Regulatory panel: The evolving perception of probabilistic applications in the nuclear regulatory environment.

(Probabilistic analyses in nuclear safety in Spain)

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0 CSN

- **CSN: Consejo de Seguridad Nuclear (Nuclear Safety Council)**
  - **Spain’s Nuclear Regulatory Authority**
  - **Two branches: nuclear safety & radiological protection**
  - **Technical staff (more than 200 technicians)**
  - **Inspection and evaluation tasks**

1 Probabilistic methods

- **Fields featuring probabilistic analyses:**

  - **Probabilistic Safety Analysis (PSA)**
  - **Deterministic Safety Analysis: BEPU (Best-Estimate Plus Uncertainty) analysis of accidents**
  - **Probabilistic Fracture Mechanics (PFM)**
  - **Earth Sciences:**
    - **probabilistic seismic hazard analysis (PSHA)**
    - **Analysis of precipitations, floods, etc**

A TRANSVERSAL MATTER: Uncertainty analyses of results of calculations are present in (almost) every field of nuclear safety and radiological protection !!!

1.1 BEPU methods in accident analysis

- **Deterministic safety analysis (DSA) of accidents**
  - **Accidents & transients in a nuclear plant are categorized according to their frenquency (i.e. probability per unit time)**
  - **In each category, design-basis scenarios (DBS) are defined**
  - **DBS are simulated with physical models (codes) and regulatroty acceptance criteria for the results are checked.**

- **DSA methodologies:**
  - **Conservative: pessimistic models & assumptions. No uncertainty analysis.**
  - **BEPU (Best Estimate Plus Uncertainties): realistic models & assumptions. Includes sensitivity & uncertainty analyses.**

1.1 BEPU methods in accident analysis (cont.)

- **BEPU methodologies are mostly probabilistic:**
  - **Black-box approach, uncertainty propagation from inputs & models.**
  - **Wilks' nonparametric method (based on simple random sampling) is widely applied.**
  - **More complex (and efficient) methods are being developed and used.**

- **10 CFR 50.46 (*ECCS Rule*): it was amended in 1989, and opened the door to BEPU methodologies in accident analyses (in LOCA/ECCS analyses).**
- **In Spain, conservative DSA is still widely applied. But there is a growing number of applications featuring BEPU methods.**

1.2 Probabilistic Safety Analysis (PSA)

- **PSA in Spanish plants:**
  - **Licensees are required per binding regulation (IS-25) to develop Level 1 and Level 2 PSA analyses for at-power/shutdown states, internal events/internal fires & floods, Spent Fuel Pool. Most of the above has been completed for all plants.**
  - **PSA models are to be updated on a continuous basis, following CSN guidance (GS-1.15).**
  - **PSA applications by licensees include**
    - Maintenance Rule (IS-15/10CFR50.65) (in use at Control Room)
    - Transition to NFPA-805 in lieu of App. R (IS-30) compliance
    - Risk-Informed In service testing/In service inspection
    - Risk-informing plant modifications, Tech Spech and other changes o the licensing basis

1.2 Probabilistic Safety Analysis (PSA) (cont.)

- **PSA in CSN:**

Current Applications

- **SISC** *(Sistema Integrado de Supervisión de Centrales):* **Integrated System for NPP Oversight.**
  - Inspection subject and risk impact of findings
  - Support of the indicator system – (IFSM) →(equivalent to NRC-MSPI)

- **Incident Analysis (Precursors)**
  - Support of the Operating Experience Area to determine the risk significance
  - Criteria to recommend an inspection after events at NPPs

- **PSA information system (Internal)**
- **Risk insights for periodic safety review (PSR)**
- **CSN makes use of licensees' models, and is also working with University to develop a PWR generic model; objective: have an independent risk view**

1.3 Dynamic PSA & IDPSA (TSO Important Tasks within RIR)

- Most often, licensing applications presented to the Regulatory Body are supported with safety analyses relying on computational tools. This includes DSA and PSA.
- The increasing trend to introduce risk arguments in licensing issues increases the need for computerised analysis.

What is the Regulator's task?

Perform their own analysis to verify the quality, consistency, and conclusions of licensee's assessments.

What is not?

Perform a parallel analysis that starting from the same assumptions reaches the same conclusions.

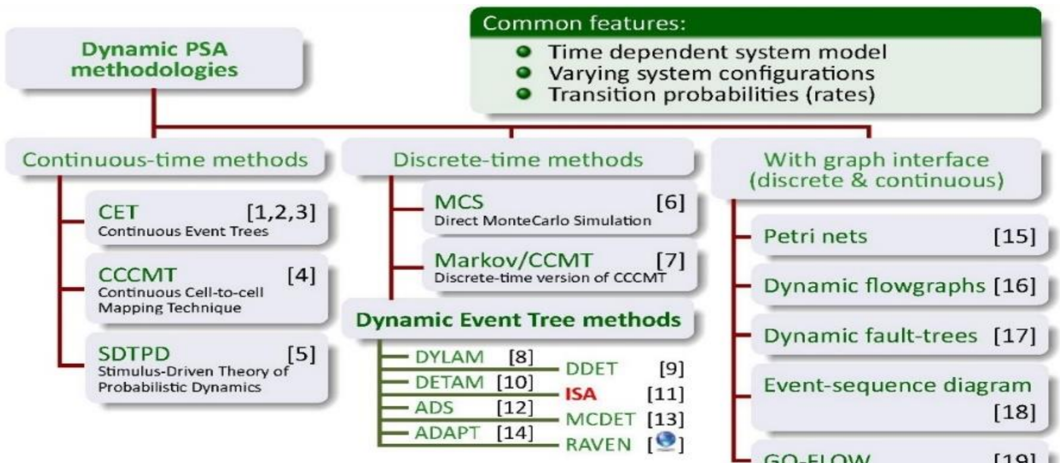
Among the many issues to be checked we can mention:

- Verification of PSA envelopes: success criteria are adequate for all sequences.
- Verification of DSA envelopes: protection systems are able to cope with all accident scenarios, not only with a predetermined set.
- Extension of the protection scope to include operator actions, particularly in PSA. Complex aspects like available times are a potential source of inconsistencies.
- Mutual consistency between PSA success criteria and Technical Specifications derived from DSA.
- Identification of meaningful *"what if?"* questions.

A sound **combination of deterministic and probabilistic checks**, complementary pieces an **integral method**, is required for verifying that all the decision ingredients are properly and consistently weighted.

- Usual risk indicators like **CDF** or **LERF** are not enough to address all these issues.
- Exceedance frequencies of DSA safety limits can be used as additional risk indicators allowing for a consistent interpretation of current regulations in the risk domain.
- An integral approach to the analysis of Technical Specifications is also possible where deterministic (LCO*) and probabilistic (SR*, CT*) aspects are combined in a natural way.
- There is also room for improvements in the analysis of operating events. Current approaches focusing on ET/FT techniques and CDF/LERF metrics give only a partial view of incident implications.

1.3 Dynamic PSA & IDPSA (General Frameworks and references)



Main source: Aldemir, T., A survey of dynamic methodologies for probabilistic safety assessment of nuclear power plants. Annals of Nuclear Energy 52 (2013) 113-124.

Time uncertainty

- Some dynamic events can only occur at the time of its stimulus activation (non-stochastic events).
  Example: An automatic system starts-up when its setpoint is reached.
- Stochastic events occur with a random delay after its stimulus activation.
  Example: A corrective operator action upon activation of an alarm.
- Time uncertainties are often dominant over other uncretainties.
- Extension of parametric uncertainty techniques to time uncertainty is not always possible.

ISA is especially designed to deal with time uncertainties.

1.3 Dynamic PSA & IDPSA (ISA Applications)

ISA applications have been developed in the following areas:

- Verification of PSA event trees (correctness and completeness).
- Assessment and verification of success criteria and available times.
- Analysis of safety margin erosion upon significant plant changes.
- ...

Other possible ISA applications:

- Precursor analysis of initiator-type incidents.
- Technical support in emergency management (accident evolution forecast).

1.3 Dynamic PSA & IDPSA (Recommendations for Future Work)

❶ Use of PSA fault trees for dynamic DynamicPSA

- Event outcome probabilities P_{i_k} and P_{i_m} in equation (1) are in most cases probabilities of plant system configurations.
- Fault trees are adequate tools for modelling and quantifying system configurations.
- PSA fault trees represent safety function failures. However they have system configurations embedded.
- Depending on the modelling technique in PSA, configuration fault trees can be very difficult to extract from safety function fault trees.

Some efforts should be devoted to develop techniques to derive configuration fault trees from PSA fault trees

❷ Efficient methods for failure domain integration

- Exceedance frequency calculations require integrating the probability density in the failure/damage domain.
- In general, integration limits cannot be represented by an analytical function.
- For low dimension sequences, numerical methods using multiple one-dimension integration can be very efficient and accurate.
- However, as the number of dimensions increases, the required number of calculations explodes.
- Monte Carlo integration methods always require a high number of simulations to get the required accuracy.
- For small failure domains, Monte Carlo methods are very inefficient since most simulations fall outside the failure domain.

Efficient and accurate integration methods should be explored. Crieria to choose optimum methods should be defined.

❸ Development of surrogate models

- Best estimate simulations usually take a significant time
- Replacement of simulation codes by surrogate models may significantly speed-up simulations.
- However, non-physical surrogate models can easily result in non-physical results.
- A new technique called Transmission Functions is being developed to implement physical ultra fast simulation methods.
- The concept of Transmission Function is an extension of the Transfer Function of linear systems.
- Identification methods for Transmission Functions rely on a Data Base of transient simulations performed with best estimate codes.
- Surrogate models built-up with Transmission Functions are able to perform time uncertainty analysis.

References:

- J. M. Izquierdo, S. Galushin, and M. Sánchez, Transmission Functions and Its Application to the Analysis of Time Uncertainties in Protection Engineering, Process Safety and Environmental Protection, (2013), http://dx.doi.org/10.1016/j.psep.2013.07.004.
- J. M. Izquierdo, C. Paris, and M. Sánchez, The Theory of Transmission Functions and Its Application to Design Verification of Large Scale Safety Systems, International Refereed Journal of Scientific Research in Engineering (IRJSRE), Volume 2, Issue 3, pp. 06–26, March, (2017).

❹ Incorporation of big data techniques

- ISA applications generate a huge amount of useful data.
- All of them are stored in a Data Base.
- Big data methods can be very useful for clustering, classification, visualization of variables or domains, etc.

1.4 Probabilistic Fracture Mechanics

- **Leak Before Break (LBB)** methodology was used at the beginning of the 90s by the Spanish Nuclear Power Plants (NPP) following a deterministic approach. The application was licensed by the Spanish Nuclear Safety Council (CSN).
- The LBB approach is based upon the application of **advanced fracture mechanics** to demonstrate that high fluid energy piping is very unlikely to experience double ended ruptures.
- The prior was possible when **NRC regulations** were discussed and changes to them were suggested to permit the use of advanced fracture mechanics technology (both deterministic and probabilistic) in the licensing process in lieu of requiring the postulation of arbitrary, full double-ended pipe ruptures or their equivalent slot type pipe breaks.
- Due to the approval of LBB, **NPP submitted an application to modify the approach of the GDC nº4 of 10 CFR50**, for the exemption to avoid the need of guillotine primary piping rupture postulation with the propose of eliminating pipe whip restraints.

1.4 Probabilistic Fracture Mechanics

- CSN participated within the **NEA (Nuclear Energy Agency) IAGE (*Integrity and Ageing of Components and Structures*) metallic subgroup in the PROISIR (Probabilistic Structural Integrity of a PWR Reactor Pressure Vessel Benchmark)**. For this purpose, Tecnatom company was contracted and the task was conducted by means of the probabilistic structural calculation Software FAVOR (Fracture Analysis of Vessels-Oak Ridge Heat-up).
- CSN has also knowledge of **xLPR (*Extremely Low Probability of Rupture*) software**, which was developed by NRC and EPRI and is currently used in US NPP for different applications such as Leak Before Break.
- Currently, in Spain there is **no licensing process based in probabilistic fracture mechanics**, but licensees are allowed to present any development on this field anytime for its approbation. Therefore, CSN should be ready to validate it.
- In the next years, **probabilistic seismic approach** will be developed by licensees and it will involve the work of different areas of the CSN. An important effort will be necessary to oversee this project.

1.5 Earth Sciences

- **Probabilistic Seismic Hazard Analysis (PSHA)**

  - **As required by CSN, every Spanish NPP has developed a PSHA applying the SSHAC methodology, level 3 (USNRC), that combines probabilistic analysis with the treatment of expert opinion. This task has been just finished, producing the seismic hazard curves for different exceedance frequencies and corresponding UHS at control points in every site (foundation of NPP safety structures).** [UHS = Uniform Hazard Spectra]

  - **Currently these results are under evaluation in CSN, checking them with the seismic design basis in every site and considering improvements already implemented in every plant regarding seismic design, according to seismic margin required.**

  - **Maybe some NPP must launch the development of its Seismic-PSA in order to confirm design robustness or identify additional improvements to be implemented.**

  - **Probabilistic methods are most appropriate tool to check the suitability of seismic design bases in an NPP site and the adequacy of safety margins available to face DEC situations.** [DEC = Design Extension Conditions]

1.5 Earth Sciences (cont.)

- **Probabilistic Hazard Assessment regarding extreme weather conditions**

  - **Probabilistic methods, and statistical analysis of extreme values,** are usual tools applied to analyze recorded series of historical data in the field of natural hazards and extreme events regarding nuclear installations safety analysis.
    - Local intense precipitations, flooding and water level associated, extreme winds, extreme temperatures, etc.
  - In general, as in the case of seismic events, the use of probabilistic methods is a powerful tool to study the behavior and time evolution of phenomena or events associated to extreme weather conditions (and to limit uncertainties).
  - From a regulatory standpoint, typically probabilistic methodologies are most appropriate to validate NPP design bases regarding extreme weather conditions and to quantify safety margins available to face DEC situations.

2.1 Panelist questions

- **How much has the perception of probabilistic approaches changed over the last three years in your Agency?**

  - **In recent years, there is a growing perception that probabilistic methods are necessary and helpful. E.g.**
    - **probabilistic uncertainty analyses of the results of deterministic fields exist in almost every field of nuclear and radiological sicience.**
    - **PSA, PFM, PSHA, etc, are well-established and accepted methodologies**

2.2 Panelist questions (cont.)

- **Have some of the requirements changed to allow increased use of probabilistic analyses?**

  - **In accident analyses, generic BEPU methods are required to prove the bounding character of conservative methodologies.**
  - **PHSA have been developed for all spanish plants.**

2.3 Panelist questions (cont.)

- **Compared to 3 years ago, how does the regulatory staff feel about using or reviewing applications with probabilistic analyses?**
  - **This feeling has not changed in recent years. Maybe, the technical staff is still more aware about the necessity and usefulness of probabilistic methods.**

2.4 Panelist questions (cont.)

- **What is your regulatory agency’s approach toward new technologies such as machine learning and artificial intellegence?**
  - **CSN is promoting R&D developments on this field.**

2.5 Panelist questions (cont.)

- **What would be the role of probabilistic vs, deterministic analyses for the licensing of new reactors (e.g. SMR, non-light water reactors)**
  - **No licensing of new plants in Spain !!**
  - **Rather, licensing work of decommisioning is needed**

THANK YOU FOR YOUR ATTENTION !!

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