Assessment of the ice throw and ice fall risks nearby wind energy installations

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TÜV SÜD Industrie Service GmbH, Winterwind, February 4th, 2015

Wind energy is the leading source of renewable energy in Germany, moving towards a nuclear-free and carbon-free generation profile.

High population density

→

Building new wind farms is connected with a complex approval procedure

Wind energy is the leading source of renewable energy in Germany, moving towards a nuclear-free and carbon-free generation profile.

High population density → **Building new wind farms is connected with a complex approval procedure**

one important topic:

assessment of the risk of ice throw and ice fall near the wind turbines

Ice throw and ice fall in the German approval process:

- Wind turbines in Germany are not allowed to operate during ice formation!

  - ➢ **installation of a functional ice detection system**
  - ➢ **subsequent shut-down of the turbine**

  → **have to be confirmed**

Ice throw and ice fall in the German approval process:

- Wind turbines in Germany are not allowed to operate during ice formation!

  - ➢ installation of a functional ice detection system
  - ➢ subsequent shut-down of the turbine

  → have to be confirmed

- Residual risk of ice fall from stopped wind turbines

  has to be investigated for roads, paths or other objects of interest within the range of **1.5 x (rotor diameter + hub height)**

(German Guideline – Richtlinie für Windenergieanlagen, Liste der Technischen Baubestimmungen)

Ice Fall Simulation (1/7)

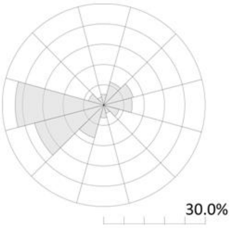
Calculation model using Monte Carlo simulations
to determine the probably affected area around the wind turbine

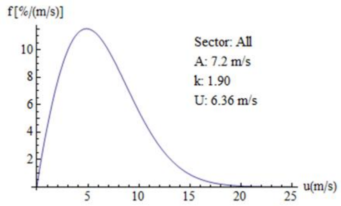
Input parameters:

- Hub height
- Rotor diameter
- Rotor revolution under icing conditions

(Hub height, rotor diameter and rotor revolution under icing conditions: turbine specific parameters)

- Wind properties (distribution of wind speed and direction)
- Ice fragment properties





Ice properties

4 scenarios of ice fragments were identified, based on

- the characteristic ice formation processes
- with assumed proportions

Scenario A:	rime ice with a mass of 90 g
Scenario B:	rime ice with a mass of 240 g
Scenario C:	clear ice with a mass of 70 g
Scenario D:	clear ice with a mass of 180 g

Ice properties

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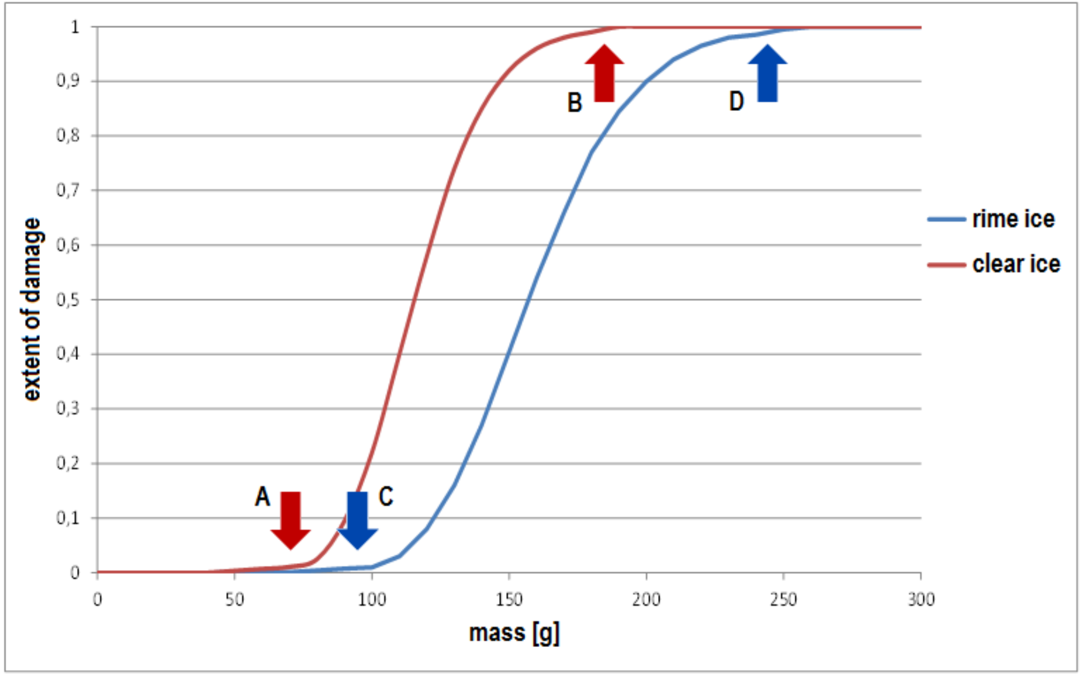
4 scenarios of ice fragments were identified, based on

- the characteristic ice formation processes
- with assumed proportions
- the expected extent of damage of accelerating ice pieces falling from a WTG to the ground

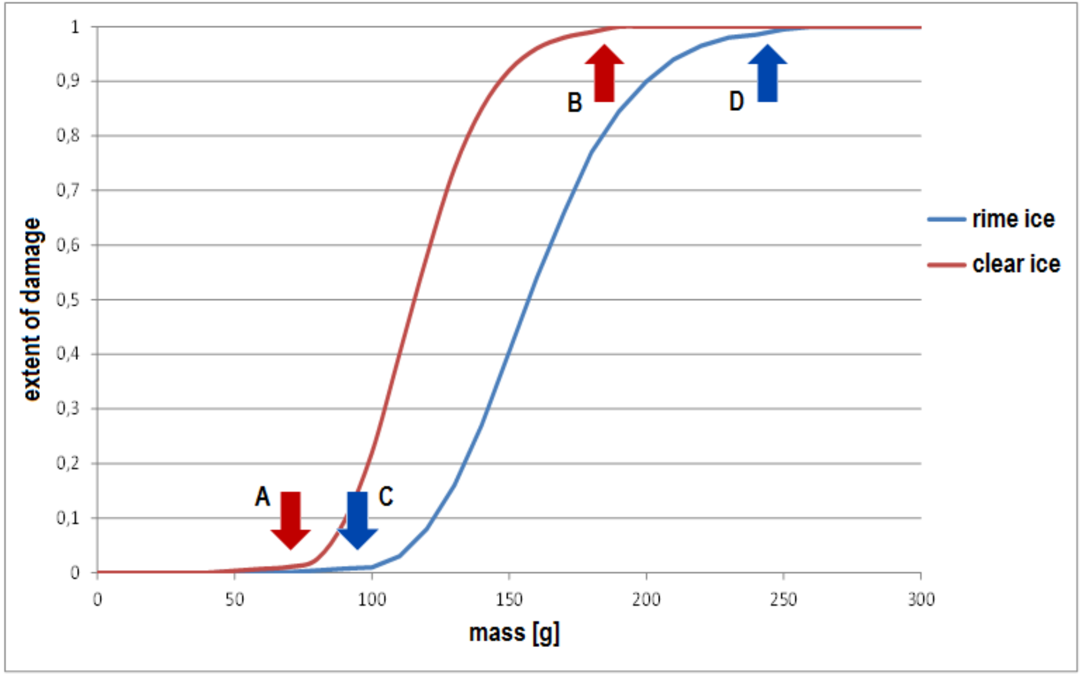
Ice properties



90 g rime ice (Scenario A)
70 g clear ice (Scenario C)
beginning of slight injuries

Extent of damage – related to a height of 140 m (a typical hub height) and to the masses and density of the ice pieces

Ice properties



240 g rime ice (Scenario B)
180 g clear ice (Scenario D)
fatality has to be assumed

90 g rime ice (Scenario A)
70 g clear ice (Scenario C)
beginning of slight injuries

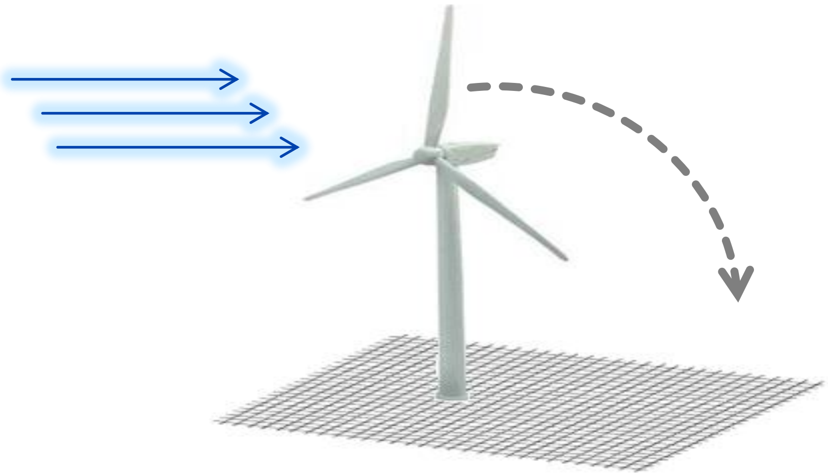
Extent of damage – related to a height of 140 m (a typical hub height) and to the masses and density of the ice pieces

Ice Fall Simulation (4/7)

Input parameters:

- Hub height
- Rotor diameter
- Rotor revolution
- Wind properties
- Ice fragment properties

calculation of the x, y and z acceleration using the equation system of motion



Ice Fall Simulation (5/7)

For each scenario 5 Mio iterations are performed.

hit of an ice fragment on a flat surface
with the WTG in the centre

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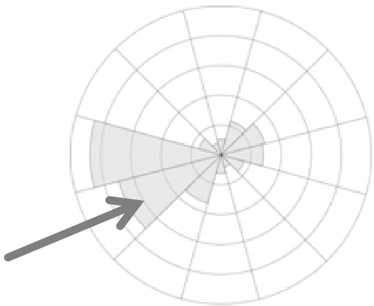
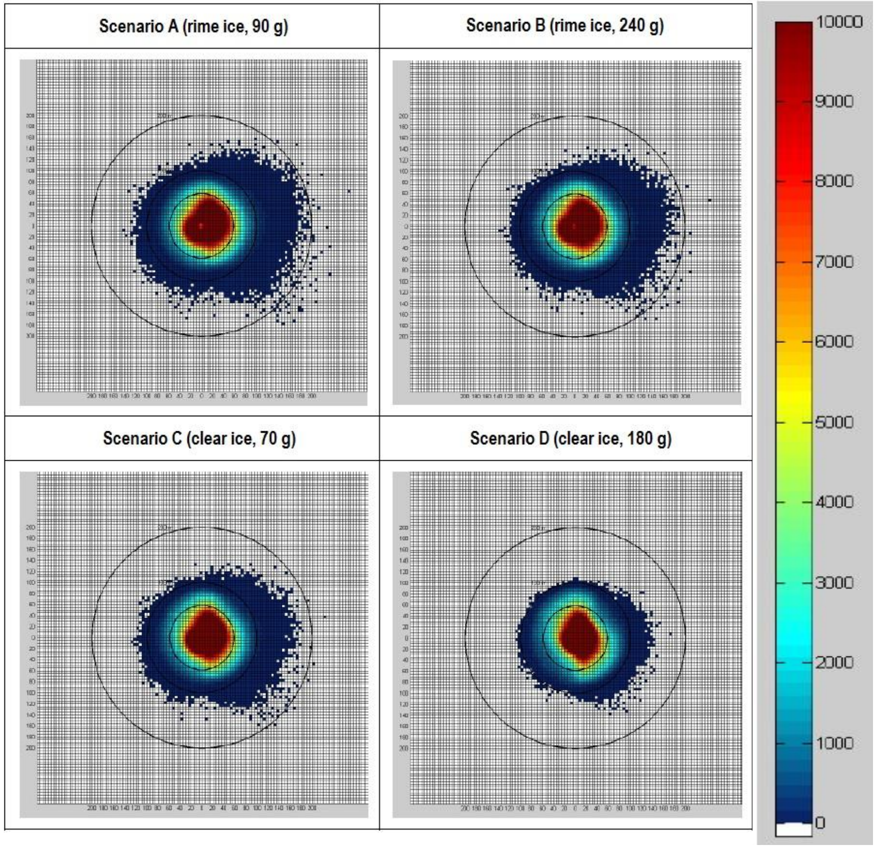


where
– the current wind regime (wind speed and wind direction)
and
– the radial and azimuthal position of the ice fragment on the rotor blade are randomly chosen

Ice Fall Simulation (6/7)

Content | Initial Situation | **Simulation** | Consequence | Frequency | Risk



Results of the simulation:

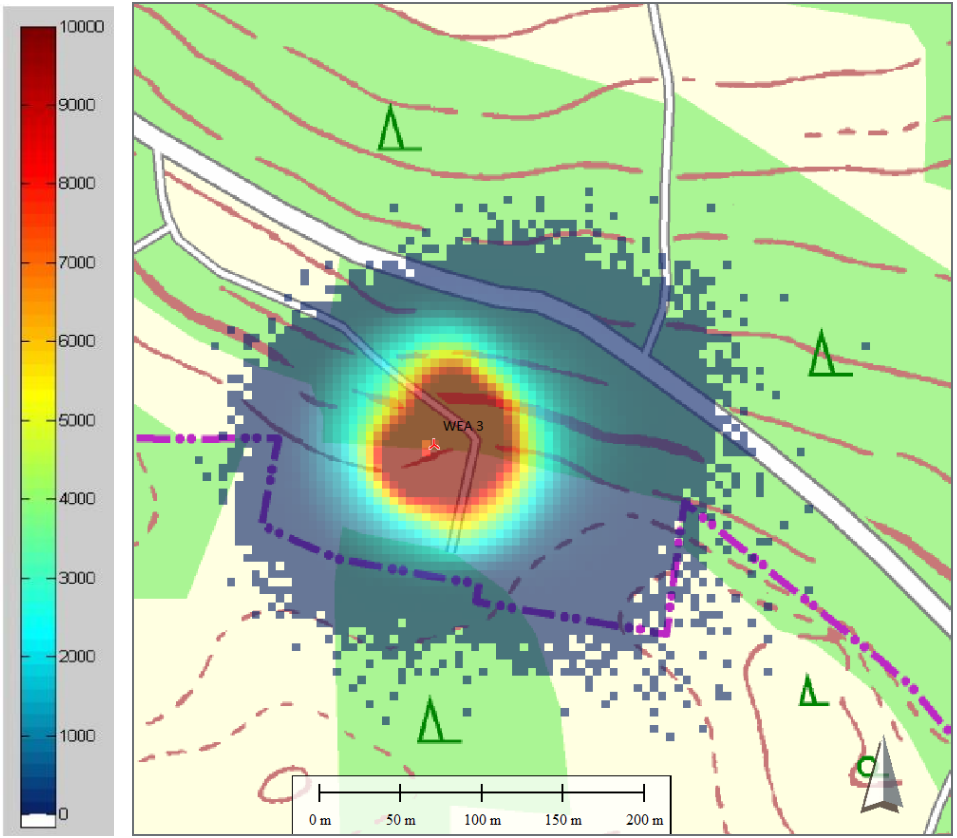
theoretically affected area by ice fall

Example for a WTG with
141 m hub height
117 m rotor diameter

Colouring: total amount of hits per cell

Grid: areas of 5 m x 5 m
Range rings: rotor radius, 100 m, 200 m

Ice Fall Simulation (7/7)



Results of the simulation:

theoretically affected area by ice fall

transferred to a topographical map
(example Scenario A)

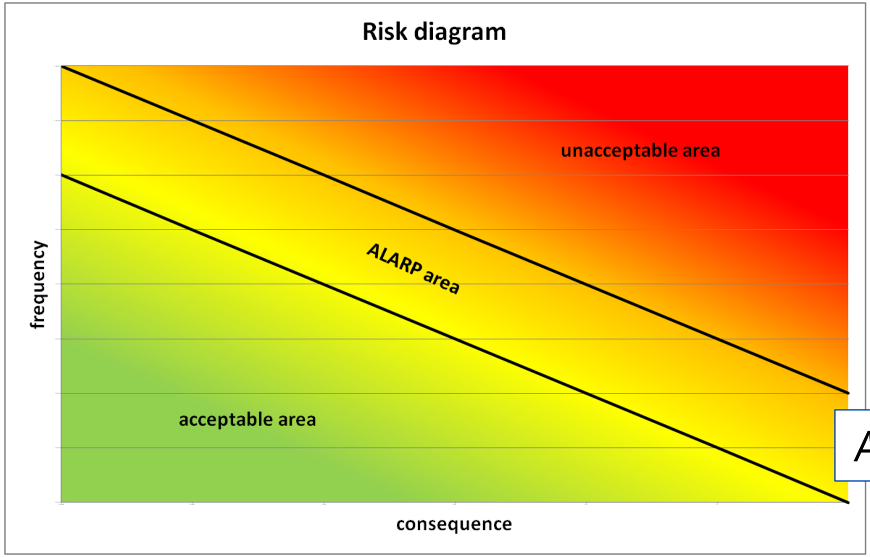
Are roads, footpaths or other objects of interest affected?

Is a risk analysis necessary?

Risk assessment

Risk is defined as

the product of the **consequence of an event** with its **frequency**:



$$R_{scenarioi} = C_{scenarioi} \cdot P_{scenarioi}$$

ALARP area = as low as reasonably practicable

Consequence (1/3)

For determining the extent of damage, the so-called **probit function** is used.

The probit function is defined by

$$\Pr = -17.56 + 5.3 \cdot \ln S$$

with $S = \frac{1}{2} m v^2$ as the kinetic energy of the ice fragment

Consequence (2/3)

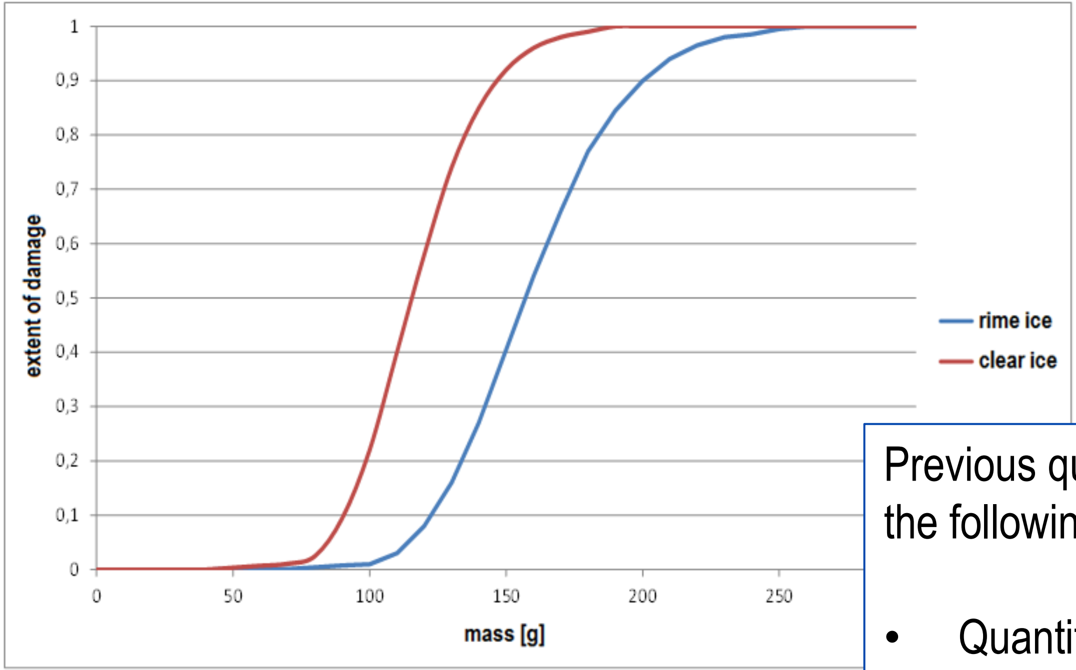
The resulting Extent of Damage (EoD) can be estimated from the following table:

The value of the probit function defines the first and the second digit of the value of the extent of damage.

in this example: 0.84 (84%)

%	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00
0	-	2.67	2.95	3.12	3.25	3.36	3.45	3.52	3.59	3.66
10	3.72	3.77	3.82	3.90	3.92	3.96	4.01	4.05	4.08	4.12
20	4.16	4.19	4.23	4.26	4.29	4.33	4.36	4.39	4.42	4.45
30	4.48	4.50	4.53	4.56	4.59	4.61	4.64	4.67	4.69	4.72
40	4.75	4.77	4.80	4.82	4.85	4.87	4.90	4.92	4.95	4.97
50	5.00	5.03	5.05	5.08	5.10	5.13	5.15	5.18	5.20	5.23
60	5.25	5.28	5.31	5.33	5.36	5.39	5.41	5.44	5.47	5.50
70	5.52	5.55	5.58	5.61	5.64	5.67	5.71	5.74	5.77	5.81
80	5.84	5.88	5.92	5.95	5.99	6.04	6.08	6.13	6.18	6.23
90	6.28	6.34	6.41	6.48	6.55	6.64	6.75	6.88	7.05	7.33
-	**0.00**	**0.10**	**0.30**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
99	7.33	7.37	7.41	7.46	7.51	7.58	7.65	7.75	7.88	8.09

Consequence (3/3)



This relation was considered by defining the 4 scenarios of ice fragments as well!

Previous quantitative approach considers the following relation:

- Quantitative value of 1: fatality
- Quantitative value of 0.1: severe injury
- Quantitative value of 0.01: slight injury

Frequency of ice fall events

- estimation based on the WECO project *(Wind Energy Production in Cold Climate)*
- observation of a WTG, counting ice pieces around the test site in Switzerland
- 200 ice falls over 3 winters were detected

As it is expectable that not all the pieces were found,
200 ice fall events per year are assumed in the risk assessment.

(a more site-specific improvement is planned)

Determining the Frequency (2/3)

Relevant cross section area

Which is the significant target group?

Driver	**Pedestrian**
Relevant Area: 2 m² (windscreen)	Relevant Area: 0.04 m² (head)
Resulting probability: $P_T = 0.08$	Resulting probability: $P_T = 0.0016$

Exposition

(time per year spent in the hazardous area)

Driver	Pedestrian
Velocity depends from the type of road	Velocity of 5 km/h assumed
for 60 km/h the driver stays for 0.3 s in one grid cell (5 m x 5 m)	the pedestrian stays for 3.6 s in one grid cell (5 m x 5 m)

Utilization Categories

Calcuation values for the frequency used for days with ice fall conditions

	Category	Meaning
10	Regularly used	This way is – due to its size, its accessibility and its position to villages and towns – assumed to be used regularly. This means, it has to be assumed that this way is used by one and the same jogger or pedestrian at each day we assume ice fall conditions.
3.16	Often used	For this kind of way not all of the attributes above are applicable. So leads e. g. a higher distance to villages or a worse accessibility to the assumption that this way is not used at each day by joggers or pedestrians.
1	Sporadically used	These are ways, which can be clearly identified as ways from the aerial view, but which are definitely not used as a main ways and which conditions allows the conclusion that it is used sporadic.
0.316	Rarely used	These are ways, which can be identified as ways from the aerial view and which conditions allows the conclusion that it is used sporadic.
0.1	Usually not used	Ways which can be rarely identified as such from the aerial view, which are a lot of kilometres away from the next buildings or which are identified as blind alleys are seen as usually not used.

Risk assessment

Calculation of the risk for each scenario using the previous parameters

$$R_{scenarioi} = C_{scenarioi} \cdot P_{scenarioi}$$

As we don't know exactly the mass distribution and the fraction of rime and clear ice,

we assume **each scenario has the same probability**:

$$R = 0.25 \cdot \sum_{i=AtoD} C_{Szenarioi} \cdot P_{Szenarioi}$$

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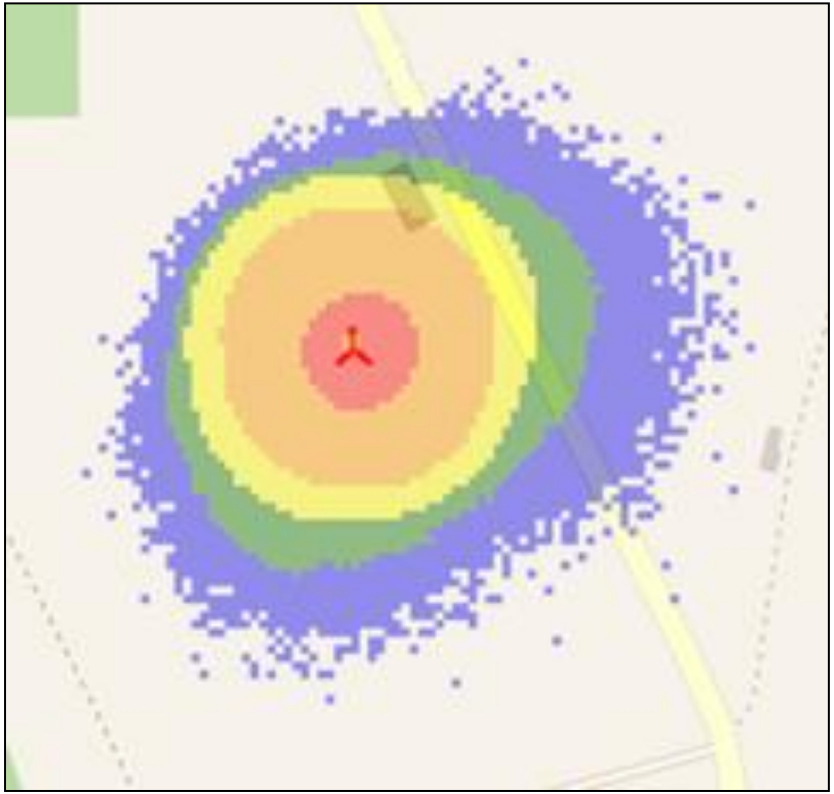
This risk is calculated for each grid cell.

Final risk → **sum of the risks for all grid cells, which are crossed by a pedestrian or a driver.**

Risk assessment – practical interpretation (1/2)

The risk results are transferred to a topographical map, similar to the ice fall simulation results.

Colouring: **risk crossing a grid cell**



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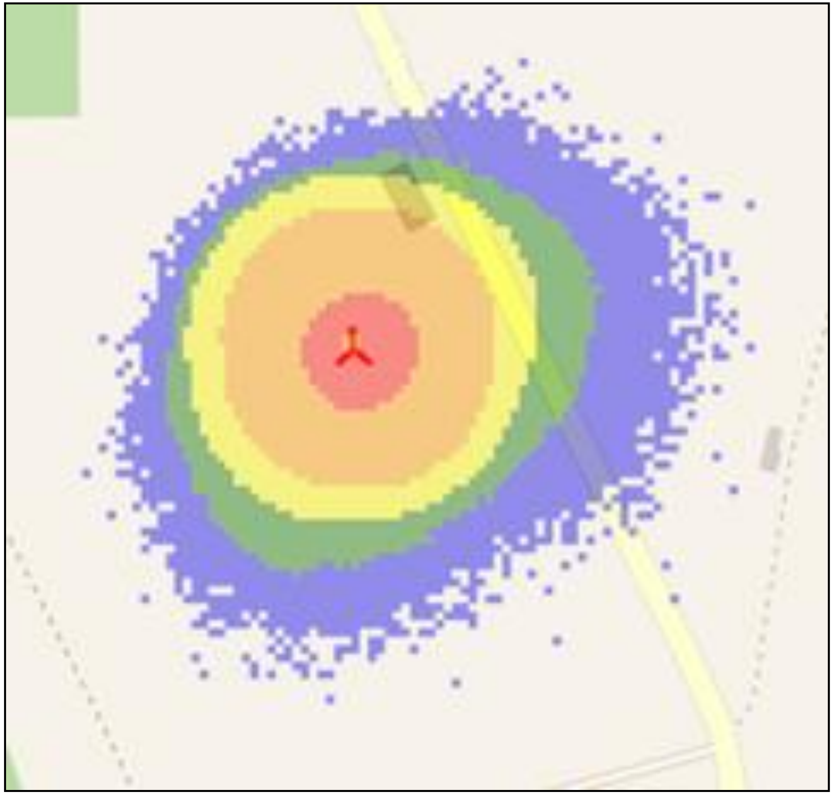
R < 1E-08	negligible
1E-08 <= R < 1E-07	acceptable
1E-07 <= R < 1E-06	tolerable
1E-06 <= R < 1E-05	high
R >= 1E-05	unacceptable



Are sanctions necessary?

Risk assessment – practical interpretation (2/2)

Useful for comparison:

Reference values for risk

Cause of Death / Industry Sector	Frequency (as 1 in 'X')	Frequency (as $1x10^{x}$)
Death from smoking 20 cigarettes/day	1 in 200	$5x10^{-3}$
Deaths from regular recreational rock climbing	1 in 250	$4x10^{-3}$
The HSE lower level of tolerable risk to workers	1 in 1,000	$1x10^{-3}$
Drinking 1 bottle of wine/day	1 in 1300	$7.5x10^{-4}$
The HSE lower level of tolerable risk to population at large	1 in 10,000	$1x10^{-4}$
Death in off-shore oil & gas industry Death from all forms of road accident Deaths - Working in the construction industry (UK)	1 in 14,564 1 in 16,800 1 in 17,000	
Dutch criteria for minimum individual risk in existing establishments	1 in 100,000	$1x10^{-5}$
Death by murder in UK	1 in 100,000	$1x10^{-5}$
Deaths in the "service industries"	1 in 333,000	
Dutch criteria for 10 fatality incident The UK HSE "Broadly Acceptable" level of risk Risk of electrocution in the home	1 in 1,000,000	$1x10^{-6}$
Death - Gas incident (fire, explosion or carbon monoxide poisoning)	1 in 1,510,000	
Dutch Criteria for 100 fatality incident	1 in 10,000,000	$1x10^{-7}$
Winning 6 numbers in the National Lottery **Risk at 500m from death by toxic cloud at Bathside Bay** Being struck by lightning (England & Wales 1995-99)	1 in 14,000,000 1 in 16,000,000 1 in 18,700,000	

Contact details

Industrie Service

Choose certainty.
Add value.

Thank you for your attention!

If you have any further question, don‘t hesitate to contact us:

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