Behavior Analysis of Molten Fuel Discharged Directly into Water without Free-Fall in Air

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CONTENTS

1. Introduction

Background

- The coolant is injected into the reactor cavity for various purposes in severe accident management.
  - One is to prevent the breakage of a reactor vessel caused by the thermal or physical load from the molten corium in a lower head of a reactor vessel.
- In spite of pursuing the strategy for the ex-vessel cooling, the lower head of a reactor vessel can be broken due to the insufficient water level in a reactor cavity.
- According to the water level, the behavior of molten fuel varies in water.

Purpose of this Paper

- To analyze the behavior of molten fuel discharged directly into water without free-fall in air
  - Modeled Test: TROI-#82 (W10)
    - ✓ Experimental test performed in the TROI (Test for Real cOrium Interaction with water) facility
  - Used Code: TEXAS-V
    - ✓ Developed by the University of Wisconsin-Madison for the simulation of FCI [1].

2. Modeled Test: TROI-82

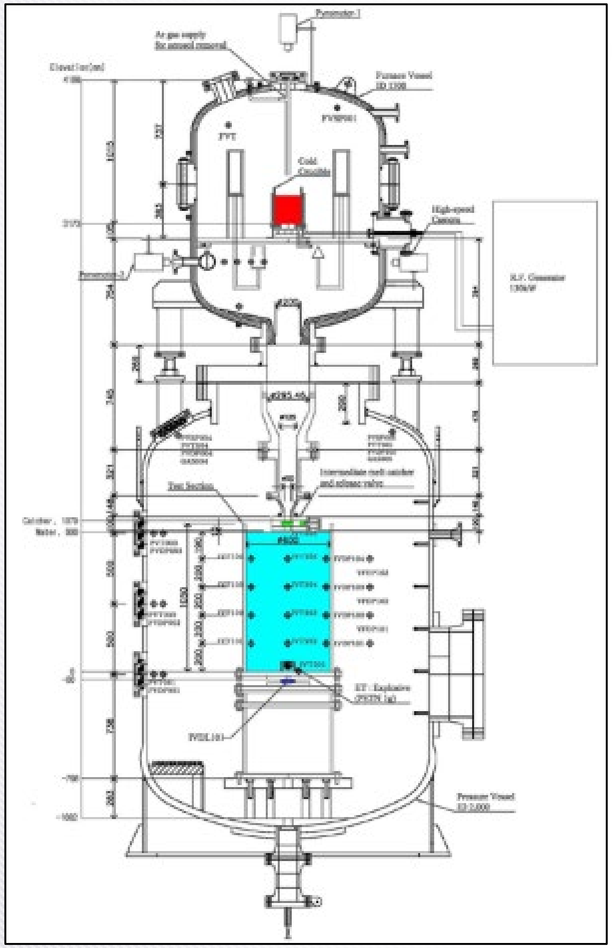

Fig. Schematics of TROI-82

Table. Conditions of TROI-82

Melt	
UO_2 : ZrO_2 (w.t. %)	70:30
Maximum temperature (K)	3021
Charged mass (kg)	32.7
Released mass (kg)	13.5
Plug/puncher diameter (m)	0.1 / 0.085
Corium jet diameter (nozzle diameter) (m)	0.05
Height of corium release valve (m)	1.0
Corium release Valve-to-water surface distance (m)	0.0
Test section	
Water mass (kg)	283
Water pool depth (m)	1.0
Cross section area (m^2)	0.283
Initial temperature (K)	300
Pressure vessel	
Initial pressure (air) (MPa)	0.151
Initial temperature (K)	300

3. Analysis Method

TEXAS-V code

- Analyzed variables in Premixing phase
  - Jet breakup model
  - Fragmentation instability
    - ✓ Rayleigh–Taylor instability (RTI)
    - ✓ Kelvin-Helmholtz instability (KHI)
    - ✓ Boundary layer stripping (BLS)
  - Coefficient for KHI
    - ✓ 0.005 ~ 0.02

For the explosion phase in the test and simulations

- Pressure wave generated from external triggering device installed on the bottom of the test section was modeled.

Table. Simulation Cases for TROI-82

Name of simulation case	Jet breakup model	Applied fragmentation instability	Coefficient for KHI
T-C1	Trailing edge	RTI	-
L-C1	Leading edge	RTI	-
L-C2-0.02	Leading edge	RTI, KHI, BLS	0.02
L-C2-0.01	Leading edge	RTI, KHI, BLS	0.01
L-C2-0.005	Leading edge	RTI, KHI, BLS	0.005

4. Results: Premixing Phase

Sequence

- 0.0 s: valve open signal is generated, and corium lump starts to move
- 0.1 s: melt jet reaches the water surface
- 0.56 s: triggering signal is generated

Melt jet behavior

- The initial velocity was set to 1.0 m/s. The velocity increased by the gravity.
- As the coefficient for KHI increases, the mass portion of the corium particle increases.

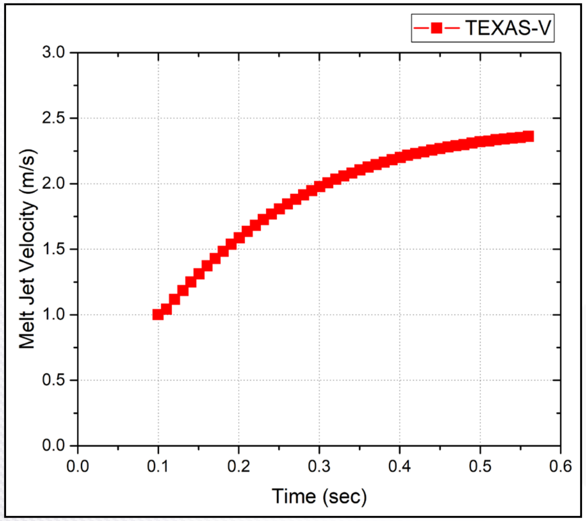

Fig. Melt jet velocity

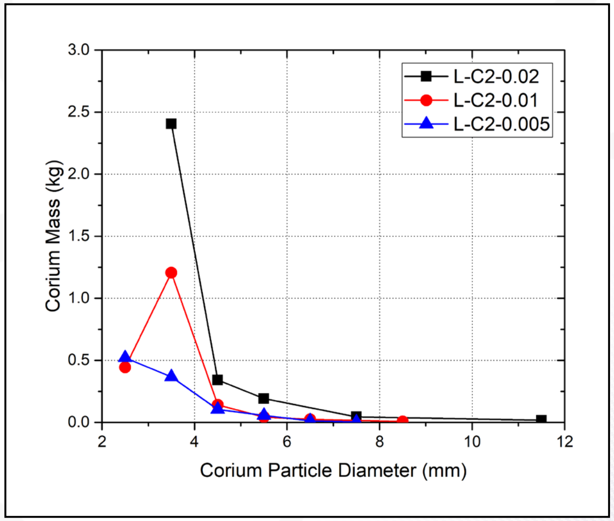

Fig. Mass distribution of corium particle size

5. Results: Explosion Phase

Effect of triggering pressure wave

- The impulse generated by the pressure wave from the triggering device was ~3.0 kPa·s.

T-C1 and L-C1 cases

- Underestimated impulse
  - Exclusion of the fragmentation on the side of the jet

L-C2 cases

- Overestimated impulses
- Highly varied with the coefficient for KHI
- Not big effect of BLS on the explosion in the simulations

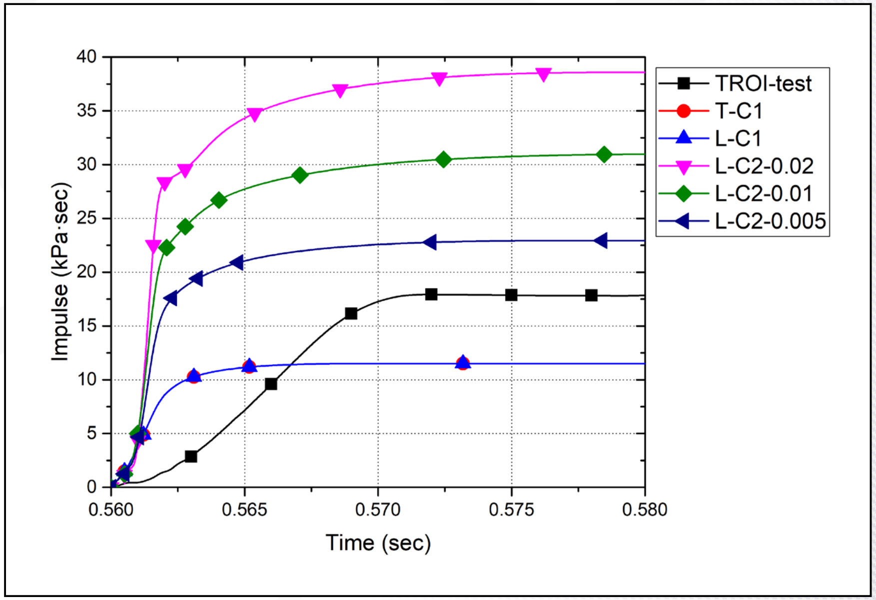

Fig. Impulses of steam explosions

6. Discussions

Related with the Reviewer's comment on this paper (underlined in text)

❖ Jet breakup in this submerged condition ?

- Most of the current model validation have been done for the database of jet impinging on the water surface (with freefall in air)
  - ✓ Not considering the jet impinging effect on the water level
  - ✓ But, it was actually considered in the model. And, it has been validated until now.

- On the other hand,
  jet breakup in this submerged condition (without the jet impinging effect)
  - ✓ Very slow initial jet velocity; however,
    No jet breakup in the TROI-79, 82 condition (just velocity increase)
    - ➢ Re-validation of the models, and
    - ➢ Need of new jet breakup model for this condition
      - Need of theoretical approach, not parametric.
      - Need of more data..

7. Conclusions

» Behavior of Molten Fuel Discharged Directly into Water without Free-Fall in Air

- The melt jet stream fell to the bottom as a lump in the water
  - In a previous paper [3] on the visualization of FCI, images of corium in the TROI-79 test for the ex-vessel cooling condition taken by a high-speed camera, revealed a thick film around the surface of the melt jet

» Analysis for the steam explosion in this condition

- Exclusion of the fragmentation by the KHI
  can cause the underestimation of the steam explosion impulse

- Need to set the proper coefficient for the KHI
  - Overestimation of the KHI: possibly causing either ① or ②

    ① More fragmented particles,
    → Larger impulse of SE

    ② (foreseen) Much more fragmented particles
    → More cooled particles
    → More solidified particles
    → Smaller impulse of SE

References

[1] M. L. Corradini et al., "User`s Manual for TEXAS: One Dimensional Transient Fluid Model for Fuel-Coolant Interaction Analysis," University of Wisconsin-Madison (Mar. 2012).

[2] S.-W. Hong, S. H. Kim, and R.-J. Park, "Comparison of Triggered Explosion Behavior by Corium Injection Modes in TROI Facility," Nuclear Technology, 206, 3, 401 (2020).

[3] Y. S. Na, et al., "Fuel-Coolant Interaction Visualization Test for In-Vessel Corium Retention External Reactor Vessel Cooling (IVR-ERVC) Condition," Nuclear Engineering and Technology, 48, 1330 (2016).

[4] (article in production) https://doi.org/10.1080/00295450.2020.1820827

Acknowledgement

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korean government (Ministry of Trade, Industry, and Energy) (No. 20193110100090).