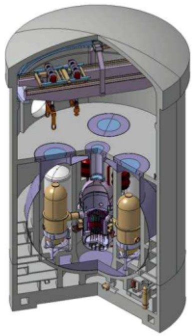
IMPRECISE PROBABILITIES WORKSHOP, 27th-29th of May 2015

Why bother with non-probabilistic models in risk analysis ?

Eric Chojnacki



Why bother with non-probabilistic models in risk analysis ?

Conclusion

- Uncertainty plays a key role in risk acceptance ; it cannot be ignored

- A large part of the uncertainty in risk assessment is about the reasoning process and is subjective.

- Imprecise probabilities models provide a large choice of tools for representing and processing information

- What is a "good" uncertainty model ?

What is a model ?

"to an observer B, an object A* is a model of an object A to the extent that B can use A* to answer questions that interest him about A." Marvin Minsky

A "good" uncertainty model is a model which helps an analyst to handle the uncertainty of his problem. So the quality of an uncertainty model not only depends on the problem but also on its ability to be accepted by a community : are expert s confortable to express their knowledge in the theoritical frame.

Plan

- **Uncertainty in risk : why it cannot be ignored**
  - Risk is about an uncertain event
  - Deterministic/probabilistic approaches
- **Uncertainty and reasoning process**
  - Some telling failures
  - Analysis of a paradox
- **Hox to handle uncertainties : what solutions**
  The « norm » compliancy or the research
  The non probabilistic models of uncertainty
- **Results derived from an OECD/CSNI benchmark on TH computer codes**
  The non probabilistic models of uncertainty
- **Conclusion**

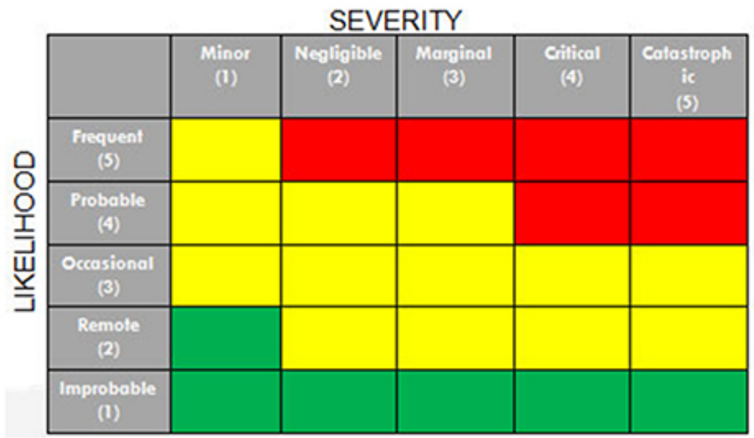
Uncertainty in risk : why it cannot be ignored

Definitions

1°) **Risk** is an **uncertain event** or condition that, if it occurs, has an effect on at least one objective.

2°) **Risk** is **the probability** or threat of quantifiable damage, injury, liability, loss, or any other negative occurrence that is caused by external or internal vulnerabilities, and that may be avoided through preemptive action.

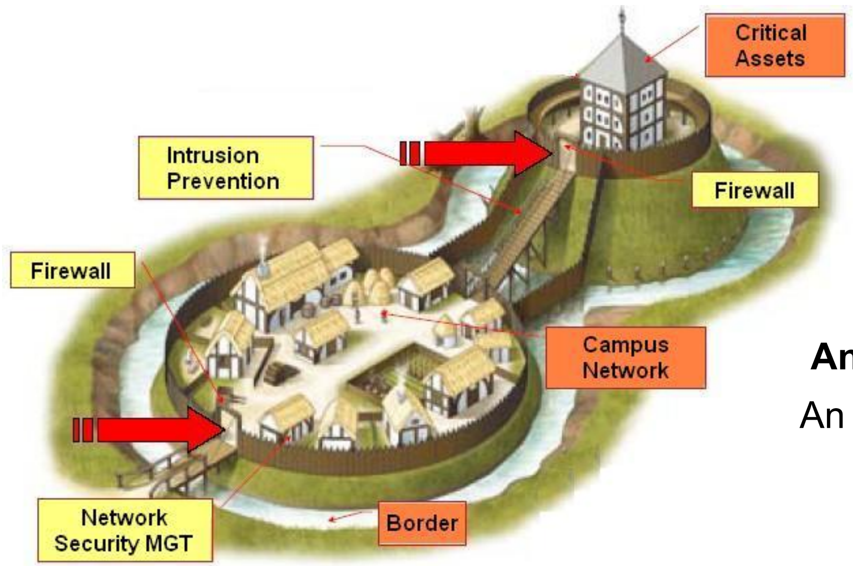
Questions asked of risk analyst : is it safe, safety measures need to be taken, is it unsafe ?



Risk = Event (gravity, severity) * likelihood

Uncertainty and reasoning process

Deterministic approach or « centred event » : defence in depth model



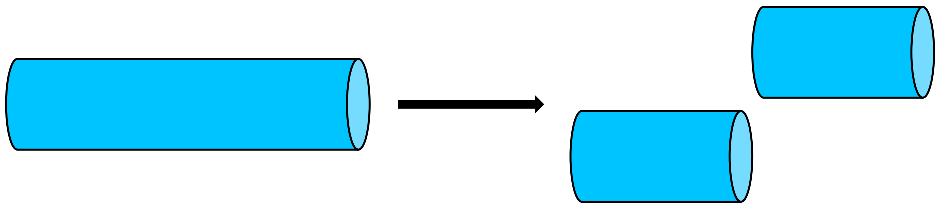
Principle : adding defence lines so that the worst event cannot go through all of them

Another view of the deterministic paradigm : the weak link.

An unwished event is a link and the worst event is the weak link

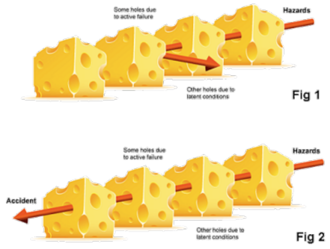
Which event is the « ***worst-realistic***» event ?

In nuclear safety : the double large break loss of coolant accident ?

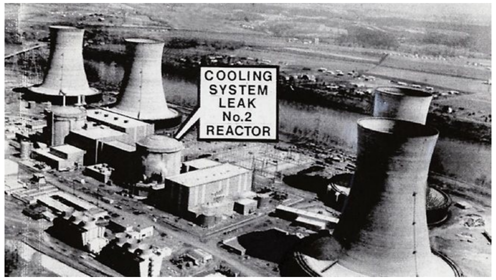


"Well, ladies and gentlemen, we skimped on maintenance a tiny bit, and look what happened: our wings fell off, and we're going to crash. We've learned from this experience, and we'll apply what we've learned to improve the flying experience for our future passengers."

Deterministic paradigm or « centred event » Vs nuclear risk

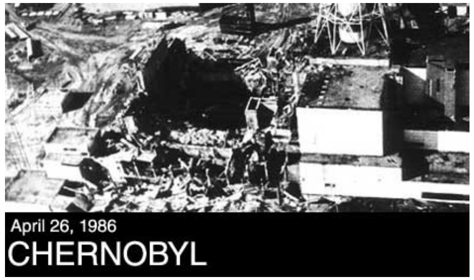


1979 USA TMI : small releases but core fusion
Multiplicity of "small" dysfunctions



Defence in depth

Tchernobyl - M Gorbatchev :
"Some atomic experts had stated that NPPs were safer than samovars and that we could build one on Red Square." ».



Re-emergence of an « old » paradigm : « scenario centred »

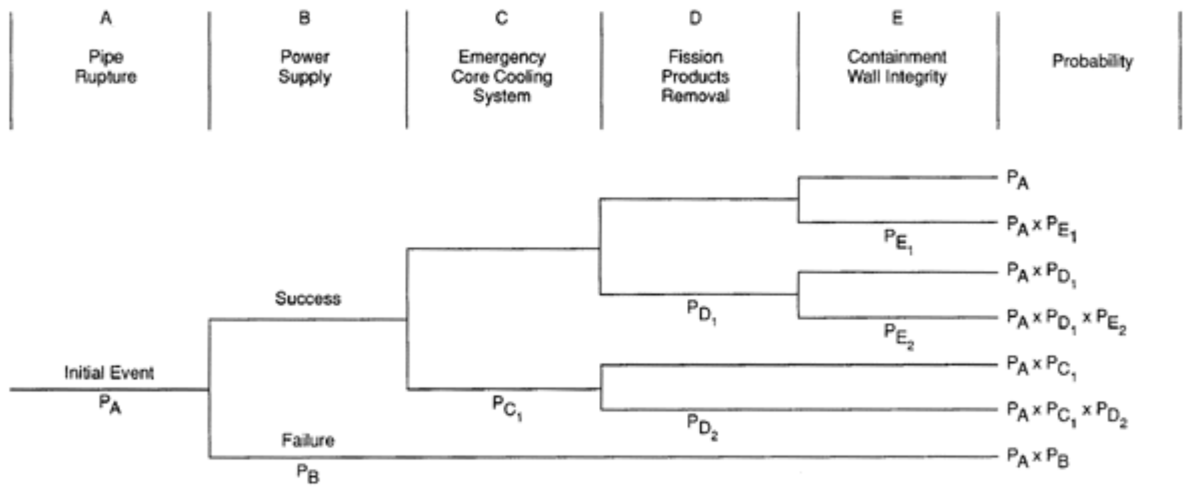
Air force Capt. Ed Murphy : "if anything can go wrong, it will"

A scenario is a chain of numerous events : « the unexpected is almost certain »

A reliable component :
success = 0,999
failure = 0.001

A system made up of reliable components
success 0,999*0,999*….*0,999 -> 0
failure ~1

Probabilistic paradigm or « scenario centred » Vs nuclear risk



Severe accident: 10^{-6}/NPP year ~0,01 expected in the world for lifetime operation

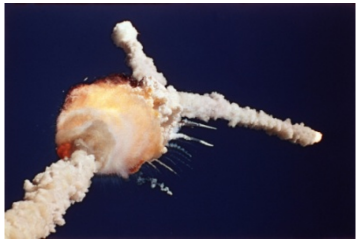
In nuclear safety , both paradigms are used.

In France the deterministic approach is largely predominant,
in USA , the probabilistic one is given more importance .

Uncertainty and reasoning process

What goes wrong with probabilities ?

Some telling failures :

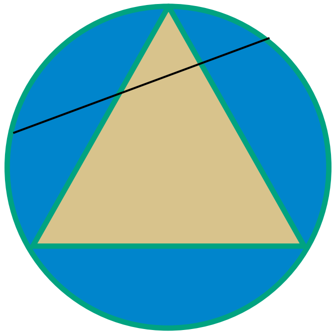


NASA expected 0.01 for 100 launches
observed 2 failures

Nuclear expected 0.01 for operation lifetime over the world
observed 2 severe accidents

What is the probability of an event ?

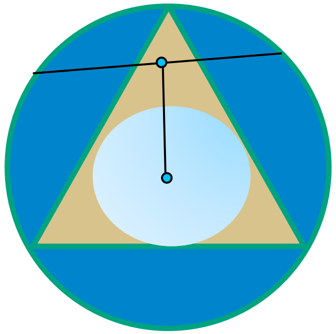
The Bertrand paradox (1888) goes as follows :
Consider an equilateral triangle inscribed in a circle.
Consider the event : “the chord is longer than a side of the triangle”.
What is the probability of this event ?



First solution :
A chord is defined by its endpoints,.
For symmetry reasons, the first endpoint can be one of the vertices of the triangle.

Event “a chord”
take a vertex as endpoint,
choose randomly the other endpoint on the circumscribed circle
check if (or not) is longer than the side
The probability is therefore :

What is the probability of an event ?



Second solution :
A chord is defined by the location of its middle. Indeed, the line joining the middle to the centre of the circle is perpendicular to the chord.
Event = "a point"
choose randomly a point within the circumscribe circle
Check the length of the chord
(The chord is longer than a side of the triangle, if its middle is within the incircle,)
so the probability is the ratio of the area of incircle and circumscribed circles.

Third solution:
The middle is located on a diameter. So the probability is

Moral of the story :
The probability of an event does not exist, it depends on the process leading to this event.

And what about the probability of a one hundred year flood, or a severe accident ?

For most risk analysts, probabilities are acknowledged as subjective (but not arbitrary).

Uncertainty handling : compliance or research issue ?

What does the ISO norm tell ?

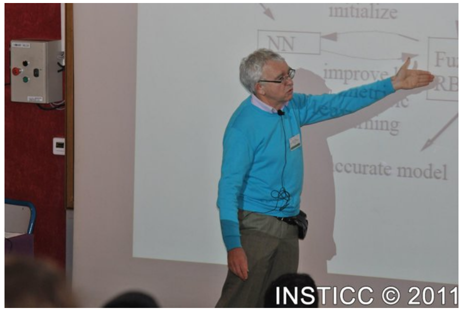
Extract from the © BIPM-JCGM 200:2008 (Joint Committee for Guides in metrology)
« uncertainty should be grouped into two categories, Type A and Type B, according to whether they were evaluated by statistical methods or otherwise"

Type A : pertaining to stochastic events
Type B : pertaining to the degree of knowledge of models and their parameters

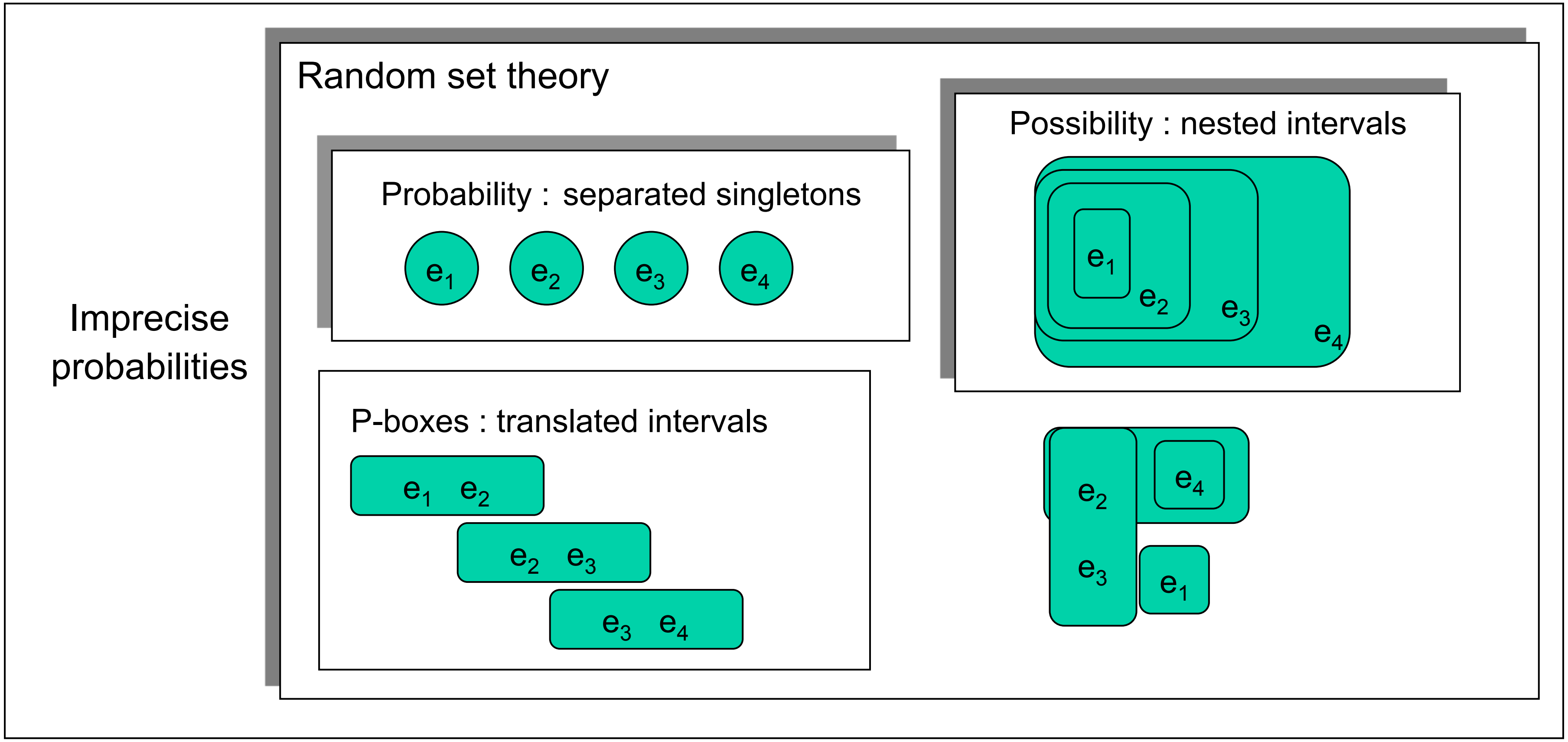
and the committee's recommendation is "that they be combined to yield a variance according to the rules of mathematical probability theory"

For evaluating nuclear risk, the ISO norm is not very helpful. More advanced approaches are needed .

What can researchers teach to engineers ?



The non probabilistic models of uncertainty



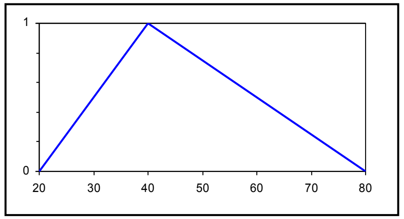
Question from engineers to reseachers : interesting but operational ?

Translation : uncertainty is even more of a nightmare than what I have ever dreamed of.

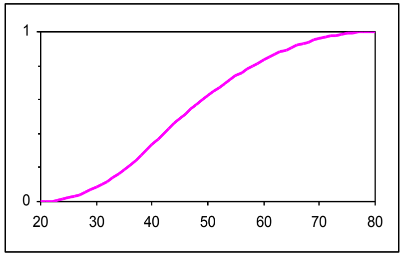
Decision : why not a phd student ?

Uncertainty in theory : what does a partial knowledge mean ?

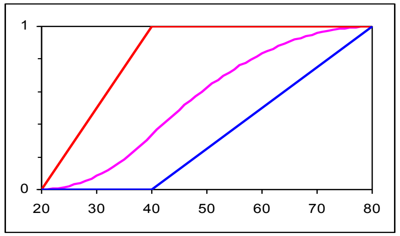
Daily beef eaten by an adult



PhD 2002-2005



CDF probability

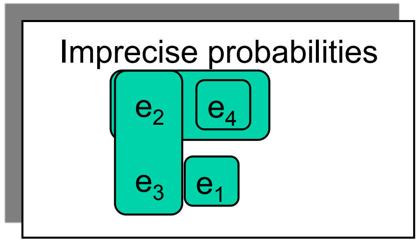


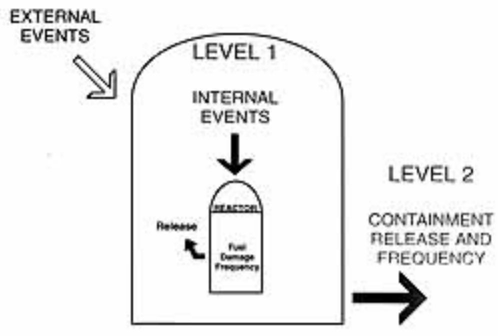
Possibility or P-box

NB The non-informative prior is difficult in practice : eg the same parameter has opposite effects depending on quantities of interest.

A cooler water injection is positive for temperature clad but can fragilise the rod

Uncertainty in practice : how to compute ?





Level 1 and level 2 probalistic risk assessment.

The requirements

Imprecise probabilities require interval computations

Imprecise probabilities may lead to unusuable results

Example : opinion poll with or not the « no-opinion » people as «hanging belief mass »

accuracy : ~3% (probabilité theory)

or ~25% (by DST theory) considered as unrealistic by most of pollsters

When no theoritical proof exists , how to get some practical proof ?

An application : the BEMUSE OECD/CSNI Program

BEMUSE Program : A LBLOCA Uncertainty Study

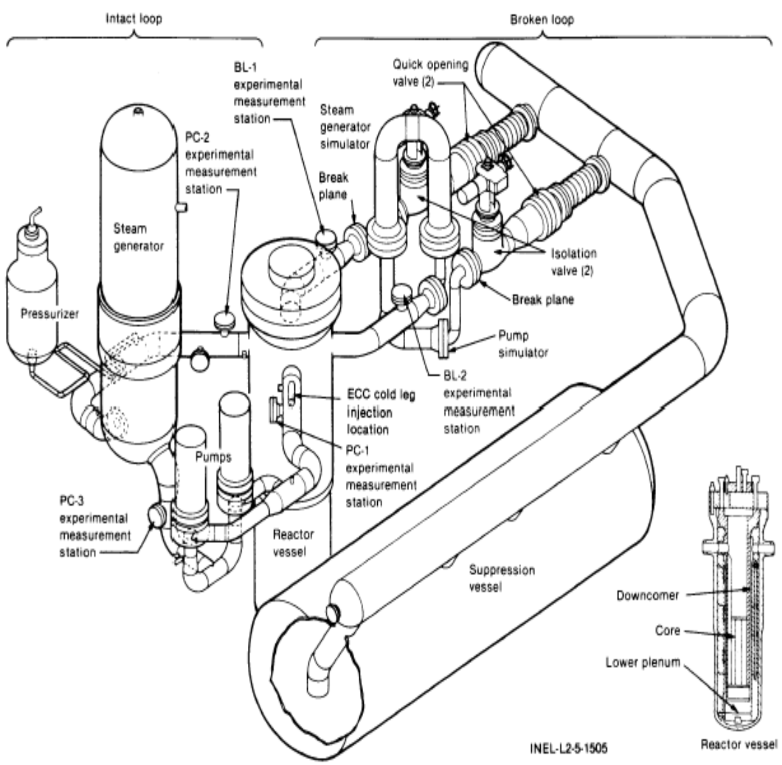


Figure A-1. Axonometric projection of LOFT system.

The BEMUSE program is divided in two steps. The first step consists to perform an uncertainty analysis on an experimental test and the second step on a NPP. Each of these two steps is made up of three phases :

- **First step (Phases 1, 2 and 3): an uncertainty analysis of LOFT L2-5**

- Phase 1 : a priori presentation of the uncertainty evaluation methodology to be used by the participants ,
- Phase 2 : re-analysis of the ISP-13 exercise, post-test analysis of the LOFT L2-5 test calculation,
- Phase 3 : uncertainty evaluation of the L2-5 test calculations, first conclusions on the methods and suggestions for improvement.

- **Second step (Phases 4, 5 and 6): performing this analysis for a NPP-LB.**

- Phase 4 : best-estimate analysis of a NPP-LBLOCA,
- Phase 5 : sensitivity studies and uncertainty evaluation for the NPP-LB (with and without methodology improvements resulting from phase 3),
- Phase 6 : status report on the area, classification of the methods, conclusions and recommendations.

BEMUSE Program :

Phase 1 : An integral facility LOFT L2-5 - 10 participating organisations (*)

Phase 2 : A Nuclear Power Plant Zion - 14 participating organisations

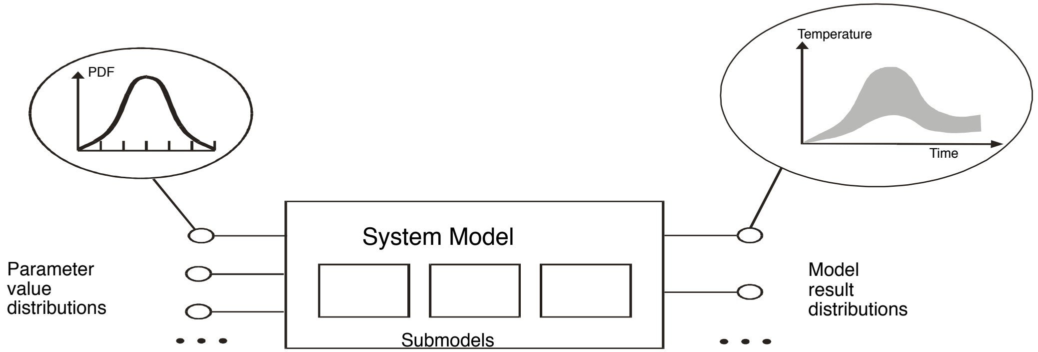
	Numb.	Organisation	Country	Name	E-mail	Code
	1	AEKI	Hungary	A.Guba I.Tóth I. Trosztel	guba@aeki.kfki.hu tothi@aeki.kfki.hu trosztel@aeki.kfki.hu	ATHLET 2.0A
*	2	CEA	France	T.Mieusset P.Bazin A.de Crécy	thomas.mieusset@cea.fr pascal.bazin@cea.fr agnes.decrecy@cea.fr	CATHARE2 V2.5_1 (r5_567)
	3	EDO	Russia	S.Borisov	borosov_sl@grpress.poldolsk.ru	TECH-M-97
*	4	GRS	Germany	T.Skorek H.Glaeser	Tomasz.Skorek@grs.de Horst.Glaeser@grs.de	ATHLET 2.1B
*	5	IRSN	France	J.Joucla P.Probst	jerome.joucla@irsn.fr pierre.probst@irsn.fr	CATHARE2 V2.5_1 mod6.1
	6	JNES	Japan	A.Ui	ui-atsushi@jnes.go.jp	TRACE ver4.05
*	7	KAERI	South Korea	B.D.Chung	bdchung@kaeri.re.kr	MARS 3.1
*	8	KINS	South Korea	D.Y.Oh	k392ody@kins.re.kr	RELAP5/mod3.3
*	9	NRI-1	Czech Republic	R.Pernica M.Kyncl	per@ujv.cz milos.kyncl@ujv.cz	RELAP5/mod3.3
*	10	NRI-2	Czech Republic	Jiri Macek	mac@ujv.cz	ATHLET 2.1 A
*	11	PSI	Switzerland	A.Manera J.Freixa	annalisa.manera@psi.ch jordi@freixa.net	TRACE5rc3
*	12	UNIPI-1	Italy	A.Petruzzi F.d'Auria	a.petruzzi@ing.unipi.it d5808@ing.unipi.it	RELAP5/mod3.2
	13	UNIPI-2	Italy	A.Del Nevo F.d'Auria	a.delnevo@ing.unipi.it d5808@ing.unipi.it	CATHARE2 V2.5_1 mod6.1
*	14	UPC	Spain	M.Pérez F.Reventós L.Batet	marina.perez@upc.edu francesc.reventos@upc.edu lluis.batet@upc.edu	RELAP5/mod3.3

BEMUSE Program : a Monte-Carlo approach used by all the participants

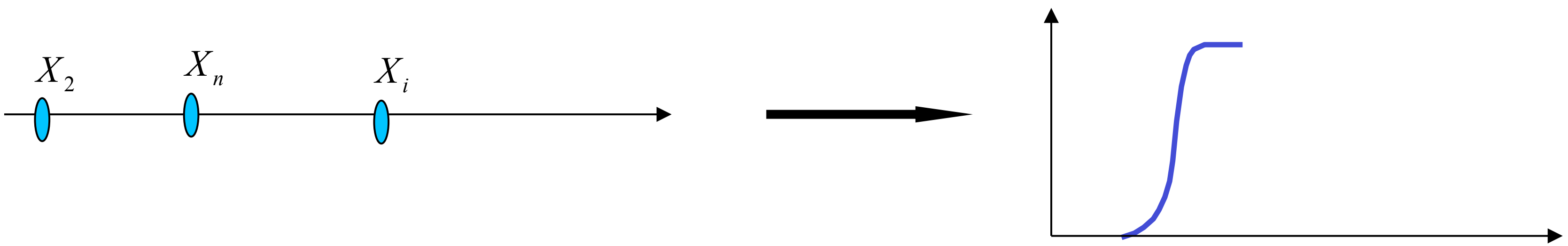
Principle of probalistic methods :

Y = risk model (X_1, …, X_n) , the quantity of interest its percentile α (95%) denoted Y_α

If Xi are random variables, by simulating a given number of values , we can evaluate Y_α by Monte-Carlo simulation



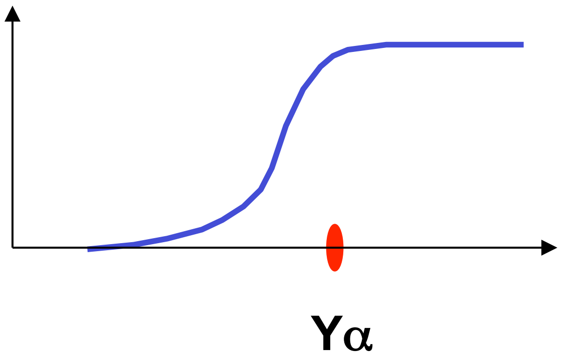
Monte-Carlo principle



CDF(x) =(number of Xi < X) / sample size

BEMUSE Program : a Monte-Carlo approach used by all the participants

A hundred year flood means α = 0.99



$Y_{(i)}$ ordered occurrences

Theorem order statistics $P(Y_{(k)} \le Y_\alpha \le Y_{(l)}) = Beta_{(k,N-k+1)}(\alpha) - Beta_{(l,N-l+1)}(\alpha)$

Operationality of these methods :

No need to reduce the number of uncertain parameters

Limited cost ~100 computational runs are required to derive a confidence interval of the desired percentile

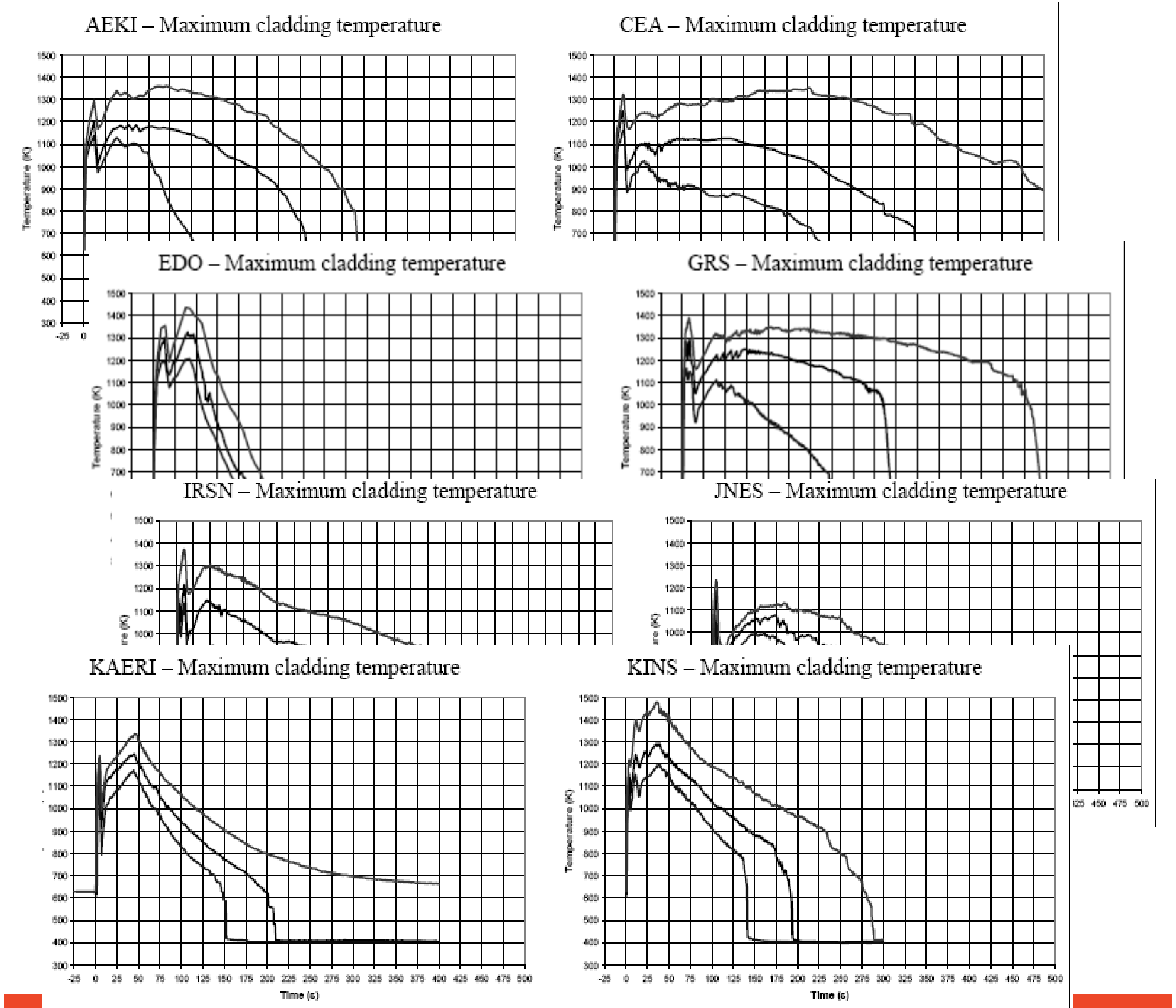
BEMUSE Program : 50 random parameters, 10 output quantities

Number of computer code runs and the corresponding calculations for interest quantities

N	Percentile	confidence intervals = numerical accuracy	
	95%	95%	99%
60	57	[$X_{(52)}$, $X_{(60)}$]	$\geq X_{(60)}$
100	95	[$X_{(90)}$, $X_{(99)}$]	[$X_{(89)}$, $X_{(100)}$]
200	190	[$X_{(184)}$, $X_{(196)}$]	[$X_{(182)}$, $X_{(198)}$]
500	475	[$X_{(465)}$, $X_{(485)}$]	[$X_{(462)}$, $X_{(487)}$]

The interval span is the numerical accuracy of the MC simulation at a given confidence level

BEMUSE results : uncertainty quantification of the cladding temperature

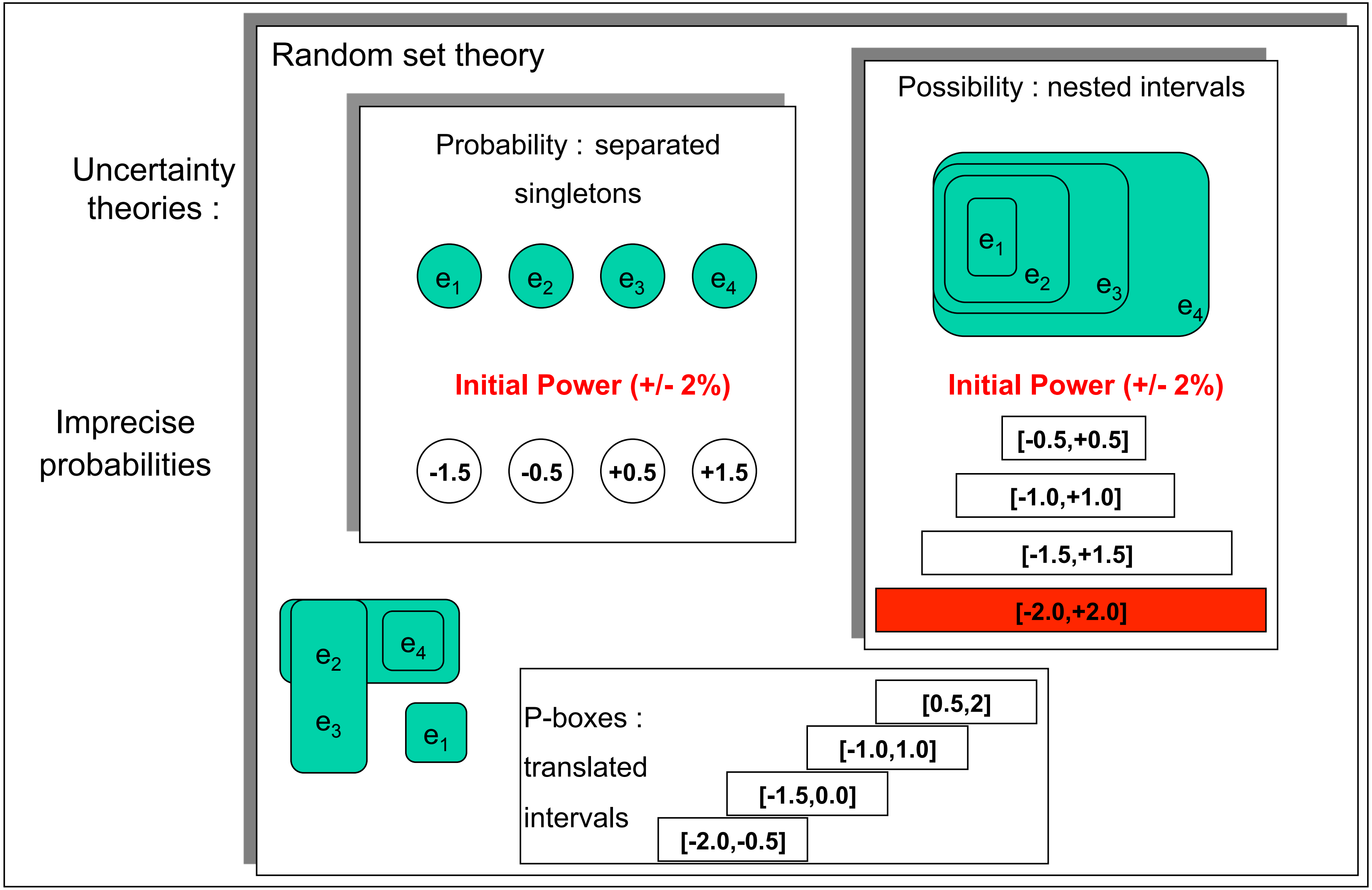


IRSN-IRIT BEMUSE contribution

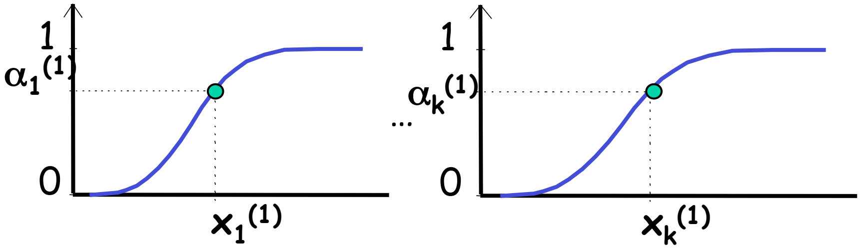
The 8 out 10 most influential uncertain input parameters considered as possibilistic

Name	Nom. Value	Variation Range
Liquid-wall friction	1	[0.8;1.9]
Fuel conductivity(Tfuel<2000K)	1	[0.9;1.1]
Vapour-wall heat transfer (forced convection regime)	1	[0.5;2]
Peaking factor hot rod	1	[0.95;1.05]
Heat transfer "flashing"	1	[0.05;1]
Initial Upper header mean temperature +10°K	1	[1;4]
Initial loop mass flow rate +/-4% (head pump)	1010	[810;1210]
Friction form loss in the Pressurizer line	1	[0.5;2]
Hot gap size hot rod	1	[0.8;1.2]
Initial Power +/-2% (power before scram)	1	[0.98;1.02]

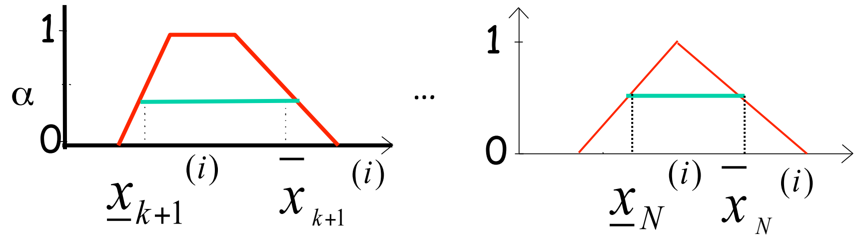
IRSN-IRIT uncertainty modelling



MC algorithm extended to imprecise variables

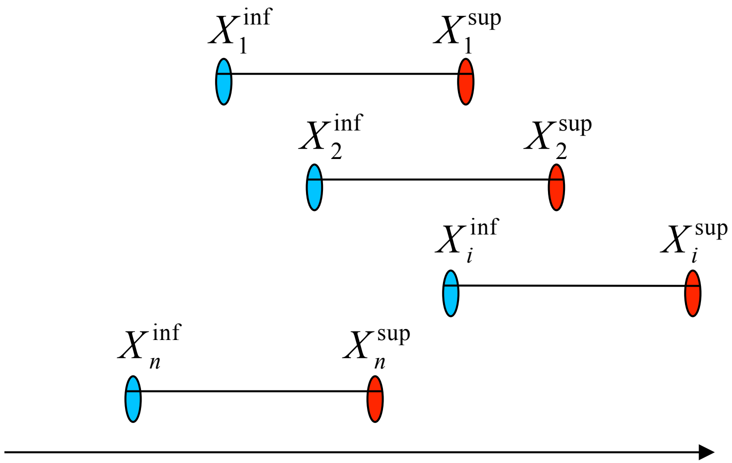


random variable

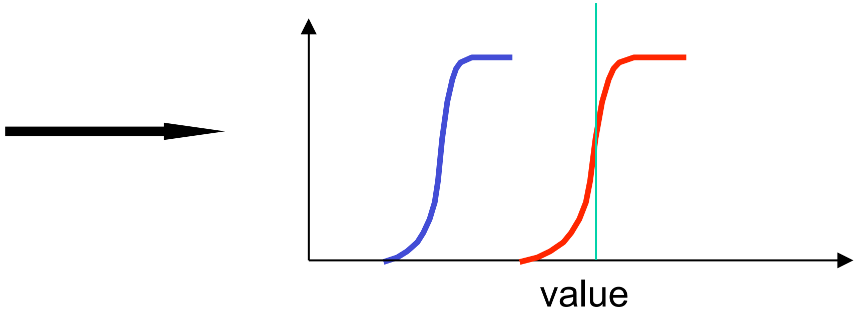


Imprecise variable

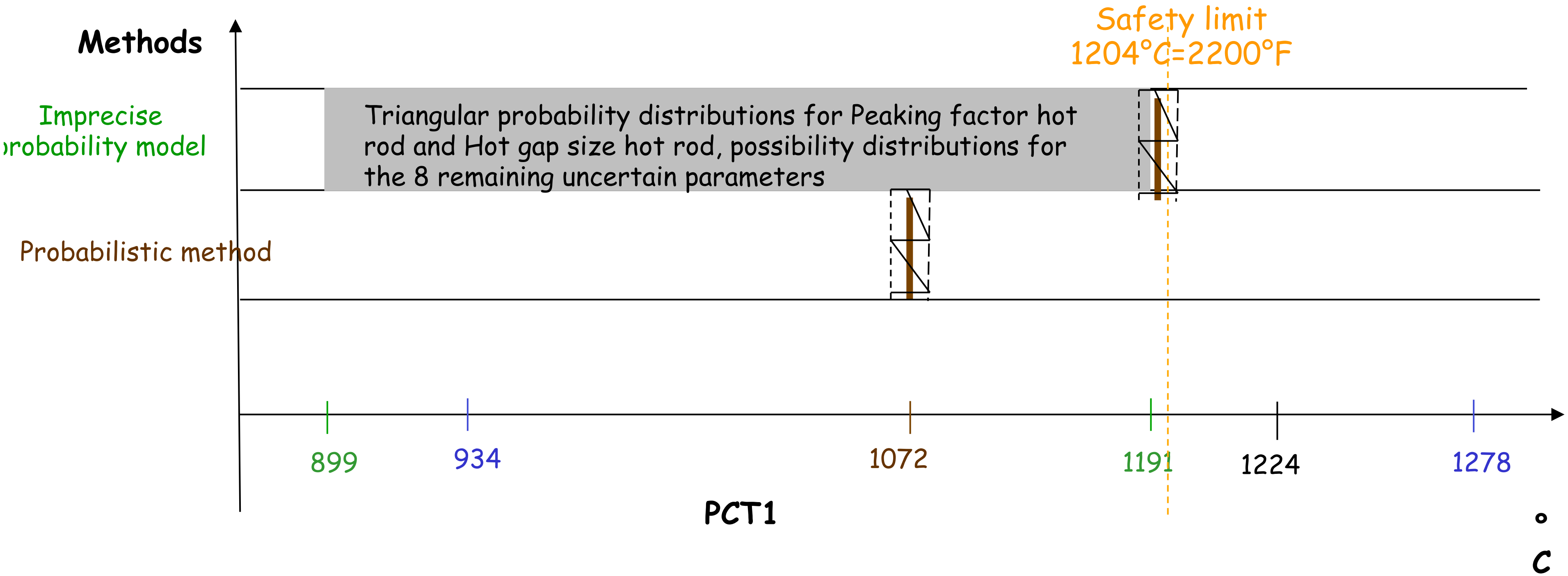
At each step : a value or an interval is selected, so that the result of any output quantity is an interval



A pair of CDFs instead of a single one



BEMUSE results : 95%-percentile of PCT

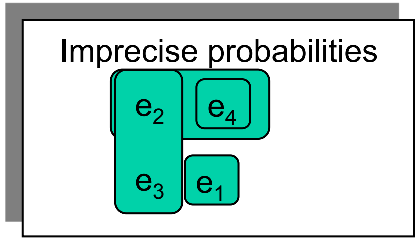


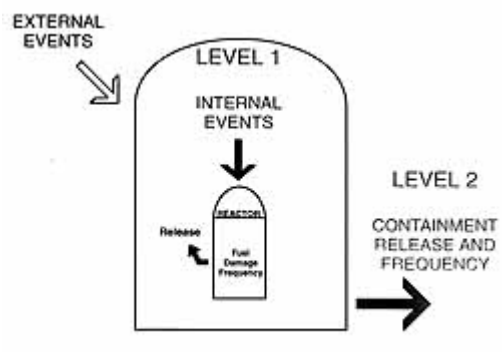
- Epistemic uncertainties or effect of pdf choices : ~190°C

This effect is very similar to the user effect observed between BEMUSE participants : 860°C to 1150°C

- Numerical accuracy : ~ 30°C (sample size 500) relatively weak with respect to user effect or epistemic uncertainties

Uncertainty in theory and practice : some promising results





Level 1 and level 2 probalistic risk assessment.

Monte-Carlo algorithms extented to non probabilistic models

A practical guide for uncertainty elicitation with imprecise probability models

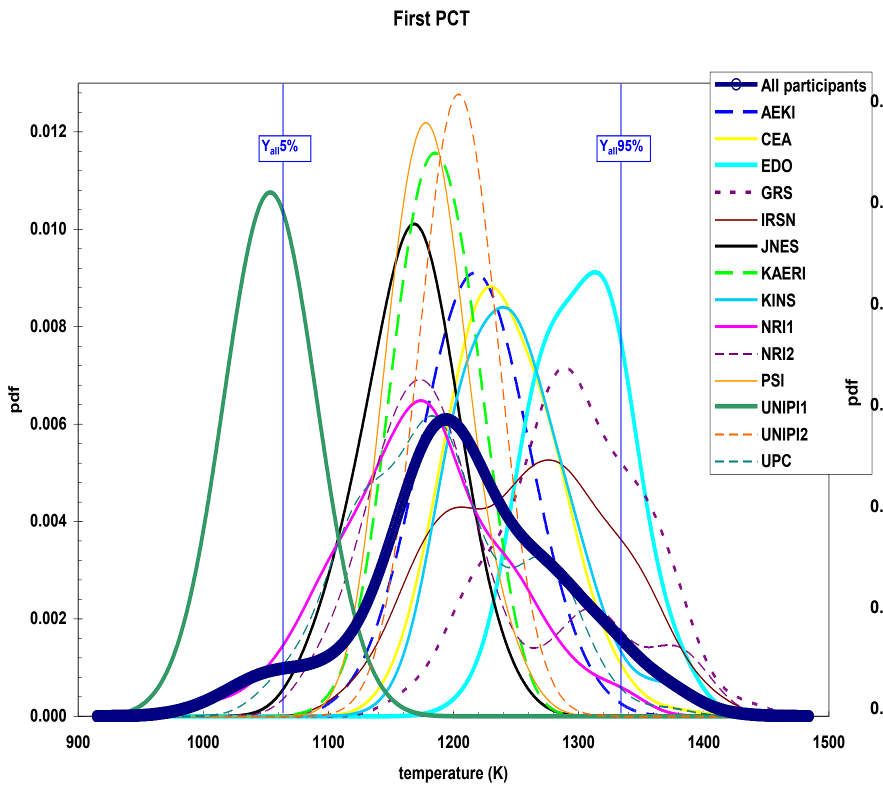
Objectives :

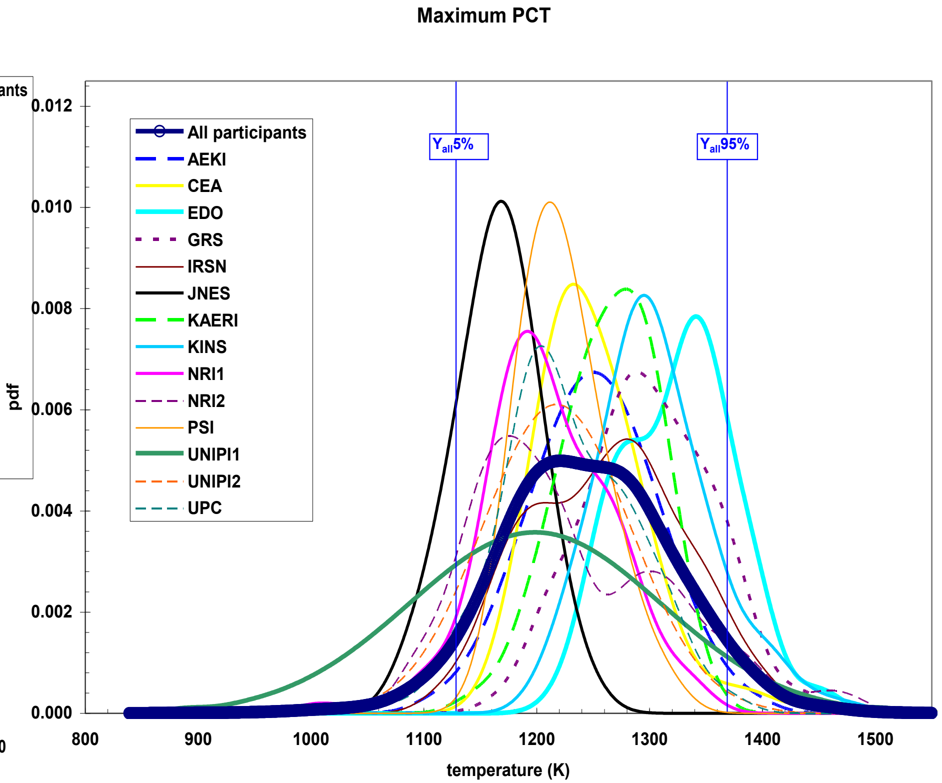
Information scoring

information synthesis

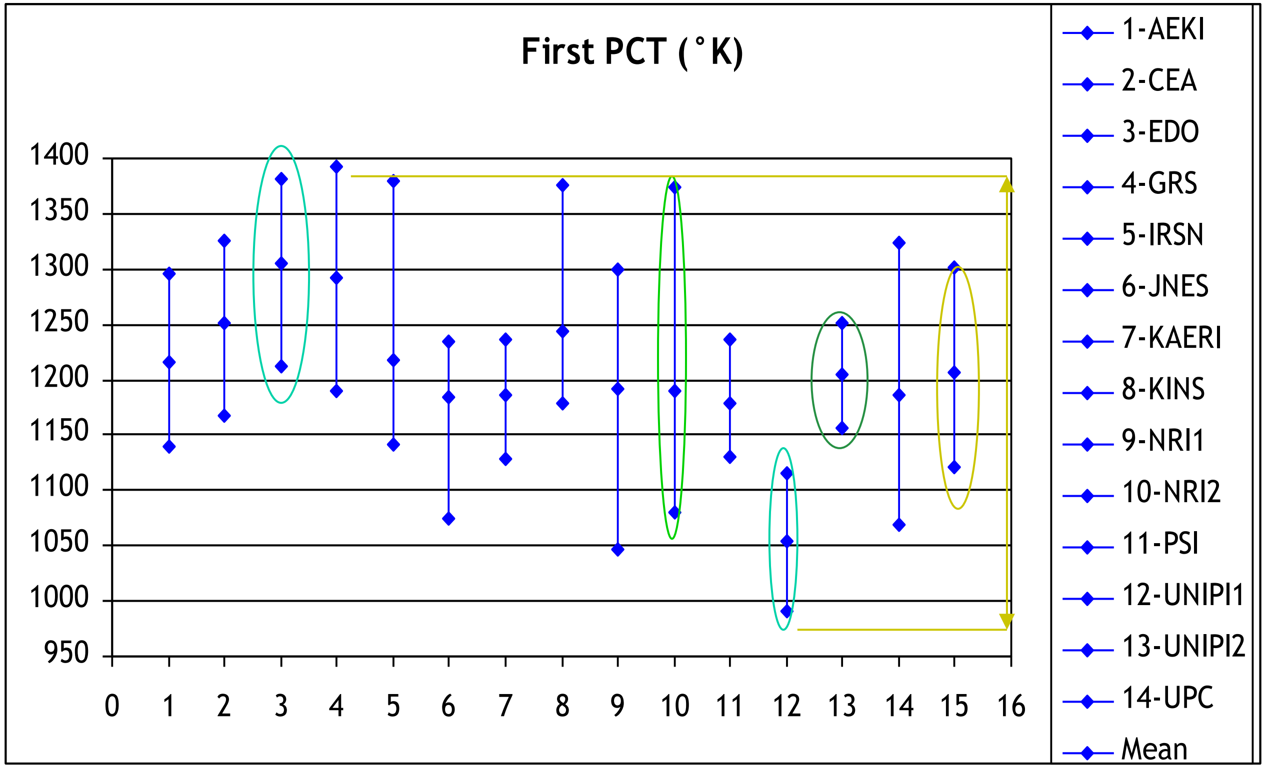
PhD 2005-2008

BEMUSE Program : the CDF provided by participants as information sources





How to score the participants results : a simplification step



Some visual results :

1°) Large differences between uncertainty bands

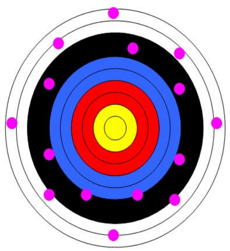
2°) No overlapping between uncertainty bands

3°) Mean, Min-Max … what aggregation operator is right ?

Principle of Information scoring

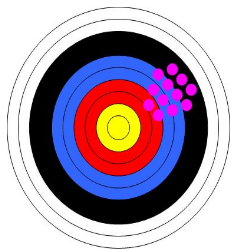
JCGM 200:2008 : International vocabulary of metrology

Trueness



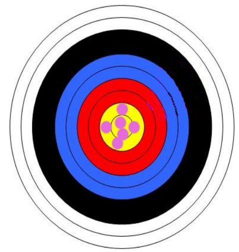
closeness of agreement between the average of an infinite number of replicate measured quantity values and a reference quantity value

Precision



closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions

Accuracy



closeness of agreement between a measured quantity value and a true quantity value of a measurand

Probabilistic Risk Analysis Cambridge 2001 T. Bedford, R. Cooke

Calibration

measures the coherence between information provided by the source and the experimentally observed value

Informativeness

measures the precision of the information

Score

measures the quality of the information

Information scoring

	1PCT (K)			2PCT (K)			T_{inj} (s)			T_q (s)		
	Low	Ref	Up	Low	Ref	Up	Low	Ref	Up	Low	Ref	Up
CEA	919	1107	1255	674	993	1176	14.8	16.2	16.8	30	69.7	98
GRS	969	1058	1107	955	1143	1171	14	15.6	17.6	62.9	80.5	103.3
IRSN	872	1069	1233	805	1014	1152	15.8	16.8	17.3	41.9	50	120
KAERI	759	1040	1217	598	1024	1197	12.7	13.5	16.6	60.9	73.2	100
KINS	626	1063	1097	608	1068	1108	13.1	13.8	13.8	47.7	66.9	100
NRI1	913	1058	1208	845	1012	1167	13.7	14.7	17.7	51.5	66.9	87.5
NRI2	903	1041	1165	628	970	1177	12.8	15.3	17.8	47.4	62.7	82.6
PSI	961	1026	1100	887	972	1014	15.2	15.6	16.2	55.1	78.5	88.4
UNIPI	992	1099	1197	708	944	1118	8.0	16.0	23.5	41.4	62.0	81.5
UPC	1103	1177	1249	989	1157	1222	12	13.5	16.5	56.5	63.5	66.5
Exp. Val.		1062			1077			16.8			64.9	

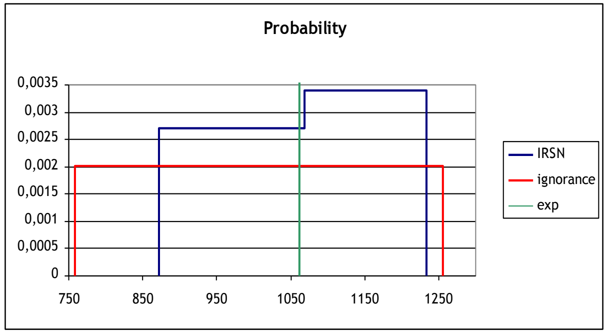
Score = Inf * Cal

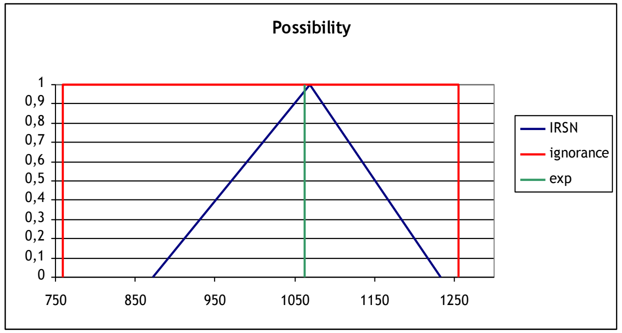
An example: T_{inj}

informativeness = 0 for 9-UNIPI (smallest and largest value)

calibration = 0 for 5-KINS (experimental value outside of the confidence interval)

For a set of quantities, the global scoring is taken as the average of single scorings





$$I(p,u) = \sum_{i=1}^{B} p_i \log\left(\frac{p_i}{u_i}\right) \qquad Cal_p(s) = 1 - \chi^2_{B-1}\left(2 * N * I(r,p)\right)$$

BEMUSE-phase 3 : information scoring results

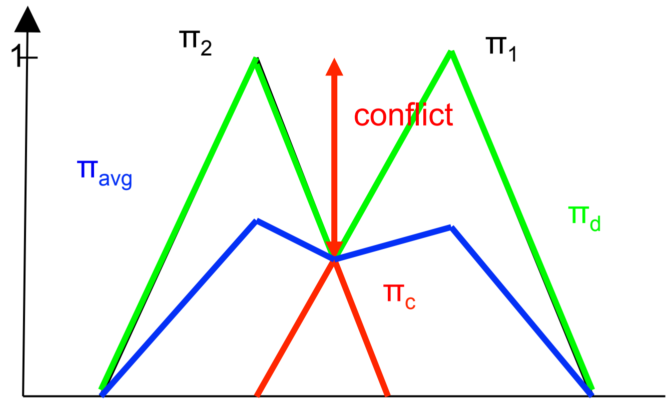
Evaluation : informativeness, calibration

Participants	Infor. Proba	Calib. Proba	Global Proba	Infor. Poss	Calib. Poss	Global Poss
CEA	8	5	6	8	7	7
GRS	4	1	1	3	6	6
IRSN	5	2	2	6	1	1
KAERI	9	5	7	9	8	8
KINS	3	5	5	7	3	3
NRI1	7	2	3	5	5	4
NRI2	6	8	8	4	2	2
PSI	1	10	10	1	10	10
UNIPI	10	2	4	10	4	5
UPC	2	9	9	2	9	9

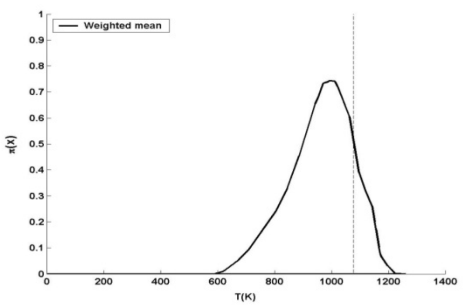
Good agreement with the "visual" analysis

and also between formal methods (4 out of 5 first organisms, the last 2 are common)

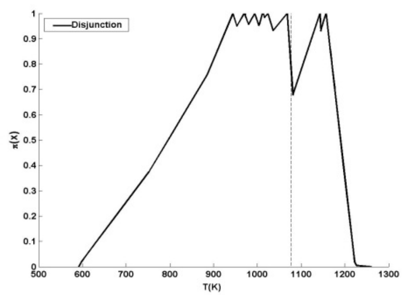
Information fusion : three main fusion operators



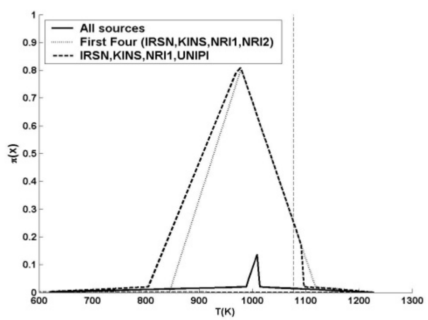
Weighted average



Disjunctif (→ union)



Conjunctif (→ intersection)



An automatic way of identifying conflicts between participants

Conclusion for the 2nd thesis

Information scoring

Extension to possibilistic formalism of R. Cooke's probabilistic information scoring

High similarity with probabilistic formalism

PhD 2005-2008

Information synthesis

Development of a larger choice of fusion operators

Identification of concordant/discordant participants, code/user effects

« information synthesis methods seem a convenient tool to progress towards a rational consensus and help to better understand the differencies between participant results. » final BEMUSE report

Why bother with non-probabilistic models in risk analysis ?

Conclusion

- A risk evaluation of a complex system needs to aggregate a set of different knowledges (the human part of it is of prime importance)

  Risk evaluation is more an epistemic than an ontic issue ?

- For these reasons, in some applications imprecise probabilities are useful

  They can facilitate debates between experts useful to improve risk analysis

Engineers are generally more concerned about the suitability of a model than its label : "frequentist", "Bayesian", "DST" ….

"the proof of the pudding is in the eating"