

Development of Startup & Shutdown Permit Limits Based Upon Historical Data from Combustion Sources Monitored by CEMS

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Startup (SU) / Shutdown (SD) Emissions Background

- In the past 20 years...
 - Evolution towards more non-baseloaded units and therefore more startups and shutdowns
 - Evolution of the Operating Permit Program to create enforceable limits for all operating scenarios
 - 1999 EPA SU/SD policy guidance discussing SU/SD exemptions and enforcement discretion
- Why Conduct a SU/SD Data Analysis?
 - Required by permit and/or regulating agency
 - To minimize routine reportable events and corresponding exposure to enforcement discretion
- SU/SD emissions are very unit- and site-specific and depend on many factors such as size, type, ancillary pre-heat equipment, equipment integrity and safety concerns, fuel type(s), add-on controls, method of operation, ambient conditions/seasonal variations, etc...
- Emissions during SU/SD can account for a large portion of annual emissions

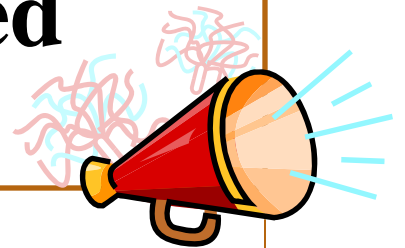
Herman, A.H.; Perciasepe, R. "State Implementation Plans: Policy Regarding Excess Emissions During Malfunction, Startup, and Shutdown" EPA Policy Memorandum, 1999.



SU/SD Limit Architecture

- SU/SD limits are commonly in units of:
 - concentration (ppmc or lb/MMBtu)
 - mass (lb/hr or lbs) and/or
 - duration
- There are unique data aggregation and validation considerations associated with:
 - the definition of the SU/SD period
 - partial operating hours
 - SU/SD that spans multiple hours
 - “mixed” hours that contain both SU/SD and steady state data, and
 - Data Acquisition & Handling System (DAHS) implementation complexity

Why Develop a Standardized SU/SD Analysis Protocol?



- Without a standardized protocol, SU/SD permit limit architecture and derivation of limits varies widely, even within states and for similar units.
- Developing a standardized SU/SD analysis protocol will help facilities streamline the development of unit-specific SU/SD limits.
- One component of this protocol should be to utilize the Upper Prediction Bound (UPB). The remainder of this presentation discusses how the UPB was used to develop SU/SD duration and mass emission limits for a 3x1 combined cycle turbine facility.

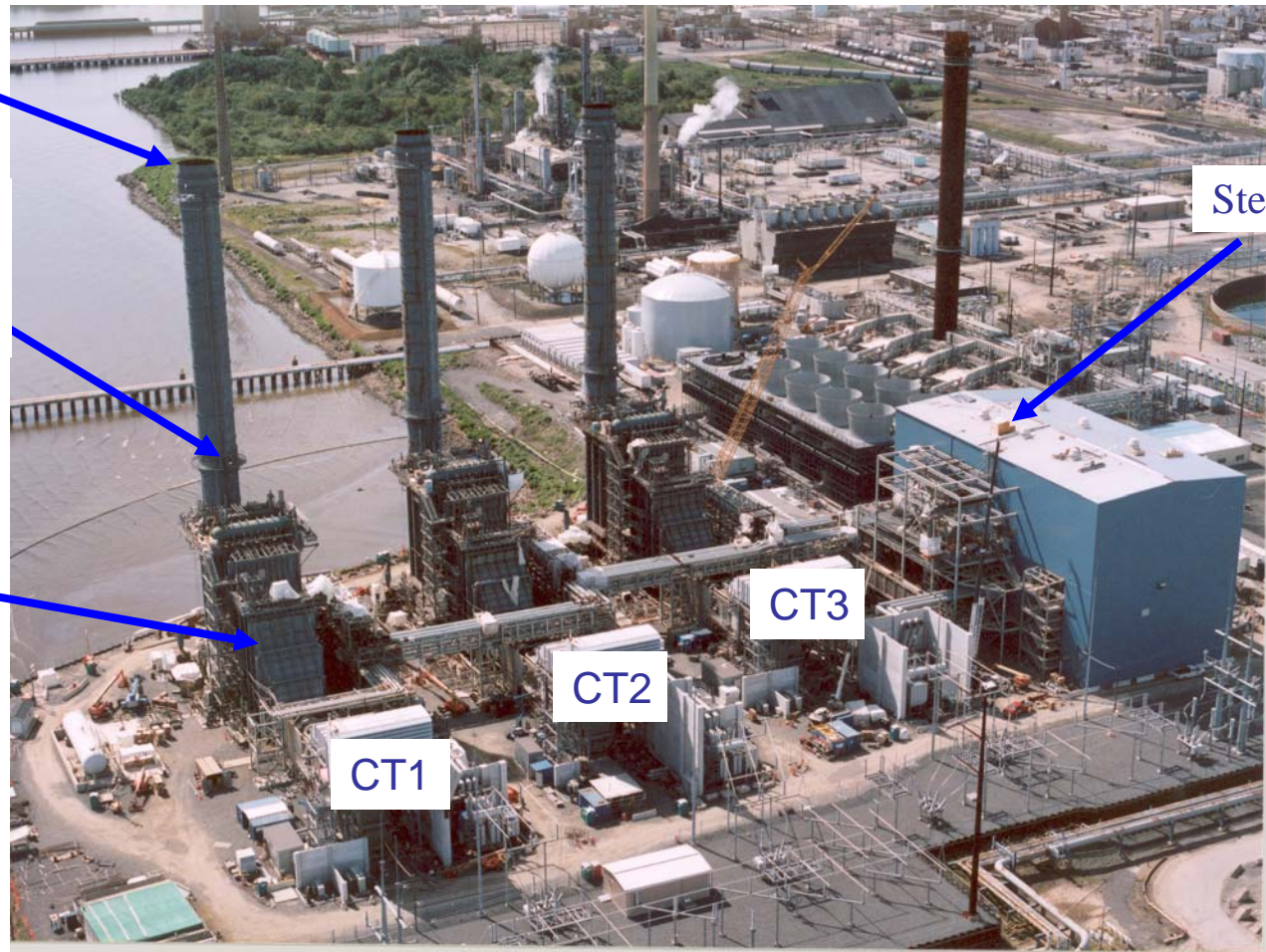
Combined Cycle Power Plant

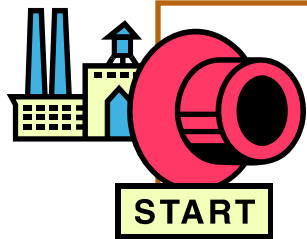
Exhaust Stack 275ft

CEMS Sampling &
Exhaust Testing
Platform ~120ft

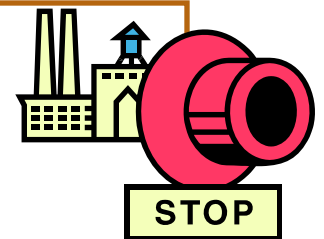
HRS&G & SCR

Steam Turbine





Working Startup & Shutdown Definitions



- Define parameters and apply them consistently during analysis
- Complicating Factors
 - Hot (<8hrs), Warm (8-48hrs) & Cold (>48hrs) SUs
 - SU/SD sequences dependent upon multiple units (1x1, 2x1, 3x1)
 - 3x1 SU/SD most common & conservative estimates for less common 1x1 & 2x1 SU/SD
 - Evaluated 3x1 SU/SDs to simplify proposed mass emission limits
 - Ideally SU/SD signals would be automated in DAHS
- SU begins with fuel flow and ends when steady state NO_x & CO emission limits are satisfied on the minute level w/ CEMS data
- SD begins when steady state NO_x and CO emission limits are no longer satisfied on the minute level w/ CEMS data and ends with cessation of fuel flow

Example SU/SD Documentation

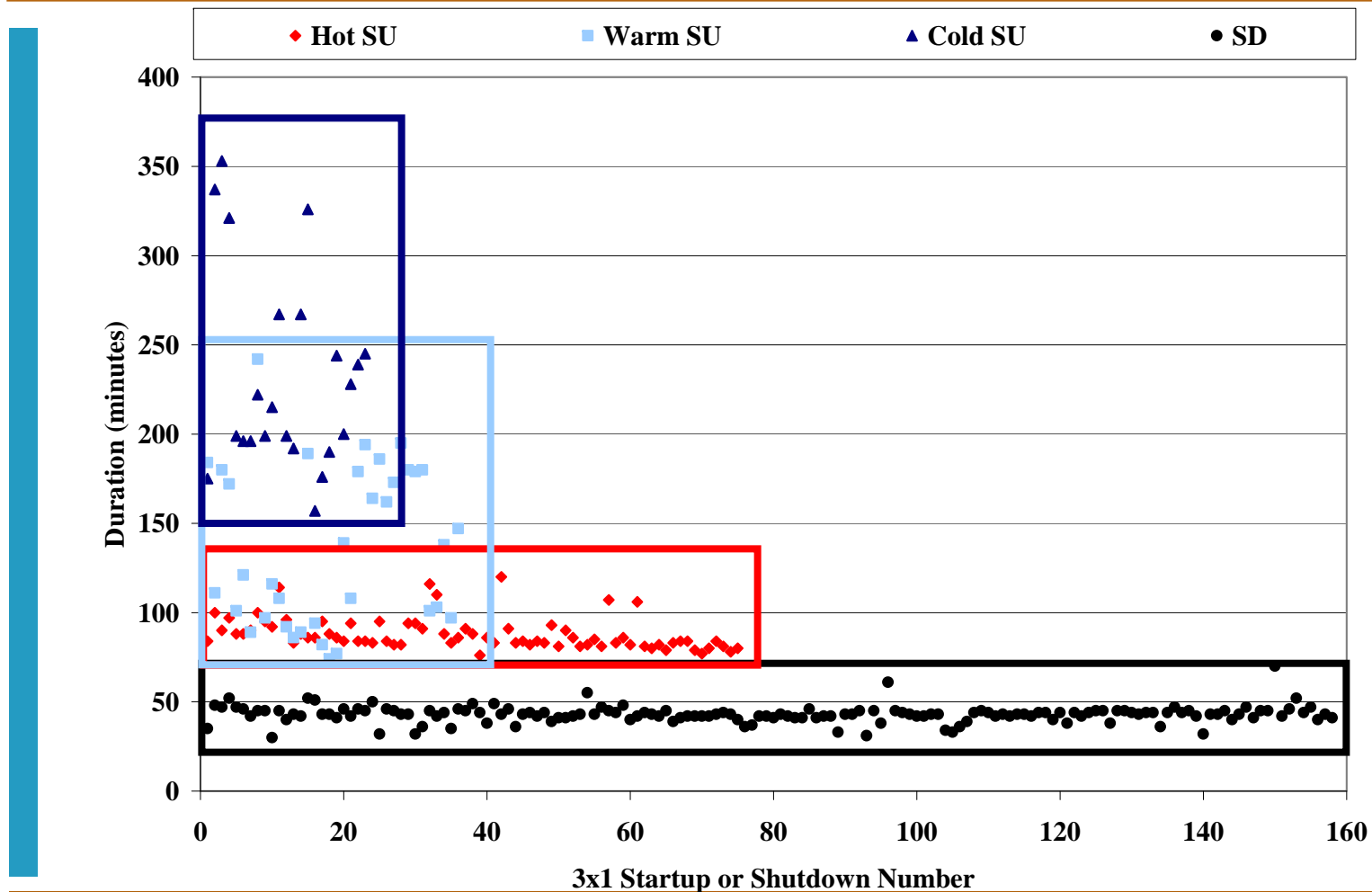
STARTUPS

Start Date	Start Time	End Date	End Time	Unit	Startup Type	Individual CT			Aggregated CTs		
						Duration (min)	CO Mass (lb)	NO _x Mass (lb)	Duration (min)	CO Mass (lb)	NO _x Mass (lb)
1/17/2007	4:58	1/17/2007	5:26	CT1	HOT	29	305	57	163	2,469	399
1/17/2007	4:04	1/17/2007	5:27	CT2	HOT	84	1,685	214			
1/17/2007	4:35	1/17/2007	5:24	CT3	HOT	50	479	128			
1/25/2007	2:07	1/25/2007	5:10	CT1	WARM	184	929	486	424	2,286	1,046
1/25/2007	2:36	1/25/2007	5:11	CT2	WARM	156	768	367			
1/25/2007	3:43	1/25/2007	5:06	CT3	WARM	84	589	193			
4/2/2007	0:55	4/2/2007	4:13	CT1	COLD	199	3,234	439	508	5,184	1,183
4/2/2007	1:24	4/2/2007	4:20	CT2	COLD	177	908	436			
4/2/2007	2:37	4/2/2007	4:48	CT3	COLD	132	1,042	308			

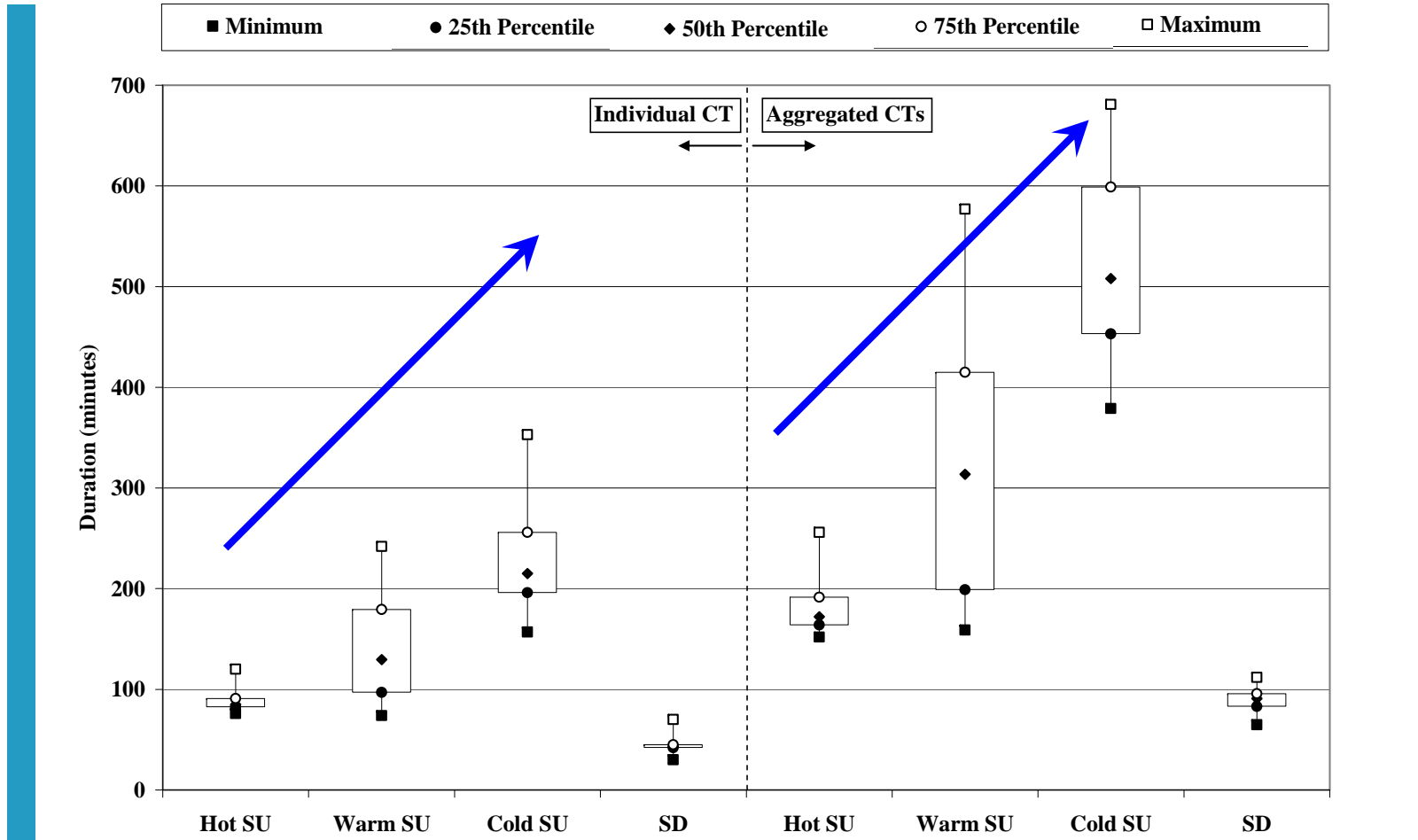
SHUTDOWNS

Start Date	Start Time	End Date	End Time	Unit	Individual CT			Aggregated CTs		
					Duration (min)	CO Mass (lb)	NO _x Mass (lb)	Duration (min)	CO Mass (lb)	NO _x Mass (lb)
1/17/2007	22:59	1/17/2007	23:06	CT1	8	101	11	76	452	159
1/17/2007	23:07	1/17/2007	23:41	CT2	35	187	74			
1/17/2007	23:08	1/17/2007	23:40	CT3	33	164	74			
1/29/2007	22:20	1/29/2007	22:26	CT1	7	90	11	98	406	165
1/29/2007	22:17	1/29/2007	23:03	CT2	47	158	77			
1/29/2007	22:20	1/29/2007	23:03	CT3	44	158	77			
4/2/2007	21:36	4/2/2007	21:43	CT1	8	61	8	69	318	128
4/2/2007	21:42	4/2/2007	22:10	CT2	29	144	61			
4/2/2007	21:39	4/2/2007	22:10	CT3	32	113	58			

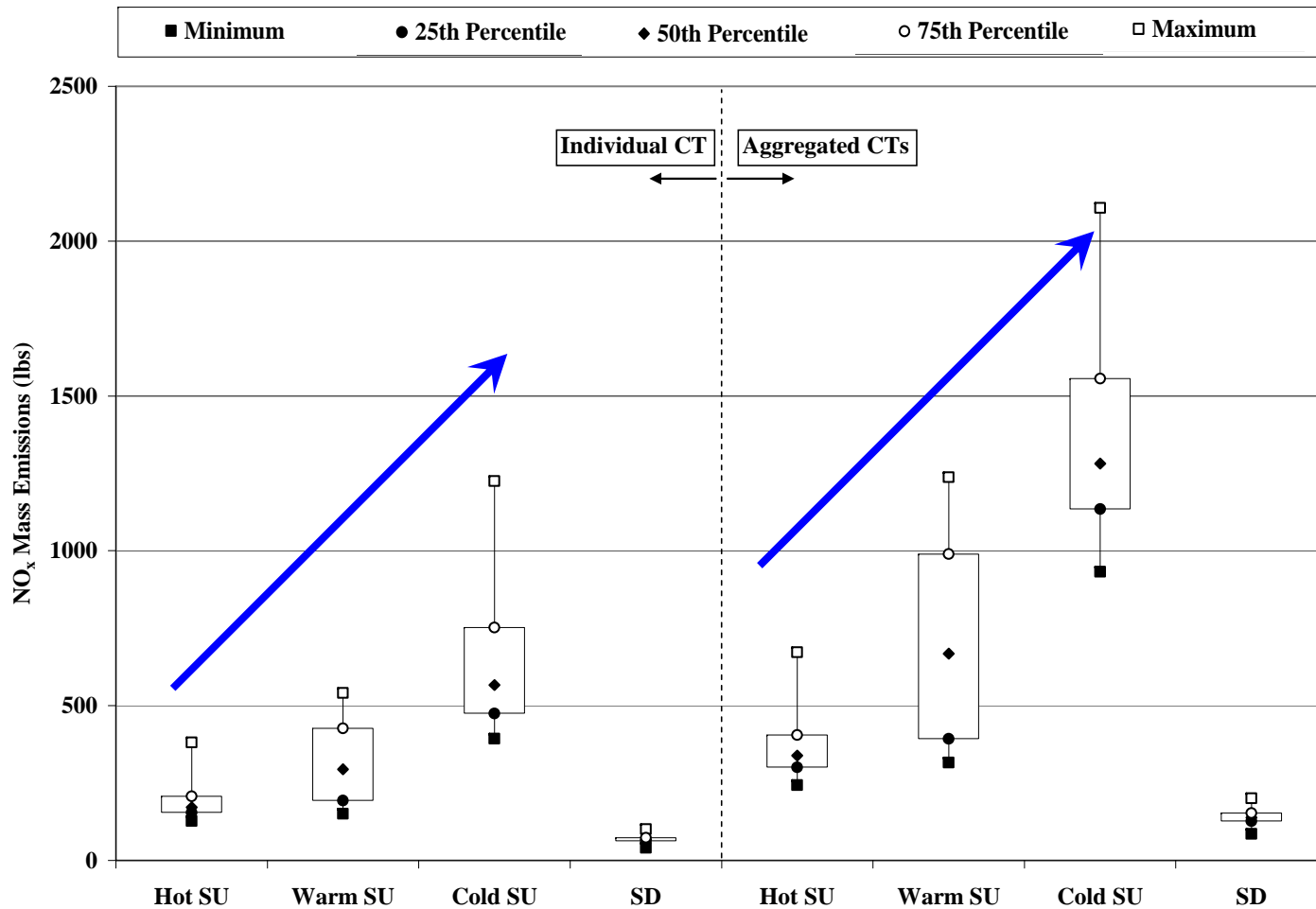
Individual CTs Hot, Warm & Cold Startups & Shutdown Duration Raw Data



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



NO_x Mass Emissions Box Plots for Individual and Aggregated CTs Hot, Warm and Cold SUs & SDs



Upper Prediction Bound Equations

- UPB based on one sample (duration)

$$\text{UPB} = \bar{Y} + z \cdot s \cdot \sqrt{1 + \frac{1}{n}}$$

- UPB for a new observation based on a regression of Y (mass) on X (duration)

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

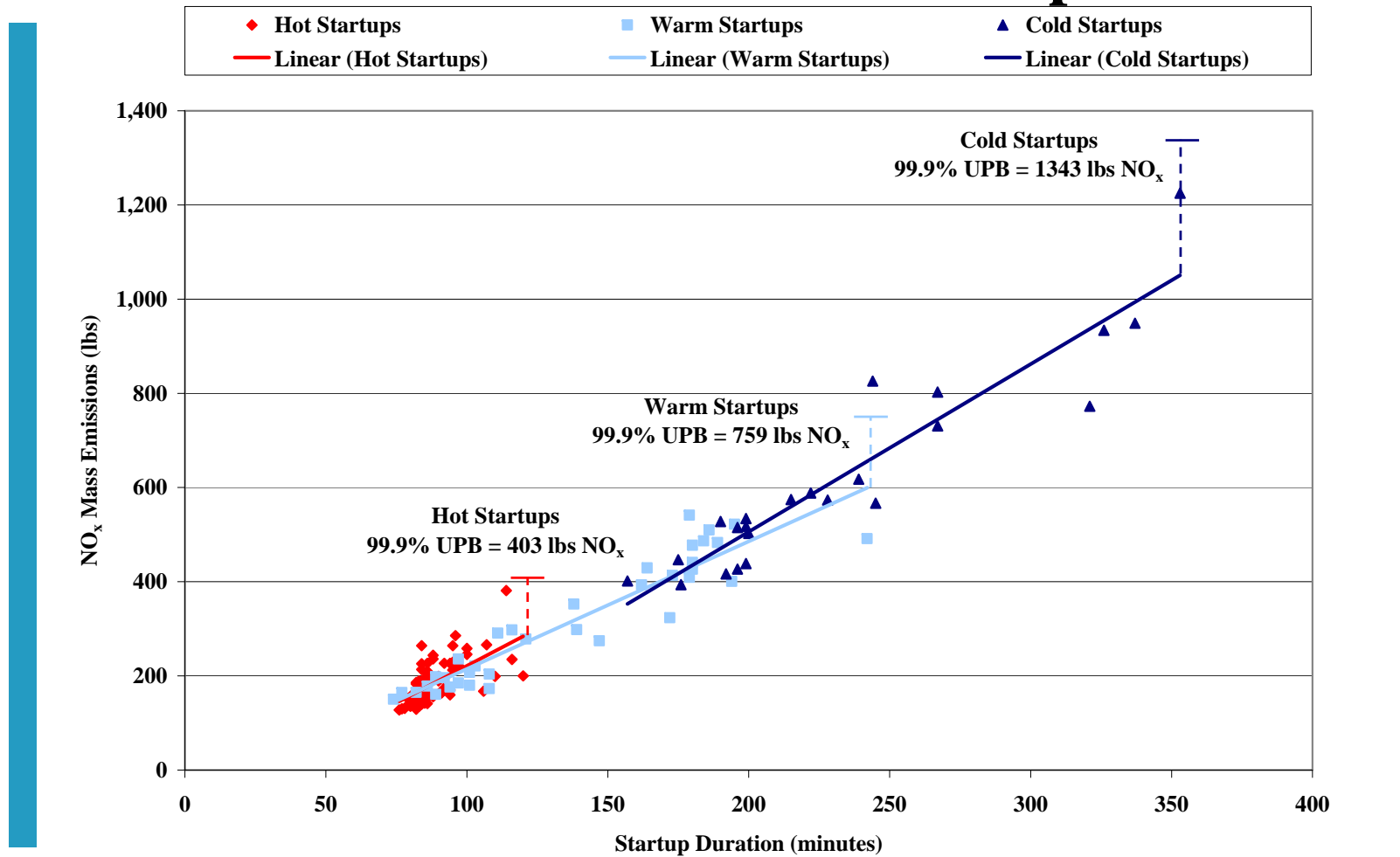
Kleinbaum, D.G.; Kupper, L.L.; Muller, K.E.; Applied Regression Analysis and Other Multivariate Methods, Second Edition, PWS-Kent, 1988; pp 56.

How to Determine a Critical Value (z)?

Critical Value (z)	Approximate Odds Of Exceeding SU/SD UPB	Estimated # SU/SD Per Year	Estimated # Years w/o Exceedance
1	2 out of 10	200	0.05 (18 days)
2	2 out of 100	200	0.5
3	1 out of 1,000	200	5
4	3 out of 100,000	200	500
5	3 out of 10,000,000	200	50,000
6	1 out of 1,000,000,000	200	5,000,000

- As z increases so does the UPB magnitude
- Determined z = 3 gave representative proposed limits
- z < 3 determined not conservative enough
- z > 3 determined overly conservative
- May depend upon size of data set and estimated # of SU/SD per year

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

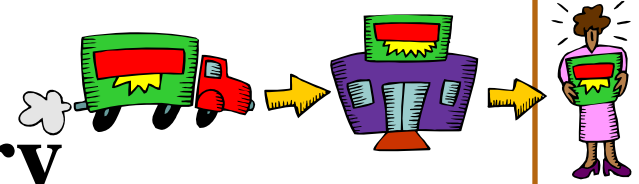


Hot, Warm, Cold SU & SD Duration, CO & NO_x Mass Emissions and Proposed Duration & Emission Limits Summary

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

- Magnitude of proposed limits (lbs or tons) is many times higher than steady state limits
 - 3.5 ppmvdc NO_x ~ 25 lb NO_x/hr
 - 13.4 ppmvdc CO ~ 60 lb CO/hr
- CEMS analyzers must be scaled properly to accurately envelope the highest pollutant concentrations during SU/SD

SU/SD Duration & Mass Analysis Process Summary



- Verify pollutant CEMS can properly record emissions during SU/SD
- Download SU/SD DAHS minute data
 - If needed, develop SU/SD definitions and apply them consistently
 - Create summary tables (duration/mass emissions)
 - More data points the better
- Plot the duration and emissions raw data and box plots
 - Investigate outliers/erroneous data
- Evaluate the upper duration prediction bound based on one sample
 - Calculate at different levels for comparisons & propose duration limits
- Evaluate the upper emissions prediction bound based on a regression of Y on X (*mass emissions are dependent upon operational duration*)
 - Requires statistical software
 - Calculate at different durations and critical values (z) for comparisons
 - Calculated UPB at maximum duration value and $z = 3$ & propose limits
- Organize, present and describe the proposed limits
- Consult DAHS vendor prior to deciding on permit limits
- Discuss with regulatory agency and refine as necessary

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- Coauthors
 - Eric A. Suess, Professor of Statistics
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 - Sean Gregory, P.E.
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Questions, Comments?

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Biography

- David Suess graduated with a Ph.D. in analytical chemistry from the University of California at Riverside where his thesis describes five years of research related to studying the size and composition of individual particle emissions from combustion sources. Following his graduation he began work as an environmental consultant and most recently has co-founded DSG Solutions which is a small and growing environmental consulting company that specializes in supporting the energy industry with air management and compliance matters related to Continuous Emission Monitoring Systems.