ASAMPSA_E SEVENTH FRAMEWORK PROGRAMME	Advanced Safety Assessment Methodologies: extended PSA	EURATOM

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Synthesis of the initial survey related to PSAs End-Users needs

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Summary:

The ASAMPSA_E project aims at identifying good practices for the development of extended PSAs that include low-probability internal and external hazards which can lead to extreme consequences, and at discussing the application of extended PSAs for NPP safety enhancement decision making in the European context.

A first questionnaire related to End-Users needs (ASAMPSA_E/WP10/D10.1/2013-4) has been disseminated at international level to PSA End-Users in November 2013 in order to identify the needs for guidance for the performance and application of extended PSA.

This document presents the analysis of the responses to the survey.

A draft version has been used to present the responses to the survey and discuss End-Users' needs during an international workshop organized on 26, 27 and 28 May 2014 in Uppsala (Sweden).

The final version of this document has been prepared by incorporating the comments received from the project partners and the outcomes of the discussions at the Uppsala workshop.

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SUMMARY

This document presents the analysis of the responses to a survey related to End-Users' needs in terms of guidance for the performance and application of extended PSAs. The task is part of the ASAMPSA_E project which aims at identifying good practices for the development of extended PSAs that include low-probability internal and external hazards which can lead to extreme consequences, and at discussing the application of extended PSAs for NPP safety enhancement decision making in the European context (see www.asampsa.eu for more details on this project).

The PSA End-Users' survey was conducted by means of a questionnaire consisting of 100 questions. The questionnaire was distributed to several organizations responsible for nuclear safety. 34 organizations have sent their answers to the questionnaire. Considering the number of respondents, their roles and activities and their geographical distribution, it is justified to consider that a good representativeness of all potential PSA End-Users has been achieved.

As a preliminary remark, it should be reminded that at the end of a previous European project (ASAMPSA2), End-Users have underlined that a strong link should be made in the ASAMPSA2 guidelines between the definition of the top level objectives of a PSA (i.e. its intended uses and applications) and the choice of methods and tools to execute the different tasks and solve the identified issues. We consider that this expectation should also be considered for the elaboration of ASAMPSA_E guidance.

In the Chapter 1 of the present document, the scope and background of the ASAMPSA_E project, the objectives of the End-Users survey and some information on the respondents are given.

In Chapter 2, lessons learnt by respondents from past real events/hazards for PSA developments are presented.

There is a general consensus on the existing influence of the operating experience on the PSA studies. However, the information is generally confidential, and therefore some events may not be widely accessible. Examples of past real events mentioned by respondents include: earthquake, external flooding, low river level due to a prolonged period of drought, abrasive storm, high temperatures, lightening, clogging of the pumping station, ice formation, grid disturbance.

PSA was available in some cases, but not for the majority of considered events. In some cases, additional PSA studies or simplified analyses have been developed; the following events have been mentioned: earthquake, high wind, airplane crash, extremely high temperature, extremely low temperature, extreme snow load, tornadoes, events for low power and shutdown states and Spent Fuel Pool.

Most of the existing external hazard-PSAs involve a L2 PSA as well.

Combinations of external hazards with significant consequences for safety have been experienced by a few respondents. The experienced combinations of the external hazards include: flood and wind; high air temperature in combination with high humidity resulting in production of droplets; combination of ice frost and wind. In most

cases, combinations of external hazards are not taken into account in PSAs and few lessons about combinations have been learned for PSA development so far.

For natural or man-made external hazards that already occurred and concerned a whole site, multi-unit issues have not been so often included in a detailed risk analysis report. In most cases, single unit PSAs have been used with specific modifications to account for multi-unit aspects.

A majority of respondents has decided to revise or to extend their PSA after the Fukushima accident. The revision or extension of PSA concerning Spent Fuel Pool is taken into consideration by most of the respondents, followed by the revision or extension of PSA concerning some relevant hazards, low power and shutdown modes, revision or extension of PSA concerning PSA level 2 and multi-unit PSA. The revision or extension of PSA concerning PSA level 3 has obtained the lowest interest from respondents. The following issues were also mentioned in responds: risk-informed emergency preparedness, severe accident response, especially for seismic scenarios, combination of hazards including seismic induced fires and floods, long-term accidents.

Generally speaking, respondents considered that the Fukushima accident highlighted the need to analyse in more detail several aspects of PSAs but did not raise any new PSA issue.

Specific needs for new competences have been identified after the Fukushima accident, mentioning the following areas: external hazard characterization; external hazard probabilistic modelling and assessment; analysis of combinations of hazards. A NRC initiative should be mentioned: being aware of the increased need for PSA expertise, a process for training specific individuals to provide them the necessary PSA skills was developed.

For most of the respondents the requirements for PSA have been or will be changed after the Fukushima accident. The new requirements involve the reinforcement of the quality of PSA, and the extension of PSA scope (comprehensive Level 1 PSA for all internal and external hazards, consideration of spent fuel pool and multi-unit effects, LPSD events).

Concerning the report on lessons learned from the Fukushima event for PSA developments which will be initiated in the ASAMPSA_E project, the following needs have been mentioned:

- description of event sequences and timeline of events; specification of damages for safety systems and equipment; description of human responses and their implications for HRA; estimated frequency of hazards that have occurred (separately or in combination); estimated frequency of the event sequence(s) which led to core damage;
- impact on the reference list of hazards, screening methodologies and criteria, combination of hazards, human reliability assessment methodologies (including consideration of specific emergency organization), and extended mission time to be considered;
- identification of the main deficiencies of the current PSA methodology and requirements for the further development (including multi-units risk assessment covering at least the Level 2 PSA);
- a best practice on how to model loss of non-safety and safety systems in combination with external hazards. The report should cover PSA techniques for assessing the impact of component protection.

More generally, expectations for guidance based on lessons learned from past real events (including the Fukushima accident) include:

- to provide a state-of-the-art full-scope methodology for L1 and L2 external hazard PSA for all operating modes of the plant (full power, low power and shutdown operating modes). The methodology must take into account the simultaneous impact of the possible combinations of the external events;
- recommendations for external hazards PSA development, also with practical examples, on hazards screening and calculation, SSCs fragility data and safety goals on CDF and LERF;
- insights about international activities for assessing integrated site risk, extreme external events, and mitigation measures;
- information concerning the Human Reliability Analysis and multi-unit accident management;
- lessons related to human and organizational factors.

Most of the responses show that safety goals have not been modified after Fukushima accident. However, the current surrogate safety goals for nuclear power plant are defined for single units, and the efforts to establish a new set of quantitative safety goals for multi-unit sites should be acknowledged.

A large majority of respondents has considered that the implementation of the defence-in-depth concept should be reinforced after the Fukushima accident. A broader and deeper application of defence-in-depth concepts should be considered so as to cope better with the most severe challenges.

Some of the respondents feel that the current PSA techniques are suitable to assess real external hazards, but most of them have considered that HRA methodologies should be revised or replaced with some more realistic methodology, considering that especially for external hazards PSA, stress level and different conditions to perform the operator actions must be taken into account. HRA methodologies should be extended also, to cover complex situations originating from external hazards affecting multiple units.

Chapter 3 of the document deals with definition and scope of extended PSAs.

A majority of respondents have endorsed the proposed definition of an extended PSA. However, many of them have provided comments. Based on the comments and on the discussions during the Uppsala workshop, the following definition can be considered:

"An extended PSA (probabilistic safety assessment) applies to a site of one or several Nuclear Power Plant(s) (NPP(s)) and its environment. It intends to calculate the risk induced by the main sources of radioactivity (reactor core and spent fuel storages, other sources) on the site, taking into account all operating states for each main source and all possible relevant accident initiating events (both internal and external) affecting one NPP or the whole site."

A majority of respondents considers that the analysis of both risks for the environment/offsite population and risks for the plant (mainly the fuel and the containment) should be the primary goal of an extended PSA, and at least risks for the plant (Level 1 + Level 2) should be assessed. Ideally, risks for the environment and offsite population should also be addressed. If possible, and in order to obtain useful results in a reasonable time, this should not be done with a full-scope Level 3 PSA but with simplified models (for atmospheric/environmental dispersion and dose impact) applied to the release categories obtained in PSA Level 2.

About long-term management of a severe accident, one respondent feels that since risks are supposed to be assessed, a PSA should include this issue and include an assessment of releases that go well beyond any mission time that is considered for the analysis of accident progression.

Chapter 4 of the document discusses the uses and applications of extended PSAs.

Among all potential reasons for uses and applications of PSA, “Assessment of the overall level of safety” and “Identification of safety improvements to reduce overall risk” are the two that are most often chosen as being most important, whatever the demands come from laws, regulators, companies’ policies, wishes from internal experts or recommendations from external experts.

“Support periodic safety reviews” and “Comparison with safety criteria” are mainly demanded by laws and regulators, while “Support NPP design or design modifications”, “Identification of potential weaknesses in design and operation” and “Use of extended PSAs for optimizing NPP test and maintenance programs” are mainly demanded by companies’ policies and internal experts. “Assessment of off-site consequences of accidents” has also been mentioned.

There are no major differences between the uses claimed by the utilities, the TSOs, and the regulators, even if the regulators are more focused on risk-informed applications (“Risk-informed regulation” and “Use of extended PSAs to evaluate safety significance of events or non-conformities and for event importance ranking”).

The PSA is required by the regulators. While the initial development was mostly initiated on a voluntary basis, it was later on included in the regulatory framework of most countries that participated in the survey.

Half of the respondents would support the elaboration of a common set of safety objectives for Level 2 PSA (at least on a European level). The efforts to reach a common understanding of international consensus on appropriate risk criteria should be continued. For some respondents, common safety objectives/goals/targets (for both Level 1 and Level 2 PSA) are considered as a prerequisite to use results of PSA to judge properly about the safety of a specific NPP design.

A broad majority of organizations consider that it is important or very important to define a decision making process based on extended PSAs.

Comments also show that there is a strong expectation for a common understanding and definition of the terms of “core damage”, “large” / “early” releases.

A large majority of respondents believe that risk metrics should be defined for extended PSAs which should take into account:

- multi-unit site,
- spent fuel pool,
- evacuation of people near the site.

These risk metrics should also:

- be representative for the whole scope of an extended (comprehensive) PSA including all the attributes of PSA scope (radioactivity sources, types of initiating events, etc.),

- include an unambiguous definition of undesired consequences and measures of such consequences,
- allow to compare with the risk from other power producers.

There is general consensus that PSA results should be made available to the public.

Results presentation and, more generally, documentation are identified as very important for all PSAs, including extended PSAs.

Having commonly accepted risk targets/objectives (for both Level 1 and Level 2 PSA) is considered as useful for analysis of the PSA results.

The specific expectations/needs concerning results presentation for extended PSAs are:

- consistency of presentation for all events (internal events as well as internal and external hazards)),
- the analysis of the results should be done for the purpose of supporting the decisions motivating the PSA,
- proper guidance for aggregation of the risk from different hazards and/or different sources (reactor core, spent fuel pool, etc.) should be developed,
- results should include information considering: scope, limitations and uncertainties of each PSA, uncertainty analysis, sensibility analysis, importance factor for the major contributors to the risk measures.

The results and insights should be understandable to the PSA stakeholders. The model inputs and assumptions should be well documented and traceable.

Treatment of uncertainties is considered as very important for extended PSA. The main specific issue for extended PSA is consideration and treatment of uncertainties of extreme external events, as low probability events, consistency with treatment of uncertainties in other PSA and their minimization. A common issue with current PSA remains the treatment of model uncertainties.

Development of framework/guideline for interpretation of the results that include uncertainties is recommended.

Chapter 5 of the report deals with quality of extended PSA, i.e. the technical adequacy for the intended uses and applications.

A large majority thinks that a future PSA guideline should include specific guidance on quality of extended PSAs and assigns this task a high level of priority.

A majority also considers that the significant difference (depending on hazards) of level of quality/detail/realism is a real problem for extended PSAs, in particular for their uses and applications.

The following expectations related to future guidelines are expressed : "a way forward in improving PSA quality (especially for external events) is to develop specific and detailed methodology guidance in the major steps of external events PSA, including hazard assessment, plant response and fragility analysis and PSA model development in particular. Presently, such systematic guidance is available only for seismic PSA".

Chapter 6 of the document addresses technical needs for extended PSA development.

The *draft list of external hazards* proposed in the questionnaire is considered as a comprehensive input list for the screening process; the organization of the list could be improved by grouping some events according to a logical approach.

The project could focus on methodological developments for a short list of external hazards arising from end-users' needs. The ten most relevant external hazards for the respondents are the following:

- storm, strong wind,
- biological infestation,
- earthquake,
- aircraft crash,
- external flooding,
- lightning,
- snow packs,
- extreme air temperatures,
- external explosion,
- external fire.

Based on potential extension of PSAs in the future, the most frequently mentioned external hazards are the following:

- external flooding,
- extreme air temperatures,
- storm/high wind,
- aircraft crash.

Most of the respondents also consider that *the list of internal hazards* provided in the questionnaire is comprehensive; nevertheless, a few end-users point that it should be extended and include all internal hazards listed in IAEA Specific Safety Guide SSG-25 – Periodic Safety Review of NPPs.

For the screening process and criteria, some guidance which allows the screening of hazards does already exist. Majority of respondents are of opinion that present methods to perform screening analysis are not satisfactory, especially for external hazards. In particular, they do not satisfactorily address the following issues:

- combined event treatment,
- quantification of event frequencies for quantitative screening analysis,
- detailed rules for application of screening criteria as well as some practical examples,
- impact assessment of the different hazards.

Screening criteria used worldwide also present a large heterogeneity with a lack of technical justification.

It would be useful to provide a state of the art of existing methods, to complete existing screening methodologies on the missing points (see above), to define a common set of screening criteria with adequate technical justifications.

About *methodologies for internal hazard assessments*, most of the respondents consider that available methodologies are appropriate for PSAs. A few respondents are of the opinion that existing methodologies should be improved in order to achieve more realistic assessment of the hazard frequency and of the consequences of the hazard (mainly for fire and flooding); they also point out that no specific methodology exists for internal explosion, internal missiles nor for fragility curves construction for internal hazard. Although an important majority of respondents consider uncertainties related to the internal hazard's characterization in their PSA, some deficiencies are mentioned such as the lack of data to perform quantitative uncertainties analysis, the relevance of model or codes to propagate properly uncertainties. As a consequence, respondents perform limited uncertainty studies. There is a lack of commonly shared practices to consider uncertainties related to the characterization of internal hazards.

Concerning *methodologies for external hazard assessments*, although half of the respondents seems satisfied, a majority believes that existing methodologies are not satisfactory, except for seismic hazard assessment. The most important weaknesses and deficiencies in existing methodologies concern hazard frequencies determination, because it is difficult to assess very low hazard frequencies, with no or limited data.

A review of the existing methods concerning external hazard frequencies determination could be done. As scientific obstacles remain, it could also cover future research projects. Guidance on methodologies for external hazards assessment should include the use of mathematical models and practical examples of calculations and should be more detailed in the area of treatment of dependencies (hazard impact, loss of safety functions, SSC failures).

For a majority of respondents, uncertainties related to the characterization of external hazards are considered in their PSA. This is most often the case for seismic PSA as the treatment of uncertainties is included in the PSHA process. For other external hazards, some organizations indicate that the treatment of uncertainties cannot be considered complete due to the limitations in assessment methodologies and data. Expert judgements play a significant role and are associated to high uncertainties. The use of expert judgements could be improved by using more systematic methods. A state of practice and methods used should be provided; methodologies to characterise all uncertainties should be more detailed. The need is to better characterize the probability and associated uncertainties of rare but still credible events. Frequency ranges for the different external hazards considered in PSAs also have a large heterogeneity according to organizations. It could be interesting to try to harmonize frequency ranges and to evaluate different methods applying expert judgement.

For the majority of the respondents, *climate change* is not yet taken into account but it is found relevant for a number of hazards (extreme temperatures, droughts and flooding, sea level, wind and storms, lightning, tornadoes or more generally meteorological extremes).

A majority of respondents do not consider *combinations of external hazards* in their PSAs. Yet, almost all are willing to consider these combinations in the future. They underline the lack of a commonly shared methodology, even if the often cited SKI Report 2:27 is used. The main difficulties they mention are the following:

- selection and prioritization of the possible combinations,
- assessment of the probabilities for the selected combinations given the dependency between hazards,

- development of relevant integral PSA models (calculating SSCs fragility with respect to more than one single external hazard ...).

The project should provide a state of practice and methods to select critical combinations of external hazards and to assess associated probabilities and develop guidance on these issues.

There is no consensus about consideration or not of independent internal or external hazard(s) occurring during the progression of an accident (before core melt, during the short-term period after core melt or during the long-term period after core melt): this issue requires further investigations.

A large majority is of the opinion that it is necessary to analyse simultaneous accident progression in the core and in the spent fuel pool. The probabilistic methods need to be improved to address accurately the simultaneous progression of the accident in the core and in the spent fuel pool.

Concerning *general issues related to introduction of hazards in PSAs (common to L1 and L2)*, it has first been pointed out that appropriate failure mode and fragility analysis methodology would be necessary and useful for the complete range of hazard and the associated loads. Identification and quantification of correlated failures is also important.

A majority also believes that present methods for human reliability assessment are not suitable or should be improved for hazard conditions taking into account the following considerations:

- need to obtain a coherent HRA approach for all initiators (internal events, internal hazards, external hazards) and for both PSA Level 1 and Level 2,
- accessibility,
- multi-units aspects (e.g., because of their impact on organizational issues).

There is a majority of respondents which believes that for extended PSA mission times should be defined. However, a significant minority has the opposite opinion. The definition of stable plant end states to consider in extended PSAs as well as appropriate mission times should be assessed by the project.

Seasonal variations should be considered in extended PSAs (at least for some applications).

A majority believes that a specific approach should be developed in extended PSAs for multi-unit sites.

With regard to introduction of hazards in extended L1 PSAs, the ASAMPSA_E project intends to address the characterization of internal events generated by external hazards or hazard combinations and to develop guidance including the following items:

- determination of the status of the equipment depending on the amplitude (frequency content) and the duration of the external event (e.g., fragility curve – structure analysis for fixed SSCs and malfunction of active SSCs),
- consequences from a failing SSC on other SSCs (related to the classification of the equipment),
- characterization of the transient, depending on the amplitude of the external hazard,
- short-term and long-term effects,
- HRA,

- integration of hazard analysis,
- fragility or failure probability of SSCs,
- system function analysis,
- completeness of L1 PSA,
- uncertainty analysis.

A majority of respondents believes that the list presented in the questionnaire covers all relevant issues related to introduction of external hazards in extended L1 PSA. However, the following additional items have been suggested:

- multi-unit effects,
- consideration of both core and SFP affected,
- deployment of new equipment/systems,
- external events-induced fires and floods,
- quality of PSAs,
- safety goals (e.g., determining an acceptable external hazard CDF value, in order to perform the decision making process),
- multiple hazard-induced initiating events,
- modelling the dependencies among SSCs failure behaviour in case of a given hazard,
- compilation of hazard equipment lists and walk downs,
- risk profile,
- importance analysis,
- hazard and induced initiating events characterisation,
- mission time to be considered for SFP damage,
- characterization of the safety systems' behaviour, depending on the amplitude of the external hazard,
- frequency and parameter of hazards estimation.

Concerning issues related to L2 PSAs, a majority believes that internal or external hazards will not lead to relevant accident sequences which are significantly deviating from the traditionally analysed sequences and that present analysis methods (deterministic and probabilistic) are appropriate. However, some respondents provided examples where deviation from the "traditional" accident progression might be observed: long duration, simultaneous events in core and spent fuel pool, different evolutions in the three Fukushima reactors, containment structure failure, control room destruction and combinations of challenges which were not considered before. They also mention the need of extension in terms of integrating e.g. multi-unit and spent fuel pool cases and the need of improvements regarding the additional calculation of new accident sequences (concerning e.g. the spent fuel pool or multi-unit cases). On the other hand, a majority believes that extended Level 2 PSA will identify relevant release categories and / or source terms which are beyond or different of what is known from traditional L2 PSA (e.g., in terms of frequency and / or characteristics).

A majority finds it reasonable to integrate the effect of internal hazards induced by external hazards in extended L2 PSAs.

A significant majority considers that the further evolution of the external and/or internal hazard in the plant(s) and on site during the severe accident could influence its progression (for instance, after core damage has occurred, the progression of an internal fire might continue or earthquake aftershocks could occur, resulting in further malfunction of equipment necessary for severe accident management). However, respondents also emphasize the increase in complexity of taking into account such scenarios; procedures like screening could be considered to reduce the necessary computational effort.

Existing methodologies and tools for accident progression analysis (e.g. integral codes like MAAP, MELCOR or ASTEC) are considered suitable to perform support studies for extended Level 2 PSAs. Nevertheless possible shortcomings in terms of complex cases like SFP, HRA, Dynamic Event Tree have been mentioned. In particular, optimisation of the codes for SFP analysis could be identified as an open topic.

Finally, the majority of participants approves the idea of addressing the long-term management of radioactivity; however the complexity of the task has been mentioned as well as the indistinct definition of the duration of “long term” management.

In Chapter 7 of the document, the outcomes and recommendations of the End-Users Uppsala workshop are presented.

Recommendations issued at the Uppsala workshop are presented below. They reflect:

- end-Users survey responses,
- discussions during the workshop.

They have been reviewed by the workshop participants who have also defined a priority level based on the following scale:

- Type A: most important end-users needs (for which the project should produce adequate guidance),
- Type B: intermediate needs (which the project will address if possible),
- Type C: less important needs (not to be addressed by the project).

Recommendations related to general considerations on extended PSAs:

1. ASAMPSA_E shall examine which type of cost/time analysis is acceptable to limit resources needed for external/internal hazards PSAs (type A).
2. ASAMPSA_E shall address risk monitoring and training applications of extended PSA (type C).
3. ASAMPSA_E shall address PSA communication towards public (type C).
4. ASAMPSA_E shall at least address the 10 most important external hazards for the End-users (type A):
    - Earthquake,
    - Flooding,
    - extreme air temperatures,
    - snow pack,

- lightning,
- storm (tornadoes, hurricane, …),
- biological infestation,
- aircraft crash,
- external fire,
- external explosion.

ASAMPSA_E shall consider also:

- internal fires, floods and explosions,
- heavy load drops, high energy line break (HELB), missiles, chemical releases;
- other extreme weather conditions,
- transport of dangerous substances, accidents in facilities located in the vicinity of NPP,
- releases into the waters and ground.

ASAMPSA_E shall also examine the interest of integrated (all hazards and IE) or separated PSA model.

5. Some End-Users have expressed interest on best practices to model ageing in PSA. The End-Users workshop participants have considered that it is not feasible to handle this difficult topic in the framework of ASAMPSA_E (type C).
6. ASAMPSA_E shall consider a modification of the definition of extended PSA based on End-Users remarks: "An extended PSA (probabilistic safety assessment) applies to a site of one or several Nuclear Power Plant(s) (NPP(s)) and its environment. It intends to calculate the risk induced by the main sources of radioactivity (reactor core and spent fuel storages, other sources) on the site, taking into account all operating states for each main source and all possible relevant accident initiating events (both internal and external) affecting one NPP or the whole site."
7. ASAMPSA_E shall provide practices and methods to model the combinations/correlations/dependencies of hazards (in terms of both occurrence and impact on SSCs) (type A).
8. Concerning the combinations/correlations/dependencies of hazards, some different rules can be provided depending on the time frame (for example, addition of independent hazards may be considered for long lasting accident) (type B/C).
9. ASAMPSA_E shall address methodology for simultaneous accident progression in core and SFP (type A).
10. ASAMPSA_E shall group the list of hazards to develop its guidance (type A).
11. ASAMPSA_E shall discuss the level of conservatism (same level in all PSA parts …?) (type A).
12. ASAMPSA_E shall provide guidance on the place of extended PSA in risk informed approach and decision-making (type B).
13. Concerning result presentation (type A) :
    - Risk aggregation guidance will be useful,
    - Results shall be understandable,
    - Risk targets are useful but not essential,
    - Treatment of uncertainties is essential (for external hazards, low probability events with high uncertainties),

- Need for guidance for results interpretation and use.

Introduction of uncertainties in L1 PSA may be crucial (?)

14. ASAMPSA_E shall address specific guidance on quality of extended PSAs (type B).

    Associated to quality, the <u>necessity to be aware of risks</u> should be clearly emphasized in the application of extended PSAs: this is the main product of PSAs (extended) and must be associated to communication, training of operators, decision-making on plant safety.

    PSA "capability" concept (closely associated with PSA application) may be used instead of quality.

    (ASAMPSA_E shall examine the methodologies (to perform PSA) to be applied depending on the PSA application (see also IAEA standards, US-NRC regulatory guides)).

15. ASAMPSA_E shall examine how to include mobile equipment in PSA (type A).
16. ASAMPSA_A shall clarify the vocabulary on "mission time", "scan time". "Mission time" for NPP may be the time needed until stable state conditions are reached. "Mission time of each equipment" can be different (type A).

    ASAMPSA_E shall examine what does it means for L1PSA, L2PSA and provide guidance to model long lasting accident.

17. ASAMPSA_E shall develop a glossary, common for all PSAs (type A).
18. ASAMPSA_E shall precise how and when "seasonal PSA (winter/summer)" must be developed. An example could be useful (type A).

Recommendations related to hazards screening and modelling

19. According to the End-Users survey, existing screening guidance have to be adapted or completed for each application. ASAMPSA_E shall examine why and how to do this adaptation/complement (type A).

    ASAMPSA_E shall examine how to reduce heterogeneity in quantitative screening criteria (collect and examine the screening values).

    ASAMPSA_E shall examine which hazards must not be screened out and why.

    ASAMPSA_E shall comment how far the impact of the hazards must be considered in the screening out process (in case of cliff edge effect, no screening out ...?).

20. ASAMPSA_E shall examine the relevance of conditional core melt probabilities and conditional containment failure probabilities (and conditional LER probability) in the screening criteria (type A).
21. ASAMPSA_E shall examine PSA practices for modelling induced internal floods and internal fires (type A).
22. ASAMPSA_E shall examine SFP accident screening practices (type A).
23. ASAMPSA_E shall discuss the link between screening criteria and design basis conditions (type A):
    - PSA should focus on area that are not in the design basis – example : specific combinations like hazards + induced effects,
    - PSA should include hazards in the design basis (useful for PSR for example).
24. ASAMPSA_E shall discuss the sum of hazards frequencies (final comparison with numerical safety target) (type B).

25. ASAMPSA_E shall examine what to do if the sciences cannot provide information for low frequencies events or extremely high uncertainties on their amplitude (type A).
26. Deficiencies on internal hazards modelling shall be covered in ASAMPSA_E (type A):
    - More realistic assessment of the hazard frequency or consequences have to be developed for internal fire and flooding assessment
    - No specific methodologies exist for internal explosion, missiles or quantification of internal hazards due to inappropriate human actions
    - The methods for hazard curves and fragility curve constructions are not described.
27. In ASAMPSA_E project, uncertainties assessment methodology for internal hazards shall be compared and good practices identified (type A). Is the fragility curves approach always relevant (example: spurious signal in case of fire)?
28. In ASAMPSA_E, existing methods for external hazards modelling shall be presented and compared including uncertainties (type A).
29. ASAMPSA_E shall examine how experts' judgement shall be used for external hazards characterisation and how uncertainties can be considered (type B).
30. ASAMPSA_E shall introduce the effects of climate changes and present available methodologies. Need for updating PSA (type A).
31. ASAMPSA_E shall examine the role of statistical analysis method (e.g. EVT) based on observation in comparison with approaches trying to identify which combination of factors can lead to the worst meteorological events (not observed) (type A).
32. ASAMPSA_E shall examine how PSAs can introduce information coming from meteorological modelling. Example: variations from past worst cases? (type A)
33. ASAMPSA_E shall provide information on activities performed to assess catalogue completeness and reliability, on how to assess the maximum possible earthquake (Mmax), identify, analyse and assess (potentially) active faults relevant to the safety of the site …(type A).
34. In a region with low seismicity like Sweden, an earthquake M 8 is "possible" (and observed in paleo history) with a return period 1 million years … ASAMPSA_E shall examine how can such information be presented in a PSA (type A).
35. ASAMPSA_E shall insist on the need to update periodically the design-basis hazards curve (type A).

Recommendations related to introduction of hazards in L1 PSAs

36. ASAMPSA_E shall identify some best practices for external hazards SCC fragility analysis
    - At which temperature an electronic device fails,
    - Shaking tables for active equipment …,
    - Fragility curves database

    ASAMPSA_E shall share opinion on available information related to fragility of equipment (database ….). Emergency diesels are so important that related methodologies / data should be specifically analysed in ASAMPSA_E (type A).

37. ASAMPSA_E shall examine (on examples) the importance of non-safety systems robustness/behaviour/positive vs negative impact in case of external hazards on final CDF/RF (example, in extreme cold temperature conditions, ventilation can accelerate pipe freezing if not stopped) (type A).
38. For seismic PSA, ASAMPSA_E shall examine the interest of advanced PSA methodologies using “earthquake signal” (temporal ground motion parameters) impacts on SSCs and interest in comparison with “classical” methodologies (PGA …) (type A).
39. Seismic PSA may be based on the use of generic fragility curves for components … How can the PSA End-Users justify their use? ASAMPSA_E guidance shall comment this issue from partner experience (type A).
40. SFP specific issues for earthquake to be considered in ASAMPSA_E (type A):
    - Fragilities of the pools, racks.
    - Sloshing of the pool water (one combination of hazards, what are the consequences for accident progression? See TEPCO presentation during End-Users workshop in Uppsala),
    - Loss of cooling.
41. The following topic shall be discussed in ASAMPSA_E (guidance needed): induced internal hazards are potential source of conservatism (if included), of non-conservatism (if not included) (type A).
42. For flooding (type A):
    - ASAMPSA_E shall compare some applications for flooding assessment in EU stress-tests before developing guidance,
    - fragility of equipment may be easily presented (failure in case of room flooding) (according to some experts in Uppsala workshop),
    - ASAMPSA_E shall present methodology to address long term flood
    - The uncertainties may be higher for natural than for man-made hazards (according to some experts in Uppsala workshop).
43. ASAMPSA_E shall develop guidance to assess frequencies of LHS events (how to arrive from an external hazard to an IE?) (type B).
44. ASAMPSA_E shall develop guidance to calculate frequencies of LOOP and recovery time (these frequencies shall be updated with grid modernization). How to consider the recovery time of grid? (type B).

Recommendations related to introduction of hazards in L2 PSAs

45. ASAMPSA_E shall identify issues associated to external hazards that may need significantly differences in comparison with L2PSA methodologies for internal IE (type A), e.g.:
    - Induced effects (internal hazards) by external hazards,
    - Earthquake aftershocks,
    - External hazards impact on containment function …
46. For ASAMPSA_E guidance on L2 PSA (type A) :
    - Extended L2PSA shall include long term management of radioactivity in the containment and release in environment.
    - ASAMPSA_E shall consider in long term strategies both in-vessel retention and ex-vessel retention

47. ASAMPSA_E shall examine existing containment venting strategies optimization versus L2PSA results (status today: different strategies, depending on NPPs – is it consistent with L2PSA results?) (type A).
48. ASAMPSA_E shall examine SAMG sufficiency, especially for shutdown state (SAMG needed to develop event trees …) (type B).
49. For shutdown states of reactor, ASAMPSA_E shall propose guidance for open RCV or RCS situations: FP release (effect of air ingress), thermal radiation effect on the containment integrity (open RCV case, heat load) (type A).
50. ASAMPSA_E shall examine how can be calculated the conditional probability of SFP fuel degradation after core melt (depending on common system core/SFP, on location of SFP – inside vs outside containment). ASAMPSA_E shall examine how far, in case of SFP fuel degradation (inside a containment), the containment function can survive (depending on pressurisation, hydrogen production, thermal radiation load …). ASAMPSA_E will need to map the NPP configurations of reactor core versus SFP (independence) (type A).

Recommendations related to common issues for multi-units PSA (for external hazards)

51. ASAMPSA_E shall clearly identify deficiencies of single units PSA and promote development of multi units PSA (type A).
52. ASAMPSA_E shall examine if a new set of risk metrics for multi-units is necessary (type B).
53. ASAMPSA_E shall consider experience of countries like Canada having already developed multi-units PSA (type B).
54. ASAMPSA_E shall in particular examine HRA modelling demand for multi-unit PSA (e.g. team sufficiency if shared between units, site management complexity, equipment restoration possibilities, inter-reactor positive or negative effects …) (type A).
55. For comments in ASAMPSA_E guidance (type C):
    - Earthquake can affect multi-units. The ground motion is correlated but can be different for each reactor (this is an issue examined in Japan).
    - True for other external hazards.

Recommendations related to common issues for HRA modelling (for all external hazards)

56. ASAMPSA_E shall examine how to improve HRA modelling for external hazards conditions to tackle the following issues (type A):
    - The high stress of NPP staffs,
    - The number of tasks to be done by the NPP staffs,
    - The impossibility, for rare events, to generate experience or training for operators actions (no observation of success/failure probability, e.g. simulator),
    - The possible lack of written operating procedures (or non-precise procedures),
    - The possible wrong information in the MCR or maybe the destruction of the MCR,
    - The methodologies applicable to model mobile barrier installation (for slow developing event),

- The methodologies available to model use of mobile equipment (pumps, DGs) and conditional failure probability (human and equipment),
- The methodologies applicable to model equipment restoration (long term accident sequences, specific case of multi-units accidents …).

57. Methodologies to develop modelling of "warning" for slowly developing external events (type A).
58. ASAMPSA_E may organize a workshop with HRA specialists (type C).
59. ASAMPSA_E guidance may address error of commission (type B/C).

Recommendations related to specific issues of interest from experience of past real events

60. ASAMPSA_E guidance shall explain how to introduce in L1-L2PSA a more diverse modelling of internal and external electrical disturbances. The Forsmark NPP experience presented during the ASAMPSA_E End-Users workshop in Uppsala shall be considered as a starting point (include in PSA voltage surge on plant grid (e.g. lightning)) (type A).
61. ASAMPSA_E guidance shall precise methodologies available to quantify the frequency of loss of heat sink due to natural hazards (e.g. clogging effect). An additional question that can be addressed is criteria (from PSA perspective) from which a design change can be needed? The Cruas NPP example provided by EDF (loss of heat sink) during the ASAMPSA_E End-Users workshop in Uppsala shall be considered as a starting point (type A).
62. From Le Blayais NPP example, ASAMPSA_E shall precise for external flooding PSA that :
    - Conditional CDF can be calculated depending on event flooding amplitude,
    - Initiating flooding event (amplitude, frequency) can be modelled separately.

    This can be a starting point for some ASAMPSA_E guidance on external flooding (type A).

CONTENT

GLOSSARY

COG	CANDU owner's group
EPZ	Emergency planning zone
FMEA	Failure mode and effects analysis
FMECA	Failure mode, effects, and criticality analysis
HCLPF	High Confidence, Low Probability of Failure
HEP	Human error probability
HRA	Human reliability analysis
IE	Initiating event
INPO	Institute of nuclear power operation
LPSD	Low power and shut down
LUHS	Loss of ultimate heat sink
PSR	Periodic safety review
SBO	Station black out
SD	Shut down
SFP	Spent fuel pool
TSO	Technical support organization
WANO	World Association of Nuclear Operators

1 INTRODUCTION

1.1 PRESENTATION OF THE ASAMPSA_E PROJECT

Initiated after the Fukushima nuclear accident, the ASAMPSA_E project aims at identifying good practices for the development of extended PSAs that include low-probability internal and external hazards which can lead to extreme consequences, and at discussing the application of extended PSAs for NPP safety enhancement decision making in the European context (see **www.asampsa.eu** for more details on this project).

Extended PSAs intend to calculate the risks induced by the main sources of radioactivity (reactor cores and spent fuel storages) on a NPP site, taking into account all operating states and all possible accident initiating events affecting one NPP or the whole site.

1.2 BACKGROUND

A previous EURATOM FP7 project named ASAMPSA2 has developed best-practice guidelines for L2 PSA developments and applications in relation with knowledge gained from research activities (cf. http://www.asampsa2.eu/ and [2]). This project ended in December 2012.

According to the practice in most countries, shutdown states, spent fuel pools and external and internal hazards did not receive much attention in PSAs. Moreover, lessons learnt from the Fukushima accident could not be taken into account in ASAMPSA2.

The ASAMPSA2 guidelines were discussed in March 2011 during a final workshop (Helsinki) with the End-Users and scientific community (in particular from SARNET) who recognized the quality of this document and suggested some possible improvements and follow-up activities ([1]). Those which are interesting for the ASAMPSA_E project are summarized hereafter.

Topic 1 - Link between objectives of a PSA resolution of technical issues

According to the End-Users, a strong link should be addressed in the guidelines between the definition of the top level objectives of a PSA (i.e. its intended uses and applications) and the choice of methods and tools to execute the different tasks and solve the identified issues.

This expectation should also be considered for the elaboration of ASAMPSA_E guidance.

Topic 2 - Extension of L2 PSA guidance for shutdown reactor states and external events

An extension of the existing ASAMPSA2 guidelines for shutdown states has been recognized as a topic of interest but the major point for guidance improvement was the extension to external hazards. In particular the significant contribution of external hazards to the global risk was discussed during the final ASAMPSA2 workshop.

This topic is part of the objectives of the ASAMPSA_E project.

Topic 3 - Risk metrics and safety objectives

The elaboration of L2 PSA risk metrics that could be applied commonly for all European plants and that could be understood easily by "non L2 PSA experts" has been seen as an additional possibility for harmonization at European level. The issue of safety objectives has also been identified as a topic of interest for possible future developments.

Both topics are included in the ASAMPSA_E activities.

Topic 4 - Plant Safety: link between severe accident management options and L2 PSA results

Different severe accident management strategies have been implemented on some NPPs, even if the initial plant design is similar. International comparison between the different approaches should help experts understanding the origin of differences and to contribute to the reinforcement of some options. L2 PSA can be an efficient tool to support such a comparison. Sharing experience, at European level, based on L2 PSA outcomes, can be an efficient way to discuss the efficiency of the different possible severe accident management strategies.

This topic is included in ASAMPSA_E.

1.3 OBJECTIVES OF THE DOCUMENT

A first questionnaire related to End-Users needs which should be taken into account within the ASAMPSA_E project has been disseminated at international level to PSA End-Users in November 2013 ([3]). It addressed the following topics:

- Lessons learnt from past real events/hazards for PSA developments
- Definition and scope of extended PSAs
- Uses and applications of extended PSAs
- Quality of extended PSAs
- Technical needs : initiating events; introduction of hazards in PSAs

The objective of the present document is to present the results of the analysis of the responses to the questionnaire in order to specify the needs for guidance for the performance and application of extended PSA.

A preliminary version of this document has been presented and discussed during an international workshop organized on 26, 27 and 28 May 2014 in Uppsala (Sweden).

This report presents the analysis of the responses received from End-Users and incorporates the outcomes from the Uppsala workshop.

1.4 INFORMATION ABOUT RESPONDENTS

1.4.1 LIST OF RESPONDENTS

The list of the 34 organizations, who have answered the questionnaire, is presented in the following table.

	Organization	Country
1	Areva	France / Germany
2	Bel V	Belgium
3	Cazzoli Consulting	Switzerland
4	CNSC	Canada
5	CSN	Spain
6	EDF	France
7	ENEL	Italy
8	FKA	Sweden
9	Fortum	Finland
10	GRS	Germany
11	IEC (IBERDROLA)	Spain
12	INR	Romania
13	INRNE	Bulgaria
14	IRSN	France
15	Jansi	Japan
16	JSI	Slovenia
17	KAERI	Korea
18	Kozloduy NPP	Bulgaria
19	MVM Paks II	Hungary
20	NRC	USA
21	NRG	The Netherlands
22	NRSC	Armenia
23	NUBIKI	Hungary
24	RELKO Ltd	Slovakia
25	Ringhals	Sweden
26	Risk Pilot AB	Finland
27	RNPP	Ukraine
28	SNSA	Slovenia
29	SNSI (VATESI)	Lithuania
30	Tractebel Engineering	Belgium
31	TUS	Bulgaria
32	UJV	Czech Republic
33	VUJE	Slovakia
34	ZP NPP	Ukraine

Table 1 - List of respondents

All have answered to most of the questions of the survey. Moreover, many comments have been provided.

1.4.2 ROLES AND ACTIVITIES OF RESPONDENTS

The roles of the respondents are the following:

- TSOs: 19 organizations (56%), including TSOs for regulators, TSOs for utilities, service providers and research organizations;
- Utilities: 9 organizations (26%);
- Regulators: 5 organizations (15%);
- Vendors: 1 organization (3%).

Most regulators are PSA reviewers and/or end-users. Only one organization (US NRC) is also PSA developer / practitioner.

Almost all TSOs have an activity of PSA developers/practitioners (18/19); 13 mentioned that they have an activity of PSA reviewers and 7 mentioned that they are also end-users.

According to the answers to question Q1) of the survey, the overall activities of respondents split as follows (some respondents have multiple activities):

- 24 PSA developers/practitioners (i.e. 70% of respondents have an activity of developer/practitioner);
- 19 PSA reviewers (i.e. 56% of respondents have an activity of PSA reviewer);
- 18 PSA end-users (i.e. 53% of respondents have an activity of PSA end-user).

1.4.3 PSAS DEVELOPED BY RESPONDENTS

Among the 24 organizations who are PSA developers/practitioners:

- all have developed internal event L1 PSAs;
- 21 have developed internal events L2 PSAs;
- 4 have developed internal events L3 PSAs.

Three other organizations mentioned that they have partially developed internal event L3 PSAs or that these activities are in progress.

Concerning internal hazard PSAs, the answers received from the 24 organizations that have an activity of PSA developers/practitioners, show that:

- 23 have developed internal hazard L1 PSAs;
- 17 have developed internal hazard L2 PSAs;
- 4 have developed internal hazard L3 PSAs.

Two organizations mentioned that they have developed full scope internal hazard PSAs. The main internal hazards addressed in internal hazard PSAs by the other respondents are the following (including ongoing activities):

- internal fire (18 answers for L1 PSAs; 12 for L2; 1 for L3);
- internal flooding (15 answers for L1; 10 for L2; 1 for L3);
- load drop (3 answers for L1; 2 for L2; 1 for L3);
- explosion (2 answers for L1; none for L2; 1 for L3);
- turbine missiles (1 answer for L1; 1 for L2);
- high energy line break (1 answer for L1; 1 for L2; 1 for L3);
- releases of toxic substances (1 answer for L1; 1 for L2; 1 for L3).

Concerning external hazard PSAs, the answers sent by the 24 organizations that have an activity of PSA developers/practitioners show that:

- 22 have developed external hazard L1 PSAs;
- 12 have developed external hazard L2 PSAs;
- 4 have developed external hazard L3 PSAs.

One organization mentioned that they have developed a full scope external hazard PSAs. Other answers indicated that some organizations have developed full scope excluding earthquake external hazard PSAs (3 for L1, 2 for L2 and 1 for L3). The main external hazards addressed in external hazard PSAs by the other respondents are the following (including ongoing activities):

- earthquake (13 answers for L1 PSAs; 8 for L2; 1 for L3);
- meteorological events (6 answers for L1; 3 for L2; 1 for L3);
- aircraft crash (4 answers for L1; 2 for L2);
- external flooding (3 answers for L1; 1 for L2; 1 for L3);
- man-made hazards, impact of the neighbouring industry or transportation (3 answers for L1; 3 for L2);
- electromagnetic hazard (1 answer for L1; 1 for L2);
- explosion, pressure waves (1 answer for L1);
- dust storm (1 answer for L1);
- terrorist attack (1 answer for L2).

1.4.4 GEOGRAPHICAL DISTRIBUTION

The geographical distribution of respondents is the following: Armenia, Belgium (2 organizations), Bulgaria (3 organizations), Canada, Czech Republic, Finland (2 organizations), France (3 organizations), Germany (2 organizations), Hungary (2 organizations), Italy, Japan, Korea, Lithuania, Romania, Slovakia (2 organizations), Slovenia (2 organizations), Spain (2 organizations), Sweden (2 organizations), Switzerland, The Netherlands, Ukraine (2 organizations), USA.

From this distribution, one can state that the answers to the survey come from:

- 17 different countries of the European zone (including 15 countries of the European Union);
- 2 countries in North America;
- 2 countries in the Asian zone.

There is a maximum of 3 organizations from the same country.

However, some of the respondents have worldwide activities (especially some TSOs and service providers).

1.5 METHODOLOGICAL ASPECTS

Based on the number of respondents, their roles and activities and their geographical distribution, it is justified to consider that a good representativeness of all potential PSAs End-Users has been achieved.

The different topics addressed in the survey are considered in the same order in the following sections. For each question, the following aspects have been assessed:

- distribution of the responses, and, if relevant, analysis based on the profile of the respondents (e.g. authority, TSO, utility),
- presentation of the tendency of the majority of the respondents,
- presentation of the most significant/recurrent/interesting comments,
- Interpretation in terms of end-users practices and needs.

2 LESSONS LEARNT FROM PAST REAL EVENTS/HAZARDS FOR PSA DEVELOPMENTS

2.1 LESSONS LEARNT FROM PAST REAL EVENTS/HAZARDS (OTHER THAN FUKUSHIMA) FOR PSA DEVELOPMENTS

This section aims at collecting information about lessons learnt from internal or external hazards which have already concerned NPPs in operation in Europe or in other countries and their impact for PSA developments.

IAEA states in [6] that: "*3.16. The process of safety assessment for facilities and activities is repeated in whole or in part as necessary later in the conduct of operations in order to take into account changed circumstances (such as the application of new standards or scientific and technological developments),* ***the feedback of operating experience****,[…]*

3.17. Despite all measures taken, accidents may occur. The precursors to accidents have to be identified and analysed, and measures have to be taken to prevent the recurrence of accidents. ***The feedback of operating experience from facilities and activities — and, where relevant, from elsewhere — is a key means of enhancing safety****. Processes must be put in place for the feedback and analysis of operating experience, including initiating events, accident precursors, near misses, accidents and unauthorized acts, so that lessons may be learned, shared and acted upon*" (Principle 3 related to leadership and management for safety).

Q3) A - Do you consider that application of the IAEA Safety Principle 3 influences the PSAs developed in your country?
If yes, what types of events have been reconsidered?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	27	4	3
INDUSTRY (utilities +vendor)	11	-	-
TSO	13	3	2
REGULATORS	3	1	1

Table 2 – Question Q3) A - Distribution of answers

31 of responses were given, and the general consensus (27 responses) was that there is an indubitable influence of the operating experience on the PSA studies. All the utilities responses sustain the awareness of this influence. More than 2/3 of the TSO organizations share this opinion, as well as 60% of the respondent regulators.
It is mentioned in the responses that whenever necessary, PSA studies are updated based on operating experience feedback. IAEA Periodic Safety Reviews for NPP, SSG-25 (2013) and some national PSA guidelines were mentioned

to be applied in the process. The extension of PSA scope has been made in agreement with the IAEA Safety Principles, as well as with the national nuclear safety regulations.

Mainly, the operating experience is used to ensure the completeness of the spectrum of initiating events, but the use for assessment of the initiating event frequencies, reliability data (both for equipment and human failure), common cause events and failure modes are mentioned also.

Hungary has the same answers for utility (Paks NPP) and TSO (NUBIKI).

A wide range of types of events that have been reconsidered following the feedback from operating experience was specified. A general reference was made that external hazards were reconsidered, but sometimes more specific examples of the reconsidered events were given, as follows:

- LOOP/Station black-out (NRG)
- seismic events (NRG, RNPP, IEC)
- success of in-vessel retention of corium (Fortum)
- fires, external flooding (dam failures) (IEC, SNSA)
- common cause failure on safety-related electrical bus bars (IRSN)
- events initiated during shutdown operating modes (INR)
- aircraft crash (SNSA)
- internal and external hazards for spent fuel pool (ZP NPP)

Areva has given a comprehensive answer, referring to the advanced reactors case also:

Those events from the operating experience identified as relevant for the PSA are considered for the assessment of the IE frequencies. Types of events considered are mainly transients during plant operation (e.g. Loss of Main heat sink, Reactor / Turbine Trip). For external events analysis of German NPP, the spectrum of events includes the following: high water level, airplane crash, explosion pressure wave, earthquake, extreme weather conditions such as extreme temperatures, storm , snow and ice, lightning, external fire and ship collision with the water intake structure; the spectrum is analysed for its relevance to the site.

To develop EPR PSA, the operating feedback on French fleet was used, for completeness of the initiating events list and for the assessment of the initiating event frequencies and reliability data.

Q4) A – Do events concerning a NPP located in your country influence the PSA of other plants (also located in your country)?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	25	6	3
INDUSTRY (utilities +vendor)	8	3	-
TSO	14	2	2
REGULATORS	3	1	1

Table 3 – Question Q4) A - Distribution of answers

Most of the respondents have considered that events that occurred at one NPP, have influenced the PSA of other plants located in the country (25 responses from 31). The positive answers represent the opinions of almost 2/3 of the industry, more than 2/3 of the TSO and 60% of the regulators.

Negative answers were given by almost 27% of the industry, 11% of the TSO and 20% of the regulators.

If the question would have had a N/A option for the responses, a clearer picture would have been obtained, by differentiating the cases where there is only one plant in the country (as Slovenia) from those when no influence has been observed.

Hungary has the same answers for utility (Paks NPP) and TSO (NUBIKI). France has the same answers for utility (EDF) and vendor (AREVA).

A special situation should be mentioned, in case of Nordic countries, for which components failure data are evaluated for all Nordic BWRs. Another example of influence was referring to seismic basis re-evaluated in Kozloduy NPP, following the earthquake occurred near Belene site.

Also, even if there is only one plant, it was specified that Cernavoda NPP has a feedback program to assess and implement the design modifications and improvements from Unit 2 to Unit 1, in order to maintain an equivalent level of nuclear safety within the units.

B- Do events concerning a NPP located outside your country influence the PSA of the plants located in your country?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	26	5	3
INDUSTRY (utilities +vendor)	9	2	-
TSO	13	3	2
REGULATORS	4	-	1

Table 4 – Question Q4) B - Distribution of answers

Most of the respondents consider that the PSA is influenced by events occurred at a NPP located outside of their country (26 respondents from 31).

Negative answers were received from approximately 18% of the utilities, and 16% of the TSO.

The positive answers were given by more than 80% of utilities, more than 70% of TSO, and 80% of regulators.

As supporting examples of this influence, the following could be mentioned:

- according to German PSA guidelines, PSA updated for a PSR have to use the state-of-the-art, which implies a consideration of the national and international operating experience (GRS);

- components failure data are evaluated for all Nordic BWRs. Fire frequencies; CCF-data are evaluated within the Nordic PSA collaboration, including German CCF-data also (FKA);
- for EPR PSAs, the events occurring in NPPs of similar design are reviewed to identify the relevant initiating events (Areva);
- the re-evaluated seismic basis in Kozloduy NPP, following the earthquake in the Vrancea seismic zone in 1977 has to be taken into account for PSA of Belene NPP, if the construction of the plant will continue (Kozloduy NPP).

Korea has given a partial positive answer, since most PSAs are performed in a plant-specific way; when reliability data are not available or very rare, the generic data from NUREG-6850 is used, with Bayesian updating. (KAERI)

Information obtained from operational experience, which include events concerning others NPP's, might be used for multiple purposes, such as:

- assessment of necessity for updating the safety analyses (deterministic and probabilistic);
- improving the plant design;
- input for Ageing Management Program;
- improving the operating practices and plant staff training programs.

An interesting opinion was mentioned, that unless the local authority enforces a quick action following a known event that occurred in other foreign plants, it may take some time before the incorporation of the information in the PSAs.

C - If yes, how are obtained information about these events?

According to respondents, the information about events that may be incorporated in analyses is normally obtained through information exchange facilitated by international organizations: IAEA, OECD NEA, ENSREG, WENRA, WANO, COG, INPO. More specifically, there have been made references to IAEA's IRS system, NRC's information notices, topical OEF Reports (issued by IAEA, OECD-NEA WGOE, EU Clearinghouse), OECD NEA working groups (OPDE, ICDE, FIRE), cooperation projects.

The use of international databases providing reactor year of operation such as PRIS of IAEA to assess for instance the large break LOCA frequency, EPRI pipe rupture frequencies (internal flooding), SQUG database (earthquake) was specified also. (EDF)

For Cernavoda NPP, the procedure "External Operating Experience Feedback" is in place, for screening the applicability of the information provided by external organizations like COG, WANO, INPO and IRS. In case of major events (e.g. WANO Significant Operating Experience Reports/Significant Event Reports, events level 2 or higher on INES scale), an Abnormal Condition Report is issued, and the analysis is performed using a gap analysis template. (INR)

In some responses, besides the sources of information that could be used, it is also specified that the respondents are sharing their information, for instance:

- nordic countries represent a specific case, because they are sharing components failure data (evaluated for all Nordic BWRs). Fire event frequencies, CCF-data are evaluated within the Nordic PSA collaboration, including also German CCF-data. (FKA)

- canadian nuclear regulator and licensees regularly review OPEX from different sources, such as IAEA Incident Reporting System, WANO Event Report Program (WER), as well USNRC License Event Report (LER). Significant operating experience and events are also shared within CANDU Owner's group (COG). (CNSC)
- for events at NPPs located in the U.S., NRC collects such information through its operating experience program. U.S. licensees share such information through the Institute of Nuclear Power Operations (INPO). For events at NPPs outside the U.S., information might be obtained by information exchange or with the use of national databases, including operating experience shared by the World Association of Nuclear Operators (WANO). (NRC)

An interesting opinion was mentioned, concerning the fact that in most cases, the information is confidential, and therefore some events may not be widely accessible.

Q5) For high amplitude natural or man-made external hazards that already concerned NPPs in your country,

A - Have detailed risk analysis been performed?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	26	6	2
INDUSTRY (utilities +vendor)	9	2	-
TSO	13	4	1
REGULATORS	4	-	1

Table 5 – Question Q5) A - Distribution of answers

In a majority of cases, detailed risk analyses have been performed (26 positive responses from 32 answers). The positive answers were given by more than 80% of the utilities, more than 70% of the TSO, and 80% of the regulators.

The negative answers were based on the consideration that no severe external hazards have affected the specific NPPs (case of Hungary, Switzerland, Germany), or because the re-quantification of the seismic event and extreme meteorological impacts have started after the Fukushima event (RELKO). Negative answers were received from approximately 18% of utilities and 22% of TSO.

Some respondents have given examples for which external hazards risk analyses have been or are going to be performed:

- seismic events (CNSC, ENEL, NRSC, IEC, Jansi, Kaeri, TUS)
- high winds (CNSC, NRSC, TUS)
- flood (EDF, TUS)
- loss of external grid (FKA)
- freezing of sea water intake (Risk Pilot, TUS)
- snow, rainfall, dust storm and low temperatures (NRSC)

- extreme weather analysis is ongoing (ENEL)
- air pressure and man-made events (aircraft crash, accidents in near-by industrial plants and transportation) (IEC)
- detailed risk analysis for high and low river levels, fires outside of the site have to be performed. (TUS)
- airplane crash (detailed deterministic analyses of the secondary containment resistance to the impact of a reference airplane; detailed probabilistic analyses to validate the reference airplane against a probabilistic acceptance criterion), external explosion of a gas-carrier boat (deterministic analysis to determine the possible scenario; probabilistic analysis in order to estimate the probability of occurrence) (Tractebel)
- low Danube river level caused by prolonged period of drought (INR).

Cernavoda Unit 1 had experienced a low Danube river level that required extended plant shutdown in August 2003 (Unit 2 was still under construction at that time). The low river level event was due to a prolonged period of drought all over Europe, when the Danube level and flow reached the lowest values in the last 160 years. After the event, some design changes have been implemented, to provide water also for the worst case drought scenarios. A specific emergency operating procedure has been established to provide instructions to the operating staff in safety dealing with critically low river level situations. Based on the long time available for response, specific actions can be implemented in accordance with the specific APOP and Severe Accident Management Guidance response for maintaining the cooling safety function in the worst case drought scenario.

B – Was a PSA available for these events?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	14	18	2
INDUSTRY (utilities +vendor)	5	6	-
TSO	8	9	1
REGULATORS	1	3	1

Table 6 – Question Q5) B - Distribution of answers

For this question, 32 answers were received. Only 14 positive answers were given, comparing to 18 negative answers. The positive answers were received approximately from 45% of the utilities and the TSO, and 20% of the regulators. The negative answers were given approximately by 55% of the utilities, 50% of the TSO and 60% of the regulators.

It may be concluded that PSA was available in some cases, but not for the majority of considered events.

Some of the negative answers given were induced by the fact that extreme events haven't occurred in the specific country (case of Hungary, Switzerland, Germany), or in case of seismic events, only Seismic Margin Analysis for some plants was performed (CNSC, IEC).

Even for positive answers, it was specified that simplified analyses were performed (FKA, RELKO).

As interesting insight, it was specified that in France, no external flooding PSA existed before Le Blayais event. However, the corresponding sequences were included in internal events PSAs. After this event, a risk analysis was performed with the existing internal event L1 PSA to calculate the conditional core melt probability. (IRSN)

C – Was an additional PSA part developed?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	13	18	3
INDUSTRY (utilities +vendor)	6	5	-
TSO	5	11	2
REGULATORS	2	2	1

Table 7 – Question Q5) C - Distribution of answers

31 answers were received to this question. Following the answers, it seems that in some cases (42% of answers), additional PSA studies have been developed. The positive answers represent approximately 55% of the utilities, more than 30% of the TSO and 40% of the regulators. The negative answers came from approximately 45% of the utilities, more than 60% of the TSO and 40% of the regulators.

An additional PSA part was developed in the following cases:

-high winds (CNSC, UJV)

-seismic events

Seismic PSAs have been developed and/or are being developed (ENEL, ZP NPP, CNSC, UJV). Level 1 full power seismic PSA was performed for the Mochovce plant, and the project is planned for Bohunice V2 plant also. The project will be extended to L2 PSA and for all operating modes in case of both plants (RELKO)

-model and data was improved (FKA)

-PSA has been updated (INRNE, TUS)

-to assess conditional core melt probability (IRSN)

-external events level 1 and level 2 PSA for low power and SD and for Spent Fuel Pool (RNPP)

-PSA was extended by the following scenarios: airplane crash, abrasive storm, extremely high temperature, extremely low temperature, extreme snow load, tornadoes. The scenario of extreme precipitation is planned to be added. (UJV)

Negative answers were given based on the following reasons:

- no extreme events occurred (Hungary, Switzerland, Germany)
- a full scope PSA is required for the license and the PSA is updated at every 10 years (NRG)
- PSA scope extension is required by the French regulations, and seismic PSA is underdevelopment, although no earthquake occurred on French power plant. Nevertheless, internal event level 1 PSA can be used and adapted for event analysis to assess the conditional core damage probability knowing the occurrence of the hazard and the equipment unavailability induced by the hazard. (EDF)

Q6)If you applied PSA methodologies for the assessment of hazards that already occurred, did you include L2 PSA (risk of release) or only L1 PSA (CDF) in such analysis?

The distribution of the responses is given below:

	L2 PSA	Only L1 PSA	No answer
TOTAL ANSWERS	14	12	8
INDUSTRY (utilities +vendor)	5	4	2
TSO	8	6	4
REGULATORS	1	2	2

Table 8 - Question Q6) - Distribution of answers

26 answers were received to this question.

L2 PSA is used for hazard risk assessment in 41% of cases, by approximately 45% of the utilities, 44% of the TSO and 20% of the regulators.

L1 PSA is used a little bit less, only in 35% of cases, by approximately 36% of the utilities, 33% of the TSO and 40% of the regulators. The reasons for this is that only PSA L1 is available (as for instance case of NRSC), or because the accident precursor methodology is developed focused on Level 1 PSA (CNSC).

NRC uses a surrogate/cursory LERF analysis, even if a detailed Level 2 is not usually available.

It might be concluded that most of the studies used for risk assessment induced by hazards are L2 PSA, even if they are developed only for some cases:

-seismic PSA (INRNE, TUS)

-loss of external grid (FKA)

-L2 at full power, low power and shutdown PSA (RELKO).

Q7) A - Did natural or man-made external hazards occur that were not included in PSAs (i.e. treated, either in a qualitative or in a quantitative way) but were important for safety?
If yes, can you provide some examples?

The distribution of the responses is given below:

	YES	NO	Not applicable	No answer
TOTAL ANSWERS	11	18	3	2
INDUSTRY (utilities +vendor)	6	4	1	-
TSO	5	10	2	1
REGULATORS	-	4	-	1

Table 9 - Question Q7) A - Distribution of answers

32 answers were received to this question. Positive answers were given by approximately 54% of the utilities and 28% of the TSO.

Negative answers were received from approximately 36% of the utilities, 55% of the TSO and from 80% of the regulators.

In most of the cases, it was considered that there are no external hazards (natural or man-made) occurred that were not included in PSA but had an impact on safety (18 responses from 32).

The negative answers were given on the following considerations:

- site specific hazards are generally modelled (including qualitative screening) either in the PSA models, or in the “other hazards” evaluation sections (NRC);
- the occurred hazards were included in the PSAs at least in the form of contribution to initiating event frequency (loss of off-site power, abrasive storm) (UJV).

Still, there are some cases in which these hazards happened, and were important for safety, the examples being as follows:

- external flooding;
- high river flow rates beyond the original design basis values have occurred and led to a revised design basis and additional protection measures (Bel V);
- during 70s (before PSA) in annual outage (a cold or refuelling outage) sea water started to flow over the discharge side's bulkhead gate into the main seawater piping. Water could have flown through open maintenance hatches into the turbine hall if the water level would have risen higher (Fortum);
- December 1999 – flooding of Blayais site (IRSN);
- Plant experience mudflow event which did not affect the plant but in future could potentially affect service water system equipment. This event was screened out by impact in current PSA model. It should be included in the next revision of EE PSA model (NRSC);
- Lightning;
- A lightning strike in the external grid and loss of external and part of internal grid due to man-made failure. Examples: Loss of one of four battery train during outage, loss of two of four trains in the internal grid (Forsmarks incident) (FKA);
- Lightning has caused some disturbances during 80s. Due to a failure of instrumentation room ventilation in 1985 cold outside air was blown towards instrumentation cubicles, leading into some disturbances like false fire alarms (Fortum);
- seismic event (RNPP, Tractebel);
- high flow or temperature in the river (Tractebel);
- low river levels, freezing of water intake, high wind (they occurred, but with low frequency and are not considered in a quantitative way) (TUS);
- Meteorological events (hail, typhoon); biological (jellyfish); geological (landslide, debris flow) (Kaeri).

Other significant hazards:

- December 2005 - Paluel site: ice formation on the grid transformers leading to shutdown of all four reactors and isolation from the external power supply (IRSN);

- December 2009 - Cruas units 3 and 4: total loss of the heat sink occurred due to the clogging of the pumping station filters due to a massive arrival of vegetable matters (IRSN);
- December 2009 - Fessenheim unit 2: partial loss of heat sink occurred due to the clogging of the pumping station filtering drum screens due to vegetable matters (IRSN).

B - Have you developed any lessons related to safety from these events?
If yes, please specify.

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	14	14	6
INDUSTRY (utilities +vendor)	6	3	2
TSO	8	8	2
REGULATORS	-	3	2

Table 10 - Question Q7) B - Distribution of answers

28 answers were received to this question. Half of the responses (14) have declared the development of safety lessons from the events, half of them were on the opposite way.

Approximately 54% of the utilities and 44% of the TSO were developed lessons for safety from the events.

On the other hand, approximately 27% of the utilities, 44% of the TSO and 60% from the regulators have not developed lessons for safety, from vary motives.

As examples of safety lessons given, the following could be mentioned:

-revised design basis and additional protection measures for external flooding (Bel V);

-systematic review and reinforcement of the protection of the plant against all potential sources of external flooding including weather combinations causally linked (such as wind and waves). This systematic review was consistent with the requirements reinforcement (EDF);

-implementation of design changes to provide water also for worst case drought scenarios, and development of a specific emergency operating procedure to provide instructions for safely dealing with critically low river level situations (INR);

-development of strategies for Severe Accident Management (SAM) and accomplishment of measures (availability of equipment, staff, procedures) (Kozloduy NPP, TUS);

-providing mobile diesel pumps and generators to support the safety function of service water pools susceptible to a tornado (RNPP);

-better addressing the details in operational and emergency procedures (UJV);

-improvement of operating instructions to be better prepared for extreme weather conditions (Risk Pilot);

-plant improvements have been made after the PSA has been completed. In the cold air case a modification of the system was made, but when PSA was completed in 1989, a new system was designed and implemented (Fortum).

C - Have you developed any lessons related to PSAs from these events?

If yes, please specify.

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	7	18	9
INDUSTRY (utilities +vendor)	2	6	3
TSO	5	9	4
REGULATORS	-	3	2

Table 11 - Question Q7) C - Distribution of answers

A majority of the responses (18 answers from 25) shown that not so much PSA lessons have been developed related to occurred hazards.

Positive answers were given by approximately 18% of the utilities and 27% of the TSO. Negative answers were received from approximately 54% of the utilities, 33% of the TSO and from 60% of the regulators.

Some negative answers were given because no external hazards have happened, or because of the following:

- no known events besides the mechanical failure of systems or equipment, event that was incorporated in Swiss PSAs after it happened (Cazzoli Consulting);
- PSA does not cover failure of the component protection as a single or a common cause failure (FKA).

As lessons learnt, the following were specified:

- it was considered that mudflow event in future could potentially affect service water system equipment and it should be included in the next revision of EE PSA model (NRSC);
- one of the loss of offsite power external events (caused by frost ice) led to conclusion that this external hazard should be modelled in more detail. On the base of another event (hurricane Kyrill), the PSA model of NPP Dukovany was extended by one more initiating event. (UJV);
- all external hazards other than seismic events have been evaluated; only tornado was found to have sufficient enough impact to be considered a risk to plant safety (RNPP);
- the occurred hazards will be included in the next PSAs of Kozloduy NPP on the basis of the considered PSA integrated model for envelop of the internal and external hazards relevant to the site (Kozloduy NPP, TUS).

IRSN mentioned that in general, all occurred events are analysed in details and lesson learned are derived:

- Probabilistic precursors analysis which can lead to plant design /operational modifications;
- The PSA models are modified in order to take into account the new events;
- The input data (initiators, frequency, HRA) are adapted in order to take into account the recent operating experience.

It is good to know that even if no lessons were developed, those events have been good examples when developing the PSA. (Fortum)

Q8) A - Did NPP(s) located in your country already experience any combinations of natural and/or man-made external hazards that had significant consequences for safety?
If yes, can you briefly describe examples of those combinations and their consequences for safety?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	10	21	3
INDUSTRY (utilities +vendor)	6	5	-
TSO	3	13	2
REGULATORS	1	3	1

Table 12 - Question Q8) A - Distribution of answers

31 answers were received. Positive answers were given by approximately 54% of the utilities, 16% of the TSO and by 20% of the regulators. Negative answers were received from approximately 45% of the utilities, 72% of the TSO and from 60% of the regulators.
Looking at the answers, maybe the question was too restrictive, some combination of hazards might have occurred, but without significant consequences for safety, due to various reasons. The results could be different if the question would have been split into two parts, one related to the occurrence and the other related to the significance. The consequences are linked to the provisional existing measures, specific to each NPP.
It may be seen that in most of the cases, no combinations of external hazards with significant consequences for safety have been experienced (21 answers from 31). Still, there are some cases in which they have occurred, and were specified as follows:
- combination of flood and wind hazard due to a storm at Le Blayais. The flood itself is the consequence of a combination of storm surge and wind generated waves (swell). As consequences were experienced loss of safety system functions and loss of offsite power, leading to the automatic scram of three units (EDF, IRSN);
- high air temperature in combination with high humidity that produced water droplets affecting the electronic cabinets in OKG Sweden (FKA);
- extreme rainfall plus dam failures have led to safety margins re-analysis (IEC);
- earthquake and flooding, loss of off-site power and loss off ultimate heat sink (Kozloduy NPP, TUS);
- two major storms (Gudrun and Per), with high wind speed and high water level (Ringhals);
- flooding (Ft Calhoun), tornadoes, hurricanes, several along the Gulf and East Coasts. The plants were required to shut down and several losses of off-site electric power have been experienced. In the case of Fort Calhoun Station, the flood waters remaining on site for an extended period of time (months) and were impacted by the combination of multiple natural/man-made events (record snowfall/meltdown, record precipitation, intentional releases from upstream dams). North Anna Power Station was impacted by a seismic event that exceeded the Safe Shutdown Earthquake criteria. There were no adverse safety consequences from these events (NRC);

- combination of ice frost and wind. The weight of electric power lines significantly increased due to ice frost, what lead to changing the position of the wires down. Consequently, strong wind moved the wires together and causes short circuit and loss of 400 kV line (UJV).

An interesting fact was specified by GRS: even if there are no such occurrences, the technical document on PSA-methods of the German PSA Guideline require an assessment of extreme weather conditions (e.g. lightning, storm, snow, ice) and combinations of these hazards.

B - Have any lessons related to safety been developed from these combinations of hazards?

If yes, can you please specify?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	8	19	7
INDUSTRY (utilities +vendor)	5	5	1
TSO	2	12	4
REGULATORS	1	2	2

Table 13 - Question Q8) B - Distribution of answers

27 answers were received. Positive answers were received from approximately 45% of the utilities, 11% of the TSO and from 20% of the regulators. Negative answers were received from approximately 45% of the utilities, 66% of the TSO and from 40% of the regulators.

It may be concluded that not so much lessons have been developed for safety from these combinations of hazards (19 negative answers from 27).

As lessons related to safety specified, the following could be mentioned:

- PSA has improved the modelling of combination of external events (but not man-made) (FKA);
- development of strategies for Severe Accident Management (SAM) and accomplishment of measures (availability of equipment, staff, procedures) (Kozloduy NPP, TUS);
- lessons-learned from the flooding and seismic events have spurred efforts that are now being considered as part of the Fukushima Lessons-Learned activities the NRC is pursuing. In particular, the NRC is developing probabilistic approaches in conjunction with other US entities to address the issue of hazard characterization for use in PSA. NRC is also pursuing work in the area of seismically-induced fires and floods (NRC);
- reassessment of flooding hazard and improvement of protection measures (IRSN);
- some addition of manual actions were added (Ringhals).

C - Are combinations of (natural and/or man-made) external hazards considered in the PSAs you consider?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	11	19	4
INDUSTRY (utilities +vendor)	6	5	-
TSO	4	11	1
REGULATORS	1	2	3

Table 14 - Question Q8) C - Distribution of answers

More negative answers than positive (19 comparing to 11) were given. Positive answers were received from approximately 54% of the utilities, 22% of the TSO and from 20% of the regulators. Negative answers were given by approximately 45% of the utilities, 61% of the TSO and by 40% of the regulators.

Comments related to considerations of combinations of external hazards were mentioned case by case, as follows:

- combination of wind and biological infestation leading to Loss of Ultimate Heat Sink and Loss of Offsite Power (EDF);
- combinations of hazards have not been systematically considered in plant-specific PSA up to now. According to the revised guidelines, at least a screening of the relevance of combinations of hazards/events is necessary (GRS);
- combinations are considered on a limited basis. We have a few external hazards models, but limited to severe weather, flooding, fire and seismic. Fires that could occur following a seismic event are addressed qualitatively and in a relatively cursory fashion (NRC);
- no correlations are taken into account but independent loss of heat sink and electrical power are considered in generic internal event PSAs (IRSN);
- in some cases, combination of external hazards can lead to an initiating event, which has been addressed already in the PSA model (ice frost + wind = loss of offsite power). In such cases, the combination is addressed in the PSA, but not explicitly (UJV).

D - Have any lessons related to PSAs been developed from these combinations of events?
If yes, can you please specify?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	10	19	5
INDUSTRY (utilities +vendor)	4	6	1
TSO	5	11	2
REGULATORS	1	2	2

Table 15 - Question Q8) D - Distribution of answers

According to received answers (29), not so many lessons related to PSA have been developed from the combinations of events (19 negative answers comparing to 10 positive ones).

The positive answers were given by approximately 36% of the utilities, 27% of the TSO and by 20% of the regulators. The negative answers were received from approximately 54% of the utilities, 61% of the TSO and by 40% of the regulators.

NRC gave a positive answer, recognizing that multiple combinations of events are possible for various contributors related to natural hazards (e.g. flooding). However, it mentioned also that the specific characterization of such events is not usually modelled in detail in the PSA (NRC).

NRSC gave a negative answer, but mentioned that currently is cooperating with IAEA to implement a project aimed to apply Fault Sequence Analysis (FSA) method for Armenian NPP. The objective of the project is to identify critical combinations of external hazards to be analysed in detail and if necessary to be included in PSA model.

The few examples of the lessons learnt are given below:

- the following combinations have been analysed and are considered to be introduced into the PSA models: extremely strong wind + snow storm; extreme temperature + extremely strong wind (UJV);
- combinations will be taken into consideration in the future for extreme meteorological conditions (RELKO);
- a PSA integrated model for envelop the internal and external hazards relevant to the site is considered (TUS);
- improvement of the spent fuel pool cooling EPR in case high winds impacting external power supply and heat sink (IRSN);
- PSA has improved the modelling of combination of external events (but not man-made) (FKA).

Fortum gave more details regarding the lessons learnt: improvements have been made for diesel generator air intake to prevent blocking due to snow or freezing rain. High wind can cause loss of offsite power and at the same heavy snowfall or freezing rain can block the air intakes. Sheet-metal panels are better attached and maintained, because metal sheets can cause loss of power if they are blown to the switchyard. Cleaning of the diesel generator cooling water intake has been improved to prevent blocking that can be caused by extra sea vegetation. High wind can cause loss of offsite power and at the same time loosen extra sea vegetation that can block the cooling water intake. Improvements have been made to prevent frazil ice that can clog the intake of sea water and service water pumps and the intake screens of the diesel cooling pumps. Strong wind can increase the possibility of frazil ice and at the same time cause loss of offsite power.

Q9) A - Did internal hazards or events occur in NPPs located in your country as a consequence of a natural or man-made external hazard?

If yes, can you please describe such events?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	13	17	4
INDUSTRY (utilities +vendor)	4	6	1
TSO	7	9	2
REGULATORS	2	2	1

Table 16 - Question Q9) A - Distribution of answers

A majority of negative answers (17 comparing to 13 positive ones) was received. Positive answers were received from approximately 36% of the utilities, 38% of the TSO and from 40% of the regulators.

Negative answers were given by approximately 65% of the utilities, by 50% of the TSO and 40% of the regulators.

It may be concluded that sometimes, internal hazards occurred in NPP as a consequence of natural or man-made external hazards. Their description is given below:

- Loss of internal grid due to man-made event in external grid (Forsmark incident) (FKA);
- a trip occurred due to high river flow in 2012 and in 2013 (SNSA);
- on April 22, 2008, Cernavoda Unit 2 experienced a turbine-generator trip, on a loss of line signal, during a violent thunder storm. Partial loss of class IV "EVEN" occurred due to the fact that the transfer to EVEN transformer could not be performed (the transformer was isolated for maintenance). Adequate fuel cooling has been assured during the whole time of "partial loss of class IV event" (INR);
- electric transformer fire at the Chuetsu-oki earthquake. Driving joint failure of reactor building crane at the Chuetsu-oki earthquake (Jansi);
- loss of heat sink (Cruas), Loss of grid (Paluel)(IRSN);
- human-induced SBO, SGTR (Kaeri);
- there was a possibility of internal flooding through open hatches during outage when sea water level was high (Fortum);
- various events including tornadoes, storms, winter storms, and seismic events have occurred during the years affecting NPPs. These have resulted in LOOP events and reactor trips but with no significant safety consequences (NRC);
- minor internal flooding due to the storm and high water level occurred, but with no impact on reactor safety (Ringhals).

The most detailed answer (describing 3 cases) was given by Bel V:

- high river level (due to high tide and storm surge) caused internal flooding of the machine hall since the condenser was open for maintenance/repair and the water level in the Circulating Water outlet channel was too high (about 40 cm, causing overflow towards the condenser). In the machine hall, a water level of 40 cm was reached. Some cable rooms were also flooded. No safety equipment was lost. Some pumps needed for the cooling of secondary auxiliaries circuits could have been lost if the water level in the machine hall would have been slightly higher;
- loss of Offsite Power due to heavy wind. The unit was in cold shutdown (refuelling ended) and the primary circuit in mid-loop conditions. The 380 kV grid was not available (disturbed grid due to heavy wind conditions) and the

power supply to the plant was assured by the 150 kV auxiliary grid. Repair work on the roof of the turbine hall was ongoing. There was a pile of badly fixed metal plates on top of the turbine hall roof and due to the wind some metal plates were blown away and one plate fell on the 150 kV transformer, leading to a short-circuit, loss of the 150 kV power supply, and thus total loss of offsite power. The emergency diesel generators started and reloaded correctly all necessary equipment. The 380 kV grid was restored after 20 minutes. The temporary loss of RCS cooling did not lead to a measurable change in RCS water level since the decay heat was low (unit stopped since 3 weeks);

- two events (one at each site) with loss of the 150 kV grid due to (respectively 3 and 5) overturned pylons during high storm wind. The 380 kV grid remained available. There was no Loss of Offsite Power, but one (out of two) external power sources was unavailable during at least one week.

B - Did they have any significant safety consequences?

If yes, can you please comment them?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	2	25	7
INDUSTRY (utilities +vendor)	1	9	1
TSO	1	12	5
REGULATORS	-	4	1

Table 17 - Question Q9) B - Distribution of answers

The majority of answers (25 negative answers compared with 2 positive) have shown that no significant safety consequences were related to the occurrences of external hazards.

The only positive answers were given by FKA, and IRSN. Their comments are given below:

- loss of heat sink or loss of offsite power are significant to safety (IRSN).

The negative answers were given by approximately 81% of the utilities, 66% of the TSO and by 80% of the regulators. In all cases, no significant safety consequences occurred, operating procedures being efficiently applied. In some cases, hazards have resulted in LOOP events and reactor trips, but with no significant safety consequences (NRC).

Even with no safety consequences, sometimes an event could be conservatively notified to regulatory authority – for instance, according to the criterion "A failure of one or more components of a Standby Safety System which caused a significant reduction in the effectiveness of the system, such that the system would fail to fully meet its design requirements" (INR).

C - Have any lessons related to safety been developed from these events?

If yes, can you please specify?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	13	12	9
INDUSTRY (utilities +vendor)	5	3	3
TSO	6	7	5
REGULATORS	2	2	1

Table 18 - Question Q9) C - Distribution of answers

The received answers (25) were divided almost equally between the positive option (13 answers) and the negative one (12 answers).

The positive answers were given by approximately 45% of the utilities, 33% of the TSO and by 40% of the regulators.

Negative answers were given by approximately 27% of the utilities, 38% of the TSO and by 40% of the regulators.

The cases when lessons learnt were developed are specified below:

- design reinforcements or operating procedures modifications in order to prevent the occurrence of the event or to mitigate consequences of the event (EDF, IRSN);
- comprehensive initial and periodic design review program of the plant systems shall be assured (INR);
- for human-induced SBO, keeping the relevant operating procedure is very important for safety (Kaeri);
- development of strategies for Severe Accident Management (SAM) and accomplishment of measures (availability of equipment, staff, procedures) (Kozloduy NPP);
- following events like tornadoes, hurricanes, earthquakes, task forces were put in place to conduct a lessons learned review for several events (i.e., Hurricane Andrew and Hurricane Katrina) (NRC);
- some addition of instructions for preparation/information was added (Ringhals);
- procedures were changed so that when high river flows occur, the plant starts to use the cooling towers. This reduces the need for river cooling so debris in the river don't have the impact on the cooling system (SNSA);
- maintenance or repair activities on the condenser (with open condenser) should not be allowed if high river levels due to high tide and storm surge are announced (Bel V).

D - Have any lessons related to PSAs been developed from these events?
If yes, can you please specify?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	9	16	9
INDUSTRY (utilities +vendor)	4	4	3
TSO	3	10	5
REGULATORS	2	2	1

Table 19 - Question Q9) D - Distribution of answers

25 answers were received to this question. Negative answers are almost double (16 answers), comparing to positive answers (9). Positive answers were received from approximately 36% of the utilities, 16% of the TSO and from 40% of the regulators. Negative answers were given by approximately 36% of the utilities, 55% of the TSO and by 40% of the regulators.

It may be seen that not so much lessons related to PSA have been developed from these events.

The lessons learnt specified are as follows:

- initial event frequency is re-evaluated if it is relevant (EDF);
- for human-induced SBO, it is valuable to assess in advance safety significance for such an event through a precursor study (Kaeri);
- the US NRC recognizes the importance several of these initiators may have on overall plant safety and its currently developing PSA models that encompass several hazards in a unified model approach (NRC);
- the cooling system clog frequency due to high river flows was recalculated (CNSA);
- improvement of PSA models and data (IRSN);
- it is considered the development of PSA integrated model, including all internal and external hazards (Kozloduy NPP, TUS).

Q10) A - For natural or man-made external hazards that already occurred and concerned a whole site, have the multi-units issues been considered in a detailed risk analysis (event report)?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	9	21	4
INDUSTRY (utilities +vendor)	2	7	1
TSO	7	10	2
REGULATORS	-	4	1

Table 20 - Question Q10) A - Distribution of answers

30 answers were given to this question. There were much more negative answers (21) received than positive answers (9).

Positive answers were given by approximately 18% of the utilities and 38% of the TSO. Negative answers were received from approximately 63% of the utilities, 55% of the TSO and from 80% of regulators.

According to the answers, multi-unit issues have not been included in detailed risk analysis report so often.

The comments that sustained the positive answers are given below:

- due to recurrent external flooding risks in the surroundings of a river site (without flooding of the site platform, but with a smaller margin than the one expected for the design basis flood), a new and more detailed hazard analysis for high river flow rates (including combinations with wind waves and heavy on-site rain) has been performed and has led to a revised protection concept for the whole site (i.e., a peripheral site protection for the revised design basis events) and also in a defence-in-depth perspective, to protection measures for the individual units (i.e., additional equipment and procedures to cope with beyond-design basis flooding events) (Bel V);
- nothing have yet occurred, but multi-unit impact is considered for all relevant and applicable events (VUJE).

Negative answers were sustained by the following comments:

- no severe external hazards have affected the Paks NPP so far. Partial blockage of the service water filters has already been experienced. Blockage of service water filters apparently may affect multiple units at the Paks NPP, and the issue is currently the subject of re-evaluation whether blockage of the filters needs to be considered in detailed risk analysis or not (Nubiki);
- there were no external hazards events that exceeded the design basis for a multi-unit site (GRS);
- only one unit is in operation (Armenian NPP Unit 2). Systems of Unit 1 (unit shuttled down) used for Unit 2 are considered as a part of Unit 2 technological infrastructure (including compartments from fire point of view) (NRSC);
- for the specific hazard "airplane crash", detailed deterministic analysis has been achieved in order to analyses the effects on buildings, electrical power supply, heat sink, core and spent fuel pool (Tractebel).

B - Have multi-unit PSAs been used to assess multi-units issues or only single unit PSAs with specific boundary conditions or model modifications (please mark with an X)?

The distribution of the responses is given below:

	Multi-unit PSA	**Single unit PSA - specific modifications**	**None**	**No answer**
TOTAL ANSWERS	3	18	8	5
INDUSTRY (utilities +vendor)	1	8	-	1
TSO	2	8	7	2
REGULATORS	-	2	1	2

Table 21 - Question Q10) B - Distribution of answers

In most of the cases (18 answers from 29), single unit PSA have been developed with specific modification, from one unit to another.

3 answers mentioned to use multi-unit PSA to assess multi-unit issues (1 utility and 2 TSO).

As comment to this option, it was mentioned that the performed L1PSA of Kozloduy NPP envelop both VVER-1000 units, but one of the units was a referent unit. (Kozloduy NPP, TUS)

A majority of answers (18) mentioned to use single unit PSAs, with specific boundary conditions or model modifications, in assessing multi-unit issues. These answers were received from approximately 72% of the utilities, 44% of the TSO and from 40% regulators.

Comments provided for this option are given below:

- the PSA for External Events has been developed for a Reference Unit for the site, taking into consideration whether some systems or components or structures are shared with other units (ENEL);
- the other unit PSA is under way. Improvements based on PSA results have been made for both units (Fortum);
- PSA model for Cernavoda unit 2 has been developed based on the PSA model for Cernavoda unit 1, with specific modifications (INR);
- there is an initiative in place to study and analyses multi-unit issues in more details within the risk analysis for the four units of the Paks NPP (Nubiki, Paks NPP);
- one site in Switzerland has 2 units; Level 1 is performed only for Unit 1, and credit is given to possible connections of systems from unit 2. However, common cause failures between units are not considered. Moreover, the multi-unit approach is not required by ENSI (Cazzoli Consulting);
- for seismic PSA, the systems which are shared by several units were not taken into account (EDF);
- multi-unit LOOP may be considered (Risk pilot);
- L1 PSAs for 900 MWe and 1300MWe plants consider explicitly the initiators affecting the whole site (IRSN);
- only one unit is in operation. Systems of Armenian NPP Unit 1 (which is shuttled down) used for Unit 2 are considered as a part of Unit 2 technological infrastructure (including compartments from fire point of view) (NRSC);
- single unit PSA, but the interconnections are taken into consideration (electrical power supply and water sources) (RELKO).

Q11) What are your criteria/reasons to revise your PSAs for natural or made-man external hazards that happen to one NPP (“your” plant(s) or any other plant(s))? Please provide example?

No answer was given by 4 respondents (1 utility, 2 TSO and 1 regulator).

Some of respondents have considered that the question is not applicable, for the following reasons:

- PSA was not used for external hazards. (Bel V, IEC)
- Only one unit is in operation (Armenian NPP Unit 2). Armenian NPP Unit 1 is shuttled down (NRSC)

As reasons to revise the PSA in case of external hazards were specified the following:

- Regulatory requirements (Switzerland, Bulgaria, Ukraine)
    - after Fukushima accident, a seismic PSA has been requested from the regulatory body (both in a post stress test phase for Units in operation and in a PoSAR phase for units in completion) (ENEL);

- "stress tests" results and recommendations are undisputable reasons to develop detailed external events and hazards analysis (TUS);
- safety significance (IRSN);
- specific aspects having impact on availability of safety systems that are considered to achieve and maintain plant safe state (VUJE);
- if the external hazards that happen to one NPP have different consequences or accident progression than what is modelled in the PSA or that the occurrence of these hazards challenges the frequencies considered in the PSA (NRG);
- information obtained from the internal and external operational experience is used also to assess the necessity for updating the safety analyses (deterministic and probabilistic), but there are no special remarks for external hazards. The procedure "External Operating Experience Feedback" is used for screening for applicability the information provided by external organizations like COG, WANO, INPO and IRS. For the major events (e.g. WANO significant Operating Experience Reports/Significant Event Reports, events level 2 or high on INES scale), an Abnormal Conditions Report is issued, and the analysis is performed using a gap analysis template. This means that the existing processes, procedures and work practices are compared with the recommendations given in the reports, and in case when a gap is identified between current situation and recommended aspects, actions are defined to fill in the gap (INR);
- if the external hazard triggered an initiating event or impaired components of safety systems, PSAs available should be revised if the occurred damages are appropriately modelled (GRS);
- although there are no written criteria/reasons for updating the PSA in response to an actual event, it is obvious that significant events (such as Fukushima) will trigger the review and update of the existing PSA to ensure the occurred events have been adequately considered in the PSA (CNSC, RNPP);
- there is no formal criterion. If an event occurs in one plant; it would be treated case by case. If happens in multiple plants, whether it is a generic issue or not, it would be examined. However, if an event revealed a new or unknown event sequence or accident progression, this information would be considered for future PSA model development or upgrade of existing models (NRC).

- Updating requirements
    - we update our PSA annually on new knowledge and plant histories. Frequencies, probabilities and success criteria are updated. If new phenomena are found out they are included in the PSA as soon as we have good understanding of their effects and origin (Fortum);
    - PSAs are supposed to be updated regularly to incorporate the latest design or operations changes, as well as the technical advancement in understanding of the hazards or the evaluation methods (CNSC, FKA, Ringhals- 2 years, EDF-10 years);
    - most of the PSA changes come out of periodic PSRs (every 10 years), when PSA is reviewed and revised if needed. Also the Rules on operation safety of radiation of nuclear facilities allow the SNSA

to require an extraordinary safety review (which can also result in the PSA changes) in the following cases:

- if it becomes apparent that safety barriers are deteriorated to a degree where their capacity to contain radioactive substances is reduced;
- if the operational indicators deteriorate significantly or for an extended period;
- if the frequency of events, important for safety, increases;
- if the safety culture deteriorates to a degree where radiation or nuclear safety may be threatened;
- if operational limits and conditions are breached on a recurrent basis;
- if application of operational experience feedback from another radiation or nuclear facility or new knowledge of radiation or nuclear safety might have notable effects on the safety of the radiation of nuclear facility, or
- if acquires significant evidence of the challenged radiation or nuclear safety.

Of course the plant has its own procedures and guidelines on when and how to review and revise the PSA. (SNSA)

Kozloduy answer was referring to modification criteria for updating/revision of existing PSA in general, specifying plant modifications; operating experience; Thermal-Hydraulic Analysis (THA); operational documentation (instructions for normal operation and emergency procedures; regulatory requirements; PSA methods; PSA reviews.

Q12) Did insights from real natural or man-made external hazards that have occurred on your plant or in your country already challenge some screening criteria in use for external hazards (for PSA or DBA)?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	6	24	4
INDUSTRY (utilities +vendor)	2	8	1
TSO	3	14	1
REGULATORS	1	2	2

Table 22 - Question Q12) - Distribution of answers

According to the received answers (30), insights from external hazards did not challenge many time the screening criteria in use for external hazards (24 negative answers comparing to only 6 positive ones).

Positive answers were received from approximately 18% of the utilities, 16% of the TSO and 20% of the regulators.

Negative answers were given by approximately 72% of the utilities, by 77% of the TSO and by 40% of the regulators.

Most of the answers were negative, based on the fact that:

- there have not occurred large scale real natural or man-made external hazards in the country, to the extent to threaten plants (Kaeri);

- applications of the EDF hazard screening methodology are under development (EDF);
- hazards screening method under development (IRSN);
- for Belgian NPPs, quantitative screening criteria are not in use for the selection of external natural or man-made hazards to be considered as DBA or in PSA. On the other hand, for external man-made hazards considered as design basis accidents (DBA), the acceptance criteria according to the Standard Review Plan (NUREG-800), section 2.2.3, are in use (i.e., the expected rate of occurrence of unacceptable radiological exposures due to these accidents should not exceed an order of magnitude of 10^{-7} per reactor year for each hazard type (e.g., aircraft crash, external explosion, external fire). For some external man-made hazards (e.g. toxic gas releases) these criteria have been challenged during re-assessments in recent PSRs (Bel V).

Only few examples, sustaining the positive answers, were given:
- it challenges some criteria used, but only for the DBA part, not for the PSA part (Tractebel);
- the floods that impacted Fort Calhoun in 2011 have had an impact on the understanding of the likelihood of such an event taking place. The NRC required the licensee to place specific procedures that would require entering a safe shutdown configuration at specific flood elevations during such an event. The NRC has also initiated a discussion with other US government agencies on the impact of upstream dam failures (NRC);
- as a result of Fukushima and the stress test result the screening external events have to be re-assessed. Focus for both PSA and DSA just now is to re-evaluate the way of how to combine events. The most important external events to re-evaluate the screening criteria for are analysis of spent fuel pool (SFP) and analysis of seismic events; other important events are solar storms (Ringhals);
- history of seismic activity has driven to revisit the possibility of a design-base earthquake taking place on-site (RNPP);
-the scope of DBAs have been expanded (Risk pilot).

Q13) In case you use PSA for assessment of real external hazards that have occurred in your country, are existing PSA modelling techniques (e.g. HRA in harsh conditions, induced failures in the plant) suitable?

The distribution of the responses is given below:

	YES	NO	Not applicable	No answer
TOTAL ANSWERS	7	13	11	3
INDUSTRY (utilities +vendor)	4	3	4	-
TSO	3	9	6	1
REGULATORS	-	1	1	2

Table 23 - Question Q13) - Distribution of answers

Following the received answers (31), not so much of the respondents have considered that the existing PSA modelling techniques (e.g. HRA in harsh conditions, induced failures in the plant) are suitable to assess real external hazards (13 negative answers versus 7 positive ones).

Positive answers were given by approximately 36% of the utilities and 16% of the TSO.

Negative answers were received from approximately 27% of the utilities, 50% of the TSO and 20% of the regulators.

Many respondents (approximately 36% of the utilities, 33% of the TSO and 20% of the regulators) have considered that the question is not applicable, because:

- up to now, PSA is not used for external hazards (Bel V);
- haven't experienced the real external hazards (Canada, Hungary, Slovakia);
- no PSA of external hazards have been developed (IEC);
- PSA is not in use for assessment of real external hazards that have occurred. Although if we will use it, it is necessary to revisit modelling of issues like stress level of operator in case of external hazards (NRSC).

Some of the respondents feel that the current PSA techniques are suitable to assess real external hazards (Fortum, Risk Pilot, GRS, Ringhals, RNPP)

Many respondents have denied the adequacy of existing PSA methods in assessing real external hazards, considering that:

- PSA is used for assessment of conditional core damage probability considering the occurrence of the external hazard and its functional consequences on the NPP (induced failures are considered as certain and HEP are not reassessed) (EDF);
- the PSA technique for assessing the impact of component protection is not sufficient (FKA);
- HRA methodologies should reflect more adequately the harsh conditions induced by an external hazard or combinations of hazards (INR, UJV, TUS);
- more detailed analyses are needed in the area of HRA and induced failures (RELKO, SNSA);
- high level PSA methods applicable to any event already exists; details of methods may not exist (NRC);
- techniques to assess HRA in harsh conditions, for the purpose of PSA are currently under development (Kaeri).

2.2 LESSONS LEARNT FROM THE FUKUSHIMA ACCIDENT FOR PSA DEVELOPMENTS AND APPLICATIONS

In addition to existing public documents (for example [8]), this section aims at collecting information about lessons learnt from the Fukushima accident for PSA developments.

Q14) After the Fukushima accident did you decide to revise, complete or extend your existing PSAs?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	24	7	3
INDUSTRY (utilities +vendor)	9	2	-
TSO	12	4	2
REGULATORS	3	1	1

Table 24 - Question Q14) - Distribution of answers

31 of answers were received. Majority of respondents have decided to revise or to extend their PSA studies (24 positive answers comparing to 7 negative) after the Fukushima. Positive answers were given by approximately 81% of the utilities, by 2/3 of TSO and 60% of the regulators.
Negative answers were received from approximately 18% of the utilities, 22% of the TSO and from 20% of the regulators.
The negative responses were based mainly on the fact that the decision to update PSA is under the responsibility of utilities. TSO for regulators have to follow the authority requirements, and TSO for utilities must follow the utilities requirements.
Some of the positive answers were sustained by comments, as follows:
- for the Paks NPP review of risk analysis for external hazards had begun prior to the occurrence of the Fukushima accident. The accident gave a large momentum to this review and draw special attention to the issues of SFP accidents, level 2 PSA for external events and multi-unit considerations (Paks NPP, TUS);
- the U.S. NRC is currently developing a Level 3 PSA that will include Level 1 (internal and external events), 2, and 3 PSA, LPSD, Multi-unit PSA and spent fuel pool PSA for a specific plant. These additional modes are not expected to be part of the NPPs PSAs in the near future (NRC).

The following 18 organizations (5 utilities, 10 TSO, 3 regulators) have decided to revise or to extend the PSA concerning Spend Fuel Pool (SFP): CNSC, ENEL, GRS, IEC, INR, IRNE, IRSN, JANSI, KAERI, NRC, NRSC, Ringhals, RNPP, SNSA, UJV, VUJE, ZNPP, RELKO.
The following 16 organizations (5 utilities, 10 TSO, 1 regulator) have decided to revise or to extend the PSA concerning list of relevant hazards: CNSC, EDF, ENEL, FKA, INR, IRNE, IRSN, JANSI, KAERI, Kozloduy NPP, NRSC, Ringhals, RNPP, TUS, VUJE, RELKO.
The following 12 organizations (3 utilities, 8 TSO and 1 regulator) have decided to revise or to extend the PSA concerning low power / shutdown modes: ENEL, GRS, IEC, IRNE, IRSN, JANSI, KAERI, NRC, NRSC, RNPP, VUJE, RELKO.
The following 11 organizations (1 utility, 9 TSO, 1 regulator) have decided to revise or to extend the PSA concerning PSA L2: GRS, INR, IRNE, IRSN, JANSI, KAERI, NRC, RNPP, UJV, VUJE, RELKO.
The following 3 organizations (2 TSO and 1 regulator) have decided to revise or to extend the PSA concerning PSA L3: JANSI, KAERI, NRC.
The following 11 organizations (2 utilities, 7 TSO, 2 regulators) have decided to revise or to extend the PSA concerning multi-unit PSA: CNSC, EDF, ENEL, INR, IRNE, IRSN, JANSI, KAERI, NRC, VUJE, RELKO.
Other issues that were taken into consideration for revision were:
- aircraft crash, explosion pressure wave, external flooding and earthquake (PSA level 1) (all the hazards specified in the German PSA guideline must be regarded) (GRS);
- severe accident response, especially for seismic scenario (VUJE);
- analysis of seismic events, solar storms (Ringhals);
- a feasibility study for risk-informed emergency preparedness and EPZ (KAERI);
- long term accident (EDF, UJV);

- to extend the scope of initiating events. Sometimes, the developments are not a complete PSA (IRSN);
- combination of hazards + seismic induced fires and floods (NRSC).

There were respondents that have taken or intend to take into consideration all the issues specified as options for revision/extension, like KAERI and JANSI. In some cases, the work on specific topic was started before Fukushima accident (NRSC, Paks NPP). The revision or extension of PSA concerning Spend Fuel Pool is taken into consideration by most of the respondents.

The revision or extension of PSA concerning list of relevant hazards is another issue considered by a large number of respondents. The revision or extension of PSA concerning PSA level 2 and multi-unit PSA have risen an equal interest among the respondents.

The revision or extension of PSA concerning PSA level 3 have obtain the lowest interest from respondents, maybe because the availability of resources, or because other issues have been considered as having higher priority.

Q15) A - Have the resources allocated to PSA development/review in your organization been modified after the Fukushima accident?

The distribution of responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	9	20	5
INDUSTRY (utilities +vendor)	4	6	1
TSO	3	12	3
REGULATORS	2	2	1

Table 25 - Question Q15) A - Distribution of answers

29 answers were received at this question.

Approximately 36% of the utilities, 16% of the TSO and 40% of the regulators have experienced modification of their allocated resources for PSA. For approximately 54% of the utilities, 66% of the TSO and 40% of the regulators, there were no modifications of the resources allocated for PSA.

According to majority of answers, there are no modifications in the resources allocated for PSA (20 negative responses versus 9 positive). If the resources were changed, they have been increased (case for all positive answers).

In case of EDF, the negative answer was given because the resources allocated to PSA development were reviewed before the Fukushima accident. EDF have specified also the area for increasing the resources, seismic PSA.

B – Have some specific needs for new competences been identified?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	14	15	5
INDUSTRY (utilities +vendor)	7	3	1
TSO	6	9	3
REGULATORS	1	3	1

Table 26 - Question Q15) B - Distribution of answers

29 responses were received to this question. There is an equal distribution between positive and negative answers. Positive answers were received from approximately 63% of utilities, 33% of the TSO and from 20% of the regulators. On the other hand, approximately 27% of the utilities, half of the TSO and 60% of the regulators did not identify any specific needs for new competences.

Generally speaking, there are no new items, but existing items need to be analysed more in depth. This is a general trend, not totally driven by Fukushima event occurrence and its consequences.

As specific needs for new competences, could be mentioned the following:

- external event assessment specialists (definition of very rare events impacting the plant), containment mechanical response specialists (AREVA);
- external hazards characterization (EDF);
- frequency estimation of natural phenomena (FKA);
- external hazards probabilistic modelling (IRSN);
- meteorological experts, for example calculation/treatment of extreme temperatures (Ringhals);
- analysis of hazards combination. In order to cover this issue NRSC launched a co-operation with IAEA aimed to familiarize with and apply Fault Sequence Analysis (FSA) method for Armenian NPP. The objective of the project is to identify critical combinations of external hazards to be analysed in detail and if necessary included in PSA model (NRSC).

NRC initiative should be mentioned – being aware of the increased need for PSA expertise, NRC has developed a process to train specific individuals to provide them the necessary PSA skill.

Q16) Did or will requirements for PSAs change after the Fukushima accident (regarding for instance the quality of PSA, their scope or the level of the study)?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	17	12	5
INDUSTRY (utilities +vendor)	4	6	1
TSO	10	5	3
REGULATORS	3	1	1

Table 27 - Question Q16) - Distribution of answers

29 answers were received to this question. For most of the respondents the requirements for PSA have changed or will be changed (17 positive answers versus 12 negative).

Positive answers were received from approximately 36% of the utilities, 55% of the TSO and from 60% of the regulators. For approximately 54% the utilities, 27% of the TSO and 20% of the regulators, the requirements for PSA did not change after Fukushima accident.

Between the arguments used for negative answers, the following could be mentioned:

- the requirements for evaluation of internal and external hazards were reinforced/ established before Fukushima NPP accident (EDF, Kozloduy NPP);
- a full scope (internal events plus hazards) L1, L2 and L3 PSA is already required for over 15 years (NRC).

The positive answers were sustained by the following arguments:

- the quality of PSA was reinforced (UJV, VUJE, ENEL) and
- a broader scope of external hazards modelling is required (IRSN, UJV, VUJE)
    - two new requirements have been added to the regulation in light of Fukushima, the consideration of spent fuel poolpool and multi-unit effects (CNSC);
    - it is expected that we will have to take into account all operating modes (including Lower Power and Shutdown) and all hazards (including natural extreme external events) (Kaeri);
    - the scope is now not more limited only to L1 PSA for internal events, but must at least consider external events such as earthquake (ENEL);
    - additionally researches on spent fuel storage (internal fires and flooding) (RNPP);
    - changes in assessment for external flooding, changes in requirement for plants to complete flood hazard re-evaluations, and changes in seismic re-evaluations (NRC);
    - the requirements for the scope of the PSA will change to include PSA for SFP as well as a Level 3 PSA, which is currently not mandatory (it is possible that Level 3 will be mandatory only for the new NPP) (SNSA);
    - more detailed seismic PSA and external hazard PSA (focusing on extreme meteorological conditions) are required by the regulator (RELKO);
- it is recommended that the safety assessment of a NPP does also entail a comprehensive Level 1 PSA for all internal and external hazards, i.e. Hazards PSA (HPSA). In addition, the adequate consideration of all possible dependencies should be ensured for each analytical step. A standardized approach for performing a comprehensive Hazard PSA has been developed for all kinds of internal and external hazards (GRS);
- there are plans to develop detailed national PSA requirements. PSA requirements will be developed based on IAEA SSG-3 document, best international practice, results of VVER Regulatory Forum's PSA Working Group activities and the results of ASAMPSA_E project (NRSC);
- Presumably more attention will be paid on the scope of external events considered, mission time (longer than 24h), non-reactor events. Many of these requirements were though discussed already before Fukushima (Risk Pilot).

A report on Fukushima lessons for PSA developments will be initiated in the ASAMPSA_E project.

Q17) Do you have specifics recommendations/expectations for this report?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	23	9	2
INDUSTRY (utilities +vendor)	7	3	1
TSO	14	4	-
REGULATORS	2	2	1

Table 28 - Question Q17) - Distribution of answers

32 answers were received to this question.

A majority of respondents (23 positive answers versus 9 negative) have specific recommendations or expectations for the report. The recommendations were received from approximately 63% of the utilities, 77% of the TSO and from 40% of regulators.

Approximately 27% of the utilities, 22% of the TSO and 40% of the regulators did not make any specific recommendations for the report.

The recommendations made for the report are specified below:

- the report should assess the impact on reference list of hazards, combination of hazards, screening methodologies and criteria, human reliability assessment methodologies (including consideration of specific emergency organization), extended mission time (AREVA, NRSC);
- the report needs to give a best-practice for estimation of frequency estimation of natural hazards and screening criteria for external hazards. Screening criteria should not be limited to the design basis for the plants. The report should give a best practice how to model loss of non-safety and safety service system in combination with external hazards (example: loss of heating of building during cold but not extreme weather). The report should include failure and recovery of external grid including switchyard and power lines within the external event modelling. The report should cover PSA technique for assessing the impact of component protection (FKA);
- the report on Fukushima lessons for PSA developments should identify the main deficiencies of the current PSA methodology (IRSN) and requirements for the further development (JSI);
- multi-units risk assessment (covering at least the Level 2 PSA) (KAERI);
- the report should focus on the following issues: clear description of event sequences and timeline of events; specification of damages that safety systems and equipment suffered; description of human responses and their implications for HRA; estimated frequency of hazards occurred (separately and combination of thereof); estimated frequency of the event sequence, which led to core damage (Paks NPP, Nubiki);
- focus on handling or method for combination of events, simplified seismic PSA, calculation/treatment of extreme temperatures, SPF PSA, Multiple unit PSA (Ringhals).

Expectations from the report include:

- recommendations developed for improving the modelling issues of external hazards in PSA (INR);

- external hazards PSAs development, also with practical examples, on hazards screening and calculation, SSCs fragility data and safety goals on CDF and LERF (ENEL);
- insights about international activities for assessing integrated site risk, extreme external events, and mitigation measures (such as the Level 3 PSA project and SPAR models) (NRC);
- information concerning the Human Reliability Analysis and multi-unit management (Tractebel);
- lessons related to human and organizational factors (UJV);
- to provide a state of the art full scope methodology for L1 and L2 external hazard PSA for all operating modes of the plant (full power, low power and shutdown operating modes). The methodology must take into account the simultaneous impact of the possible combinations of the external events (RELKO).

Q18) Have safety goals (quantitative and technical basis) applicable in your country (and/or by your company) been modified taking into account lessons learnt from the Fukushima accident?

The distribution of the responses is given below:

	YES	NO	No answer
TOTAL ANSWERS	8	24	2
INDUSTRY (utilities +vendor)	3	7	1
TSO	5	13	-
REGULATORS	-	4	1

Table 29 - Question Q18) - Distribution of answers

32 answers were received to this question. Most of the respondents (24 negative answers versus 8) have responded that safety goals have not been modified after Fukushima accident. Negative answers were received from approximately 63% of the utilities, 72% of the TSO and from 80% of the regulators.

Opinions of approximately 27% of the utilities and the TSO are that the applicable safety goals have been modified.

The positive answers were detailed by the following comments:

- release quantity criteria of 137-Cs as 100TBq was added (JANSI);
- french NPPs should now resist to additional beyond design conditions for some external hazards - earthquake, external flooding (including extreme rainfalls), extreme wind, lightning, hail, and tornadoes. Reinforcements are requested for severe accident prevention, mitigation and also crisis management (IRSN);
- emergency procedures were supplemented. Additional sources for external power were found. (ZP NPP)
- Safety goals are intact but technical basis was reconsidered (VUJE);
- some aspects of the stress-test could be considered as recommendations for modification/increasing of the safety goals (TUS).

Most of the received answers were negatives, sustained by the following motivations:

- in Hungary, the safety goals have not been changed yet because of the lessons learnt from the Fukushima accident. Safety regulations as a whole have not been modified either. However, there is a draft version of safety regulations that takes into account the findings from the Fukushima event, currently being reviewed for approval;
- by now, there are no clearly stated recommendations on quantitative safety goals on external hazards PSAs (e.g. external hazard CDF as a % of the internal events PSA) (ENEL);
- there are no changes to safety goals, but several plant safety improvements are (being) implemented since the ENSREG stress test (Bel V);
- the current surrogate safety goals for nuclear power plant are on single unit basis. CNSC and Canadian nuclear industry are working towards establishing a new set of quantitative safety goals for multi-unit sites (CNSC).

Q19) Do you consider that the implementation of defence-in-depth concept should be reinforced after the Fukushima accident?
If yes, what will be your recommendations for this (in relation with PSA developments and applications)?

The distribution of the responses is given below:

	YES	NO	No opinion	No answer
TOTAL ANSWERS	26	2	2	4
INDUSTRY (utilities +vendor)	7	2	-	2
TSO	16	-	1	1
REGULATORS	3	-	1	1

Table 30 - Question Q19) - Distribution of answers

30 answers were given to this question, but 2 respondents had no opinion on the subject.

A crushing majority of respondents (26 positive answers versus only 2 negative) have considered that the implementation of defence-in-depth concept should be reinforced after the Fukushima accident. Positive answers were given by approximately 63% of the utilities, 88% of the TSO and by 60% of the regulators. 2 utilities have considered that the implementation of defence-in-depth concept does not need to be reinforced after the Fukushima accident.

The motivations for the respondent positive answers are summarized below:

- this is already recommended by WENRA (AREVA);
- the main recommendations, since the ENSREG stress test, are related to reinforcement of defence-in-depth for extreme natural hazards (earthquake, flooding, extreme meteorological conditions), for Complete SBO and Complete LUHS, for (single- or multi-unit) severe accidents, and for emergency preparedness in case of hazards affecting a whole site or multiple units. This is mainly done in a deterministic way, without making use of PSA. PSA developments for external hazards would be useful to corroborate or further improve these safety enhancements (Bel V), to assess the effectiveness and sufficiency of the implemented measures (IRSN), and to rank the improvements (EDF);

- a number of changes have been made on the deterministic side in the German Safety Requirement for NPP, in order to reinforce DiD. There are, however, no specific recommendations on PSA development and applications in light of PSA applications (GRS);
- a broader and deeper application of defence-in-depth concepts should be considered so as to cope better with the most severe challenges. Low-probability but high-consequence internal and external hazards that could lead to simultaneous breaching at all levels of DiD should be taken into consideration, and enhancing the independence between the actions and equipment used to respond to escalating accident conditions at different DiD levels is necessary also (INR);
- to strength existing/ establish new structures/ safety systems/components in order to be able to provide longer term safety functions performance (INRNE);
- hazard level to be considered in relation to the level of Defence-in-Depth (Jansi, Kaeri, RELKO);
- PSA incorporating severe accident counter measures (Jansi);
- more consideration of long term accidents in the PSA and of severe accident management on the long term (NRG, UJV);
- the defence-in-depth should be reinforced, as are taken into account the possible direct impact of external events on one hand and on the other hand that they could provoke additional internal hazards in NPPs. Development/improvement of the monitoring of the external events (flooding, etc.) and prevention stage in the DiD (TUS).

The existing U.S. regulations incorporate the defence-in-depth philosophy. In addition, the NRC's Fukushima Near-Term Task Force recommended establishing a logical, systematic, and coherent regulatory framework for adequate protection that appropriately balances defence-in-depth and risk considerations – the Commission is currently evaluating staff recommendations in this area.

A lesson learned from all historical (i.e. real) severe accidents is that operator errors were involved in all cases and either initiated the accident (e.g. Chernobyl, Bohunice A1) or worsened its progression (e.g. TMI2). For some situations, HRA methodologies assign very low probability (such as 1E-5) to operator failure.

Q20) Do you think that HRA methodologies should be revised or change for something more realistic?

The distribution of the responses is given below:

	YES	NO	No opinion	No answer
TOTAL ANSWERS	26	6	1	1
INDUSTRY (utilities +vendor)	9	2	-	-
TSO	15	3	-	-
REGULATORS	2	1	1	1

Table 31 - Question Q20) - Distribution of answers

33 responses were given to this question.

Approximately 81% of the utilities, 83% of the TSO and 40% of the regulators have considered that HRA methodologies should be revised or changed for something more realistic. On the other hand, approximately 18% from the utilities, 16% of the TSO and 20% of the regulators do not consider that HRA methodologies need to be revised or changed.

Most of the answers were in favour of revision or change (26 positive answers versus 2 negative), and they were complemented by the following arguments:

- applying realistic HRA methodologies is felt to be one of the major difficulties in current PSA approaches, for both Level 1 and Level 2 PSA. It is necessary to make HRA methodologies to be able to cover the following aspects:
  - stress-level during extreme events (external hazards leading to large infrastructural damages) (NRSC); Moreover, during such type of scenario the operator has likely to perform more actions simultaneously (ENEL);
  - complex situations originating from external hazards affecting multiple units (NRSC, Bel V);
  - treatment of errors of commission (NRSC); they should be included in PSA, first for events with high probability) (FKA);
  - large time windows analysis (NRSC);

- the usual HRA methodologies underestimate error probabilities under stressful situations, when the psychological effects are impossible to predict. It all differs from action to action of course, but for some of them, especially for those involving complex decision-making, higher HEP values are needed (IRNRE, Cazzoli, RNPP, TUS, UJV);

- more considerations for simulator training and operating experience in HRA methodologies is needed. (NRG) A data base developed specifically for operator failure probabilities in harsh conditions could be beneficial in obtaining better results (INR);

- for PSA level 2, the severe accident emergency organization structure (i.e., support from the Technical Support Center to the operator) applicable in most or all NPP should be modelled in the HRA (Areva, RELKO).

Negative opinions for revision were sustained by the following comments:

- it is very difficult to claim that the HRA assigned human error probabilities are too low and not realistic. The current practice is that the licensees follow the consensus HRA methodology and re-assess the importance human interactions, once they are found important to safety. Some human interactions are also subject to uncertainty analysis (CNSC);

- the key thing is that HRA methods should be properly justified and fit for the purpose of the PSA in which they are used. Very low probability can be acceptable if properly justified. In HRA methodologies, for some situations, the human error probability may be very high, more than 10^{-1}. Nevertheless, the HRA existing methodologies should be updated to take into account the hazard consequences in relation with operator action (for instance room accessibility for local action) on the power plant (EDF);

- it seems it is not a question HRA methodologies but a question of level of details in the HRA analysis or what can be taken into consideration in a L1 PSA or L2 PSA. There are some limitations on the precise modelling of accident progression, list of human actions, context (IRSN);

- it is an open question whether certain HRA methodologies lead to systematically optimistic results or if some HRA experts produce optimistically biased results. Before methods are changed, a better understanding of the role of the HRA expert in the assessment seems to be merited. Nonetheless, an improvement and extension of HRA in the PSA (as well as deterministic analyses) is needed. This includes an improvement of the data bases of human error events related to NPP staff and operation (GRS);

- there are two aspects of HRA (methodology): available resources (including uniform applicability and manageability) and consistency and objectivity of the HEP estimations. Nowadays HRA methods use some level of simplification, and on the other hand used methods are traceable and manageable. Potential drawback of an improvement (e.g. more sophisticated method) could be lack of consistency and traceability (VUJE).

Conclusions

Following the answers, it may be concluded that:

There is a general consensus on the existing influence of the operating experience on the PSA studies. All the utilities responses sustain the awareness of this influence. The information about events that may be incorporated in analyses is normally obtained through information exchange facilitated by international organizations: IAEA, OECD NEA, ENSREG, WENRA, WANO, COG, INPO.

For high amplitude natural or man-made external hazards that already concerned NPPs, in a majority of cases, detailed risk analyses have been performed. PSA was available in some cases, but not for the majority of considered events. Even for positive answers, it was specified that simplified analyses were performed.

In some cases, additional PSA studies have been developed. PSA study was extended by the following scenarios: earthquake, high winds, airplane crash, extremely high temperature, extremely low temperature, extreme snow load, tornadoes, events at low power, shutdown and Spent Fuel Pool.

Most of the studies used for assessment of hazards are L2 PSA, even if they are developed only for some cases.

There were not so many external hazards (natural or man-made) occurred that were not included in PSA but had an impact on safety, but the existing examples include: external flooding, lightning, seismic event, high temperature, low river levels, freezing of water intake, high wind. Some lessons for safety have been developed in these cases, but not so much PSA lessons have been developed related to the occurred hazards.

It was good to know that even if no lessons were developed, those events have been good examples in PSA developing process.

In most of the cases, no combinations of external hazards with significant consequences for safety have been experienced. Not so much lessons have been developed for safety from these combinations of hazards, and even less lessons related to PSA. Not many combinations of (natural and/or man-made) external hazards are considered in the PSAs studies. Still, in Germany, even if there are no such occurrences, the technical document on PSA-methods of the German PSA Guideline require an assessment of extreme weather conditions (e.g. lightning, storm, snow, ice) and combinations of these hazards.

Sometimes, internal hazards occurred in NPP as a consequence of natural or man-made external hazards. Still, even if they have induced LOOP events and reactor trips, no significant safety consequences were related to the occurrences of external hazards. Some lessons related to safety have been developed from these events, but significantly fewer lessons related to PSAs were developed.

For natural or man-made external hazards that already occurred and concerned a whole site, multi-unit issues have not been so often included in a detailed risk analysis report. In most of the cases, single unit PSA have been developed, with specific modifications, from one unit to another.

Insights from real natural or man-made external hazards that have occurred did not challenge the screening criteria in use for external hazards (for PSA or DBA).

As reasons to revise the PSA in case of external hazards were specified the following: regulatory requirements, safety significance, updating requirements.

Majority of respondents have decided to revise or to extend their PSA after the Fukushima accident.

In some cases, the work on specific topics was started before Fukushima accident. There were respondents that have taken or intend to take into consideration all the issues specified as options for revision/extension. The revision or extension of PSA concerning Spend Fuel Pool is taken into consideration by most of the respondents, followed by the revision or extension of PSA concerning list of relevant hazards, the PSA concerning low power / shutdown modes, the revision or extension of PSA concerning PSA level 2 and multi-unit PSA.

The utilities have considered that the revision or extension of the PSA concerning Spend Fuel Pool and the list of relevant hazards are high priority topics, followed by the revision or extension of the PSA concerning low power / shutdown modes. The same situation happened for TSO.

The regulators have considered that the revision or extension of the PSA concerning Spend Fuel Pool is the highest priority, followed by PSA concerning multi-units.

The revision or extension of PSA concerning PSA level 3 has obtain the lowest interest from respondents, maybe because the availability of resources, or because other issues have been considered as having a higher priority.

Other issues that were taken into consideration for revision were:

- aircraft crash, explosion pressure wave, external flooding and earthquake, solar storms (PSA level 1);
- a feasibility study for risk-informed emergency preparedness;
- severe accident response, especially for seismic scenario;
- combination of hazards + seismic induced fires and floods;
- long term accident.

There were no major modifications in the resources allocated for PSA, but in the cases when the resources were changed, they have been increased (case for all positive answers).

Generally speaking, there are no new items, but existing items need to be analysed more in depth. This is a general trend, not totally driven by Fukushima event occurrence and its consequences. NRC initiative should be mentioned – being aware of the increased need for PSA expertise, a process to train specific individuals to provide them the necessary PSA skill was developed.

As specific needs for new competences, were mentioned the following areas: external hazards characterization; external hazards probabilistic modelling and assessment; analysis of hazards combination.

For most of the respondents the requirements for PSA have changed or will be changed. The new requirements involve the reinforcement of the quality of PSA, and the extension of PSA scope (comprehensive Level 1 PSA for all internal and external hazards, consideration of spent fuel pool and multi-unit effects, LPSD events).

The recommendations made for the report on Fukushima lessons for PSA developments which will be initiated in the ASAMPSA_E project are the following:

- it should assess the impact on reference list of hazards, screening methodologies and criteria, combination of hazards, human reliability assessment methodologies (including consideration of specific emergency organization), and extended mission time to be considered;
- multi-units risk assessment (covering at least the Level 2 PSA);
- it should give a best practice how to model loss of non-safety and safety service system in combination with external hazards. The report should cover PSA technique for assessing the impact of component protection.

Expectations from the report include:

- to provide a state of the art full scope methodology for L1 and L2 external hazard PSA for all operating modes of the plant (full power, low power and shutdown operating modes). The methodology must take into account the simultaneous impact of the possible combinations of the external events;
- recommendations for external hazards PSAs development, also with practical examples, on hazards screening and calculation, SSCs fragility data and safety goals on CDF and LERF;
- insights about international activities for assessing integrated site risk, extreme external events, and mitigation measures;
- information concerning the Human Reliability Analysis and multi-unit management;
- lessons related to human and organizational factors.

Most of the responses show that safety goals have not been modified after Fukushima accident. Still, the current surrogate safety goals for nuclear power plant are on single unit basis, and the efforts to establish a new set of quantitative safety goals for multi-unit sites should be acknowledged.

A crushing majority of respondents have considered that the implementation of defence-in-depth (DiD) concept should be reinforced after the Fukushima accident. A broader and deeper application of defence-in-depth concepts should be considered so as to cope better with the most severe challenges. Low-probability but high-consequence internal and external hazards that could lead to simultaneous breaching at all levels of DiD should be taken into consideration, and enhancing the independence between the actions and equipment used to respond to escalating accident conditions at different DiD levels should be considered.

Some of the respondents feel that the current PSA techniques are suitable to assess real external hazards, but most of them have considered that HRA methodologies should be revised or changed for something more realistic, considering that especially for external hazards PSA, stress level and different conditions to perform the operator actions must be taken into account. It was considered that the usual HRA methodologies underestimate error probabilities under harsh conditions. Moreover, during such type of scenario the operator is likely to perform more actions simultaneously. HRA methodologies should be extended also, to cover complex situations originating from external hazards affecting multiple units.

3 DEFINITION AND SCOPE OF EXTENDED PSAS

Section 3 contains questions about definition and scope of extended PSA. The following particular questions are also presented:

- spreading of environmental releases,
- scope of consideration of internal and external hazards,
- objectives and applications of extended PSA,
- necessity to consider malevolent acts and ageing.

The following definition is used at the beginning of the ASAMPSA_E project:

"An extended PSA (probabilistic safety assessment) applies to a site of one or several Nuclear Power Plant(s) (NPP(s)) 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. "

An extended PSA includes an extended L1 PSA, which calculates scenarios of fuel damage (and their frequencies) and an extended L2 PSA which calculates scenarios of radioactive release (frequencies, kinetics and amplitude of release). It could include an extended L3 PSA which calculates the risk outside the site (health, economy and environment).

An extended PSA should cover for example:

- risk contribution from both reactors and spent fuel pools,

- risk contribution from:

  - internal initiating events,
  - internal hazards (internal flooding, internal fire, etc.),
  - single and correlated external hazards (earthquake, external flooding, external fire, extreme weather conditions or phenomena, oil spills, industrial accident, explosion, etc.),
  - and risk contribution from the possible combinations of previous events."

Q21) Do you endorse the above definition of an extended PSA (text in bold)?

Majority of the respondents (79%) answered "Yes". However, many of them provided comments to the definition. In general, the definition of extended PSA is consistent with the approach being taken in developing a site PSA. As a definition for a comprehensive PSA, it is suitable. This is separate from the issue of when a comprehensive PSA is necessary, versus when it is not. It was noted that it could be necessary to supplement the above-mentioned definition by requirement that extended PSA should be performed as realistic and detailed as possible. Comments are mainly related to the extend list of initiating events (e.g., transportation risk, seismically induced floods) and to necessary assessment of all radioactive sources on site, not only reactor core and spent fuel storages. For example, there was a serious incident in 2003 in Paks due the malfunction of a tank cleaning system used for removal of magnetite deposits from fuel assemblies. Even if the use of this system was temporary, we consider that potential large releases from cleaning tank accidents should be looked at in an extended PSA in this case.

Almost one-fifth of respondents answered “No”. They are related to Utilities and their TSOs. All of them provided comments on the definition of extended PSA.

Distribution of responses by respondents’ role is the following:

- Regulatory authorities and TSO
  - 91% - endorse the definition of an extended PSA
  - 9% - no, new definition was proposed
- Utility and vendors
  - 58% - endorse the definition of an extended PSA
  - 42% - no, new definition was proposed
- Service and research companies
  - 82% - endorse the definition of an extended PSA
  - 18% - no, new definition was proposed

The following observations are made:

- majority of respondents have endorsed the presented definition of an extended PSA, with some modifications;.
- new variants of the definition are proposed by respondents that did not endorse the presented definition of an extended PSA which are consistent with comments made by respondents that endorsed the presented definition;
- from regulatory point of view, the presented definition of an extended PSA is acceptable, while from the utility point of view, it requires modification;
- based on the synthesis of comments of all respondents, the following definition can be considered:

  “A ~~extended~~ comprehensive PSA (probabilistic safety assessment) applies to a site of one or several Nuclear Power Plant(s) (NPP(s)) and its environment.

  It intends to calculate the risk (which could be identified as CDF, LERF or risk to population) induced by the main sources of radioactivity (reactor core and spent fuel storages, other sources) on the site, taking into account all operating states for each main source and ~~all possible~~ the most relevant accident initiating events (both internal and external) affecting one NPP or the whole site;
- further activities are needed to develop integrated site risk metrics for multiple-unit sites.

Nota: Participants of the ASAMPSA_E Uppsala End-Users workshop [11] have agreed on the following definition: “An extended PSA (probabilistic safety assessment) applies to a site of one or several Nuclear Power Plant(s) (NPP(s)) and its environment.

It intends to calculate the risk induced by the main sources of radioactivity (reactor core and spent fuel storages, other sources) on the site, taking into account all operating states for each main source and all possible relevant accident initiating events (both internal and external) affecting one NPP or the whole site."

Q22) Currently performed Level 2 PSAs include almost exclusively releases into the air. The case of Fukushima, where a large part of radioactivity has been released into the ocean, is not considered in many PSAs.
Do you think that "extended" PSAs should enlarge the scope to the releases into the waters and ground?

Majority of the respondents (74%) answered "Yes". Given the meteorological conditions during the accident at Fukushima, the vast majority of releases were dispersed in the ocean. At Chernobyl too, a large contamination of the water ways has been and is still a concern. Certainly releases of radioactivity through liquid pathways should be considered. This is the base also for accidents that are predicted to release radioactivity to the ground (after erosion of the concrete basemat). However, the decision on the considered releases should be based on:

- 1) the site (plant) characteristics and location. If support analyses show that the impact is negligible or small be compared to the air releases then they may be excluded from analysis;
- 2) scope of PSA. In order to compute short-term health effects of nuclear disasters, releases to the water or the ground are very likely not relevant. If a PSA (level 2 or 3) is restricted to this purpose, then considering these releases is of lower importance. However, for a more complete picture on medium-term to long-term effects of a nuclear accident (loss of land, socio-economic impact, etc.), the complete releases should be considered and determined within the PSA.

Many respondents have pointed out that currently there are no appropriate methodology (taking into account difficulties with uncertainties of calculations), models and analytical tools available. The current Level 3 methodology has its limitation and cannot evaluate the impact of waterborne and underground releases. New research should be carried out to evaluate the impact of radioactive releases to the water (including fresh water body and the oceans) and ground. The international community should cooperate in developing a new methodology to evaluate such impacts.

Almost one-fifth of respondents answered "no" or "no opinion". There is not a simple yes/no to this question. It depends on the application of the extended PSA, and more specifically, the consequence metrics are to be used. For instance, if the extended PSA is focused primarily on estimating risks to public health and safety, these risks are likely to be dominated by airborne releases. On the other hand, if the extended PSA is also focused on estimating environmental impacts close to the site or total accident costs, then modelling non-airborne pathways could be important (even though in the case of environmental impact statements and cost-benefit analyses they are usually said to be a small fraction of the airborne pathway impacts). It was also expressed that there are too much uncertainties on the predominant factors for ground and water dispersion and releases: this scope is not realistic in the frame of this project.

Distribution of responses by respondents' role is the following:

- Regulatory authorities and TSO
  - 64% - yes
  - 9% - no
  - 27% - no opinion
- Utility and TSO
  - 58% - yes
  - 34% - no
  - 8% - no opinion
- Service and research companies
  - 91% - yes
  - 9% - no
  - 0% - no opinion

In our opinion, a large number of service and research companies that answered "yes" may reflect their willingness and availability to provide engineering services to consumers.

Q23) In your opinion, should some risk contributions due to internal hazards be calculated systematically in extended PSAs (please mark with an X)?

- Internal fire
- Internal flooding
- Internal explosion
- Other (please comment)

15% of respondents answered "no" or "no answer". The main reason is as follows: risk contributions due to internal hazards have to be systematically taken into account but do not have to be calculated systematically. If systematically means compulsory, the answer is "no" because it contradicts PSA philosophy; this is the objective of the screening process to select the internal hazards for which contribution to the risk needs to be calculated. Quantifications should occur where relevant and a wide range of quantification approaches shall be possible.

Remaining respondents (85%) marked all listed internal hazards (but a little bit less (62% of total) for explosions). They consider that a systematic analysis of all the internal hazards should be performed. The list of internal hazards that require detailed analysis (modelling) and quantification should be design- and plant-specific. Other potentially important internal hazards can include:

- heavy load drops;
- high-energy piping breaks (if not considered within internal flooding PSA);
- turbine and other missiles;

- release of gases, oil spills, steam or noxious substances.

Further to the above note on what should be analysed systematically, they believe that, in accordance with existing PSA guides, IAEA recommendations and utility requirements, screening of internal hazards should be used to focus the analysis on hazards that require detailed analysis and to minimize the emphasis on hazards that are unimportant to risk. The screening process includes qualitative and quantitative screening, and it has to be applied consistently using pre-defined screening criteria to ensure that no risk contributor from any hazard relevant to the plant is omitted. Risk contribution of hazards screened out quantitatively should be considered and described in the overall risk characterization even if no detailed ("systematic") quantification is applied to the screened-out hazards.

Distribution of responses by respondents' role is the following:

- Regulatory authorities and TSOs
  - 46% - internal fires, floods, and explosions
  - 36% - only internal fires and floods
  - 18% - no or no answer
- Utility and vendors
  - 67% - internal fires, floods, and explosions
  - 25% - only internal fires and floods
  - 8% - no or no answer
- Service and research companies
  - 91% - internal fires, floods, and explosions
  - 0 % - only internal fires and floods
  - 9% - no or no answer

The following observations are made:

- majority of respondents believe that internal fires, floods, and explosions should be systematically analysed, many of them proposed additional internal hazards to be considered. Also it was noted that risk contributions due to internal hazards have to be systematically taken into account but do not have to be calculated systematically. Quantifications should occur where relevant and a wide range of quantification approaches shall be possible;
- in general, risk contribution due to internal explosion is assumed to be less important than risk contributions due to internal fire or internal flooding, but this may depend on plant specificities;
- In our opinion, a large number of service and research companies that selected the whole list of internal hazards may reflect their willingness and availability to provide engineering services to consumers.

Q24) In your opinion, should some risk contributions due to external hazards be calculated systematically in extended PSAs (please mark with an X)?

- Earthquake
- External flooding
- External fire
- Extreme weather conditions or phenomena
- Airplane crash
- Other (please comment)

More than one-fifth of respondents answered “no” or “no answer”. The main reason is as follows: risk contributions due to external hazards have to be systematically taken into account but do not have to be calculated systematically. If systematically means compulsory, the answer is “no” because it contradicts PSA philosophy; this is the objective of the screening process to select the external hazards for which contribution to the risk needs to be calculated. Quantifications should occur where relevant and a wide range of quantification approaches shall be possible. On the other hand, it was mentioned that it is difficult to answer that a given hazard needs to be systematically considered for PSA modelling. The screening phase fits for this purpose. However it is our experience that the consideration of some extreme weather phenomena and marine infestations (affecting the ultimate heat sink or the external grid) are often screened-in for modelling. Earthquake is also often modelled as the associated risk contribution is not negligible considering the low risk level achieved.

Remaining respondents marked different external hazards: 79% - earthquakes, 76% - external fires, 56% - external floods, 71% - extreme weather conditions, 59% - airplane crash. External hazards need to be calculated systematically, taking into account the site characteristics. Only those hazards relevant to the site should be calculated in detail; however the risk analysis of the hazards on the site should be comprehensive. A screening procedure should be derived to get a list of relevant site-specific external hazards and relevant combinations of external hazards from a given generic comprehensive list of external hazards. The screening process included qualitative and quantitative screening, and it has to be applied consistently using pre-designed screening criteria to ensure that no risk contributor from any hazard relevant to the plant is omitted. Risk contribution of hazards screened out quantitatively should be considered and described in the overall risk characterization even if no detailed ("systematic") quantification is applied to the screened-out hazards.

Distribution of responses by respondents’ role is the following:

- Regulatory authorities and TSOs
  - 82% - earthquakes
  - 82% - external flooding
  - 36% - external fires
  - 64% - extreme weather conditions or phenomena
  - 36% - airplane crash
  - 18% - no or no answer
- Utility and vendors

  - 67% - earthquakes
  - 58% - external flooding
  - 50% - external fires
  - 67% - extreme weather conditions or phenomena
  - 67% - airplane crash
  - 33% - no or no answer
- Service and research companies
  - 91% - earthquakes
  - 91% - external flooding
  - 82% - external fires
  - 82% - extreme weather conditions or phenomena
  - 73% - airplane crash
  - 9% - no or no answer

The following observations are made:

- majority of respondents believe that earthquakes, external fires and floods, extreme weather conditions and airplane crash should be systematically analysed. Many of them noted that risk contributions due to external hazards have to be systematically taken into account but do not have to be calculated systematically. Quantifications should occur where relevant and a wide range of quantification approaches shall be possible;
- transport of dangerous substances, accidents in industrial or military facilities located in the vicinity of NPP have been proposed to be systematically analysed;
- a comprehensive list of external hazards was attached to the questionnaire (see Appendix 1). This comprehensive list can be a good starting point for the above systematic analysis. Thus it is not necessary to repeat the detailed list in response to this question;
- based on the number of responses, external hazards can be arranged by order of priority: 1) earthquakes, 2) external floods, 3) extreme weather conditions, 4) airplane crash, 5) external fires;
- in our opinion, a large number of service and research companies that selected many of external hazards may reflect their willingness and availability to provide engineering services to consumers.

Q25) In your opinion, an extended PSA should include a risk quantification for (please mark with an X):

- All possible internal and external hazards
- Or only for a limited number of hazards, identified as the most relevant
- All possible combinations
- Or only a limited number of combinations, identified as the most relevant

Regarding inclusion of risk quantification in an extended PSA, 32 organizations expressed an opinion while 2 did not.

In 41% of expressed answers, respondents consider that a risk quantification for all possible internal and external hazards should be included. Their exclusion depends on the probability and in many cases several events that give insignificant effects are screened out. In some cases, it is almost impossible to establish a realistic frequency also due to lack of data. Conservative assumptions shall be avoided or handled with specific attention. But, in all cases, appropriate screening of hazards, initiating events, accident sequences, etc. should be permitted, consistent with PSA standards and the current state of practices. Note that only combinations relevant to the site should be considered.

A slight majority (59% of expressed answers) answered that extended PSA should include risk quantification for a limited number of hazards, identified as the most relevant. They argue their position that the internal and external hazards and their combinations should be classified taking into account the site characteristics. There are three groups of hazards and combinations of hazards, the first group contains hazards without relevance (the risk can be neglected), the second group contains hazards for which a rough risk estimation is sufficient (it can be shown that the risk is less than a given threshold) and the third group contains all the hazards for which a comprehensive risk analysis is necessary.

Regarding combinations, 28 organizations expressed an opinion while 6 did not.

For 29% of expressed answers, risk quantification for all possible combinations should be included in an extended PSA.

Remaining respondents (71% of expressed answers) supports that extended PSA should include risk quantification for a limited number of combinations, identified as the most relevant. The answers are basically the same as the answers to the previous two questions above. A systematic analysis needs to be performed to identify those combinations of hazards that are relevant and require detailed analysis based on their frequency of occurrence and/or impact on plant systems, structure and equipment. The residual risk from those hazards that are not subject to detailed analysis due to their low risk significance should also be described (e.g. by a bounding risk assessment).

Distribution of responses by respondents' role is the following:

- Regulatory authorities and TSOs
    - 36% - all possible internal and external hazards
    - 64% - or only for a limited number of hazards, identified as the most relevant

    - 27% -all possible combinations
    - 73% - or only a limited number of combinations, identified as the most relevant
    - 0% - no answer
- Utility and vendors

- 42% - all possible internal and external hazards
- 58% - or only for a limited number of hazards, identified as the most relevant

- 25% -all possible combinations
- 58% - or only a limited number of combinations, identified as the most relevant
- 17% - no answer

- Service and research companies
    - 36% - all possible internal and external hazards
    - 64% - or only for a limited number of hazards, identified as the most relevant

    - 18% -all possible combinations
    - 64% - or only a limited number of combinations, identified as the most relevant
    - 18% - no answer

Hazards due to malevolent acts (sabotage, terrorism, war) are assessed in safety analysis, however due to obvious reasons these assessments are only accessible to a limited group.

Q26) Do you think extended PSAs should address the risk due to malevolent acts? (Sensitive details of the assessment could remain secret, but the overall risk contribution could be disclosed)

Approximately two-thirds of respondents (65%) think that extended PSAs should not address the risk due to malevolent acts. The choice was argued as follows: estimates of risk contribution due to malevolent acts would be subject to very high (epistemic) uncertainties (poor knowledge of potential scenarios, little or no operational feedback, …) and therefore lack of credibility. Malevolent acts are pure arbitrary and it is almost impossible to assign a set of meaningful numbers to the threats of interest. Thus the PSA for malevolent acts will only give some numbers without any basis. Basically, the protection against malevolent acts is deterministic, the probabilistic approach in this field is not considered as relevant (nevertheless PSA insights could be used as inputs for the analysis). It is recommended that the malevolent acts remain in the scope of deterministic safety analysis. However, PSAs can be used to inform decision-making activities with respect to security at NPPs by identifying the most vulnerable systems and evaluating potential scenarios assuming that a malevolent act has taken place at a specific area within a site.

Positive answers (35%) are mainly based on the possibility to increase the plant security and safety and to develop safety-security interface. It was pointed out that the malevolent acts should be in the area of security rather than safety. However, it was stressed that the current use is insignificant: NPP already carries very large risks and the potential for disastrous consequences is too high. It should be demonstrated that risks from malevolent acts are negligible (an impossible task, since the potential of consequences for each and every existing plant is large regardless the initiator). But in general, without this risk contributor, the spectrum of risk contributors presented in PSAs (and the total risk value) is not complete. Respondents also indicated issue related to difficulties arising from quantification of parameters.

Distribution of responses by respondents' role is the following:

- Regulatory authorities and TSOs
  - 27% - yes
  - 73% - no
- Utility and vendors
  - 25% - yes
  - 75% - no
- Service and research companies
  - 55% - yes
  - 45% - no

The following observations are made:

- overall tendency is that malevolent acts should not be included in extended PSA;
- however, a PSA study of malevolent acts can be performed to complete integrated picture of risk, and to enhance plant security;
- majority of respondents (including those who answered "yes") believe that malevolent acts are related more to security that safety, pointed out difficulties to access probabilities and a very large number of uncertainties;
- in our opinion, a high number of service and research companies that answered "yes" may reflect their willingness and availability to provide engineering services to consumers.

Q27) Do you consider ageing should be reflected in extended PSAs?

All respondents provided their answers:

Yes	22
No	12

Approximately two-thirds of respondents (62%) supported the consideration of ageing in extended PSA. PSA should be as close as possible to the real state of the plant, and therefore, should reflect as-built and as-operated conditions (including ageing). PSAs should be regularly updated, taking into account the most recent operational feedback. In this way, not only effects of ageing (e.g., degrading reliability or increasing unavailability) but also effects of equipment replacement (e.g., improved reliabilities) could be reflected to some extent. Without involving the aging process, the risk profile is not fully correct, but the consensus methodology should be developed.

Those respondents that do not support including ageing effects in an extended PSA comment their position as follows: PSA should be updated regularly with sufficiently short intervals. Thus, any ageing effects would be reflected in updated PSA results. NPP operators should aim at continuously reducing the risk level of their plants, despite existing ageing effects, by implementing a comprehensive ageing management and back fitting program. Thus, explicit consideration of ageing in the PSA adds no value. Using PSA results for timescales on which ageing becomes relevant (i.e. 20 years) seems to be a questionable approach.

Distribution of responses by respondents' role is the following:

- Regulatory authorities and TSOs
  - 73% - yes
  - 27% - no
- Utility and vendors
  - 50% - yes
  - 50% - no
- Service and research companies
  - 73% - yes
  - 27% - no

The following observations are made:

- the question was about direct modelling of ageing in extended PSA. Majority of respondents supported consideration of ageing in extended PSA. However, the overall tendency of respondents can be reflected by the US NRC comment "A simple yes or no answer does not seem appropriate. Most PSAs do account for ageing in the sense that the data used to estimate failure probabilities includes ageing-related failures that have occurred in-service. However, it is still beyond the state-of-practice to actually model ageing mechanisms within the PSA, and in this sense an extended PSA cannot consider aging without significant resource expenditures";
- ageing is an open issue for overall PSA but not exclusively for extended PSA. NPP lifetime extension measures are underway, so the ageing effect should be assessed in PSA for that purpose. PSA with reflected ageing is a more credible tool for proving that NPP life extension does not pose a significant risk;
- the following expectation of respondents is also observed: critical ageing effects should be included in a basic or normal PSA. Ageing is important part of a living PSA concept and shall always be reflected in new versions of the PSA for a plant. There is an opinion that for most of the components ageing shall not affect the failure rate. Maintenance and testing shall keep the failure frequencies on a constant level or even try to reduce the failure rates to lower values. Extended PSA should give the best practice of how to model ageing in PSA.

Q28) Are you supporting the idea:

- to have separate PSA studies for each hazard
- to have a global study, that aggregates all hazards?

Please justify your choice, in terms of advantages-disadvantages.

The answers are the following:

global study	26
separate PSAs	4
No answer	4 (no answer (2), no opinion (1) or not understood question (1)).

<u>Comments supporting to have a global study</u>

The global study seems necessary to 26 organizations. The expected benefits of such a study are the followings:

- to be able to obtain both an overall picture of risk for a plant along with a contribution of the different hazards;
- to enable the achievement of results at the right level for applications, particularly in terms of importance factors;
- to be easier to maintain than several separate models.

In terms of development of this type of global study, difficulties are however mentioned such as the impact on the size of models and on the amount of resources needed for its development. A question is raised about the scope of such a study. Should it be limited to the most significant hazards or should it take into account all plausible hazards? For some organizations (8), the development of such a global model must begin with the development of detailed models for each hazard which will be then aggregated into a single model. Thus to ease this aggregation and to get a consistent global model, one must take into account the dependencies between hazards and use consistent methods and the same data base for each specific model.

<u>Comments supporting to have separate PSA studies</u>

For 3 organizations, the aggregation of hazard models into a global model would not make sense because of the differences in level of detail and of the uncertainties. A "simple" risk aggregation could then hide significant problems for a given hazard.

One respondent thinks that hazard PSA are not yet mature studies (ongoing development). However, these hazard PSAs can be considered – without any aggregation – as a global study for a given plant.

<u>There is a majority which supports to have a global study</u>. However some difficulties are expected with this kind of model, which need to be discussed (size of the model, amount of resources, scope, etc.).

Q29) Do you think that the primary objective of your PSAs is:

- evaluation of risks
- identification of safety improvement
- fulfilment of authority’s requirements?

33 respondents provided answers. Majority of respondents (40%) selected all three objectives as the primary objectives for their PSA. A general tendency is that PSA should be used mainly to identify and evaluate risks and to make improvements for decreasing and optimizing the relative risk distribution, with understanding that the authority's requirements are obligatory for fulfilment. The following was commented by US NRC: "PSAs are used for all 3 of these. For instance, PSA results are used for comparison with the Safety Goals (evaluation of risks), PSA results are used to inform whether new regulatory requirements should be imposed (either to provide reasonable assurance of adequate protection of public health and safety or to realize a substantial safety improvement that is cost-justified), and PSA results are used in the enforcement process to establish the severity of a performance deficiency or accident precursor. Since extended L3 PSAs are very costly to do at this time, and necessitate site-specific analysis (rather than a fleet-wide approach), it is most likely that an extended PSA would be used for informing underlying components of each of these 3 items."

Almost one-fourth of respondents selected the option "identification of safety improvement".
One-fifth of respondents selected both, evaluation of risks or identification of safety improvement, as the primary objective, while roughly the same number of respondents selected only evaluation of risks. No respondents selected the last option "fulfilment of authority's requirements".

Distribution of responses by respondents' role is the following:

- Regulatory authorities and TSOs
  - 46% - all objectives
  - 18% - evaluation of risks
  - 18%- identification of safety improvement
  - 18% - both, evaluation of risks and identification of safety improvement
- Utility and vendors
  - 42% - all objectives
  - 8% - evaluation of risks
  - 42%- identification of safety improvement
  - 8% - both, evaluation of risks and identification of safety improvement
- Service and research companies
  - 45% - all objectives
  - 20% - evaluation of risks
  - 10%- identification of safety improvement
  - 25% - both, evaluation of risks and identification of safety improvement

The following observations are made:

- from a technical perspective, respondents believe that the primary PSA objectives can be ordered as follows: 1 - identification of safety improvement; 2 - evaluation of risks; 3 - fulfilment of authority's requirements. Wherein, the first two are the primary objectives with understanding that the authority's requirements are obligatory for fulfilment in any country;

- other than the objectives mentioned above, the PSA has some other important objectives in Canada, such as the identification of plant vulnerabilities to internal hazards, the identification of systems important to safety and support of safe operation, etc.

Q30) Please define the "ideal extended PSA" for your case, and specify the main differences between your current PSA and the ideal one. Please detail the main difficulties to develop the ideal one.

This is a much challenging question to answer and analyse. 31 respondents proposed different definitions of their "ideal extended PSA" and associated main difficulties.

From responses of regulatory authorities (and TSOs), the following definition can be synthesized:

- **PSA of Levels 1 Level 2 that covers all relevant initiators among the potential internal events, internal hazards and external hazards, for all relevant plant operating states, and for all locations of fuel assemblies (core, spent fuel storage) at the plant.**

Key attributes of an "ideal extended PSA":

- analysis of all potential sources of large releases (reactor and spent fuel pool) and all possible operating states;
- full coverage of initiating events (internal events, internal and external hazards, and their combinations) relevant in terms of potential severe accidents
- systematic approach to screen initiating events that need detailed modelling and risk quantification by applying predefined screening criteria
- explicit estimation of cumulative residual risk from all screened-out initiating events as surrogate risk factors (at least an upper bound estimate)
- realistic risk quantification regardless of the initiating event and possibility of comparing and ranking of risks (reactor vs. spent fuel pool, nominal power vs. shutdown states, etc.)
- facilitated assessment/development of emergency/accident management procedures and provision of comprehensive information for off-site emergency planning
- definition of PSA end states for both level 1 and level 2 PSAs to enable the assessment of consequences and frequencies of severe accidents
- an integrated, computerized risk model and documentation for the entire analysis (all radioactivity sources, all initiating events, all plant operating states in level 1 and level 2 analysis, etc.) that can be directly applied to compare the analysis results with risk criteria and are traceable, easy to review and reproduce and appropriate as a basis for numerous PSA applications in a risk-informed decision-making framework in an extended sense.

The main difficulties to develop the ideal one include:

- the resources to cover a complete range of internal and external hazards, to process a large amount of detailed plant data;
- the lack of the consensus methodology or state of practice (e.g., for appropriate modelling of hazard types; for developing a full PSA for spent fuel pools or dry storage casks);
- the lack of previous experiences;
- the lack of appropriate data and a lot of uncertainties.

From responses of utilities and vendors, the following definition can be synthesized:

- **Level 1 and Level 2 PSA is one that covers all internal events, internal hazards and external hazards which are applicable to NPP site (with the same level of detail/realism), for all plant operating states and for all radioactive sources on site.**

The main difficulties to develop “ideal extended PSA” are the same as for regulatory authorities, with some additional aspects stipulated by the definition:

- to identify all dependencies between systems, components and human actions and finally to implement this in the model
- to develop a respective powerful PSA-tool beyond the classical FT/ET tools (e.g. dynamic models) which is able to handle all these issues with acceptable effort for the PSA model developer and user and provides acceptable calculation times.

The following observations are made:

- the differences exist between the definition of “ideal extended PSA” in respondents’ case and definition of an “extended PSA” (proposed by respondents under Q21). The following aspects are not mentioned in majority of responses for “ideal extended PSA”: sources of radioactivity other than reactor core and spent fuel pool; consideration of risk to population.
- slight differences must be brought between ideal "theoretical" PSA and ideal "practical" PSA for the sake of safety improvements. Many definitions under Q21 and Q30 for extended PSA are related to ideal "theoretical" PSA and, therefore, the above ideal extended PSA cannot be considered as a reasonable objective and an ideal "practical" PSA has to be defined. This would be more pragmatic and should achieve the best balance between project needs, resources, safety and uncertainties. The ideal "practical" PSA could include relevant initiators and hazards, provide justifications for its scope, have fit-for-purpose and graded approaches for each and every hazard, provide explicit limitations and uncertainties for each and every initiator and hazard
- similar to Q21, respondents from the utility side provide requirements for more detailed, more comprehensive and more complicated PSA than other respondents.

Q31) If you consider that an "ideal extended PSA" requests too many resources, which part would you consider as worthwhile, having in mind a balance between effort and usefulness?

The ideal "practical" PSA requires a lot of resources but not too many, by definition. Having in mind the balance between effort and usefulness, the following worthwhile areas or goals are considered by respondents (sorted by the number of references):

1) Upgrading of hazard analysis, including:
   - good screening process, screening criteria at different levels (former hazard frequency, qualitative hazard risk and finally quantitative hazard risk),
   - feasible combination of external events,
   - development of methods for construction of hazard curves and fragility curves for external hazards taking into consideration all possible combination. It should be developed using state-of-the-art knowledge in these domains;
2) Development of PSA according to the definition of an extended PSA;
3) Development of PSA for the most important and most probable internal and external events and hazards relevant for NPP. According to IRSN, development of simplified additional PSA modelling (even with conservative assumptions) seems to be the only solution to extend the scope of PSA with limited resources. If some risk dominant accidents are identified, it can then either be modelled with more realistic assumptions or conduct to NPP improvement;
4) Development of PSA for multi-unit site, considering multi-units events;
5) Human reliability analysis for hazards conditions;
6) Extension of level 2 PSA to shutdown states.

Q32) Which part of an extended PSA would you request OR be willing to develop? What will be your motivation for it?

Not all respondents provided their answers (some of them) made reference on the previous questions.

Summarizing the information obtained, the following studies of an extended PSA are going to be developed by respondents:

- upgrade of hazard analysis (to get more accurate calculation/risk insights) (Areva);
- the whole site PSA for multi-unit sites and the PSA for external hazards (CNSC);
- firstly, the hazard screening methodology and secondly a set of graded probabilistic approaches, including hazards characterization and consequences on NPP analysis, thirdly detailed PSA dedicated to the most relevant events and hazards (the main motivation is to reach a balance between effort and usefulness in order to guaranty a high safety level) (EDF);

- seismic PSA (ENEL, RNPP);
- development of data for initiating event frequencies down to 10-6/year and understanding of consequences for events that are beyond design, projects that reduces uncertainties of other data (FKA);
- PSA extension (L2 PSA for spent fuel pool, L2 PSA for shutdown and external hazard, combination of hazard events with other initiating events/hazards, site-specific Hazards PSA) (Germany);
- combination between a hazard PSA Level-1 identified as having an important impact on safety and another hazard, induced by the first one, may provide interesting issues for discussions (INR);
- feasible combination of external events (INRNE);
- external hazards analysis for each reactor depend on screening results (IRSN);
- combined PSA of internal event, internal fire and internal flood caused by external hazard of earthquake coupled with tsunami (Jansi);
- multi-unit PSA Level 1 & 2, and relevant risk metrics (KAERI);
- all parts of an extended PSA, a long standing effort to risk-inform the licensing basis of NPPs with respect to internal fire (U.S. NRC);
- parts of L1 PSA: Identification of critical combinations of external hazards to be analysed in PSA, Incorporation of ageing aspects in PSA model. Issues related to fire PSA (NRSC);
- all internal and external hazards which are applicable for the NPP site; all radioactive sources on site; all operating mode of the units (Kozloduy NPP);
- level 3 PSA (according to recent authority requirement it is a vital task) (MVM Paks II);
- extending PSA to external events other than earthquakes including both the reactor and the spent fuel pool, advancement in developing methods to characterize fragility of SSCs for different types of external events and the associated loads, creating an integrated risk model (only for level 1 PSA first), modelling multi-unit effects and risk impact of external events. Full scope PSA, comprehensive (extended) PSA to have better, more credible risk assessment and to support risk-informed applications (safety management and regulation) (NUBIKI);
- verify the existing analysis to ensure that we do not miss any hazards/event (Ringhals);
- assessment of the most important and most probable internal and external events and hazards relevant for the NPP, incl. man-made and the possible combinations of them (TUS);
- higher credit of the PSA under concern and, consequently, broader area of applications both on the utility and on the regulatory side (UJV).

Also was mentioned that the main incentive to extend PSA would come from the revised WENRA reference Levels (in particular, for issue O - PSA) (Bel V). Regulatory body (SNSA) has already requires PSA L1 and L2 for all modes of operation, and considering to add all sources of radiation and also requirement for L3.

Interpretation of the obtained results reveals the following areas on the further PSA activities:

- full scope PSA (all operational modes and radioactivity sources, all internal and external hazards),
- enhancing the existing PSA (incl. methodology aspects, screening, reducing of the uncertainties, etc.),

- seismic PSA,
- whole site PSA for multi-unit sites, consideration of the hazards combination,
- PSA Level 3.

Q33) Do you intend to include extended PSA in safety approach or in decision-making process?

Yes	31
No	1
No answer or no opinion	2

More than 90% of respondents answered that they intend to include extended PSA in safety approach or in decision-making process, or pieces of extended PSAs are being used for decision-making. Several respondents mentioned that there is no difference between using extended PSA and using basic PSA in safety approach or in decision-making process, and PSA studies have been already used in practice.

At the same time, a number of issues/concerns of the using of extended PSA were identified by the respondents:

- introduction of conservative modelling due to lack of data may hide or adversely affect risk insights from other parts of the modelling (Areva);
- the reliability of the results, depending on the reliability of the input data (such as hazard curves or fragilities). If the input data do not reflect the "as-is" status of the plant, the results would be meaningless (ENEL);
- how to treat the case where the risk by external hazard becomes far larger than that by internal events or internal hazard (Jansi);
- consistency of the different parts of extended PSAs should be ensured (realism) (IRSN);
- the quality of the PSA model (reflecting to the trust that the PSA model represents correctly the current configuration of the unit) (Kozloduy NPP);
- to fill in the existing gaps in PSA as a pre-condition for decision making to be based on an extended PSA (Nubiki);
- provided that the extended PSA is well developed and based on credible data (data may be a big problem), it should be credible and used in decision making process without specific difficulties (UJV).

Regulators highlight the importance of education/training of the non-practitioners on how to use PSA to make adequate decisions. Several respondents addressed the issue with the treatment of uncertainties in the decision making process.

Interpretation of the obtained results reveals the following needs for end-users:

- to develop a common framework and to ensure consistency with already available PSA and the associated decision making approaches;
- to develop practical guidance and tools to help make the decision making process "simple", structured and transparent;

- to develop the regulations on the use of PSAs, including appropriate criteria for risk-informed decision making using extended PSA.

4 USES AND APPLICATIONS OF EXTENDED PSAS

This section intends to identify extended PSAs application that end-users consider as being most important. It will help the ASAMPSA_E project to make its efforts commensurate to end-users' needs.

4.1 REGULATORY FRAMEWORK

Q34) A - Are PSAs required in your country by the regulator?

All, with the exception of one country, answered Yes.

In one country the PSA is required for new reactors, for currently operating NPP's is not obligatory.

In one country the PSA is required currently to some extent (for some administrative acts), with the foreseen increased importance given by the newly updated Atomic Law.

B – Or are they developed on a voluntary basis?

Only five respondents answered Yes.

In several participating countries the PSA was developed on a voluntary basis in the past (in the framework of the PSR), but nowadays PSA is required by the regulator.

In one country the PSA is developed on a voluntary basis and all currently operating reactors have at least an at-power, internal events PSA model that calculates core damage frequency ("Level 1") and large early release frequency (partial "Level 2").

Q35) Do you have regulatory requirements on external hazards PSAs?

In all countries, with the exception of two, it is required to consider external hazards in PSA.

The requirement refers to L1 and L2 PSA, for all operating modes, for existing and new units.

In one country it is also required to consider external hazards in the transfers between states.

One of the respondents commented that their PSA Guideline and its supplementary documents are currently revised including methods for L2 PSA. In current guideline the following internal and external hazards are covered: fire, internal flooding, aircraft crash, explosion pressure wave, external flooding and earthquake. The risk contribution of other external hazards such as toxic clouds, external fires, ship collision with intake structures, extreme weather conditions (e.g. lightning, storm, snow, ice and combinations of these), and biological phenomena have to be only roughly estimated.

In one of the countries the requirement on external hazards is for new reactors only. For currently operating reactors there is no requirement for external events PSAs.

In one country the regulatory body does not establish detail requirements for external hazards PSA, but it requires include in PSA at least those external hazards that are analysed in detail performing NPP site evaluation.

Q36) In view of the fact that most of the work performed within a PSA carries a disclaimer with respect to liabilities, but also given that the Italian judiciary set a precedent two years ago with respect to criminal responsibility of technical personnel in failing to inform the public about seismic risks in Abruzzo.

A – Do you think that PSA results should be made available for the public?

All, with the exception of three countries, answered Yes.

One argument for not making the results public is that the current public does not fully understand the meaning of a PSA. The risk of the abuse of the information for the sabotage actions against the plants by terrorists is identified.

Proposal to speak about the safety improvements that have been done due to the PSA conclusion, the impact of the improvements on safety (between the starting date of the plant and now) and usage of percentages is made.

Suggestion is made for making available only the brief summary with removal of the sensitive information's.

Concerns about extent, type and interpretation of the results are given in the comments of the respondents.

Proposal for presentation of the PSA results in the suitable format, which would avoid results misinterpretation and which would provide clear understanding of the results is given.

In some countries the results are made public, but not the analysis (PSA model). Specific risk information that is deemed sensitive from a security perspective may be withheld from public disclosure.

One of the respondents suggested that the lessons for plant safety, beside numerical results, should be made available to the public.

B - Do you think that an extended PSA performed by the operators should go well beyond the local authority requirements and attempt to explore as carefully as possible areas that are not covered by requirements?

Opinions about this question were divided (12 Yes, 14 No) with no clear consensus.

Several answers indicate that the question was not fully clear, and difficulty to understand the term "well beyond".

Several respondents stated that the regulatory requirements should be considered as a required minimum and not use PSA as a tool to fulfil the authorities' requirements.

Need for constant update of regulation following closely all new knowledge and trends is identified in order to assure the performance of comprehensive PSA is identified.

The limitations considering the resources set the licensees top priority to comply with the regulatory requirements in some of the countries.

Application of time/cost analysis in order to identify relevant hazards for extended PSA, in order not to spend too many resources to calculate a CDF related to a hazard with very low probability of occurrence (e.g. meteorites' impacts, solar storms etc.) is suggested.

Need for investigation beyond the local authority requirements done by research organization is recognized.

Conclusions and/or recommendations for the project from Section 4.1 REGULATORY FRAMEWORK

The PSA is required by the regulators with initial development initiated on a voluntary basis that later developed in the inclusion in the regulatory framework.

The regulatory requirements include consideration of external hazards in PSA. The type and extent of the external hazards that are considered in the PSA differs between the countries.

The regulatory requirements should be considered as a required minimum.

Need for constant update of regulation following closely all new knowledge and trends is identified in order to assure the performance of comprehensive PSA.

There is general consensus that PSA results should be made available to the public.

The PSA results should be formatted for the public in order to be comprehensible avoiding results misinterpretation. Specific risk information that is deemed sensitive from a security perspective should be withheld from the public disclosure.

4.2 USES AND APPLICATIONS OF EXTENDED PSAS

The following uses and applications can be identified:

- support NPP design or design modifications,
- support periodic safety reviews,
- assessment of the overall level of safety,
- comparison with safety criteria,
- identification of potential weaknesses in design and operation,
- identification of safety improvements to reduce overall risk,
- use of extended PSAs to verify application of the concept of defence-in-depth,
- use of extended PSAs for optimizing NPP test and maintenance programs,
- use of extended PSAs for optimizing NPP technical specifications,
- use of PSA to support exemptions to technical specifications,
- use of extended PSAs to evaluate safety significance of events or non-conformities and for event importance ranking,
- use of extended PSAs to improve operators training programs,
- risk-informed regulation (cf. [4]),
- risk informed classification of SSCs,
- risk informed in-service inspection,
- development and improvement of plant procedures, especially EOP,
- severe accident management,
- emergency planning,
- assessment of off-site consequences of accidents,
- support plant lifetime extension,
- prioritization of research,

- assessing protection against internal and / or external hazards (in addition to deterministic approaches).

The answers given by the respondents are summarized below according to the questions in the questionnaire.

Q37) Please provide your opinion on the prioritization of the uses and applications of extended PSA (select the 5 tasks of the above list which you consider the most important). Since prioritization may be a function of different aspects, could you provide SEPARATELY your list (1 to 5) on the basis of:

A - demands from laws and regulators

B - demands coming from your company (safety policies, upper management)

C - wishes from internal experts on safety and risk evaluation

D - recommendations from external experts or independent reviewers

The following table synthetize the answers to the questions 37A, 37B, 37C and 37D.

	A	B	C	D
Support NPP design or design modifications	24%	26%	24%	9%
Support periodic safety reviews	38%	15%	15%	9%
Assessment of the overall level of safety	50%	35%	41%	12%
Comparison with safety criteria	47%	9%	12%	12%
Identification of potential weaknesses in design and operation	35%	32%	38%	6%
Identification of safety improvements to reduce overall risk	50%	41%	32%	24%
Use of extended PSAs to verify application of the concept of defence-in-depth	24%	12%	12%	3%
Use of extended PSAs for optimizing NPP test and maintenance programs	6%	24%	12%	6%
Use of extended PSAs for optimizing NPP technical specifications	3%	15%	9%	15%
Use of PSA to support exemptions to technical specifications	3%	12%	3%	0%
Use of extended PSAs to evaluate safety significance of events or non-conformities and for event importance ranking	9%	18%	15%	0%
Use of extended PSAs to improve operators training programs	6%	9%	6%	6%
Risk-informed regulation	3%	9%	12%	6%
Risk informed classification of SSCs	3%	9%	15%	6%
Risk informed in-service inspection	3%	3%	3%	0%
Development and improvement of plant procedures, especially EOP	9%	12%	18%	6%
Severe accident management	24%	9%	18%	6%
Emergency planning	0%	3%	3%	6%
Assessment of off-site consequences of accidents	12%	6%	6%	12%
Support plant lifetime extension	3%	15%	15%	3%
Prioritization of research	0%	6%	3%	0%
Assessing protection against internal and / or external hazards (in addition to deterministic approaches)	12%	21%	24%	6%
No answer	24%	29%	35%	71%

Table 32 - Question Q37) A – B – C – D – Synthesis of answers

All the items have been chosen at least one time by one organization, which shows that all the items are actual applications of extended PSA.

"Assessment of the overall level of safety" and "Identification of safety improvements to reduce overall risk" are the two most chosen items, whatever the demands come from laws, regulators, companies' policies, wishes from internal experts or recommendations from external experts.

"Support periodic safety reviews" and "Comparison with safety criteria" are mainly demanded by laws and regulators, while "Support NPP design or design modifications", "Identification of potential weaknesses in design and operation" and "Use of extended PSAs for optimizing NPP test and maintenance programs" are mainly demanded by companies' policies and internal experts. Finally, external experts also demand "Use of extended PSAs for optimizing NPP technical specifications" and "Assessment of off-site consequences of accidents". It should be noted that 71% of the respondents indicated having no specific demands from external expert or reviewers.

There are no major differences between the uses claimed by the utilities, the TSOs, and the regulators, even if the regulators are more focused on risk-informed applications ("Risk-informed regulation" and "Use of extended PSAs to evaluate safety significance of events or non-conformities and for event importance ranking").

The detail of the answers is given in the following tables.

Please provide your opinion on the prioritization of uses and applications of extended PSA on the basis of :	Demands from laws and regulators (Q37A)					Demands coming from your company (safety policies, upper management) (Q37B)				
	Total	Vendor (1)	TSOs (18)	Regulators (5)	Utilities (10)	Total	Vendor (1)	TSOs (18)	Regulators (5)	Utilities (10)
No answer	24%	0%	22%	20%	30%	29%	100%	33%	40%	10%
Support NPP design or design modifications	24%	100%	22%	20%	20%	26%	0%	11%	20%	60%
Support periodic safety reviews	38%	100%	50%	20%	20%	15%	0%	17%	20%	10%
Assessment of the overall level of safety	50%	100%	61%	40%	30%	35%	0%	44%	0%	40%
Comparison with safety criteria	47%	100%	56%	60%	20%	9%	0%	6%	20%	10%
Identification of potential weaknesses in design and operation	35%	0%	28%	80%	30%	32%	0%	33%	0%	50%
Identification of safety improvements to reduce overall risk	50%	0%	50%	60%	50%	41%	0%	39%	20%	60%
Use of extended PSAs to verify application of the concept of defence-in-depth	24%	100%	22%	20%	20%	12%	0%	17%	0%	10%
Use of extended PSAs for optimizing NPP test and maintenance programs	6%	0%	6%	0%	10%	24%	0%	22%	0%	40%
Use of extended PSAs for optimizing NPP technical specifications	3%	0%	0%	0%	10%	15%	0%	11%	0%	30%
Use of PSA to support exemptions to technical specifications	3%	0%	0%	0%	10%	12%	0%	6%	0%	30%
Use of extended PSAs to evaluate safety significance of events or non-conformities and for event importance ranking	9%	0%	11%	0%	10%	18%	0%	11%	40%	20%
Use of extended PSAs to improve operators training programs	6%	0%	6%	0%	10%	9%	0%	6%	20%	10%
Risk-informed regulation	3%	0%	6%	0%	0%	9%	0%	6%	40%	0%
Risk informed classification of SSCs	3%	0%	6%	0%	0%	9%	0%	11%	0%	10%
Risk informed in-service inspection	3%	0%	6%	0%	0%	3%	0%	0%	20%	0%
Development and improvement of plant procedures, especially EOP	9%	0%	6%	20%	10%	12%	0%	17%	0%	10%
Severe accident management	24%	0%	39%	20%	0%	9%	0%	17%	0%	0%
Emergency planning	0%	0%	0%	0%	0%	3%	0%	6%	0%	0%
Assessment of off-site consequences of accidents	12%	0%	11%	0%	20%	6%	0%	6%	0%	10%
Support plant lifetime extension	3%	0%	6%	0%	0%	15%	0%	11%	20%	20%
Prioritization of research	0%	0%	0%	0%	0%	6%	0%	6%	20%	0%
Assessing protection against internal and/or external hazards (in addition to deterministic approaches)	12%	0%	11%	20%	10%	21%	0%	28%	0%	20%

Table 33 - Question Q37) A – B – Distribution of answers

Please provide your opinion on the prioritization of the uses and applications of extended PSA on the basis of :	Wishes from internal experts on safety and risk evaluation (Q37C)					Recommendations from external experts or independent reviewers (Q37D)					Total number of time the item was chosen
	Total	Vendor (1)	TSOs (18)	Regulators (5)	Utilities (10)	Total	Vendor (1)	TSOs (18)	Regulators (5)	Utilities (10)	
No answer	35%	0%	22%	60%	50%	71%	100%	61%	100%	70%	
Support NPP design or design modifications	24%	100%	22%	20%	20%	9%	0%	11%	0%	10%	28
Support periodic safety reviews	15%	0%	22%	20%	0%	9%	0%	11%	0%	10%	26
Assessment of the overall level of safety	41%	0%	61%	20%	20%	12%	0%	17%	0%	10%	47
Comparison with safety criteria	12%	0%	17%	20%	0%	12%	0%	17%	0%	10%	27
Identification of potential weaknesses in design and operation	38%	100%	39%	20%	40%	6%	0%	6%	0%	10%	38
Identification of safety improvements to reduce overall risk	32%	100%	33%	20%	30%	24%	0%	28%	0%	30%	50
Use of extended PSAs to verify application of the concept of defence-in-depth	12%	100%	6%	20%	10%	3%	0%	6%	0%	0%	17
Use of extended PSAs for optimizing NPP test and maintenance programs	12%	0%	6%	0%	30%	6%	0%	0%	0%	20%	16
Use of extended PSAs for optimizing NPP technical specifications	9%	0%	0%	0%	30%	15%	0%	11%	0%	30%	14
Use of PSA to support exemptions to technical specifications	3%	0%	0%	0%	10%	0%	0%	0%	0%	0%	6
Use of extended PSAs to evaluate safety significance of events or non-conformities and for event importance ranking	15%	0%	28%	0%	0%	0%	0%	0%	0%	0%	14
Use of extended PSAs to improve operators training programs	6%	0%	6%	0%	10%	6%	0%	6%	0%	10%	9
Risk-informed regulation	12%	0%	17%	0%	10%	6%	0%	11%	0%	0%	10
Risk informed classification of SSCs	15%	0%	17%	0%	20%	6%	0%	6%	0%	10%	11
Risk informed in-service inspection	3%	0%	6%	0%	0%	0%	0%	0%	0%	0%	3
Development and improvement of plant procedures, especially EOP	18%	100%	22%	20%	0%	6%	0%	11%	0%	0%	15
Severe accident management	18%	0%	28%	0%	10%	6%	0%	11%	0%	0%	19
Emergency planning	3%	0%	6%	0%	0%	6%	0%	11%	0%	0%	4
Assessment of off-site consequences of accidents	6%	0%	6%	0%	10%	12%	0%	17%	0%	10%	12
Support plant lifetime extension	15%	0%	22%	20%	0%	3%	0%	6%	0%	0%	12
Prioritization of research	3%	0%	6%	0%	0%	0%	0%	0%	0%	0%	3
Assessing protection against internal and / or external hazards (in addition to deterministic approaches)	24%	0%	33%	20%	10%	6%	0%	11%	0%	0%	21

Table 34 - Question Q37) C – D - Distribution of answers

Q37) E – Are there other uses and applications of extended PSAs which you consider important?

Others uses and applications mentioned by participants are:

- risk monitoring,
- probabilistic index (e.g. Mitigation Systems Probabilistic Index (MSPI))
- risk profiles R(t),
- training of plant management for improved risk awareness,
- risk-informed configuration control,
- maintenance effectiveness monitoring (reliability monitoring),
- support to deterministic analysis (selection of accident scenarios),
- reconsideration of the management and behaviour of the safety systems, backup power and water sources, and planning of improving measures.

Q38) A - Do you consider that an extended PSA (as defined in section 3) is needed for the above uses and applications you consider important?

Yes	31
No	2
No answer	1
Comments	4

Comment supporting the need of extended PSA for the above uses and applications explain that the response is depending on the possibility to develop realistic data with low uncertainties. The use of conservative data would reduce the usefulness and acceptance of PSA.

Comment supporting that an extended PSA is not necessarily needed for the above uses explains that it is already interesting to perform risk informed analysis with existing PSAs (but weaknesses need to be mastered to provide relevant insights). If an extended PSA is available, it obviously can be used taking care that its nature does not affect the risk insights (see response to Q33).

Evaluation of answers:

There is a large majority which believes that extended PSA are needed for their uses and applications.

Q38) B - If yes, for which uses and applications?

The following table synthetize the answers to the questions 38B.

No answer	6
All of them	13
Support NPP design or design modifications	5
Support periodic safety reviews	3
Assessment of the overall level of safety	10
Comparison with safety criteria	2
Identification of potential weaknesses in design and operation	7
Identification of safety improvements to reduce overall risk	9
Use of extended PSAs to verify application of the concept of defence-in-depth	3
Use of extended PSAs for optimizing NPP test and maintenance programs	0
Use of extended PSAs for optimizing NPP technical specifications	1
Use of PSA to support exemptions to technical specifications	1
Use of extended PSAs to evaluate safety significance of events or non-conformities and for event importance ranking	0
Use of extended PSAs to improve operators training programs	1
Risk-informed regulation	1
Risk informed classification of SSCs	1
Risk informed in-service inspection	1
Development and improvement of plant procedures, especially EOP	1
Severe accident management	4
Emergency planning	3
Assessment of off-site consequences of accidents	1
Support plant lifetime extension	1
Prioritization of research	0
Assessing protection against internal and / or external hazards (in addition to deterministic approaches)	3

Table 35 - Question Q38) B – Synthesis of answers

Comment: One participant explained that extended PSA could be useful for most of risk-informed applications but is not the only solution. Combined approach using both PSA with limited scope and classical deterministic safety analyses (for the uncovered scope) can be used in decision process making.

Evaluation of answers:

There is a majority which believes that extended PSA are needed for all uses and applications mentioned in question 37. For the others extended PSA is at least needed for the evaluation of the overall level of safety, identification of safety improvement and potential weaknesses in design and operations.

Q38) C - If yes, could you provide your opinion on the reasons why you consider that current PSAs (e.g. limited to internal event) are not adequate enough for each of the uses and applications you consider important (please mark with an X):

i. scope of the PSAs (shutdown states, SFP, hazards, …),
ii. level of the PSAs (L1, L2, …),
iii. quality of the PSAs,
iv. level of details of the PSAs,
v. resources allocated to PSAs development and application,
vi. technical issues,
vii. tools issues,
viii. other reasons

The following table synthetize the answers to the questions 38C.

Scope of the PSAs (shutdown states, SFP, hazards, …)	20
Level of the PSAs (L1, L2, ...)	12
Quality of the PSAs	8
Level of details of the PSAs	12
Resources allocated to PSAs development and application	6
Technical issues	6
Tools issues	8
No answer	10

Table 36 - Question Q38) C – Synthesis of answers

There is a majority which believes that not extended PSA are not adequate enough for overall risk assessment because of the limitation of the scope. The two other main reasons are the limited level of the PSA and the limited level of details of the PSA. Tools, quality, resources allocated and technical issues do not seem to be issues for the majority of the participants.
Many comments explain that a limited scope PSA probably miss a large part of the overall risk.

4.3 SAFETY / RISK TARGET AND DECISION MAKING

Q39) One objective of an extended PSA is the assessment of risks from the operation of a NPP. But what definition of risk should we use as primary goal (please mark with an X)?

- Risk to the environment/offsite population
- Risk to the plant (e.g., to the fuel for Level 1, to the containment, as specific to Level 2)
- Both
- Other

All 34 end users provide responses to Q39.

More than half of respondents consider that both risk to the environment/offsite population and risk to the plant in terms of CDF and LERF should be the primary goal. Most of them argue their position that the first aim of the analysis is to improve the plant safety; therefore, at least risks to the plant (Level 1 + Level 2) should be assessed. Ideally, risks to the environment and offsite population should also be addressed. If possible, and in order to obtain useful results in a reasonable time, this should not be done with a full-scope Level 3 PSA but with simplified models (for atmospheric/environmental dispersion and dose impact) applied to the release categories obtained in PSA Level 2. However, some respondents who selected the option “both” stated that it should be interesting to determine the risk to the environment but it should not be the objective of an extended PSA. From regulatory point of view, the option “both” was commented by US NRC as follows: the main purpose of an extended PSA from a regulatory perspective is to assess risk to the health and safety of the public. The US NRC has published a safety goal policy statement that provides an acceptable level of risk associated with the societal benefits of nuclear power plant operation. Subsidiary risk metrics have been derived from that policy statement, such that core damage frequency and large, early release frequency are the endpoints of interest for most PSAs in the U.S.

About one-third of respondents have selected the option “risk to the environment“. In general, they pointed out that NPP operation represents risk to the environment and public. The risk to the plant is just one part of that, the internal part. But if we look at it as a whole, risk to environment and public should be evaluated, managed and regulated.

Less than one-fifths of respondents have chosen the option “risk to the plant“. They are mostly related to Utilities and their TSO.

Distribution of responses by respondents’ role is the following:

- Regulatory authorities and TSO
    - 55% - option “both”
    - 27% - risk to the environment
    - 18% - risk to the plant
- Utility and TSO
    - 50% - option “both”
    - 33% - risk to the environment
    - 17% - risk to the plant
- Service and research companies
    - 64% - option “both”
    - 27% - risk to the environment
    - 9% - risk to the plant

The following was commented by GRS: "it is important to recognize that the fundamental safety objective is the protection of the population and the environment, therefore assessing the respective risk is the primary goal of any safety assessment. In this respect, PSA level 1 and level 2 risk metrics are intermediary or auxiliary metrics suitable for a (conservative) estimation of the offsite risk, if defined appropriately. Simultaneously, PSA level 1 and level 2 are limited to the plant and its properties. For this reason, these parts of the PSA are generally well suited for the discussion between licensee and regulator as well as for the improvement of overall plant safety. Moreover, there are sophisticated and proven methods, tools as well as generally accepted risk metrics available for PSA level 1 and level 2. Performing a PSA up to level 2 is currently becoming a generally accepted practice for NPP. Conversely, there are no generally accepted PSA level 3 risk metrics, or even a consensus on the need for a PSA level 3. Moreover, PSA level 3 introduces significant additional uncertainties and for some aspects of risk (socio-economic impact) also subjective/controversial assumptions. Insights from PSA level 3 are highly relevant either to siting decisions or for off-site emergency planning (by state bodies). Finally, it has to be recognized that appropriately chosen PSA level 2 metrics can be taken as a good leading indicator metric for offsite consequences. Therefore, the primary goal of the PSA should be on PSA level 1 and level 2 risk. With respect to the latter, a comprehensive quantification of the source terms released to the environment should be done. These could be summarized into an "integral release risk", i.e. product of released activity in Bq times release frequency (appropriately scaled to a reference isotope like e.g. Cs-137). Both short term releases (leading indicator for short-term irradiation risk) and long-term total release (leading indicator for loss of land and potentially late cancer risk) should be used. However, level 3 investigations should be done in order to supplement and complete the risk assessment."

Based on distribution of responses, we can assume that expectations of the respondents related to risk definition are irrelevant to their profiles (regulatory authority, utility or research institution). In fact, majority of respondents (more than 80%) concluded that all aspects/targets of the extended PSA have to be complexly developed concerning the risks of internal and external events and hazards and their combinations to the plant and to the environment/offsite population. Assessment of the risk to the environment/offsite population requires development of Level 3 PSA. Level 3 PSA still lacks common methodology and corresponding standards/guidelines in addition to the large uncertainties in the obtained results.

When elaborating a generic guidance for PSA, the different national requirements on safety goals (or the lack thereof) must be taken into account. In addition, different definitions of LERF are the cause for differing practices with respect to the type and the depth of the analyses. Rather than talking of safety goals, for which a common understanding depends on national laws, it can be useful to harmonize a common set of safety "objectives", the difference between goals and objectives being what is required to satisfy national requirements and what should be required internally by the plant licensee/management for operation of the plant.

Q40) A - Could you please provide examples of useful set of safety objectives?

More than half (56%) of respondents preferred not to respond to the question or answered "no". Some of them explain their choice as follows: instead of trying to answer this question, they strongly suggest that further research be performed and harmonization efforts be made to support the whole area of developing a commonly acceptable set of safety objectives. Such research ought to be conducted in the ASAMPSA_E project, too.

14 respondents provided examples of safety objectives. They are detailed in Appendix 3 (see 11.3) and can be split into the following areas:

1) CDF and LERF prescribed by national regulations or internationally recognized requirements. This group (26% of total) includes responses with or without numerical values. If numerical values are shown, they are consistent with IAEA probabilistic safety criteria, e.g. core damage frequency shall be less than 10-5 event per reactor year, taking into account all the internal events, internal hazards and external hazards;
2) Safety objectives proposed by WENRA for accidents with core melt (O3) – 6 % of total;
3) Dose level to the population and environmental contamination level - 6% of total;
4) Quality and envelop of the safety requirements, sustainability and efficiency of safety systems, level of the defined safety criteria, degree of people and environment protection – 3% of total.

One respondent mentioned that different set of safety objectives should be used depending on the number of units at NPP site: commonly used objectives for single unit (CDF, SRF/LRF, individual and population dose, risk profile (early fatality, latent cancer fatality)) and an integrated site risk metrics should be newly defined for multi-unit sites.

Another one suggested the following set of safety objectives:

- the "integral release risk" (product of released activity (in Bq) times the release frequencies) must not be higher than x Bq/a AND a single release category must not contribute more than y % to the release risk;
- the area of square kilometers contaminated by Cs-137 (or equivalent) about a threshold of X kBq/m² has to be below a frequency above Y / y.r.

Distribution of responses by role of respondents is the following:

- Regulatory authorities and TSO (11 respondents). It should be noted that almost all regulatory authorities provide examples of useful set of safety objectives, while most of TSO for regulators decided not to respond to the question.
    - 55% - safety objectives
    - 45% - no
- Utility and TSO (12 respondents)
    - 33% - safety objectives
    - 67% - no
- Service and research companies (11 respondents)
    - 45% - safety objectives
    - 55% - no

The following observations are made:

- despite intensive international activities on development of appropriate safety objectives (e.g., useful set was established by US NRC, IAEA safety objectives in INSAG12, WENRA) and ongoing efforts on validity of safety goals in different countries, there are many end users (especially from Utilities and their TSOs) that are still not completely satisfied by the usefulness of existing scope/definitions or formulations of safety objectives;
- from regulatory point of view, appropriate safety objectives and criteria are established;
- probabilistic safety criteria (CDF and LERF) are generally recognized as a useful set of safety objectives;
- further activities are needed to develop integrated site risk metrics for multiple-unit sites.

In addition to examples of safety objectives, respondents underlined that there are differences in the understanding of risk metrics on which safety objectives are based (see 11.3).

B - Would you endorse a common set of European safety objectives for level 2 PSA?

Half of European respondents (16 from 30 respondents) would endorse European safety objectives for level 2 PSA, while 3 end users would not support the objectives and 9 end users choose the option “no opinion”. All non-European users, except of Japan, have no opinion on European safety objectives.

Respondents that would endorse European safety objectives noted that safety objectives for Level 2 PSA should be harmonized (at least on a European level). The efforts to reach a common understanding of / international consensus on appropriate risk criteria should be continued. Without common safety objectives/goals/targets (both PSA Level 1 and 2) it is not possible to use results of PSA to judge properly safety of a specific NPP design. Many respondents agree with the idea of developing commonly acceptable safety objectives and this opinion refers to level 2 PSA, too. However, some of them consider that endorsement may not need to be aimed at. Such objectives could rather be proposed and/or laid down in guidelines.

Distribution of responses by role of respondents is the following:

- Regulatory authorities and TSO (11 respondents).
  - 27% - yes
  - 9% - no
  - 64% - no opinion
- Utility and TSO (12 respondents)
  - 50% - yes
  - 17% - no
  - 33% - no opinion
- Service and research companies (11 respondents)

- 73% - yes
- 0% - no
- 27% - no opinion

The following observations are made:

- common set of safety objectives for level 2 PSA would be endorsed by half of end users, mainly from engineering and research companies;
- majority of regulatory authorities and utilities have no opinion on endorsement of a common set of safety objectives for level 2 PSA. In some extent it may indicate wariness and responsibility of decision makers under uncertain conditions with development of the common set of safety objectives;
- in case of non-European country, it may be used as a reference for safety objectives.

C- If so, would you be prepared to help in formulating one?

Majority of respondents that would endorse the set of safety objectives have answered “Yes” (more than 80%).

Concerning risk metrics, some respondents of the final ASAMPSA2 survey pointed out that there was a need for further discussions and harmonization on risk definitions (LERF, LRF, SRF, etc.) and that an “integral risk approach” is missing. The ASAMPSA_E project aims to elaborate some specific risk metrics, adapted to extended L1-L2 PSA (use of the INES scale was proposed as an example in ASAMPSA2). End users pointed out that a common set of European safety objectives will facilitate the understanding of the safety level for different reactors. The set of European safety objectives can be considered as a basis for all NPPs and type of reactors, and for each PSA to build additional specific safety objectives relevant to the unit/plant.

Q41) Do you believe that risk metrics should be defined for extended PSAs? If yes, please, rank this issue on a scale from 1 (very unimportant) to 5 (very important).

Yes	25
No	5
No answer or no opinion	4
Comments	9

Some comments from organizations supporting that there is no need to define risk metrics for extended PSAs state that existing risk metrics can be used or that there is no specific need for extended PSAs. Another respondent uses L3 criteria and considers that metrics are already formulated in the IAEA guides. Other comments also conclude that existing risk metric should be harmonised rather than defining new risk metrics.

A large majority (83%) of respondents who expressed an opinion for this question believe that risk metrics should be defined for extended PSAs, and rank this issue as a 4.0 on scale from 1 (very unimportant) to 5 (very important).

Comments make evidence that there is a strong expectation for a common understanding and definition of the terms of “core damage”, “large” / “early” releases.

US NRC suggests that an extended L3 PSA can be performed without such metrics, and the results can then be scrutinized to develop metrics that are useful indicators for when the Level 3 results have important thresholds. This would then allow for more meaningful use of the metrics for PSAs that end at Level 2. And in fact, this is the process by which CDF and LERF requirements in oversight decision making were defined in the US.

Distribution of responses by role of respondents is the following:

- Regulatory authorities and TSO (11 respondents).
    - 27% - yes
    - 9% - no
    - 64% - no opinion
- Utility and TSO (12 respondents)
    - 50% - yes
    - 17% - no
    - 33% - no opinion
- Service and research companies (11 respondents)
    - 73% - yes
    - 0% - no
    - 27% - no opinion

The following observations are made:

- among existing metrics (CDF/LERF), work on a common LERF definition can be useful (see Q40);
- definition of other metrics (e.g. to deal with level 1 PSA success sequences with non-negligible releases) may also be an interesting topic for an extended PSA.

Q42) Would you have some specific expectations/needs concerning risk metrics for extended PSAs?

Yes	17
No	9
No answer or no opinion	5
Comments	9

All that have answered yes have made comments.

Comments supporting specific expectations/needs concerning risk metrics for extended PSAs for extended PSAs conclude that a new risk metric should include:

- multiunit site,
- spent fuel pool,
- evacuation of people near the site,

- be representative for the whole scope of an extended (comprehensive) PSA including all the attributes of PSA scope (radioactivity sources, types of initiating events, etc.),
- include an unambiguous requirement (and definition) of undesired consequences and measures of such consequences,
- quantified so that it is possible to compare with the risk from other power producers.

One comment that do not support specific expectations/needs concerning risk metrics for extended PSAs for extended PSAs conclude that the scope of ASAMPSA_E should be limited to make more realistic analysis.

The ASAMPSA_E project also aims to provide best practice guidelines for the definition of appropriate criteria for decision making based on extended PSAs.

Q43) A - Do you believe that a decision making process based on extended PSAs should be defined?

Yes

If yes, please, rank this issue on a scale from 1 (very unimportant) to 5 (very important):

No

No opinion

Distribution of responses, 34 respondents:

- Yes: 24 respondents,
- No: 6 respondents,
  - Answer No without comment: 2 respondents,
  - Answer No, because there is no difference between the decision making process based on extended PSA and limited scope PSA (not-extended) : 3 respondents,
  - Answer No because this is pre-mature, and it is more important at this point to focus on what can and cannot be reasonably accomplished in terms of the development of extended PSAs: 1 respondents,
- no answer or no opinion : 3 respondents,
- Other: 1 (1 respondent correlate the result to the definition of decision making process).

Ranking of this issue on a scale from 1 (very unimportant) to 5 (very important):

Among the 24 organizations which answered yes:

- 20 of them have ranked the importance of the issue with notes distribution between 3 and 5 and with average ranking of 4.2;
- 3 of them have not ranked the importance of the issue;
- 1 of them has used another scale, ranking the importance of 5 metrics (CDF, LRF, LERF...).

So a huge majority of organizations consider that it is important or very important to define a decision making process based on extended PSAs.

The organizations which have different advice consider that there is no significant difference between the decision making process based on extended PSA and limited scope PSA (not-extended).

NRC consider that it is premature and underline that at this point it is most important to focus preliminary on what can and cannot be reasonably accomplished in terms of the development of extended PSAs.

GRS, NRC and EDF underline in their comments, that not only PSA insights could or should be used in decision making process: decision making process using PSAs can be either risk-based or risk-informed.

There is a comment from Cazzoli Consulting which declare that comparing the PSA results with existing IAEA principles and objectives shows the violation more or less of all of them and that shutting down all plants worldwide (should be decided)?

Q43) B – In your opinion, what will be the main challenges to implement a decision making process based on extended PSA?

Several organizations pointed out, more or less directly, that decision process making is rather risk informed than risk based. So, in order to limit ambiguity, the phrase "decision making process based on extended PSA" may be replaced by "decision making process using on extended PSA"

The table above is a tentative to group the challenges identified by the respondents, in a limited number of topics with their number of citations.

Challenges to implement decision making based on (using) extended PSA	Number of citations
To address PSA uncertainties and hazards assessment uncertainties	5
Efficient and reasonable use – in the DM - of inhomogeneous PSA (depending on hazards) with different levels of quality, detail, realism or conservatism	5
Establish well balanced decision making process. How to balance PSA result with other safety approach (such as defence-in-depth, design basis, safety margin and deterministic safety analysis results...)	4
How to convince high level management to be confident in PSA and provide increased resources	3
Define appropriate criteria or safety goals	3
Exact definition of risk metrics	2
PSA extended to regional area (with several nuclear sites)	1
Calculation time	1
The time constraint for real time use by the emergency organization	1
Balance between public safety and health versus plant availability and investment protection	1
Understandability and scope of guidelines	1
the systematic refusal by authorities and operators to assess off-site risks with respect to safety/source and radiation protection/environment	1

(following IAEA definition of safety (L2) and radiation protection (L3)). AS OF NOW ALMOST EVERYBODY HAS FOCUSED ON FREQUENCIES ONLY!!! not on risks as defined by IAEA General safety objective, AND only for internal events, AND only one unit on the site.	

Table 37 - Question Q43) B – Synthesis of answers

Q44) Do you think the issue of criteria for decision making based on extended PSAs is important?

Yes

If yes, please, rank this issue on a scale from 1 (very unimportant) to 5 (very important):

No

No opinion

Distribution of responses, 34 respondents:

- Answer Yes: 24 respondents,
- Answer No: 5 respondents (the five organizations which answer “no”, also answer “no” to question n° 43 – A; this seems logical),
- No answer or no opinion : 5 respondents.

Ranking of this issue on a scale from 1 (very unimportant) to 5 (very important):

Among the 24 organizations which answered yes:

- 22 of them have ranked the importance of the issue with notes distribution between 2 and 5 and with average ranking of 4,02;
- 1 of them have not ranked the importance of the issue;
- 1 of them has used another scale, ranking the importance of 5 metrics (CCDP, CLERP, LRF, CDF, LERF).

So a huge majority of organizations consider that the issue of criteria for decision making process based on extended PSAs, is important.

Q45) Would you have some specific expectations/needs concerning definition of probabilistic safety criteria for decision making?

Yes

If yes, please, describe your requirements/expectations/needs:

No

No opinion

Distribution of responses, 34 respondents

- Answer Yes: 17 respondents
- Answer No: 7 respondents

- No answer or no opinion : 10 respondents

Seventeen organizations have expressed comments or specific expectations. The comments and expectations are very various and it doesn't clearly appear any widely common specific expectations. We can underline that nobody has expressed comment against the definition of probabilistic safety criteria for decision making. Then the following comment expressed by IRSN "this *issue may be complex and should be discussed within the project*" seems to be an appropriate conclusion of the analysis of the answers.

In order to illustrate the diversity of comments, the list of the comments *(in italics*) with a classification tentative is provided below.

- Expectation about international harmonization (1 comment):
  - *It is the international harmonization*
- Expectations about easy use of the defined criteria in the risk informed decision process making (2 comments):
  - *Criteria that would enable to make straightforward decisions*
  - *Be an appropriate basis to compare risk levels in association with different decision options in an extended PSA*
- Expectation about usefulness and representativity of the criteria (1 comment)
  - *Definition of "recommended" probabilistic safety criteria that could be used in some decision makings, considered as representative to show their usefulness*
- Expectation about appropriate use of PSA in risk informed applications, in a consistent way with the level of conservatisms (1 comment):
  - *Need to take account of the nature of an extended PSA if it turns to be very conservative for some aspects (see Q33: Introduction of conservative modelling due to lack of data may hide or adversely affect risk insights from other parts of the modelling.). In addition a careful treatment of the PSA assumption is necessary*
- Expectation about definition of criteria to manage risk of external hazard with regional area consequences (comment from Japan)
- Expectation of consistence applicability of criteria for internal events as well as internal and external hazards (2 comments):
  - *Probabilistic safety criteria should be applicable in a consistent way to all events (internal events as well as internal and external hazards)*
  - *We expect that it will be clearly endorsed that PSA applications criteria defined and used to assess results of PSA with limited scope to internal events, are absolutely not suitable to assess results of extended PSA (including internal and external hazards) and can't be used without change for extended PSA applications.*
- Definition of appropriate risk criteria for all three levels of PSA (1 comment):

  - *Appropriate risk criteria should be formulated for all three levels of PSA, they should be focused on the information available at that level of the PSA. Risk criteria/objectives should cover the risk to the plant as well as the major risks to the environment (even if leading indicator criteria are used), to this end an appropriate set of criteria should be used. Risk criteria should also facilitate decisions on plant improvements and the ranking of issues with respect to their impact on plant risk.*
- Expectation about uncertainties management (1 comment):
  - *Risk informed decision making should appropriately consider the uncertainties in the PSA and obtained risk measures* (and a reference document is proposed)
- Expectation about metrics (1 comment):
  - *Exact definition of the risk metrics*
- Expectation to *discuss this complex issue within ASAMPSA_E Project* (1 comment);
- Comments which are perhaps too general or too shortly developed to clearly understand what the writer has in mind (2 comments):
  - *Level of safety margin*
  - *Definition of differentiated levels of the probabilistic safety criteria …*
  - *To give priority to the public safety and health*
- *Comment which refer to external documentation and that hasn't been analyzed* (1 comment).

4.4 RESULTS PRESENTATION AND UNCERTAINTIES

The ASAMPSA_E project aims to improve existing methods for the extended PSA results presentation to provide a clear view of the risk induced by a NPP.

Q46) Do you think the issue of results presentation is important for extended PSAs?

There is clear agreement that the issue of results presentation is very important for extended PSAs.

Results presentation and, more generally, documentation are extremely important for all PSAs, including extended PSAs. Issue associated with identifying the "best" way to present results (including an appropriate characterization of uncertainties) to various stakeholders is identified.

Q47) Would you have some specific expectations/needs concerning results presentation for extended PSAs?

Different opinions are identified in the answers (15 Yes, 10 No).

Consistent presentation of results is suggested, which can be applied to all events (internal events as well as internal and external hazards), so that the relative contributions of each hazard type can be compared.

Presentation of results as in L1 PSA in order to show that there is no significant risk contributor is recommended.

Results presentation in support to the meeting of the general safety objectives is suggested.

Need for development of proper guidance for aggregation of the risk from different hazards and/or different sources (reactor core, spent fuel poolpool, etc.) is acknowledged.

PSA results (including E_PSA) should also include information considering: scope, limitations and uncertainties of each PSA, uncertainty analysis, sensibility analysis, importance factor for the major contributors to the risk measures.

The results and insights should be understandable to the PSA stakeholders and that both be traceable to inputs and assumptions. Obtained risk measures should be in line with the measures used in regulation and international practices.

Specific documentation requirements are provided in numerous documents (e.g., IAEA safety guides, ASME/ANS PRA standards) but their applicability on "extended PSA" should be checked.

Q48) Do you think it is possible to analyse PSA results without having commonly accepted risk targets/objectives?

The majority (20 YES, 7 NO) thinks that having commonly accepted risk targets/objectives would be very useful but not essential.

Comment was made that the analysis of the results should be done for the purpose of supporting the decision(s) motivating the PSA. Many decisions rely on common targets/objectives (e.g., criteria for CDF and DCDF) but not all. Irrespective of any target/objective, a PSA gives an enormous amount of information that can be analysed. For example safety improvements may derive from PSA, different risk insights can be identified from PSA (characterization of internal and external hazards, the fragilities of the SSCs, the plant response to the events or hazards, the important human interactions, the cliff-edge effect), relative risk comparison and ranking, design trade-offs, cost-benefit analyses.

Comment was given that the predefined risk targets may result in increased use of the biased probabilities for initiating events and single failures. Also it may have effect on willingness to improve and expand the PSA model of the plant. PSA is identified, in one of the response, as a tool for detecting vulnerabilities in the plant design.

Q49) Do you think the issue of treatment of uncertainties is important for extended PSAs?

All that provided answer (32 YES, average ranking 4.0) think that the issue of treatment of uncertainties is important for extended PSAs.

This question is identified as relevant for overall PSA and is not exclusive for extended PSA.

The treatment of uncertainties is recognized as very important and required by the current PSA standards. The PSA standards and guidance documents provide the current positions, but changes to improve the use of PSA are recommended.

Q50) Would you have some specific expectations/needs concerning treatment of uncertainties for extended PSAs?

In general (19 Yes, 10 NO) most of the answers include specific expectations considering uncertainties in extended PSA.

The main issue identified in answers for extended PSA is consideration and treatment of uncertainties of extreme external events (low probability events), consistency with treatment of uncertainties in other PSA and their minimization and interpretation of the results that include uncertainties.

Utilization of uncertainties as a measure to assess the quality of PSA is also proposed, with no specific details given.

The current expectations/needs concerning treatment of uncertainties for extended PSAs are identified as similar to those associated with non-extended PSAs.

Conclusions and/or recommendations for the project from Section 4.4 RESULTS PRESENTATION AND UNCERTAINTIES

Results presentation and, more generally, documentation are identified as very important for all PSAs, including extended PSAs.

The specific expectations/needs concerning results presentation for extended PSAs are:

- Consistency of presentation for all events (internal events as well as internal and external hazards)
- The analysis of the results should be done for the purpose of supporting the decisions motivating the PSA
- Proper guidance for aggregation of the risk from different hazards and/or different sources (reactor core, spent fuel pool and other sources) should be developed
- Results should include information considering: scope, limitations and uncertainties of each PSA, uncertainty analysis, sensibility analysis, importance factor for the major contributors to the risk measures
- The results and insights should be understandable to the PSA stakeholders and that both be traceable to inputs and assumptions

  Having commonly accepted risk targets/objectives is assessed as useful for analysis of the PSA results.

  The treatment of uncertainties is assessed as very important for overall PSA including extended PSA. The main specific issue for extended PSA is consideration and treatment of uncertainties of extreme external events, as low probability events, consistency with treatment of uncertainties in other PSA and their minimization. A common issue with current PSA remains the treatment of model uncertainties.

  The need for development of framework/guideline for interpretation of the results that include uncertainties is recommended.

4.5 EXAMPLES OF EXTENDED PSA APPLICATION

Q51) A - Based on you experience, can you provide examples of practical applications of existing internal/external hazards PSAs for plant management during normal operations (e.g. maintenance, time available for restoration of equipment …)?

The most frequent answers of Q51A) are:

- Maintenance optimization and scheduling (ENEL, INR, KAERI, MVM Paks II.Zrt., NRG, NUBIKI, RELKO Ltd, SNSA, Tractebel)
- Optimizing NPP technical specifications/operational guidelines (CSN, INR, KAERI, MVM Paks II.Zrt., NUBIKI, INRNE)
- Event analysis, based on PSA (Kozloduy NPP, CNSC, MVM Paks II.Zrt., NUBIKI)
- Plant risk monitor (EDF, MVM Paks II.Zrt., NUBIKI, RELKO Ltd)
- Risk informed in-service inspection (IBERDROLA, INR, KAERI)
- Training programs (MVM Paks II.Zrt., NUBIKI)
- Plant modifications. For example, different results of the L1PSA and L2PSA of Kozloduy NPP are taking into account in the Modernisation Program of 5th and 6th unit of the plant (TUS).

Q51) B - Based on you experience, can you provide examples of practical applications of existing internal/external hazards PSAs for reinforcement of accident prevention provisions?

The most frequent answers of Q51B) are:
- design modifications/improvements (CSN, EDF, FORTUM, FKA, INR, IRSN, MVM Paks II.Zrt., NUBIKI, RELKO Ltd, Tractebel, VUJE),
- identification of potential weaknesses in design and operation (EDF, FKA, IBERDROLA, INR, JSI, KAERI, Kozloduy NPP, NUBIKI, NRG, RELKO Ltd),
- improvement in seismic safety (FKA, MVM Paks II.Zrt., NUBIKI, SNSA),
- operators training programs (EDF, IBERDROLA, INR, RELKO Ltd),
- improvements against extreme weather (FKA, MVM Paks II.Zrt., NUBIKI),
- reinforcement of fire protection (EDF, IRSN, SNSA, VUJE),
- improvements against internal explosion (EDF, IRSN).

Q51) C - Based on you experience, can you provide examples of practical applications of existing internal/external hazards PSAs for reinforcement of severe accident management provisions?

The most frequent answers of Q51C) are:
- improvement of severe accident management and SAMG (TUS, ENEL, IBERDROLA, INR, KAERI, MVM Paks II.Zrt., NUBIKI, RELKO Ltd),
- improvements in seismic safety (JSI, MVM Paks II.Zrt., NRC, NUBIKI).

- *Analysis based on the profile of the respondents (e.g. authority, TSO, utility) or based on experience of the respondent in terms of PSA development*

Concerning question 51, it is not found specific dependence between tendencies of comments in correspondence to the profile of the respondents.

- *Presentation of the most significant/recurrent/interesting comments for question Q51 A), B) and C)*

Kozloduy NPP claims that the existing internal/external hazards PSAs can be used to support the NPP decision making process for NPP safe operation. For Q51A), EDF comments that the risk informed applications using extended PSA could be more or less the same as for non-extended PSA.

Some of the examples for Q51B), for reinforcement of accident prevention provisions in particular NPP are:

- the large safety enhancement program and the numerous improvement measures implemented at the Paks NPP between 1994 and 2003. The improvements in seismic safety, supported by seismic PSA and the completed PSA for extreme weather phenomena (MVM Paks II.Zrt. and NUBIKI);

- cooling towers, deployed at Loviisa NPP to provide enough cooling, if cooling provided by sea water is for any reason not available (FORTUM);

- reinforcement of fire protection into the electrical building, implemented on the 1300 MWe NPP in the framework of the Third periodic safety review, based on the internal fire PSA results (EDF).

Some of the examples for Q51C), for particular reinforcement of severe accident management provisions in NPP are:

- installation of Venturi scrubber for mitigation of the containment pressurization and FP release in ambient air by eventual severe accident (TUS);

- safety measure involving installation of passive hydrogen recombiners was implemented as a result of internal events PSA which identified a scenario with hydrogen accumulation and subsequent explosion (RNPP).

- *Interpretation in terms of end-users practices and needs*

Comments and the practical examples confirm the interest of internal/external hazards PSAs for plant management during normal operation, for reinforcement of accident prevention provisions and for reinforcement of severe accident management provisions.

- *Conclusions and/or recommendations for the project*

Most of the answers about practical applications of existing internal/external hazards PSAs in Q51 A), B) and C) concern improvements of design and maintenance in NPPs, training programs, and also improvements concerning internal fire and external events as seismic, extreme weather, and also for prevention of accidents and severe accidents' mitigation.

Q52) Are some specific criteria applied for internal/external hazards PSAs applications (different from internal initiating events PSA)?

- *Presentation of the tendency of the majority of the respondents*

26 organizations answered negatively, 6 organizations did not answer or have no opinion for this question and two organizations answered affirmatively – ENEL (Italy) and NRSC (Armenia).

For ENEL, the possibility of occurrence of multiple IEs ought to be considered as a specific criterion for internal/external hazards PSAs. For NRSC, the comment underlines that the screening criteria for internal initiating events is 1E-07 [1/y] whereas for external hazards, it is 1E-06 [1/y].

Another comment points out that the screening process which is standard part of all approaches for analysis of internal and external hazards might be considered as a specific approach for internal/external hazards PSAs.

- *Analysis based on the profile of the respondents (e.g. authority, TSO, utility) or based on experience of the respondent in terms of PSA development*

Organizations that sent comments are TSOs and utilities.

- *Presentation of the most significant/recurrent/interesting comments*

One comment underlines that most countries have defined global criteria including the whole risks internal event, internal and external hazards. Criteria defined for whole risk assessment are less tight than criteria defined for internal events.

- *Interpretation in terms of end-users practices and needs*

End-users answers and comments highlight the needs to fix specific criteria for internal/external hazards PSAs applications.

- *Conclusions and/or recommendations for the project*

Generally, almost no specific criterion is applied for internal/external hazards PSAs applications.

Q53) Did you already encounter difficulties in internal/external hazards PSA conclusions due to the gap between the frequencies of initiating events taken into account in DBA (typically between 10^{-2} and 10^{-4} per y.r) and expectation for LERF (typically below 10^{-6} per y.r)?

- *Presentation of the tendency of the majority of the respondents*

From 34 organizations, 9 answers are affirmative (Yes), 19 answers are negative (No) and 6 organizations did not answer.

There are frequent answers as:

- challenge is to analyse (the low-frequency) external events (FKA, IRSN, RINGHALS, Risk Pilot AB, UJV)
- DBA frequency classification does not concerns PSA modelling (GRS, NRC, Cazzoli Consulting).

For some of organizations the question was unclear and they could not provide answer.

- *Analysis based on the profile of the respondents (e.g. authority, TSO, utility) or based on experience of the respondent in terms of PSA development*

For Q53, no dependency was found between tendencies of answers/comments and the profile of the respondents.

- *Presentation of the most significant/recurrent/interesting comments*

A very comprehensive answer has been provided by Cazzoli Consulting – for instance the real problem for comparisons is that risks are not consistently defined for DBAs and severe accidents. The most recurrent is the comment concerning the challenge to analyse external events with low-frequency level (FKA, IRSN, RINGHALS, Risk Pilot AB, UJV).

For FKA, the problem is not due to frequencies level but it is to specify frequencies for external events of different degrees, and to understand the total effects of the external events. In many cases the effects on non-safety system are critical within design basis. For beyond design external events, the effects on safety systems are also difficult to identify.

- *Interpretation in terms of end-users practices and needs*

End-users answers and comments highlight the needs to analyse the frequency of external events.

- *Conclusions and/or recommendations for the project*

There is challenge to analyse the low frequency of external events.

5 QUALITY OF EXTENDED PSAS

The answers given by the respondents are summarized below according to the questions in the questionnaire.

The notion of quality of a PSA has to be distinguished from the notion of “quality Assurance”. The quality of a PSA refers to its technical adequacy with its intended uses and applications.

Q54) In addition to existing international documents which generally have a more limited scope, do you think the guidelines for extended PSAs should include specific guidance on quality of extended PSAs?

The answers are the following:

	Yes	No	No answer
Total (34)	28	5	1
Vendor (1)	1	0	0
TSOs (18)	14	3	1
Regulators (5)	5	0	0
Utilities (10)	8	2	0

Table 38 - Question Q54) – Synthesis of answers

If yes, could you indicate the level of priority you would grant this item (from 1, very low priority to 5, high level of priority)

	Yes	level of priority
Total (34)	28	4,1 / 5
Vendor (1)	1	2 / 5
TSOs (18)	14	4,2 / 5
Regulators (5)	5	4,3 / 5
Utilities (10)	8	4,3 / 5

Table 39 - Question Q54) – Level of priority

Two comments from utilities point out the difficulty to cope with uncertainties when dealing with external hazards. These uncertainties result from the difficulty to obtain realistic data and to consider in a realistic manner the consequences of a hazard.

Four comments, from regulators, TSOs and a vendor precise that guidelines related to PSA quality already exist and can be applied to an extended PSA (however, no precise reference has been provided). In relation to these comments, three comments precise that the need is more related to the hazard consequences assessment methods and models (multi-sources scenario, long term assessment).

Extended PSAs might lead to different level of quality/detail/realism for the different hazards taken into account.

Q55) Do you think that significant difference (depending on hazards) of level of quality/detail/realism could be a real problem for extended PSAs, for their uses and applications?

The answers are the following:

	Yes	No	No answer
Total (34)	22	9	3
Vendor (1)	1	0	0
TSOs (18)	12	4	2
Regulators (5)	2	2	1
Utilities (10)	7	3	0

Table 40 - Question Q55) – Synthesis of answers

Among the twenty comments, ten comments from both vendor, utilities regulators and TSOs mentioned that the introduction of conservative modelling (due to lack of data, lack of support analysis (e.g. vulnerability analysis) and lack of methodology to define hazards frequencies) may hide or adversely affect risk insights from other parts of the modelling and may lead to distortion of the obtained results and consequent decisions made on the basis of those results. These conservatisms may also introduce difficulties when comparing different extended PSAs and when comparing PSA results with safety goals.

One comment indicates that such differences in realism are particularly penalizing if risk inform application are foreseen. "*Issues include how to objectively define these differences, whether the differences are as large as* *stated by some critics, what are the sources of these differences, and what (if anything) should be done to reduce/eliminate these differences.*"

On the other hands, two comments precise that such differences in level of detail/realism are not a real problem as long as the differences are known and the models are conservative. They, however, may involve restriction in the utilization of extended PSA.

Several comments present the expectation related to future guidelines and key issues to reduce the conservatisms of hazard analysis. It is thus mentioned that "*a way forward in improving PSA quality (especially for external events) is to develop specific and detailed methodology guidance in the major steps of external events PSA, including hazard assessment, plant response and fragility analysis and PSA model development in particular. Presently, such systematic guidance is available only for seismic PSA*". The allocation of more resources to the external hazards (in comparison with the work done, in the past, on internal events) is mentioned as a way to cope with current difficulties. Two comments propose to allocate the resources based on a first assessment of the contribution of the potential hazards on the risk (for example with a ranking). Thus, the level of quality/detail/realism would be justified by the risk potential of each hazard.
In addition, a comment highlights the importance of the assessment of the hazards impacts on non-safety classified systems (even for hazards within design bases).

6 TECHNICAL NEEDS

6.1 INITIATING EVENTS

6.1.1 *EXTERNAL HAZARDS TO BE CONSIDERED IN THE ASAMPSA_E PROJECT*

Draft lists of external hazards to be considered in the ASAMPSA_E Project are presented in Appendix 1.
The answers given by the respondents are summarized below according to the questions in the questionnaire.

Q56) Do you think that the Appendix lists are comprehensive lists of external hazards, covering all single external hazards that should be considered in an extended PSA for a nuclear power plant?
If your answer is NO, please specify additional external hazards that should be added to the list.

Yes	22
No	7
No answer:	5
Comments:	12

For the majority of respondents, the Appendix lists are comprehensive lists of external hazards, covering all single external hazards that should be considered in an extended PSA.

Concerning the additional external hazards that should be added to the list, biological fouling is mentioned twice and referring to the SKI report 02:27: ice storm, ice barrier, land rise, meteotsunami and external grid disturbances leading to voltage surges are also suggested.

Comments: some respondents think that this list could be simplified by grouping some events taking as an example EPRI list or AIEA guide. One respondent considers that the list puts on the same level quite different categories of events such as “extreme air temperature” and “fish” and “forest fire”.

Conclusions and/or recommendations for the project

The presentation of the lists of hazards could be improved by grouping some events according to a logical approach.

Q57) Do you consider that some hazards of these lists would be irrelevant for all sites? If your answer is YES, please specify which ones.

Yes	15
No	15
No answer:	4
Comments:	18

Most of the respondents’ comments mention a list of irrelevant hazards either considering their NPP’s location (for instance no risk of avalanches for a NPP far from mountains), or deeming that the hazard frequency is very low (for instance meteorite) or the impact of the hazard on the NNP is negligible (for instance air pressure or humidity).

Few respondents’ comments mention the difficulty to assume a hazard irrelevancy in a general approach, but point out the necessity of a site specific approach which could be considered as the first step of the screening process.

Contaminated land, radon, fissures, and faults are considered by five respondents as irrelevant hazards for NPP.

Interpretation in terms of end-users practices and needs

To answer this question, most of respondents implement a kind of screening process adapted to their site location using some screening criteria such as hazard exclusion (not site relevant) or frequency, hazard consequence on NPP.

Screening process seems to be done based on an initial list of external hazards less extensive than the one in the appendix of the questionnaire but focused on relevant external hazards for the considered NPP. This approach could allow optimizing screening process.

Conclusions and/or recommendations for the project

The appendix list of external hazards could be consider as a comprehensive input list of the screening process even if some external hazards could be very quickly screened out considering NPP location.

Q58) Please list the ten most relevant natural external hazards for your nuclear power plant site(s), geographical region or country as appropriate (column B). For each hazard please indicate in column C any other hazards that you think need to be considered in combination with the hazard in column B. Please indicate for each hazard in column B, if it has already been considered in your PSA (column D). For each hazard listed in column B which is not considered in your current PSA, please indicate if you intend to include it in your PSA in the future (column E).

Considering the various types of external hazards given by the respondents, it has been deemed more relevant to refer to the appendix list of external hazards to present a synthesis of all the answers.

The following table provides the result of the synthesis for natural external hazards. When no specific phenomenon was mentioned, the answer has been affected to the corresponding generic hazard (for instance flooding or earthquake with no particular phenomenon such as extreme rain falls or vibratory ground motion, the answer is considered in flooding or earthquake).

The figures in bolt represent the external hazard most often considered by the respondents.

		Number of answers	*Additional hazards to be considered to account for combined effects (number of response)*	*Considered in existing PSA (Y/N) (number of response)*	*Potential consideration in your PSA in the future (Y/N) (number of response)*
Seismotectonic (earthquake)		**25**	Internal fire (7) Tsunami (3) Internal flooding (4) External Flooding (5) High temperature (1) Hail (1)	Y (20) N (7)	Y (3) N (3)
1	Vibratory ground motion	1			
2	Long period ground motion	2			
3	Surface faulting (fault capability)	2			
4	Liquefaction	**7**	considered as a hazard to be combined with earthquake		
5	Dynamic compaction (seismically induced soil settlement)				
6	Tsunami	4			
Flooding		**19**	Strong wind (6) Extreme rainfall (2) Landslide (1) Snow melt (2)	**Y (9)** **N (14)**	**Y (8)** **N (5)**
7	Extreme rainfall (note links to other meteorological phenomena)	3			
8	Floods resulting from snow melt	2			
9	Flooding due to off-site precipitation with waters routed to	1			

	the site				
10	Extreme ground water	2			
11	Flood due to obstruction of a river channel (downstream or upstream) by landslides, ice, jams caused by logs or debris, or volcanic activity)	1			
12	Floods resulting from changes in a river channel due to erosion or sedimentation				
13	Flood resulting from large waves induced by volcanoes, landslides or avalanches in water basins or by waterspouts				
14	Floods and waves caused by failure of water control structures (dam failure)	1			
15	Watercourse containment failure				
16	Seiche (fluctuation in water level of a lake or body of water)	1			
17	Seawater level: high tide	3			
18	Seawater level: wind generated waves	2			
19	Seawater level: storm surge	1			
20	Seawater level: impact of human made structures such as tide breaks and jetties				
21	Instability of the coastal area due to erosion or sedimentation				
22	Tsunami (see Seismotectonic)				
Meteorological events: Extreme values of meteorological phenomena					
23	Precipitation	4			
24	Extremes of air temperature (high and low)	**16**	Freezing (8) High water temperature (6) High wind (4) Snow (3)	Y (6) N (11) Some yes mention rough or conservative risk assessment	Y (11) N (2)
25	Extremes of ground temperature	3			
26	Extremes of sea (or river) temperature	**9**	See 24		
27	Humidity				
28	Air pressure				
29	Extreme drought (low river level)	**12**	Extreme air and water temperature (4) Dust storm (1)	Y (2) N (8)	Y (4) N (3)
30	Snow pack	**18**	Wind (14) Man made hazard (transportation) (1) Earthquake (1)	Y 11) N (5)	Y (7) N (4)(screened out)
31	Icing	**10**			
32	Hail	3			
33	Permafrost				

34	Snow melt (see Flooding)	2			
35	Seawater level (see Flooding)				
Meteorological events: Rare meteorological phenomena					
36	Lightning	**18**	Fire (1) Wind and rain (8) Low/high temperature (1)	Y (4) N (10)	Y (3) N (3)
37	Storm (Tornado, Hurricane, Tropical Cyclone, Typhoon), **high wind**	**30**	Snow (6) Flooding (4) Missiles (4) Lightning (7) Rain (1) Loop (2) Release of on-site chemical storage (1) High temperature (1)	Y (15) N (10)	Y (10) N (5)
38	Blizzard	4			
39	Wind blown debris (external missiles)	1			
40	Sandstorm, dust storm	4			
41	Saltspray/saltstorm				
42	Waterspouts	2			
43	Snow avalanche				
44	Ice flows / frazil	**8**			
45	Mist / fog	1			
46	Solar flares	1			
Biological / Infestation		**29** **biological**	**Wind (3)** **Snow (1)** **Lower river level (2)**	**Y (3)** **N (5)**	**Y(2)** **N (1)**
47	Seaweed, Alga	**8**			
48	Fish	**5**			
49	Jellyfish	**6**			
50	Marine growth	**4**			
51	Crustaceans, molluscs (shrimps, clams, mussels, shells)	**6**			
52	Birds	1			
53	Airborne swarms	1			
54	Infestation by rodents and other animals				
Geological					
55	Slope instability (landslide, rock fall)				
56	Debris flow, mud flow	1			
57	Ground settlement (natural or man-made; mining, ground water extraction, oil/gas production)				
58	Sinkholes: collapse of natural (caverns, karstic caves) and man-made cavities (inactive or active mines)				

59	Ground heave				
60	Leeching, soluble rocks (limestone, gypsum, anhydrite, halite)				
61	Unstable Soils (quick clays etc.)	1			
62	Volcanic eruption (includes other effects than seismic)	1			
63	Groundwater (see flooding)				
64	Meteorite (includes other effects than seismic)	1			
65 *	Contaminated land				
66 *	Radon				
67 *	Fissures				
68 *	Faults	1			
	* probably not relevant for external hazard assessment				
Forest fire					
69	Forest fire	3			

Table 41 - Question Q58) – Synthesis of answers for natural external hazards

The following table provides a synthesis of the answers for human induced external hazards.

70	Aircraft crash	**20**	Fire (4) Explosion (2) Release of chemical in on-site storage (1)	Y (7) N (8)	Y (5) N (2)
71	External fire (due to human activities)	**14**	High temperature (1) Internal fire and flooding (1)	Y (3) N (4)	Y (5) N (0)
72	External explosion	**15**	Fire (2) Toxic gases (1)	Y (3) N (1)	Y (2) N (0)
73	Asphyxiant and toxic gases	**9**			
74	Corrosive gases or liquids	2			
75	Radioactive gases or liquids	2			
76	Electromagnetic interference (disturbance of external grid)	**5**			
77	Collision of floating bodies with water intakes and UHS components	3			
78	Oil spills	**8**			

Table 42 - Question Q58) – Synthesis of answers for human induced external hazards

The following table summarizes the ten most relevant external hazards for the respondents:

1	Storm, strong wind
2	Biological infestation
3	Earthquake
4	Aircraft crash
5	External flooding
6	Lightning
6	Snow pack
8	Extreme air temperature
9	External explosion
10	External fire

Table 43 - Question Q58) – Ten most relevant external hazards

<u>Interpretation in terms of end-users practices and needs</u>

The lists of relevant external hazards to be considered in PSA is established in accordance with the site specific conditions (as an example, volcano is considered once for Japan).

Among the most relevant external hazards according to respondents, three man made external hazards and eight natural external hazards are mentioned.

For the column D of the table related to external hazards considered in the respondent's PSA, it is important to note that "considered" means analysed but not modelled in detail in the PSA. Some respondents mention the fact that external hazards are taken into account in the screening analysis and as a result of this analysis could be screened out. For some other respondents, a partial or a rough risk assessment is implemented, relying on conservative or partial data including large uncertainties.

The majority of additional hazards to be considered to account for combined effects are induced by the first external hazard considered (for instance tsunami after an earthquake) or physically correlated (for instance storm and rain). Some independent hazard combinations are mentioned such as for instance: earthquake/hail, or earthquake/high air temperature, regardless of the likely low probability of these kinds of combination.

Considering the number of "no" for a considered external hazard in PSA (column C) and the number of "yes" for a potential consideration in PSA in the future (column E), some proposal for potential end-users needs related to the external hazard PSA modelling could be identified:

- External flooding,
- Extreme air temperature,
- Storm/high wind,
- Aircraft crash.

The conclusions and/or recommendations for the project

The project could focus on methodological developments for a limited number of external hazards (say 10 specific hazards) seen most relevant from end-users' responses (see Table 43) or needs (see list above).

6.1.2 INTERNAL HAZARDS TO BE CONSIDERED IN THE ASAMPSA_E PROJECT

A draft list of internal hazards to be considered in the ASAMPSA_E Project is presented in Appendix 2.

Q59) Do you think that the Appendix 2 list is a comprehensive list of internal hazards, so that it covers all single internal hazards that should be considered in an extended PSA for a nuclear power plant?

The table form Appendix 2 of the questionnaire, provides a draft list of internal hazards based on IAEA Safety Guide NS-G-1.11.

Presentation of the tendency of the majority of the respondents

Concerning question 59, from 34 organizations there are 32 answers, 22 answers are affirmative (Yes), 10 answers are negative (No) and 2 organizations don't give answer.

Most of the organizations that give negative answer points that the list of internal hazards may be extended/reviewed by adding:

- failure of electrical supply systems (TUS-Bulgaria),
- failure of safety equipment (TUS-Bulgaria),
- all internal hazards (TUS-Bulgaria) listed in IAEA SSG-25: PSR of NPPs (2013), including the following hazards pointed by other organizations:
- electromagnetic (EDF, Kozloduy NPP, INRNE) and radio frequency interferences (Kozloduy NPP, INRNE),
- drops of heavy loads (Kozloduy NPP, INRNE, MVM Paks II.Zrt., NUBIKI, UJV),
- steam release (Kozloduy NPP, INRNE, NUBIKI),
- hot gas release (Kozloduy NPP, INRNE),
- cold gas release (Kozloduy NPP, INRNE),
- deluge and spray (Kozloduy NPP, INRNE),
- toxic and/or corrosive liquids and gases (Kozloduy NPP, INRNE, MVM Paks II.Zrt., NUBIKI), dangerous (chemical) substances (EDF, IBERDROLA, JSI),
- vibration (Kozloduy NPP, INRNE),
- subsidence (Kozloduy NPP, INRNE),
- high humidity (Kozloduy NPP, INRNE),
- loss of internal and external services (cooling water, electricity, etc.) (TUS, Kozloduy NPP, INRNE),
- high voltage transients (TUS, Kozloduy NPP, INRNE, JSI),
- loss or low capacity of air conditioning (which may lead to high temperatures) (TUS, Kozloduy NPP, INRNE),
- smoke Induction (Main Control Room ventilation isolation) (JSI).

Analysis based on the profile of the respondents (e.g. authority, TSO, utility) or based on experience of the respondent in terms of PSA development

Concerning question 59, it is not found specific dependency between tendencies of answers and comments in correspondence to the profile of the respondents.

Presentation of the most significant/recurrent/interesting comments

A wide part of the presented list of additional internal hazards (as pointed by TUS, Kozloduy NPP and INRNE) may be based on IAEA Specific Safety Guide SSG-25 – Periodic Safety Review of NPPs. Most of the proposed internal events of TUS, Kozloduy NPP, INRNE, EDF, IBERDROLA, JSI, MVM Paks II.Zrt., NUBIKI and UJV are close to those recommended in this guide.

Some of the organizations who answered positively (Yes) to question 59, give additional comments for clarification for the list of internal hazards:

- AREVA claims that no random collapse of structures is considered (triggered ones, e.g. by an earthquake);
- FKA points that the event pipe failures, pipe whip, fluid jets are part of the internal flooding assessment. With existing demands on LOCA assessment these failure modes shall not cause core damages. These failure modes are also used in developing in-service inspection program with the aim to have extreme low risk for core damage. These shall not be important for a PSA;
- the VUJE comment is that the presented list is probably not comprehensive but sufficient for ASAMPSA scope. May be that pipe failures and pipe whips are not hazards but failure modes that can be induced by seismic event.

Interpretation in terms of end-users practices and needs

The answers/comments are a base for fixing and clarifying the list and the scope of internal hazard events using information and recommendation from existing safety guides or other documents and from experience of the organizations who carry out PSAs.

Conclusions and/or recommendations for the project

For the presented answers of Q59 of 32 organizations - 22 organizations answered affirmative in correspondence that the list of internal hazards is comprehensive so that it covers all single internal hazards that should be considered in an extended PSA for a nuclear power plant. Most of the 10 organizations who answered negatively (No) have proposed additional events to extend the list.

Most of the proposals for extension of internal hazards and for including specific internal hazards (if they are appropriate), cover the recommendation of IAEA Specific Safety Guide SSG-25 – Periodic Safety Review of NPPs, which may be consider as good reference concerning this item.

6.1.3 SCREENING PROCESS AND CRITERIA

The answers given by the respondents are summarized below according to the questions in the questionnaire.

Q60) If you have developed internal and / or external hazards PSAs, which guides and / or other methodology documents were used for qualitative and / or quantitative screening of external hazards?

	Screening criteria have been used	Screening criteria have not been used	No answer
Internal hazards	17	4	12
External hazards	23	5	5

Table 44 - Question Q60) – Synthesis of answers

The majority of participants uses a set of documents as ASME/ANS standards (RA-Sa-2009), IAEA guides (e.g. No. SSG-3), US NRC documents and IPEEE experience. Some respondents have developed their own criteria based on the existing standards. 3 participants mentioned country standards (Germany, Switzerland and Ukraine).

External hazards PSAs:

There are many references dealing more or less in detail with selected external events ([9] and [12] to [43]), but SKI Report 02:27 ([12]) is the most frequently listed. It also includes a list of potentially relevant external events. For seismic hazard, the IAEA reports Safety Report Series 28 ([21]) and Safety Standards series No. NS-G-3.3 ([18]) are specifically cited (although NS-G-3.3 is now outdated and replaced by SSG-9 since 2010).

Internal hazards PSAs:

Some respondents indicated that fire PSA screening was performed based on EPRI Fire PRA Methodology and NUREG6850 and flooding PSA on EPRI–1019194. But the screening process used in the analysis of fires and flooding may differ from that of external hazard. Scenarios may be screened out from further detailed analysis whose cumulative frequency is below x % of the total core damage risk based on coarse initial analysis assumptions.

Interpretation in terms of end-users practices and needs

Existing guides allow the study of screening. They are sometimes applied without change but more often they have been interpreted.

Conclusions and/or recommendations for the project

Define commona common criteria set containing best practices to share.

Q61) Do you think that available methodology and criteria to perform screening analysis of internal and external hazards for the purposes of PSA are appropriate and comprehensive?

Yes	13
No	15
No answer or not applicable	6

If no, please specify the most important weaknesses and deficiencies in existing methodologies

There is a majority which believes that present methods to perform screening analysis for the different hazards are not satisfactory, and especially not for external hazards.

<u>From the comments supporting the view that available methodology and criteria to perform screening analysis of internal and external hazards for the purposes of PSA are not satisfactory</u> it can be concluded that existing methods do not address in sufficient depths and/or detail:

- treatment of combined events [5 times],
- quantification of event frequencies for quantitative screening analysis [5 times],
- detailed rules for application of screening criteria as well as some practical examples [4 times],
- impact assessment of the different hazards [4 times],
- real technical justification for screening values used worldwide [1 time].

<u>Comments supporting that available methodology and criteria to perform screening analysis of internal and external hazards for the purposes of PSA are satisfactory</u> conclude "yes" for the ENSI guide (Cazzoli Consulting) and "yes" for internal hazard (Tractebel).

<u>Interpretation in terms of end-users practices and needs</u>

It would be useful to complete existing methodologies on the missing points (see above).

<u>Conclusions and/or recommendations for the project</u>

Provide state of the art methods on combined event treatment and quantification of event frequencies. Collect and analyse existing justification for screening values (link with Q62).

Q62) If you have applied a screening approach, which quantitative screening criteria (values) were used for screening of internal and external hazards?

27 organizations answered this question (7 did not).

<u>Presentation of the tendency of the majority of the respondents:</u>

No quantitative screening criteria defined (as it depends on the potential impact to the plant): 3 times,

No quantitative screening criteria used: 3 times (e.g. : Qualitative criteria were used for fire PSA).

For the others, their initiating events are screened out based on a wide range of absolute criteria:

- Occurrence frequency from 10-4 to 10-10/year.r,
- Contributing to the CDF from 10-6 to 10-10/year.r.

But 1E-07/year.r for frequency and for contribution is the value most often used.

	Occurrence Frequency / year.r					
	10-4	10-6	10-7	10-8	10-9	10-10
Number	1	3	5	1	1	1

	Contribution CDF /year.r					LERF	Releases	FDF		
	10-6	10-7	10-8	10-9	10-10	10-7	10-8	10-7	10-8	10-9
Number	2	4	2	1	1	1	1	1	1	1

CDF : core damage frequency / LERF : large early release frequency / FDF : fuel damage frequency
Table 45 - Question Q62) – Synthesis of answers

The use of absolute criteria differs from one to another organization:

- some respondents add criteria so that the cumulative total of screened out items must not exceed those thresholds;
- cliff edge effect is considered: the frequency of the hazard is less than <10-6/yr, unless there is evidence that this frequency is near a 'cliff edge' effect; if so, the hazard may be screened out if the frequency is <10-7/yr (one respondent);
- some respondent define different screening criteria according to the hazard (for instance 1E-7 for internal and 1E-9 for external initiating events).
- one respondent also used screening criteria for FDF.

One respondent uses a mixed approach between absolute and relative criteria:

10% of CDF for internal hazards and less than 1E-7 for external hazards.

Relative criteria are also used:

1% of the internal events CDF for the event frequency and the total of screened out initiating event frequencies should be lower than 10% of the internal events CDF.

For internal hazard a cumulative frequency is defined in most cases:

Fire zone – In case that its contribution to the cumulative CDF/FDF is less than 10-7 per year

Flood scenario – In case that its contribution to the cumulative CDF/FDF is less than 10-8 per year

Analysis of fires and flooding - Those scenarios are screened out from further detailed analysis whose cumulative frequency is below 1 % of the total core damage risk based on coarse initial analysis assumptions.

Relative criterion is used for quantitative screening of fire scenarios, which corresponds to 1-10% of the total CDF contribution. The exact value depends on the number of scenarios to be analysed in detail and on the results obtained for all fire scenarios.

For seismic events:

In case of "earthquake" hazard a comprehensive Level 1 Seismic PSA has to be performed if the site specific intensity exceeds intensity VII.

The seismic events with probability <1e-10/yr are also not considered.

Different CDF depending on the range:

- Seismic events - 1E-7 for frequency in the range 1E-1 – 1E-6,
- Seismic events - 1E-8 for frequency in the range 1E-7 and below.

Interpretation in terms of end-users practices and needs

There is a lack of real technical justification for screening values used worldwide.

Conclusions and/or recommendations for the project

Screening values have a large heterogeneity. Is it due to the regulatory framework?

Topics to discuss: Is it necessary/possible to reduce this heterogeneity? How to do?

It could be interesting to collect and analyse existing justification for screening values.

Internal hazard assessment for PSAsQ63) Do you think that available internal hazard assessment methodologies are appropriate and comprehensive for use in PSA, i.e. for describing the hazard frequency - hazard intensity relationship?

If no, please specify the most important weaknesses and deficiencies in existing methodologies

Yes	23
No	6
No answer:	5

Presentation of the tendency of the majority of the respondents

Most of the respondents consider that available internal hazard assessment methodologies are appropriate and comprehensive for use in PSA.

For five respondents (2 TSO, 3 utilities), the main insufficiencies mentioned are as followed:

- Although an internal fire and flooding methodologies (EPRI) exist and are appropriate, more realistic assessment of the hazard frequency or consequences have to be developed,
- non-specific methodologies exist for internal explosion, missiles or quantification of human induced hazard ((i.e. internal hazards due to inappropriate human actions),
- the methods for hazard curves and fragility curves construction are not described.

Conclusions and/or recommendations for the project

Existing methodologies for internal hazards assessment (mainly fire and flooding) should be improved to reduce conservative approaches as well as for hazard frequency than for hazard consequences and uncertainties assessment. New methodologies should be developed to deal with internal hazards such as (this list could not be exhaustive) internal explosion, missiles and quantification of human induced internal hazard.

Q64) Are uncertainties related to the characterization of internal hazards considered in your PSA (i.e. treated quantitatively and completely)?

Yes	21
No	9
No answer:	4
Comments:	14

Presentation of the tendency of the majority of the respondents

An important majority of respondents consider uncertainties related to the internal hazard's characterization in their PSA, either implemented in present studies or planned for studies still under development.

Different methods are used to consider uncertainties related to internal hazard's characterization:

- uncertainties in frequencies of exceedance are determined and treated for detailed hazard PSA,
- a conservative approach is used, which treats the uncertainties by covering them with appropriate margins,
- sensitivity studies are performed.

Some deficiencies are mentioned such as the lack of data to perform quantitative uncertainties analysis, the relevance of model or codes to propagate properly uncertainties.

As a consequence, main respondents perform limited uncertainty studies.

Conclusions and/or recommendations for the project

There is a lack of commonly shared practices to consider uncertainties related to the characterization of internal hazard.

6.1.4 EXTERNAL HAZARD ASSESSMENT FOR PSAS

Q65) Do you think that available external hazard assessment methodologies are appropriate and comprehensive for use in PSA, i.e. for describing the hazard frequency - hazard intensity relationship?

Yes	14 (TSO 7, Utility 5, Regulator 2)
No	14 (TSO 8, Utility 4, Vendor 1)
No answer	7

(One respondent answered Yes and No)

Half of respondents seems satisfied. But in fact, there is a majority which believes that present external hazard assessment methodologies are not satisfactory, except for earthquake.

Comments supporting that available external hazard assessment methodologies for use in PSA are satisfactory conclude "yes" for seismic hazard assessment (cf. EPRI guideline "Seismic Probabilistic Risk Assessment Implementation Guide").

Comments supporting that available external hazard assessment methodologies for use in PSA are not satisfactory conclude that the most important weaknesses and deficiencies in existing methodologies concern hazard frequencies determination [10 times], because it is hard to assess very low hazard frequencies, with no or limited data.

In addition to this, significant work is needed in some areas as:

- assessment of human factor in case of external hazards,
- the treatment of dependencies (hazard impact, safety functions, SSC failure),
- the methods for fragility curve constructions.

Interpretation in terms of end-users practices and needs

The methodologies should include the use of mathematical models and practical example of calculations and should be more detailed in some areas as: human factor, treatment of dependencies, and methods for fragility curve constructions.

Conclusions and/or recommendations for the project

A review of the existing methods concerning hazard frequencies determination could be done. As scientific obstacles remain, it could cover future research projects.

Q66) In particular, do you think that available external hazard assessment methodologies are appropriate and comprehensive to characterise uncertainties?

If no, please specify the most important weaknesses and deficiencies in existing methodologies

Yes	7 (TSO 1, Utility 4, Regulator 12)
No	12 (TSO 8, Utility 2, Vendor 1)
No answer	16

(One respondent answered Yes and No)

There is a majority which believes that present methods to characterise uncertainties for external hazards are not satisfactory, except for earthquake.

Comments supporting that available external hazard assessment methodologies to characterise uncertainties are satisfactory conclude "yes" for seismic hazard assessment.

Comments supporting that available external hazard assessment methodologies to characterise uncertainties are not satisfactory conclude that the most important weaknesses in statistical uncertainties are due to insufficient (or insufficiently representative) data and choice of appropriate statistical model. Extending and extrapolating existing external hazard studies reflects in the impossibility to characterize the uncertainties in a proper manner, i.e. too much conservative assumptions lead to too high uncertainties. Uncertainties become more important as the return period increase.

Another difficulty is that different hazards and their effect on the plant, and the assumptions made in dealing with these uncertainties can lead to varying degrees of conservatism in the estimates of risk.

Interpretation in terms of end-users practices and needs

The methodologies to characterise all uncertainties should be more detailed. The need is to better characterize the probability and associated uncertainties of rare but still credible events.

Conclusions and/or recommendations for the project

There is a lack of commonly shared practices to consider uncertainties related to the characterization of external hazards.

Q67) If you have developed external hazard PSAs,

A - What kinds of hazard assessments have been used as a basis for external hazard PSA (e.g., assessments previously used for establishing the design basis; hazard updates obtained during PSR process; or hazard updates by studies performed within the framework of the PSA)?

For question 67) in general, the following answers have been received :
No answer or haven't developed external hazard PSA : 12
No answer: TSO 2, Utility 2, Regulator 3
Haven't developed external hazard PSA : TSO 5
For external hazard, have developed only earthquake PSA: TSO 2, Utility 2

For question 67) A - the majority of participants have used as a basis for external hazard PSA, hazard updates by studies performed within the framework of the PSA [10 times], then hazard updates obtained during PSR process [5 times] and assessments previously used for establishing the design basis [4 times].

B – which hazard assessment methodologies were used in your PSA for the different kinds of external hazards (e.g. PSHA for earthquakes, extreme value theory for meteorological events, etc.)?

There is a significant majority that uses the PSHA methodology for earthquakes [11 times], and the extreme value theory for meteorological events [7 times].
Other kinds of hazard assessments are used, depending on the phenomenon:

Lightning: Assessment of occurrence frequency per square kilometre and characterisation of important hazard parameters (e.g. peak value, steepness and charge of lightning current, specific energy) based on measured data for lightning

Tornadoes: A combination of qualitative and quantitative assessment for tornadoes (subject to refinement and review currently), and for another organization the NUREG/CR-4461 was used.

Floods: statistical flood population sample described by the theoretical distribution function; in addition the PMF (Probable Maximum Flood) was evaluated (based on ANSI/ANS 2.8-1992),

Aircraft accidents: DOE Standard 3014-2006 was used.

One respondent indicated engineering judgement of the failure probabilities.

C – for the different external hazards considered in your PSAs, please specify what frequency range (or range for return period) is considered?

For seismic PSA, frequencies considered are equal to or greater than 10-6/y [5 times] or 10-4/y [3 times] depending on the organizations (minimum frequency:0 or 10-1/y).

For other hazards, frequencies considered are very heterogeneous:

For one respondent, return periods are of 100 and 10 000 years (frequencies down to 10-4/year).

Two respondents are trying to assess events with frequencies down to 10-6/year, one other indicated that weather data for return periods up to 10000 years have been extrapolated to one million years (also frequencies down to 10-6/year).

One respondent indicates different frequencies according to hazard (floods: up to 10-6/year, aircraft accident: up to 1E-6/year, high winds and tornadoes: up to 10-8/year)

There are also hazard frequencies equal to or greater than 10-7/y, up to 10-9/y and one respondent considers that frequencies have to be considered up to 10-12/year.

For lightning, one respondent indicates that simply using a frequency range did not appear appropriate, because there is a more complex relationship between hazard frequency and potential hazard induced losses (damage) due to the fact that hazard induced losses cannot be described adequately by a single loss (or hazard intensity) indicator in this case.

Interpretation in terms of end-users practices and needs

No needs expressed.

Conclusions and/or recommendations for the project

Frequencies ranges values have a large heterogeneity according to organizations.

It could be interesting to have a discussion on the definition of frequency range, what kind of consideration should be taken into account.

Q68) A - Were external manpower resources involved in hazard assessment apart from the PSA team?

If yes, to what extent and in which analysis areas (technical disciplines)

Yes	20
No	5
No answer	8

There is a significant majority that uses external manpower resources for hazard assessment for earthquakes [13 times], and for other hazards (ocean science experts, sea flooding experts, hydrology experts, meteorology experts, fire and explosion) [8 times].

2 organizations used external resources for collection of measured historical data, for expert advice on hazard assessment methodologies for extreme weather phenomena and for hazard assessment for lightning.

B - To what extent were they involved in the approval process?

Yes	3
No	6
No answer	22

3 respondents involve external manpower resources in the approval process: external manpower resources are involved in peer review [1 time], or involved in 15% of the total approval process [1 time], or highly involved [1 time].

Q69) Are uncertainties related to the characterization of external hazards considered in your PSA (i.e. treated quantitatively and completely)?

Q66 : methodologies to characterise uncertainties are satisfactory		Q69 : Are uncertainties related to the characterization of external hazards considered in your PSA	
Yes	7	Yes	16
No	12	No	7
No answer	16	No answer	11

Table 46 – Comparison of answers to Question Q66) and Question Q69)

For a majority, uncertainties related to the characterization of external hazards are considered in their PSA. It can be noticed that several organizations change from No (Q66) to Yes (Q69), this can be explained by uncertainties partially treated.

This is most often the case for seismic PSA as the treatment of uncertainties is included in the PSHA process.

For others external hazards than earthquake, some organizations indicate that the treatment of uncertainties cannot be considered complete due to the limitations in assessment methodologies and data (Q66 : assessment of very low hazard frequencies, and limited data) [3 times]. One organization treats uncertainties by a discussion for each analysed event (different sources, judgement of possible variation within each source of uncertainty…). And one respondent indicated that uncertainty analysis is performed.

Conclusions and/or recommendations for the project

Provide state of the art practices and methods used.

Q70) What is the role of expert judgement in selecting, screening and probabilistic modelling of external hazards in your PSA, and what is the way of applying expert judgement in these analysis steps?

The role of expert judgement in PSA is significant for all participants and applies to all or part of the process according to organizations.

Most of the time, expert judgement has been used during all processes for external hazards PSA [5 times], with a focus on hazards characterizations [6 times]. An expert judgement is also used to determine impact or consequence of external hazards, as well as to determine the most relevant aspects of phenomena to set basic assumption for PSA model.

Expert judgement is also used if a specific input data is insufficient, or when there are no continuous variables to describe the phenomenon (e.g. biological blockage) [2 times].

In some case, the use of expert judgement had been limited to identify or to review the list of external hazards and to screening [2 times].

One respondent used expert judgement because of lack of relevant methodologies.

In the development of the PSHA expert judgement has been also used. For detailed licensing reviews an expert assessment framework may be a requirement.

Interpretation in terms of end-users practices and needs

Expert judgements have a significant role and are associated to high uncertainties. It could be improved by using systematic methods.

Conclusions and/or recommendations for the project

The opportunity to evaluate different methods applying expert judgement could be considered by the project.

Q71) Could you provide examples of best practice of external hazard assessment from non-nuclear industry: please contribute references and industry reports (in PDF format) of hazard assessment studies that you consider to be best-practice?

Yes	1
No	8
No answer	25

Only one example in Bulgaria (Refineries "Plama" JSC – Pleven and "Neochim" – JSC – Dimitrovgrad).

Q72) How do you take climate change into account in natural hazards characterization?

Among the 34 participants, 28 answered the question. All participants do not seem to have the same level of understanding of the issues linked to climate change, since one expresses doubts and another assumes that it does not impact hazard assessment, while the majority either already take it into account or recognize that it is relevant, even though they do not take it into account yet. For the majority of the respondents (13), climate change is not yet taken into account but it is found relevant for a number of hazards. The most often cited hazards are extreme temperatures, droughts and flooding, sea level, wind and storms (or more generally meteorological extremes), but others are mentioned too, like tornadoes or lightning, for which information may be more difficult to find. 7 already deal with climate change in their estimations, but one considers that regular updating is sufficient to take on-going climate change into account, while others mentioning regular updates still do not consider that they take climate change into account. It seems that the respondents who are already taking climate change into account are mainly utilities. 5 respondents do not find climate change consideration necessary.

Q73) How do you take climate change into account in the estimation of summer high temperature extremes?

From the 34 participants, 25 answered the question, and a large majority (18) does not take climate change into account for the estimation of summer high temperature extremes. One however mentions considering climate change on a case by case basis. Among the 7 respondent taking it into account, 4 use Extreme Value Theory (EVT) with non-constant parameters and 3 use suitably downscaled climate simulation results. Surprisingly, 3 of the respondents answering here that they take climate change into account did not answer doing so, at least for temperature, to the previous question. Only one utility uses another methodology besides EVT with non-constant parameters.

6.1.5 COMBINATION OF HAZARDS AND EVENTS

Q74) Are you considering combinations of hazards in your PSAs?

If yes, please detail the methods used to identify relevant combinations.

Yes	12
No	18
No answer	4

Most of the time, relevant combinations are identified by expert judgements [3 times].SKI Report 2:27 is also used [2 times] or the combinations were screened out with the same methodology as single events [1 time]. Detailed FMECA analyses are indicated as a methodology to identify relevant combinations [1 time].

For external hazard other than earthquake, organizations are focusing on combination of correlated events [2 times].

For earthquake one respondent identifies relevant combinations to some extent: earthquake and liquefaction; earthquake and tsunami; seismics-induced internal flooding and fires.

If no, are you willing to consider these combinations in the future? Please detail the main difficulties for this, in your opinion.

Are you willing to consider these combinations in the future

Yes	11
No	3

Lack of methodology commonly shared [7 times], even if SKI Report 2:27 is used.

Main difficulties are as follows:

- selection and prioritization of the possible combination,
- assessment of the probabilities for the supposed combinations given the dependency between hazards
- development of relevant integral PSA models (calculating SSCs fragility with respect to more than one single external hazard ...)

Presentation of the most significant/recurrent/interesting comments

One respondent proposes a way to select critical combinations by using Fault Sequence Analysis (FSA) methodology developed by IAEA. It is currently implementing for Armenian NPP.

Interpretation in terms of end-users practices and needs

Standards should be developed.

Conclusions and/or recommendations for the project

Provide state of the art practices and methods used: selection of critical combinations, association of the probabilities for hazards combination.

Q75) In your opinion, should the following combinations of hazards and events be considered in extended PSAs:

A - Independent internal or external hazard occurring during the progression of an accident (before core melt and during the short term period after core melt)?

B - Independent internal or external hazard occurring during the long term period after a severe accident (i.e. after core melt has occurred)?

C – Other combinations?

	YES	NO	No answer	
Q75A	12 (TSO 7, Utility 3, Regulator 2)	18	3	Independent internal or external hazard occurring during the progression of an accident (short term period after core melt)
Q75B	15 (TSO 10, Utility 3, Regulator 2)	16	3	Independent internal or external hazard occurring during the long term period after a severe accident
Q75C	8 (TSO 3, Utility 4, Vendor 1)		24	Other combinations

Table 47 - Question Q75) – Synthesis of answers

Comments related to Q75A:

- Not relevant [13 times],
- Merit an investigation [5 times],
- Only if there is a high probability of occurrence, need case by case analysis [4 times],
- Impossible to do [1 time].

Comments related to Q75B:

- Not relevant [7 times],
- Merit an investigation [6 times],
- Only if there is a high probability of occurrence, need case by case analysis [4 times],
- Impossible to do [2 times].

4 organizations move from No to Yes (independent hazards during the long term period after a severe accident could be considered if their probability of occurrence is sufficiently high (e.g., depending on the mission time to be considered - see Q80)); in the case of earthquake, effects of aftershocks can be considered.

2 organizations move from Yes to No (considerationc of such events would make the scope too uncertain and potentially large).

Answers / Comments related to Q75C (8 answers):

- dependent combined hazards [5 times],
- combination of an initiating hazard and induced others (for example: seismic + flooding) [2 times],
- combinations that have a probability larger than E-7 [1 time],
- combination of external hazards at least one of which is long-term. For example - high temperature during the summer together with earthquake. Usually high temperature is mitigated by ventilation systems, which can fail in case of earthquake [1 time].

Interpretation in terms of end-users practices and needs

Consideration of combination of events (external + internal) is one of the main PSA extensions planned within ASAMPSA_E and one of the main deficiencies in the current PSA methodology.

Conclusions and recommendations for the project

ASAMPSA_E project should to put special emphasis on the analysis of combinations of events (external + internal).

Q76) Do you think that it is necessary to analyse simultaneous accident progression in the core and in the spent fuel pool?

Yes	27
No	3
No answer	4

If yes: are the required methods available (deterministic as well as probabilistic)?

Yes	6
No	5
Partly	4 (analysis methods are available but have some shortcomings when applied to simultaneous accidents in the core and the SFP)
Ongoing	1 (EPRI)

Conclusions and/or recommendations for the project

The probabilistic methods need to be improved to address accurately the simultaneous progression of the accident.

6.2 INTRODUCTION OF HAZARDS IN PSAS

6.2.1 GENERAL ISSUES

Q77) Safety and non-safety systems could fail if they are loaded beyond their design basis. Do you think that existing methods to quantify the failure mode and failure probability in hazard PSAs are satisfactory?

Yes	17
No	7
No answer	10
Comments	22

Comments supporting that existing methods to quantify the failure mode and failure probability in hazard PSAs are satisfactory conclude that existing FMEA and/or External hazard fragility analysis can be used to determine the HCLPF for safety and non-safety systems. These methods can be complex and need large resources and data since each hazard needs hazard specific fragility analysis.

Comments supporting that existing methods to quantify the failure mode and failure probability in hazard PSAs are not satisfactory conclude that the methodology is best developed for seismic events but it is not as mature for other kinds of hazards. Appropriate failure mode and fragility analysis methodology would be necessary and useful for the complete range of hazard and the associated loads. Identification and quantification of correlated failures are also important.

Non-safety systems: Some respondents also mentioned that methodology on fragility evaluation of non-safety related SSCs should be developed in more details.

There is a majority which believes that present methods of quantify the failure mode and failure probability in hazard PSAs are satisfactory. However, a significant minority has the opposite opinion. The different statements might reflect the experience or the lack of experience in performing fragility analysis for external hazards.

Q78) Do you think that in extended PSAs a specific approach should be developed for multi-unit sites?

Yes	25
No	5
No answer	4
Comments	23

Comments supporting that in extended PSAs a specific approach should not be developed for multi-unit sites:

The 5 organizations who think that in extended PSAs a specific approach should not be developed for multi-unit sites (3 utilities, 2 TSO) did not give any comment.

Comments supporting that in extended PSAs a specific approach should be developed for multi-unit sites:

25 organizations consider it necessary that in extended PSA a specific approach is developed for multi-unit sites. However, 4 respondents state that this development should be limited to the sites where this may be important (due to a high interdependence between the units of the same site) and has a potential impact in terms of releases.

Among the issues to be addressed in this context:

- the existence of shared systems and possible interconnections between units (13),
- the consideration of human resources shared in the context of external events, given the planned organization (10),
- the identification of initiating events concerned (7). 2 responses specify that only the external events affecting the whole site should be treated,
- the existence of identical systems in the units (2),
- the potential for the units to be in different modes at the time of the hazard (2),
- the potential for the propagation of an event from one unit to another one (2),
- the common cause failures (1),
- the existence of spatial dependencies (1).

Some responses identify the need to adapt the metrics and targets in the multi-unit framework (4). In terms of availability of methods, two organizations believe that the methods already exist (CANDU experience or application of the same approaches as for current PSA). One organization believes that the rules and guidelines corresponding to this type of analysis should be developed. The other answers do not treat this topic.

<u>There is a majority which believes that in extended PSAs a specific approach should be developed for multi-unit sites.</u> The issues worth to be treated in this development are proposed and could be discussed within the project. Also the need for specific guidelines to be developed could be discussed.

Q79) Most hazards affecting plant safety will also very much impact on the staff. Do you think the present methods on human reliability assessment are suitable for such conditions?

Yes	12
No	19
No answer	4
Comments	25

(One respondent answered Yes and No)

<u>Comments supporting that present methods on human reliability assessment are suitable for hazard conditions</u> conclude that the current available human reliability assessment methods are suitable to all accident scenarios, including external hazards. But the PRA practitioners should be careful on how to choose and apply the methodology to the specific hazard analysis.

Some respondents also propose to assess the applicability of existing human reliability analysis methods in extended PSAs (not limited to seismic PSA only).

Comments supporting that present methods on human reliability assessment are not suitable for hazard conditions conclude that the currently used HRA methods simply consider “stress” or variants thereof. How hazard impacts should translate into “stress” and how specific environmental conditions in the plant after hazard impact would impact on the staff is an open question, for example could the operator crew be injured by the hazard. Fortunately, there is a lack of data regarding the probabilistic impact of such conditions on NPP staff.

Some other interesting comments which could be mentioned:

- need to obtain a coherent HRA approach for all initiators (internal events, internal hazards, external hazards) and for both PSA Level 1 and Level 2;
- accessibility;
- multi-units aspects (because of their impact of the number of persons required to manage the situation).

There is a majority which believes that present methods on human reliability assessment are not suitable for hazard conditions. However, a significant minority has the opposite opinion. The different statements may perhaps be due to the different views on how to treat the epistemic uncertainty in HRA in general and during hazards in particular.

Q80) Do you think that mission times for extended PSA should be defined in a particular way?

Yes	23
No	8
No answer	3
Comments	27

Comments supporting that mission times for extended PSA should be defined in a particular way conclude that standard mission time (usually 24 hours) need to be adapted depending on the scenario (e.g. increased in case of external hazard with a long duration) and the level of the PSA. However, some comments underline the heterogeneity of mission times considered on the basis of the definition of stable plant state (from 24 hours to 70 years!).

Comments supporting that mission times for extended PSA don’t need be defined in a particular way conclude that PRA mission times, as set forth in the ASME/ANS PRA Standard, should be long enough that a stable plant state has been achieved. Extended PSAs should follow the same definitions as for existing PSA requirements.

There is a majority which believes that for extended PSA mission time should be defined. However, a significant minority has the opposite opinion. The different statements may perhaps be due to the different views on how mission times are assessed in the PSA. For example, many of those who responded negatively uses mission times that are long enough (until a stable plant state has been achieved). The definition of stable plant state should be assessed.

Q81) Do you think that seasonal variations (e.g., meteorological circumstances can vary in winter and summer) should be considered in an extended PSA, given their potential influence on risk metrics (CDF, LRF, etc.) or on PSA applications?

Yes	22
No	8
No answer	4
Comments	23

Comments supporting that seasonal variation should be considered in an extended PSA take screening of impossible event combination and risk monitoring as examples.
Many comments underline that consideration of seasonal variation should depend on the applications of the PSAs (may not be relevant when the PSAs aim at assessing an annual risk, while for assessments focused on a narrower time window (e.g., additional risk posed by maintenance activities during periods with increased storm/tornado potential), this may be critical).

Comments supporting that seasonal variation should not be considered in an extended PSA states that the seasonal variations already are considered in the annual baseline PSA application. The seasonal variation are captured in the frequencies and the failure modes for the specific weather.

There is a majority which believes that seasonal variations should be considered in an extended PSA. However, a significant minority has the opposite opinion. The different statements may perhaps be due to the different views on what is the perception of what is included in the term PSA, is it only the annual risk baseline or all kind of application that uses PSA. For example, many of those who responded positively raises risk monitor where seasonal variation should be considered.

6.2.2 ISSUES RELATED TO L1 PSA

With regard to introduction of hazards in extended L1 PSAs, the ASAMPSA_E project intends to address the characterization of internal events generated by external hazards or hazard combinations.
The guidance will include the following items:

- determination of the status of the equipment depending on the amplitude (frequency content) and the duration of the external event (e.g., fragility curve – structure analysis for fixed SSCs and malfunction of active SSCs)
- Consequences from a failing SSC on other SSCs (related to the classification of the equipment)
- Characterization of the transient, depending on the amplitude of the external hazard
- Short-term and long-term effects
- HRA

- Integration of hazard analysis
- Fragility or failure probability of SSCs
- System function analysis
- Completeness of L1 PSA
- Uncertainty analysis

Q82) A - Do you think that this list covers all the issues related to introduction of external hazards in extended L1 PSAs?

Yes	2020
No	11
No answer	3
Comments	12

B - Could you please identify the 5 items for which you consider it is the most important to develop guidance?

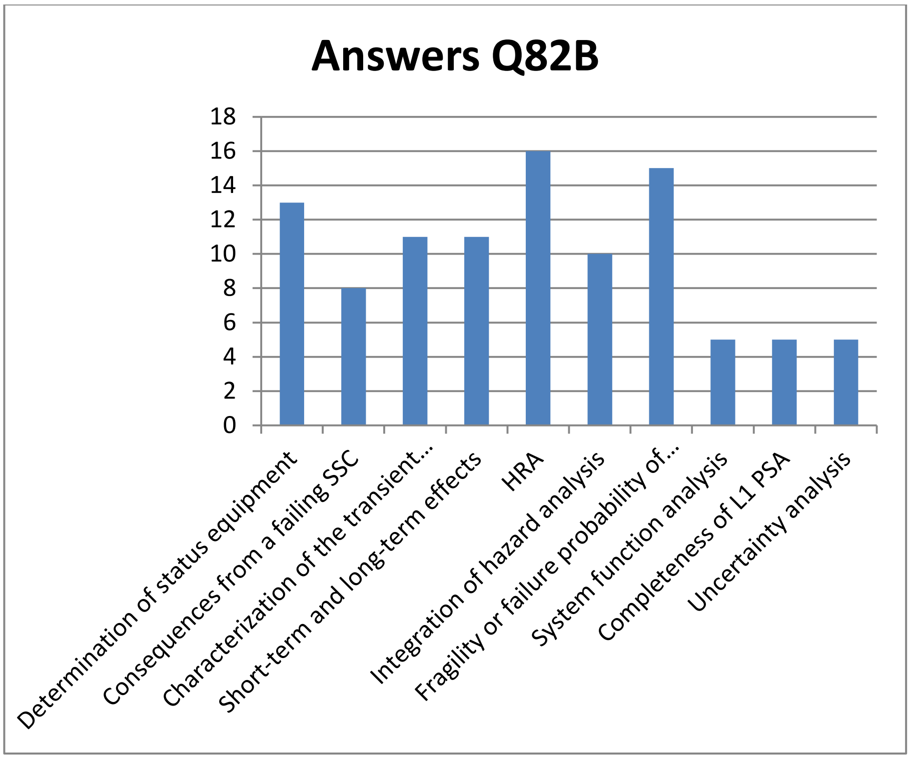

Figure 1 – Question Q82) B - Synthesis of answers

Comments supporting that the list do not cover all the issues related to introduction of external hazards in extended L1 PSA identify the following issues (with their number of occurrences):

- multi-unit effects (1)

- both core and SFP affected (2)
- deployment of new equipment/systems (1)
- external events-induced fires and floods (1)
- quality(1)
- safety goals (determining an acceptance external hazard CDF value, in order to perform the decision making process)(1)
- multiple hazard-induced initiating events (3)
- modelling the dependencies among SSCs failure behaviour in case of a given hazard (1)
- compilation of hazard equipment lists and walk downs (1)
- risk profile (1)
- importance Analysis (1)
- hazard and induced initiating events characterisation (3)
- mission time for SFP damage (1)
- characterization of the safety systems' behaviour, depending on the amplitude of the external hazard (1)
- frequency and parameter of hazards estimation (1)

There are no comments supporting that the list do cover all the issues related to introduction of external hazards in extended L1 PSA.
There is a majority which believes that the list covers all the issues related to introduction of external hazards in extended L1 PSA. However, a significant minority has the opposite opinion. The different statements might reflect the experience or the lack of experience in developing PSA models for external hazards.

6.2.3 ISSUES RELATED TO L2 PSA

Q83) A - Do you think that internal or external hazards could lead to relevant accident sequences which are significantly deviating from the traditionally analysed sequences?

Yes	12
No	19
No answer	3
Comments	13

Comments supporting the deviation of sequences provide some examples which were supposed to alter the "traditional" accident progression: long duration, simultaneous events in core and spent fuel pool, different evolutions in the three Fukushima reactors, containment structure failure, control room destruction and combinations of challenges which were not considered before.

Comments supporting the similarity of sequences point out that most "new" challenges end up in sequences which have been analysed traditionally, e.g. station black out, or containment with failure to close the ventilation systems. Availability of SAM may be different, partly because of human factors, affecting the relative frequencies of sequences, but basically not changing the set of relevant sequences to be analysed.

There is a majority which believes that internal or external hazards will not lead to relevant accident sequences which are significantly deviating from the traditionally analysed sequences.
However, a significant minority has the opposite opinion. The different statements may perhaps be due to different views on what are "traditional" analyses. As an example, there may be participants who "traditionally" analyse accidents with a failure to close the containment ventilation. For such participants it may be familiar to imagine sequences with a containment failure due to an external event.

B - Do you think that present analysis methods (deterministic and probabilistic) are appropriate?

Yes	21
No	4
No answer	9
Comments	14

Comments supporting the present analysis methods (deterministic and probabilistic) stated out the general appropriateness of current methods, but also mentioned the need of extension in terms of integrating e.g. multi-unit and spent fuel pool cases.

Comments supporting the inappropriateness of present analysis methods (deterministic and probabilistic) mentioned explicitly the insufficiency of code predictability in multi-unit and spent fuel pool cases. A missing risk target problematic as well as the software/computer performance dependence of the methods was mentioned.

There is a majority, that believes that the present analysis methods are appropriate. However, further improvements regarding the additional calculation of new accident sequences concerning e.g. the spent fuel pool or multi-unit cases have been demanded.

Q84) Do you think that extended Level 2 PSA will identify relevant (in terms of frequency and / or characteristics) contribution of release categories and / or source terms which are beyond or notably different of what is known from traditional L2 PSA?

Yes	188
No	13
No answer	3
Comments	18

Comments mentioning an impact of extended Level 2 PSA predicted possible changes in frequencies and in source terms relating to the extension of further sequences. The accident of Fukushima was stated to underline the importance of this extension.

Comments seeing no significant impact of extended Level 2 PSA saw the additional aspect already implied in the traditional PSA and predict only small expected changes e.g. in frequencies.

There is a majority that believes in an impact of an extended Level 2 PSA. However, a significant number of comments saw only little effect especially when the traditional Level 2 PSA was applied in a comprehensive way.

Q85) Is it reasonable to take into account the effect of internal hazards induced by external hazards on the progression and management of a severe accident (i.e. after core melt has occurred)? For instance, earthquakes might cause internal flooding or storms might induce internal fire (e.g. by compromising electrical connections).

If yes: please specify how you think such effects should be treated in the extended L2 PSA.

Yes	200
No	6
No answer	8
Comments:	24

Comments backing to take into account the effect of internal hazards induced by external hazards suggest similar procedures as in extended Level 1 PSA, newly modelled branches, additional expert judgement or integrated global risk models for the most relevant external/induced internal hazards.

Comments not backing the necessity of taking into account of internal hazards induced by external hazards have not been given in this questionnaire.

There is a significant majority that finds it reasonable to integrate the effect of internal hazards induced by external hazards, however the precise procedure to do so is not uniformly agreed about.

Q86) The outcome of a severe accident (including the resulting radioactive releases) could be influenced by the further evolution of the external and/or internal hazard in the plant(s) and on site during the severe accident progression. For instance, after core damage has occurred, the progression of an internal fire might continue or earthquake aftershocks could occur, resulting in further malfunction of equipment necessary for severe accident management. Do you suggest taking into account such impact in extended L2 PSAs?

If no, please specify your reasons.

If yes, please specify how you think such impact should be treated in the extended L2 PSA and/or for which particular internal or external events this impact should be considered.

Yes	2020
No	6
No answer	88
Comments:	29

Comments considering the evolution of external and/or internal hazards during the severe accident progression emphasized on the necessity to consider the severity and the probability of the event. Methods such as screening or the re-evaluation of branch possibilities have been suggested to reduce the complexity.

Comments not considering the evolution of external and/or internal hazards during the severe accident progression state the very high complexity of the necessary analyses as well as the increase in complexity for computational calculations.

There is a significant majority that considers the evolution of external and/or internal hazards as beneficial to the process, however in nearly all answers the increase in complexity has been emphasized. Procedures like screening have been considered to reduce the necessary computational effort.

Q87) In your opinion, are existing methodologies and tools for accident progression analysis (e.g. integral codes like MAAP, MELCOR or ASTEC) suitable to perform support studies for extended Level 2 PSAs (including accidents in spent fuel pools and for open RPV)?

If no, what is missing?

Yes	2020
No	5
No answer	7
Comments	16

Comments for the suitability of the existing integral codes underlined the performance of the code with examples of already performed calculations. Nevertheless possible shortcomings in terms of complex cases like SFP, HRA, Dynamic Event Tree have been mentioned.

Comments denying the suitability of the code mentioned cases, in which certain phenomena like steam explosions, or rare events could not be calculated successfully with the existing codes.

There is a significant majority that considers integral programs like MAAP, MELCOR or ASTEC as suitable for the calculations, however open topics for the optimisation of the code (e.g. SFP) have been identified.

Extended L2 PSA per definition deals with accident sequences where the hazards have such an impact that fuel melting (in the core and / or in the spent fuel pool) occurs. This implies that all preventive measures failed.

Q88) Do you think it is reasonable and feasible to perform human reliability analysis for mitigative actions under such disturbed conditions?

If no, would you suggest any generic assumptions for human mitigative actions (e.g. simply ignoring it, or assuming an approximate success probability)?

If yes, could you suggest how you would assess human mitigative actions under such conditions?

Yes	288
No	3
No answer	3
Comments	27

<u>Comments for the performance of human reliability analysis</u> underline the importance of HRA and a need of either developing new methods or using existing tools like THERP or SPAR-H. The further improvement of HRA was said to be one of the tasks of the ASAMPSA_E project.

<u>Comments against the usage of human reliability analysis</u> state that the assumption of an approximate success probability is sufficient or that the influence can be ignored.

<u>There is a large majority that considers the usage of human reliability analysis for mitigative actions is appropriate,</u> however further investigations and research has to be performed to validate and improve existing HRA concepts.

Mission times in PSAs are related to the duration of the accident progression. Very late radioactive releases can occur, in harsh conditions due to external hazards if NPP stabilization is not obtained or if additional external occurs (secondary earthquake …). Such late release may not be addressed in existing L2 PSA.

Q89) Do you think that the issue of long term management of radioactivity in post-accident conditions should be addressed and potential additional releases somehow evaluated within extended Level 2 PSAs?

Yes	21
No	99
No answer	4
Comments	18

<u>Comments for addressing long term management of radioactivity within extended Level 2 PSA</u> underline the importance of certain cases like the evaluation of releases via the underground in case of a basemat melttrough. In general the evaluation was said to be performed until a safe and stable situation inside the NPP is reached. It was mentioned that late releases could also have an impact on the environment and population around an NPP and therefore be necessary.

Comments against the fact of addressing long term management of radioactivity within extended Level 2 PSA state the high complexity and difficulty due to a large amount of possible scenarios. Additionally the assignment to level 2 tasks instead of level 3 tasks was questioned.

The majority of participants approves the idea of addressing the long term management of radioactivity, however the complexity of the task has been mentioned as well as the indistinct definition of the duration of "long term" management.

7 OUTCOMES OF THE UPPSALA END-USERS WORKSHOP

7.1 PRESENTATION OF THE WORKSHOP

Based on a draft version of the present document, the analysis of the answers to the questionnaire have been presented and discussed with End- Users during an international workshop organized on 26, 27 and 28 May 2014 in Uppsala (Sweden).

In addition to the survey, the workshop aimed at:

- identifying additional End-Users needs and additional opinions related to guidance for development and use of extended PSAs,
- answering the question: "Where should efforts be placed to establish useful guidance (or complete existing ones) for the development and use of extended PSA for NPPs?",
- and providing recommendations for the ASAMPSA_E project.

Presentations and main outcomes of the workshop are presented in the minutes [11].

The presentations of the analysis of the answers to the questionnaire did not raise objection from the End-Users who were present at the workshop.

7.2 RECOMMENDATIONS

Recommendations issued from the Uppsala workshop are presented in the following paragraph.

These recommendations reflect:

- the End-Users survey responses,
- the discussions during the workshop.

They have been reviewed by the workshop participants who have also defined a priority level based on the following scale:

- Type A: most important end-users needs (for which the project should produce adequate guidance),
- Type B: intermediate needs (which the project will address if possible),
- Type C: less important needs (not to be addressed by the project).

7.2.1 GENERAL CONSIDERATIONS ON EXTENDED PSAS

N°	Recommendations	WP	Type
1	ASAMPSA_E shall examine which type of cost/time analysis is acceptable to limit resources needed for external/internal hazards PSAs. Comment: the ASAMPSA_E response to this recommendation will depend on partners' experience.	30	A
2	ASAMPSA_E shall address risk monitoring and training applications of extended PSA.		C
3	ASAMPSA_E shall address PSA communication towards public		C
4	Concerning the scope of the ASAMPSA_E project, ASAMPSA_E shall at least address the 10 more important external hazards for the End-users : • Earthquake • Flooding • Extremes air temperatures • Snow pack • Lightning • Storm (tornadoes, hurricane, …) • Biological infestation • Aircraft crash • External fire • External explosion. ASAMPSA_E shall consider also : • Internal fires, floods and explosions, • heavy load drops, high energy line break (HELB), missiles, chemical releases; • Other extreme weather conditions, • transport of dangerous substances, accidents in facilities located in the vicinity of NPP, • Releases into the waters and ground. ASAMPSA_E shall also examine the interest of • Integrated (all hazards and IE) or separated PSA model	21 22 30 40	A
5	Some End-Users have expressed interest on best practices to model ageing in PSA. The End-Users workshop participants have considered that it is not feasible to handle this difficult topic in the framework of ASAMPSA_E.		C
6	ASAMPSA_E shall consider a modification of the definition of extended PSA based on End-Users remarks : "An extended PSA (probabilistic safety assessment) applies to a site of one or several Nuclear Power Plant(s) (NPP(s)) and its environment. It intends to calculate the risk induced by the main sources of radioactivity (reactor core and spent fuel storages, other sources) on the site, taking into account all operating states for each main source and all possible relevant accident initiating events (both internal and external) affecting one NPP or the whole site."	50	Done

7	ASAMPSA_E shall provide practices and methods to model the combinations/correlations/dependencies of hazards (in terms of both occurrence and impact on SSCs).	21 22	A
8	Concerning the combinations/correlations/dependencies of hazards, some different rules can be provided depending on the time frame (for example, addition of independent hazards may be considered for long lasting accident)	21 22	B/C
9	ASAMPSA_E shall address methodology for simultaneous accident progression in core and SFP.	22 40	A
10	ASAMPSA_E shall group the list of hazards to develop its guidance	50	A
11	ASAMPSA_E shall discuss the level of conservatism (same level in all PSA parts ...?)	30	A
12	ASAMPSA_E shall provide guidance on the place of extended PSA in risk informed approach and decision-making. How to consider hazards if related PSA are not mature yet?	30	B
13	Concerning result presentation - Risk aggregation guidance will be useful, - Results shall be understandable, - Risk targets are useful but not essential, - Treatment of uncertainties is essential (for external hazards, low probability events with high uncertainties), - Need for guidance for results interpretation and use. Introduction of uncertainties in L1 PSA may be crucial (?)	30	A
14	ASAMPSA_E shall address specific guidance on quality of extended PSAs. Associated to quality, the <u>necessity to be aware of risks</u> should be clearly emphasized in the application of extended PSAs: this is the main product of PSAs (extended) and must be associated to communication, training of operators, decision-making on plant safety. PSA "capability" concept (closely associated with PSA application) may be used instead of quality. (ASAMPSA_E shall examine the methodologies (to perform PSA) to be applied depending on the PSA application (see also IAEA standards, US-NRC regulatory guides))	30	B
15	ASAMPSA_E shall examine how to include mobile equipment in PSA.	22	A
16	ASAMPSA_A shall clarify the vocabulary on "mission time", "scan time". "Mission time" for NPP may be the time needed until stable state conditions are reached. "Mission time of each equipment" can be different. ASAMPSA_E shall examine what does it means for L1PSA, L2PSA and provide guidance to model long lasting accident.	22	A
17	ASAMPSA_E shall develop a glossary, common for all PSAs	30	A

		21 22 40	
18	ASAMPSA_E shall examine how and when "seasonal PSA (winter/summer)" must be developed. An example could be useful.	22 30	A

Table 48 – Recommendations 1 to 18: general considerations on extended PSAs

7.2.2 HAZARDS SCREENING AND MODELLING

N°	Recommendations	WP	Type
19	According to the End-Users survey, existing screening guidance have to be adapted or completed for each application. ASAMPSA_E shall examine why and how to do this adaptation/complement. ASAMPSA_E shall examine how to reduce heterogeneity in quantitative screening criteria (collect and examine the screening values). ASAMPSA_E shall examine which hazards must not be screened out and why. ASAMPSA_E shall comment how far the impact of the hazards must be considered in the screening out process (in case of cliff edge effect, no screening out …?).	30	A
20	ASAMPSA_E shall examine the relevance of conditional core melt probabilities and conditional containment failure probabilities (and conditional LER probability) in the screening criteria.	30	A
21	ASAMPSA_E shall examine PSA practices for modelling induced internal floods and internal fires.	22	A
22	ASAMPSA_E shall examine SFP accident screening practices.	30	A
23	ASAMPSA_E shall discuss the link between screening criteria and design basis conditions: - PSA should focus on area that are not in the design basis – example : specific combinations like hazards + induced effects - PSA should include hazards in the design basis (useful for PSR for example).	30	A
24	ASAMPSA_E shall discuss the sum of hazards frequencies (final comparison with numerical safety target).	30	B
25	ASAMPSA_E shall examine what to do if the sciences cannot provide information for low frequencies events or extremely high uncertainties on their amplitude. Example: PSA shall present uncertainties as they are, which use of percentile value (%-ile value) is meaningful…?	30	A

26	Deficiencies on internal hazards modelling shall be covered in ASAMPSA_E: -More realistic assessment of the hazard frequency or consequences have to be developed for internal fire and flooding assessment -No specific methodologies exist for internal explosion, missiles or quantification of internal hazards due to inappropriate human actions -The methods for hazard curves and fragility curve constructions are not described.	21 22	A
27	In ASAMPSA_E project, uncertainties assessment methodology for internal hazards shall be compared and good practices identified. Is the fragility curves approach always relevant (example: spurious signal in case of fire)?	22	A
28	In ASAMPSA_E, existing methods for external hazards modelling shall be presented and compared including uncertainties.	21	A
29	ASAMPSA_E shall examine how experts judgement shall be used for external hazards characterisation and how uncertainties can be considered.	21	B
30	ASAMPSA_E shall introduce the effects of climate changes and present available methodologies. Need for updating PSA.	21	A
31	ASAMPSA_E shall examine the role of statistical analysis method (e.g. EVT) based on observation in comparison with approaches trying to identify which combination of factors can lead to the worst meteorological events (not observed).	21	A
32	ASAMPSA_E shall examine how PSAs can introduce information coming from meteorological modelling. Example: variations from past worst cases?	21	A
33	A fact: clear underestimation by the 1999 earthquakes map when compared to recent earthquakes. One reason is that PSHA interprets historical data (based only on 100 years of records). It is need today to introduce faults sources. ASAMPSA_E shall provide information on activities performed to assess catalogue completeness and reliability, on how to assess the maximum possible earthquake (Mmax), identify, analyse and assess (potentially) active faults relevant to the safety of the site …	21	A
34	A fact: in a region with low seismicity like Sweden, an earthquake M 8 is “possible” (and observed in paleo history) with a return period 1 million years … ASAMPSA_E shall examine how can such information be presented in a PSA.	21	A
35	ASAMPSA_E shall insist on the need to update periodically the design-basis hazards curve.	21	A

Table 49 - Recommendations 19 to 35: hazards screening and modelling

7.2.3 INTRODUCTION OF HAZARDS IN L1 PSAS

N°	Recommendations	WP	Type
36	ASAMPSA_E shall identify some best practices for external hazards SCC fragility analysis - At which temperature an electronic device fails, - Shaking tables for active equipment …, - Fragility curves database ASAMPSA_E shall share opinion on available information related to fragility of equipment (database ….). Emergency diesels are so important that related methodologies / data should be specifically analysed in ASAMPSA_E.	22	A
37	ASAMPSA_E shall examine (on examples) the importance of non-safety systems robustness/behaviour/positive vs negative impact in case of external hazards on final CDF/RF (example, in extreme cold temperature conditions, ventilation can accelerate pipe freezing if not stopped).	22	A
38	For seismic PSA, ASAMPSA_E shall examine the interest of advanced PSA methodologies using “earthquake signal” (temporal ground motion parameters) impacts on SSCs and interest in comparison with “classical” methodologies (PGA …).	22	A
39	Seismic PSA may be based on the use of generic fragility curves for components … How can the PSA End-Users justify their use? ASAMPSA_E guidance shall comment this issue from partner experience.	22	A
40	SFP specific issues for earthquake to be considered in ASAMPSA_E: • fragilities of the pools, racks. • sloshing of the pool water (one combination of hazards, what are the consequences for accident progression? See TEPCO presentation during End-Users workshop in Uppsala), • loss of cooling.	22	A
41	The following topic shall be discussed in ASAMPSA_E (guidance needed): induced internal hazards are potential source of conservatism (if included), of non-conservatism (if not included).	30	A
42	For flooding : -ASAMPSA_E shall compare some applications for flooding assessment in EU stress-tests before developing guidance, -fragility of equipment may be easily presented (failure in case of room flooding) (according to some experts in Uppsala workshop), -ASAMPSA_E shall present methodology to address long term flood, -the uncertainties may be higher for natural than for man-made hazards (according to some experts in Uppsala workshop).	21	A
43	ASAMPSA_E shall develop guidance to assess frequencies of LHS events (how to arrive from an external hazard to an IE?).	21 22	B
44	ASAMPSA_E shall develop guidance to calculate frequencies of LOOP and recovery time	21	B

	(these frequencies shall be updated with grid modernization). How to consider the recovery time of grid?	22	

Table 50 - Recommendations 36 to 44: introduction of hazards in L1 PSAs

7.2.4 INTRODUCTION OF HAZARDS IN L2 PSAS

N°	Recommendations	WP	Type
45	ASAMPSA_E shall identify issues associated to external hazards that may need significantly differences in comparison with L2PSA methodologies for internal IE, e.g. : - Induced effects (internal hazards) by external hazards, - Earthquake aftershocks, - External hazards impact on containment function …	40	A
46	For ASAMPSA_E guidance on L2 PSA : - Extended L2PSA shall include long term management of radioactivity in the containment and release in environment. - ASAMPSA_E shall consider in long term strategies both in-vessel retention and ex-vessel retention.	40	A
47	ASAMPSA_E shall examine existing containment venting strategies optimization versus L2PSA results (status today: different strategies, depending on NPPs - is it consistent with L2PSA results?).	40	A
48	ASAMPSA_E shall examine SAMG sufficiency, especially for shutdown state (SAMG needed to develop event trees …)	40	B
49	For shutdown states of reactor, ASAMPSA_E shall propose guidance for : - Open RCV or RCS situations : FP release (effect of air ingress), thermal radiation effect on the containment integrity (open RCV case, heat load),	40	A
50	ASAMPSA_E shall examine how can be calculated the conditional probability of SFP fuel degradation after core melt (depending on common system core/SFP, on location of SFP - inside vs outside containment) ASAMPSA_E shall examine how far, in case of SFP fuel degradation (inside a containment), the containment function can survive (depending on pressurisation, hydrogen production, thermal radiation load …) ASAMPSA_E will need to map the NPP configurations of reactor core versus SFP (independence).	40	A

Table 51 - Recommendations 45 to 50: introduction of hazards in L2 PSAs

7.2.5 COMMON ISSUES FOR MULTI-UNITS PSAS (FOR ALL EXTERNAL HAZARDS)

N°	Recommendations	WP	Type
51	ASAMPSA_E shall clearly identify deficiencies of single units PSA and promote development of multi units PSA.	22 40	A
52	ASAMPSA_E shall examine if a new set of risk metrics for multi-units is necessary.	30	B
53	ASAMPSA_E shall consider experience of countries like Canada having already developed multi-units PSA.	22 40	B
54	ASAMPSA_E shall in particular examine HRA modelling demand for multi-unit PSA (e.g. team sufficiency if shared between units, site management complexity, equipment restoration possibilities, inter-reactor positive or negative effects …).	22 40	A
55	For comments in ASAMPSA_E guidance :- Earthquake can affect multi-units. The ground motion is correlated but can be different for each reactor (this is an issue examined in Japan). - True for other external hazards.	22	C

Table 52 – Recommendations 51 to 55: common issues for multi-units PSAs (for all external hazards)

7.2.6 COMMON ISSUES FOR HRA MODELLING (FOR ALL EXTERNAL HAZARDS)

N°	Recommendations	WP	Type
56	ASAMPSA_E shall examine how to improve HRA modelling for external hazards conditions to tackle the following issues : - the high stress of NPP staffs, - the number of tasks to be done by the NPP staffs, - the impossibility, for rare events, to generate experience or training for operators actions (no observation of success/failure probability, e.g. simulator), - the possible lack of written operating procedures (or approximative procedures), - the possible wrong information in the MCR or maybe the destruction of the MCR, - the methodologies applicable to model mobile barrier installation (for slow developing event), - the methodologies available to model use of mobile equipment (pumps, DGs) and conditional failure probability (human and equipment), - the methodologies applicable to model equipment restoration (long term accident sequences, specific case of multi-units accidents, …).	22 and 40 (TBD)	A
57	Methodologies to develop modelling of “warning” for slowly developing external events.	22	A
58	ASAMPSA_E may organize a workshop with HRA specialists.	50	C
59	ASAMPSA_E guidance on error of commission	22	B/C

Table 53 – Recommendations 56 to 59: common issues for HRA modelling (for all external hazards)

7.2.7 SPECIFIC ISSUES OF INTEREST FROM EXPERIENCE OF PAST REAL EVENTS

N°	Recommendations	WP	Type
60	ASAMPSA_E guidance shall explain how to introduce in L1-L2PSA a more diverse modelling of internal and external electrical disturbances. The Forsmark NPP experience presented during the ASAMPSA_E End-Users workshop in Uppsala shall be considered as a starting point (include in PSA voltage surge on plant grid (e.g. lightning)) Comment : examples of assessment may be more useful and feasible in the framework of ASAMPSA_E.	22	A
61	ASAMPSA_E guidance shall identify methodologies available to quantify the frequency of loss of heat sink due to natural hazards (e.g. clogging effect). An additional question that can be addressed is criteria (from PSA perspective) from which a design change can be needed? The Cruas NPP example provided by EDF (loss of heat sink) during the ASAMPSA_E End-Users workshop in Uppsala shall be considered as a starting point. Comment : examples of assessment may be more useful and feasible in the framework of ASAMPSA_E.	22	A
62	From Le Blayais NPP example, ASAMPSA_E shall explain for external flooding PSA that : • Conditional CDF can be calculated depending on event flooding amplitude, • Initiating flooding events (amplitude, frequency) can be modelled separately from PSA, This can be a starting point for some ASAMPSA_E guidance on external flooding.	21 22	A
63	ASAMPSA_E may ask meteorological institutes information on climatic events to complete D10.3	10	B
64	Past earthquakes in Romania (it affected a Bulgaria NPP) and Armenia could complete D10.3	10	A
65	ASAMPSA_E may propose a format for a database to get information on past events.	10	B

Table 54 – Recommendations 60 to 65: specific issues of interest from experience of past real events

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9 LIST OF TABLES

10 LIST OF FIGURES

11 APPENDIX

11.1 APPENDIX1

The following table provides a draft list of natural hazards to be considered in the ASAMPSA_E project.

Seismotectonic (earthquake)	
1	Vibratory ground motion
2	Long period ground motion
3	Surface faulting (fault capability)
4	Liquefaction
5	Dynamic compaction (seismically induced soil settlement)
6	Tsunami
Flooding	
7	Extreme rainfall (note links to other meteorological phenomena)
8	Floods resulting from snow melt
9	Flooding due to off-site precipitation with waters routed to the site
10	Extreme ground water
11	Flood due to obstruction of a river channel (downstream or upstream) by landslides, ice, jams caused by logs or debris, or volcanic activity)
12	Floods resulting from changes in a river channel due to erosion or sedimentation
13	Flood resulting from large waves induced by volcanoes, landslides or avalanches in water basins or by waterspouts
14	Floods and waves caused by failure of water control structures (dam failure)
15	Watercourse containment failure
16	Seiche (fluctuation in water level of a lake or body of water)
17	Seawater level: high tide
18	Seawater level: wind generated waves
19	Seawater level: storm surge
20	Seawater level: impact of human made structures such as tide breaks and jetties
21	Instability of the coastal area due to erosion or sedimentation
22	Tsunami (see Seismotectonic)
Meteorological events: Extreme values of meteorological phenomena	
23	Precipitation
24	Extremes of air temperature (high and low)
25	Extremes of ground temperature

26	Extremes of sea (or river) temperature
27	Humidity
28	Air pressure
29	Extreme drought
30	Snow pack
31	Icing
32	Hail
33	Permafrost
34	Snow melt (see Flooding)
35	Seawater level (see Flooding)
Meteorological events: Rare meteorological phenomena	
36	Lightning
37	Storm (Tornado, Hurricane, Tropical Cyclone, Typhoon)
38	Blizzard
39	Wind blown debris (external missiles)
40	Sandstorm, dust storm
41	Saltspray/saltstorm
42	Waterspouts
43	Snow avalanche
44	Ice flows / frazil
45	Mist / fog
46	Solar flares
Biological / Infestation	
47	Seaweed, Alga
48	Fish
49	Jellyfish
50	Marine growth
51	Crustaceans, molluscs (shrimps, clams, mussels, shells)
52	Birds
53	Airborne swarms
54	Infestation by rodents and other animals
Geological	
55	Slope instability (landslide, rock fall)

56	Debris flow, mud flow
57	Ground settlement (natural or man-made; mining, ground water extraction, oil/gas production)
58	Sinkholes: collapse of natural (caverns, karstic caves) and man-made cavities (inactive or active mines)
59	Ground heave
60	Leeching, soluble rocks (limestone, gypsum, anhydrite, halite)
61	Unstable Soils (quick clays etc.)
62	Volcanic eruption (includes other effects than seismic)
63	Groundwater (see flooding)
64	Meteorite (includes other effects than seismic)
65 *	Contaminated land
66 *	Radon
67 *	Fissures
68 *	Faults
	* probably not relevant for external hazard assessment
Forest fire	
69	Forest fire

The following table provides a draft list of human induced external hazards based on IAEA Safety Guide NS-G-1.5 (cf. [9]).

70	Aircraft crash
71	External fire (due to human activities)
72	External explosion
73	Asphyxiant and toxic gases
74	Corrosive gases or liquids
75	Radioactive gases or liquids
76	Electromagnetic interference
77	Collision of floating bodies with water intakes and UHS components
78	Oil spills

11.2 APPENDIX 2

The following table provides a draft list of internal hazards based on IAEA Safety Guide NS-G-1.11 (cf. [10]).

1	Internal explosion
2	Internal fire
3	Internal flooding
4	Internal missiles
5	Collapse of structures and falling objects
6	Pipe failures
7	Pipe whip
8	Fluid jet

11.3 APPENDIX 3

Examples of safety objectives provided by respondents in response to question Q41) a – are presented below.

The first three examples are illustrating the differences in the understanding of “Large” and “early”.

IAEA INSAG-12 Releases Targets

“27. The target for existing nuclear power plants consistent with the technical safety objective is a frequency of occurrence of severe core damage that is below about 10–4 events per plant operating year. Severe accident management and mitigation measures could reduce by a factor of at least then the probability of large off-site releases requiring short term off-site response. Application of all safety principles and the objectives of paragraph.25 to future plants could lead to the achievement of an improved goal of not more than 10–5 severe core damage events per plant operating year. Another objective for these future plants is the practical elimination of accident sequences that could lead to large early radioactive releases, whereas severe accidents that could imply late containment failure would be considered in the design process with realistic assumptions and best estimate analyses so that their consequences would necessitate only protective measures limited in area and in time.”

This description implies that “large” refers to a release large enough to require emergency counter-measures off-site, and that “early” refers to the need for those measures to be performed “short term”. By implication, for new plants, if the core damage frequency target is 1E-5, then the LERF target could be considered to be 1E-6/ry.

Large Release Targets in Scandinavia

In both Finland and Sweden, release targets for severe accidents exist. For example, in Finland, according to Decision of the [Finnish] Council of State: “Limit for a severe accident.

The limit for the release of radioactive materials arising from a severe accident is a release which causes neither acute harmful health effects to the population in the vicinity of the nuclear power plant, nor any long-term restrictions on the use of extensive areas of land and water. For satisfying the requirement applied to long-term effects, the limit for an atmospheric release of cesium-137 is 100 TBq. Regarding the long term (starting three months after the accident), the combined fall-out consisting of nuclides other than Caesium-isotopes shall not cause a hazard greater than would arise from a Caesium release corresponding to the above-mentioned limit. The possibility that, as the result of a severe accident, the above mentioned requirement is not met shall be extremely small.”

This 100 TBq limit is also used similarly in Sweden.

Large Release Targets in the US

NUREG/CR-6595 provides guidance on defining and assessing LERF. The basis for the guidance is taken from the US NRC Safety Goal Policy document, and is: “The early fatality QHO [Quantitative Health Objective] defined in the NRC Safety Goal Policy is: "The risk to an average individual in the vicinity of a nuclear power plant of prompt fatalities that might result from reactor accidents should not exceed one-tenth of one percent (0.1 percent) of the sum of prompt fatality risks resulting from other accidents to which members of the U.S. population are generally exposed."

NUREG/CR-6595 presents analysis which relates this objective to release fractions. It concludes that:

"Three types of assumptions have been utilised in analysing the above information in the IPE database for exploring a possible definition of LERF:

(1) LERF consists of the total frequency of all release classes that occur under the early containment failure or containment bypass categories of the containment failure mode matrix.

(2) LERF consists of the frequency of release classes associated with the early failure and bypass containment failure modes which have release fractions of the volatile/semi-volatile fission products (Iodine, Caesium, Tellurium) equal to or greater than about 2.5 to 3% (based on the insights of the Large Release Study discussed above).

(3) A third alternative, based on a memorandum prepared for the ACRS, is that LERF is the frequency of early failure and bypass containment failure modes that have a release fraction of iodine equal to or greater than about 10%."

UK "Dose Bands"

UK targets in Safety assessment principles (SAPs) are expressed in terms of doses to persons onsite or offsite and mortality risk. These metrics are the result of a level 3 PSA.

Dose bands are defined with frequency targets adapted to the doses.

In France, for Gen III EPR NPP the following set of safety objectives are used:

In order to fulfil the overall safety goal: 10-5/y (core melt frequency including internal events, internal and external hazards), the following set of safety objectives are used as orientation values:

Internal events core melt frequency power state: 10-6/y

Internal events core melt frequency shutdown state: 10-6/y

Internal hazards core melt frequency all operating states: 3 10-6/y

External hazards core melt frequency all operating states: 5 10-6/y.

In Lithuania, the Law on Nuclear Safety included the fundamental safety objective and all 10 fundamental safety principles as it is formulated by IAEA.

Probabilistic safety criteria:

Analysing the all NPP operational states and considering uncertainty, a NPP unit at all stages in the lifetime of NPP shall meet the following probabilistic safety criteria:

. core damage frequency shall be less than 10-5 event per reactor year, taking into account all the internal events, internal hazards and external hazards

. core damage frequency shall be less than 10-6 event per reactor year, taking into account all the internal events only (internal hazards and external hazards are excluded)

. large release frequency shall be less than 10-6 event per reactor year, taking into account all the initiating events

. large early release frequency shall be less than 10-7 event per reactor year, taking into account all the initiating events which could lead to large early release.

NPP unit shall be designed and operated so that the likelihood of occurrence of an accident with serious radiological consequences is low as reasonably achievable and the radiological consequences of such an accident would be mitigated to the fullest extent practicable.

WENRA safety objectives

Safety objectives proposed by WENRA for accident with core melt (O3) are the following:

- "reducing potential radioactive releases to the environment from accidents with core melt, also in the long term[1], by following the qualitative criteria below:

o accidents with core melt which would lead to early[2] or large[3] releases have to be practically eliminated[4];

o for accidents with core melt that have not been practically eliminated, design provisions have to be taken so that only limited protective measures in area and time are needed for the public (no permanent relocation, no need for emergency evacuation outside the immediate vicinity of the plant, limited sheltering, no long term restrictions in food consumption) and that sufficient time is available to implement these measures."

[1] Long term: considering the time over which the safety functions need to be maintained. It could be months or years, depending on the accident scenario.

[2] Early releases : situations that would require off-site emergency measures but with insufficient time to implement them.

[3] Large releases : situations that would require protective measures for the public that could not be limited in area or time.

[4] In this context, the possibility of certain conditions occurring is considered to have been practically eliminated if it is physically impossible for the conditions to occur or if the conditions can be considered with a high degree of confidence to be extremely unlikely to arise (from IAEA NSG1.10).