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## ASTEC and SARNET – integrating severe accident research in Europe

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### **Abstract:**

Considerable efforts are being continuously made by IRSN and GRS on the development of the source-term evaluation code ASTEC, ranging from the initial stage of core uncovering to the final situation of long-term corium stabilization, long-term containment integrity, and fission product retention or release to environment. Between 1999 and 2003, ASTEC has progressively reached a larger European dimension through the VASA and EVITA projects of the European Commission Framework Programme .

The SARNET European Network of Excellence, coordinated by IRSN, has started in April 2004. It will provide an appropriate frame for achieving a sustainable integration of the European research capacities on Severe Accidents. SARNET will clearly become a reference in terms of research priorities in the field of Severe Accidents. Progressively all the research activities in this field will become strongly coordinated by the Network, which will contribute to an optimised use of European resources. Through education and training programmes, SARNET will develop synergies with educational institutions and thus keep attractive the concerned domain of activity for students and young researchers.

In SARNET frame, a substantial effort is being made to disseminate ASTEC and to perform jointly-executed research activities with the ultimate objective of providing physical models for integration into ASTEC and making it the European reference integral code. These activities will focus on key safety issues such as: reflooding of a degraded core and in-vessel corium coolability; molten-corium-concrete interaction, particularly regarding long-term corium coolability; fission product behaviour, especially iodine chemistry in circuits and containment; effects of high burn-up and MOX fuel on core degradation and fission product release. In parallel, the scope of application of the ASTEC code will be extended to reactor types other than PWR, in the short term through a higher number of sequences on VVER, and in the longer term through model adaptation and validation for BWR, CANDU and RBMK..

## **1 INTRODUCTION**

Since several years, IRSN and GRS have been jointly developing a system of calculation codes, so-called “integral” code, ASTEC (Accident Source Term Evaluation Code) to simulate the complete scenario of a hypothetical severe accident in a Light Water Reactor, from the initial event until the possible radiological release of fission products out of the containment. ASTEC has progressively reached a larger European dimension through the VASA [1] and EVITA [2] projects of the European Commission (EC) Framework Programme (FwP).

In 2004, 49 organisations have networked in SARNET [3] (Severe Accident Research Network of Excellence in the 6<sup>th</sup> FwP) their capacities of research in order to resolve the most important remaining uncertainties and safety issues for enhancing, in regard of Severe Accidents (SA), the safety of existing and future Nuclear Power Plants (NPPs). This project

has been defined bearing in mind the necessity to optimise the use of the available means and to constitute sustainable research groups. SARNET will tackle the fragmentation that exists between the different R&D national programmes, notably in defining common research programmes and developing common computer tools and methodologies for safety assessment. ASTEC will play an important role in SARNET as the main integrator of knowledge generated by R&D for most types of NPPs in Europe: models will be developed, validated on experiments, and integrated into ASTEC. This code will thus become the reference European SA integral code.

## **2 ASTEC CODE: CONTEXT AND STATUS**

### **2.1 Context**

ASTEC is being jointly developed by IRSN and GRS to describe the behaviour of a whole severe accident, including the behaviour of engineered safety systems and procedures used in Severe Accident Management (SAM). Its development was based in a first stage (1995-1999) on former codes, respectively at IRSN the ESCADRE system of codes and at GRS the containment codes RALOC and FIPLOC. The version ASTEC V1.0 was released mid-02, and the latest one V1.1 mid-2004.

Its application range covers:

- Evaluation of the possible radiological release out of the containment,
- Accident management studies, concerning the measures of prevention and mitigation of severe accidents,
- PSA2 (Probabilistic Safety Analysis level 2) studies, including the determination of uncertainties,
- Physical analyses of scenarios to improve the understanding of the phenomenology, including support to experimental programs.

It is currently intensively used for IRSN PSA2 on PWR 900 MWe and for the interpretation of Phébus FP experiments.

Beyond SARNET, an intensive international collaboration has been set up with several countries: Russia (Kurchatov Institute, SEC-NRS soon), Canada (AECL under the COG agreement) and India (BARC).

### **2.2 ASTEC in past european projects**

In 1998-2000, the VASA project [1] (Validation Strategy of Severe Accident Codes, 4<sup>th</sup> FwP), coordinated by GRS, focused on analyzing the current approaches in different European countries to validate the SA codes and on reaching a consensus on the procedure to come to a common European validation strategy. One of the conclusions was the recommendation to apply this strategy on specific cases in order to reach the goal of an integral, fast running and also sufficiently reliable European code, capable to solve the risk-oriented issues.

Then, ASTEC has progressively reached a larger European dimension with the EVITA project [2] (5<sup>th</sup> FwP), coordinated by GRS with a strong IRSN support, devoted to code validation by independent users who applied the VASA approach. 19 organisations (researchers, licensing authorities and industry) from 8 countries applied the code to two types of process:

- Validation on high-quality experiments such as International Standard Problems (ISP) of OECD,

- Benchmarks on plant applications on PWR and VVER with activation of safety systems (spray, venting, etc..).

Each case included a comparison with internationally used codes which mostly represent the State of the Art in modelling: detailed codes for validation, integral codes for plant applications.

One of the partners' conclusions was that the level of ASTEC models was near the state of the art in most domains: core degradation early-phase, fission product (FP) transport in the primary circuit, containment thermalhydraulics and aerosol depletion, iodine behaviour in containment liquid and gas phases. In particular, FP modelling accounts for all the outcomes of the Phébus FP experimental program. For instance, the aerosol deposit profile along the Phébus circuit is quite well modelled, although like the majority of codes it underestimates the deposition measured in the vertical section of the hot leg above the bundle and overestimates the deposit in the Steam Generator. This result confirms that the modelling of the competitive condensation of supersaturated vapour phenomena (on a structure, on aerosols or nucleation to form aerosols) is well grounded. Another example is the aerosol concentration decrease in the Phébus containment which is also satisfactorily described with adequate reproduction of the distribution between diffusiophoresis and settling, and diffusive deposition on vertical wall, supposed to be enhanced by local turbulent effect.

Of course understanding and thus adequate modelling was still missing, like in all other codes, in some domains such as reflooding of a degraded core or iodine chemical kinetics in primary circuit, etc..

Obviously partners recommended to continue efforts of validation and plant application.

With respect to computing time, the EVITA users accepted the definition from the VASA project as target, that is one day of accident should not need more than 12 hours of calculation, including post-processing.

Finally, recommendations of improvements were given on two aspects:

- Code user-friendliness: easier management of input decks, post-processing and visualisation of results, users' support including training courses for experienced users too, more complete and detailed code documentation.
- Increase of code numerical robustness for plant applications, particularly the two new modules CESAR-DIVA that calculate the circuit thermal hydraulics and the core degradation.

## 2.3 Main code features

ASTEC models most of the main physical phenomena (except steam explosion). It has a modular structure, each of its modules simulating a reactor zone or a set of physical phenomena (Figure 1):

- *CESAR module* for 2-phase (in the current version, steam and H<sub>2</sub> in gas phase) thermal-hydraulics in the Reactor Cooling System (RCS), using a 5-equation numerical approach with a drift flux correlation for water velocity.
- *DIVA module* for in-vessel core degradation, until melt-through or mechanical failure of vessel lower head. Degradation of control rods (Ag-In-Cd or B<sub>4</sub>C materials) is also modelled. Most models are derived from the the ICARE2 IRSN mechanistic code for core degradation.
- *ELSA module* for release of FP, actinides and structural materials (Ag, In, Cd, Sn, etc) from the core, using a semi-empirical approaches with 3 FP classes (volatile, semi-volatile and non-volatile) for intact fuel rods by only modelling the dominant phenomena for each class. Release from debris beds or from a corium molten pool is modelled.
- *SOPHAEROS module* for aerosol and vapour transport through the RCS via gas flow to the containment. Using twelve families of species and five states (suspended aerosols,

vapour on walls, etc.), the mechanistic or semi-empirical approaches model the main vapour-phase and aerosol phenomena.

- *RUPUICURV module* for DCH (**D**irect **C**ontainment **H**eating), i.e. corium discharge into the cavity after vessel lower head rupture (vessel blowdown, cavity pressurization) and partial entrainment into the containment. The model was adapted to the geometry of annular space cavity as in western european PWR.
- *MEDICIS module* for MCCI with a lumped-parameter approach for corium layers (the *WEX* MCCI module, developed by GRS, is also present as alternative for the user in the latest version ASTEC V1.1). Corium remaining in the cavity interacts with substrate concrete leading to concrete ablation and release of incondensable gases ( $H_2$ ,  $CO$ ,  $CO_2$ ...) into the containment. Water injection upon the corium surface is accounted for.
- *CPA module* for containment thermal hydraulics and aerosol behaviour, based on a “lumped-parameter” approach. CPA describes phenomena such as gas distribution, pressure build up, hydrogen combustion and the behaviour of engineered safety systems such as sprays, as well, as aerosol and FP transport and depletion.
- *IODE module* for iodine behaviour in the containment. This module describes in a kinetic approach the chemical transformations of iodine in aqueous and gas phases, iodine mass transfer between sump and atmosphere and its adsorption/desorption on painted and metal walls.

Data are exchanged between the ASTEC modules through a dynamic memory at macro-time steps, i.e. evolving throughout the calculation (see Figure 1).

To allow a great number of accident scenarios to be studied in a safety analysis, a compromise must be found between modelling detail and calculation time: one day of accident is simulated in a few hours on a PC computer. This need to find the right compromise is a considerable challenge for integral codes such as ASTEC.

## 2.4 ASTEC validation

The ASTEC validation strategy consists in comparison with results of experimental programmes performed in in-pile or out-of-pile facilities, at various scales, and by benchmarks on reactor calculations with other codes. The basic validation matrix aims at covering predominant phenomena occurring in severe accidents and to estimate the model uncertainties. The “minimal “ validation matrix of ASTEC V1 has been defined by IRSN and GRS to be used again at each important code release. It comprises a “minimum” set of about 25 experiments that allows the applications to reactor-cases to be tackled with an acceptable degree of confidence. These experiments are of 3 different types:

- Analytical experiments that address a single phenomenon (separate-effect tests);
- Coupled-effect tests that address a few phenomena;
- Integral experiments (PHEBUS-FP, CORA...) that allow checking of the correct reproduction of coupling between phenomena and the completeness of the modelling with respect to significant phenomena. Moreover, this kind of experiment has often been performed at large scale allowing better extrapolation to reactor scale. In a similar way, the application to the TMI-2 severe accident is an essential exercise.

As far as possible, reference experiments that mostly belong to the list of ISP OECD exercises were selected: PACTEL, CORA-13, VANAM M3.... The ISP 46 (Phébus FPT1) calculation is one example of integral calculations coupling most modules. A continuous effort of interpretation of all the integral Phébus FP tests is also performed with modules focusing on some subset of phenomena, e.g. SOPHAEROS for FP behaviour in the circuit.

Another EUROSAFE paper shows some results of ASTEC validation, performed by VEIKI (Hungary) in EVITA frame, on EREC containment experiments in VVER conditions [4].

Besides the experiments selected in the basic matrix, the extensive validation matrix gathers all experiments that are calculated (or have been calculated with previous code versions). It represents more than one hundred experiments, some of which are not yet “open”.

The conclusions of the latest ASTEC validation campaign are globally satisfactory: the discrepancies obtained with the experimental measurements remain acceptable in most cases. Nevertheless, some phenomena that can significantly influence reactor safety are not yet reproduced with enough precision or fully understood. These scientific challenges, mostly identified in the SARNET project, address mainly:

- Reflooding of degraded cores, with subsequent hydrogen and FP release,
- Late-phase core degradation and in-vessel corium coolability,
- Very high burn-up fuel and MOX fuel behaviour,
- Retention of FP in complex structures such as steam generators,
- Iodine behaviour in RCS,
- MCCI, in particular for the long-term corium coolability.

## **2.5 ASTEC plant applications**

The ASTEC modules are currently being intensively used for IRSN PSA level 2 of 900 MWe French PWRs. A significant number of scenarios that differ in initiating event and in the actuation of safety systems are being analysed. ASTEC V1 is also foreseen to be used in the future PSA level 2 analyses to be performed by IRSN and by GRS.

Furthermore, in the EVITA frame, several benchmarks on plant applications have been performed including comparison with other integral tools such as the MELCOR and MAAP4 codes. These were performed on several reactor types: French PWR 900, German Konvoi 1300, VVER-440/V-213 and V-230, and VVER-1000. These benchmarks are being extended in the SARNET frame.

The following Figures present one example of ASTEC V1 applications that were performed in EVITA:

- Figure 2 presents a standard ASTEC circuit topology used for simulating a French PWR 900.
- Figure 3 shows the comparison of primary pressure between ASTEC V1 and MAAP4 results for a Loss of Steam Generator Feedwater sequence on a French PWR900.

## **3 MAIN FEATURES OF THE SARNET NETWORK**

The SARNET network [3] gathers about 190 researchers and 20 doctoral students from 49 organisations in 18 countries. It started in April 2004 for a period of 4 years. Partners contribute to a “Joint Programme of Activities” (JPA) consisting of 3 types of activities:

- Integrating activities:
  - Implementing an advanced communication tool for fostering exchange of information,
  - Developing ASTEC, which will capitalize in terms of models the knowledge produced within SARNET,
  - Developing Scientific Databases, in which all the results of research programmes will be stored,
  - Developing a common methodology for Probabilistic Safety Assessment (PSA) of NNPs.
- Jointly executed research activities:

- Harmonizing and re-orienting the research programmes, and defining commonly new ones,
- Analysing commonly the experimental results provided by research programmes in order to elaborate a common understanding of concerned phenomena.
- Spreading of excellence activities:
  - Developing educational courses and text (source) books;
  - Promoting personnel mobility between the various European organisations.

In order to preserve the interest of the different organizations, a clear policy in terms of knowledge management, notably regarding access rights, has been defined. One essential outcome of R&D programmes will be models to be implemented in ASTEC and safety assessment methodologies, which will be available for all the SARNET members, or other European organizations for use for safety assessment or improvement of NPPs.

By fostering collaborative work on developing and validating ASTEC, SARNET will make this code as the European reference for any kind of water-cooled NPP existing in Europe. By fostering collaborative work in the domain of code development and PSA, SARNET will create the necessary conditions for harmonizing the approaches and making Europe a leader in SA computer code and risk assessment methodology.

Through a periodic review of priorities and co-programming of work amongst organisations, SARNET will allow a more efficient use of available means and budget. Three main topics of R&D have been defined:

- CORIUM Topic, where the 3 following domains will be studied:
  - Hydrogen generation during core reflooding, B<sub>4</sub>C and fuel burn-up impact on core degradation, and more generally remaining questions on the core degradation early-phase,
  - Coolability of a molten corium pool in the vessel lower plenum, including in-vessel melt retention strategies; vessel integrity and corium release to cavity,
  - Ex-vessel corium behaviour during interaction with concrete or ceramic; corium coolability (molten pool or debris beds).
- CONTAINMENT Topic, where the 3 following domains will be studied:
  - Hydrogen distribution in the containment and combustion/detonation,
  - Fuel-Coolant Interaction,
  - Direct Containment Heating.
- SOURCE TERM Topic, where the 3 following domains will be studied:
  - Evaluation of the fission product source to the containment, either focused on iodine speciation or under air ingress conditions,
  - Aerosol impact on source term: retention in the secondary side of steam generator and leakage through cracks in the containment wall, re-volatilisation in RCS,
  - Iodine behaviour in containment.

Through an education and training programme addressing young scientists, SARNET will consolidate on the long term the European excellence in the SA domain.

As the end-products developed by the Network (ASTEC, PSA guides, scientific databases) may be used not only for R&D activities but also for industrial applications, most of the European Industry and Safety Authorities (or Technical Support Organizations) are contributing to SARNET. In return, the end-products of the Network that will capitalize the large amount of knowledge acquired in this area will contribute to a better prevention and mitigation of SA in European NPPs, including those of Russian design, and thus to the improvement of safety of existing and future European NPPs.

## **4 ASTEC IN SARNET**

26 SARNET partners collaborate on the adaptation, validation and application of ASTEC. IRSN is coordinating the whole ASTEC Topic. The collaborative work is divided in three Work-Packages (WP), coordinated by IRSN and GRS, that are described below.

### **4.1 Users Support and Training, Integration and Adaptation (WP USTIA)**

The objective of these activities is:

- To distribute the code versions, their updates and their documentation to code users, provide a support and training for code users and organize information exchange between code developers and users (Users Club),
- To integrate knowledge issued from SARNET into the code and adapt ASTEC to all types of water-cooled NPPs operated in Europe.

An IRSN-GRS team is responsible for:

- Analysing the requests of ASTEC users and proposing solutions (code adaptation or users recommendations). The MARCUS Maintenance tool has been already set up to make easier the dialogues (Web and automatic e-mails) between users and developers and to increase the maintenance efficiency by keeping the full tracks of all users' requests.
- Delivering the code versions and documentation: the latest version ASTEC V1.1 was delivered on a CD-ROM to all partners during the June Users' training course. This CD-ROM contained the code source, documentation, test cases... The next version V1.2 is under development by IRSN and GRS and will be released in June 2005.
- Organizing periodically Users club meetings to exchange information on the code use and status, and examine users requests and discuss their priority. The 1<sup>st</sup> users' training course was organized by IRSN in Aix-en-Provence in June 2004 and gathered 36 participants from 20 organisations.

The ASTEC Topic kick-off meeting was organized by IRSN in Aix-en-Provence in April 2004 and gathered 32 participants from 21 organisations.

An ASTEC Web site is being developed and maintained within the SARNET Web portal to make easier the exchange of information and documents between the development team and the SARNET users. An e-learning site will be opened and maintained in 2005.

In parallel, specifications of developments requested by ASTEC users to model other NPP types than PWRs will be prepared. For VVER, only small model adaptations seem necessary (INRNE, TUS, UJV, UJD, ARCS are involved) and the main objective will be to extend the number of accident sequences to be calculated. The involved partners will be: GRS and KTH for BWR; INR for CANDU; LEI for RBMK. First reports on the description of the specificities of these NPP with respect to PWR are foreseen in January 05. The next task in 2005 will consist in specifications of model extensions.

As for implementation of new modelling by partners, only CEA is concerned in the first period. Preliminary discussions have began between CEA and IRSN on improvements of the models of corium behaviour in the lower head.

### **4.2 ASTEC physical model assessment (WP PHYMA)**

This activity will consist of comparisons between ASTEC and experimental data. It will provide inputs for the WP above, and for the definition of research priorities in the severe accident domain.

The Table 1 shows the validation matrix that has been defined for the 1<sup>st</sup> period. Five domains are covered: In-vessel phenomena (thermal hydraulic and degradation phenomena); ex-vessel corium (MCCI, corium cooling); containment behaviour; source term; and integral experiments Phébus.FP. Some VVER-specific experiments will be studied: PMK2, PACTEL, COLIMA. Two organizations will focus their efforts on validation on RBMK and CANDU-specific experiments. About a dozen of ASTEC applications have also been proposed on Phébus.FP experiments, including integral applications on the whole experiments. ASTEC results will also be compared to results of detailed codes such as ICARE/CATHARE, ATHLET-CD, SCDAP/RELAP5, COCOSYS, TONUS, CONTAIN...

On the medium and long term, this activity will use as input the new experimental data produced in the frame of SARNET.

For the short and medium term, the work is organized as follows:

- 1<sup>st</sup> year (April 04 – March 05) with two tasks in parallel:
  - Assessment by participants of the ASTEC V1.1 version. This will update and complete the information derived from assessment works performed earlier by GRS and IRSN and in the EVITA frame.
  - Elaboration of a large assessment matrix to be used for the campaign of assessment of the ASTEC V1.2 version.
- Next period (2005-06): Assessment of the version V1.2 following the here above defined assessment matrix. This phase will last 2 years and lead to a complete and detailed assessment of ASTEC V1.2.

For the longer term, the assessment activity will continue following the same scheme:

- Updates and complements taking into account code evolution and new experimental results generated in the frame of SARNET.
- Full revision of the assessment for major code versions (as for V1.2).

The first results of these validation tasks will be presented at the 1<sup>st</sup> ASTEC Users' Club foreseen during the first-year SARNET Progress meetings in Köln in February 05.

### **4.3 ASTEC reactor application and benchmarking (WP RAB)**

The objective is to evaluate and improve the capability of ASTEC to simulate reactor transients, including safety systems and main SAM procedures. This activity will consist of ASTEC reactor applications and benchmarking with other codes. It will provide inputs for the WP USTIA and for the definition of research priority in the severe accident area. The Table 2 shows the plant application matrix that has been defined for the 1<sup>st</sup> period: 5 types of reactors will be analyzed, PWR-900, Westinghouse 1000, Konvoi 1300, VVER-1000, VVER-440/V213. ASTEC will mainly be compared to the integral codes MELCOR and MAAP, but also to some specialized codes such as ICARE/CATHARE, ATHLET-CD, SCDAP/RELAP5...

For the short and medium term, the work is organized as follows:

- 1<sup>st</sup> year (April 04 – March 05) with three tasks in parallel:
  - Assessment by participants to update and complete for ASTEC V1.1 the benchmarking activity performed in the frame of EVITA and COLOSS projects (5<sup>th</sup> FwP). First applications have begun: small groups of users, with a task leader, have been defined, each on a given reactor type, in order to increase exchanges on code use feedbacks within these groups. In parallel, the ASTEC development teams are improving the input decks of the VVER-1000 and VVER-440 calculations from the delivered CD-ROM and making them available on the SARNET site.
  - Elaboration of a large reactor sequence matrix to be used for the benchmarking activity of the version V1.2, in close connection with the task below.

- Elaboration of a first set of ASTEC reference input decks for reactor applications (PWR and VVER). Beyond this task, the set will be periodically updated.
- Next period (2005-06) with reactor calculation and benchmarking activity with the version V1.2. For BWR, CANDU and RBMK will start e analysed in this period. This phase will last 2 years and should lead to a complete and detailed assessment of ASTEC V1.2.

For the longer term, this activity will continue taking into account code evolution and new reactor concepts or SAM procedures.

## 5 PERSPECTIVES ON ASTEC

Following the EVITA outcomes (see §2.2), main efforts focus in 2004-05 on 2 axes of improvement:

- Improvement of code numerical robustness: the review of recent ASTEC plant applications underlined the need to analyse more deeply the origin of code crashes or numerical instabilities, especially on the two modules CESAR and DIVA. These prevent the code user to perform easily sensitivity studies. Thus a plan of consolidation of these 2 modules and of their coupling has been elaborated by IRSN: review and improvement of less reliable models, analysis of portability problems on different computers, use of elementary test-cases... And calculations of variants of main accidental sequences (e.g. by activation of safety systems) will be multiplied. A first outcome of this consolidation work should benefit to the next version V1.2.
- User-friendliness: several tools have been delivered to users (pre-processing of input decks, interactive front-end processor for the TIC post-processing tool) and will be improved according to the users' feedback. A parallel action is under way at GRS: coupling to ASTEC of the GRS visualisation tool ATLAS (Fig.4).

In parallel, some model developments continue, often in relation with the work of preparation or interpretation of experimental programmes, for instance: ARTEMIS (IRSN) and CCI-OECD on MCCI; EPICUR and CHIP (IRSN) on iodine behaviour; ARTIST (PSI) on aerosol retention in SG; TOSQAN (IRSN) and Thal (Becker Technologies) on containment thermalhydraulics and aerosol behaviour.

The next version ASTEC V1.2 should mainly include the following model improvements:

- Reflooding of cores either intact or slightly damaged, i.e. with first flows of corium mixtures (CESAR and DIVA modules),
- Model improvements for release of semi-volatile FP, structural materials & control rods (feedback ISP46) (ELSA module),
- Mass transfer gas-liquid / walls (IODE module),
- Evolution of corium layers configurations ((de-)stratification, flip-flop) (MEDICIS module).

Another longer term action, performed by GRS, concerns the CPA improvement of H<sub>2</sub> combustion model for fast turbulent deflagrations.

In 2005 an important action will begin at IRSN: merging of DIVA module with the ICARE2 IRSN core degradation mechanistic code. This action will allow users of future ASTEC versions to take benefit of the quality of the ICARE2 models. It will be part of the ASTEC V2 family of versions, the specifications of which will be set up end of 2005, also accounting for the feedback of the work performed in the first 18 months of SARNET.

## 6 CONCLUSION

Considerable efforts are being continuously made by IRSN and GRS on the development of the source-term evaluation code ASTEC, ranging from the initial stage of core uncovering to the final situation of long-term corium stabilization, long-term containment integrity, and fission product retention or release to environment. In the frame of the SARNET European Network, a substantial effort is also being made to disseminate ASTEC and to perform jointly-executed, severe accident research activities with the ultimate objective of providing physical models for integration into ASTEC and make the code the European reference integral code. Most ASTEC models are today close to the state of the art but key areas for model improvements have already been identified for the next versions, consistently with SARNET R&D priorities: degraded-core reflooding and in-vessel corium coolability; molten-corium-concrete interaction, particularly regarding long-term corium coolability; fission product behaviour, especially iodine chemistry in circuit (in particular kinetics) and containment, and effects of high burn-up and MOX fuel on core degradation and fission product release. Ongoing validation is also planned, particularly on future IRSN experiments (ARTEMIS, EPICUR, CHIP,...), international experiments (CCI-OECD, ARTIST...) and in near future on German Thal experiments.

Another objective of the SARNET efforts is the extension of the scope of application of the ASTEC code to reactor types other than PWR, in short term through a higher number of sequences in VVER and in longer term to modelling adaptation to BWR, CANDU and RBMK. SARNET will provide an appropriate frame for achieving a sustainable integration of the European research capacities on Severe Accidents. By capitalizing the acquired knowledge in ASTEC and in Scientific Databases, SARNET will produce necessary conditions for preserving the knowledge produced by thousands of man-years and diffusing it to a large number of end-users. SARNET will clearly become a reference, in terms of research priorities in the field of Severe Accidents, having impact on national programmes and fund allocations. Progressively all the research activities in this field will become strongly coordinated by the Network, which will contribute to an optimised use of European resources.

Through education and training programmes, SARNET will develop synergies with educational institutions and thus keep attractive the concerned domain of activity for students and young researchers. This will also contribute to enhance and preserve in a sustainable way the European scientific leadership in the field of Severe Accidents.

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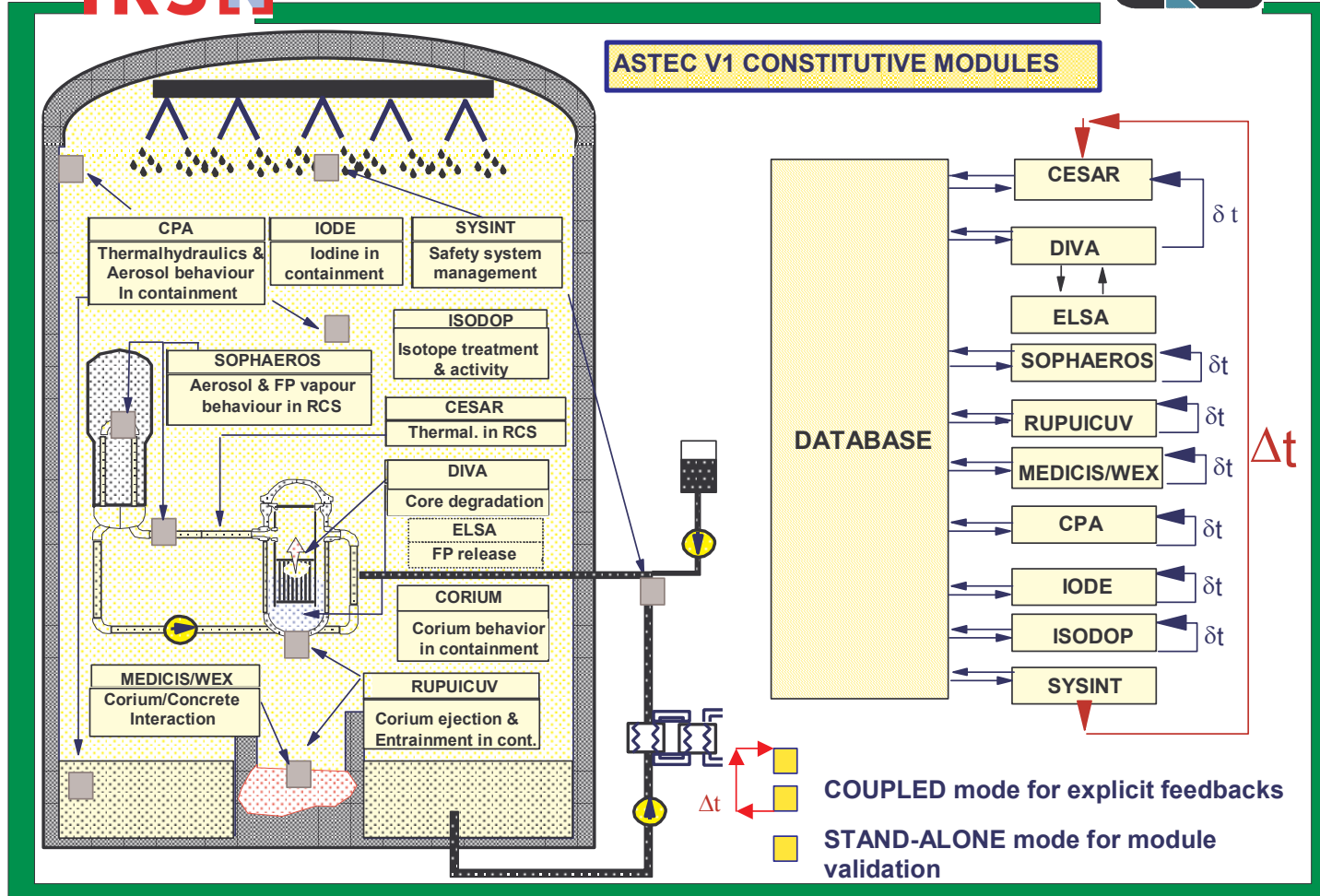


Fig. 1: ASTEC V1 modules and running modes

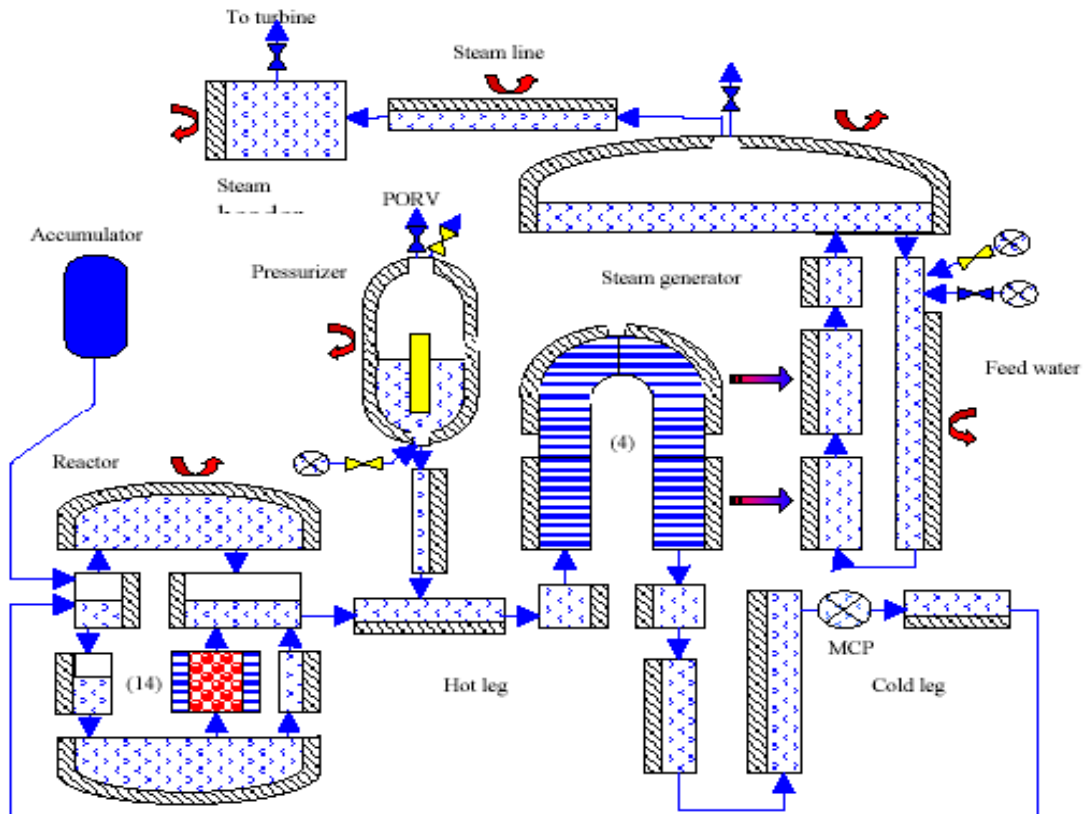


Fig. 2: CESAR-DIVA modelling of the French PWR 900 plant

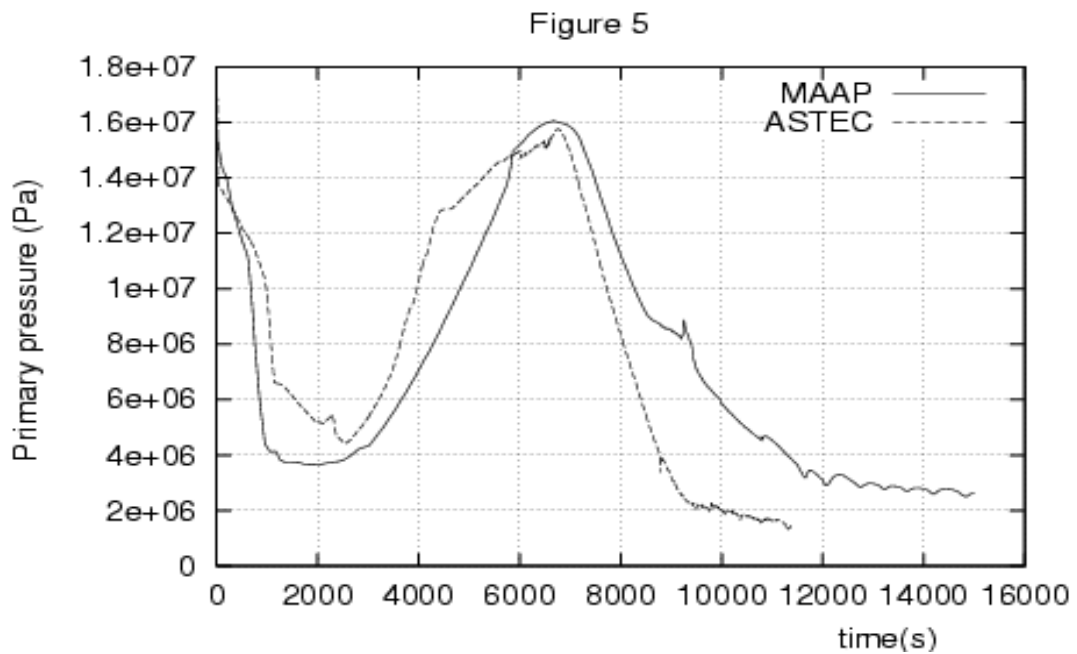


Fig. 3: Comparison of primary pressure between ASTEC V1 and MAA4 calculations of a LFW sequence in a French PWR 900 plant (EVITA project, 5<sup>th</sup> FwP)

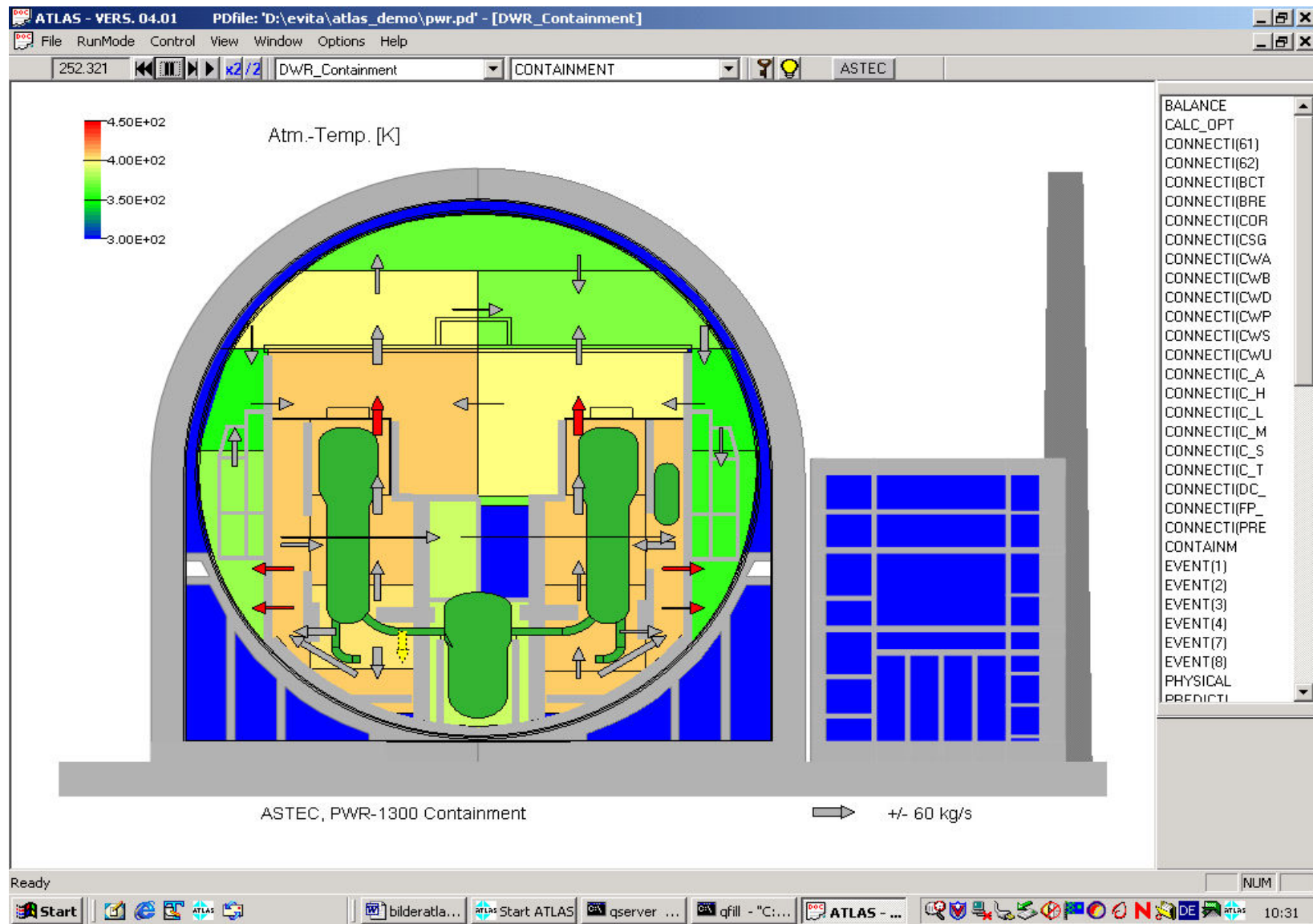


Fig. 4: Example of ATLAS view of results of an ASTEC V1.0 calculation on a Konvoi 1300 MWe

**Table 1: ASTEC V1.1 validation matrix in SARNET 1<sup>st</sup> period**

<b>PARTNER</b>	<b>PHENOMENA</b>	<b>ASTEC MODULE</b>	<b>CODE FOR COMPARISON</b>	<b>EXPERIMENT</b>
<b>ARCS</b>	Molten corium concrete interaction (MCCI)	MEDICIS	COCOSYS-WEX	ACE L4, MACE M4
<b>BUTE</b>	RCS thermalhydraulics in VVER (DBA)	CESAR	-	PMK2
<b>CEA</b>	RCS thermalhydraulics and core degradation	CESAR-DIVA	-	TMI-2
<b>CIEMAT</b>	Thermalhydraulics and iodine in containment	CPA-IODE	-	Phébus FPT2 ( <i>coupled calculation</i> )
<b>EDF</b>	RCS thermalhydraulics and core degradation	CESAR-DIVA	-	TMI-2
<b>ENEA</b>	RCS thermalhydraulics and core degradation	CESAR-DIVA	I/C, S/R5	TMI-2
	Thermalhydraulics and iodine in containment	CPA-IODE	MELCOR	Phébus FPT1 (ISP46) ( <i>coupled calculation</i> )
<b>FZK</b>	H <sub>2</sub> production during core reflooding	DIVA	S/R5	QUENCH-04, 06, 07, 11
<b>GRS</b>	Thermalhydraulics and spray in containment	CPA-THY	COCOSYS	HDR-E11-1
	MCCI	MEDICIS	COCOSYS-WEX	MACE-M3B, 1 LACOMERA exp.
	Iodine in containment	IODE	COCOSYS-AIM	Phébus FPT1 (ISP46) iodine part
	Integral behaviour	ASTEC	Existing calculations	Phébus FPT1 (ISP46) out of iodine part
<b>IKE</b>	Late-phase of PWR core degradation	DIVA	KESS and ATHLET-CD	Phébus FPT4
	Early-phase of PWR core degradation, and H <sub>2</sub> production during core reflooding	DIVA	KESS and ATHLET-CD	CORA 13 (ISP 31) incl. quench phase
<b>INR</b>	Core degradation	CESAR-DIVA	-	Re-calculation of a delivery test-case
	FP transport in RCS for CANDU	SOPHAEROS	-	Exploratory plant application to a CANDU accident sequence
	Integral behaviour	ASTEC	Existing calculations	Phébus FPT2 ( <i>non-regression</i> )
<b>IRSN</b>	H <sub>2</sub> production during core reflooding	DIVA	SCDAP/RELAP5 (FZK), I/C (IRSN)	QUENCH exp. to select
	DCH in “open” cavity geometry	RUPUICUV	-	SNL-SUP1

<b>PARTNER</b>	<b>PHENOMENA</b>	<b>ASTEC MODULE</b>	<b>CODE FOR COMPARISON</b>	<b>EXPERIMENT</b>
	MCCI	MEDICIS	-	ACE L2-5-7
	Thermalhydraulics/aerosol behaviour in containm.	CPA	TONUS	TOSQAN-MISTRA-ThAI (ISP47)
	Integral behaviour	ASTEC	Existing calculations (incl. I/C)	Phébus FPT1 (ISP46)
<b>IVS</b>	RCS thermalhydraulics in VVER	CESAR	RELAP5-3D	PACTEL (SBLOCA exp. from IMPAM-VVER)
<b>JRC-Petten</b>	FP deposition and resuspension in primary circuit	CESAR-SOPHAEROS	-	STORM SD and SR exp. (incl. ISP40)
	Core degradation	DIVA	Overview of other SA code results	Phébus FPT2
	Fission product release	DIVA-ELSA	Overview of other SA code results	Phébus FPT0-1-2
	Thermalhydraulics/aerosols in containment	CPA	Overview of other SA code results	Phébus FPT2
	Integral behaviour	ASTEC	-	Phébus FPT2 ( <i>variants</i> )
	Fission product deposition in RCS	SOPHAEROS	Overview of other SA code results	Phébus FPT1
<b>JSI</b>	Thermalhydraulics/aerosols in containment	CPA	CONTAIN	KAEVER (ISP44)
<b>KTH</b>	Late-phase of PWR core degradation	DIVA	MVITA	FOREVER, SIMECO
<b>LEI</b>	Thermalhydraulics / aerosols in RBMK containment	CPA	COCOSYS	Unintended Single Main Safety Valve Opening transient in Ignalina RBMK
<b>TUS</b>	FP release and transport	DIVA (ELSA)-SOPHAEROS	-	COLIMA (PLINIUS project)
	Thermalhydraulics / aerosols in containment	CPA	-	LACE LA4
	Integral behaviour	ASTEC	Existing calculations	Phébus FPT1 ( <i>non-regression</i> )
<b>UJV</b>	FP transport in RCS	SOPHAEROS	MELCOR 1.8.5	Phébus FPT1-2
	Core degradation	DIVA	ICARE2	Phébus FPT2
<b>UPI</b>	RCS thermalhydraulics and core degradation	CESAR-DIVA	S/R5, MELCOR	TMI-2
	Fission product deposition in RCS	SOPHAEROS	MELCOR, ECART	Phébus FPT1
	Thermalhydraulics in containment	CPA	MELCOR, FLUENT, FUMO	TOSQAN (ISP47)

**Table 2: ASTEC V1.1 benchmarks on plant applications in SARNET 1<sup>st</sup> period**

REACTOR TYPE	PARTNER	SEQUENCE	MODULES	CODE FOR COMPARISON
Westinghouse 1000	<u>EA</u>	SBO	CESAR-DIVA then +CPA	MELCOR
	TRACTEBEL	SBO, SBLOCA	CESAR-DIVA then +CPA	MELCOR
Konvoi 1300	<u>GRS</u>	MBLOCA	CESAR-DIVA-CPA	MELCOR
	IKE	MBLOCA (I/V only)	CESAR-DIVA-CPA	ATHLET-CD
	NRG	MBLOCA	CESAR-DIVA-CPA	MAAP4
PWR 900	<u>IRSN</u>	SBLOCA	All (incl. MEDICIS)	ICARE/CATHARE
	F-ANP/SAS	SBO	All (incl. MEDICIS)	MAAP4
	ENEA	SBO	All (incl. MEDICIS)	MELCOR 1.8.5
VVER-1000	<u>UJV</u>	LBLOCA (incl. FP)	CESAR-ELSA-DIVA-CPA-SOPHAEROS	MELCOR 1.8.5
	UJV	LBLOCA (cont. only)	CPA	MELCOR 1.8.5
	UPI	SBO (I/V only)	CESAR-DIVA	MELCOR, S/R5
	KTH	SBO	CESAR-DIVA-CPA	MELCOR
	INRNE	SBO, SBLOCA	CESAR-DIVA-CPA	MELCOR
	TUS	SBLOCA	CESAR-DIVA-CPA	SCDAP/RELAP5
VVER-440/213	VUJE	SBO	CESAR-DIVA-CPA	MAAP4/VVER
	IVS	SBO	CESAR-DIVA-CPA	MAAP4/VVER
	UJD	SBO	CESAR-DIVA-CPA	MELCOR
	VEIKI	PRISE	CESAR-DIVA-CPA	MELCOR

*J.P. Van Dorsselaere (IRSN), H.J. Allelein (GRS)*



## ASTEC and SARNET

# Integrating Severe Accident Research in Europe

# Contents

- ✓ ASTEC code
- ✓ ASTEC in past European projects
- ✓ SARNET Network of Excellence on SA
- ✓ ASTEC in SARNET
- ✓ ASTEC perspectives
- ✓ Conclusions

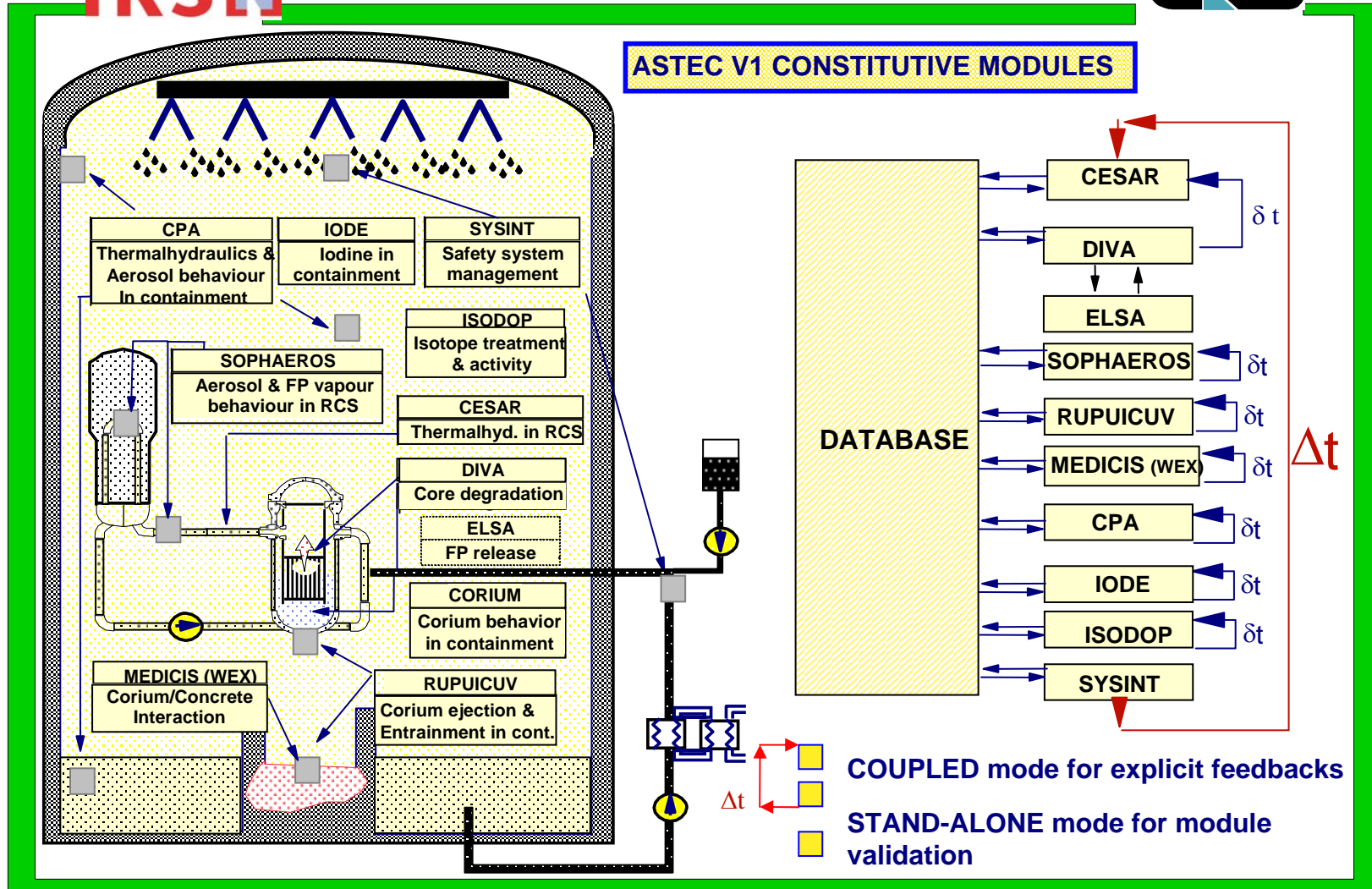
# ASTEC code (1): context

- IRSN/GRS cooperation since 1996 on integral code for severe accident (SA) source term in present/future LWRs (PWR, BWR, VVER).
- Main scope of applications:
  - Evaluation of source term, i.e. the possible radiological release out of containment,
  - Applications to PSA-level2 (including determination of uncertainties),
  - Accident management studies (prevention, mitigation),
  - Physical analyses of scenarios to improve the understanding of the phenomenology, including support to experimental programs.
- Specifications:
  - "Reasonable" calculation time : < 12h CPU/day of accident,
  - Accounting for safety systems and their availability (SAM).
- Important international collaboration, notably through VASA and EVITA projects (FwP of EC).

# ASTEC code (2): modules and operating mode

IRSN

GRS



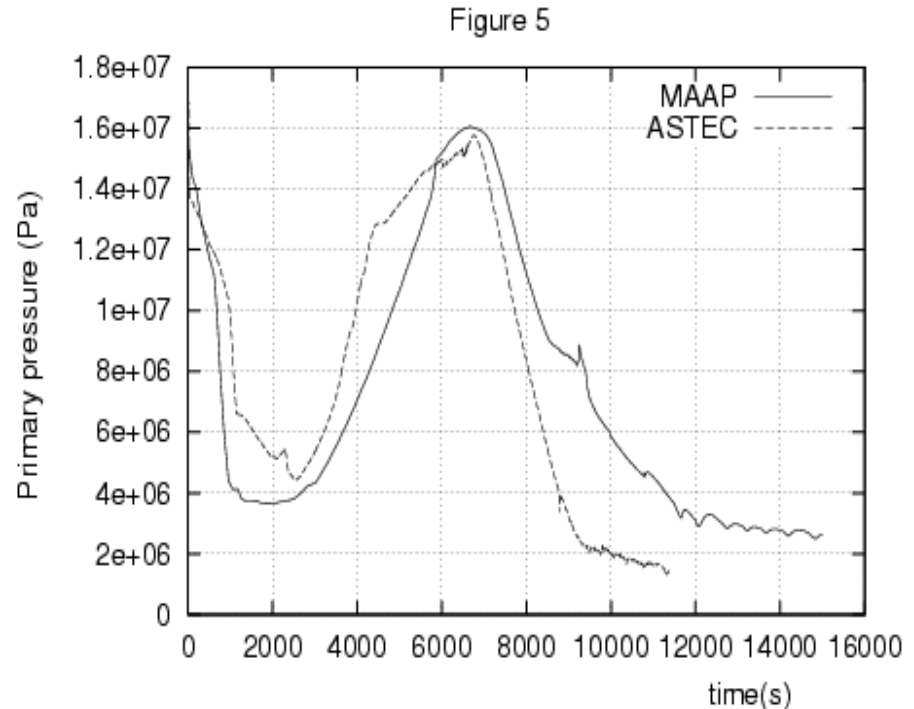
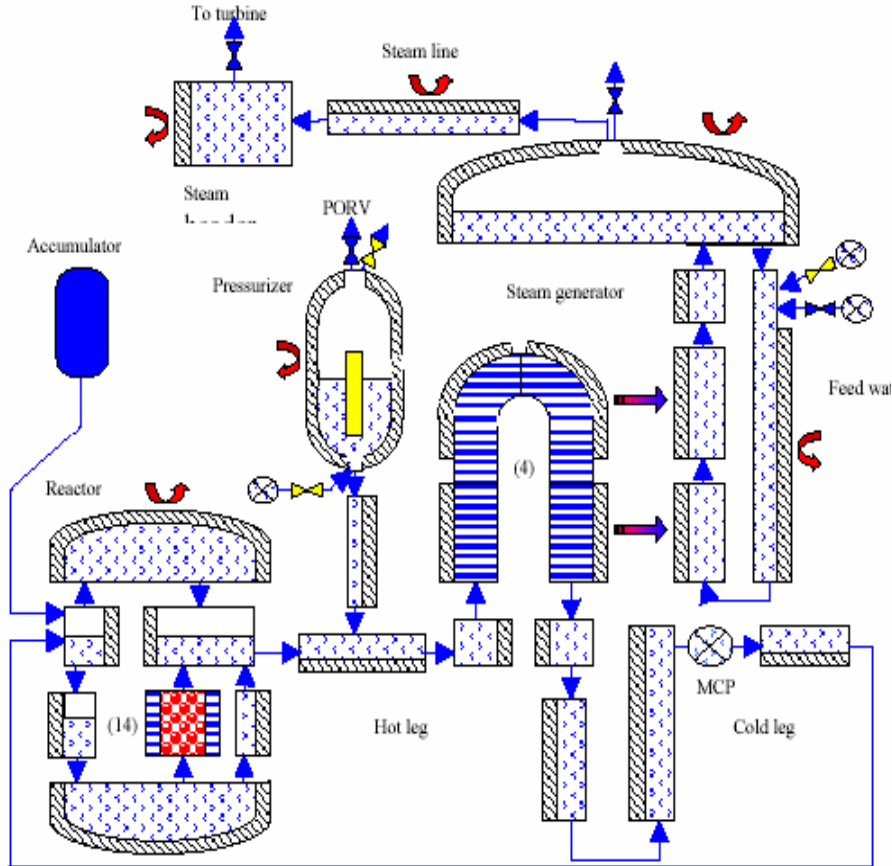
# ASTEC code (3): status

- 1<sup>st</sup> version V1.0 released mid-02; latest one V1.1 mid-04.
- Validation: intensive efforts (~10 persons/year) on comparison against experiments:
  - Validation benefits from extensive previous work: ESCADRE (IRSN) and RALOC-FIPLOC (GRS), ICARE2 validation (IRSN mechanistic core degradation code), EVITA project,
  - Matrix covers many analytical + integral experiments (esp. ISPs): **Falcon, STORM SR-SD, VANAM M3, RTF, LOFT-LP-FP2, CORA 13 & W2, ERECT5, PACTEL/ISP33, Phébus FPT1, +TMI-2 accident...** To be added: **ThAI**.
- Plant applications:
  - Code currently intensively used for IRSN PSA2 900 MWe,
  - 1<sup>st</sup> complete plant applications with V1.1 on PWR (including a fully new MCCI module) and VVER.
- Used by KI (Russia), AECL (Canada), BARC (India).

# ASTEC in past European projects (1)

- **VASA** (**V**alidation Strategy of **S**evere **A**ccident Codes, 1998-2000, 4<sup>th</sup> FwP), coordinated by GRS ⇒ Recommendation to apply a common European validation strategy on specific cases in order to reach the goal of an integral, fast running and reliable European code, able to solve the risk-oriented issues.
- **EVITA** (**E**uropean **V**alidation of **I**n**T**egral code **A**STEC, 2000-2003, 5<sup>th</sup> FwP), coordinated by GRS (with IRSN strong support): code validation by independent users (18 organisations from 8 countries),
  - Comparison/experiments (≈20 such as ISP) and detailed codes,
  - Benchmarks on plant applications on PWR and VVER with integral codes (were limited to RCS/core degradation or to containment behaviour).→ *Outcomes: modelling level near state of the art in most domains but needs of improvements of robustness and of users' tools.*

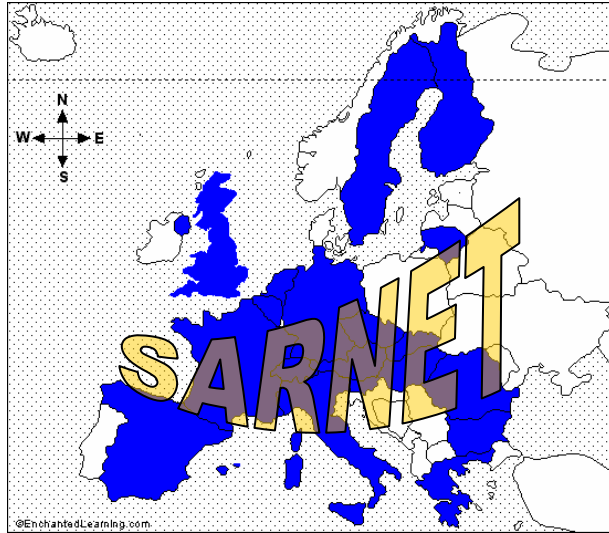
# ASTEC in past European projects (2)



Example of comparison of primary pressure evolution (right figure) between ASTEC V1 (left figure: RCS mesh) and MAAPE4 calculations of a SBO sequence in a French PWR 900 plant (EVITA project).

See also VEIKI presentation (EVITA project) on [EREC](#) exp. in EUROSAFE-2004.

# SARNET (1): presentation



**Severe Accident Research Network of Excellence (6<sup>th</sup> FwP) on R&D about SA in existing and future NPP.**

= 49 organisations from 18 countries (≈190 researchers + 20 PhD students), representing research, utilities, TSOs, universities, vendors.

- Started in April 04 for a 4-year duration (and beyond),
- Coordination by IRSN (J.C. Micaelli), with a Governing Board and a Management Team (8 Topical coordinators from CEA, FZK, GRS, IRSN, KTH, PSI),
- "Consortium Agreement" for definition of organisation, intellectual property, distribution of EC grant to partners.

# SARNET (2): objectives and content

## Objectives :

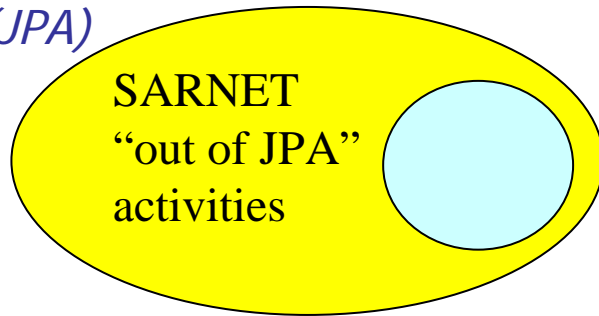
- Improve scientific knowledge in SA and reactor safety,
- Optimise use of available competence and resources in Europe,
- Perpetuate experience, keep memory of what has been done and disseminate knowledge.

## Activities :

- Capitalization of knowledge and access to this knowledge :
  - Integration of knowledge generated in SARNET (within Topics CORIUM, SOURCE TERM & CONTAINMENT) into the ASTEC code,
  - Advanced PSA2 methodologies,
  - Networking of experimental data bases.
- Jointly executed research :
  - Syntheses of knowledge (interpretation and modelling work),
  - Identification of research needs, definition of priorities and programmes.
- Formation:
  - Educational courses, SA book, mobility of young researchers, seminars.

# SARNET (3): operating mode

National programs +  
kernel called *Joint Programme of Activities (JPA)*



## Outputs from National Programs :

- Exp. programs and facilities description reports (exp. grids, measurements,..)
- Experimental results (when "open")
- Interpretation and Modelling reports
- **ASTEC versions (IRSN -GRS dev. work)**

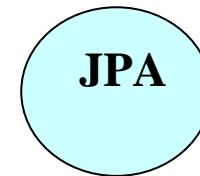
## Outputs from JPA :

- Synthesis on review of experiments and models
- Synthesis on joint interpretation and physical understanding of phenomena
- **Synthesis on models and recommendations for ASTEC**
- Next joint R&D programme : re-orientation and new prog.

## Jointly Executed Research:

Reviews, analyses.. between partners with the objective to commonly solve the Safety issues

**ASTEC assessment**



# ASTEC in SARNET (1): Partners

- Global coordination of ASTEC Topic by IRSN,
- 25 organizations (outside of IRSN-GRS), which represents a total of about 40 to 50 users.

- |                      |                    |                       |                        |
|----------------------|--------------------|-----------------------|------------------------|
| ➤ IRSN               |                    | ➤ INRNE (Bulgaria)    | → VVER-1000 adaptation |
| ➤ GRS                | → BWR adaptation   | ➤ IVS (Slovak. Rep.)  |                        |
| ➤ ARCS (Austria)     | → VVER adaptation  | ➤ JRC-IE (EC)         |                        |
| ➤ BUTE (Hungary)     |                    | ➤ JSI (Slovenia)      |                        |
| ➤ CEA (France)       |                    | ➤ KTH (Sweden)        | → BWR adaptation       |
| ➤ CIEMAT (Spain)     |                    | ➤ LEI (Lithuania)     | → RBMK adaptation      |
| ➤ DIMNP (Italy)      |                    | ➤ NRG (Netherlands)   |                        |
| ➤ EA (Spain)         |                    | ➤ TRACTEBEL (Belgium) |                        |
| ➤ EDF (France)       |                    | ➤ TUS (Bulgaria)      | → VVER-440 adaptation  |
| ➤ ENEA (Italy)       |                    | ➤ UJD (Slovak. Rep.)  | → VVER adaptation      |
| ➤ FRA/Paris (France) |                    | ➤ UJV (Czech rep.)    | → VVER adaptation      |
| ➤ FZK (Germany)      |                    | ➤ VEIKI (Hungary)     |                        |
| ➤ IKE (Germany)      | → BWR adaptation   | ➤ VUJE (Slovak. Rep.) |                        |
| ➤ INR (Romania)      | → CANDU adaptation |                       |                        |

*In red: task leaders for adaptation to NPPs.*

# ASTEC in SARNET (2): USTIA Work-Package

## ASTEC Uusers Support and Ttraining, Integration, Aadaptation.

- Support to code users by IRSN-GRS:
  - Code maintenance and “hot line” (through MARCUS web tool),
  - Delivery of code versions: V1.1 in June 04, V1.2 in June 05,
  - Web site with Forum, news, input decks....
- Users’ Clubs : 1<sup>st</sup> one in February 05 at Köln.
- Users’ training and learning:
  - 1<sup>st</sup> training course for code use (only beginners: 36 users) in June 04.
  - E-learning (basis = exercises of the training courses) in 2005.
- Code adaptation:
  - Model developments: in 1<sup>st</sup> stage only by CEA/DEN on I/V late-phase (DIVA module),
  - Specif. by partners of model extension to VVER, BWR, CANDU, RBMK and to future NPP designs; same for SAM simulation.
  - Preparation of ASTEC V2 specifications with inputs from all partners, incl. model proposals in Topical WP, requirements from PSA2 and R&D priorities.

# ASTEC in SARNET (3): PHYMA Work-Package

ASTEC PHYsical Model Assessment: validation by comparison to experiments, first with ASTEC V1.1, then with V1.2.

- Validation scope in the first matrix (includes 42 applications):
  - All phenomena are covered,
  - Some VVER-specific experiments: PACTEL, COLIMA, PMK2,
  - Several applications to Phébus.FP integral experiments,
  - Application to RBMK real transient in Ignalina reactor,
  - Difficult to find CANDU-specific experiments ⇒ *changed in exploratory reactor-calculations in CANDU circuit or containment.*  
→ *As much as possible, “open” high-quality experiments (such as ISP..).*
- Comparison with applications of detailed codes on these experiments in order to evaluate ASTEC performance.

# ASTEC in SARNET (4): PHYMA Work-Package

ASTEC MODULE	PARTNER	PHENOMENA	CODE FOR COMPARISON	EXPERIMENT
CESAR	BUTE	RCS thermalhydraulics in VVER (DBA)		PMK2
	IVS	RCS thermalhydraulics in VVER	RELAP5-3D	PACTEL ( <i>SBILOCA exp. from IMPAM-VVER</i> )
DIVA	IKE	Late-phase of PWR core degradation	KESS and ATHLET-CD	Phébus FPT4
		Early-phase of PWR core degradation, and H <sub>2</sub> production during core reflooding	KESS and ATHLET-CD	CORA 13 (ISP 31) incl. quench phase
	FZK	H <sub>2</sub> production during core reflooding	SCDAP/RELAP5	QUENCH-04, 06, 07, 11
	IRSN	H <sub>2</sub> production during core reflooding	SCDAP/RELAP5 from FZK, ICARE/CATHARE from IRSN	QUENCH exp. to select
	KTH	Late-phase of PWR core degradation	MVITA	FOREVER and SIMECO exp.
	UJV	Core degradation	ICARE2	Phébus FPT2
	JRC-PT	Core degradation	Overview of other SA code results	Phébus FPT2
	INR	Core degradation	FZK and IRSN results	CORA 13 (ISP 31)
ELSA (DIVA)	TUS	FP release and transport	-	COLIMA ( <i>PLINIUS project</i> )
	JRC-PT	FP release	Overview of other SA code results	Phébus FPT0-1-2 ( <i>coupled application of DIVA and ELSA</i> )
CESAR-DIVA	CEA	RCS thermalhydraulics and core degradation	-	TMI-2 ( <i>formally in RAB frame</i> )
	UPI	RCS thermalhydraulics and core degradation	SCDAP/RELAP5, MELCOR	TMI-2 ( <i>formally in RAB frame</i> )
	EDF	RCS thermalhydraulics and core degradation	-	TMI-2 ( <i>formally in RAB frame</i> )
	ENEA	RCS thermalhydraulics and core degradation	ICARE/CATHARE, SCDAP/R5	TMI-2 ( <i>formally in RAB frame</i> )
SOPHAEROS	JRC-PT	FP deposition/resuspension in primary circuit	-	STORM SD and SR exp. (incl. ISP40)
	JRC-PT	FP transport in RCS	Overview of other SA code results	Phébus FPT1 ( <i>coupled application of SOPHAEROS and CESAR</i> )
	UJV	FP transport in RCS	MELCOR 1.8.5	Phébus FPT1-2
	UPI	Fission product deposition in RCS	MELCOR, ECART	Phébus FPT1
	INR	FP transport in RCS for CANDU	-	Exploratory CANDU plant applications
	TUS	FP release and transport	-	COLIMA ( <i>PLINIUS project</i> )
RUPUICUV	IRSN	DCH in "open" cavity geometry	-	SNL-SUP1

# ASTEC in SARNET (5): PHYMA Work-Package

ASTEC MODULE	PARTNER	PHENOMENA	CODE FOR COMPARISON	EXPERIMENT
MEDICIS	GRS	MCCI	COCOSYS-WEX	MACE-M3B, 1 LACOMERA exp.
	ARCS	Molten corium concrete interaction (MCCI)	COCOSYS-WEX	ACE L4, MACE M4
	IRSN	MCCI	-	ACE L2-5-7
CPA	JRC-PT	Thermalhydraulics / aerosols in containment	Overview of other SA code results	Phébus FPT2
	JSI	Thermalhydraulics / aerosols in containment	CONTAIN	KAEVER (ISP44)
	TUS	Thermalhydraulics / aerosols in containment	-	LACE LA4
	IRSN	Thermalhydraulics / aerosol in containment	TONUS	TOSQAN-MISTRA-ThAI (ISP47)
	LEI	Thermalhydraulics / aerosols in RBMK containment	COCOSYS	Real transient in Ignalina RBMK-1500
CPA-THY	GRS	Thermalhydraulics and spray in containment	COCOSYS	HDR-E11-1
	UPI	Thermalhydraulics in containment	MELCOR, FLUENT, FUMO	TOSQAN (ISP47)
CPA-IODE	CIEMAT	Thermalhydraulics and iodine in containment	-	Phébus FPT2 ( <i>coupled calculation</i> )
	ENEA	Thermalhydraulics and iodine in containment	MELCOR	Phébus FPT1 (ISP46) ( <i>coupled calculation</i> )
IODE	GRS	Iodine in containment	COCOSYS-AIM	Phébus FPT1 (ISP46) iodine part
ASTEC	INR	Integral behaviour	Existing calculations	Phébus FPT2 ( <i>integral calculation</i> )
	IRSN	Integral behaviour	Existing calc. (incl. ICARE/CATHARE)	Phébus FPT1 (ISP46) ( <i>integral calculation</i> )
	JRC-PT	Integral behaviour	-	Phébus FPT2 ( <i>variants of integral calculations</i> )
	GRS	Integral behaviour	Existing calculations	Phébus FPT1 (ISP46) ( <i>out of iodine part</i> )
	TUS	Integral behaviour	Existing calculations	Phébus FPT1 ( <i>integral calculation</i> )

Basis for definition of a larger and updated validation matrix for the work to be performed in the next years (merging with EVITA matrix, new experiments..).

# ASTEC in SARNET (6): RAB Work-Package

**ASTEC Reactor Application Benchmarking:** benchmarks on plant-applications with integral codes, first with ASTEC V1.1, then with V1.2.

- Benchmarking scope:
  - In 1<sup>st</sup> stage: 5 types of NPP (only PWR and VVER),
  - Also includes TMI-2 accident,
  - Progressive approach: most calculations first focusing on RCS, in-vessel and containment phenomena, i.e. w/o FP modules. The extension to FP modules and then to ex-vessel modules will be done in a 2<sup>nd</sup> stage.
- *EVITA experience: high interest to build small groups of users working on the same NPP (example: Forum of Bulgarian ASTEC users in Oct.04).*
- Then, in March 05, elaboration of a larger reactor sequence matrix to be used for ASTEC V1.2 (complete sequences, SAM, other scenarios such as LBLOCA and SGTR).
- Mid-05: elaboration of 1<sup>st</sup> ref. input decks for plant applications on PWR and VVER.

# ASTEC in SARNET (7): RAB Work-Package

REACTOR TYPE	PARTNER	SEQUENCE	MODULES	CODE FOR COMPARISON
Westinghouse 1000	<a href="#">EA</a>	SBO	CESAR-DIVA then +CPA	MELCOR
	TRACTEBEL	SBO, SBLOCA	CESAR-DIVA then +CPA	MELCOR
Konvoi 1300	<a href="#">GRS</a>	MBLOCA	CESAR-DIVA-CPA	MELCOR
	IKE	MBLOCA (I/V only)	CESAR-DIVA-CPA	ATHLET-CD
	NRG	MBLOCA	CESAR-DIVA-CPA	MAAP4
PWR 900	<a href="#">IRSN</a>	SBLOCA	All (incl. MEDICIS)	ICARE/CATHARE
	F-ANP/SAS	SBO	All (incl. MEDICIS)	MAAP4
	ENEA	SBO	All (incl. MEDICIS)	MELCOR 1.8.5
VVER-1000	<a href="#">UJV</a>	LBLOCA (incl. FP)	CESAR-ELSA-DIVA-CPA-SOPHAEROS	MELCOR 1.8.5
	UJV	LBLOCA (cont. only)	CPA	MELCOR 1.8.5
	UPI	SBO (I/V only)	CESAR-DIVA-CPA	MELCOR, SCDAP/RELAP5
	KTH	SBO	CESAR-DIVA-CPA	MELCOR
	INRNE	SBO, SBLOCA	CESAR-DIVA-CPA	MELCOR
	TUS	SBLOCA	CESAR-DIVA-CPA	SCDAP/RELAP5
VVER-440/213	<a href="#">VUJE</a>	SBO	CESAR-DIVA-CPA	MAAP4/VVER
	IVS	SBO	CESAR-DIVA-CPA	MAAP4/VVER
	UJD	SBO	CESAR-DIVA-CPA	MELCOR
	VEIKI	PRISE	CESAR-DIVA-CPA	MELCOR

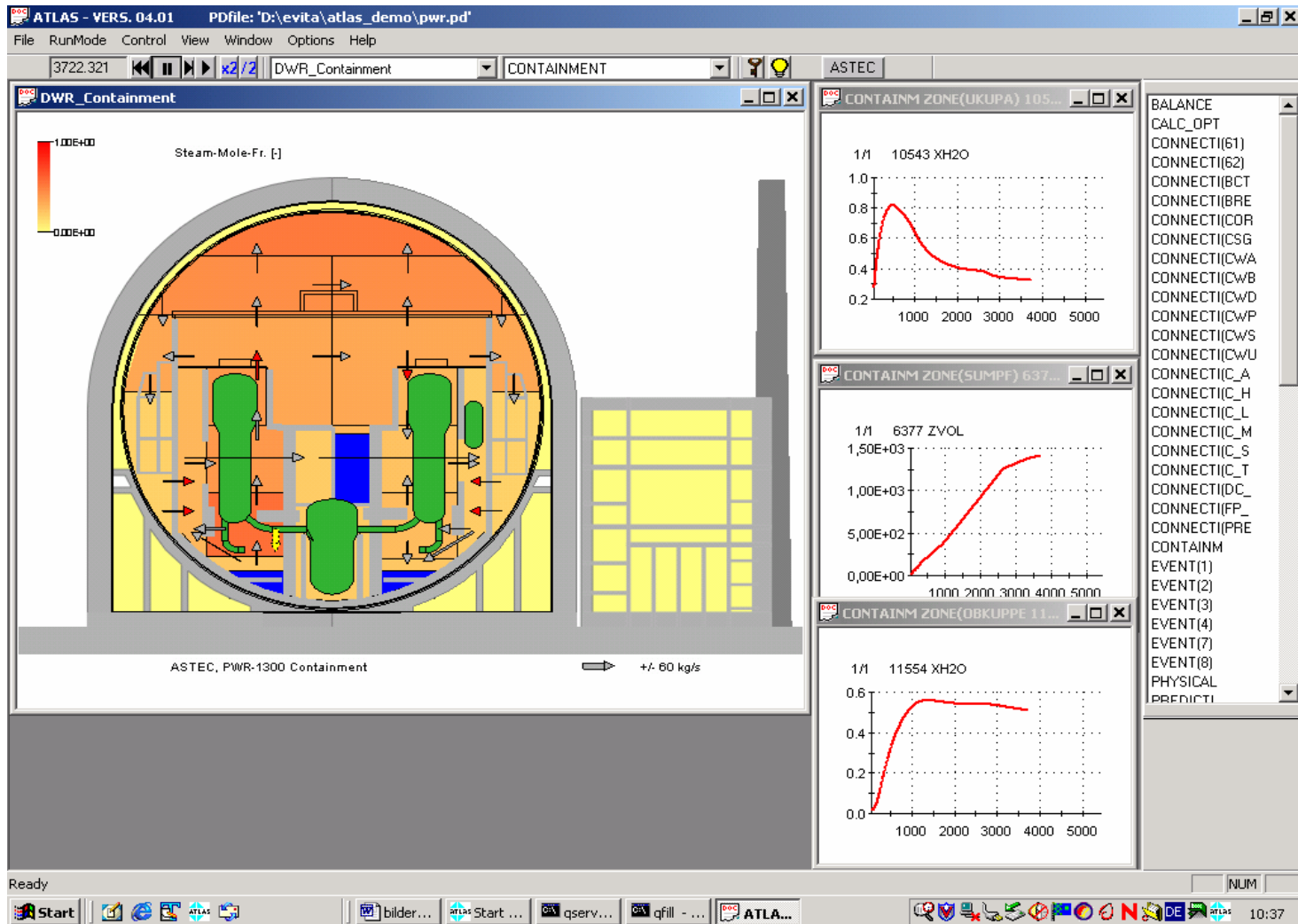
*In blue: Task leaders*

+ TMI2 application by CEA, UPI, EDF and ENEA.

# ASTEC perspectives (1): short-term

- Main efforts in 2004-05 on:
  - Code numerical consolidation (portability, review of less robust models, variants of sequence calculations...),
  - User-friendliness: account for users' feedback on existing tools; coupling to GRS ATLAS tool (see next slide).
- ASTEC V1.2 (June 05) should contain a few model improvements:
  - New model for reflooding of intact or slightly damaged cores,
  - Model improvements of semi-volatile FP release and of iodine mass transfer to containment walls,
  - New model in MEDICIS module of evolution of corium configurations during MCCI (layer inversion).

# ASTEC perspectives (2): ATLAS tool

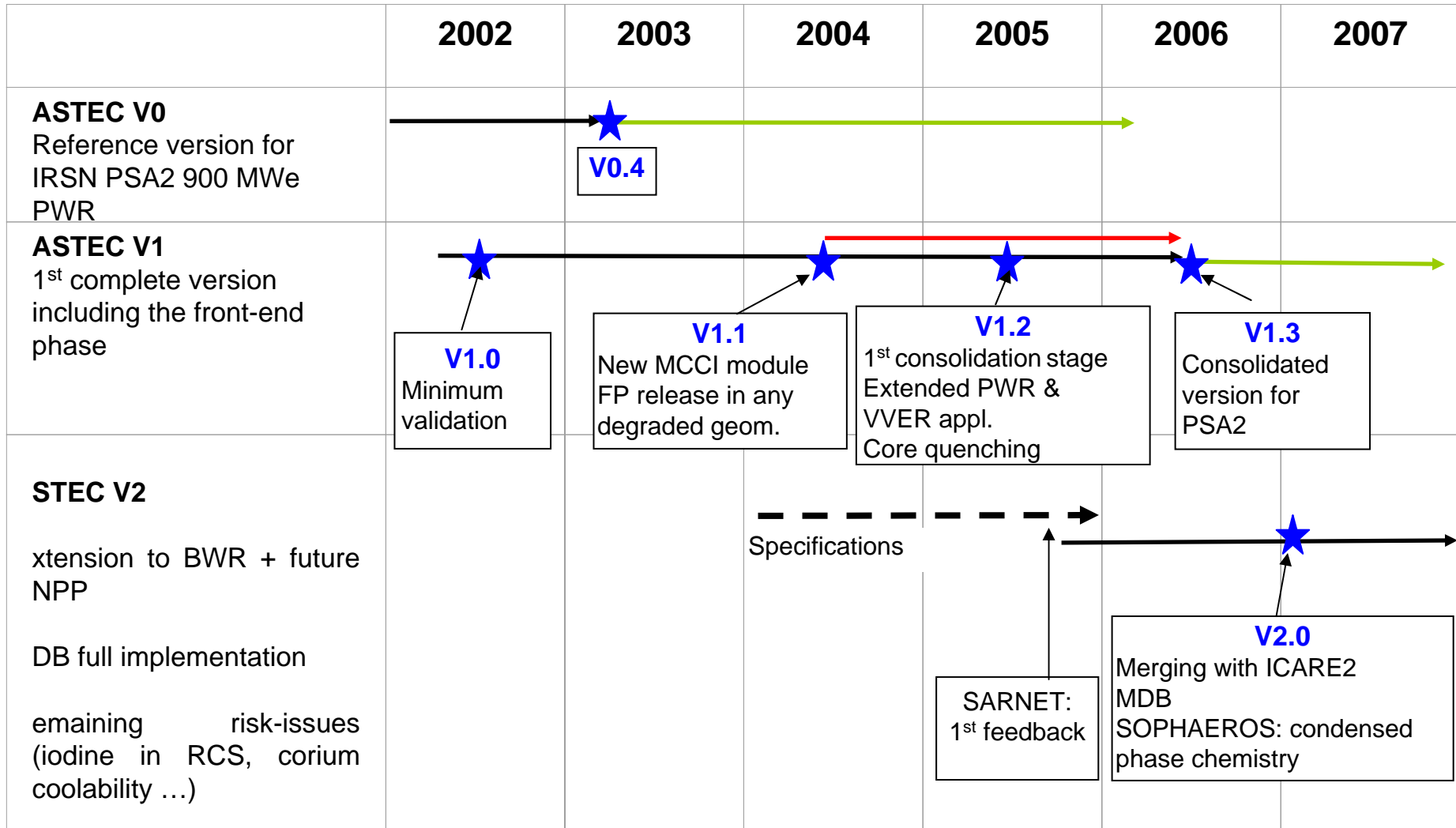


ATLAS visualisation of ASTEC V1 Konvoi 1300 MBLOCA results

# ASTEC perspectives (3): long-term

- Longer term actions:
  - Continuation of model developments in close relation with experimental on-going or future programs:
    - On MCCI (**ARTEMIS** in IRSN, **CCI-OECD**),
    - On iodine (**CHIP**, **EPICUR** both in IRSN),
    - On aerosol retention (**ARTIST**),
    - On containment thermalhydraulics/aerosols (**TOSQAN** in IRSN, **Thal**).
  - Improvements of H<sub>2</sub> combustion model in containment (CPA module) to better account for highly turbulent deflagrations.
- Preparation of next family of versions ASTEC V2:
  - Merging in 2005 of DIVA with IRSN ICARE2 detailed code for core degradation,
  - Requirements and specifications end of 2005 (incl. SARNET feedback).

# ASTEC perspectives (4): time-schedule of versions



calculations after vessel failure

EUROSAFE  
 merging with ICARE2

Development Consolidation

Maintenance

Release

# Conclusions

- Substantial efforts to make ASTEC the European reference integral code through SARNET jointly-executed R&D:
  - Providing physical models to be integrated into ASTEC,
  - Extending code scope of application to all European NPP types.
- Key issues for further ASTEC model developments by IRSN-GRS in consistence with SARNET priorities: core reflooding, long-term MCCI, iodine in RCS, HBU-MOX fuels.
- SARNET will provide sustainable integration of European R&D capacities on SA (capitalization through ASTEC, PSA2, databases) and orientate national programmes, contributing to an optimised use of resources. Synergies will develop with educational institutions and will keep attractive the domain for young students and researchers.

→ *First international SARNET seminar in Autumn 05.*