APPENDIX 9.6:

INPUT DATA FOR ISO 9613 CALCS

Noise Prediction Model

1. There are a number of empirical or semi-empirical sound propagation models in common use. One of these is ISO9613-2 which is the International Standard used to predict noise propagation.

2. In 1995 a study was carried out by Energy Technology Support Unit ("ETSU") `Noise Propagation from Wind Farms' funded by the EU and the DTI to look at the practical modelling of wind farms using ISO9613-2 and to check the accuracy of the model compared with others. This study involved the measurement of noise over varying distances from a high powered loudspeaker mounted on an elevated mast over an extended period of time. The report concluded that in the presence of a positive wind vector blowing from the source to the receiver the model generally predicts levels that lie within 1dB(A) ISO9613-2 of those measured. This was also my findings during field measurements at a wind farm site in Scotland with a positive wind vector.

3. This data has subsequently been reanalysed in greater detail and in 2004 a paper was published by Alberola J, Findell I H, Bullmore A J, Ramon P entitled `Variablility of sound propagation arsing under different meteorological conditions'. The paper concluded that beyond 300m the overall variability in noise is controlled by meteorological factors and in downwind conditions it supports the premise that ISO9613-2 does accurately predict noise levels for the propagation over flat land.

4. The noise levels produced by the wind turbine at each of the nearest wind turbine neighbours has been calculated using a computer model, which is based on ISO 9613, Acoustics – Attenuation of Sound During Propagation Outdoors [1996]. The propagation model described in Part 2 of the standard provides a method for predicting sound pressure levels based on either a short-term downwind condition (i.e. worst case) or a long term average. The IOA `good practice guide to the application of ETSU-R-97 for the assessment and rating of wind turbine noise' refers to the use of ISO 9613 for the calculation methodology.

5. The computer model utilises octave band frequency data of the wind turbine to assess and predict the noise contribution with the turbine in operation.

6. The ISO propagation model provides a method for calculating the sound pressure level at a specific position by taking the sound power level for the turbine in separate frequency bands and subtracting a number of attenuation factors according to the following:

7. Predicted sound pressure level = $Lw + D – A_{geo} – A_{gr} – A_{bar} - A_{misc}$

8. The prediction modelling uses octave band frequency sound power level data for the wind turbine and corrects the level for the following additional propagation factors and attenuation:

Lw - Wind Turbine Sound Power Level Warranted

Vestas V90 3MW Turbine Warranted Noise Levels (including uncertainty factor)

Table 1	
Wind speed (m/s)	**Sound Power Level (Type A) at 10m height L_{WA} dB**
2	**97.9**
5	**100.9**
6	**104.2**
7	**106.1**
8	**107.0**
9	**106.9**
10	**105.6**
11	**105.2**
12	**105.3**

Note: Conversion from LAeq to LA90 turbine noise assumed to be -2dB(A) as per ETSU-R-97 and IOA good practice guidance.

9. The sound power level of the equipment is measured in accordance with IEC 61400-11:2002 `Wind turbine generator systems – Part 11: Acoustic noise measurement techniques'. The noise is measured downwind of the turbine and the measurement is then corrected for test conditions and distance assuming a point source at hub height in accordance with DS/EN61400-11.

10. It is standard practice in wind turbine prediction calculations to allow for measurement accuracy. However, the above sound power levels are warranted using the example of the Vestas V90 3MW power mode 0 setting (Vestas advise that a measurement uncertainty of +2dB is included in the warranted levels).

D – Directivity Factor

11. Where the sound radiated from the wind turbine in the direction of interest is higher than that for which the sound power level is specified then an adjustment known as the directivity factor is applied. The sound power level of the wind turbine in this case has been measured in a down wind direction, which corresponds to a worst-case propagation condition and therefore there is no need for any further directivity adjustment.

12. In the situation where the wind is blowing away from the receptor the wind gradient causes the sound waves to be bent upwards at the upwind position. The effect of the wind can reduce noise levels at the receptor position by 10dB(A) or more in the upwind scenario.

13. At any given wind turbine neighbour position, depending upon the wind direction and wind speed, the effect of the wind turbine will vary. This is due to changes in turbine sound power output with wind speed and the fact that during certain wind directions the turbine rotor may face the wind which is directed towards the specific receptor (i.e. turbine is upwind) and in other wind conditions it may be at a different angle to the receptor (i.e. downwind or crosswind). I have provided noise prediction levels based on a `worst case' situation for the most sensitive wind speed and direction

conditions. Under these conditions we have assumed that there will not be any wind directional attenuation (i.e. we assume that the wind is blowing downwind from the wind turbine position).

14. There have been a number of studies in relation to the effects of wind on noise levels and some broad observations on attenuation have made their way into certain guidance notes. For example, under the Minerals Planning Guidance ("MPG11"): 1993 `*The Control of Noise at Surface Mineral Workings'* it states "*Meteorological records of wind speed and direction can provide a useful reference from which both MPAs and operators may recommend that a fixed allowance of 2dB(A) should be incorporated in predictive modelling, having first considered site-specific conditions, e.g. elevation, general topography, and natural or artificial wind shielding.'*

15. More recently a study published in 2002 by McKenzie, Bullmore and Flindell entitled `*The Effects of Wind Speed and Direction on Ambient and Background Noise Levels in the Suburban Environment'* provided information on some long term monitoring of noise levels from an airport site and a road/rail site during varying wind speeds and directions. The report showed that at the road/rail site at wind speeds around 3m/s "*the wind direction becomes more important with the trend lines separating by 5.5dB day-time and by 7dB night-time for the noisiest and quietest wind directions."*

16. Studies of the propagation of noise from wind turbines have been carried out for ETSU. The study undertaken by ISVR in 1990 entitled `The Prediction of Propagation of Noise From Wind Turbines with regard to community Disturbance' (ETSU WN 5066) provides test data on wind turbines at various distances and at angles to wind direction that indicates the effect of the wind on noise levels. Figures 6.18a, 6.18b and 6.19 of this document show the attenuation measured, which would indicate that there is likely to be additional attenuation expected in the frequency spectra as a result of wind direction from 60 degrees downwind of the turbine to the downwind position relative to the upwind position. The graphs show a difference of up to 10dB when comparing upwind and downwind of the wind turbine from 2kHz upwards and attenuation at lower frequencies albeit variable. The conclusion of the report states that "*The upwind noise shadow was clearly found at a low level microphone'*. The attenuation at 60 degrees was less clear with the report concluding that this was "*possibly because the directivity of the source gives an apparent increase in attenuation crosswind".* (ref. page 66).

17. The Wyle Research report from October 1988 indicates that upwind attenuation varies with distance and angle of wind relative to receptor and source, but shows significantly higher attenuation than 10dB(A) upwind and around 4dB(A) for the crosswind scenario with distances of around 550 metres and above.

18. According to the `Good practice guide to the application of ETSU-R-97 for wind turbine noise assessment' it states: *"Based on evidence from the Joule project in conjunction with advice in BS8233 and ISO 9613-2, it seems reasonably conservative to assume that for a range of headings from directly downwind (0^o) up to 10 degrees from crosswind (80^o), there may be little to no reduction in noise levels; once in cross wind directions (90^o) then the reduction may be around 2dB(A); and when upwind the reduction would be around 10dB(A)".*

A_{geo} - Geometrical Divergence

19. The geometrical divergence of sound waves accounts for the spherical spreading in the free field from a point source resulting in attenuation depending on distance, which relates to the following correction:

A_{geo} = 20 x log (d) + 11 [where d = distance from the turbine]

20. For each of the wind turbines the noise source may be considered as a point source beyond a distance corresponding to one rotor diameter.

Receiver height assumed = 4m

A_{atm} - Atmospheric Absorption

21. When sound energy propagates through the atmosphere it is attenuated as a result of the conversion of the sound energy into heat. The attenuation is dependent upon the relative humidity and the temperature of the air through which the sound energy is travelling. The attenuation is also dependent upon the frequency content of the sound energy with higher levels of attenuation towards higher frequencies.

22. The attenuation therefore depends upon the distance from the sound source and according to ISO9613 is calculated according to the following formula:

A_{atm} = d x α [Where d = distance from the turbine

a = atmospheric absorption coefficient in dB/m]

23. From ISO9613 Part 1 [1996] I have used values of `a' corresponding to a temperature of 10°C and a relative humidity of 70%. This will give an indication of the lowest likely atmospheric attenuation as examples worked at 20deg C and -5deg C indicate a reduction of around -0.5dB(A) on those values calculated. The values for each one-third octave band are given below in **Table 2**.

Table 2: Atmospheric absorption attenuation based on temperature of 10°C and a relative humidity of 70%

Third Octave Band Centre Frequency (Hz)	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**
Atmospheric Absorption Coefficient (dB/km)	0.0785	0.122	0.186	0.28	0.411	0.584	0.797	1.04
Third Octave Band Centre Frequency (Hz)	**315**	**400**	**500**	**630**	**800**	**1k**	**1.25k**	**1.6k**
Atmospheric Absorption Coefficient (dB/km)	1.31	1.6	1.93	2.33	2.87	3.66	4.86	6.73
Third Octave Band Centre Frequency (Hz)	**2k**	**2.5k**	**3.15k**	**4k**	**5k**	**6.3k**	**8k**	**10k**
Atmospheric Absorption Coefficient (dB/km)	9.66	14.3	21.5	32.8	50.2	76.9	117	175

24. For atmospheric absorption I have limited the attenuation levels to a maximum of 10dB for the purpose of the calculations.

A_{gr} – Ground Effect

Ground Effect for Calcs = 0.5 (mixed ground absorption)

25. The ground effect is a result of the interference of sound reflected by the ground which interferes with the direct sound propagating from the wind turbine to the receiver. The prediction of the ground effects is relatively complex and is dependent upon a number of factors including ground conditions, source height, receiver height and the propagation height between the source and receiver. The ground conditions are described according to a variable `G' which varies between 0 for `hard' ground and 1 for `soft' ground. Hard ground refers to paving, concrete and any sites with low porosity. Soft ground refers to grassland, trees or other vegetation. I have assumed a ground factor of G = 0.5 to represent typical ground conditions. I have taken the source height as being the height of the turbine nacelle and a receiver height of 4 meters. This is the agreed industry standard when allowing for any manufacturers uncertainty factors.

(i) Recent field measurements of the wind turbines would indicate that using G=0.5 (i.e. mixed ground) would over predict the resultant wind turbine noise level. In a recent presentation for the Institute of Acoustics by a leading consultant on wind turbine noise it was stated that a harmonised study for the EU on noise propagation showed that ISO9613 does generally over predict the measured turbine noise level.

(ii) According to the `Good practice guide to the application of ETSU-R-97 for wind turbine noise assessment' the ground factor with warranted sound power levels G is advised to be = 0.5.

A_{bar} – Barrier Attenuation

26. When there is a solid barrier between any noise source and the receiver position the noise level will be reduced. The level of attenuation resulting will depend upon the barrier position, barrier size, receiver position and frequency content relative to the noise source. For the purpose of these calculations, we have **not** included for any local screening from existing buildings, which exists at some of the wind turbine neighbour positions. Additionally, we have **not included** the potential screening benefits from the topography in the situation where the wind is blowing from the turbine towards the wind turbine neighbour and the turbine nacelle and blades are below the `line of sight' of the landscape.

27. According to the `Good practice guide to the application of ETSU-R-97 for wind turbine noise assessment' topographic screening effects should generally be limited to no more than 2dB, and then only if there is no direct line of sight between the highest point on the turbine rotor and the receiver location. The assessment gives separately, the likely attenuation from screening of the landscape at receptors, based on the good practice guide methodology.

A_{misc} – Miscellaneous Other Effects

28. This additional attenuation effect described in ISO9613 allows for the effects of propagation through foliage, industrial plants and housing. I have not taken account of any such effects and in my expert opinion they are unlikely to significantly reduce noise levels below those predicted.