Overview of ASTEC topic after 19 months

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SUMMARY

In the Work-Package "Users' Support, Training, Integration and Adaptation", 2 code versions were released by IRSN-GRS to 29 organisations: ASTEC V1.1 in June 04 and V1.2 in July 05. A Users' training course and a Users' club were organized. Discussions between users and the maintenance team were active and fruitful. Some partners prepared specifications of model adaptations to VVER, CANDU, BWR and RBMK. Preliminary links with other SARNET Topics such as recommendations of new models were identified. In the Work-Package "Physical Model Assessment", applications to 20 experiments were performed, covering most physical phenomena (except core reflooding). Integral applications were done on the TMI2 accident and on Phébus FPT experiments. Most results were satisfactory. In the Work-Package "Reactor Application and Benchmarking", benchmarks on 15 different scenarios were performed with integral codes such as MAAP4 and MELCOR or detailed codes. They concerned PWR900, Konvoi 1300, Westinghouse 1000, VVER-440/V213 and VVER-1000 reactors. A close and efficient collaboration took place between "Circles" of users on a same reactor type. Despite a lack of robustness of V1.1, most plant applications reached vessel lower head failure. Some results with coupling of fission product modules were also available. The next stage of work will concern the assessment of the ASTEC V1.2 version that benefits from a first stage of numerical consolidation work.

A. INTRODUCTION

The ASTEC Topic, coordinated by IRSN, is composed of 3 different Work-Packages:

- USTIA (Users Support, Training, Integration and Adaptation): IRSN-GRS delivery and maintenance of versions, users' training and support, model specifications and developments by partner, in particular for extension to VVER, BWR, CANDU, RBMK,
- PHYMA (PHYsical Model Assessment): validation against experiments by partners,
- RAB (Reactor Applications and Benchmarking): benchmarks by partners with other codes on plant applications for PWR900-1300, Konvoi 1300, West.1000, VVER-440, VVER-1000, CANDU, BWR.

Twenty-five partners (out of IRSN and GRS) worked on ASTEC in the 1st 18-months period. Two more have joined the Topic recently: PSI (Swiss) on assessment of aerosol behaviour modelling and RUB (Germany) on validation of the containment models.

B. STATUS OF USTIA WORK-PACKAGE

B.1 ASTEC code progress and perspectives

The latest ASTEC V1.2 version was released by IRSN and GRS in July 05. The main evolutions concern a first step of code numerical consolidation that should allow partners to perform more easily complete plant applications with activation of most or all modules. A limited number of model developments was included in this version, mainly the reflooding of intact or slightly degraded cores, and the evolution of configurations of corium layers in Molten-Corium-Concrete-Interaction (MCCI). Other improvements concern fission product (FP) modules.

New developments or improvements are already under way at IRSN and GRS in the perspective of release of version V1.3 mid-06. Besides continuous feedback of interpretation of experimental programmes on FP models, the main developments concern reflooding of degraded cores and hydrogen combustion in containment for fast turbulent deflagration conditions.

End of 2005, the general objectives and specifications of the next generation of versions ASTEC V2 will be released by IRSN-GRS. They will account for the outcomes of the ASTEC Topic WPs (needs, feedback of use, extension to other reactor types than PWR...), and for the outcomes of the other SARNET Topics.

B.2 Code release and maintenance

The release of versions V1.1 in June 04 (the updated version V1.1 p2 was available in Dec.04 directly through the SARNET Web portal) and then V1.2 in July 05 was done on a CD-ROM containing:

- Code source,
- Executable programs on PC/Linux, PC/Windows,
- Automatic installation procedures on UNIX and PC,
- Users‘ tools,
- Documentation: physical models, users' manuals,
- Delivery test cases: 20 validation cases, 10 plant applications.

The Table below lists the 27 partners of IRSN and GRS.

Table 1: ASTEC Topic partners

ARCS (Austria)	FRA/Paris (France)	JRC-IE (EC)	TUS (Bulgaria)
BUTE (Hungary)	FZK (Germany)	JSI (Slovenia)	UJD (Slovak. Rep.)
CEA (France)	GRS (Germany)	KTH (Sweden)	UJV (Czech rep.)
CIEMAT (Spain)	IKE (Germany)	LEI (Lituania)	VEIKI (Hungary)
DIMNP (Italy)	INR (Romania)	NRG (Netherlands)	VUJE (Slovak. Rep.)
EA (Spain)	INRNE (Bulgaria)	PSI (Swiss)	
EDF (France)	IRSN (France)	RUB (Germany)	
ENEA (Italy)	IVS (Slovak. Rep.)	TRACTEBEL (Belgium)	

A specific tool MARCUS, based on Web and e-mails, was set up by IRSN to make easier the discussions on code anomalies between the users and the IRSN-GRS Maintenance team, and to keep a track of all these discussions. About 100 anomaly cards were fulfilled in 18 months. All partners agree on the high interest of this tool. Besides, Forums of discussion were also used on the Advanced Communication Tool (ACT) of the SARNET portal (see Figure 1 below): questions on user-data, general recommendations, exchange of experience between users. After 1.5 year, this represents 15 subjects and 45 questions/answers.

A 1-week users' training course, mostly devoted to beginning users, was held by IRSN in Aix-en-Provence in June 04, gathering about 40 users. Besides the presentation of the code informatic environment and of the main features of the models, all code inputs were presented and explained. Exercises with increasing complexity were performed on PC computers by each trainee.

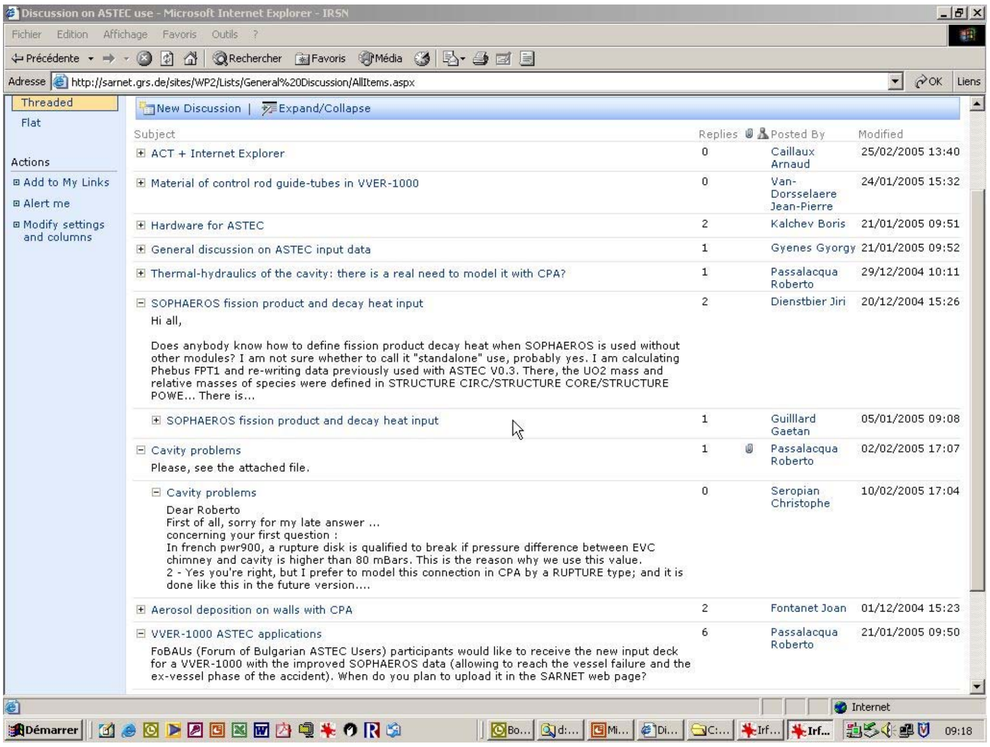

Figure 1: Example of Forum of discussion on ASTEC on SARNET web portal

One year after start of SARNET, the 1st Users' Club was hosted by GRS in Köln from 24 to 27 February 2005. It gathered 45 participants from all 29 organizations and 8 members of the ASTEC IRSN-GRS team. The double objective of this meeting, first to allow direct and fruitful discussions between code users and developers, secondly to get an overview of progress of work, was successfully reached. The 2nd Users' Club will take place in Spring 2006.

B.3 Model developments by partners

CEA is working on improvements of DIVA late-phase models (in close collaboration with IRSN). In particular the modelling of thermal transfers between corium layers in the vessel lower plenum has been improved, in particular allowing to account for thermodynamic equilibrium. Good progress being reached, these improvements will be part of the next ASTEC V1.3 version. Validation will be done in 2006 on the late phase of TMI2 accident and on SIMECO (KTH) experiments. Some exploratory work is also done by CEA on vessel external cooling.

UJV proposed specifications of different hydro-accumulator (HA) models. Following these specifications, IRSN included in V1.2 an isothermal model (like the one present in MAAP4) as option to ASTEC adiabatic one in order to get better results on scenarios with slow injection.

B.4 Specifications of model adaptations/extensions to simulate other NPPs

As a first step, reports have been written on identification of specificities of different reactor types with respect to PWR (geometry, materials, phenomena, safety systems…):

- VVER-1000 by INRNE, with review by UJV.
- VVER-440 by TUS-EI, with completion by VUJE for V213 reactor type.
- CANDU by INR. The main differences concern the core geometry: D_2O coolant, horizontal pressure tubes, twice fluid passage through the core, very large quantity of water in core, no fuel melting but sagging of fuel bundles. Applicable codes are SCDAP/RELAP5 (used in INR) and MAAP4-CANDU.
- RBMK by LEI. The main differences concern the core geometry with each fuel channel being considered as a kind of reactor pressure vessel in a PWR. The currently used codes are SCDAP/RELAP5 (with an important limitation of simulation of only one fuel channel) and COCOSYS for the containment.

For VVER-440 (for the two types: 213 and 230) and VVER-1000, many calculations with ASTEC have already been performed for several years: thus only model improvements of limited extent are foreseen for these reactor types.

For BWR, KTH proposed a risk-oriented approach, focusing on most important risks, i.e. six main threats for containment integrity, and then performing a backward analysis to identify and rank the highest-priority model adaptations or evolutions. Review of proposals and support of KTH development work will be performed by GRS and to a lesser extent by PSI. Other partners could be involved in that domain in 2006.

The next step in Sept.05 is the identification and ranking of model adaptations. Reports are being delivered for each reactor type. They will be probably updated in 2006, taking into account the feedback of some exploratory code applications.

C. Status of PHYMA Work-Package

More than twenty ASTEC V1.1 applications were performed (see Table 1 below). They involved almost all modules and included VVER-specific experiments.

Table 1 – Validation tasks performed in PHYMA first 18 months

ASTEC module	Phenomena	Partner	Experiment
CESAR	RCS t/h (VVER)	IVS	PACTEL T2.1
		BUTE	PMK2
DIVA	Core degradation	IKE	CORA13 *(ISP31)* Phébus FPT4
	Core degradation (VVER)	INR	CORA-W2
	Core reflooding	FZK	QUENCH-06 *(ISP45),* 08, 11
ELSA	FP release	JRC	Phébus FPT0-FPT1
MEDICIS	MCCI	ARCS	MACE M4
		GRS	MACE M3B, COMET-L1, OECD-CCI2, BETA 5.2
		IRSN	ACE L2, L5, L7
RUPUICUV	DCH	IRSN	CES-SUP2
SOPHAEROS	FP transport in RCS	JRC	Phébus FPT0-FPT1
		UJV	Phébus FPT1
		TUS	COLIMA *(Plinius)*

ASTEC module	Phenomena	Partner	Experiment
CPA	Cont. t/h	IRSN	TOSQAN-MISTRA-ThAI *(ISP47)*
		ENEA	Phébus FPT1
		CIEMAT	Phébus FPT2
		JRC	Phébus FPT0-FPT1
		JSI	KAEVER *(ISP44)*
		LEI	RBMK real transient
SOPHAEROS	FP transport in RCS	JRC	Phébus FPT0-FPT1
		JRC	TUBA , STORM
		TUS	COLIMA *(Plinius)*
All	Integral experiment	INR	Phébus FPT2
		TUS	Phébus FPT1 *(ISP46)* - FPT2

The main conclusions of PHYMA calculations during the first 18 months are the following ones (all obtained with ASTEC V1.1 except PACTEL):

- RCS thermalhydraulics: good ASTEC V1.2 results on PACTEL T2.1 experiment in VVER-440 geometry (see Ref. [2]]); good agreement on the early phase of the PMK2 transient but less good one after hydro-accumulator injection.
- Core degradation: good results on CORA-13 (out of quench phase), Phébus FPT4 (see Figure 2 below) and acceptable results on QUENCH-06.
- FP release and transport in RCS: consistency of trends of sensitivity studies on FPT0 and FPT1 with former interpretation by IRSN. Overestimation of aerosol deposits in STORM and TUBA TT28 turbulent flow tests but comparable to the literature results. Discrepancies for mechanical resuspension STORM test at high carrier gas velocity (same results than with former version ASTEC V1.0).
- MCCI: MEDICIS and WEX good results on experiments with homogeneous real corium melts, using different approaches, in particular on selection of corium freezing temperature. For simulation of experiments with stratified corium, good WEX results on BETA but evidence of remaining modelling uncertainties in WEX and MEDICIS blind applications to COMET-L1. Further experimental results are necessary to progress, in particular on heat flux spatial distribution and on oxide/metal heat flux. Reasonable results on MACE M3B and M4 experiments with water injection (see Figure 3 below).
- Containment thermalhydraulics: good results on several ISP and on Phébus.FP (the latter are consistent with former IRSN interpretation). The first comparison with a real transient in the Accident Localisation System (ALS) of the Ignalina RBMK showed some good results (see Figure 4 below) but also the need of CPA model improvements.
- Phebus.FP integral calculations: they ran correctly until their end and their results confirmed the trends that were observed in former applications (e.g. in ISP46). The effect of core axial meshing is limited. Some results have been improved with respect to ISP46 ones, especially Sn and Mo release and iodine behaviour in containment sump.

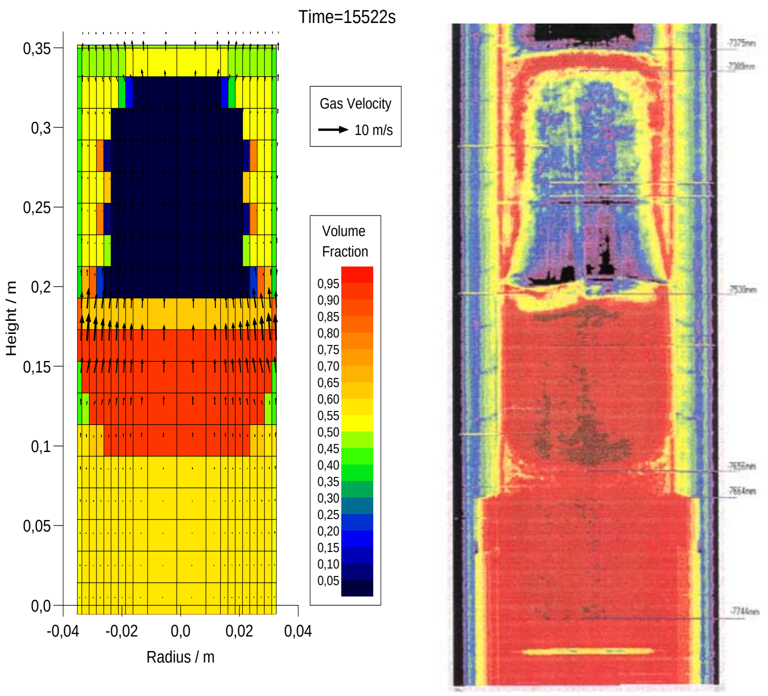

Figure 2: Comparison ASTEC/measurements on the final state of Phébus FPT4 (left: calculated by DIVA; right: post-test radiography)

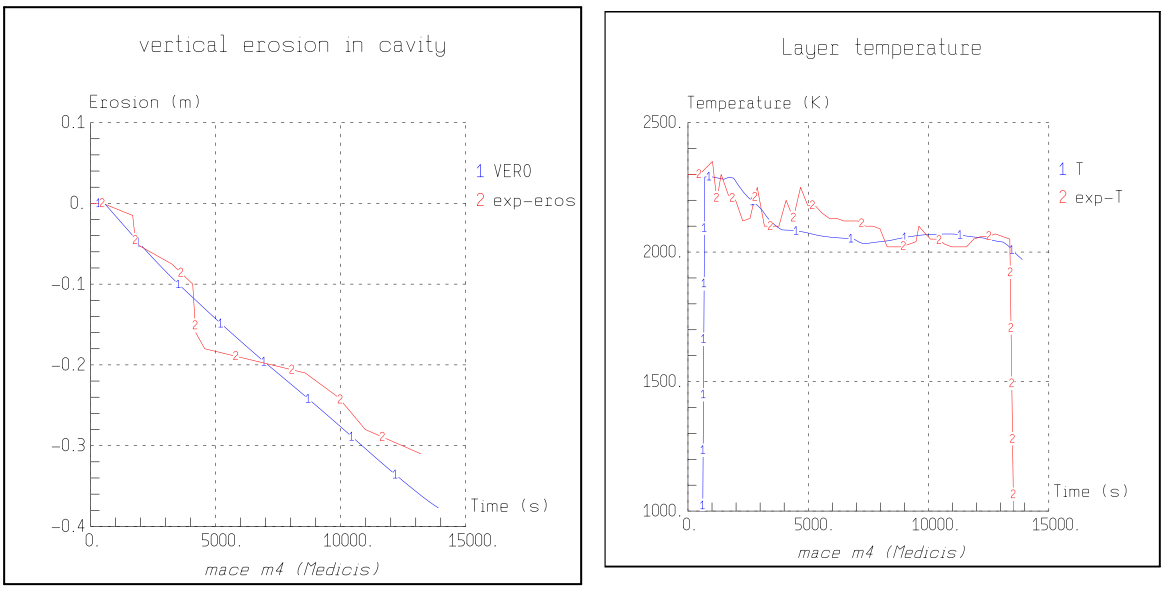

Figure 3: Comparison of MEDICIS results with measurements on the MACE M4 experiment (left: vertical erosion, right: corium temperatures)

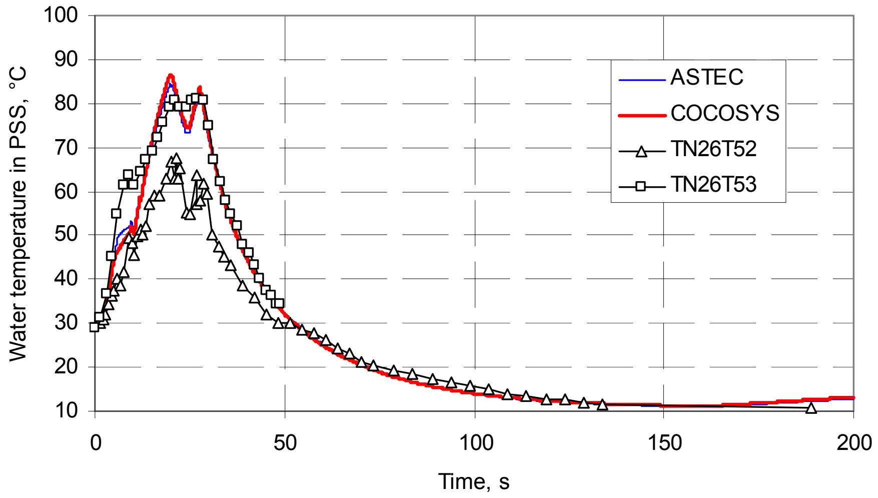

Figure 4: Comparison of calculated and measured water temperature in Ignalina ALS condensing pool

A general validation matrix was built for use during the 2 or 3 next PHYMA years: it is composed of “open” experiments (often ISP-OECD), about 10 per module, and includes VVER-specific phenomena.

Partners recently began to calculate again the same experiments with ASTEC V1.2. The objective is first to check either progress on results or at least non-regression. Then work will be extended to other phenomena, such as core reflooding, or to a deeper analysis of discrepancies with experimental results.

D. Status of RAB Work-Package

Twenty-two ASTEC V1.1 plant applications were performed, including comparison with integral or detailed codes (see Table 2 below). They concerned 5 different reactor types.

Table 2 – Benchmarking tasks performed in RAB first 18 months

Reactor type	Sequence	Partner	Modules	Code for comparison
West.1000	SBO	EA	CESAR-DIVA (In-vessel)	MELCOR
	SBLOCA	TRACTEBEL	CPA (containment)	MELCOR
Konvoi 1300	MBLOCA	GRS	CESAR-DIVA-CPA	MELCOR
		IKE	CESAR-DIVA (In-vessel)	ATHLET-CD
		NRG	CESAR-DIVA-CPA	MAAP4
PWR 900	LFW of SG	IRSN	All	ICARE/CATHARE
		F-ANP SAS	All	MAAP4
		ENEA	All	MELCOR
VVER-1000	LBLOCA	UJV	CESAR-ELSA-DIVA-CPA-SOPHAEROS	MELCOR
	SBLOCA	UPI	CESAR-DIVA-CPA	MELCOR
	SBO	KTH	CESAR-DIVA-CPA	MELCOR

Reactor type	Sequence	Partner	Modules	Code for comparison
	SBO, SBLOCA	INRNE	CESAR-DIVA-CPA	MELCOR
	SBLOCA	TUS (EI)	CESAR-DIVA-CPA	SCDAP/R5
	LBLOCA	UJV	CPA (containment)	MELCOR
VVER-440/213	SBO MBLOCA	VUJE	CESAR-DIVA-CPA All	MAAP4/VVER
	SBO	IVS	CESAR-DIVA-CPA	RELAP5-3D MAAP4/VVER
	SBO	UJD	CESAR-DIVA-CPA	MELCOR
	PRISE	VEIKI	CESAR-DIVA-CPA	MAAP4/VVER
TMI2	Phases 1 and 2	EDF	CESAR-DIVA	MAAP4
		CEA	CESAR-DIVA	-
		ENEA	CESAR-DIVA	ICARE/CATHARE SCDAP/R5

The main conclusions of RAB calculations (all obtained with ASTEC V1.1 except for VVER-440 applications) during the first 18 months are the following ones:

- Westinghouse 1000: the SBO calculation reached normally the time of vessel lower head failure. A CPA calculation of the SBLOCA sequence was performed using MELCOR inputs to the containment: these preliminary results can be considered as correct in terms of time of occurrence and of global thermalhydraulic trends, but differences with MELCOR must be still explained.
- Konvoi 1300: the ASTEC MBLOCA calculation with activation of 4 Low Pressure Safety Injection (LPSI) pumps reached lower head failure (see Figure 5 below).
  - The agreement between MELCOR and ASTEC on timing of main events and trends of containment pressure is acceptable. ASTEC hydrogen in–vessel production is lower than in MELCOR.
  - Some differences appeared with MAAP4 results. They concern mainly the RCS blow-down, the accumulators influence, and the pump characteristics.
- PWR 900: the complete ASTEC V1.1p2 calculation with all modules reached the normal end. First comparison of results was done with MELCOR 1.8.5 and MAAP4 (Ref. [1]), focusing on in-vessel phenomena. Discrepancies come mainly from different core degradation models.
- VVER-1000:
  - Most SBLOCA calculations reached lower head failure (see Figure 6 below), but some showed problems of portability on different computers. ASTEC and MELCOR results seem globally coherent for the in-vessel phase of the accident. But a more detailed analysis showed discrepancies on the influence of hydro-accumulators and on evolution of in-vessel hydrogen as a function of break size.
  - The LBLOCA (in cold leg) calculation could reach vessel bottom head failure only without activating SOPHAEROS (numerical difficulties in back-flows RCS situations). The LBLOCA (in hot leg) calculation ran up to vessel bottom head failure with SOPHAEROS, the agreement with MELCOR results being relatively good during the core heat-up phase and the first phase of core damage. Then, differences were obtained on core degradation (including much lower ASTEC cumulated hydrogen production) due to modelling differences, but leading nevertheless to close vessel failure times. The agreement on volatile FP release from core was good, but less good for non-volatile

ones. SOPHAEROS results were not acceptable because of an inadequate modelling of upper plenum structures, leading to a too large FP deposition. The agreement on containment thermalhydraulic behaviour was relatively good.

- VVER-440/V-213 (see Ref. [2]): the four calculations with stand-alone and/or coupled ASTEC modules showed a good agreement with results of MELCOR 1.8.5, MAAP4/VVER or RELAP5-3D. Note that the MBLOCA calculation ran correctly until its end involving all modules (incl. FP and MCCI ones), which is an important milestone for ASTEC applications to VVER-440. The first try to run a coupled PRISE calculation was not successful.
- TMI2: good results on phases 1-2 (i.e. before core reflooding) (Ref. [1]).
- CANDU: good results of an exploratory SOPHAEROS application on a sequence of rupture of inlet header in the Primary Heat Transport circuit (PHT). Using external inputs on pressure and temperature conditions, SOPHAEROS results can be considered as physically well-grounded (see Figure 7 below). A containment calculation is under preparation.

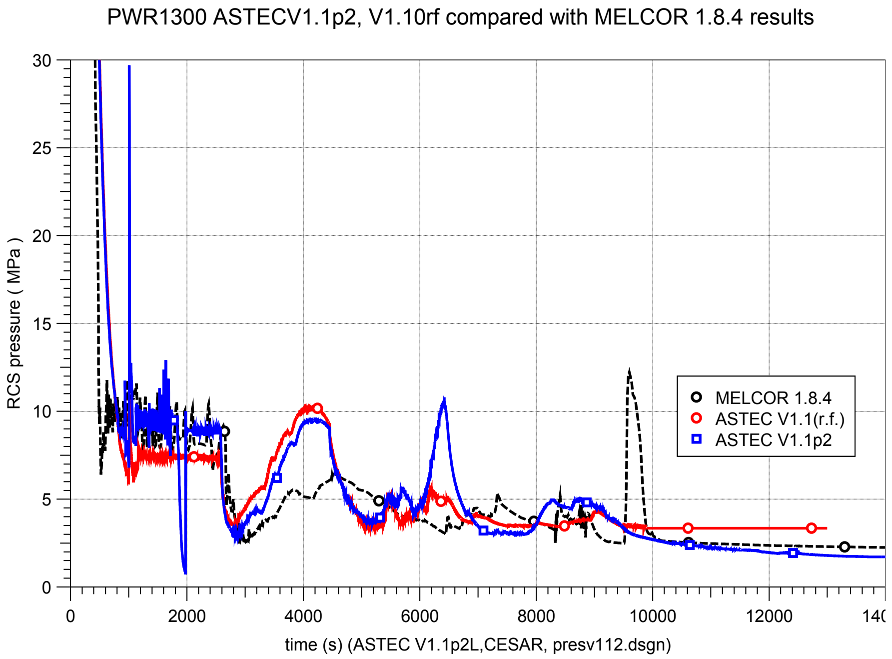

Figure 5: Primary pressure comparison ASTEC-MELCOR on Konvoi 1300 MBLOCA

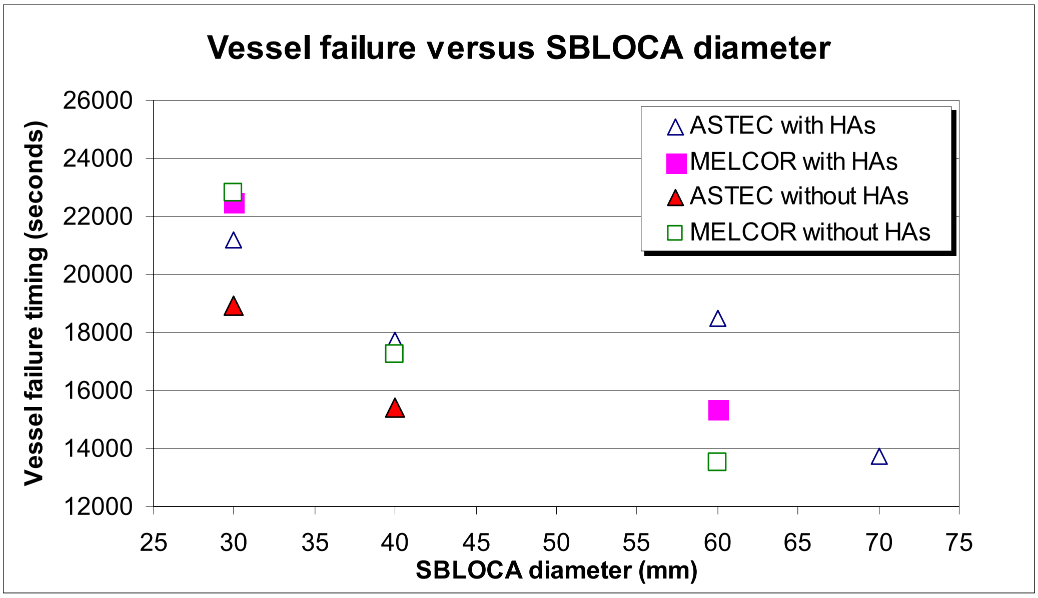

Figure 6: Comparison ASTEC-MELCOR on timing of VVER-1000 vessel failure (SBLOCAs)

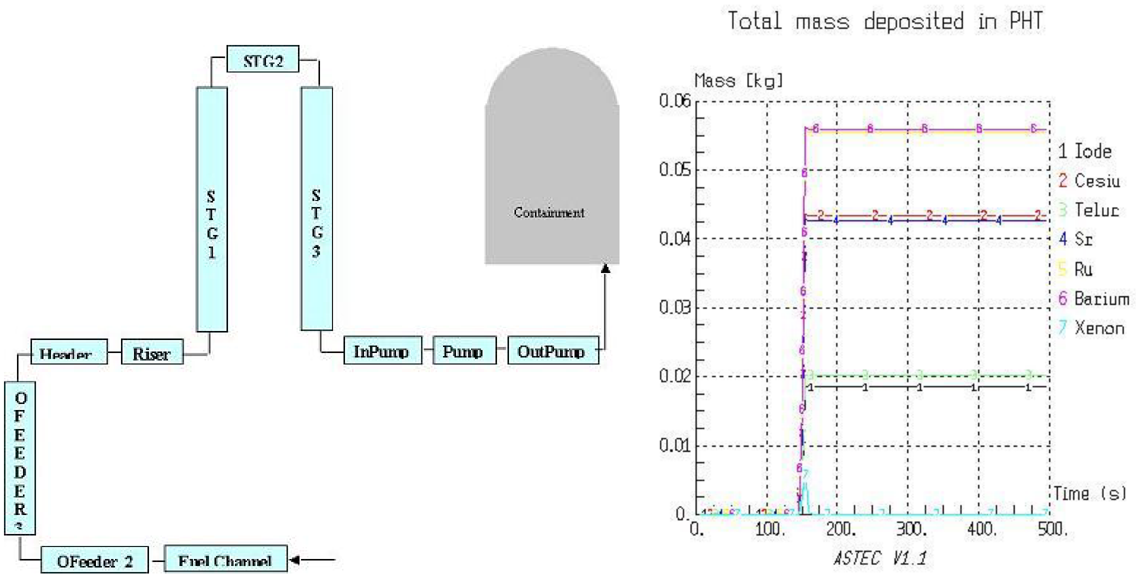

Figure 7: (left) Simplified ¼ CANDU PHT; (right) evolution of FP deposits in PHT

A general matrix of ASTEC plant scenarios was defined for the 5 above reactor types for use during the next RAB 2 or 3 years for benchmarks with other codes. It included diverse Severe Accident Management (SAM) measures such as RCS depressurization, spray systems, containment venting, etc….

Besides the existing FoBAUs (Forum of Bulgarian ASTEC users), a new Group of users was set up: SHAUG or Slovakian-Hungarian ASTEC Users Group. Intensive and frequent discussions took place within these groups. Progress towards reference input decks (1 per reactor type) has been done.

Partners are currently calculating again the same sequences with ASTEC V1.2. The objective is first to check either any progress on results or at least non-regression and to check in details the reliability of the ASTEC input decks. The first recent V1.2 results concern calculations on VVER-1000 and VVER-440 respectively by the FoBAUs and SHAUG users (see Ref.[2] for the latter).

Then, for PWR and VVER, the work will focus, for a limited number of scenarios, on performing complete calculations of sequences, involving most modules until iodine behaviour in containment, and more deeply analysing the benchmarking results. For RBMK, next applications by LEI will concern the simulation of the RCS and core steady-state, before testing exploratory calculations on transients. As to CANDU, INR work will aim at a coupled calculation SOPHAEROS-CPA-IODE.

E. LINK WITH OTHER TOPICS

The ASTEC Topic intensively uses the ACT for news for ASTEC users, Forums of discussion, access to code versions, etc…

A first status of modelling analysis in the 3 Topics Corium, Containment, Source term has been done. It identified the proposals of modelling to be implemented later on into ASTEC with a preliminary time-schedule. These inputs show that most new models will not be ready before 2006.

PSA2 Topic plans to set up in 2006 some tests of advanced dynamic reliability methods using ASTEC as a test bed. The PSA2 members have also defined general requirements for the use of integral codes in PSA2.

F. CONCLUSIONS

After training on ASTEC code use, twenty-nine partner organizations have been working for 18 months on ASTEC V1.1 assessment. Despite a lack of robustness of ASTEC V1.1 code that prevented to multiply sensitivity calculations on plant applications, good progress of work was reached. Positive conclusions can be drawn from validation work, particularly on core degradation and on containment thermalhydraulics phenomena. First benchmarks on plant applications were done either on in-vessel results or on containment ones. Improvements should come from the V1.2 version, released in July 05, that benefits from a first stage of numerical consolidation work.

In 2006 more complete specifications of model extension to BWR, CANDU and RBMK will be defined, along with exploratory plant calculations.

The overall feedback from all participants to the Users’ Club was positive. The 2nd one will take place in Spring 2006. Deeper links with other Topics will be demonstrated in near future. “Circles” of users collaborate closer and closer and exchange of experience and information is gradually increasing: that shows the networking on ASTEC becomes more efficient.

REFERENCES

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[2] Barnak M., Jancovic J., Kostka P., Kubisova L., Matejovic P., Slaby J., Stubnova S., “ASTEC applications to VVER-440/V213 design nuclear power plants", ERMSAR-2005, Session “Code Application and PSA2 methodology”, Aix-en-Provence, 14-16 Nov.05

GLOSSARY

ALS	RBMK containment Accident Localisation System
DCH	Direct Containment Heating
LBLOCA	Large Break Loss of Coolant Accident sequence
LFW	Loss of steam generator Feedwater sequence
LPSI	Low Pressure Safety Injection pumps
MBLOCA	Medium Break Loss of Coolant Accident sequence
MCCI	Molten-Corium-Concrete-Interaction
PRISE	Primary to secondary circuit leak sequence
RCS	Reactor Coolant System
SAM	Severe Accident Management
SBLOCA	Small Break Loss of Coolant Accident sequence
SBO	Station Black-Out sequence
SG	Steam Generator