Analysis of Steam Explosion in Stratified Melt-Coolant Configuration

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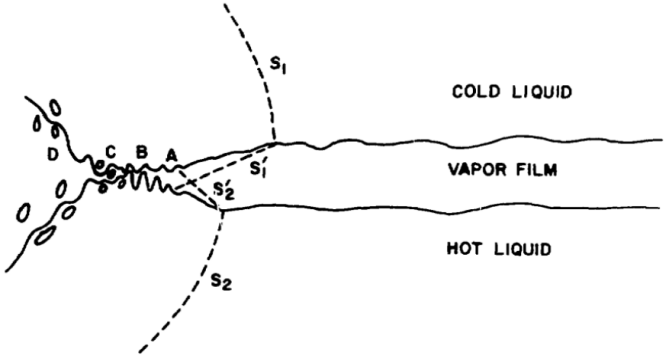
Outline

- Introduction
  - Stratified steam explosion
  - Experimental observations
  - Safety impact
- MC3D simulations
  - Experiment PULiMS-E6
  - Parametric analysis
- Proposal for SAFEST experiment
  - Stratified steam explosion in SES facility

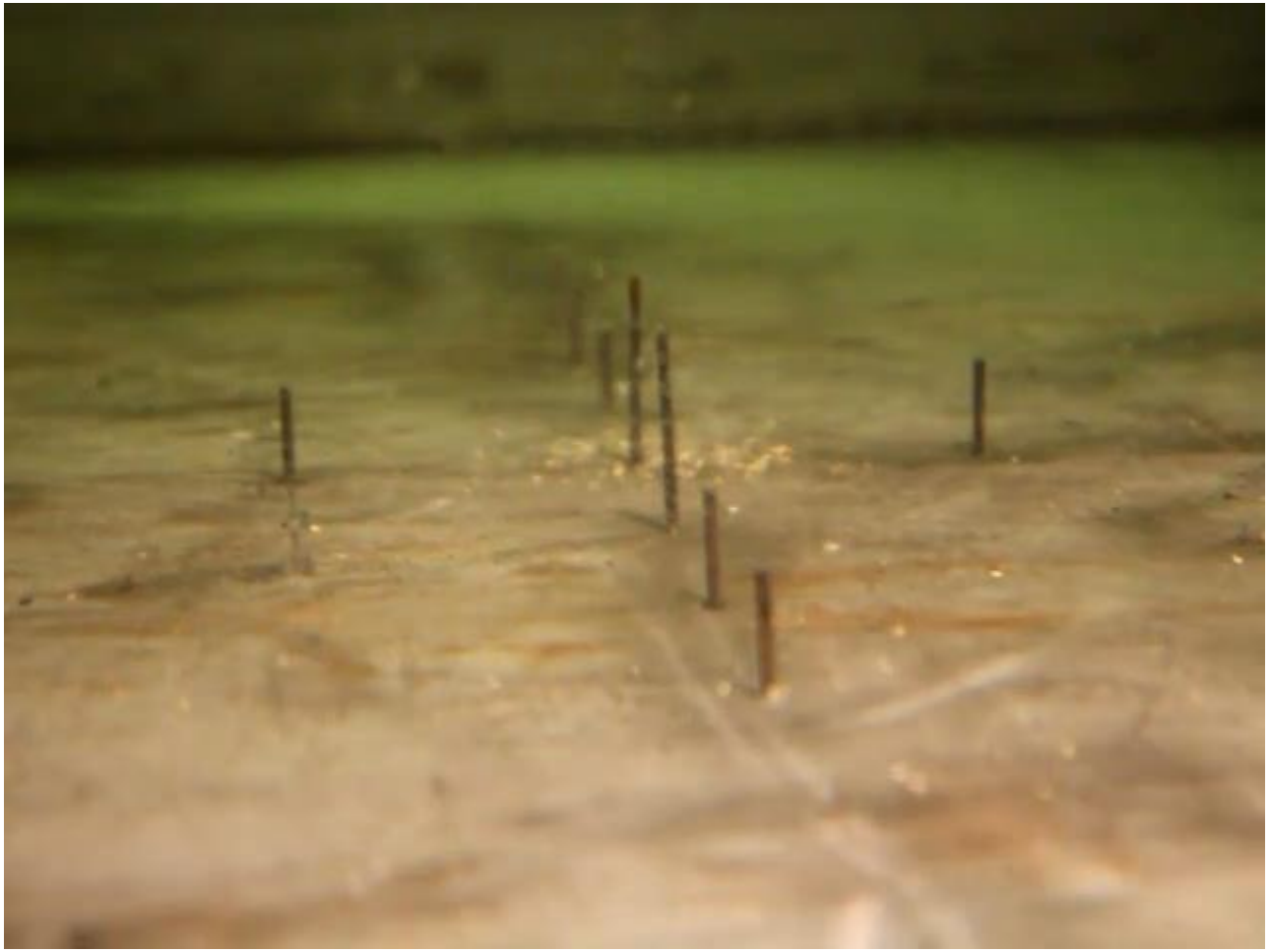
Introduction

- Stratified melt-coolant configurations were long believed as being incapable to generate strong explosive interactions
  - Based on hypothesis that no premixed layer forms and that mixing occurs during explosion itself



- Recently performed experiments in PULiMS and SES facilities (KTH, Sweden) revealed that strong SE may develop
  - Oxidic corium simulants (Bi_2O_3/WO_3, ZrO_2/WO_3)
  - Considerable melt-coolant premixed layer
  - Spontaneous steam explosions

Premixed layer formation



- PULiMS experiment, KTH
- Melt splashed up to 10 cm above melt surface

Stratified steam explosion

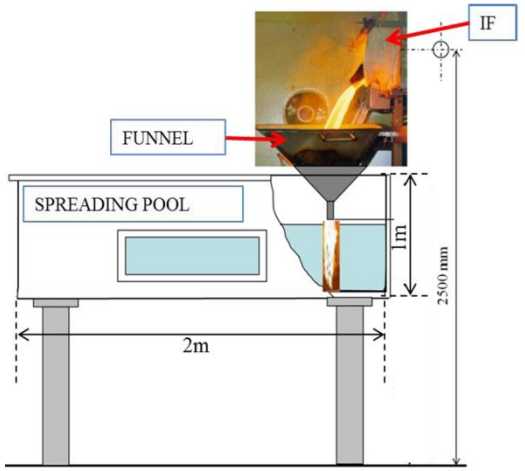
- PULiMS experiment, KTH
- Violent interaction before explosion → Additional premixed layer formation?

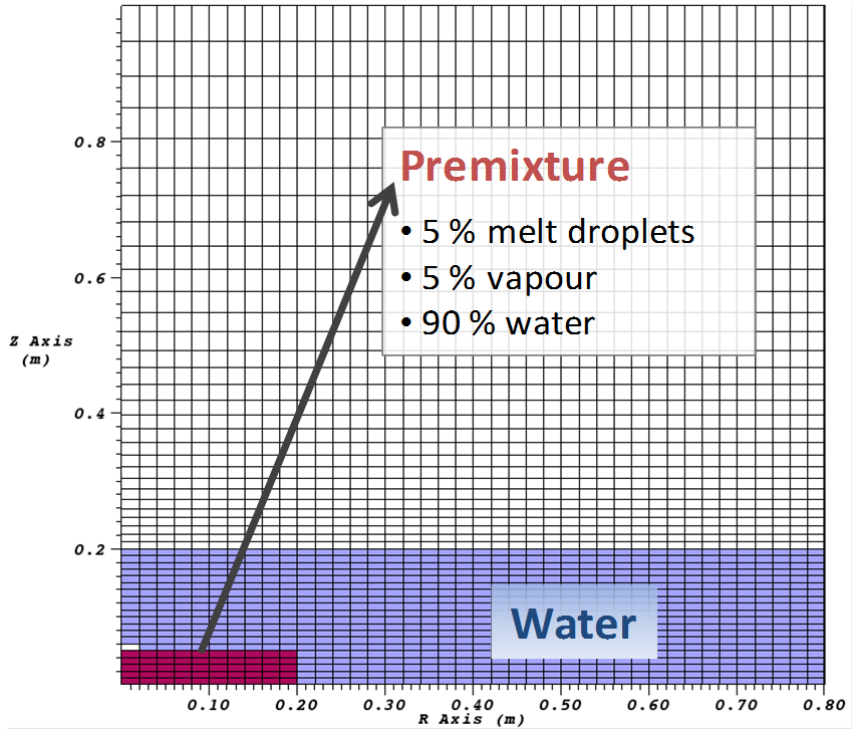
Safety impact

- Potentially important impact on safety related issue of FCI in NPP
  - Observed spontaneous triggering in stratified conditions may provide a triggering mechanism also for steam explosion in conventional melt jet-coolant pool configuration.
  - Observed strong stratified steam explosions may present an increased threat in reactor conditions due to the large area of the cavity floor, where the melt can potentially spread in stratified melt-coolant configuration.

MC3D analysis

- Purpose
  - To better understand stratified SE phenomenon
- Experiment PULiMS-E6
  - Best instrumented (in open literature)
- Simulations with MC3D v3.7.7
  - Premixing prescribed
  - Explosion calculated
  - Various parametric simulations performed
    - Melt fraction, Void fraction, Premixing layer thickness, Droplet size, Spread melt area, Water height, Trigger strength and position, 2D/3D

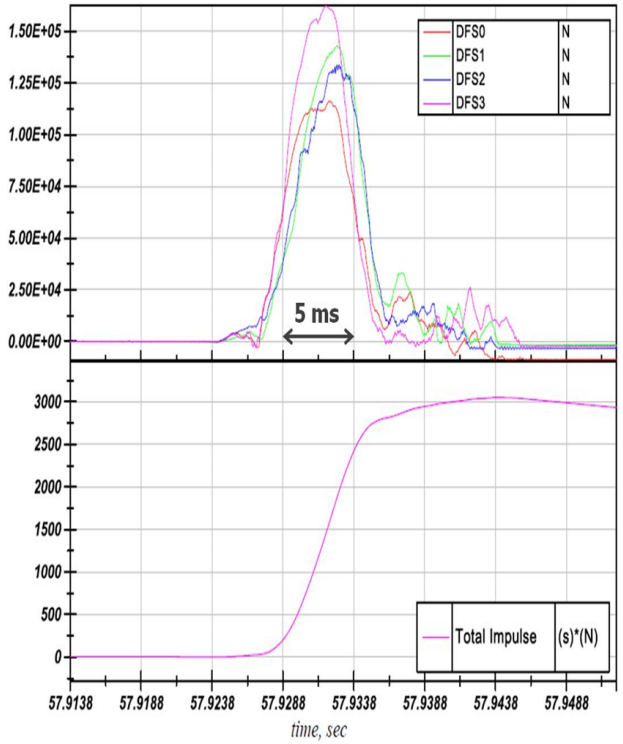




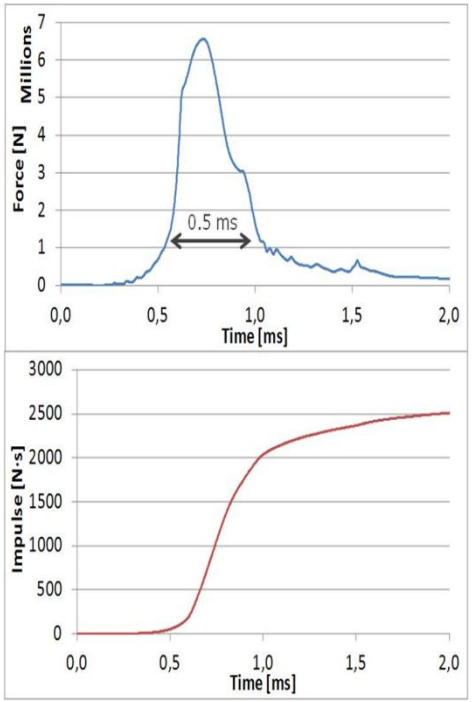
Best fit simulation

Premixture: 5 cm thickness
40 cm diameter
3 mm droplets
5% melt, 5% void, 90% water

Experiment



Simulation

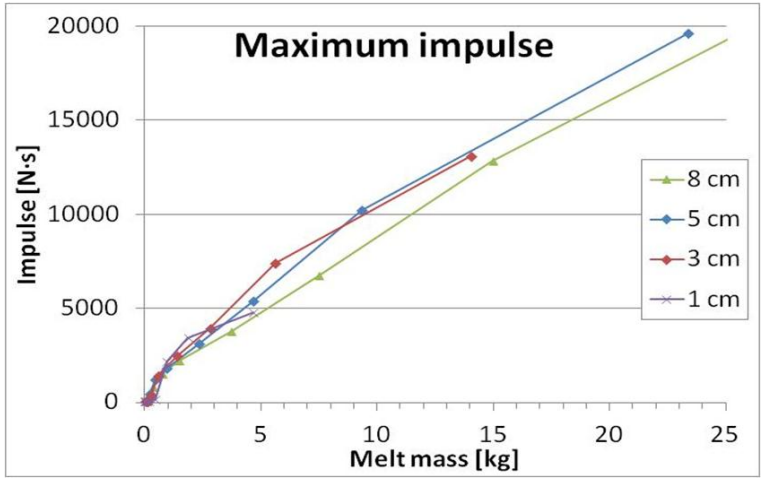


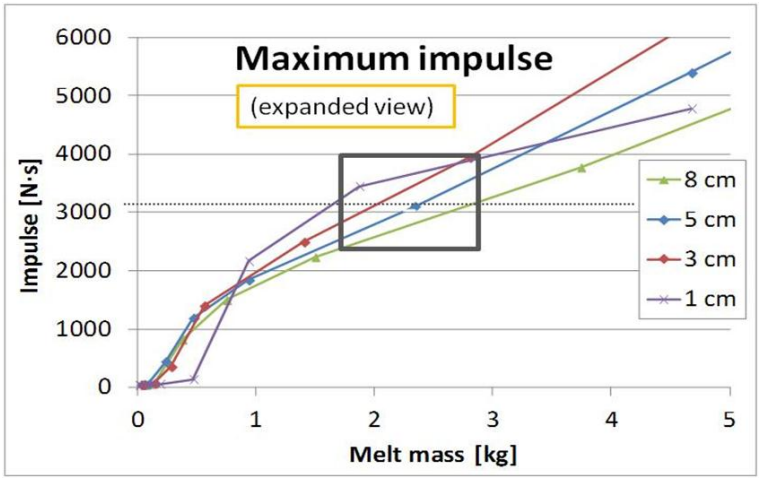
	Experiment	Simulation
Total impulse (Ns)	3051	3107
Maximum force (N)	0.55×10^6	6.6×10^6
Maximum pressure (MPa)	4.3 (cake area)	52 / 3.4 (cake/whole area)
Approx. signal width (ms)	5	0.5

- Good agreement of explosion strength may be obtained, but …
- Explosion duration significantly underpredicted
  - Force measurement reflects facility dynamics
- Indication that some melt might be mixed not earlier than during the explosion itself
  - Like in initial hypothesis of stratified SE

Parametric analysis

Premixed layer characteristics

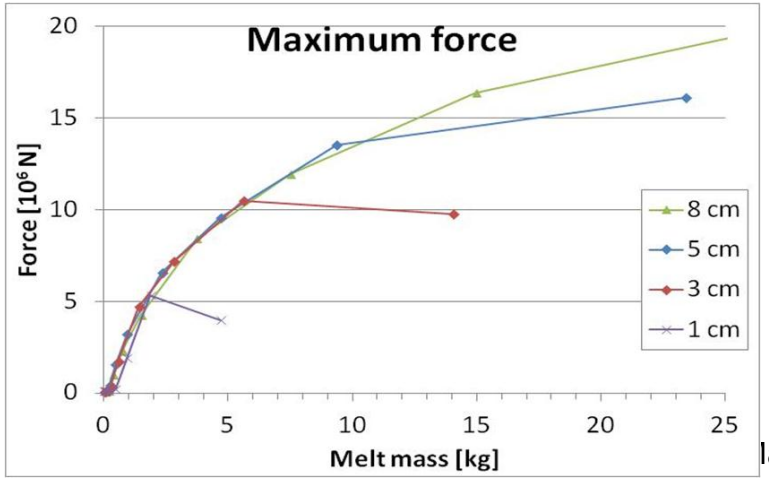




Melt:
0.1% - 50%

Layer:
1 cm - 8 cm

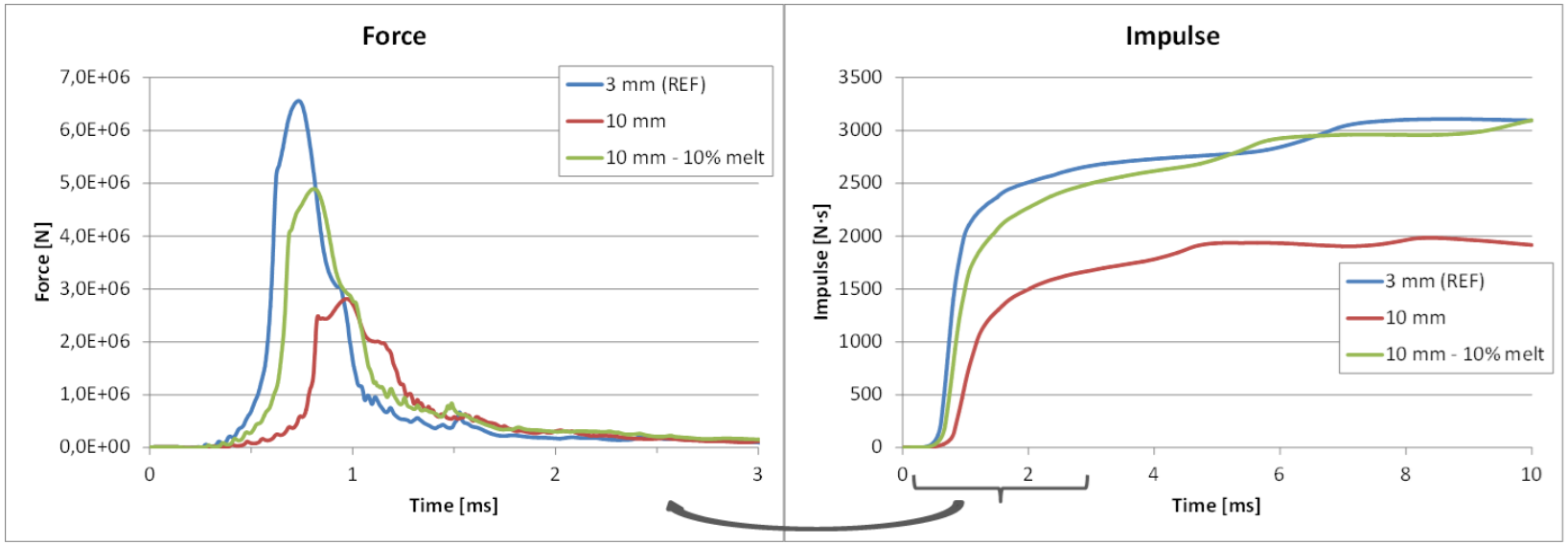
(Void 5%)



- Explosion strength depends mainly on melt mass (if melt <50%, last right point 50%)
- 2.3 kg ± 0.5 kg melt available for explosion (12% of 19 kg poured)

Parametric analysis

Influence of droplets size: 3 mm → 10 mm (Sauter)



- Same explosion strength (10 mm) for 2x larger melt mass in premixture
  - 5% melt fraction (3 mm) → 10% melt fraction (10 mm)
  - 2.3 kg melt (12% of poured melt) → 4.6 kg melt (24% of poured melt)
- No significant effect on explosion duration

Parametric analysis

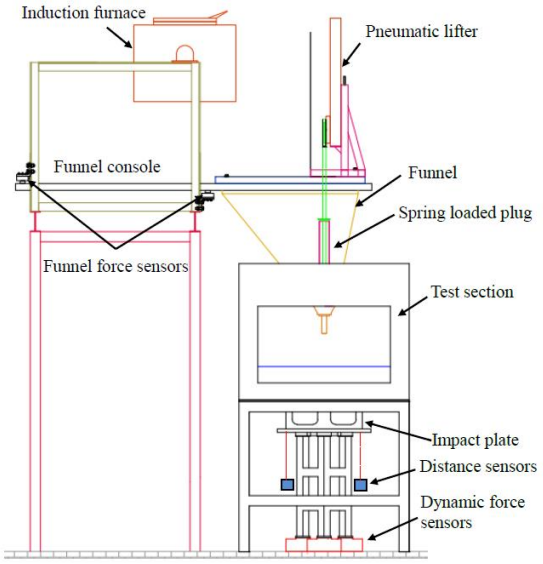
- Influence on SE strength (for same melt mass)
  - Melt mass: YES ↑
  - Droplets size: YES ↓
  - Melt volume fraction: ~NO (if <50%, above reduced)
  - Layer thickness: ~NO
  - Void volume fraction: ~NO (for 5-50%, outside reduced)
  - Spread melt area: YES ↑ (impulse and duration increase with size)
  - Water height: YES ↑ (linearly increase with water height)
  - Water subcooling: ~NO (10-40 K)
  - Trigger strength: ~NO (for 1-5 MPa, below lower)
  - 2D/3D (preliminary, rough 3D mesh): YES ↓ 3D 30% lower strength
  - Trigger position (preliminary): ~NO (no influence on impulse, but higher maximum pressure in cell for side triggering)

Conclusions

- Melt mass involved in explosion seems to be larger than estimated from premixed layer formation video (first video)
  - Additional mixing occurred during observed violent interaction before steam explosion (second video)?
- Order of magnitude longer explosion duration in experiment than in simulation
  - It seems that some melt might be premixed not earlier than during explosion itself (like in initial hypothesis of stratified SE)
  - Force measurement reflects facility dynamics
- Better instrumented experiments would be needed to get more insight in the processes during FCI in stratified conditions
  - SAFEST stratified steam explosion experiment on SES (KTH) facility

SAFEST experiment on SES

- 7. FP EU SAFEST project
  - Severe Accident Facilities for Europe Safety Targets
  - Establishing free access to SAFEST research infrastructure to investigate important SA phenomena
- SES facility at KTH
  - Steam Explosion Stratified
  - Investigation of FCI in stratified melt coolant configuration
- 1st call for proposals
  - Deadline: 28.2.2015
  - Experiment: 8.2015-6.2016



SAFEST SES experiment proposal

- User group: JSI (leader), IRSN, CEA, IKE
- Scientific questions to be answered
  - Premixed layer formation, SE self-triggering, propagation, strength
- Experimental conditions to be fulfilled
  - Reliable stratified steam explosion experiment with improved instrumentation, Good visualization
- Instrumentation
  - High speed high resolution camera, pressure measurements in test section, debris sieving (+ past PULiMS/SES instrumentation)
- Experimental conditions
  - Like PULiMS-E5 experiment (+ 2nd experiment with underwater melt release)