Scenario comprehensiveness in risk analysis

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Motivation

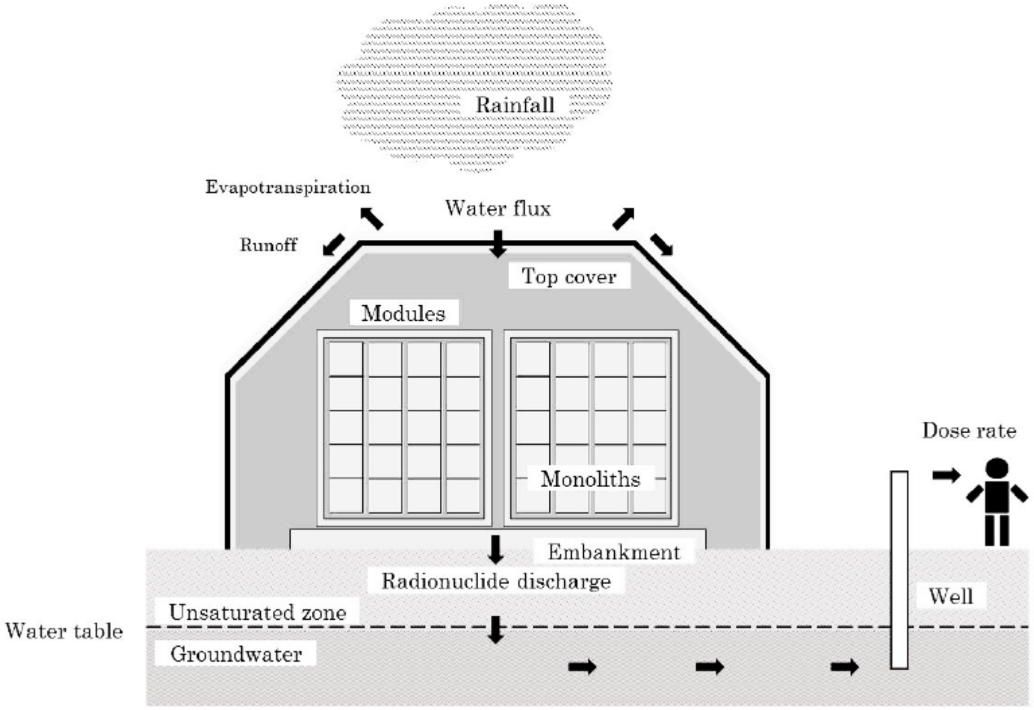
- Decisions on safety-critical systems are informed by risk assessments
- System evolution is uncertain
- Uncertainty is often addressed by scenario analysis
- Challenge: how to evaluate the *comprehensiveness* of the scenarios?
- Its interpretation has been largely dependent on the different approaches to scenario analysis
- We suggest quantifying *residual uncertainty*

Residual uncertainty & comprehensiveness

- The number of possible futures is infinite
- The information about these may be imprecise (i.e., epistemically uncertain)
- Residual uncertainty: uncertainty about the risk estimate
- <u>Comprehensiveness is achieved if residual uncertainty is sufficiently small to conclusively assess whether the system is safe or not</u>
- The evaluation of comprehensiveness requires the quantification of residual uncertainty

Case study: near-surface nuclear waste disposal

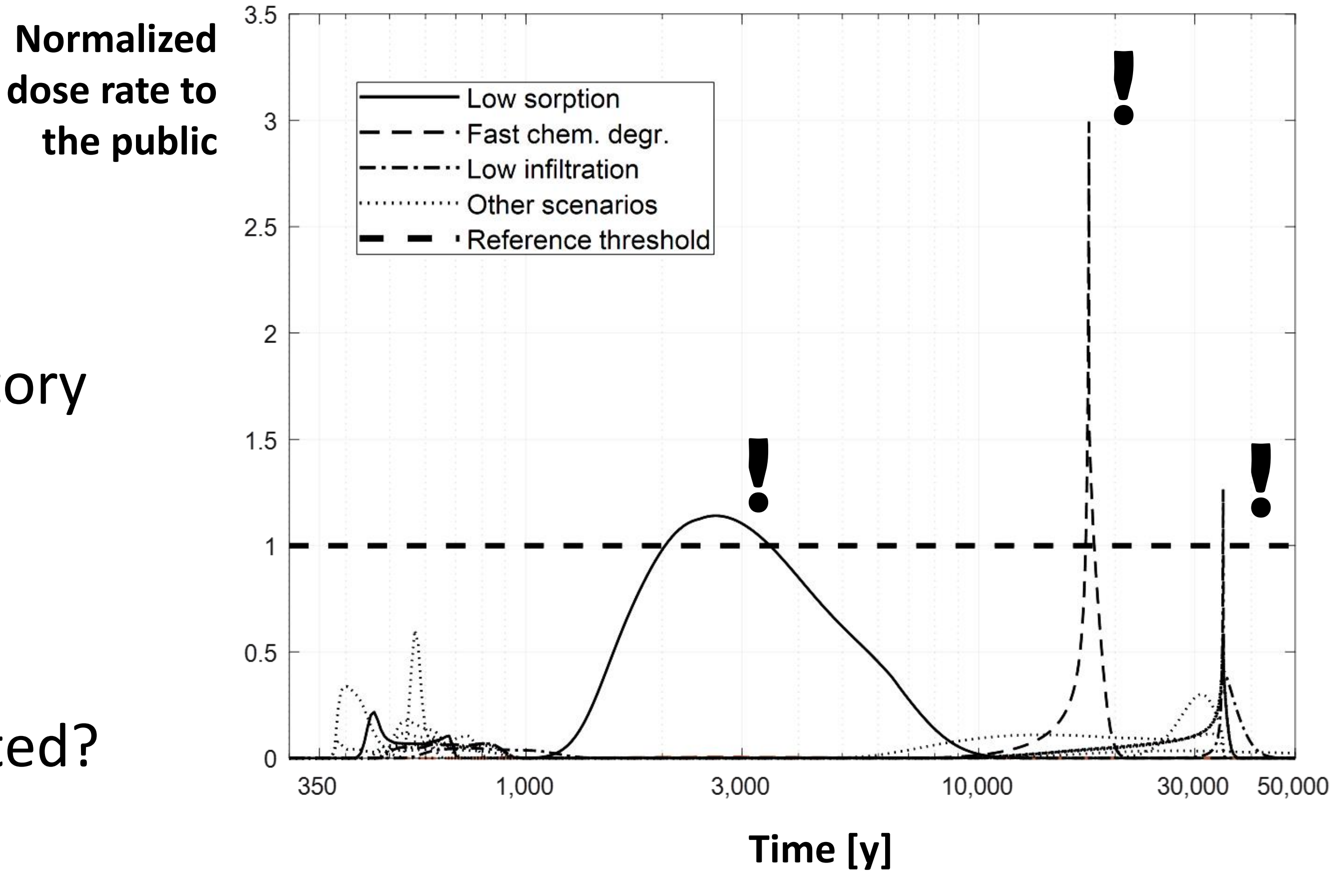
- We consider a nuclear waste repository



- NOTE! We did not carry out an actual safety assessment

``Pluralistic´´ scenario analysis

- A scenario is a combination of assumptions about system evolution
- Scenario impacts are checked against a reference safety threshold (e.g., regulatory limit)
- How likely are the violating scenarios?
- Should additional scenarios be formulated?
- How much is the residual uncertainty?



- Comprehensiveness can only be interpreted as *representativeness*

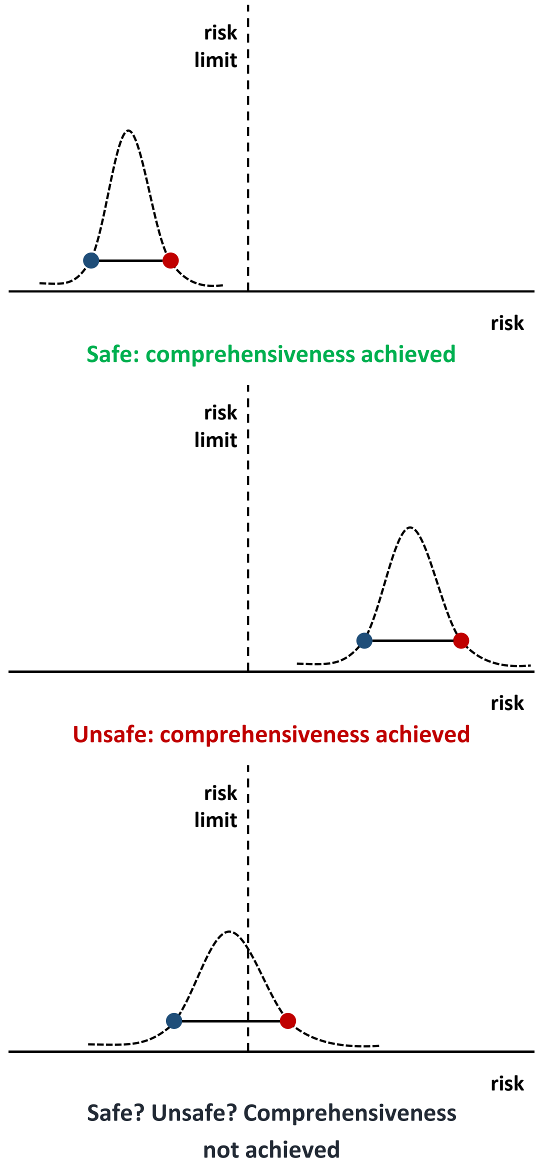
Probabilistic scenario analysis

- A scenario is an event in a probability space
- Residual uncertainty can be quantified by estimating bounds on risk
- Comprehensiveness is achieved if the risk limit is outside the risk bounds

Large uncertainty in the risk estimate (...) may not be critical if the (...) intervals about the risk estimate (...) are clearly below the regulatory levels of concern.

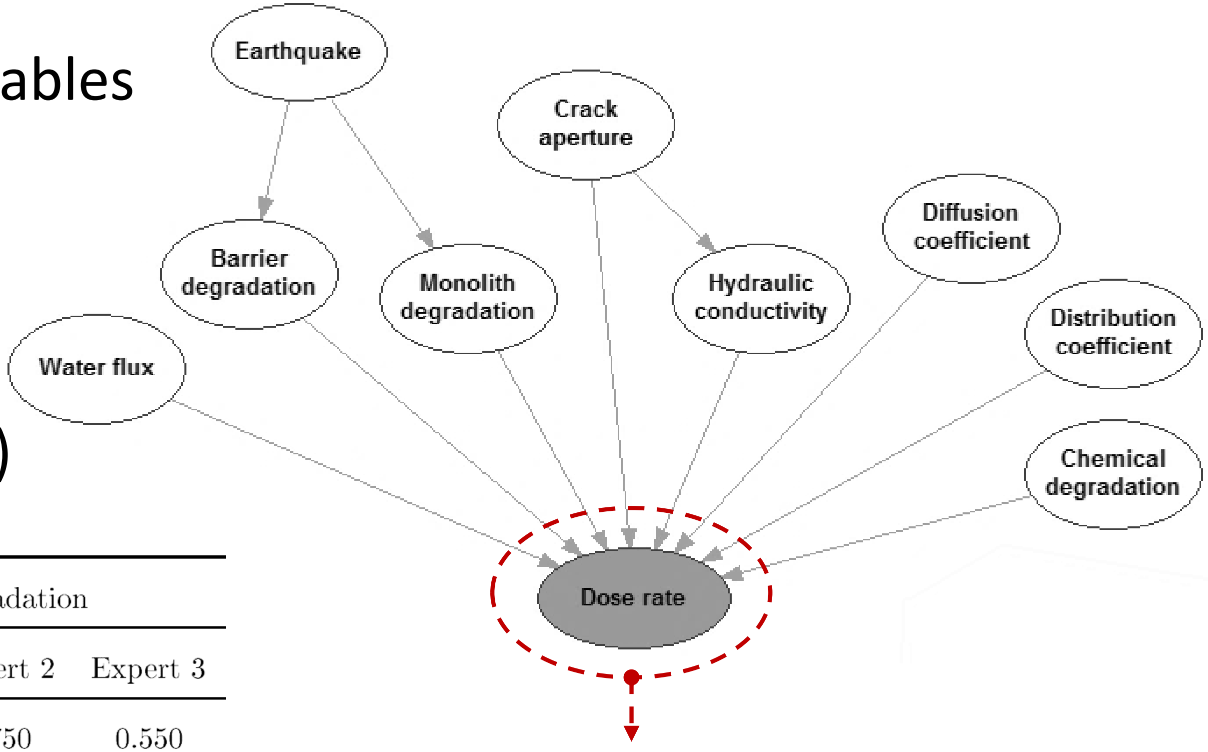
(...) when these (...) intervals overlap the regulatory levels of concern, consideration should be given to (...) reduce the uncertainty.

Helton et al., 2000



Bayesian network for the dose rate

- The nodes represent the factors significant for system evolution
- Nodes are associated to discrete random variables
- Scenarios are combinations of nodes’ states
- Risk is assessed as the total probability of violating the reference safety threshold (p_{vio})



Violation of the reference safety threshold?

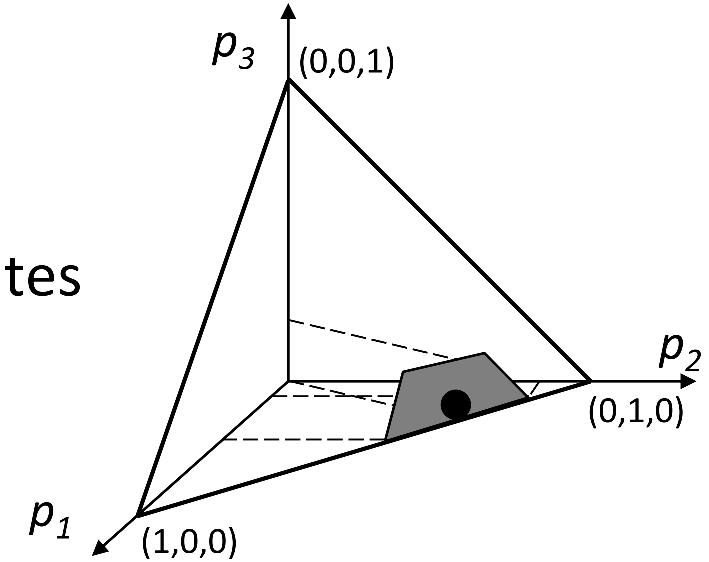
Diffusion coefficient		
State	Expert 1	Expert 2
Low	0.500	0.750
High	0.500	0.250

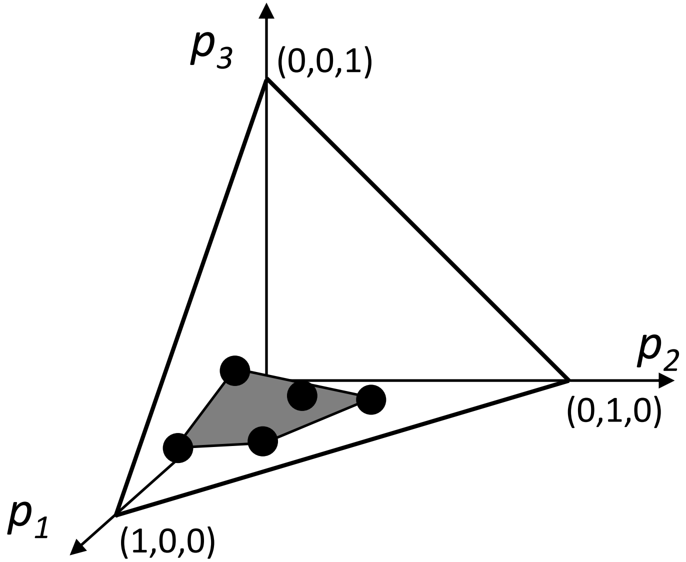
Distribution coefficient		
State	Expert 1	Expert 2
Low	0.500	0.750
High	0.500	0.250

Chemical degradation			
State	Expert 1	Expert 2	Expert 3
Fast	0.500	0.750	0.550
Slow	0.500	0.250	0.450

Uncertainty in probabilities

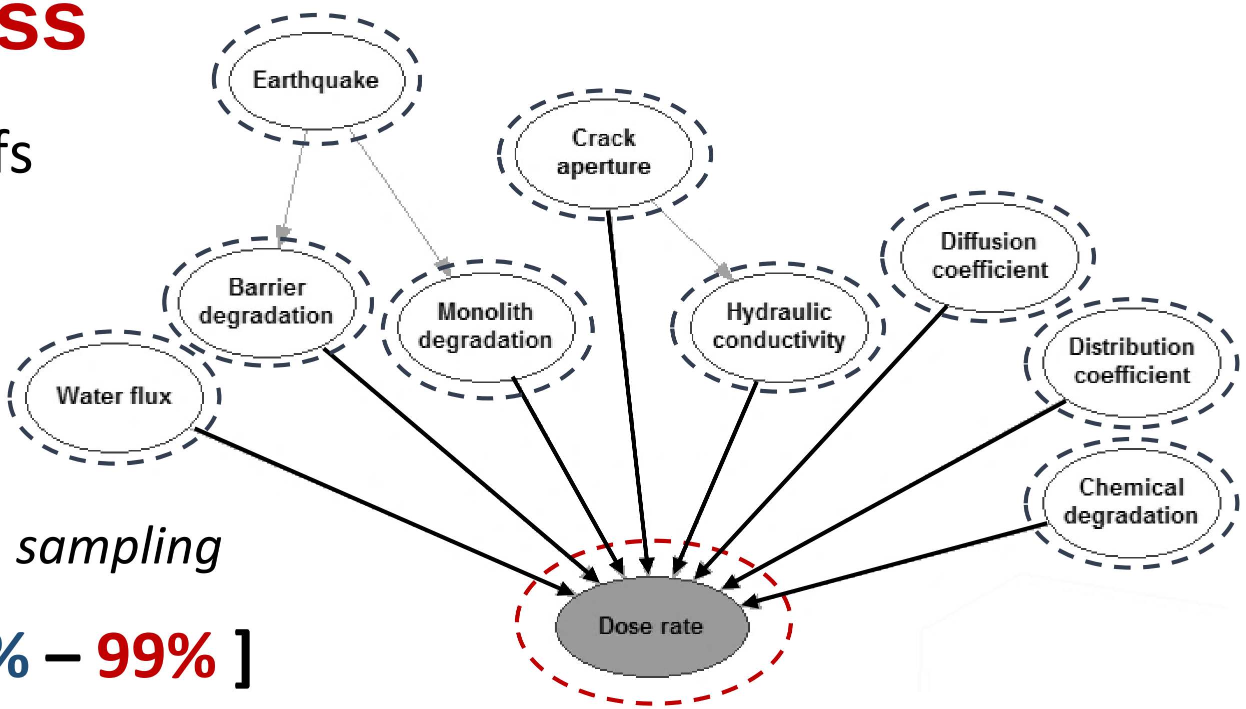
- Probability information is imprecise
- We employ feasible probability regions instead of point estimates
- For computational simulation, we derive credible probability intervals (Imprecise Dirichlet Model)
- For expert judgments, we take all possible weighted averages of the different beliefs
- By optimization (multilinear programming), we estimate the risk interval $\left[\underline{p}_{vio}, \overline{p}_{vio}\right]$

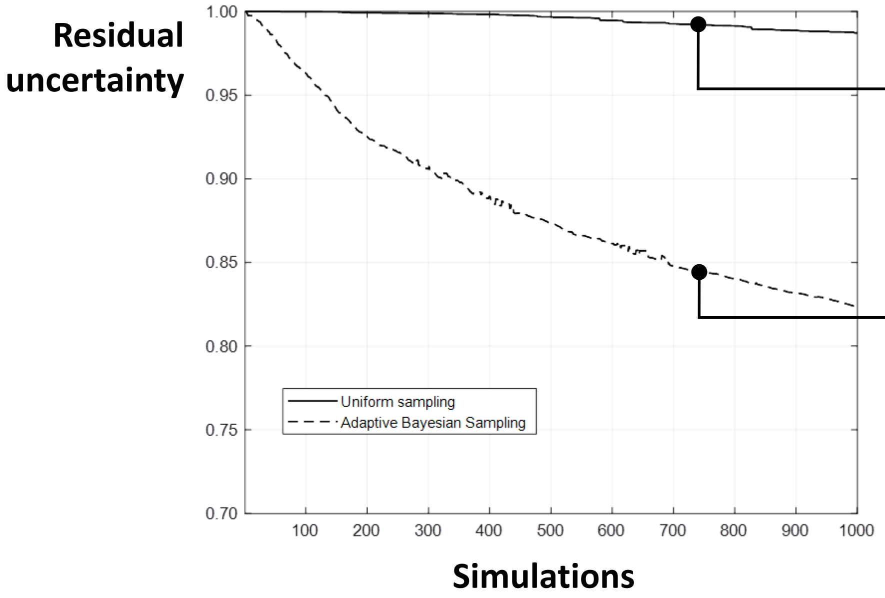




Evaluating comprehensiveness

- The network is initialized with experts' beliefs
- The conditional probabilities for the *Dose rate* are obtained by computer simulation





Uniform sampling

[0.03% – 99%]

Adaptive Bayesian Sampling

[3.30% – 86%] ***- 16.4%***

residual uncertainty

- The residual uncertainty is large: comprehensiveness may have not been achieved

Conclusions

- We have addressed the issue of evaluating comprehensiveness in scenario analysis
- Our generalized interpretation of comprehensiveness is based on the conclusiveness of safety statements
- The evaluation of comprehensiveness requires the quantification of the residual uncertainty about risk

The disclosure of uncertainty enables (...) the decision maker to evaluate the degree of confidence that one should have in the risk assessment

Helton et al., 2000

- Probabilistic approaches appear most suitable