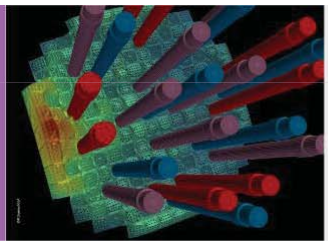


PROBABILISTIC SAFETY ASSESSMENT FOR INTERNAL AND EXTERNAL EVENTS ON NUCLEAR POWER PLANTS AND ON MITIGATION STRATEGIES / H2020 EUROPEAN PROJECTS: NARSIS, R2CA AND BESEP

Evelyne Foerster (CEA), Nathalie Girault (IRSN), Atte Helminen (VTT)

Three projects

New Approach to Reactor Safety ImprovementS, NARSIS, 2017-2022, Coordinator: Evelyne Foerster (CEA)

Reduction of Radiological Consequences of design basis and extension Accidents, R2CA, 2019-2023, Coordinator: Nathalie Girault (IRSN)

Benchmark Exercise on Safety Engineering Practices, BESEP, 2020-2024, Coordinator: Atte Helminen (VTT)

NARSIS

New Approach to Reactor Safety ImprovementS, NARSIS, 2017-2022,
Coordinator: Evelyne Foerster (CEA)

Overview of the H2020-NARSIS project (2017-2022)

New Approach to Reactor Safety ImprovementS www.narsis.eu

- **18 partners** across Europe: academic & research organisations, operators, TSOs, SME
- **Main objectives:**
  - **Identifying gaps** between practice and needs **in existing PSA methodologies for external events and multi-hazard analyses**
  - **Improving parts of these methodologies,** based on & complementing other European projects:

ASAMPSA_E SEVENTH FRAMEWORK PROGRAMME Advanced Safety Assessment Level 2 PSA

INFRARISK Novel indicators for identifying critical INFRAstructure at RISK from Natural Hazards

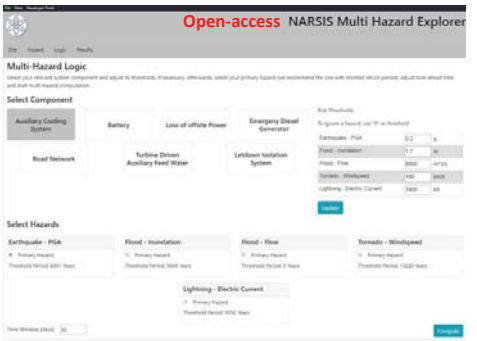
MATRIX New Multi-Hazard and Multi-Risk Assessment Methods for Europe

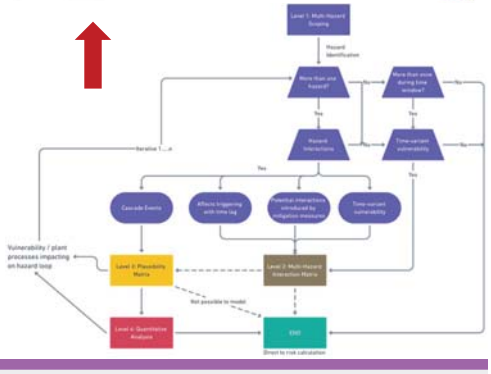
  - **External hazards & related secondary effects / combinations considered:**
    - ✓ Earthquake & secondary effects (excluding tsunamis),
    - ✓ Tsunamis
    - ✓ Riverine and coastal flooding (e.g., storm surge)
    - ✓ Extreme meteorological hazards (high winds, rainfall, heat waves, ice, hail)
    - ✓ Volcanoes (tephra)

Overview of the H2020-NARSIS project (2017-2022)

- **Methodology adopted for the scientific improvements:**
  - ➢ Full reviews of existing methodologies
  - ➢ Verification & testing of the applicability and effectiveness of the proposed developments within a safety assessment process
  - ➡ Using generic & real simplified NPP test cases located on real decommissioned sites

- **Main achievements:**
  - Ø **Better characterization of external hazards**
  - ➡ Focus on hazards identified as top priorities by the PSA end-user's community
  - Ø **Multi-Hazard assessment framework & scenarios**
  - ➡ Modelling of hazard combinations & related secondary effects useful for PSA (e.g., extreme weather correlated events)

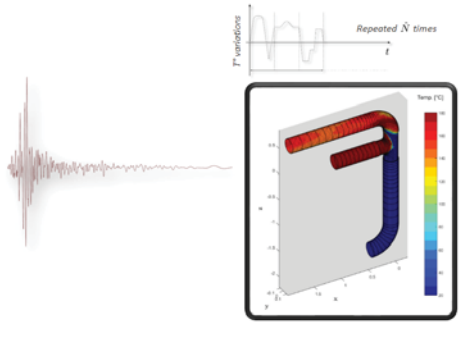




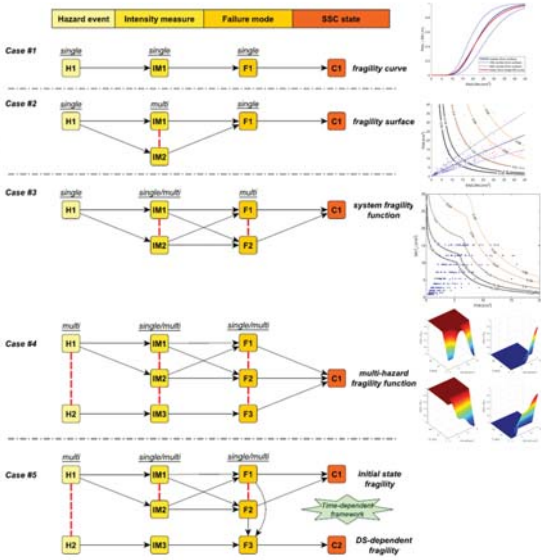
Overview of the H2020-NARSIS project (2017-2022)

- **Main achievements:**
  - ➢ **Better fragility assessment for the main critical SSCs:**
    - ✓ Multi-hazard scenarios
    - ✓ functional losses, human factors,
    - ✓ ageing pathologies (e.g., damaging phenomena, corrosion),
    - ✓ interdependencies under single or multiple external aggressions
    - ✓ cumulative effects (seismic PSA): aftershocks modelling, fatigue + earthquakes, soil-structure interactions

Earthquake + pre-existing damage (thermal fatigue)



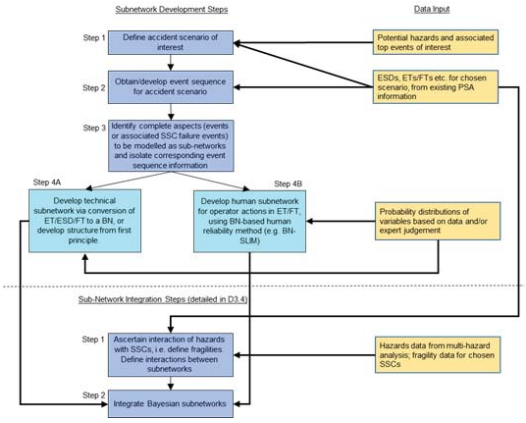
Multi-Hazard Fragility Framework
(Bayesian Networks, vector-valued fragility)



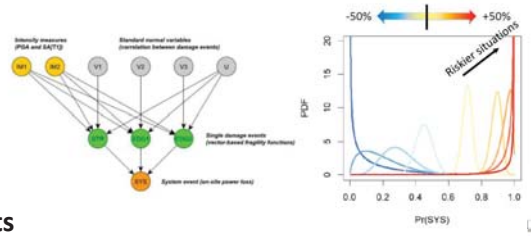
Overview of the H2020-NARSIS project (2017-2022)

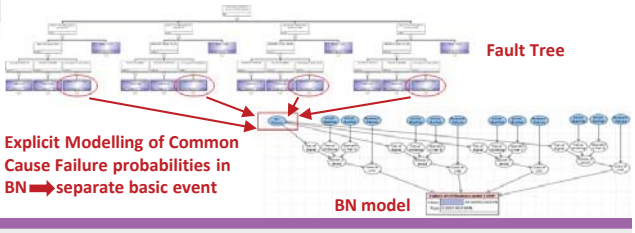
- **Main achievements:**
  - **Multi-risk integration & uncertainty reduction: Bayesian Networks (BN)**
    - ✓ Support to risk-informed decision making and risk metrics comparison within extended PSA
    - ✓ Better processing and integration of expert-based information within PSA: investigating the applicability and benefits of using modern uncertainty theories to both represent experts' judgments in flexible manner and aggregate them to be used in a comprehensive manner.

Integration of multi-hazards, technical & human aspects



Boosted Beta Regression method for BNs ➡ Probabilistic sensitivity analysis





- **47 scientific reports**
- **2 software tools :**
  - ✓ Open-access Multi-Hazard Explorer
  - ✓ Decision-Support prototype (SAMG demonstration)

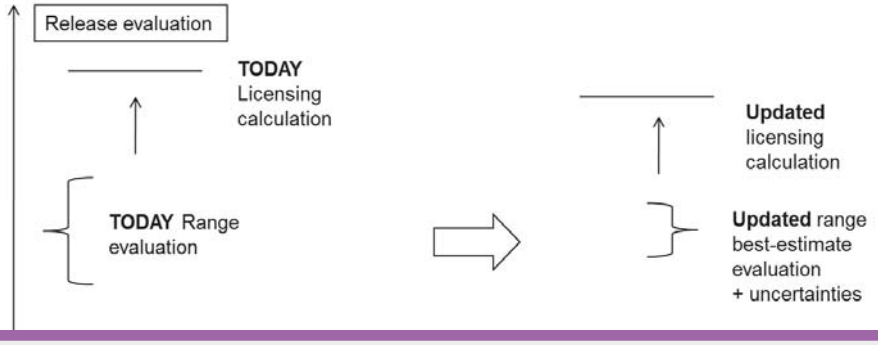
R2CA

Reduction of Radiological Consequences of design basis and extension Accidents, R2CA, 2019-2023, Coordinator: Nathalie Girault (IRSN)

Overview of the H2020-R2CA project (2019-2023)

Reduction of **R**adiological **C**onsequences of design basis & design extension **A**ccidents: https://r2ca-h2020.eu

- 17 partners in Europe: academic & research organisations, operators, TSOs
- Main objectives
  - Evaluate more realistic safety margins through RC evaluation of bounding scenarios (reduction of conservatisms & decoupling factors) + uncertainties
  - Increase NPP safety by developing AMPs and a smart tool for early diagnosis of accidents (incl. guidelines for new safety devices & some ATF evaluations)



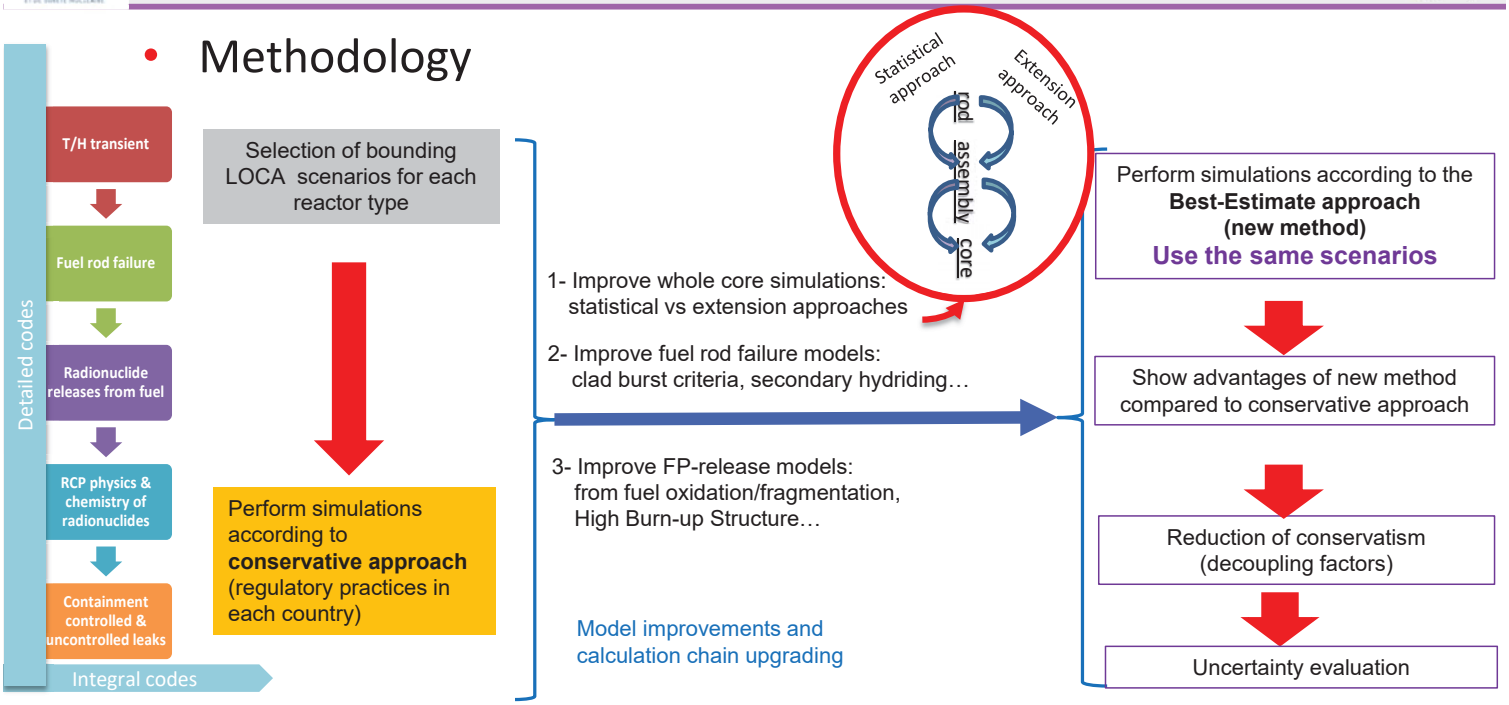
  - Scope
    - ✓ DBA& DEC-A conditions
    - ✓ LOCA & SGTR scenarios
    - ✓ PWRs, EPR, VVERs & BWR

Overview of the H2020-R2CA project (2019-2023)

- Key challenging areas
  - Formulation of best-practices for RC calculations of LOCA and SGTR scenarios
    - ✓Best-estimate approaches reducing some conservatisms & decoupling factors
  - Harmonisation of the RC evaluation methodologies for all existing and foreseen NPPs
    - ✓Derivation of principles for EP&R action optimisation (i.e. for population protection measures)
  - Development of technological innovations in the reduction of RC (innovative devices, AMPs, diagnosis tools and E-ATFs)
    - ✓Improvement of AMPs: new instrumentation, optimized procedure, neural network
  - Use of Artificial Intelligence functionalities to anticipate accidental configurations
    - ✓Elaboration of an expert system based on AI for identification of rod defects from RCS activity variation

Overview of the H2020-R2CA project (2019-2023)

- Methodology



Overview of the H2020-R2CA project (2019-2023)

- Main expected Achievements
  - Improvements of a large variety of simulation tools (from mechanistic to integral) and calculation chains for RC evaluation through code coupling codes
  - Modelling improvements at all levels of the calculation chains from :
    - ✓Update of models regarding FP transport/behaviour & cladding/fuel evolution
    - ✓Use of models/tools at different scales: mechanistic/detailed to meso & integral tools
    - ✓Code couplings
  - More accurate evaluations of LOCA & SGTR RC evaluations with respectively:
    - ✓Better calculation of failed rod number: updated core modelling approaches (statistical or multi-scale core meshing & new correlations for clad failure criteria
    - ✓Better modelling of defective rod behaviour: improvements of iodine spiking models and establishment of clad failure criteria due to secondary hydriding
  - Demonstration of the capabilities of prognosis evaluation tools to anticipate accidental configuration through Artificial Intelligence functionalities
  - Evaluation of new devices (i.e. new safety devices, ATFs) & AMPs for increased NPP safety

BESEP

Benchmark Exercise on Safety Engineering Practices, BESEP, 2020-2024, Coordinator: Atte Helminen (VTT)

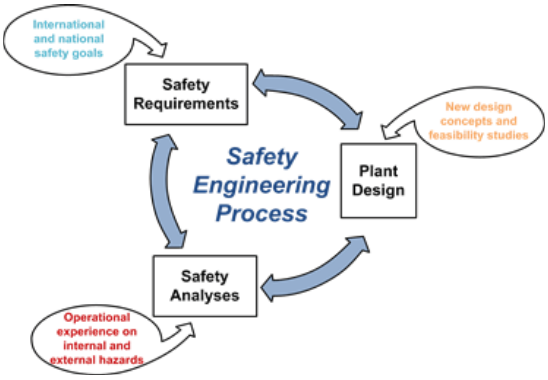
Overview of the H2020-BESEP project (2020-2024)

- **7 partners** across Europe: Research organisations, Licensees and TSOs
- **Main objective** of BESEP is to support safety margins determination by developing best practices for safety requirements verification against external hazards, using efficient and integrated set of Safety Engineering practices and probabilistic safety assessment
- **Web pages:** www.besep.eu

Overview of the H2020-BESEP project (2020-2024)

Key challenge area

- Safety Engineering process connects together the main elements of safety design: safety requirements , safety analyses and plant design
- In case there is a change in one of the main elements, the change should be reflected in the two other elements
- With better Safety Engineering process, modified safety requirements can be implemented to the actual plant design more efficiently

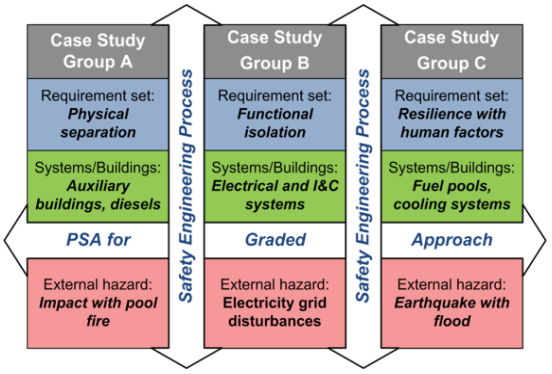


Overview of the H2020-BESEP project (2020-2024)

Methodology

Benchmark Exercise between project Partners:

1. Specification of case study requirements and allocation of requirements under specific topics creating a set of requirements
2. Development of pool of case studies having relevance to external hazards and specification of case study groups
3. Cross-case comparison within case study groups
   - Efficiency and integration of different safety analysis methods in Safety Engineering process to verify the compliance of safety margins and safety requirements
4. Cross-group comparison between case study groups
   - Amount of work and effort used in safety margins and requirement verification compared to the risk significance of external hazard to plant safety
5. Best practices and recommendation on closer connection of safety analysis methods



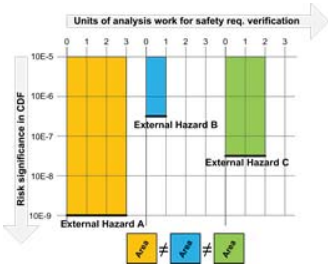
(Example ideas from project planning phase)

Overview of the H2020-BESEP project (2020-2024)

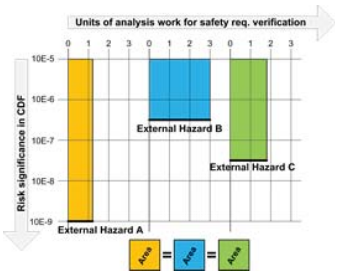
Expected key results

- Best practices for the verification of evolving and stringent safety requirements against external hazards
- Guidance on the closer connection of deterministic and probabilistic safety analysis and human factors engineering for the determination and realistic quantification of safety margins.
- Guidance on the creation of graded approach for the deployment of more sophisticated safety analysis methods, such as upgrades of simulation tools, while maintaining the plant level risk balance originating from different external hazards.

Situation before BESEP…



… and after BESEP



General conclusions of three projects

The three projects of EURATOM Horizon 2020 programme:

- Help improve the best practices for the safety assessment of internal and external events and for the planning of mitigation strategies
- Support the harmonisation of safety assessment methodologies between European countries applicable to different existing NPP designs and foreseen concepts, such as Small Module Reactors
- Help tighten cooperation between the different sides of nuclear industry, i.e. utilities, vendors, national safety authorities and technical support organisations
- Bring together experts from the different areas of safety assessment, such as Deterministic safety analysis, Probabilistic safety analysis and Human factors engineering
- Foster new experts for the industry, who eventually take the responsibility of continuous development in nuclear safety

THANK YOU!