Steering Committee Meeting of the ISTC #3831 Large Scale MCCI project –development grant at VNIIEF Offices in Nizhny Novgorod, Russia, 26-27th January 2010

Present

Collaborators	**VNIIEF, Sarov, Russia**
David Bottomley - ITU Karlsruhe	Alexei Kondrashenko
Juri Stuckert – KIT Karlsruhe	Mikhail Mochalov
André Fargette – AREVA-ANP-Erlangen	Viktor Peshkov
Kreshna Atkhen –Electricité de France (EDF) Lyon	Anton Blikov
Christophe Journeau – CEA Cadarache	Stanislav Peleskov

Albert Gozal – ISTC Moscow

Introduction

This was the final meeting of this Project Development Grant (just one week before the end). This meeting had originally been scheduled in November between the 2nd and the 3rd tests so that the experience of the results to date could be incorporated into the final test. However it had been called off at very short notice as there were delays in the 2nd test but also entry permits to the town of Sarov, where VNIIEF is sited, had been withheld. This was very annoying for all the collaborators, nevertheless a proposal was made to hold a meeting at the end of January 2010 in the VNIIEF offices in Nizhny Novgorod just as all tests had been completed. They would also be able to bring the test pieces with them to Nizhny Novgorod. This suggestion was accepted by the PDG (Project Development Grant) collaborators. The project reporting was done on the first day and a meeting with OKBM was held at the VNIIEF offices during the 2nd day to exchange information about activities and identify potential areas of interaction/collaboration in the reactor safety field.

The aim of the Large Scale MCCI Project was to perform three 1000 kg tests have the meeting at of a UO_2 –ZrO_2 corium and study its interaction with concrete. The Large Scale MCCI project was to cost about 980k$ (in 2008). A 9 month project development grant (from 1st May 2009 to 31st Jan 2010 of 98k$ or 10%) was offered to develop the technique and perform three MCCI tests of a medium scale 60 to 100 kg of corium melt and using a ZrO_2-FeO melt to avoid export control problem (as would be the case if it had contained UO_2) . There had been an early preparatory meeting in Moscow in 2007 and then a more detailed discussion of the technical aspects at the ISTC in Moscow in May 2008 before the PDG grant. Then there had been an initial project meeting at the ISTC Moscow in July 2009 to consider the results of the first test and refine the technique. The latter considered the type of thermocouples to use and their exact positioning.

Final Test Description

VNIIEF have developed a chemical heating technique (PTC – PyroTechnic Compound) using briquettes made by pressing together Zr and Fe2O3 powder (d=50mm & h=20mm of 120g) that are wrapped in Al foil. The reaction 3Zr +2Fe2O3 = 3ZrO_2 + 4Fe generates the heat (2840 kJ/kg - with a useful energy release of ~900 kJ/kg). This should generate a melt of 62%ZrO_2 & 38% Fe that would react with the concrete. The concrete selected was 2/3 limestone and 1/3 siliceous. The idea behind this choice is to favor an isotropic ablation profile (induced by the large amount of CO_2 released by the concrete). Any ablation artifacts could therefore be detected. The concrete crucible (60cm diameter & 70cm height) is cast complete with an array of thermocouples already in the concrete. The central cavity is 40 cm diameter and 55 cm height: the wall thickness is therefore 10cm and the bottom 15cm thick.

The thermocouples are mainly type K with 2 high temperature W/W-Re thermocouples. The Type K thermocouples were positioned along each of 3 radii of the crucible bottom at depths of 5cm, 10cm, 20cm, 25cm, and 30cm (see Fig. 1). There were a total of 32 K-type thermocouples (20 inside the crucible bottom and 12 inside the crucible sidewall) these were unable to resist the high temperatures of the melt and were mainly used to follow the advance of the ~1300°C isotherm (upper limit of K-type thermocouple) through the degrading concrete. There were 2 W/W-Re thermocouples which were positioned in center of the concrete cavity bottom on the boundary between melt and concrete. Three pyrometers were also installed inside crucible bottom (see Fig.1). They had high temperature metal (W, Ta, Mo) plates on top of steel tubes set in the bottom of the concrete crucible flush with the surface of the concrete bottom. They were positioned equidistant from each other & the centre, close to the centre of the cavity. There were glass optical fibre cables inside the steel tube, aimed at the refractory metal plate and able to measure by pyrometry the temperature of the plate and therefore the interfacial concrete/corium temperature.

There were also two video cameras monitoring the progress of the melt and its growth from a horizontal position and from a vertical position; the latter viewed the surface via a mirror positioned directly above the crucible.

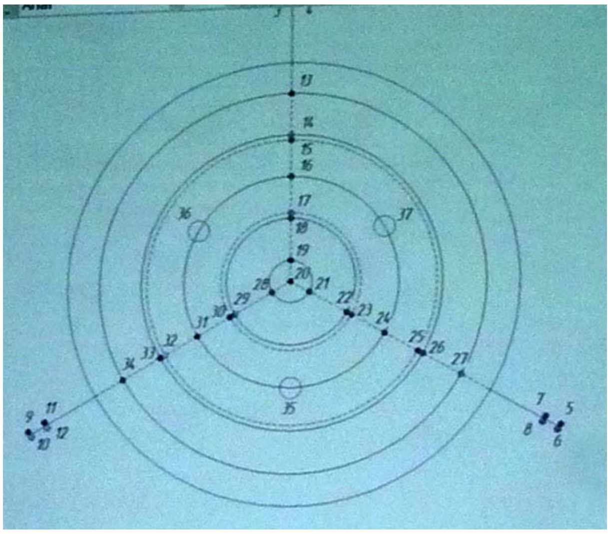


Fig. 1 Positions of sidewall TC (1-12), bottom TC (13-34) and pyrometer plates (35 – 37). High temperature TC: 19 and 20.

Fig.2 Concrete crucible filled with PTC. 4 gas burners above PTC.

Around the surface of the crucible there were 4 propane /air gas burners to maintain the corium surface at about 1800°C and to stop it crusting over so that briquettes would react properly with the melt. These were in operation from the beginning (see Fig.2).

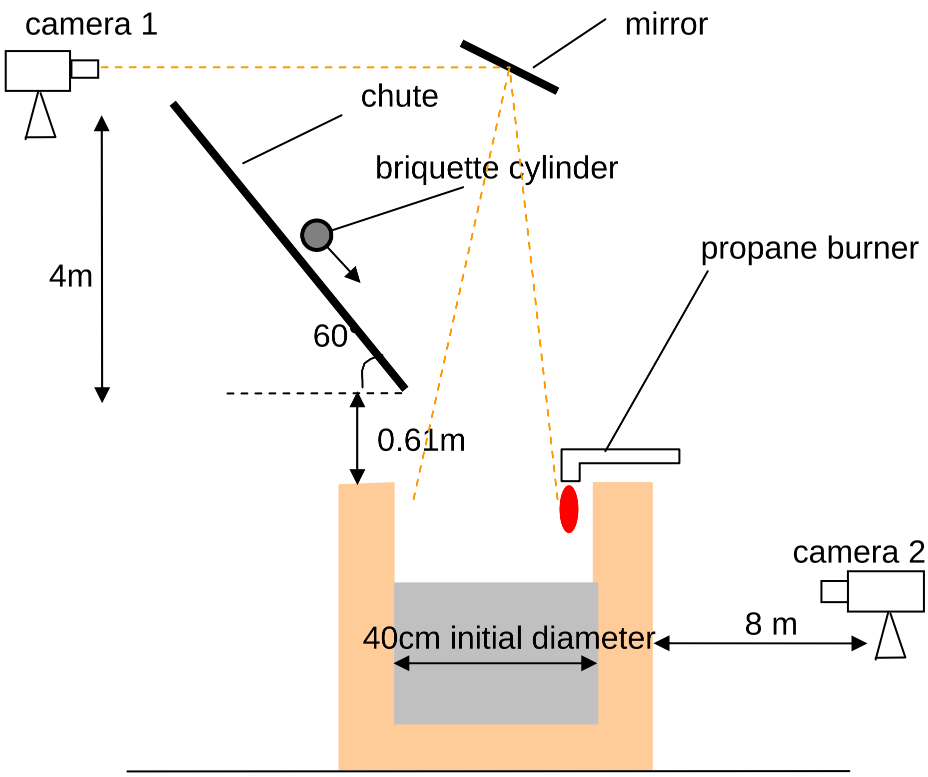


Figure 3: test-rig setup

There was a slide down which the briquettes were launched in to the crucible (see Figs. 3 & 4). This stood 5.2 m high at an angle of 60°, the outlet of this slide was ~60cm above the centre of the corium melt and the briquettes landed in the corium at a speed of ~10ms^{-1}. The crucible was initially packed with 6 special briquettes of Zr & FeO powder of each 720g. These were then covered with a further layer of free mixed powder. Ignition wires were inserted into the mass. From a safe distance the mass was ignited and when the W/W-Re thermocouples started to measure high temperatures (ie the burning of the initial mass had reached the bottom after ~30 sec) the first briquettes were added down the slide.

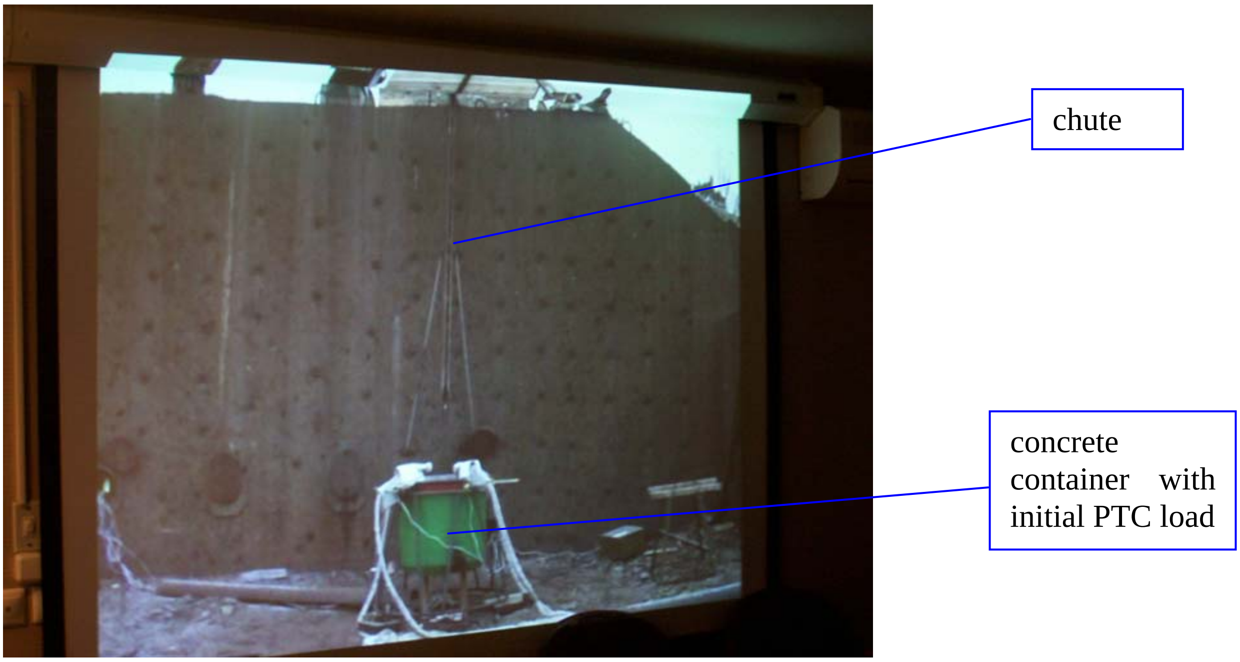
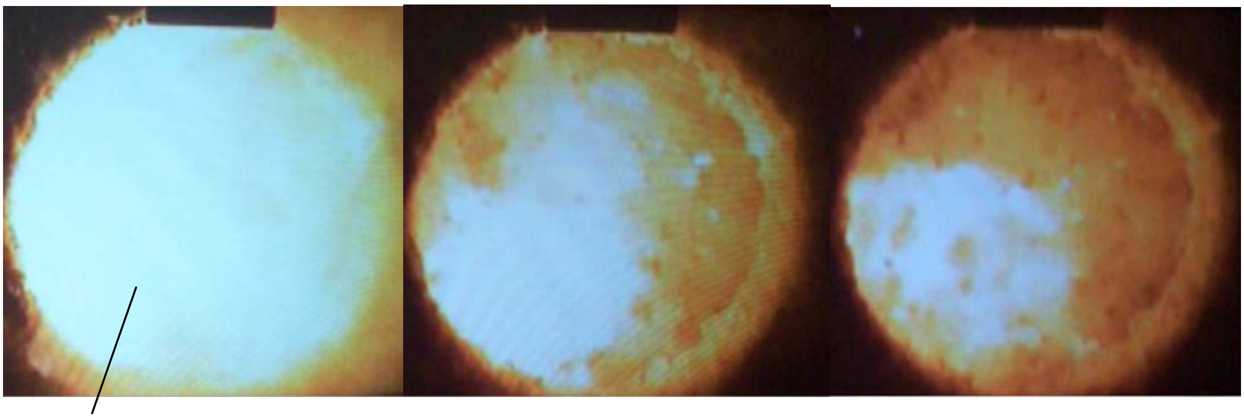


Figure 4: Picture of the actual test-rig

They were then added approximately every 7s (100g/s of PTC equivalent to 280kW) for about 500s until the total corium weight was about 100kg. The glowing melt surface varied between bright yellow/white where there was no crust to orange where crust was seen (see Fig. 5). The briquettes ignited with explosive force upon falling into the corium with clear agitation & bubbling in the melt and also spitting out considerable number of glowing particles of corium from the crucible. The total weight of these particles was measured after the experiment as 1.5 - 2 kg. The propane burners were continued and the melt and crucible temperatures were monitored by thermocouples and videos. For 10-20mins after the gas burners were stopped there were still flames to be seen from the surface of the partially white-hot melt. The surface of the melt was still at 50°C (in an air temperature of ~0°C) after 18 hours.



a) Briquette impact zone b) a few seconds later c)note the thin crust

Figure 5: Melt surface just after briquette introduction and a few seconds later. Note the progressive formation of a very thin and semi-solid crust forms away from the briquette impact zone a short while later

The pyrometers on the bottom of the concrete cavity functioned for approx. 2-3 minutes and indicated temperatures of ~2500-3000°C for the temperature of the melt. There was no great difference between the readings of the 3 different metals. The Type K thermocouple readings depended on the depth at which they were embedded in the concrete: the high temperature (W/W-Re) and the deeper K thermocouples lasted for about an hour. W/W-Re thermocouples gave temperatures of 2440°C & ~2600°C. It was thought the reason that these HT thermometers lasted so well was that even with melting of the thermocouple there could be connection maintained across the W/W-Re wires with the Fe content of the melt.

Post-test Examination

Figure 6a: concrete basemat after disassembly

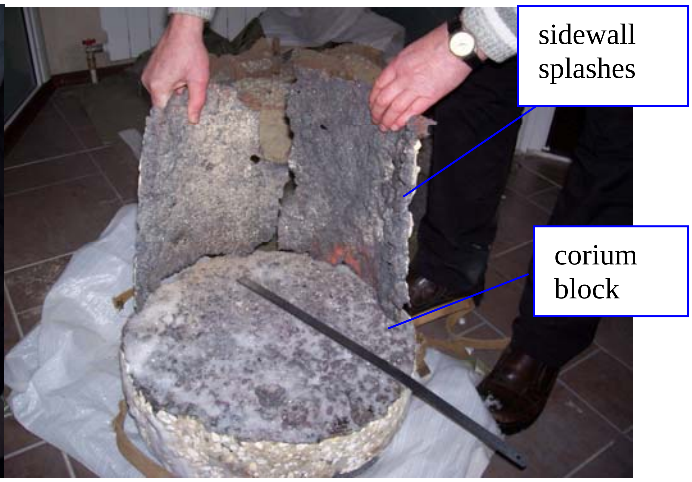


Figure 6b: corium block

The concrete crucible had broken up with disassembly (see Fig. 5) but there was also a reddish zone (heat-affected) zone in the middle of the concrete walls & bottom. The concrete around the tablet had mostly broken off, but it was noted that the limestone/chalk chips in the concrete were still intact even when they lay close to the corium in the interaction zone. This, it was noted, was different to the results in Cadarache, where the limestone chips had often disintegrated and had discharged CO_2 on heating. This may be the result of a different limestone mineral with better properties.

The post test examination of the tablet of frozen corium revealed that corium mass was about 45cm dia. & ~20cm deep and had eroded the limestone concrete sides by 25mm and base by 30mm in a uniform manner (see Fig 6 for photo & Fig. 7 for diagram). There was also a thin layer of solidified corium on the walls of the crucible. Iron seems to be well distributed in the corium block since a magnet was attracted by all sides of the mass. There was a slightly deeper area of attack slightly to one side of the centre of the concrete base and this was seen to correspond to the zone where the briquettes fell into the melt and ignited.

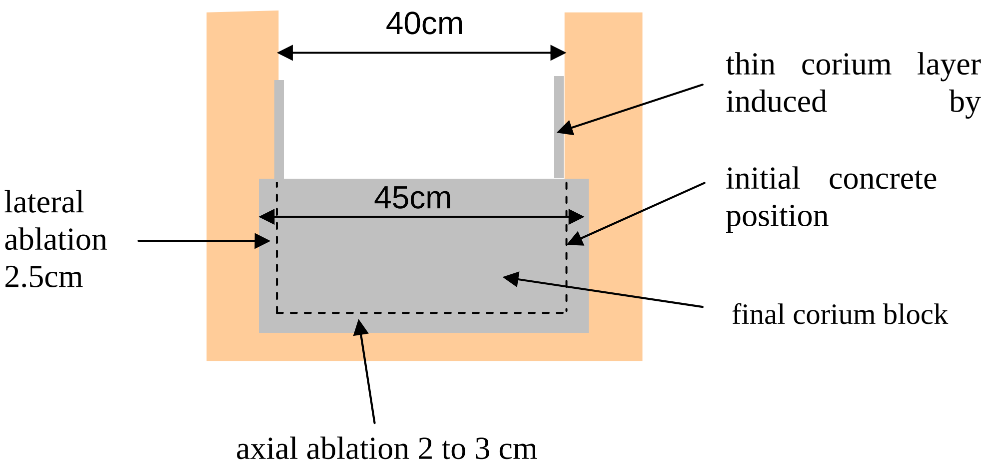


Figure 7: final erosion profile

The tablet was approximately 105kg with frozen lateral scale (on crucible sidewall above the tablet) of 25kg (including 2kg splash) giving 130kg in total. This was made up of 102kg of PTC +1kg Al foil + 19kg concrete ablation and gave an estimate of 8kg (mass balance) as concrete destroyed above melt surface. Close-up views of the corium tablet are seen in Figs. 8 (top) & 9 (side view).

Figure 8: Frozen melt tablet. Top view. D=450 mm.

Figure 9: Frozen melt tablet. Side view. H~185 mm.

Thermocouple Data

The thermocouple traces at 5cm started in 5sec & 10cm depth started 9 sec later, with those at 15mm started after 30sec. At 20mm depth the max temperature recorded was ~1400°C, & at 30mm depth it was ~700°C. Max. temperatures were recorded after ~37mins. In hindsight they would have used more high temperature W/W-Re thermocouples (apparently we had advised them that not so many were necessary !).The temperature rise of the surface thermocouples was too fast to give a thermal flux and there was also a discussion about the evaluation of the data to obtain thermal heat fluxes, however it was thought that the heat flux to the concrete was similar to CEA's tests and in a typical range for a MCCI simulation (100-200kW/m²).

Final Planning

The final session considered the administrative aspects and commenced with a request to explain the last minute cancellation of the previous visit in November '09: the severe annoyance and the costs that had been incurred were stressed (there had been several explanations given). It was said that there had been a long delay by ISTC administration in the delivery of Zr powder to VNIIEF.

A time table for the reporting of this final test was elaborated. Dr. Kondrashenko considered it would need 2 months for him to get all the necessary permissions from Rosatom. This would probably not be before the CEG-SAM meeting in Madrid (nor could he come to this meeting). It was proposed that this would be done by April '10 for distribution to the collaborators. They would then give their comments in the course of the next month(s) and aim for a final project text for Jun'10. Dr. Kondrashenko would be available for the CEG-SAM in September '10 in St. Petersburg for a presentation.

It was noted that this technique has very many possibilities: insertion of Fe components at any time down the chute would be possible or having steel rebars in the concrete crucible. These would not change the heating pattern in the melt (as happens in the induction heating).

The full size project still has problems of organization: eg export control for experiments that contain UO_2. One solution would be to extend the existing project and start talks with Rosatom for the permission. The next stage would be to find its financing (given the lack of support from ISTC). Even with a contribution from VNIIEF, external funding from the collaborators (or elsewhere) of ~400k$ would be needed.

2) Meeting with OKBM (27th Jan '10)

On the 2nd day a visit to a nearby reactor manufacturer was unfortunately unable to take place but instead we were met by a 4 –person team including the Director of research (Mikhail Bolshukhin) and his colleague (Vladimir Panov) an expert in modeling. They are mostly active in the production of the rapid reactors of small dimensions and have designed the floating reactor in St. Petersburg for flexible response for power needs near a coastal site. They do a lot of modeling and have connections with IBRAE in Moscow. CJ gave a presentation on the background of this MCCI project where we are collaborators, followed by a description of the SARNET2 network and the MCCI work package to which this project is most related. JS then followed this with a presentation of the Quench facility and its results (some of which is also part of a collaboration with other Russian institutes including IBRAE). Finally DB gave a presentation of ITU's work on refractory ZrC examinations and on ternary oxides ceramics needed for MCCI research as well as some slides on liquefied cladding interaction with fuel.

They found our work very interesting but it would need reflection on what aspects could be the basis of a collaboration.

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