NARSIS

New Approach to Reactor Safety ImprovementS

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Final Workshop

Progress in Probabilistic Safety Assessment for nuclear installations

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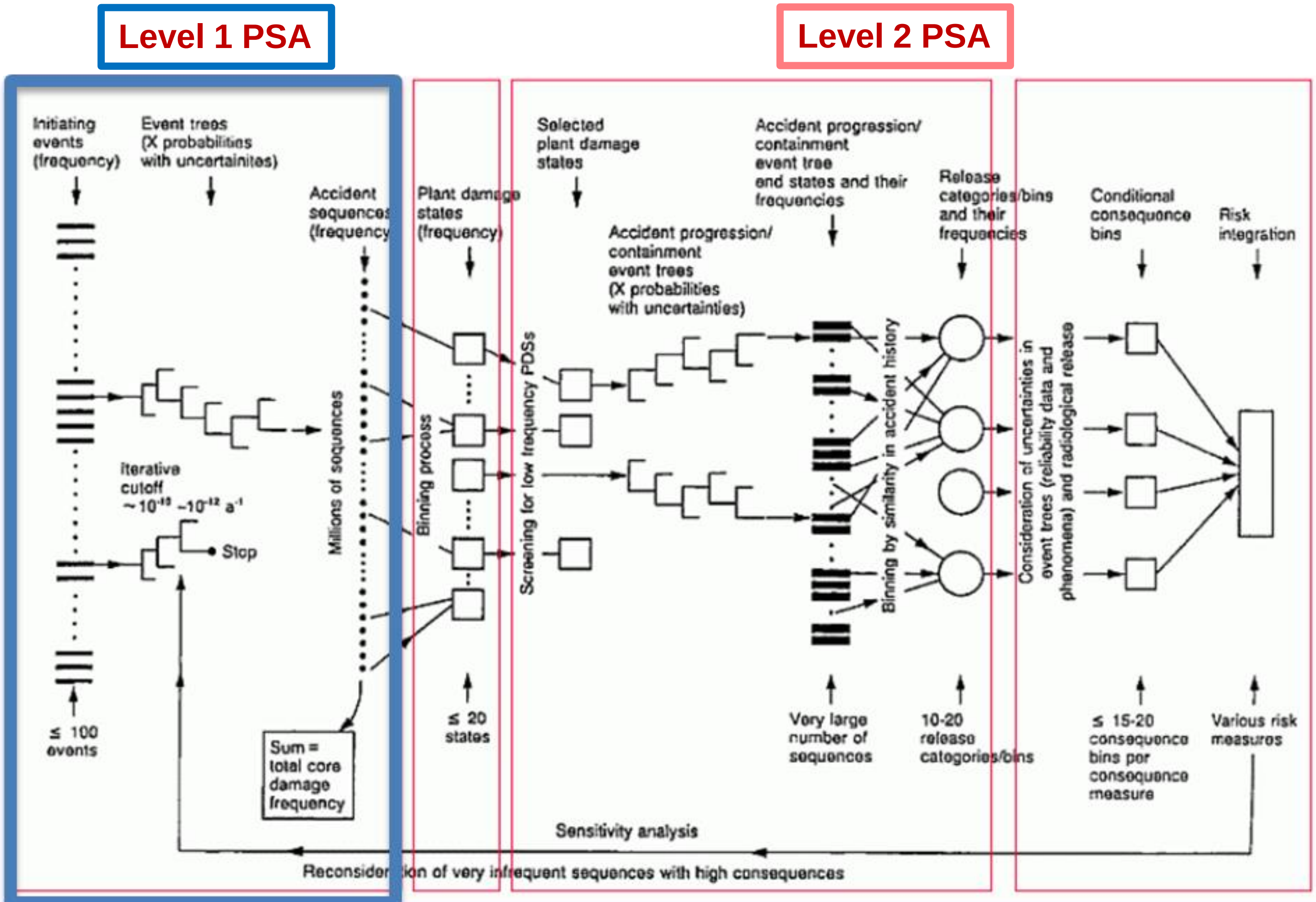
Multi-hazard PSA in the nuclear field: Recommendations & perspectives

NARSIS Team

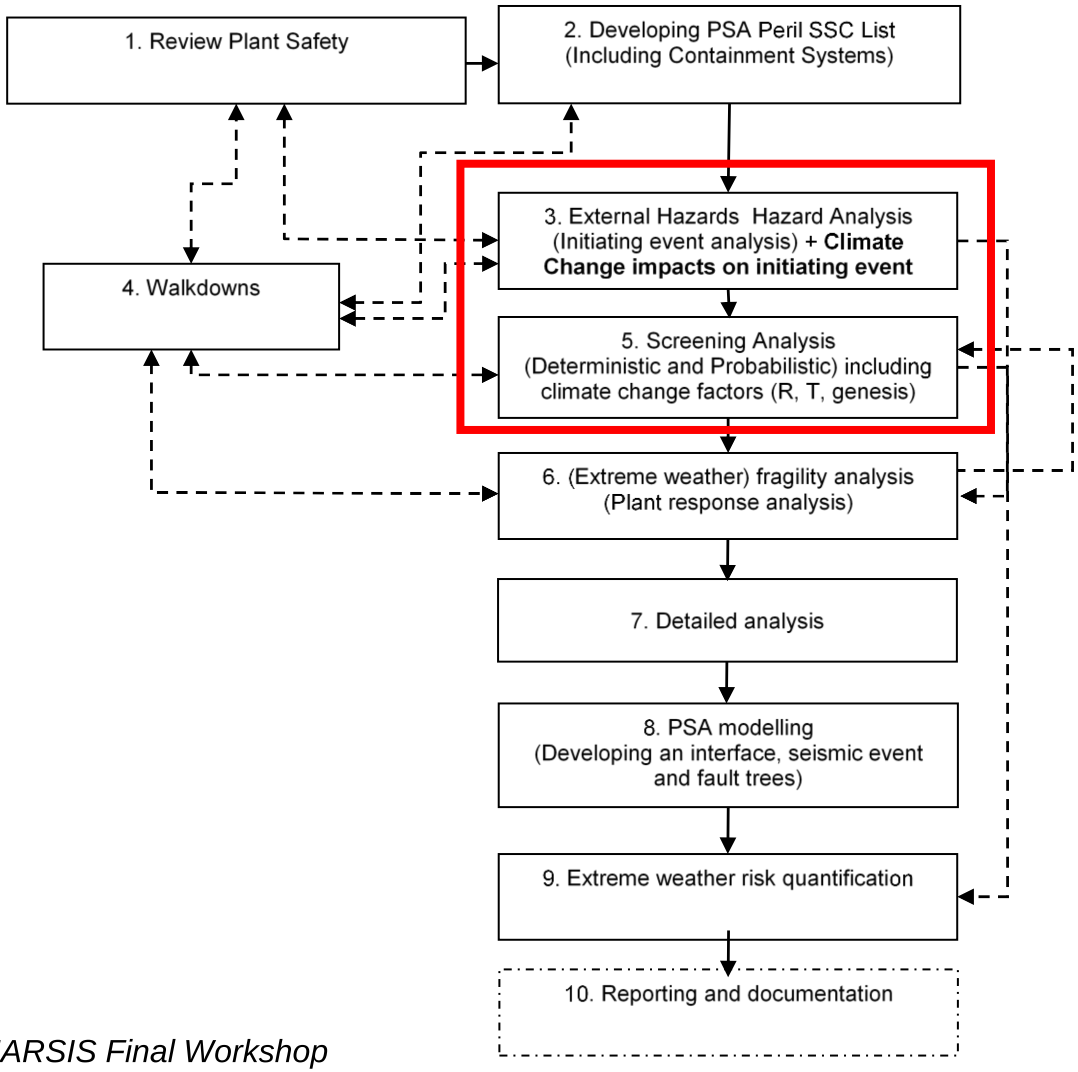
The Multi-Hazard framework

Recommendations for use in PSA



The Multi-Hazard framework

Recommendations for use in PSA



Flow chart for extended Level 2 PSA showing the proposed location of the multi-hazard framework component

The Multi-Hazard framework
Recommendations & perspectives

- **Detailed methodology for a multi-hazard assessment of NPPs fully documented in NARSIS reports (D1.7, D1.9)**
- **Multi-hazard analysis is very plant specific,** for environmental reasons as well as NPP vulnerability**.** It requires a **Risk-targeted hazard definition:**
  - **Pre-screening of main critical SSCs** to keep only relevant hazard parameters for analysis
  - **Evaluation of the modellability of the multi-hazard scenario**
    - Proceeding to the numerical calculations of the occurrence probability of the given scenario and of its effects on the NPP, by using different modelling methods (mechanical, stochastic, empirical)
  - **Going from single to multi-hazard analysis involves:**
    - the identification of secondary hazards;
    - the consideration of interrelation between single hazards (spatial + temporal interactions);
    - defining the time window and overlapping of event consequences (associated plant checks, damage repairs and safety procedures)

The Multi-Hazard framework
Recommendations & perspectives

- **Uncertainty quantification needed at each step, from the hazard source to the site effects,** given the large variability of events, the quantity and reliability of datasets and the random nature of natural hazards
- **Complexity of the dynamic vulnerability loop put into hazard analyses**
- **Non stationarity of some extreme events** (flooding, extreme weather) **due to climate change or human activities** (e.g., land use evolutions)

  → **Multi-hazard analyses should be updated if conditions change**

➢ **The identification of possible hazard combinations/interactions is a crucial step of the method.**

- **The challenge is to be exhaustive → multi-expert contributions and expert elicitation required**

The Multi-Hazard framework
Recommendations & perspectives

- **Multi-hazard scenarios require a combined process with uncertainty analysis, operational management plans and human processes → there is a need for:**
  - **Methods to incorporate human factors within a multi-hazard approach → e.g., BN-SLIM (D2.8)**
  - **Methodologies to constrain uncertainties in the components' modelling (causes and consequences) → D3.3**
  - **Reactor safety analysis results (DSA & PSA) → D4.5**

- **Complexity of dependent hazards**
  - **Uncertainty analysis depending on the location**
  - **Difficulty to model explicitly with the interactions**
  - **Link into NPP processes very fuzzy… unexpected hazards often govern**

  ⇒ **Not brought in explicitly into the software**

The Multi-Hazard framework
Perspectives

- **Further works needed:**
  - **All hazard types to be considered**
    - Volcano – low water combination through «preliminary analysis», being one of the governing analyses before mitigation
    - Tornado - underestimated generally
  - **Some hazard combinations may have been missed due to specific fragility loops, and/or dynamic hazard loops**
  - **Only decommissioned sites considered and analyses limited to German, Italian & Spanish sites**

Multi-hazard Fragility assessment
Recommendations & perspectives

- **Classification of fragility models w.r.t. to levels of components: various IMs, failure modes, hazards**
- **Fragility functions for seismic loading:**
  - **Carefully selected vector-IMs** make excellent candidates in terms of IM **sufficiency and efficiency**, when compared to scalar IMs
  - **Vector-valued fragility functions** tend to generate **less dispersion** (i.e., aleatory uncertainty due to record-to-record variability) **than scalar-IM fragility curves**
  - The **conditional spectrum method** for the selection of input ground-motion records appears to be **compatible with the derivation of vector-based fragility functions**
- **Statistical tools to cover most of the multi-hazard cases:**
  - **Multivariate GLM regression** is to be used for **the estimation of fragility parameters given a set of conditioning variables**
  - **System reliability theory** is able to combine hazard-specific failure modes in order to **model the functionality states of a given SSC**

Multi-hazard Fragility assessment
Recommendations & perspectives

- **Further works needed in order to:**
  - **Address the link between vector-IM fragility functions and vector-IM hazard assessment** (e.g., vector-based PSHA in the seismic case)
  - **Consider cliff-edge effects** (e.g., beyond the lognormal assumption)
  - **Incorporate dynamic fragility models into PSA models** (e.g., accounting fro cumulative effects, ageing mechanisms..)

Multi-Risk integration, uncertainty
Recommendations & perspectives

- **BNs vs. classical ET/FT analysis?**
  - **FT is a specific deterministic case of a BN:** it can be equivalently converted to BN with the same top event probability
  - **BN can complement existing PSA:**
    - Analysis of meaningful or potential dependence of variables plant-wide (e.g., every plant component is linked to another via hazards that affect them)
    - More important dependencies can be brought together under one BN object
    - Some systems can function as separate BN objects without the same Bayesian inference capabilities between objects (similar to FT-ET combination).
  - **Some advantages for BN:**
    - Diagnostic inference helps in fault diagnostics and sensitivity analysis for posterior probabilities of basic and intermediate events → unforeseen dependencies may be identified
    - Possible to include multi-state or even continuous variables
    - Alternate approach to CCF modelling, with correlation based approach (between failures) rather than conditional probability → reduction in the number of CCF nodes
    - Can be used as a surrogate model

Multi-Risk integration, uncertainty
Recommendations & perspectives

- **BN Readiness level for plant safety analyses in engineering practice?**
  - **Fully ready for system-level implementation.**
  - **For plant-wide implementation, non negligible computational & human efforts required** (even if converting first from existing ET/FT)
    - Some specific technical aspects can help reducing computational load → however **judicious examination as to what systems most need extensive BN implementation** (Bayesian inference may not be required everywhere)
- **Surrogate modelling can become a key component of PSA:**
  - **Various types of analyses possible**
  - **Sensitivity analysis and uncertainty propagation possible with lower numerical costs**
  - **Flexible approach, which is able to account for different sources of information in adequate formal setting** (expert opinions, observations, numerical results)

Multi-Risk integration, uncertainty
Recommendations & perspectives

- **E-BEPU:**
  - **Deterministic & probabilistic analysis** together including **uncertainties**
  - **Safety margins** identified **more accurately**
  - **Cliff edge effects analysis possible**
  - But it can **computationally intensive**
- **Extra-probabilistic uncertainty theory applicable for expert knowledge modelling**
- **Bayesian Integrated Uncertainty and Sensitivity Analysis (BIGUSA) methodology for plant scale uncertainty and sensitivity analysis (severe accident scenarios)**
  - **Quantitative and qualitative assessment of uncertainty sources and interactions between them** (not possible with standard approach (Monte Carlo and Wilks)

Multi-Risk integration, uncertainty
Recommendations & perspectives

- **Further works needed:**
  - **Application to more complex cases**
  - **Dynamic BN to include transient conditions & time evolutions**
  - **BNs in support for accidents in diagnosis**
  - **Use of non parametric BNs** (most system events/variables represented as continuous variables)
  - **Improving inference algorithms for object-oriented BNs** to allow for diagnostic capabilities across BN objects, in a computationally feasible manner
  - **Lower the computational costs**
  - **Have FTs and BNs in a same PSA tool, to use them together**