

## L2 PSA methods harmonization

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### Abstract

A part of the activities performed in the SARNET PSA2 work package is to examine the feasibility of achieving some degree of harmonization in the future by development of guidelines.

Thus, during the ERMSAR 2007 meeting, the status of a feasibility study on level 2 PSA methods harmonization concerning the assessment of some physical phenomena in a level 2 PSA was presented. The following issues were selected: hydrogen combustion, consequences of vessel failure, melt corium and concrete interaction, iodine chemistry.

This paper reminds some elements of the work done on this subject and then presents the progress made and the difficulties encountered for harmonizing level 2 PSA methods in the frame of SARNET. It examines:

- Is the method applied to reach a certain level of harmonization to assess some physical phenomena estimated applicable to all physical phenomena to consider in the event tree?
- What method can be used to interface the level 1 and the level 2 PSAs considering the objectives of the level 2 PSA?
- What definition of final reactor states can be given in a level 2 PSA and how the large and the large early releases may be defined?
- The use of expert judgment in L2 PSA

Prospects concerning future work on harmonization of methods for level 2 PSA are given as a conclusion, especially within the ASAMP2 project of the 7<sup>th</sup> Euratom FP.

### A - Background

In the first phase of SARNET Work Packages 5.1 and 5.2, an understanding was reached regarding the SARNET partners choices of methodology in their Level 2 PSAs, including the assessment of uncertainties [1]. From these first studies, there is a clear consensus that Level 2 PSA is regarded as having reached an acceptable level of maturity and the same general approach has been consistently applied in the PSAs conducted in EC member states.

Nevertheless, given the different national requirements placed on Level 2 PSA, there are appreciable differences in how these Level 2 PSAs are implemented in practice in terms of scope and content.

In particular, for the detailed evaluation of severe accident phenomena, which is a key issue for L2 PSAs, there is a clear recognition that an agreed and consistent prescription for how analyses should be performed and, in particular, how uncertainty is accounted for, is still lacking.

That is why, within the SARNET workpackage 5.1 and 5.2, the initial detailed comparison of methodologies used by the Partners has been supplemented by a separate task examining the feasibility and need for the harmonization of Level 2 practises in EC member states. The paper describes the main outcomes of this activity within SARNET and suggests some

prospects to reach some progress in harmonization within the ASAMPSA2 project of the 7<sup>th</sup> Euratom FP.

## **B – Method used by the SARNET Partners to progress towards harmonization**

The method used by the Partners was already described in the ERMSAR 2007 [1] and was applied during the last periods of activity:

- 1) Identify the most important issues to be addressed,
- 2) For each issue, assess how the breakdown into key sub-issues can be achieved, given the current knowledge basis,
- 3) For the selected issues, a pragmatic methodology may include the following aspects:
  - Compile and review what has been done so far and based on this:
    - Describe them in a qualitative way addressing the key physical and chemical features,
    - Identify what may be regarded as a good practice from the review,
    - Derive general recommendations and, if possible, quantitative values on how to deal with the problem in a Level 2 PSA,
    - Identify how generic, or plant-type specific or plant specific the guidance is,
    - Agree on common areas where further research/development activities need to be performed.

This methodology has been applied to some of the key issues that should be addressed in a level 2 PSA: hydrogen combustion, consequence of RPV failure, Iodine behaviour, MCCI, interface between level 1 and level 2 PSA, definition of final reactor states in level 2 PSA, definition of large and large early release in level 2 PSA and partially to expert judgement.

## **C – Examples of outcome for L2 PSA harmonization from SARNET activities**

The following chapter summarizes some preliminary conclusions from the SARNET activities related to L2 PSA harmonization.

### **C1 Physical phenomena**

#### **Hydrogen distribution and combustion**

The method described above has been successfully applied and has led to a set of 19 recommendations which concern:

- the different phases during which the hydrogen risk should be considered and the different sources of hydrogen production to consider,
- the necessity to take into account the possibility of multiple burns,
- a specific (simplified) treatment of some containment by-pass situations,
- hydrogen distribution inside the containment (including the definition of containment zones, the characterization of the different mixing mechanisms, the limitation of the use of concentrations categories, flammability limits and inerting efficiency, calculation codes to use for supporting studies and the characteristics of the nodalization to use),
- the way to consider the hydrogen passive auto catalytic recombiners efficiency,
- the conditions of hydrogen ignition to apply (ignition criteria, ignition sources, ignition location...),

- hydrogen combustion with the different regimes to consider, the question of combustion completeness, the models or codes to use to assess the peak pressure for the different regimes of combustion with the nodalization to use.

In addition, some conclusions have also been included on the different approaches for uncertainties assessment. Those conclusions are quite general and applicable to the assessment of uncertainties for the different physical phenomena. In addition, the identification of key issues for uncertainty treatment concerning hydrogen combustion was also proposed.

To illustrate the kind of recommendation obtained, one example concerning methods for the assessment of the peak pressure resulting from a combustion is given hereafter: « *In case of no risk of deflagration to detonation transition (DDT) demonstrated by the sigma criteria use, the peak pressure may be assessed on the base of adiabatic isochoric complete combustion (AICC) peak pressure. In case of DDT risk, two methods may be used to assess the pressure loads:*

- *combustion calculations using a lumped parameter model*
- *AICC model with corrective factors.*

*In case of detonation, the peak pressure may assumed on the base of:*

- *combustion calculations using a lumped parameter model,*
- *the Chapman Jouget pressure for detonation regimes. »*

It was pointed out that the different recommendations are rather general and that they give orientations to perform the assessment but do not give particular figures or criteria to apply which would be, in most cases, design dependent. On the contrary, it was also pointed out that no PSA2 partner has already applied up to now together all the methods and advices indicated in the different recommendations, and that the set of recommendations covers the most difficult questions to address for the issue concerned.

It was also concluded that the proposal of the set of recommendations specific to hydrogen distribution and combustion has been possible due to a well established state of the art on a majority of the different issues, the issue of ignition being an exception for which R and D efforts were estimated necessary to establish such a level of knowledge.

### **Consequences of RPV failure**

The evaluation of this issue followed a similar approach and was performed under a number of headings, including:

- a. Conditions of RPV failure (including size and location of vessel breach, conditions of corium discharge to reactor cavity).
- b. Vessel rocketing.
- c. High pressure melt ejection (HPME) and direct containment heating (DCH).
- d. Ex-vessel steam explosion.
- e. Specific design features, e.g. cavity door (or door seal) failure.
- f. Event tree organization.
- g. Principles of event tree modelling.
- h. Uncertainties considered and methods for assessment.

In a similar way than for the hydrogen issue, a set of 14 recommendations was established and covered the different headings above except the ex-vessel steam explosion one for which no recommendation has been proposed and R and D efforts still estimated necessary before to be able to propose enough basic recommendations.

It is interesting to note that one of the recommendations concerns the event tree organization. It was noticed that, according to the state of knowledge (no coupled calculations considering all the immediate consequences of reactor vessel failure), the different potential consequences of the melt release in the reactor cavity (vessel rocketing, melt dispersal and direct containment heating, cavity failure, ex-vessel steam explosion, containment failure) may be only assessed separately and lead to consider successive events in the event tree. It was then recommended to carefully take care, in the event tree organization, of the dependencies between the different phenomena.

As for hydrogen issue, some conclusions have also been included on the different approaches for uncertainties assessment. The identification of key issues for uncertainty treatment was also proposed.

### **Iodine behaviour**

Although a similar approach was applied for iodine behaviour issue than for previous ones, this approach did not lead to a set of recommendations to consider when addressing the issue in a level 2 PSA but rather led to produce elements about how to reach the expected harmonization. So, a potential harmonization approach was described and includes:

- Establishing the set of conditions necessary to justify chemistry effects of only secondary importance in a Level 2 PSA framework. The best approach for sequences where such conditions can not be met remains uncertain. However, the following elements were suggested.
- Establishing a framework identifying key influences for the development of a general simple modifying factor approach, e.g. reasonably enveloping assumptions on containment iodine speciation.
- Understanding the limitations of iodine models currently used to support PSA studies
- Evaluating the above elements to ensure the approaches are not divergent. Performing benchmark analyses and sensitivity studies / uncertainty analyses to understand the implications of adopting iodine chemistry models.

This approach was submitted to the SARNET Source Term Work Package and elements of answers coming from this WP are expected to demonstrate the feasibility of the recommended approach.

### **MCCI**

The evaluation followed a similar approach than for the other issues. Thus, the different SARNET PSA2 partners described the methods they used to assess the MCCI issue in their level 2 PSA.

On the basis of these descriptions, a list a sub-issues has been established, for which the methods used by the different partners have been compared.

An analysis of the differences of partners approaches was done according to a classification considering separately the differences in:

- the assumptions on initial and boundary conditions used,
- the models included in the codes used,
- the assessment of the codes and of their limitations,
- the interpretation of the experimental work,
- the quantification methods in the event tree,
- the results in function of plant properties or characteristics.

A set of recommendations have been derived from this comparison extracting good practices when considered as identified, or suggesting a set of methods when an unclear advantage of one method compared to another one appeared.

The recommendations finally obtained concern:

- the different consequences of MCCI to investigate in a level 2 PSA,
- the careful evaluation of plant specific vulnerabilities during the MCCI phase,
- the assessment of water presence in the cavity at RPV failure,
- the debris quenching at RPV failure,
- the representativeness of the severe accident calculations as regards the MCCI initial conditions,
- the physical models qualification,
- the uncertainty to associate to the calculations results,
- the basemat failure before complete erosion due to mechanical effect,
- the conservative hypothesis to associate to melt top cooling,
- the conditions to consider for containment over pressurization,
- the most important uncertainties to consider.

### **Generalisation of the approach to all physical phenomena**

As a conclusion, it may be pointed out that the application of the methodology to different physical phenomena, with different levels of maturity in the knowledge, leads to propose finally

- set of general recommendations or advices about how to address the issue,
- or to propose an approach to reach the harmonization expected.

One exception concerns the ex-vessel steam explosion issue for which it may be estimated that more effort would lead to a similar result.

This conclusion leads the different SARNET PSA2 partners to consider as possible (but time consuming) to apply the methodology to all different physical phenomena represented in the event tree.

### **C2 Interface between Level 1 and Level 2 PSA**

Interface between level 1 and level 2 PSA seems to be a quite standardized part of a level 2 PSA: it consists of the binning of the level 1 PSA sequences leading to core damage (CD) in so-called Plant Damage States (PDS): each PDS groups CD sequences from L1 PSA that are supposed to have a similar accident progression during the severe accident phase.

This general principle is applied by all L2 PSA practitioners but when looking the details of applications, some important differences are observed. In that context, interface between level 1 and level 2 PSA has been identified by the SARNET participants as an issue where operational practices should be harmonized.

Like other issues, a questionnaire [2] has been issued and a compilation of the answers has been established. The identification of the best practices and the proposal of recommendations have not been fully achieved within SARNET but the following points may be mentioned:

- The scope of the existing L2 PSAs (and interface) varies from one study to the other (initial reactor state, internal events, external events ...);
- Two methods are used :
  - in integrated project (level 1 and level 2), the same probabilistic tool is used (mainly RiskSpectrum) and the notion of PDS is used for convenience (regrouped sequences that similarly behave in the Containment Event Tree);
  - otherwise, in case of a non-integrated project, more information has to be transferred from level 1 PSA to level 2 PSA via the definition of the PDS;
- For most of non-integrated level 1- level 2 PSA, the following approach is used :
  - the level 2 PSA experts identify which information is needed in the severe accident event tree ; in general 10 to 20 attributes are needed ;
  - the level 1 event trees are extended with new head events allowing the calculation of the PDS attributes ;
  - through the extension of the level 1 event tree, all core damage sequences are broken down into the PDS.
  - in theory, a very large number of PDS should be obtained ; but the application of a reasonable cut-off frequency allows to keep a reasonable number of PDS ;
  - the number of PDS generated is between 100 and 300 and the number of PDS which are analysed in detail in level 2 PSA varies from 17 to 300 depending on the level of detail (and resources) of the L2 PSA.
- The precise definition of core damage may vary from a reactor to another but for most of SARNET participants, a significant fraction of L1 PSA core damage sequences may lead to limited damage and minor consequences (very limited release) ; in some cases, L1 PSA conservatisms are identified and some sequences are not considered in level 2 PSA ; for most of SARNET participants, the achievement of a L2 PSA conducts to the update of the L1 PSA model;
- The precise definition of a limited core damage seems to vary from one study to the other and could be probably better harmonized ;
- The precise use of the notion of sequences or cut sets from level 1 PSA, and also the treatment of system dependencies may vary from one study to another and some attempts of harmonization could be proposed ;
- The quantity of work needed to update the L1-L2 interface obviously vary a lot from a SARNET participant to the other, showing that all approaches are not comparable ; harmonization may have sense by identifying the practices allowing easy updates of the L1-L2 interface.

All these points exhibit an interest for a more precise harmonization of methodologies for the level 1 / level 2 interface. This harmonization will be finalized within the ASAMPSA2 project.

### C3 Definition of final reactor state in level 2 PSA

The definition of final reactor state is important in level 2 PSA because the analyses are ended when this state is reached. At the end of the calculation, the quantitative results of a level 2 PSA can be expressed in terms of release categories. Each release category corresponds to a kinetics of radioactive release from the initiator of the accident to the final reactor state.

A questionnaire has been established and 9 partners have answered and provided their views on this subject. The terms “plant safe state”, “plant final state” and “plant stable state” are sometimes used in level 2 PSAs. The meanings of these terms were not well defined. The SARNET participants worked up to the common understanding and harmonized use of these terms.

The following general summary can be drawn from the results of the questionnaire survey [3]:

1. A level 2 PSA usually ends when no more significant releases to the environment have to be expected. “Significant” means that the amount of fission products released to the environment before reaching the stable state is at least two orders of magnitude higher than afterwards. Radioactivity release from the stable state has no additional significant health effects.

The final states of the PSA level 2 are given in various forms, the participants mainly used:

- the characteristics of radioactive release to the environment
- plant state, determined by the underlying accident sequences.

In the performed level 2 PSAs, the time to reach the stable state varies between 48 hours to 15 days (IRSN).

2. Differences can be observed as far as naming of the end states is concerned. However, the terms safe state or final safe state cannot be considered appropriate for use in a level 2 PSA. Use of the term of “final safe state” is not seen acceptable because there is always some release of fission products into the atmosphere. At best, a stable plant state without very harmful impact on the environment can be reached under such circumstances. It is suggested that the term stable state be used, if any. Also, one can consider partial or limited core damage states as a subset of a stable plant state.
3. In the level 2 PSAs in question the participants usually identified and considered the systems and components necessary to maintain a stable state after a severe accident. The assumptions made in relation to the behaviour and modelling (failure and restoration) of these systems under severe accident conditions somewhat vary. Failure of these systems as well as the circumstances and likelihood of restoration beyond design conditions have to be further studied. Also, the physical models of core reflood and coolability of a degraded core are in need of further examination. Furthermore, iodine behaviour and the impact of hostile environment on critical components can be considered as areas for more detailed examination and improvement too.

The following recommendations have then been formulated.

1. For a L2 PSA the severe accident progression should be analysed until the plant stable state is reached. Stable states are to be considered and defined as final plant states. Criteria

to insure the stability of the state are that no more significant radionuclide release to the environment is expected, the core/debris coolability is ensured for long term.

2. The categorization of the final states should be done according to the:
  - radioactive release into the environment (source term based) and/or
  - the plant final states (sequence based).
3. The sequences with limited core damage are to be considered as final plant state in L2 PSA to ensure completeness. All the core damage sequences of level 1 PSA should be categorized into plant final states in L2 PSA

#### **C4 Definition of large and large early release**

Because it is difficult to make conclusions, especially risk informed decisions on a spectrum of release categories, LERF (large early release frequency) or LRF (large release frequency) are often used as a relevant result from L2 PSAs.

For an objective of harmonization it was considered as relevant to compare the different practices of the SARNET participants. A questionnaire was elaborated and 11 of the participants have answered from their local practices.

The analysis of answers was also completed by an historical description of the definitions of LERF (or LRF), initially introduced in the USA and then in other countries and international organizations (IAEA).

The analysis has conducted the SARNET participants to the following conclusions:

The introduction of large release, as characterised by the LERF and LRF definitions, is connected with the need to have a simple quantitative criterion to understand the results of level 2 PSA, especially for risk informed decisions. This should complement the presently used level 1 Core Damage Frequency, CDF, which is widely used, but too far from the real plant risk.

On the other hand, the only really complex evaluation of plant risk is level 3 PSA and large release is only a surrogate for this evaluation. It is still worthwhile having a widely accepted definition of large release because:

- Level 3 PSA is a very complicated task, its inclusion in a flexible system like “living PSA” is beyond existing potential,
- Many assumptions not connected with the plant are included in level 3 PSA, whereas large release is only related to the plant design and on-site accident management

For these reasons, level 3 is impractical for risk informed decisions of the plant operator, it can be more used by regulatory body or authorities responsible for emergency planning.

The large release definition is connected with safety goals and objectives. Comprehensive evaluation of these goals and objectives would require detailed consequence analyses, either a complete level 3 PSA or at least an analysis of typical non-stochastic health consequences in the vicinity of the plant. Because of different local conditions, experience and uncertainties such a quantitative criterion prepared in one country could not be directly transferred to different countries, or even other sites within a country, and it would have to be updated often.

From the history of large release use in USA and Finland, it seems that even a definition which was developed more on estimate of consequences, can be linked with reasonable safety goals and verified to fulfil the objectives related with them.

This is the case of the two definitions cited in the SARNET report [4], which are the basis of various precise definitions in individual countries:

- 1) **LERF** - Early release of such magnitude, that early (non-stochastic) fatalities in the plant environment can be expected. This is expressed as a release of iodine into the off-site environment of more than 3% – 10% of the core inventory in the early timeframe (i.e. before off-site countermeasures can reasonably be expected to be in place). It is assumed that the release of other radiologically important species except noble gases (with smaller health effects) will not be higher. Because the inventory is dependent mainly on the reactor power, the real percentage of it should be based on the criteria that the LERF means smaller activity of  $^{131}\text{I}$  than 100000 TBq or other radionuclide mixes with similar consequences. Based on available data, the most significant isotopes will be  $^{131}\text{I}$ , and  $^{132}\text{I}$  (mostly as product of Te). “Early” means the release before vessel bottom head failure or shortly (at least two hours) after it. In case of channel type reactors, RBMK or CANDU, “early” has to be linked either to scenario type or directly off-site emergency procedures.
- 2) **LRF** - Release of such magnitude that extensive (over large areas) off-site measures should not be foreseen; including sheltering, evacuation, resettlement and food restrictions connected with significant economic impacts. If a release of this magnitude is not reached, early fatalities should be negligible and the off-site measures to reduce late (stochastic) fatalities are limited to food restrictions. The criterion is 0.05% to 0.1% of core inventory released into the off-site environment of any radiologically important specie (except noble gases), the usual reference isotope is  $^{137}\text{Cs}$ . Weighted mix of isotopes can be used as more precise. This definition should not be denoted as LERF, but LRF, as it covers also late releases. Like in the first case, the important fraction of inventory is related to the reactor type, its power and also burnup. For this reason 100-200 TBq of  $^{137}\text{Cs}$  is a more precise definition.

Regarding the general considerations mentioned above, the SARNET participants have also proposed some specific recommendations for L2 PSA practitioners on this issue:

- The precise definition of LERF or LRF noting both magnitude and timing constraints should be mentioned, even if its nature is not to serve as a regulatory requirement or safety objective.
- Using both definitions LERF and LRF concurrently improves the insight into the nature of risk, on the other hand, decisions are easier if based on only one criterion.
- We should have always in mind that large or large early release represents a boundary between “medium” and “unacceptably high” consequences; which is difficult to be fixed, caution is needed when comparing it to a quantitative safety target,
- When we speak about the LERF frequency or compare it with regulatory limits, the mean value of LERF frequency should be used and its uncertainty mentioned.
- Only on a special legal request some higher percentile (e.g. 95 percentile) may be used instead of mean value,
- The lower large release definition (LRF) is suitable for new plant designs (Generation III+) where releases of the order of the higher definition are practically excluded by the design,
- The length of the “early” interval should be specified more exactly, especially when

using the higher large release (LERF) definition where it is the time between the “start of warning time period” and the vessel bottom head failure + 2 hours.

- The “start of the warning time period” time is not the time of initial event, but some time when the control of the accident is lost and extensive core degradation becomes probable; it should be harmonized with the start of off-site emergency.

### **C5 The use of Expert Judgement (EJ) in PSA level 2 [5]**

A lot of research done in the area of Knowledge Psychology between the 1950’s and the 1970’s showed all the problems that have experts to deliver high quality opinions. All this research triggered the design of protocols oriented to get distributions from individual experts avoiding biases, especially overconfidence (tendency to provide narrower distributions than what could be expected from the actual expert’s knowledge). An outstanding protocol developed during the 1970’s was the Stanford Research Institute (SRI) protocol; see Merkhofer (1987).

In the early 1970’s, Prof. Rasmussen’s group was performing the first large scale PSA with formal treatment of uncertainties, the Reactor Safety Study (reported as document WASH-1400). This was the first time EJ was used in a large-scale application in the nuclear area. Nevertheless, unaware of the large improvements achieved in this field, the way EJ was used is what we could call Engineering Judgement (his staff based distributions on scientific literature review and the systematic used of specific distributions, as it is the case of the log-normal distribution).

A huge step forward happened in the mid-1980’s. The SNL/NUREG-1150 protocol was developed at SNL as collaboration between scientists dedicated to nuclear safety and experts in the field of EJ. This protocol was planned as a mean to get a lot of information for large-scale risk studies, as for example PSA for NPPs and Performance Assessments (PA) studies for radioactive High Level Waste (HLW) repositories, and took as a reference the SRI protocol. The steps of this protocol are the following (USNRC, 1990):

1. Selection of issues (Issues identified as key contributors to risk are identified and selected according to expected impact and probability criteria)
2. Selection of experts
3. Training (experts are trained in order to avoid biases and to help them giving answers in probabilistic terms)
4. Presentation of issues (The target is getting unambiguous definitions for the parameters whose uncertainty will be characterised)
5. Preparation and discussion of analyses
6. Elicitation of experts’ opinions (analysts get experts’ opinions via a structured session)
7. Aggregation of results (Individual experts’ opinions are aggregated to get one single distribution per parameter)
8. Review (by peers)
9. Documentation (all activities developed are documented, every result must be supported by documentation that explains how it was obtained)

This protocol was successfully applied in the NUREG-1150 study, where PSA studies were developed for five commercial US NNPs. Regarding PSA level 2, four expert panels were

convened to study fourteen accident progression, containment loadings, and structural response issues. Additionally, one more expert panel was convened to assess probability distribution functions for eight uncertain parameters related to the source term. The NUREG-1150 analysis staff and members of US National Laboratories provided distributions, via Engineering Judgement, for parameters that had been judged of lesser importance. In fact budgeted problems forced them to tackle via Engineering Judgement parameters that originally should have been studied via EJ. Certainly the NUREG-1150 study has been the most systematic EJ application ever done.

In the late 1990's, a set of European organisations developed the 'Benchmark Exercise on Expert Judgement Techniques in PSA Level 2' as a concerted action under the European Commission Framework Programme 4; see Cojazzi and Fogli (2000). The targets of this concerted action were to benchmark available EJ protocols in Europe by assessing distributions for uncertain parameters (7) in a severe accident issue (fuel coolant interaction), and to study the benefits of using these protocols. Most of the protocols were essentially based in the SNL/NUREG-1150 protocol, yet including specific features, one was based on Knowledge Engineering and another one was essentially an Engineering Judgement protocol. The key feature of this benchmark was that parameters assessed by experts were the real results measured in an experiment (FARO test L-24) actually performed at the JRC-Ispra laboratories. Protocols were benchmarked on real data coming from experiments relevant to PSA level 2. Estimates provided by individual experts using no protocol, estimates provided by the same experts participating in protocols and aggregated protocol estimates were compared. Though results were not statistically conclusive in all areas of comparison, when they were, aggregated protocol estimates provided the best results. This is an encouraging result in favour using structured EJ protocols as a reasonable way of getting input distributions for PSA level 2.

SARNET WP5 gave us the opportunity to check that the use of EJ has become a normal practice in European organisations dealing with PSA level 2 studies; all partners use EJ, either implemented as a formal protocol or via Engineering Judgement, to characterise the uncertainty of some of the key parameters in their studies.

### **D Conclusion - After SARNET, prospects within the ASAMPSA2 of the 7<sup>th</sup> Euratom FP**

The effort achieved within SARNET workpackage WP5.1 and WP5.2 has shown that a certain level of harmonization for level 2 PSA was possible through a direct comparison and analysis of Partners already existing methodology. This harmonization does not consist of a precise definition of what must be done but in a list of advices concerning the key issues and existing methodologies that are considered as acceptable by the Partners. This activity is also a way for the identification of issues where R&D knowledge is still needed for a robust quantification of risks.

Nevertheless, the SARNET activities have some limits identified by the Partners and that justify pursuing the efforts on harmonization:

- this activity was not identified at the beginning of SARNET as a major output but only as a feasibility study ; that is why, only a limited part of level 2 PSA issues has been examined for harmonization,

- the documentation produced within SARNET may be considered as disparate and not assembled in a unique guideline (it was not the initial objective),
- the SARNET activities did not provide interaction with the End-Users Community of L2 PSAs (Safety Authority, TSO, Utility, Designers, Vendors, Research Organizations ...) and had some limited views on application of L2 PSAs.

The identification of these limitations has helped to elaborate and propose the ASAMP2 project [9] in the framework of the 7<sup>th</sup> Euratom FP. This new project includes an End-Users group allowing an easy interaction with the technical groups and will mainly cover Gen II and Gen III and, to a limited extent, the Gen IV reactors.

The way of working will be different with an attempt of exhaustive identification of issues relevant for L2 PSAs and the resources of the ASAMP2 project will be allocated between these issues. The Annexe 1 provides a draft plan of the guideline that will be elaborated within ASAMP2. An important element of methodology was added in the ASAMP2 project, i.e. to consider two “levels” of level 2 PSA: the “limited scope” and the “full scope” methodologies. This element is estimated to be a way to solve the difficulty of harmonizing, considering the diversity of possible approaches.

The general methodology used within SARNET and described in part B will be also applied within the ASAMP2 and will be completed by a focus on applications of L2 PSAs.

The link between ASAMP2 and SARNET II will be kept, especially to discuss the conclusions in terms of further needs in severe accident R&D.

## **E - Conclusion**

The SARNET activities on L2 PSA have provided a useful framework allowing exchanges between some of the L2 PSAs practitioners in Europe. Although a complete harmonization of practices was not the initial objective, these activities have shown that progress on harmonization was achievable, either for the quantification of severe accident phenomena and induces risks, or for the methodologies used for the risk quantification.

The foundations for a new European project, ASAMP2, have been raised ...

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## ANNEX – DRAFT PLAN OF THE ASAMPSA2 GUIDELINES

The draft plan of the ASAMPSA2 guidelines is provided here for information.

It may evolve later but shows a lists of issues quite larger than the points examined within SARNET L2 PSA activities.

- 1 - Introduction
- 2 - Objectives and potential applications of L2 PSA
- 3 - General structure of a level 2 PSA and presentation of results
  - 31 - L1-L2 PSA interface
  - 32 - Accident Progression Event Tree (APET)
  - 33 - Release Categories and result presentation
- 4 - Best practices for the Gen II PWR, Gen II BWR L2 PSAs. Extension to Gen III reactors.
  - 41 - L1-L2 interface.
  - 42 - Human Factors
    - 421 - Examples of human actions (from severe accident management guide, support of crisis organization, systems recovery...)
    - 422 - Methods for the human factor quantification
  - 43 - Quantification of physical phenomena and containment loading
    - 431 - Definition and calculation of representative thermal-hydraulics sequences for each PDS
    - 432 - In-vessel core degradation
      - a - Core degradation
      - b - Induced-RCS rupture including Induced-SGTR
      - c - Hydrogen production
      - d - Restoration of core-cooling
      - e - Vessel cooling from outside
      - d - Consequences of in-vessel water injection (coolability, hydrogen production, RCS pressurization ... )
      - e - Containment atmosphere composition (recombiners/igniter effect) and containment pressurization
      - f - Containment venting
      - g - Hydrogen distribution/combustion
      - h - Corium criticality
      - i - In-vessel steam explosion and consequences (leak in the RCS, vessel rupture, containment rupture)
      - j- Vessel rupture (delay, break size ...)
    - 433 - Vessel rupture phase
      - a - Direct Containment Heating, including H2 combustion and vessel uplift
      - c - Ex-vessel steam explosion
      - d - Corium criticality
    - 434 - Ex-vessel phase (MCCI)
      - a - corium coolability
      - b - Basemat lateral and axial erosion
      - c - Impact of water injection
      - d - Production of steam and incondensable gases
      - e - H2/CO combustion
      - f - Evolution of containment atmosphere composition and long term pressurization
      - g - Containment venting
      - h - drywell erosion
      - i - poll scrubbing
      - h. - Melt propagation into ducts and channels
  - 44 - Containment performance (tightness)
    - 441 - Initial containment performance (pre-existing leakage)
    - 442 - Failure of the isolation system
    - 442 - Evaluation of containment performance in severe accident conditions
      - a - Quasi- static loading / dynamic loading - Structural response, structural analyses, fragility curve (leak or break)
      - b - Specific issues : example the impact of a steam explosion in the vessel pit on the overall structure behaviour)
      - c - drywell/supression pool performance
    - 443 - Containment penetrations performance (tightness) in severe accident conditions

- 444 - Identification of specific containment bypass ways (example: case of existing pipes in the plant foundations, cavity door failure for VVER)*
- 45 - Systems behaviour in severe accident conditions*
  - 451 - Sump recirculation, CHRS, Spray system*
  - 452 - RCS safety valves*
  - 453 - Steam Generator*
  - 454 - Instrumentation*
  - 455 - Pedestall cavity flooding systems*
  - 455 - H2 recombiners/Igniters*
  - 456 - Core catcher*
  - 457 - Reliability of passive systems*
- 46 - Source term assessment*
  - 461 - Definition of release categories*
    - a - identification of key parameters for source term assessment*
    - b - example of release categories*
    - c - screening frequency*
  - 462 - Group of fission products*
  - 463 - Source term assessment by integral codes*
  - 464 - Source term assessment by dedicated (fast-running) source term models*
  - 465 - Radiological consequences*
- 47 - APET/CET*
- 7 - Specific issues of Gen IV reactors*
- Appendices*
  - List of plant data that should be available for the L2 PSA*
  - Severe accidents codes*
  - Event trees codes*