OVERVIEW OF SARNET DEPLOYMENT AND PROGRESS

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Since April 2004, 49 European organisations network in ***SARNET*** (Severe Accident Research and management NETwork) 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.

The SARNET project in one of the projects supported by the EURATOM part of the 6th Frame Work Programme of the European Commission. It tackles 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. SARNET comprises most of the actors involved in SA research in Europe.

To reach these objectives, all the organizations networked in SARNET contribute to a so-called Joint Programme of Activities (JPA), which can be broken in several elements:

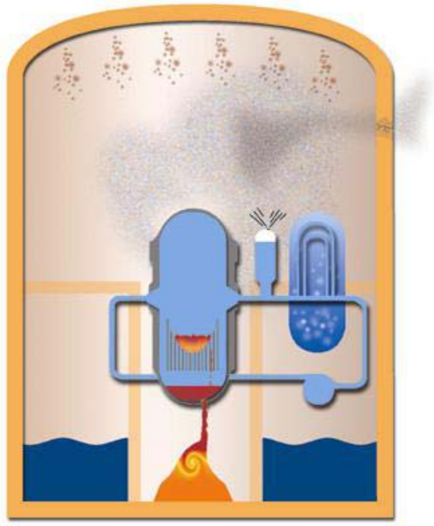
- Implementing an advanced communication tool for fostering exchange of information;
- Harmonizing and re-orienting the research programmes, and defining commonly new ones;
- Analysing commonly the experimental results provided by research programmes in order to elaborate a common understanding of concerned phenomena;
- Developing ASTEC code (integral computer code used to predict the NPP behaviour during a postulated SA), which capitalizes in terms of physical models the knowledge produced within SARNET;
- Developing Scientific Databases, in which all the results of research programmes are stored;
- Developing a common methodology for Probabilistic Safety Assessment (PSA) of NNPs;
- Developing educational courses and text (source) books;
- Promoting personnel mobility between the various European organisations.

A few organizations are covering a wide range of competences though not complete, whereas others are specialized in very specific areas and thus complementarities are developing. The critical mass of competence for performing experiments needed in the SA domain, analysing them, developing models and integrating them into ASTEC is achieved for most types of NPPs in Europe.

INTRODUCTION

The current Nuclear Power Plants (NPPs) existing in Europe are designed with the principles of defence in depth. In particular, they incorporate a strong containment and engineering systems to protect the public against radioactivity release for a series of postulated accidents. In some low probability circumstances, some severe accident sequences may result in core melting and plant damage leading to dispersal of radioactive material into the environment and thus constituting a health hazard to the public well beyond the borders of the State where the damaged plant is located.

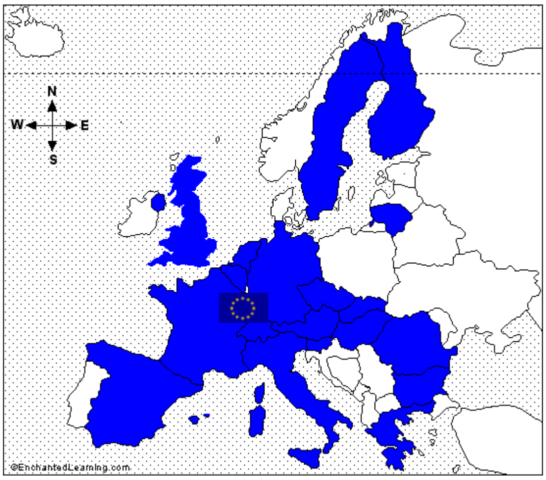
Remarkable achievements have been obtained in the field of Water Reactor SA, thanks in particular to the numerous European actions undertaken within the 4th and 5th Framework Programmes (FP) of European Commission. In spite of the accomplishments reached, a limited number of specific issues remain where research activities are still necessary in order to reduce further uncertainties that are considered of importance and to consolidate severe accident management plans: core reflooding, iodine chemistry, ex-vessel melt coolability, timing of base-mat failure are examples of remaining issues underlined by the Phenomena Identification and Ranking Table (PIRT) action conducted within the EURSAFE thematic network of the 5th FP [1].



It is therefore crucial that the best state of knowledge on severe accident phenomenology, qualified computer tools and appropriate methodology should be used uniformly throughout Europe, in order to evaluate the corresponding risks and update former evaluations, taking into account notably the inevitable evolutions in reactor operations (e.g. new type of fuel, higher burn-up, extension of plant life). Additional appropriate engineering devices and/or accident management measures may have then to be developed and implemented in order to reduce the risks to an acceptably low level.

Up to now, research programmes on Severe Accidents are usually decided first at national levels, though co-operation agreements are often concluded around these national programmes, but on a case by case basis. Facing the inevitable reduction of the national budgets in this field, it is now necessary to coordinate better the national efforts to optimise the use of the available expertise and experimental facilities in order to resolve the remaining issues. This coordination will take benefits of, and strengthen, the existing complementarities between the different laboratories throughout Europe (corium/fission product chemistry experts, small scale/large scale testing, simulants/real materials, experimentalists/model developers/code developers).

Therefore, a number of European R&D organizations, including technical supports of safety authorities, industry, utilities and universities, have decided to seize the opportunity offered by the European Commission in the framework of FP6 to network in SARNET (Severe Accident Research and management NETwork) their capacities of research in the severe accident area in a durable way in order to resolve outstanding severe accident safety issues for enhancing the safety of existing and future NPPs.



SARnet

19 Countries
49 organisations
18 Research Organizations
10 Universities
11 Industry Organizations
6 Safety Authorities or Technical Support
200 researchers
20 PhD students

The general objectives of SARNET are to:

- Tackle the fragmentation that exists between the different R&D organizations, notably in defining research programmes and developing/qualifying computer tools;
- Harmonize the methodologies applied for assessing risk and improve Level 2 PSA tools;
- Diffuse the knowledge to Associated Candidate Countries more efficiently and associate them to the definition and the conduct of our research programmes more closely;
- Bring together top scientists in severe accident to be a world leader in advanced computer tools for severe accident risk assessment.

In overall 49 organizations decided to join the project, coming from 16 Member States (Austria, Belgium, Czech Republic, Finland, France, Germany, Greece, Hungary, Italy, Lithuania, the Netherlands, Slovakia, Slovenia, Spain, Sweden, United Kingdom), 2 Candidate States (Bulgaria, Romania), Switzerland and the Joint Research Centre of the European Community. The network started its activity on April 1st , 2004 for a four-year period (duration of the contract with the European Commission) and is coordinated by IRSN [2].

THE JOINT PROGRAMME OF ACTIVITIES

To achieve the objective of SARNET a Joint Programme of Activities (JPA) has been defined. All the organizations networked in SARNET contribute to the JPA, which can be, beyond management activities, broken down in 3 elements:

- Integrating activities to strengthen links between organisations;
- Joint research activities to resolve remaining outstanding issues;
- Spreading excellence activities;

The integral code ASTEC [3], commonly developed by IRSN and GRS, is the main integrating component and contributes efficiently to the diffusion of the knowledge. Activities linked to ASTEC thus appear as “Integrating activities”, whereas some of them contribute also to the range of “Spreading excellence activities”. Furthermore, most of the “Joint research activities” have links with ASTEC as it is one of their ultimate goals to provide physical models to be integrated in ASTEC. The exchange of information on the detailed models developed by the various experts through interpretation of experiments will lead at medium and long term to generic common models used in the different detailed codes (example of ICARE/CATHARE and ATHLET-CD for core degradation). Besides, adequate models will be derived from these detailed models and will be included in the common reference ASTEC code.

The R&D needs are periodically updated and the objectives of future experiments are defined taking into account the outcome of the collaborative work on risk studies. A consensus could be reached on closure of some issues and would allow to redistribute competence and manpower on open ones in concert with other international projects (e.g. ISTCs, OECD projects…).

The programme, which is described below, may be revised, depending on the results of the negotiation with the European Commission. The integrating elements of the programme are considered of highest importance and will remain the key elements of the JPA.

MAIN ACHIEVEMENTS

Integrating Activities

One integrating activity is the implementation of an Advanced Communication Tool (ACT) for aiding information exchange. ACT is a key concept to achieve SARNET goals; it provides unified support for efficient communication within the network, concerning:

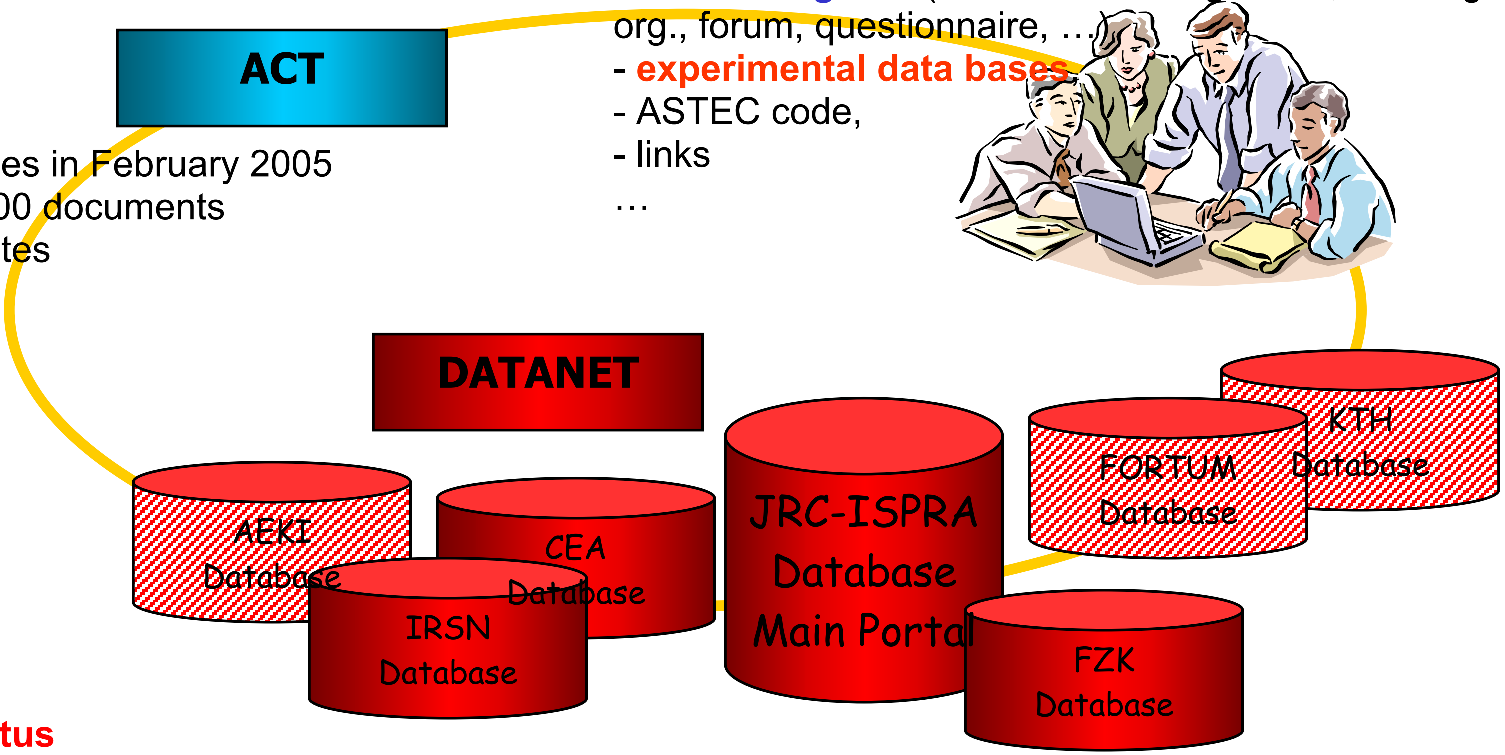
- Access, search, publication of documents and codes (concept of knowledge storage),
- Contact and communicating with partners (interactive and collaborative services),
- Joint co-ordination of actions/programmes (co-operative management of the network),
- List of links to satellite community projects (R&D projects, related sites).

A platform has been thus developed and deployed. Access is given by Web Browsers, enabling access from any Internet connection. After one year, around 200 users of SARNET have been granted access to this tool and the ACT is now used intensively.

Construction of DATANET, the SARNET experimental database network, has started. The objective is to develop and maintain an instrument that insures preservation, exchange and processing of SA experimental data, including all related documentation. The data of concern are both existing experimental data that SARNET partners are willing to share within the network and all new data produced within SARNET. It is based on the STRESA tool developed by JRC Ispra and consists of a network database with several local databases (or nodes). From the central database, it is possible to get connections with other local databases; direct connections to the local databases are also possible, which increases the potential and the power of this type of system. After 18 months, five nodes already exist (the central one at JRC Ispra, and local ones at FZK, IRSN, AEKI and CEA); three are under preparation (KTH, FORTUM and CIEMAT). Training weeks have been organized at JRC Ispra. The results of about 50 experiments have been implemented so far.

A WEB portal supplies SARNET partners with an access (reading and or writing) to:
- **networking tool** (document management, meeting org., forum, questionnaire, …)
- **experimental data bases**
- ASTEC code,
- links
…

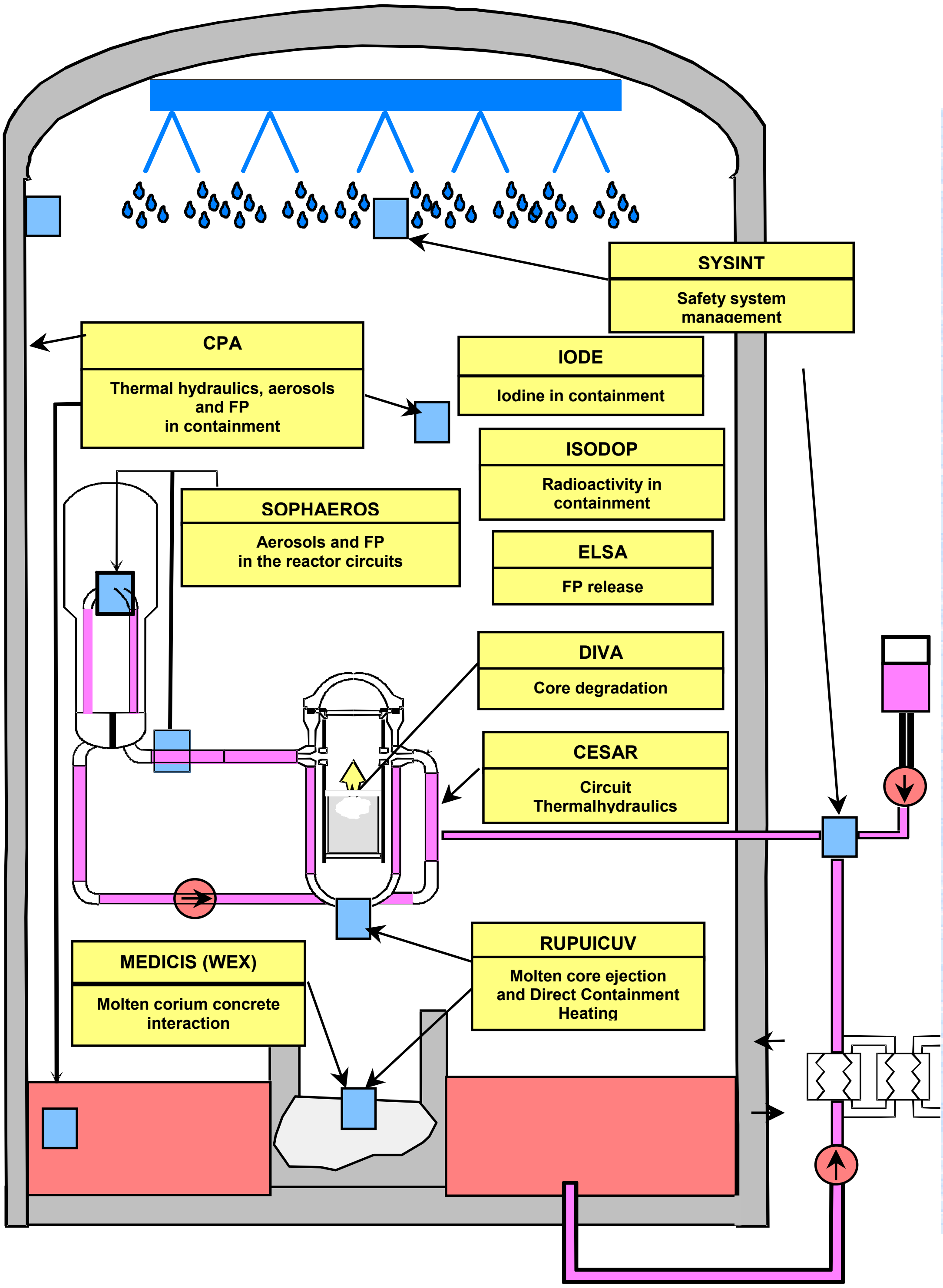
ACT Status
- 200 users
- 1500 accesses in February 2005
- More than 200 documents
- 10 Topical sites



DATANET Status
- 4 nodes are open (JRC, FzK, IRSN, CEA)
- 3 are under works (FORTUM, AEKI, KTH)
- 2 are foreseen (CIEMAT, VTT)

- Implementation of 10 experimental programmes is underway
- More than 50 tests results already implemented

Another integrating activity is the development, qualification and the maintenance of the SA integral analysis code ASTEC. Twenty-nine organisations collaborate on the adaptation and qualification of this code. Developed by IRSN and GRS, it describes the behaviour of a whole NPP under SA conditions, including Severe Accident Management (SAM) engineering systems and procedures. It is extensively used by IRSN for Level 2 PSAs for 900 MWe PWRs. It is the main integrator of knowledge in SARNET.



ASTEC

■ *Integral numerical simulation of reactor accident with core melt-down (Severe Accidents)*

■ *IRSN-GRS property: ~ 10 m-y/y in charge of software development and user support*

■ Has been distributed to 29 SARNET organizations

■ SARNET scientists support for model improvement and physical assessment:

- ASTEC capitalizes in terms of models all the knowledge produced in the frame of the Network
- 40 trained users contribute to joint validation programme (mobilizes around 20 m-y/year)
- Major version delivered in July 2005, next one mid-06

■ *Size:* ~ 350 000 instructions

■ *Speed*: ~ 3-10 hours to compute 24 h of transients

A close and efficient collaboration between ASTEC users and developers has been set up using ACT and the MARCUS tool for code maintenance. A 1-week training course was held in June 04. Two code versions were released to the SARNET partners: V1.1 mid-04 and V1.2 mid-05. The 1st ASTEC Users' Club, held in February 05, was very fruitful for direct discussion with developers. Model developments are under way by CEA/DEN, in close collaboration with IRSN, on in-vessel late-phase (DIVA module) and on vessel external cooling. Concerning other reactor types, specifications are under way for VVER-440 and VVER-1000, and are planned for BWR.

Validation progress has also been good. The code has been applied to more than 20 experiments (analytical and integral). Results were good on core degradation and MCCI. Partners independent from the developers confirmed IRSN-GRS results on several ISPs (44, 45, 46, 47) and on the PHEBUS FPT0/1 tests. FZK adopts from now the code to prepare and analyse its experiments (QUENCH, DISCO and later on LIVE). Code results compared to containment data of an Ignalina RBMK transient gave preliminary acceptable results. Several plant applications are also under way on various NPP (PWR, VVER-440, VVER-1000, CANDU), including benchmarks with other codes (MELCOR, MAAP, …).

Harmonization of Level 2 PSA methodology and development of advanced tools is also an integrating activity. Level 2 PSA is a powerful tool to assess plant-specific vulnerability regarding NPP SA. It evaluates possible SA scenarios in terms of frequency, loss of containment integrity and radioactive release into the environment and quantifies the contribution of prevention and mitigation measures in terms of risk reduction. Different approaches are used in Europe, derived from what has been implemented in the USA. A description and comparison of the main elements of methods used by the different partners to develop their PSA has been written. A State on the Art Report on Dynamic Reliability methods has been produced and the limitations of classical methods, which could be exceeded, were identified. Examination of the benefit of one of the possible methods (Monte Carlo Dynamic Event Tree –MCDET- method,) is ongoing on a specific example. The description in "engineer language" of a second potential method achieved (Stimuli Driven Theory of Probabilistic Dynamic -SDTPD) was achieved. The follow-up will include testing the applicability of these 2 dynamic reliability methods.

Research priority assessment is also an integrating activity. It identifies research priorities and intends to re-orientate progressively the existing national programmes, to contribute to launch new ones in a coordinated way, eliminating duplications and developing complementarities. This activity has been be initiated during the second year, and in close collaboration amongst participants (those mainly involved in EURSAFE [3]), representing Technical Support Organizations (TSO), industry and utilities, including organisations of Associated Candidate Countries. Two types of action have been initiated:

- Assessment of progress within the joint programme of activity and in the related national programmes
- Re-evaluation of EURSAFE listing and results

A revision of EURSAFE conclusions should be ready by the end of 2005.

Spreading of Excellence Activities

The second major type of activity concerns spreading of excellence. The more experienced organisations have started to contribute diffusing the excellence by preparing an educational course on SA phenomenology, addressing PhD students and researchers. The first course will be given at Cadarache from January 9 to 16 2006. The emphasis in this course will be on teaching and providing insights rather than information transfer. This course will include 3 hours of teaching on the topic of Safety Assessment with a short description of the PSA methodology. A PSA Level 2 short course will be developed later in 2006. The teachers for the various subjects in the course have been identified.

Besides this, the content of a text book on SA phenomenology has been set up. This book covers historical aspects of Light Water Reactor (LWR) safety and principles, phenomena concerning in-vessel accident progression, both early and late containment failure, fission products (FP) release and transport; it contains a description of analysis tools or codes, of management and termination of SA, as well as environmental management. It also gives elements on Generation 3 LWRs. Preliminary text for the book will be developed by the contributors as they participate as teachers in the course. Serious writing will be done in 2006. Prof. Sehgal will be the Editor of the book. The partners who have agreed to work together in preparing the first course and writing this book are universities, TSOs, national laboratories and industrial organizations that share their great talent and experience within SARNET.

These spreading of excellence activities are complemented by a mobility programme under which students and researchers can go into different laboratories of SARNET for training. The Mobility Program accelerated starting with summer of 2005, when seven researchers headed for trainings of different durations ranging from few weeks to almost 1 year. The sending organizations have been CIEMAT (Spain), LEI (Lithuania), INR (Romania), ULB (Belgium), Demokritos (Greece) and TUS (Bulgaria) and the host organizations have been PSI (Switzerland), ULB (Belgium), IRSN (France), VTT (Finland), EDF (France), GRS (Germany) and FZK (Germany). The delegates have been notably trained to specific computer codes, to use them to interpret experimental results available in SARNET or to perform reactor scenario calculations to provide boundary conditions for future experiments. Several other delegations should be initiated soon.

Jointly Executed Research Activities

These activities constitute the basis of the network. In spite of the accomplishments reached in SA research, some issues remain where research activities are still needed to reduce uncertainties considered important and to consolidate SA management plans. These remaining issues were identified by the PIRT in the EURSAFE FP5 thematic network [1]. The PIRT addressed the whole spectrum of SA situations, extending from core uncovery to long term corium stabilization, long term containment integrity, and FP retention or release to the environment. Joint research activities in SARNET are executed to help resolve these remaining issues. They are split into three areas: **containment integrity**, **corium behaviour** and **source term**. In all three areas, the same method has been adopted: review and selection of available relevant experiments, synthesis of analyses and interpretation of data from these experiments, and model review, synthesis and proposals of models for ASTEC. To day more than 20 expert have been constituted, each one is dedicated to a specific aspect of severe accident phenomenology. More than 50 recent or underway experimental programmes from 18 SARNET organisations produce the necessary inputs. Significant progress have been achieved in the different domains, details are developed in companion papers, only some elements are illustrated below.

The research efforts on energetic phenomena that could potentially threaten containment integrity concern hydrogen behaviour and fast interactions in the containment. For the former,

the hydrogen combustion and associated risk mitigation is studied, concentrating on the formation of combustible gas mixtures, local gas composition and potential combustion modes, including reaction kinetics inside catalytic recombiners. Hydrogen distribution within the containment is studied to assess the risk of high concentrations. Experimental programmes on combustion with gradients (ENACCEF) and recombiner kinetics (REKO-3) have started. The PROCO combustion model, improved using the first experimental results, will be transferred to ASTEC. In ISP-47, data from the TOSQAN, MISTRA and ThAI facilities were used for further validation of lumped-parameter and CFD codes. Limitations of CFD codes (especially commercial codes) were identified with respect to wall condensation modelling and saturation conditions. Specific topics such as mitigation system modelling, sprays and recombiners have been identified as future tasks.
Concerning fast interactions, fuel coolant interaction is studied to increase the knowledge of parameters affecting steam explosion energetics during corium relocation into water, and determine the risk of vessel or containment failure by investigation of specific processes like premixing, melt fragmentation and particle heat transfer mode. The last test in the ECO facility was performed, while the KROTOS facility is being constructed and X-ray imaging for pre-mixing visualisation has been developed. In the OECD programme SERENA, reactor case calculations were performed and progress towards synthesis of experiment interpretations achieved. Direct Containment Heating (DCH) processes are studied, including melt dispersion into various reactor compartments, heat transfer and chemical processes such as production and combustion of hydrogen. A DISCO experiment with the geometry of a French reactor was performed in the EC-LACOMERA programme, which will be used as a benchmark for lumped parameter code calculations. A joint technical report on DCH is in progress.
Corium behaviour is a large topic dealing with more than half of the issues selected in the EURSAFE PIRT. The corium area ranges from early phase of core degradation to late phase core degradation and ex-vessel corium recovery, and a major effort is also being aimed at developing the thermodynamic and material databases. Joint activities have been deployed, such as the contribution to the definition and the interpretation of OECD-CCI tests around the MCCI programme, with a contribution to the benchmark exercise and the associated model improvement, and a contribution to the definition and interpretation of PLINIUS and LACOMERA tests: QUENCH-10 on air ingress in bundle geometry, COMET-L1 and L2 to study MCCI in 2D geometry, LIVE or VULCANO-COMET tests in preparation. Similar activities have been carried out for ongoing and new ISTC programmes: ISTC PARAMETER and core top flooding models, ISTC METCOR and impact on thermo-mechanical vessel behaviour, ISTC CORPHAD and NUCLEA data base qualification. In the International Source Term Programme (see below), FZK and IRSN have started to harmonize their test matrices on Zircaloy oxidation by air/steam mixtures and on B_4C oxidation and degradation.
In Source Term area, the main safety-related issues addressed are the effect of air ingress, i.e. the influence of an oxidising environment on release and circuit source term phenomena, iodine volatility in the primary circuit, particularly for silver-indium-cadmium release (as these absorber elements play a significant role in iodine chemistry), containment by-pass in the case of steam generator tube rupture, aerosol retention in containment cracks, aerosol remobilization, and aerosol and iodine behaviour in the containment. These are dealt with in several work packages where technical discussion 'circles' clustering participants around specific issues are highlighted, bringing experimentalists and modellers closer together. The main achievements have been detailed in [4]. A large part of the activity is devoted to the definition/preparation of the so-called International Source Term Programme launched by IRSN, CEA and EDF with the support of the European Commission [5]. Concerning Fission

Products (notably Ruthenium) release from irradiated fuel under very oxidising conditions, a large effort has been devoted to the interpretation of available AECL data and of RUSET (AEKI). It has been drawn that Ruthenium release occurs in oxide form after an incubation period during which full oxidation of fuel and cladding occurs. From RUSET and VTT tests, it has been noticed that oxide forms can stay volatile enough in lower temperature regions to be transported to the reactor containment. It has been emphasized that water vapour likely suppresses decomposition of RuO_4 on stainless steel. This result is of major importance for source term as it shows that depending on conditions, some ruthenium may reach the containment in a stable volatile form. Further data are required (RUSET, VTT tests & VERDON).The conditions in future tests VERDON [5] are being defined by pre-test calculations.

Concerning iodine chemistry in the circuit IRSN has provided an overall interpretation of iodine chemistry in the circuit. Under reducing conditions, and without absorber material, iodine chemistry seems relatively straightforward, the iodine being transported predominantly as caesium (and rubidium) iodide. In oxidizing conditions the picture is more complicated since Cs take up in forms other than CsI affects iodine chemistry. Hence, iodine can either still be principally CsI or tends to form other metal iodides such as with control rod materials or, if these are not present, conditions become conducive to HI formation. These statements still need to be confirmed : future CHIP tests will provide useful data for a full understanding. The CHIP programme [5] will provide kinetic and thermodynamic data on iodine transport to primary circuit (RCS) breaks under reactor accident conditions. Two complementary sets of tests are planned, analytical and phenomenological.

Regarding radio-active Aerosols Issues, three scenarios are being addressed: steam generator tube rupture (SGTR) sequences, remobilisation from RCS deposits and transport of aerosols through containment cracks.

Several facilities have investigated aspects of the aerosol retention within the steam generator under SGTR conditions: PSAERO/HORIZON, PECA/SGTR and ARTIST. PSAERO/HORIZON tests have shown that resuspension is important in aerosol retention within horizontal tubes and that sudden velocity changes enhance resuspension. The PECA/SGTR tests showed that in the break stage, under all conditions tested, the mass retained was less than 20% of that injected. For flow rates above 100 kg/h, the higher the gas velocity, the lower the total mass depleted on tube surfaces, but at lower flow rates this trend is not maintained. These results were consistent with the small decontamination factors (DFs) measured under similar conditions (dry secondary side) in ARTIST.

Revolatilisation tests are being performed in the small-scale REVAP facility where samples from PHEBUS are being tested under different conditions. These tests show that the extent of Cs revaporisation is very high (~95%) on flat metallic substrates. During slow temperature ramping under flowing steam, it starts at 550°C and is rapid until 750°C; it continues to 1000°C but it is practically finished by then. Radiotracer testing confirms that CsOH deposits on stainless steel have the same behaviour as that of the PHEBUS sample deposits. Further tests are needed to achieve a correlation of results.

Retention of aerosols in containment cracks can be effective, particularly in the presence of steam (SIMIBE tests). More data are needed to support the theoretical developments underway.

The experimental facilities involved in Containment Chemistry are: PHEBUS FP, CAIMAN, SISYPHE, the Chalmers facility, PARIS [5] and EPICUR [5].

AEA Technology has started the compilation of an Iodine Data Book which aims to provide a critical review of the data used in the development and validation of iodine chemistry models. The first part, covering aqueous inorganic iodine radiation chemistry, was produced in the

first year of the project. Particular attention is being given to the interpretation of some PHEBUS observations. The CAIMAN programme gave also some interesting results: in the presence of paints, irradiation and high temperature, organic iodide can be the dominant form of volatile iodine; in alkaline conditions, gaseous iodine concentrations decrease by several orders of magnitude. The nature of mass transfer regime between sump and gas has been specifically addressed in SISYPHE . The two main effects of evaporating conditions are to increase the kinetics of transfer from the liquid to the gaseous phase and to change the steady state iodine concentrations, the sump iodine concentration being reduced. The well-known two-film model has been modified to extend it to this type of conditions.
The effect of radiation on the nature of containment atmosphere and the effect of metallic impurities in the sump have been investigated in the PARIS [5] and Chalmers experimental programmes, respectively. The organic iodine formation models are based on a simultaneous consideration of thermal and radiolytic mechanisms both in gas and liquid phases. There are however discrepancies in the aqueous modelling, essentially concerning the organic sources. Data from the EPICUR [5] programme will be suitable for validation of these models.

CONCLUSION

The four-year SARNET Network of Excellence started in April 2004 with the ambitious but highly important objective to provide an appropriate frame for achieving within a couple of years a sustainable integration of the European severe accident research capacities.
By capitalizing the acquired knowledge in ASTEC code and in Databases (DATANET), SARNET has started to produce conditions necessary for preserving the knowledge produced by thousands of person-years of research, and diffusing it to a large number of end-users. The ASTEC code is being actively used and DATANET being used to store experimental data.
By fostering collaborative work in the PSA2 domain, SARNET has started to create the necessary conditions for harmonizing the approaches and making Europe a leader in SA computer code and risk assessment methodology.
Through an education and training programme, concretised by a first 5-days educational course and a text book foreseen in the beginning of 2006, addressing young scientists, SARNET has started to develop synergies with educational institutions to keep attractive this domain of activity for students. Through detachments of young researchers in the first year, the mobility process has been initiated and expansion is expected.
By fostering collaborative work in the technical domains of containment integrity, corium behaviour and source term, SARNET has started to progress to solve remaining outstanding issues and to provide ASTEC with modelling recommendations. Proposals have been elaborated for the modelling of ruthenium release under oxidizing conditions, for the modelling of retention of aerosols in containment wall cracks. Several recommendations are expected in the coming years from the different specialized collaborative groups.
Finally, SARNET is developing a methodology to periodically assess progress and identify remaining needs in term of research, SARNET should thus become a reference, in terms of research priorities in the field of SA, having impact on national programmes and associated budgets.

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