Joint Environmental Programme JEP

Air quality impacts associated with black start operation

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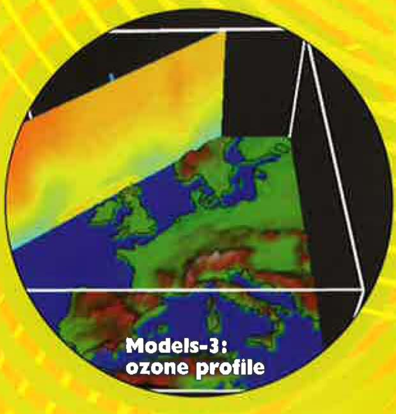
Revision 1



JOINT ENVIRONMENTAL PROGRAMME

This report has been produced by the Joint Environmental Programme ("the JEP") that is funded by eight of the leading electricity generators in the UK. The objective of the JEP work programme is to understand and increase knowledge of the environmental science and impacts associated with the production of electricity from coal, gas, gasoil and biomass fired power plant.

The main drivers for the programme come from the national and international legislative and regulatory initiatives which now address the full range of emissions-related impacts. The JEP takes a forward look at trends in legislative and regulatory thinking, identifies any gaps and major uncertainties in the scientific knowledge raised by such new proposals together with the modelling, data and other research requirements that arise. This ensures that the representative companies are well placed to make a constructive contribution to national and European debate from initial concepts right through to the practicalities of implementation. Close liaison is maintained, through regular meetings, with UK Regulatory bodies to ensure the correct focus for the programme and JEP members are representatives on a number of European advisory bodies.

The major areas of current activity cover:

Air Quality – the impact of power plant emissions on air quality both locally and more widely across the UK in relation to other sources

- Pollution and Health – the relationships between atmospheric emissions from power plant and human health effects
- Pollution and the Natural Environment – effects of pollutant deposition on ecosystems
- Understanding Emissions – quantifying emission levels and assessing their significance
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Compliance Monitoring – development of protocols to support application of consistent best practice in the monitoring and reporting of emissions across JEP power plants

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The work is undertaken either by in-house experts within the member companies or when appropriate through contracts with leading environmental consultancies and universities.
To facilitate informed debate on key environmental issues related to electricity production, the results from the JEP research studies are shared externally with relevant stakeholders through external publications. There have also been more detailed monograph reviews (listed overleaf) which summarise many years of work on a specific topic.

JEP Companies: RWE Generation UK, E.ON UK, Drax Power Ltd, Scottish & Southern Energy, EDF Energy, Centrica, EPUKi and Uniper UK

Some Recent Reports and Publications from the JEP

External Reports

Pollution Inventory 2017 Electricity Supply Industry Methodology

Predicted and measured SO_2 concentrations presented in air quality management plan annual reviews 2001-2012

Water Use at Thermal Power Plants

Evaluation of ADMS5 for Air Quality Management Plan dispersion modelling

ESI-IED compliance protocol for utility boilers and gas turbines

Monograph Reviews

Ashes to Assets? Studies of the usefulness and environmental management of ash from coal fired power stations.

The Acid Tests? Studies of the ecological effects of atmospheric pollutants

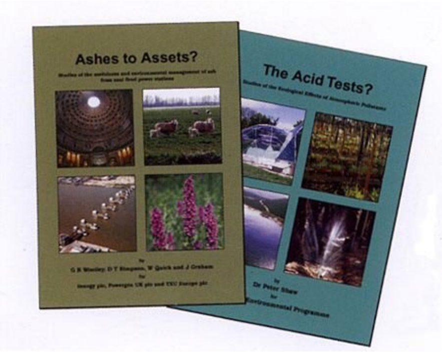
Crumbling Heritage? Studies of the effect of 'acid rain' on historic buildings

Flying Chemistry Studies of the long range atmospheric transport of pollutants

Generating Emissions? Studies of the local impact of gaseous power station emissions

Using Water Well? Studies of Power Stations and the aquatic environment

Borne on the Wind? Understanding the dispersion of power station emissions



Copies of these monographs and more details on the current JEP programme can be obtained from the JEP secretary by sending your request in an Email to jepsec@jep.website

JEP Companies: RWE Generation UK, E.ON UK, Drax Power Ltd, Scottish & Southern Energy, EDF Energy, Centrica, EPUKi and Uniper UK

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Air quality impacts associated with black start operation

by

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Summary

During a black start event, power generation plants would be under the instruction of National Grid and would be required to operate to enable other plants to start. This instruction could foreseeably result in a plant operating in a manner which could breach permit conditions for normal operation in terms of emission limit values or annual operating hour caps. In order to avoid this situation, operators have requested a permit condition to allow derogation from certain permit conditions when operating under a black start instruction.

An assessment of the potential air quality impacts associated with such operation for a short duration and an extended duration black start period has been carried out for a range of different power station types to allow an informed consideration of the above issue by the environmental regulators.

The analysis demonstrated that:

- For coal plant operating at abnormal emission levels during black start events, there is no risk of non-compliance for the short-term National Air Quality Objectives (NAQOs) for NO_2, CO or PM_{10} or for the SO_2 daily mean NAQO. Very low risks (<2% probability) of non-compliance were derived for the SO_2 hourly mean NAQO for an extended event and for the SO_2 15 minute NAQO for a short duration event. The only potential concern relates to the 15 minute SO_2 objective when coal plant runs continuously in an extended event, where a worst case 25% chance of non-compliance was identified. The overall risk can be considered as low because (i) the chance of an extended event occurring is extremely low, (ii) there is at least a 75% probability of compliance, and (iii) the chance of the FGD plant being unavailable across the entire plant for the entire duration of the event is also low.

- For biomass plant operating at abnormal emission levels during black start events, there is no risk of non-compliance for the short-term NAQO for NO_2.

- For CCGT plant operating at abnormal emission levels during black start events, there is no risk of non-compliance for the short-term NAQOs for CO, NO_2 or formaldehyde.

- For gas fired OCGT plant operating above an annual cap of 500 operating hours during black start events, there is no risk of non-compliance for the short-term NAQO for CO and a very low risk of non-compliance (<2%) for the short-term NAQO for NO_2 for an extended event only.

- For gas-oil fired OCGT plant operating above an annual cap of 500 operating hours during black start events, there is no risk of non-compliance for the short-term NAQOs for CO, SO_2, PM_{10} or NO_2.

Revision 1 of this report contains an additional assessment of the short-term air quality risks associated with formaldehyde emissions from a CCGT plant during black start operation, as later requested by the environmental regulators. There is also a correction to the stated assumptions associated with the specification of buildings within the gas-fired OCGT modelling case.

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1 Introduction

Black start events in which there is a national grid failure have a low probability, but significant consequences in terms of health and safety (e.g. loss of power, heating, lighting, traffic signalling and refrigeration), economics (loss of power to industrial and commercial premises) and the environment (operation of large numbers of high emission back-up generators). As such it is essential that the time to repower the grid is kept as short as possible. To restore the electricity grid in the event of a black start situation, National Grid would issue an instruction for generation plants such as large power stations and smaller open cycle gas turbines (OCGTs) to operate. Plants would be under the instruction of grid and would be required to operate to enable other plants to start. This instruction could foreseeably result in a plant operating in a manner which could breach permit conditions for normal operation in terms of emission limit values (ELVs) or annual operating hour caps.

In order to avoid this situation, operators have requested a permit condition to allow derogation from certain permit conditions when operating under a black start instruction.

UK regulators have requested an assessment of the potential air quality impacts associated with such operations to allow an informed consideration of the above issue.

National Grid have provided two worst-case operational scenarios for black start events (National Grid, 2018) based upon their experience and knowledge as a system operator. These are representative of a short duration black start event (henceforth ‘short duration event’) and an extended duration black start event (henceforth ‘extended event’).

It was agreed with the regulators that the assessment would focus on relevant short-term human health-related local air quality impacts in urban and rural environments for representative examples of the following existing transmission grid connected plant types running under the above two black start scenarios:

- Coal-fired
- Biomass-fired (converted coal plant)
- Gas-fired Combined Cycle Gas Turbines (CCGTs)
- Gas-fired Open Cycle Gas Turbines (OCGTs)
- Oil-fired OCGTs

During the course of the project, regulators additionally requested (i) an assessment of the potential daily mean NO_x impacts at sensitive ecosystems during black start events and (ii) an assessment of the potential short-term impacts of formaldehyde emissions from CCGTs during black start events. These additional elements are covered in Appendix A and Appendix B to this report, respectively.

2 National Air Quality Objectives

The National Air Quality Objectives (NAQOs) which could potentially be at risk of non-compliance depend on plant type and fuel. A full list of relevant short-term NAQOs is provided in Table 1.

Table 1: Short-term National Air Quality Objectives

Substance	Averaging period	Standard (ug/m^3)	Allowed exceedances	Equivalent percentile
SO_2	15 minutes	266	35	99.90
	Hourly	350	24	99.73
	Daily	125	3	99.18
NO_2	Hourly	200	18	99.79
PM_{10}	Daily (E+W)	50	35	90.41
	Daily (Scotland)	50	7	98.08
CO	8 hours (daily running maximum)	10000	0	100

Following discussion with the UK regulators it was agreed that the assessment should focus on the following NAQOs

- Short duration event – 15 min mean SO_2 and 8 hour daily maximum CO
- Extended event – 15 min, hourly and daily mean SO_2, hourly mean NO_2, 8 hour daily maximum CO

For completeness, PM_{10} impacts were also modelled for coal plants and gas-oil OCGTs for operation under black start conditions through the whole year.

3 Plant emissions during black start

In assessing air quality impacts for representative plants during black start events, it is necessary to consider conditions giving worst case emissions, as these may be different to normal operation and lead to non-compliance with Emission Limit Values (ELVs) or operating outside a permitted envelope (e.g. exceeding annual caps on permitted hours of operation). A set of scenarios was developed by operators and agreed with the Environment Agency and these are listed in Table 2.

Table 2: Potential abnormal operating conditions during black start

Plant	Scenario
Coal	FGD out of service on all units[1], increasing SO_2 and dust emission concentrations.
	Increase in CO emission concentrations due to load/combustion variations.
Biomass	Selective Non-Catalytic Reduction (SNCR) out of service[1] on all units increasing NO_x emission concentrations.
Gas – CCGT	Increase in NO_x and/or CO emission concentrations due to variable load/combustion conditions or fault development.
Gas – OCGT	Running for more than permitted 500hrs in a year increasing total NO_x and CO mass emissions.
Gas-Oil – OCGT	Running for more than permitted 500hrs in a year increasing total NO_x and CO mass emissions.

[1] Potential reasons could include insufficient availability of power, operating at loads below which the abatement can function efficiently, operating with load variations that do not provide sufficient stability for the abatement to be started up, or a black start event occurring during when the abatement is out of service due to maintenance.

Following on from these assumptions, representative plant and emission parameters required for modelling impacts were agreed with the UK regulators. The key parameters are presented in Table 3. In the case of coal, biomass and CCGT plants, the emissions represent abnormal operation, whereas for the OCGT plant the emissions represent normal operation, but are set at the top end of the emission range based on a recent review of new and existing OCGTs operating in the UK (Griffiths et al., 2018).

Guidance for the Atmospheric Dispersion Modelling System (ADMS) model suggests that buildings are only likely to affect dispersion where they are greater than one third of the stack height (CERC,2016). Based on a review of building heights typical of the power station types considered, buildings were included for the CCGT case (128m x 34m with a 36.5m height representing a combined four unit boiler house) and the gas-fired OCGT case (98m x 31m with a 19m height representing a combined four unit gas turbine hall).

Table 3: Representative plant and emission parameters for black start assessment (note that CCGT and OCGT emission rates are per stack)

Parameter	Coal	Biomass	CCGT	OCGT (gas)	OCGT (gas-oil)
Station capacity (MW_e)(all units)	2000	2600	1400	600	130
Stack height (m)	150	150	75	33	61
Number of stacks	1	1	4	4	2
SO_2 emission concentration (mg/Nm^3)	3450	*n/a*	*n/a*	*n/a*	55
SO_2 emission rate (g/s)	6769	*n/a*	*n/a*	*n/a*	12.1
Dust emission concentration (mg/Nm^3)	140	*n/a*	*n/a*	*n/a*	5.9
Dust emission rate (g/s)	275	*n/a*	*n/a*	*n/a*	1.3
NO_x emission concentration (mg/Nm^3)	*n/a*	155	140	470	300/827[1]
NO_x emission rate (g/s)	*n/a*	346	76.5	184	66/182
CO emission concentration (mg/Nm^3)	1000	*n/a*	1000	100	100/12.5[1]
CO emission rate (g/s)	1962	*n/a*	547	39.2	22/2.8

[1] Old/new plants. Note that newer OCGTs can have higher NO_x emissions due to optimisation for efficiency resulting in higher combustion temperatures.

4 Assessment methodology

4.1 General approach

Table 4 shows the NAQOs potentially at risk of non-compliance for the two periods of black start operation and plant type.

Table 4: NAQOs assessed by plant type and black start period

Parameter	SO_2 15 minute	SO_2 Hourly	SO_2 daily	NO_2 hourly	CO 8-hourly	PM_{10} daily
Coal	SDE, EE	EE	EE	-	EE	EE
Biomass	-	-	-	EE	-	-
Gas CCGT	-	-	-	EE	EE	-
Gas OCGT	-	-	-	EE	EE	-
Gas-Oil OCGT	SDE, EE	EE	EE	EE	EE	EE

SDE = Short duration event, EE = Extended event

To assess the risk of non-compliance, an initial conservative screening assessment has been undertaken by modelling impacts assuming abnormal black start emission conditions described in Section 3 extend through a whole calendar year. Where the process contribution (PC) due to emissions from the plant alone was below the 10% significance threshold specified in Environment Agency Guidance (Environment Agency, 2016a), the impacts can be deemed insignificant and no further analysis undertaken. Where the PC is above the significance threshold, the predicted environmental concentration (PEC) comprising the PC plus the background concentration (See Section 4.2) has been calculated. Where the PEC demonstrates compliance with NAQOs, no further analysis was undertaken.

Where compliance cannot be demonstrated using the above screening approach, the risk of non-compliance can be assessed using the statistical methods outlined in Section 4.3.

4.2 Modelling parameters

Model application details
ADMS version 5.2 has been used (CERC, 2016). ADMS is a well-established dispersion model, which has been used extensively for industrial power stations and has undergone several validation studies (see for example: JEP, 2004 and 2008). NO_2 impacts have not been explicitly modelled using the ADMS chemistry module, rather the Environment Agency recommended scaling factor of 0.35 has been applied to account for short-term conversion of NO_x to NO_2.

Topography
Variations in local topography where sustained gradients greater than 1:10 exist can have a significant effect on the dispersion of emissions. For modelling purposes in this study, terrain is assumed to be flat.

Buildings
Buildings in the vicinity of discharge stacks have the potential to increase ground level pollutant concentrations by causing the plume to 'downwash' into the building wakes. In previous air dispersion modelling studies of JEP coal and biomass plant it has been agreed with regulators that these effects are insignificant, so they have not been considered for such plant in this study. As discussed in Section 3, ADMS guidance suggests that buildings are only likely to affect dispersion where they are greater than one third of the stack height, hence only the CCGT and gas-fired OCGT assessments include buildings.

Modelling grid
For coal and biomass plant, impacts have been modelled at ground level across a 40 x 40km grid centred at the stack, with 250m grid point separation. These sizes and resolution are sufficient to capture maximum impacts from a 150m stack. For CCGT plant, a 7.5km x 7.5km grid with spacing of 125m was used, whilst for the smaller OCGT plant, a 4km x 4km grid with a spacing of 50m was used.

Background concentrations
Representative coal and biomass conversion plant release combustion gases from >150m high stacks. In such cases it has been agreed practice with regulators for many years, as part of the stations' Air Quality Management Plans, to add annual mean background concentrations to modelled short term PCs to give short term PECs for comparison with air quality objectives. In the case of CCGT and OCGT plant, the generic regulator approach is adopted for calculating short term PECs, i.e. by adding twice the annual mean background to the short term PC. For NO_2, total impacts have been assessed assuming annual mean rural and urban background concentrations of 15μg/m^3 and 31μg/m^3, respectively. For SO_2 an annual mean concentration of 2μg/m^3 has been assumed and for CO an annual mean concentration of 400μg/m^3 representing a conservative upper limit for all but the most polluted urban areas (See https://uk-air.defra.gov.uk/data/gis-mapping/, 2009 CO mapping).

Meteorological data and surface roughness
Modelling has been undertaken using five years of sequential hourly measurements from a coastal meteorological monitoring site (St Athan, 2010-2014) and five years from a central inland site (Waddington, 2012-2016). Representative surface roughness lengths of 0.3m for the plant sites and 0.1m and 0.2m, respectively, for the meteorological monitoring sites have been used.

4.3 **Probabilistic assessment**

Where modelled impacts from abnormal black start operation through the whole year do not demonstrate compliance with the NAQOs, statistical methods may be appropriate to determine the risk of non-compliance for the two black start scenarios (short duration event and extended event).

Hypergeometric function
This approach has previously been used by the Environment Agency Air Quality Modelling Assessment Unit (AQMAU) to assess the risk of NO_2 non-compliance for limited periods of diesel generator operation (Environment Agency, 2016b) and guidance on assessing low hour impacts of a range of specified generators (Environment Agency, 2019a and 2019b). A weakness of this method is that continuous periods of black start operation do not, by definition, comprise of randomly selected hours, and meteorological conditions occurring in sequential hours are serially correlated.

The hypergeometric function calculates the probability of an exceedance for any sampled hour (or 15mins or day) from the number of exceedances modelled over the calendar year, assuming black start operation throughout. So the probability of compliance can be checked by reporting the cumulative probability of up to the permitted number of exceedances over a given period. The probability of an exceedance for each modelled hour is calculated assuming no re-sampling of that hour, i.e. the probability changes for each subsequent hour sampled. Each sampled hour corresponding to a period of plant operation is assumed to be randomly selected.

Sequential hourly analysis
The effects of the serial correlation of the meteorological conditions can be estimated by Monte Carlo techniques. In this alternative approach, the hourly time series of modelled impacts is sampled for every possible continuous period of short duration or extended black start operation (starting and/or ending in the calendar year of interest). The probability of non-compliance over the black-start period is then estimated numerically by dividing the resulting number of non-compliant samples by the total number of samples. In the case of low load plant (eg coal), there are expected to be few, if any exceedances outside of the black start period, so checking NAQO non-compliance over the black start period is a good indicator for the whole year.

5 Results and analysis

5.1 Coal plant

Table 5 shows the modelled process contribution (PC) based on operation at the black start emission levels in Table 3 for the entire year for the maximum 8-hour mean concentration of CO, and the 90.41st percentile daily concentration for PM_{10} for a coal plant. This is based on the maximum at any point on the grid over the 5 years modelled.

Table 5: Black start compliance assessment for CO and PM_{10} (coal plant)

Parameter	Met Site	NAQO µg/m³	PC µg/m³	PC/ NAQO
CO max 8 hour mean	Coastal	10000	153	1.5%
	Central	10000	158	1.6%
Daily PM_{10} 90.41st %ile	Coastal	50	3	6%
	Central	50	2	4%

It can be seen that even assuming operation at abnormal black start emissions for the entire year, the CO and PM_{10} PCs are below the corresponding 10% significance threshold.

Table 6 presents the modelled PECs and maximum number of exceedances for the 15 min, hourly and daily SO_2 NAQOs, based on operation for the entire year at the abnormal black start emission conditions in Table 3. The PCs are not presented separately, as the SO_2 background comprises only 2 µg/m³ and hence forms only a small proportion of the PEC. As the PECs are well above the corresponding NAQOs, further statistical analysis is required. For SO_2, using the sequential analysis approach, the maximum probabilities of non-compliance for locations across the modelling grid for a single continuous period of short duration and/or extended duration black start operation are presented for each met year modelled at both met sites.

For the SO_2 15 minute mean, ADMS produces a single 15 minute mean concentration for each hour of met data processed. It is assumed that this value is the same for each 15 minute period in that hour. Hence, to check SO_2 15 minute mean compliance, the sequential analysis assesses the 9th highest ADMS output over the black start period. This is equivalent to assessing the 36th highest for all 15 minute periods covered by the model outputs over the black start period.

An alternative approach recommended by EA to assessing 15min SO_2 impacts is to multiply each modelled hourly mean impact by a factor of 1.34. This provides alternative estimates of 15min mean concentrations, which can be assessed for probability of non-compliance as previously described. This approach increases the maximum probability of 15min non-compliance for the extended event from 25% to 30%, whilst the probability of non-compliance over a short duration event remains about the same (both for 2011 coastal meteorology).

For the SO_2 daily mean, the analysis was carried out using modelled hourly mean concentrations at the location of maximum daily mean exceedances. In the case of 2014 coastal meteorology a marginally higher maximum probability of daily mean non-compliance (0.8% compared to 0%) was obtained at the location of maximum hourly mean exceedance, so this is reported in Table 6.

Table 6: Probability of ambient SO_2 non-compliance for coal plant running under black start conditions

Met site/year	15 min SO_2				Hourly SO_2			Daily SO_2		
	Maximum PEC (µg/m³)	Maximum exceedances	Maximum probability of non-compliance (%)		Maximum PEC (µg/m³)	Maximum exceedances	Maximum probability of non-compliance (%)	Maximum PEC (µg/m³)	Maximum exceedances	Maximum probability of non-compliance (%)
			SDE	EE			EE			EE
Coastal 2014	572	652	0.4	9.0	477	80	**1.6**	208	10	**0.8**
Coastal 2013	577	690	0.2	14	452	84	0.0	179	9	0.0
Coastal 2012	571	754	0.6	16	486	115	0.0	169	7	0.0
Coastal 2011	580	1218	**1.2**	**25**	499	161	0.0	227	15	0.0
Coastal 2010	572	560	0.2	9.0	459	65	0.0	166	5	0.0
Central 2016	575	399	0.2	3.3	474	59	0.0	139	5	0.0
Central 2015	609	920	**0.7**	**15**	532	147	**1.8**	220	12	0.0
Central 2014	614	588	0.1	11	502	82	0.0	221	9	0.0
Central 2013	603	526	0.3	7.9	500	80	0.0	200	10	0.0
Central 2012	656	423	0.1	5.2	453	57	0.0	148	6	0.0

SDE = Short duration event, EE = Extended event

To summarise, the highest probability of a coal plant causing a breach of any NAQO in the event of a short duration event is 1.2%, for the 15min SO_2 NAQO at a coastal location. For an extended event, the equivalent figure is 25%. It should, however, be noted that would only be the case if all FGD units linked to each individual boiler were to remain non-operational for the full duration of the extended event, which is extremely unlikely.

5.2 Biomass plant

Table 7 shows the modelled process contribution (PC) based on operation at the abnormal black start emission level in Table 3 for the entire year for the 99.79th percentile of hourly mean concentrations of NO_2 for a biomass plant. This is based on the maximum at any point on the grid over the 5 years modelled, applying the 0.35 NO_x to NO_2 conversion factor.

Table 7: Black start compliance assessment for NO_2 (biomass plant)

Parameter	Met Site	NAQO µg/m^3	PC µg/m^3	PC/ NAQO
Hourly NO_2 99.79th %ile	Coastal	200	6.5	3%
	Central	200	7	4%

In both cases the PC is below the 10% significance threshold, even assuming operation at abnormal black start emissions for the entire year, so black start NO_2 impacts are insignificant.

5.3 CCGT plant

Table 8 shows the modelled process contribution (PC) based on operation at the abnormal black start emission levels in Table 3 for the entire year for the 99.79th percentile hourly concentration of NO_2 and the maximum 8-hour mean concentration of CO for a CCGT plant. This is based on the maximum at any point on the grid over the 5 years modelled. Where the PC is greater than the 10% significance threshold, the predicted environmental concentration (PEC) comprising the sum of the PC and the background (BG) concentration is also presented and compared to the NAQO. Note that the background concentration for calculating the short-term PEC is based on twice the annual mean background concentrations set out in Section 4.2, in line with Environment Agency guidance (Environment Agency 2016a).

Table 8: Black start compliance assessment for NO_2 and CO (CCGT plant)

Parameter	Met Site	NAQO µg/m^3	PC µg/m^3	PC/ NAQO	BG µg/m^3	PEC µg/m^3	PEC/ NAQO
Hourly NO_2 99.79th %ile	Coastal	200	55.7	27.9%	30 (rural) 62 (suburban)	85.7 117.7	43% 59%
	Central	200	172	85.8%	30 (rural) 62 (suburban)	201.7 233.7	101% 117%
CO max 8 hour mean	Coastal	10000	1218	12.1%	800	2018	20%
	Central	10000	3095	31%	800	3895	39%

It can be seen that even assuming operation at black start emissions for the entire year, the CO PEC remains well below the corresponding NAQO. The same applies for the NO_2 PEC at the coastal site.

Further statistical analysis has been undertaken to assess the probability of compliance with the NO_2 NAQO using the Central met data. Table 9 presents the maximum number of exceedances for the rural and suburban cases in each year based on the Central met site data. These were determined by applying the 0.35 NO_x to NO_2 conversion factor to the emissions in Table 3 prior to running the ADMS model and allowing for a background of twice the rural and suburban annual means in the exceedance calculation. Note that the decimal places result from adjustments performed by ADMS to account for meteorological hours with missing data. It can be seen that 2014 is the only year with more than 18 exceedances and hence the only year in which the NAQO could be exceeded.

Table 9: Number of hourly exceedances of 200 μg/m^3 of NO_2 based on running all year with abnormal black start emissions

Met Site	Year	Number of exceedances of 200 μ/gm^3 Rural background 30 μg/m^3	Number of exceedances of 200 μg/m^3 Suburban background 62 μg/m^3
Central	2012	1.0	5.0
Central	2013	6.1	11.2
Central	2014	20.3	31.4
Central	2015	2.0	7.1
Central	2016	1.0	3.0

Using the hypergeometric mean function in Excel to determine the probability that there will be 19 or more exceedances based on a random sample of hours in 2014 equivalent in total to the duration of an extended event, a result of effectively zero is obtained and the value might be expected to remain negligibly small even if serial correlation were taken into account (e.g. the Environment Agency guidance recommends that probabilities determined using the hypergeometric mean analysis should be multiplied by a factor of 2.5, to account for 4-hours sequential correlation).

Although a black start event shouldn't therefore be expected to cause a non-compliance by itself, its occurrence might still cause a marginal increment in the total number of exceedances taking place over the year. This might in principle drive a non-compliance, in those cases where the number of already occurring exceedances (e.g. exceedances occurring over the rest of the year, when the plant is operating under normal conditions) is by itself sufficiently close to the threshold of non-compliance. It is however found that the probability of an exceedance does not rise above 1% for the extended event case until it was assumed that there were 16 or more exceedances in the background data (i.e. there are three exceedances during the extended event).

Further analysis was undertaken for the worst case year (2014) by modelling the individual hourly NO_2 concentrations at the worst-case impact location, in terms of the number of exceedances, for the rural and suburban background cases and determining the maximum number of hourly exceedances of 200 μg/m^3 in any individual extended event period. The results are presented in Table 10. It can be seen that there were no periods in which there were more than 11 exceedances, well below the 18 exceedances allowed under the NAQO.

Table 10: Maximum number of hourly exceedances of 200 µg/m^3 of NO_2 in any individual extended event period for 2014

Scenario	Year	Number of exceedances of 200 µg/m^3 Rural background 30 µg/m^3	Number of exceedances of 200 µg/m^3 Suburban background 62 µg/m^3
Extended Event	2014	8.1	10.1

Overall the analysis suggests that the probability of an exceedance of the short-term NO_2 NAQO due to a CCGT operating with abnormal NO_x emissions during a black start event is negligible.

There are also no short-term air quality risks associated with formaldehyde emissions from a CCGT plant during black start operation (Appendix B).

5.4 Gas-fired OCGT plant

Table 11 shows the modelled process contribution (PC) based on operation at the emission levels in Table 3 for the entire year for the 99.79th percentile hourly concentration of NO_2 and the maximum 8-hour mean concentration of CO for a gas-fired OCGT plant. This is based on the maximum at any point on the grid over the 5 years modelled. Where the PC is greater than the 10% significance threshold, the predicted environmental concentration (PEC) comprising the sum of the PC and the background (BG) concentration is also presented and compared to the NAQO. Note that the background concentration for calculating the short-term PEC is based on twice the annual mean background concentrations set out in Section 4.3, in line with Environment Agency guidance.

Table 11: Black start compliance assessment for NO_2 and CO (gas-fired OCGT plant)

Parameter	Met Site	NAQO µg/m^3	PC µg/m^3	PC/ NAQO	BG µg/m^3	PEC µg/m^3	PEC/ NAQO
Hourly NO_2 99.79th %ile	Coastal	200	184	92%	30 (rural) 62 (suburban)	214 246	107% 123%
	Central	200	161	81%	30 (rural) 62 (suburban)	191 223	96% 112%
CO max 8 hour mean	Coastal	10000	137	1.4%	Not considered as PC is insignificant		
	Central	10000	113	1.1%			

It can be seen that even assuming operation at abnormal black start emissions for the entire year, the CO PC remains well below the 10% significance threshold.

The NO_2 NAQO is exceeded by the PEC based on the full year running, hence further statistical analysis has been undertaken.

Table 12 presents the maximum number of exceedances for the rural and suburban cases in each year based on the two met sites. The results are in bold where there are more than 18 exceedances. It can be seen that this occurs on two occasions when using the rural background and on 8 occasions when using the suburban background.

Table 12: Number of hourly exceedances of 200 µg/m^3 of NO_2 based on running all year

Met Site	Year	Number of exceedances of 200 µg/m^3 Rural background 30 µg/m^3	Number of exceedances of 200 µg/m^3 Suburban background 62 µg/m^3
Coastal	2010	12.4	**18.7**
Coastal	2011	**20.5**	**34.9**
Coastal	2012	**19.1**	**28.2**
Coastal	2013	14.4	**20.5**
Coastal	2014	10.6	**22.2**
Central	2012	7.0	9.1
Central	2013	7.1	**25.5**
Central	2014	11.2	**27.4**
Central	2015	17.1	**47.4**
Central	2016	5.0	15.1

The hypergeometric mean formula in Excel was used to determine the probability that there will be 19 or more exceedances based on a random sample of hours equivalent in total to the duration of an extended event for all years with more than 18 exceedances. The Environment Agency scaling factor of 2.5 was also applied. In all cases the hypergeometric mean resulted in a probability that was effectively zero. The probability of an exceedance does not rise above 1% for the extended event case until it was assumed that there were 14 or more exceedances in the background data (i.e. there are five exceedances during the extended event).

Further analysis was undertaken for the years with more than 18 exceedances assuming suburban background concentrations by modelling the individual hourly NO_2 concentrations at the worst-case impact location in terms of exceedances and determining the maximum number of hourly exceedances of 200 µg/m^3 in any individual extended event period. The results are presented in Table 13. It can be seen that there is only one period in which there were more than 18 exceedances, namely the 2015 dataset using Central met data. Taking each of the possible continuous individual extended event periods within 2015 there were 155 individual extended event periods with more than 18 exceedances. This results in a probability of 1.8% that a randomly selected extended event period will have 18 exceedances or more.

Table 13: Maximum number of hourly exceedances of 200 µg/m^3 of NO_2 in any individual extended event period for years selected for additional analysis

Met Site	Year	Number of exceedances of 200 µg/m^3 Rural background 30 µg/m^3	Number of exceedances of 200 µg/m^3 Suburban background 62 µg/m^3
Coastal	2010	-	11.4
Coastal	2011	7.2	9.2
Coastal	2012	8.1	8.1
Coastal	2013	-	5.1
Coastal	2014	-	7.4
Central	2013	-	10.2
Central	2014	-	9.1
Central	2015	-	25.2

The emission levels for gas-fired OCGTs in Table 3 are based on normal emissions for plant with limited abatement, which are typically limited to 500 hours operation per year. As the assessment demonstrates that even when operating for the full year at these emission levels, there would be minimal probability of a breach of air quality standards, this confirms that operating above the 500 hour annual limit due to a short duration or extended black start event, would pose no risk to air quality.

5.5 Gas-oil fired OCGT plant

Table 14 shows the modelled process contribution (PC) based on operation at the emission levels in Table 3 for the entire year for the 99.79th percentile hourly concentration of NO_2, the maximum 8-hour mean concentration of CO, the 90.41st percentile daily concentration for PM_{10} and the 99.9th 15 minute, 99.73rd hourly and 99.18th daily percentile concentrations for SO_2 for a gas-oil fired OCGT plant. This is based on the maximum at any point on the grid over the 5 years modelled. Where the PC is greater than the 10% significance threshold, the predicted environmental concentration (PEC) comprising the sum of the PC and the background (BG) concentration is also presented and compared to the NAQO.

As Table 3 includes different emission levels for NO_x and CO from old and new OCGT plants, Table 14 includes separate results for both ages of OCGT for these species.

It can be seen that even assuming operation for the entire year, the PCs for CO, PM_{10} and SO_2 remain below the 10% significance threshold for the respective NAQOs. The same applies for the hourly NO_2 NAQO using the OCGT emission levels for old plant in Table 3.

The PCs derived using the NO_x OCGT emission levels for old plant in Table 3 are around 25% of the hourly NO_2 NAQO, but the PEC is well below the NAQO for both the rural and suburban background concentrations.

The emission levels for gas-oil fired OCGTs in Table 3 are based on normal emissions for plant with limited abatement which are typically limited to 500 hours operation per year. As the assessment demonstrates that even when operating for the full year at these emission levels, there would be no breaches of air quality standards, this confirms that operating above the 500 hour annual limit due to a short duration or extended black start event, would pose no risk to air quality.

Table 14: Black start compliance assessment for NO_2, CO, PM_{10} and SO_2 (gas-oil OCGT)

Parameter	Met Site	NAQO µg/m³	PC µg/m³	PC/ NAQO	BG µg/m³	PEC µg/m³	PEC/ NAQO
Hourly NO_2 99.79th %ile (old)	Coastal	200	18.0	9.0%	Not considered as PC is insignificant		
	Central	200	19.3	9.6%			
Hourly NO_2 99.79th %ile (new)	Coastal	200	49.5	24.7%	30(rural) 62 (suburban)	79.5 111.1	40% 56%
	Central	200	53.1	26.6%	30 (rural) 62 (suburban)	83.1 115.1	42% 58%
CO max 8 hour mean (old)	Coastal	10000	18.0	0.2%	Not considered as PC is insignificant		
	Central	10000	18.8	0.2%			
CO max 8 hour mean (new)	Coastal	10000	2.3	0.02%	Not considered as PC is insignificant		
	Central	10000	2.9	0.01%			
Daily PM_{10} 90.41st %ile	Coastal	50	0.26	0.52%	Not considered as PC is insignificant		
	Central	50	0.21	0.42%			
15 min SO_2 99.9th %ile	Coastal	266	10.4	3.9%	Not considered as PC is insignificant		
	Central	266	11.1	4.2%			
Hourly SO_2 99.93rd %ile	Coastal	350	9.3	2.6%	Not considered as PC is insignificant		
	Central	350	9.9	2.8%			
Daily SO_2 99.18th %ile	Coastal	125	5.5	4.4%	Not considered as PC is insignificant		
	Central	125	6.0	4.8%			

6 Conclusions

The analysis demonstrates that:

- For coal plant operating at abnormal emission levels during black start events, there is no risk of non-compliance for the short-term NAQOs for NO_2, CO or PM_{10} or for the SO_2 maximum daily mean NAQO. Very low risks (<2% probability) of non-compliance were derived for the SO_2 hourly mean NAQO for an extended event and for the SO_2 15 minute NAQO for a short duration event. The only potential concern relates to the 15 minute SO_2 objective when coal plant runs continuously in an extended event, where a worst case 25% chance of non-compliance was identified. This is clearly an extremely unlikely scenario, especially as it assumes FGD does not operate for the whole period on all boilers. The overall risk can be considered as low because (i) the chance of an extended event occurring is extremely low (ii) there is at least a 75% probability of compliance (iii) the chance of the FGD plant being unavailable across the entire plant for the entire duration of the event is also low and (iv) recent changes to the UK operational coal fleet mean that 150m is an extremely pessimistic representative stack height for assessing worst case air quality impacts.

- For biomass plant operating at abnormal emission levels during black start events, there is no risk of non-compliance for the short-term NAQO for NO_2.

- For CCGT plant operating at abnormal emission levels during black start events, there is no risk of non-compliance for the short-term NAQOs for CO, NO_2 of formaldehyde.

- For gas fired OCGT plant operating above an annual cap of 500 operating hours during black start events, there is no risk of non-compliance for the short-term NAQO for CO and a very low risk of non-compliance (<2%) for the short-term NAQO for NO_2 for an extended event only.

- For gas-oil fired OCGT plant operating above an annual cap of 500 operating hours during black start events, there is no risk of non-compliance for the short-term NAQOs for CO, SO_2, PM_{10} or NO_2

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Appendix A: Assessment of potential daily mean NO_x impacts on sensitive ecosystems during black start events

The Environment Agency has requested an assessment of the potential daily mean NO_x impacts on sensitive ecosystems during a black start event. The assessment and results are set out in this Appendix.

As set out in Table 2 of the main report, abnormal black start operating conditions relating to NO_x releases are not anticipated for coal plant hence this Appendix does not consider coal plant impacts. One UK coal station has Selective Catalytic Reduction (SCR) fitted, however as the station has historically run without SCR, the risks of operation without SCR during a black start event can be considered negligible as such impacts are recognised as such within the current authorised operational envelope.

A.1 Critical levels for ecosystems and assessment criteria

The Environment Agency guidance (Environment Agency, 2016a) for assessing impacts on protected conservation areas sets a maximum daily average of 75µg/m^3 for NO_x (the daily critical level) for the assessment of impacts on ecosystems.

The guidance requires assessment at any Special Protection Areas (SPAs), Special Areas of Conservation (SACs) and Ramsar sites within 10km of a power station (15km for coal-fired or oil-fired power stations). For emitters greater than 50MW_{th}, such as the power plants considered in the main report, assessment of impacts on SSSIs within these distances is also typically required.

Assessment is also required at any local nature sites (ancient woods, local wildlife sites and national and local nature reserves) within 2km of a power station.

The guidance sets the following criterion for screening out short-term impacts on SPAs, SACs, Ramsar sites and SSSIs as insignificant:

- the short-term PC is less than 10% of the short-term environmental standard for protected conservation areas

For local nature sites the criterion for screening short-term impacts out as insignificant is:

- the short-term PC is less than 100% of the short-term environmental standard

It should be noted that the EU ambient air quality directive (Directive 2008/50/EC) only sets an annual mean critical level for NO_x and the daily critical level is specific to the UK Air Quality Strategy based on recommendations set out in the World Health Organisation (WHO) air quality guidelines (WHO, 2000).

Based on guidance from both the WHO and the Air Pollution Information System (APIS), the maximum daily mean NO_x critical level of 75µg/m^3 is only intended to apply where SO_2 and O_3 are close to their critical levels. Specifically, APIS states that 'NO_x is not sufficiently toxic alone, and the critical level for NO_x should only be applied where levels of SO_2 and O_3 are close to their critical levels' (APIS, 2016). The WHO NO_x critical level guideline conclusions state that 'to take combination effects with SO_2 and O_3 into account, the critical levels for these compounds are included in the critical level for NO_x'. It is then stated that 'Experimental evidence exists that the [short-term] critical level decreases from around 200µg/m^3 to 75µg/m^3 when in combination with O_3 or SO_2 at or above their critical levels' [WHO, 2000].

Reviewing SO_2 and O_3 concentrations in the vicinity of a range of UK power stations demonstrated no evidence of areas where SO_2 concentrations were greater than the most precautionary critical level of 10µg/m^3 where lichens are present, or the 5000ppb hours critical level for ozone (based on (semi-)natural vegetation communities dominated by perennials, 6 month growing season mid-April to mid-October). As such 75µg/m^3 presents a very precautionary environmental assessment level, and the 200µg/m^3 figure referenced by WHO would be more appropriate for the majority of UK locations.

A.2 Modelling methodology

The ADMS modelling followed the same approach as set out in the main report, with the exception of the grid size used. As the assessment of ecosystem impacts is focused on a larger area relative to health effects and the impacts at precise locations (such as residential receptors) is less important, impacts on ecosystems are generally modelled at lower resolution to reduce modelling run times and provide a spatially consistent assessment of impacts over habitats sites. As such, the biomass plant impacts were modelled on the grid and resolution set out in the main report (40 x 40km; 250m), whilst impacts for the CCGT and OCGT plants were modelled on a 20 x 20km grid with a resolution of 200 metres.

A.3 Background concentrations

Background levels of NO_x were based on a review of mapped concentrations available at https://uk-air.defra.gov.uk/data/gis-mapping/. The 2018 mapping shows that NO_x concentrations were below 20µg/m^3 at all UK rural locations and this was selected as the rural background. Concentrations were below 30 µg/m^3 at all but the most urbanised UK locations. Given that protected conservation areas are much less likely to be present in heavily urbanised areas, a background location of 31µg/m^3 was selected as the suburban background concentration. This figure was used to ensure the suburban NO_x concentration was not below the corresponding urban NO_2 concentration used in the main report.

A.4 Assessment and results

The assessment methodology is based on an initial screening of the maximum impact based on full load operation all year against the 75µg/m^3 critical level. Plants which are not screened out are then assessed against several measures of risk to determine an overall risk level.

In the tables, risks and impacts of less than 10% and PEC impacts below the critical level have been highlighted in green as a broad indicator of low risk for short-term effects. In all cases, impacts were assessed based on the worst-case year of five years of meteorology for the coastal and central locations.

A.4.1 Stage 1 Screening: Maximum PEC assessed against the 75µg/m^3 critical level

Table A1 compares the maximum modelled daily mean NO_x process contribution (i.e. the PC) in combination with the rural and suburban background concentrations (i.e. the PECs) to the 75µg/m^3

critical level for each power plant type using the coastal and central meteorology based on full load operation all year. For the biomass station, the background (BG) is based on 1 x the annual mean background concentration, whilst for the CCGT and OCGT plants it is based on 2 x the annual mean background concentration, consistent with the main report.

It can be seen that the maximum PECs associated with the biomass plant are well below the 75µg/m^3 critical level, hence biomass plants can be screened out from further assessment in relation to Natura 2000 sites.

It can also be seen that the maximum PC for the gas-oil fired OCGT (old) plant is below 100% of the 75µg/m^3 critical level, hence this plant can be screened out with respect to impacts on local nature sites.

Table A1: Stage 1 Black start compliance assessment against the 75µg/m^3 NO_x critical level based on 100% annual load factor

Station Type	Met Site	Critical level µg/m^3	PC µg/m^{-3}	PC/ CLev	BG µg/m^3	PEC µg/m^3	PEC/ CLev
Biomass	Coastal	75	15.4	21%	20 (rural) 31 (suburban)	35.4 46.4	47% 62%
	Central	75	17.7	24%	20 (rural) 31 (suburban)	37.7 48.7	50% 65%
Gas CCGT	Coastal	75	144	192%	40 (rural) 62 (suburban)	184 206	245% 275%
	Central	75	164	219%	40 (rural) 62 (suburban)	204 226	272% 301%
Gas OCGT	Coastal	75	330	440%	40 (rural) 62 (suburban)	370 392	493% 523%
	Central	75	246	328%	40 (rural) 62 (suburban)	286 308	381% 411%
Gas-Oil OCGT (old)	Coastal	75	45	60%	40 (rural) 62 (suburban)	85 107	113% 143%
	Central	75	35	47%	40 (rural) 62 (suburban)	75 97	100% 129%
Gas-Oil OCGT (new)	Coastal	75	123	164%	40 (rural) 62 (suburban)	163 185	217% 247%
	Central	75	96	128%	40 (rural) 62 (suburban)	136 158	181% 211%

A.4.2 Stage 2a assessment: Maximum PEC assessed against a 200 µg/m^3 critical level

As noted in Section A1, a critical level of 200µg/m^3 is more appropriate as a genuine environmental assessment level for power stations given the prevailing SO_2 and O_3 concentrations in the UK. Table A2 compares the PC and PEC at the maximum impact point based on full load operation all year to a 200µg/m^3 critical level. It can be seen that the gas-oil fired OCGT plant PECs are well below this critical level. The PC from the gas-fired OCGT plant and gas-oil fired OCGT plants are below 100% of the 200µg/m^3 critical level and hence can be considered insignificant with respect to impacts on local nature sites using this environmental assessment level.

Table A2: Black start compliance assessment against a 200µg/m³ NO_x critical level based on 100% annual load factor

Station Type	Met Site	Critical level µg/m³	PC µg/m³	PC/ CLev	BG µg/m³	PEC µg/m³	PEC/ CLev
Gas CCGT	Coastal	200	144	72%	40 (rural) 62 (suburban)	184 206	92% 103%
	Central	200	164	82%	40 (rural) 62 (suburban)	204 226	102% 113%
Gas OCGT	Coastal	200	330	165%	40 (rural) 62 (suburban)	370 392	185% 196%
	Central	200	246	123%	40 (rural) 62 (suburban)	286 308	143% 154%
Gas-Oil OCGT (old)	Coastal	200	45	23%	40 (rural) 62 (suburban)	85 107	43% 54%
	Central	200	35	18%	40 (rural) 62 (suburban)	75 97	38% 49%
Gas-Oil OCGT (new)	Coastal	200	123	62%	40 (rural) 62 (suburban)	163 185	82% 93%
	Central	200	96	48%	40 (rural) 62 (suburban)	136 158	68% 79%

A.4.3 Stage 2b assessment: Fraction of grids where PC > 75µg/m³ critical level

The ADMS model was set up to produce output indicating the number of daily exceedances of 35 µg/m³ and 13µg/m³ in each grid square based on full load running all year for each plant type. These values correspond to the head-room between twice the annual mean rural and suburban background concentrations and the 75µg/m³ critical level (i.e. 75 – (2x20) = 35, 75 – (2x31) = 13). Grid squares with a value of zero ensure the PEC will be less than 75µg/m³ for the corresponding rural and suburban scenarios. As the critical level only applies to protected conservation areas, the actual level of risk is site-specific. Assessing the fraction of the 20 x 20km local area (i.e. within 10km of the power station) over which the critical level is exceeded can, however, be used as a generic risk indicator reflecting the area at risk if a habitat site is located within it.

Table A3 shows the fraction of the 20 x 20 km grid over which the PEC would be exceeded based on full load operation all year. It can be seen that the 75µg/m³ critical level is exceeded over less than 8% of the grid for the rural background. Figures are higher for the suburban background, but very low in the case of gas-oil fired OCGT (old) plants.

Table A3: Fraction of 20 x 20km grid over which the 75µg/m^3 NO_x critical level is exceeded based on 100% annual load factor

Station Type	Met Site	Rural background	Suburban background
Gas CCGT	Coastal	3.6%	30.4%
	Central	4.0%	33.5%
Gas OCGT	Coastal	6.6%	48.8%
	Central	7.8%	61.5%
Gas-oil OCGT (old)	Coastal	0.1%	2.6%
	Central	0.1%	2.7%
Gas-oil OCGT (new)	Coastal	2.7%	21.8%
	Central	2.8%	21.4%

A.4.4 Stage 2c assessment: Fraction of grids where PC > 200µg/m^3 critical level

Stage 2c provides the same assessment as Stage 2b but using a 200µg/m^3 critical level. In this instance the ADMS model was set up to produce output indicating the number of annual exceedances of 138µg/m^3 and 160µg/m^3 in each grid square based on full load running all year for each plant type. This corresponds to the head-room between twice the annual mean rural and suburban background concentrations and the 200µg/m^3 critical level.

Table A4 shows the fraction of the 20 x 20 km grid over which the PEC would be exceeded based on full load operation all year. It can be seen that the critical level is exceeded over less than 0.5% of the grid for the both the rural and suburban backgrounds.

Table A4: Fraction of 20 x 20km grid over which a 200µg/m^3 NO_x critical level is exceeded based on 100% annual load factor

Station Type	Met Site	Rural background	Suburban background
Gas CCGT	Coastal	0.00%	0.01%
	Central	0.01%	0.01%
Gas OCGT	Coastal	0.30%	0.40%
	Central	0.20%	0.30%
Gas-oil OCGT (old)	Coastal	0.00%	0.00%
	Central	0.00%	0.00%
Gas-oil OCGT (new)	Coastal	0.00%	0.00%
	Central	0.00%	0.00%

A.4.5 Stage 3 assessment: Further consideration of gas-fired CCGT plant impacts

A.4.5.1 Impact of assumed background concentration

The gas-fired CCGT plant assessment has used twice the annual mean background for the assessment of short-term impacts following the recommendations in the Environment Agency guidance. In practice, background NO_x concentrations will primarily be from ground level sources such as traffic emissions and it is unlikely that high background concentrations at ground level will coincide with high process contributions from an elevated point source such as a CCGT gas-fired power station with a 75 metre stack, as the weather conditions that cause high background concentrations at ground level do not cause high point source contributions at ground level and vice versa. High process contributions from point sources such as power stations normally occur during warm convective and/or windy conditions which mix the plume to the ground, but which also tend to dilute concentrations deriving from ground level sources. During weather conditions that cause high traffic ground level concentrations the plume from a power station will generally be above the inversion layer and disperse over a much larger area. Therefore, the maximum impact from the power station is very unlikely to occur when the maximum impact from ground level sources occurs. As such, the annual mean concentration is likely to be a better representation of the background concentration during short-term process contributions.

Table A5 presents the fraction of the 20 x 20 km grid over which the PEC would be exceeded based on full load operation all year using the annual mean rural and suburban background concentrations and applying the 75μg/m^3 critical level.

It can be seen that the fraction of the grid over which an exceedance could be generated drops to very low levels of less than 3% using the 75μg/m^3 critical level. This drops to zero using the 200 μg/m^3 critical level.

Table A5: Fraction of 20 x 20km grid over which 75μg/m3 NO_x critical level is exceeded using annual mean background based on 100% annual load factor

Station Type	Met Site	Rural background	Suburban background
Gas CCGT	Coastal	1.3%	2.2%
	Central	1.4%	2.5%

A.4.5.2 Impacts based on short duration and extended black start events

The CCGT plant assessments in Tables A3 and A4 have a significant level of precaution built in as they are based on the station running for 365 days a year as opposed to running during a short duration or extended black start event. If it assumed that there are no exceedances of the critical level during normal operations, the hypergeometric mean can be used to assess the specific risks associated with a short duration or extended black start period.

Table A6 presents the average risk of a PEC based exceedance based on black start operation during a short duration or extended event based on all grid squares using the 75μg/m^3 critical level. Note that no additional scaling factor has been applied to the hypergeometric mean, as the chance of consecutive exceedances for daily mean concentrations is likely to be much lower than for hourly concentrations, hence a more randomly distributed set of exceedances is a reasonable assumption.

It can be seen from Table A6 that once the black start periods are taken into account, the risk of an exceedance in any grid square becomes very low at less than 1% for a short duration event for rural or suburban backgrounds, less than 1% for an extended event for a rural background and less than 4% for an extended event for an urban background. The risk effectively drops to zero for all situations using a 200µg/m^3 NO_x critical level.

Table A6: Risk of an exceedance of the 75µg/m^3 NO_x critical level based on short duration or extended event black start running based on all grid squares

Station Type	Met Site	Rural background		Suburban background	
		SDE	EE	SDE	EE
Gas CCGT	Coastal	0.05%	0.31%	0.62%	3.6%
	Central	0.04%	0.24%	0.56%	3.4%

SDE = Short duration event, EE = extended event

A.4.5.3 Summary of CCGT plant impacts

Table A1 demonstrates that the maximum grid impacts associated with the CCGT plant are substantial in terms of both the PC and PEC. However this is based on the assumption that the plant operates for the entire year with abnormal black start emissions and that there is a habitat site located at the maximum impact point.

Table A3 assesses the spatial level of the risk showing that for a rural location, there is only a risk of exceedance if a habitat site is located in one of the top 4% of impacted grid squares within 10km of the site. For suburban backgrounds, this risk applies to 30-35% of the area within 10km. The calculated PEC is based on twice the annual mean background, however in practice this is overly precautionary for high stacks and the annual background is likely to be more appropriate. Using the annual background reduces the area of risk to less than 3% of the grid for suburban areas and less than 1.5% for rural areas as shown in Table A5.

Taking into account the actual risk of an exceedance based on a short duration or extended period of black start operation, the risk of an exceedance in any particular grid square becomes very low, even using twice the annual mean background concentration. It is less than 1% using a rural background (short duration or extended event) and using a suburban background (short duration event) and less than 4% using a suburban background for an extended event.

The assessments discussed above are based on the highly precautionary 75µg/m^3 NO_x critical level. Using a 200µg/m^3 critical level as a more appropriate environmental assessment level reduces the fraction of the grid over which full load operation could lead to an exceedance to 0.01% or less (See Table A4) and the black start period risks to effectively zero.

Based on the assessment results, it can be concluded that there is a low risk that the operation of CCGT plant during a black start period will have a detrimental impact on local ecological sites.

A.4.6 Stage 3 assessment: Further consideration of OCGT plant impacts

The approach to assessing OCGT plant impacts is different from that used for biomass plant and CCGT plant as the OCGT plants are already limited to 500 hours of operation. As such, the 500 hour operation represents an accepted level of risk and the assessment process is focussed on the additional risk associated with operation for an additional short duration or extended black start event.

For each of the OCGT plant types, the average risk of a PEC based exceedance associated with 500 hours, 500 hours plus a short duration event and 500 hours plus an extended event per year (rounded to the appropriate number of days in each case) has been calculated across the 20 x 20 km grid using the hypergeometric mean and applying rural and suburban background concentrations. The increase in risk associated with moving from 500 hours per year to 500 hours plus the hours associated with a short duration and extended event has then been calculated.

A.4.6.1 Results for OCGT plants

Tables A7, A8 and A9 present the results for a gas-fired OCGT plant, a gas-oil fired OCGT (old) plant and a gas-oil fired OCGT (new) plant respectively.

Table A7: Risk of an exceedance of the 75µg/m^3 NO_x critical level based on 500, 500+SDE and 500+EE hours of running based on all grid squares for a gas-fired OCGT plant

Station Type	Met Site	Rural background	Suburban background
500 hours			
Gas OCGT	Coastal	1.47%	12.8%
	Central	1.36%	13.7%
500 hours + SDE			
Gas OCGT	Coastal	1.52%	13.2%
	Central	1.42%	14.2%
500 hours + EE			
Gas OCGT	Coastal	1.80%	15.5%
	Central	1.72%	17.0%
Increase moving from 500 to 500+SDE hours operation			
Gas OCGT	Coastal	0.05%	0.42%
	Central	0.05%	0.50%
Increase moving from 500 to 500+EE hours operation			
Gas OCGT	Coastal	0.34%	2.76%
	Central	0.35%	3.28%

SDE = Short duration event, EE = extended event

Table A8: Risk of an exceedance of the 75µg/m^3 NO_x critical level based on 500, 500+SDE and 500+EE hours running based on all grid squares for an gas oil-fired OCGT (old) plant

Station Type	Met Site	Rural background	Suburban background
500 hours			
Gas-oil OCGT (old)	Coastal	0.004%	0.47%
	Central	0.003%	0.31%
500 hours + SDE			
Gas-oil OCGT (old)	Coastal	0.005%	0.48%
	Central	0.003%	0.32%
500 hours + EE hours			
Gas-oil OCGT (old)	Coastal	0.006%	0.58%
	Central	0.004%	0.40%
Increase moving from 500 to 500+SDE hours operation			
Gas-oil OCGT (old)	Coastal	<0.001%	0.02%
	Central	<0.001%	0.01%
Increase moving from 500 to 500+EE hours operation			
Gas-oil OCGT (old)	Coastal	0.001%	0.12%
	Central	0.001%	0.09%

Table A9: Risk of an exceedance of the 75µg/m^3 NO_x critical level based on 500, 500+SDE and 500+EE hours of running based on all grid squares for a gas oil-fired OCGT (new) plant

Station Type	Met Site	Rural background	Suburban background
500 hours			
Gas-oil OCGT (new)	Coastal	0.50%	5.0%
	Central	0.33%	4.6%
500 hours + SDE			
Gas-oil OCGT (new)	Coastal	0.51%	5.1%
	Central	0.34%	4.7%
500 hours + EE			
Gas-oil OCGT (new)	Coastal	0.62%	6.0%
	Central	0.43%	5.6%
Increase moving from 500 to 500+SDE hours operation			
Gas-oil OCGT (new)	Coastal	0.16%	0.16%
	Central	0.01%	0.01%
Increase moving from 500 to 500+EE hours operation			
Gas-oil OCGT (new)	Coastal	0.13%	1.1%
	Central	0.10%	1.1%

A.4.6.2 Summary of OCGT plant impacts

A.4.6.2.1 Gas-fired OCGT plant

Table A1 demonstrates that the maximum grid impacts associated with a gas-fired OCGT plant are substantial in terms of both the PC and PEC. However this is based on the assumption that the plant operates for the entire year and that there is a habitat site located at the maximum impact point.

Table A3 assesses the spatial level of the risk showing that for a rural location, there is only a risk of exceedance if a habitat site is located in one of the top 8% of impacted grid squares within 10km of the site. For suburban backgrounds, this risk applies to 50-60% of the area within 10km.

Table A7 shows that taking into account the actual risk of an exceedance based on an additional short duration or extended event period of black start operation the risk of an exceedance in any particular grid square becomes very low at less than 2% in absolute terms for short duration or extended event operation using a rural background, with the increase in risk compared to 500 hour annual operation being less than 0.4%.

The absolute risk of an exceedance in any particular grid square using a suburban background is 13-14% based on 500 annual hour operation, but increases by no more than 0.5% for an additional short duration event and by less than 3.5% for an additional extended event. As such the increase in risk, above the accepted risk level is small.

The assessments discussed above are based on the highly precautionary 75µg/m^3 NO_x critical level. Using a 200µg/m^3 critical level as a more appropriate environmental assessment level reduces the fraction of the grid over which full load operation could lead to an exceedance to less than 0.5% (see Table A4) and the black start period risks to effectively zero.

Based on the assessment results, it can be concluded that there is a low risk that the operation of gas-fired OCGT plant during a black start period will have a detrimental impact on local ecological sites.

A.4.6.2.2 Gas-oil fired OCGT (old) plant

Table A1 demonstrates that the maximum grid impacts associated with a gas-oil fired OCGT (old) plant are moderate in terms of both the PC and PEC. However, this is based on the assumption that the plant operates for the entire year and that there is a habitat site located at the maximum impact point.

Table A3 assesses the spatial level of the risk showing that there is only a risk of exceedance if a habitat site is located in one of the top 0.1% and 3% of impacted grid squares within 10km of the site using a rural and suburban background respectively.

Table A8 shows that taking into account the actual risk of an exceedance based on an additional short duration or extended event period of black start operation, the risk of an exceedance in any particular grid square becomes very low at less than 0.01% in absolute terms for short duration or extended event operation using a rural background and less than 0.6% using a suburban background. The change in risk compared to 500 hour annual operation is less than 0.15% in either case.

The assessments discussed above are based on the highly precautionary 75µg/m^3 NO_x critical level. Using a 200µg/m^3 critical level as a more appropriate environmental assessment level reduces the fraction of the grid over which full load operation could lead to an exceedance (See Table A4) and the black start period risks to effectively zero.

Based on the assessment results, it can be concluded that there is a low risk that the operation of gas-oil fired OCGT (old) plant during a black start period will have a detrimental impact on local ecological sites.

A.4.6.2.3 Gas-oil fired OCGT (new) plant

Table A1 demonstrates that the maximum grid impacts associated with a gas-fired OCGT plant are substantial in terms of both the PC and PEC. However this is based on the assumption that the plant operates for the entire year and that there is a habitat site located at the maximum impact point.
Table A3 assesses the spatial level of the risk showing that for a rural location, there is only a risk of exceedance if a habitat site is located in one of the top 3% of impacted grid squares within 10km of the site. For suburban backgrounds, this risk applies to around 22% of the area within 10km.

Table A9 shows that taking into account the actual risk of an exceedance based on an additional short duration or extended event period of black start operation, the risk of an exceedance in any particular grid square becomes very low at less than 0.7% in absolute terms for short duration or extended event operation using a rural background, with the increase in risk compared to 500 hour annual operation being less than 0.2%. The absolute risk of an exceedance in any particular grid square using a suburban background is around 5% based on 500 annual hours of operation, but increases by no more than 0.2% for an additional short duration event and by less than 1.2% for an additional extended event. As such the increase in risk, above the accepted risk level is small.

The assessments discussed above are based on the highly precautionary 75µg/m^3 NO_x critical level. Using a 200µg/m^3 critical level as a more appropriate environmental assessment level reduces the fraction of the grid over which full load operation could lead to an exceedance (See Table A4) and the black start period risks to effectively zero.

Based on the assessment results, it can be concluded that there is a low risk that the operation of gas-oil fired OCGT plant (new) during a black start period will have a detrimental impact on local ecological sites.

A.5 Conclusions

The assessment has demonstrated that for all the plant types considered, the risk of an exceedance of the daily mean NO_x critical level is low. This low risk should be considered in combination with the risk of a black start event actually occurring, which reduces the total risk level still further.

Even in a worst-case scenario any exceedance of the daily mean critical level due to black start operations will be transient in nature with the maximum possible number of daily exceedances limited to the number of additional days associated with a short duration or extended black start event.

A.6 References

APIS, (2016). Air Pollution Information System, Critical Levels of Nitrogen Dioxide data source, http://www.apis.ac.uk/popup/no_clevel

Environment Agency (2016a), *Air emissions risk assessment for your environmental permit.* Last updated 2 August 2016. Available at: https://www.gov.uk/guidance/air-emissions-risk-assessment-for-your-environmental-permit

WHO, (2000). Air quality guidelines for Europe, Second Edition (CD ROM version), World Health Organization, Chapter 11, Effects of nitrogen-containing air pollutants - critical levels http://www.euro.who.int/en/health-topics/environment-and-health/airquality/publications/pre2009/who-air-quality-guidelines-for-europe,-2nd-edition,-2000-cd-romversion

Appendix B: Assessment of potential short term formaldehyde impacts during black start events

The Environment Agency and National Resources Wales have requested an assessment of the potential short-term impacts of formaldehyde (HCHO) emissions during a black start event. Formaldehyde emissions are only likely to be an issue in relation to CCGT plant operating at high CO emission concentrations due to variable load/combustion conditions or fault development.

B.1 Impact Assessment

Black start impacts of CCGT plant were assessed based on a CO emission concentration of 1000 mg/Nm^3 (273.15K, 101.3 kPa, dry, 15% O_2) as shown in Table 3 of the main report, assuming operation at these abnormal emission concentrations for the entire year. Formaldehyde impacts have been assessed based an assumed HCHO:CO ratio of 1:100 and assuming an annual mean background HCHO concentration of 2.5 µg/m^3 in line with previous work presented to the UK regulators (Graham & Griffiths, 2015) which incorporated public domain HCHO gas turbine emission measurements and ambient HCHO monitoring campaign measurements. The maximum hourly CO concentrations were scaled by a factor of 1/100 to derive the HCHO process contributions.

Table B1 presents the modelled maximum hourly HCHO concentration as a process contribution (PC, deriving from emissions from the generic CCGT plant) and the predicted environmental concentration (PEC, the PC plus twice the annual mean background concentration) using the two sets of meteorological data representative of a coastal location and a central inland location. The PC and PEC are assessed against the maximum short-term hourly HCHO Environmental Assessment Level (EAL) taken from the Environment Agency air emissions risk assessment guidance (Environment Agency, 2016a).

It can be seen that, although the PC is higher than the Environment Agency 10% insignificance criterion for screening out short-term impacts (Environment Agency, 2016a), the PEC remains well below the EAL for both cases.

The assessment represents a worst-case scenario as:

- It assumes operation for the entire year with elevated CO and formaldehyde emissions to ensure that the worst-case meteorological hour is captured in the assessment, as opposed to operation only during a limited duration black start event

- It is based on the maximum grid impact over five years of meteorology

- It assumes twice the annual mean background concentration in line with regulatory guidance (Environment Agency, 2016a), which is unlikely to be case during the maximum impact from a 75 metre CCGT stack, as the meteorological conditions which typically lead to plume grounding are likely to lead to dilution of background ground level concentrations.

Taking the above into account, it can confidently be concluded that there are no short-term air quality risks associated with formaldehyde emissions from a CCGT plant during black start operation.

Table B1: Black start compliance assessment for HCHO for CCGT plant

Parameter	Met Site	NAQO µg/m^3	PC µg/m^3	PC/ NAQO	Background µg/m^3	PEC µg/m^3	PEC/ NAQO
Hourly HCHO 100th %ile	Coastal	100	35.7	36%	5	40.7	41%
	Central	100	48.7	49%	5	53.7	54%

B.2 References

Graham D P & Griffiths S J , (2015). Formaldehyde and Methane Emissions from Gas Turbines, Presentation to Regulators, October 2015

Environment Agency (2016a), *Air emissions risk assessment for your environmental permit.* Last updated 2 August 2016. Available at: https://www.gov.uk/guidance/air-emissions-risk-assessment-for-your-environmental-permit