# Modellare l'incertezza nell'analisi del Rischio

*The uncertainty of risk*
*The risk of uncertainty*

# Risk & Uncertainty

# The (uncertain) flow of the presentation

## PART I: The uncertainty of risk

- Problem Setting: SAFETY, RISK, QRA, PRA
- Uncertainty: types and sources
- Worries
- Frameworks of uncertainty/information/knowledge representation

## PART II: The risk of uncertainty

- Decision maker dreams and nightmares

# The (risky) flow of the presentation

## PART III: “Things I know”

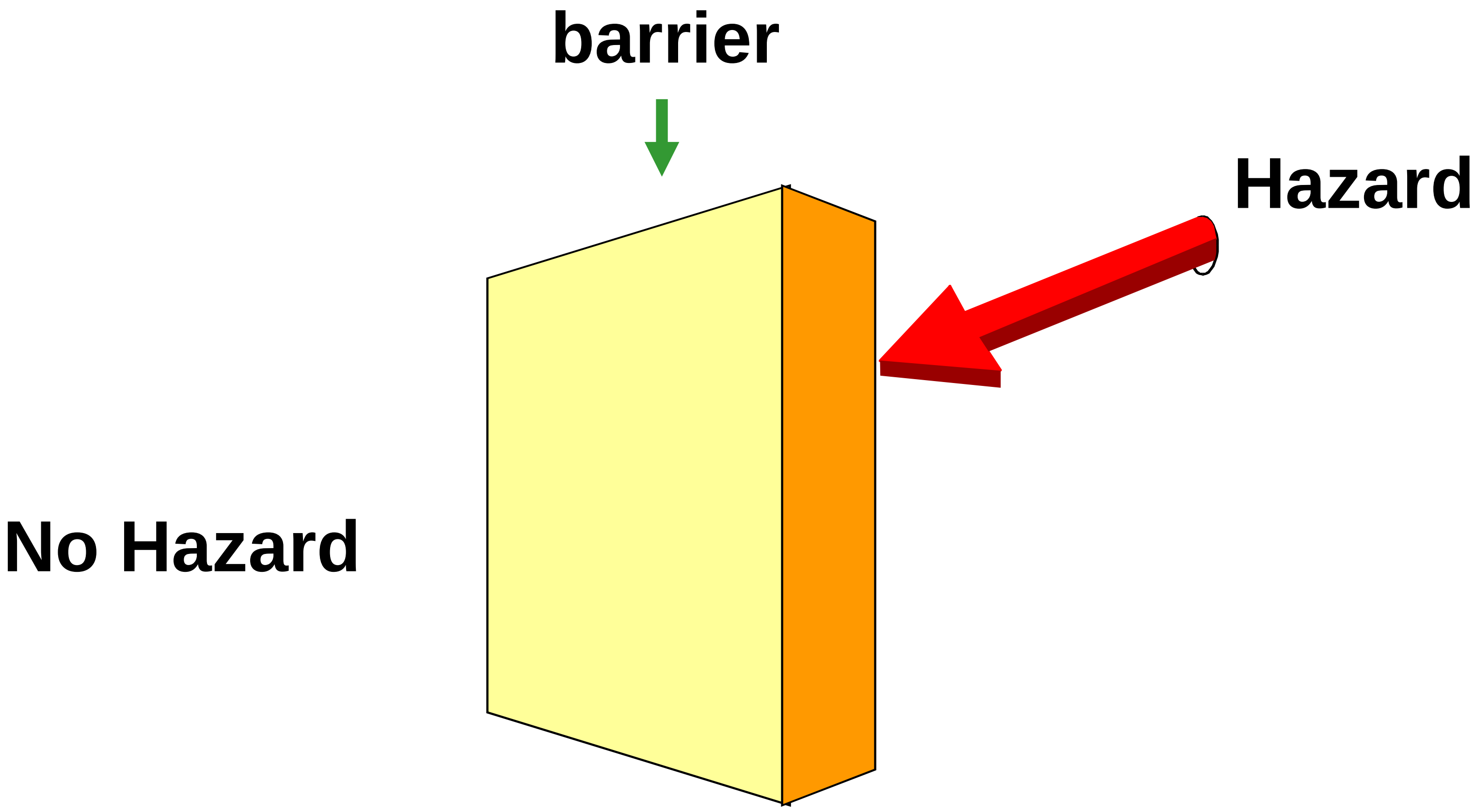
- “Faithful” representation of information and introduction of knowledge

## PART IV: Jingles

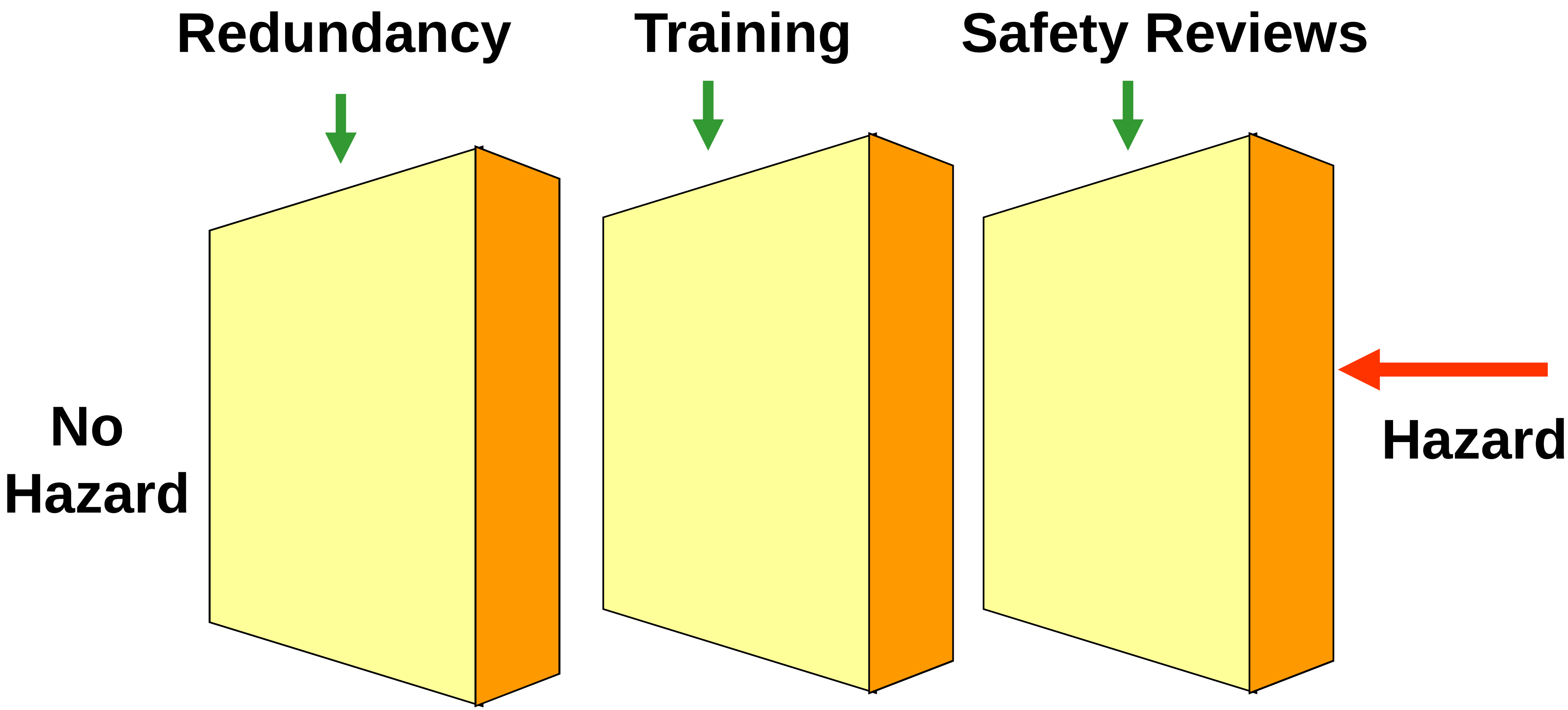
- Conclusions
- Advertisement
- Thanks

# Safety

# The parmesan cheese model

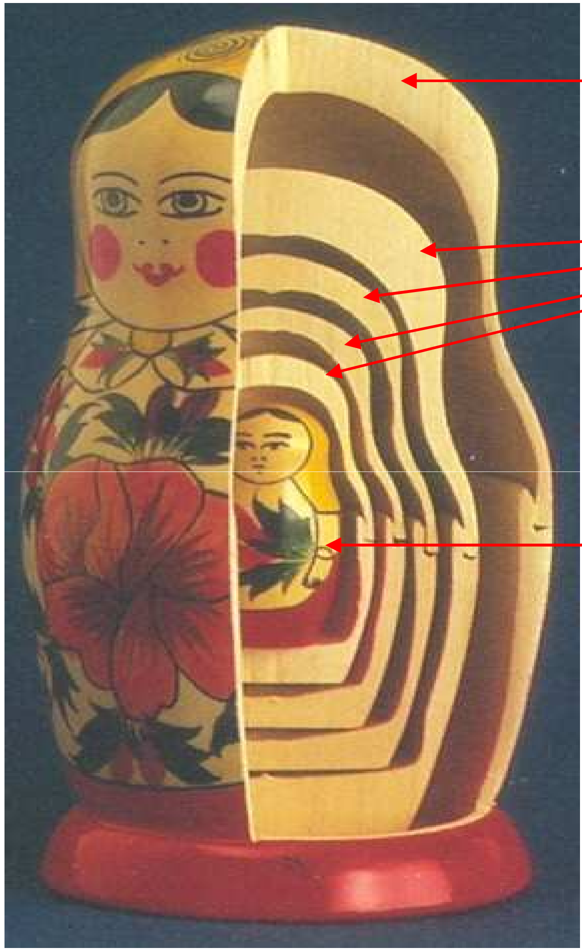


# Multiple barriers



# Redundancy example

# Multiple barrier system example



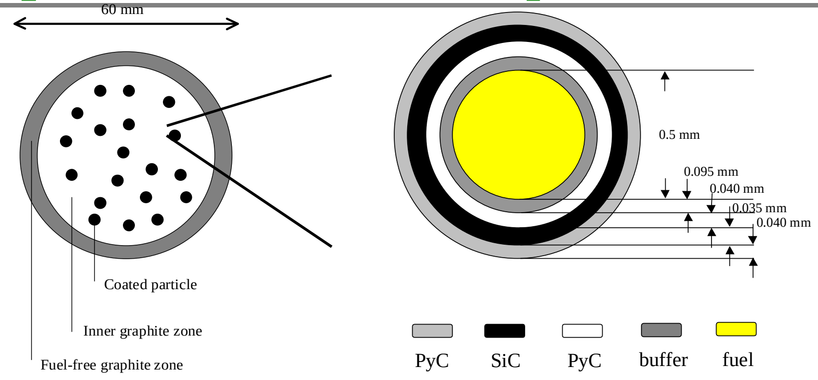
**Geological Barrier**

**Technical Barriers**

**Embedding**
**Storage cask**
**Over packs**
**Backfill**

**Waste**

# Multiple barrier system example



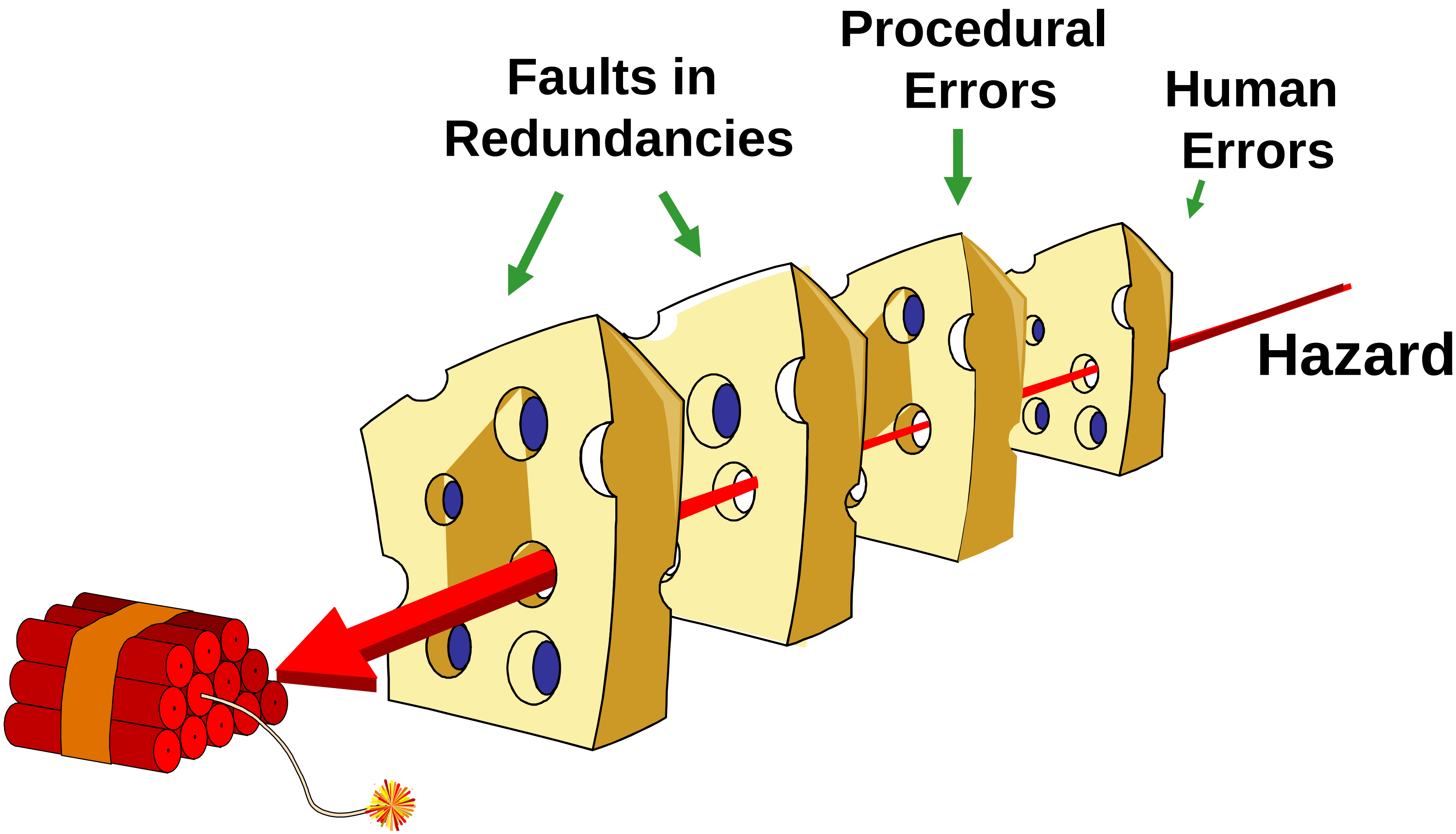

**Graphite matrix** | **Outer PyC** | **SiC** | **Inner PyC** | **Kernel**

# Risk

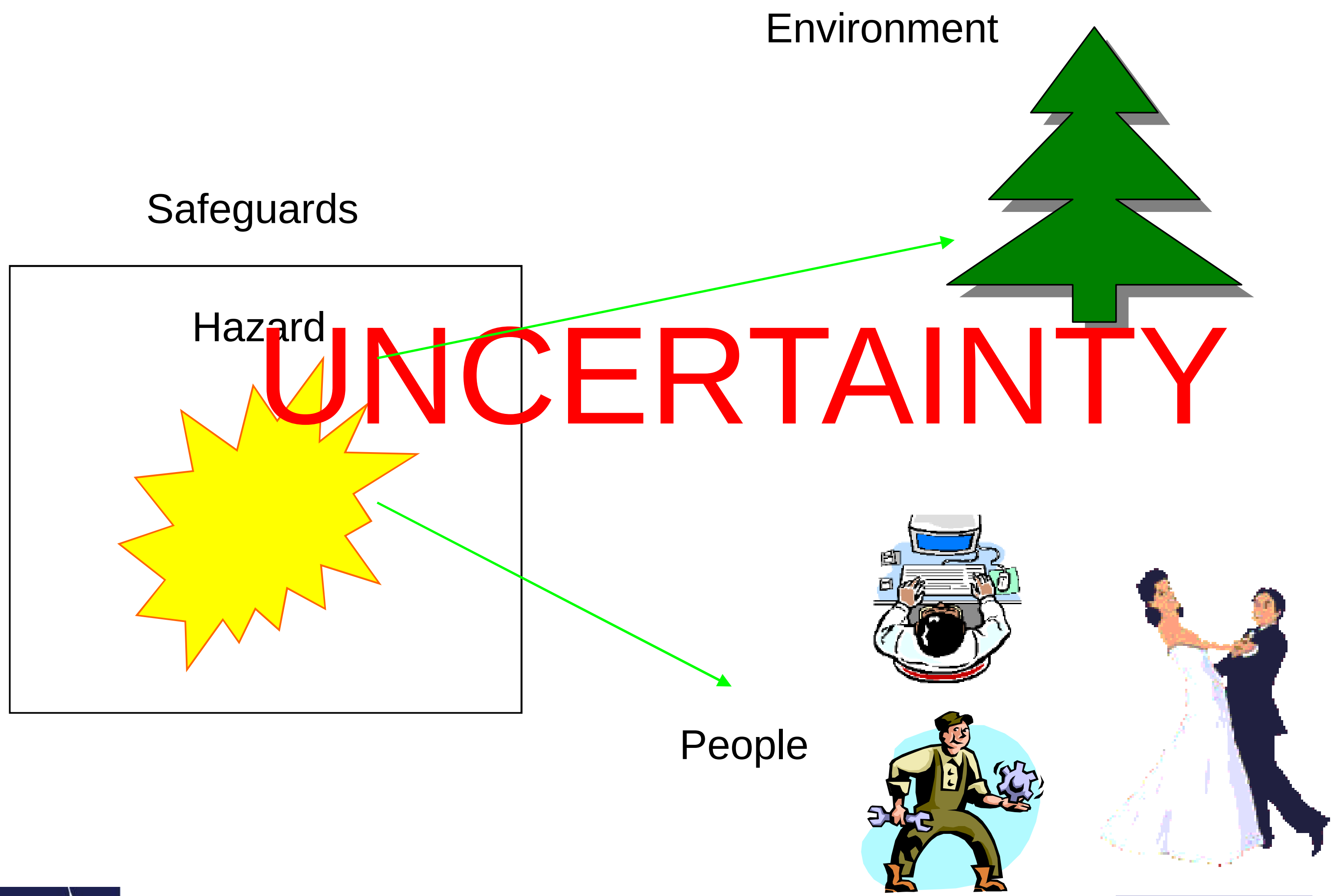
# Reality: an example of a protection barrier

Not all risk mitigation strategies work...

# The swiss cheese model



# The concept of Risk



# PART I:
# The uncertainty of risk

# Risk and Quantitative Risk Analysis (QRA)

## Risk = (*A*, *C*, *U*)

1. **What undesired conditions may occur?** $\Rightarrow$ **Accident, *A***

2. **What damage do they cause?** $\Rightarrow$ **Consequence, *C***

3. **What is the likelihood (uncertainty) of occurrence?** $\Rightarrow$ **Uncertainty, L(*U*)**

## Quantitative Risk Analysis Model=(*a*, *c*, l(*u*), *K*)

# Risk and Quantitative Risk Analysis (QRA)

**Alternative 1**

- **Design configuration 1**
- **Redundancy allocation 1**
- **Evacuation plan 1**

**Alternative 2**

- **Design configuration 2**
- **Redundancy allocation 2**
- **Evacuation plan 2**

**RISK 1**

**A**

**RISK 2**

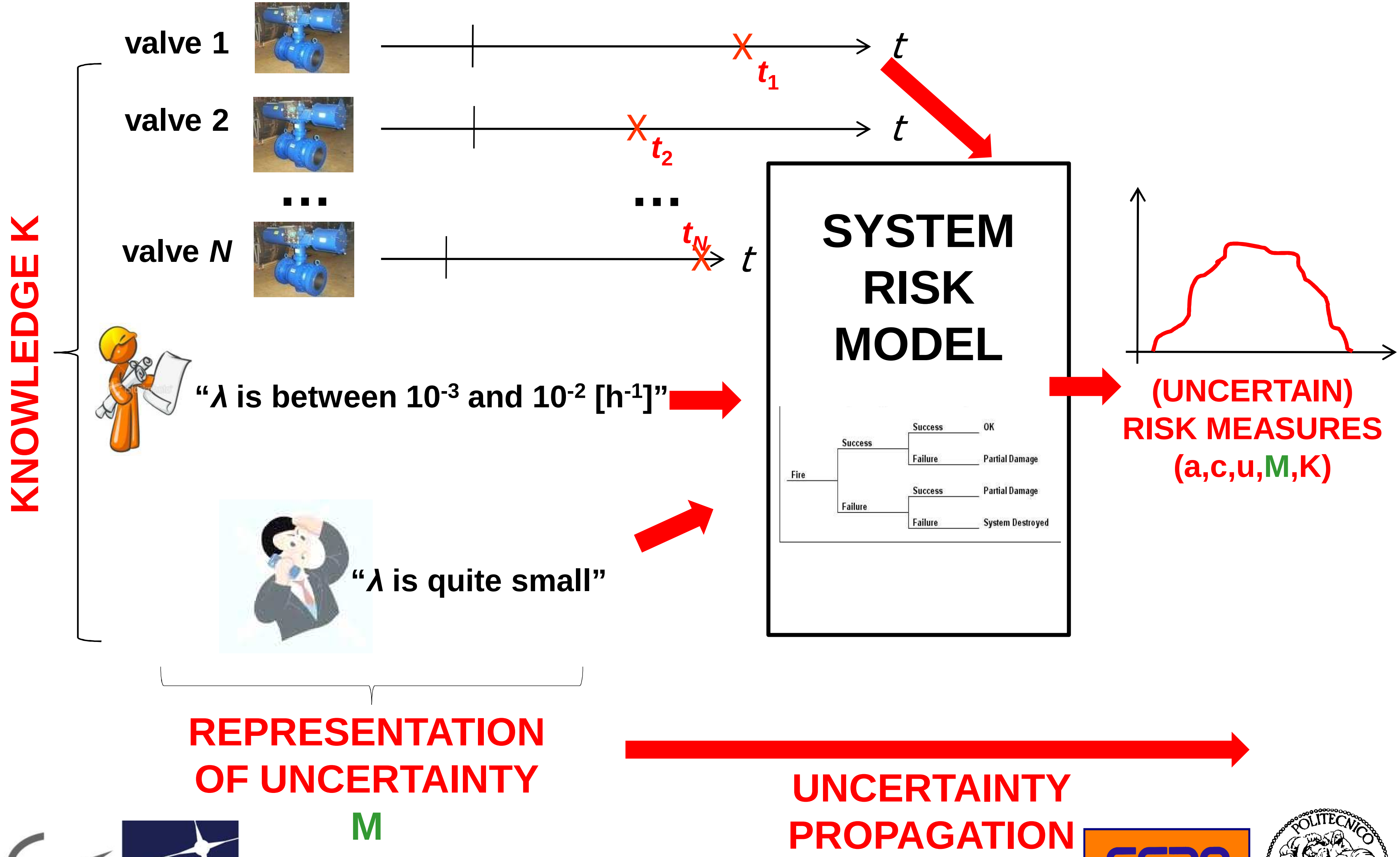
**C:** How many fatalities $C_1$?

**L:** What is the likelihood of having $C_1$ fatalities or more?

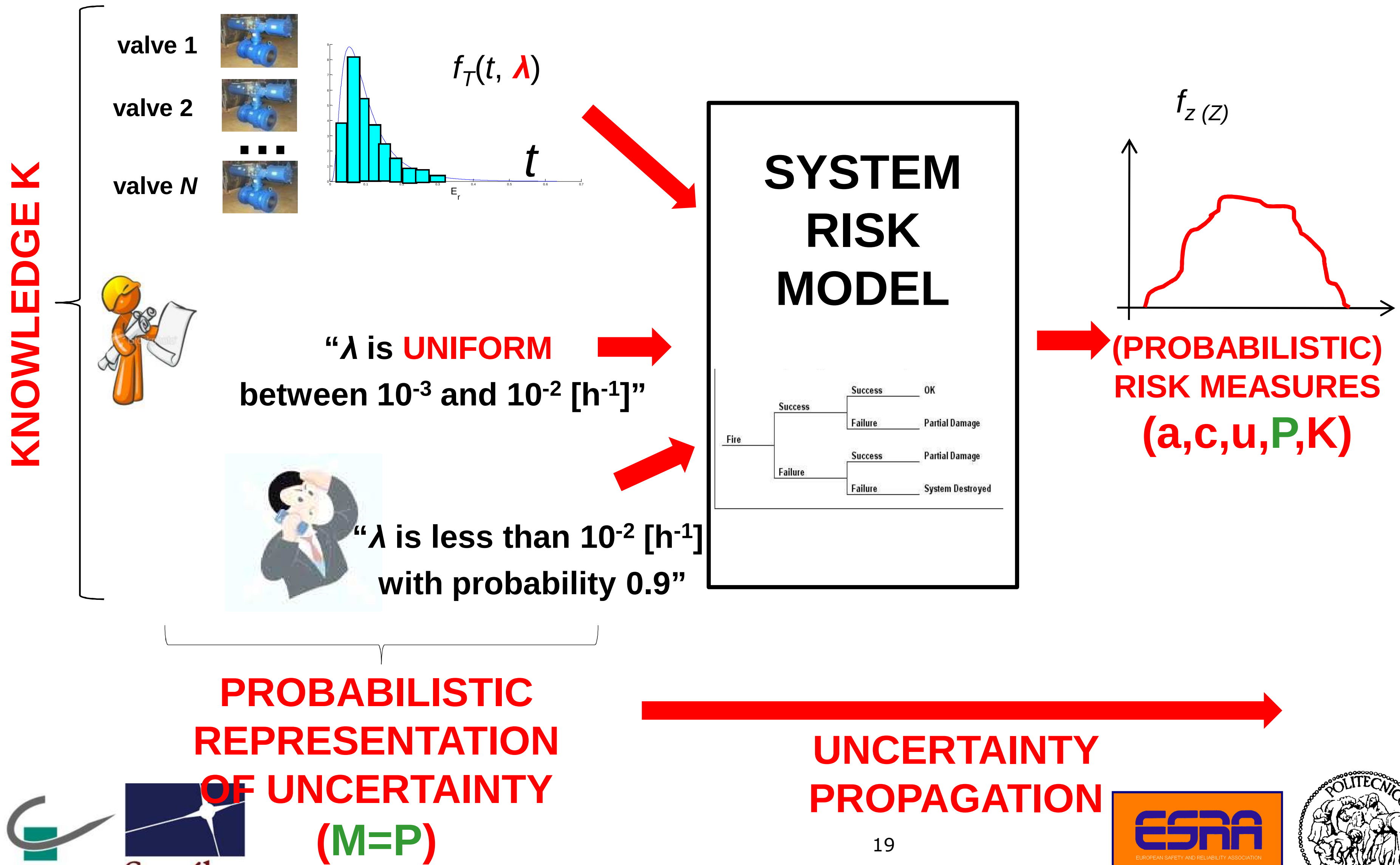
**C:** How many fatalities $C_2$?

**L:** What is the likelihood of having $C_2$ fatalities or more?

# Quantitative Risk Analysis



# Probabilistic Risk Analysis

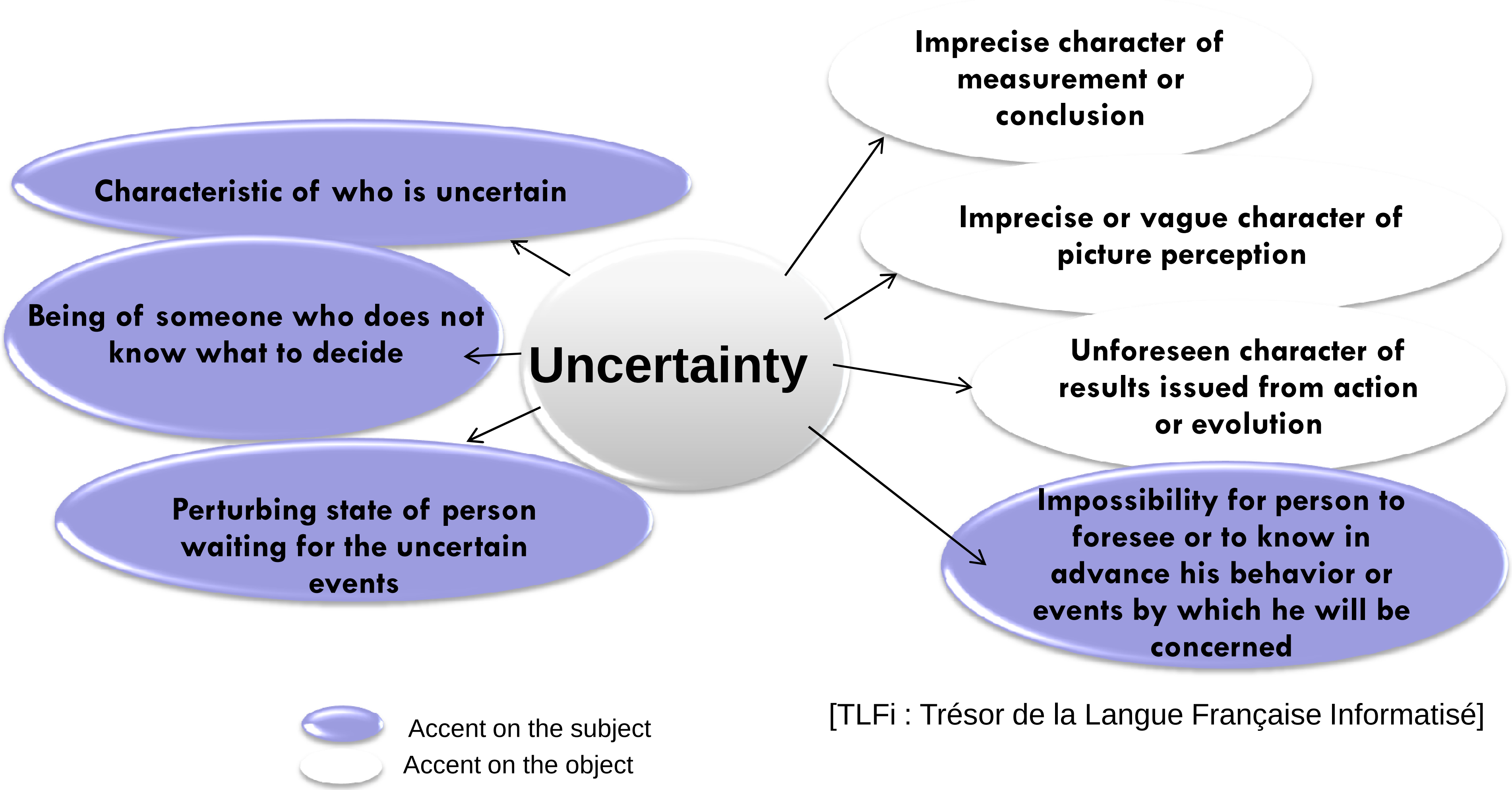


# Uncertainty

*Uncertainty is not in the things but in our head: uncertainty is lack of knowledge*

*J. Bernoulli*

# Uncertainty (in the dictionary)




[TLFi : Trésor de la Langue Française Informatisé]

Adapted from S. Farnoud and S. Tillement, IFIS Toulouse 2010

# Uncertainty (in the epistemology)

Uncertainty

from latin *certitudo*

From latin *certus*

From the latin verb *cernere*
« discern, decide »

from latin *cerno* : from common indo-european *(s)ker* : cut, which pairs it with the ancient greek *krino* : shear

Adapted from S. Farnoud and S. Tillement, IFIS Toulouse 2010

# Uncertainty (in the history)

2000 – De Finetti, Knight, Zadeh, …

**Modern era** – Laplace, Carnap, Shackle, Gödel

**Renaissance** – Descartes, Pascal, Kant

1500

**Middle Ages**

Incoherence of philosophies of Ghazali, necessity to prove the validity of reason, independent from reason.

500

**Antiquity**

0

- 500

-1000

– Socrate, Platon, Carnéade
– Sophism
– Skepticism
– 500 before J.C. Empédocle d'Agrigente (father of **rhetoric**), Gorgias
– **Mathematics** were used to create confidence [Philippe De Wilde 2010].
– **Logic** provides reasoning rules to reduce uncertainty.
– **Religion** provides a narrative to create confidence [Philippe De Wilde 2010].
– **Mythe** was the first attempt to reduce uncertainty [Gérald Bronner 1997].

**Prehistory**

-3000

– The development of Homo sapiens in an uncertain environment: predator, war …. Chimpanzees still live in this environment [Philippe De Wilde 2010].
– Evolution has selected the anatomy of the brain that is optimized to some degree to cope with uncertainty[Philippe De Wilde 2010].

Adapted from S. Farnoud and S. Tillement, IFIS Toulouse 2010

# Uncertainty in QRA

<u>aleatory uncertainty</u>

» irreducible uncertainty
» property of the system
» random fluctuations / variability/ stochasticity

<u>epistemic uncertainty</u>

» reducible uncertainty
» property of the analyst
» lack of knowledge or perception

Adapted from G. Apostolakis, Workshop LA 2010 and M. Beer, Seminar Paris 2012



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# Uncertainty in QRA

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Adapted from G. Apostolakis, Workshop LA 2010 and M. Beer, Seminar Paris 2012



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# Uncertainty in QRA

- *Epistemic* uncertainties are further categorized as being due to
  - *parameter* values,
  - *model* assumptions, and
  - *incomplete* analyses
    - "*Known unknowns*" : initiating events, failure modes or mechanisms are known but not included in the model
    - "*Unknown unknowns*": phenomena or failure mechanisms are unknown

$$\textbf{Risk} = (A, C, U) \neq (a, c, l(u), K)$$

Adapted from G. Apostolakis, Workshop LA 2010



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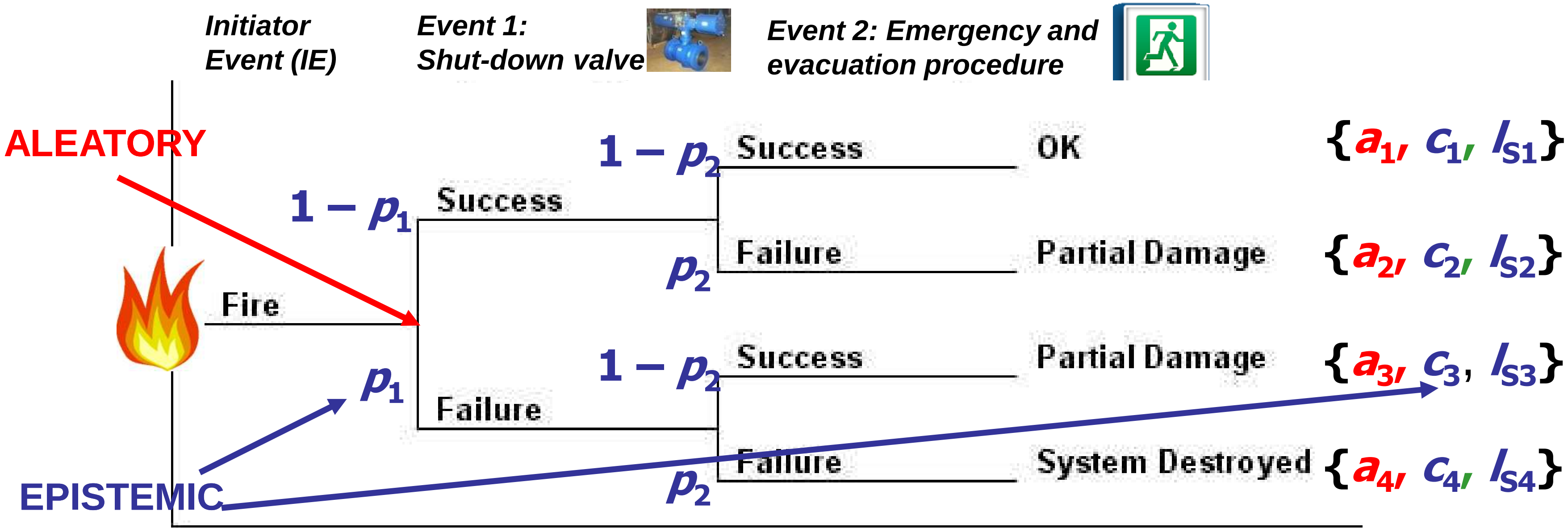
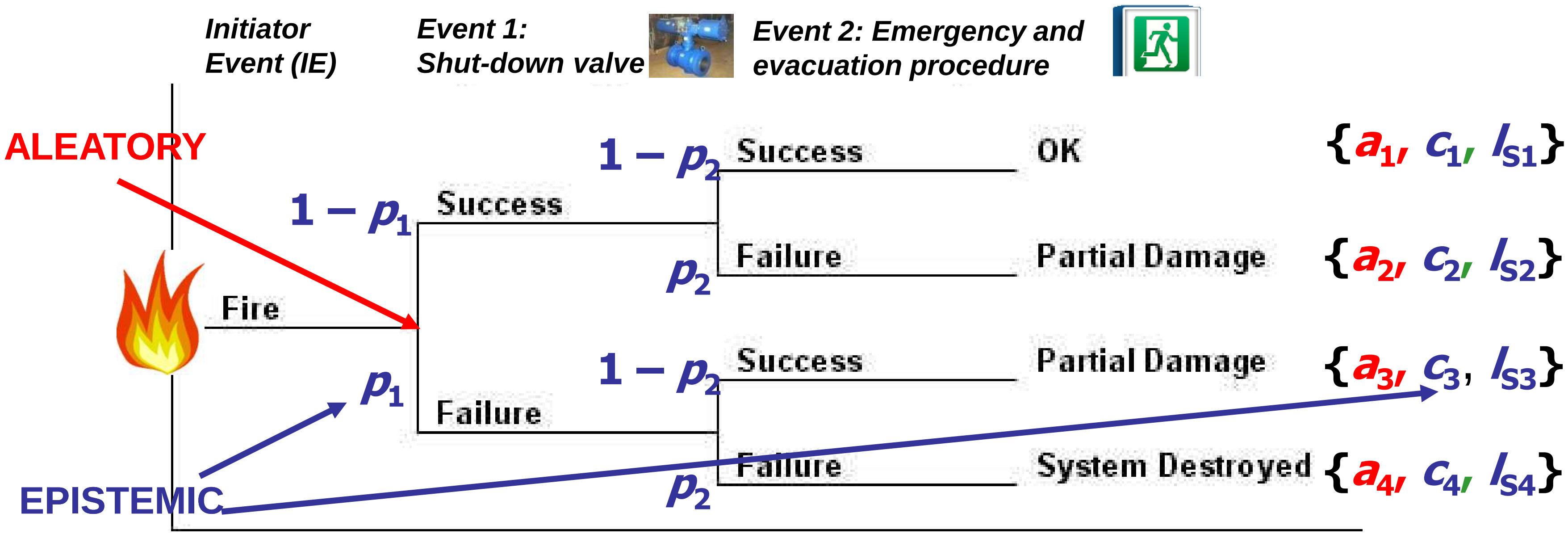
# (aleatory and epistemic) Uncertainty in QRA




**ALEATORY**: **variability**, **randomness** (in **occurrence** of the **events** in the **scenarios)**

**EPISTEMIC**: **lack of knowledge/information (**on the **values** of the **parameters** of the **probability** and **consequence** models)

# (aleatory and epistemic) Uncertainty in PRA



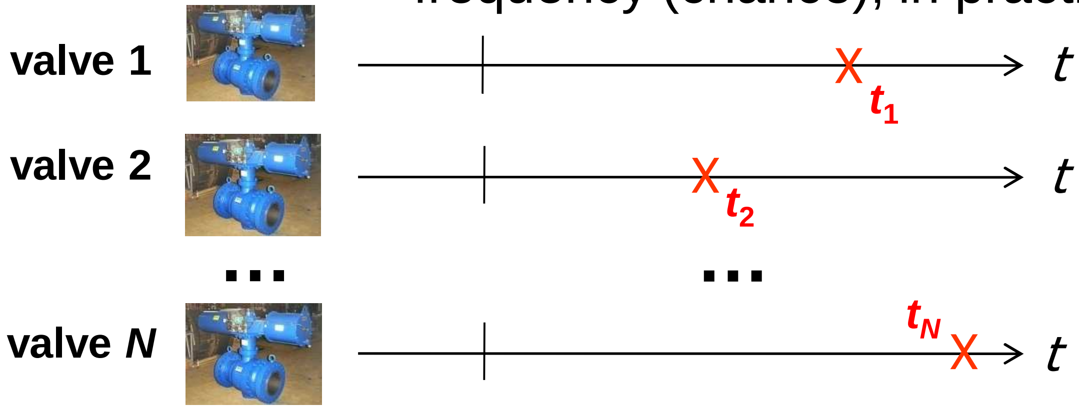

**Probability used for representing both randomness and incomplete information/partial knowledge**

**Aleatory: STOCHASTIC MODELS**

**Epistemic: PROBABILITIES**

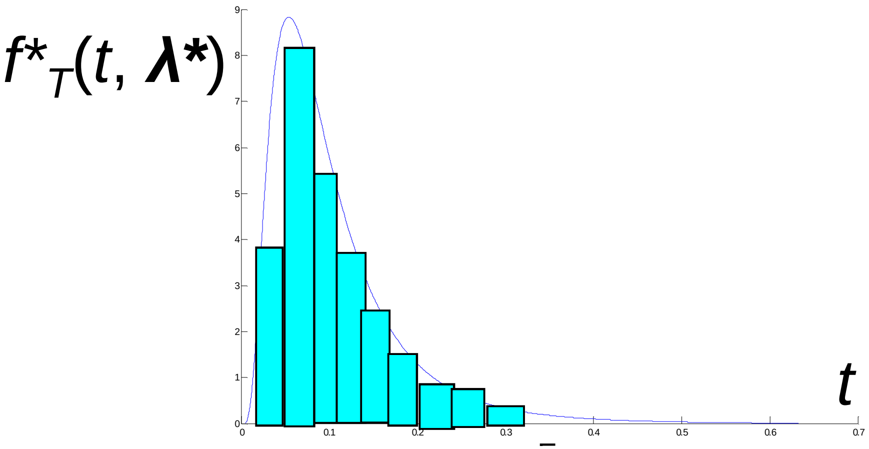
# Probablistic representation of epistemic uncertainty in PRA

Sufficiently informative (statistical) **data**: P=limiting relative frequency (chance); in practice, estimated value P*




**Hardware** failure occurrence times:
**Event 1** = failure of shut-down valve

Realizations of a random variable → Probability Density Function



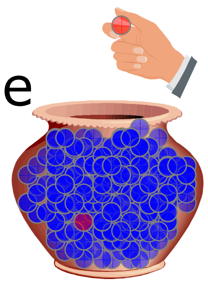
# Probablistic representation of epistemic uncertainty in PRA

Scarce (possibly qualitative) **data**: P(A/K)=Subjective probability (knowledge-based probability)

## P(A/K)

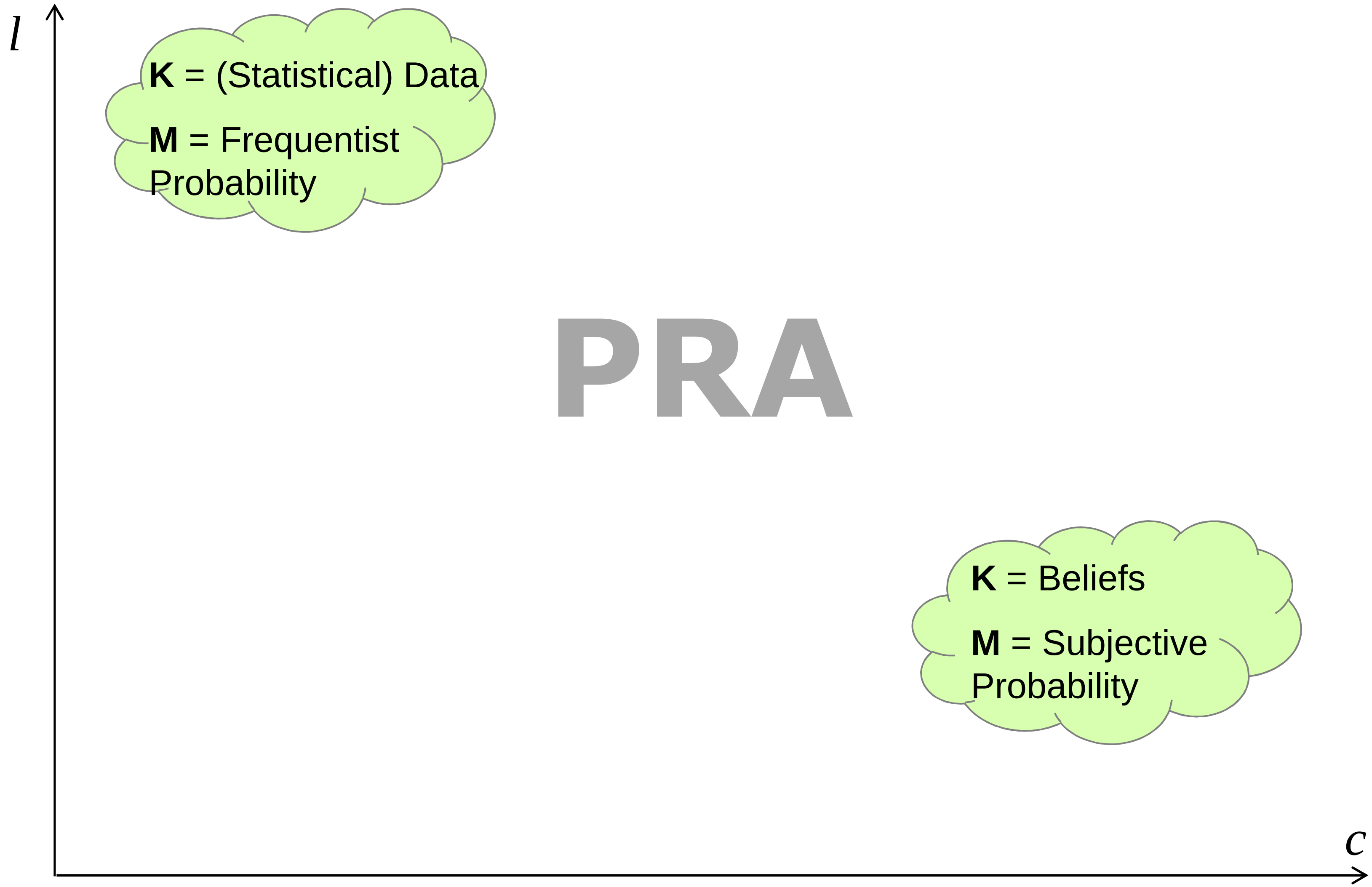
- Betting interpretation:
  - The probability of the event A, P(A), equals the amount of money that the assigner would be willing to bet if he/she would receive a single unit of payment in the case that the event A were to occur, and nothing otherwise.

- Comparison with a standard
  - The assessor compares his/her uncertainty about the occurrence of the event A with e.g. drawing a favourable ball from an urn that contains P(A) · 100 % favourable balls (Lindley, 2000).



Adapted from T. Aven, Workshop LA 2010

# Epistemic Uncertainty



# Statement

PRA is a mature methodology.

# Worries

## Worries: known unknowns

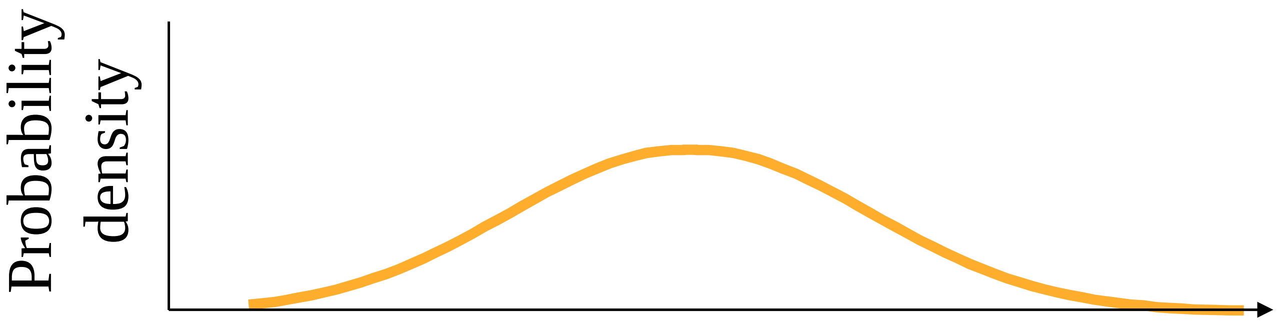
*In risk analysis assumptions are made that may be convenient but not really justified from the available information and knowledge:*

- Distributions are stationary (unchanging in time)
- Variables, experts are independent of one another
- Uniform distributions model “complete” uncertainty

# Worries: known unknowns

## Instability

Uniform + Uniform + Uniform + Uniform




*The more (uncertain) inputs, the more certainty in the output…?*

Adapted from S. Ferson, Workshop LA 2010

# Frameworks of uncertainty/information/knowledge representation

# Uncertainty representation

## *Tools for representing uncertainty*

- **Probability distributions :** good for expressing variability (aleatory), but information/knowledge (data)-demanding and difficult to justify when information/knowledge is incomplete (choice of a single distribution not satisfactory)

- **Sets (numerical intervals)**: good for representing incomplete information/knowledge (epistemic), but a very crude representation of uncertainty



Adapted from D. Dubois, Workshop LA 2010

# Uncertainty representation

## *Representations that allow for both aspects of uncertainty*

- Capable of distinguishing between (aleatory) uncertainty due to variability from (epistemic) uncertainty due to incomplete information/knowledge
- *More informative than the sets of pure interval (or classical) logic*
- *Less demanding than single probability distributions*
- *Explicitly allowing for missing information*

**Blend intervals and probability**



Adapted from D. Dubois, Workshop LA 2010

# Uncertainty representation

## *Blending intervals and probability*

- ✓ Sets of probabilities: imprecise probability theory ([P*(A), P*(A)])
- ✓ Random sets: Dempster-Shafer Theory ([Bel(A),Pl(A)])
- ✓ Fuzzy sets: <u>numerical</u> possibility theory ([Π(A,N(A)])

**Instead of a single degree of probability, each event A has a degree of belief (certainty) and a degree of plausibility which “bound all probabilities”**



Adapted from D. Dubois, Workshop LA 2010

# Uncertainty representation

## *Practical ways for representing probability sets*

- Fuzzy (numerical) intervals (possibility theory)
- Probability intervals (bounding the probabilities of events)
- Probability boxes (pairs of pdfs or cdfs)

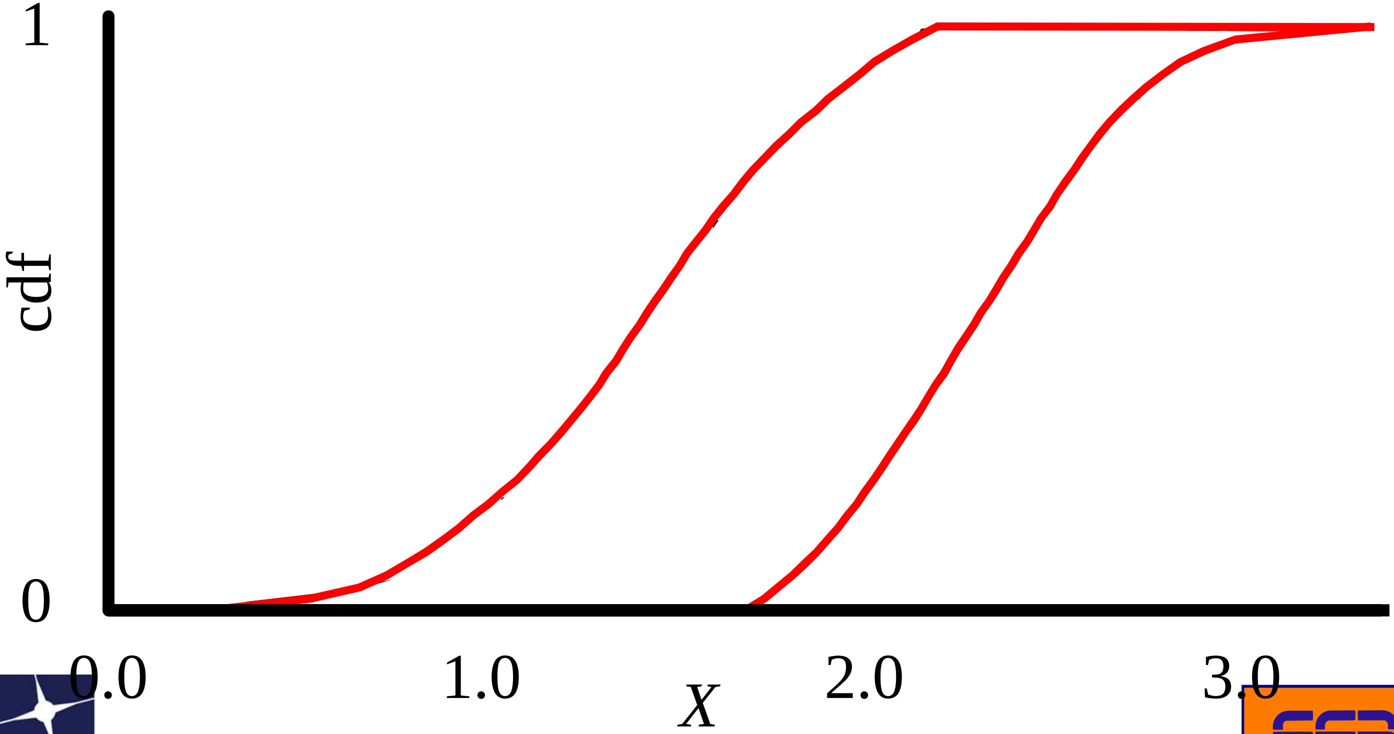


Adapted from D. Dubois, Workshop LA 2010

# Uncertainty representation

*Example: P-box*

Interval bounds on a cdf






Adapted from S. Ferson, Workshop LA 2010

# Uncertainty representation

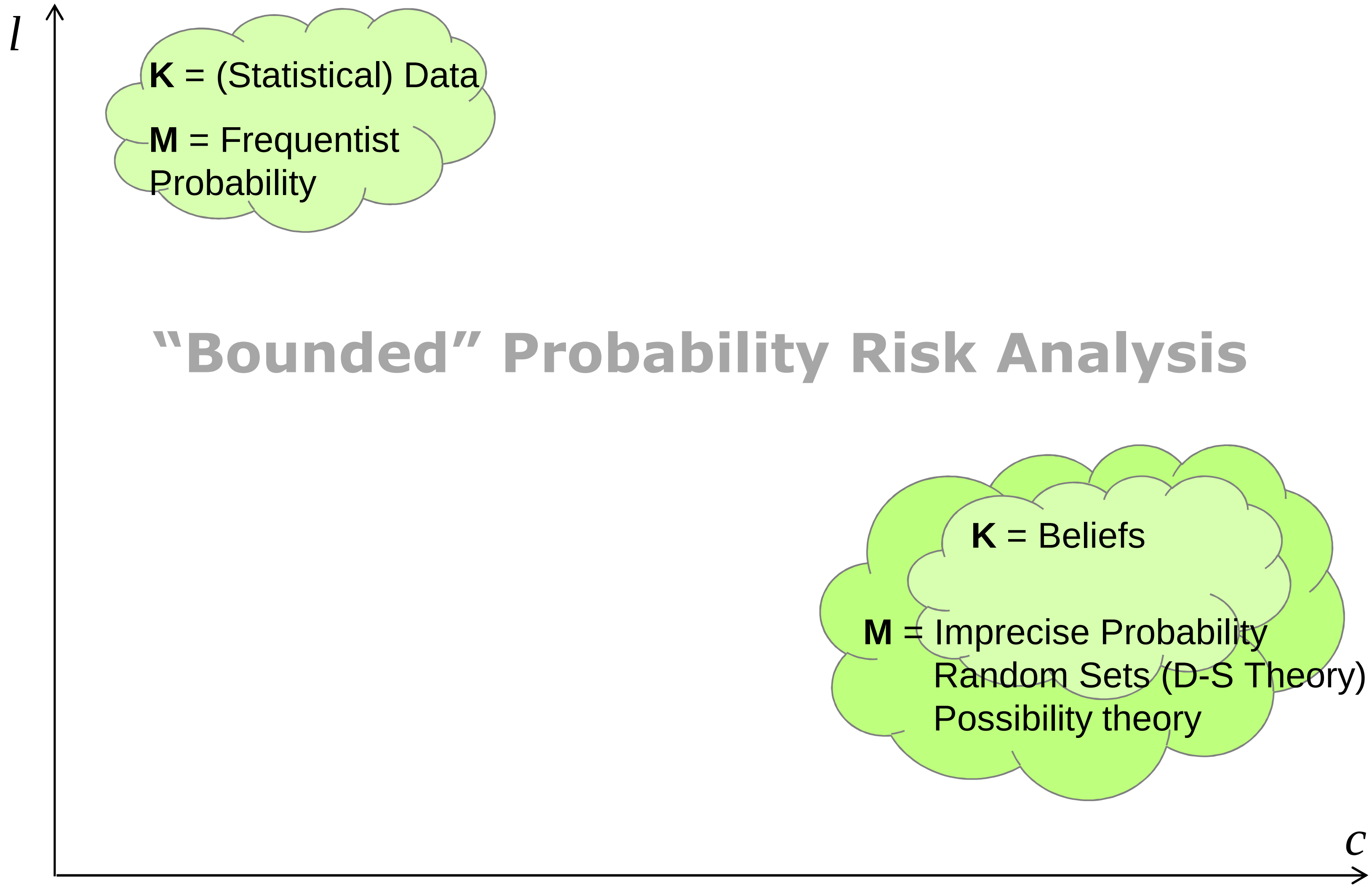
## *Probability Bounds: what they do*

- Bridge qualitative information and quantitative data
- Distinguish aleatory and epistemic
- When data are abundant = probability theory
- When data are sparse = conservative and optimistic bounds



Adapted from S. Ferson, Workshop LA 2010

# Epistemic Uncertainty



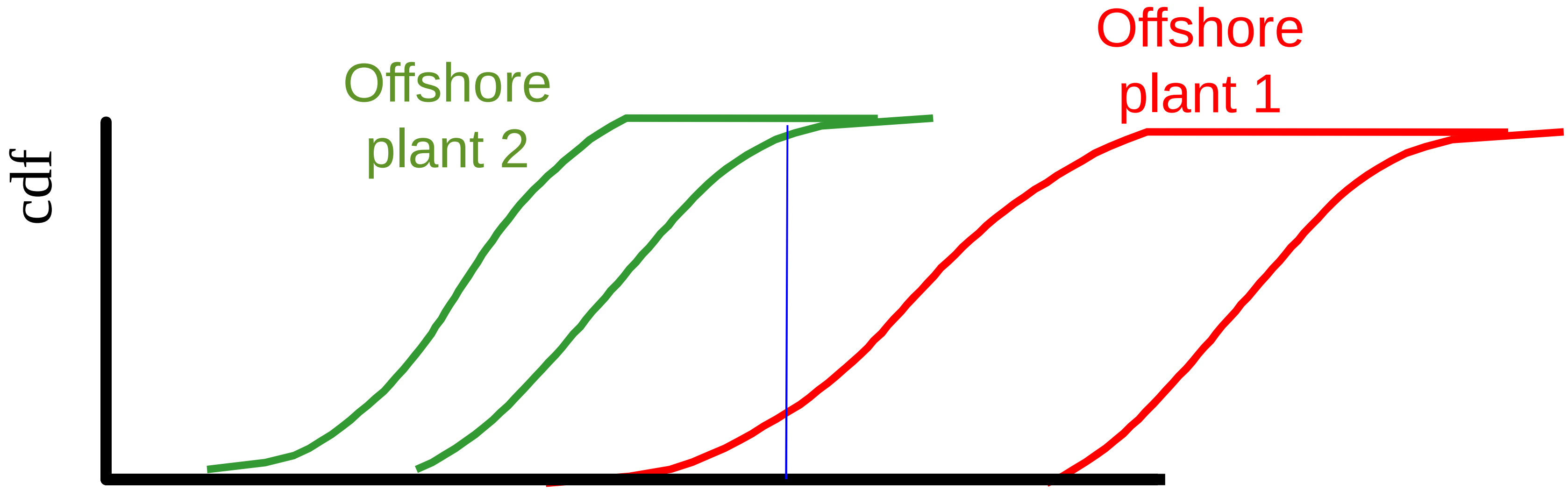
# PART II:
# The risk of uncertainty

## Decision maker dreams…

# *Probability Bounds: how to use the results*

- When uncertainty makes no difference

bounding gives confidence in the reliability of the decision





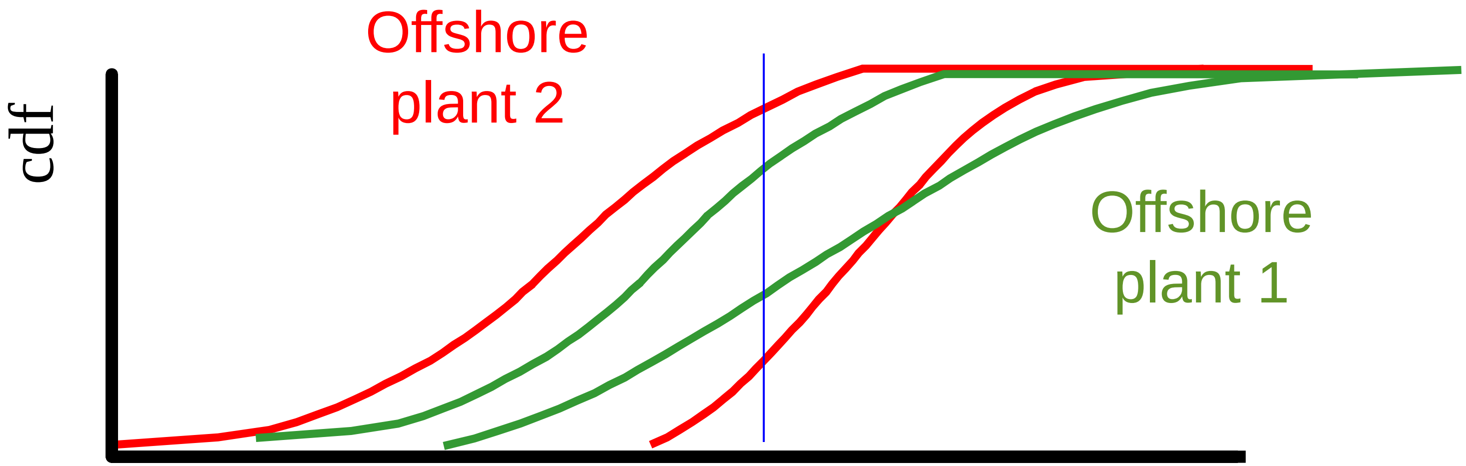

Adapted from S. Ferson, Workshop LA 2010

# ...and nightmares

## *Probability Bounds: how to use the results*

- When uncertainty swamps the decision

identify issues to further investigate



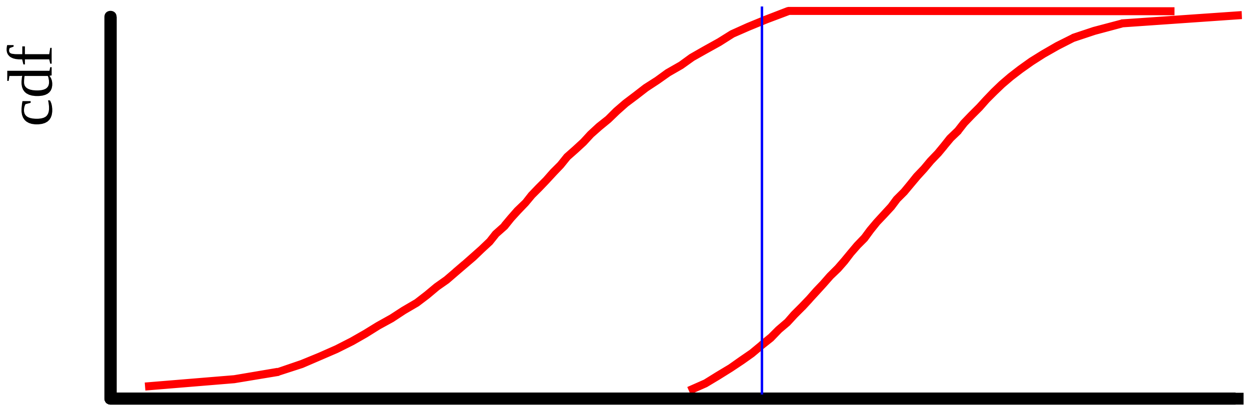

*results should not mislead decisions*



Adapted from S. Ferson, Workshop LA 2010

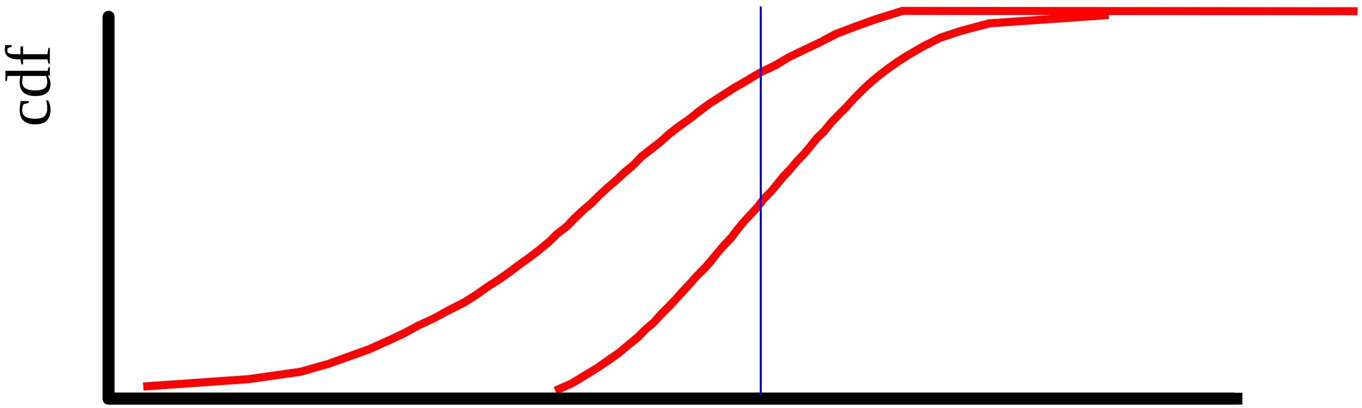
# PART III:
# “Things I Know”

# Things I know: Information-based bounds



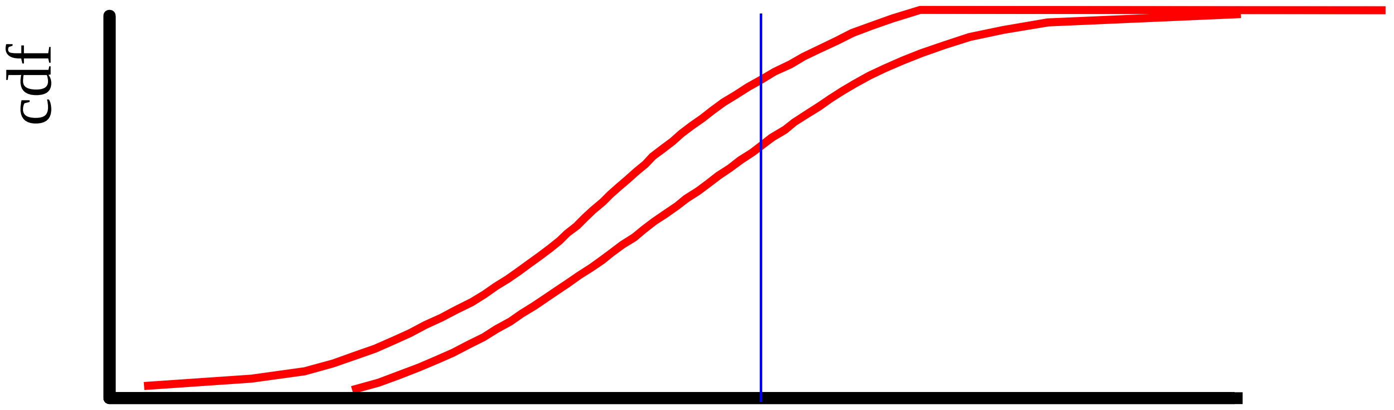

<u>Do not</u> add knowledge that is not included in the available information

# Things I know: (expert) knowledge-based bounds




Do add expert knowledge
when reliable

## Things I know: (expert) knowledge-based bounds




Do add expert knowledge
when reliable

# PART IV:
# Jingles

# Concluding remarks

# Concluding remarks

## *Probability Bounds Framework*

- Combines interval and probability methods: analyst can relax (towards interval analysis) or tighten (towards probability analysis) his/her assumptions, depending on what the information/knowledge justifies
- Allows distinguishing aleatory uncertainty (modeled by probabilty) from  epistemic uncertainty (modeled by bounding interval analysis)



Adapted from S. Ferson, Workshop LA 2010

## Concluding remarks

### Theoretical issues

- Operational definitions (betting-like? standard comparison-like?), according to given behavioral rationality

- Dependence and independence (objective and epistemic) of information/knowledge

- Information and knowkedge fusion

- Mathematical operations (e.g. Dempster rule of combination)



Adapted from D. Dubois, Workshop LA 2010

# Concluding remarks

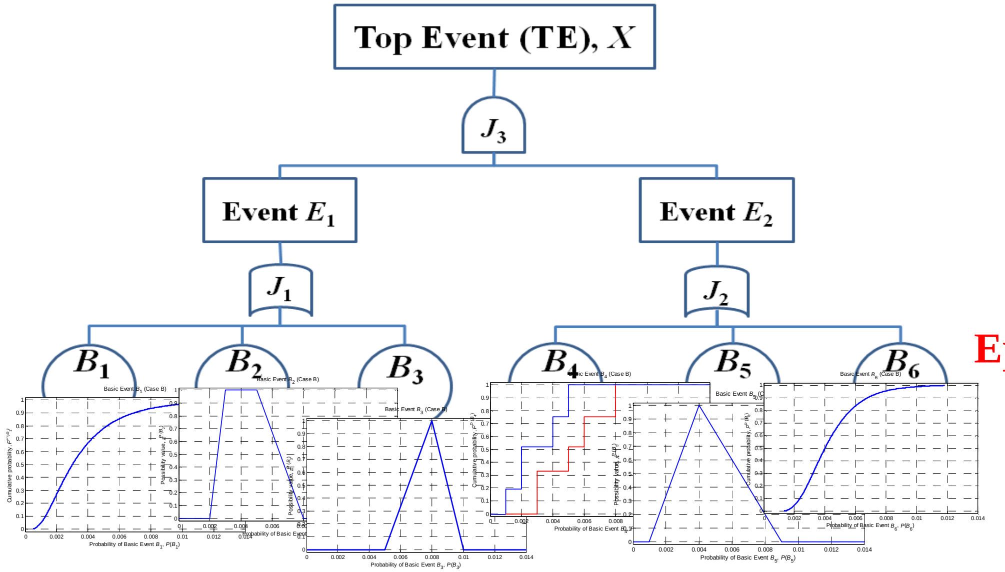
## Practical issues

- Constructing bounding (imprecise) probabilities, from data (statistics with interval data), from experts (elicitation of upper/lower bounds for faithful representaton of incomplete information/knowledge)
- Uncertainty propagation (computational challenges of blending Monte Carlo simulation with interval mathematics)
- Representation of results with meaningful summary measures
- Updating with additional evidence
- Accounting for dependences in information sources, when fusing them



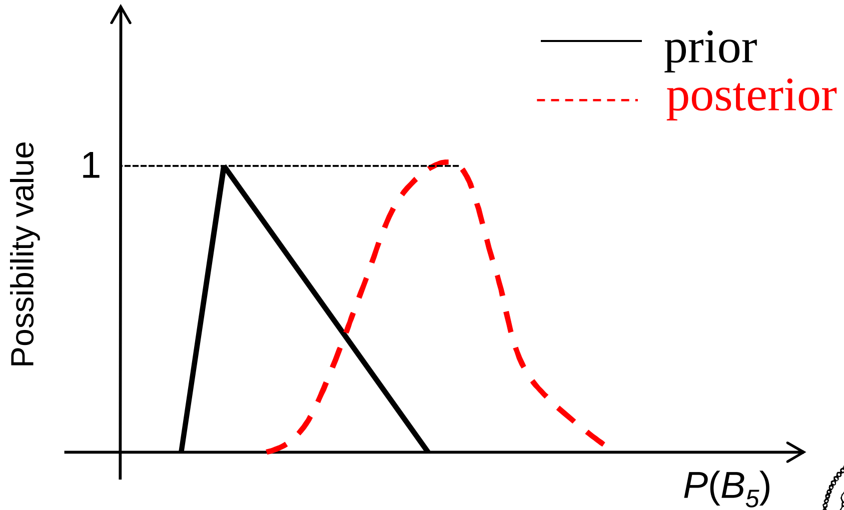
Adapted from D. Dubois, Workshop LA 2010

# Updating…

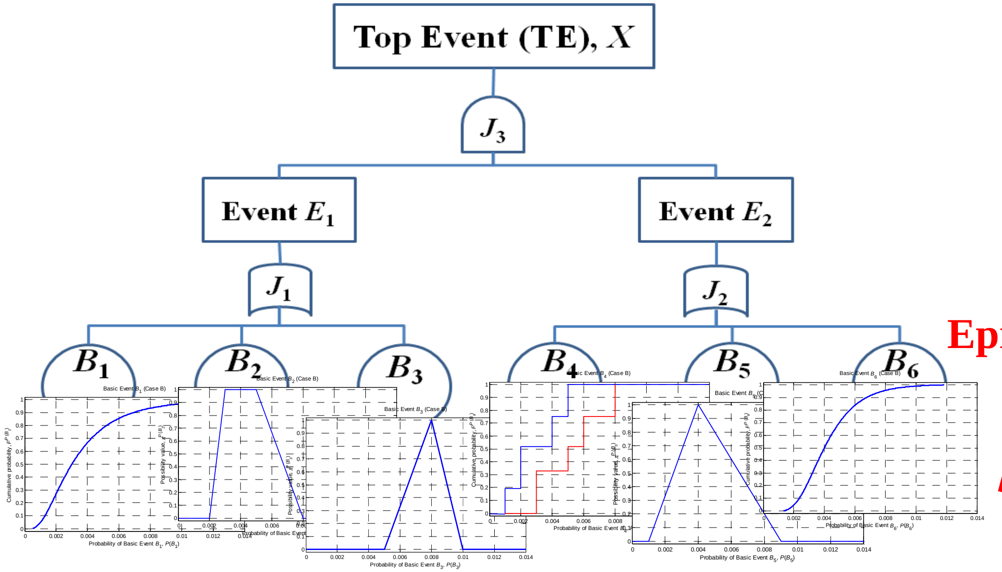



**Epistemically-uncertain Basic Event (BE) probabilities**

3 additional tests:
2 failures, 1 success

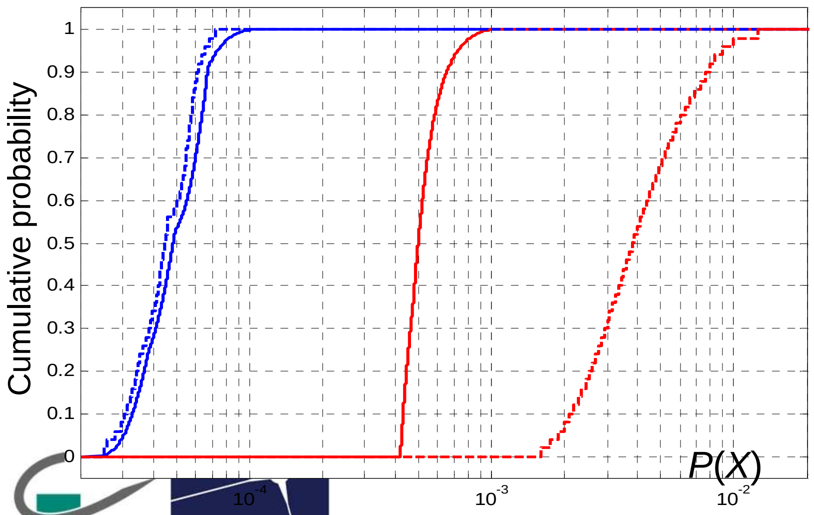


# Dependences…

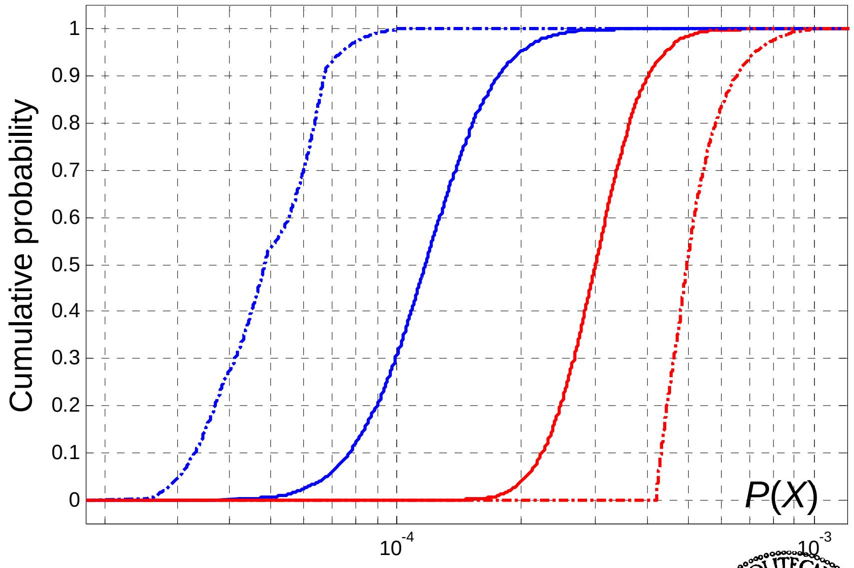



**Epistemically-uncertain Basic Event (BE) probabilities**

***"Objective"* dependence between *BEs***



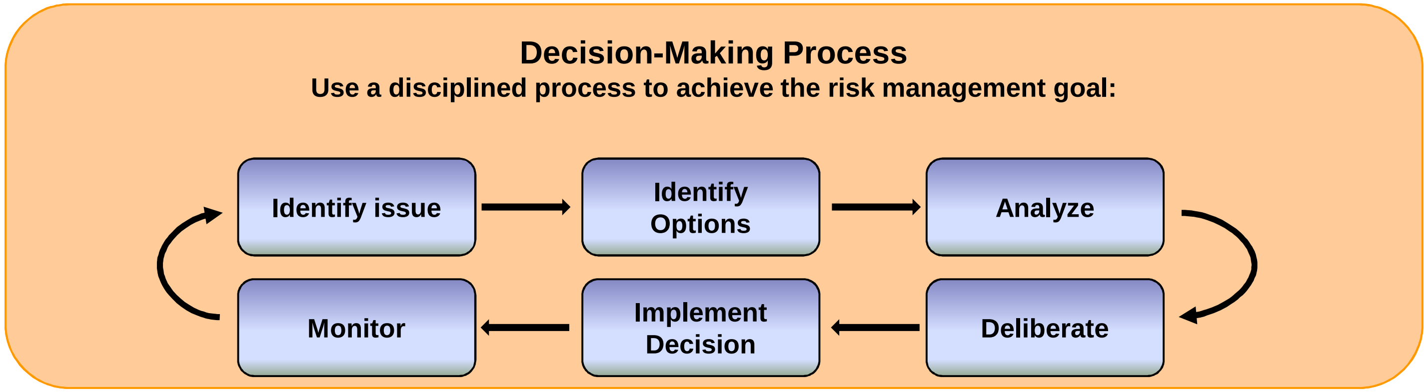

***"Epistemic"* dependence between BE *probabilities***



# Concluding remarks

## The Decision Making process

- QRA results are one input to a subjective decision-making process
- Analytical results are debated and stakeholder values are included, within a deliberative process of decision-making



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## Concluding remarks

**The one million euros question**

€ € € € € €

"OK, these approaches are interesting, but does all of this actually make any practical difference in real-world decisions?"

€ € € € € €

(€ Are probability bounds/imprecise probabilities a more proper starting point than pure probability theory for robust and confident decision making, faithful to information and knowledge?€)

(€ How to do it in practice? information before knowledge for faithfulness to information and unbiased exploitation of knowledge– bounds "as large as justified by information" + expert knowledge (without forcing) to see the effects in a "sensitivity analysis- like process?€)

# ...and nightmares


the bombing in Norway on 22 July 2011, when a man placed a car-bomb outside the government office and massacred a number of people on the island of Utøya outside Oslo.

**PERFECT STORMS**


the eruption of the Icelandic volcano which paralyzed the air traffic over the Atlantic and western Europe for a while in 2010

the failure of the BP Deepwater Horizon platform

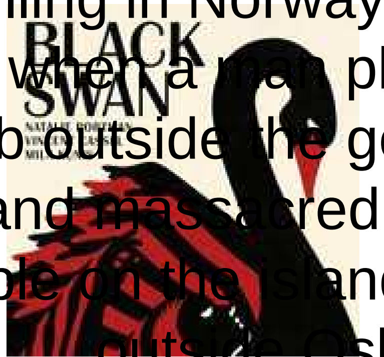



the Fukushima Daiichi nuclear disaster in Japan in March 2011

9/11 attacks on the US

the financial crisis that started in 2008

# ...and nightmares

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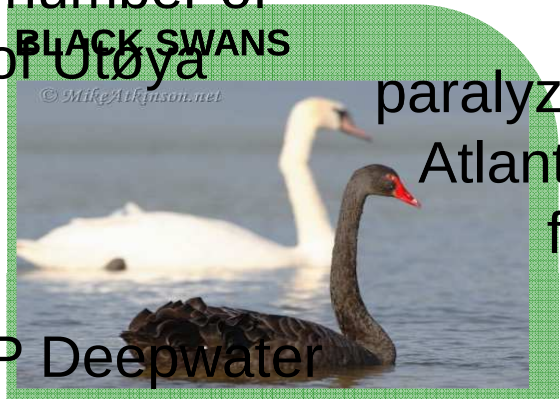



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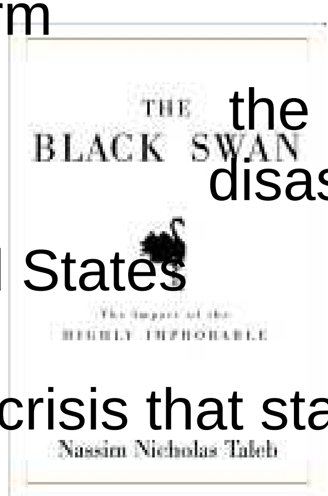
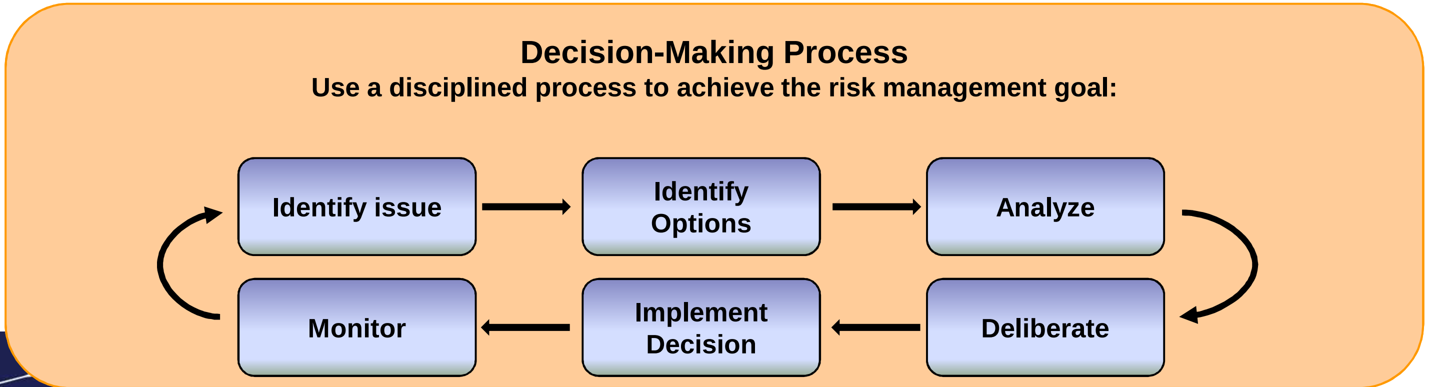



the financial crisis that started in 2008

# The Decision Making process

- QRA results are one input to a subjective decision-making process
- Analytical results are debated and stakeholder values are included, within a deliberative process of decision-making

Coherently with safety concepts such as defense-in-depth, multiple barriers and design basis accidents, conservatism in the decisions is added where appropriate (to protect from the known and unknown unknowns)

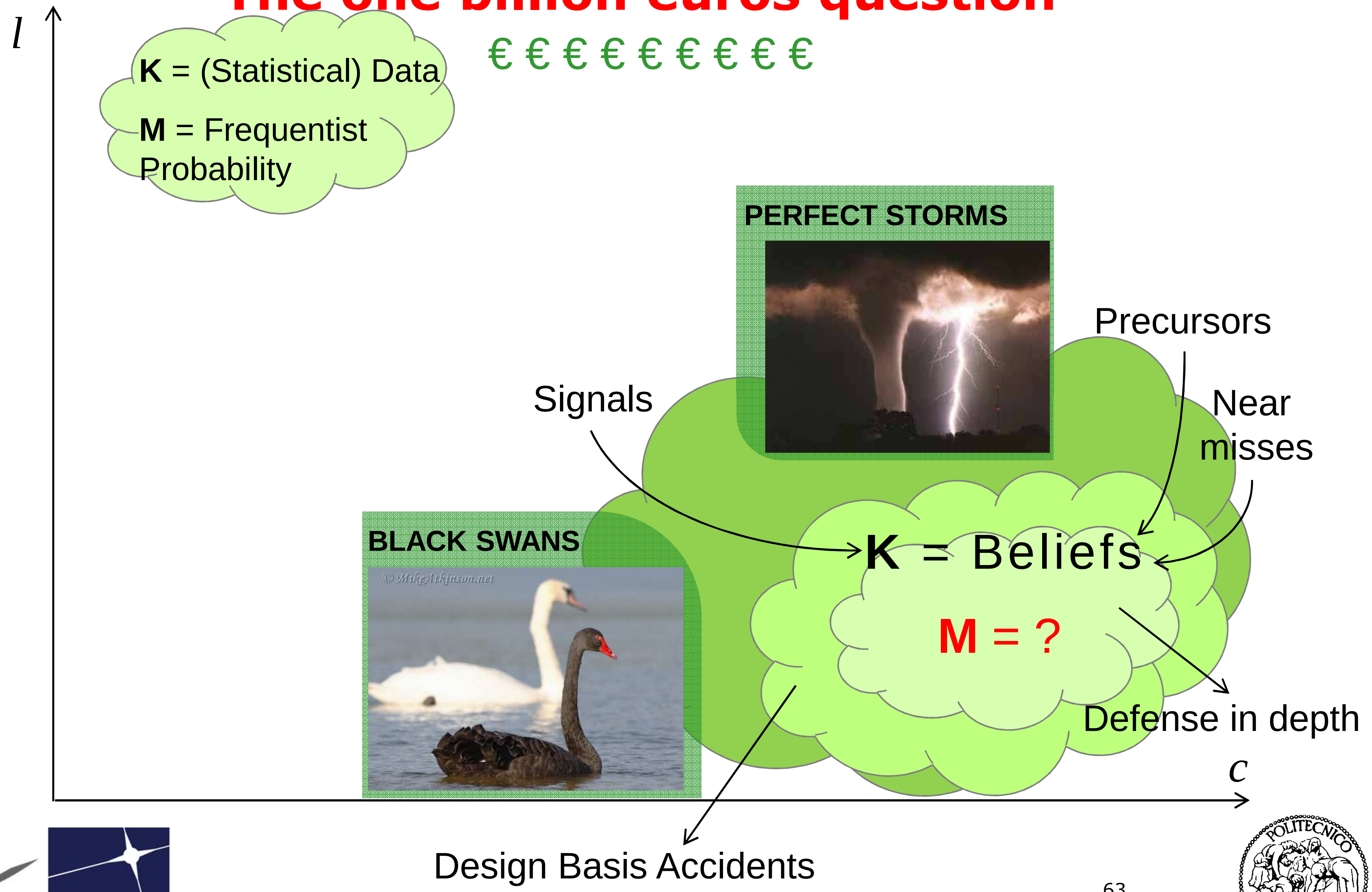





Adapted from G. Apostolakis, Workshop LA 2010 and ANS DC 2012

# Concluding remarks

## The one billion euros question



# Final remarks

There are known knowns

*l*

One should expect that the expected can be prevented, but the unexpected should have been expected

PERFECT STORMS

Precursors

Near misses

But there are also unknown unknowns – the ones we don't know we don't know.

Signals

BLACK SWANS

We also know there are known unknowns; that is to say we know there are some things we do not know.

*c*

Knowing ignorance is strength, ignoring knowledge is sickness

# Final remarks

There are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns – the ones we don't know we don't know.

One should expect that the expected can be prevented, but the unexpected should have been expected

Knowing ignorance is strength, ignoring knowledge is sickness

PRA is a mature methodology, but there is still work to be done in order to render our systems safer.