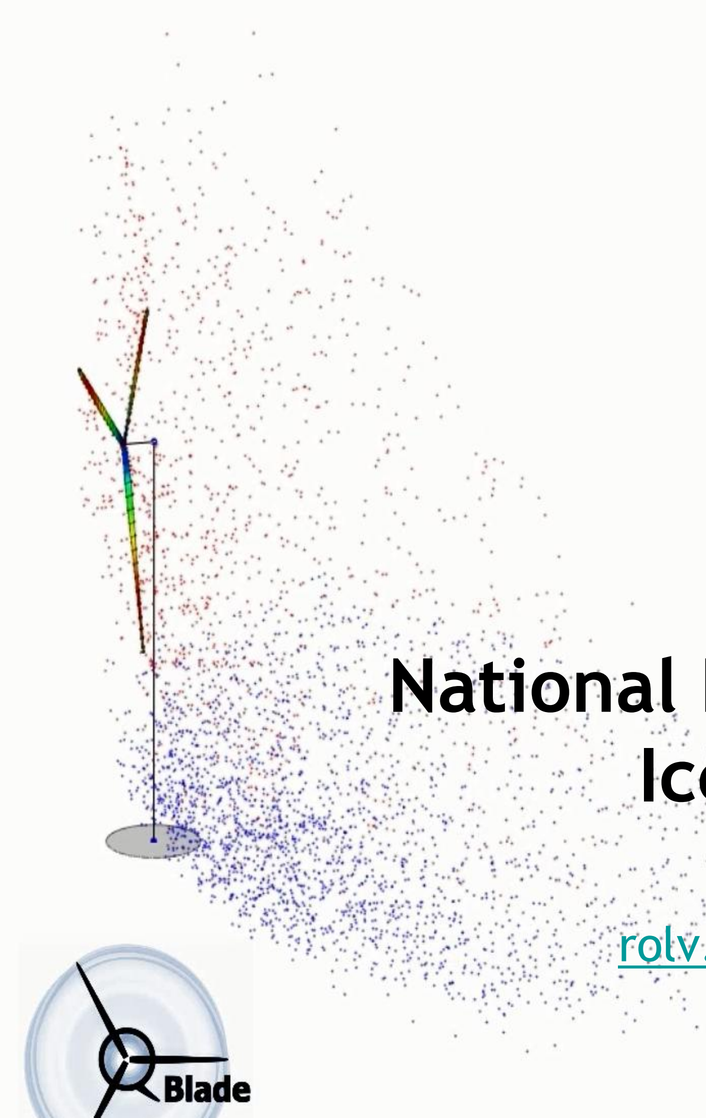

Roger Flage, IRIS
Bushra Butt, NVE

National Norwegian Guidelines: Ice-throw hazard

Rolv Erlend Bredesen
rolv.bredesen@vindteknikk.no

The goal of the project is to prepare easily understood and relevant advise for wind farm concessionaires (owners/operators) and to the general public:

- 1) How to communicate the risk of injury and damage to the general public caused by ice throw and ice fall.
- 2) Relevant measures handling the risk of injury and damage.
- 3) Clarify the criminal and compensatory liability for incidents involving injury.

- The Norwegian Guideline is meant as a supplement to the IEA Wind Task 19's internationally harmonized guidelines regarding ice throw risk assessments

Summary of available background knowledge and guidelines

- New studies
  - IceThrower!
  - Enercon study!
  - Austrian study!

- Current knowledge and the way forward in state-of-the-art risk assessments has been reviewed
  - Peer-reviewed article
  - WindEurope presentation
  - WindEurope audio

WindEurope Conference & Exhibition 2017 IOP Publishing
IOP Conf. Series: Journal of Physics: Conf. Series **926** (2017) 012001 doi:10.1088/1742-6596/926/1/012001

Understanding and acknowledging the ice throw hazard - consequences for regulatory frameworks, risk perception and risk communication

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Abstract. This study attempts to provide the necessary framework required to make sufficiently informed decisions regarding the safety implications of ice throw. The framework elaborates on how to cope with uncertainties, and how to describe results in a meaningful and useful manner to decision makers. Moreover, it points out the moral, judicial and economical obligations of wind turbine owners such that they are able to minimize risk of ice throws as much as possible. Building on the strength of knowledge as well as accounting for uncertainty are also essential in enabling clear communication with stakeholders on the most important/critical/vital issues. With increasing empirical evidence, one can assign a higher confidence level on the expert opinions on safety. Findings regarding key uncertainties of ice risk assessments are presented here to support the ongoing IEA Wind Task 19's work on creating the international guidelines on ice risk assessment due in 2018 (Krenn et al. 2017)[1-6]. In addition the study also incorporates the findings of a Norwegian information project, which focuses on the ice throw hazard for the public (Bredesen, Flage, Butt, Winterwind 2018)[7-9]. This includes measures to reduce damage and hazard from wind turbines for the general public. Recent theory of risk assessment questions the use of risk criteria for achieving optimum risk reduction and favours the use of the ALARA (as low as reasonably achievable) principle. Given the several practical problems associated with the ALARA approach (e.g. judicial realization), a joint approach, which uses a minimum set of criteria as well as the obligation to meet ALARA is suggested (associated with acceptable cost). The actual decision about acceptance criteria or obligations is a societal one, thus suggestions can be made at best. Risk acceptance, risk perception and risk communication are inextricably linked and should thus never be considered separately. Risk communication can shape risk perception, which again is vital for defining risk acceptance. Moreover, risk communication should be seen as an opportunity to demonstrate trustworthiness and an open, responsible and caring attitude. It is important for the wind industry to avoid accidents: In Winterwind 2017 (Ronsten)[10], the importance for the wind power community to proactively take safety measures for passers-by and service personnel was emphasized: Establishing good practices and communication routines is key to avoid accidents. Visually attractive ways of presenting the risk of ice throw are recommended.

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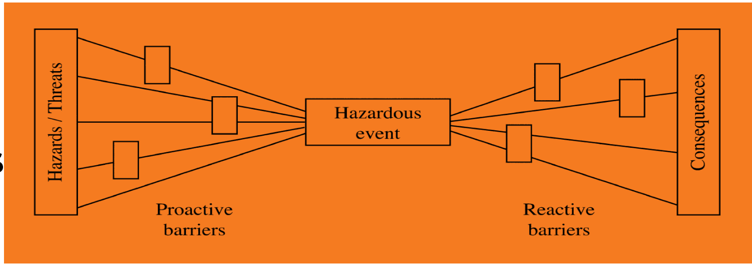
There is a requirement from NVE to evaluate the extent of icing and to assess the risk of ice throw/ice fall when applying for a wind farm license in Norway

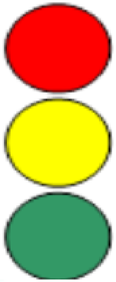
- A recommended list of the most important items in such an evaluation are presented together with short guidance on how to perform said work.
- NVE wishes to recommend a practical easy recipe that the developer can follow within a reasonable financial framework

- The terms are meant to prevent injuries to the public.

Are the relevant risks controlled?

- Evaluate the **extent of icing**
- Assess the risk of icethrow/fall
  - Register the use of area that may be exposed to ice throw in the area
  - Who is at risk?
  - **Describe the causal and consequence picture**
    - Relevant initiating events, causes and **consequences**
    - barriers mitigating the risk, barrier failure
  - **Describe the uncertainty**
    - e.g. likelihood of described event and associated consequence occurring
    - Probability maps
  - Assess the confidence in and the quality of the performed analysis
    - e.g. using strength of knowledge indices: (high/medium/low),
    - e.g. Sensitivity on critical assumptions (NUSAP elements with radarcharts)
- Evaluate the identified risk with acceptance critera
- **Assess whether and what measures should be taken**



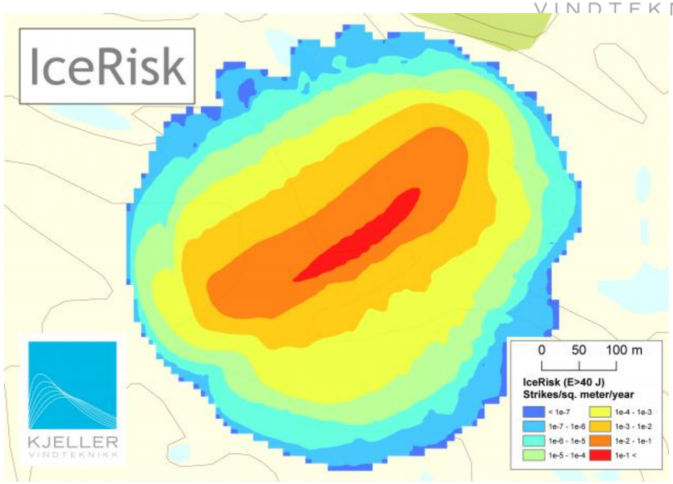


Task 19 International guidelines (quantitative ice throw risk assessments)

- An international expert group has agreed on the required aspects of ice throw risk assessments and will present guidelines

Prevalent approach for ice risk assessments

- 1) Mathematical trajectory/calculation model
  - Turbine parameters:
    - Hub height
    - Rotor diameter
    - Operational mode
  - Topography
  - Physical parameters
    - Air density
    - Vertical wind profile
    - Radial distribution of ice on blades
    - No. of relevant fragments
- 2) Wind and Icing data
  - Wind statistics representative for periods when icing and melting may occur
  - Estimation of amount of ice fragments



- 3) Risk assessment
  - Probability of Persons present
  - Calculation of risk level
  - Threshold for accepted risk levels
  - Safety measures
  - Consideration of uncertainties

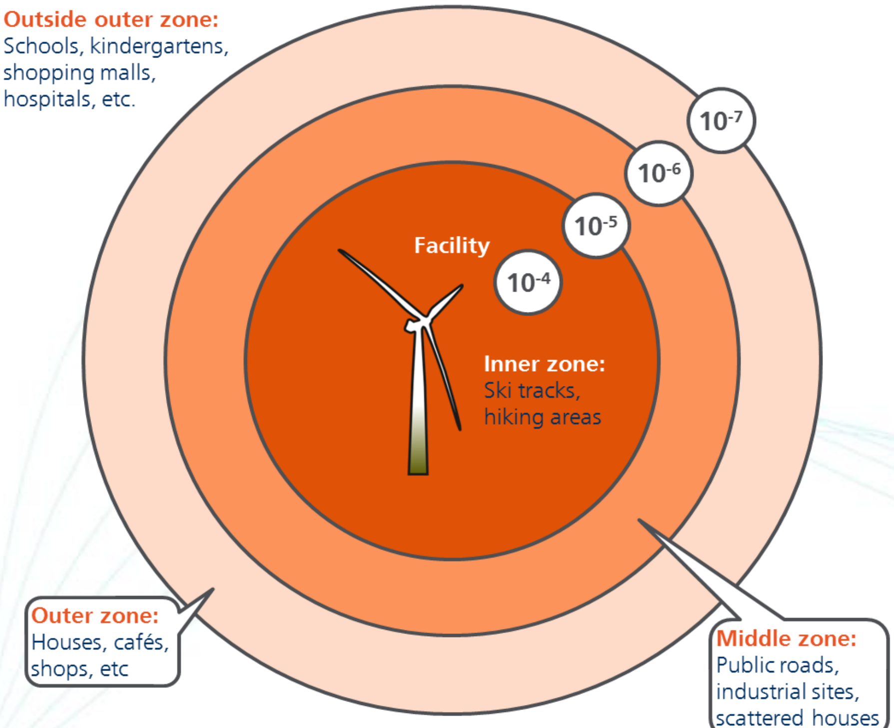
It is recommended to make realistic assumptions on the input parameters

- mathematical trajectory model
- wind speed data
- size and shape of used ice fragments

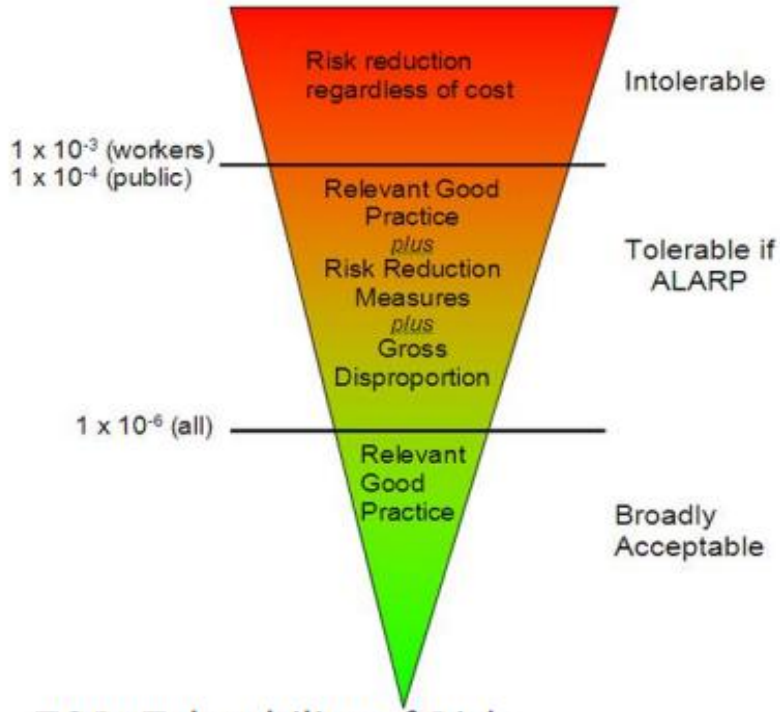
- Unless the uncertainty is specified it is recommended to make **conservative assumptions for the following parameters:**
  - Number of ice fragments
  - Likelihood / exposure of people
  - Vulnerability / probit function
  - Thresholds for accepted risk level
  - Effectivity of measures

Risk comparison using individual risk metrics:

1) LIRA
(localized individual risk per annum)



2) IRPA
(individual risk per annum)



TOR: Tolerability of Risk

ALARP: As Low As Reasonably Practicable

Source: www.railssa.com

Suitable risk mitigation measures in addition to the detailed planning of wind farm

- Designed signs
- Warning routines
- Possible sound and light signals
- Direct warning systems (e.g. sms/app)
- Detection systems
- Establish public knowledge about the risk
- Consider physical safeguards and/or curtailment options
    - (e.g. to stop the turbine during periods of particularly high risk).

- Relocate and mark ski tracks and hiking trails
- Temporary cordons to prevent traffic during periods of high risk

Establish public knowledge and sufficient understanding

- Signs and warning routines/systems should be supplemented with continuous and effective information transfer that helps the users of the area to understand the specific danger
  - newspaper articles in local media
  - brochures / information in pocket format that can be distributed
  - QR codes on signs and more comprehensive information boards at the main entrance of the wind power plant.

- It is an advantage that the information about the risk is correct and effective

Thank you for your attention!

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20 YEARS ANNIVERSARY 1998 - 2018

Bonus slides

Strength of knowledge index

- *The knowledge is judged as weak if one or more of these conditions is true:*
  - *w1) The assumptions made represent strong simplifications.*
  - *w2) Data/information are/is non-existent or highly unreliable/irrelevant.*
  - *w3) There is strong disagreement among experts.*
  - *w4) The phenomena involved are poorly understood; models are non-existent or known/believed to give poor predictions.*
- *If, on the other hand, all (whenever they are relevant) of the following conditions are met, the knowledge is considered strong:*
  - *s1) The assumptions made are seen as very reasonable.*
  - *s2) Large amounts of reliable and relevant data/information are available.*
  - *s3) There is broad agreement among experts.*
  - *s4) The phenomena involved are well understood; the models used are known to give predictions with the required accuracy.*
- *Alternatively divide into weak, moderate-weak, moderate, moderate-strong, and strong background knowledge*

Strength of knowledge index

1. If risk is found acceptable according to probability with large margins, the risk is judged as acceptable unless the strength of knowledge is weak (in this case the probability based approach should not be given much weight).
2. If risk is found acceptable according to probability, and the strength of knowledge is strong, the risk is judged as acceptable.
3. If risk is found acceptable according to probability with moderate or small margins, and the strength of knowledge is not strong, the risk is judged as unacceptable and measures are required to reduce risk.
4. If risk is found unacceptable according to probability, the risk is judged as unacceptable and measures are required to reduce risk.

- *The judgement on the strength of knowledge can be made according to the following criteria*
  - *The reasonability of the assumptions made*
  - *Amount and relevance of data*
  - *Agreement/consensus among experts*
  - *How well phenomena involved are understood*
- *The strength of knowledge can be classified as*
  - *Poor background knowledge (red)*
  - *Medium strong background knowledge (yellow)*
  - ***Strong background knowledge (green)***

Bonus

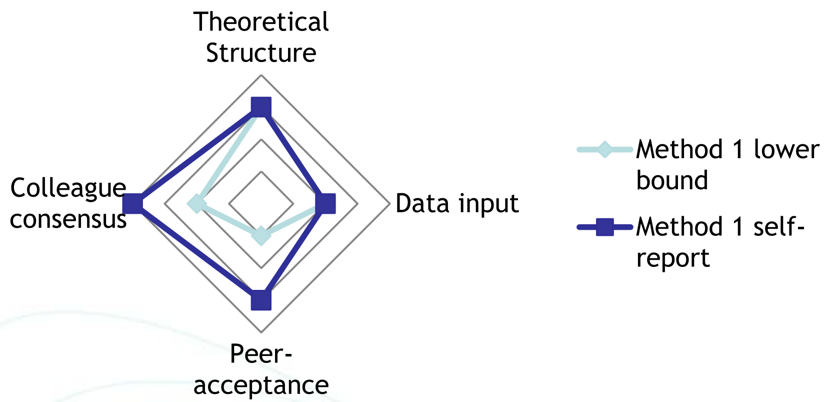
- More detailed strength of knowledge assessment using NUSAP elements is possible

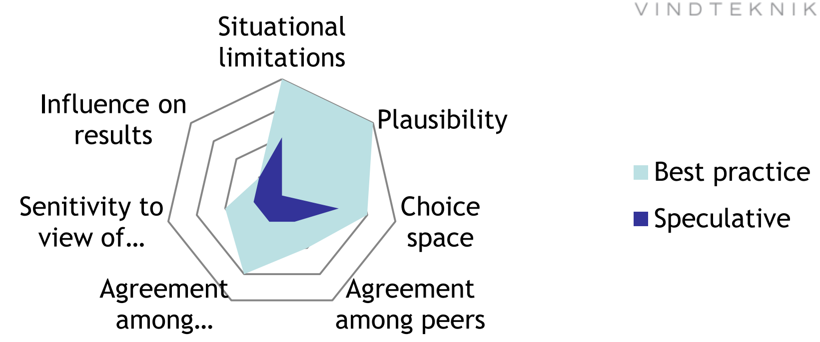
With NUSAP we are able to provide numerical statements with considerable nuance of expression.

- Numerical, Unit, Spread, Assessment, Pedigree
- A NUSAP element for the uncertainty on the amount of ice debris thrown from a turbine may look like this list of values and scores: Numeral, 8.8 tons; Unit, kg/year; Spread, [7.5tons,10 tons]; Assessment, (High > 90 % probability/confidence); Pedigree (3,2,3,4). Here, the Pedigree score are given according to the following table (A) indicating that the assessment was based on a theoretical model and calculated data, and that this use is accepted among colleagues, and colleagues including rebels would bring consensus regarding the use of the model and calculated data.

Radar charts and kite diagrams

A: Pedigree to assess research
B: Pedigree to assess assumptions





	Method 1 lower bound	Method 1 self-report
Theoretical Structure	3	3
Data input	2	2
Peer-acceptance	1	3
Colleague consensus	2	4

	Best practice	Assess assumptions
Situational limitations	4	2
Plausibility	4	0
Choice space	3	2
Agreement among peers	2	1
Agreement among stakeholders	3	1
Sensitivity to view of analyst	2	1
Influence on results	1	1

Relevant pedigree matrices (A, B):

- Pedigree matrix for research (Funtowicz and Ravetz, 1990)

Score	Theoretical Structure	Data input	Peer-acceptance	Colleague consensus
4	Established theory	Experimental data	Total	All but cranks
3	Theory-based model	Historic / field data	High	All but rebels
2	Computational model	Calculated data	Medium	Competing schools
1	Statistical processing	Educated guesses	Low	Embryonic Field
0	Definitions	Uneducated guesses	None	No

- Pedigree scheme used to assess assumptions (Flage, 31.05.2017, based on van der Sluijs et al., 2005a, 2005b)

Score	Influence of situational limitations (time, money, etc.)	Plausibility	Choice space	Agreement among peers	Agreement among stakeholders	Sensitivity to views of analyst	Influence on results
4	No such limitations	Very plausible	No alternatives available	Complete agreement	Complete agreement	Not sensitive	Little or no influence
3	Hardly influenced	Plausible	Very limited number of alternatives	High degree of agreement	High degree of agreement	Hardly sensitive	Local impact in the calculations
2	Moderately influenced	Acceptable	Small number of alternatives	Competing perspectives	Competing perspectives	Moderately sensitive	Important impact in a major step in the calculation
1	Importantly influenced	Hardly plausible	Average number of alternatives	Low degree of agreement	Low degree of agreement	Highly sensitive	Moderate impact on end result
0	Completely influenced	Fictive or speculative	Very ample choice of alternatives	Controversial	Controversial	Extremely sensitive	Important impact on end result

Ice-throw workshop, Winterwind 2018

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Will the authorities intervene? Yes, if we don’t act responsibly

- Terms are ment to ensure public safety
- Require proper risk assessments
- Increase risk understanding
- Employ suitable mitigation options
- Keep the risk as low as reasonably achievable (associated with cost)
- Communicate efficiently

But we don´t want to see this....

The Newspaper

Wind turbine kills young skier in north Sweden

Umeå 9 February 2011

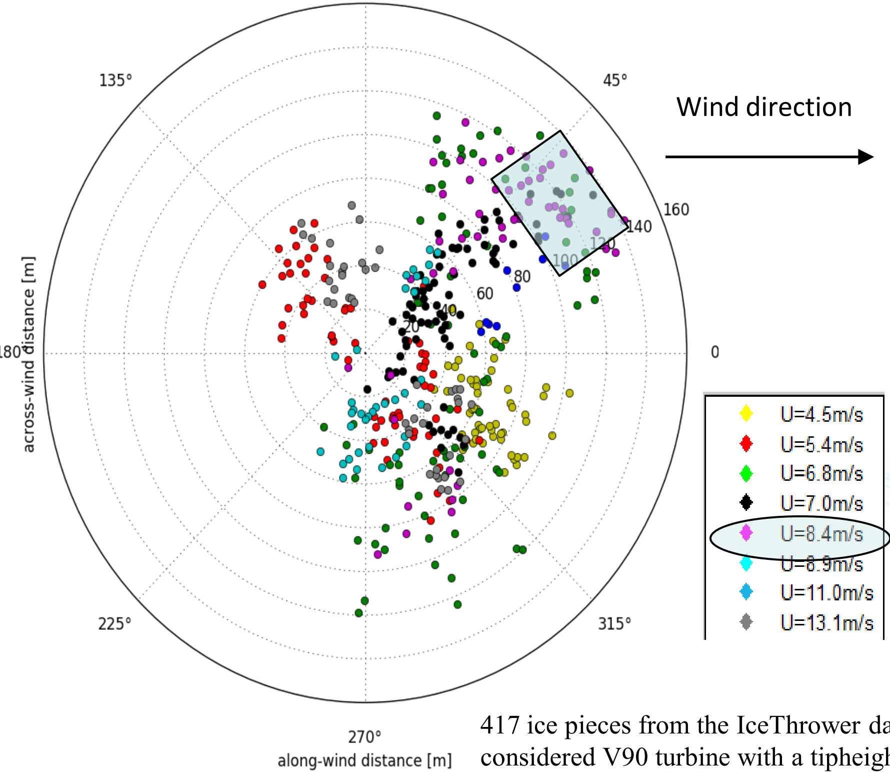
A 5 year old girl out skiing with her parents was killed yesterday in western Lapland as she was hit by a huge ice block falling off a nearby wind turbine.

12 | Winterwind 2011 | 2011-02-09

Courtesy:
Göran Ronsten

Bengt Göransson
(2011)

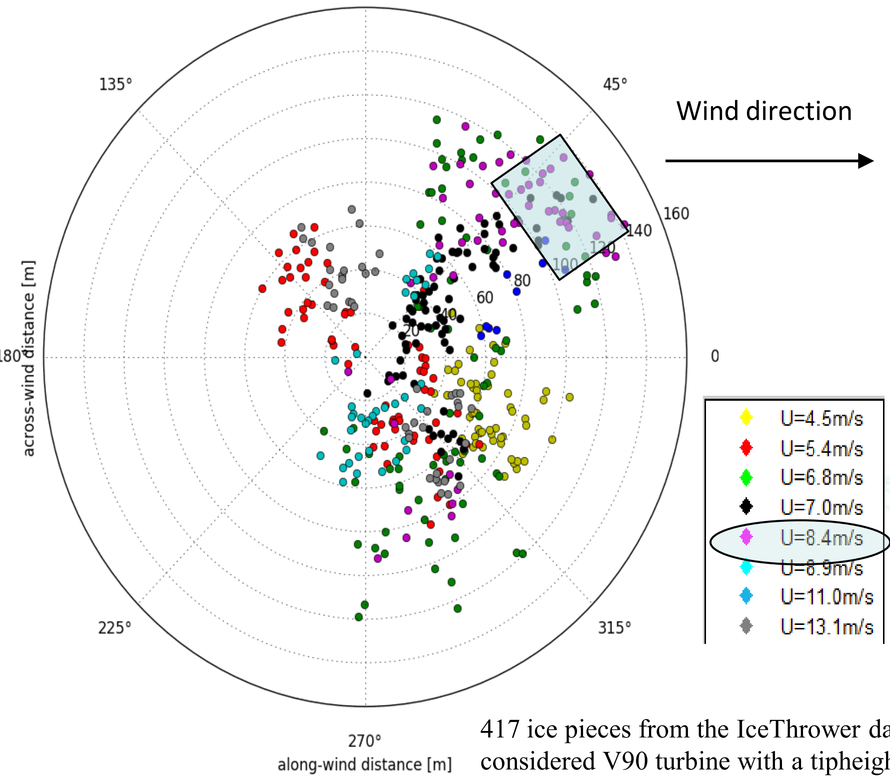
Todays topics



417 ice pieces from the IceThrower database for the considered V90 turbine with a tipheight of 140 m.

- Discussion on the H+D distance recommended in the IceThrower project (Göransson, Pöyry)
- Agreed aspects of risk assessment by Task 19 (Barup, Enercon)
- Ice and blade throw simulations (Sarlak, DTU)
- HSE Best practice in Canada (Godreau, TechnoCentre E.)

Large uncertainty in the observed strike probability



417 ice pieces from the IceThrower database for the considered V90 turbine with a tipheight of 140 m.

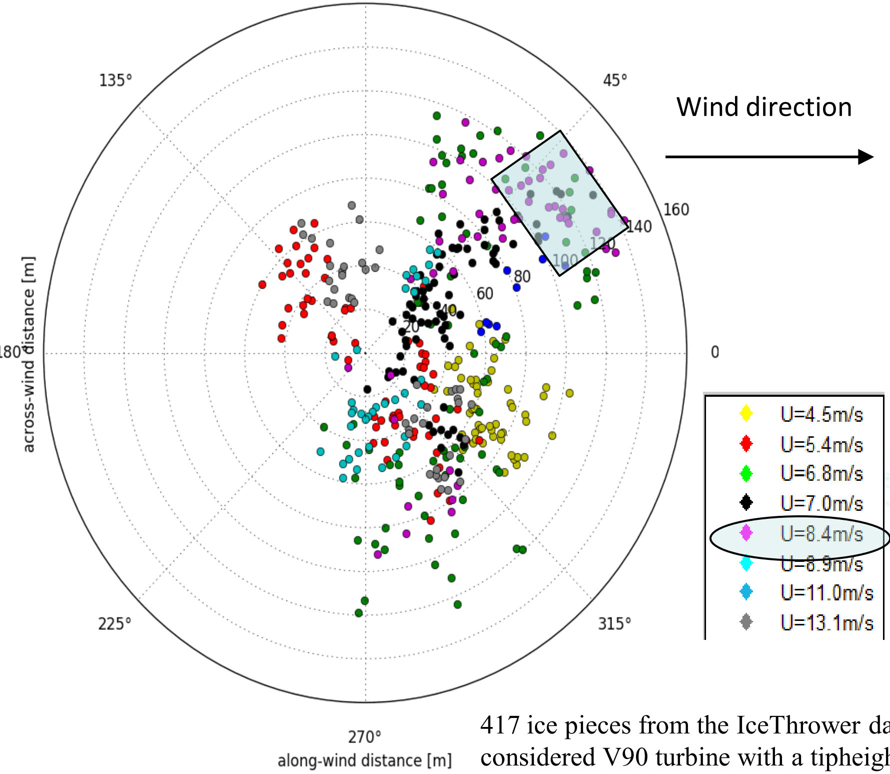
- Areal focus vs all episode aveage
- The uncertainty of the risk at distance 120 +- 20 m is in the range from 5x10^-6 as an all-sector/all-episode value to a focus of 1.25 x 10^-2 strikes per square meter per episode.
- Order 3.4 in difference (factor 2500).

IceThrower database - episode E

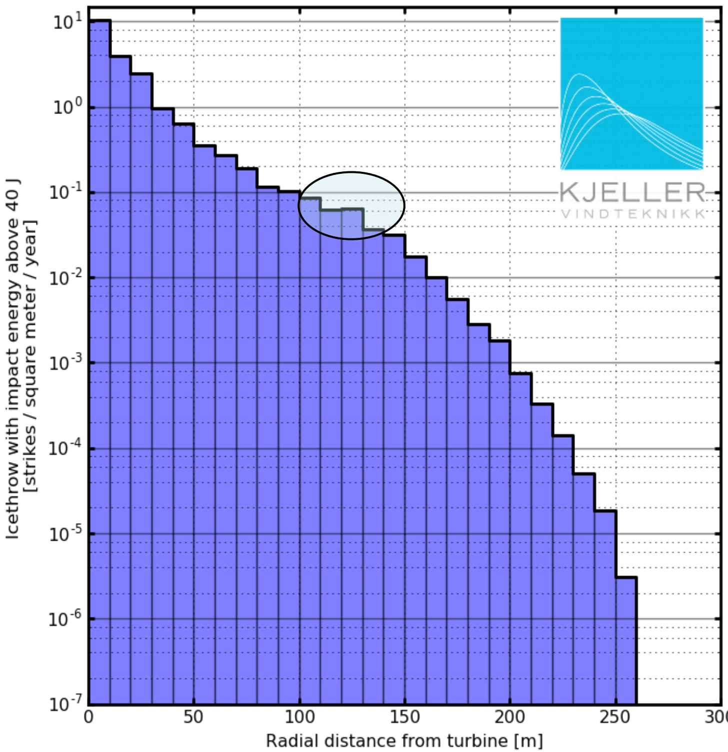
20 strikes in a 40 m x 40 m region at 120 m distance:

0.0125 strikes per square meter for the episode

Modelled assumed upper limit: 0.06 strikes/square meter/year



417 ice pieces from the IceThrower database for the considered V90 turbine with a tipheight of 140 m.



Bonus

Part 2: Acknowledge that relevant risks has to be managed and controlled

- Assessments **informs** decision makers
- Understanding is achieved by identifying and describing risks in a risk management process
  - Quantitative assessment: **Risk = probability x consequence**
  - Qualitative assessment: **Risk = consequence and associated uncertainty**
  - Both
- Recommendation: As low as reasonably achievable

National Norwegian guidelines on the risk of ice throw for the public (2018)

- Strengthening the attention on ice throw and ice fall
- The communication of risk for injury is a challenge
- **There is a need for a standardization of measures handling/mitigating the risk**
- Events causing damage or injury may trigger compensatory and criminal liability.
  - owners/operators/board members/HSE

Photo: prisonpath.com

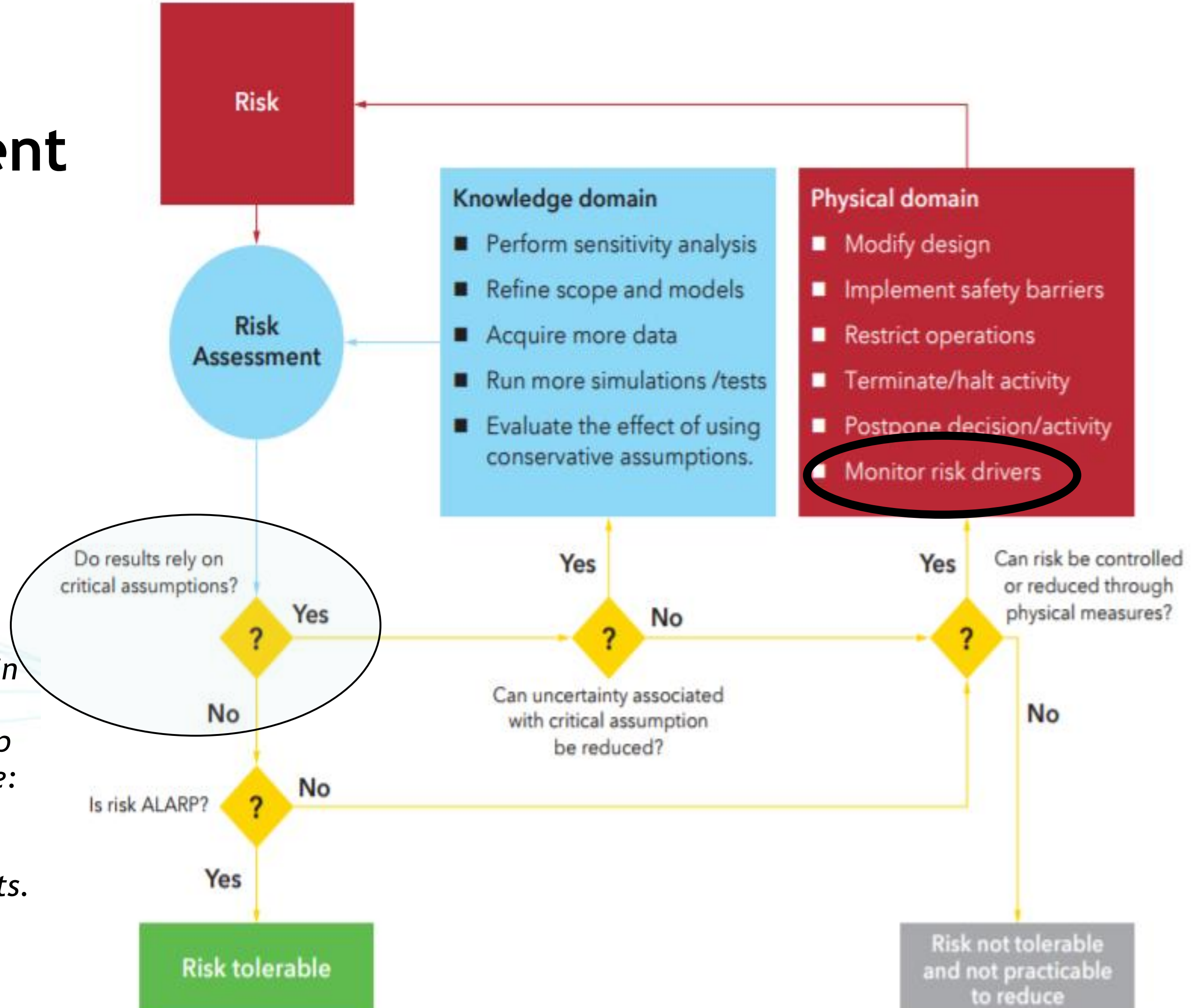
- The default warning system is reasonably located signs
  - Personal responsibility of public to respect a well designed warning system.

Risk communication should be seen as an opportunity to demonstrate trustworthiness and an open, responsible and caring attitute

- Risk assessment and management
  - **Recent theory of risk assessment question the use of risk criteria for achieving optimum risk reduction. The precision issue of risk assessments is acknowledged**
  - Minimize the risk of ice throw (moral, judicial and economical obligation)
  - Describe assessment results in a meaningful and useful manner
  - Risk acceptance, risk perception and risk communication are inextricably linked and should thus never be considered separately
- **Communicate clearly and early with stakeholders**
  - Build on the strength of knowledge
  - Account for uncertainty
- Risk acceptance criteria
  - Favor use of the as low as reasonably achievable/practicable principle
  - The actual decision about acceptance criteria or obligations is a societal one, suggestions can be made at best
  - **Risk communication can shape risk perception, which again is vital for defining risk acceptance**

The risk management process -
sufficient understanding and confident decision-making

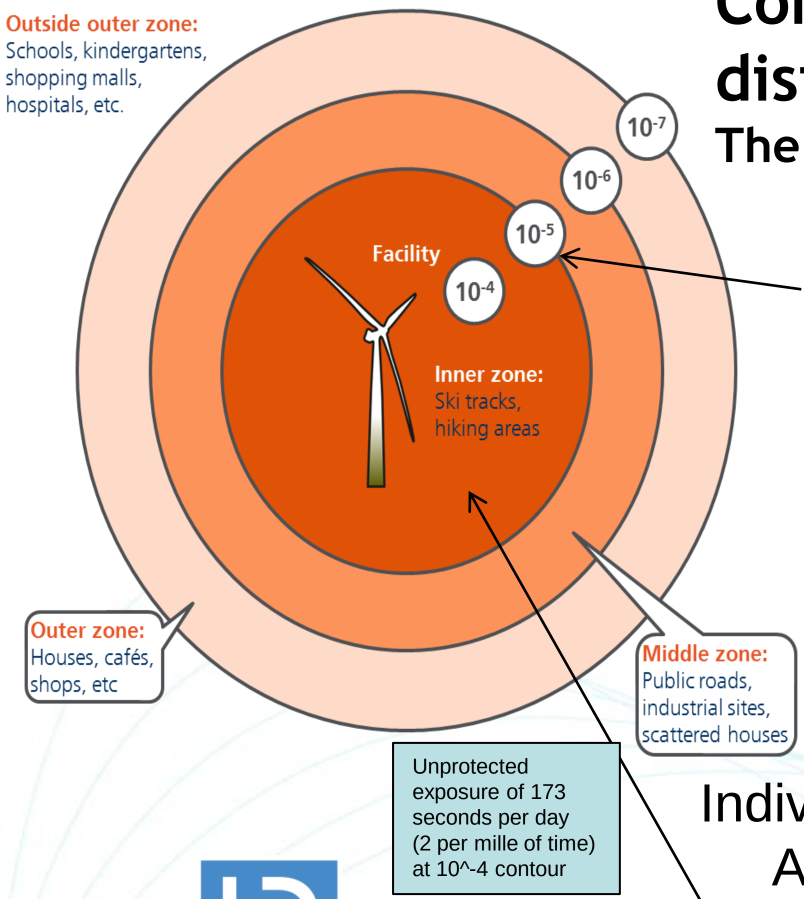
- *Risk assement as a tool to gain risk understanding, which is necessary to manage and keep the risk under control. Source: DNV-GL (2016)[36] Enabling confidence: Adressing uncertainty in risk assessments. Courtesy of Frank Børre Pedersen (DNV-GL).*



Comparable zones and consultation distances

The Norwegian Directorate for Civil Protection (DSB)

KJELLER VINDTEKNIKK



- Risk acceptance criteria (LIRA): 10^-5 for third person (combined from all sources at facility)
- The **suggested** acceptance criteria shall motivate further risk mitigating efforts
- ALARP – As low as reasonably practicable independent on risk acceptance criteria
- http://www.lr.org/en/news-and-insight/articles/evaluating-risk-caused-by-ice-throw-from-wind-turbines.aspx

Lloyd's Register Consulting

Individual Risk per Annum (IRPA):

- 1. person: 4 · 10-5
- 2. person: 3 · 10-6
- 3. person: 2 · 10-7

Group risk per Annum (PLL):

- 3. person: 1 · 10-4
- 2. and 3. person: 2 · 10-4
- 1., 2. and 3. person: 3 · 10-4

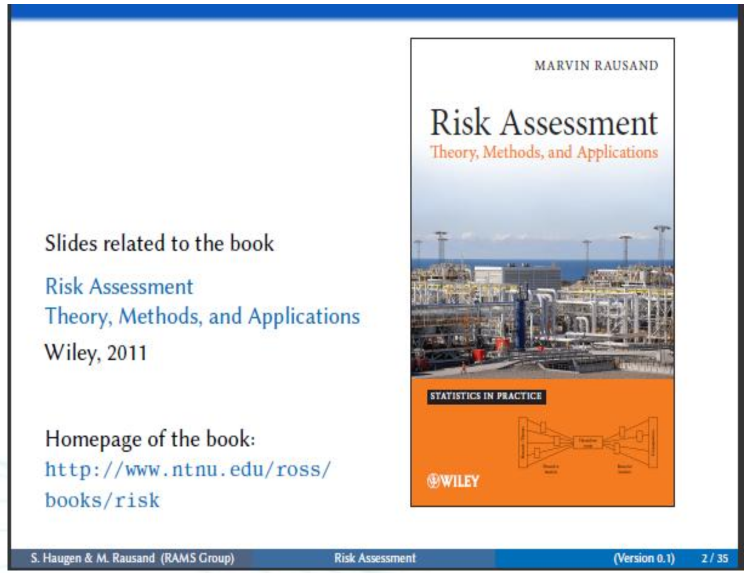
A risk index such as indvidual risk (IRPA/LIRA) does not describe all aspects

- Aspects of risk not covered within risk assessment scope
- Model error
- Aspects of model predictions not conveyed by risk metrics.

- The risk analysis shall identify the relevant initiating events and develop the causal and consequence picture. How this is done depends on which method is used and how the results are to be used. However, the intent is always the same: to describe risk

Risk assessment and management standards

- The Norwegian Standard on Risk assessment (NS 5814:2008) is already included in the Recommended Practices by IEA Wind Task 19 (2017) through the reference [30] as it follows the Norwegian standard closely.
- [30] M. Rausand, Risk Assessment. Theory, Methods and Applications, John Wiley & Sons, ISBN 978-0-470-63764-7, 2011.
- https://www.ntnu.edu/ross/books/risk
- ISO 31000:2018 Risk Management. Final Draft International Standard Draft (FDIS) replaces ISO31000:2009.
- ISO Guide 73:2009 Risk management – Vocabulary. Confirmed valid after review in 2016. https://www.iso.org/obp/ui/#iso:std:iso:guide:73:ed-1:v1:en



Resource for the risk assessment listed in IEA Wind Task 19 recommended practices (2017). The referenced book (left) follows the Norwegian Standard: Requirements for risk assessment (right) closely (NS 5814:2008).

http://www.ntnu.edu/ross/slides-risk, http://frigg.ivt.ntnu.no/ross/risk/slides/ch4-risk-metric.pdf