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# Benchmark calculation of OECD/MCCI experiments using MELCOR and ASTEC code

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## 1. Introduction

Molten corium concrete interaction (MCCI) is a significant concern in the design and safety assessment of nuclear reactors because it can result in the release of radioactive materials, which can pose a serious threat to public health and the environment.

To better understand the mechanisms involved in MCCI, the OECD initiated the MCCI project. This project implied extensive experimental studies to investigate the behavior of corium and concrete under various conditions, as well as the development of computer codes to simulate MCCI. The experiments consisted of 6 cases (CCI-1 to 6 tests) [1].

MELCOR is a fully integrated, engineering-level computer code developed by Sandia National Laboratories for the Nuclear Regulatory Commission (NRC) to model the progression of severe accidents in pressurized water reactors. MELCOR 2.2.18019 version was used in this research [2].

ASTEC was developed by the Institute for Radiological Protection and Nuclear Safety (IRSN), which makes it possible to simulate all phenomena that take place during a water-cooled reactor meltdown accident [3]. The version of the ASTEC is ASTEC V2.2.0.1.

In this paper, we calculated the OECD CCI-2, 3, 4, and 5 experiments using the MELCOR and ASTEC code and compared the results with the experimental data.

## 2. Benchmarking of OECD/MCCI

We simulated the experiment of CCI-2 to 5. CCI-2 and 3 experiments were carried out in the MCCI-1 project, and further CCI-4 and 5 were conducted in the MCCI-2 project to expand the database of these experiments. Each experiment had a different objective, but every experiment was carried out with the same test facility. The objective of each case is shown in table 1.

Table 1. Objective of OECD/MCCI project.

| Case | | Objective |
|---|---|---|
| MCCI-1 | CCI-2 | Effects of external flooding on the coolability of molten core material |
| | CCI-3 | Effect of a sacrificial steel plate on the coolability of molten core material |
| MCCI-2 | CCI-4 | Effect of non-condensable gases on the coolability of molten core materials |
| | CCI-5 | Effect of flow blockage on the coolability of molten core material |

Table 2 indicates the composition of concrete for each case [1]. Two kinds of concrete were used in the experiments: Limestone Common Sand (LCS) for CCI-2,4 and Siliceous for CCI-3, 5.

LCS has a high content of non-condensable gas. The non-condensable gas contributes to the molten corium cooling mechanism in the following way when the upper coolant is present.

1) Melt eruption with non-condensable gas
2) Provide a path for water ingression

However, siliceous contains less non-condensable gas such as $CO_2$, and it include a lot of $SiO_2$. It makes the viscosity of corium lower, so that the corium spreads widely.

Table 2. Composition of concrete [1].

| Constituent | Wt% | | | |
|---|---|---|---|---|
| | CCI-2 | CCI-3 | CCI-4 | CCI-5 |
| | LCS | Siliceous | LCS | Siliceous |
| $SiO_2$ | 21.61 | 59.91 | 25.99 | 58.27 |
| CaO | 25.88 | 16.79 | 27.81 | 20.20 |
| $Al_2O_3$ | 2.49 | 3.53 | 2.78 | 3.51 |
| $Fe_2O_3$ | 1.39 | 1.49 | 1.40 | 1.33 |
| MgO | 11.47 | 0.85 | 9.21 | 0.92 |
| MnO | 0.03 | 0.04 | 0.00 | 0.00 |
| SrO | 0.00 | 0.04 | 0.00 | 0.00 |
| $TiO_2$ | 0.135 | 0.155 | 0.17 | 0.15 |
| $SO_3$ | 0.505 | 0.434 | 0.91 | 0.45 |
| $Na_2O$ | 0.31 | 0.66 | 0.39 | 0.49 |
| $K_2O$ | 0.55 | 0.81 | 0.54 | 0.80 |
| $CO_2$ | 29.71 | 9.80 | 23.80 | 9.50 |
| $H_2O$, Free | 3.255 | 2.293 | 3.58 | 1.90 |
| $H_2O$, Bound | 1.11 | 1.40 | 3.42 | 2.88 |

CCI-4 has the same composition of concrete as CCI-2, but the initial corium composition is different (Table 3 [1]). The initial corium of CCI-2 consists of only oxidized metals, while the CCI-4 experiment includes pure Fe and Zr (oxide corium is 78%). Pure Fe and Zr are closely related to reactor integrity because they affect the amount of hydrogen and CO generation during the MCCI.

Table 3. Initial corium composition [1].

| Constituent | Wt% | | | |
|---|---|---|---|---|
| | CCI-2 | CCI-3 | CCI-4 | CCI-5 |
| $UO_2$ | 60.62 | 56.32 | 56.52 | 56.32 |
| $ZrO_2$ | 24.90 | 23.13 | 21.53 | 23.13 |
| $SiO_2$ | 3.39 | 11.17 | 4.05 | 11.17 |
| MgO | 1.14 | 0.12 | 1.36 | 0.12 |
| $Al_2O_3$ | 0.41 | 0.64 | 0.49 | 0.64 |
| CaO | 3.13 | 2.21 | 3.75 | 2.21 |
| Cr | 6.41 | 6.41 | 4.70 | 6.41 |
| Zr | | | 4.61 | |
| Fe | | | 2.99 | |

Table 4 lists the experimental details. Corium composition, basemat size, initial melt mass and temperature, power supply operation, and criteria for water addition were set differently in each experiment.

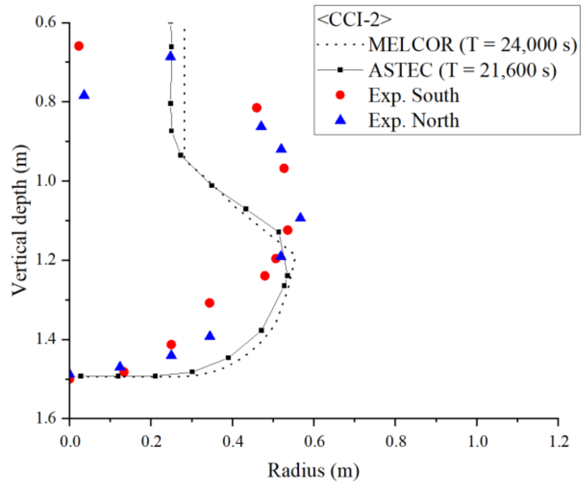
### 3. Calculation result

Figures 1 compares the ablation depth calculated by MELCOR and ASTEC with the experimental date the OECD/MCCI.

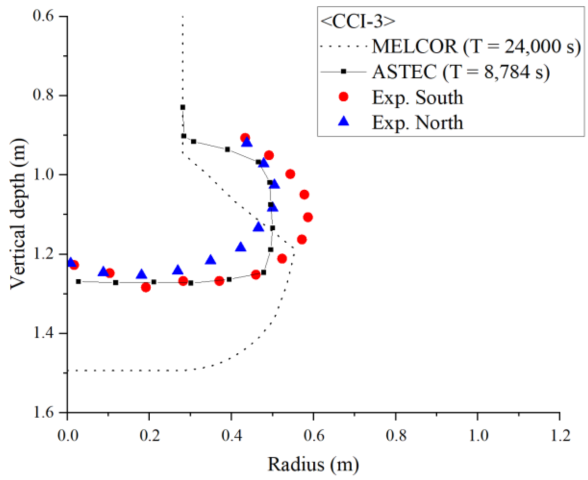
The colored symbols represent experimental data, while the lines represent the results of code calculations. All MELCOR calculations were conducted for 24,000 seconds, while the calculation times for ASTEC differed for each case.

With the exception of CCI-3, the results of MELCOR and ASTEC showed a similar trend and were consistent with the experimental results. The reason for the different between MELCOR and ASTEC in the CCI-3 was due to the accident elapsed time.

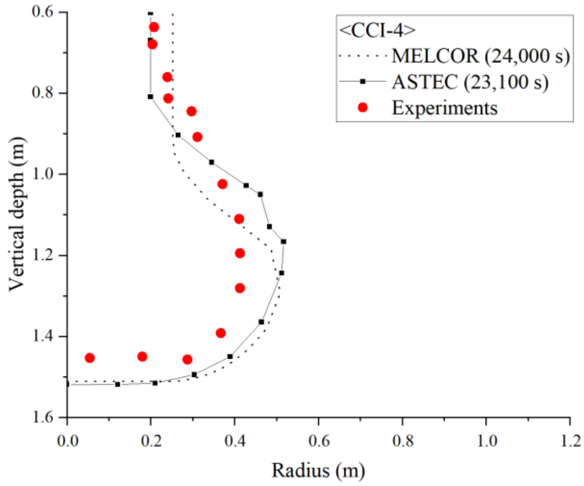
In CCI-2 and 4, ablation depth was deeper in the axial direction, whereas in CCI-3 and 5, ablation occurred more actively in the radial direction. This was caused by the differences in the content of $SiO_2$ in the concrete. An increase in $SiO_2$ reduced the viscosity of the molten corium, leading to wider erosion.



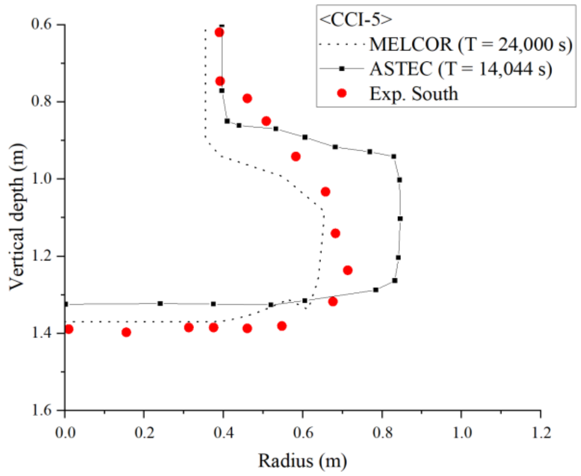

(a) CCI-2.




(b) CCI-3.



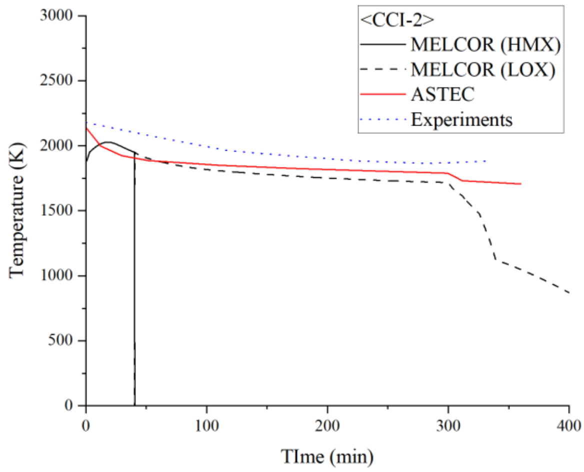

(c) CCI-4.



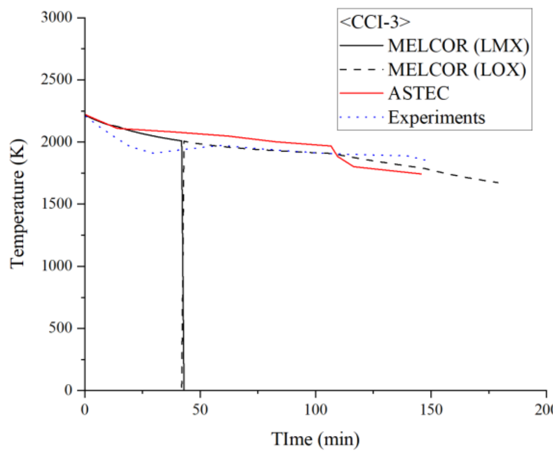

(d) CCI-5.

Fig. 1. Variation of ablation depth over time.

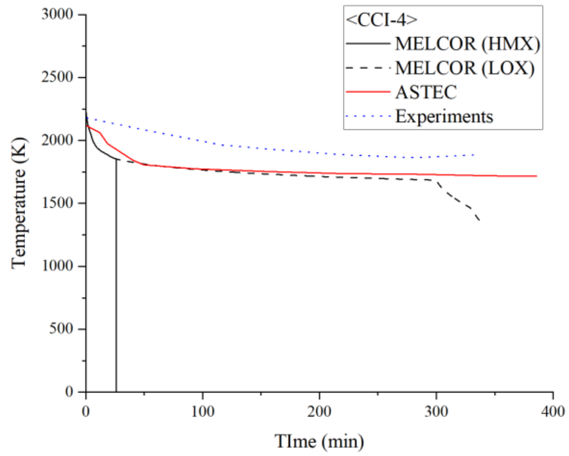
Figure 2 indicates the temperature of the molten corium. In MELCOR, as the accident progressed, the composition of the corium changed from a heavy mixture layer (HMX) or a low mixture layer (LMX) to a light oxide layer (LOX).



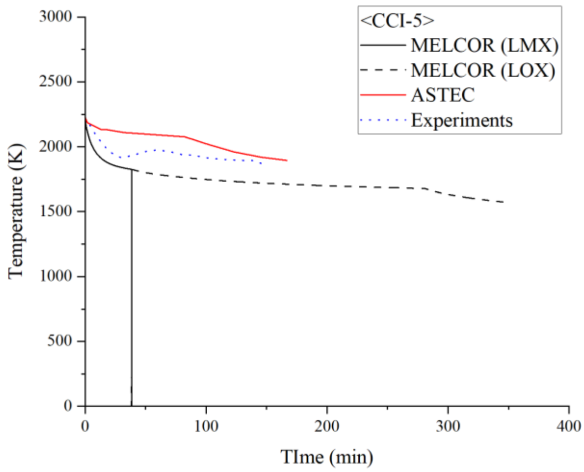

CCI-2.




CCI-3.




CCI-4.




(a) CCI-5.

Fig. 2. Temperature of the molten corium.

## 4. Conclusions

In this research, the experimental results of CCI were comparing with the calculated results of MELCOR and ASTEC code. The ablation depth and temperature of the molten corium was computed. The comparison shows that the calculation results from both codes are quite similar to the experimental results, but there are differences in some cases due to the differences in accident elapsed time. To further improve the accuracy of the codes, the researchers plan to conduct sensitivity analyses to identify the factors that have a significant impact on the results of each code. This will help to determine which factors are most important for predicting the behavior of molten corium and may also provide insights into how to improve the codes for future use

## REFERENCES

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Table 4. Experimental details.

| Parameter | CCI-2 | CCI-3 | CCI-4 | CCI-5 |
|---|---|---|---|---|
| Corium | 100% oxidized PWR + 8 wt% LCS | 100% oxidized PWR + 15 wt% SIL | 78% oxidized BWR with 7.7 wt% SS and 10 wt% LCS | 100% oxidized PWR + 15 wt% SIL |
| Basemat cross section | 50 cm × 50 cm | | 50 cm × 40 cm | 50 cm × 50 cm |
| Initial melt mass (depth) | 400 kg (25 cm) | 375 kg (25 cm) | 300 kg (25 cm) | 590 kg (25 cm) |
| Initial melt temp. | 1880 ℃ | 1950 ℃ | 1850 ℃ | 1950 ℃ |
| Power supply operation prior to water addition | Constant @ 120 kw | Constant @ 120 kw | Constant @ 95 kw | Constant @ 145 kw |
| Criteria for water addition | 1) 5.5 hr of operation | | 1) 7.0 hr of operation | 1) 6.0 hr of operation |
| | 2) ablation 5 cm of limit | | | |
| Inlet water flowrate/temp | 2 lps/20 ℃ | | | |