

# WGRISK CSNI ACTIVITIES IN THE LEVEL 2 PSA FIELD: AN INTERNATIONAL POINT OF VIEW.

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## **Abstract**

*The WGRISK is one of the Principal Working groups of the OECD/AEN/CSNI. The main WGRISK mandate is to promote and help the use and development of PSA (Probabilistic Safety Assessment) in OECD member countries, by providing a forum of information exchange, and producing State-of-the Art Reports (SOAR), organizing Workshops, writing technical notes or Technical Opinion Papers (TOP).*

*For a long time Level 2 PSA is an important field for WGRISK and several tasks were carried out on this topic.*

*A first SOAR was published in 1997. Later on, two important workshops were organized (the first one relating to Level 2 PSA developments and results, and the second one relating to associated Uncertainties).*

*Presently an updating of the SOAR has been written, as well as a TOP. The TOP was published in April 2007 and the SOAR is envisaged before June 2007.*

*The paper describes the important findings of these different tasks and the main conclusions.*

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## **Introduction**

The paper gives an overview of the WGRISK past activities (First SOAR and workshops), and provides a more detailed information on the two recent products (Updated SOAR and TOP) which represent the present position of the group on Level 2 PSA. It has to be noted that these documents were prepared by the WGRISK and were also reviewed by the GAMA which is the OECD/AEN/CSNI working group in charge of accidents and severe accidents analysis. The following text is mainly based on extracts of these papers.

## **A - Past Activities**

### **A-1 First State-Of-The-Art-Report (SOAR)**

The state of the art in performing Level 2 PSAs up to 1997 has been described in [1] based on the existing studies for 19 pressurised water reactors and boiling water reactors. The report provides an overview of the methodologies used for the Level 2 PSAs and describes how the insights obtained have been used to develop Severe Accident Management strategies. The report also provides a comparison of key features adopted in the US NRC NUREG-1150 study, examples of US Individual Plant Examination (IPE) studies and the other PSAs that had been carried out at that time.

The contents of this report are the following:

- Task description and working methodology
- Results and Insights from recent Level 2 PSA
- Key Severe Accident Issues
- Severe Accident Management
- Available methodology for qualitative Level 2 analysis
- Evaluation of Level 2 PSA models and quantification
- Integrated and PSA informed approach to decision making

It has to be noted that , although at the beginning of use of Risk Informed Decision Making, this report includes, in addition to a large part of methodological considerations, a very important and interesting list of plants modifications and backfits relying on Level 2 PSA results (Improvement of existing systems, addition of new systems, accident management...)

#### A-2 International Workshop on Level 2 PSA and Severe Accident Management [2]

This Workshop was held in March 2004 in Köln (Germany), hosted by GRS. This workshop was organised when considering that:

- A lot of work has been carried out since the 1997 report was issued, especially improvement in the modelling in severe accident codes
- Many new Level 2 PSAs have been completed since the 1997 report was issued, especially on VVER reactors
- Level 2 PSAs have led to the development and implementation of plant specific severe accident management.
- Most of the Level 2 PSAs in the last report were performed at full power. A lot more experience is now available concerning low power and shutdown.

The main findings of this workshop were the following:

- Although in their overall principles the presented methodologies are still similar to the NUREG 1150, there are high differences in the application of the method (Number of supporting physical calculations, realistic/conservative approaches, Level 1/Level 2 interface..).
- Detailed analysis underline the importance of plant specific studies (some limited design differences could lead to very important results differences).
- Several Advanced methods are under development (Physical uncertainties, dynamic Event Trees..)
- Many recent studies (especially relating to VVER plants) led to important plants safety improvements.
- This workshop was an important Forum for information exchange on Level 2 PSA and showed that many activities are still on-going on level 2 PSA in most of the countries,

- This workshop could be considered as an interesting input for an updating of the WGRISK SOAR Report and also to the Workshop relating to uncertainties (see paragraph below)

### A-3 Workshop on Evaluation of Uncertainties in Relation to Severe Accidents and Level 2 Probabilistic Safety Analysis [3]

This Workshop was held on 7-9 November 2005 in Aix-en-Provence, France. The meeting was hosted by the IRSN.

The Workshop was organised jointly by three OESD/NEA/CSNI Working Groups: WGRISK, GAMA and IAGE.

#### ***Key points raised in the discussion:***

##### *(i) Role of uncertainties analysis*

- Full-scope PSA is desirable in order to understand the impact of uncertainties and to suitably address it. Documents have been developed (e.g. at the USNRC) on what is meant with appropriate quality in PSA. Treatment of uncertainties is a major element of PSA quality.
- The focus should be on uncertainties that impact the decision-making. A scoping exercise to decide where further investigations should be directed would be very useful. There is a need to formalise treatment of uncertainties in the context of decision making in order to increase consistency and transparency.
- Understanding uncertainties is important for PSA and for defining the direction of future R&D. It can also be useful for plant improvements or for the design of new plants. For a good (PSA-based) assessment of the benefits, uncertainty is important.
- Emergency planning can benefit substantially from Level 2 PSA and related uncertainties.
- The credibility of PSA resides in robustness of methods and in code prediction credibility. Code prediction also depends on user, i.e. on parameter input and/or model selection. In this context (as for experts judgment), the issue of human reliability comes into the picture.

##### *(ii) Sources and nature of uncertainties*

- An uncertainty has both aleatory and epistemic components and a clear separation between them and their relative contribution is difficult to make. With an epistemic component additional information could be obtained (e.g. experiments, observations etc) and this uncertainty can be reduced with new knowledge and its influence can be reduced accordingly. With an aleatory component, there may be a need to modify the design (including procedures), if it is shown to be significant. They are both important and can influence the quality of PSA and the decision making process.
- Important epistemic (state-of-knowledge) uncertainties should be identified. This can be helpful for devising new joint international research projects. Common understanding of R&D needs is a priority.

*(iii) Severe accident code analysis*

- Parameter sensitivity analyses of code predictions are useful to understand uncertainty propagation. However, one should be cautious about interpretations of the scatter of predictions, as scatter may not correctly represent uncertainty.
- SA code analysis is a significant part of a Level 2 PSA. For their correct use, it is necessary to have an appreciation of the qualification limits these codes have – and where code limitations are relevant for overall PSA.

*(iv) Expert judgement/opinion*

- Experts' opinion is useful, for example, for eliminating phenomena when they are not relevant. This, however, may be plant-specific.
- Expert judgement is needed, but transparency is essential in this context. Right issue decomposition and sound overall experience are needed in order to ask the right questions. ROAMM are becoming more widely used: also in this context, problem decomposition is important.
- Expert judgment is a point that requires attention. As an example, steam explosion depends on expert judgment, but this may not be strongly based. There is a concern on the burden posed on experts. A benefit of uncertainty analysis is to reduce the burden on experts.
- There is a need to precise what expert judgment is, when it comes into essence, the basis for judgment etc. A prescription on how expert judgment should be used and how limitations are accounted for does not exist today.

*(v) Future development*

- One should aim to achieve consensus on uncertainty methods. Since all sources of uncertainty are link together, consideration must be given to the Level 1 – Level 2 PSA interface.
- Level 2 PSA is common practice now, some general guidelines on how it should be carried out have been put forward, e.g. in Germany. However, a generally agreed and well-established prescription for how it should be performed and in particular on how uncertainty is accounted for, is lacking. In reality, there are appreciable differences on how Level-2 PSA's are carried out.
- For the future, efforts should be put on trying to harmonise the way Level-2 PSA is to be carried out, or at least to identify the most important items to be addressed. A suitable approach may include the following points:
  - a) Compile and review what has been done so far and based on this
  - b) Extract what can be considered good practice
  - c) Agree on common areas where further activity needs to be performed
- There is not a single method suitable for every situation and assessment. Increased international co-operation on methods and guidance regarding uncertainty analysis would be desirable, where guidance should incorporate a certain amount of flexibility. However,

full harmonisation on methods may not be necessary as there can be merits on some degree of differentiation.

- Should one conduct benchmark of PSA teams? A grouping of NPPs and a comparative exercise for similar (existing) NPP could be considered.

### ***Recommendations:***

Some recommendations were issued following the discussions:

- Update the OECD Report on "Level 2 PSA Methodology and Severe Accident Management" including a chapter on uncertainty
- Development of a guidance document or handbook to reflect good practices on treatment of Level 2 PSA uncertainties.
- Guidance on expert judgment process
- Development of plant specific importance measures and ranking for phenomenological issues in Level 2 PSA for decision making (e.g., research prioritisation, regulatory and utility applications)
- Other issues: L1/L2 PSA interface, Shutdown fault uncertainty, Comparison studies....
- Consideration should be given to conducting an international benchmarking exercise, comparing outcome from different teams on Level 2 PSA for similar (existing) NPPs, with emphasis on uncertainty treatment

### ***Summary of discussion***

From the discussion, there is good agreement that Level 2 PSA is now a commonly used key tool for many NPP applications and the uncertainty analysis forms an integral part of it. Uncertainty analysis is used to confirm robustness of results with respect to any acceptance criteria and therefore serves to underpin the quality of a Level 2 PSA. Increasing demand for in-depth treatment in current and future applications include for example:

- SAM (e.g. IVR strategy for high power reactors)
- Risk-informed decision making
- New reactor licensing

It is also clear that there are different views, emphasis and priorities on a number of issues reflected by the key points raised during the discussion (see summary above). From the discussion, a number of recommendations were made, including the development of guidance documents, as a way forward.

## **B- New State-Of-The-Art-Report (SOAR)**

Since the first SOAR, there have been significant developments in that more Level 2 PSAs have been carried out worldwide for a variety of nuclear power plant designs including some that were not addressed in the original report. In addition, there is now a better understanding of the severe accident phenomena that can occur following core damage and the way that they should be modelled in the PSA, and a new version of the SOAR was written [4]

## B-1 Results and insights from recent Level 2 PSAs

The main development is that Level 2 PSAs that have been carried out in Eastern Europe for VVER-440 and VVER-1000 reactors, and the results and insights from these PSAs are presented. In addition, the comparison that was carried out of the VVER-440/213 reactors at Paks and Dukovany carried out under the European Union (EU) SARNET project is described. Although this concluded that there was broad agreement between the two studies, it indicated how small differences in the design could lead to significant differences in the results of the analysis.

## B-2 Key severe accident issues

The original report described the key severe accident issues related to the accident progression, the performance of the containment and the phenomena associated with the release and transport of radioactive material. Since then, extensive research has been carried out worldwide and this has led to a better understanding of many of these phenomena and the resolution of some key issues. An example of this is the work sponsored by NRC to reassess three key containment failure mechanisms – in-vessel steam explosion, direct containment heating and melt through of a Mark 1 containment liner. The conclusion reached is that, in some cases, the probability of these failure modes is very low.

Another improvement is the knowledge base for the design and implementation of mitigation features for current and evolutionary designs of light water reactors. An example of this is the implementation of the severe accident management strategy of in-vessel melt retention for Loviisa. The research has also provided the justification for not providing mitigation – for example, not inerting the containment of a Mark III BWR where an alternative means of hydrogen control such as the provision of igniters can be employed. Finally, the EU EURSAFE project has contributed to establishing a consensus on severe accident issues where large uncertainties still existed. One phenomenon that has recently been identified is air ingress into the reactor pressure vessel during severe accidents leading to oxidation of the core material. It is expected, but not demonstrated, that the effects of air ingress are more limited for events initiated at full power.

## B-3 Severe accident management

Over the past 10 years many of the nuclear power plants worldwide have now got a capability for severe accident management. This has been driven partly by the Severe Accident Management Guidance (SAMG) developed by owners groups for plant specific applications. A recent example of this is the application of the Westinghouse Owners Group SAMG to CANDU reactors which is more difficult due to the complex core damage mechanisms that occur.

Recent developments on severe accident management strategies for PWRs and BWRs have focused on the long term stabilisation and coolability of molten core material after a severe accident. This has addressed: in-vessel retention by flooding the area round the lower head of the vessel, and ex-vessel retention involving the cooling and stabilisation of the molten core material by a number of different means. However, there are still gaps in the state of knowledge of knowledge of these accident management measures – for example, on the ex-

vessel coolability for deep beds with top flooding and on in-vessel melt retention through ex-vessel flooding, particularly for higher core power (and power density) designs.

Reviews have also been carried out in a number of countries on the modelling of the severe accident management measures in the Level 2 PSA. The inclusion of these actions has led to a reduction in the core damage frequency/ large early release frequency/ source term frequencies. Reviews are ongoing on how the validity of human activity modelling in emergencies could be improved, since these activities were not included in the scope of existing Human Reliability Analysis methods.

The EU has undertaken two studies: SAMIME (Severe Accident Management Implementation and Expertise in the European Union) and SAMOS (the viability of using computerised aids to assist in severe accident management). The integrated use of severe accident analyses in the development of severe accident management strategies is illustrated in the EC sponsored study on the Optimisation of Severe Accident Management Strategies for the Control of Radiological Releases (OPTSAM).

#### B-4 Available methodology for qualitative Level 2 analysis

The current trend is for the scope of the Level 2 PSAs being produced to be extended to cover low power and shutdown conditions. This has led to other attributes being included in the definition of the set of plant damage states used to take account addition factors – for example, the decay heat level and whether the reactor coolant system and the containment are open or closed.

Although there are still differences in the approach used to carry out the accident progression analysis in that some of the studies carried out in the last 10 years have used the small Containment Event Tree (CET) approach with 10 to 30 nodes and others have used the large Accident Progression Event Tree (APET) approach with more than 100 nodes, it is generally agreed either approach can be used to model all the phenomena that can occur following a severe accident. This is illustrated by the analysis carried out for Laguna Verde, where both approaches were used. The conclusion was drawn that, in general, both studies showed similar trends in the accident progression features and in source term behaviour. In the small CET approach, Decomposition Event Trees or Phenomenological Fault Trees have been used. In addition, the MCDET approach has been developed which is a significant departure from the current APET-based approach to Level 2 PSA.

The issue of the Level 2-Level 3 PSA interface was not discussed in the original report. In the review carried out, differences have been noted in the number or the Release Categories/ Source Term Categories defined in recent Level 2 PSAs. In addition there are differences in the way that they have been defined – that is, some are sequence based and some are source term based.

#### B-5 Level 2 PSA models, uncertainties and quantification

Many of the recent Level 2 PSAs based on a small CETs approach have used Decomposition Event Trees or Phenomenological Fault Trees to take account of uncertainties in the severe accident phenomena and to investigate specific issues. The Risk Oriented Accident Analysis Methodology (ROAAM) has also been used for the assessment and management of rare, high consequence hazards. For example, this approach has been used for Loviisa to investigate the

adequacy of the overall level of safety achieved at the plant and to guide the development of severe accident management guidelines. A notable development in the methodology has been made in the Level 2 PSAs being carried out in France where physical models have been used in the quantification of the Accident Progression Event Trees where the construction of the physical models is based on validated code calculations.

#### B-6 Integrated and PSA-informed approach to decision making

The Level 2 PSAs produced in the past 10 years have been used to identify plant improvements that could be made to reduce the risk. This has been done within the framework of a risk-informed approach that has been developed and applied in many of the member countries during this period. An example of this is the plant specific PSAs that have been produced for the VVERs that have been used to assist the decision making process on plant safety improvements and to determine the effectiveness of the SAMG.

#### B-7 Integrated severe accident analysis codes

The computer codes used for the analysis of severe accidents have undergone further modelling improvements and validation/ benchmarking. This applies to the integrated codes and the separate phenomenon codes. These include: MAAP (Modular Accident Analysis Program developed by EPRI); MELCOR (developed Sandia National Laboratory in the USA); ASTEC (Accident Source Term Evaluation Code developed in France and Germany); and THALES-2 (the Thermal Hydraulics and radionuclide behaviour Analysis of Light water reactor to Estimate Source terms under severe accident conditions code developed in Japan). The capabilities of these codes are described in the text.

### **C- Technical Opinion Paper**

The technical Opinion Paper[5] can be considered as the present conclusion of the WGRISK concerning the Level 2 PSA. The objective of the paper is to summarize all the important work carried out on this topic (methods, data, results, applications..), as well as the limitations and the necessary improvements in the future.

The main message of this Technical Opinion Paper is that the Level 2 PSA methodology may now be seen as mature. This is reflected by the large number of high quality analyses that have been performed in recent years and used to identify the potential vulnerabilities to severe accidents and the accident management measures that could be implemented.

The Level 2 PSA is now seen as an essential part of the safety analysis that is carried out for all types of nuclear power plants worldwide. The information provided by the Level 2 PSA is being used by plant operators and Regulatory Authorities as part of a risk informed decision making process on plant operation and more specifically on issues related to severe accident management.

A consistent framework has been established with the development of the individual components of the Level 2 PSA methodology and guidance has been produced by international organisations for carrying out the analysis. In practice, however, there are still differences in the approach and the level of detail in the individual steps that have been carried out in different analyses, partly due to the different objectives that have been defined

for these studies. Quality standards and guidelines are currently being developed for Level 2 PSA which should address many of these differences.

The acceptability of the methodology since the early studies in the 1980s is due largely to the significant progress made in the understanding of severe accident and source term phenomenology and in the model development in the current generation of integrated severe accident analysis codes. The research and development activities have continued internationally, albeit at a reduced scale, with emphasis on improving the state of knowledge and providing further data for model validation and improvement.

Further development in Level 2 PSA is likely to see its integration within a Living PSA and its use for risk-informed applications. This requires improvement in the Level 2 PSA methodology in a number of areas, including: the Level 1/ Level 2 PSA interface, the modelling of safety system recovery and human reliability analysis.

The epistemic uncertainty related to some Level 2 PSA issues is regarded as being quite large. The impact of this on risk-informed decision making will also require further consideration of uncertainty treatment in a more integrated manner.

Finally, given the role that integrated severe accident codes (supported by research) have played in the acceptance of Level 2 PSA, future Level 2 PSA research and development activities should be aimed at making these codes play a more central and integral role in the PSA quantification process. Such a shift is likely to alter (and quite possibly diminish) the role of expert judgement and phenomenological event tree modelling in the quantification.

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## **References**

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[5] Recent Development in Level 2 PSA and Severe Accident Management, report, Draft version March 2007

[6] Technical Opinion Paper (2007) - Final Draft approved by the CSNI