Overview of progress in level 2 PSA activities

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SUMMARY

The main objectives of the level 2 PSA (Probabilistic Safety Assessment) activities in the frame of SARNET are methods comparison, improvement and harmonization within Europe. Three main subjects are of interest for the group:

- Classical methods for level 2 PSA development,
- Methods to assess uncertainties,
- Dynamic reliability methods.

17 partners are involved in these activities and, more recently, three organizations more have contributed to these activities.

Main recent progress done are briefly presented and commented.

Based on the analysis of partners’ answer to a specific questionnaire, a status of practices and guidelines in the EC has been established. This status helps to clarify if harmonization of practices is possible in the EC and how.

Harmonization of methods, with the general aim to provide guidelines for level 2 PSA development, has started on different subjects:

- Some physical phenomena assessment (progress presented in a companion paper) with the perspective of an extension to all physical phenomena,
- Definition of large early releases and of reactor final states (for a common presentation of level 2 PSA results),
- Level 1 and level 2 PSA interface.

A comparison of the different functionalities offered by the main probabilistic software (EVNTRE, RISK SPECTRUM, KANT) has been achieved. As part of the comparison, a specific short size event tree has been developed to investigate the different software performances. The review of software to apply uncertainty and sensitivity methods that can be used in support to level 2 PSA has been initiated. The different software have been identified and the description of their different functionalities as regards the different methods is on going.

A benchmark exercise, on hydrogen distribution and combustion issue, to compare dynamic reliability methods with classical ones has been specified and organized in two steps without, and then with uncertainties assessment (conclusions presented in a specific paper).

In parallel, the development of the Stimuli Driven Theory of Probabilistic Dynamics (SDTPD) method has been pursued for a more global application than the benchmark exercise. In this frame, the RISK TEC plate form associating different partners is under development.

A. INTRODUCTION

The main objectives of the SARNET level 2 PSA (or PSA2) activities are methods comparison, improvement and harmonization within Europe. These activities, coordinated by IRSN, are organized into three Work-Packages, which concern respectively:

- The methods for level 2 PSA development (WP 5.1),
- The methods for uncertainties assessment (WP 5.2),
- The improvement of classical methods using dynamic reliability methods (WP5.3).

17 partners are involved in the different activities and recently, three organizations more also contribute to the actions (table below).

Partners	WP5.1	WP5.2	WP5.3
IRSN (coordinator)	**X**	**X**	**X**
AREVA	**X**	**X**	**X**
AVN	**X**		
CEA		**X**	**X**
CSN			**X**
EDF	**X**	**X**	
GRS	**X**	**X**	**X**
INR	**X**		**X**
JRC		**X**	
LEI	**X**	**X**	**X**
NNC	**X**	**X**	
PSI	**X**	**X**	
SWP	**X**	**X**	
TUS	**X**	**X**	
ULB			**X**
UJV	**X**	**X**	**X**
VEIKI	**X**	**X**	**X**
ISAR		**X**	
RELCON (SWP support)	**X**		
UPM (in the frame of a mobility programme)			**X**

Table 1: SARNET PSA2 partners

B. OVERVIEW OF THE ACTIVITIES

The figures 1 and 2 give an overview of the activities achieved, on going and forecasted in the frame of the SARNET PSA2 Work Packages.

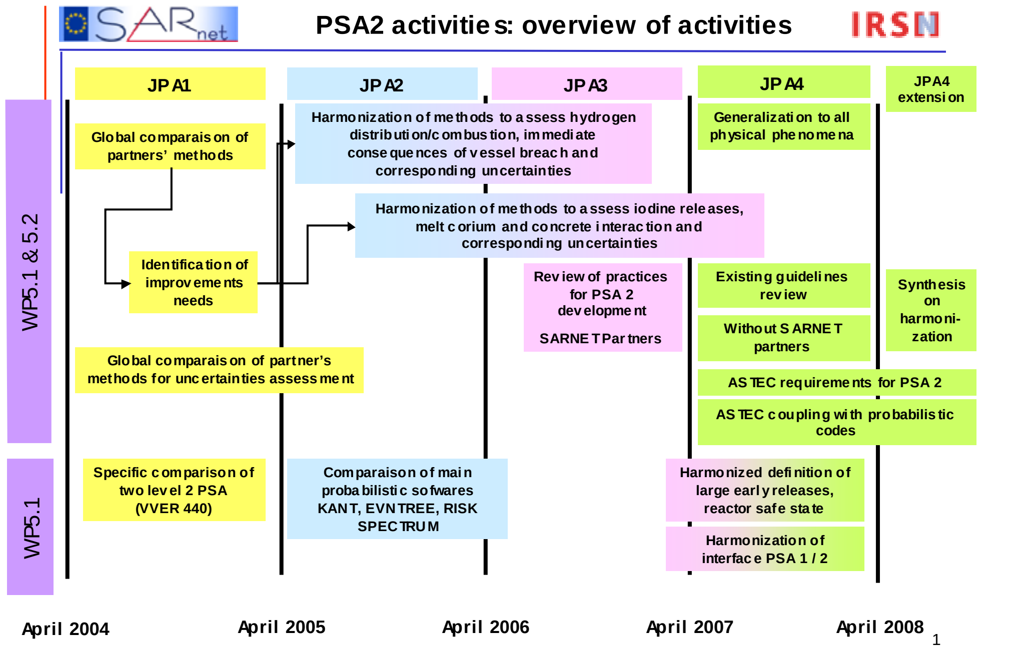

Figure 1: overview of SARNET PSA2 activities – part 1

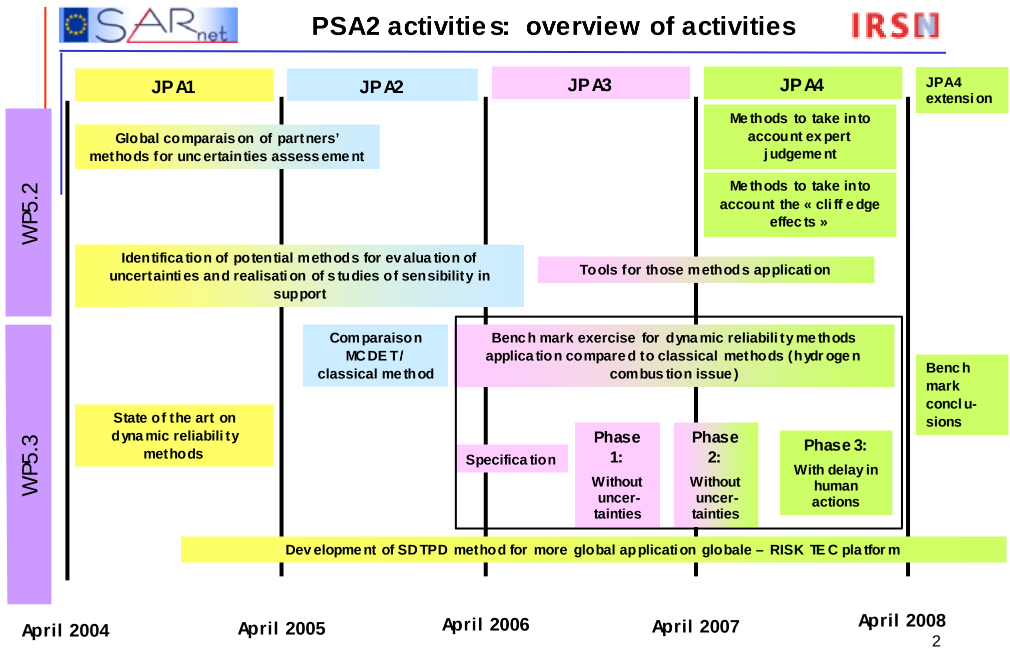

Figure 2: overview of SARNET PSA2 activities – part 2

The initial period of the SARNET was mainly devoted:

- To describe and compare the partners' methods. The comparisons deal with all elements of methods which are usually part of a level 2 PSA (including uncertainty assessment and sensitivity analysis aspects) ([1], [2])

- To establish states of the art on specific subjects. Two topics were so selected: dynamic reliability methods, uncertainty and sensitivity methods in support of PSA level 2. Main conclusions of the corresponding work were presented in respectively [3] and [4].

Besides, during the initial period of activity, first themes for potential methods harmonization were selected. Also, the status of partners’ needs, experience and intentions concerning dynamic reliability methods was established [1].

Then, the activities were focussed on:
- Harmonization of methods. A feasibility study of harmonization of some level 2 PSA issues (all concerning physical phenomena) has been undertaken and is the subject of a companion paper [5] and so will not been commented in details here. Based on the analysis of partners’ answers to a specific questionnaire, a status of practices and guidelines in the EC has been established and is commented in section C. Search of harmonized methods has been also initiated on several subjects (definition of large early releases, of reactor stable states, level 1 and level 2 PSA interface),
- Comparisons of software. The comparisons, which results are illustrated in section D, concern the probabilistic software used by the partners and the software to apply uncertainty and sensitivity analysis methods in support to level 2 PSA,
- The definition and achievement of a benchmark exercise to compare dynamic reliability methods with classical ones. The subject of this benchmark is the assessment of the risk of containment failure due to hydrogen combustion considering, as events that could influence the risk, the core reflooding and the spray system operating (that could intervene at any time), and the hydrogen ignition due to recombiners effect or to any other random source of ignition). The results of the benchmark is commented in [6] and will not been addressed here,
- The development and implementation of the Stimuli Driven Theory of Probabilistic Dynamics. Some elements of the corresponding activity are presented in section E.

Future work is commented in the conclusion part of this paper.

C. STATUS OF PRACTICES AND GUIDELINES IN THE EC

The objective of the task is to achieve a survey on Level 2 PSA guidelines used (or not used) and try to seek answers for:
– Can we arrive at a consensus on harmonization (at least partial)?
– How to achieve harmonization? And,
– Where seems to be difficulties?

A questionnaire comprising 34 “issues” addressing questionable (by experience) details of IAEA guidelines has been established and the partners responses were analysed.
The evaluation scheme leads to categorize the questions into 6 groups
- Is harmonization desirable (general issues)?
- Is harmonization desirable (performance details)?
- Is harmonization possible?
- Is simplification desirable?
- Is more guidance suitable for a selection of specific issues?
- General (guidelines being used, peer review, phenomena for uncertainties).

Main conclusions may be expressed as it follows:
- Limited harmonization can be reached and is desirable over “local practices”. A common set of guidelines may be a starting point; and sharing of tools and resources is desirable;
- Some areas for harmonization have been definitively identified:

- Common safety goals;
- Commonly agreed mission times,
- Simplification of analyses but the extent of simplifications is to be better endorsed. Detailed analyses for all accident progression issues may or should not be required depending on plant specific issues,
- Differences in architecture of event trees are not significant,
- More species than noble gases, Iodine and Caesium should be tracked for source terms assessment,
- Accident management measures are better addressed with sensitivity studies,

- Weaknesses of existing guidelines are underlined in different areas:
  - It should be made cleared that PSA is intended for plant personnel,
  - Familiarization with Severe Accident Management (SAM) and SAM systems should be stressed,
  - Better guidance expected on level 1 / level 2 interface, selection of “representative” sequences, definition of sequences at shutdown, scope of supporting calculations, treatment of iodine and ruthenium,
  - Discussion of possible pitfalls.

These conclusions confirmed the interest on harmonisation’s aspects and the themes of harmonization which had been already selected.

D. COMPARISON OF SOFTWARE

As mentioned in the overview of the activities of the PSA2 WP, the comparison of software covers two aspects: the comparison of the probabilistic software used by the partners to develop and quantify their level 2 PSA, and the software to apply uncertainty and sensitivity analysis methods in support to level 2 PSA

D.1 Probabilistic software

The codes involved in the comparison are: KANT, EVNTRE and RISK SPECTRUM, which are the three software used by the partners. The comparison was detailed and organized according to the following themes:

- Level1 and level 2 PSA interface,
- Event trees limitations,
- Quantification models,
- Grouping of the event tree sequences,
- Data type able to be used,
- Possible uncertainties treatment methods,
- Possible sensitivity analysis treatment methods,
- Software environment,
- Data presentation,
- Modelling facilities,
- Results presentation.

As example of the comparison of the different software functionalities the following figures illustrate the event tree representation with KANT and RISK SPECTRUM (figures 3 and 4), the histogram representation of a specific release category with KANT (figure 5). It may be pointed out that no graphical representation of the event tree like figures 3 and 4 is available with EVNTRE, while no histogram representation like figure 5 is available with RISK SPECTRUM and EVNTRE.

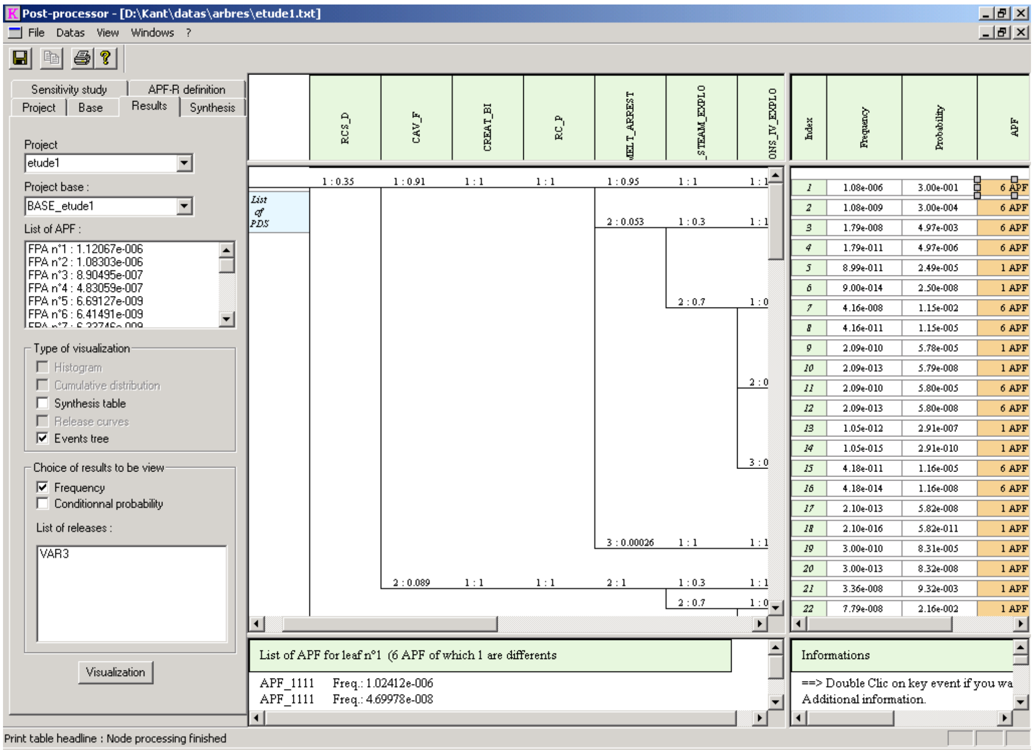

Figure 3: event tree representation with KANT

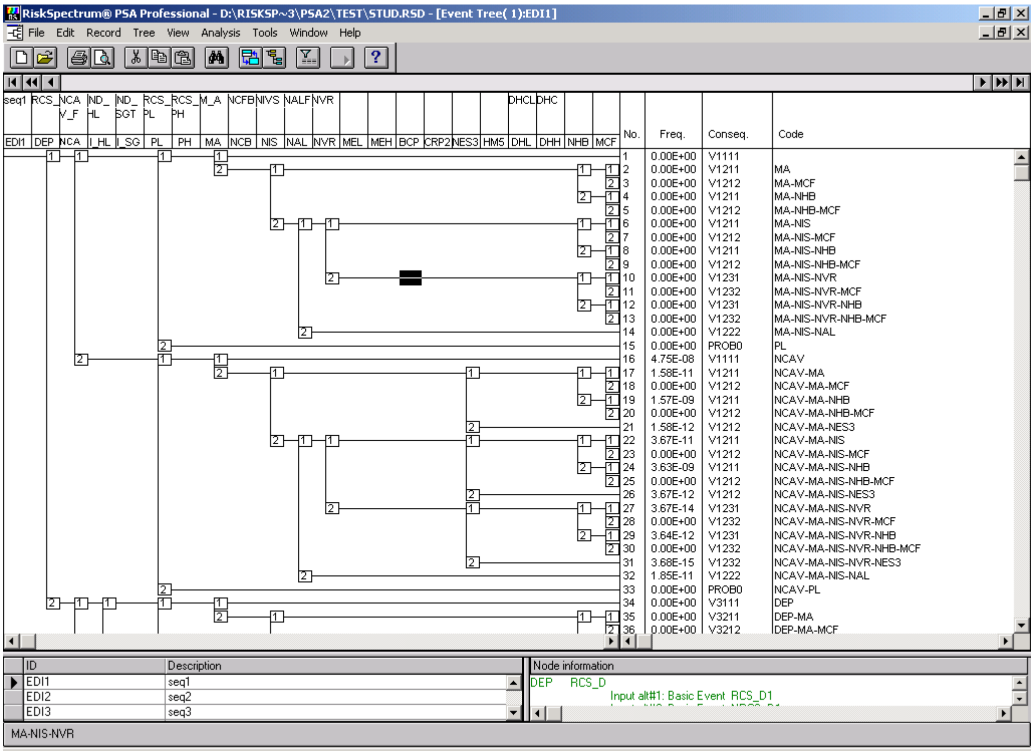

Figure 4: event tree representation with RISK SPECTRUM

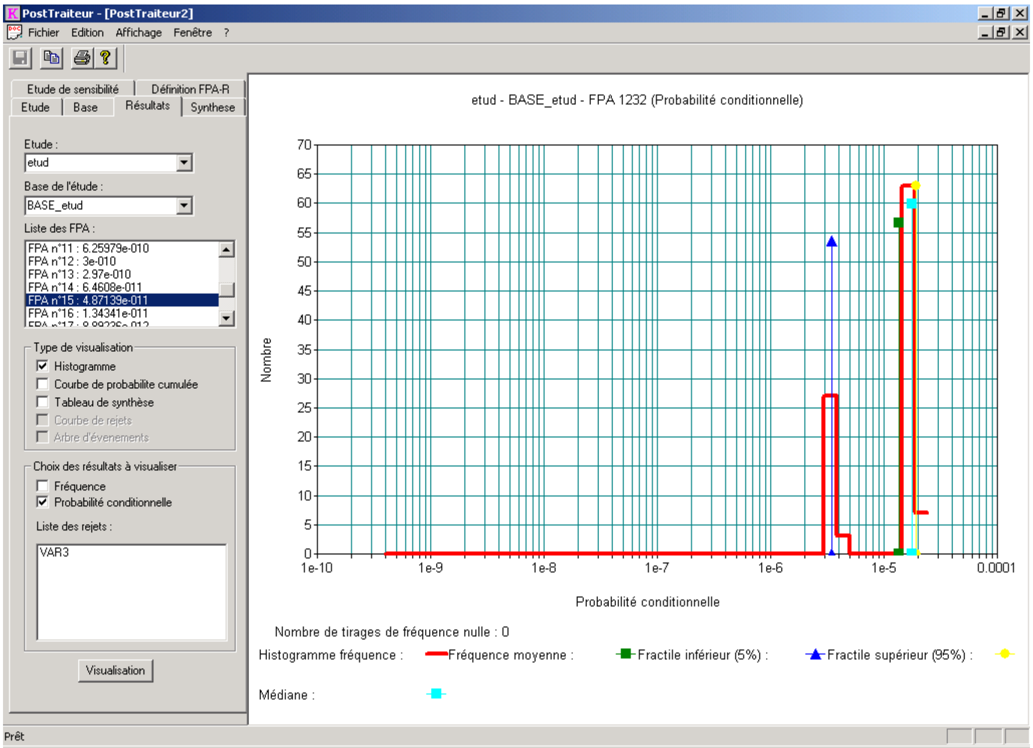

Figure 5: histogram of conditional probability for a specific release category (KANT)

The computational performances of the three codes (KANT, EVNTRE, and RISK SPECTRUM) have been assessed considered an application example. The example describes an accident progression up to early containment failure and does not reflect a real situation. This example is represented by 6 initiating sequences, 9 interfaces variables, 17 questions and 4 grouping variables.

The aim of the case study is to give s ideas on the capabilities and differences of the different software used. The following table gives the results obtained in terms of CPU times, and cumulative probabilities obtained.

	KANT		EVNTRE		RISK SPECTRUM
	Point estimate	Uncertainty distribution	Point estimate	Uncertainty distribution	Point estimate
Total frequency of bins (CONT. BYPASS + MELT ARREST+ ALPHA EARLY CF	3.60523e-06	3.60523e-006	3.605E-06	3.6052E-06	3.60523e-006
CPU time	<5 s	<9 min	<1s	<2s	<5 s

Table 1: final results of the application example

One may mention that, due to the specification of the application example, RISK SPECTRUM was not able to establish uncertainty distribution of the results. It main be pointed out that the software give the same results (point estimate) but with different CPU times.

Finally, the comparison leads to establish the main advantages and disadvantages of the software which are presented in the following table.

	Main advantages	Main disadvantages
KANT	. Detailed representation of the events as systems behavior, human actions and physical phenomena, . Quantification models for each event in the APET, which assess the probability of each possible response and the values of the dynamic variables. It may use external models, . Specific programming language to implement these models in a flexible way, . Deals with large and complex event trees that can be structured in sub-trees, and allows multiple branches at each node, . Permits the plant damage states automatically regrouping by criteria related to interface variables values and/or frequency, and permits to consider the level 1 sequences that constitute a plant damage state, . Quantification with different groups of plant damage states selected with logic rules, . Automatically grouping and regrouping of accident sequences in accident progression families according with logic rules, and corresponded probabilities calculation, . Random simulations of parameter values by Monte-Carlo methods, . Statistic treatment of results, constituting histograms of values and calculating mean values, median, and fractiles, . User assistance for data visualisation and allocation and results exploitation using different visual functions, . Direct results presentation with Microsoft Office tools, . Iterative control of the event tree calculation, . Fast running	. Does not permits an integral PSA thus, dependences with level 1 cannot be considered correctly (KANT is not suitable for Level 1 modelling), . Does not consider the uncertainties of PDS frequencies
RISK SPECTRUM	. Treatment of the complete PSA Level 1 at the same time as the Level 2. This is especially true for uncertainty analysis, . User friendly interface, . Fast running, . Calculations with multiple plant damage states summing the results possible, . Allows multiple branches at each event tree node, . Allows grouping of the APET sequences	. Treatment (and definition of distributions) of physical variables not possible . Calculation of complex mathematics or arithmetic functions not possible, . No linking with external models, . Does not permit the direct comparisons of variables
EVNTRE	. Deals with large and complex event trees with multiple branches, . Permits events quantifications using user-defined subroutines, . Available as source code, so that modifications are possible, . Fast running, . Allows the uncertainty analyses by Monte Carlo simulations, . Permits automatically grouping of accident sequences in accident progression families according with logic rules, . Allows calculations with multiple plant damage states summing the results	. Does not permits an integral PSA thus, dependences with level 1 can not be considered correctly (EVNTRE is not suitable for Boolean modelling for Level1), . User ‘unfriendly’ interface, . Permits only comparison of variables with parameters for calculation branches split fractions (for nods with more than 2 branches).

Table2: comparison of the software functionalities

D.2 Software for uncertainty and sensitivity analysis methods

As mentioned in the overview of activities, a detailed review of uncertainty and sensitivity analysis methods that can be used in support of PSA level 2 was performed during the second year of SARNET activity [4].

This work has been prolonged by a review of the different software available to apply the different methods identified. Commercial or free, specialised or general software have been considered for this review. The corresponding software are Crystal Ball, DAKOTA, Open Turns, R, SIMLAB, SUNSET, SUSA, URANIE, and for reliability studies: Phimeca Software and STRUREL. For the different software identified, the list of functionalities has been established, and the possibility of coupling with the probabilistic software and with ASTEC code is now being checked.

The corresponding work, to be finalized, will be useful for the different partners of the different Work Packages.

E. DEVELOPMENT AND IMPLEMENTATION OF THE STIMULI DRIVEN THEORY OF PROBABILISTIC DYNAMICS

Large efforts have been done in the development and implementation of the Stimuli Driven Theory of Probabilistic Dynamics (SDTPD), in the perspective of the benchmark exercise contribution and more global applications. Considerable progresses were made on both theoretical and practical aspects notably with the introduction of the concept of transmission functions and with informatics implementation. The software package (SCAIS - System of Codes for Integrated Safety Assessment) under development in the frame of the RISK TEC platform will include the following different modules:

- <u>The Distributed Plant Simulator</u>, As a wide range of different phenomena, not covered by just a single simulation code, has to be represented, the plant simulator has to comprise a set of codes interrelated by coupling techniques;

- <u>The Procedures Simulator Simpro</u>, which simulates the actions of the human operators in a Nuclear Power Plant (NPP). Current approach is to simulate the Emergency Operation Procedures while further developments will eventually lead to simulate every procedure that take part in normal operation of the NPP;

- <u>The Dendros Scheduler</u>, which manages the communications among the different processes contributing to the tree development, arranges for the opening of a new branch whenever certain conditions are met. Each new branch is started on a separate process initialized to the transient conditions where the branch occurred;

- <u>The Probability Calculation Module</u>. It performs the computation of the fault trees corresponding to each system involved in the sequence under simulation. The current approach implies the use of Binary Decision Diagrams (BDD). On going developments will lead to the integration of SDTPD Method.

Following figures give the general architecture of the SCAIS module. 7 organizations (4 from SARNET) are involved in the development: Département de Métrologie Nucléaire (ULB), Laboratory of Nuclear Installation Safety (LEI), Department of Applied Mathematics (KTU), Modelling and Simulation Department (CSN), Department of Energy Systems (UPM), Institute of Technology Research (ICAI), Indizen Technologies SL.

Main activities during recent past period were concentrated on:

- Development of the path and risk assessment modules,
- Modernization of the old version of the procedure Simulator,
- Incorporation of the Binary Decision Diagrams (BDD) tool.

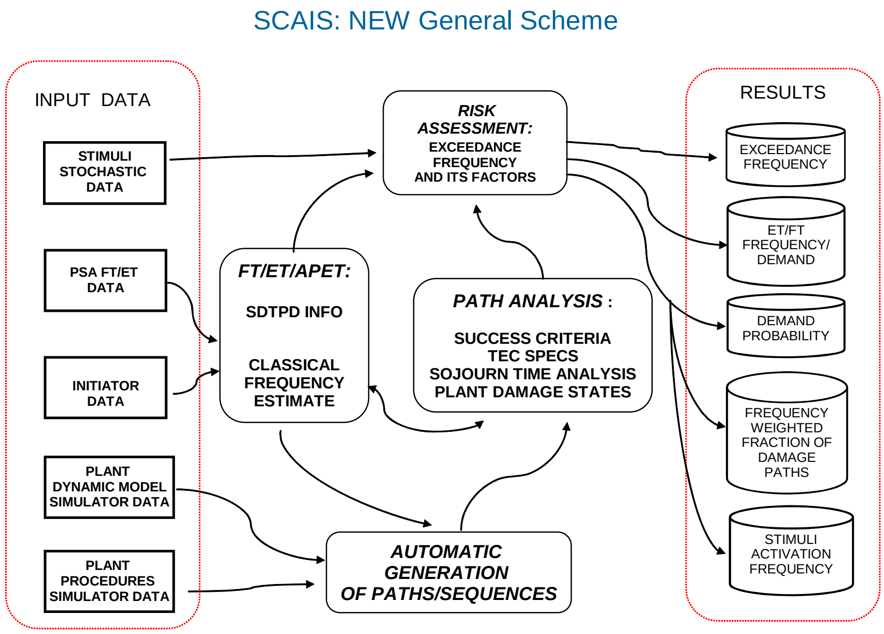

Figure 6: SCAIS - System of Codes for Integrated Safety Assessment) scheme

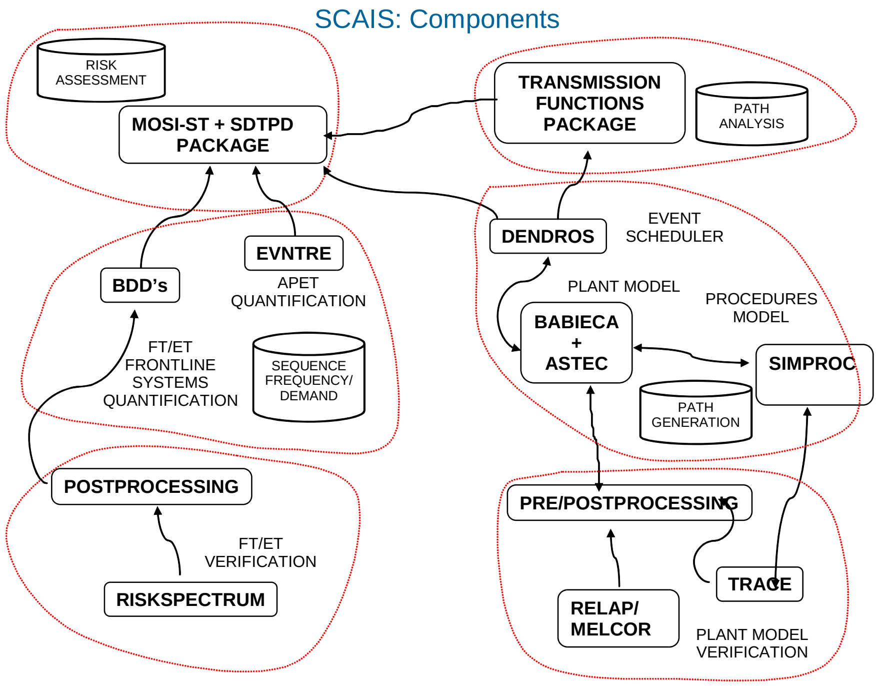

Figure 7: SCAIS components

F. CONCLUSIONS

Good progresses have been obtained in the frame of the SARNET PSA2 activities in accordance with the initial objectives.

A general comparison of the SARNET partners’ methods was performed in the first period of activity and in parallel, states of the art on dynamic reliability methods, on uncertainty and sensitivity methods in support of PSA level 2 were established.

As part of more recent activities, a status of practices and guidelines in the EC has been established and this status gives interesting views on “how to achieve harmonization” on level 2 PSA methods. In parallel, feasibility study of harmonization of some level 2 PSA issues (all concerning physical phenomena) has been undertaken and has lead to propose recommendations of harmonized methods to take into account in a level 2 PSA hydrogen distribution and combustion and immediate consequences of vessel breach. Activities on harmonization aspects are being pursued and include:

- The finalization of the work on harmonized methods to take into account melt corium and concrete interaction and to assess iodine releases,
- The definition of principles of harmonization of the methods to take into account the different physical phenomena,
- A short synthesis describing existing guidelines for level 2 PSA development,
- The proposal of harmonized definition of large early releases and of reactor stable states, for level 1 / level 2 PSA interface,
- A synthesis concerning the use of expert judgments by the different partners as regards the state of the art of methods of expert judgment,
- A global synthesis of the work performed on harmonization aspects. Furthermore, several SARNET PSA2 partners expect to continue this activity in the frame on FP7.

Besides harmonization aspects, the comparison of probabilistic software and the identification and characterization of software to apply uncertainty and sensitivity analysis methods in support to level 2 PSA give to the partners good technical elements of choice.

Another important aspect of the activities concerns the development and use of dynamic reliability methods where good progress was obtained in the SDTPD development and definition and achievement of a benchmark exercise to compare dynamic reliability methods with classical ones.

Besides activities on harmonization aspects, future activities will concern:

- Establishing, in close relationship with ASTEC Work Packages, requirements for ASTEC use in a level 2 PSA,
- Investigations on the possibility of ASTEC coupling with probabilistic codes, in a perspective of a future step of the benchmark exercise using ASTEC and of practical and systematic ASTEC applications for level 2 PSA,
- The description of methods to take into account cliff edge effects,
- The specification of a third step of the benchmark exercise to introduce the separation of epistemic and stochastic uncertainties (to be quantified separately), delays in human actions achievements, a better modelling of steam condensation and the achievement of this third step of the benchmark. A final conclusion of the benchmark will be established and will propose perspectives on dynamic reliability methods practical use,
- the continuation of the development of the platform including the development of the SDTPD method.

G. REFERENCES

[1]. B. Chaumont et al. Overview of SARNET progress on PSA2 topic. ERMSAR 2005 seminar 14 to 16 November 2005 Aix-en Provence

[2]. J. Eyink, H. Löffler. Comparison of the partners’ approaches for physical phenomena assessment in level 2 PSA. ERMSAR 2005 seminar 14 to 16 November 2005 Aix-en Provence

[3]. P.E. Labeau. Accident sequences simulation methods based on dynamic reliability concepts. ERMSAR 2005 seminar 14 to 16 November 2005 Aix-en Provence

[4]. N. Devictor, R. Bolado. Uncertainty and sensitivity methods in support of PSA level 2. CSNI workshop 7 to 9 November 2005 Aix en provence

[5]. ML Ang, E. Grindon, B. Chaumont, H. Löffler. Harmonization of level 2 PSA issues: feasibility study based on hydrogen combustion, consequences of vessel failure, iodine chemistry and MCCI. To be presented during the ERMSAR 2007 seminar Karlsruhe

[6]. E. Raimond and T. Durin. Comparison between classical and dynamic reliability approaches. Specification and results of a benchmark exercise. To be presented during the ERMSAR 2007 seminar Karlsruhe