MCCI Accident Analysis for CANDU-6 Plant using ISAAC4

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1. Introduction

MCCI(Molten Core Concrete Interaction) is the one of the severe accident phenomena which can occur when the molten corium is transferred into the calandria vault and interact with the concrete wall. During MCCI process, the various gases including steam and combustible gases are generated by concrete decomposition and metal oxidation. Decay heat and the heat by chemical reactions in the MCCI pool are released. In case of CANDU-6 Plant where the calandria vault is initially filled with the water, the massive steams are generated after the release of melt which can cause the overpressure of containment. Also, the concrete wall can be eroded significantly by concrete decomposition. As a result of the continuous MCCI for long term period, the vault floor will experience a melt-through inevitably if MCCI cannot be mitigated. In this paper, accident analysis for CANDU-6 plant was performed using ISAAC4 code[1] to investigate the effect of the emergency water injection into the vault on the concrete erosion during MCCI process.

2. Methods and Results

PSA(Probabilistic Safety Analysis)[2] scenarios which have relative high frequencies were analyzed using ISAAC4 to define a conservative MCCI condition and the sensitivity analysis were done in terms of a number of major relevant parameters regarding MCCI phenomena.

2.1 Selection of Accident Scenario

Based on the PSA results for CANDU-6 plant, total 13 accident scenario are selected considering the CDF(Core Damage Frequency) and PDS(Plant Damage State). The cumulative percent of CDF and PDS for selected analysis scenario is 46.4% and 93.0% respectively.

2.2 Scenario Analysis

Accident analyses were conducted for 13 scenarios. The general and default input of ISAAC4 parameter file for CANDU-6 plant was used. From the results, among 13 scenarios, MCCI occurs in 5 scenarios which are IE-SEC-S62, P01-IEF-RSW-S14, IE-CL4-S59, IE-ESC-S64, S20-S03-ESCB-S9.

As shown Table I, it is confirmed that the S20-S03-ESCB-S9 has the maximum erosion rate of 6.84 cm/hr for about 20 hrs. This results is from accident progression that the uncover of calandria vessel is faster than the other scenarios because of the break of End Shielding Cooling(ESC) system. Therefore the decay heat of corium is relatively higher due to early failure of calandria vessel. The scenario S20-S03-ESCB-S9 experiences the failure of calandria vaults floor.

Table I: Scenario Analysis Results

Scenario	Calandria Vessel Fail(hr)	Concrete Erosion Start(hr)	Erosion Rate (cm/hr)	Downward Erosion Depth(m)
IE-ESC-S63	37.92	44.71	5.28	1.44
P01-IEF-RSW-S14	49.93	58.75	5.22	0.69
IE-CL4-S59	46.59	54.02	5.81	1.04
IE-ESC-S64	37.96	44.65	5.23	1.43
S20-S03-ESCB-S9	11.47	16.48	6.84	2.00[1)]

1)Floor concrete of calcandria vault fails at erosion depth 2 m.

2.3 Sensitivity Analysis on Erosion Depth by MCCI

The level of concrete erosion by MCCI mainly depends on the concrete property, heat transfer coefficient, initial environment condition such as corium temperature and mass, cooling water mass and temperature in the calandria vault.

For MCCI sensitivity analysis using ISAAC4 code, 7 parameters which had been suggested as the sensitivity parameters by the ISAAC/MAAP[3] developer are enlisted in Table II. The table includes the convective heat transfer coefficient of corium, jet entrainment coefficient in the Ricou-Spalding correlation which mean how large a fraction of the molten jet from the lower plenum will be entrained and become particulated in the pool, the emissivity of corium surface, heat transfer coefficient for film boiling, rear density and flat plate CHF Kutateladze number. The separate sensitivity calculations for each sensitivity parameter were performed for scenario S20-S03-ESCB-S9. In these calculations, it was assumed that the CVWM (Calandria Vault Water Make-up) starts at 24 hrs after the failure of calandria vessel. Based on the results of separate MCCI sensitivity calculation, a synthetic conservative combination of sensitivity parameters was determined and the erosion depth was investigated comparing the results from various cases.

Table II: MCCI Sensitivity Parameters

Parameter	Range	General (default)	Definition	Conservative Combination
HTCMCS (W/m2/K)	2000 - 5000	3500	sideward convective heat transfer coefficient of corium	2500
HTCMCR (W/m2/K)	2000 - 5000	3500	downward convective heat transfer coefficient of corium	5000
ENT0C	0.025 - 0.06	0.045	jet entrainment coefficient in the Ricou-Spalding correlation	0.025
ECM	0.7 - 0.99	0.85	emissivity of corium surface.	0.7
HTFB (W/m2/K)	100 - 400	300	coefficient for film boiling heat transfer	100
DCSRCN (kg/m3)	157– 417	300	rebar density	417
FCHF	0.0036 - 0.3	0.1	flat plate CHF Kutateladze number	0.015

2.4 Sensitivity Calculation Results

As separate calculation results for 7 MCCI parameters in Table II, it was found that the erosion depth is not so sensitive for parameter of ENT0C, ECM, HTFB, DCSRCN. The erosion depth for the parameters of HTCMCS, HTCMCR, and FCHF is presented in Fig. 1,2 and 3. Especially as shown Fig. 3, it is seen that the vault would fail if FCHF value is smaller than 0.01 and this is FCHF has very decisive effect on the overall erosion result. In this report, 0.015 was chosen as the conservative value along the range where the CVWM could be meaningful. Fig. 4 shows that the conservative case progresses 1.95 m of maximum erosion which means the melt-through is prevented.

3. Conclusions

In this paper, the water injection effect on MCCI in CANDU-6 plant was studied using ISAAC4 code and a conservative MCCI condition was defined by scenario analysis and a number of sensitivity calculations. Even though FCHF has relatively large impact on the final MCCI consequences, the analysis result given by a reasonably conservative combination of the conditions shows that the water injection would mitigate the MCCI in the calandria vault.

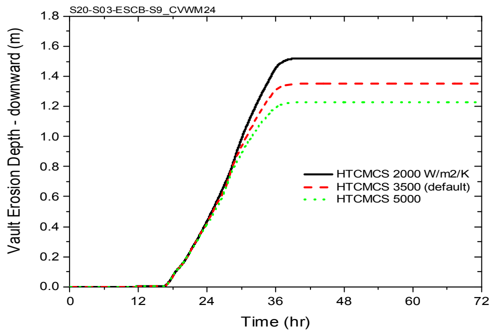

Fig. 1. Downward erosion depth for HTCMCS parameter

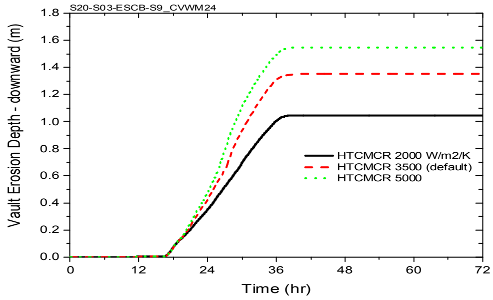

Fig. 2. Downward erosion depth for HTCMCR parameter

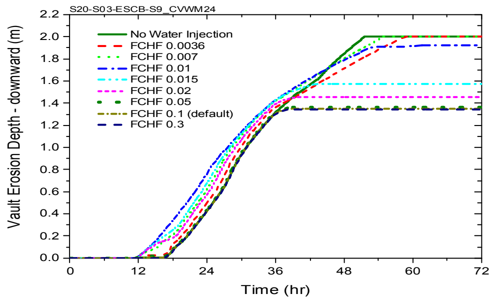

Fig. 3. Downward erosion depth for FCHF parameter

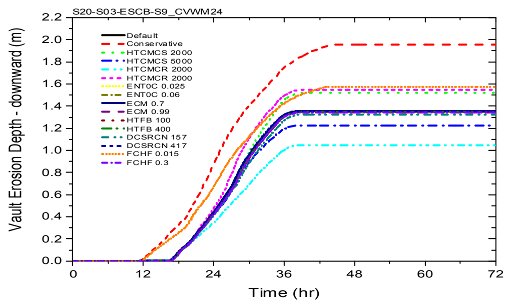

Fig. 4. Downward erosion depth for sensitivity cases

REFERENCES

[1] ISAAC Computer Code User's Manual, KAERI/TR-3645/2008, December, 2008.
[2] Level 2 PSA report for Wolsong NPP Unit #1, KHNP, 2015
[3] EPRI, "Modular Accident Analysis Program (MAAP4)," Fauske & Associates, Inc., 1999.