distribution (for a 3 sigma upper bound $z = 3$)

Similar to the duration analyses, presented above, the upper prediction bound can be used to predict future startup and shutdown NO_x and CO mass emissions values. Each 99.9% upper prediction bound is calculated at the maximum duration value for each dataset to develop a conservative upper bound for startup and shutdown NO_x and CO mass emissions. Future startup and shutdown NO_x and CO mass emissions values are expected to be less than or equal to the 99.9% upper prediction bounds with an approximate 99.9% confidence. The proposed NO_x and CO mass emission limits, summarized in Table 2 below, round the upper prediction bounds to the next highest fifty pounds.

Proposed Startup/Shutdown Emission Limit Summary

Presented below within Table 2 is a summary of the proposed startup and shutdown emission limits, which are based upon the upper prediction bounds discussed above. The "Individual CT" values are intended to represent conservative values for an individual CT during a 1x1, 2x1 or 3x1 operational sequence, whereas the "Aggregated CTs" values are intended to represent conservative values for multiple CTs during either a 2x1 or 3x1 operational sequence. To reiterate, future startup and shutdown duration, NO_x and CO mass emissions values are expected to be less than or equal to the 99.9% upper prediction bound values with an approximate 99.9% confidence. These proposed values may be used to revise/update historical startup or shutdown duration limits or be used to implement new startup and shutdown NO_x and CO mass emission limits.

Table 2 - Hot, Warm, Cold Startup & Shutdown Duration, CO & NO_x Mass Emissions and Proposed Duration & Emission Limits Summary

Event Type		Proposed Duration Limit (hours)	Proposed NO_x Mass Emissions Limit (lbs)	Proposed CO Mass Emissions Limit (lbs)
Individual CT	Hot SU	2.0	450	2,500
	Warm SU	5.0	800	3,900
	Cold SU	7.0	1,350	10,650
	Shutdown	1.0	150	900
Aggregated CTs	Hot SU	4.5	800	4,950
	Warm SU	11.0	1,700	7,900
	Cold SU	13.5	2,400	15,350
	Shutdown	2.0	250	1,300

DATA ANALYSIS PROCESS SUMMARY

Although the discussion above utilizes emissions data from three GE Frame 7FA combined cycle CTs, this analysis process can be applied to emissions from any combustion unit. To summarize, the process would entail:

- Verifying pollutant CEMS is properly configured to monitor and record emissions during the transient events of interest (e.g. startup or shutdown periods).

- Download applicable startup/shutdown operational and emissions minute data from the DAHS and compile in a usable manner (e.g. summary tables illustrating the start and end time and total duration as well as the pollutant emissions of interest for each transient event). When clearly defined startup and shutdown DAHS signals are not available, clear startup and shutdown definitions must be determined and adhered to throughout the dataset preparation process. The more events utilized in the data analysis the better; however, due to many circumstances the amount of startup and shutdown events may be limited.

- Plot the duration and emissions data similar to Figures 1 and 2, above, and prepare descriptive statistics data similar to Table 1, above. This process will allow for a thorough review of the data that may allow for the identification of erroneous data or outliers that may need to be removed from a dataset.

- Evaluate the upper prediction bound for the duration data using the equation for a new observation based on one sample. This equation is simple enough to be evaluated within a traditional spreadsheet, but can also be evaluated using a variety of statistical software packages. Calculating the upper prediction bound at various levels may be a useful data analysis comparison process. As mentioned above, the forecasted number of startups or shutdowns that may exceed the 99.9% upper prediction bound (e.g. $z = 3$) will be approximately 1 out of 1,000. In comparison, the forecasted number of startups or shutdowns that may exceed the 97.7% upper prediction bound (e.g. $z = 2$) and the 99.997% upper prediction bound (e.g. $z = 4$) will be approximately 1 out of 100 and 1 out of 100,000.

- Evaluate the upper prediction bound for the pollutant emissions data using the equation for a new observation based on a regression of Y on X. Unfortunately, this equation is not simple enough to be evaluated within a typical spreadsheet format, but can be evaluated using a variety of statistical software packages. Calculating the upper prediction bound at various durations and levels may be a useful data analysis comparison process. The analysis presented above calculated the upper prediction bound utilizing the maximum startup or shutdown duration for each dataset. Other options would be to calculate the upper prediction bound at a value less than the maximum (e.g. the 95th percentile value). However, with limited datasets using values other than the maximum duration, may lead to non-conservative proposed permit limits. As shown in Table 1, above, the cold startup dataset only included 23 separate events. For this reason, the maximum duration value was utilized to calculate the upper prediction bounds as discussed above.

- Organize, present and describe the proposed limits that have been determined.
- Prior to deciding on any permit limits, the facility and/or regulatory agency should also consult the applicable DAHS vendor to verify appropriate startup and shutdown limits can be programmed into the DAHS for automatic recordkeeping, alarming and reporting purposes. Soliciting DAHS vendor input prior to implementation of new permit limits may allow for a smoother transition with the development and implementation of any new permit limits.

The process described above may be used by any facility seeking to implement new startup or shutdown limits to avoid any possibility of a regulatory agency applying their enforcement discretion during startup and shutdown emissions or as justification to modify startup or shutdown limits that were not developed using site specific CEMS data. Furthermore, regulatory agencies may also find this process useful where startup and shutdown emission limits are not commonly included within their jurisdiction's air permits. The process described above may be of help to streamline an implementation process to develop startup and shutdown emission limits based upon historical CEMS data for many facilities by applying a consistent data analysis method.

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KEYWORDS

Startup, Shutdown, Continuous Emission Monitoring System, CEMS, Upper Predictive Bound, Air Permitting, Emission Limits, Combustion, Simple Cycle, Combined Cycle, Combustion Turbine.