DESIGN ASSESSMENT OF CRANK UP AND SHUT DOWN EMISSION IN TRANS AMADI GAS TURBINE PLANT

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ABSTRACT

In response to utility deregulation and rising energy demand, a number of new gas turbine-based facilities have been designed and built. A greater understanding of simplified and consolidated gas turbine operations, diffuser, emissions laws, and exhaust emissions as a function of temperature and load condition has been made possible by the proliferation of apps available to regulators and the general public. As long as they abide by specific operating or fuel use constraints, many projects utilizing simplified gas turbines are admissible as non-Prevention of Substantial Deterioration (PSD) projects. To keep annual emissions below the PSD trigger levels, this is done. Regulators will dispute the accuracy of the computations if annual emission estimates are made under typical operating conditions without taking into account the elevated NOx/CO/VOC emission levels observed during crank up and shutdown. Another characteristic of combined-cycle projects, particularly those using SCR for post-combustion NOx reduction, is increased emissions during start-up and shutdown (SCR). Medium-duty combined-cycle plants, for instance, might run for 16 hours per day, five days per week, and 52 weeks per year. This would amount to 260 starts and stops for each unit. Before it will activate, the SCR mechanism in the Heat Recovery Steam Generator must attain a target temperature of roughly 575 degrees Fahrenheit on the SCR grid (HRSG). It may take 180 minutes for combined-cycle units to reach this temperature, thus further research into the elevated emissions may be required. To avoid thresholds of the NAAQS or PSD importance, research into air dispersion modeling must take into account both emission increases and lower plume buoyancy (due to reduced air flow and pile output temperature). This page describes the emission patterns that take place when a gas turbine starts up and shuts down, how to estimate annual emissions, how to assess how startup emissions affect air quality, and how to comply with emission regulations.

Keywords: *Design Assessment, Gas Turbine Plant, Emission, VOC*

BACKGROUND

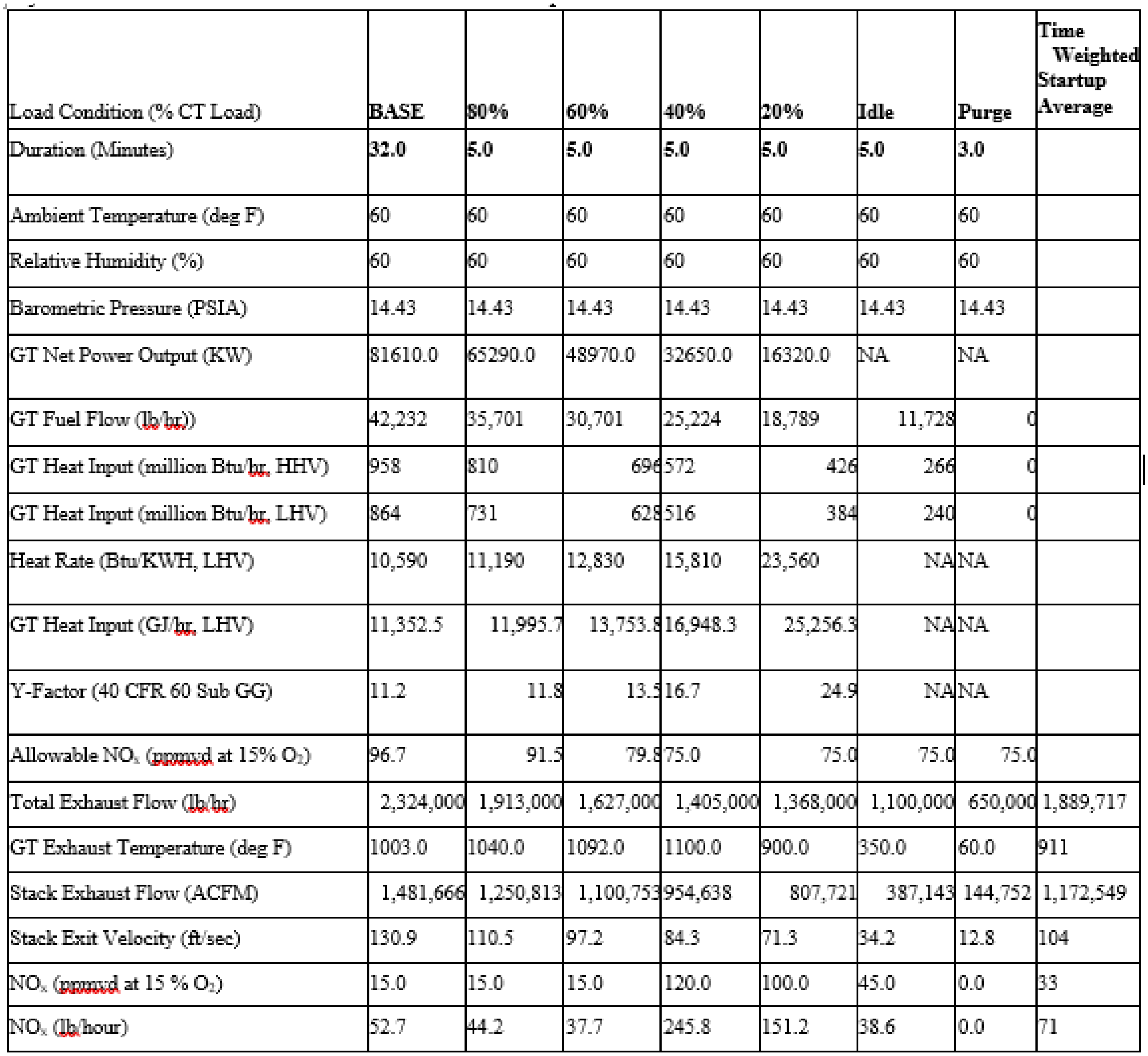
An increasing number of new gas turbine-based power projects have been planned and are now being built as a result of utility deregulation and rising electricity demand. Authorities and the general public may now learn more about duct-firing, emissions controls, and emission rates that change with temperature and load thanks to the proliferation of applications [1].

Gas turbines with a simple cycle (Peaking Applications)

Gas turbines used in industry and aviation can provide power ranging from significantly less than a megawatt to well over 200 megawatts. Low-sulfur condensate oil is used as a backup fuel most of the time and natural gas as the primary fuel. Gas turbines are a substantial generator of nitrogen oxides (NOx), carbon monoxide (CO), and volatile organic compounds (VOCs) in the environment since they burn low sulfur and low ash fuels (VOC). The typical approach for reducing NOx emissions in peaker applications is reservoir pressure into the combustion systems, sometimes referred to as DLN (dry, low NOx) combustors [2].

Simple-cycle gas turbines are ideal for producing power during peak load periods because they can start producing electricity as soon as 10 to 30 minutes after being turned on. Table 1 demonstrates that gas turbines have a superior heat rate and lower emissions as load increases.

Table 1. To illustrate, below is a sample crank up profile for a dry, low-NOx combustion Simple Cycle Gas Turbine with an 80 MW nominal output.



Load Condition (% CT Load)	**BASE**	**80%**	**60%**	**40%**	**20%**	**Idle**	**Purge**	**Time Weighted Startup Average**
Duration (Minutes)	**32.0**	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**	**3.0**	
Ambient Temperature (deg F)	60	60	60	60	60	60	60	
Relative Humidity (%)	60	60	60	60	60	60	60	
Barometric Pressure (PSIA)	14.43	14.43	14.43	14.43	14.43	14.43	14.43	
GT Net Power Output (KW)	81610.0	65290.0	48970.0	32650.0	16320.0	NA	NA	
GT Fuel Flow (lb/hr))	42,232	35,701	30,701	25,224	18,789	11,728	0	
GT Heat Input (million Btu/hr, HHV)	958	810	696	572	426	266	0	
GT Heat Input (million Btu/hr, LHV)	864	731	628	516	384	240	0	
Heat Rate (Btu/KWH, LHV)	10,590	11,190	12,830	15,810	23,560	NA	NA	
GT Heat Input (GJ/hr, LHV)	11,352.5	11,995.7	13,753.8	16,948.3	25,256.3	NA	NA	
Y-Factor (40 CFR 60 Sub GG)	11.2	11.8	13.5	16.7	24.9	NA	NA	
Allowable NO$_x$ (ppmvd at 15% O$_2$)	96.7	91.5	79.8	75.0	75.0	75.0	75.0	
Total Exhaust Flow (lb/hr)	2,324,000	1,913,000	1,627,000	1,405,000	1,368,000	1,100,000	650,000	1,889,717
GT Exhaust Temperature (deg F)	1003.0	1040.0	1092.0	1100.0	900.0	350.0	60.0	911
Stack Exhaust Flow (ACFM)	1,481,666	1,250,813	1,100,753	954,638	807,721	387,143	144,752	1,172,549
Stack Exit Velocity (ft/sec)	130.9	110.5	97.2	84.3	71.3	34.2	12.8	104
NO$_x$ (ppmvd at 15 % O$_2$)	15.0	15.0	15.0	120.0	100.0	45.0	0.0	33
NO$_x$ (lb/hour)	52.7	44.2	37.7	245.8	151.2	38.6	0.0	71

CO (ppmvd at 15 % O_2)	15.0	15.0	25.0	75.0	200.0	1000.0	0.0	118
CO (lb/hour)	32.1	26.9	38.3	93.5	184.1	522.7	0.0	89
VOC's (ppmv, wet basis)	1.9	1.9	1.9	1.9	9.4	28.5	0.0	4.6
VOC's (lb/hour)	2.4	2.0	1.7	1.5	7.2	17.6	0.0	3.8
PM-10 (lb/hour)	5.0	5.0	[illegible]	5.0	5.0	5.0	5.0	5.0

The amount of load, the ambient temperature, and the level of pollution all have a significant effect on the emissions from gas turbines. To emphasize this point, Figure 1 shows the average NOx emission rates (lb/hr) from a gas turbine as a function of operational temperature and load. The following results are obtained in Figure 1 if we assume a stable condition for NOx production (150 ppmvd at 15% O2). Below roughly 20 degrees Fahrenheit, when gas turbine generators are close to their limit, NOx emissions tend to be constant.

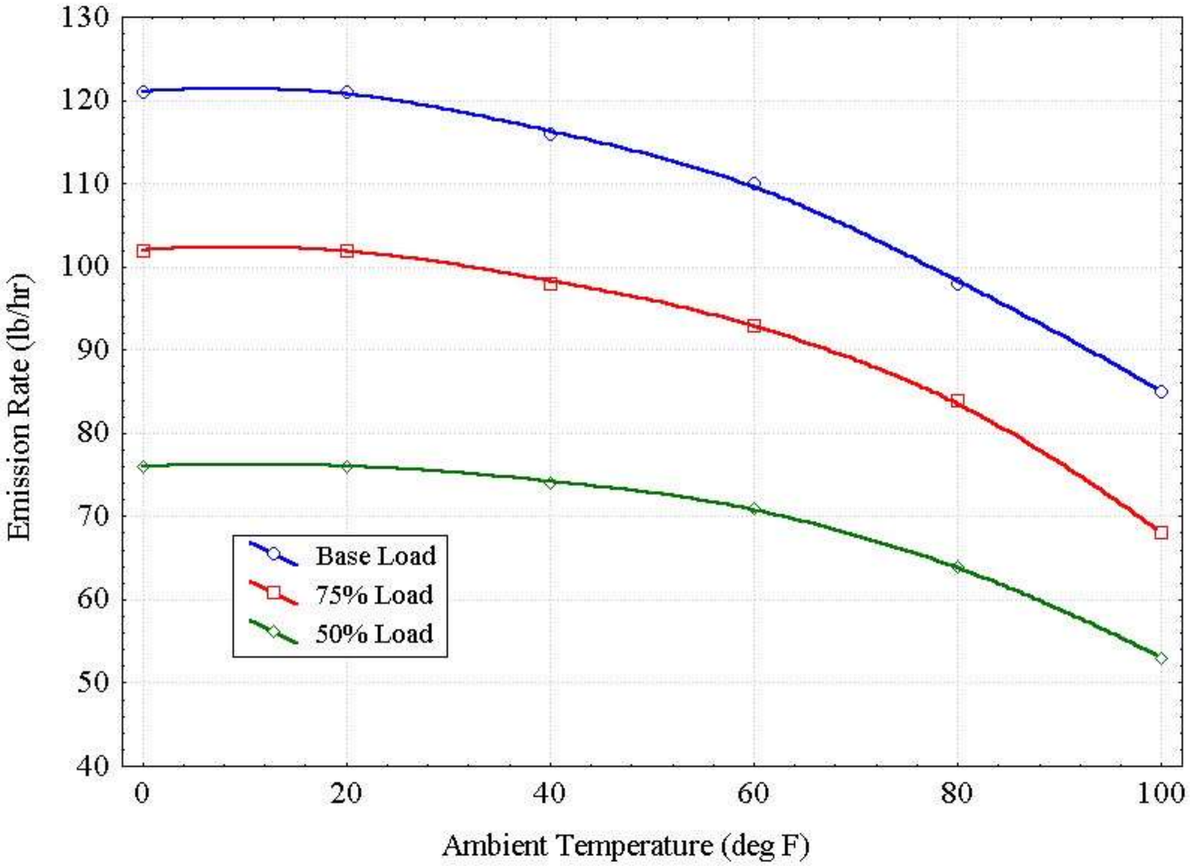


Figure 1. NOx emissions from combustible machines as a function of load and ambient temperature for a typical gas turbine working at a constant NOx concentration (ppmvd at 15% O2) in the exhaust.

Emissions from DLN combustors may drop below 50% load. Increased CO and VOC emissions result from part-load operation. If emission concentrations increase during part load operation and a distinct profile is produced, the part load curve may reflect the "worst case" licensing condition. Some contaminants' full load emissions data may make it challenging to operate in compliance. The restriction on air permits should be lifted during start-up, minimal operational load, and shutdown if part-load operation is temporary. Applications for permits should recommend increased hydrocarbon and carbon monoxide emissions for combustion turbines with reduced loads [3].

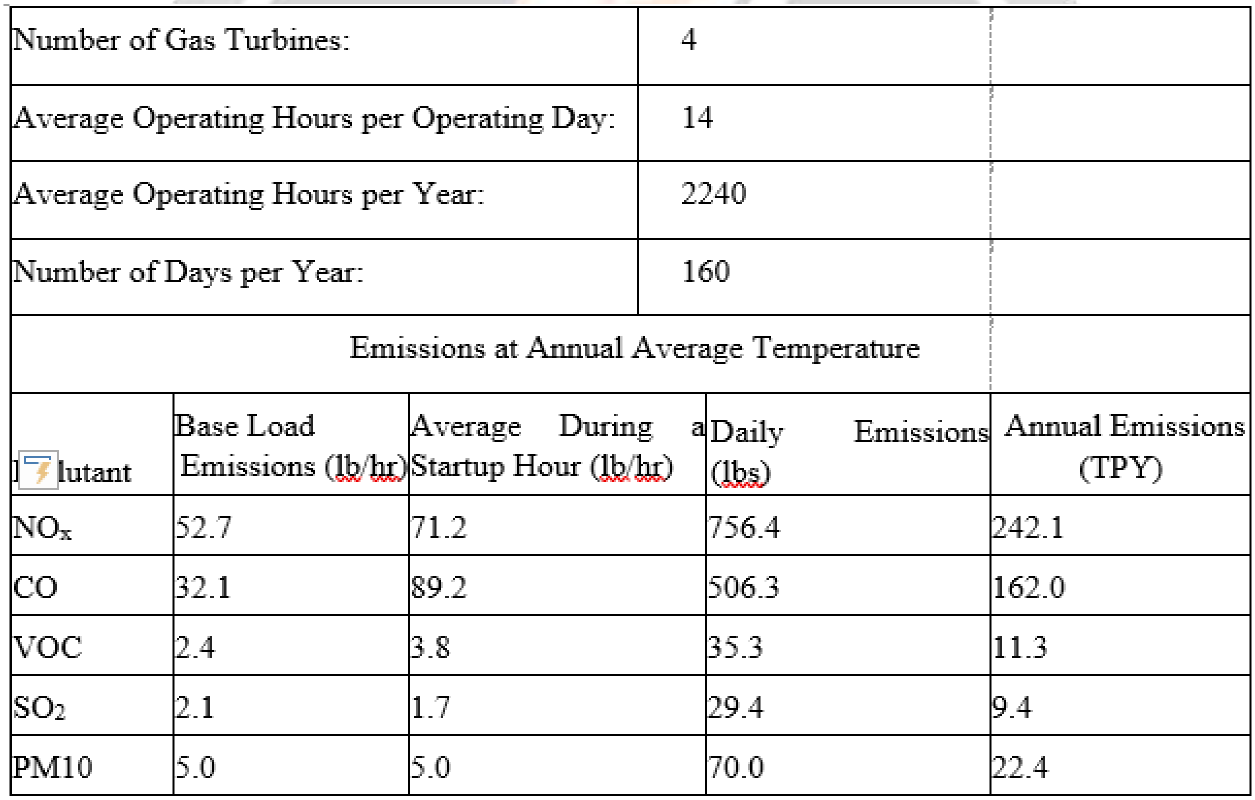
In the initial permit application, provide a safety margin to all emission rates to account for engine-to-engine variation in performance, fuel composition, uncertainty in stack testing (and ongoing monitoring), and potential future improvements (e.g., increase power output at a later date). There is a 2-4% inaccuracy in the mass emission rates of turbofans.

In order to prevent annual emissions from exceeding PSD trigger constraints by limiting operational hours or fuel usage, many simplified gas turbine facilities are receiving non-PSD3 permission. Greater NOx/CO/VOC emissions at startup and shutdown are not taken into account in annual emission estimates conducted under typical operating loads.

Determination of Annual Emissions

Reduce the emissions from gas turbines in bursting units by using emissions data that is representative of the plant's yearly average temperature. For licensing purposes, it would be wise to use emissions and performance figures from a lower temperature range (60 degrees F) (above 80 degrees Fahrenheit). Table 2 can be used to calculate annual emissions, assume one hour for crank up and the remainder of the day at base load, if Table 1 is indicative of a plant with four gas turbines operating 14 hours per day, 160 days per year. The unit's shutdown emissions were not taken into account because it shuts down more quickly than it starts.

Table 2. A four-unit peaking facility's estimated annual emissions with start-up emissions included in.



Number of Gas Turbines:		4		
Average Operating Hours per Operating Day:		14		
Average Operating Hours per Year:		2240		
Number of Days per Year:		160		
Emissions at Annual Average Temperature				
lutant	Base Load Emissions (lb/hr)	Average During a Startup Hour (lb/hr)	Daily Emissions (lbs)	Annual Emissions (TPY)
NO$_x$	52.7	71.2	756.4	242.1
CO	32.1	89.2	506.3	162.0
VOC	2.4	3.8	35.3	11.3
SO$_2$	2.1	1.7	29.4	9.4
PM10	5.0	5.0	70.0	22.4

Annual NOx, CO, VOC, and SO2 emissions are 236.1, 143.7, 10.9, and 9.6 tons, respectively, if initial emissions are omitted (PM10 would remain the same). Since gas turbine engine and emissions performance differs by fuel type, environmental factors, and turbine type, every application for a permit must also contain site-specific engine and emissions performance tests. It might be essential to increase the margin for the emission rates if the manufacturer doesn't guarantee low-load emissions.

Combined-cycle turbines

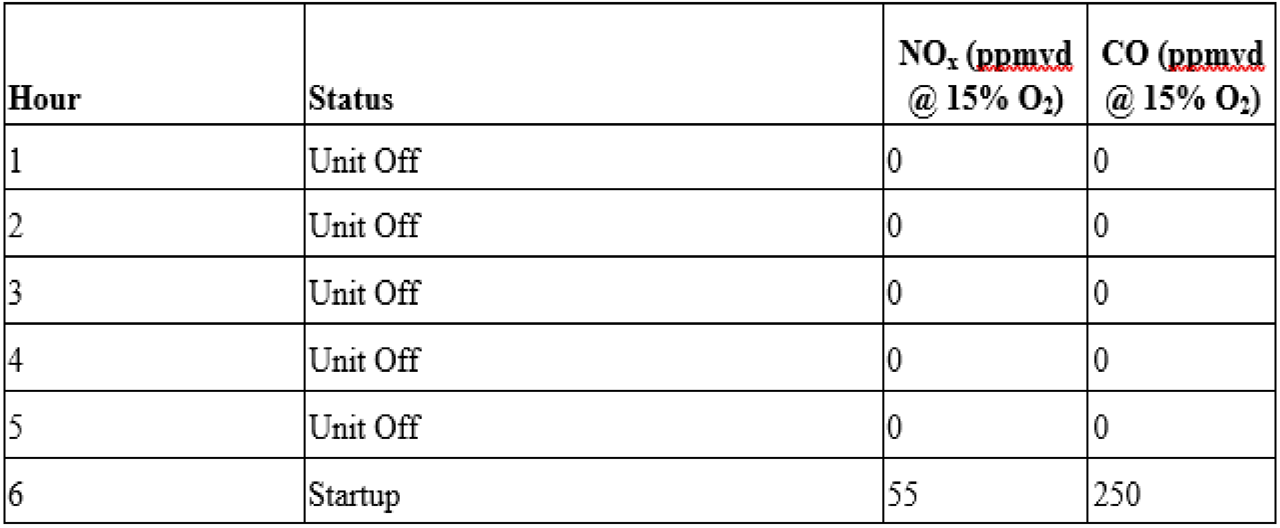
In consolidated gas turbine installations, HRSGs generate steam for a steam turbine-generator. Combine cycle power plants are used for intermediate loads due to their thermal efficiency. Heat recovery from HRSG duct firing can be used to increase steam cycle power. HRSGs enable SCR-like post-combustion NOx controls (SCR).

When cranking up and shutting down, consolidated gas turbines release more pollutants. With 260 cranking and shutdown events per unit, medium-duty combined-cycle plants run for 16 hours per day, five days per week, 52 weeks per year. When the SCR grid in the Heat Recovery Steam Generator reaches 575 degrees Fahrenheit, the SCR system turns on (HRSG). Since combined-cycle units require 120 to 180 minutes to achieve this temperature after a cold start, further research may be necessary to understand the rise in emissions.

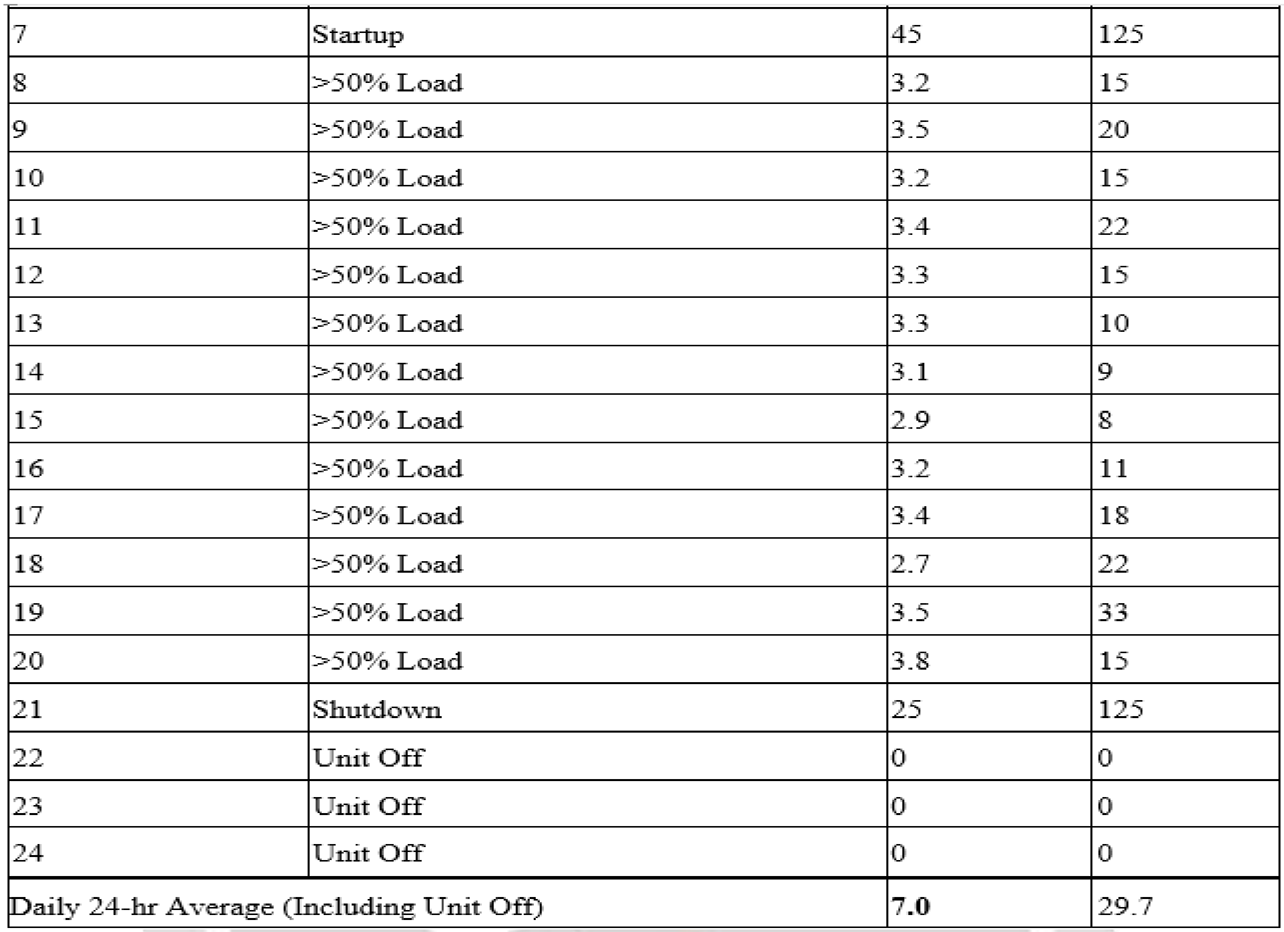
Hourly limitations and annual tons are used to govern combined gas turbine emissions (TPY). Other states have 30-day emission averaging periods or 24-hour emission caps. In these circumstances, start-up and shutdown emissions must be taken into account. The fictitious combined cycle plant in Table 3 uses SCR to reduce NOx but does not have an oxidation catalyst. At 15% O2, NOx is limited to 3.5 ppmvd and CO to 30 ppmvd. There are 16 hours in a day. The unit may release NOx less than 3.5 ppmvd at 15% oxygen and CO less than 25 ppmvd at 15% oxygen while operating at loads greater than 50%. (with minor excursions).

To guarantee 24-hour compliance, offline emissions (0.0 ppm and 0.0 lb/hr) and crank up/shutdown emissions must be watched. The average NOx and CO values at 15% O2 are 7.0 and 29.6 ppmvd, respectively, including off-line hours. NOx and CO are also above 3.5 and 30 ppmvd, respectively. The facility's average NOx and CO emissions at 15% O2 are 3.3 and 16.4 ppmvd, respectively, if crank up and shutdown emissions are permitted. NOx and CO average 10.5 and 44.6 ppmvd @ 15% O2, respectively, surpassing 24-hour limits, if all operational data, including crank up and shutdown times, is averaged.

Table 3. Take the hypothetical case of a moderate load combined - cycle power plant subject to 24-hour average NOx/CO limits.



Hour	Status	NO_x (ppmvd @ 15% O_2)	CO (ppmvd @ 15% O_2)
1	Unit Off	0	0
2	Unit Off	0	0
3	Unit Off	0	0
4	Unit Off	0	0
5	Unit Off	0	0
6	Startup	55	250



7	Startup	45	125
8	>50% Load	3.2	15
9	>50% Load	3.5	20
10	>50% Load	3.2	15
11	>50% Load	3.4	22
12	>50% Load	3.3	15
13	>50% Load	3.3	10
14	>50% Load	3.1	9
15	>50% Load	2.9	8
16	>50% Load	3.2	11
17	>50% Load	3.4	18
18	>50% Load	2.7	22
19	>50% Load	3.5	33
20	>50% Load	3.8	15
21	Shutdown	25	125
22	Unit Off	0	0
23	Unit Off	0	0
24	Unit Off	0	0
Daily 24-hr Average (Including Unit Off)		**7.0**	29.7

MODIFIED REQUIREMENTS FOR SOURCE PERFORMANCE

The operation of a benchmarking instrument during periods of crank up, shutdown, or operator error is not notable, and emissions over the applicable emission limit during such times are not regarded as violating the applicable emission limit (New Source Performance Standards, 40 CFR 60.8(c)4).

At intermediate load combined-cycle facilities with duct firing, duct burners (regulated under 40 CFR 60, Subpart Da)5 won't be running during crank up and shutdown, hence these facilities should only be regarded as 40 CFR 60, Subpart GG6 units (i.e., stationary gas turbines) during these times. It is advised to exclude these hours from compliance averaging calculations because there is no national regulation that applies during gas turbine cranking and shutdown. The mass output of these units must still be monitored in order to determine whether annual or other periodic mass output limits are being met.

Regardless of the wording in the NSPS, the EPA recommends minimizing emissions during crank up and shutdown [7].

NEW EMISSIONS REQUIREMENTS FOR SIPS UNDER FEDERAL REGULATION

Businesses are given additional latitude in some states to operate during transitional periods without paying taxes. While some jurisdictions set quantitative caps based on specific situations, others offer broad exceptions from emission restrictions during crank up and shutdown.

Assistant Administrator for Air, Noise, and Radiation Kathleen Bennett restated the EPA's position on State Implementation Plans (SIPs) managing excess emissions during malfunctioning, cranking, shutdown, and maintenance in memos dated September 28, 1982 and February 15, 1983.

In accordance with an EPA letter from 1982, any emissions that are higher than the permissible level are unlawful because they could degrade air quality and make it more challenging to meet or maintain ambient air quality standards. The EPA does concede that in situations where breakdowns occur suddenly and inevitably due to causes beyond the owner's or operator's control, sanctions may not be appropriate. Because of this, a State or the EPA may decide not to use its "enforcement discretion" in such situations.

One of the major unanswered issues with the previous policy is whether or not a state can go beyond this "enforcement discretion" strategy by incorporating a clause into its SIP that would, in the case of a regulatory action for excess emissions, exempt a source from sanctions if the source can demonstrate that it meets predefined objective criteria (an "affirmative defense"). According to this regulation, states may, at their discretion, offer this defense when excessive emissions are caused by a malfunction, crank up, or shutdown.

An affirmative defense provision that would imperil the Clean Air Act's principal requirement to meet and maintain the NAAQS was not approved by the EPA. The EPA is prohibited from giving its approval under Section 110(1)8 if a proposed modification to a SIP "would interfere with any relevant requirement respecting achievement and reasonable future advancement."

The EPA also offered recommendations for how to handle emissions surges that could happen during crank up and shut down. Since they are anticipated, excessive emissions at certain times are not automatically excused. The EPA does agree that for some source types, even the strongest emissions control methods might not always work during crank up and shutdown. Narrowly tailored SIP adjustments that consider the potential effects on ambient air quality caused by the incorporation of these allowances may be used to discuss these technological limitations in the underlying standards in regions where no single source or cluster of sources is large enough to result in an extrapolation of the NAAQS or PSD increments. In these scenarios, as part of its justification for the SIP modification, the State is expected to evaluate the impact of the most extreme emissions that could happen at crank up and shutdown.

Even with careful planning, design, and operation procedures, it is possible for specific types of sources, given the types of control technology available, that the ordinarily applicable emission restriction cannot be attained during brief periods of emissions during crank up and shutdown. Due to these technological limitations, it may be necessary to work with the EPA to develop specifically tailored SIP revisions that take them into account and specify that the otherwise applicable emissions constraints need not apply during strictly focused crank up and shutdown periods, unless a specific source or a small number of sources have the potential to result in an extrapolation of the NAAQS or PSD increments. For these changes to be approved, each of the following conditions must be met:

1. It's crucial to keep the modifications to a small group of sources that apply a limited number of clearly specified mitigation strategies (such combined-cycle plants that burn natural gas and use selective catalytic reduction, for instance).
2. Due to technical limitations, this group of sources requires a control method that cannot be applied during crank up or shut-down;
3. Third, it's crucial to minimize the frequency and duration of machine crank-ups and shutdowns;
4. The state should take into account the worst-case emissions that might happen during crank-ups and shutdowns as part of the justification for the SIP modification;
   Making every effort to lessen the adverse effects of emissions on the quality of the air around us during crank up and shutdown;
   The source must have made significant efforts during planning, design, and operation to satisfy the otherwise applicable emission constraint, and the facility must always be operated in accordance with best practices for minimizing emissions; and
   A signed, contemporaneous operating log or other suitable proof must be used to document every action taken by the owner or operator during crank up and shutdown.

Gas turbine projects are among the most well-known categories of sources that fall within this description and meet the seven requirements. This means for the owner or operator of a gas turbine facility that state authorities may demand a thorough investigation of how emissions during crank up and shutdown may affect air quality throughout the permitting process. We go through modeling techniques for both simple cycle and mixed cycle gas turbine projects below. The owner/operator of a gas turbine plant will seek to get either a higher level applicable during operation below minimum load or an exemption from emission restrictions during crank up and shutdown, whichever would give them the most flexibility in their daily operations.

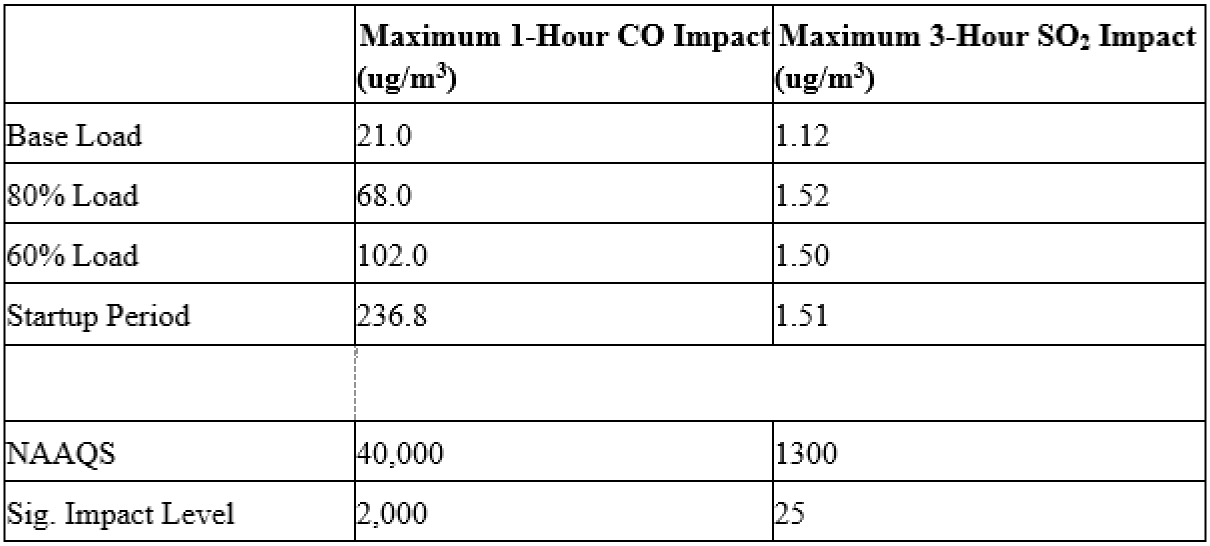
CONSEQUENCES FOR AIR QUALITY

Dispersion modeling methods can be used to quantify the impact of emission sources on air quality. Before, only significant new sources (like PSD projects) required this kind of analysis; however, this need has since been expanded to cover non-PSD gas turbine projects in a number of states. Computer programs like SCREEN3, ISCST3, and ISC-PRIME are examples of common EPA models. It is crucial to consider both the increased emissions that happen during gas turbine start-up and shutdown as well as the decreased plume buoyancy that happens during the crank-up cycle when conducting an air dispersion modeling research (as a result of the lower air flow and stack exit temperature). This is required to avoid any potential infractions of the PSD significance levels or the National Ambient Air Quality Standards.

Utility-Scale Peaking Gas Turbine Installations

Only the emissions during the crank up sequence need to be assessed in order to show the impact on air quality. This is due to the fact that a gas turbine's shutdown procedure only needs a few minutes to finish, whereas the cranking operation could take up to thirty minutes. In this assessment, a six-unit configuration was simulated using the ISCST3 model using emission rates and stack exit parameters from Table 1. (stack height of 80 feet, stack diameter of 15.5 feet). To increase the level of conservatism, all six units were anticipated to start up simultaneously, and the initial emissions profile was projected to last up to three hours. The goal of the study was to demonstrate that the 1-hour CO ambient air quality standard and the 3-hour SO2 ambient air quality standard would not be jeopardized by the increased CO emissions and lower plume buoyancy that occur during a facility start-up. The results of the modeling analysis are shown in Table 4. Comparing anticipated effects to the SIL is still a useful evaluation even though PSD increments and the SIL do not apply to non-PSD projects.

Table 4. The findings of a dispersion modeling study conducted to assess the immediate effects on air quality of simultaneously starting up six simple cycle gas turbines.



	Maximum 1-Hour CO Impact (ug/m^3)	**Maximum 3-Hour SO_2 Impact (ug/m^3)**
Base Load	21.0	1.12
80% Load	68.0	1.52
60% Load	102.0	1.50
Startup Period	236.8	1.51
NAAQS	40,000	1300
Sig. Impact Level	2,000	25

There are a few obvious truths. First off, despite CO emissions (lb/hr) being 2.8 times higher at crank up than they are at full load (see Table 1), the effects at ground level are 11.3 times worse due to lower plume buoyancy. The NAAQS and SIL are considerably exceeded by the highest CO concentration forecasted in this scenario, which is 236.8 ug/m3. The effects on ground-level CO in this case, with all six units starting up simultaneously, are still minimal. The number and types of gas turbines used, the fuel used, the time it takes to crank up, the crank up emission profiles, the height and diameter of the stack, the height of nearby buildings (downwash concerns), the distance to plant fence lines, the terrain, the weather, and other factors will all affect how each case turns out.

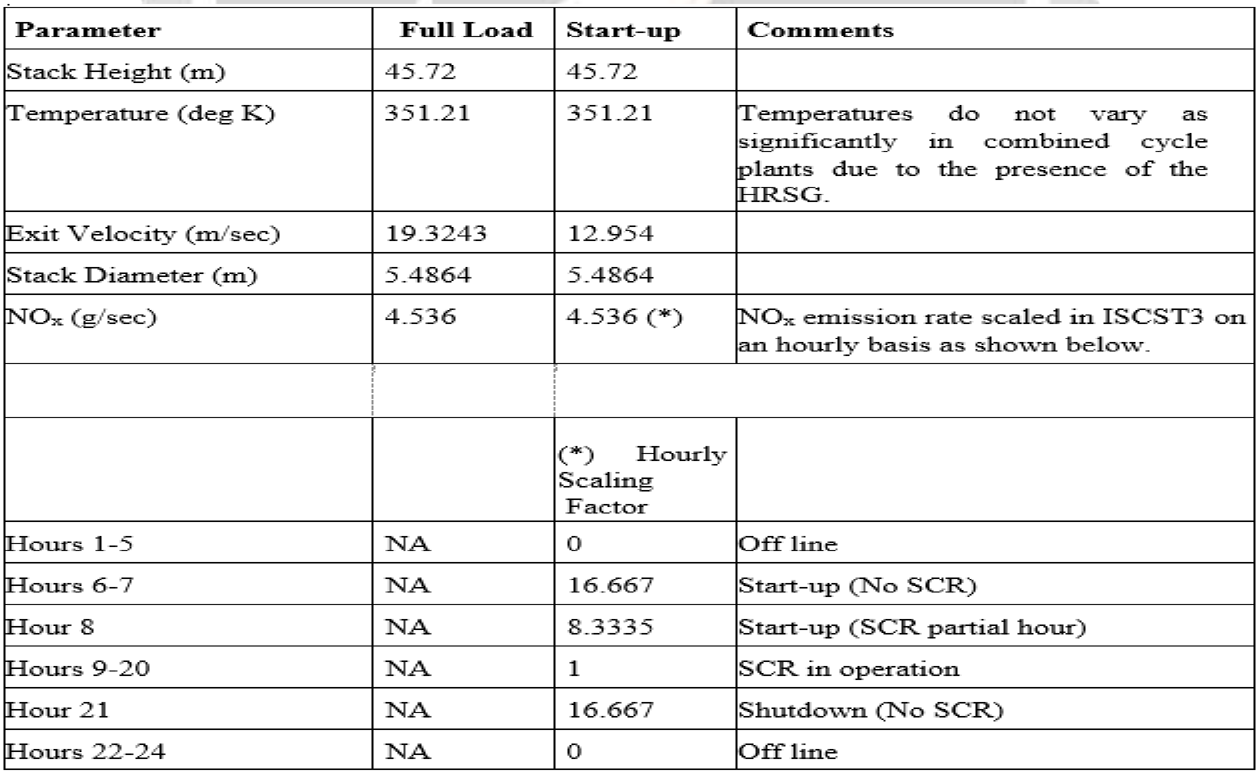
The SO2 emissions produced when natural gas is used as the fuel for gas turbines are so minimal that it could seem pointless to consider how they might affect the environment. If distillate oil is a potential backup fuel for the gas turbines, this analysis must take that into account.

Power Plants with Combined-Cycle Intermediate-Loading Capacity

The air quality impact evaluation for these facilities is more rigorous because the majority of large combined-cycle plants would require PSD approval. For this scenario, four 180 MW gas turbines were planned to operate in a combined cycle with duct firing, with NOx emissions being reduced to 4.5 ppmvd @15% O2. When loaded between 50% and 100%, the units are functional. Additionally, it was predicted that the plant could function as a base load facility for 8760 hours a year or as an intermediate load facility for up to 16 hours a day, seven days a week. It is impossible to meet the NAAQS without first determining the facility's NOx, SO2, CO, and PM10 emissions at maximum operation, 75% load, and 50% load for the entire year. Typical PSD modeling compares to SIL, pre-construction monitoring level of significance. The basic cycle example's methodology can also be used to model the profile of initial emissions.

The most intriguing assessment of this facility, however, focuses on the possible effects of operating at intermediate load versus operating at full capacity on the annual NOx SIL. The daily NOx emissions profile was fed into the ISCST3 model, and the hourly scaling factors listed in Table 5 were utilized to conduct the study. In order to increase the NOx emission rate to the mass emission rate associated with 75 ppmvd @ 15% O2 (i.e., SCR not in operation) for the first two hours of operation, a scaling factor of 16.667 was used. For the third operational hour, a factor of 8.335 was used (assumes SCR turned on after 30 minutes into the third hour, for an overall startup period from first firing to SCR in operation of 150 minutes). After eleven more hours of full load simulation, a final hour without SCR was anticipated (16.667 scaling factor). It is critical to remember that any genuine modeling attempt must use real data and that the scaling factors used in this study are hypothetical.

Table 5. Intermediate Load Facility Emissions Parameters from a Sample Integrated Cycle Plant.



Parameter	**Full Load**	**Start-up**	**Comments**
Stack Height (m)	45.72	45.72	
Temperature (deg K)	351.21	351.21	Temperatures do not vary as significantly in combined cycle plants due to the presence of the HRSG.
Exit Velocity (m/sec)	19.3243	12.954	
Stack Diameter (m)	5.4864	5.4864	
NO_x (g/sec)	4.536	4.536 (*)	NO_x emission rate scaled in ISCST3 on an hourly basis as shown below.
		(*) Hourly Scaling Factor	
Hours 1-5	NA	0	Off line
Hours 6-7	NA	16.667	Start-up (No SCR)
Hour 8	NA	8.3335	Start-up (SCR partial hour)
Hours 9-20	NA	1	SCR in operation
Hour 21	NA	16.667	Shutdown (No SCR)
Hours 22-24	NA	0	Off line

According to the modeling results, for a total of 8760 hours per year, the largest annual NOx effect was only 0.28 ug/m3, which is less than the 1.0 ug/m3 SIL. However, the greatest yearly NOx effect for moderate load operation was 1.33 ug/m3, which is greater than the SIL. The owner or operator of the source could, for example, aim to improve the cranking sequence and emissions to stop the PSD SIL from being activated. More modeling of other sources and "increment" consumption would therefore be required as a result.

CONDITIONS OF PERMIT

Most gas turbine projects undergo first source testing utilizing EPA Reference Test Methods9 to demonstrate that they adhere to regulatory emission limits. Contrarily, these test techniques hardly often replicate transient situations. Even in the unpredictable startup and shutdown conditions, using CEMS enables precise monitoring of NOx and CO emissions. Illinois recently awarded permits come with conditions that allow for the computation of specific facility cranking emission factors. An example of a requirement statement "Unless continuous emissions monitoring is carried out for the particular pollutant, emissions of NOx, CO, and VOC (also known as volatile organic compounds, or VOM) must be detected at turbine beginning in accordance with an agency-approved plan. In order to take into account the intermittent and transient character of crank up, the permittee may alter the EPA reference methods9 for these measures."

Permit conditions like the one mentioned above are becoming more and more common in order to comply with the EPA SIP rule on excess emissions during crank up and shutdown.

CONCLUSION

In recent years, as the number of gas turbine installations has increased, so has the focus on the pollutants produced by the turbines and their effects on the quality of the air they produce. This study's calculations and examined modeling scenarios are aimed to act as a springboard for the development of policies and procedures to assess gas turbine crank up emissions.

Each project must be judged on its own merits because there are an infinite number of different gas turbine configurations, site layouts, stack characteristics, fuels, operating scenarios, topographical implications, and emission profiles. What might have small impacts on air quality for one gas turbine project in one location could have huge impacts in another location for a project of a similar size.

The owner/operator may think about changing the structure of the plant (by installing higher stacks, for example) to reduce initial emissions to a more tolerable level if they have unacceptably negative effects. Delaying the activation of multiple units at once is one operational enhancement that could help to mitigate the effects of poor air quality.

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7. Personal E-Mail correspondence with Mr. Sims Roy, USEPA, RTP, September 5, 2000.

8. Clean Air Act Amendments of 1990. P.L. 84-189, approved July 14, 1955; as last Amended by P.L. 101-549, approved November 15, 1990; 42 U.S.C. §~ 7401 *et seq*.
9. 40 CFR 60, Appendix A, Reference Test Methods.