

# LIVE EXPERIMENTS ON THE IN-VESSEL MELT POOL BEHAVIOUR WITH EXTERNAL COOLING CONDITIONS AND THE SIMULATION RESULTS WITH A COUPLED MELCOR-PECM APPROACH

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## ABSTRACT

The LIVE program investigates late in-vessel melt pool behaviour in case of a severe accident under large scale 3D conditions and different relocation modes. The melt retention by flooding the reactor vessel externally is regarded as an effective severe accident management strategy. One question is how the melt pool heat transfer to the vessel walls depends on different external cooling conditions. In this paper, the melt's thermal behaviour, such as melt temperature, heat flux and crust profiles, of two LIVE tests with different external coolant temperatures are compared: one with nucleate boiling condition, the other with sub-cooling condition. Other test conditions, such as simulant material, heating power and the upper boundary condition were similar in the two experiments.

The experimental results are simulated with coupled MELCOR and PECM codes. The program DINAMO, which was developed at KIT, was used to realize this coupling exchange. Using DINAMO it is possible to add new or enhanced models to the nuclear safety code MELCOR without the necessity of changing the MELCOR source code. Thus, it is possible to combine the advantages of the CFD-based Phase-Change Effective Convectivity Model (PECM) and MELCOR as an integral code. Implementing the advantages of the PECM code to MELCOR, such as the temperature distribution in the molten pool, heat flux distribution on the curved vessel wall and treatment of non-eutectic solidification, the prediction accuracy of MELCOR can be considerably improved concerning the analysis of core melt behaviour in the lower plenum during a core melt accident.

## KEYWORDS

LIVE, corium, in-vessel retention, MELCOR, PECM

## 1. INTRODUCTION

The in-vessel melt retention (IVR) by flooding the reactor vessel wall externally is an effective severe accident management strategy [1]. The effectiveness of this method is dependent on whether the local heat flux from the melt pool through the wall is lower than the critical heat flux (CHF) removable by the external cooling water.

Until now a numerous experimental and analytical studies have been performed to characterize the upward and downward heat transfer behaviour of the oxide melt pool. The experimental conditions differ

in geometry (3D or 2D), simulant materials (water, salt or prototypical corium), boundary cooling conditions (isothermal or not) and simulation of the internal heat sources (direct electrical heating, inductive heating, microwave, transient cooling and so on) [2-7]. The predictability of the results is therefore limited by the different experimental geometries, boundary conditions and simulant materials.

The objective of this study is focused on the influence of the boundary conditions on the heat transfer behaviour of a melt pool. Crust formation takes place in an oxide pool if external cooling is performed. The boundary of liquid melt/crust is isothermal under crust formation. The influence of the external cooling-water temperature on the heat transfer behaviour of the melt pool is the experimental part of this research. In the case of external cooling, the outer surface of the vessel wall is most probably under nucleate boiling condition. This signifies that the temperature of the outer lower vessel-wall maintains at an isothermal level of about 100 °C (approximate boiling temperature of water), if nucleate boiling occurs. If film boiling occurs, the outer temperature of the vessel-wall is dominated by the local steam, which can be non-isothermal. The heat flux distribution in the case of nucleate boiling could be different as the one under subcooled coolant, in which the vessel outer surface temperature is non-isothermal. In this paper, results of two LIVE experiments are compared which were performed with different outer vessel wall boundary condition. In LIVE-L11 the vessel wall was under nucleate boiling condition, whereas in LIVE-L10 it was under sub-cooling condition.

The IVR is also a research topic within the WASA-BOSS-project (Weiterentwicklung und Anwendung von Severe Accident Codes – Bewertung und Optimierung von Störfallmaßnahmen). Within this project, in which several German research institutions participate, the task of the KIT-IKET is to improve the nuclear safety code MELCOR to predict a core melt accident in the lower plenum. This is done by an external coupling of new models to MELCOR based on the work of Szabó [8]. Therefore, the program DINAMO (Direct Interface for Adding Models) was developed [9], which allows the coupling of additional models to MELCOR without the necessity of a complex modification of the MELCOR source code. In order to improve the prediction of the IVR in MELCOR the Phase-Change Effective Convectivity Model (PECM) [10] was coupled to MELCOR in cooperation with the Royal Institute of Technology (KTH) in Sweden [11]. In this work the coupled MELCOR-PECM approach is used to simulate the experiments LIVE-L10 and LIVE-L11 in order to show the new possibilities, which can be obtained by coupling external models to MELCOR.

## **2. DESCRIPTION OF THE LIVE-FACILITY**

The LIVE 3D test vessel simulates the hemispherical lower plenum of reactor pressurized vessel of a PWR in 1:5 scale [12, 13]. The melt surface can be either free surface by covering the test vessel with an insulation lid [14, 15] or cooled with a water-cooled lid. The test vessel with cooling lid is shown in Figure 1 (left). The test vessel wall and the cooling lid are made of stainless steel SS316Ti. The inner diameter of the test vessel is 1 m and the wall thickness is ~25 mm. The test vessel is enclosed in a cooling vessel to enable external cooling with either water or air. Cooling water for the cooling of the side wall flows in at the bottom and out via a side outlet at the top of the cooling vessel. The space between the test vessel and the cooling vessel is 21 cm. The decay power of the melt is simulated by 8 horizontal planes of electrical resistance heating coils, which can be controlled individually to realize homogenous power generation in the melt pool. The distance between two neighbouring heating planes and between the windings is approximately 45 mm. The maximum possible homogenous heat generation is 29 kW. The liquid simulant melt is prepared in an external heating furnace, which can tilt and pour the liquid melt into the test vessel either centrally or near the vessel wall via a pouring spout.

The LIVE-3D test vessel is extensively instrumented. Melt pool temperatures are measured with 80 thermocouples (MT) distributed in the melt. 26 pairs of thermocouples are mounted on the vessel inner and outer surface at different polar angles (inclination to the vertical axis from the spherical centre) and

azimuthal orientations. The wall temperatures enable the determination of the downwards heat flux distribution through the vessel wall. Crust solidification process along the vessel wall and the melt boundary temperature are monitored with 7 thermocouple trees (CT) mounted perpendicularly to the wall. The crust temperatures are important parameters for the determination of the boundary position at the melt/crust interface [16]. In Figure 1 (right) the arrangement of thermocouples in the melt and near the wall at one azimuthal cut is shown. Two video cameras are installed for the observation of melt pouring process. The vessel is placed on three weighting cells, so that the weight changes during melt pouring and melt extraction can be controlled. A more detailed description of the instrumentation is given in [17].

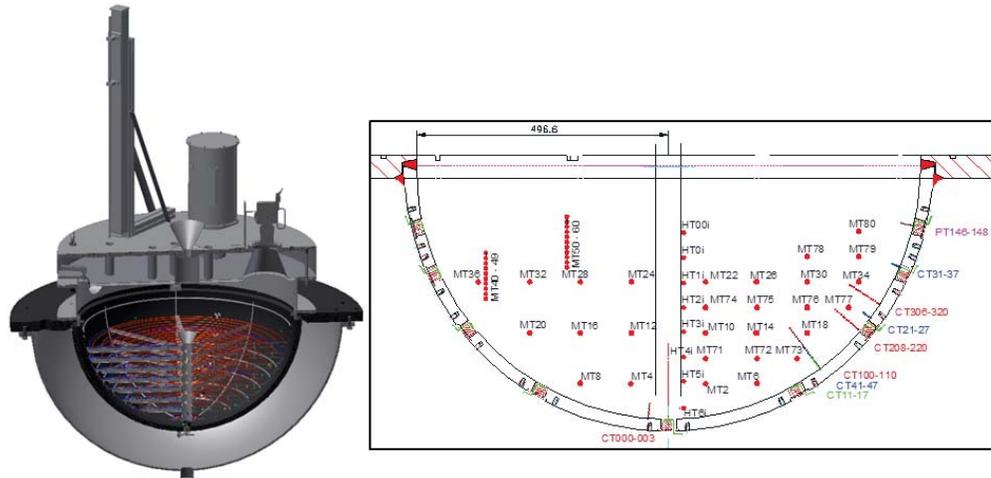


Figure 1: LIVE vessel with top insulation (left) and instrumentation in the test vessel (right)

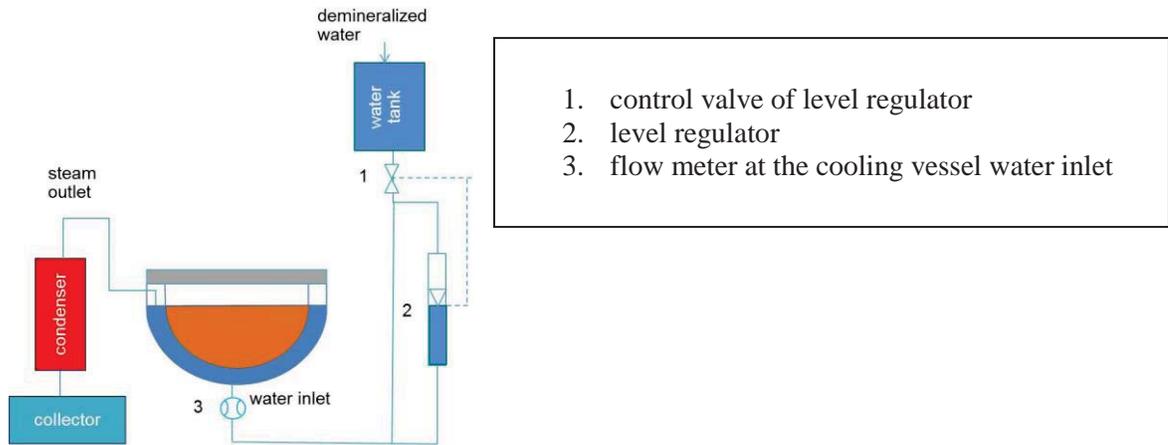
### 3. PERFORMANCE OF LIVE-L10 AND LIVE-L11

Two LIVE tests with similar test conditions are studied: LIVE-L10 and LIVE-L11. In both tests a non-eutectic mixture of 20 mol% NaNO<sub>3</sub> - 80 mol % KNO<sub>3</sub> was used. The liquidus temperature of this mixture is 284.4 °C. There are following similar test conditions in L10 and L11 tests:

- Melt pool height: 410 mm
- Heating plateaus: The heat input was volumetric. Five heating plateaus in the order of 21kW, 16.4kW, 9 KW, 16.4kW-II, 21kW-II were performed in L11 and in L10 after the second melt pouring. Each heating plateau has reached thermodynamic steady state before the power was switched to the next one. The last heating plateau was terminated by melt extraction.
- Upper boundary: the test vessel was covered with an insulation lid.
- Initial cooling water temperature: cooling vessel was filled with cooling water in ambient temperature.

The difference between the two tests was the applied external cooling condition during the test. In LIVE-L10, a cooling water support with high flow rate was established, which resulted in a water outlet temperature below the boiling temperature. In contrast, in LIVE-L11 the cooling water outlet temperature was at boiling temperature. To realize this condition, the evaporated water was compensated with a very

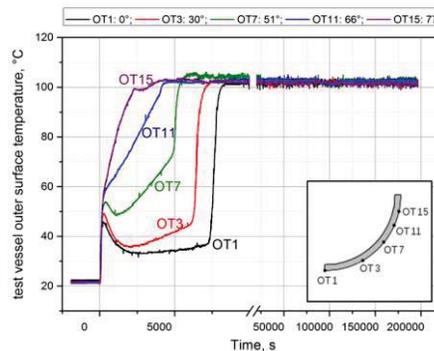
low and non-continuous flow in order to maintain the water level constant. The water control system is illustrated in Figure 2.



**Figure 2: Cooling water flow control system in LIVE-L11**

#### 4. EXPERIMENTAL RESULTS

In LIVE L11 the heat-up of the external cooling water took place from the top to the bottom surface gradually. The cooling water began boiling after about 2 hours with 21 kW heating power. Also, after 2 hours, the measured temperature of the entire outer surface of the test vessel was uniformly at about 100 °C (Figure 3).



**Figure 3: Temperature of the test vessel outer surface in LIVE-L11**

During the thermodynamic steady state, the melt shows continuous gradient from bottom to melt surface. Figure 4 shows the development of the melt temperature during the two tests. The melt temperature at same heating power in different heating phases shows reproductive values, which were independent on the external cooling conditions as shown in Figure 5 (left). The melt temperature at the same heating power is identical in the two tests independent from the external cooling condition. The relatively high temperature at the vessel bottom could be a local effect of the intensive heating of the lowest heating

plane, which could not be distributed volumetrically at this location. The thick crust layer at vessel bottom intensified this phenomenon by limiting space for the natural convection.

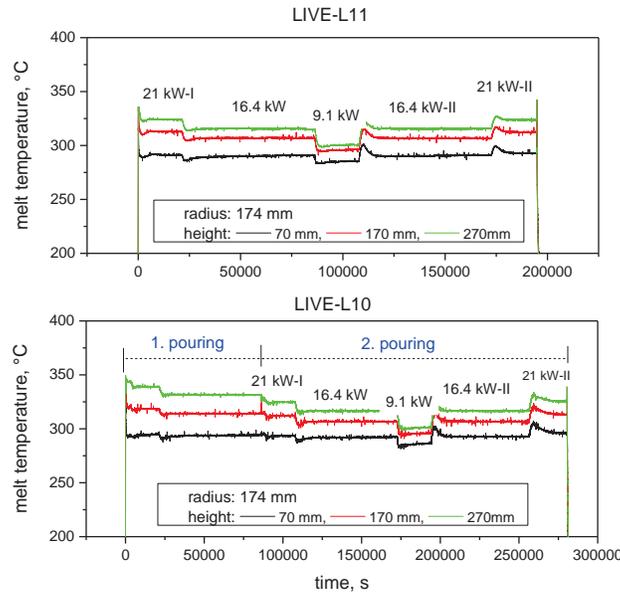


Figure 4: Temperature progression during the test period in LIVE-L11 (top) and LIVE-L10 (bottom)

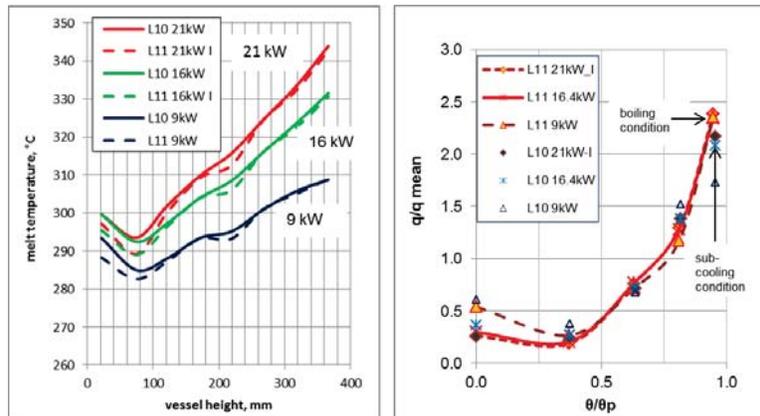


Figure 5: Melt temperature vertical profile at radius 30 mm (left) and heat flux profiles (right) in LIVE-L10 and L11

The steady state heat flux profiles of the two tests are compared in their normalized values (Figure 5 (right)). The normalized heat flux is the ratio of  $q/q_{\text{mean}}$  by comparing the local heat flux “ $q$ ” with the mean heat flux “ $q_{\text{mean}}$ ”. The normalized polar angle is  $\theta/\theta_p$  by comparing the local polar angle “ $\theta$ ” with the polar angle at the melt surface “ $\theta_p$ ”. Also similar a heat flux distribution is observed in the two tests through the lower and middle part of the vessel. Near the melt surface, however, the heat flux is higher under boiling water as coolant than the one under subcooled cooling water. This can be a result of the different vertical heat flow within the vessel wall, even if the heat flux from the melt pool to the wall

inner surface is the same. In case of an isothermal outer surface temperature under boiling condition, the vertical temperature gradient within the vessel wall is low. Therefore, at the hottest wall region a higher heat flux through the vessel wall to the cooling water with little loss to the other directions in the wall can be found.

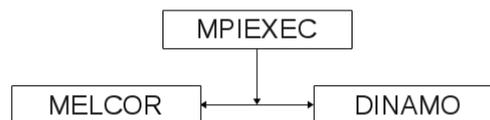
## 5. NUCLEAR SAFETY CODE MELCOR

The nuclear safety code MELCOR (Methods for Estimation of Leakages and Consequences of Releases) is developed and provided by Sandia National Laboratories (SNL). MELCOR is the leading system code for the integral analysis of severe accidents in a nuclear power plant and therefore widely used for Probabilistic Safety Analyses (PSA). The development of MELCOR started after the severe accident in the nuclear power plant in Three Mile Island (TMI-II) in 1979. In order to perform fast calculations or severe accident progression a lumped parameter approach is used. Over the years of the MELCOR development a plurality of models or even entire standalone programs have been implemented in MELCOR. Therefore, in contrast to other system codes, the simulation of an entire nuclear power plant during a severe accident can be simulated with MELCOR. However, this variety of models and programs from different developers leads to a non-consistent programming philosophy in MELCOR, which makes the analysis and modification of the source code very difficult. More information on MELCOR and the models used to describe a severe accident can be found in the code manual of the MELCOR-code [18].

In order to establish a communication with other programs, MELCOR 1.8.6 contains a coupling interface based on the MPI-standard (Message Passing Interface). A previous version of this coupling interface, which used the PVM-standard (Parallel Virtual Machine) to establish the coupling exchange, was used to couple MELCOR with the system code RELAP5 [19]. The coupling interface based on was used by Szabó in order to couple the CFD-code GASFLOW with MELCOR to improve the prediction of the hydrogen distribution in the containment in a Loss of Coolant Accident (LOCA) in a nuclear power plant [8].

## 6. COUPLING OF NEW MODELS TO MELCOR

In order to couple MELCOR 1.8.6 using the MPI-standard with another program, the use of a communication program is necessary. This program, MPIEXEC, which was developed by SNL, coordinates the execution of the program participating in the coupled system and initiates the coupling exchange. A scheme of the coupling process between MELCOR and another program (DINAMO in this example) via MPIEXEC is shown in Figure 6.



**Figure 6: Scheme of the coupling process between MELCOR and DINAMO using the communication program MPIEXEC**

The program DINAMO (Direct Interface for Adding Models) was developed within the WASA-BOSS-project at the Institute of Nuclear and Energy Technologies (IKET). DINAMO contains a coupling interface, which allows the communication and data exchange with MELCOR using the MPI-standard, as

well as an interface for the implementation of additional models. The implemented models can then via the coupling interface be used in MELCOR to improve the prediction of severe accidents. Additional information on the coupling process as well as an example of the implementation of a simple model into MELCOR using DINAMO can be found in the publication by Dietrich [9]. Using DINAMO to couple additional models to MELCOR, it is possible to extend and improve MELCOR without a complex modification of the MELCOR source code.

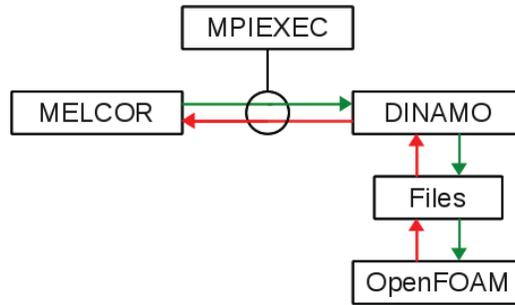
## **7. THE PHASE-CHANGE EFFECTIVE CONVECTIVITY MODEL**

The Phase-Change Effective Convectivity Model (PECM) is used to simulate molten core material or debris heat up in the lower head of a reactor pressure vessel during a severe accident in a nuclear power plant. It was developed based on CFD analysis at KTH in 2009 by Tran [10]. In contrast to a complete CFD analysis of the lower plenum in the PECM only the energy equation has to be solved. The convective terms in the energy equation are approximated by characteristic velocities. These characteristic velocities are calculated by empirical correlations obtained from CFD-analysis and experimental studies on the behaviour of a molten pool. In comparison to CFD-analysis with the PECM a significant reduction of the calculation time of up to a factor of 200 can be achieved according to Tran [10].

Compared to the current model in MELCOR, which treats the molten oxidic material as a uniform continuum with uniform material properties, the PECM provides the possibility of obtaining a distribution of the melts properties according to the local temperature. Also, in contrast to the MELCOR model with the PECM a non-eutectic solidification process in the molten material can be taken into account [20]. The calculation times in the PECM are similar to the calculation times for a similar configuration in MELCOR. Therefore, the coupling of the PECM is able to improve MELCOR's possibilities to simulate molten material in the lower plenum without significant increase of the calculation time.

## **8. COUPLING OF THE PECM TO MELCOR**

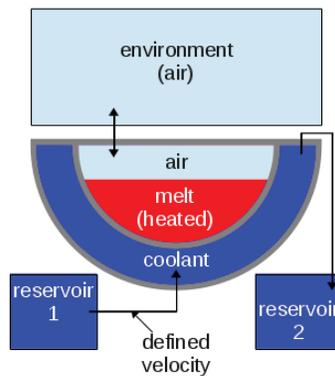
The PECM solves the energy equation on a numerical grid similar to CFD-simulations. The provided nodalisation of MELCOR for the lower plenum is too coarse for this purpose. Tran implemented the PECM as a User Defined Function (UDF) in the commercial CFD-software ANSYS FLUENT for his calculations [10]. The models coupled to MELCOR via DINAMO, however, are intended to be available to every user of MELCOR. Therefore, the PECM was implemented in the open-source software OpenFOAM. OpenFOAM as a CFD-software provides the required numerical grid as well as the possibility to modify solvers for the implementation of the PECM. A more detailed description as well as the verification of the correct implementation of the PECM in OpenFOAM is presented by Dietrich [11]. Based on the implementation of the PECM in OpenFOAM an interface for the communication with OpenFOAM in DINAMO was developed. In order to couple the PECM to MELCOR the coupling process shown in Figure 6 has to be modified. The modified coupling process is shown in Figure 7. A detailed description of the coupling process and the exchanged data is also presented in [11].



**Figure 7: Scheme of the extended coupling process for the implementation of the PECM (OpenFOAM) in MELCOR using the program DINAMO**

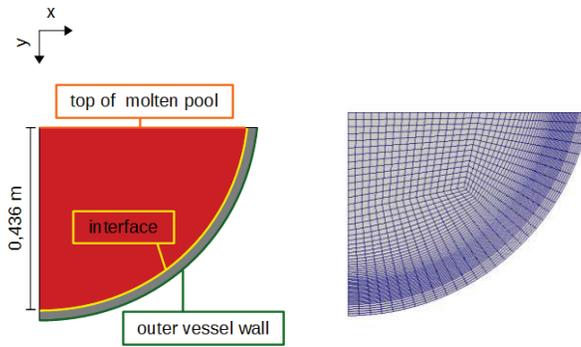
## 9. SIMULATIONS OF THE LIVE-FACILITY

In the present work the previously described experiments LIVE-L10 and LIVE-L11 are simulated using the coupled MELCOR-PECM-system. Therefore the MELCOR-input used for the simulations of the experiment LIVE-L1, presented by Dietrich [11], was modified according to the specifications in LIVE-L10 and L11. The main difference between the input for LIVE-L1 and the modified input is the amount of salt melt which is investigated in the LIVE-vessel. In LIVE-L1 as one of the first experiments performed in the LIVE-facility about 120 l of molten material was used [21]. In the experiments LIVE-L10 and L11 about 210 l of molten salt was investigated. A schematic of the MELCOR input can be seen in Figure 8.



**Figure 8: Illustration of the MELCOR data set for the LIVE-facility [11]**

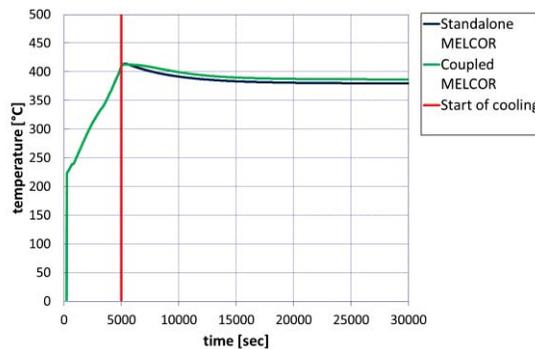
Due to the fact that it was not possible to start the simulation in MELCOR for the LIVE-facility with molten material in the lower plenum, in the present simulations the material used in the experiments drops at the beginning of the calculation as solid material into the LIVE-vessel. This material is liquefied by the application of a volumetric heat source. After all of the material is liquefied the external cooling condition is applied and in the coupled system the calculations within the PECM are started. Due to this different approach only the steady states which were found in the experiments were simulated. The numerical grid used in the PECM as well as an illustration of the calculation domain can be seen in Figure 9.



**Figure 9: Calculation domain in OpenFOAM for the PECM with boundaries used for the coupling exchange highlighted (left) and the numerical grid used to solve the PECM (right)**

Figure 9 also shows the active boundary conditions for the coupling. The simulation with the PECM is initialized by the temperature of the molten material in MELCOR. During the coupled calculation the boundary conditions at the “outer vessel wall” and the “top of the melt” are updated every coupling timestep by the temperatures of the “coolant” and the “air” above the molten material (see Figure 8) as calculated by MELCOR. Based on these temperatures a heat flux is calculated using heat transfer coefficients and applied at the corresponding boundaries. At the end of the coupling timestep the temperature at the “interface” between the material in the LIVE-facility and the LIVE-vessel is send to MELCOR and used as the new temperature for the inner wall of the LIVE-vessel.

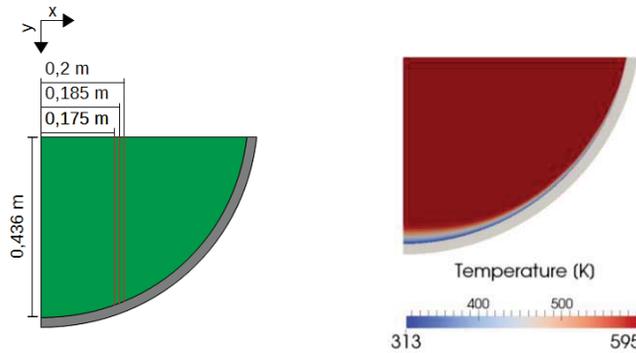
In this paper the simulations of the stationary states observed in the experiments LIVE-L10 and LIVE-L11 at a volumetric heating power of 21 kW are presented. In Figure 10 the development of the temperature in the molten material as calculated by standalone MELCOR and MELCOR with the PECM for the experiment LIVE-L10 is shown.



**Figure 10: Melt temperature development calculated by MELCOR for the LIVE-L10 experiment**

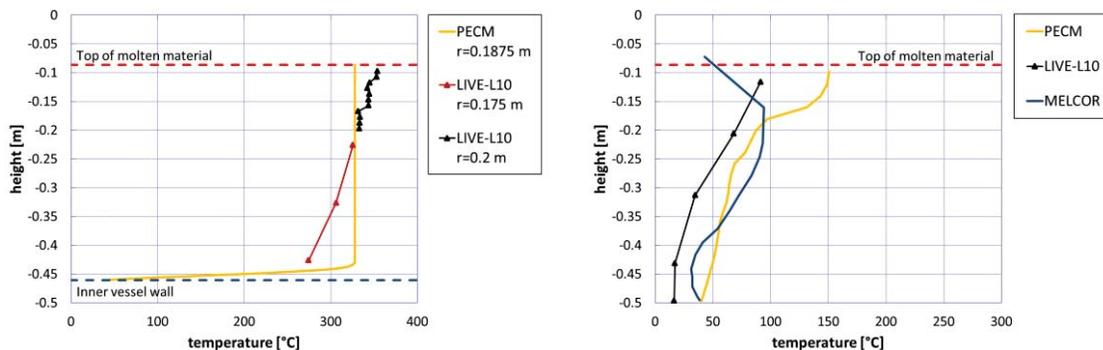
It can be seen that the steady state is reached after about 20 000 seconds. The start of the PECM is indicated in the figure as “start of cooling”. At this point all the material in the lower plenum of the LIVE-facility is liquefied and the area of the coolant (see Figure 8) is flooded with water. According to the specifications in LIVE-L10 a constant coolant support was established to realize the steady state. It can be

observed that the temperatures in MELCOR and the PECM slightly differ and that due to the use of the PECM the temperature in MELCOR is higher compared to standalone MELCOR calculations. Due to the fact that MELCOR assumes a uniform temperature for the molten material in the lower plenum a more detailed description of the temperature distribution lower plenum cannot be obtained in the standalone simulation. In the coupled simulation with the PECM however a local temperature distribution can be obtained. This temperature distribution along with an illustration of the evaluation lines of the PECM-simulation can be seen in Figure 11.



**Figure 11: Illustration of the lines used for the evaluation of the PECM-simulation (left) and the local temperature distribution calculated by the PECM in the coupled simulation (right)**

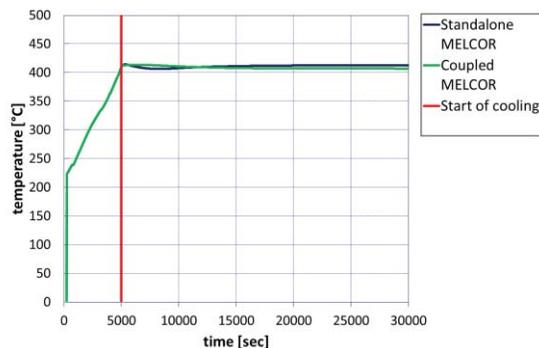
The temperature profile along a vertical axis at a radius of 0.1875 m from the centre of the LIVE-facility is shown in Figure 12. It can be seen that the PECM is capable of reproducing the mean temperature in the molten pool more accurate than the MELCOR calculations, which significantly overestimate the temperature. However, the temperatures near the cooled wall of the LIVE-facility are overestimated by the PECM. This was also found by Tran [10], who compared the results of the PECM with CFD-results of a core melt in the lower plenum.



**Figure 12: Melt temperature vertical profiles for the LIVE-L10 experiment at a radius of 0.1875 m calculated with the MELCOR-PECM-approach in OpenFOAM compared to the experimental findings (left) and the temperature of the inner vessel wall calculated by MELCOR-PECM and standalone MELCOR compared to the experimental findings (right)**

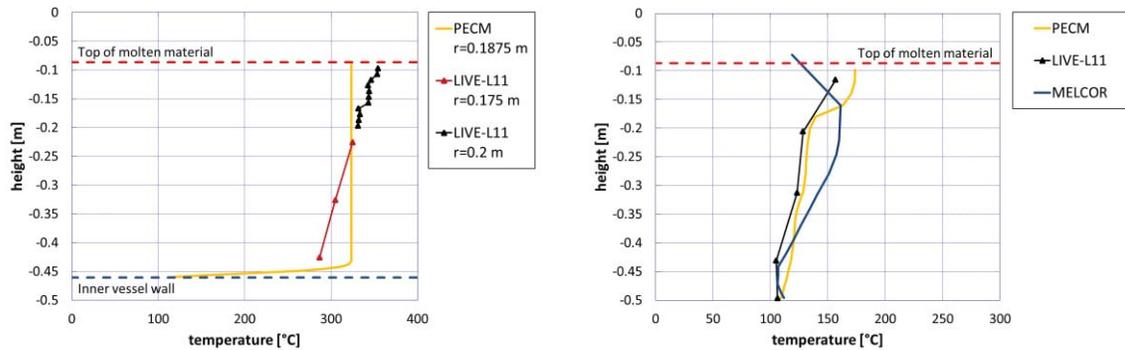
Figure 12 also shows the temperature profiles along the inner wall of the vessel of the LIVE-facility in the coupled MELCOR-PECM-simulation compared to the experimental results and a standalone MELCOR calculation. It can be seen, that both MELCOR as well as the coupled approach overestimate the actual temperature in the vessel wall. This is probably based on the nodalisation of the coolant region in MELCOR. Here, one control volume for the entire coolant area is used. The resulting uniform temperature in the coolant of about 30 °C leads to the observed deviations. However, it can be seen that with the PECM the trend of the temperature profile is captured better compared to the standalone MELCOR simulation.

For the LIVE-L11 experiment also the steady state with a volumetric heating power of 21 kW was simulated. As mentioned, the difference between LIVE-L10 and LIVE-L11 is the different method for the coolant support. The support of water is controlled by the amount of steam generated by the boiling of the coolant exiting the coolant control volume. So, the temperature of the water in the coolant control volume is always close to the boiling temperature. In MELCOR version 1.8.6, which is used within this work, it is not possible to calculate a heat transfer between the outer lower head wall (outer LIVE-vessel wall) and the adjacent coolant if the temperature of the wall was lower than the boiling temperature of the coolant. Therefore, the heat transfer model was modified to take into account the heat transfer without boiling of the coolant. This approach was used for the simulation of LIVE-L10 and was originally presented in [9]. The temperature development for the LIVE-L11 experiment in MELCOR compared to the coupled MELCOR-PECM approach is shown in Figure 13.



**Figure 13: Melt temperature development in MELCOR for the LIVE-L11 experiment**

It can be seen that similar to the temperature profile for LIVE-L10 (see Figure 10) the temperatures in MELCOR are very close. The steady state in these simulations also can be observed after about 20 000 seconds. However, the temperature in standalone MELCOR is now slightly higher than the temperature in the coupled system. The temperature profile calculated in OpenFOAM with the PECM along a vertical line at a radius of 0.1875 m from the centre of the LIVE-facility can be seen in Figure 14. Similar to the results for the LIVE-L10 experiment (Figure 12) the temperatures in the PECM match the medium temperatures in the LIVE facility. Also, it can be seen, that despite the higher temperature in MELCOR for LIVE-L11 the temperatures in the PECM are in the same range as the temperatures calculated for LIVE-L10.



**Figure 14: Melt temperature vertical profiles for the LIVE-L11 experiment at a radius of 0.1875 m calculated with the MELCOR-PECM-approach in OpenFOAM compared to the experimental findings (left) and the temperature of the inner vessel wall calculated by MELCOR-PECM and standalone MELCOR compared to the experimental findings (right)**

The temperature profile along the inner wall of the LIVE-vessel is shown for the steady state with a volumetric heating power of 21 kW compared to the experimental findings in LIVE-L11 and a standalone MELCOR-calculation is shown in Figure 14. It can be seen that the temperatures calculated by the coupled MELCOR-PECM-approach match the temperatures in the LIVE-facility better than the once calculated by MELCOR. In comparison to the temperature profile along the vessel wall found in LIVE-10 (Figure 12) the calculated temperatures in LIVE-L11 are closer to the actual values in the experiment. This is most probably based on the fact that for the heat flux at the outer vessel wall in the PECM and in MELCOR the reference temperature is the boiling temperature of the coolant. It can be observed that the PECM is able to improve the prediction of the behaviour of the molten salt in MELCOR. However, compared to CFD-analysis there are still significant deviations in the temperature profile. The temperature at the inner wall of the LIVE-vessel, which influence the heat transfer through the vessel wall, are, especially in LIVE-L11, significantly better captured than in the standalone MELCOR calculations.

## 10. CONCLUSIONS

Two LIVE 3D experiments with external coolant either with subcooled or boiling temperature were performed. The temperature of the external cooling water has little influence on the melt pool behaviour, such as the melt temperature distribution or the heat flux from the melt pool to the crust or even to the inner vessel wall surface as long as an crust layer exists. However, a higher heat flux rate near the melt surface was observed under boiling condition. The isothermal wall outer surface temperature in this case is suggested to limit the vertical heat transfer inside the vessel wall at this area.

The steady state of the experiments LIVE-L10 and L11 with a volumetric heating power of 21 kW was calculated with a coupled MELCOR-PECM-approach. The program DINAMO, developed at the IKET, was used to couple MELCOR with the PECM. DINAMO allows the coupling of new or additional models to the nuclear safety code MELCOR without the necessity of a complex modification of the MELCOR source code. In order to couple the PECM to MELCOR the new model was implemented into the open-source software OpenFOAM. By the implementation of an interface for the communication with OpenFOAM in DINAMO a coupling of the PECM with MELCOR was achieved. For the simulation of the LIVE-facility with the coupled system an input for MELCOR as well as a numerical grid for the simulation in OpenFOAM was developed. The simulations of the steady states showed that the temperature of the melt inside the facility is better captured by the coupled approach than in the standalone MELCOR calculations. For LIVE-L11 the vessel wall inner temperature calculated in

MELCOR was significantly higher than the temperature for LIVE-L10 with standalone MELCOR whereas in the experiments as well as in the coupled simulations the mean temperatures were very close. The results obtained using the PECM with MELCOR showed that there are still significant deviations in the temperature profiles in the molten material compared to the experimental findings. The temperature profile along the inner vessel wall of the LIVE-Facility calculated by the coupled approach shows for LIVE-L11 a very good agreement with the experimental findings. The wall surface temperature profile calculated by MELCOR shows a different contour of the temperature profile and the high temperature near the top of the molten material is not captured. For LIVE-L10 the contours of the wall temperature profiles in the experiment and the coupled approach are in a good match however the entire profile is overestimated by the simulation. It could be observed that using DINAMO new models can be used in MELCOR without the need of detailed knowledge of the MELCOR source code. As shown by coupling the PECM with MELCOR, these models can improve MELCOR's ability to simulate a severe accident in a nuclear power plant and therefore optimize security measures in NPPs.

## ACKNOWLEDGMENTS

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