IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Combining probability and possibility to respect the real state of knowledge on uncertainties in the evaluation of safety margins

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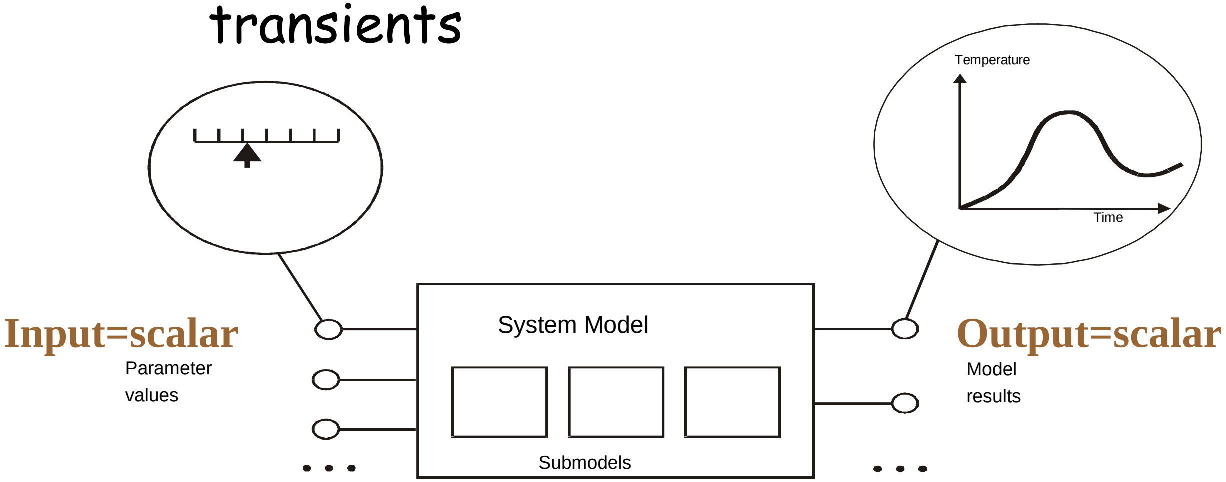
Uncertainty analysis: why?

- IRSN: expert in research and specialised assessments into nuclear and radiological risk serving french public authorities.
- Safety assessment: computer codes simulation of accidental transients



Safety criterion

« Ouput<Output_crit? »

  - Approximation of the physical reality
  - Ill-known data (imprecision, uncertainty range)
- Conservative codes: penalizing results
- Best-Estimate codes: take into account uncertainty

Classical probabilistic uncertainty analysis

- Uncertainty quantification by a PDF + specification of dependencies between uncertain parameters
- Uncertainty propagation through the computer code by Monte-Carlo simulations
- Statistical analysis
  - Likelihood of the code response to be above a safety limit
  - Uncertainty margin

Estimation of α-percentile: (α=5%,95%)

y_α ? $P(Y \leq y_\alpha) = F_Y(y_\alpha) = \alpha$

Classical probabilistic approach

- Easy to perform
- Direct estimation of percentiles by order statistics + numerical accuracy due to the sample size : no response surface, no statistical tests,…..

But:

- Need to specify an unique PDF for each uncertain parameter + dependencies between parameters

➡ Not always available

➡ Solution in case of incomplete knowledge? Uniform law and independence between parameters

No knowledge about PDFS	$\neq$	Equiprobability
No knowledge about dependencies	$\neq$	Independence

Sketch of the presentation

1) RAFU method and uncertainty analysis

- ❖ Hybrid-type methods

- ❖ RAFU approach: computational cost reduction strategy and integration of numerical accuracy

2) Application to the evaluation of uncertainty margins for a nuclear reactor

1-1) Uncertainty analysis based on hybrid-type methods

(1) Modeling of uncertainty sources

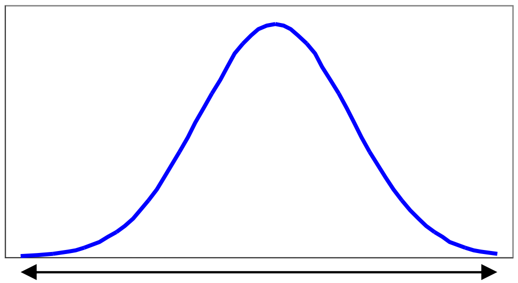
- Variability (aleatory uncertainty)

No reduction of uncertainty margin by increasing the state of knowledge

→ **Variability inside a given population (weight)**

Time failures of some class of components

⇒ **Modeling:** random variable



Dispersion of measures

(1) Modeling of uncertainty sources

- Imprecision, lack of knowledge (epistemic uncertainty)

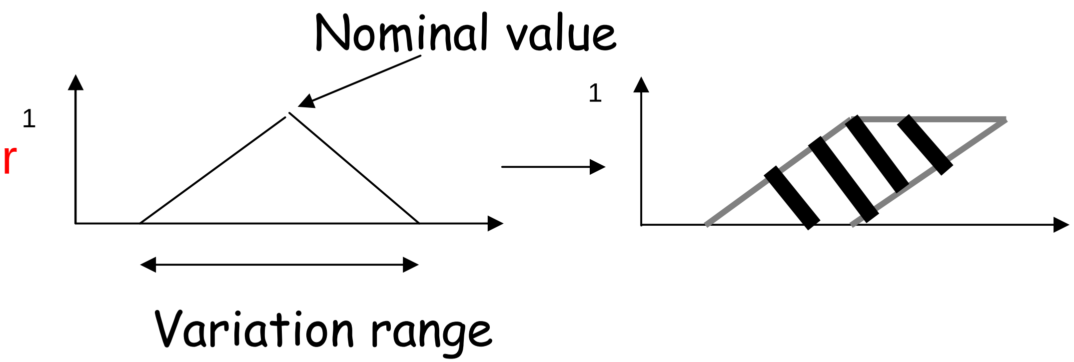
Reduction of uncertainty margin by increasing the state of knowledge

→ **Systematical error: measurement not fully reliable**

Poor quantity of data

Subjective uncertainty: expert providing imprecise valued quantities

⇨ **Modeling:** fuzzy number

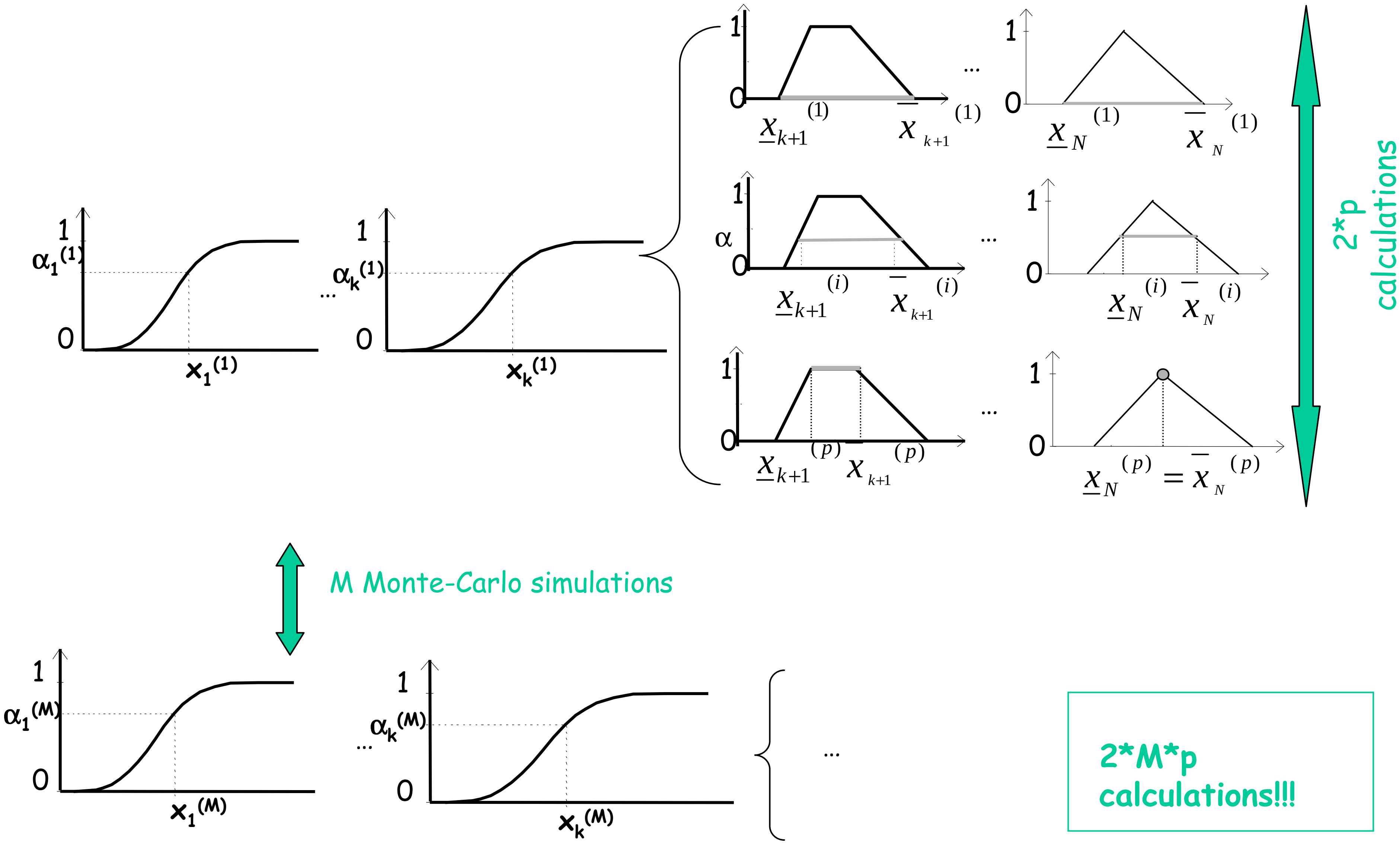


⇨ **Partial probabilistic modeling** (requires less information for its construction than the probabilistic one)

- Relax the assumption related to the choice of an unique PDF

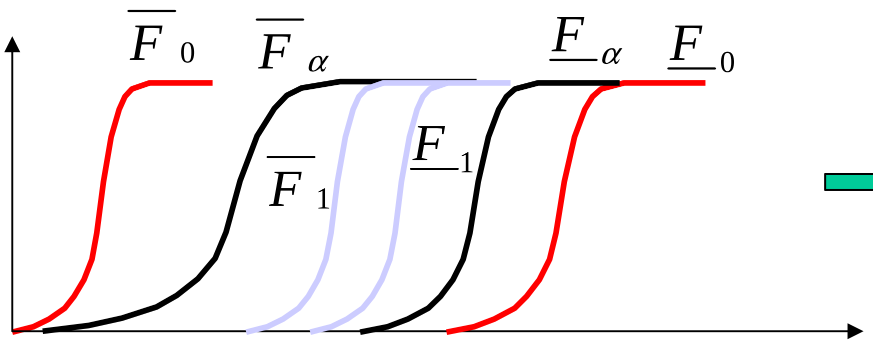
Random or fuzzy variable according to the available knowledge and to the nature of the information?

(2) Propagation through computer code (sampling procedure)



(3) Statistical analysis

- Pairs of cumulative distribution functions



Which $[\overline{F}\,;\underline{F}\,]$ to choose as statistical summary?

- Ferson *et al*: α={0,1}
- Baudrit *et al*: α=average

- Extension of classical statistical estimation techniques to hybrid-type framework:

  ➡ Couple of lower and upper percentiles

- <u>2 Main drawbacks</u>: - computational cost: 2*M*p calculations (p~20), not possible when using complex computer codes

  - requires interval calculations

1-2) RAFU method

Main characteristics

RAFU method = RAndom/FUzzy method

- Hybrid-type method: combination of possibility and probability for uncertainty representation

- RAFU propagation:

  - Integration of a computational cost reduction strategy deriving the optimal sampling procedure (i.e minimal #calculations) corresponding to the analyst's choices

  - Measure the sample size effect on the uncertainty margin estimation

RAFU propagation

Set a decision step before propagating uncertainties

→ Selection of a triplet of parameters $(\gamma_S, \gamma_E, \gamma_A)$ specified by the analyst:

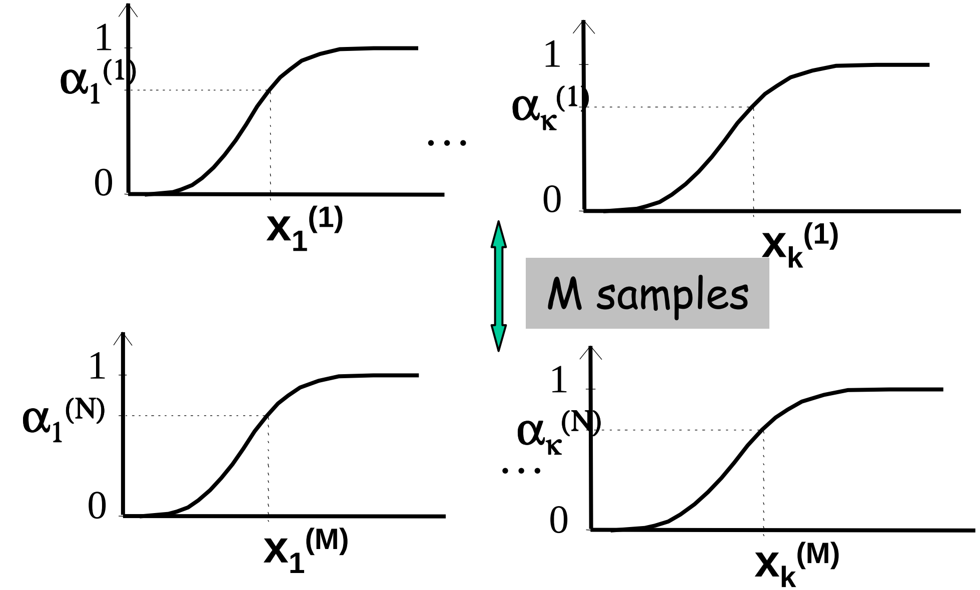
- γ_S (aleatory uncertainty): statistical quantity the analyst is interested in + dependence structure
  - Mean/variance of the code output: γ_S={« mean »/ «variance »}
  - Given percentile: γ_S={q%}
  - Probability of exceeding a given threshold x: γ_S={F(x)}

- γ_E (epistemic uncertainty): how intervals are drawn from possibility distributions

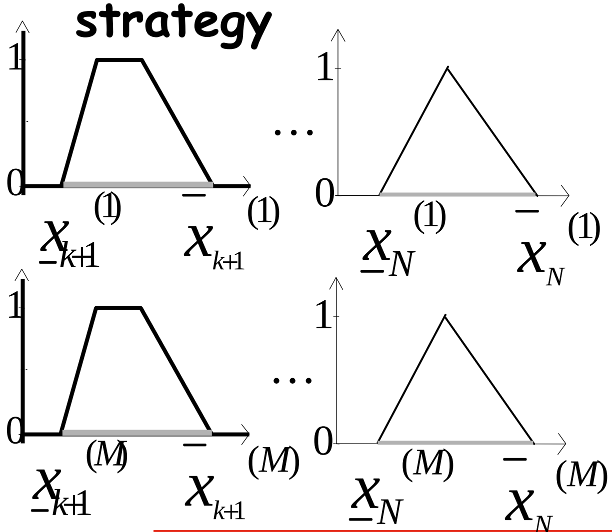
  - Pessimistic strategy (conservative Decision-maker's behavior): $\gamma_E=\{0\}$ (maximal imprecision)
  - Optimistic strategy: $\gamma_E=\{1\}$ (minimal imprecision)
  - Average strategy (compromise between pessimistic and optimistic behaviors): $\gamma_E=\{av\}$

- γ_A: desired numerical accuracy associated to statistical estimation (sample size effect or numerical uncertainty) or maximal number of affordable code runs

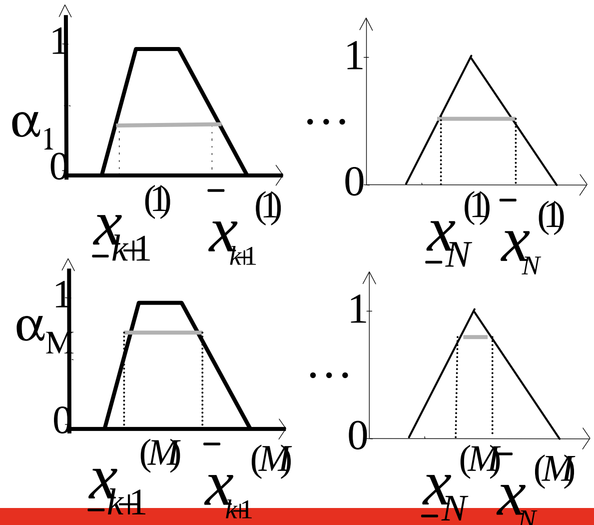
Derive the optimal sampling procedure according to (γ_S, γ_E, γ_A)



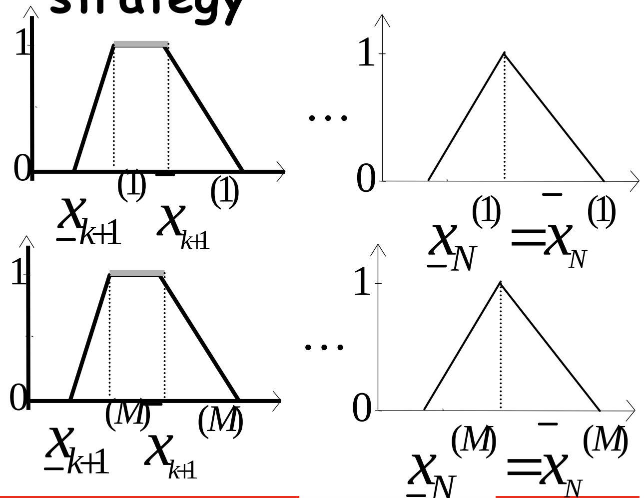
« Pessimistic » strategy



« Average » strategy



« Optimistic » strategy



Advantages of the RAFU method

- Reduction of the computational cost: M instead of M*p interval calculations for a « pessimistic »/ «optimistic »/ «average » Decision Maker (useful when working with complex computer codes in nuclear safety)

→ Example: if M=200, p=20:

With the classical hybrid method: 4000 interval calculations

With the RAFU method: 200 interval calculations (Baudrit *et al*) et 400 for Ferson *et al.*

- Integration of the numerical accuracy of the result (Effect of the sample size on the final uncertainty margin)

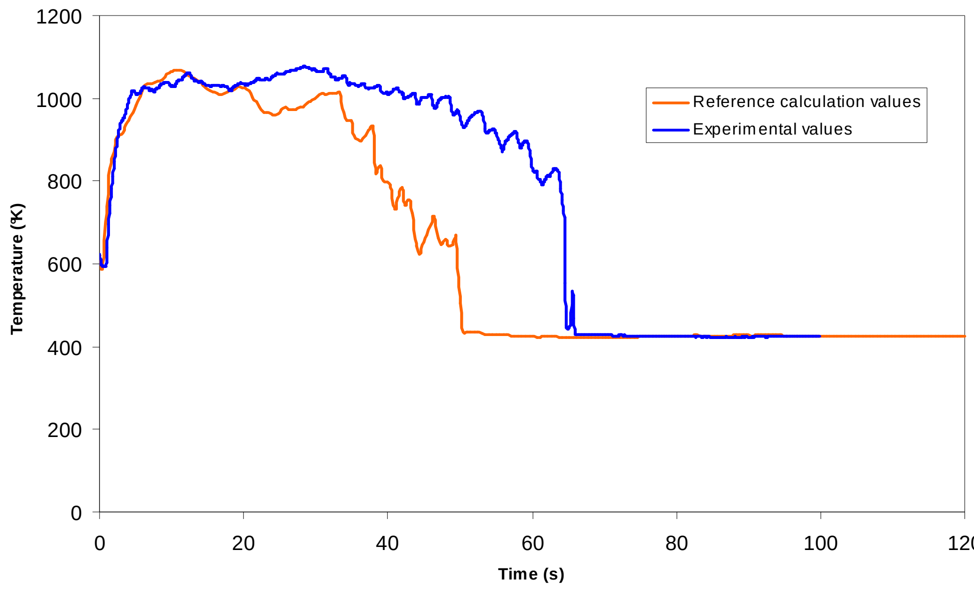
2) Application to the evaluation of uncertainty margins for a nuclear reactor

Description of the test-case :

- Zion reactor, USA

- Simulation with the thermohydraulical CATHARE code of a LB-LOCA (Large Break-Loss of Coolant Accident)

→ First peak cladding temperature



Numerical tests (CATHARE/SUNSET)

The 10 most influential uncertain input parameters (similar results for uncertainty margin estimation as in the case of 54, cf. IRSN results)

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]

Numerical tests

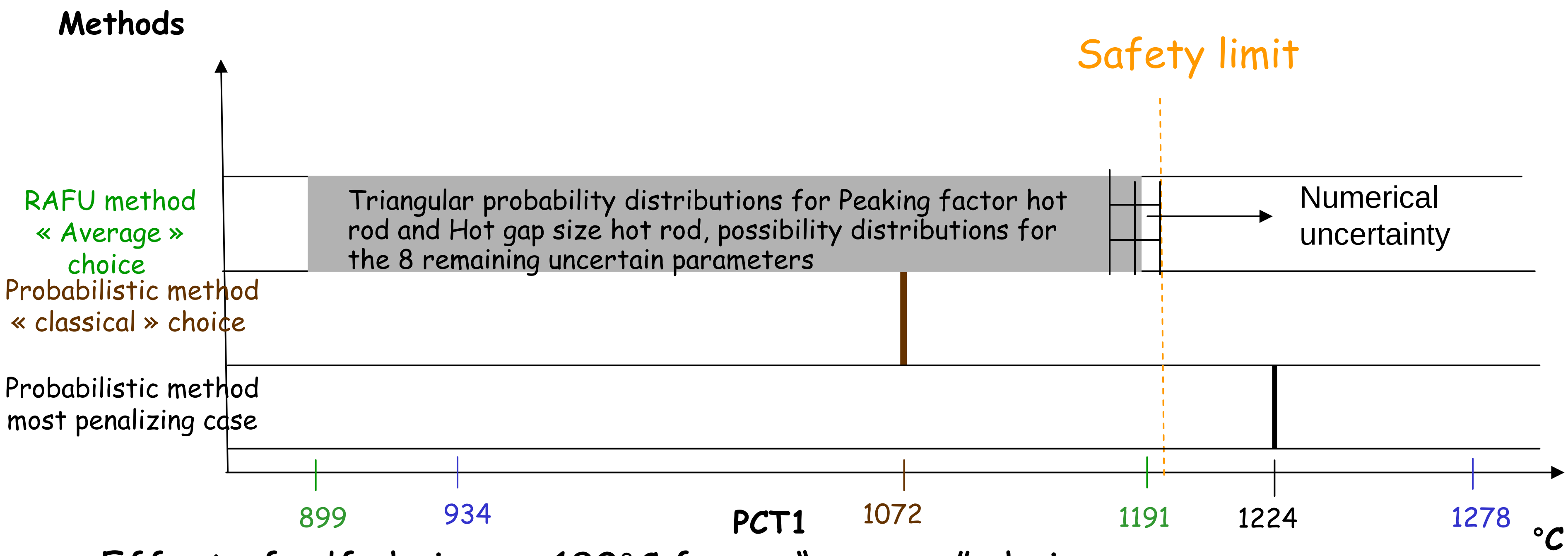
- Uncertainty modeling: knowledge = nominal value and variation range

Probabilistic method = «classical choice »	RAFU method = « real knowledge »
Triangular probability distribution Mode = Nominal value, Support = Variation range	Triangular possibility or probability distribution Mode = Nominal value Support = Variation range

- RAFU parameters (γ_S,γ_E ,γ_A)

γ_S	95%-percentile
γ_E	« Average »/ « Reasonable » choice (similar to "independence" in probability theory)
γ_A	95%-accuracy #interval samples: 200

95%-percentile



- Effect of pdf choices: ~192°C for an "average" choice
- Effect of dependencies: ~152°C

Computational cost reduction: 400 computer runs instead of 8000

Numerical uncertainty is not negligeable ; numerical uncertainty margin expected to be larger for smaller #samples.

Conclusion

- Probabilistic methods: easy to perform (Monte-Carlo), direct estimation of percentiles with order statistics

→ Caution with the choice of an unique pdf and a dependence structure in presence of incomplete knowledge

→ Unjustified reduction of uncertainty margins, relevant decision-making process?

- RAFU method:

  - Take into account the lack of knowledge and the nature of uncertainty + integrate a computational cost strategy respecting the analyst's choice and provide numerical uncertainty margin

  - Extension of Monte-Carlo techniques (same statistical tools as in the probabilistic framework)

→ Larger but more relevant uncertainty margins (to integrate in an iterative process? Helpful to refine the knowledge on uncertainty sources?)

→ Interval calculations