RELAP5/ATHENA Users Seminar
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Water Bulk Acceleration by Rapid Air Injection

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1 · Introduction

High coherence : large load

Low coherence : small load

Accident scenario

Core melting

↓

Flowing out of P. V.

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Pouring into coolant pool

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Steam explosion

↓

Bubble growth

↓

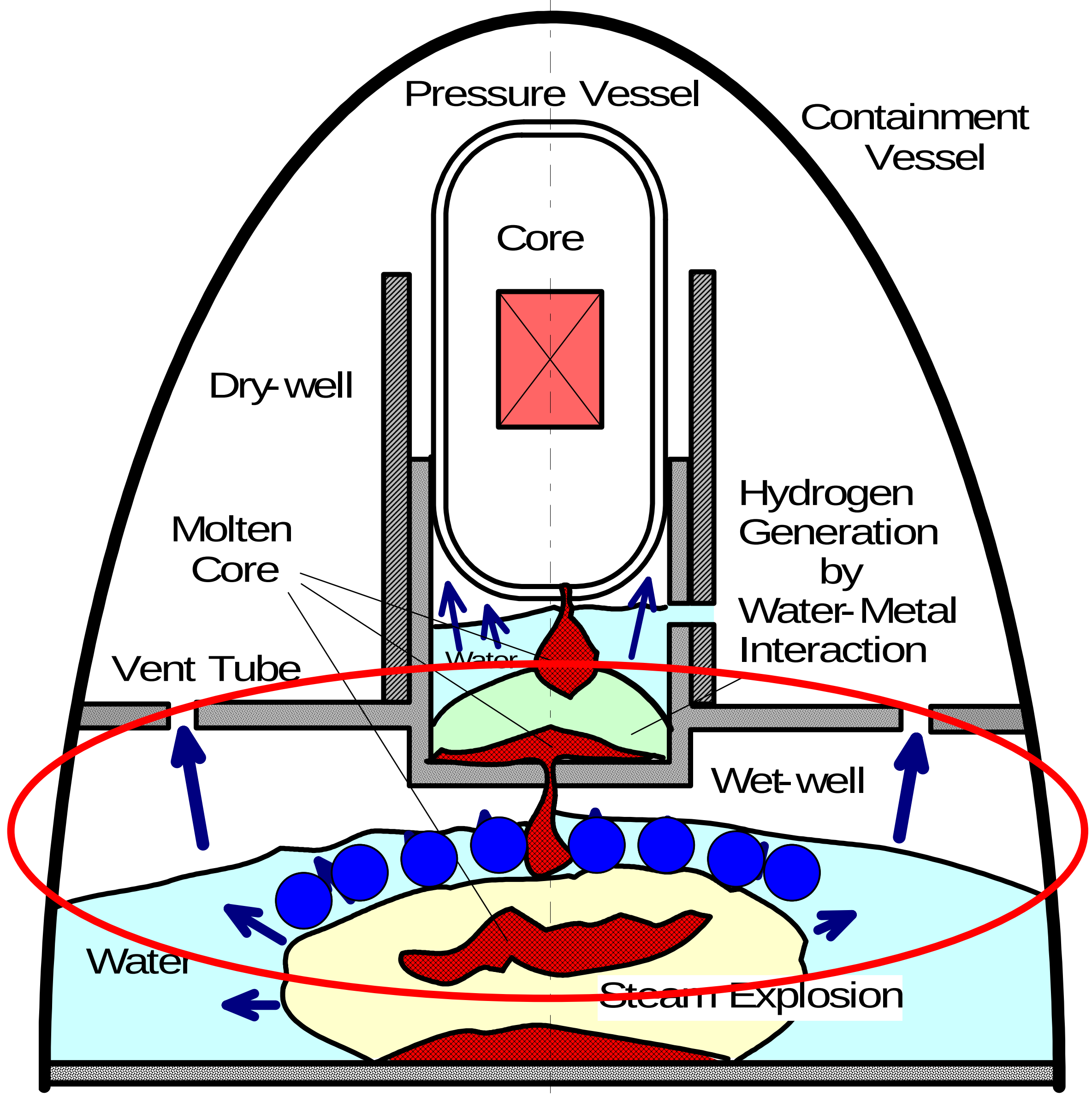
Water bulk acceleration

[Coherent behavior]

↓

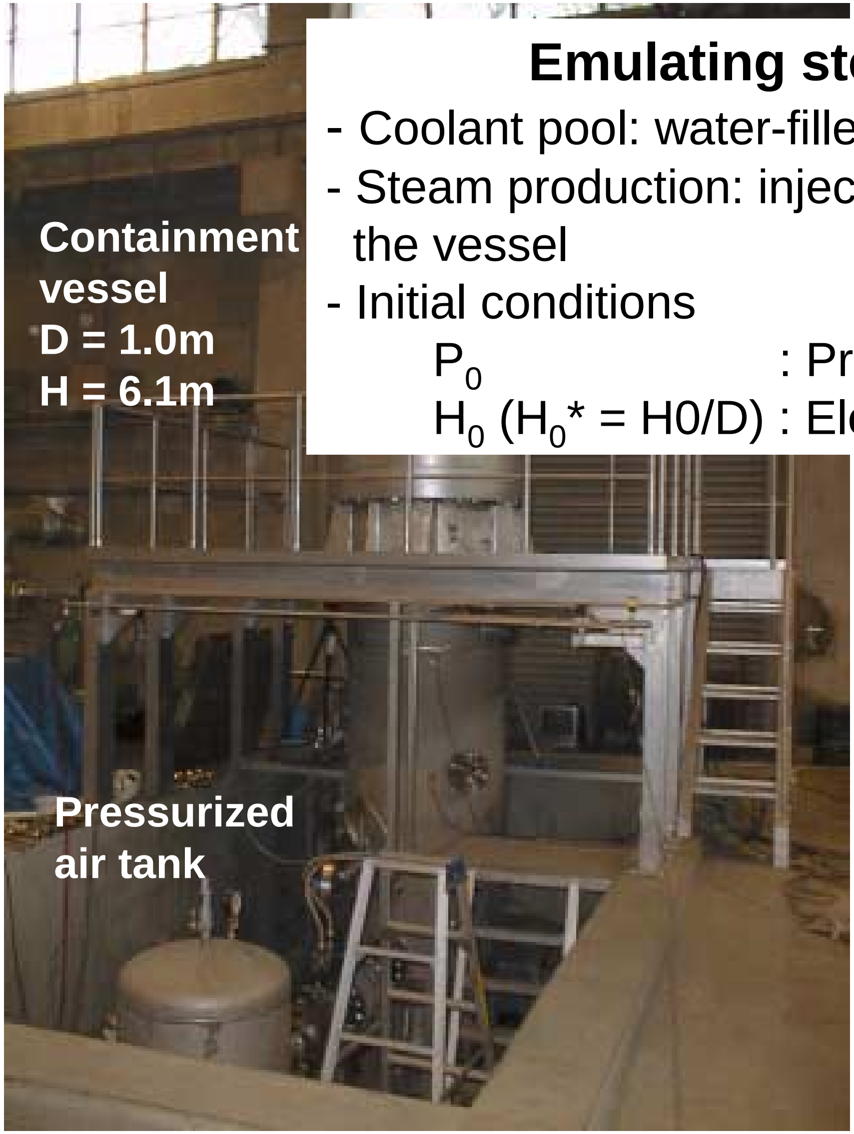
Water hammer

Structure destruction

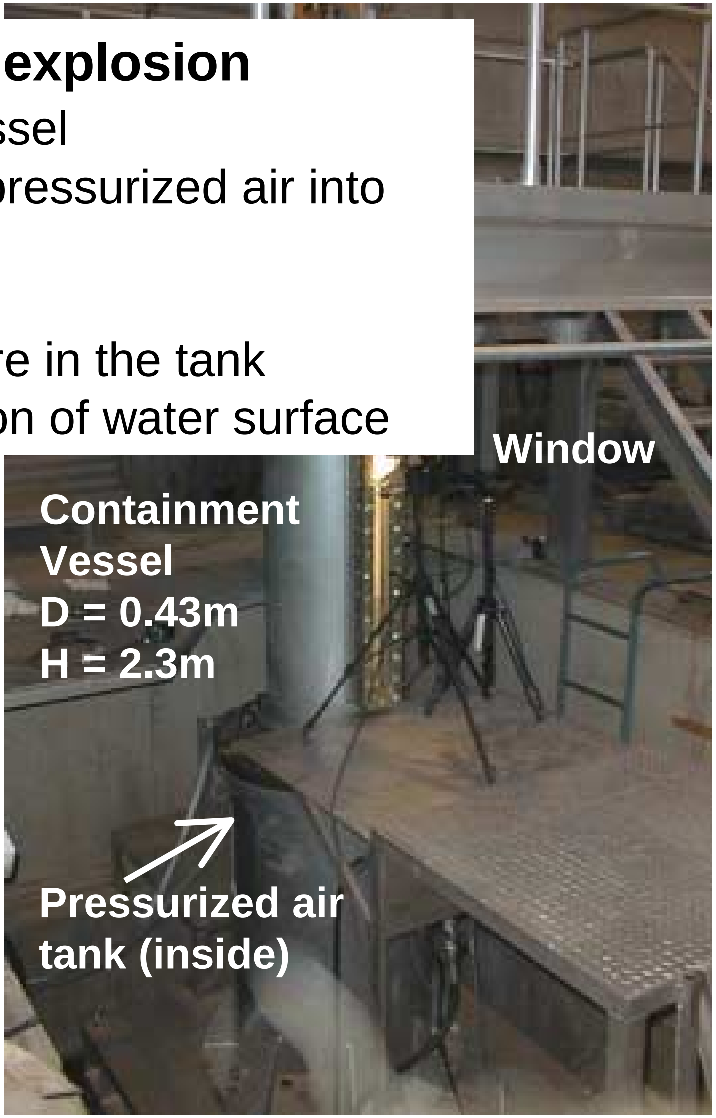


Emulating steam explosion

- Coolant pool: water-filled vessel
- Steam production: injecting pressurized air into the vessel
- Initial conditions
  - P_0 : Pressure in the tank
  - H_0 ($H_0^* = H0/D$) : Elevation of water surface

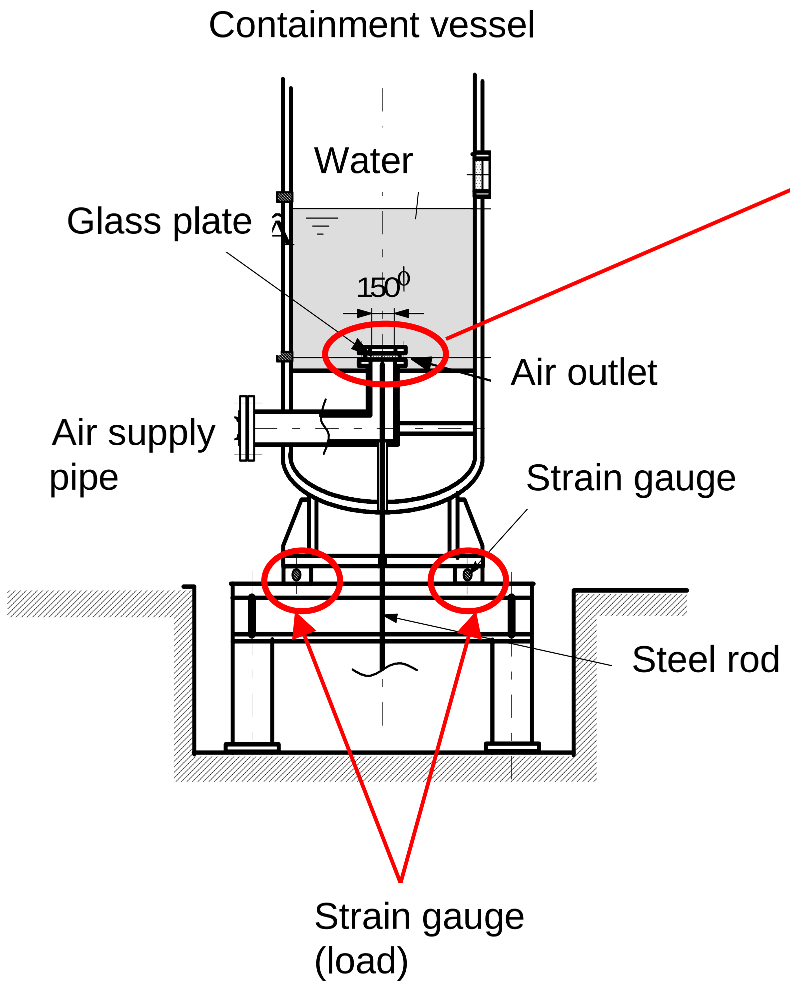


Large vessel apparatus



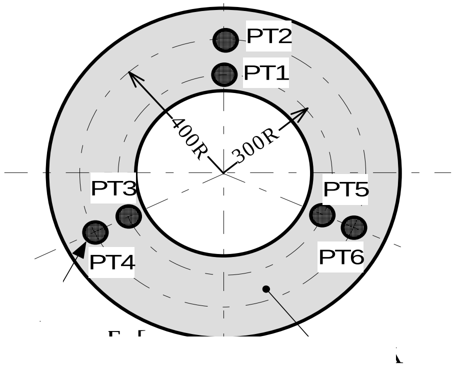
Small vessel apparatus

2.Experiment (Cont'd)



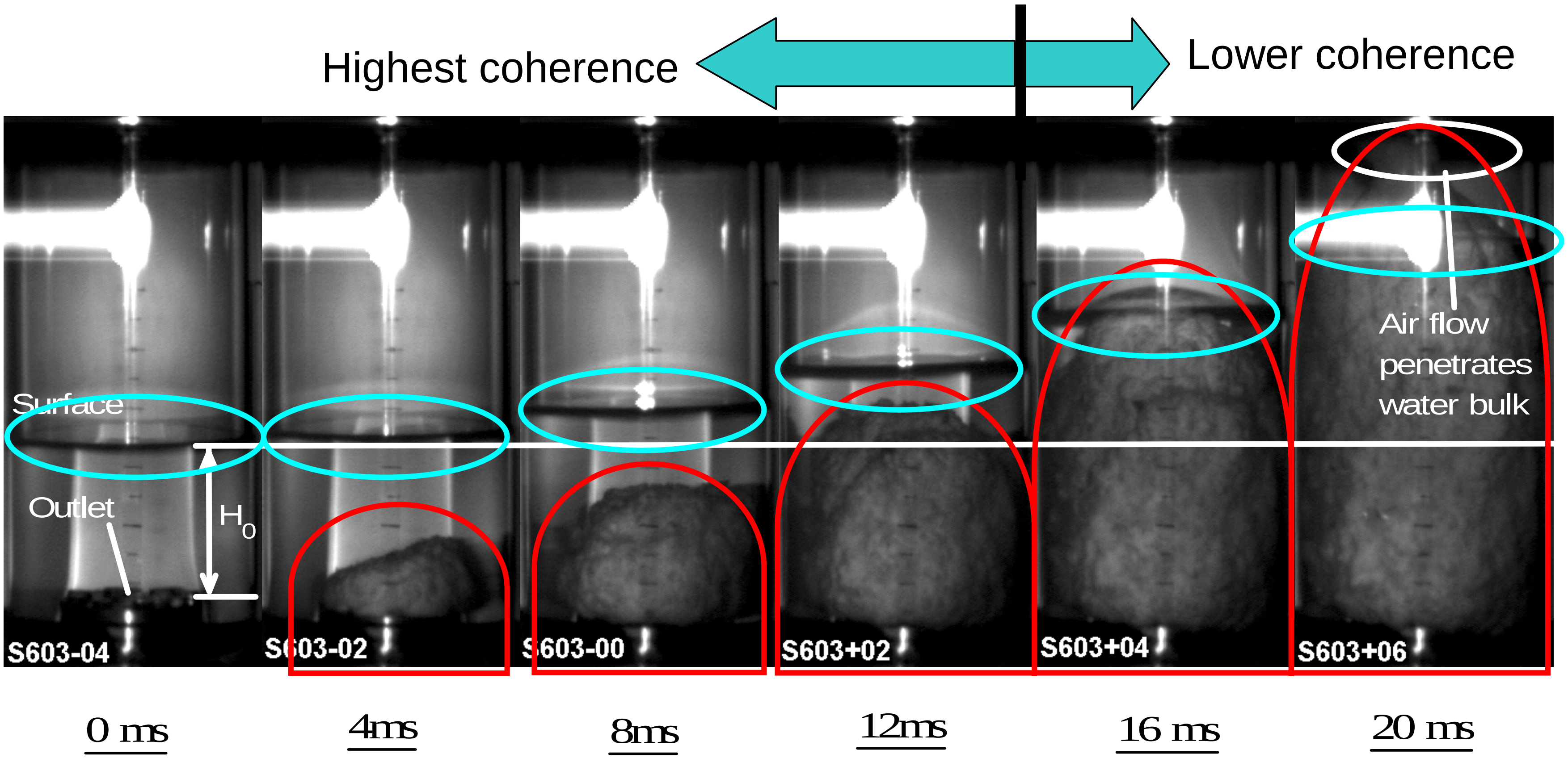
Air outlet (photo)

- One outlet
- Opening by glass plate fracture



Pressure transducers to detect water hammer under orifice plate

Rapid injection of pressurized air into the water-filled vessel (The large vessel apparatus)



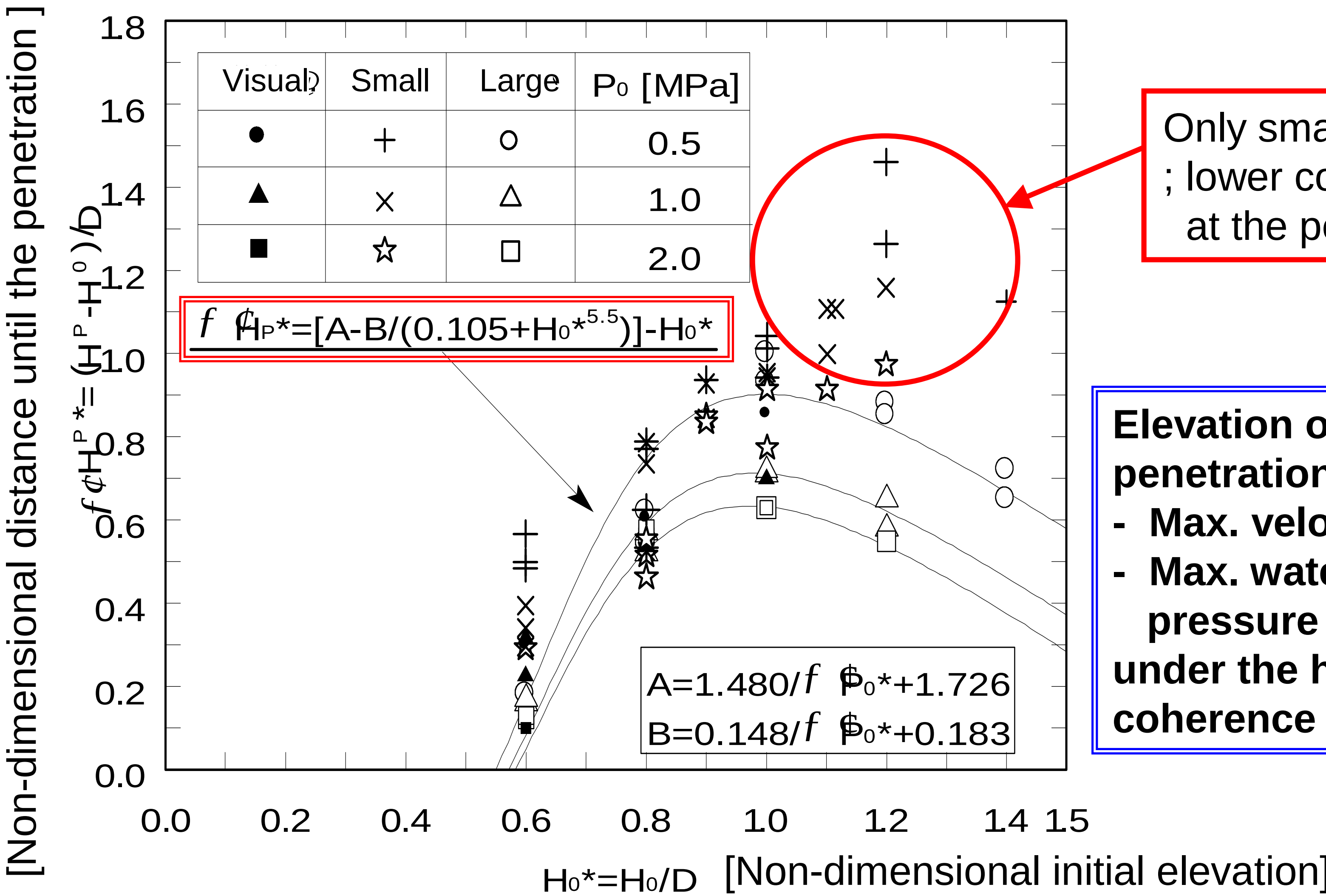
Bubble growth after air injection (small vessel, visualization)

Initial conditions

P_0(Initial pressure at the air tank) ＝ 1.0MPa

H_0*(Depth of water layer to outlet, non dim.)＝0.8 [as 0.345m in the small vessel]

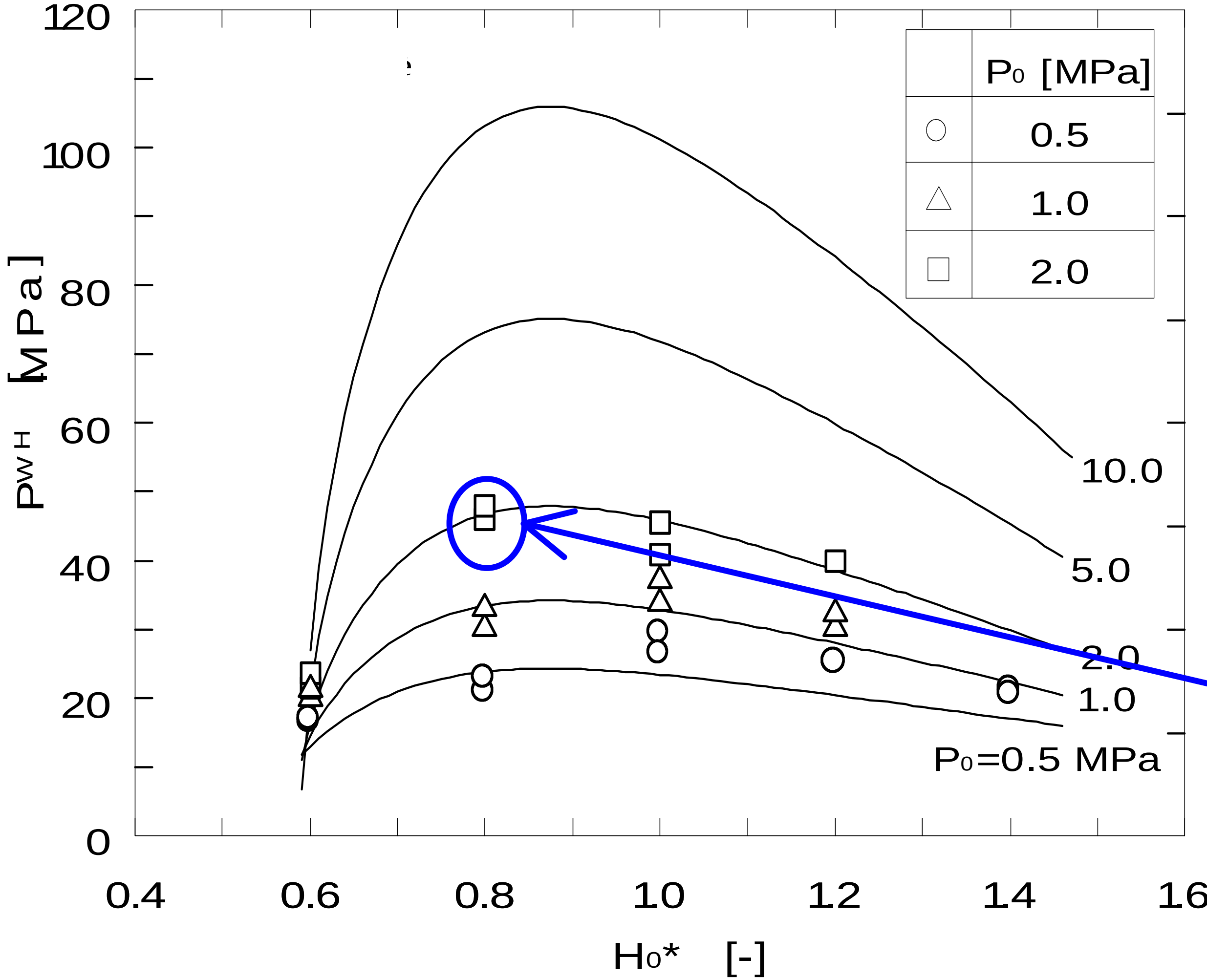
Recording speed 500 frames/s



Elevation of the air penetration is at
- **Max. velocity**
- **Max. water hammer pressure (> 10MPa)**

under the highest coherence

Elevation of the air penetration



$$P_{wh} = \rho c u_p$$

ρ = 1,000 kg/m^3
c = 1,500 m/s

If orifice was built at the elevation, water hammer load would be …

- 211 MN in the large vessel apparatus
- 21.6 MN in the small vessel apparatus

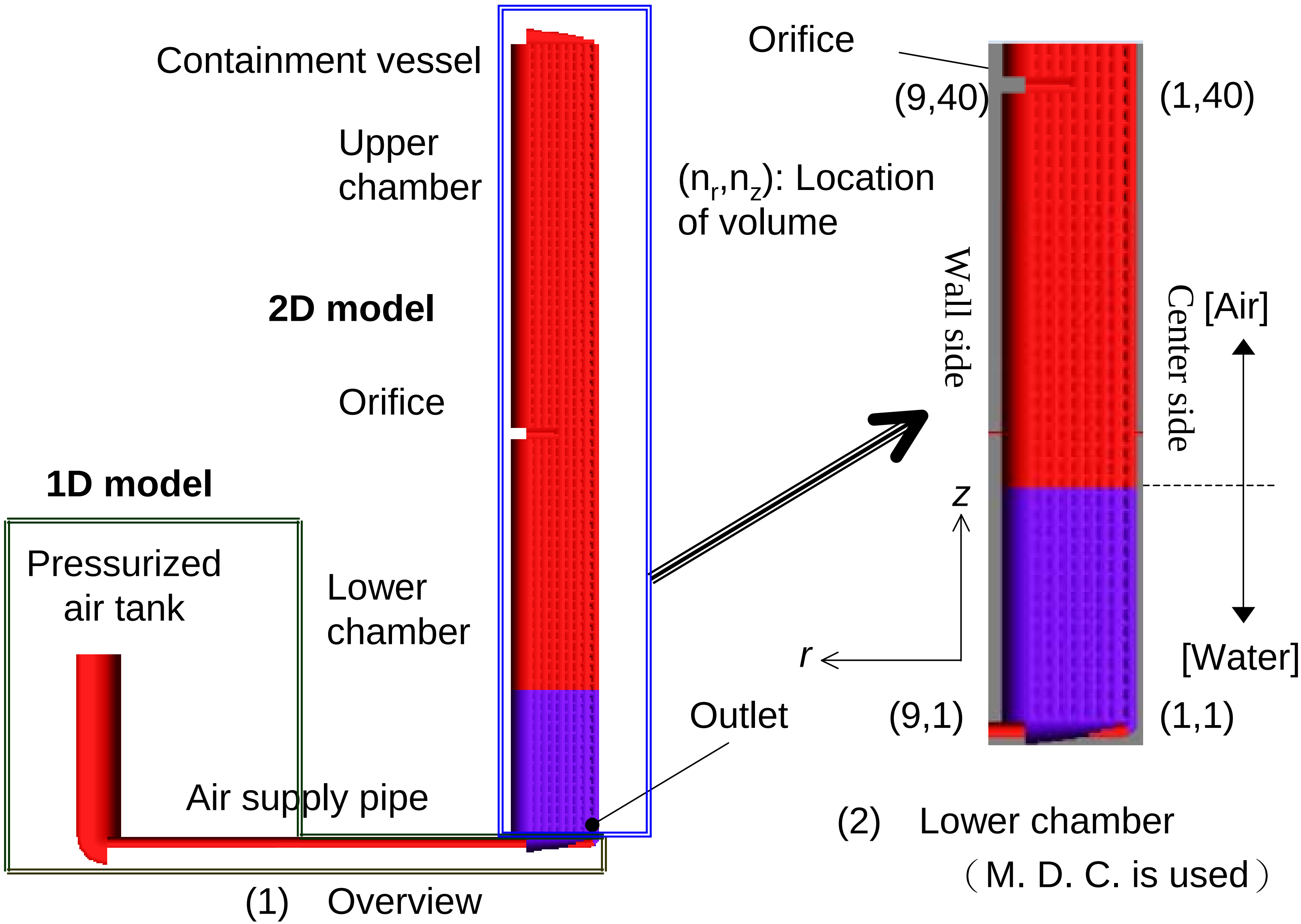
Predicted W.H. pressure at the penetration elevation

Code requirement for analysis of the bulk acceleration

- High reliability in heat and hydrodynamic analysis of nuclear plant
- Multi-dimensional & Multi-phase analysis
- Each fluid is treated as independent in the code
- Stable computation under high acceleration (100 times of g =9.8 m/s^2)

RELAP5-3D is adapted, because …

- Version up from RELAP5/MOD3
- Multi-Dimensional Component (M.D.C) is introduced
- 2 fluid model (gas and water) is applied
- Good result qualitatively in 1D analysis

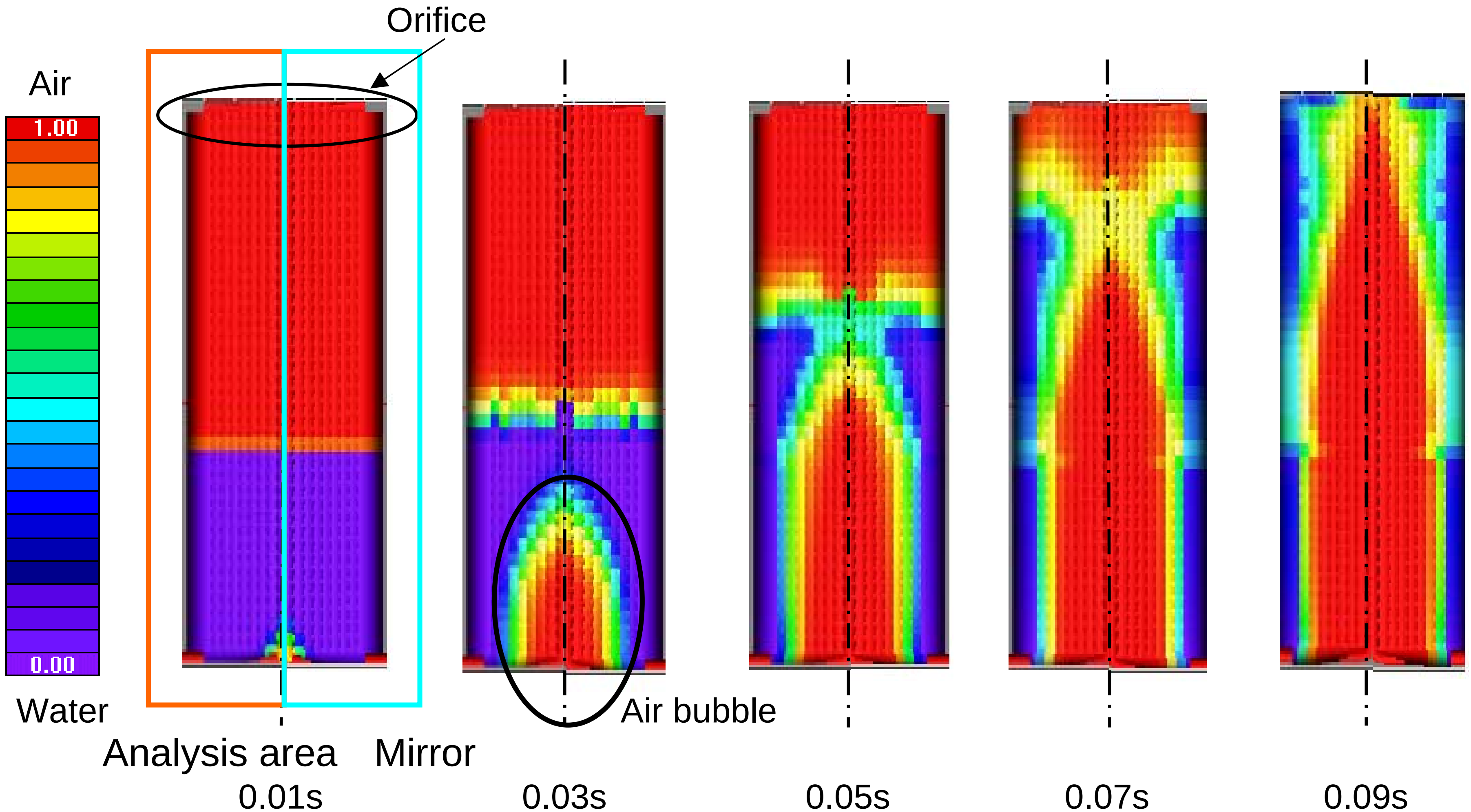


Analysis model for the large vessel exp.

List of components in the analytical model

Component Name		Dimension	Model	Number of volumes (junctions)	Remarks
Pressurized Airtank		1D	Pipe Componet	16	
Air Supply Pipe		1D	Pipe Componet	15	
Outlet		1D	Valve (motor)	(1)	Opening rate and property table were given.
Containment Vessel	Lower Chamber	2D (Cylinderical)	M. D. C.	360 = 9[r] * 40[z]	Width of nodalized volume was constant.
	Orifice	1D	Junction	(6)	
	Upper Chamber	2D (Cylinderical)	M. D. C.	360 = 9[r] * 40[z]	Width of nodalized volume was constant.

3・Analysis (Cont'd)

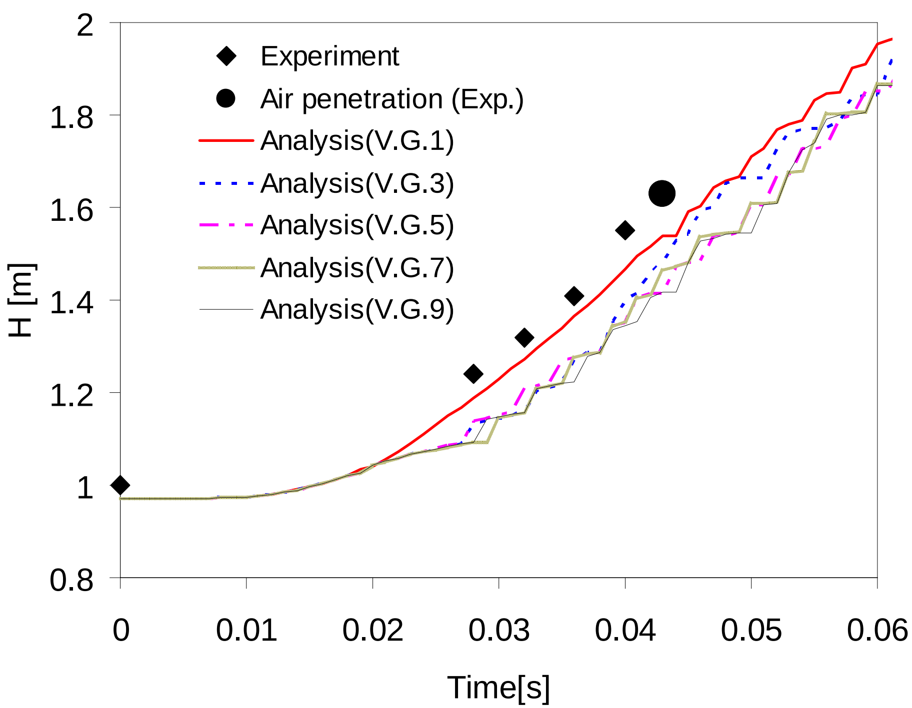


Void fraction in the lower chamber after pressurized air injection；

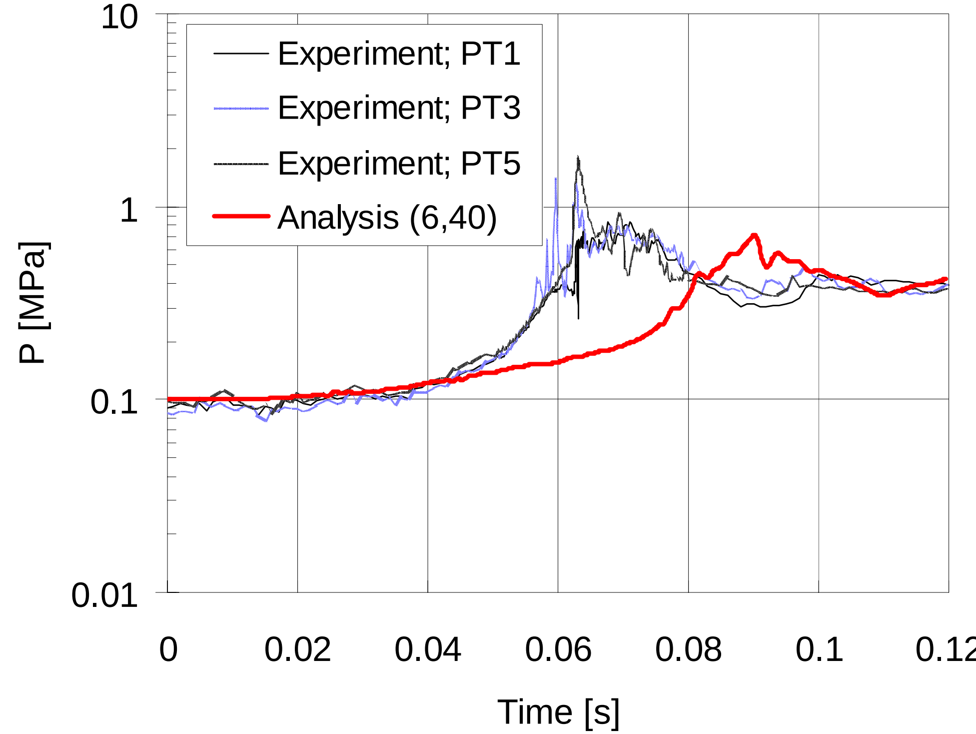
Large vessel、P_0=2.0MPa, H_0^*=1.0 (H_0=1.0m)

→ Acceleration was simulated enough qualitatively

Comparison with the large vessel experiment
; P_0=2.0MPa, H_0*=1.0 [1.0m]



Elevation of water surface



Pressure under orifice plate

- Air penetrated at lower elevation
  → Higher P_0, Larger error
- Air penetrated at higher elevation
  → Quantitatively better result

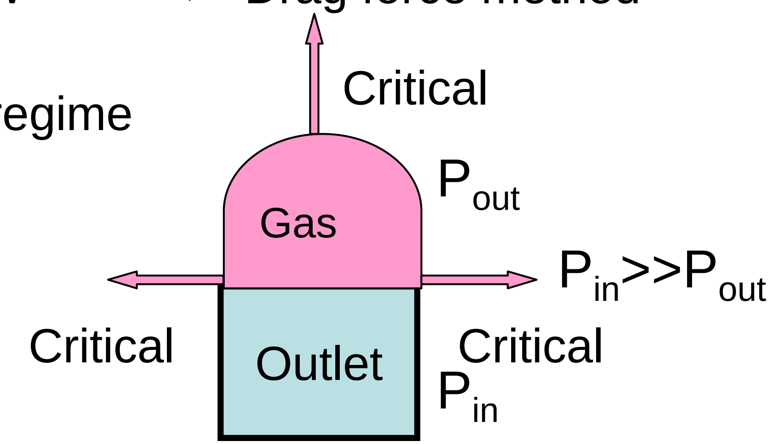
- Delayed following the acceleration
- W. H. pressure distribution : constant → (the penetration) → 1D(r) → 2D(r-θ)
- Pressure spike = Numerical instability?

Factors of the bulk acceleration (transaction at interface)

— Condensed gas with momentum

— Momentum conservation without phase transition

- Interfacial friction
  - Vertical bubbly, or slug flow → Drift flux method
  - Other vertical flow, horizontal flow → Drag force method
- Virtual mass term
  - Independent of direction or flow regime



Cause of error between the experiment and the analysis

- Under-estimation of interfacial friction against 2D critical air flow
- Shorter critical flow condition time, better result quantitatively
  - High elevation; decreased pressure drop due to bubble growth
- The penetration continues critical flow condition.

Summary

1. 2D analysis by RELAP5-3D simulated water bulk acceleration by rapid air injection qualitatively.

2. Improvement of interfacial friction force against 2D critical gas flow is required to estimate scale of water hammer load by the acceleration.

Next analysis plan

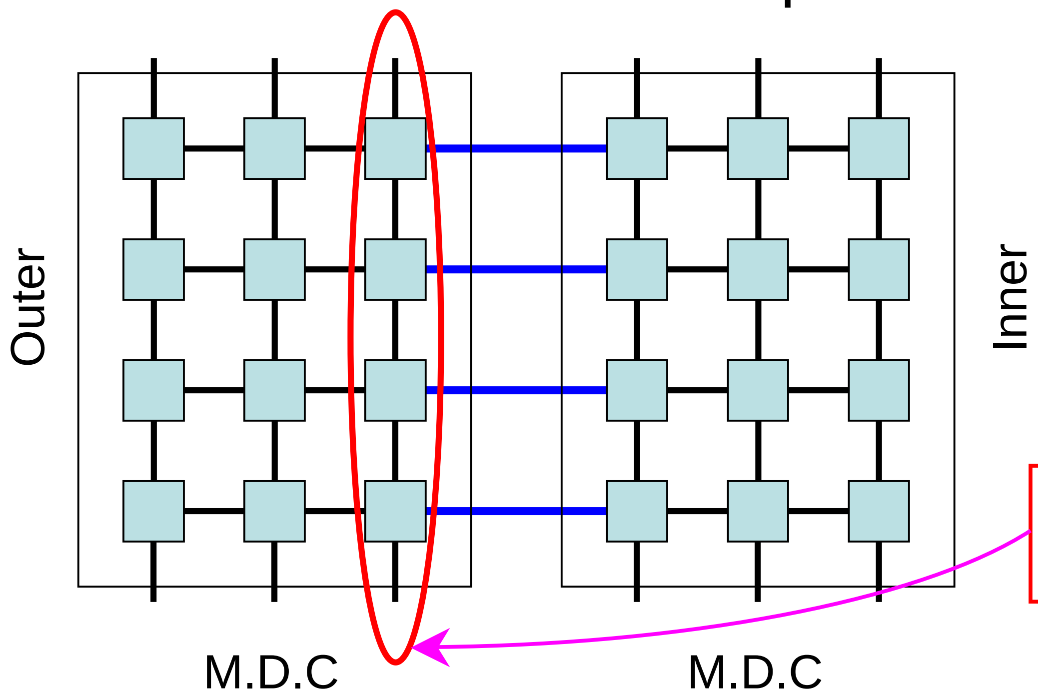
- Full 2D/3D analysis ; Effect of 2D/3D connection
- Water bulk acceleration by rapid **steam** injection (Influence of condensation)

Improvement request to next version of RELAP5-3D

- More volumes along *x*/*r* direction in the Multi-Dimensional Component

Now: 1 to 9 → Next: 1 to 20 (99?)

- Connection among the Multi-Dimensional Components



Closed process at each M. D. C. ?

↓

Strange transient is computed.

Ex. P < 0.1MPa,a at some volumes

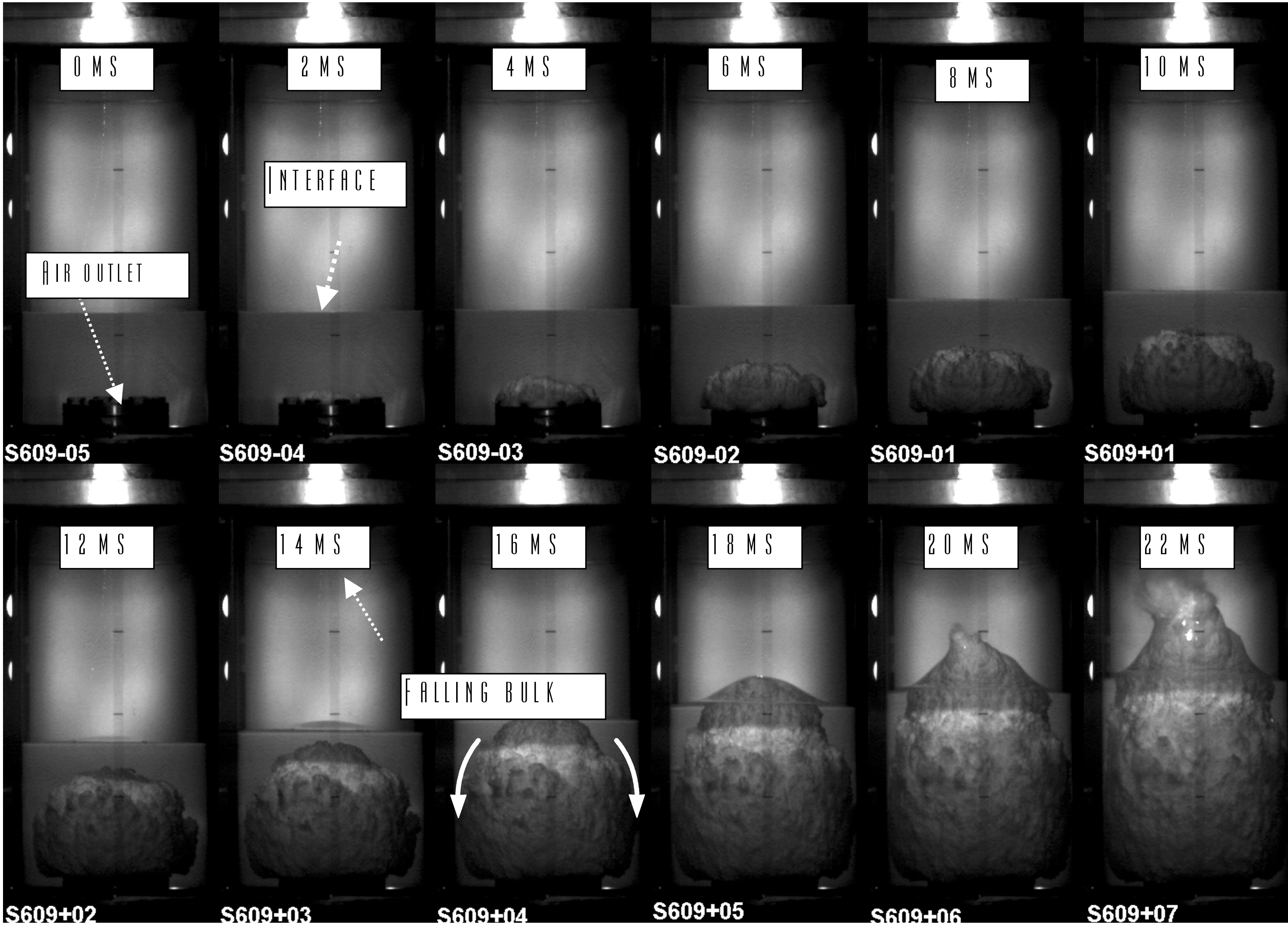
Following slides are used only
At Q & A time.

Expected quantity of molten debris at the experiment

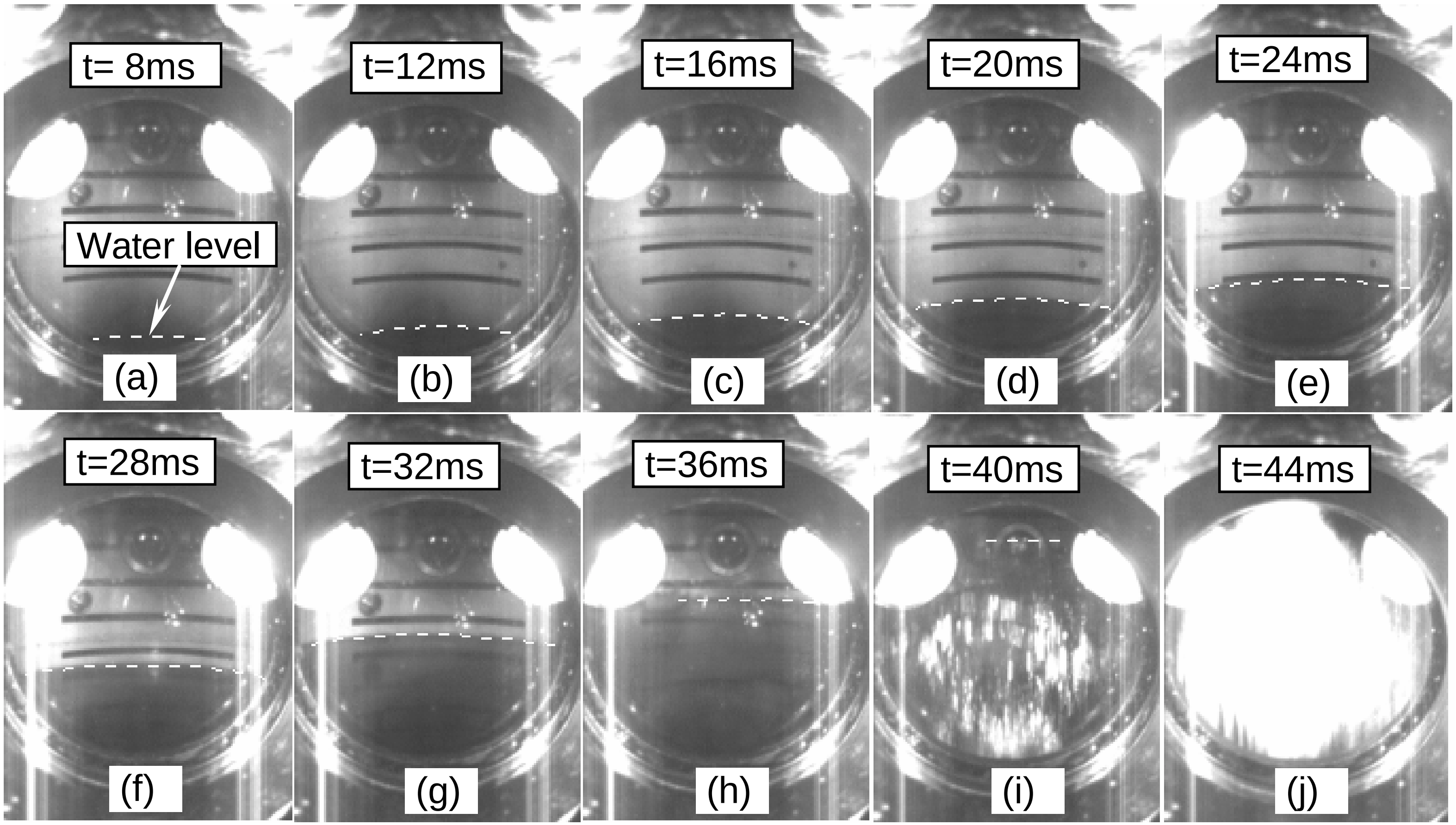
Type of apparatus			Large vessel	Small vessel
Volume of the air tank [m^3]			0.47	0.037
P_0 [MPa]	0.27	Mass [kg]	1.518E+00	1.195E-01
		Vol. [L]	3.035E-01	2.390E-02
	0.5	Mass [kg]	2.811E+00	2.213E-01
		Vol. [L]	5.621E-01	4.425E-02
	1	Mass [kg]	5.621E+00	4.425E-01
		Vol. [L]	1.124E+00	8.850E-02
	2	Mass [kg]	1.124E+01	8.850E-01
		Vol. [L]	2.248E+00	1.770E-01

∗In ideal steam explosion, 0.62 kg steam is generated by 1kg grained debris of 2842K, under atmospheric pressure surrounding.

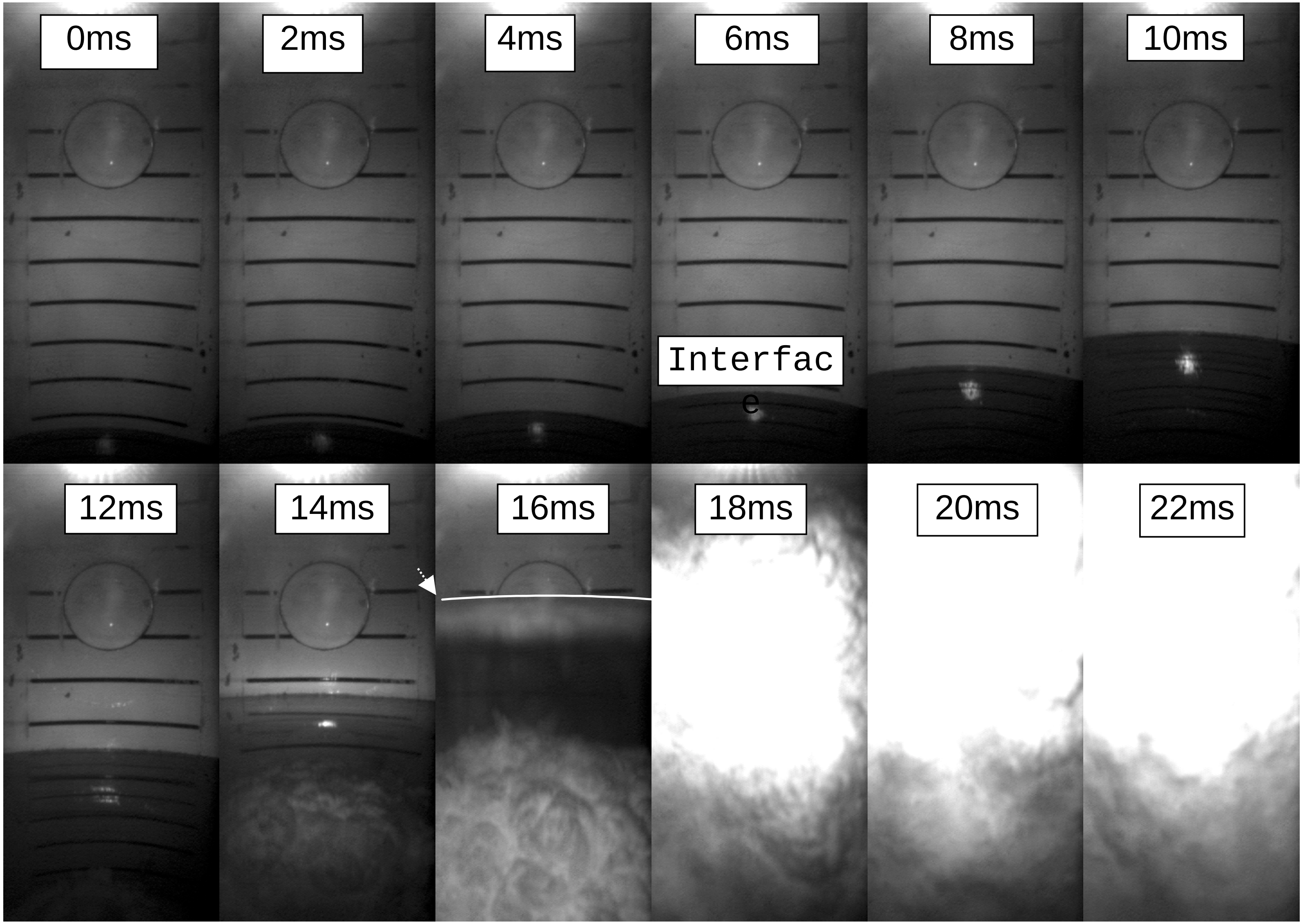
∗Weight ratio of the debris is assumed as 5.0.



Growing bubble （visualization）；P_0=0.5MPa, H_0*=0.8

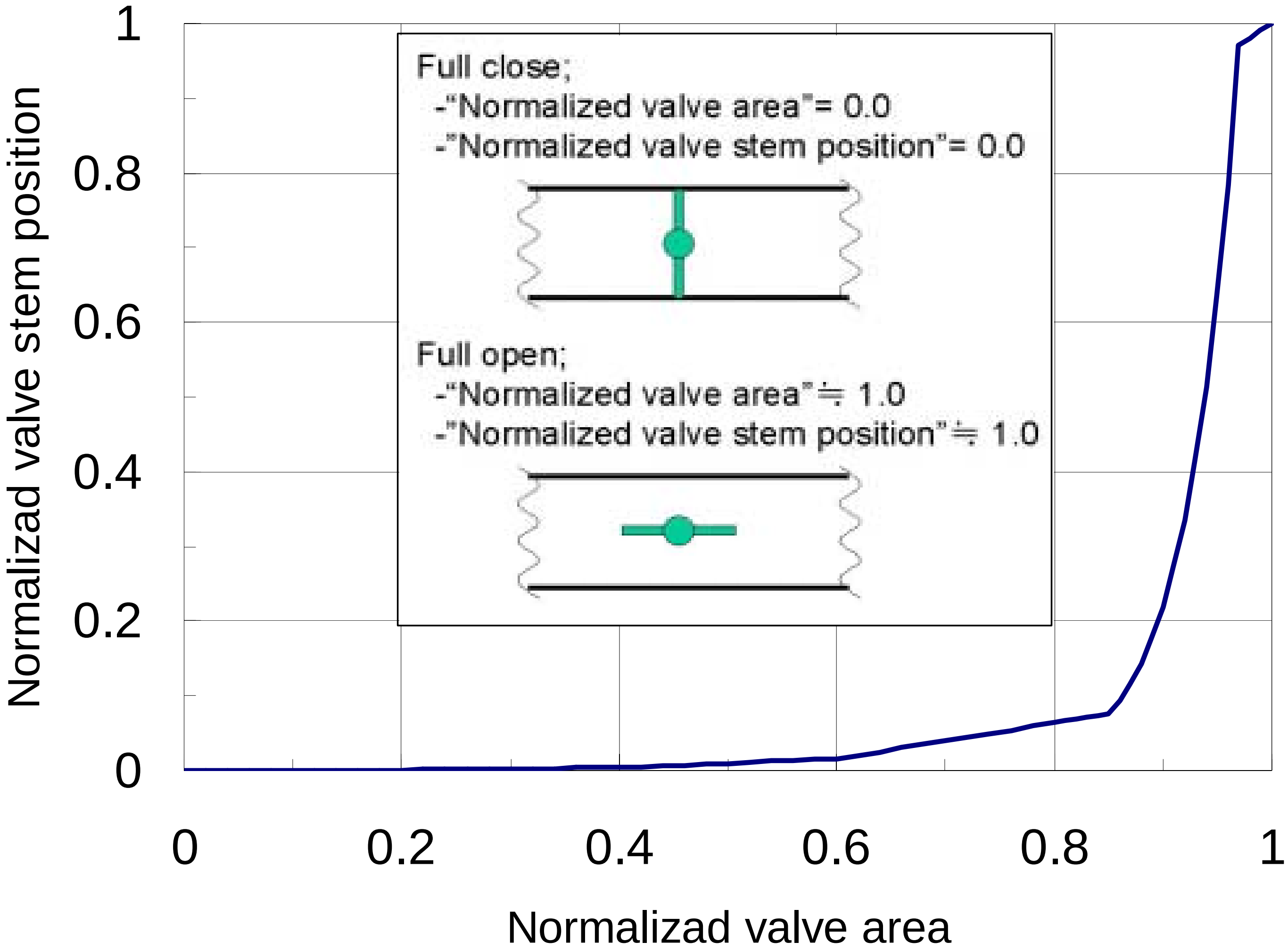


Rising water bulk (Large vessel、P_0=2.0 MPa、H_0^*=1.2)



Rising water bulk (Small vessel、P_0=2.0MPa、H_0^*=1.2)

Valve property table



Opening rate

- 100 [1/sec]

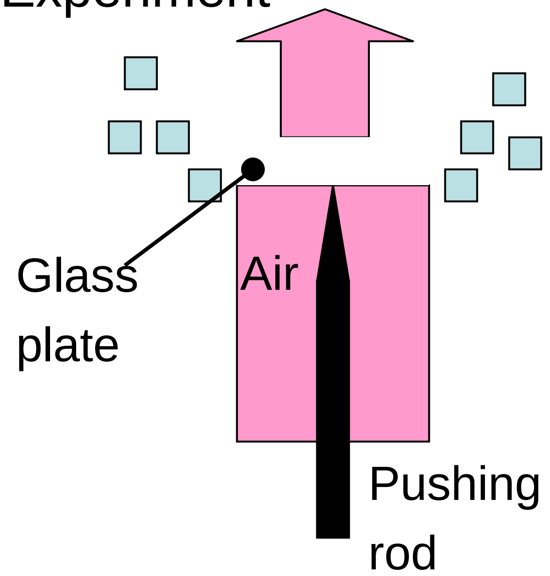
in P_0 = 2.0 MPa

1.0 MPa

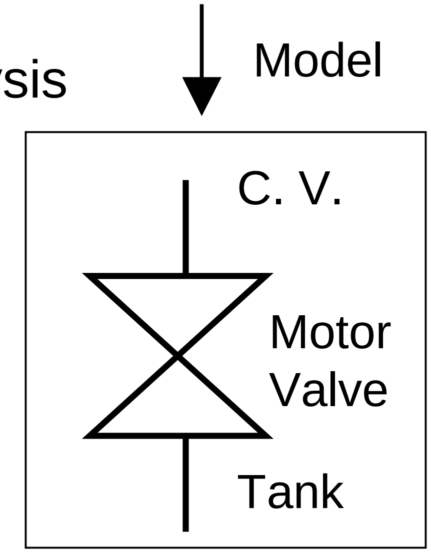
- 50 [1/sec]

in P_0 = 0.5 MPa

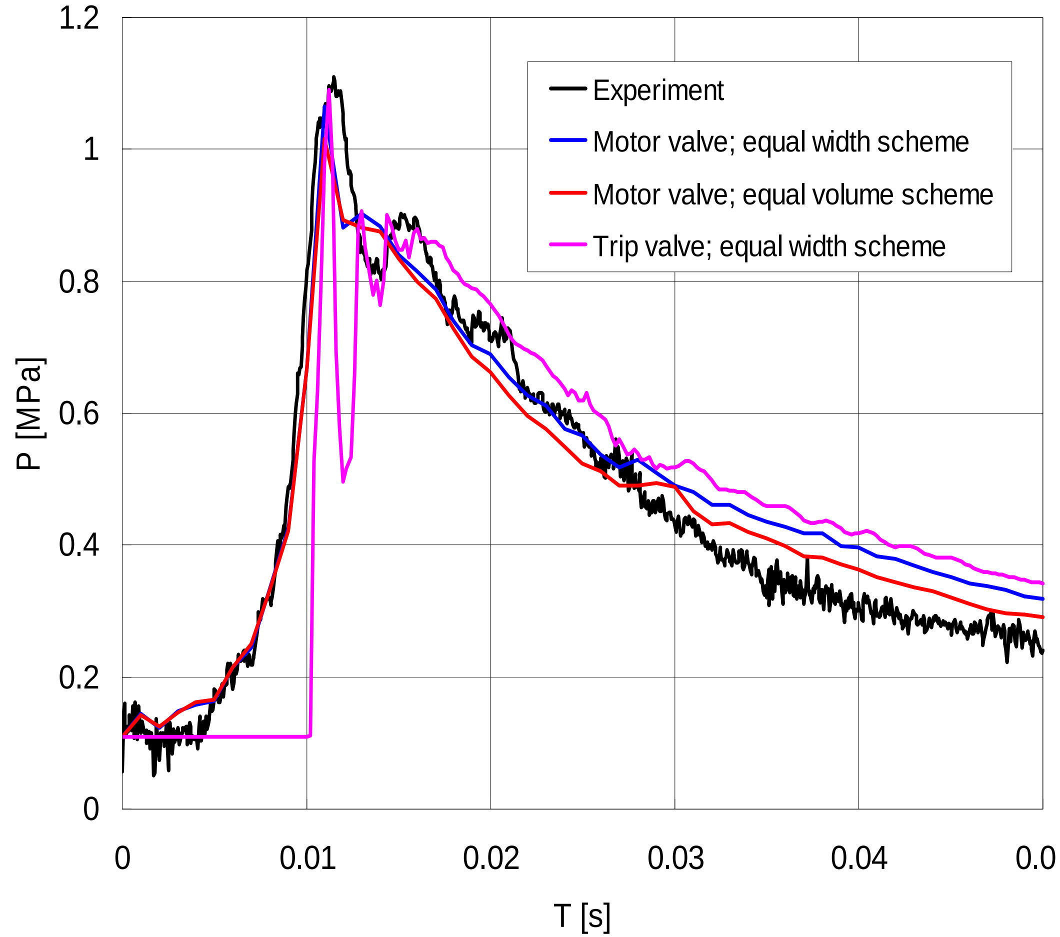
Experiment



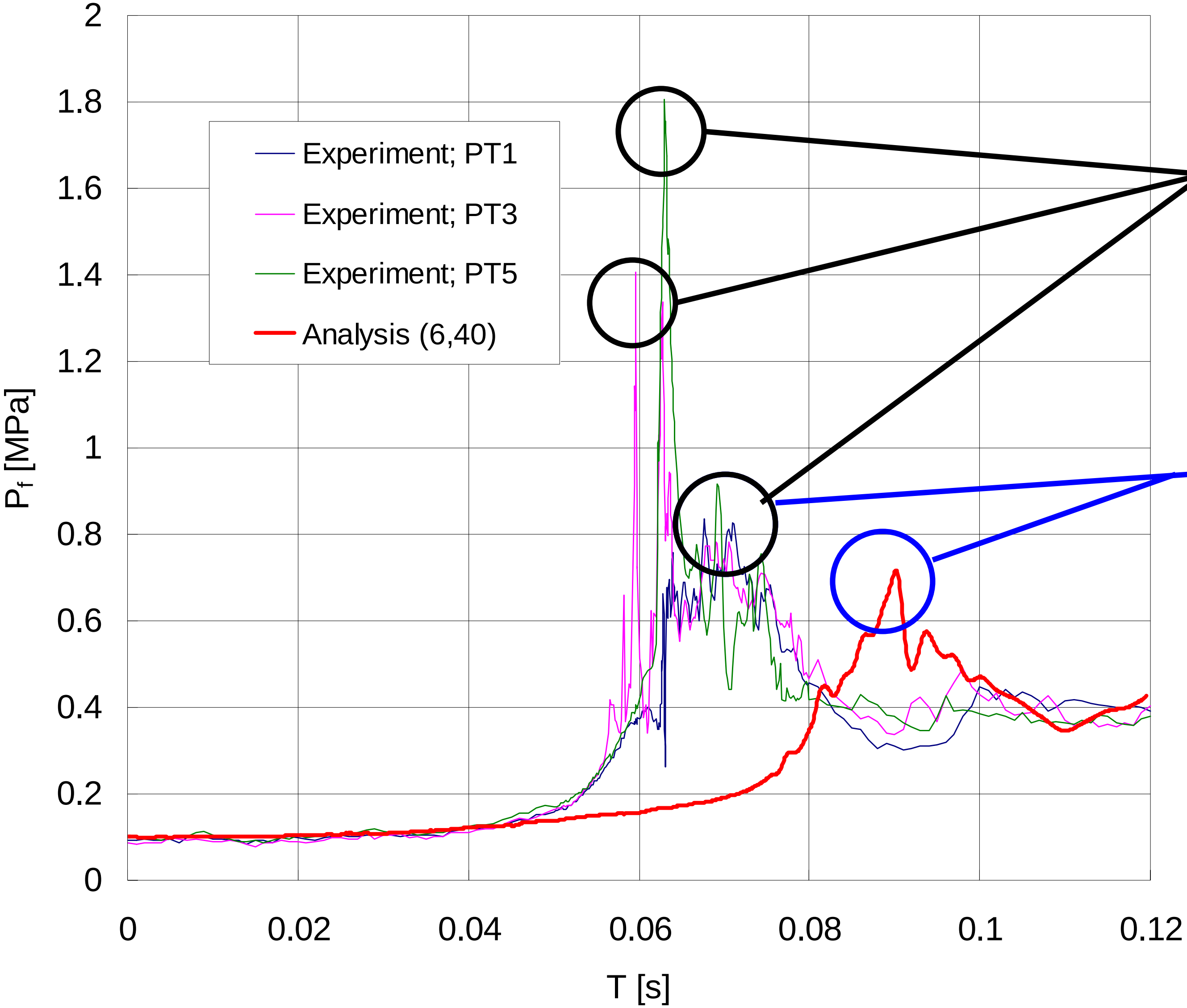
Analysis



Emulating opening process at air outlet



Pressure on bottom sidewall of C. V.
(P_0=2.0MPa, H_0=1.0m)



W.H pressure due to water bulk impact

- Velocity
- Damping of sonic speed in mixed fluid

Time lag

Velocity of the bulk is lower then in the experiment.

Position of the “air penetration” is lower than in the exp.?

Figure 8 Pressure under the orifice plate; P_0=2.0MPa, H_0=1.0m (inner side)