



The progress of ALISA project Access to Large Infrastructures for Severe Accidents in Europe and in China

X. Gaus-Liu, A. Miassoedov, C. Journeau, Y. Liao, N. Cassiaut-Louis

► To cite this version:

X. Gaus-Liu, A. Miassoedov, C. Journeau, Y. Liao, N. Cassiaut-Louis. The progress of ALISA project Access to Large Infrastructures for Severe Accidents in Europe and in China. The 8th European Review Meeting on Severe Accident Research - ERMSAR-2017, May 2017, Varsovie, Poland. hal-02418119

HAL Id: hal-02418119

<https://hal.science/hal-02418119>

Submitted on 18 Dec 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

The Progress of ALISA Project: Access to Large Infrastructures for Severe Accidents in Europe and in China

X. Gaus-Liu^{a,*}, A. Miasoedov^a, C. Journeau^b, Y. Liao^c, N. Cassiaut-Louis^b

^a Karlsruhe Institute of Technology (KIT), Hermann-von-Helmholtz Platz-1, 76344 Eggenstein-Leopoldshafen, Germany

^b The Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA), France

^c China Nuclear Power Technology Research Institute(CNPRI), Jiangsu building, Yitian Road, Shenzhen 518026,PR China

Abstract

The ALISA project: Access to Large Infrastructure for Severe Accidents, is a unique project between European and Chinese research institutions in the area of severe accident research. The project provides mutual access to large research infrastructures for European organizations and Chinese partners, thus allow the optimal use of the resources in the extremely complex field of several accident analysis. Eight operative facilities from six Chinese research organizations are provided access to European users and six facilities from KIT and CEA are provided access to the Chinese partners. The Project started on July 1st, 2014 and has four years duration. Two runs of call for proposals have been undertaken in the past project period, followed by evaluation and selection of proposals by the User Selection Panel of the opposite side. Thus till November 2016, all the facilities in Europe and 6 facilities in China have received proposals. That means, the European facilities, namely QUENCH, LIVE, DISCO, HYKA from KIT, and KROTO, VITI from CEA, have received approved proposals from Chinese partners; and the Chinese facilities, namely COPRA from Xi'an Jiaotong University (XJTU), HYMIT and WAFT from Shanghai Jiaotong University (SJTU), and IVR2D, IVE3D from CNPRI and MCTHBF from Nuclear Power Institute of China (NPIC), have received proved proposals from European users. The nature of most Chinese proposals reflects the high demand to check the safety design of their own reactor type. Since some EU and Chinese proposals investigate similar phenomena but with different scale and geometry, such like LIVE and COPRA, HYKA, HYMIT and MCTHBF, the comparison of the test results will provide a broader range of applicability. Some other proposals investigate different aspects of a same severe accident strategy, such as LIVE and IVR2D/IVR3D. The combined knowledge from the experiments can provide comprehensive understanding of the phenomena of in-vessel melt retention with external cooling.

Till November 2016, three tests have been successfully performed. HYKA test series and HYMIT test were related with hydrogen issue in containment, and KROTO test in CEA was focused on the Fuel Coolant Interaction. Reporting work is undergoing. Other tests are now in detailed planning, most of them are planned at different time in 2017.

Keywords: ALISA, severe accident experiments

1. Introduction

Severe accidents are the focus of intensive research in reactor safety due to its significant potential of serious damage. The release of radioactive products could have consequences beyond the boarder of a nation where an accident occurs, therefore collaborations among nations are crucial in order to share best-state knowledge on severe accident phenomenology, qualified computer tools and appropriate methodology [1]. This research also reflects a commitment to the defense-in-depth approach. In the framework of the Severe Accident Research Network of Excellence (SARNET), a common view on the ranking of the research priorities in the field of severe accident were prepared and six high priority issues on severe accident management have been identified [2].

The complex nature of these phenomena demands the development of specific research. Therefore optimized use of resources and the collaboration at international level is very important. The main thrust of ALISA project (Access to Large Infrastructures for Severe Accidents) is towards large-scale tests under prototypical conditions. These experiments will help the understanding of core degradation, melt formation and

*Corresponding author

Email address: xiaoyang.gaus-liu@kit.edu (X.Gaus-Liu)

relocation and core coolability in real reactors by scaling-up, as well as by providing data for the improvement and validation of computer codes applied for safety assessment such as ASTEC, MELCOR, MAAP, which are the tools to guide accident mitigation concepts.

The importance of the ALISA project for the European and Chinese severe accident research is reflected in three aspects:

- 1) The access to large scale experimental facilities enable to investigate most important processes from the early core degradation to late in-vessel phase pool formation in the lower head, continuation to ex-vessel melt situations and to the hydrogen behavior in the containment.
- 2) The results of the project will be applicable both to the European and Chinese reactor taking into account the main Light Water Reactor (LWR) types.
- 3) The project offers a unique opportunity for Chinese experts to get an access to large-scale facilities in Western research organizations and vice versa, to improve understanding of material properties and core behavior under severe accident conditions, and to become familiar with the high-level safety concepts in nuclear power plants of the other side.

2. The management of the ALISA Project

ALISA period starts on July 2014, and has a duration of 4 years. NPIC becomes a new member in the project since November 2016. Thus up from November 2016, there are two European partners, and six Chinese partners in the ALISA project. The European partners are Karlsruhe Institute of Technology (KIT) and Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA). The Chinese partners are as following:

- China Nuclear Power Technology Research Institute (CNPRI)
- Hong Kong City University (CityU HK)
- Shanghai Jiao Tong University (SJTU)
- Xi'an Jiao Tong University (XJTU)
- State Nuclear Power Software Development Center Company (SNPSDC)
- Nuclear Power Institute of China (NPIC)

The major aim of ALISA is to offer severe accident experimental facilities in the European Union for Chinese scientists and experimental facilities in China for scientists working in the European Union and EURATOM Associated Countries. For the potential users of chinese facilities, two calls for proposal were widely distributed. The first call were widely published among EU organizations per Email on February 20, 2015, and the second call on January 11, 2016. In parallel same actions were undertaken by ALISA Chinese project manager. The content of call for proposals includes the rule for access, the technique details of facilities, contact person, and formular for proposal submission. Submitted proposals from Chinese partners were assessed by an European User Selection Panel. A globally symmetrical scheme applies for European Union (and Associated States) users proposing experiments in China. After proposal selection, the experimental details were discussed between users or user groups and the corresponding facility operators.

The selected experiments in China were funded by the Chinese project, while the experiments in Europe (for Chinese users) were funded by the EURATOM FP7 project.

The updated EU and Chinese facilities to access up from November 2016 are ordered in the following sub-work package:

- WP1.1 In vessel corium coolability:
 - QUENCH (KIT) - Large-scale tests on the early and late phases of core degradation
 - LIVE (KIT) - Large-scale tests on behaviour of the corium melt pool
 - IVR (CNPRI) - 2D in-vessel retention test facility
 - IVR3D (CNPRI) -3D 1:5 scaled vessel external cooling facility
 - COPRA (XJTU) - 2D large scale in-vessel corium pool research apparatus
 - VITI (CEA) - Small-scale corium thermos-physical properties or thermochemistry tests
 - CIS (NPIC) -2D full scale ERVC facility
- WP1.2 Ex-vessel corium coolability
 - DISCO (KIT) - Large-scale tests on melt dispersion and on direct containment heating
 - KROTOS (CEA) - Medium-scale fuel coolant interaction tests
- WP1.3 Containment behaviour
 - HYKA (KIT) - Hydrogen safety test facilities
 - FUSAM (CNPRI) - Containment thermal-hydraulic and hydrogen distribution
 - HYMIT (SJTU) - Mid-scale hydrogen behavior test facility
 - WAFT (SJTU) - Water film test facility
 - MCTHBF (NPIC) - Mid-scale containment thermal hydraulic and hydrogen behavior

As a result of the first call for proposals, six proposals were submitted by EU organizations for the experiments in Chinese facilities, of which 2 were for the COPRA facility, and one proposal for each of the IVR, REPEC-II, GADOC and HYMIT facilities. Four European facilities (KROTOS, LIVE, QUENCH and HYKA) were addressed in the experimental proposals submitted from Chinese organisations.

After the second call for proposals, three proposals on VITI and one on DISCO facility were submitted. For the Chinese facilities, proposals on each of WAFT and IVR3D were principally accepted; one proposal on COTHYD was suggested to be swifited to MCTHBF with revision due to the delay of commisioning of COTHYD. The facility owner of MCTHBF in NPIC has agreed this suggestion. Since GADOC facility is out of operation, the proposal on GADOC is replaced by an alternative proposal on IVR3D, which investigates the same phänomea.

The large number of proposals from both EU and Chinese organizations demonstrates a high interest in the severe accident issues covered in the WP1.1. Till November 2016, two experiments in European facilities and one experiment in Chinese facilities were successfully performed. They are HYKA test in KIT and KROTO test in CEA, and HYMIT test in SJTU. Other experiments are undergoing intensive preparation. Most of these experiments are foreseen to be conducted in 2017.

3. Proposed ALISA experimental programs

3.1 Experimental programs in European facilities

- QUENCH- Large-scale tests on the early and late phases of core degradation experiment proposed by XJTU

Bundle experiments in the QUENCH facility are designed to study the early and late phases of core degradation in prototypic geometry for different reactor designs and different cladding alloys [3]. Hydrogen release during reflooding of a test bundle with genuine core inventors and interaction of core materials degradation mechanisms in different gas environment are the emphasis of research. QUENCH experiments can provide comprehensive data for model development and subsequent implementation into Severe Fuel Damage (SFD) computer codes.

In the proposed QUENCH tests, AP1000 bundle design with peroxidation and air ingress were defined. The bundle is consisted of twenty heated rods with M5 cladding, two pressurized unheated rods and two absorber rods. The heating procedure is similar as in QUENCH16. The maximum temperature before quenching is limited to 1773K. A flow of water of 50g/s initiates the quenching, hydrogen production and temperature escalation. Intensive experimental preparation is undergoing. Pretest calculations have been performed. The delivery of the expensive absorb tubes can be finally settled. The experiment is planned on the first half of 2017.

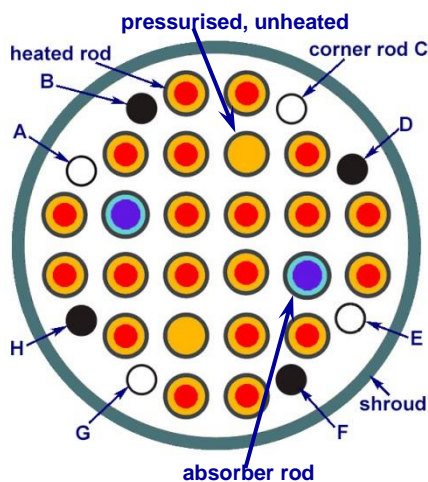


Figure 1 Proposed QUENCH test bundle

- LIVE - Large-scale tests on corium melt pool behaviour in lower head, proposed by CNPRI

The main objective of the LIVE program is to study the late in-vessel core melt behavior and core debris coolability both experimentally in large scale 2D and 3D geometry and in supporting separate-effects tests [4] [5]. The main part of the LIVE-3D test facility is a 1:5 scaled semi-spherical lower head of a typical pressurized water reactor. Binary melts composed of KNO_3 and NaNO_3 were selected as simulant melts for the experiments both in non-eutectic mixture of 80 mole% KNO_3 –20 mole% NaNO_3 and in eutectic mixture of 50 mole% KNO_3 –50 mole% NaNO_3 . Transient and the steady state behaviour of a simulated corium pool can be

investigated with top cooling or top insulation condition. The information obtained from the LIVE experiments includes heat flux distribution along the reactor pressure vessel wall in transient and steady state conditions, crust growth velocity and influence of the crust formation on the heat flux distribution along the vessel wall.

The proposal on LIVE3D investigates the heat transfer of melt pool under three different top boundary conditions. Top insulation with unfrozen melt surface, cold air flashing and rigid top cooling with water and frozen melt surface are proposed as top boundary conditions. The experiment should answer the critical issue of the influence of top boundary condition on the upward and downward heat splitting, the melt temperature distribution and the pool turbulent pattern. There are no special difficulties in the preparation. The experiment will be performed in 2017.

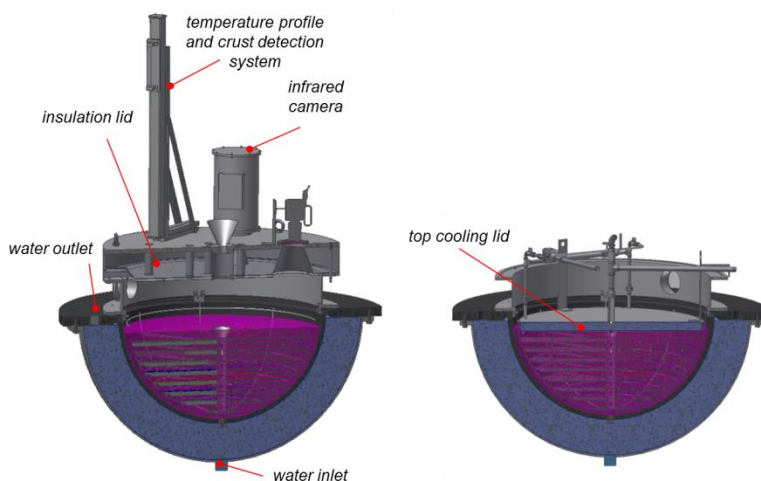


Figure 2. LIVE test facility with top insulation (left) and top cooling (right) conditions

- DISCO - Large-scale tests on melt dispersion and on direct containment heating, proposed by SNPSDC

The DISCO experiments are designed to investigate the fluid-dynamic, thermal and chemical processes during melt ejection out of a breach in the PWR pressure vessel lower head [6]. The addressed issues include pressure and temperature excursion in containment, hydrogen production, distribution and combustion in containment, final location of corium debris. The main facility containment is linearly scaled in 1:18 to a large PWR containment. The RCS and the reactor pressure vessel (RPV) are modelled by a vertical pipe with a volume of 0.08 m³. The breach in the lower head is modelled by a graphite annulus at the bottom, which is initially closed with a brass plate. The reactor pit is made of concrete and installed inside a strong cylindric steel vessel. The horizontal cooling line with flow path to the equipment rooms is simulated with steel cylinders with a scaled annular space models. The equipment room arrangement can be adjusted to the reactor design being investigated. Thermite powder of aluminum and iron oxide is used as the corium melt. The experiment is started by igniting the thermit at the upper surface. During the igniting period, the pressure can arise to 2 MPa and the temperature of the iron-alumina to 2100 °C. About 3 to 6 seconds after ignition the brass plug at the RPV bottom is melted and that initiates the melt ejection. The melt is driven out by steam and is dispersed into the cavity and beyond.

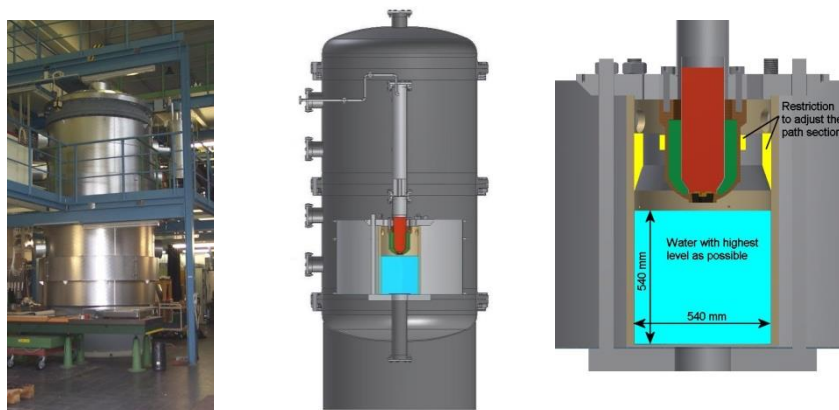


Figure 3. DISCO faciity and the design of DISCO FCI experiment

The experiment planned in the ALISA project should address the melt ejection out of an AP-1000 reactor pressure vessel into a water-filled channel between the RPV and insulation in the reactor cavity. The experiment investigates Direct Containment Heating (DCH) as well as Fuel Coolant Interaction (FCI). The experiment will complement the results of previous similar DISCO-FCI tests in different geometry and should provide insights on the melt ejection into a small reactor cavity. Steam explosion can occur, however the risk for the facility was considered as low due to the strength of the facility construction and the probability of its occurrence (no external triggering and limited mass of melt). Obtained results will be used to validate and refine the models used in the CosMetric code used at SNPSDC.

- HYKA- Hydrogen safety test facilities, proposed by SJTU

HYKA provide a number of large test vessels to investigate containment safety and hydrogen combustion [7]. In HYKA it is possible to investigate the whole spectrum of hydrogen phenomena. Research on different hydrogen sources and their distribution behavior can be conducted, as well as experiments with different ignition sources. One of the most attractive features of HYKA is the capability for well-controlled medium to large scale combustion experiments, covering all three combustion regimes, i.e. slow and fast deflagration and detonation. Stagnant or controlled air flow conditions can be simulated in horizontal or vertical orientation. The high vessel design pressures allow test parameters also beyond safety considerations.

The largest safety vessel A2 with main dimensions of 6 m in inner diameter and 9 m in height provides an empty test volume of about 220 m³. It is designed for fire and explosion tests with an operating pressure up to 10 bar. The vessel may be evacuated by vacuum pump or filled with inert atmosphere of nitrogen or steam and may be heated up to 150 °C. The vessel is equipped with many vents and ports for experiment and measurement set-ups as well as with windows for visual observations. It has three vents of 2000 mm id, four vents of 700 mm id, five vents of 400 mm id and about 40 vents of smaller inner diameters (50-250 mm). The measuring system consists of thermocouples array (gas temperature, flame arrival time); piezoelectric and piezoresistive gauges (initial pressure, explosion pressure); gas analyzer and mass spectrometer (to control mixture composition); sonic hydrogen sensors, photodiodes and ion probes (flame arrival time, flame speed), strain gauges (deformations). The data acquisition system is based on multi-channel (64) ADC with a sampling rate of 1 MHz.



Figure 4. View of the HYKA A2 vessel

The subjects of ALISA HYKA experiments are: a) the effect of mixture non-uniformity and ignition position on flame propagation regimes and maximum combustion pressure in comparison with uniform mixture of the same amount of hydrogen; and b) the ignition/extinction phenomena in presence of steam and/or water mixture. HYKA-A2 facility was involved. The dynamics of the combustion process are measured with the temperature, pressure, acoustic and optical observation using Background Oriented Schlieren Method (BOS). The ignitor test will have a hydrogen concentration of 10%-12%, certain proportion of steam and normal air. The PAR test will have a hydrogen concentration of 2%-5%, certain proportion of steam or aerosol and normal air. The ignitor and PAR will be chosen from that used in AP1000/EPR/Hualong type reactors. Four test campaigns were successfully conducted from June to September in 2016.

- KROTOS-Medium-scale fuel coolant interaction tests, proposed by City University Hong Kong

KROTOS facility is dedicated to fuel coolant interaction (jet fragmentation, debris formation, steam explosion, etc.) [8] [9]. The facility consists of four main parts: the furnace, the transfer channel, the test section and the X-Ray radioscropy system. The furnace is a water cooled stainless steel container designed to withstand 4 MPa pressure. It is equipped with a three-phase cylindrical heating resistor made of tungsten. In order to avoid heat losses, the heating element is surrounded by a series of concentric reflectors and closed by circular lids made of molybdenum. A tungsten crucible is hanged inside the heating element; its net volume is 1 liter and allows the melting of up to 6 kg of corium. The facility is developed to operate in inert atmosphere or vacuum at temperatures up to 2800 °C. The transfer channel is a vertical tube connecting the furnace and the test section. A fast hydraulic ball valve is positioned at the top and melt release cone are placed at the bottom of the transfer channel. The test section consists of a pressure vessel with a test tube inside. Both are made of strong tempered 7075 aluminum alloy, characterized by low attenuation of X Ray radiation. The pressure vessel is provided with a number of feed-through for gas connections, instrumentation and a view window. The test tube is a free standing cylinder filled with water. Its internal diameter is 0.2 m; its height is 1.6 m. A pressurized gas trigger (150 bars) is positioned at the bottom to activate the steam explosion after the premixing phase of the Fuel Coolant Interaction. Both the chamber and the test tube are heavily equipped with instrumentation in order to follow the premixing, the propagation and the explosion phases and thus to provide maximum information on FCI.

The X-Ray radioscropy system has been specifically developed to trace the fragmentation of the melt within the coolant in three phases (water, void and melt). The 9 MeV X-Ray produces collimated beams that cross the test section and a high sensitivity digital video camera captures the images. In order to obtain full information on the fragmentation process, the vertical position of the X-Ray radioscropy system can be changed between experiments to the desired level.

KROTOS test in the ALISA project has been successfully conducted on November 17th, 2016. 5.2 kg of corium (80 wt.% UO₂, 20 % ZrO₂) have been melted and heated to a measured temperature of 2790 °C. Corium has been successfully released and poured in the 645 mm deep water pool at an initial temperature of 60°C. The data is currently being analysed and processed. A meeting between CEA and Hong Kong City University and a KROTOS facility visit are planned in February 2017 to finalize the post-test activities.

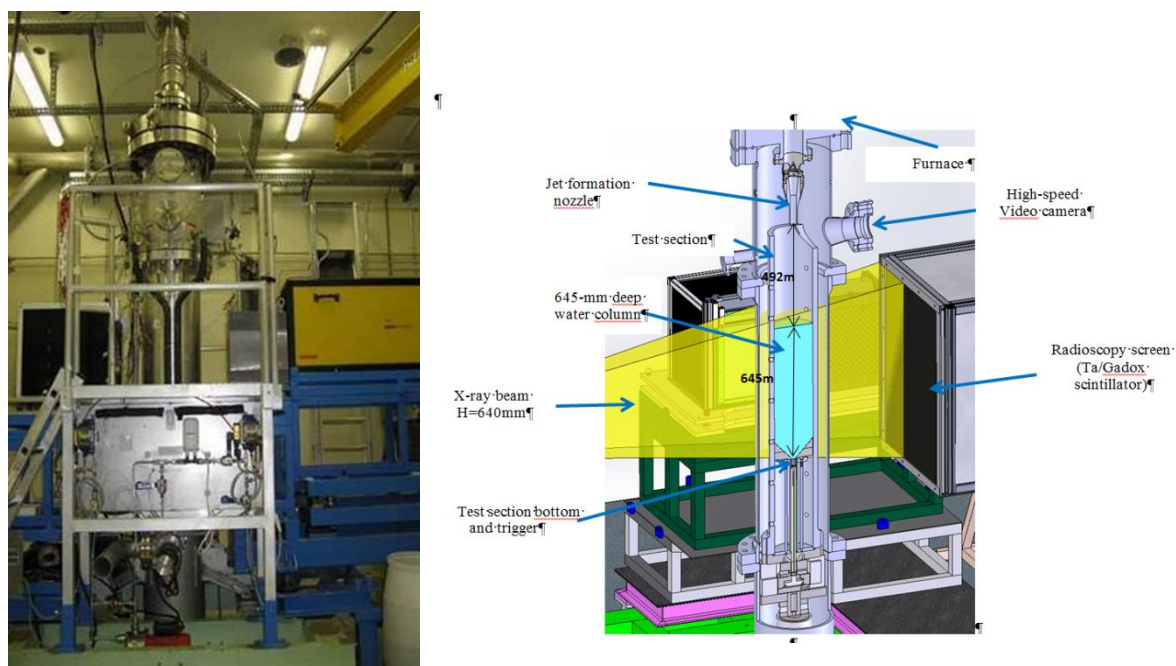


Figure 5. KROTOS facility

- VITI (CEA) - Small-scale corium thermos-physical properties or thermochemistry tests, three proposals submitted by CNPRI and HK CityU.

The VITI facility has been developed to perform viscosity and surface tension measurements on corium by aerodynamic levitation up to 2500 °C for small mass [10]. The experimental techniques are crucible heating and levitating droplet technique for contactless measurements of thermophysical properties. VITI facility allows studying solidification process of corium oxide melt (from 1000 K up to 3000 K) at different atmospheres (reductive, neutral and oxidant) in various ranges of temperatures. The sample is put in a crucible of suitable material. The aerodynamic levitation configuration enables to obtain thermo-physical properties of materials.

The liquid droplet stands on a thin (<100 nm) gas film passing through a graphite pressurized porous membrane (diffuser). A second graphite membrane (pressing membrane) stands above the droplet and is moved to reach the required pressing amplitude. The droplet is then relaxed by mechanically releasing the pressing graphite membrane, and the relaxation time constant to the equilibrium state is measured. No contact occurs between the drop and both membranes. The sample is heated by thermal radiation from the inductively heated graphite susceptor. The coupling of these two sources of heating limits thermal gradient inside the droplet. A bi-chromatic pyrometer is used to measure surface temperature of the droplet between 1300 K and 2800 K and two video cameras allow to measure precisely and continuously the radius of the droplet. Density is deduced from droplet volume; surface tension is obtained from droplet shape while viscosity is deduced from the relaxation time obtained by processing of the high speed video. Online gas spectroscopy measurements are performed.

In the ALISA project the VITI facility will be used to determine corium properties for three different sample compositions, including one composition from the corium used in the ALISA-KROTOS test described in the previous section and two corium-concrete compositions identified by Chinese partners. Two samples can be analyzed in 2017 and one in 2018.

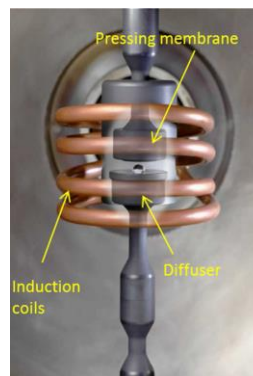


Figure 6. Aerodynamic levitation in the VITI facility

3.2 Experimental programs in Chinese facilities

- IVR2D - 2D in-vessel retention test facility, proposed by KIT

The two-dimensional IVR facility is designed to investigate the External Reactor Vessel Cooling (ERVC) of the lower plenum of RPV in order to achieve in-vessel melt retention. The objectives of the experiment are the identification of Critical Heat Flux (CHF) along the outer wall of RPV, optimization and verification of the flow channel, the characteristics of two-phase flow in different flow conditions, the effect of coolant additives on CHF, etc. Test data are of great significance for the mechanical research and engineering application of the reactor pit flooding system. The test facility is a 2D facility in 1:1 scale with a 7.6 m high nature circulation loop. 24 heating sections generate a maximum heating power of 1.2 MW, corresponding 2.4MW/m².



Fig. 7. View of the IVR-2D facility

The objective of the experiment planned in the IVR-2D facility focuses on the influence of the penetrations in the RPV lower plenum on the natural convection and CHF. The test will be performed at two different heat flux

distribution profiles in the lower head, including a melt pool with two layers (metal atop of the oxide), which is a critical issue especially for high-power reactors. The experiment will be conducted in the second half of 2017.

- IVR3D -3D 1:5 scaled vessel external cooling facility proposed by CEA/EDF/IRSN

IVR3D test facility will study three-dimensional vessel external cooling under integrated reactor component mode. The aim is to compare CHF under different cooling channel geometries and two-phase flow patterns of the coolant. The research program includes a) investigation of two-phase coolant circulation process of natural convection, venting and condensation and b) determination of the CHF in 3D geometry. The facility is now under construction and will be put into operation in 2017. The 1:5 scaled RPV lower head has a wall outer diameter of 0.92 m and a height of 1.68 m. The total height of the facility is 2.8 m. The simulation of RPV wall heat flux is realized with copper heating block bordered with stainless steel outer surface. The maximum heat flux of 1.8MW/m² can be realized. The instrumentation includes high-speed camera, temperature measurement at different level and the high-frequency pressure sensors.

The IVR-3D test in the ALISA project will study the effects of the influence of non-symmetrical top conditions due to venting and non-symmetrical gap around the RPV on the CHF. The experiment is planned in middle 2018.



Figure 8. IVR3D test facility

- COPRA - full scale in-vessel melt behavior, combined proposals by EDF/CEA/IRSN and by KIT

The COPRA facility is designed to study the natural convection heat transfer in corium pools with high Rayleigh numbers up to 10^{16} [11]. The test vessel is a two-dimensional 1/4 circular slice. With an inner radius of 2.2 m, it simulates full scale for CNNC's ACP-1000. The inner width of the slice is 20 cm. All the vertical walls of the vessel are kept thermally insulated. The curved vessel wall thickness is 30 mm and is enclosed with a regulated external cooling path. The top surface of the vessel is either in adiabatic boundary condition with an insulated upper lid, or be cooled by a specially designed cooling device.

The main objective of the proposed experiment is to gain knowledge about the transient evolution of a layer evolving towards steady-state convection. The background is the lacking knowledge of the melt pool transient heat transfer. In the tests two steady-state boundaries are supposed: a) adiabatic boundary condition on the top of the pool and adiabatic boundary condition on the side at the beginning of the experiment, and b) after a defined time, the curved vessel wall boundary is changed quickly to isothermal condition by flooding. The lateral heat flux, related to the lateral Nusselt number, the evolution of pool temperature, and the time required to reach fully established convection are the main interests of the investigation. The test results can be compared with BALI experiments due to the similar geometry and with LIVE tests due to the same simulant material. The tests are planned in 2017.



Figure 8. Test vessel of the COPRA facility

- HYMIT- Mid-scale hydrogen behavior test facility, proposed by Ivo Jozef Stefan Institute

The HYMIT facility is a medium-scale hydrogen mitigation test facility designated for investigations of hydrogen recombination and combustion behavior. The facility is designed to test the characteristics of current available ignitor and passive autocatalytic recombiners (PAR) as well as new hydrogen mitigation technologies. It can operate with hydrogen concentrations between 0 and 30 vol.%, as well as steam concentrations between 0 and 50 vol %. The main part of the facility is a steel cylinder tank which is 4 meters high and 2 meters in diameter. The tank volume is about 12 m³. The content of gas mixture, gas temperature and pressure and speed of flame can be measured with gas analyzer, thermocouple arrays, piezoelectric pressure sensors and photodiode array respectively.

The focus of the ALISA experiment is hydrogen deflagration with upward flame propagation in a homogeneous air-steam-hydrogen atmosphere. The purpose of the experiment was to perform a test with conditions similar to the ones in previous experiments in other vessels, with a similar shape but a larger volume: THAI vessel, with a volume of 60 m³, and HYKA A2 vessel with a volume of 220 m³. This will enable the investigation of the influence of scaling from small to large volumes on the characteristics of hydrogen deflagration (eventually leading to adequate modelling of hydrogen deflagration in containments of real nuclear power plants), as well as to further develop theoretical models of flame propagation.

The experiment was conducted successfully on October 17, 2016. A homogeneous mixture of air, hydrogen and steam was ignited at the vessel centre line, near the vessel bottom. Hydrogen burning did occur. The combustion was almost complete, as the measured final hydrogen concentration at three different points was less than 0.1 vol.%.



Figure 9. HYMIT test vessel

- WAFT (SJTU) - Water film test facility, proposed by GRS

The WAFT facility is dedicated to study Passive Containment Cooling System (PCCS) of GEN-III plants. The facility consists of a stainless plate (5 m long, 1.2 m wide) mounted on a metallic frame allowing for plate inclination. The surface of the plate undergoes a preparation by painting with organic zinc to maintain designated wettability. The plate surface is heated by heating oil, and the power can reach 100 kW/m^2 . A parallel plate 30 cm apart from the test plate with visualization windows constitutes a part of a rectangular channel which enables the simulation of the air gap between the containment steel envelope and the metallic baffles in the reference passive reactor design. A blower at the bottom of the channel simulates the natural circulation air flow occurring in the reference plant conditions. Variation of the reference air velocity from 0 to 12 m/s is allowed. The water film distribution box is mounted on the top of the facility to ensure uniform water film distribution of the inlet. The water film and air temperatures are measured with thermocouples, and water film thickness is measured with optical sensor, air flow velocity is measured with hot-wire anemometer, the surface wave velocity is measured with high-speed camera, and heat flux is measured with heat flux sensors.



Figure 10. WAFT facility (left) and test section (right).

The experiment planned in the ALISA project will investigate the formation of rivulets (change of wetted surface fraction). The results will be used for the validation of the applied minimum energy principle used inside existing rivulet model of the COCOSYS code. Additional investigation of specific boundary conditions will include film boiling to validate heat transfer model under these conditions and “closed chimney” (no atmospheric flow) to validate heat transfer model under steam rich bulk conditions.

- MCTHBF (NPIC)- Mid-scale Containment Thermal Hydraulic -Hydrogen Behavior Test Facility, proposed by JSI

MCTHBF is a midsize Hydrogen Mitigation Test facility. The main part is a steel cylinder tank which is 5 meters high and 2.8 meters in diameter. The tank volume is about 21 m³. It is designated to test the hydrogen recombination and combustion behavior. The mixed gas content, gas temperature and pressure and speed of flame can be measured with gas analyzer, thermocouple array, piezoelectric pressure sensors and photodiode array. It can deal with hydrogen concentrations between 0 and 35 vol.%, as well as steam concentrations between 0 and 40 vol %.

The proposal on MCTHBF investigates stratification of atmosphere containing hydrogen in the upper part of the vessel and a low-momentum vertical air jet. The topic of studies includes scaling from small to large volumes by comparing results of other previous experiments and validation of lumped-parameter and Computational Fluid Dynamics codes.

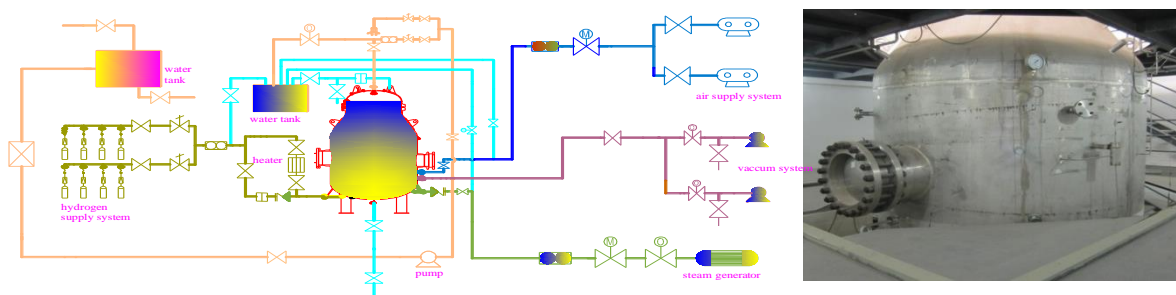


Figure 10. MCTHBF test system

4. Conclusion

Transnational access to large research infrastructures allows the optimal use of the R&D resources in Europe and in China in the complex field of severe accident analysis for existing and future power plants. ALISA project provides large-scale experimental platforms in Europe and in China for transnational access. The major aspect is to understand how the severe accident issues affect the safety of existing and future reactors and how to deduce soundly-based accident management procedures. The aim is not only to understand the physical background of severe accidents but to provide the knowledge that can help to reduce the severity of the consequences.

Due to strong links to other European projects, ALISA offers a unique opportunity for all partners to get involved in the networks and activities supporting safety of existing and advanced reactors and to get access to large-scale experimental facilities in Europe and in China. The ALISA project allows European and Chinese researches to work together so as to arrive at a wider common safety culture. By doing this, the project also helps to diffuse the European culture of research and innovation as a support to regulatory and industrial decision making both in Europe and in China.

Till November 2016, the 30 month of the project period, two runs of call for proposals were undertaken. A wide range of EU organizations have participated proposal submission. A large number of the potential users are joint partners, demonstrating the well-established collaboration among EU organizations. All the European facilities and most of the Chinese facilities have received proposals. Three experiments have been successfully conducted in 2016; the others are undergoing intensive preparation.

ACKNOWLEDGMENTS

The authors gratefully acknowledge funding by Euratom and CAEA to support the work within ALISA project.

Reference

- [1] C. Journeau , Y. Liao, H. Zhang, A. Miassoedov, W. Tian, K. Bo and X. Gaus-Liu, "Access to Large Infrastructure for Severe Accidents in Europe and in China. The ALISA Project.," The 7th European Review Meeting on Severe Accident Research (ERMSAR-2015), 2015.

- [2] W. Klein-Hessing, M. Sonnenkalb, D. Jacquemain, B. Clement, G. Dimmelmeier, G. Azarian, A. Herranz Pelbla, A. Schumm, L. Herranz Puebla, A. Miassoedov, I. Kljenak, G. Pascal, S. Bechta, S. Güntay, M. Koch, M. Koch, I. Ivanov, A. Auvinen and I. Kindolm, "Conclusions on severe accident research priorities," *Annual Nuclear Energy*, vol. 74, pp. 4-11, 2014.
- [3] M. Steinbrück, M. Grosse, L. Sepold and J. Stukert, "Synopsis and outcome of the QUENCH experimental program," *Nuclear Engineering and Design*, vol. 240, pp. 1714-1727, 2010.
- [4] X. Gaus-Liu and A. Miassoedov, "LIVE Experimental results of melt pool behaviour in the PWR lower head with insulated upper lid and external cooling," in *ICONE21*, Chengdu, 2013.
- [5] A. Miassoedov, T. Cron, X. Gaus-Liu, A. Palagin, I. S. Schmidt-Stiefe and T. Wenz, "LIVE experiments on melt behaviour in the RPV lower head.," in *8th International Conference on Heat transfer, Fluid Dynamics and Thermodynamics HEFAT2011*, Mauritius, 2011.
- [6] L. Meyer, G. Albrecht, C. Caroli and I. Ivanov, "Direct containment heating integral effects in geometries of European nuclear power plants," *Nuclear Engineering and Design*, vol. 239, pp. 2070-2084, 2009.
- [7] T. Jordan and W. Breitung, "FZK methodology for analysis of hydrogen behaviour in containments," in *Proc. of Conference on Numerical Flow Models for Controlled Fusion*, Porquerolles, 2007.
- [8] I. Huhtiniemi and D. Magallon, "Insight into steam explosions with corium melts in KROTOS," *Nuclear Engineering and Design*, vol. 204, pp. 391-400, 2001.
- [9] N. Cassiut-Louis, "X-Ray visualization and quantitative measurements of the premixing phase during KROTOS corium water interaction experiments," in *Proc. of IEEE International conference on Advancements in Nuclear Instrumentation Measurement Methods and Their Applications (ANIMMA)*, Marseille, France, 2013.
- [10] P. Piluso, J. Moneris, C. Journeau and G. Cognet, "Viscosity measurements of ceramic oxides by aerodynamic levitation," *Int. J. Thermophysics*, vol. 23, pp. 1229-1240, 2002.
- [11] Y. Zhang , L. Zhang, Y. Zhou, W. Tian, S. Qiu, G. Su, B. Zhao, Y. Yuan and R. Ma, "Natural convection heat transfer test for in-vessel retention at prototypic Rayleigh numbers-Results of COPRA experiments," *Progress in Nuclear Energy*, pp. 80-86, 2016.