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Comparative analysis of CCI-4 test simulation using COCCI and CORQUENCH

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CONTENTS

❖ Motivation

- Code Of Corium-Concrete Interaction (COCCI) is being developed by KAERI for Molten Core Concrete Interaction (MCCI) analysis with C++ focused on wider usability and improved applicability [1].
- The code is also being connected with Code Of Corium Coolability Analysis (COCCA) by EN2T which covers ex-vessel corium behaviors such as jet breakup, spreading, and cooling in the cavity.
- Verification of MCCI analysis under the dry cavity condition is the most significant for COCCI in terms of code connection with COCCA.
  - Under the wet cavity condition, simulation using the connected code would be mainly focused on the corium coolability, which is covered by COCCA.

[1] Sang Ho Kim, Sang Min Kim, Jae Hyun Ham, Hwan-Yeol Kim, Rae-Joon Park, Jaehoon Jung, Development of Computer Code for Analysis of Molten Corium and Concrete Interaction, Transactions of the Korean Nuclear Society Virtual Spring Meeting, July 9-10, 2020.

❖ Objective

- The comparative **MCCI** analysis of **CCI-4 test (dry cavity condition)** was performed using **COCCI** and **CORQUENCH**.

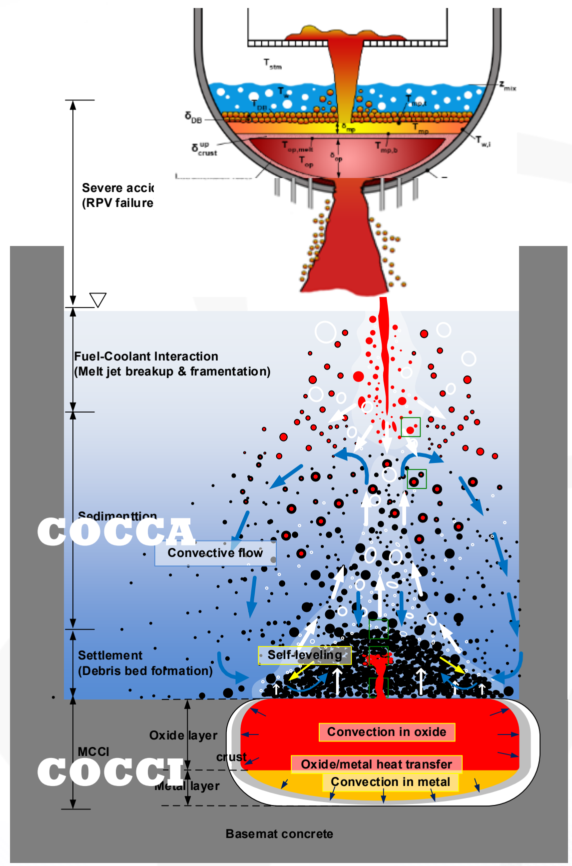

Fig. 1. Schematic of analysis range of COCCI and COCCA

❖ MCCI analysis

- There are several codes to simulate MCCI such as CORCON, CORQUENCH, COSACO, MEDICIS, TOLBIAC-ICB, WECHSL, COCO, MAAP, and so on.
  - ➢ All codes can currently analyze the case in which the corium is assumed to be instantaneously spread over the entire floor of the reactor pit under dry cavity conditions [2].
- Generally, the melt/concrete interfacial heat transfer coefficient, the concrete ablation model, and the concrete ablation temperature are the most important variables for the dry cavity condition MCCI analysis.

[2] OECD/NEA, State-of-the-Art Report on Molten Corium Concrete Interaction and Ex-Vessel Molten Core Coolability, NEA/CSNI/R(2016)15, 2017.

02 Method

❖ General characteristics of CORQUENCH

- CORQUENCH has been developed based on the MACE and OECD/MCCI experiments by ANL since the early 1990's [3].
- The code is capable of performing either a 1-D or simplified 2-D ablation calculation.
- The melt composition can range from fully metallic to fully oxidic; in all cases, the two phases are assumed to be well mixed (i.e., phase stratification is not modeled).
- In terms of heat transfer at the melt/concrete interface, CORQUENCH incorporates a transient concrete ablation/decomposition model based on integral thermal boundary layer theory.
- This model has been upgraded as a part of this work to account for the effects of transient concrete heat-up with simultaneous crust growth following initial melt contact with the concrete.

[3] M. T. Farmer, CORQUENCH Code for Modeling of Ex-Vessel Corium Coolability under Top Flooding Conditions, ANL-18/22, Aug., 2018.

02 Method

❖ General characteristics of COCCI

- COCCI is being developed to simulate the molten corium and concrete interaction in condition with or without coolant at the top [1].
  - ➢ Modeling the physical transient phenomena
  - ➢ Various geometry coordinate options
  - ➢ Various physical model options.
- By COCCA analysis, the state of the corium which is discharged to the cavity initially can be determined as a liquid or the particle debris.
- The particle debris can be turned into the liquid by the re-melting in the cavity.
- Based on geometry coordinate options, simulations on various experiments and realistic analysis of plant response to MCCI in the cavity can be performed.

[1] Sang Ho Kim, Sang Min Kim, Jae Hyun Ham, Hwan-Yeol Kim, Rae-Joon Park, Jaehoon Jung, Development of Computer Code for Analysis of Molten Corium and Concrete Interaction, Transactions of the Korean Nuclear Society Virtual Spring Meeting, July 9-10, 2020.

Comparison of CORQUENCH and COCCI

- Same models were used in CORQUENCH and COCCI for melt-concrete heat transfer and concrete ablation.

Table 1. Melt-Concrete heat transfer coefficient models and concrete ablation models in CORQUENCH and COCCI

	CORQUENCH		COCCI	
Melt-concrete heat transfer model	(1)	Kutateladze and Malenkov	(1)	Kutateladze
	(2)	CORCON gas film model	(2)	Modified Kutateladze
	(3)	CORCON gas film model with a transition to the Bradley model	(3)	Bali
	(4)	Sevon heat transfer correlation	(4)	Kutateladze and Malenkov
Concrete ablation model	(1)	Quasi-steady concrete decomposition	(1)	Quasi-steady concrete decomposition
	(2)	Fully developed	(2)	Fully developed
	(3)	Transient concrete dry-out	-	-

❖ Description of CCI-4 test

- CCI tests were performed in ANL by OECD from 2002 to 2010 after the end of MACE tests [5].
- There were total 6 tests, the purpose was obtaining the MCCI data such as ablation rate and temperature to build the simulation code.
- 100% oxide corium was used in CCI-1, 2, and 3 tests, however, about 8 w/o metal was included in the corium in CCI-4 test to verify the effect of the metal on the concrete ablation and corium coolability.
- From CCI-4 test, corium temperature and ablation depth under the dry cavity condition were mainly obtained.
- The facility for the test was used as 2-D notch-geometry with two opposing, ablating walls.

[5] Hwan-Yeol Kim, Jong-Hwa Park, Validation of Computer Code on the Evaluation of Two Dimensional Corium-Concrete Interaction, KAERI/TR-4264/2011, 2011.

CCI-4 test simulation conditions

- Same material properties were used in CORQUENCH and COCCI.

Table 2. CCI-4 test simulation conditions for CORQUENCH and COCCI

Variable	Contents
Floor size [cm × cm]	50 × 40 (only two opposing side walls can be ablated)
Concrete type	Limestone/common sand
Concrete decomposition temperature [K]	1,500
Concrete decomposition enthalpy [MJ/kg]	1.84
Weight fraction of H_2O gases in concrete	0.0706
Weight fraction of CO_2 gases in concrete	0.2402
Initial total corium mass [kg]	299.67 [UO_2 : Zr : ZrO_2 : Fe : SiO_2 : Cr : CaO : Al_2O_3 : MgO = 0.565 : 0.046 : 0.215 : 0.030 : 0.041 : 0.047 : 0.037 : 0.005 : 0.14]
Initial melt temperature [K]	2,250
System pressure [bar]	1.0
Power [kW]	95
Simulation time [s]	20,000
Water injection time [s]	(no water injection)

03 Result

❖ Comparison of ablation depth and temperature

- Both CORQUENCH and COCCI predicts ablation depth larger than experiment.
  - ➢ If transient concrete dry-out model is used, the depth will be decreased.
- COCCI predicts ablation depth larger than CORQUENCH because predicted bulk melt temperature is higher.

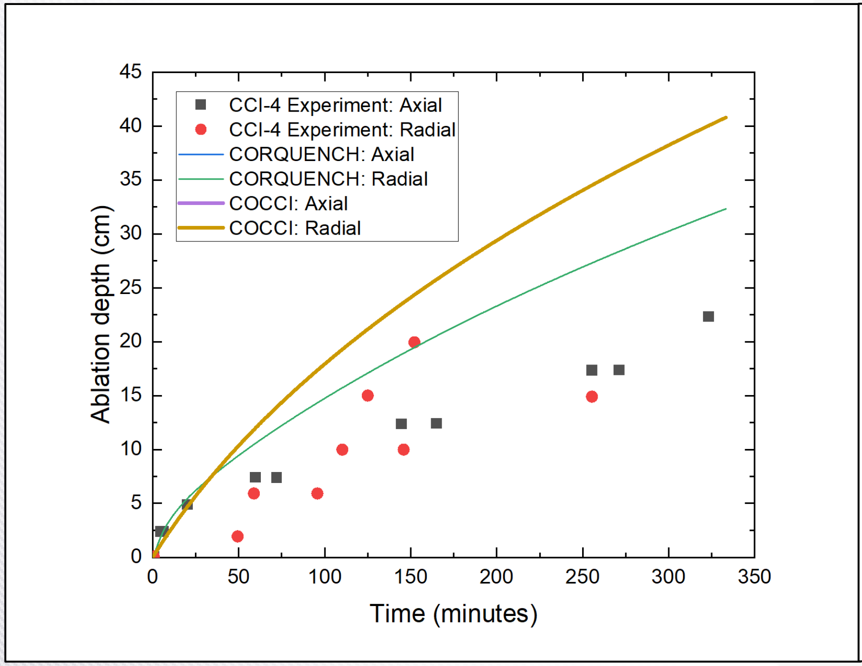

Fig. 2. Comparison of ablation depth

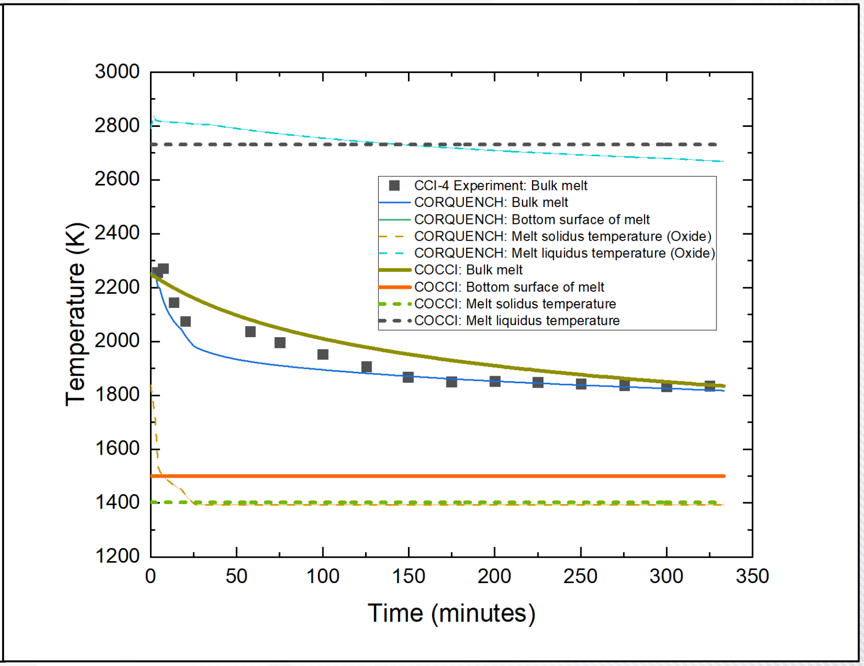

Fig. 3. Comparison of temperature

❖ Comparison of heat flux and heat transfer coefficient

- Because bulk melt temperature is higher in COCCI, heat fluxes are also higher.
- Heat transfer coefficient is almost similar because same model was used.
  - ➢ The difference of heat transfer coefficient in early phase comes from the difference of corium material properties such as heat capacity.

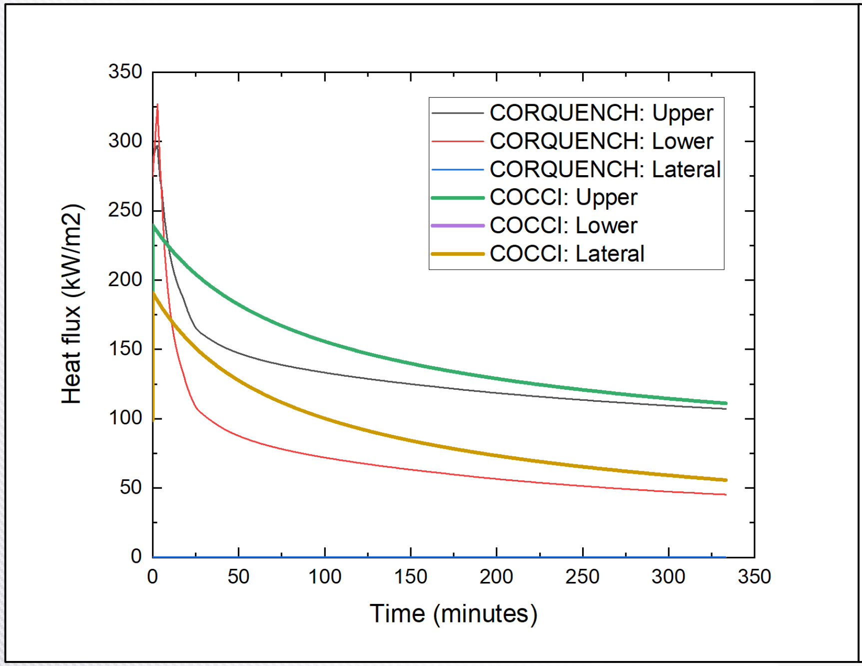

Fig. 4. Comparison of heat flux

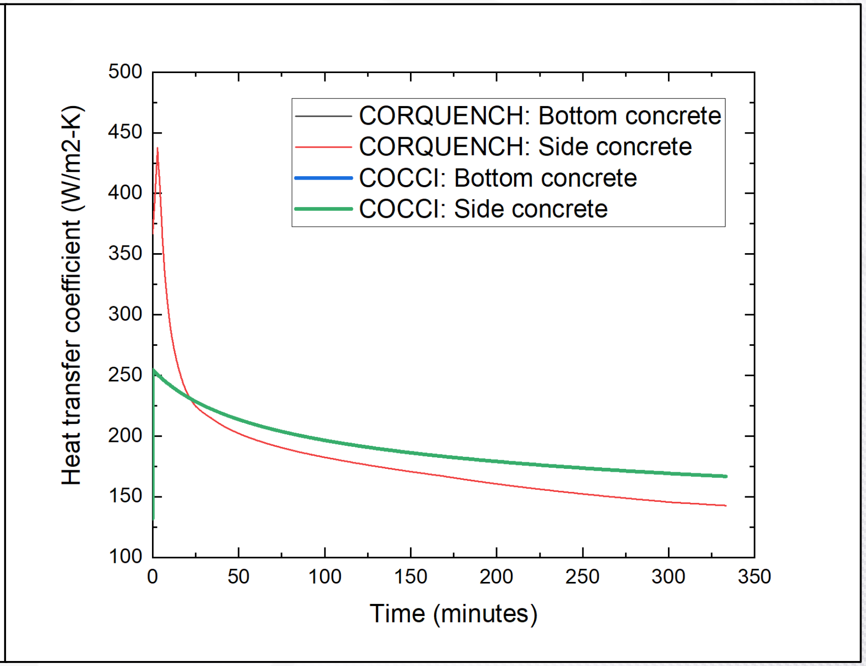

Fig. 5. Comparison of heat transfer coefficient

03 Result

❖ Comparison of elevation and mass

- In COCCI, increase rate of corium mass and volume are higher comparative to ablation rate.
  - ➢ It was assumed that the whole decomposition gas remains in corium so that the estimated bulk melt temperature is also higher in COCCI.

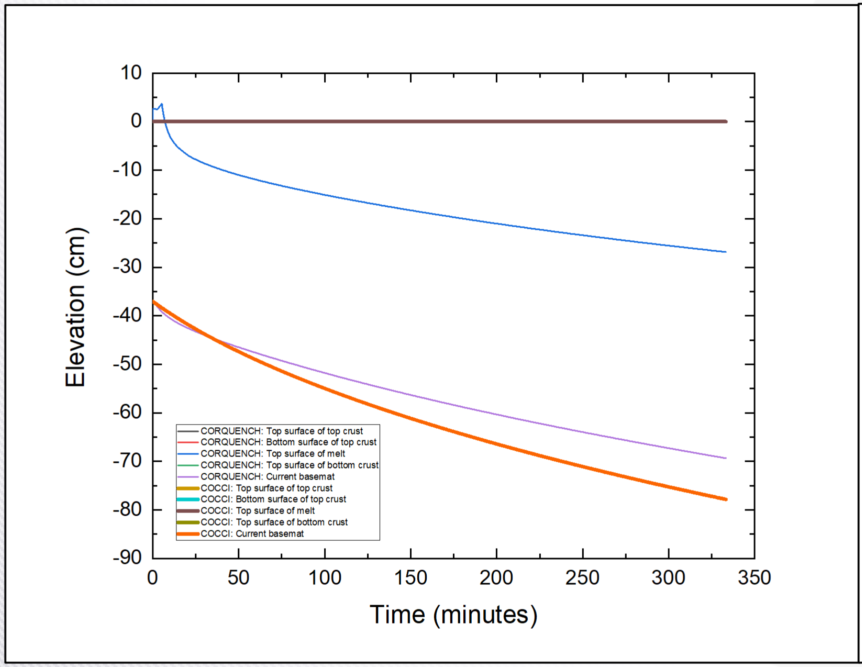

Fig. 6. Comparison of elevation

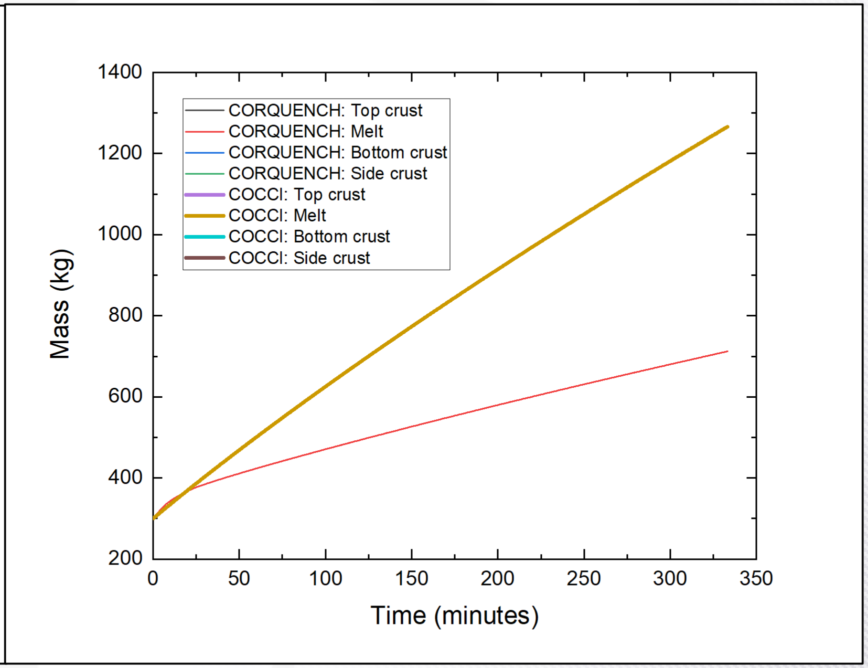

Fig. 7. Comparison of mass

04 Conclusion

❖ Summary and further study

- Both CORQUENCH and COCCI predicts ablation depth larger than experiment, because quasi-steady concrete decomposition model was used.
  - ➢ Transient concrete dry-out model will be updated for COCCI.
- The estimated heat transfer coefficient from CORQUENCH and COCCI was different in early phase because several corium material properties were different.
  - ➢ Change of all corium material properties by concrete decomposition will be updated for COCCI.
- The estimated increase rate of corium mass and volume is higher in COCCI comparative to ablation rate because it was assumed that the whole decomposition gas remains in corium so that the estimated bulk melt temperature is also higher.
  - ➢ Decomposition gas behavior model will be updated for COCCI.

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THANK YOU

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