European Research on the Corium issues within the SARNET Network of Excellence

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Abstract – *Within SARNET, the corium topic covers all the behaviors of corium from early phase of core degradation to in or ex-vessel corium recovery with the exception of corium interaction with water, direct containment heating and fission product release. The corium topic regroups in three work packages the critical mass of competence required to improve significantly the corium behavior knowledge. The spirit of the SARNET networking is to share the knowledge, the facilities and the simulation tools for severe accidents, so to reach a better efficiency and to rationalize the R&D effort at European level. Extensive benchmarking has been launched in most of the areas of research. These benchmarks were mainly dedicated to the recalculation of experiments, while, in the next periods, a larger focus will be given to integral experiments or reactor applications. Eventually, all the knowledge will be accumulated in the ASTEC severe accident simulation code through physical model improvements and extension of validation database. This paper summarizes the progress that has been achieved in the frame of the networking activities. A special focus is placed on the melt pool and debris coolability and corium-concrete interaction, in which, the effects due to multidimensional geometries and heterogeneities has been shown, during SARNET, to play a crucial role and for which further research is still needed.*

I. INTRODUCTION

SARNET is the European Severe Accident Research Network of excellence. It structures the severe accident activities of more than 50 organizations throughout the European Union and Associated Countries. Within SARNET, the corium topic covers all the behavior of corium from early phase of core degradation to in- or ex-vessel corium recovery issues with the exception of corium interaction with water, direct containment heating and fission product release. *Corium* is a mixture that would be formed during a hypothetical severe accident by the melting of reactor fuel and the incorporation of surrounding materials: cladding, control rods, structural steel, and eventually reactor pit concrete or core-catcher sacrificial materials.

The SARNET Corium topic regroups a critical mass of competence - corresponding to about 50 full time researchers within 22 organizations throughout EU member states and associated countries - to significantly improve the knowledge of corium behavior. It has been organized in three work packages dealing respectively with (i) the early phase core degradation, (ii) the late in-vessel phases and vessel melt-through and, (iii) the ex-vessel phases. It corresponds to 11 of the 21 priority items still requiring research in severe accident listed by the PIRT exercise of the EURSAFE project[1]. This paper describes the major achievements of these research activities.

II. EARLY PHASE CORE DEGRADATION

II.A. Hydrogen generation during core reflooding

One of the main accident management measures in the early phase of a severe accident is to flood the degraded reactor core. This should provide quenching of the high temperature fuel but may have the adverse effect of rapidly generating hydrogen. The EU research on this topic is mainly organized around the QUENCH tests, performed at the Research Centre Karlsruhe (FZK)[2]. Figure 1 presents the state of the rod bundle after the QUENCH-12 experiment. In this test Zr-Nb cladding alloy typical of VVERs was subjected to conditions similar than the QUENCH-06 performed with Zircaloy cladding. Quite a different behavior has been observed comparing the 2 tests: a greater spalling of oxide scales and the release of 6 times more hydrogen during the reflood phase were the main differences.

In parallel to the experimental activities, considerable collaboration between the project partners has been devoted to pre- and post-test calculations [3], modeling and code benchmarking[4] activities.

Currently, the oxidation correlations used in Severe Accidents codes have been mainly established for Zircaloy-4, whereas advanced cladding with different alloying of zirconium are being used in reactors nowadays. Figure 2 presents for instance the appearance of some cladding materials after small-scale oxidation tests at FZK. It clearly shows quite different behaviors for the four tested zirconium alloys: Zircalloy-4, Duplex, M5 and E110. Consequently, there is a definite need to study these new materials with respect to their behavior during severe accidents.

Figure 1: The QUENCH-12 experiment. Observations of intense oxide scale spalling
Top: side view from corner rod B - Bottom: cross-sectional view at 500 mm

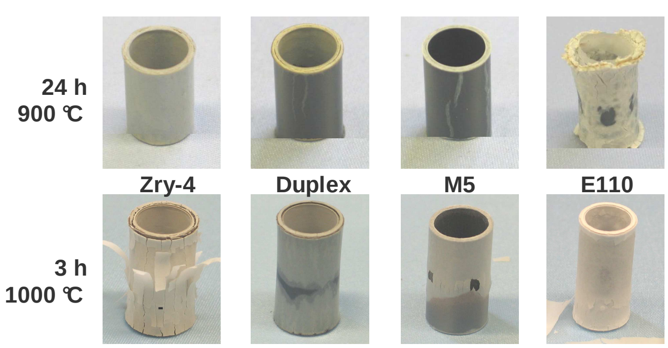

Figure 2: Appearance of cladding materials after oxydation in Ar-O_2 atmospheres

II.B. Early phase core degradation and B_4C effects

Even though this issue was not selected by the EURSAFE review[1], the need to study the effects of boron carbide on core degradation was one of the conclusions of the FP5 project COLOSS[5]. Significant improvement has been done for the early phase core degradation, in particular on the modeling of the B_4C oxidation taking into account analyses of Separate-Effect Tests (BECARRE in the VERDI furnace and BOX experiments[7]), out of pile (Quench 07/09 experiments) and In pile experiments (namely Phébus FPT3 test) regarding B_4C control rod behavior.

The main joint research activity is devoted to the interpretation of Phébus FPT-3 test [6]in which B_4C had been used in the bundle, as well as some interpretation of Quench 07/09 tests. Separate effect tests are conducted during the BECARRE program at IRSN Cadarache PICOLLO furnace on (B, C, Fe, Ni, Cr) liquid mixture, within the International Source Term Program.

The analysis of the H_2 release revealed very complex phenomena during the oxidation process including differents phases (such as preferential boron oxidation, bubbles and crust formation). As an illustration, Figure 3 presents the evolution of a steel – 5% B_4C mixture during a steam oxidation test at 1289°C with P_{steam}=0.43 bar and Q_{steam}= 60.5 g/L. During this test, bubbles were observed and a large H_2 peak that corresponded to liquid ejections.

A new oxidation correlation has been proposed by IRSN[8], based on the BECARRE experiments, the BOX experiments (FZK) and a literature review,.

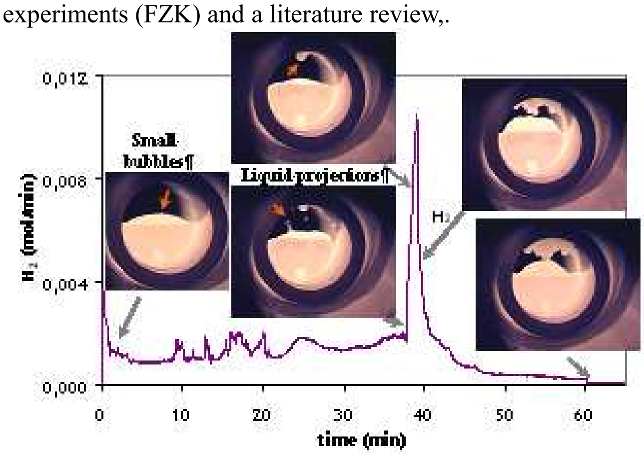

Figure 3: Phenomena observed in BECARRE during the oxidation of a steel - 5%B_4C mixture at 1289°C

II.C. Cladding oxidation by air or steam-air mixture

Whereas oxidation by air has only a secondary ranking for the core degradation, it is a key aspect of the high priority issue of fission product release during air ingress scenarios. In this case, there is a clear competition for oxygen consumption between the cladding, the fuel and the fission products – in particular ruthenium, which has a mostly-volatile oxide. In practice, the cladding is preoxidized before the air oxidation to take into account reactor scenarios.

Experimental small-scale programs have been launched at FZK, INR and IRSN to examine these phenomena and support the development of adequate models for the above physical processes. Several other institutions contribute to the work package with analysis and interpretation of the new experimental results, to improve air oxidation models. Assessment of models is done by bundle post-test calculations (QUENCH-10 and CODEX AIT, both involving an air ingress phase). The ultimate aim is to include these models in the ASTEC integral code.

Figure 4 presents for instance preoxidized CANDU Zircaloy-4 samples oxidized in humid air at various temperatures, in thermo-balance experiments performed at the Romanian Institute of Nuclear Research. A major difference between oxidation in air and in steam is that the oxidation is linear in air and parabolic in steam: this is due to the formation of nitrides that break the oxide scales. This effect is delayed and less pronounced in the case of preoxidized cladding.

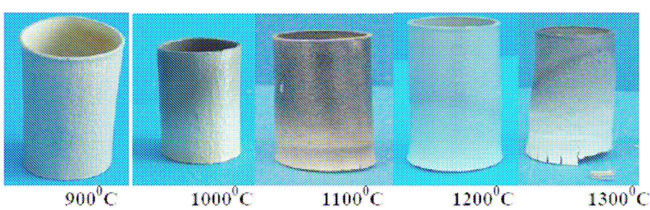

Figure 4: CANDU-type Zry-4 after oxidation in humid atmosphere at INR

III. LATE IN-VESSEL PHASES

III.A. Late phase core degradation and corium behaviour in lower head

The major experimental work currently performed for the late in-vessel phase is the LIVE experimental program at FZK. It is designed to study the formation and stability of melt pools in the Reactor Pressure Vessel.

During the LIVE-L1 test[9, 10], a molten KNO_3-$NaNO_3$ binary melt was homogeneously heated at several power plateaus over 28 hours. Heat fluxes and temperatures were measured throughout the test. At the end of the test, the liquid melt was removed, enabling the measurement of the crust thickness and crust composition analysis. The results present a clear enrichment in KNO_3, the refractory component of this binary melt. A second test has been conducted with a different pouring procedure (near the wall).

The ongoing posttest calculations have already provided interesting insights. For instance, the crust thickness is well predicted with the ACOPO correlation at large angles but is overestimated below 30°, i.e. the flux through the base is underestimated.

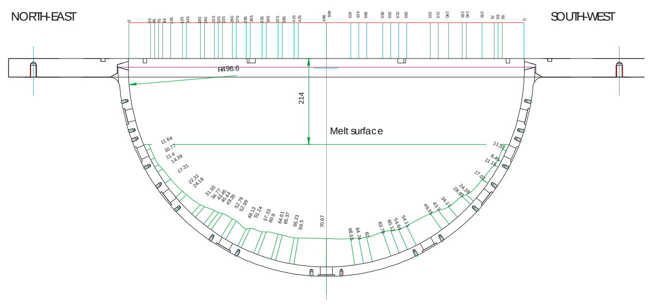

Figure 5: Crust thickness after LIVE L-1 test

In parallel to the experimental work, numerical work is performed in view of estimating the aerosol release from molten pools and to enable an accurate geometrical modelling of BWR lower heads (with numerous guide tubes) with reasonable calculation time, thanks to the Effective Conductivity Convectivity model.

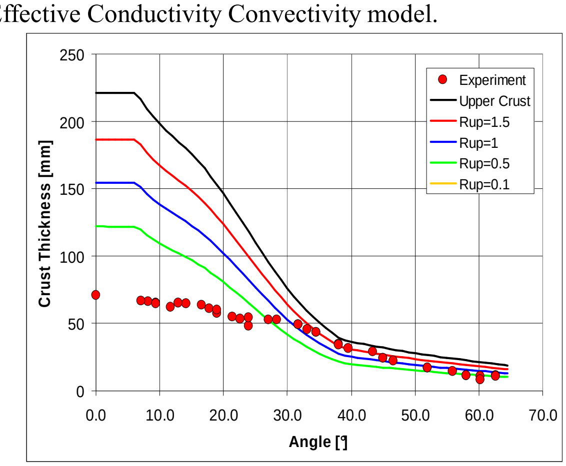

Figure 6: Comparison with experiment of LIVE L1 crust thickness estimated with the ACOPO correlation and various boundary conditions at the pool upper surface.

III.B. Vessel failure

During a severe accident, vessel integrity may be threatened by the heat from a molten corium pool. In the first two years of SARNET, the joint work on this topic had been mainly devoted to detailed discussion on the codes and models developed by the partners for creep rupture. Then a benchmark of the OECD-sponsored OLHF-1 experiment has been performed[10]. Figure 7 presents the comparison of the calculated vessel creep displacements, which were quite similar. Uncertainties remain, mainly in the knowledge of steel properties in the high temperature range and in the modeling of the crack evolution after failure. Currently a second benchmark has been launched on an EU-FOREVER test.

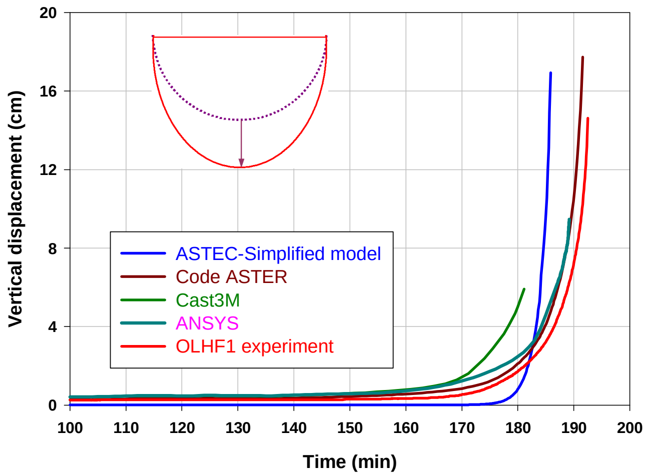

Figure 7: Comparison of OLHF-1 Calculations of the vessel displacement.

IV. EX-VESSEL PHASES

IV.A. Core and debris coolability during reflooding

Several experimental programs are running on core and debris coolability: DEFOR, DEBRIS, STYX, while IRSN is planning a new program.

On the modeling side, the WABE code (IKE) has been provided to VTT and KTH and some workshops have been held to transmit the knowledge. IKE and IRSN are discussing on the differences between their modeling approaches. Calculations on in-vessel reflooding via the downcomer by IRSN with ICARE/CATHARE V2 demonstrate that a highly degraded core at high temperature may be slowly quenched by a lateral inflow after being surrounded by water. Calculations of IKE with WABE showed similar effects for the lower head with non-homogeneous debris.

One of the new results achieved under SARNET concern the study of a heterogeneous, multidimensional debris bed where it appears that heterogeneity and multiodimensional effects can favor coolability[14, 22].

The major areas of work are:

- Realistic debris: Experimental basis.

  Experiments performed by partners in SARNET are:

- DEFOR (KTH):
  These experiments address especially the process of particulate debris formation from breakup of melt jets flowing into a water pool (Figure 8).

Figure 8: Sequence of melt pouring in water during a DEFOR test and typical debris bed.

- DEBRIS (IKE):
  A new experimental project has been started with the emphasis on verifying the constitutive laws (friction, heat transfer) under boil-off and quenching conditions, with top and bottom flooding. A stepwise approach to realistic debris has been adopted: spheres of different sizes, mixtures of spheres of different sizes, non-spherical particles, debris from breakup experiments (PREMIX, FZK; possibly also: DEFOR, KTH).
- STYX (VTT):
  Experiments with particle mixtures (sand fractions) considered to approach those of FARO debris. They have been performed under boil-off conditions with top flooding and previous experiments are now analysed.
- POMECO (KTH):
  Continued analysis on previous experiments and related scenarios are still being performed, with

emphasis on downcomer effects. New experiments are under discussion.

- SILFIDE (EdF):
  2D experiments under boil-off. Earlier results have been published in an NED special issue[14]. This programme has been terminated.
- Quenching experiments are planned at IRSN. The emphasis will lay on multidimensional effects, especially of sidewards water inflow into hot particulate debris, simulating, for instance, a degraded core flooded via the downcomer.

• Constitutive laws for friction and heat transfer in severe accident conditions are being verified through experiments, while joint calculations on the experiments and reactor scenarios are being performed. The major tools at present are ICARE/CATHARE applied by IRSN and the WABE-2D (IKE) module of ATHLET-CD. KTH and VTT use WABE for applications and the joint clarification and code improvement work. The final aim in the frame of SARNET is to propose an adequate modeling for ASTEC.

• The partners have laid different emphasis on validation work and reactor applications. Presently, IRSN examines the quenching of in-vessel states, especially of a degraded and hot core. KTH presently emphasizes particulate debris formation and multidimensional cooling features as well as effects of bed heterogeneities under boil-off condition, especially related to BWR ex-vessel scenarios with flooded cavity. Validation is mainly related to POMECO experiments and comparison with WABE results. VTT is analyzing STYX results by use of WABE, thus they concentrate on particle mixtures and boil-off of a top-fed bed. Reactor applications are also envisaged. IKE is involved in boil-off as well as quenching analyses for experiments and reactor scenarios, particularly on multidimensional behavior but also the equations required in the multidimensional codes. It is intended to combine the different works and draw conclusions. An attempt to combine, including other areas of work (as e.g. MCCI) in an extended international partnership has already been done: The NED special issue on debris coolability[14] finalised in 2006.

IV.B. Molten-Core Concrete Interaction (MCCI)

Among SARNET partners, there are five MCCI facilities:

▪ HECLA[18] in VTT is devoted to transient metal-concrete interaction test.
▪ SICOPS in AREVA Erlangen uses a high-frequency induction furnace ("cold" crucible) for the generation and sustained heating of the oxidic corium melt. The inside of the crucible holds a concrete cylinder with embedded zirconia samples.
▪ COMET in FZK is a facility in which large masses of high temperature simulants could interact with concrete. A benchmark has been conducted on COMET L2 and L3 tests. COMET has been decommissioned in 2006.
▪ VULCANO[18] in CEA Cadarache is a facility dedicated to long-term (2-4 hours) interaction of prototypic corium with concrete. In 2006, the first VULCANO test with molten oxides and metals has been performed[16]. A unique feature of this facility is that, thanks to electro-magnetic shielding, it is possible to generate more than 80 % of the sustained heating in the upper oxidic layer, as for corium decay heat.

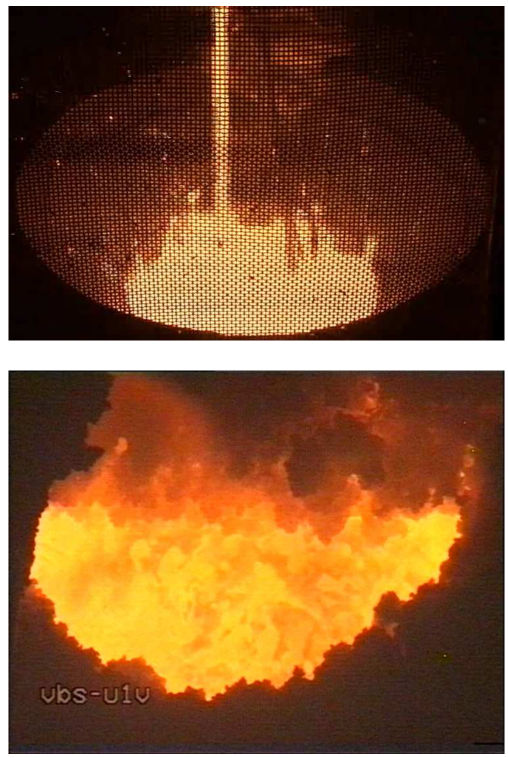

Figure 9: Corium pools during the HECLA-1 (up) and VULCANO VBS-U1 (down) tests

▪ ARTEMIS[12] in CEA Grenoble is a facility using a binary mixture of BACl2-LiCl salts at 1000 K. Specific probes allow the measurement of the interfacial temperature at the melt-crust interface, in a 1D or a 2D configuration.

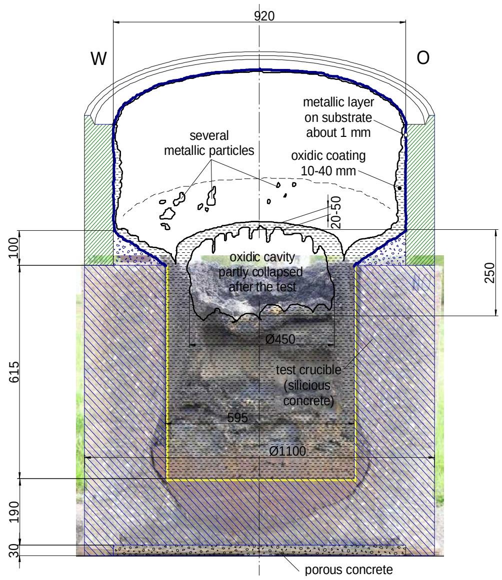

Figure 10: Final shape of the COMET L2 cavity

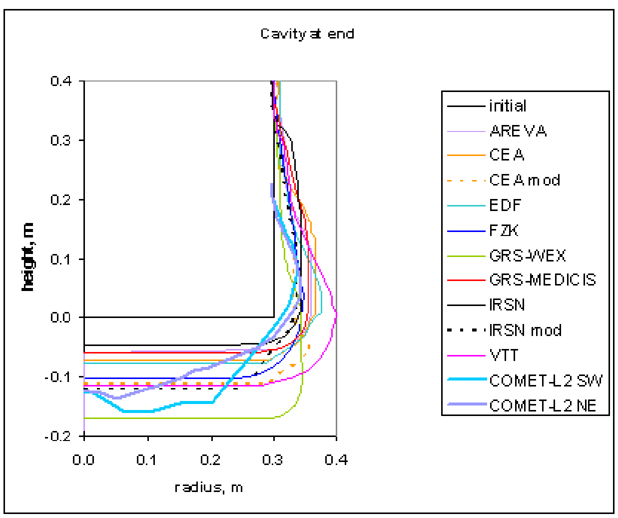

Figure 11: Benchmarking of computed COMET L2 final ablation profiles

At the start of SARNET project, there were no data on 2D MCCI experiments with prototypic material. Recent tests show an anisotropic ablation of silica-rich concretes and isotropic ablation for limestone-rich concretes. Recent information provided by the ISTC CHESS project indicates that anisotropic ablation by corium of Chernobyl granitic (silica-rich) concrete on a larger scale has also been observed.

One of the main remaining issue for MCCI is linked to the understanding of the phenomena creating this effect, both for oxidic corium and metal-oxides configurations.

Several hypotheses have been proposed to explain this behavior, but a predictive model has yet to be constructed and demonstrated. The benchmark on the COMET L2 experiment[18] (Figure 10) shows that there is still a significant scatter between the different codes (Figure 11). A new benchmark has been then launched. It is devoted to the calculation of reactor scale MCCI in order to assess the relevance of the uncertainties, found at experimental scale.

The second open issue with MCCI lies with the concrete ablation by a corium pool made of oxidic and metallic layers. New results at the VULCANO facility[16] coupled to simulant-material experiments and metal-concrete interaction tests at VTT shall provide insights to these configurations.

This issue has been ranked at a high priority level by SARNET Severe Accident Research Priority group[20]. Clearly, it affects the retention in the third barrier. Applied to reactor cases, the various models can lead to large uncertainties (ratio of 3 or more) on the ablation rate. Further research is thus necessary that will include both global and analytical tests.

IV.C. Ex-Vessel Corium Coolability

The major means to cool corium is by water flooding. The WABE-2D code developed by IKE, but also used by KTH, can model the processes occurring during cooling, including the formation of water channels in a corium pool. Whereas top cooling is not very efficient due to the presence of counter-current water-steam flows, bottom cooling is a much more efficient approach. The COMET core-catcher concept, developed by FZK, has been tested with prototypic corium melt and sustained heating at CEA Cadarache[21], and is currently being calculated with WABE at IKE.

In the calculation for Figure 12, the initial thickness of melt layer was 28 cm, according to the experiment. It increases by porosity formation. Melt layers are considered to be obtained by spreading of corium, as also foreseen for the EPR core catcher. Joint activities have been launched in order to propose and validate a simplified spreading model for ASTEC. In the EPR concept rapid cooling by water injection (as in the COMET concept) is not envisaged but confinement of the melt within top and bottom cooling boundaries.

KTH studies the use of "downcomers" that will allow for the flow of water from the top to the bottom of the corium layer and have modeled the POMECO experiment with WABE 2D[22].

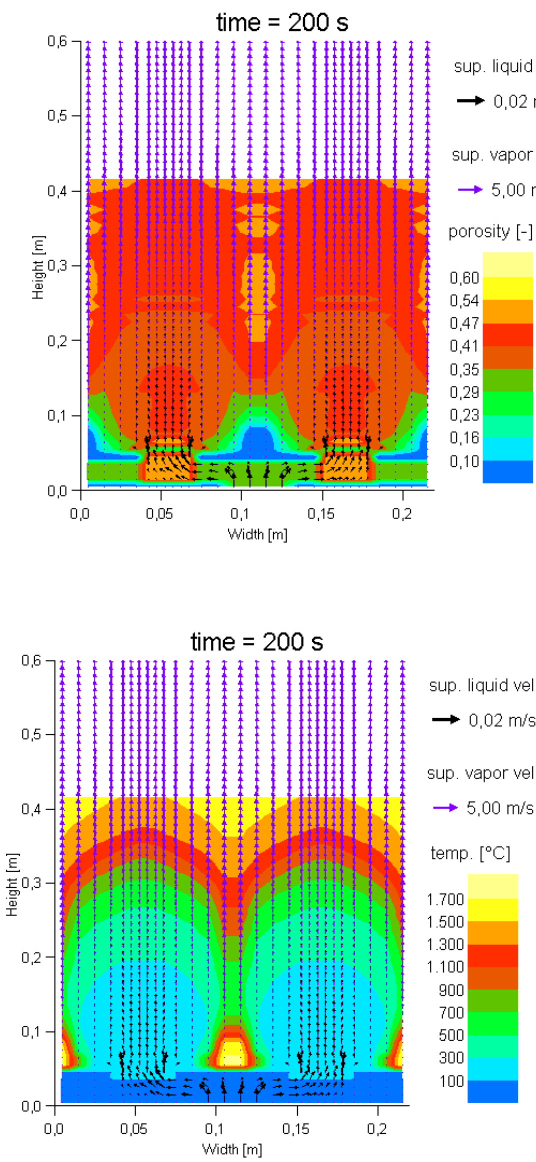

Figure 12: VULCANO VW-U1 test of the COMET concept – WABE 2D Calculations
top: porosity and bottom: temperature (1500 C: solidus temperature) after 200s.
(sup. = superficial, vel. = velocity)

V. CORIUM MATERIAL PROPERTIES

Corium is a complex multicomponent high temperature material and its properties are relatively badly known. Therefore, there is a generic need to improve our knowledge of its properties. Regarding the thermophysical properties, it is planned to compare the data gathered for LWR applications in ASTEC or during previous EC-sponsored projects as ECOSTAR [23] with those collected for CANDU applications.

Thermodynamic properties of corium need also some assessment and improvements. Most of our current knowledge is stored in the NUCLEA Database, developed within the ENTHALPY project[24]. Recent experiments have been performed at ITU to improve our knowledge of the U-Zr-O subsystem, which is the basic system of in-vessel cases (Figure 13). Tests have been performed at UJV for ex-vessel corium applications in the UO_2-SiO_2 system. Posttest analysis of corium experiments performed in the PLINIUS platform also contributes to the validation of the database [25, 25]. Finally, the ISTC CORPHAD project also provides useful information. In order to qualify the corium material analyses, a round-robin exercise has been performed between material analysis laboratories at CEA Cadarache, ITU Karlsruhe and UACh Rez on a sample from a VULCANO MCCI test.

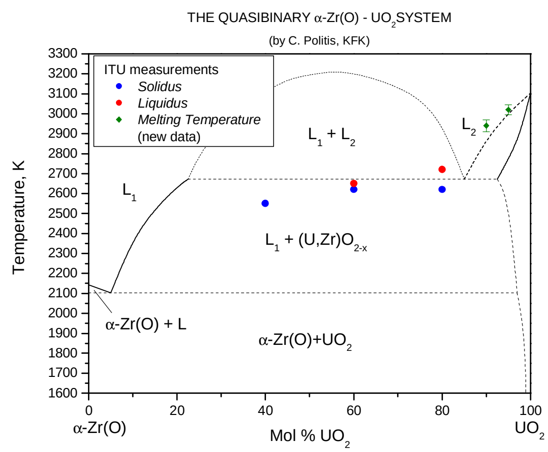

Figure 13: αZr(O)-UO_2 pseudo-binary diagram, with ITU experimental results

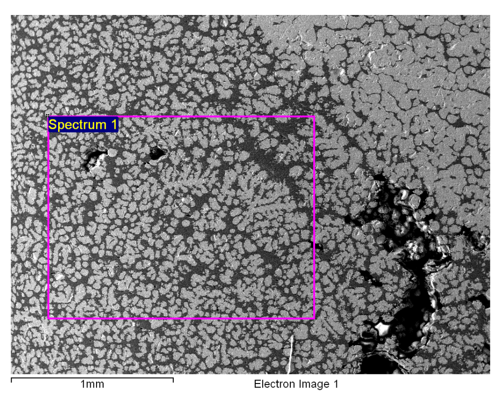

Figure 14: SEM Micrograph of a VULCANO VB-U6 sample performed by ITU within the round robin near the boundary between a corium-rich (right) and a concrete-rich (left) liquid.

VI. CONCLUSIONS AND PERSPECTIVES

Thanks to SARNET, an intense networking of research teams working on corium issues has been achieved in the last years. As a result, our knowledge of severe accidents has been improved trough experimentation, modeling and computer simulation. This includes:

- Understanding of the oxidation phenomena in steam and in air, validation of oxidation correlation. The importance of material composition has been demonstrated. Further research is required on new cladding materials, especially in relation to the hydrogen and fission product source term issues.
- Collection of data on B_4C oxidation, thanks to experiments at FZK and IRSN, which allows a consistent modeling of this phenomenon and a common interpretation of the integral test Phébus FPT3, as well some analyses of Quench 07/09 experiments.
- The launching of the late-in-vessel LIVE experiments has started a new series of modeling and analytical work.
- The different models of vessel failure by creep rupture have been compared and a common understanding of the OECD OLHF-1 test has been achieved. Modeling of the crack evolution remains to be done.
- 2D debris bed coolability analyses for inhomogeneous bed structures showed an increased coolability compared to earlier 1D particle beds. This launches a new interest in this issue both experimentally and numerically including a pursuit of the debris bed formation and its characteristics of coolability importance.
- Likewise, the recent 2D Molten Core Concrete Interaction test resulted in unexpected results with a marked ablation anisotropy for silica-rich materials. Interpretation and modeling of this behavior must be pursued.
- Core catcher concepts based on spreading (EPR) and bottom flooding (COMET, downcomers) are being studied and progress has been achieved in their modeling.

In summary, the large R&D efforts devoted by SARNET partners to corium issues have led to significant achievements and some of the issues are about to be mostly closed. Nevertheless, pursuing research on the issues related to corium-concrete interaction and to corium and debris coolability is still needed and should be part of continuation of the SARNET program.

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REFERENCES

1. D. Magallon, A. Mailliat, J.-M. Seiler, K. Atkhen, H. Sjövall, S. Dickinson, J. Jakab, L. Meyer, M. Buerger, K. Trambauer, L. Fickert, B. R. Sehgal, Z. Hozer, J. Bagues, F. Martin-Fuentes, R. Zeyen, A. Annunziato, M. El-Shanawany, S. Guentay, C. Tinkler, B. Turland, L.E. Herranz Puebla, "European expert network for the reduction of uncertainties in severe accident safety issues (EURSAFE)", Nucl. Eng. Des., 235, 309-346, 2005.

2. M. Steinbrück, ed., "Proceedings of the 12th International QUENCH Workshop, FZ Karlsruhe, ISBN 987-3-923704-57-6, 2006.

3. J. Birchley, T. Haste; C. Homann, W. Hering, "Pre-Test Analytical Support for Experiments QUENCH-10, -11 and –12", Nuclear Energy in New Europe, Portoroz, Slovenia, 2006.

4. A. Stefanova, P. Groudev, J. Georgieva, L. Sepold, M. Steinbrück, J. Stuckert, W. Hering, Ch. Homann, G. Guillard, F. Fichot, J. Duspiva, W. Erdmann, T. Hollands, T. Drath, M. K. Koch, G. Bandini, "Benchmark exercise on QUENCH-11 experiment", 2nd European review Meeting on Severe Accidnet research, ERMSAR2, Karlsruhe, 2007.

5. B. Adroguer et al., "Core Loss during a Severe Accident (COLOSS)", Proc. FISA-2003.

6. G. Repetto, O. De Luze, J. Birchley, T. Drath, T. Hollands, M. K. Koch, K. Trambauer, "Preliminary analyses of the PHÉBUS FPT-3 experiment using SA codes (ATHLET-CD, ICARE/CATHARE, MELCOR)", ERMSAR2, Karlsruhe, 2007.

7. M.S. Veshchunov, A.V. Berdushev , A.V. Boldyrev , A.V Palagin , V.E. Shestak., M. Steinbrück, J. Stuckert, "Modelling of B4C oxidation by Steam at high Temperatures based on Separate-effects Tests and its Application to the bundle Experiment QUENCH-07", report FZKA 7118, 2005.

8. N. Seiler, F. Bertrand, O. Marchand, G. Repetto, S. Ederli, "Investigations on Boron Carbide oxidation for Nuclear Reactors Safety – General Modelling for ICARE/CATHARE code applications", Nucl. Eng. Des., 238, 820-836, 2008.

9. A.Miassoedov, , T. Cron, J. Foit, B. Fluhrer, S. Schmidt-Stiefel, T. Wenz, "Results of the LIVE-I1 commissioning test on molten pool behaviour in the lower head of the RPV", Proc. Jahrestagung Kerntechnik, Karlsruhe, 22.-24.Mai 2007.

10. A. Miassoedov, T. Cron, J. Foit, S. Schmidt-Stiefel, T. Wenz, I. Ivanov, D. Popov, "Results of the LIVE-L1 experiment on melt behaviour in RPV lower head performed within the LACOMERA project at the Forschungszentrum Karlsruhe", 15th Internat. Conf. on Nuclear Engineering (ICONE-15), Nagoya, Japan, 2007 .

11. V. Koundy, F. Fichot, H.-G. Willschütz, E. Altstadt, L. Nicolas, J.S. Lamy, L. Flandi, "Progress on Lower Head Failure Predictive Models", ERMSAR2, Karlsruhe, 2007.

12. J.M. Veteau, "ARTEMIS Program: Investigation of MCCI by Means of Simulating Material Experiments", *6th International Congress on Advances in Nuclear Power Plants*, Paper 6034, Reno, Nevada, 2006.

13. C.T. Tran, T.N. Dinh, "An Effective Convectivity Model for Simulation of In-Vessel Core Melt Progression in Boiling Water Reactor", International Conference on Advances in Nuclear Power Plants, ICAPP-2007, Nice, France, 2007.

14. Nuclear Engineering and Design, Special Issue on "*Core melt accidents in LWRs, State of the art of "Coolability of Porous Debris"*", Volume 236 (19-21), October 2006.

15. B. Spindler, K. Atkhen, M. Cranga, J. Foit, M. Garcia, W. Schmidt, T. Sevon, C. Spengler, "COMET L2-L3 benchmark", ERMSAR2, Karlsruhe, 2007.

16. C. Journeau, P. Piluso, J.F. Haquet, S. Saretta, E. Boccacio, J.M. Bonnet, "Oxide-Metal Corium – Concrete Interaction test in the VULCANO facility", Proc. ICAPP '07, Nice, France, 2007.

17. M. Fischer, S. Hellmann, J.-M. Bonnet, C. Journeau, B. Tourniaire, J. M. Seiler, H. Alsmeyer, M. Bürger, S. Park, "European experimental activities on the coolability of molten corium and its interaction with concrete and ceramic material", European review Meeting on Severe Accident Research, ERMSAR, Aix en Provence (2005).

18. C. Journeau, J.-M. Bonnet, E. Boccaccio, P. Piluso, T. Sevón, P. H. Pankakoski, S. Holmström, J. Virta, "Current European Experiments on Molten Core Concrete Interaction : HECLA and VULCANO", ICAPP'08, Anaheim, Ca., 2008.

19. M. Farmer, M. T. Farmer, S. Lomperski D. Kilsdonk, R. W. Aeschlimann, S. Basu, "A Summary of Findings from the Melt Coolability and Concrete Interaction (MCCI) Program, ICAPP07, Nice, France, 2007.

20. K. Trambauer, B. Schwinges, "Evaluation of Research Priorities in the Frame of SARNET", ERMSAR2, Karlsruhe, 2007.

21. C. Journeau, H. Alsmeyer, "Validation of the COMET Bottom-Flooding Core-Catcher with Prototypic corium", Int. Congr. Advances nuclear Power plants (ICAPP06), Reno, NV, June 4-6, 2006.

22. W.M. Ma and T.N. Dinh, M. Buck, M. Bürger, "Analysis of the Effect of Bed Inhomogeneity on Debris Coolability", Pr*oc. of the 15th International Conference on Nuclear Engineering*, ICONE15-10472, Nagoya, Japan, 2007.

23. Journeau, C., Piluso, P., Frolov, K.N., "Corium Physical Properties for Severe Accident R&D", ICAPP'04, Int Congr. Advances Nucl. Power Plants, Pittsburgh, Pa., USA, 2004.

24. A. de Bremaecker et al., "European Nuclear Thermodynamic Database for In- & Ex-Vessel applications (ENTHALPY)". Proc. Symposium FISA 2003, EU Research in Reactor Safety, Luxembourg, 2003.

25. C. Journeau, F. Sudreau, S. Magne, G. Cognet, "Physico-chemical analyses and solidification path reconstruction of multicomponent oxidic spread melts", *Mater. Sci. Eng.,* **299**, *1-2*, 249-266, 2001.

26. C. Journeau, P. Piluso, "Uncertainties on Thermodynamic and Physical Properties Data Bases for Severe Accidents and their Consequences on Safety Calculations", OECD Workshop on Evaluation of Uncertainties in relation to Severe Accidents and Level 2 PSA, Aix en Provence, 2005.