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NARSIS

New Approach to Reactor Safety ImprovementS

Newsletter # 1

Edito

Welcome!

Evelyne Foerster NARSIS project coordinator

Dear reader
A warm welcome to the pages of the first issue of NARSIS Newsletter!

It is indeed a pleasure to introduce to you this new initiative adopted by our Consortium within the H2020 EURATOM NARSIS project dealing with issues related to the improvement of the safety and reliability of generation II and III reactors.

NARSIS coordinates the research efforts of eighteen partners encompassing leading universities, research institutes, technical support organizations (TSO), nuclear power producers and suppliers, reactor designers and operators from ten countries. The project aims at making significant scientific updates of some elements required for the Probabilistic Safety Assessment (PSA), focusing on external natural events such as earthquake, tsunami, flooding, high speed winds etc.

Indeed, following the Fukushima nuclear accident on March 2011, risk and safety assessments ('stress tests') were carried out on all EU nuclear power plants. The European Commission encouraged and cooperated with nuclear regulators around the world to perform similar exercises. The aim of the assessments was to check whether the safety standards were sufficient to cover unexpected extreme events. Lessons learned bring amongst others about new PSA requirements for multi-unit impact and consideration of potential combinations of external hazards.

To answer to these expectations, NARSIS proposes to improve system reliability and safety by proposing:

- A multi-hazard framework to better characterize natural external events (occurrence of concomitant external events, either simultaneous-yet-independent hazards or cascading events);
- Updated methodologies to better assess the physical and operating fragility of main SSC (Systems, Structures and Components) present in nuclear power plants (NPP), with regards to external natural aggressions, taking into account the possible interdependencies, ageing effects, fatigue, etc.;
- Approaches for a better risk integration combined with uncertainty characterization and quantification, to allow efficient risks comparison and account for all possible interactions and cascade effects;
- Better processing/integration of expert-based information within PSA, through modern uncertainty theories both to represent in flexible manner experts' judgments and to aggregate them to be used in a comprehensive manner.

The proposed improvements will be tested and validated on simplified and real NPP case studies. Demonstration supporting tools for operational and severe accident management will be also delivered.

We hope that our initiative will provide opportunity to develop new methods and to facilitate exchange of experiences and expertise among different actors involved in nuclear industry. This is very much needed where fast pace of innovation in technology and science requires continuous cross-disciplinary revision of the safety and sustainability of nuclear power generation.

We look forward to this challenge, but also to new ones we have set ourselves, such as disseminating NARSIS outcomes beyond the nuclear community and training students and young researchers with the project scientific findings.

Dear Reader, with the launch of this newsletter, we would like to broaden the circle and share the outcomes of our project with larger audience. Our objectives is to attract wide support from and involvement of any stakeholder interested in cooperative development of the nuclear safety. This newsletter aims to function as an information tool for disseminating results and outcomes of our project but also to become a forum for discussion, reflection and dialogue. Our conceptual strategy is anticipative, reflecting our wish to involve more researchers, professionals and interested groups in the debate. Starting with this issue, NARSIS Newsletter will be published every six months using an open access model allowing all interested readers to have free on line access through our web site www.narsis.eu

We will be happy to receive your comments and suggestions. Please feel free to communicate your feedback to Prof. Behrooz Bazargan Sabet (b.bazargan-sabet@brgm.fr) for inclusion in our forthcoming issues. We would also like you to help us disseminate this newsletter to your network.

We look forward to hearing from you!

WP summaries

Our different WP leaders walk you through the essential objectives of their work packages and the tasks in hand.

WP1: Characterization of potential physical threats due to different external hazards and scenarios

James Daniell
KIT

The topic of WP1 is to propose new approaches for characterization of potential physical threats a nuclear installation can be exposed to, due to different external natural hazards, focusing on some of them identified as priorities by the PSA End-Users community in the ASAMPSA_E project: earthquakes, flooding and extreme weather. New methodological developments in science dealing with risk and safety will be scrutinized and adapted to safety demands of NPPs. The movement towards a multi-hazard and multi-risk perspective for safety demands of NPPs has occurred over the last few decades. However, this has not been approached in a systematic way in terms of a systemic view of the object at risk, in this case, the various facilities operating at a NPP site (different buildings, spent fuel tank(s), power supply systems, etc.) and their physical and logical interactions including dependencies from outside supply and infrastructures. This includes – on the hazard side - consideration of all possible scenarios; however, also taking into account combinations of hazards and cascading hazards (hazards that are amplified or triggered by the occurrence of other hazards). An example for multi-hazard cascades is the failure of a dam due to an earthquake and/or its aftershocks causing induced landslides, causing large flooding. Combinations of hazards may have a significantly higher impact on plant safety than each individual hazard. Although the recent stress tests for EU nuclear power plants considered single primary hazards such as earthquakes and floods, only the resulting recommendations acknowledge secondary effects such as flood and fire following an earthquake.

In WP1, such combinations that may be significant for risk will be processed and analyzed. The impact of combinations of natural hazards on safety functions need to be reassessed as they may affect different safety functions or the same function in a more severe manner than a single hazard. A detailed review of state-of-the art for hazard and multi-hazard characterization is the first task. This will present the extensive review of existing multi-hazard approaches and procedures for natural hazard assessment with respect to nuclear hazard and safety.

In the second task, stochastic analyses of scenarios for hazards will provide a probabilistic basis which contributes to creating the accident scenarios. The systemic understanding of a NPP exposed to natural hazards requires the development of methods and models that capture the internal implications of singular hazards thus the need for the exploration of singular approaches before moving to combined hazards.

The third task of WP1 is thus the production of an integrated hazard framework for combined hazard scenarios for Safety Assessment, which shows a systematic framework for combination of hazard scenarios in order to provide an integration of the various single and cascade (internal/external) hazards that are possible at a site.

The last task is the production of an open-source generic software tool that allows the application of the multi-hazard methodology developed for users. In addition, recommendations for regulators describing best practice and identifying deficiencies in the current methodologies for hazard assessment will be provided.

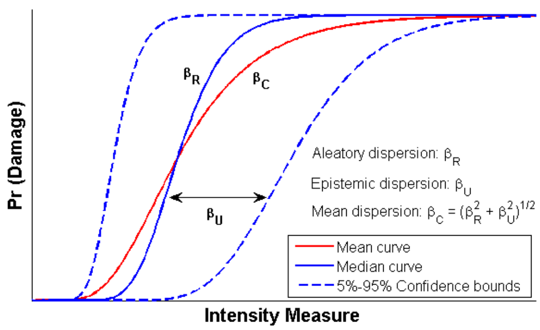
WP summaries

WP2: Fragility assessment of main NPPs critical elements

Pierre Gehl

BRGM

As a crucial step of the Probability Safety Assessment of a Nuclear Power Plant, the vulnerability of the structures, systems and components (SSC) must be quantified with respect to a wide range of external loadings induced by natural hazards. To this end, fragility curves, which express the probability of an SSC to reach or exceed a predefined damage state as a function of an intensity measure representing the hazard loading, are common tools developed in the nuclear industry. Their probabilistic nature make them well suited for PSA applications, at the interface between probabilistic hazard assessments and event tree analyses, in order to estimate the occurrence rate of undesirable top events.



Example of composite fragility curves as used in nuclear industry standards

Due to the thousands of SSCs that may be comprised within a NPP, most nuclear regulations advocate the application of Safety Factors methods, which consist in multiplying design level values with factors representing uncertainties due to capacity and demand variability. This approach has been favored by practitioners since the 1980s, due to its relative ease of implementation when compared to time-consuming numerical simulations.

The main objective of WP2 is to develop refined fragility derivation methods in order to increase the accuracy of the estimation of SSC failure rates, thanks to current advances in quantitative hazard modelling and computational capacities. Such fragility models are expected to provide the following features:

- Use of multiple intensity measures expressing a given hazard loading, in order to improve its characterization and reduce its inherent randomness: this is mostly the case for seismic loadings, where the temporal and frequency contents of a ground motion record are only imperfectly represented by a single intensity measure.

- Integration of multi-hazard interactions and cumulated effects (succession of events, ageing mechanisms, fatigue, etc.) within a harmonized multi-hazard framework. Human factors and organizational aspects, which may be the cause of additional dysfunctions, will also be incorporated to the fragility analysis.

- Design of functionality-based damage scales that account for various and potentially concurring failures modes within a single SSC, in order to create harmonized and ready-to-use fragility functions for the subsequent safety analysis of the NPP.

To this end, a statistical tool of choice will be vector-based fragility functions, which have the ability to represent probabilities of damage as a function of multiple intensity measures. Moreover, the correlation between intensity measures, failure modes and engineering demand parameters will be appropriately treated thanks to the application of system reliability methods. Due to the large number of SSCs, the first task of WP2 will be to rank the importance of these components, in order to select only the components for which a refined fragility analysis would have a significant impact on the principal safety functions of the NPP. The model reduction strategies developed in WP4 will also be used in order to reduce the computation load of the numerical simulations. Finally, the resulting fragility models will constitute the elementary building blocks upon which the Bayesian Belief Networks will be assembled in WP3.

WP summaries

WP3: Integration and safety analysis

Phil Vardon
TU Delft

The integration and quantification of risks is the subject of work package 3 of the project. In complex systems, such as nuclear power plants, many systems interact, decisions taken in response to physical changes or in systems or events, and uncertainties play an important role. As the Director General of the IAEA said in his report after the Fukushima Daiichi accident "comprehensive probabilistic and deterministic safety analyses need to be performed to confirm the capability of a plant to withstand applicable beyond design basis accidents and to provide a high degree of confidence in the robustness of the plant design". Importantly these analyses need to take into account…" the interactions between human, organizational and technical factors" and the combinations of risks at various times within the operation of a plant. This work package will address these aspects.

There have now been a number of studies resulting in valuable insights, data and models, which augment the solid engineering risk assessments to give a full range of effects that need to be considered in an overall risk assessment of potential problems. The challenge has been to find a methodology that can integrate the important contributions of technical (physical and spatial effects), social and human factors into a full picture of threats in order to design an adequate resilience. This project proposes to address these issues, by utilizing and building upon the approach of Bayesian Belief Networks, which has been extensively and successfully used in other domains (natural disasters, engineering systems, etc.), to integrate the different aspects identified.

Since the Fukushima Daiichi accident and understanding of safety-related issues, large efforts have been undertaken throughout the nuclear community to assure adequate safety margins and to avoid any cliff-edge effects in nuclear installations. One way of achieving these goals is to combine insights from probabilistic and deterministic safety analysis, using a "Best Estimate plus Uncertainty" (BEPU) analysis. Many organizations are involved in this endeavor, however in most cases, they remain predominantly deterministic or probabilistic with inclusion of some limited results from the other analysis type, without an actual integration of both methodologies. On the contrary, the proposed Extended BEPU (E-BEPU) analysis does the combination in its true sense of integration. Its main feature is that it derives the availability of safety systems by probabilistic means when performing a deterministic BEPU calculation.

Therefore, the objectives of this work package are to:

- Review and compare different approaches utilized in this and other domains;
- Build a non-parametric dynamic BBN approach for a NPP by developing and integrating sub-networks for cause and consequence of technical, organizational and human aspects;
- Develop appropriate statistical techniques for constraining the input uncertainty sources of the BBN with a particular attention paid to expert-based information;
- Develop an Extended BEPU approach, combining probabilistic and deterministic analyses.

A key aspect of this work package is a PhD project that will be mostly focused on forming quantitative risk network methods, which include conditional probabilities and linkages between technical and social aspects.

WP summaries

WP4: Applying and comparing various safety assessment approaches on a virtual reactor

Giuseppe Rastiello
CEA

Safety analyses of NPPs under operation and the design of new reactors require the development of modeling strategies combining detailed descriptions of the considered structures/systems/components with reduced computational costs. Such aspect is of paramount importance for probabilistic reliability and sensitivity analyses of NPPs, since they generally require a high number of numerical simulations. This often makes these studies not feasible in an industrial framework, especially when methods to evaluate uncertainties (on mechanical properties, external actions) are used. Modeling reduction strategies provide useful numerical tools to overcome this limitation.

Developing and validating a simplified theoretical NPP (2nd/3rd generation) representative of the European fleet is the primary main objective of WP4.

The simplified theoretical NPP will be defined focusing on the reactor, containment, and associated systems. Several critical systems and components will be identified based on the experience feedback from PSA studies of existing reactors and European stress tests, considering different scenarios and safe shutdown path. Performed in coordination with WP5, this work will also provide information concerning the determination of criteria for model reductions useful for PSAs. Such aspect is essential for developing effective model reduction strategies for external hazards events.

Several reduced modeling formulations will be developed and/or applied. Meta-modeling strategies (aka response surface, surrogate models), in particular, will be used to apply models for assessing the impact of external hazards on the fragility of critical systems/components from a probabilistic viewpoint.

Widely used in structural reliability modeling, in aircraft industries, and in different domains of natural hazard assessment (landslides, coastal flooding, earthquakes), these formulations allow PSAs based on approximate input-output relationships. Their applicability for safety analysis purposes will be analyzed by studying the simplified NPP's response to different scenarios (design based and beyond basis events, WP3) to evaluate consequence on relevant systems, functions, and equipment, as well as related uncertainties. Attention will be focused on risks associated with earthquake, flooding and tsunamis events. Possible enhancements to existing formulations will also be investigated.

A challenging scientific task will concern, in particular, the development of a new model reduction method for dealing with complex, highly nonlinear dynamic structural systems. Based on the Proper Generalized Decomposition and the LATIN method, this model will allow deriving virtual charts related to the NPP units' dynamic response and including parameters related to the seismic loading features.

The simplified NPP model will be finally used to compare existing and new (developed in NARSIS) PSA and DSA methods. Different scenarios (WP3) for physical threads (WP1) will be considered, and their consequences on the fragility and functioning of NPP system components (WP2) evaluated. Results of these analyses will the subsequently used in WP5 to support the definition of Severe Accident Mitigation Guidelines (SAMGs), FLEXible coping strategies (FLEW) and Extensive Damage Mitigation Guidelines (EDMG).

WP summaries

WP5: Supporting Tool for Severe Accident Management

Luka Štrubelj
Gen Energija

The objective of WP5 is to develop tool for supporting decision-making (DM) in the severe accident management, relying on the PSA techniques. WP5 will extend the results, insights and conclusions from WP4 in the form of structured logic models of progression of hazard-induced accident sequences, which will be used as a platform for the development of supporting DM tool for severe accident management. The DM tool would be of demonstration level showing the feasibility of developing such a tool for actual NPPs and its potential for managing and reducing the residual risk from NPPs operation.

The first task is to define the referential nuclear power plant (NPP) for which the supporting tool will be developed. It is be based on operating power plant in European Union. The safety equipment of referential nuclear power plant include design basis safety equipment, safety equipment to mitigate severe accident and mobile equipment. The design basis equipment includes high pressure injection, borated water accumulators, and low pressure safety injections. The containment is building around reactor to confine the radioactive material and prevent releases to the environment and radioactive doses to the public. After the Fukushima accident, stress tests are often allowed installation of new equipment to prevent or mitigate severe accidents – accidents with core melting such as additional energy sources, passive containment venting, passive autocatalytic and Alternative depressurization system for coolant system.

The second task is to describe severe accident management guidelines (SAMG) applicable to referential NPP. The main purpose of SAMG is to provide guidance to plant operators and the technical radioactivity release to environment. The initial hazard sequences and impacts will be defined in coordination with WP1 and WP2. Essential part of the task will be to identify the key decisions to be made by plant operators / TSC staff in response to considered hazard sequences and impacts.

In task 3 the hazard-induced damage states and development of specific accident progression event tree for demonstration purposes will be developed. This includes developing accident progression logic structure for postulated hazard damage states, where damaged equipment will be identified. The set of attributes against which all decisions will be evaluated in decision support process will be identified.

In the last task the development of supporting SAMG decision support tool will be developed. The alternative paths, based on alternative decisions will be identified. The information needed for the decision will be identified. The correlation between input and output information will be established, based on deterministic and probabilistic models results. Main input variables such as temperatures and pressure, water level, steam generator level, hydrogen concentration, etc. will be used. The main output variables shall be in support to decision making process to managers in technical support center and could include probability of reactor pressure vessel failure and containment as main physical barriers to prevent radioactive releases. The time until reactor vessel and containment fail is also important output.

WP summaries

WP6: Dissemination and Communication activities

Behrooz Bazargan Sabet

BRGM

Dissemination and exploitation of results are a way to showcase the work done in NARSIS project. Sharing results, lessons learned and outcomes and findings beyond the participating organizations will enable a wider community to benefit from technical and scientific developments of the project but also to help and inform future policy and practice. Indeed, the impact of the project is measured not only by the quality of results but also by the extent to which these results are known and used outside and in particular by the regulators.

Therefore, the goal of the work package are to:

- Raise awareness and ensure effective widespread dissemination, exploitation, take up in practice and mainstreaming of the project outcomes and results;
- Facilitate strong and effective involvement of end-users and regulators
- Provide scientific resources for nuclear and non-nuclear communities involving in safety-related issues and risk management.

To reach these goals the project relies on several tools encompassing:

- Project website that serves four main functions, namely i) creating the project identity, ii) facilitating internal integration and communication, iii) aiding project management and iv) providing a means for widespread external dissemination.
- Targeted communication tools that include i) production of project brochure(s), leaflet(s) and poster(s); ii) production of periodic newsletters distributed via e-mail and of a social media campaign; iii) production of factsheets for communication in international events and iv) development of materials for education and training purposes.
- Organization of two International Workshops during which, the consortium partners and outside experts will present and exchange about the latest NARSIS related issues and findings. Workshop proceedings will be published and widely distributed through the website.
- Production of pedagogic and training materials that will be used for engineering students' and young researchers' education. The presence of several top level universities in the Consortium will favor dissemination of theoretical and scientific findings, notably results of WP1, 2 and 3 works, in the academic world. This will contribute to the sustainability of NARSIS outcomes beyond the project
- Production of a final Handbook that aims at delivering the conclusions and recommendations of the project. The detailed analyses of the project outcomes will provide guidelines for new research, development and innovation but will also give insight for future revision of PSA regulations and standards.

EVENTS

ICNSS 2018

20th International Conference on Nuclear Safety and Security

Amsterdam, The Netherlands 6 – 7 August 2018

Canadian Nuclear Safety Commission

2018 International Severe Accident Management Conference

Ottawa, Ontario, Canada 15–18 Octobre 2018

WORLD NUCLEAR ASSOCIATION

World Nuclear Association Symposium

London, UK 5-7 September 2018

IAEA International Atomic Energy Agency *Atoms for Peace*

International Symposium on Communicating Nuclear and Radiological Emergencies to the Public

Vienna, Austria 1-5 October 2018

NENE 2018 September 10-13 PORTOROŽ SLOVENIA

27th International Conference Nuclear Energy for New Europe

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