Severe Accident Codes for L2 PSA (ASTEC Requirements)

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Abstract

In the frame of the L2 PSA SARNET workpackage, a comparison of the L2 PSAs performed by the Partners has been achieved. Different severe accident codes were used for the support calculations of these L2 PSAs. During the SARNET work, it was found that the present severe accident codes capabilities are not yet sufficient for all L2 PSA purposes. A broadly accepted code by the European stakeholders is needed to facilitate the harmonization of the methodologies applied for assessing risk and improving L2 PSAs. One objective for ASTEC is to become the European code for the integration of the current research in severe accidents, and a reference tool for safety and risk assessment in severe accident conditions.

In that context, a questionnaire was prepared to overview the L2 PSAs specialists' opinion about severe accident code capabilities. The goal of this work is to identify some requirements for a generally accepted tool by L2 PSA developers. This paper summarizes these requirements and compares them with the present status of ASTEC code.

Background

The goal of the Level 2 PSA group in the SARNET project was to describe, compare the L2 PSA methods used by the partners, and then to identify some possibilities for harmonization.

One of the most important parts of the L2 PSA methodology is the assessment of the accident progression and phenomena by computer codes. The computer codes needed to perform a L2 PSA include the codes related to the severe accident phenomenology (codes which model individual phenomena as well as the integrated codes), the structural analyses codes and the probabilistic codes for quantifying the events trees used to model the progression of the severe accident.

The participants in the SARNET project used different methods in their L2 PSA applied to different nuclear power plants. Different types of plants and L2 PSA methods may result in the use of different computer tools. To overview the different needs towards the integrated severe accident codes a questionnaire [1] has been established.

The aim of this questionnaire is to collect the user's need against integrated severe accident codes based on their present experience of L2 PSA calculations. The different needs are then identified and prioritized to help the ASTEC developers in their effort to improve the code for fitting the different purposes of L2 PSA.

The questionnaire has two major parts, one evaluating the present status and quality of the used codes, the other setting the priorities assigned to the features of the codes. It has to be mentioned here that where numerical rankings have been assigned by the users, the results are subjective and unmoderated.

The questionnaire was filled by the SARNET PSA 2 participants, AREVA GmbH, GRS, IRSN, UJV, Relcon & Vattenfall, and VEIKI. These participants performed L2 PSA for different type of reactors (PWR, BWR, VVER and EPR) as it can be seen in Table 1.

This paper presents the answers of the participants and the summary and conclusions are given.

User	PWR Reactor	Main Code	BWR Reactor	Main Code
AREVA GmbH	EPR Konvoj	MAAP MELCOR ongoing	German BWR	MELCOR ongoing
GRS	Konvoj	MELCOR 1.8.4	BL 69	MELCOR 1.8.5
IRSN	PWR-900 PWR-1300	ASTEC V0 ASTEC V1 ongoing		
Relcon & Vattenfall	Westinghouse 3 loop	MAAP	ASEA-ATOM	MAAP
UJV	VVER-440 VVER-1000	MELCOR MELCOR		
VEIKI	VVER-440	MAAP4/VVER	-	-

Table 1 - Codes used for L2 PSAs

Codes

The codes that model the phenomena of severe accidents can be divided into different groups according to their capabilities:

- Detailed, mechanistic codes:
  - Computational Fluid Dynamics (CFD) and field codes (e.g. CFX, GASFLOW, TONUS, MC3D) to model special phenomena in detail using 3D models
  - Lumped-parameter thermal-hydraulics codes with the availability of 2D or 3D models (ATHLET, CATHARE, RELAP, GOTHIC) to model a part of the severe accident phenomena with as much detail as possible
  - Lumped-parameter codes (CONTAIN, VICTORIA, COCOSYS, TRAP-MELT) to calculate a part of a severe accident on the basis of phenomenology

- Integrated codes:
  - these codes allow the calculation of accident sequences from the initiator event then taking into consideration most of the severe accident issues (Reactor Cooling System (RCS) and containment thermal-hydraulics, in-vessel core degradation, MCCI, fission product release from the fuel and transport to the environment). The physical models are elaborated with the objective of "acceptable" CPU costs (e.g. STCP, THALES, MAAP, MELCOR, ASTEC),

First a general comment on severe accident codes for L2 PSA was asked by commenting two general statements from the 1995 IAEA [2] definition of the PSA codes[1]: "the PSA codes, intended for routine application in PSA, are designed to run fast, so that they can calculate many sequences (and a number of times for a single sequence, if uncertainty analyses are required). In order to achieve these shorter run times, the modelling has to be simpler than in mechanistic codes."

Generally the participants agree with this statement, because PSA codes are intended to be used in order to have a quick overview of the whole accidental sequence, but there is no integral code existing which was developed only to serve for PSA needs. However, it should not be forgotten that for some specific phenomena occurring during a severe accident, simplified modelling is very unsatisfactory or very complicated to be used (large number of parameters difficult to fit) and of a much reduced validity. In this case it would be preferable to make use of a detailed mechanistic approach. Depending on the computing resources these mechanistic codes could be integrated in a PSA code or used as stand-alone. Some participants mention also that with the same integrated code, the modelling level of details of the modelling can be different and may conduct to very different time of calculations. A level 2 PSA can be performed with a limited number of detailed calculations or a large number of more simplified calculations depending on the L2 PSA method.

For the performed L2 PSAs, the participants have mainly used the MELCOR and MAAP codes. Only IRSN used the ASTEC code (version 0.4 for the 900 MWe PWR, version 1.3 for the 1300 MW PWRs).

The ASTEC code is the European severe accident integral code under development by IRSN and GRS. Its models are becoming more and more mechanistic with the successive versions (more true in the new series V2 of versions). Operational versions are available and have received large effort in terms of development and validation. The recent ongoing and future developments give the opportunity to make ASTEC a widely accepted tool for L2 PSA.

In the next chapters the available partners' experiences are summarized to determine the need against a code for L2 PSA.

Systems modelling

In the questionnaire, the type of the model, the difficulty of use and quality of results were asked for each system. All types of systems were listed in the questionnaire, from the often used general systems (containment, hydroaccumulator, pressurizer, main circulating pipe etc) to the special severe accident mitigation systems such as filtered vent, hydrogen recombiner, igniter etc.

The characteristics of these models are diverse, depending on the severe accident code (Table 2). The two main integral severe accident codes that are generally used for L2 PSAs, MELCOR and MAAP, are able to model all type of systems in a nuclear power plant. The system models in the MAAP code are generally plant-specific, very simple and parametric. In the MELCOR code, it may be not so evident because the user determines the nodalisation for some systems.

[1] « PSA codes » means here « integrated severe accident codes »

Systems and Severe accident phenomenon in the containment	ASTEC	MAAP or MELCOR
Hydrogen recombiner	Simplified or detailed (2 models)	Simplified physical
Hydrogen igniter	Not used/User function	Parametric
Gas (CO_2 or steam) injection	Available, not used	Assumption
Ice condenser	Not used	Simplified physical
Bubbler condenser	Available, not used	Parametric
Heat exchanger	User function	Simplified physical
Check valve	Simplified physical	Simplified physical
Spray system	Simplified Physical	Simplified physical
Fan cooling system	Not used	Parametric
Main Circulating Pump	Detailed physical	Parametric pump model
Feedwater pumps	Parametric	Parametric pump model
Makeup	Parametric control function	Parametric control function
Emergency core cooling system	Parametric control function	Parametric control function
Pumps (general)	Detailed physical	Parametric pump model
Hydro-accumulator	Detailed physical	Detailed physical-parametric
Pressurizer	Detailed physical	Detailed physical-parametric
Vessel rupture	Detailed physical	Parametric/ Simplified physical
Steam generator	Detailed physical	Parametric/ Simplified physical
Heat exchanger	User function	Parametric
Turbine	Parametric	Input
Pressurizer relief valve	Parametric	Parametric
Pressurizer safety valve	Parametric	Parametric control function
Steam generator safety valve	Parametric	Parametric
Valves (general)	Parametric	Parametric control function
Rupture disk	Parametric	Parametric
Pipes (general)	Detailed physical	Modelled by heat structures
Filtered vent system	Detailed physical	Simplified physical
Burnable gas igniter system	Simplified physical	Simplified physical
Passive cont. cooling system (ALWR)	Not used	Simplified physical
Active cont. cooling system	Detailed physical	Simplified physical

Table 2 - Comparison of the modelling of systems

In the questionnaire, the availability, need and type of the model were asked together with its assessment. The users gave slightly different opinions, but it could be caused by the different code versions (MELCOR 1.8.4 or 1.8.5 and MAAP4 or MAAP4/VVER).

Unfortunately ASTEC code was used only for two L2 PSA for the French PWRs. Due to this only a limited number of systems were in use. Specific systems for BWR and VVER type reactors are also available in the code, but these were not checked for Level 2 PSA use. The models of the systems are similar or more detailed and sophisticated in ASTEC code than in MAAP or MELCOR codes. The users agreed that the quality of the system models is largely independent of the complexity of the model.

Phenomena

In L2 PSAs the importance of the severe accident phenomena may depend on the reactor design. For example in case of a dry vessel cavity, the core-concrete interaction is an important phenomenon but the ex-vessel steam explosion is not. The main phenomena were collected in the questionnaire for different PWRs and BWRs. The importance of each phenomenon and the users opinion about the present quality of the model were asked.

It was found that most of the phenomena were modelled by simple physical or parametric models in the examined severe accident codes (MELCOR, MAAP and ASTEC). The answers pointed out that preparation of an input was straightforward for an experienced user. The codes went through a formal validation process which determined suggested parameter ranges and models. The calculation results seemed to be physically acceptable.

The primary system models were verified against detailed physical models of the most widely used system analysis codes (ATHLET or RELAP or CATHARE). According to the code to code comparison, the severe accident codes gave good results for the thermal – hydraulic prediction of the primary circuit. The containment thermal-hydraulic models of ASTEC, MAAP and MELCOR seemed to be good due to the validation of these codes.

Generally the users were satisfied with the severe accident code performance. The simple physical or parametric models in the codes give the proper results for Level 2 PSA.

There were some exceptions where the results of the codes were questionable or there were no models available. In these cases other more detailed codes or assumptions were used to determine the effect of the:

- hydrogen production, core melt and relocation
- hydrogen distribution, burn
- HPME, DCH
- MCCI
- in-vessel and ex-vessel steam explosion.

There was a question about the priority of severe accident phenomena. The participants were agreed in the importance of the phenomena. The responses were marked from 1 to 10.

There are only 2 topics were the standard deviations of the answers were large, around 3, for the others it is around 1. Where the standard deviation is large (energetic phenomena accompanying vessel failure and containment failure due to overpressure or overtemperature) the priority of these topics is around 5, while the priority value of the other topics is higher than 8 (Figure 1)

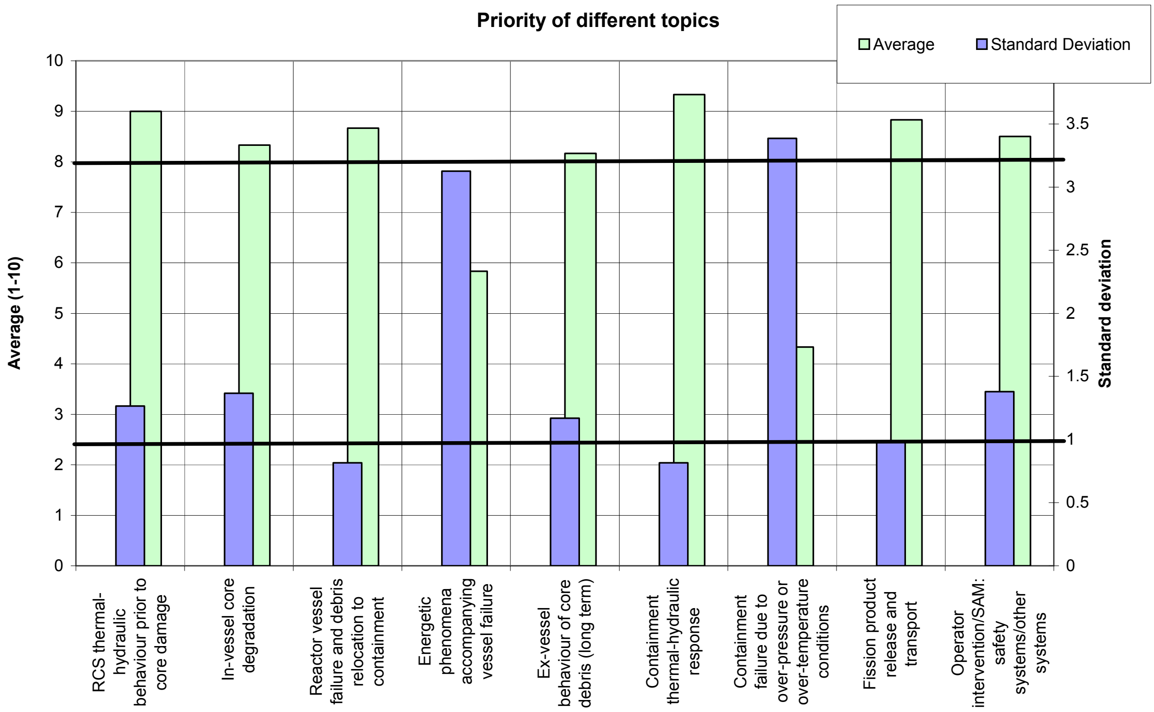

Figure 1 – Ranking of the importance of the calculation of phenomena and their standard deviation

It can be stated that a severe accident analysis code can be used for L2 PSA together with other codes which calculates the energetic fast phenomena and the structural response of the containment. It is not necessary to use only one severe accident code for all phenomena for Level 2 PSA. Some of the users would like it, but it is not a general demand.

A suitable code for Level 2 PSA deterministic calculation must predict the fission product release and transport from the fuel to the environment and thermal-hydraulics for this process.

In Table 3, the different code qualities are shown for the important topics. It should be mentioned here that the quality ranking of the models is subjective and user-dependent because there are no objective values for it. It seems that the ASTEC users (for the questionnaire) are more rigorous than the other users. The users marked the quality of the models between 1 and 5.

The ASTEC code can calculate the important topics but the quality of the used ASTEC versions (0 and 1) seems slightly weaker than MELCOR or MAAP according to the L2 PSA specialists for some topics like RCS thermal hydraulics. This result is probably not significant due to the subjective effect of notation. Only detailed benchmarking could allow robust conclusions. One has to consider the efforts of validation on ASTEC V1.3 for thermal hydraulics, either on the BETHSY integral experiments (CEA) or by comparison with CATHARE code results.

	Quality of the models		
	ASTEC	MAAP	MELCOR
RCS thermal-hydraulic behaviour prior to core damage	3	3,3	4,5
In-vessel core degradation	3	3,16	3,25
Reactor vessel failure and debris relocation to containment	2	2,5	2,75
Energetic phenomena accompanying vessel failure	-	2,3	2
Ex-vessel behaviour of core debris (long term)	4	3,3	3
Containment thermal-hydraulic response	4	4	4,5
Containment failure due to over-pressure or over-temperature conditions	3	3	3
Fission product release and transport	3	3	1,5
Operator intervention/SAM: safety systems/other systems	4	4	4

Table 3 – Quality of the calculation of phenomena (average of user responses)

There are one special comment of the need of further development for ASTEC code: the ASTEC V1 models are not able to calculate in a suitable way the physical processes after the vessel failure of EPR (corium slumps and also DCH). Relevant models are expected in the version V2.

General code performance

The other features of a severe accident code can be sometimes more important than the physical models. In the questionnaire these general characteristics were asked: first the importance, then the quality of the attributes. The importance is marked from 1 to 10 and the answers were put in a diagram (Figure 2) with their standard deviation.

It is interesting to see that, when a feature is crucial, the average value is higher than 8 and the standard deviation is small. All participants agree in the importance of these features:

- input structure,
- plot possibilities,
- stable running,
- support to users from developers
- possibility of SAMG modelling and
- documentation (input and physical description – user's manual) of the code.

There is also an agreement that the print possibilities and availability of different models for a phenomenon are not seen as essential for Level 2 PSA applications.

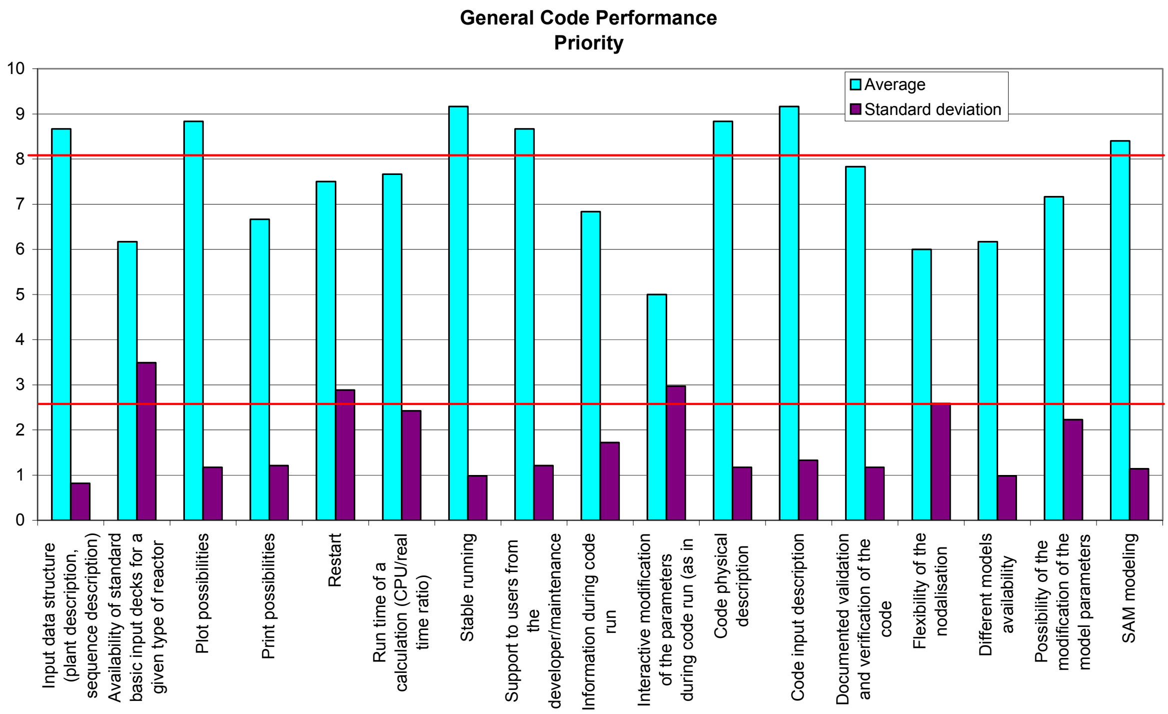

Figure 2 - Importance of the code characteristics

In the questionnaire not only the priority but the quality of the characteristics was asked.

In Table 4 the list of important features were given in priority order, together with users' opinion about their quality in ASTEC, MAAP and MELCOR codes.

	ASTEC	MAAP	MELCOR
stable running	4	3	3,5
code input description	3	4	5
code physical description	3	3	4,5
plot possibilities	4	3,3	4
input data structure	4	4	4
support to users from development/maintenance team	5	2,6	4,5
SAM modelling	5	4,5	5

Table 4 – Quality of the code characteristics (marked from 1 to 5)

Most of the L2 PSA developers intend to make a full "non-stop" code calculation for each severe accident sequence. The MAAP, MELCOR and ASTEC V1.3 code description and code structure supported the full severe accident calculations. The ASTEC V1.3 code description and structure have been improved for this type of calculations.

L2 PSA needs sensitivity and uncertainty analyses. For this reason, the separate physical processes should be calculated. This type of calculation is very easy with the ASTEC code because of its really modular structure.

Conclusion

Since 2004 substantial progress has been achieved to improve ASTEC both in modelling of important phenomena and in particular with view to calculation time for coupled calculations and code stability, the latter being one of the major drawbacks at that time.

Overviewing the answers of the L2 PSA specialists, it is turned out that the ASTEC code characteristics tend to be similar than the other integral codes (MAAP, MELCOR) used for L2 PSA supporting analyses. The models of the ASTEC code are able to simulate most of the phenomena that occur during a severe accident in a light water reactor. Some remaining needs for model modifications have been identified :

- modelling the physical process after vessel failure for EPR (it could be extended to all reactor cavity),
- the possibility to calculate the severe accident in the case of shutdown state.

The code modular structure, through which the user can choose which modules to activate or not, is perfectly suited for L2 PSA and its uncertainty or sensitivity studies. The code performances are generally good, better or equivalent than the other codes. It was found also that

- code input description
- code physical description

should be improved.

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