

Comparative Analysis of Ex-Vessel MCCI for OPR1000 Using MAAP and CORQUENCH

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1. Introduction

Studies of postulated severe accidents in nuclear reactors have long considered the consequences of molten core debris relocating from the reactor vessel onto the horizontal concrete surface of the reactor cavity. Once discharged, the resulting molten core-concrete interaction (MCCI) can lead to several significant phenomena. These include ablation of the concrete basemat, generation of steam and non-condensable gases from concrete decomposition, and chemical reactions between residual metallic components in the corium and concrete decomposition products.

Severe accident progression is traditionally analyzed using integrated system codes capable of simulating plant behavior from reactor scram through reactor vessel failure. One such code is the Modular Accident Analysis Program (MAAP), which provides comprehensive plant-level severe accident analysis. However, certain phenomena require more detailed mechanistic evaluation using specialized codes. CORQUENCH is a dedicated analysis tool designed to evaluate molten core debris cooling behavior and quenching under overlying water following the spreading phase, with particular emphasis on MCCI progression. In support of the licensing process with the NRC, KEPCO-ENC performed overall severe accident analyses for the APR1400 using MAAP4. As part of that process, supporting analyses have been carried out with the MELTSPREAD and CORQUENCH computer codes to support the application. [1]

This study presents a comparative analysis of MCCI behavior for the OPR1000 reactor using results obtained from MAAP 5.06[2] and CORQUENCH 3.03[3] based on the insights and results derived from the APR1400 analysis. The objective is to examine differences in predicted MCCI progression and debris cooling characteristics between the two codes and to assess the applicability of coupled or cross-referenced analysis approaches for severe accident evaluation.

2. Methods and Results

2.1 Assumptions

The Large break loss of coolant accident (LLOCA) sequence was selected for detailed evaluation since this particular case involved the deepest melt pool, as well as concrete ablation during spreading that led to buildup

of slag in the melt. Rather than applying an overly conservative bounding scenario, a best-estimate accident progression from MAAP was used to provide physically realistic initial conditions for the CORQUENCH analysis. Calculations were carried out using default siliceous (SIL) concrete types that are available as part of the code input. Regarding detailed modeling assumptions, all cases were run using the concrete transient heatup and decomposition (dryout) model. This particular calculation was carried out using the Ricou-Spalding melt eruption model and the containment pressure was assumed to remain at 3 Bar over the computed time interval. The floor area of the reactor cavity was determined based on the OPR1000-type nuclear power, which was used as the reference plant for the analysis

2.2 Inputs

The initial melt compositions were taken from the corresponding MAAP cases that factor in concrete ablation as provided in Table 1. The initial corium inventory used in CORQUENCH was obtained from the MAAP simulation at the time after vessel failure.

Table 1. Initial mass of corium constituent

Constituent	Initial mass (kg)
Zr	6353
Fe	11547
Cr	2380
Ni	1067
B ₄ C	591
ZrO ₂	12598
FeO	770
Cr ₂ O ₃	187
NiO	83
UO ₂	38431
SiO ₂	817
CaO	139
MgO	50
Al ₂ O ₃	121
Total	75159

2.3 Results

Principal results of the CORQUENCH analysis for the LLOCA sequence with SIL concrete are provided in Figure 1. According to the CORQUENCH code results, the core debris is quenched and stabilized in about 2 hours, whereas the MAAP code results indicate it takes 4.8 hours for the core debris to quench and stabilize. In terms of the final debris configuration, ~ 84 % of the material is stabilized as fractured crust material, while the balance of the debris (~14 %) is present as a particle bed overlying the crust. This bed forms as a result of melt eruptions. CORQUENCH predicted a maximum axial and radial erosion of 10cm, while MAAP predicted about 18cm. The interaction duration and erosion depth predicted by CORQUENCH was smaller to that predicted by MAAP.

While both codes predicted similar qualitative MCCI behavior, quantitative differences were observed in: erosion depth, interaction duration, mass of core material in debris. These discrepancies are attributed primarily to differences in modeling resolution and physical treatment of melt–concrete interaction.

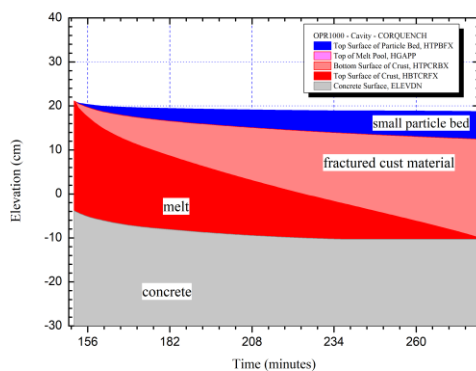


Fig. 1. Ablation area for LLOCA Case with SIL Concrete.

2.4 Discussions

The observed differences between MAAP and CORQUENCH predictions can be attributed to fundamental differences in modeling approaches. MAAP employs an integrated plant-level modeling framework with simplified treatment of ex-vessel melt progression, whereas CORQUENCH provides a more mechanistic and detailed representation of heat transfer, crust formation, and debris–concrete interaction phenomena. As a result, CORQUENCH tends to capture localized thermal-hydraulic effects more explicitly, which can influence predicted erosion rates and quench behavior.

In particular, differences in the treatment of metal oxidation and melt composition significantly influence the thermal evolution of the debris, while the level of spatial resolution affects heat flux distribution and erosion progression. These factors contribute to the discrepancies observed in MCCI duration and concrete erosion depth between the two codes.

It should also be noted that each code has inherent limitations. MAAP, as an integral system code, may not fully capture detailed MCCI mechanisms, whereas CORQUENCH is highly dependent on user-defined initial conditions and does not simulate the full system response, making the results sensitive to the selected corium composition and thermal state. Therefore, small variations in melt composition, oxidation state, and thermal conditions at the time of vessel failure or shortly thereafter can lead to noticeable differences in predicted interaction progression. This suggests that careful definition of debris initial conditions is essential when coupling system-level and detailed MCCI analysis tools.

3. Conclusions

This study compared MCCI behavior for the OPR1000 reactor using MAAP 5.06 and CORQUENCH 3.03 under consistent initial accident conditions. While both codes predicted similar overall MCCI trends, noticeable quantitative differences were observed in concrete erosion, interaction duration, and debris cooling behavior. These differences arise primarily from the level of physical detail and modeling approach used in each code, particularly in the treatment of heat transfer and melt–concrete interaction processes. The results demonstrate that the selection of initial corium conditions significantly influences detailed ex-vessel MCCI predictions. This study aims to provide insights into the consistency and applicability of ex-vessel MCCI analyses across different severe accident analysis codes. However, the present results are dependent on the selected accident scenario, assumptions and code version. Also, the results should be interpreted with consideration of code-specific inherent limitations. Therefore, further systematic investigation is required to assess the general applicability of the results.

REFERENCES

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