A Preliminary Validation and Sensitivity Analysis of FARO L-14 Experiment using Fuel-Coolant Interaction Module of CINEMA

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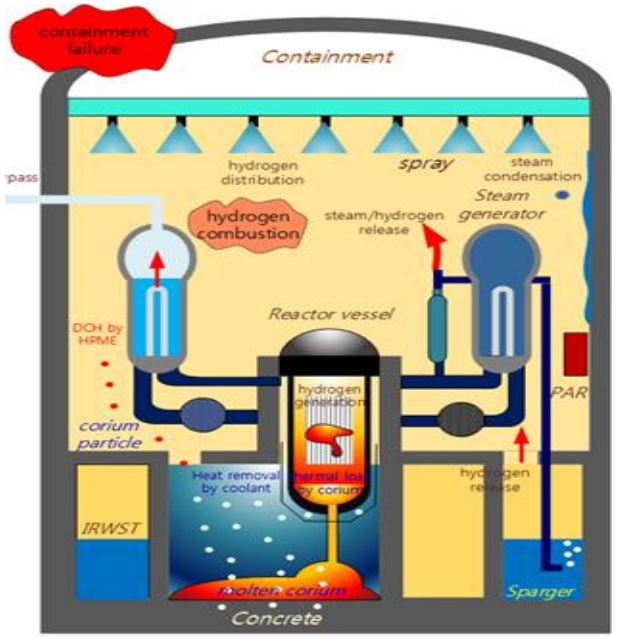
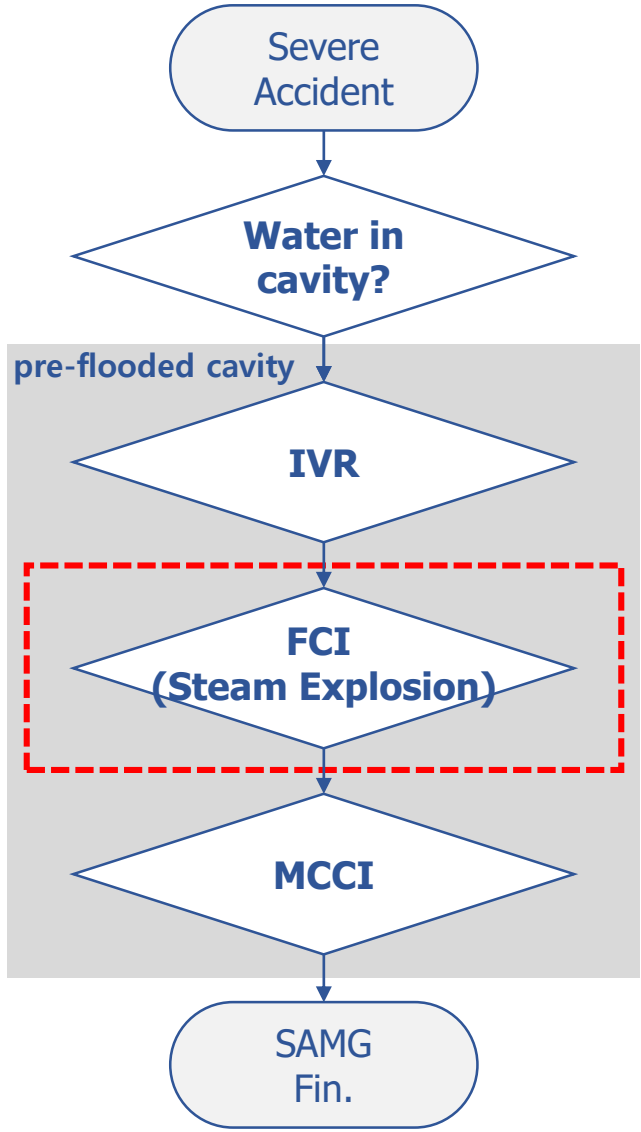
2022.10.20

I. Introduction: Background

- **Severe Accident (SA)**

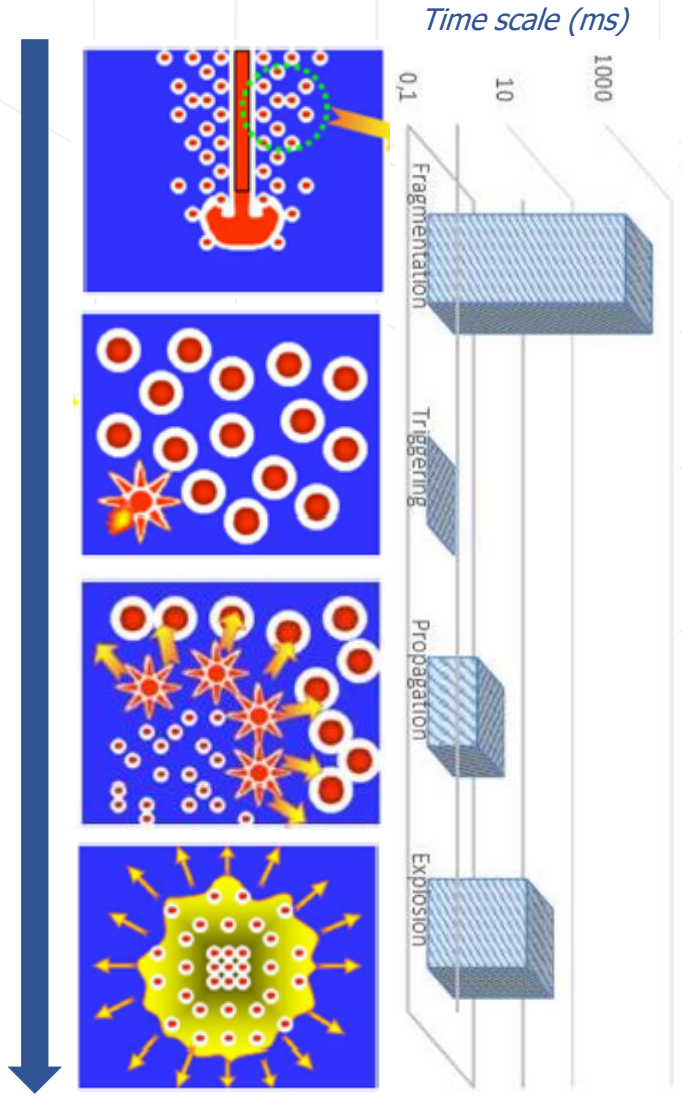


- **SAMG in Korea**: **<u>Pre-flooded cavity</u>** strategy
  - ✓ **Risk-significant SA phenomena : <u>FCI</u>** & MCCI



I. Introduction: Steam Explosion

- **Four phases of SE**
  - ✓ **Pre-mixing/fragmentation**
    - "Jet break-up" & "fragmentation"
  - ✓ **Triggering**
    - Destabilizes the premixing config. & "Initiate the SE"
      - Internal (spontaneous), external (artificial, accidentally induced)
  - ✓ **Propagation**
    - Collapse the vapor film (liq-liq contact)
      - Fine "fragmentation": thermal & hydrodynamic
      - Thermal exchanges… propagation…
  - ✓ **Expansion**
    - "Thermal energy" is converted into "Mechanical energy"

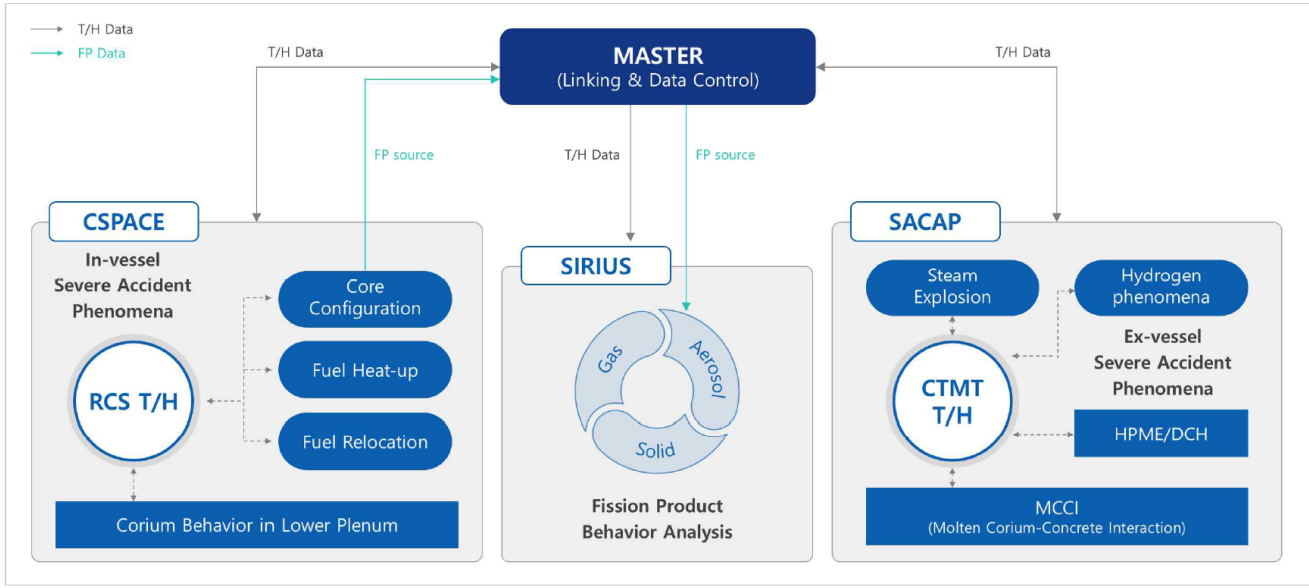


Ref. Berthoud, 2000 & SA course in 2021

I. Introduction: CINEMA Code

- **CINEMA**: **C**ode for **IN**tegrated severe accident **E**valuation and **MA**nagement
  - ✓ **대형 가압경수로형 중대사고 사고 경위 및 관련 현상 해석**
    - 정상운전, 노심가열, 노심용융, 노심재배치, 원자로용기 파손, 수소거동, 노심용융물 방출, 노심용융물-냉각수 상호작용, 노심용융물-콘크리트 반응, 격납건물 가압, 핵분열 생성물 거동
    - 중대사고 현상 **개별 독립적** / **통합 연계** 분석 가능

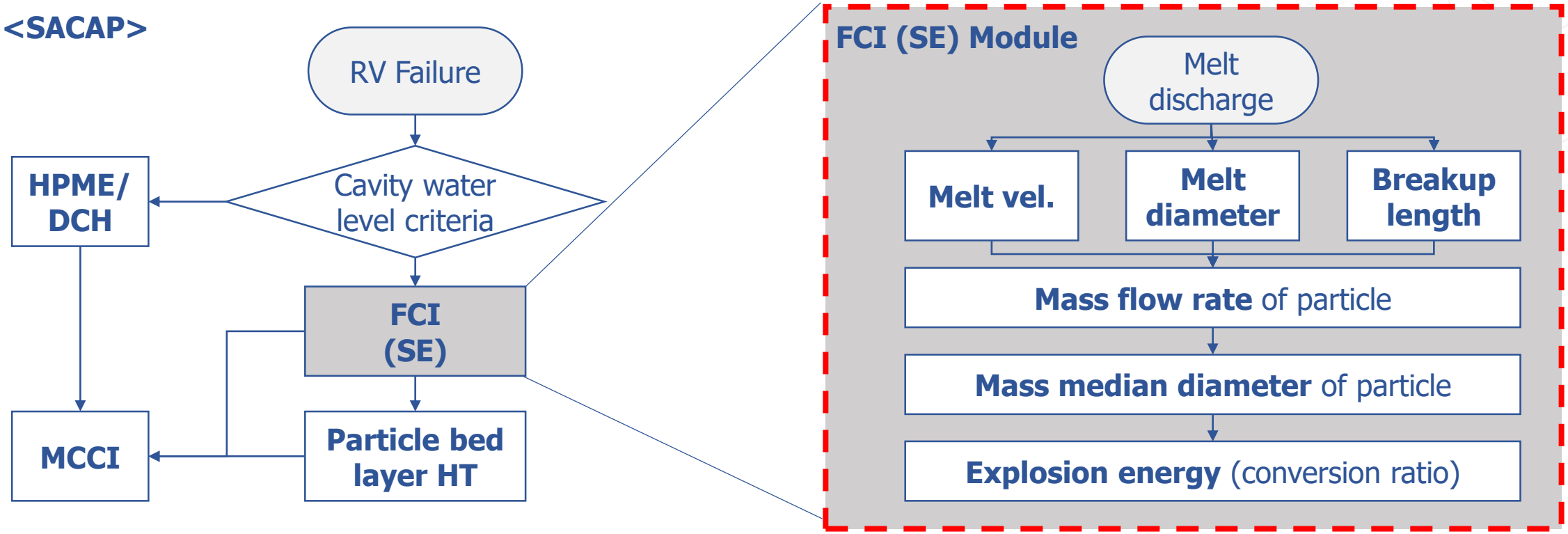
  - ✓ **Code Structure**
    - MASTER (연계 해석)
    - CSPACE (노내 현상)
    - **SACAP (노외 현상)**
    - SIRIUS (핵분열생성물)



Ref. CINEMA Theory / User manual

I. Introduction: SACAP Module

- **SACAP Analysis Model**: 격납건물 중대사고 현상 및 열수력 거동 분석 모듈
  - ✓ **SA Phenomena**
    - – **FCI (SE)**, Debris bed formation, HPME/DCH, MCCI, Hydrogen combustion, Zr Oxidation



Ref. CINEMA Theory / User manual

I. Introduction: FCI(SE) Module

- **Mixing**
  - ✓ **Melt Jet Break**:
    - Jet breakup length (Taylor type, Bo > 50)

$$\frac{L_{BR}}{D_{in}} = C_{BR}\sqrt{\left(\frac{\rho_m}{\rho_l}\right)}$$

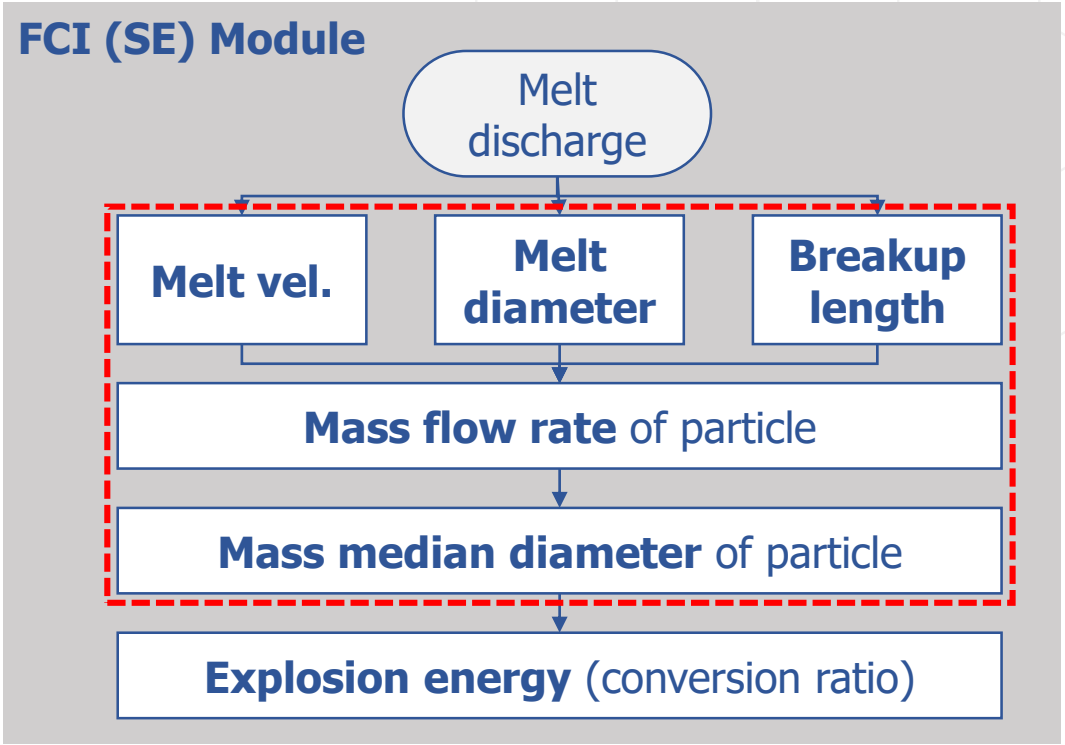
    - Melt diameter

$$Bo_p^{1/2} = C_s \left(\frac{\rho_v}{\rho_l}\right)^{1/3} \left(\frac{\rho_m}{\rho_l}\right)^{-2/3}$$

    - Mass flow rate

$$\dot{m} = \frac{1}{2}\frac{\rho_m v_{in} D_{in}}{L_{BR}}$$

  - ✓ **Mixing region**: Heat transfer of particles



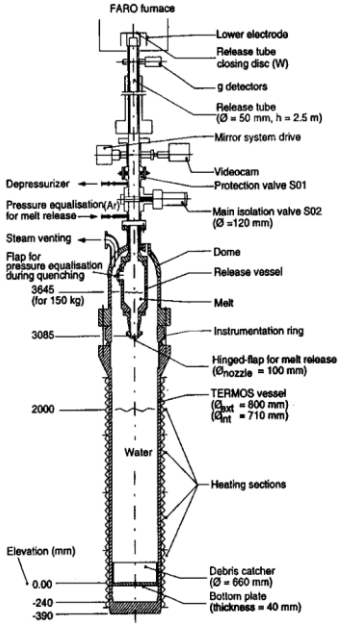
I. Introduction: Objective

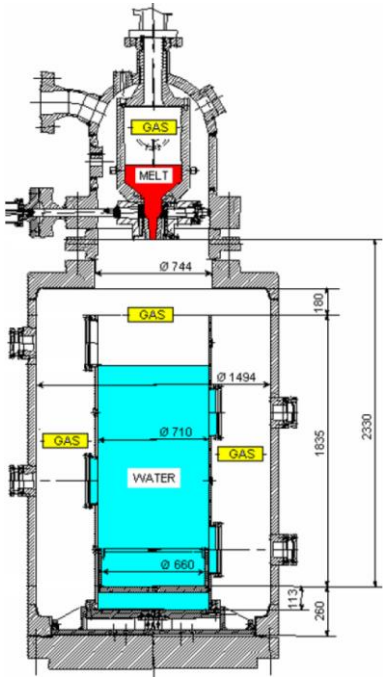
- **CINEMA User Group** work: 2022.04.18 – 2022.09.02
  - ✓ Purpose: **User experience**, **Error reporting**, **Suggestion for module improvement**, etc.
  - ✓ Selected Module: CINEMA Code ▷ SACAP Module ▷ **FCI (SE) module ("StmExp")**

- **Objective:**
  - ✓ **Preliminary validation** with representative mixing experiment (**FARO**)
  - ✓ **Code-to-Code comparison** with a **FCI code (COOLAP-II: Mixing part)**
  - ✓ **Model parameter sensitivity**
    - – Particle heat transfer related parameter

II. Method: FARO-Experiment (FARO-L14)

- **FARO tests (JRC)**
  - ✓ Large scale **FCI** experiments
  - ✓ **UO2-ZrO2** (80:20wt%)
  - ✓ **Corium** melt ~ 150 kg
  - ✓ Pressure 0.2~5MPa



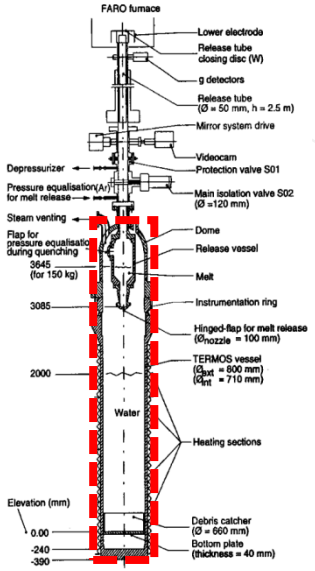


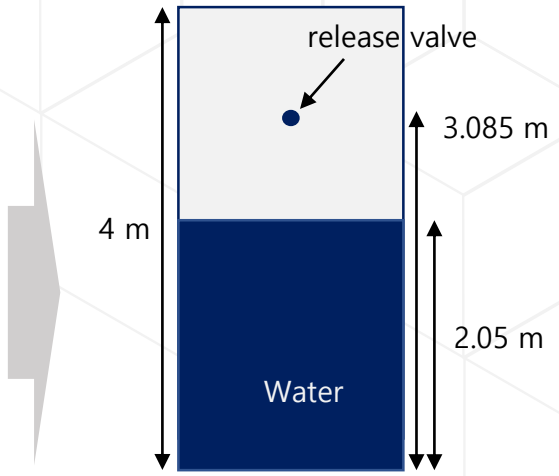
	L28	L31	L14
Melt material	UO2-ZrO2 (80:20wt%) (corium)		
Vessel type	Double	Double	**Single**
Melt mass (kg)	175	92	**125**
Melt jet diameter (m)	0.05	0.05	**0.1**
Melt initial temperature (K)	3052	3003	**3123**
System pressure (MPa)	0.51	0.22	**5.1**
Water pool depth (m)	1.44	1.45	**2.05**
Water temperature (subcool) (K)	423(3)	291(105)	**537(1)**
Debris catcher diameter (m)	0.71	0.41	**0.71**

II. Method: Numerical Input

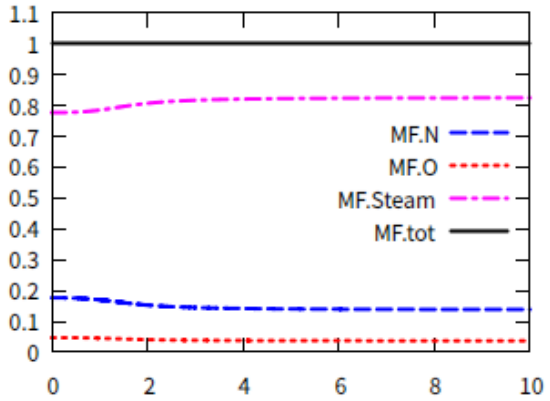
- **Simplified geometry**
- **Input parameter**

Parameter		Value
Vessel	Volume (m^3)	2.45
	Diameter (m)	0.71
	Height (m)	4.0
	Pressure (MPa)	5.1
	Temperature (K)	537
	Water height (m)	2.05
Melt jet	UO_2-ZrO_2 (-)	80w%-20w%
	Decay heat	-
	Mass (kg)	125
	Temperature (K)	3123
	Release diameter (m)	0.0048
	Velocity (m/s)	1
Model parameter	**chtc (-) ***	**0.1**
	diam (mm) **	**4.8**





Mass fraction (77 w%)



*: **Factor for heat transfer coefficient** between jet and coolant. The value is based on the sensitivity analysis.

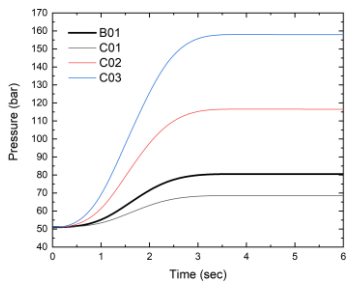
: **Mass median diameter of particle during the jet breakup. The value is based on the experimental result.

III. Results: CINEMA

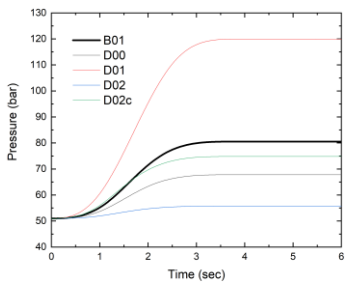
- **FARO-L14 Results (CINEMA)**
  - ✓ (preliminary) Best-estimate results

Model parameter		
	chtc (-)	0.1
	diam (mm)	4.8
	pnodeH (m)	0.02

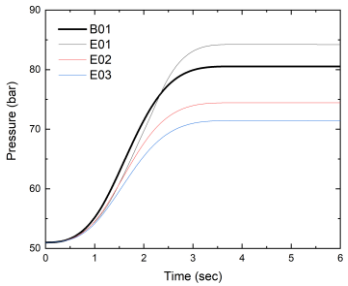
- Model parameters are selected by preliminary parameter sensitivity analysis (chtc, diam and particle node height etc.)



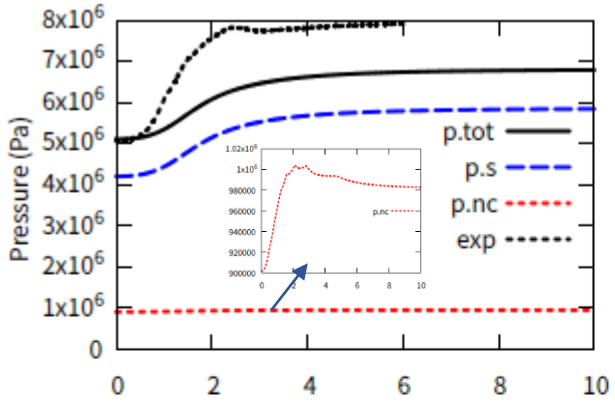
chtc



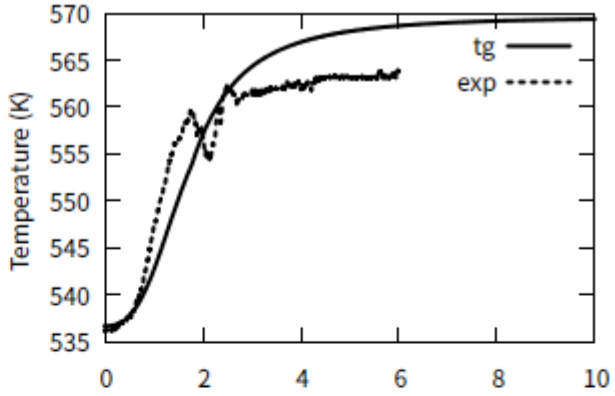
diam



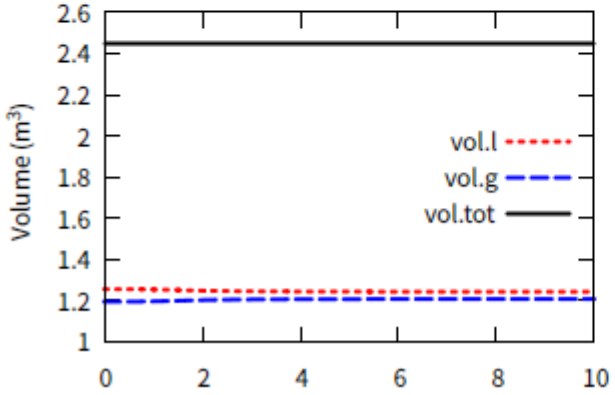
pnodeH



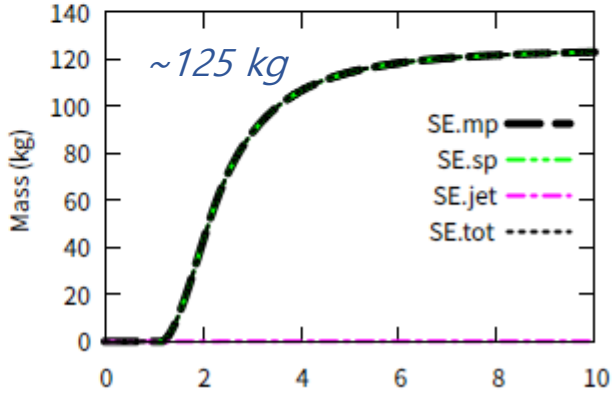
Pressure



Temperature



Volume



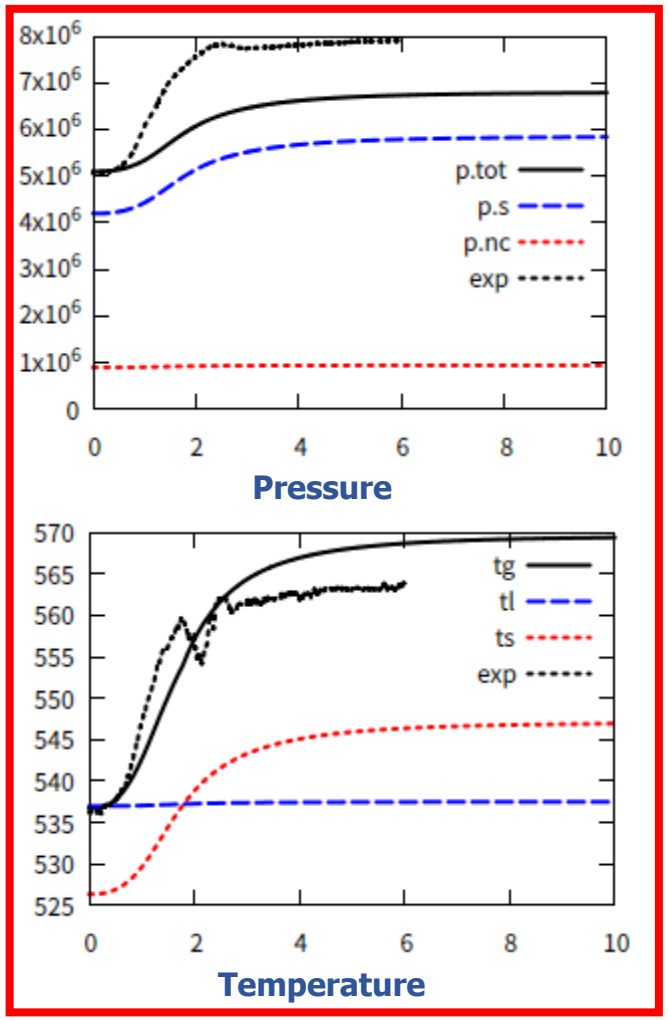
Mass

III. Results: CINEMA vs. COOLAP-II

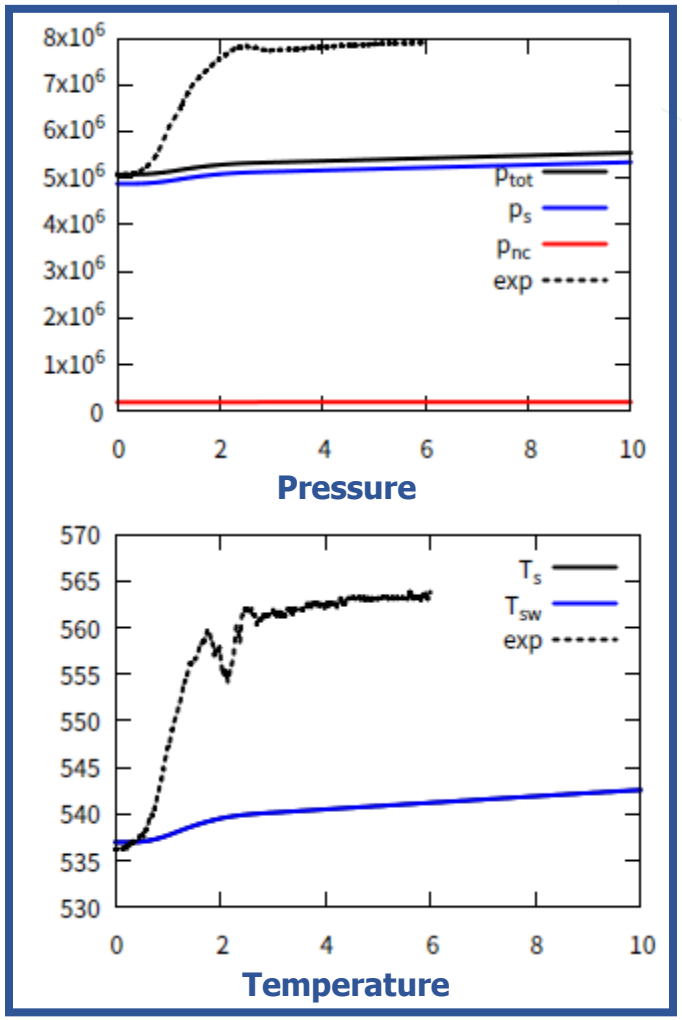
- **CINEMA vs. COOLAP-II** in FARO-L14

Model parameter settings "As CINEMA"
(not the best-estimate results for CL-II)

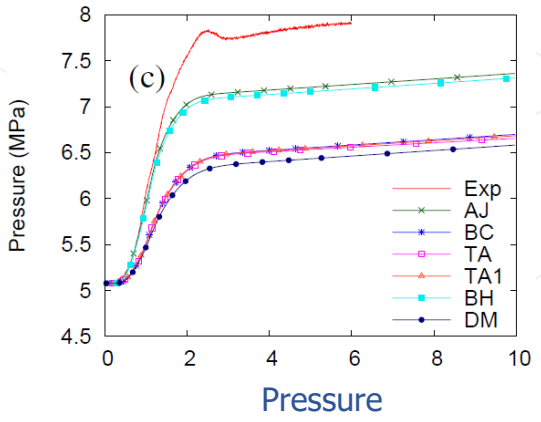
CINEMA

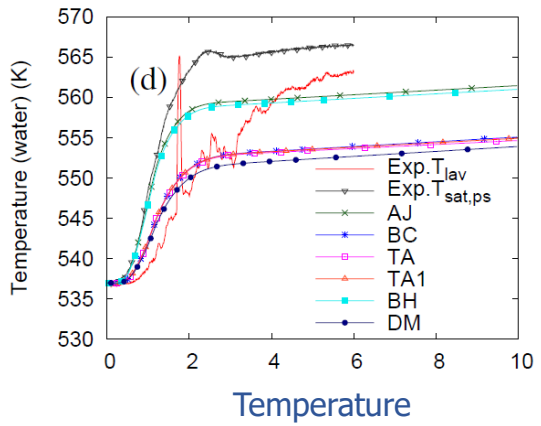


COOLAP II



Sensitivity study for
COOLAP-II model parameter



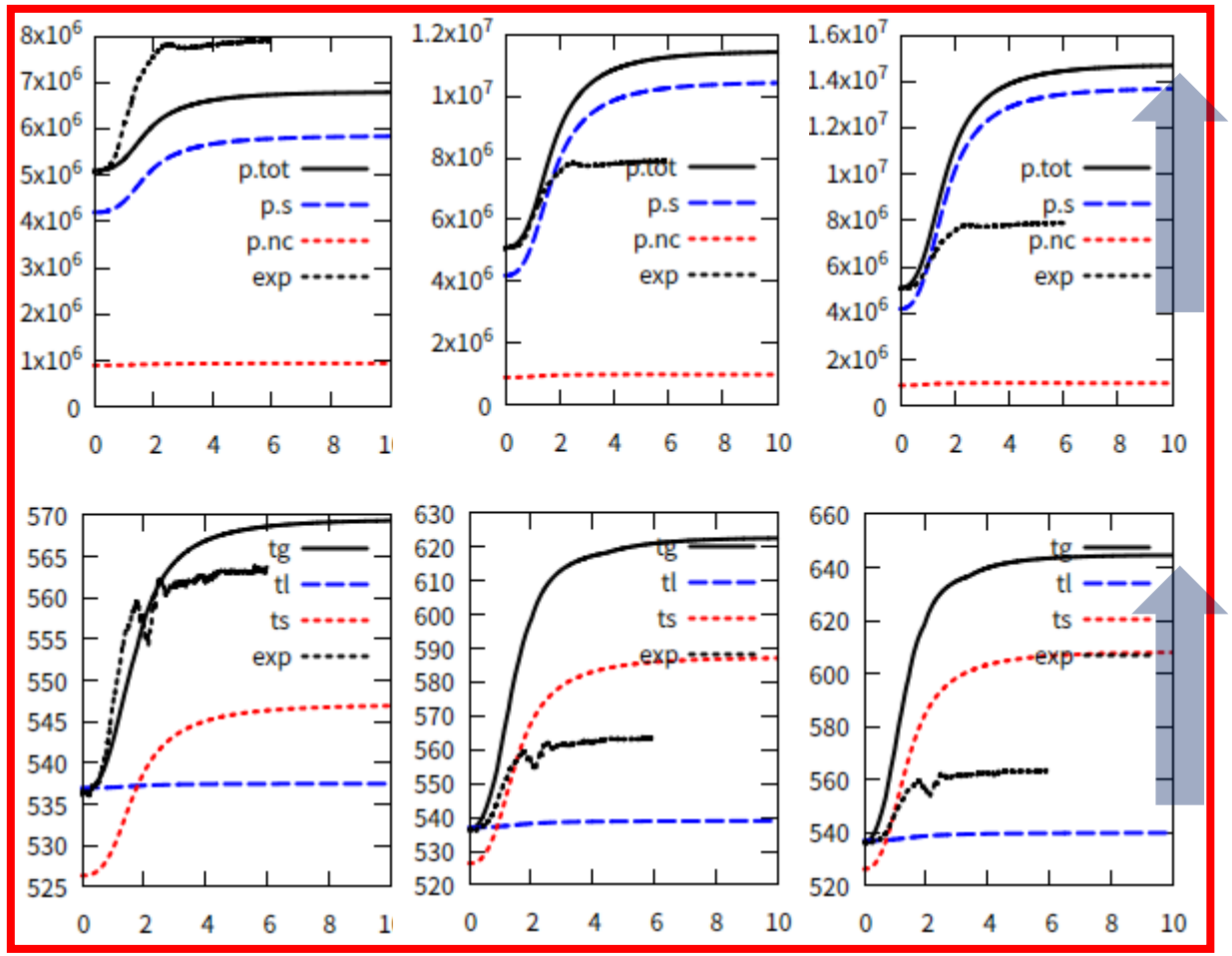


Ref. COOLAP-II Manual

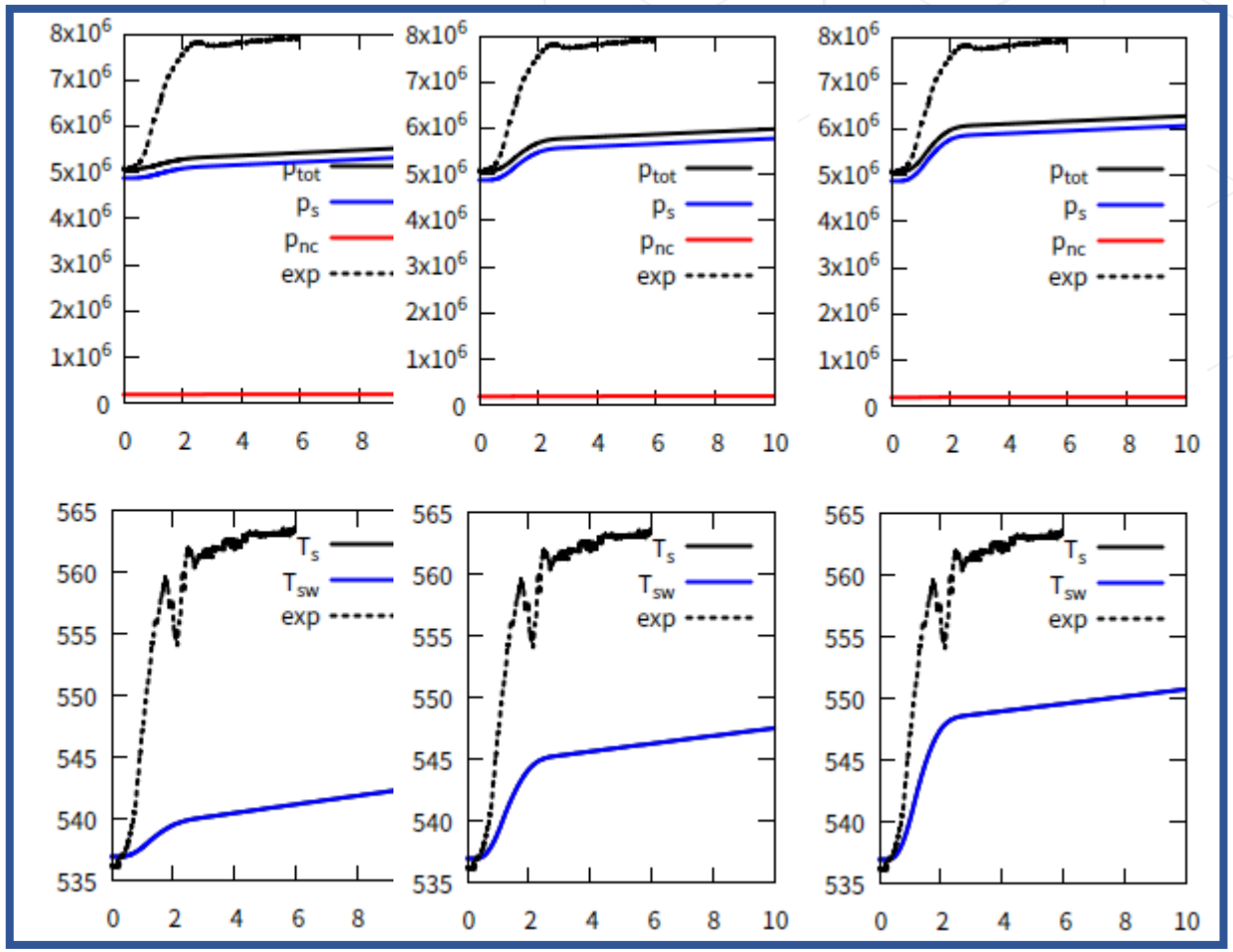
III. Results: Parameter study

- Particle heat transfer factor (chtc): 0.1(ref), 0.5, 1.0

CINEMA



COOLAP II

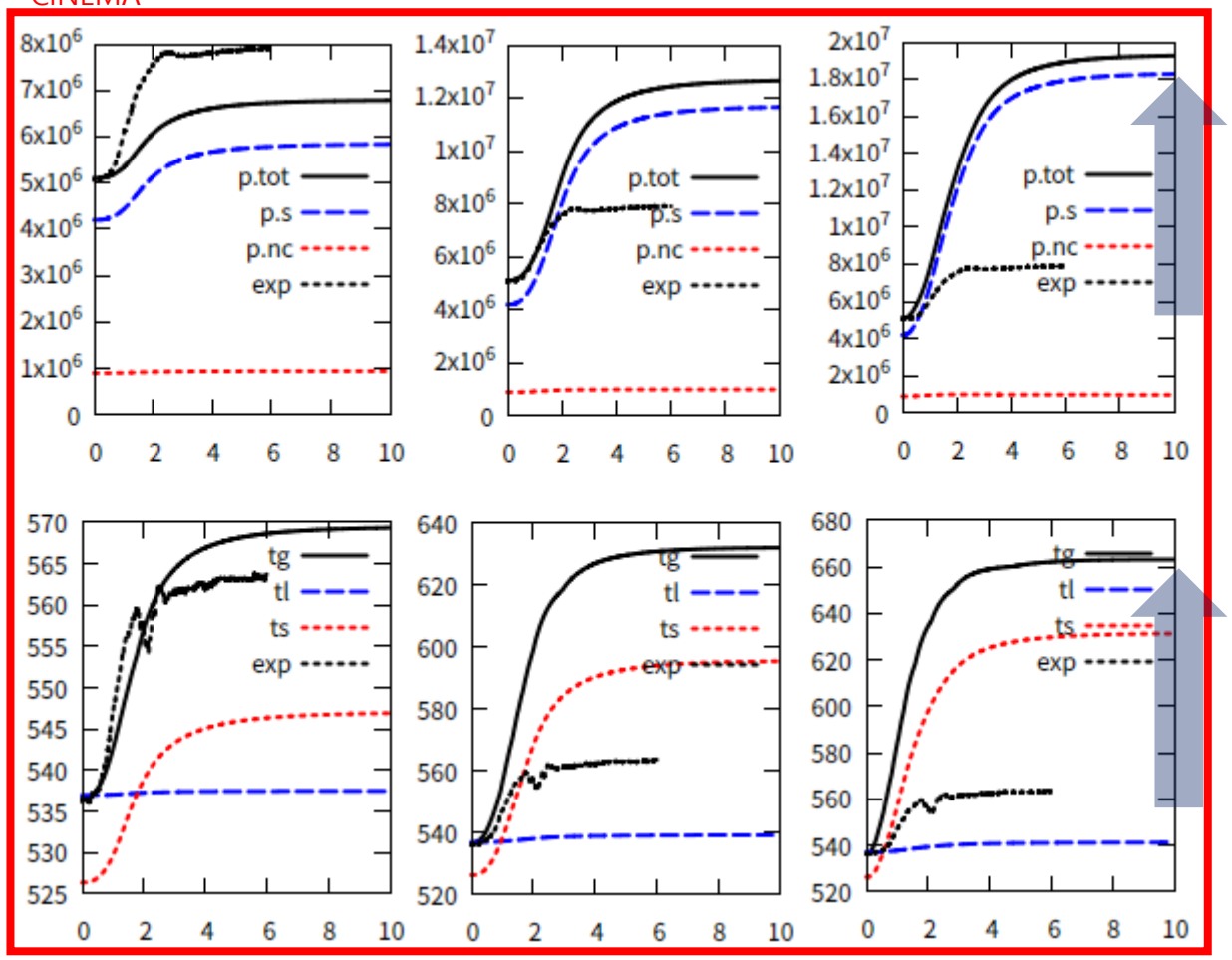


- **COOLAP II 와 비교했을 때, 입자 열전달에 의한 민감도가 상당히 크며, 두 코드 내 비교가 필요할 것으로 보임**

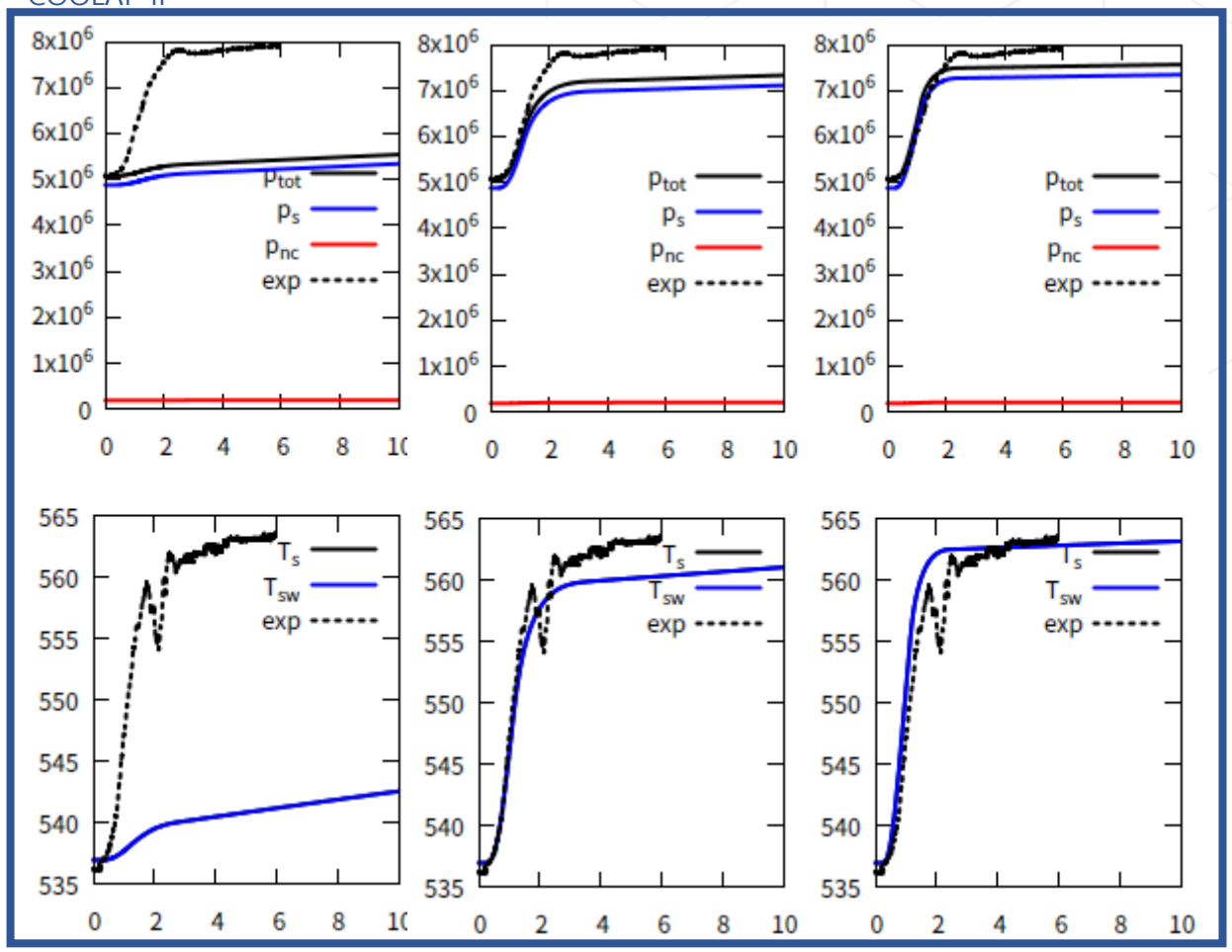
III. Results: Parameter study

- Particle diameter (diam): 4.8(ref), 2.0, 1.0 mm

CINEMA



COOLAP II



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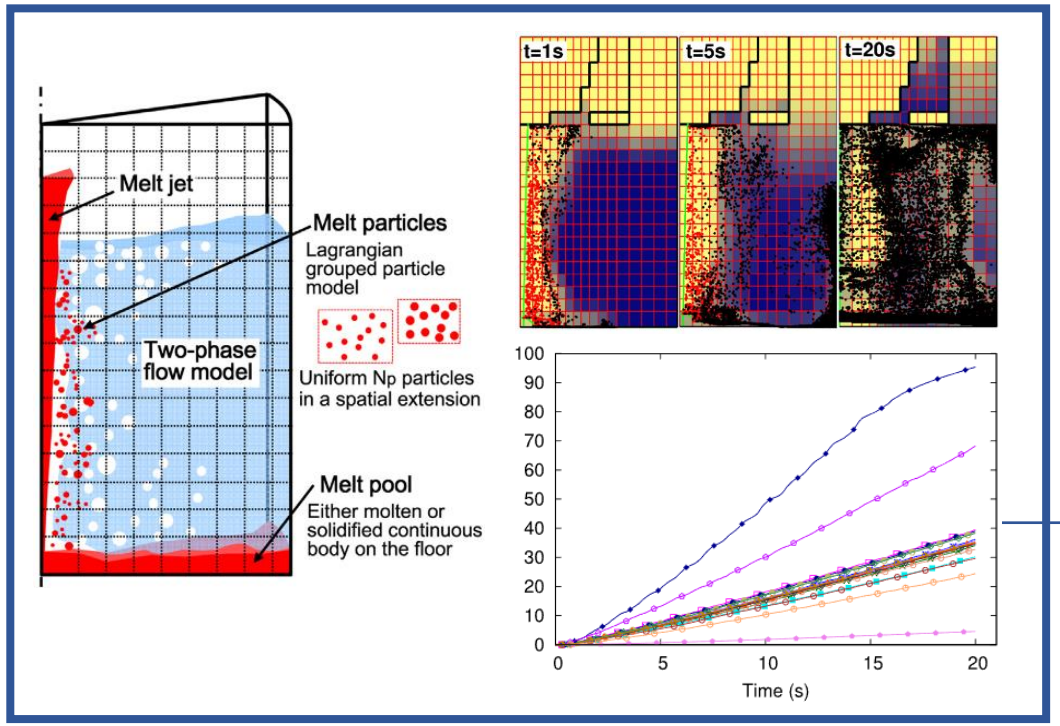
III. Results: Suggestion for Model Parameter Settings

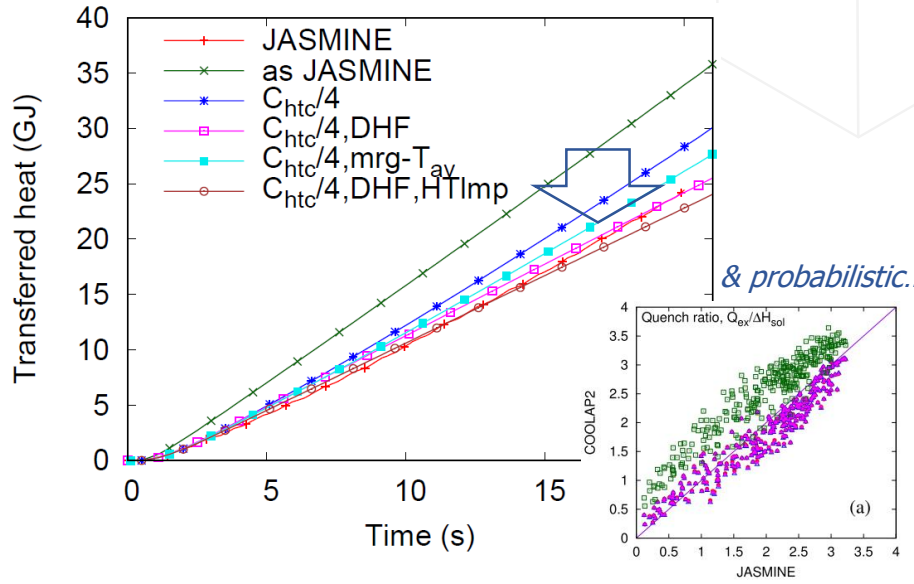
- **Model parameter settings for Reactor case in COOLAP-II**
  - ✓ FCI computer code (JASMINE)
    - – Reactor case simulation



JASMINE Results for Reactor case

Main parameters of COOLAP-II

	as JASMINE	C_{htc}/4	C_{htc}/4,DHF	C_{htc}/4,mrg-T_{av}	C_{htc}/4,DHF,HTlmp
C_{htc} for particles*1	2.0	0.5	0.5	0.5	0.5
C_{htc} for debris bed*1	0.1	0.1	0.1	0.1	0.1
DHF limitation for debris bed*2	-	-	ON	-	ON
Particle merge criterion*3	by T_{sf}	by T_{sf}	by T_{sf}	by T_{av}	by T_{sf}
Melt lump heat transfer*4	-	-	-	-	ON



COOLAP-II results compared to JASMINE

Ref. Moriyama, NED, 2016 & COOLAP-II Manual

IV. Conclusion

- **Summary**
  - ✓ CINEMA User Group work: 2022.04.18 – 2022.09.02
  - ✓ Melt mixing part of FCI (SE) Module in CIMENA:
    - Preliminary validation of FARO-L14
    - Comparison with other FCI code (COOLAP-II)
    - Sensitivity analysis with particle heat transfer parameter ('chtc' & 'diam')
    - Suggestion of Model parameter setting for Rx cases… with other codes (TEXAS, JASMINE, etc.)

- **Other Suggestions & Error Reporting during User Group**
  - ✓ Mass fraction error
  - ✓ Mass parameter (output) definition
  - ✓ Heat transfer of particle in CINEMA: Film boiling & radiation -> Convection, Nucleate boiling, CHF etc.

Thank you for your attention

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Acknowledgement

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and the Ministry of Trade, Industry & Energy (MOTIE) of the Republic of Korea (No. 20193110100050).