Group: Severe Accident Research

SAR/ITES research activities in 2020

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In 2020, the research activities of ITES/SAR were focused on the analyses and mitigation of severe accident of boiling water reactor (BWR) and the construction of a new facility ESFR-LIVE as a task in the EU Horizon2020 project ESFR-SMART.

In-vessel melt and debris retention is also a defense-in-depth strategy during the course of a severe accident scenario of BWR. The Fukushima-Accident reminds the urgent necessity of a melt retention concept specialized for the BWR reactor design. External cooling by flooding the reactor cavity, the most studied one in the past, could be functional for Pressurized Water Reactors (PWR), characterized by a small reactor pit and low position of the Reactor Pressure Vessel (RPV) in the cavity. It is not suitable for BWR with a deep und large cavity. On the other hand, the lower plenum of a BWR has a dense array of control rod guide tubes (CRGTs), which penetrate the RPV bottom vertically to the cavity. CRGTs can contribute to the cooling of a relocated debris bed or a molten pool in the lower plenum in two ways: a) cooling inside the corium by the water-cooled CRGTs and b) directing water via CRGTs to the top surface of the corium to enable top cooling. The cooling effects of CRGTs both in a non-molten debris bed and in a molten pool were experimentally simulated in the LIVE3D test facility [1]. The test configurations simulated different scenarios: no cooling at all, cooling only by CRGTs and cooling by CRGTs together with external wall cooling. 16 CRGTs are simulated and were arranged in 4 groups. The tubes were mounted on an upper lid with water distribution system, and inserted vertically approaching the bottom of the vessel. Figure 1 shows the tube inside.the vessel and the water distribution system at the upper lid.

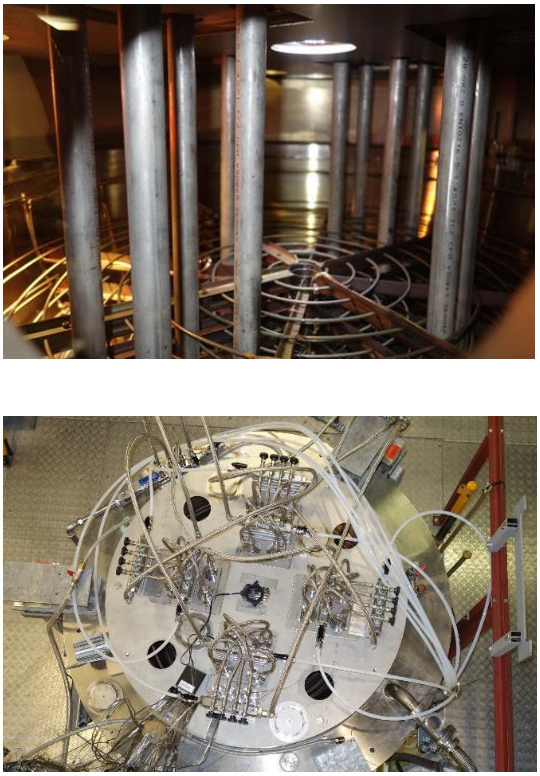

Figure 1. LIVE-BWR tests with simulants of CRGTs.

The heating and cooling of debris were performed in 6 phases, in each of which there was a high power period and a low power period, as shown by Ptotal in Figure 4, right diagram. The external water cooling were only performed in the phase 5 and phase 6 with the combination of CRGT cooling. During the high power period, the CRGT cooling could only remove a part of the power, with the consequence that the debris temperature arise continuously. During the low power period, the CRGT tubes could effectively reduce the debris bed temperature and mitigate the thermal load on the vessel wall. The cooling of CRGT tubes was more effective in a molten pool, as shown in the Figure 2, bottom. The heat removal rate via CRGT is as effective as the external cooling.

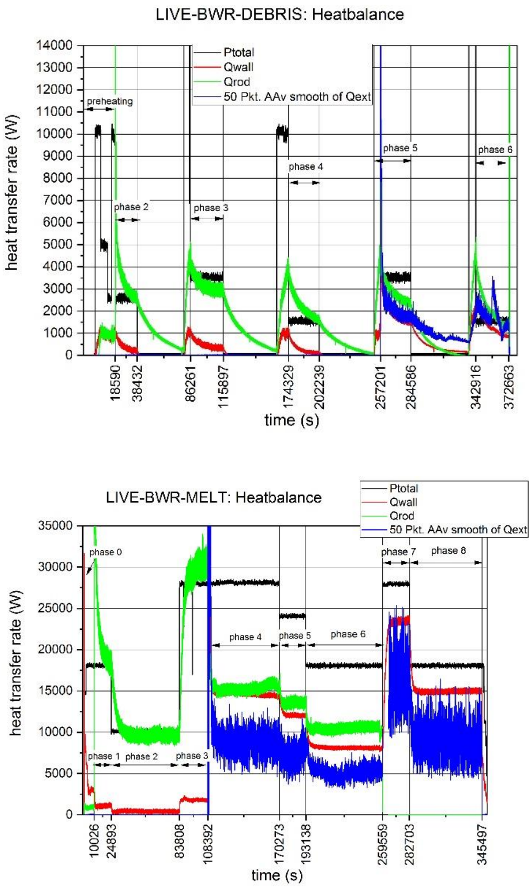

Figure 2. Power input (Ptotal) and heat transfer via CRGT tubes (Qrod) and via external cooling (Qwall). Top: Debris test, Bottom: molten pool test.

Another experiment was the investigation in melt-down of a debris bed with heterogeneous materials. This experiment was assigned by the JAEA /CLAD laboratory with the aim to understand the accident scenario of Unit 2 Fukushima accident and thus accomplish safe decommissioning of the Fukushima Daiichi Nuclear Power Station [2]. Till present, few experiments investigate a meltdown process of debris bed consisting of materials with different melting temperatures. Two experiments were performed on the LIVE3D facility: LIVE-J1 and LIVE-J2 tests. LVE J1 investigates the melt down of debris, whereas LIVE-J2 investigates a corium of debris and liquid melt with and without external cooling.

The important outcome of LIVE-J1 tests are a) the ongoing shrinkage of debris bed volume and height during the melt-down of the particles with low melting point; b) the shift of hotspot in the debris bed and thermal load on the vessel wall from bottom toward the upper region during the melting. Figure 3 shows the debris bed before and after meltdown process.

Figure 3. Appearance of initial debris bed (top) and the debris bed after the test (bottom) in LIVE-J1 test.

The third accomplishment of SAR group in 2020 is the design and construction of a new large-scale 3D vessel, ESFR-LIVE imitating the geometry of the core-catcher of a sodium cooled fast reactor (SFR) in a diameter scale of 1:6 [3]. The core catcher has the function to collect the relocated melt derived from the upper core area and to prevent local thermal attack of melt on the reactor vessel. The thermodynamics of the melt with decay heat and its heat transfer at the core catcher boundaries will be studied experimentally at KIT and numerically at CEA. The facility will be in commissioning in middle of 2021. The ESFR-LIVE test vessel simulates the typical tray geometry of an in-vessel SFR core catcher, whose cavity has a geometry of truncated cone in the lower part, and cylinder in the upper part. The inner diameter of the upper cylinder is 1 m.

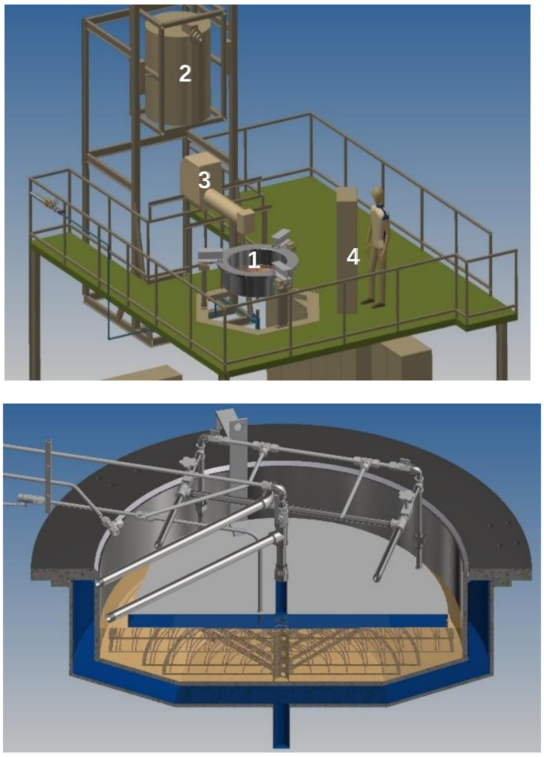

Fig.4. Top: LIVE experimental platform with ESFR-LIVE facility. 1- ESFR test vessel, 2 - heating furnace for melt preparation, 3 - pouring spout, 4 - instrumentation board. Bottom: ESFR-LIVE test vessel with all boundary cooling system.

Four planes of resistance heating element are designed to simulate the decay heat of the corium. Two planes are located in the truncated cone (HE1 and HE2) and the other two are located in the cylindrical part (HE3 and HE4). The upper two heating planes can be removed individually to enable different pool heights at the top boundary. The total heating power can reach 86.5 kW. The flexibility of the heating planes enable a large variety of the pool geometries, e.g. possible by shutdown the one or two of the lower heaters. Correspondingly, bottom crust grows upwards till the level of the lowest heater in operation. The high power provided also make it possibly for experiments with high decay power, such as debris dryout experiments.

Two experimental series in ESFR-SMART project are foreseen in 2021. The experimental data will be used for the validation of the numerical calculations with TriCAD code in CEA and for analytical analysis done by KIT and CEA.

To be published:

[1] Fluhrer, B.; Gaus-Liu, X.; Cron, T.; Stängle, R.; Vervoortz, M.; Wenz, T.; LIVE-BWR EXPERIMENTS TO STUDY THE EFFECT OF CRGT COOLING ON IN-VESSEL MELT RETENTION STRATEGY, The 19th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-19), Brussels, Belgium, March 6 - 11, 2022

[2] Madokoro, H.; Gaus-Liu, X.; et.al.; LIVE-J1 EXPERIMENT ON DEBRIS MELTING BEHAVIOR TOWARD UNDERSTANDING LATE IN-VESSEL ACCIDENT PROGRESSION OF THE FUKUSHIMA DAIICHI NUCLEAR POWER STATION, The 19th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-19), Brussels, Belgium, March 6 - 11, 2022

[3] Gaus-Liu, X. ; Bigot, B.; Journeau, C.; Payot, F.; Cron, T.; Clavier, R.; Peybernes, M.; Angeli, P. E.; Fluhrer, B.; Experiment and Numerical Simulations on SFR Core-catcher Safety Analysis after Relocation of Corium, CN291-IC336, #FR22, International Conference on Fast Reactors and Related Fuel Cycles Fr22: Sustainable Clean Energy for the Future (CN-291), 25-28 April 2022, Beijing, China.