Probabilistic Safety Assessment for internal and external events

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Summary

The design of NPPs is mostly based on deterministic safety rules and concepts (e.g. safety margins, design basis accidents), in relation with the defense-in-depth concept. Nevertheless, vulnerabilities and residual risk exist, which can be determined and quantified by Probabilistic Safety Assessments (PSAs). This area of nuclear safety is a topic where the European Commission supports harmonization of methodologies used by the stakeholders in Europe, in relation with PSA applications for NPPs safety enhancement.
Risks associated to severe accidents was identified as a field were harmonization of practices seems to be needed and first activities started within SARNET (2006-2008), and then continue in the project ASAMPSA2 (2008-2011) to develop best-practice guidelines for the performance and application of Level-2 (L2) probabilistic safety assessment (L2PSA). At the end of the ASAMPSA2 project, it was concluded that risks of severe accidents associated to reactor shutdown states but also to external hazards should lead to additional effort in terms of harmonization of practices.
The Fukushima nuclear accident in Japan, which resulted from the combination of two correlated extreme external events (earthquake and tsunami), has then convinced all nuclear stakeholders on the importance of these topics. The consequences (flooding in particular) went beyond what was considered in the initial NPP design. Such situations can and should be identified using PSA methodology. Today the new European ASAMPSA_E (Advanced Safety Assessment: Extended PSA) project is seen as a major step in the harmonization of PSA for external events, whatever the initial states of the reactors. The activities started on July 01, 2013 and will last for three years.

1. Introduction

The design of NPPs is mostly based on deterministic safety rules and concepts (e.g. safety margins, design basis accidents), in relation with the defense-in-depth concept. Nevertheless, vulnerabilities and residual risk exist, which can be determined and quantified by Probabilistic Safety Assessments (PSAs). PSAs offer a possibility to anticipate any possible degraded situation of a NPP, and to verify that the different levels of defence are sufficient. Therefore, the PSA approach is an increasingly important supplement to the deterministic approach, but suffers also from limitations in the methodologies in use and applications.

For internal initiating events, L1PSA and L2PSA are now routinely applied throughout the EU. While L1PSA approaches and methods seem to have converged to a significant extend, L2PSA methods differ very much throughout the nuclear community, as demonstrated by some comparisons of L2PSA methodologies in the EU SARNET 1 project (2006-2008). This situation was also an indication that if severe accident risks were diversely quantified depending on the country or the utility, the severe accident management provisions could also be very different from one European NPP to the other.

The European Commission has then supported, from 2008 to 2011, the ASAMPSA2 (Advanced Safety Assessment Methodologies: L2PSA) project to develop best-practice guidelines for the performance and application of L2PSA in Europe. The project has been established through a collaborative effort of 21 European organisations. At the end of the ASAMPSA2 project, the guidelines have been submitted in a workshop to international external review, open to European nuclear stakeholders and organizations associated to the OECD-CSNI working groups on risk and accident management. It should be noted that some experts involved in this workshop recommended, in particular, to complete the work done in ASAMPSA2 on risks specifically associated to reactor shut-down states and to external hazards, because these situations may contribute significantly to the risks induced by a NPP without being properly addressed in most existing L2PSA.

This final step for the ASAMPSA2 project occurred just before the Fukushima Daïchi disaster (11th of March 2011). From a severe accident risk-analysis perspective, all lessons learned from the Fukushima accident could not be incorporated in detail in the final version of the ASAMPSA2 guideline.

The Fukushima nuclear accident in Japan resulted from the combination of two correlated extreme external events (earthquake and tsunami). The consequences (flooding in particular) went beyond what was considered in the initial NPP design. Such situations should obviously be identified using PSA methodology but the current practices in Europe do not seem to be adequate. The European Commission now supports a second collaborative project, ASAMPSA_E (Advanced Safety Assessment: Extended PSA), which is seen as a major step in the harmonization of PSA for external events, whatever the initial states of the reactors.

The project ASAMPSA_E aims at identifying good practices for the assessment of such sequences with the help of Ll-L2 PSA and for the definition of appropriate criteria for decision making in the European context.

For this project, an "extended PSA" applies to a site of one or several NPPs and its environment. It intends to calculate the risk induced by the main sources of radioactivity (reactor core and spent fuel storages) on the site, taking into account all operating states for each main source, and all possible accident initiating events affecting one NPP or the whole site.

28 European organizations contribute to ASAMPSA_E. Some non-European organizations (US-NRC, JANSI, TEPCO) have expressed interest in this project. For example JANSI (the Japan Nuclear Safety Institute, which is a new TSO of Japanese utilities), was involved in the recent Vienna technical meetings. The activities started on July 01, 2013 and will last three years.

On September 17-20, 2013 the first technical meetings have been held in Vienna, defining how to proceed and how to initiate all technical activities.

2. Experience obtained in ASAMPSA2 and perspectives within ASAMPSA_E

General overview

After four years of collaborating activities, the ASAMPSA2 guidelines are now published on CORDIS: http://cordis.europa.eu/fp7/euratom-fission/funded-reports_en.html. They are also available on www.asampsa2.eu. The guidelines are in three volumes:

Volume 1 - General considerations on L2PSA [1]

This volume provides some general views on the management of a L2PSA, the existing background in many countries or international organizations and discusses the link between L2PSA results and their final application.

Volume 2 -Technical recommendations for Gen II and III reactors [2]

This volume provides recommendations regarding specific methods to be used in a L2PSA (L1/L2PSA interface, accident progression event trees, release categories, human reliability analysis, etc.) and recommendations on studies that need to be performed to support a L2PSA (physical phenomena, system behaviour, source term assessment).

Volume 3 - Specific considerations for future reactors (Gen IV) [3]

This volume is more prospective, but provides some interesting views on the applicability of existing L2PSA approaches for BWRs and PWRs to four Gen IV concepts.

One important quality of the document is that is has been judged acceptable by organizations having different responsibilities in nuclear safety activities (utilities, safety authorities or associated TSO, research organizations, designers, nuclear service companies,…). Many contents refer to recent results obtained from recent research programs in the severe accident area, in relation with SARNET 2. Each ASAMPSA2 partner was invited to complete the guidelines from its own experience and to discuss the contribution of other partners.

The final guidelines propose a set of acceptable solutions, already in use, to perform a L2PSA. These must be considered as a handbook for the teams involved in these activities, whatever their role (developers or reviewers), to improve the quality of their L2PSA.

The guidelines have to be considered as a technical complement of the other existing “high level” guidelines like those of the IAEA [4,5,6] or certain national guides. They propose practical solutions and try to define what could / should be done to obtain a state-of-the-art study.

One difficulty that has been identified is that the guidelines do not propose a single, precise, step-by-step procedure: the user is supposed to take and use the relevant information depending on his objective. This question has been discussed during the project and it was accepted that, due to the complexity of the L2PSA content (it represents a whole NPP (systems and operators), thousands of accident situations and severe accident phenomena …) and depending on the final application, different technical solutions can be implemented.

A simple example is the case of L2PSA that is developed only to calculate a bounding “Large Early Release Frequency” for regulatory purposes: in that case, many simplifications that can be acceptable only for this application can be used in the L2PSA (less realism to model the severe accident phenomena, conservative assumptions, no source term calculations…). On the contrary, a L2PSA which is developed to support, as far as possible, the optimization of severe accident management strategies for an existing Gen II NPP, with limited safety margins against severe accident loadings, may include more realist modelling, uncertainties assessment and will be more complex. For both examples, the ASAMPSA2 guidelines provide information that can be used to make the L2PSA development easier.

Last but not least, it was not the intention of the authors to define any quantitative or qualitative safety requirement. This activity is the responsibility of the national Safety Authorities. Nevertheless, some of the ASAMPSA2 partners have highlighted the importance of defining appropriate risk metrics in relation with L2PSA and propose some solutions for harmonization. This topic is seen as an area where further activities can be useful in the research area on L2PSA methodologies.

Discussion with regard to "extended L2PSA"

The principal structure of a L2PSA (L1-L2 PSA interface, accident progression event tree, release categories, L2-L3 PSA interface …) should be applicable to an extended PSA, even if several additional issues have to be considered in addition to the ASAMPSA2 guidelines, which do not cover internal and external hazards, and the spent fuel pool, and which do not do not provide much detail for reactor shut down states.

Regarding the current situation of L2PSA guidance at international and national level, there are several references which address L2PSA in particular for full power mode and which are mostly limited to internal initiating events (e.g. [4]). In addition, there are a few documents which explicitly mention shut down states of the reactor (e.g. [5]) or external events (e.g. [6]). Their relevance for ASAMPSA_E will be checked.

It is already possible to tentatively indicate several parts of the existing ASAMPSA2 guidelines which will be complemented in ASAMPSA_E:

- The sections on the L1-L2PSA interface and on the probabilistic severe accident progression modeling cover rather general topics of L2PSA. It is expected that most of the statements from ASAMPSA2 will be valid for ASAMPSA_E as well.
- ASAMPSA_E addresses accident situations where human actions are particularly difficult to perform. Therefore, the traditional approach as discussed in the ASAMPSA2 documents will have to be evaluated critically in ASAMPSA_E.
- In ASAMPSA_E, three deliverables will address the quantification of various physical phenomena. It will be one of the main tasks to identify where the common approaches provided in ASAMPSA2 are suitable, and where particular solutions are needed in an extended PSA.
- The containment can be challenged by external events (e.g. mechanical impact, heat due to fire, pressure waves). Containment response will be a wide topic to be discussed within ASAMPSA_E.
- Within the scope of an extended PSA, the boundary conditions for systems will often be different from those present in the case of internal events, due to the impact of external events, or their unavailability in shut down modes. Therefore, the impact of the boundary conditions on system behavior will be an issue in ASAMPSA_E.
- The ASAMPSA2 guidelines include statements related to risk measures which are valid for extended PSA. However, there was no complete consensus in the ASAMPSA2 community with regard to a common risk target.
- The chapter on PSA applications in ASAMPSA2 tentatively discusses the possible applications of the L2PSA. For ASAMPSA_E, many sections are of interest. However, the focus in ASAMPSA_E will have to be defined in relation with the End-Users needs (an upcoming end-user's survey is planned).

5. ASAMPSA_E general overview

The ASAMPSA_E project has been organized in five work packages with 28 participants from 18 countries (IRSN, GRS, AMEC NNC, RSE S.p.A., LRC, UJV, UNIVIE, CCA, ENEA, NRG, IEC, EDF, LEI, NUBIKI, FKA, AREVA NP SAS, NCBJ, SSTC, VUJE, NIER, VGB, TRACTEBEL, BeL V, JSI, INRNE, INR, TUS, AREXIS). Approximately 35 deliverables are planned.

ASAMPSA_E reflects many concerns which came up in the PSA field after the Fukushima Daïchi disaster:

- Identification and probabilistic modeling of the initiating events (single and correlated hazards), to be taken into consideration in an extended PSA
- How to introduce hazards in L1 PSA and all possibilities of event combinations
- General issues regarding extended PSA scope and applications (e.g. screening methodology on initiating events, risk metrics, evaluation of defense in depth, decision-making process based on extended PSA conclusions …)
- How to introduce hazards in L2 PSA and all possibilities of event combinations? (e.g. impact on Human Reliability Assessment or on possible radioactive release).

ASAMPSA_E is facing the following particular challenges:

- The seismic example (see following section) which even belongs to the more developed issues, points out the extreme difficulties in assessing external hazards.
- The number of potential hazards (more than 60 have been already identified, grouped in five topics: seismotectonic, and hydrological hazards, high amplitude or rare meteorological phenomena, biological infestation) shows the size of the task.
- As a NPP is exposed to more impacts (internal or external) its state will increasingly deviate from its normal status.
- Conditions of structures / components which may influence / prevent / mitigate an accident are difficult to evaluate.
- Human actions under extreme conditions are difficult to predict.
- Only little experience exists with extended PSA, in particular with L2PSA.

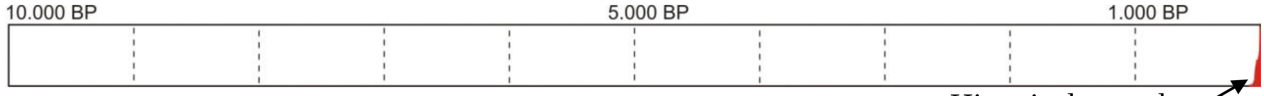
ASAMPSA_E next steps are described next

- Early 2014: PSA End-User’s opinions will be collected by a questionnaire and an international workshop. More than 100 organizations will be contacted; contributions are expected from more than 50.
- Mid-2014: structure, table of contents and main contributing partners will be defined for the future key reports.
- End-2015: final draft of deliverables will be submitted to End User with an open review process.
- Mid-2016: at the end of the project, the final ASAMPSA_E guidelines will be published.

6. ASAMPSA_E first achievements

ASAMPSA_E started just three months ago in July 2013, so only a few achievements can be reported.

For the identification and probabilistic modeling of the initiating events, a partner outside the nuclear community takes the lead (University of Vienna) and provides particular knowledge in paleoseismic science. It was demonstrated that seismic hazard assessment for very low probabilities “once in 10.000 years”) is seriously challenged by limited and incomplete earthquake data. The seismic hazard assessment requires extrapolations 10 to 100 times over data coverage.
To emphasize this point, the following figure shows the historical earthquake records of the Vienna Basin shown on the rightmost edge, in a linear time scale of 10.000 years:



For the Vienna Basin, the paleoseismological approach can support the assessment, by evaluating existing faults which did not generate earthquakes in historical times, and can indicate the potential magnitude of earthquakes due to that fault. Obviously, applicability of the paleoseismological approach within the context of PSA will be an important part of the collaboration within ASAMPSA_E.

As explained above, in addition to seismic hazards, a seed list containing more than 60 external hazards has been drafted. It is absolutely needed for practical applications to apply a screening procedure, and a methodology to quantify the risk of the relevant hazards. When comparing the historical data on hazards (approximately less than 1000 years) and the order of magnitude of PSA results (frequency of accident below 10-5 /reactor-year), we can predict that the exchanges within ASAMPSA_E will be intense …

The ASAMPA_E partners have also already examined how they can collect relevant experience or formulation of needs through an external survey by PSA end-users. Five areas will be proposed in a survey:

1 Questions related to lessons from past real events for PSA developments
2 Questions related to the definition and scope of extended PSAs
3 Questions about uses and applications of extended PSAs
   3.1 Current practice
   3.2 Future application of extended PSAs
4 Quality of extended PSAs
5 Current practices -Technical needs
   5.1 Initiating events (hazards) modelling
   5.2 Introduction of hazards in PSAs
6 Review of past high amplitude real external events
   6.1 Natural external events
   6.2 Human-induced external events

This survey will certainly foster useful exchanges in the PSA and reactor safety community.

5. Acknowledgements

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6. References

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