FCI Phenomena Uncertainties Impacting Predictability of Dynamic Loading of Reactor Structures (from OECD SERENA Programme)

Presented by

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Scope of SERENA

- Phase 1 (Completed)
  - Bring together FCI experts to make a status of code capabilities to predict steam explosion induced dynamic loading of the reactor structures
  - Reach consensus on major FCI phenomena which uncertainties impact predictability of dynamic loading of reactor structures

- Phase 2 (Proposal in preparation)
  - Carry out confirmatory research required to reduce uncertainties on these phenomena to acceptable level for risk assessment

- First joint exercise on steam explosion applied to reactor case

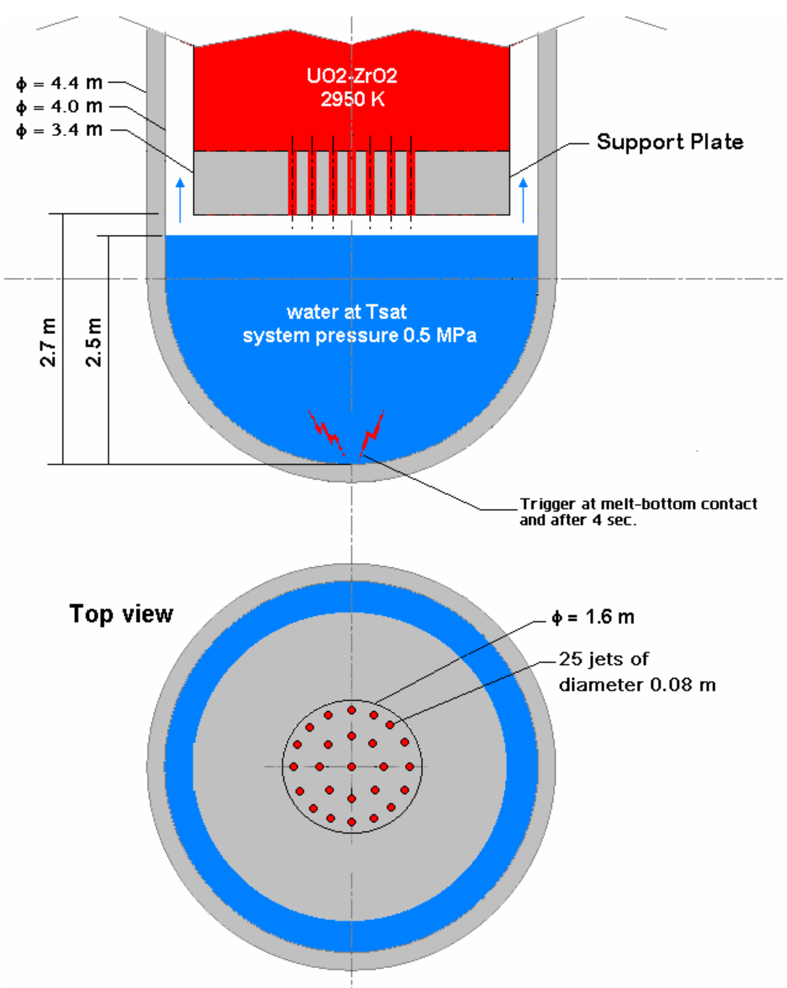
- Generic situations of interest were identified for both in- and ex-vessel
- Relevant existing experiments were selected and calculated by the different codes with the scope of
  - Establishing an initial setting of the codes on a common basis
  - Identifying FCI phenomena of importance for code/code and code/data discrepancies
- The codes were applied to reactor situations with the scope of identifying key uncertainties impacting predictability of steam explosion loads in reactors

Codes used

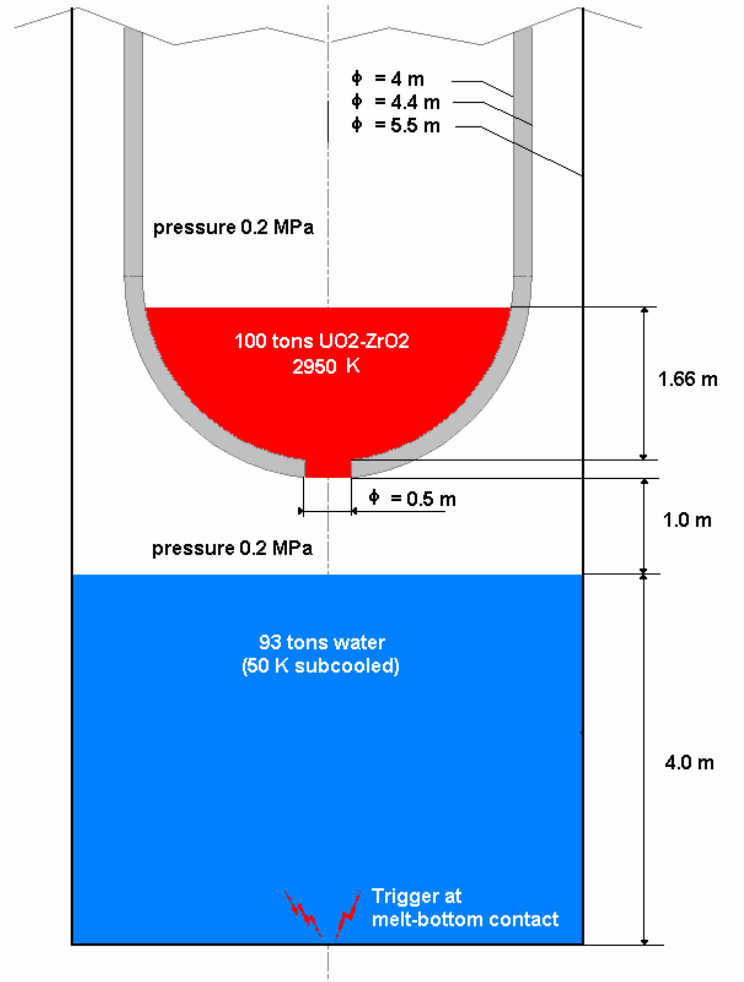
Partners	Codes
CEA/IRSN	MC3D
GRS (IKE)	IKEMIX, MC3D/IKEJET, IDEMO
FZK	MATTINA
KAERI/KMU	TEXAS V, TRACER II
NRC (UCSB, UW)	PM-ALPHA, ESPROSE, TEXAS
KINS	IFCI 6.2
JAERI	JASMINE
NUPEC	VESUVIUS
EREC	VAPEX

- Ex-vessel large pour of corium melt with metallic phases in sub-cooled water at low pressure
- In-vessel multi-jets (~10 cm diameter) into lower head and saturated water at moderate pressure
- Selected as "most relevant generic situations"

Calculated reactor situations



In-vessel



Ex-vessel

- Pre-mixing experiments
  - FARO L-28: 175 kg of UO_2-ZrO_2 melt in saturated water
  - FARO L-31: 92 kg of UO_2-ZrO_2 melt in subcooled water

- Explosion experiments
  - KROTOS K-44: 1.4 kg of alumina melt in subcooled water
  - TROI-13 and TROI-34 (blind exercise): ~2 kg of UO_2-ZrO_2 melt with and w/o trigger.

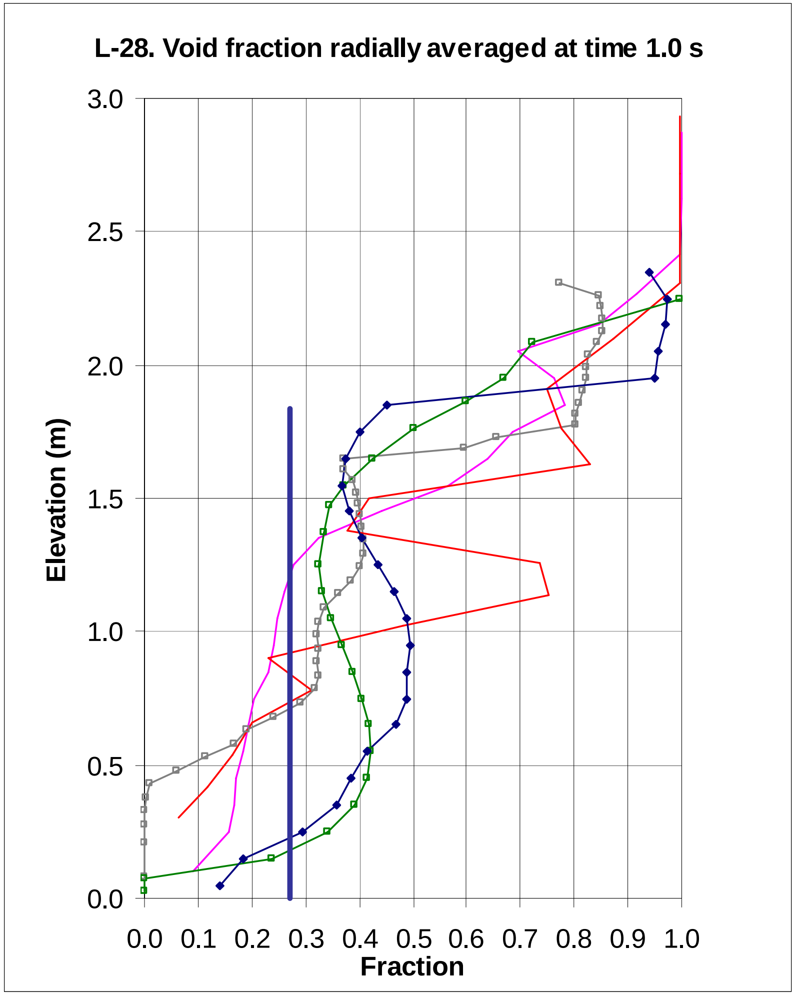
- Integral experiment: FARO L-33
  - Triggered steam explosion involving ~25 kg of UO_2-ZrO_2 melt in subcooled water at 0.4 MPa.

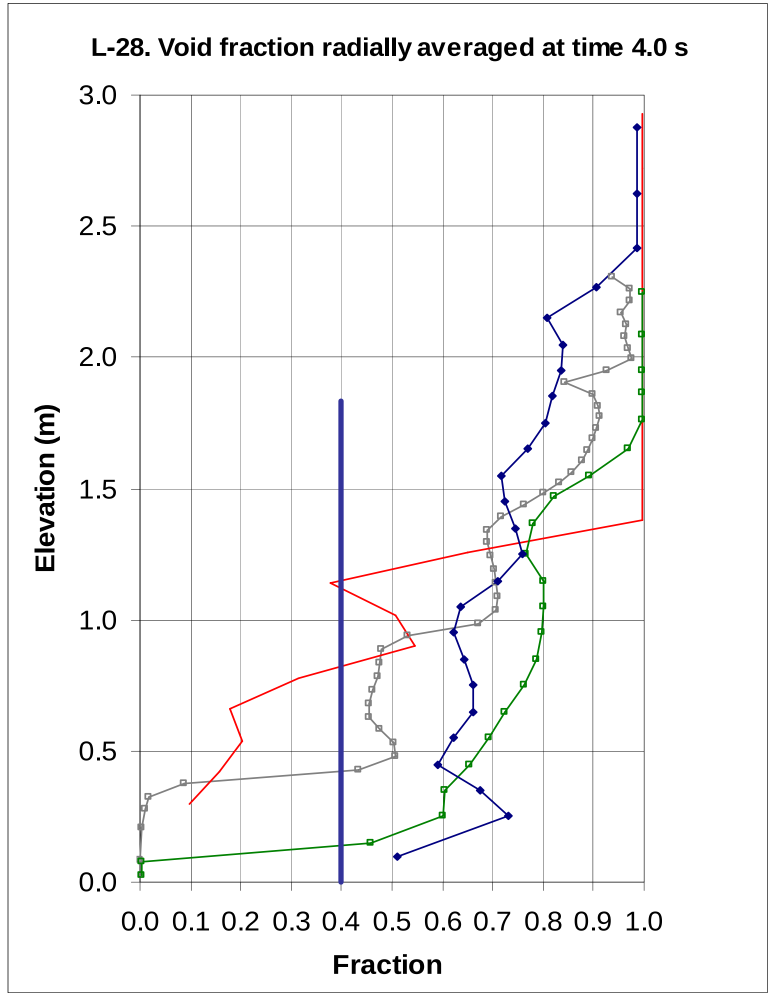
Results of pre-mixing calculations

- Code application to pre-mixing experiments showed:
  - Large scatter between code predictions and between code predictions and data
    - Did not allow determining which modelling is most appropriate
  - Codes tend to underestimate heat transfer and overestimate void when compared to data
    - Large uncertainties affect experimental data in the absence of detailed information of the pre-mixing zone internals

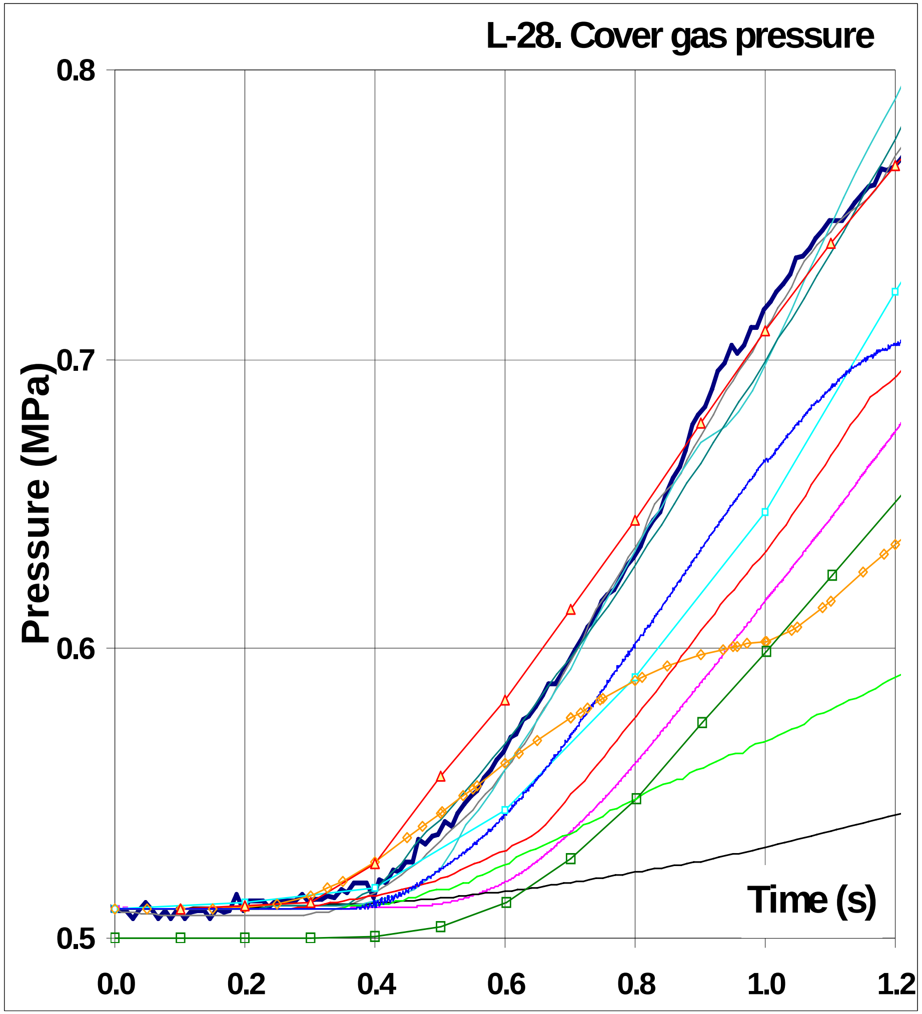
- Uncertainties on void distribution in pre-mixing recognised as a major issue as void is considered having a key limiting effect on explosion strength

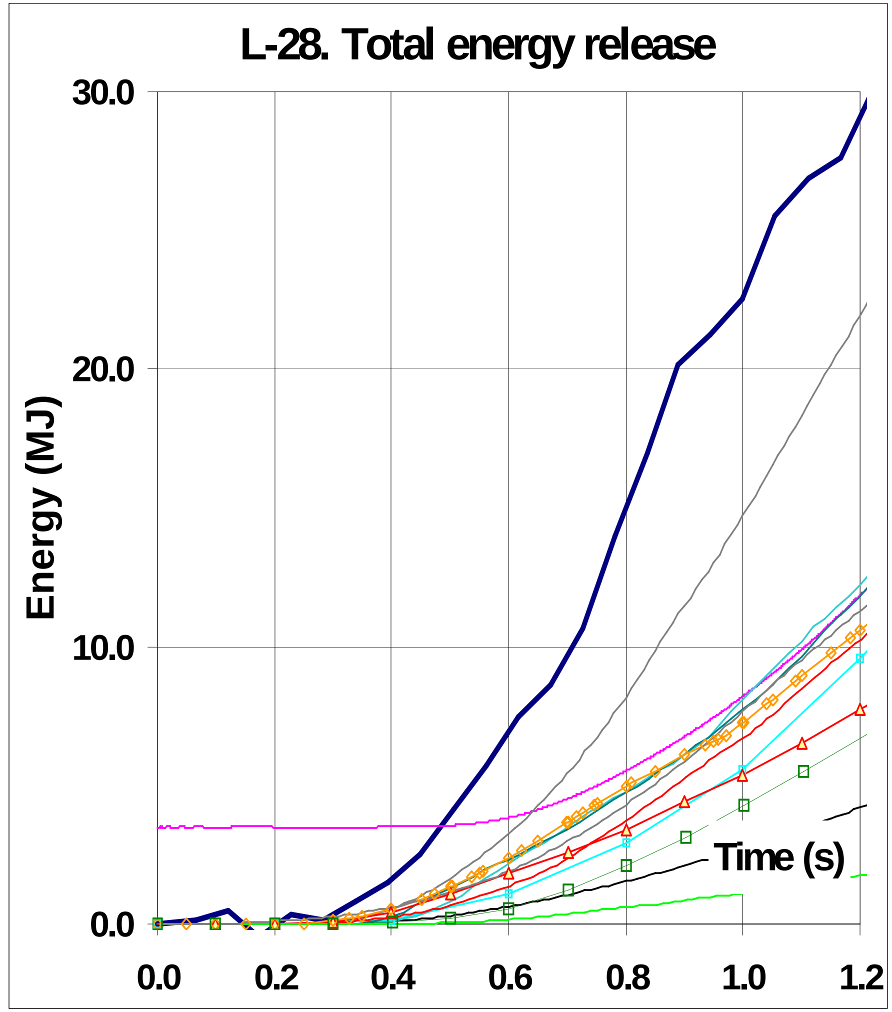
Void prediction for FARO L-28



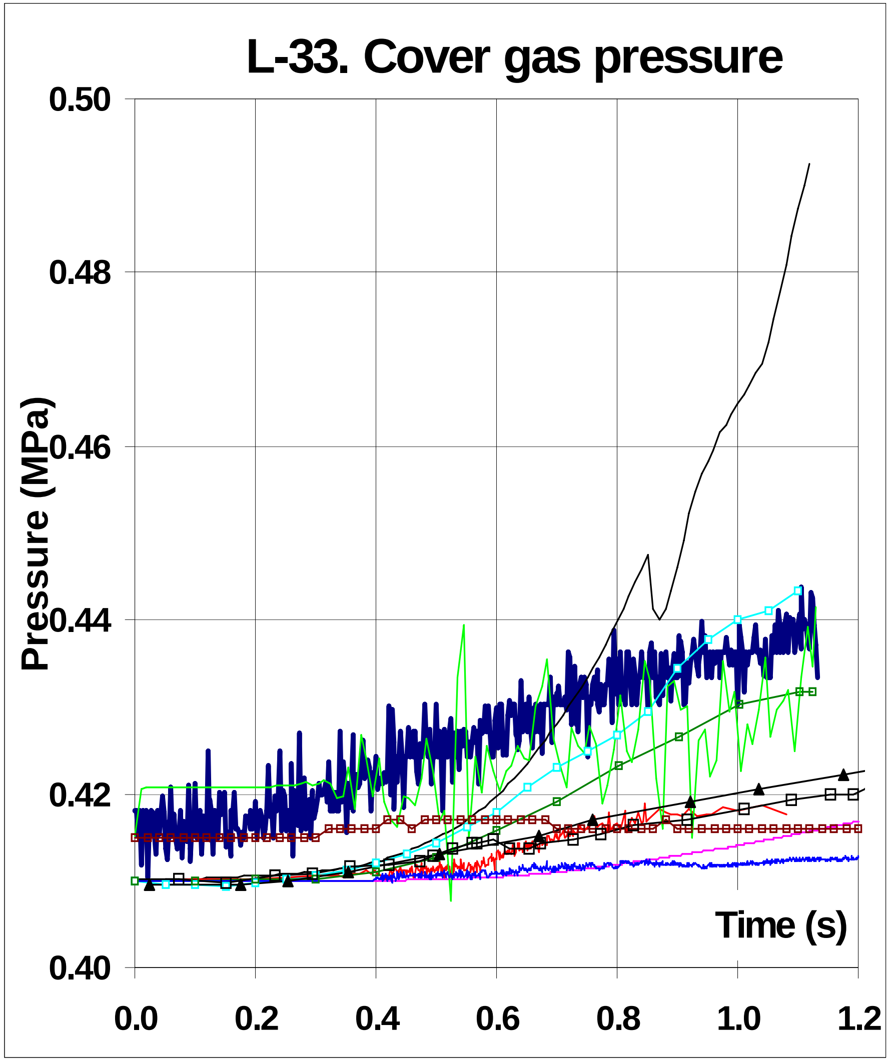


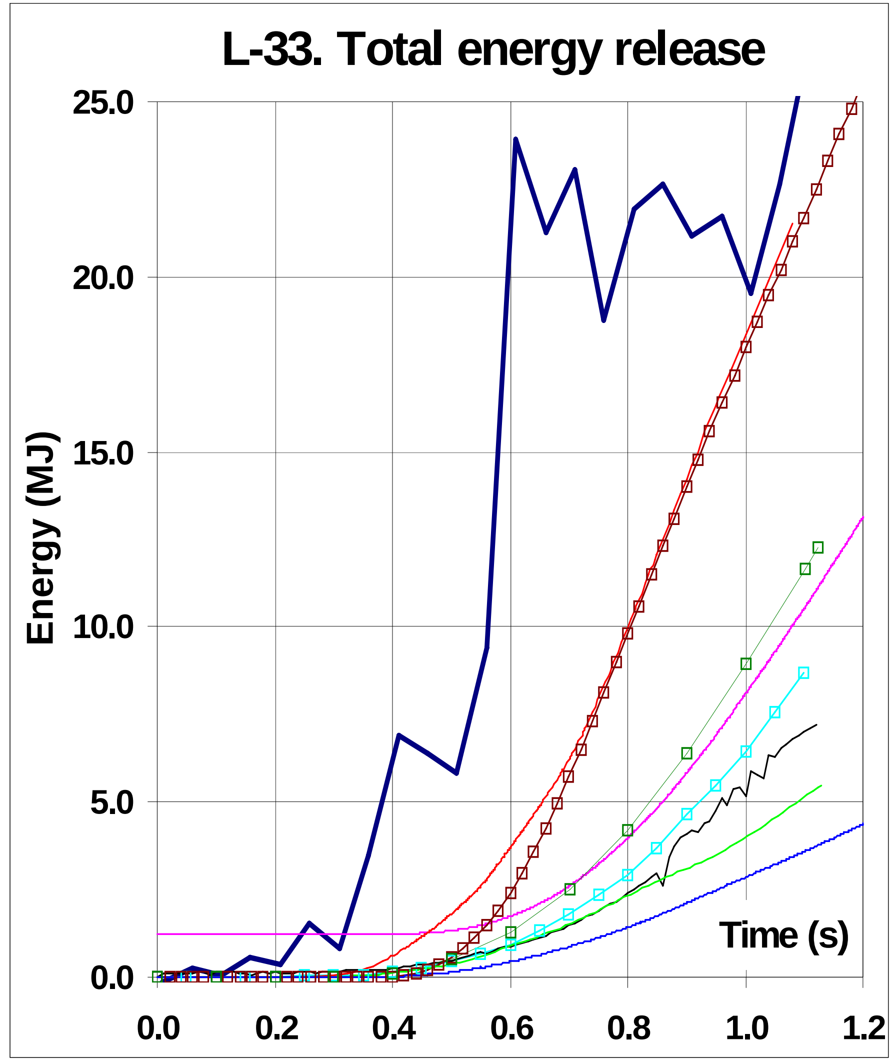
Results on FARO-L28 pre-mixing





Results on FARO L-33 pre-mixing





Results of explosion calculations (1/2)

- **Code application to pre-mixing experiments showed:**
  - Large scatter between code predictions and between code predictions and data
  - In order to get the order of magnitude of the data, key effects such as heat transfer and fragmentation parameters had to be (more or less arbitrarily) reduced from those tuned for alumina

- **Possible physical explanations for the experimentally observed reduced explosion energetics are:**
  - Melt freezing and hydrogen production premixing
  - Differences in pre-mixing (2-D geometry and void distribution)
    - ➪ Comparison with KROTOS corium still to be done

Examples of mixing in KROTOS

Corium | **Alumina**

Corium melt mixing in KT-2 (CANON). Viewing area 10 by 20 cm

Alumina melt mixing in K-57 (CANON). Viewing area 10 by 20 cm

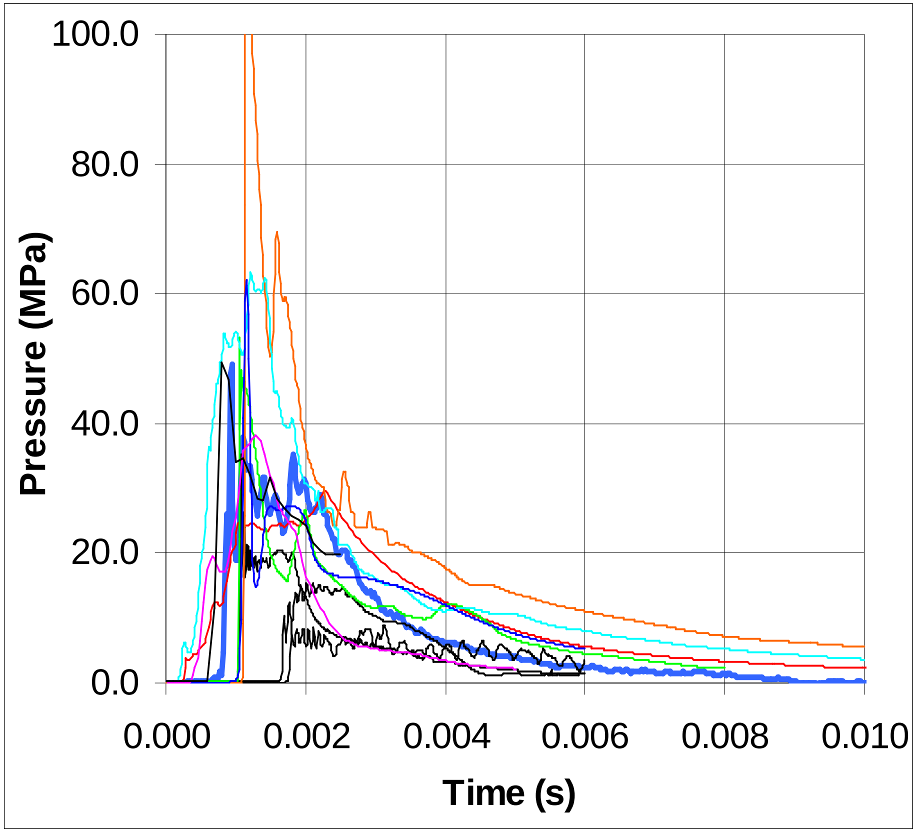
Results of explosion calculations (2/2)

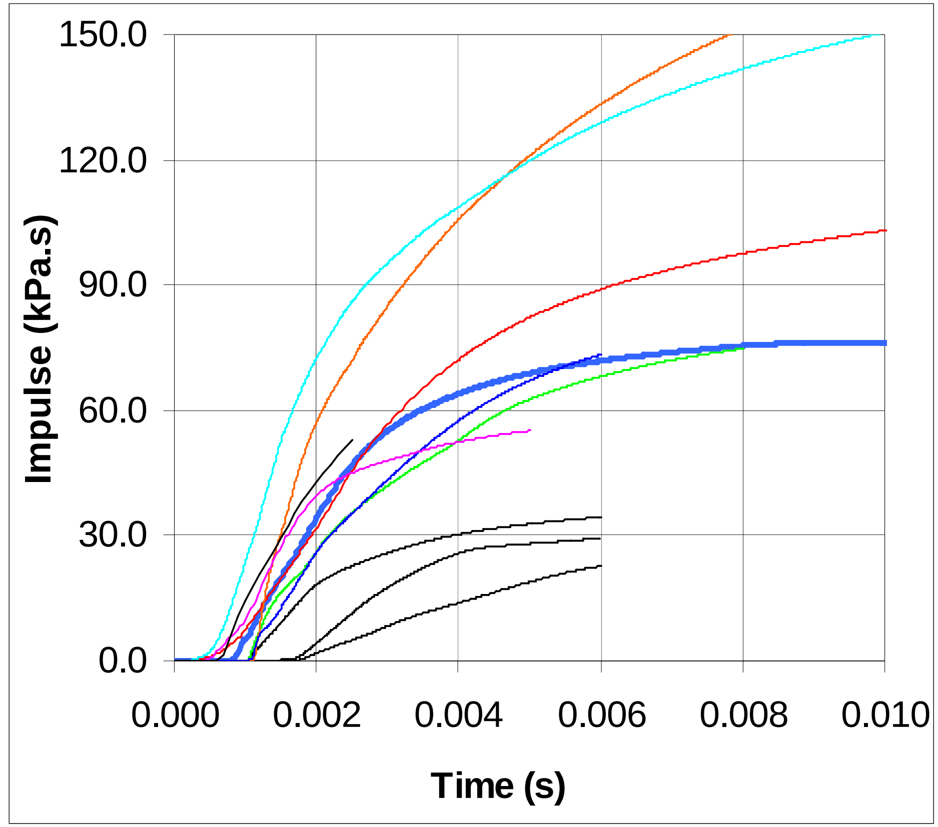
- Playing with parameters for
  - fragmentation,
  - heat release,
  - partition between steam and water

  allows, in general, to find back the order of magnitude of the data, but basic physical explanation is missing

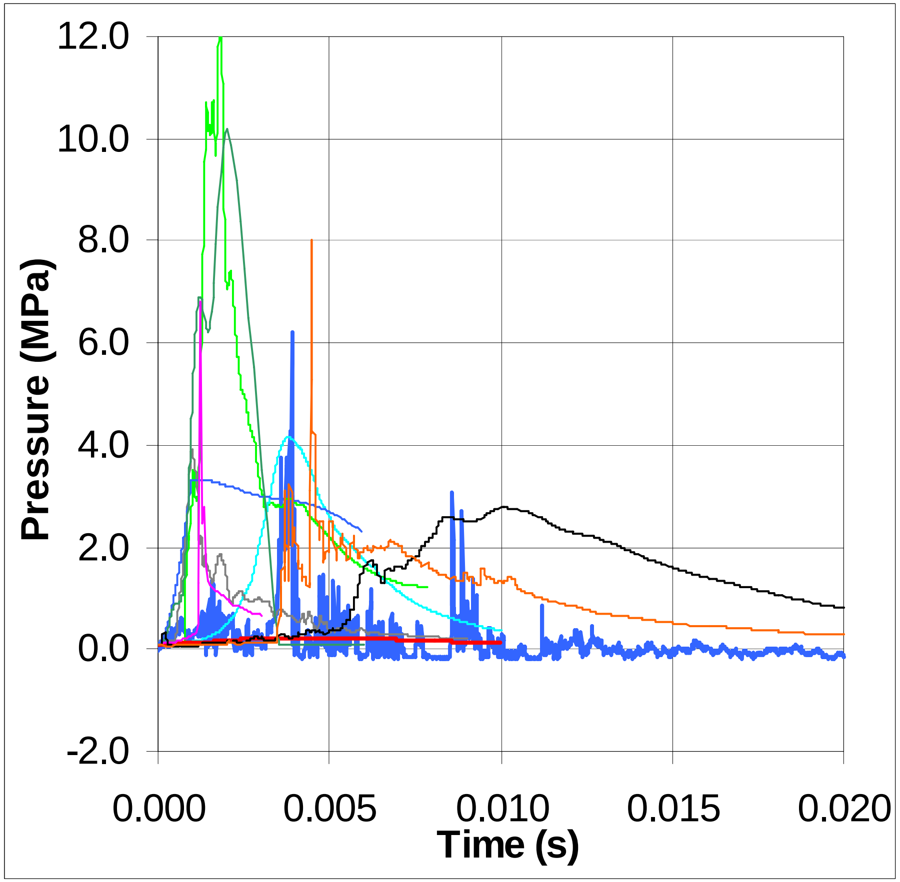
- Uncertainties on pre-mixing geometry and material behaviour considered as major issues

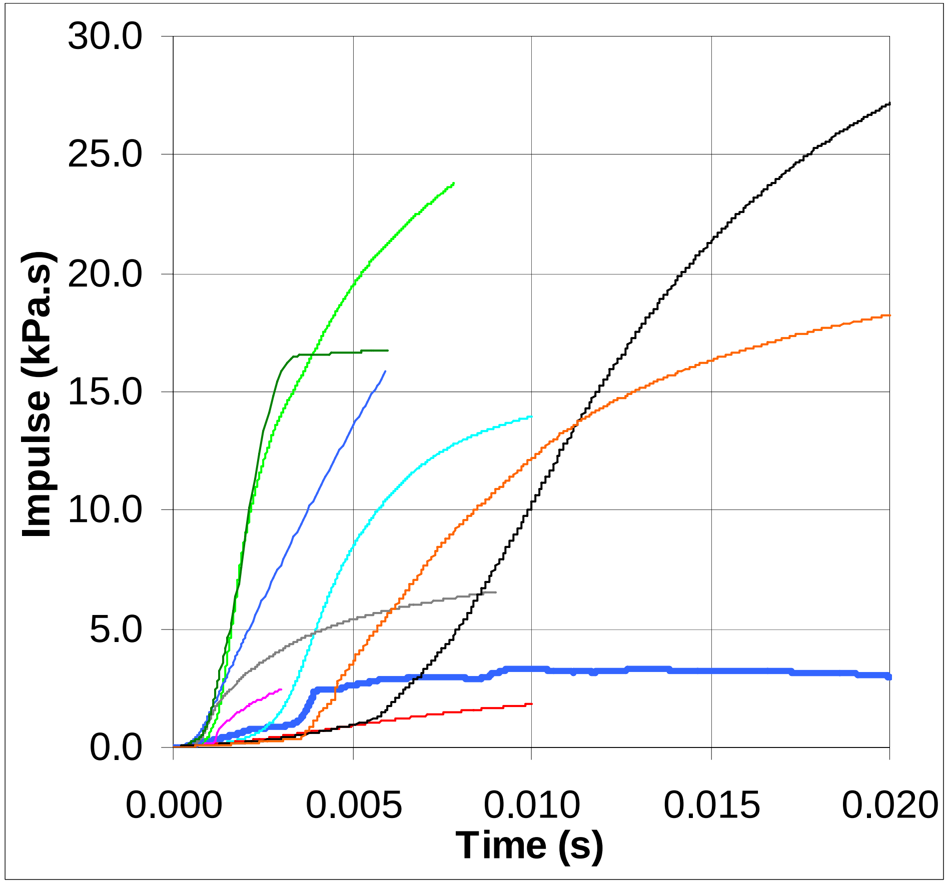
KROTOS-44 calculation results



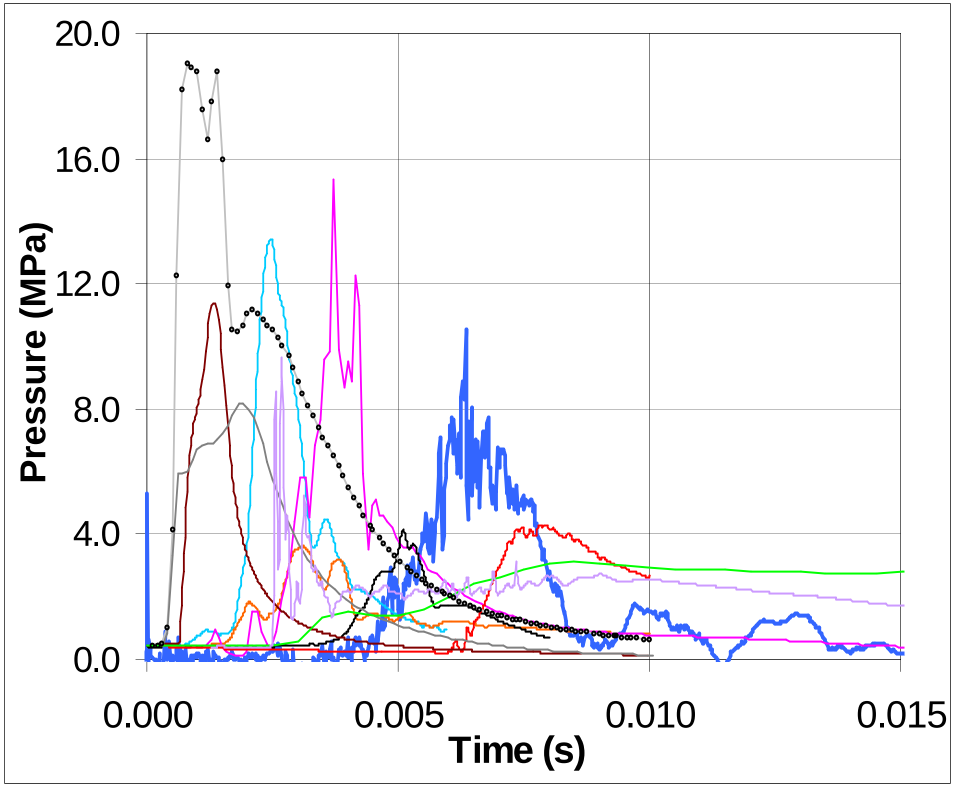


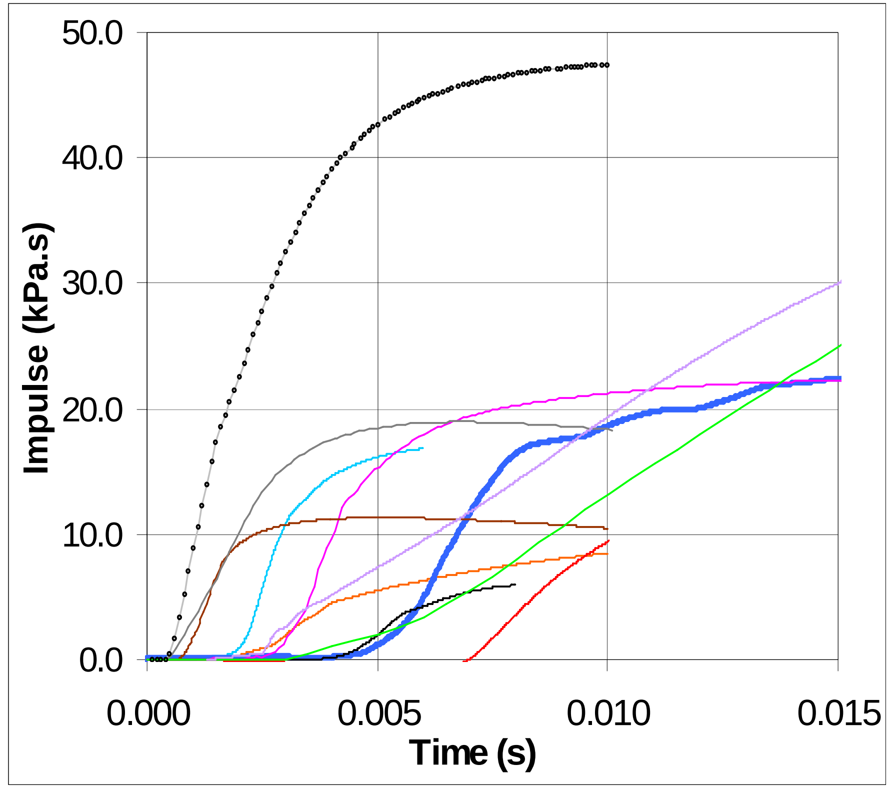
TROI-13 calculation results





FARO L-33 calculation results

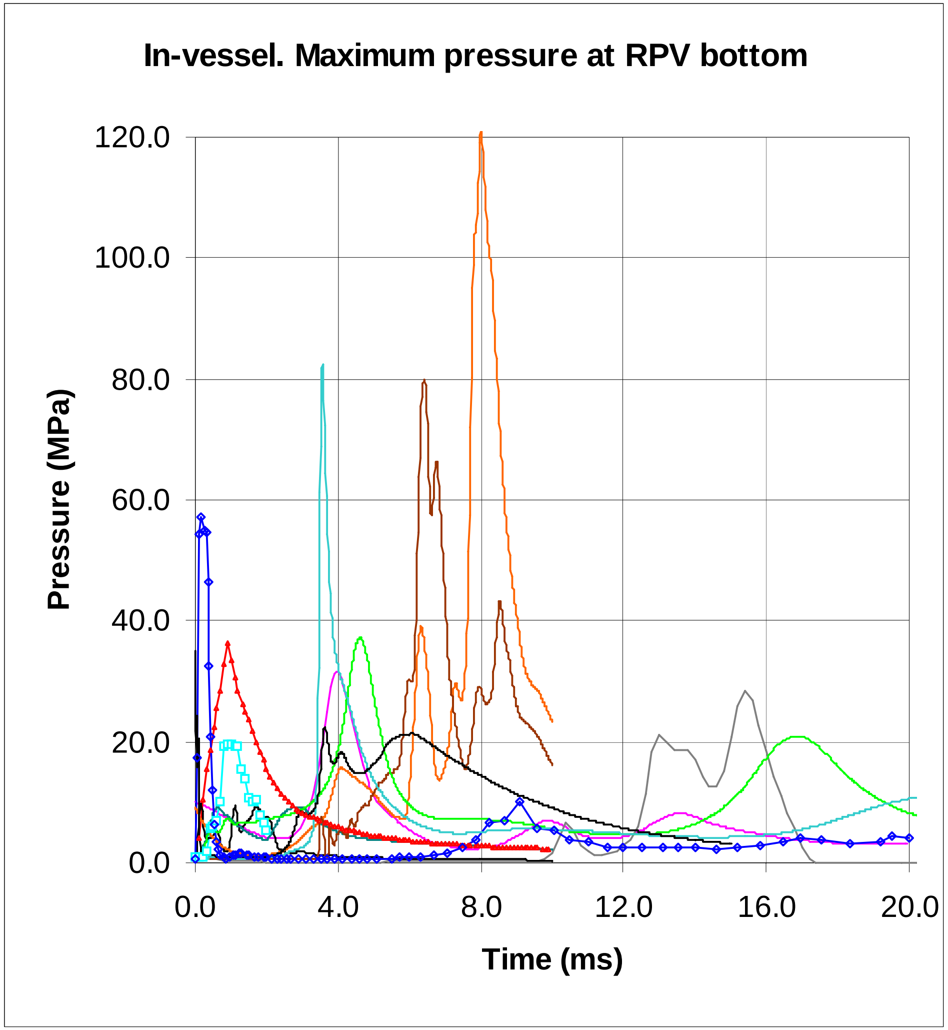


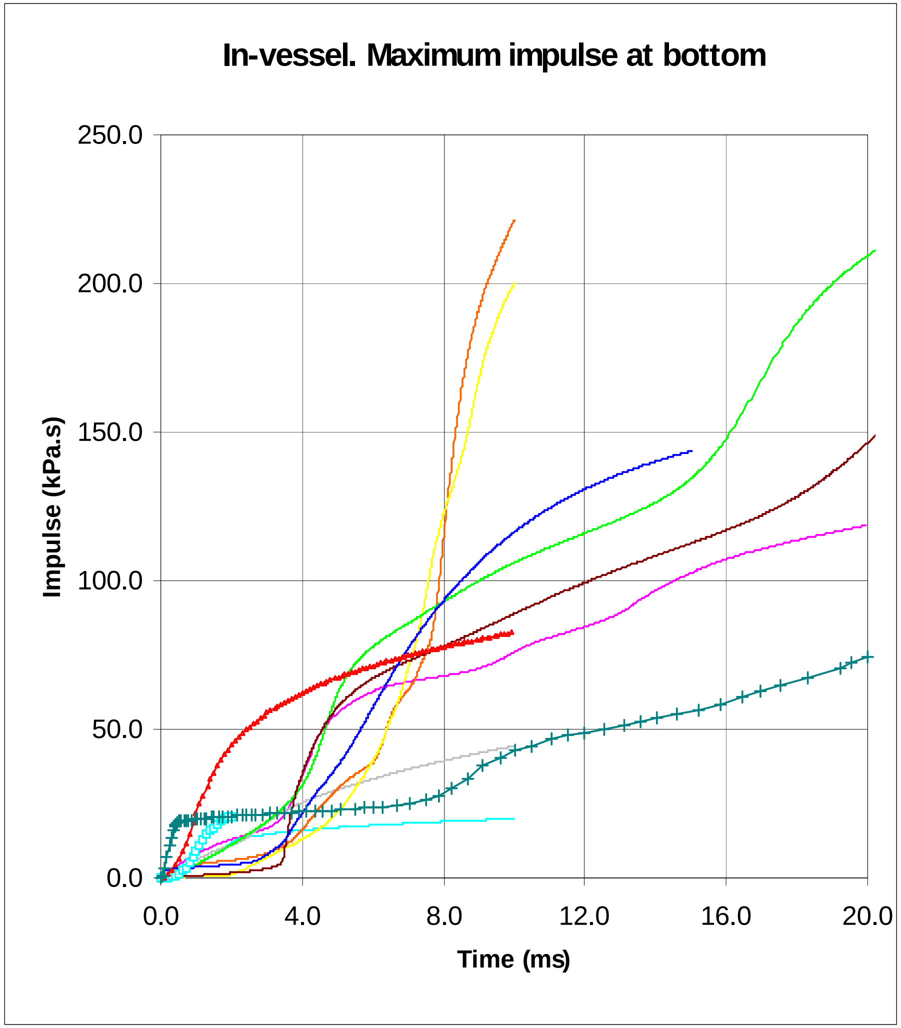


- Differences between code predictions are large

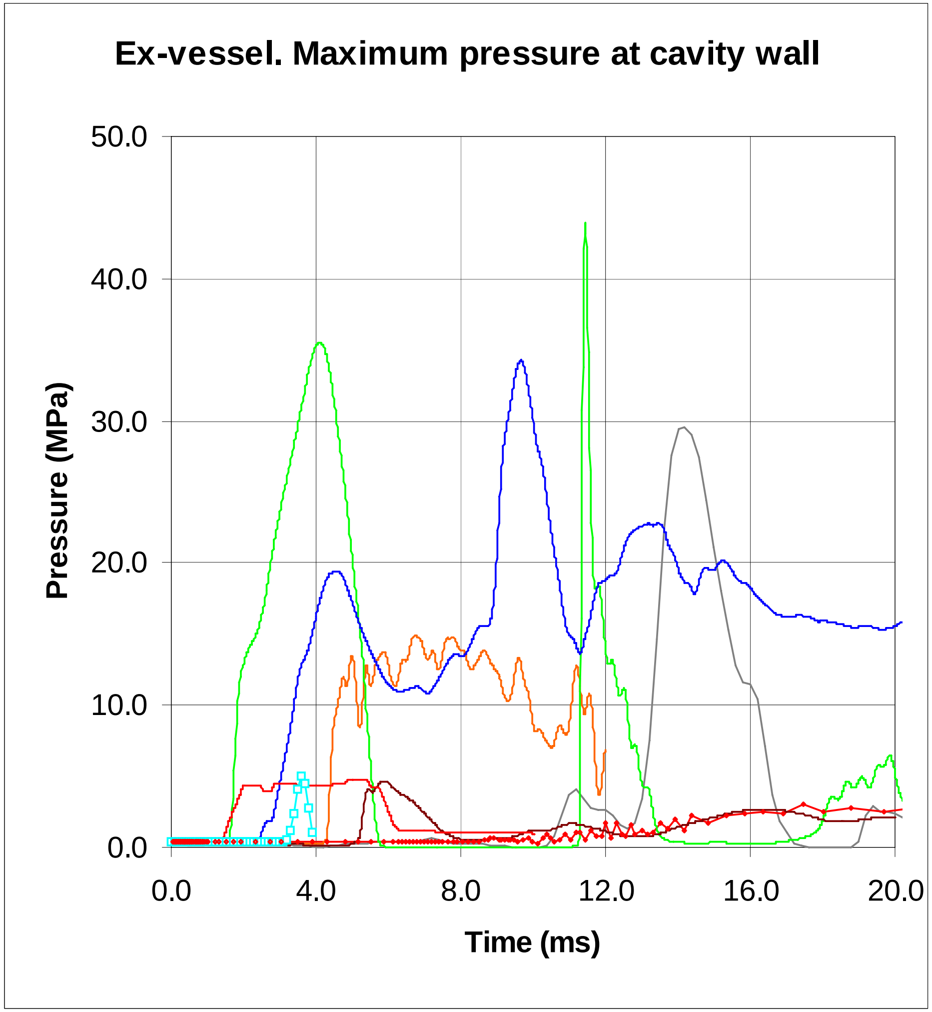
- But
  - Whatever the modelling and numerical approaches, all the codes were able to calculate the reactor situations of concern
  - Despite the variety of the approaches and parameter setting philosophy, all codes calculate loads that are rather low, due to
    - Relatively limited melt mass in pre-mixture
    - High voids
    - Venting
  - It is not clear which phenomena is dominant

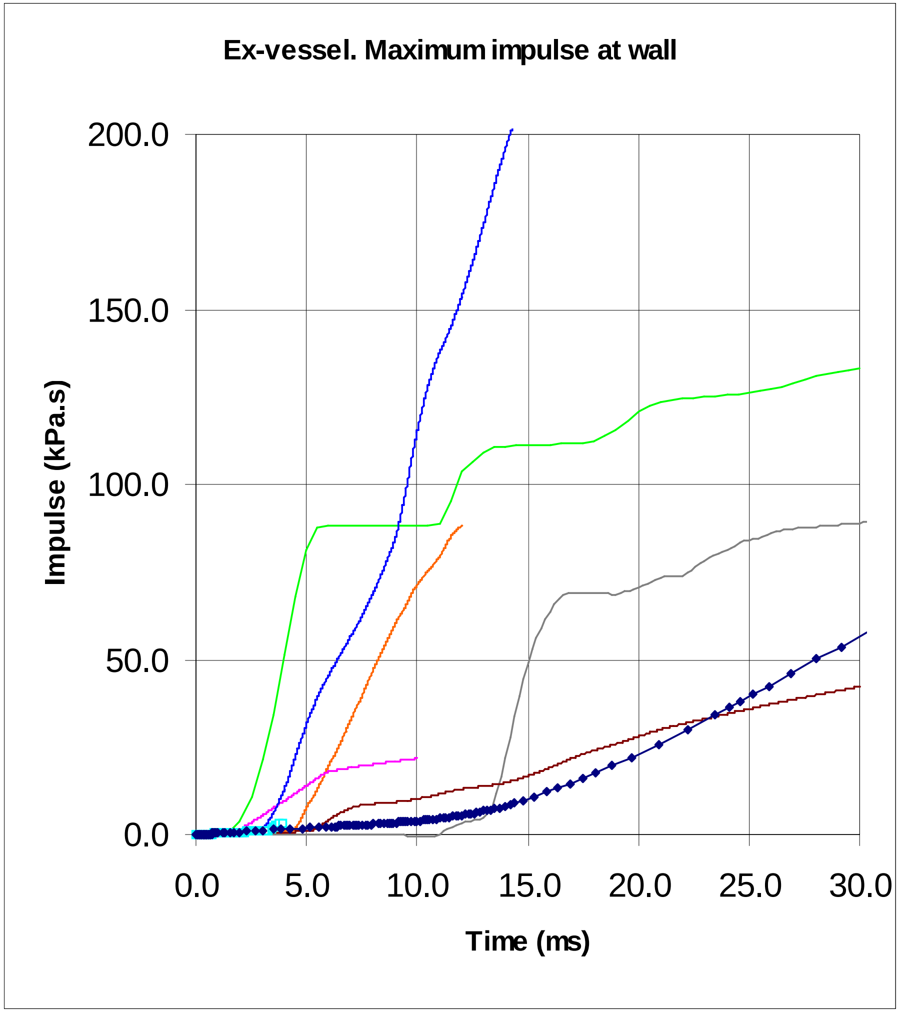
In-vessel pressures and impulses



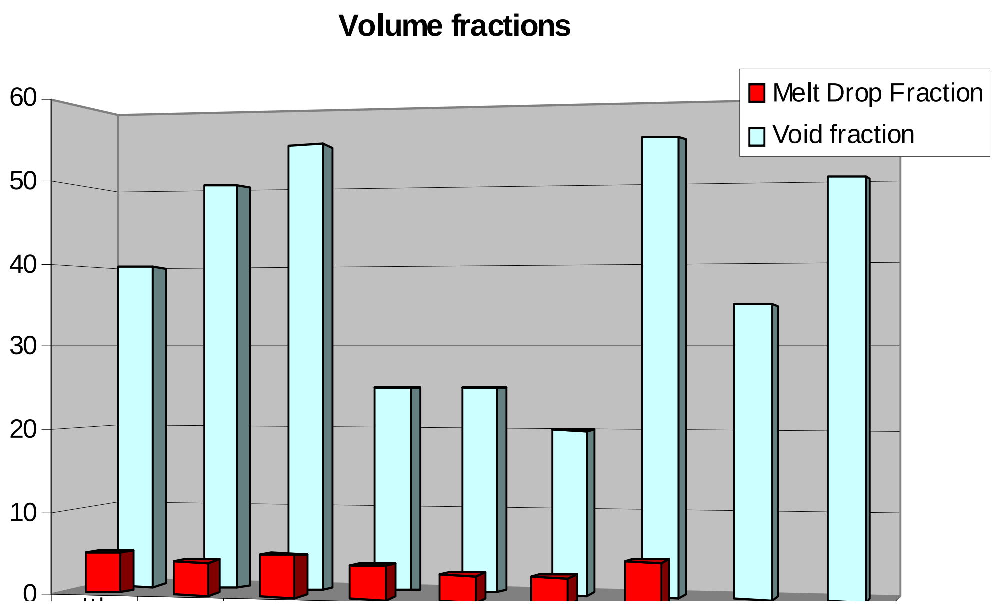


Ex-vessel pressures and impulses

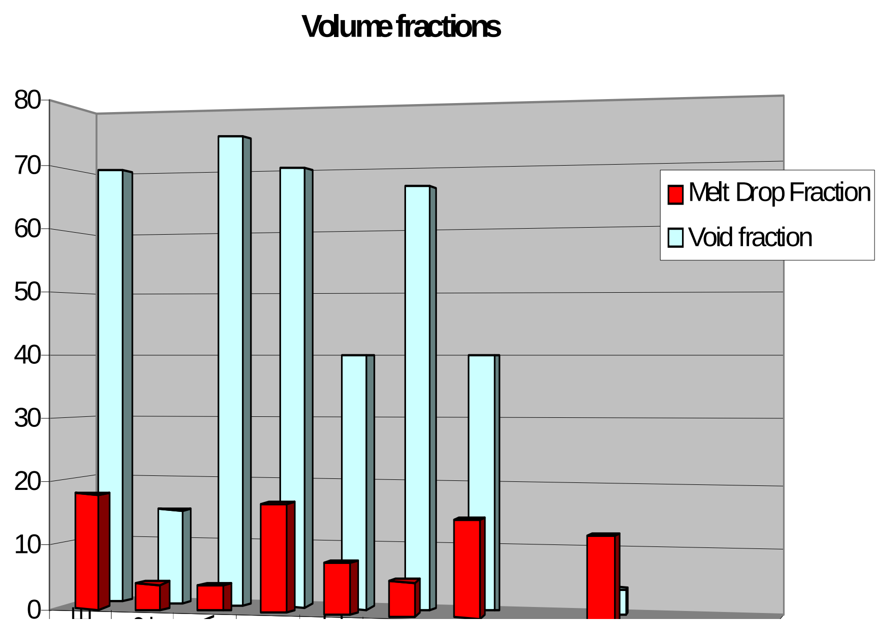




Void fraction in reactor cases



In-vessel

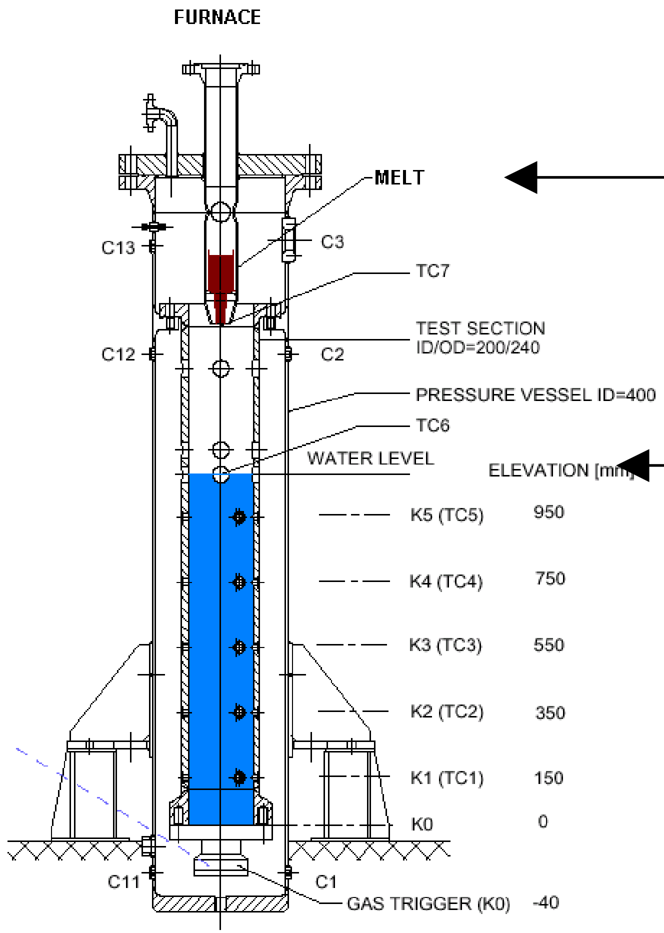


Ex-vessel

Concluding remarks (1/2)

- Phase 1 of SERENA was the most accomplished international exercise ever undertaken on steam explosion applied to reactor situations
- While the scatter of hypothesis and results is large for both pre-mixing and explosion, the reactor calculation results indicate clear tendencies
  - For the in-vessel case, the calculated loads are far below the capacity of the defined-model intact vessel
  - For the ex-vessel case, the calculated loads, even low, are above the capacity of the defined-model cavity walls
    - The scatter of the results raises the question of the containment safety margin for ex-vessel steam explosion

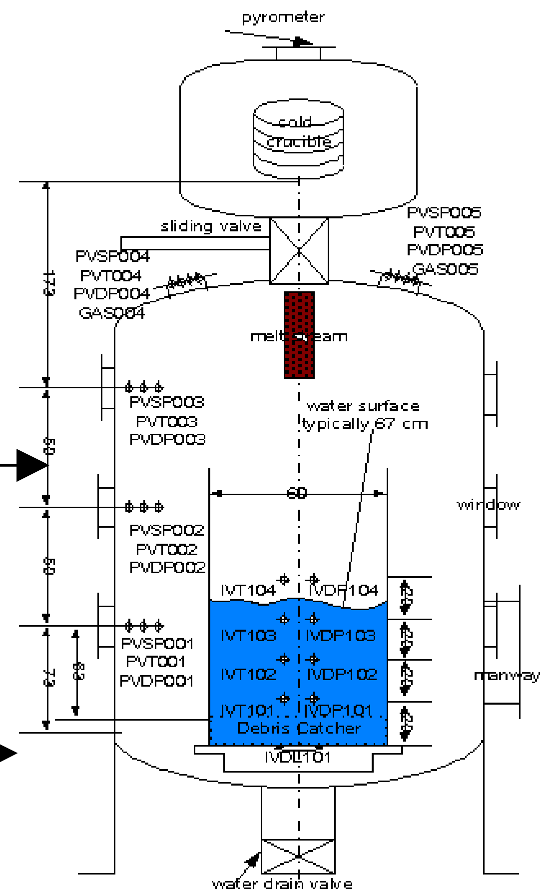
- **Confidence in the results is limited due to**
  - The large scatter of the results,
  - Only one in-vessel case and one ex-vessel case has been calculated for that might not be the worst possible
  - The uncertainties on the pre-mixing flow patterns, especially on void and pre-mixed melt mass predictions (missing detailed data on these issues),
  - The uncertainties on the material influence on the energetics (data partly available for two similar corium only)
- **Resolving these issues is required to**
  - Verify that the safety margin for in-vessel steam explosion are sufficient, actually
  - Quantify the containment safety margin for ex-vessel steam explosion



5 kg of melt
1-D geometry
New release device
X-ray radioscopy
External trigger

UO2-ZrO2-Steel-Zr-FP

20 kg of melt
2-D geometry
Intermediate catcher
Tomography
External trigger



KROTOS test section

TROI test assembly