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RISK CRITERIA FOR DEMONSTRATION OF SAFETY AT WIND TURBINE SITES

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1. INTRODUCTION

This paper provides a framework for setting quantitative risk targets for risk assessment of Wind Turbine Sites.

This document is intended to be read in conjunction with ESC document: *P154_RC002 rev. 2: Risk Criteria for Demonstration of Safety at Wind Turbine Sites Data Set.*

2. LEGISLATIVE BACKGROUND

The principal legislation regulating occupational safety hazards is the Health and Safety at Work etc. Act 1974. The core requirements require plant, equipment and systems of work that are safe so far as is reasonably practicable and cover both employees and those that may be affected by work activities.

‘‘Safe so far as is reasonably practicable’’ has come to mean that a balance between the cost of additional safety measures and the monetary value of the harms averted needs to be made, with a bias in favour of additional safety measures. This bias has come to be reflected in the term gross disproportion. In practice the regulatory bodies have defined the policy term "broadly acceptable" for a risk level below which they will not usually require further action if such risks are properly controlled.

As a starting point, the regulatory bodies will expect the duty holder to apply the safety experience accumulated (i.e. "accepted good practice") in the context of the activity being considered. This experience is usually to be found in the requirements of standards and codes of practice produced by authoritative organisations such as the British Standards Institution or the regulators themselves. It is expected that the requirements of all relevant codes and standards will be met without exception irrespective of specific risk estimates.

In many situations outside major hazard industries this approach is considered an adequate response to risk management because the necessary safety measures have been fully codified. An example of this might be the guarding of dangerous parts of machinery where compliance with British Standard BS EN 953 (now superseded by BS EN ISO 14120:2015) would usually be regarded as a sufficient response to manage the potential for injury to the machine operator.

The need to use an extended risk management process becomes greater as the numbers of people that might be harmed in a single incident increases and/or the unavailability of applicable codified standards.

In summary an occupational safety risk management process can be defined as follows:

- Identify and apply all relevant good practice (in the form of complying with relevant standards and codes of practice) precautions whether they be inherent safety, prevention, control or mitigation measures, and whether they relate to hardware, systems of work, or people and their behaviour.

- Identify what further measures might be adopted and show that they are not justified (or are justified, as the case may be) on the basis of either that they are not a major hazard or if a major hazard that the monetary value of the safety and other benefits that would accrue are grossly exceeded by the costs of implementing that measure, the depth of the analysis being greater in higher risk situations.

Adoption of appropriate risk criteria are part of this process but are a means to an end and not always an end in themselves. Showing that risks are broadly acceptable is the preferable position to be achieved and many codes and standards for new build will aim to achieve that risk level. Existing situations will often be not to current standards and require the consideration of additional safety measures.

3. SPECIFIC CRITERIA

3.1. General Public

3.1.1. Local Societal risk

Societal risk is not a property of a point on the ground but of a defined area. For a single installation the area would conventionally be that within which that installation hazards those nearby. In this case the area in which a fractured blade might 'fly'. Societal risk in this case would usually be termed the local societal risk (refer to Table 1).

Table 1. Local Societal Risk Matrix Assessments.

Frequency of specified consequence from a single event	**Societal risk Risk Tolerability**				
10^{-2}/yr – >10^{-3}/yr	Broadly acceptable	Tolerable if ALARP	Tolerable if ALARP	Intolerable	Intolerable
10^{-3}/yr – >10^{-4}/yr	Broadly acceptable	Broadly acceptable	Tolerable if ALARP	Tolerable if ALARP	Intolerable
10^{-4}/yr – >10^{-5}/yr	Negligible	Broadly acceptable	Broadly acceptable	Tolerable if ALARP	Tolerable if ALARP
10^{-5}/yr – >10^{-6}/yr	Negligible	Negligible	Broadly acceptable	Broadly acceptable	Tolerable if ALARP
10^{-6}/yr – >10^{-7}/yr	Negligible	Negligible	Negligible	Broadly acceptable	Broadly acceptable
10^{-7}/yr – >10^{-8}/yr	Negligible	Negligible	Negligible	Negligible	Broadly acceptable
Fatalities (all individuals: employees & public)	**0.001-<0.003 Fatality or Irreversible Injury**	**0.003-<0.03 Fatality or Irreversible Injury**	**0.03-<0.3 Fatality or Irreversible injury**	**0.3-<2 Fatality or Irreversible injury**	**2-10 Fatalities or Irreversible injury**

In order to apply the Risk Matrix it is necessary to estimate the average number of general public (whole or fraction) at risk in a given hazard zone. For each site it will be necessary to consider a number of locations in order to ensure the worst case has been covered.

3.1.2. Individual risk

Where an individual can be exposed to the risk for a significant period, such as a retail outlet employee, then the individual risk will become more significant due to the increased time of exposure to the hazard. Hence 'individual risk' criteria should also be used. Table 2 gives the individual risk assessment assuming ALL risks to the person are considered, including road accidents, falls, trips, etc. If only equipment failure is being considered for the cause of injury then it is common practice to lower the intolerable boundary, and make it more stringent, by an order of magnitude, to allow for the other risks that have not been considered. This is given illustrated in Table 3

Table 2. General Public Individual ALL Risk Matrix Assessments

Frequency of specified consequence associated with an individual	**Individual risk Risk Tolerability**			
10^{-2}/yr – >10^{-3}/yr	Tolerable if ALARP	Tolerable if ALARP	Intolerable	Intolerable
10^{-3}/yr – >10^{-4}/yr	Broadly acceptable	Tolerable if ALARP	Tolerable if ALARP	Intolerable
10^{-4}/yr – >10^{-5}/yr	Broadly acceptable	Broadly acceptable	Tolerable if ALARP	Tolerable if ALARP
10^{-5}/yr – >10^{-6}/yr	Negligible	Broadly acceptable	Broadly acceptable	Tolerable if ALARP
10^{-6}/yr – >10^{-7}/yr	Negligible	Negligible	Broadly acceptable	Broadly acceptable
10^{-7}/yr – >10^{-8}/yr	Negligible	Negligible	Negligible	Broadly acceptable
Fatalities: Public	**0.001-<0.003 Fatality or Irreversible Injury**	**0.003-<0.03 Fatality or Irreversible Injury**	**0.03-<0.3 Fatality or Irreversible injury**	**0.3-1 Fatality or Irreversible injury**

Table 3. Major equipment General Public Individual Risk Matrix Assessments

Frequency of specified consequence associated with an individual	**Individual risk associated with major equipment failure Risk Tolerability**			
10^{-2}/yr – >10^{-3}/yr	Tolerable if ALARP	Intolerable	Intolerable	Intolerable
10^{-3}/yr – >10^{-4}/yr	Broadly acceptable	Tolerable if ALARP	Intolerable	Intolerable
10^{-4}/yr – >10^{-5}/yr	Broadly acceptable	Broadly acceptable	Tolerable if ALARP	Intolerable
10^{-5}/yr – >10^{-6}/yr	Negligible	Broadly acceptable	Broadly acceptable	Tolerable if ALARP
10^{-6}/yr – >10^{-7}/yr	Negligible	Negligible	Broadly acceptable	Broadly acceptable
10^{-7}/yr – >10^{-8}/yr	Negligible	Negligible	Negligible	Broadly acceptable
10^{-2}/yr – >10^{-3}/yr	Negligible	Negligible	Negligible	Negligible
Fatalities: Public	**0.001-<0.003 Fatality or Irreversible Injury**	**0.003-<0.03 Fatality or Irreversible Injury**	**0.03-<0.3 Fatality or Irreversible injury**	**0.3-1 Fatality or Irreversible injury**

In order to apply the Risk Matrix it is necessary to estimate the expected likelihood of a hazardous event causing harm to the named person in the hazard zone. For each site it will be necessary to consider a number of locations in order to ensure the worst case has been covered

3.2. Company Employees

Where an individual can be exposed to the risk for a significant period, such as company employees, then the individual risk will become more significant due to the increased time of exposure to the hazard. Hence 'individual risk' criteria should also be used. Table 4 gives the individual risk assessment assuming ALL risks to the employee are considered, including falls, trips, etc. If only equipment failure is being considered for the cause of injury then it is common practice to lower the intolerable boundary, and make it more stringent, by an order of magnitude, to allow for the other risks that have not been considered. This is given illustrated in Table 5.

Table 4. Employee Individual ALL Risk Matrix Assessments

Frequency of specified consequence associated with an individual	Individual risk Risk Tolerability			
10^{-2}/yr – >10^{-3}/yr	Tolerable if ALARP	Tolerable if ALARP	Tolerable if ALARP	Intolerable
10^{-3}/yr – >10^{-4}/yr	Broadly acceptable	Tolerable if ALARP	Tolerable if ALARP	Tolerable if ALARP
10^{-4}/yr – >10^{-5}/yr	Broadly acceptable	Broadly acceptable	Tolerable if ALARP	Tolerable if ALARP
10^{-5}/yr – >10^{-6}/yr	Negligible	Broadly acceptable	Broadly acceptable	Tolerable if ALARP
10^{-6}/yr – >10^{-7}/yr	Negligible	Negligible	Broadly acceptable	Broadly acceptable
10^{-7}/yr – >10^{-8}/yr	Negligible	Negligible	Negligible	Broadly acceptable
10^{-2}/yr – >10^{-3}/yr	Negligible	Negligible	Negligible	Negligible
Fatalities: Employees	**0.001-<0.003 Fatality or Irreversible Injury**	**0.003-<0.03 Fatality or Irreversible Injury**	**0.03-<0.3 Fatality or Irreversible injury**	**0.3-1 Fatality or Irreversible injury**

Table 5. Major equipment failure Individual Risk Matrix Assessments

Frequency of specified consequence associated with an individual	Individual risk associated with major equipment failure Risk Tolerability			
10^{-2}/yr – >10^{-3}/yr	Tolerable if ALARP	Tolerable if ALARP	Intolerable	Intolerable
10^{-3}/yr – >10^{-4}/yr	Broadly acceptable	Tolerable if ALARP	Tolerable if ALARP	Intolerable
10^{-4}/yr – >10^{-5}/yr	Broadly acceptable	Broadly acceptable	Tolerable if ALARP	Tolerable if ALARP
10^{-5}/yr – >10^{-6}/yr	Negligible	Broadly acceptable	Broadly acceptable	Tolerable if ALARP
10^{-6}/yr – >10^{-7}/yr	Negligible	Negligible	Broadly acceptable	Broadly acceptable
10^{-7}/yr – >10^{-8}/yr	Negligible	Negligible	Negligible	Broadly acceptable
10^{-2}/yr – >10^{-3}/yr	Negligible	Negligible	Negligible	Negligible
Fatalities: Employees	**0.001-<0.003 Fatality or Irreversible Injury**	**0.003-<0.03 Fatality or Irreversible Injury**	**0.03-<0.3 Fatality or Irreversible injury**	**0.3-1 Fatality or Irreversible injury**

In order to apply the Risk Matrix it is necessary to estimate the expected likely hood that if the hazard (s) occurs then the named employee at risk in a given hazard zone will be harmed. For each site it will be necessary to consider a number of locations in order to ensure the worst case has been covered.

3.3. Hazards and compound hazards,

A hazard is something (e.g. an object, a property of a substance, a phenomenon or an activity) that can cause adverse effects (source ttp://www.hse.gov.uk/risk/theory/alarpglance.htm). For example:

- Blade throw from a wind turbine
- Ice throw from a turbine
- The collapse of a wind turbine tower
- The nacelle falling off.

A compound hazard is when the initial hazard occurs and the incident involves another secondary hazard. For example; if a wind turbine blade breaks and is thrown from the turbine and impacts a gas storage facility then the severity of the incident is compounded.

If a compound hazard is identified in a hazard map then this hazard should be included in calculating the severity of the compound hazard. Once the severity is calculated then the effect on people can be calculated using this process. Examples of secondary hazards on wind farm sites can be, but are not restricted to:

- Overhead Lines
- Gas storage facilities
- Gas pipelines
- Fuel Stations

4. ESTIMATING THE AVERAGE NUMBER OF PEOPLE PRESENT IN THE HAZARD ZONE, LOCAL SOCIETAL RISK

4.1. Identify the parameters

The average number of people present in the hazard zone can be derived by defining the following parameters;

- Areas of the wind farm that present a hazard to peoples from debris
- Items on a wind farm that attract Peoples
- The number and frequency of peoples visiting each item.

With these three points we can then analyse each farm to identify the probability of peoples being present in the hazard zone.

4.2. Define the parameters.

4.2.1. Areas of the wind farm that present a hazard to peoples from debris

The first parameter can be derived by understanding the maximum distance of debris throw from a wind turbine. This value can then be used to create a hazard map of each wind farm by measuring a radius around each installed WTG. This map will be called a hazard map for the purposes of this document.

The process shall use an ordinance survey or equivalent of the area.

For the purposes of a trial a 436 metre radius around each turbine has been used. This is the theoretical maximum distance that a blade form a 3MW IEC class 1 turbine can be thrown (Source: Handbook risk zoning wind turbines ECN 2005)

4.2.2. Items on a wind farm that attract peoples

A wind farm is usually built over a large area of land. This land is normally populated with a number of items that attract people. I will now identify these Items.

1. Roads
2. Domestic houses
3. Industrial outlets
4. Retail outlets
5. Local recreation amenity
6. Farmland
7. Ramblers.
8. Wind farm Maintenance personnel
9. Railway network

The map shall then be analysed to record the volume of the above items for each wind farm. The roads must be measured to attain the total number of miles of road to enable the probability to be derived.

4.2.3. Derive assumptions for likelihood of people presence for each item.

For each item an assumption must be made to enable a summation of number of peoples and the frequency of presence to be completed for each wind farm. This must be approached differently for each item.

4.2.4. Roads

The number of people a road attracts depends on the classification of road.

A class road, 1 person continuously present for 10 kilometres of road.

B class road, 1 person continuously present for 100 kilometres of road

Dual Carriage way 1 person continuously present for 5 kilometres of road.

4.2.5. Domestic houses

1 person continuously present for each house within identified hazard area.

4.2.6. Industrial outlets

Number of full time staff 25% of the time.

4.2.7. Retail outlets

Single type of merchandise 2 people 35% of the time

Multi type of merchandise 4 people 35% of the time

4.2.8. Local recreation amenity

Dependant on the amenity

4.2.9. Farmland

1 person present continuously per 1 number of Kilometres^2

4.2.10. Ramblers

1 person present continuously per 1 number of Kilometres^2

4.2.11. Wind farm maintenance staff

1 person present per 20 turbines

4.3. Calculate the probability of people presence (Local Societal)

From the hazard map each hazard zone needs to be considered separately and the number of people estimated that are in the area continuously and the value given for each item added to produce a total value. It should be noted that for a given item this can well be a fraction of a person, e.g. for a 436m radius hazard zone with ‘A road’ persons present = 1 x 0.8/10= 0.08 people. These values will be the number of people likely to be in the hazard zone continuously.

4.4. Calculation

The site hazard map should be reviewed to determine the worst case hazard zone to which to use in checking the acceptability of the site using the risk matrix above. In order to determine the worst case zone for each zone three factors have to be multiplied together. These are ‘number of people continuously in the hazard zone’ x ‘Number of overlapping hazard zones’ x ‘probability of people being hit by flying debris’. The default figure for the ‘probability of people being hit by flying debris’ is 0.2

4.5. Example

Within the hazard zone there is a ‘A road’, maintenance personnel a single outlet retailer and ramblers. Also there is overlap of two wind turbines.

Hence total number of people under threat;

‘A’ Road 0.8Km at 1 person/10Km	0.08
Maintenance Personnel 1/20 per machine	0.05
Single Outlet Retailer 2 persons for 35% time	0.70
Ramblers 1 per Km^2, Area $\pi 0.4^2$	0.50
Total = 1.33	
Total effective number of people at risk = 1.33 x 2 (number of risks) x 0.2 (probability of being hit by debris)	**0.53**
If the likely frequency of one blade failing is $<10^{-4}$ / yr then from **Table 1**	**Tolerable if ALARP**

5. ESTIMATING THE AVERAGE NUMBER OF PEOPLE PRESENT IN THE HAZARD ZONE, INDIVIDUAL RISK

5.1. Company Employee

5.1.1. Identify the parameters

- Areas of the wind farm that present a hazard to peoples from debris
- The named company employee (at the highest risk) who are frequently present in hazards area.

With these two points we can then analyse each farm to identify the probability of person being present in the hazard zone.

The Hazard map defined in 3.2.1 can be used for establishing the first parameter.

5.1.2. Wind farm maintenance staff

Maintenance Person normally present on a site.

5.1.3. Calculate the probability of people presence (employee)

It should be considered that maintenance personnel whilst on site will always be in the hazard zone. However against the above risk matrix a factor of 0.25 can be used since that is his average percentage of hours at work per year.

5.1.4. Calculation

The site hazard map should be reviewed to determine the worst case hazard zone to which to use in checking the acceptability of the site using the risk matrix above. In order to determine the worst case zone for each zone two factors have to be multiplied together. These are ‘Number of overlapping hazard zones’ x ‘probability of employees being hit by flying debris’. The default figure for the ‘probability of employees being hit by flying debris’ is 0.2

5.1.5. Example

Within the hazard zone there could be a maintenance person, also there is an overlap of two wind turbines at the location they are working.

Company employee under threat:	
Maintenance Person 1 x 0.25	0.25
Total = 0.25	
Total effective number of people at risk = 0.25 x 2 (number of risks) x 0.2 (probability of being hit by debris)	**0.1**
If the likely frequency of one blade failing is $<10^{-4}$ / yr then from **Table 5**	**Tolerable if ALARP**

5.2. General Public

5.2.1. Identify the parameters

- Areas of the wind farm that present a hazard to peoples from debris
- The named general public (at the highest risk) who are frequently present in hazards area.

With these two points we can then analyse each farm to identify the probability of person being present in the hazard zone.

The Hazard map defined in 3.2.1 can be used for the purpose of establishing parameter 1.

5.2.2. Non company employees frequently present at site (normally staff of local business located in the hazard area)

Retail, industrial or farming person normally present on a site.

5.2.3. Calculate the probability of named person presence

It should be considered that employees will be frequently on site. However against the above risk matrix a factor of 0.35 can be used since that is his average percentage of hours at work per year.

5.2.4. Calculation

The site hazard map should be reviewed to determine the worst case hazard zone to which to use in checking the acceptability of the site using the risk matrix above. In order to determine the worst case zone for each zone two factors have to be multiplied together. These are ‘Number of overlapping hazard zones’ x ‘probability of employees being hit by flying debris’. The default figure for the ‘probability of employees being hit by flying debris’ is 0.2

5.2.5. Example

Within the hazard zone there is a named retail employee, also there is an overlap of two wind turbines at the location they are working.

Retail employee under threat;	
Retail employee 1 x 0.35	0.35
Total = 0.35	

Total effective number of people at risk = 0.35 x 2 (number of risks) x 0.2 (probability of being hit by debris)	**0.14**
If the likely frequency of one blade failing is $<10^{-4}$ / yr then from **Table 3**	**Tolerable if ALARP**