

# Results of Phase-1 of OECD Programme SERENA on Fuel-Coolant Interaction

*Presented by*

**D. Magallon\***  
CEA Cadarache

*\*On secondment from JRC-Petten*

**K-H Bang**, *Korea Maritime University, Korea,*  
**S. Basu**, *Nuclear Regulatory Commission, USA,*  
**G. Berthoud**, *Commissariat à l'Énergie Atomique, France,*  
**M. Bürger**, *Institute für Kernenergetik und Energiesysteme, Germany,*  
**M.L. Corradini**, *University of Wisconsin, Madison, USA,*  
**H. Jacobs**, *Forschungszentrum Karlsruhe, Germany,*  
**R. Meignen**, *Institut de Radioprotection et de Sûreté Nucléaire, France,*  
**O. Melikhov**, *Electrogorsk Research and Engineering Centre, Russia,*  
**K. Moriyama**, *Japan Atomic Energy Research Institute, Japan,*  
**M. Naitoh**, *Nuclear Power Engineering Corporation, Japan,*  
**J-H. Song**, *Korea Atomic Energy Research Institute, Korea,*  
**N. Suh**, *Korea Institute of Nuclear Safety, Korea,*  
**T.G. Theofanous**, *University of California, Santa Barbara, USA.*

- ◆ 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 important FCI phenomena for reactor application
- ◆ Carry out confirmatory research required to reduce uncertainties on these phenomena

**First joint exercise on steam explosion applied to reactor**

**♦ Phase 1**

- Identify areas where discrepancies of calculation results by the different FCI codes induce large uncertainties in the prediction of loads in reactors
- Identify additional research needed to increase the level of confidence of the predictions

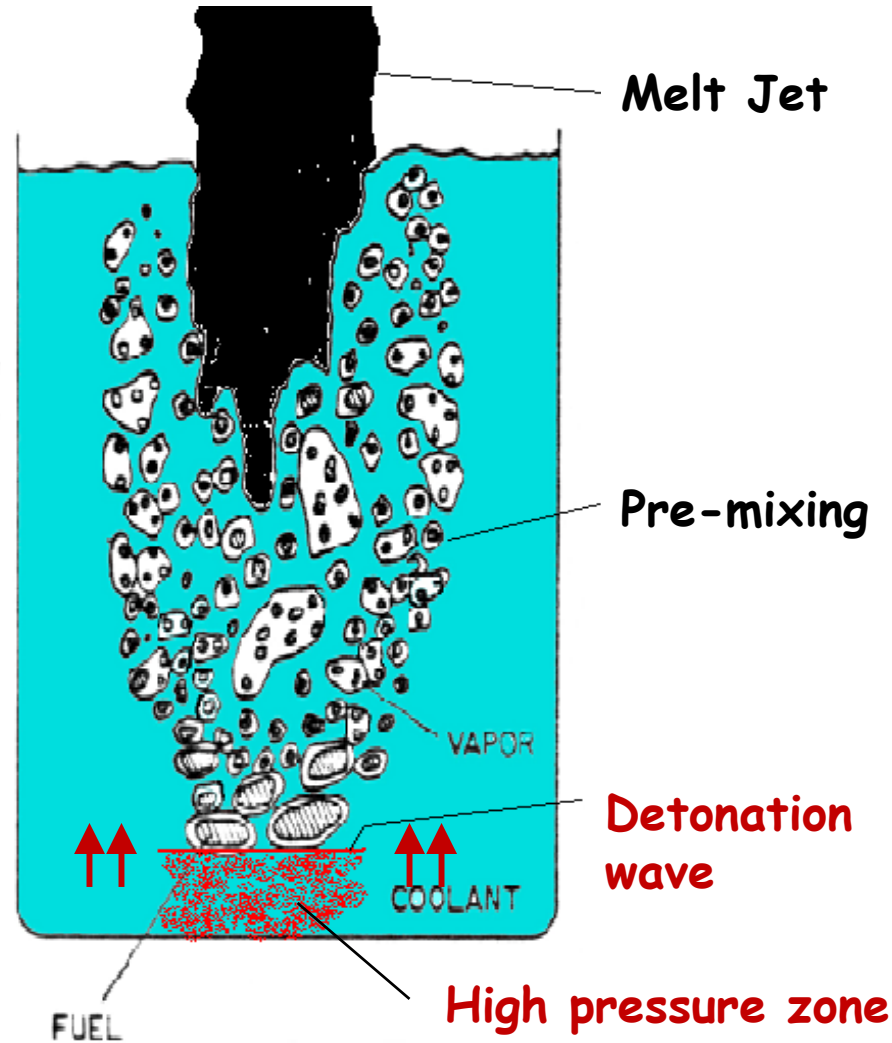
**♦ Phase 2**

- Reduce the uncertainties identified in Phase 1 to acceptable level for risk assessment by carrying out confirmatory analytical and/or experimental research

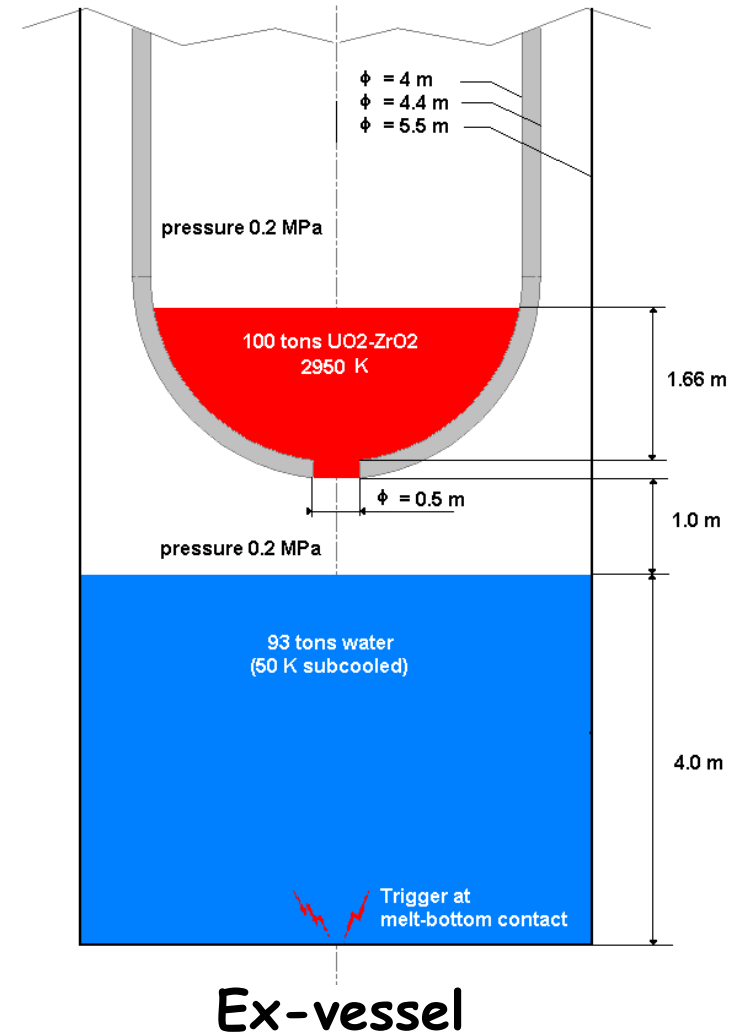
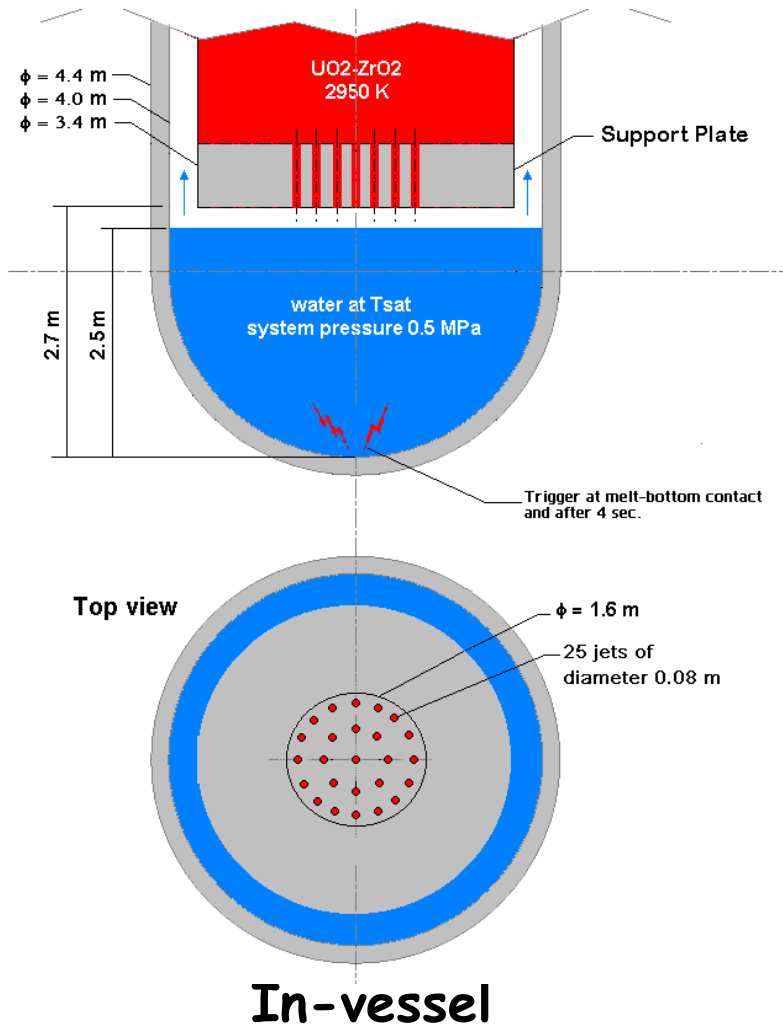
- ◆ OECD coordinated action
- ◆ Started January: 2002
- ◆ Final meeting: June 2005

- ♦ 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 (possible) discrepancies between codes and data
  
- ♦ The codes were applied to reactor situations with the scope of identifying key uncertainties impacting predictability of steam explosion loads in reactors

- ♦ Task 1: Identification of relevant conditions for FCI in NPP's and selection of relevant experiments
- ♦ Task 2: Code application to relevant pre-mixing experiments
- ♦ Task 3: Code application to relevant explosion experiments
- ♦ Task 4: Code application to reactor configurations
- ♦ Task 5: Synthesis of the findings of Phase 1 and proposal to move forward



- ♦ 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”



**♦ Pre-mixing experiments**

- FARO L-28: 175 kg of  $\text{UO}_2\text{-ZrO}_2$  melt in saturated water
- FARO L-31: 92 kg of  $\text{UO}_2\text{-ZrO}_2$  melt in subcooled water

**♦ Explosion experiments**

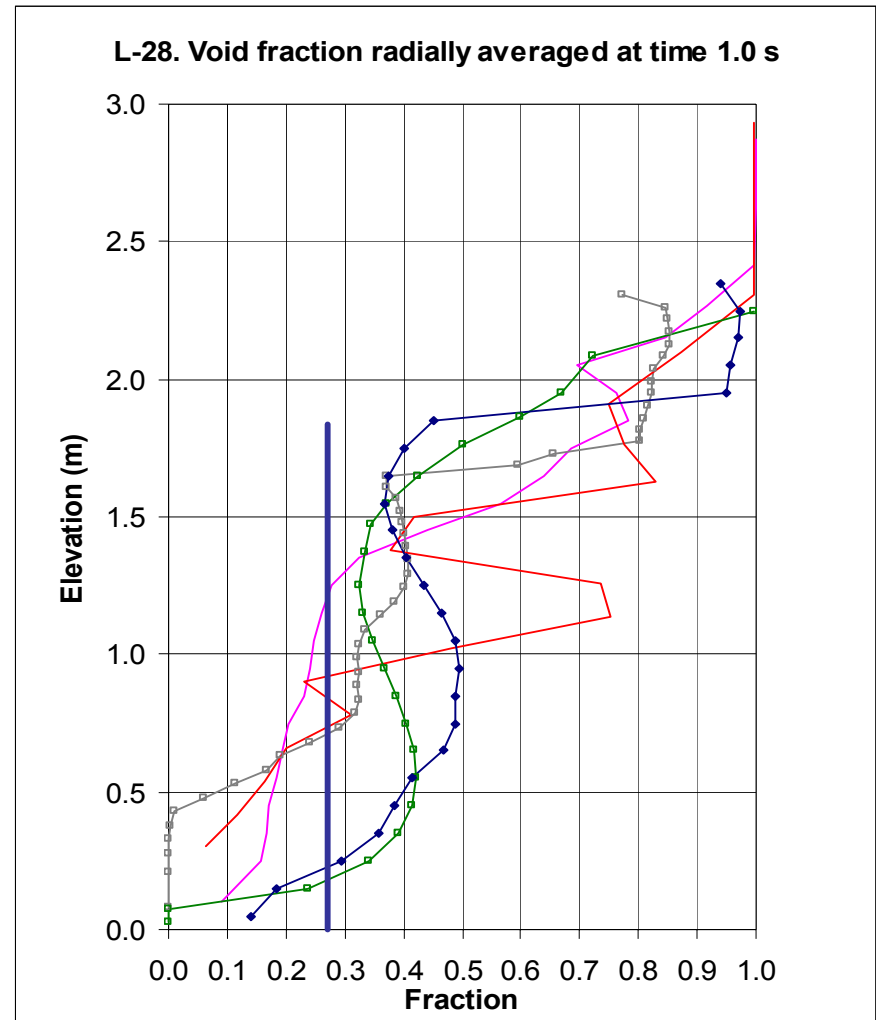
- KROTOS K-44: 1.4 kg of alumina melt in subcooled water
- TROI-13 and TROI-34 (blind exercise): ~2 kg of  $\text{UO}_2\text{-ZrO}_2$  melt with and w/o trigger.

**♦ Integral experiment: FARO L-33**

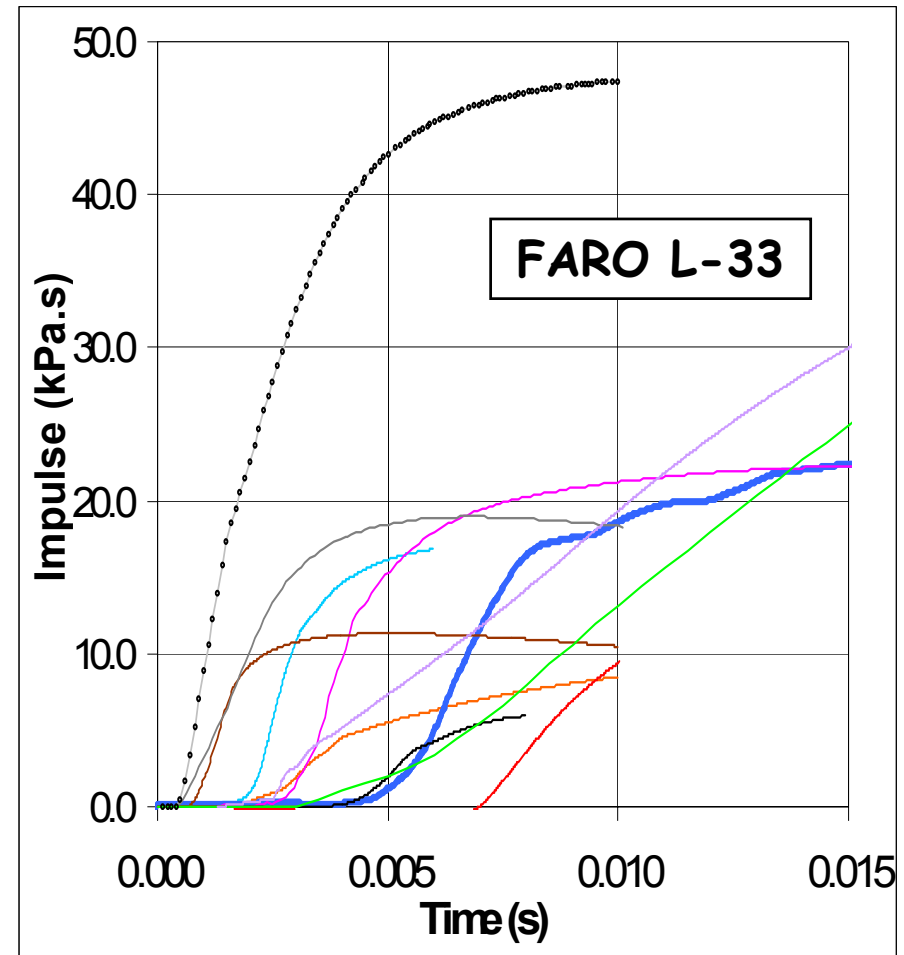
- Triggered steam explosion involving ~25 kg of  $\text{UO}_2\text{-ZrO}_2$  melt in subcooled water at 0.4 MPa.

<b>Partners</b>	<b>Codes</b>
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

- ◆ Code application to pre-mixing experiments showed:
  - Large scatter between code predictions and between code predictions and data
  - 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
- ◆ Void is a major issue, as considered having a key limiting effect on explosion strength



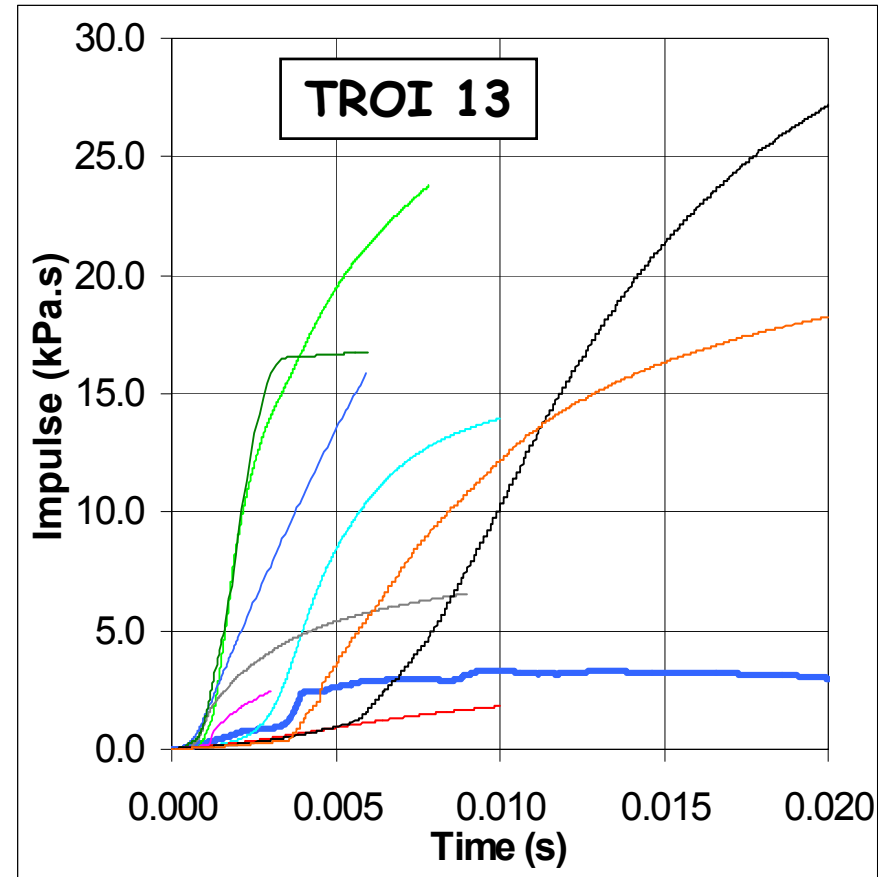
- ◆ Code application to explosion experiments showed:
  - Large scatter between code predictions and between code predictions and data
  - In order to get the order of magnitude of the data, key effects such as heat transfer and fragmentation parameters had to be (more or less arbitrarily) reduced from those tuned for alumina
  - But basic physical explanation is missing



- ◆ Possible physical explanations for the experimentally observed reduced explosion energetics are:

- Melt freezing during premixing
- Hydrogen production during pre-mixing
- Differences in pre-mixing (2-D geometry and void distribution)

↪ Comparison with KROTOS corium still to be done



**Corium**



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

**Alumina**

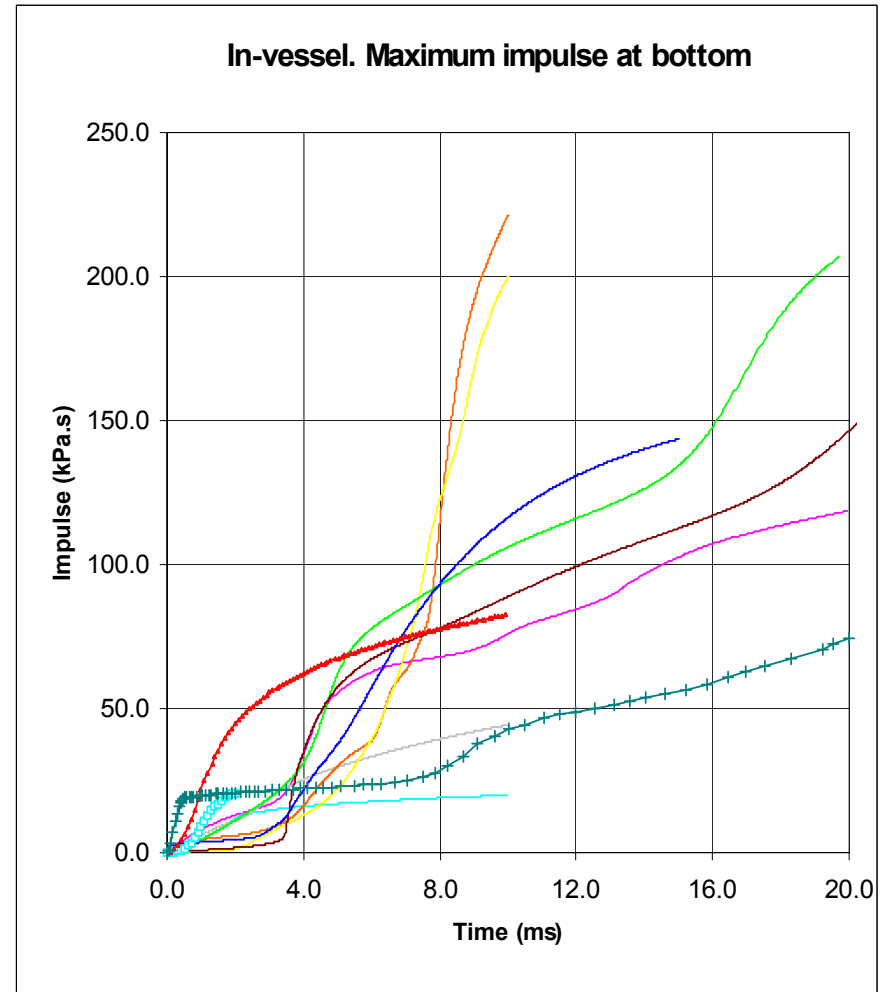
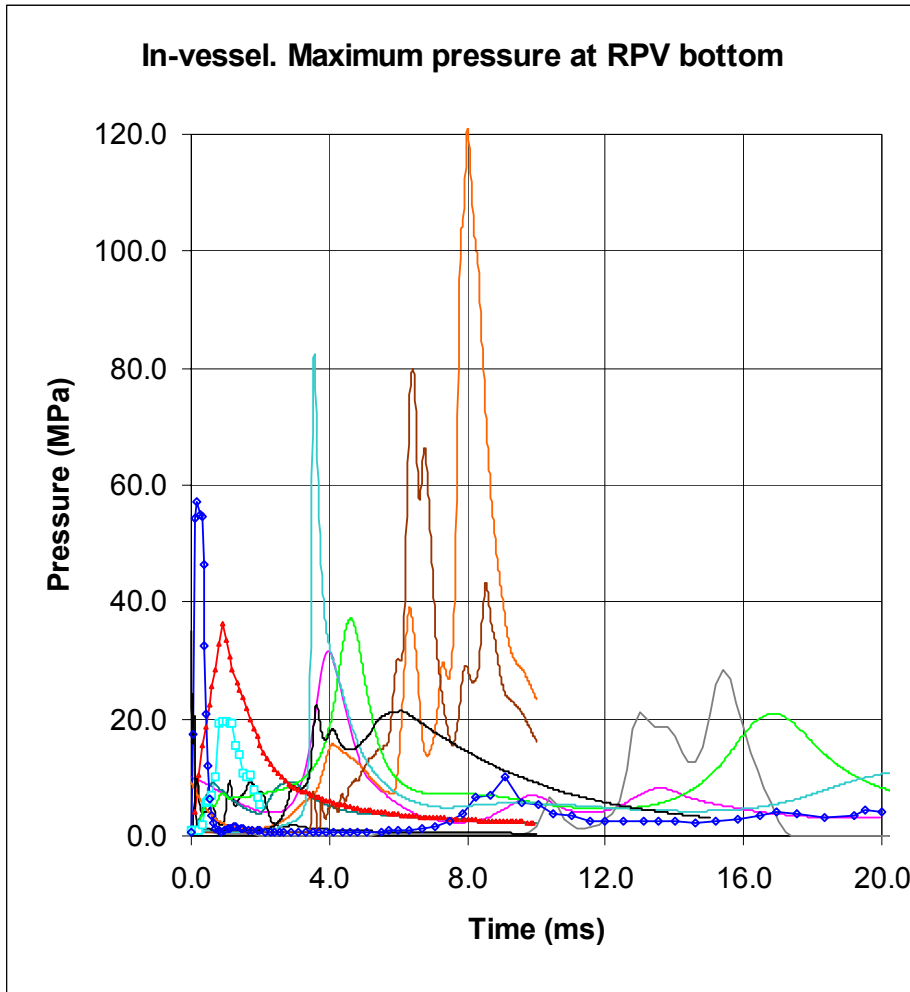


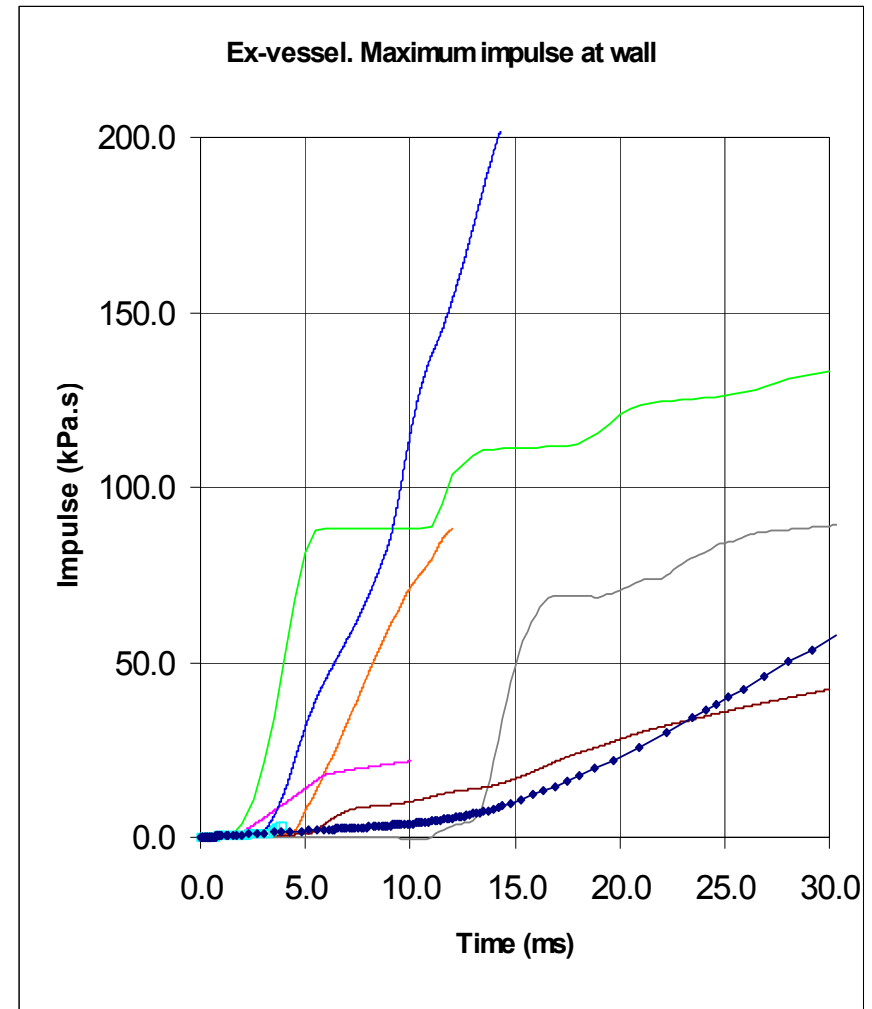
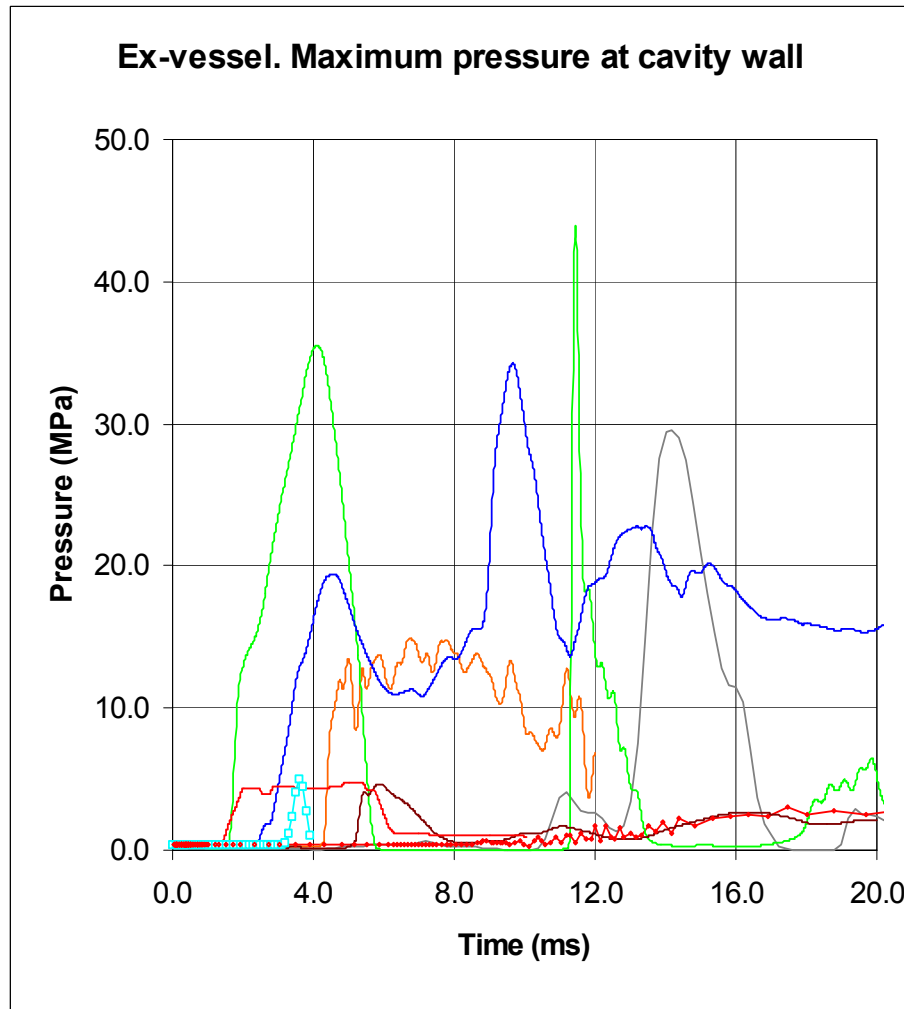
*Alumina melt mixing in K-57 (CANON).  
Viewing area 10 by 20 cm*

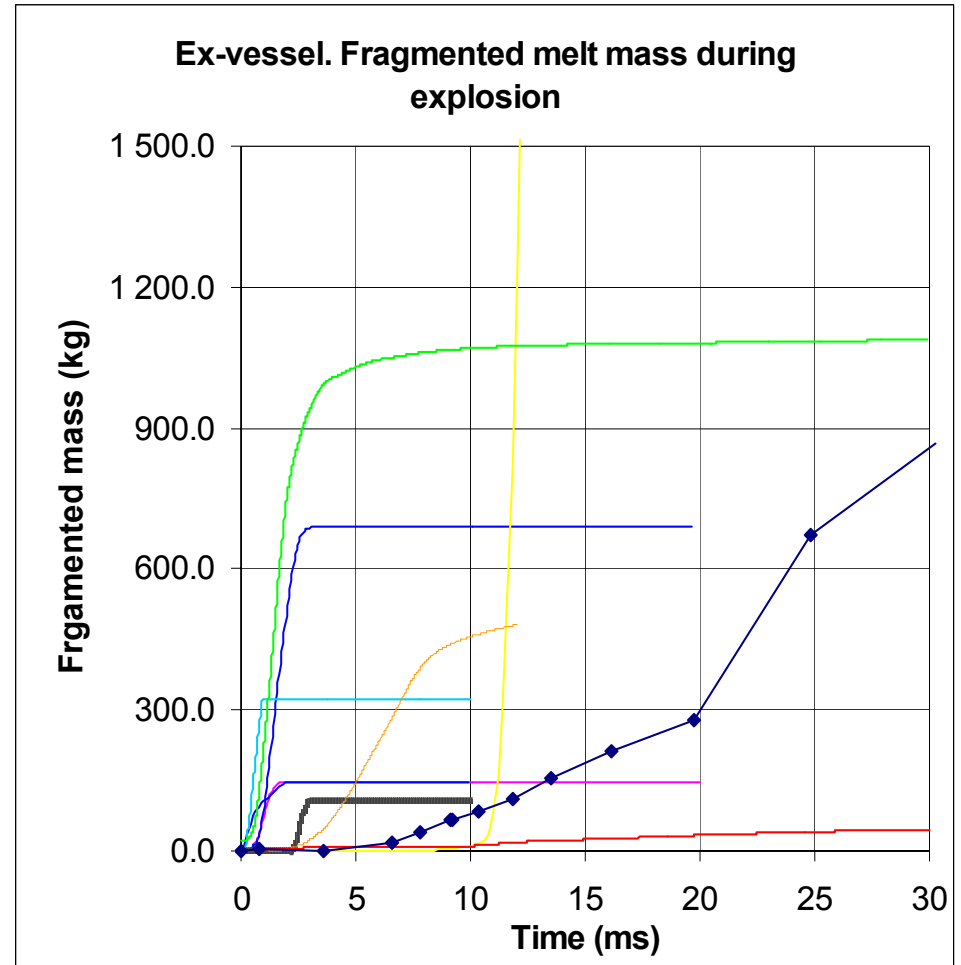
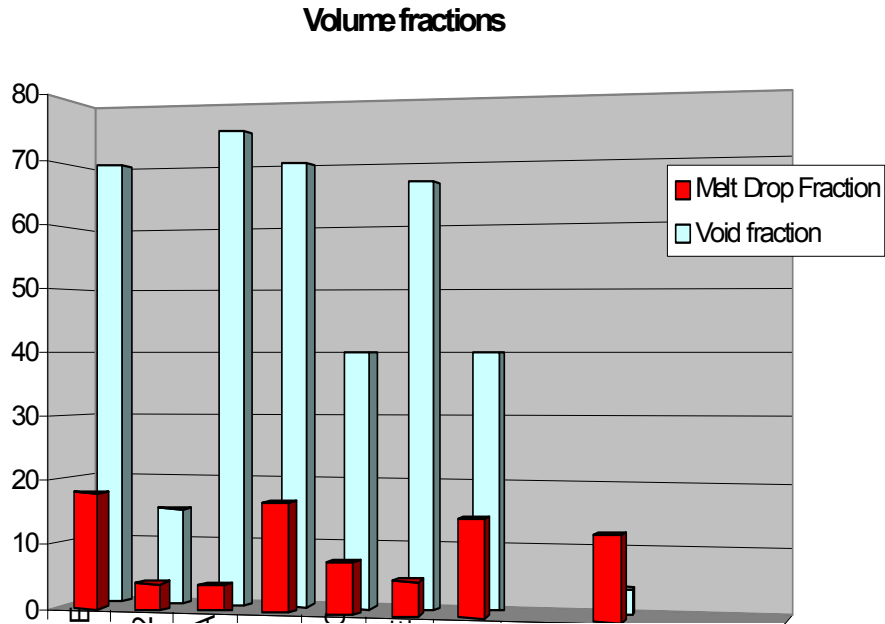
## **SERENA Summary results on reactor calculations**

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- ◆ Code application the selected reactor situations showed
  - 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**
      - Relatively limited melt mass in pre-mixture,
      - High voids
      - Venting
    - ⇒ It is not clear which phenomena is dominant







- ♦ Phase 1 of SERENA was the most accomplished international exercise ever undertaken on steam explosion applied to reactor situations
  - ♦ Despite the differences in modelling and approaches, and the large scatter of hypothesis and results for both pre-mixing and explosion, the reactor calculations 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

- ♦ These rather attractive results are balanced by the following considerations
  - Only one case has been calculated for in-vessel and ex-vessel, respectively.
  - These cases might not be the worst possible.
  - Only a few parameter variations were performed.
  - There is a tendency to predict large void in premixing, which was judged to be an overestimation of voiding according to pre-mixing experiment analysis,
  - In some cases “reduced” parameters have been used to model the explosion without firm physical reasoning.

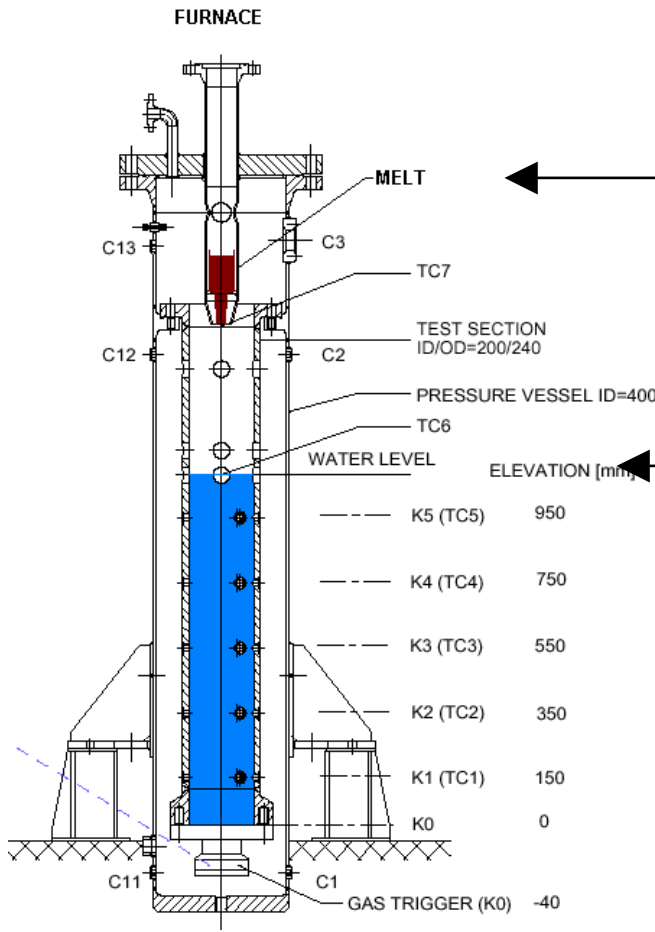
- ♦ Resolving these issues is required to
  - Verify that the safety margin for in-vessel steam explosion are sufficient, actually
  - Quantify the containment safety margin for ex-vessel steam explosion
- ♦ The first three require analytical work in continuation of Phase 1
- ♦ The uncertainties on the pre-mixing flow patterns (especially on void distribution) and geometry, and on material influence on the energetics must be addressed experimentally
  - They are proposed to be investigated in a second phase of SERENA by using KROTOS and TROI facilities

**♦ Objectives**

- To get more detailed data on pre-mixing flow patterns, in particular void distribution, and geometry
  - To determine explosion behaviour of a spectrum of corium melt compositions and conditions reflecting accident scenarios
- ♦ KROTOS and TROI facilities will be used in a complementary experimental programme**
- One (KROTOS) being more suited for investigating intrinsic FCI characteristics of the melts and equipped with high energy X-ray radioscopy device to “visualise” pre-mixing,
  - The other (TROI) being more suited for testing more reactor-like conditions by having more mass and 3-D capabilities, and equipped for tomography
- ♦ Five complementary tests are proposed to be performed in each facility**

# SERENA

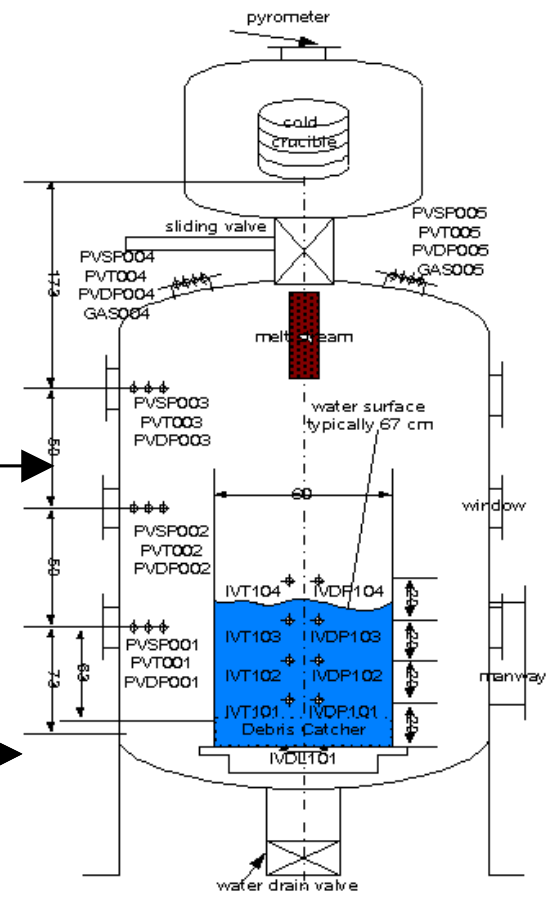
## Insight into Phase 2 proposal (2/2)



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

UO<sub>2</sub>-ZrO<sub>2</sub>-Steel-Zr-FP

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



**KROTOS test section**

**TROI test assembly**