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Blast wave attenuation by absorbing materials, water sprays and mist systems

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Pro-Science

Clean Hydrogen Partnership

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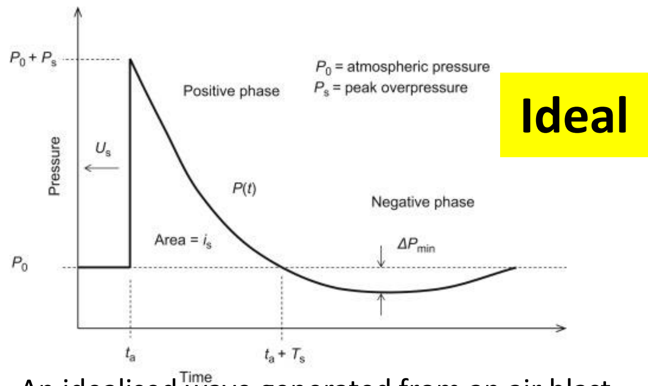
Introduction



An idealised wave generated from an air blast.

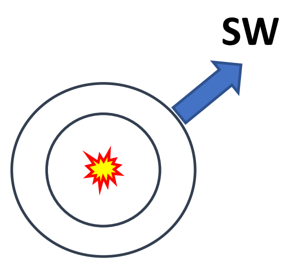
P.J. Hazell, in [Dynamic Deformation, Damage and Fracture in Composite Materials and Structures](), 2016

Energy loss of SW due to interaction with fire __extinguisher water spray__

- Momentum absorption of droplets
- Reflection of shockwaves on droplets
- Heat absorption of the droplets

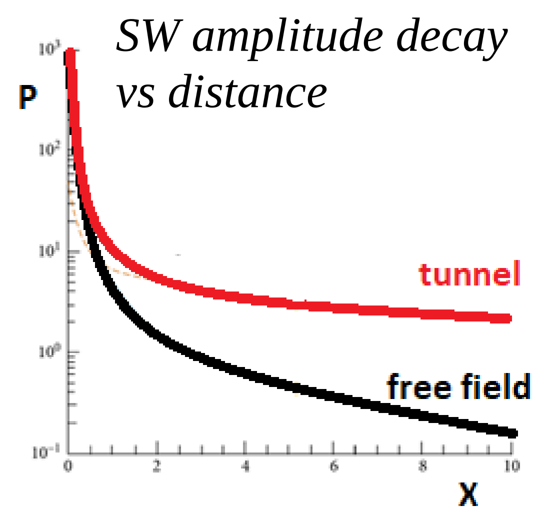
Energy loss of SW due to __reflection on absorbing material__

- Material deformation
- SW-diffusion due to reflection



Free field: SW amplitude decay mainly due to spherical 3D expansion.

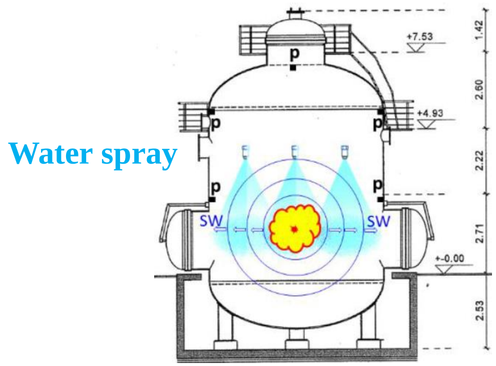
Tunnel geometries: SW amplitude decay mainly due to energy loss on the wall.



Introduction

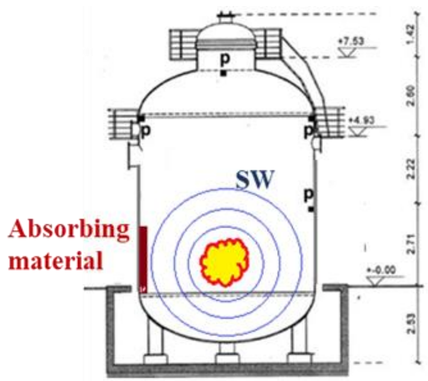
Objectives

- The scope of this work is to study the efficiency of **water spray/mist of different volumetric density** and different **absorbing materials** with different thickness to attenuate the strength of a blast or shock wave generated by an explosion.
- The tests are designed by **KIT and PS** and performed inside the HYKA A2 vessel of 220 m^3 volume (6 m diameter, 9 m height).
- **Shock wave source: H_2-combustion unit**



Water spray:

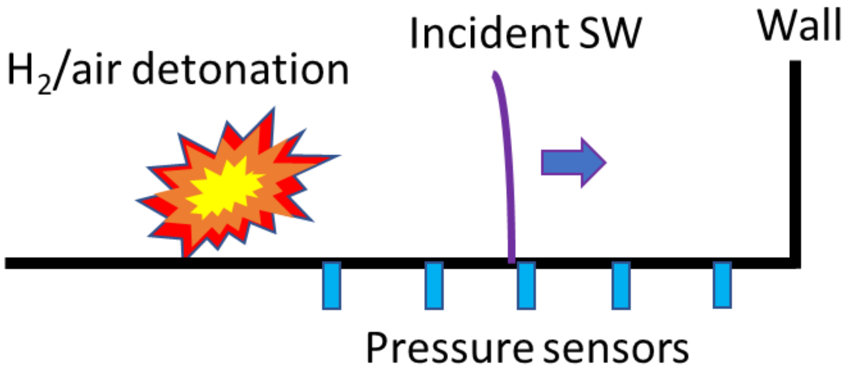
Water mass flow rate, kg/min	0	low	high
Spray	4	0	2
Mist		2	2

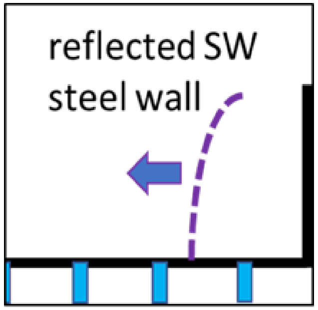


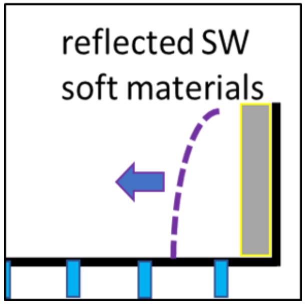
Absorbing materials:

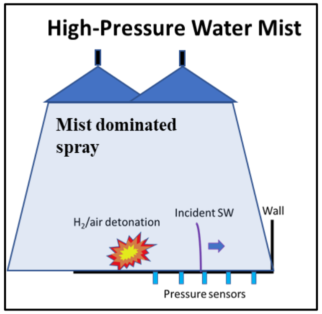
Absorbing material	Polystyrene	Foam polyurethane	Acoustic glass wool	Others
Thickness, 20 mm	X	X		Steel XXX
Thickness, 120 mm	X	X	X	Acoustic foam Thickness,50 mm X
Thickness, 200 mm	X	XX	X	

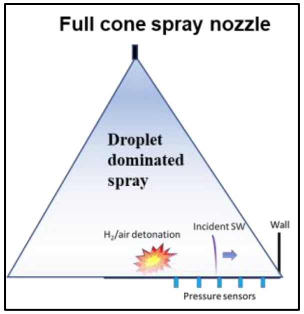
Test schematic











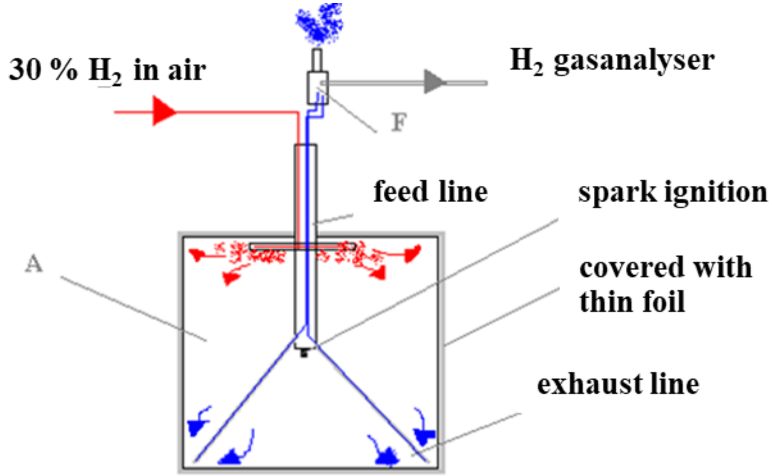
- **H_2/air detonation is used as SW source.**
- **Incident SW history and the reflected SW history are measured with a traverse of pressure sensors.**
- **The difference of the reflected SW from the steel vessel wall to the reflected SW from absorbing (soft) materials is used to quantify the shock wave attenuation effect of the absorbing materials.**
- **The shock wave attenuation due to water spray is quantified by the comparison of shock wave histories with and without spray.**

Shock wave source

Combustion unit

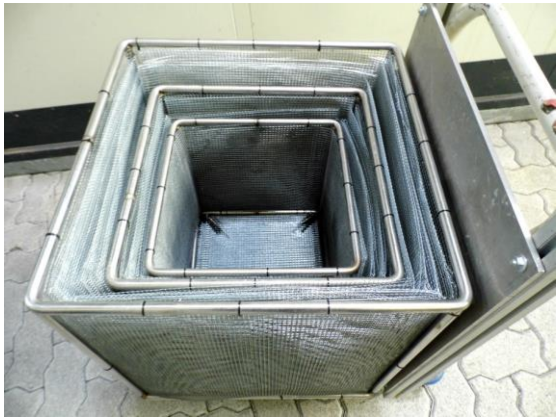
-The hydrogen combustion units are designed for the strongest possible (unconfined) combustion with low H_2 amount (½ g H_2up to 16 g H_2)

Used model = 4 g H_2



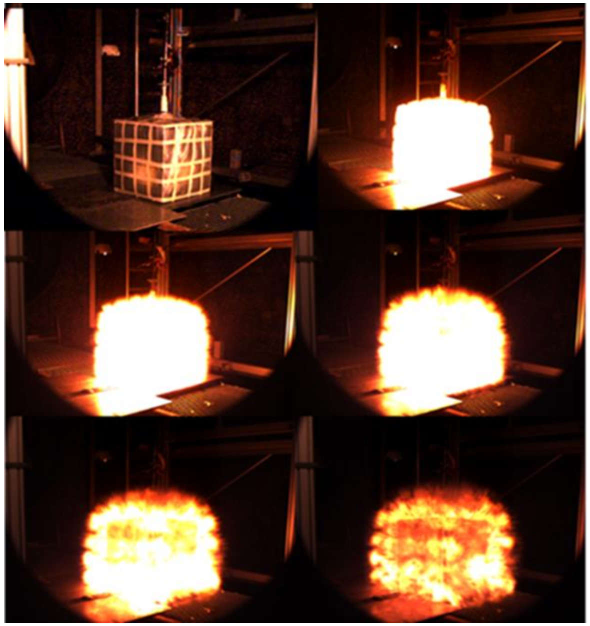
Cube size: (30% H_2 in air) = face length of 0.55 m

Obstacles were grids (6.5 x 0.65 mm; 48 layers)



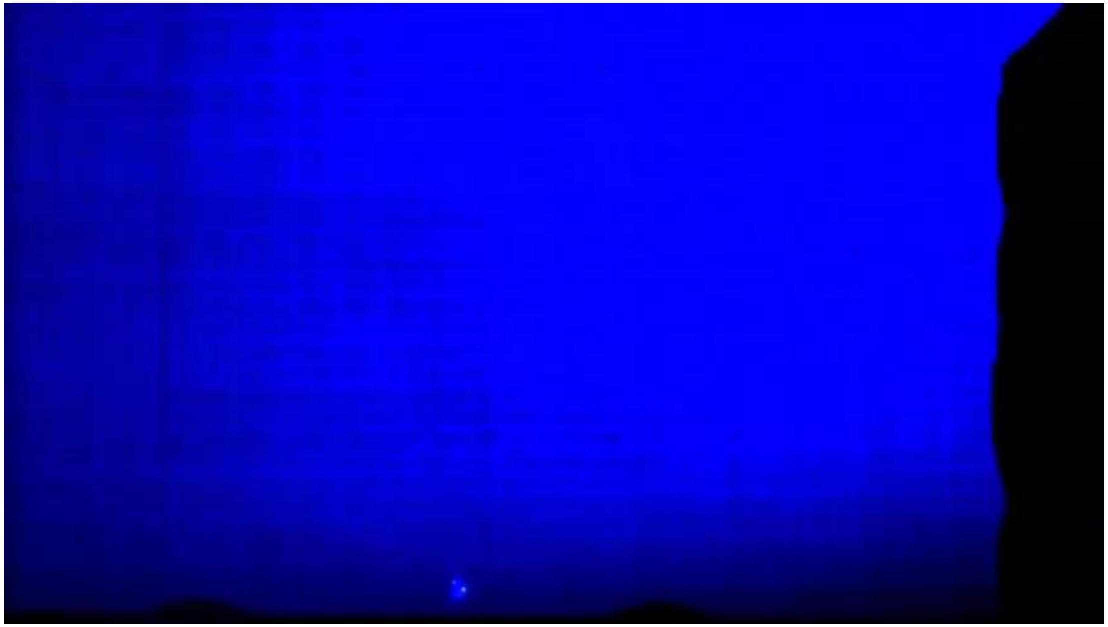
Experimental setup

4 g H_2 -detonation (5000 f/s)



Shape of the shock wave: 40000 f/s

Combustion unit



P02 **P01**

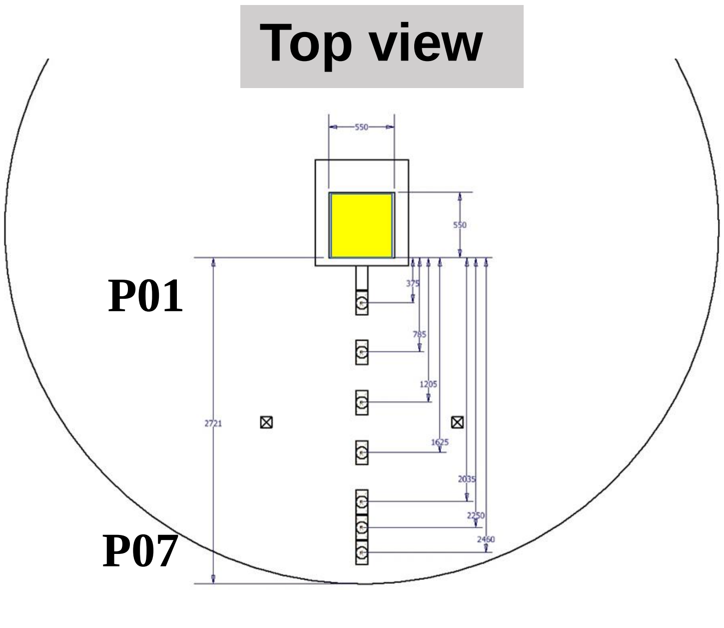
~ 1 m

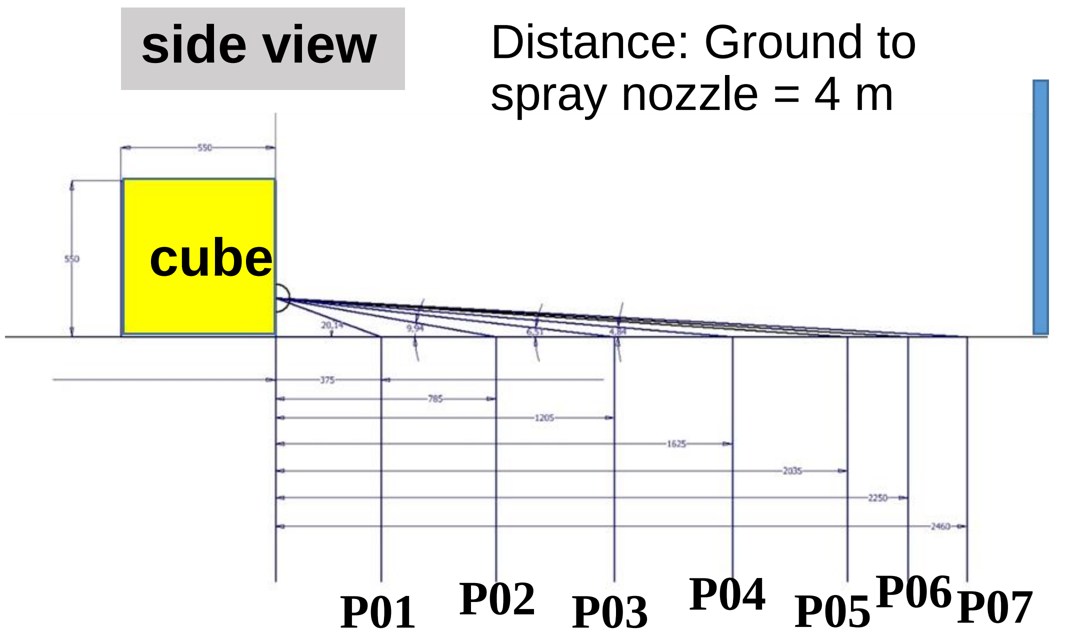
Experimental setup

Traverse of 7 pressure sensors (P01 to P07)

Data sample rate 1 µs.

Sensor	Typ / PCB	Nummer	bar
P01	113B21	21613	14
P02	112A22	25826	3,5
P03	113B28	21677	3,5
P04	112A22	25827	3,5
P05	113B28	21624	3,5
P06	113B28	21621	3,5
P07	112A22	25820	3,5





Sprinkler Systems

Mist-dominated

Pressure: 100 bar
Nozzle: Danfoss (SEM-SAFE®)
Type: HNMP-5-10-1.19-00
$H_2O_{(100\ bar)}$: 9 l/min (per nozzle head)
Droplet size: 10 – 50 µm (20 – 100 µm)

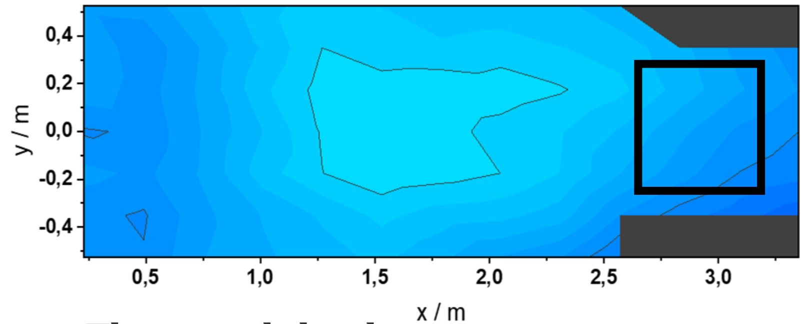
Two nozzle head:	**18 kg/min; 1-1.8 kg/min/m²**
Three nozzle head:	**27 kg/min; 1.5-3 kg/min/m²**

Droplet-dominated

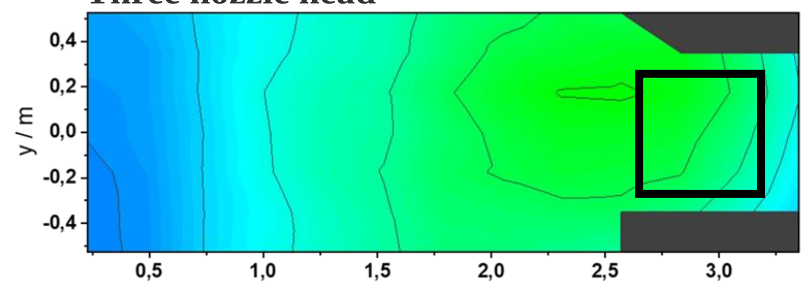
Stainless steel spiral full cone spray nozzle
Pressure: H_2O grid
Droplet size: large

40 kg/min ~4 kg/min/m²

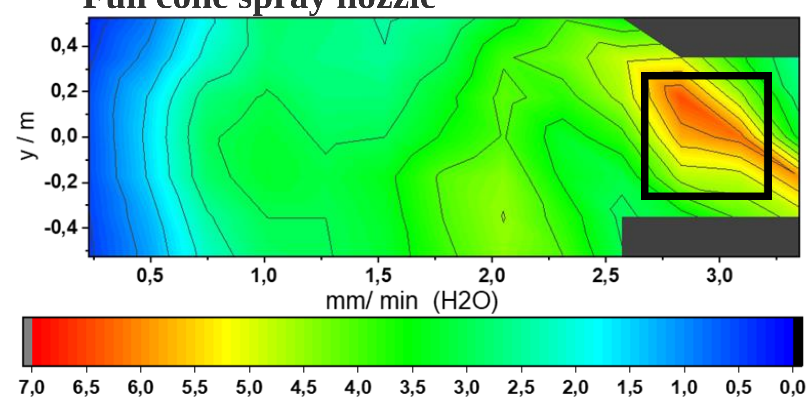
Two nozzle head



Three nozzle head



Full cone spray nozzle



Water charging on the ground

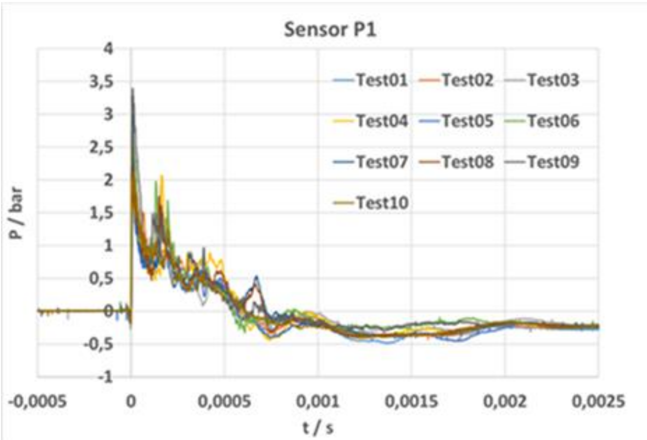
tunnel HP

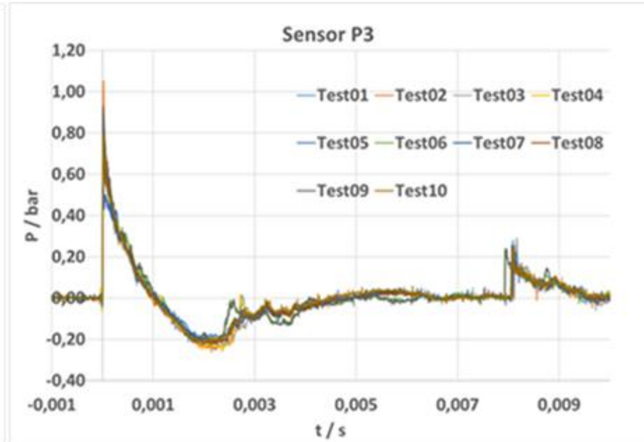
Sprinkler System “mist”: Three nozzle head

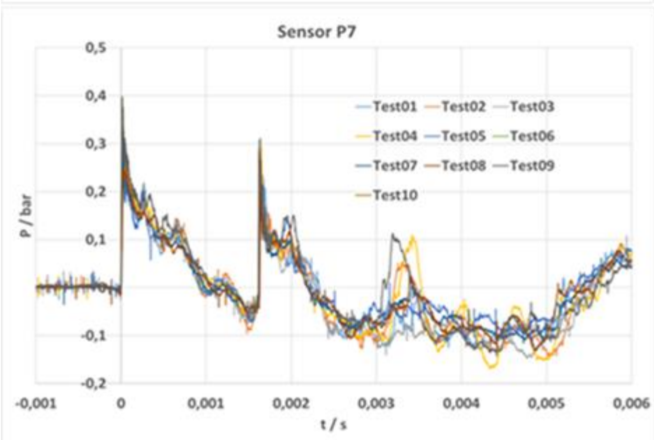
Sprinkler System “droplet”: Full cone spray nozzle

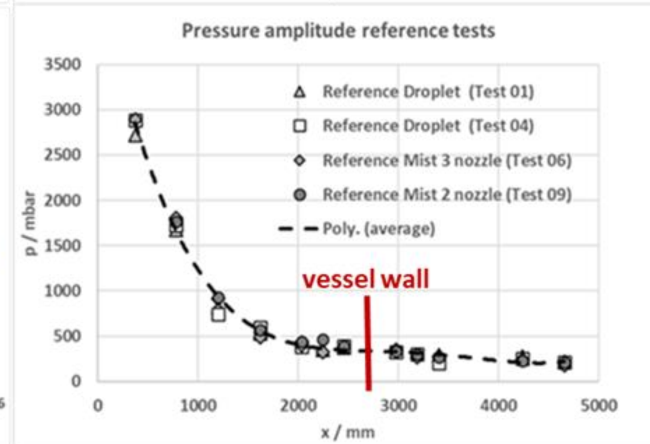
Test side

Pressure histories: *Water sprays and mist systems*









Test	
01	Reference no spray
02	droplet
03	droplet
04	Reference no spray
05	mist high
06	Reference no spray
07	mist high
08	mist low
09	Reference no spray
10	mist low

Shock wave amplitude and impulse+ of reference test are normalized to one.

Shock wave attenuation by water spray

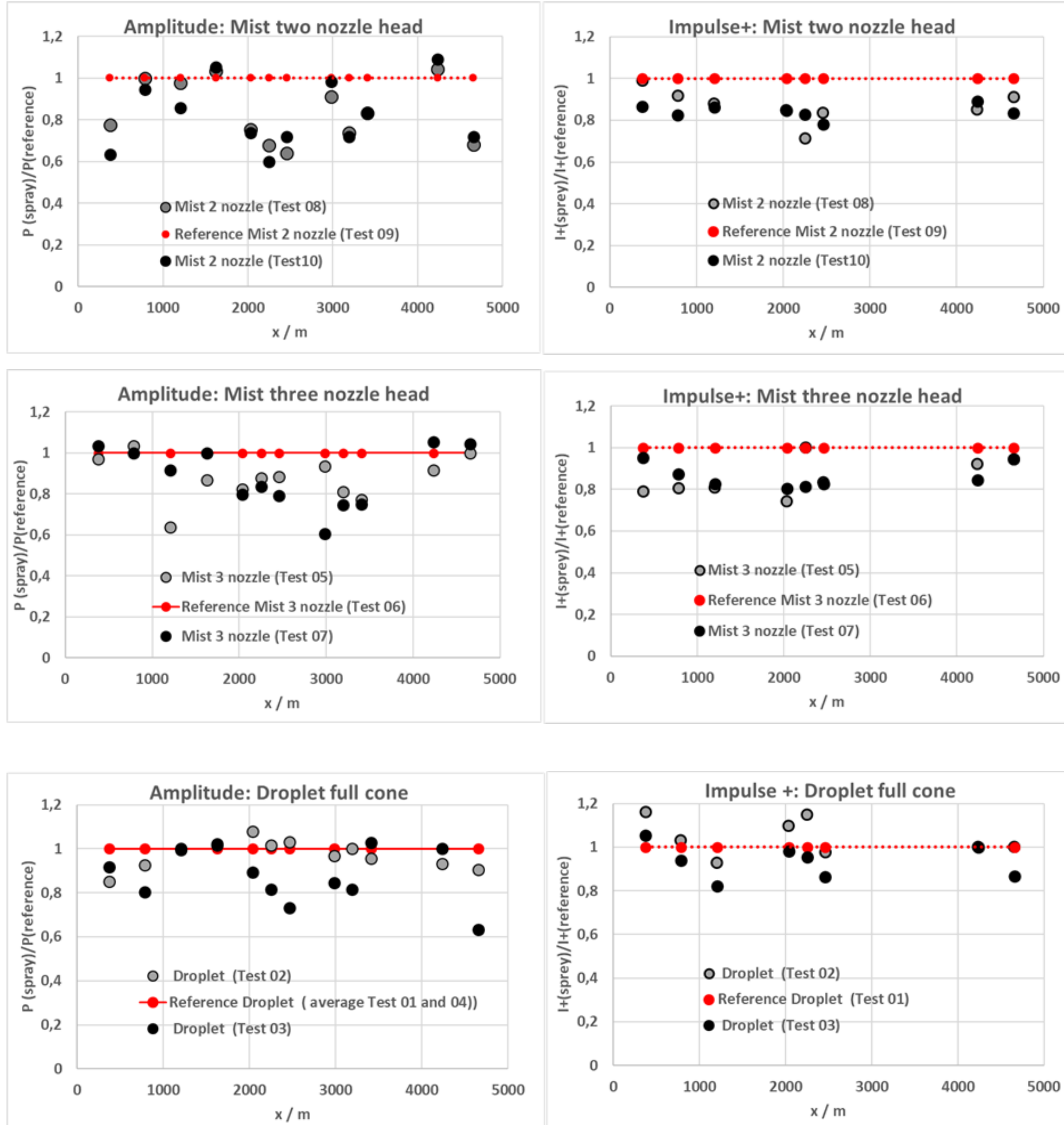
The attenuation is quantified by the comparison of shock wave amplitude and impulse+ with and without spray.

Shock wave amplitude

Droplet spray = 10 ~ 15 %
Mist spray = 10 ~ 30 %

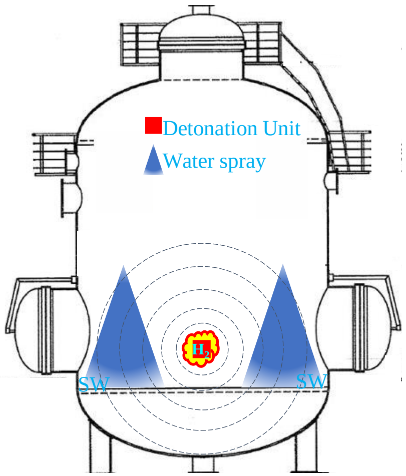
Shock wave impulse+

Droplet spray = slight effect
Mist water spray = 10 ~ 20 %

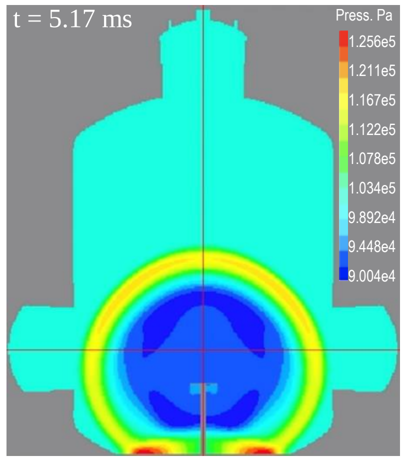


Simulation of shockwave attenuation by water spray/ mist

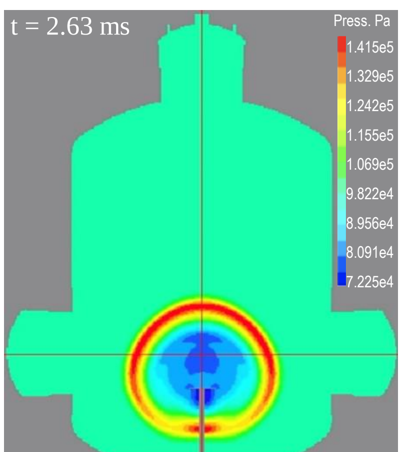
- Geometry model – HYKA A2 vessel
- Droplet breakup model in COM3D simulates interaction between shock front and droplets
- Discrete Lagrangian particle model simulates the liquid particle dynamics
- Simulation result: overpressures are deducted by 15 – 20 % due to water presence

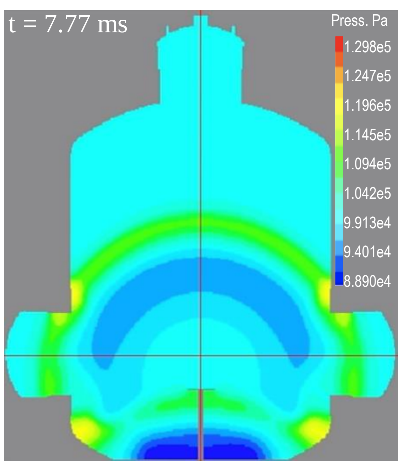


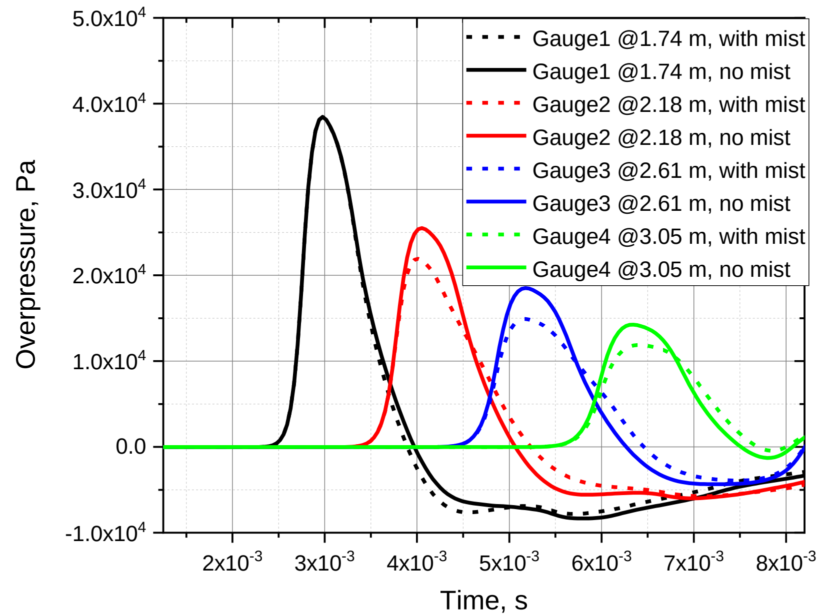
(a) Geometry



(b) CFD model



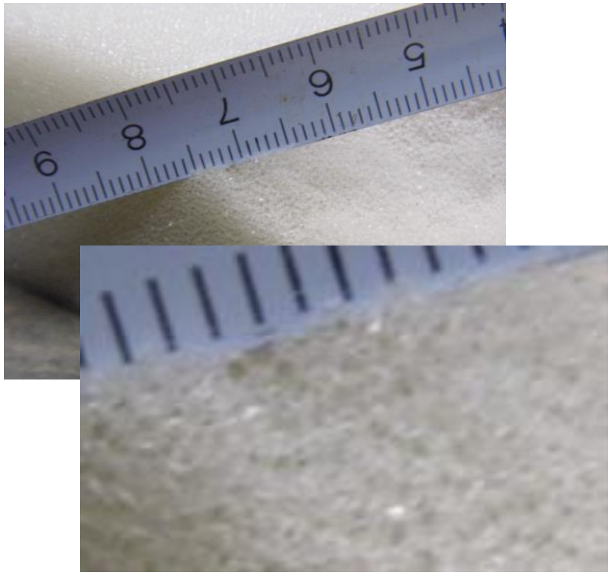




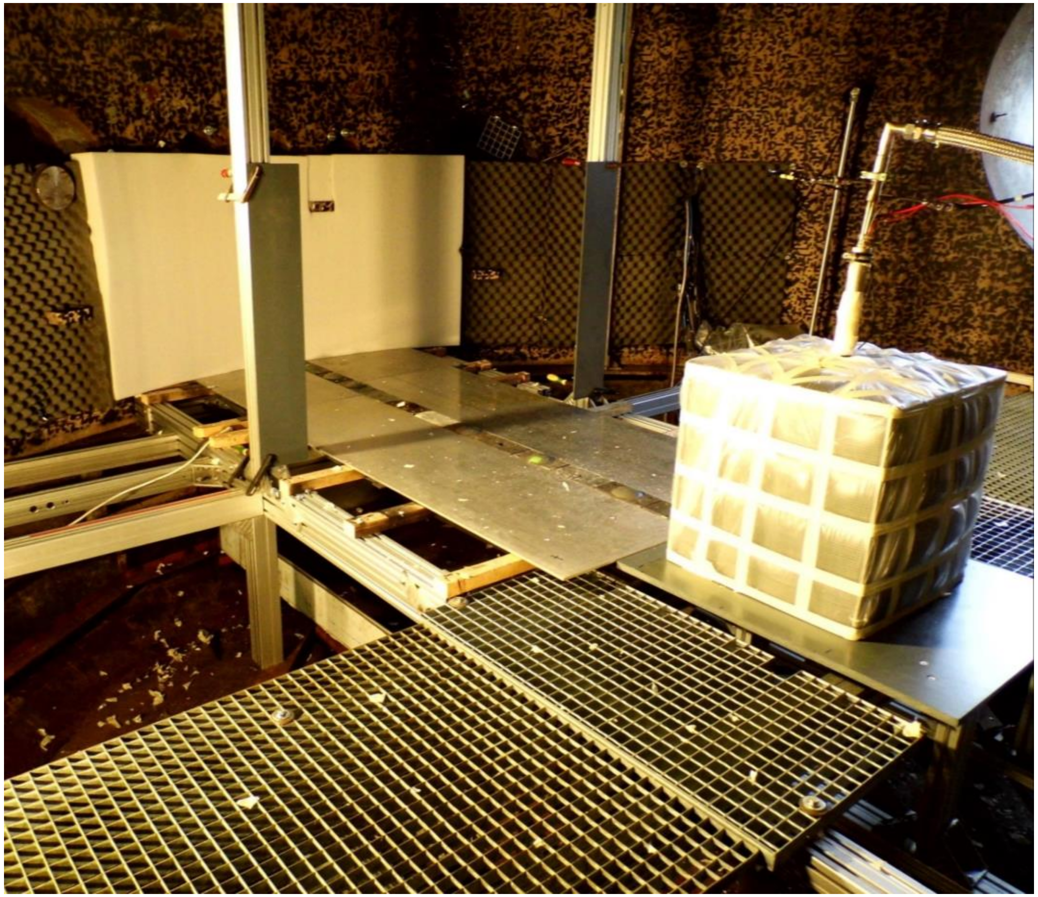
(c) Simulation result

Absorbing material

Foam polyurethane (soft foam):



Density: 25 kg/m³
Open surface structure
Bubble size: ~1/3 mm
Compression hardness: 4 kPa
(40 % deformation)



Reflection by **polyurethane plate** (2 m x 1 m x 0. 12 m)

Absorbing material

Absorbing materials (2 m x 1 m) is fixed on the wall of the safety vessel.

Expanded polystyrene

Closed surface structure

Resistance to pressure: 100 kPa (10 % deformation)

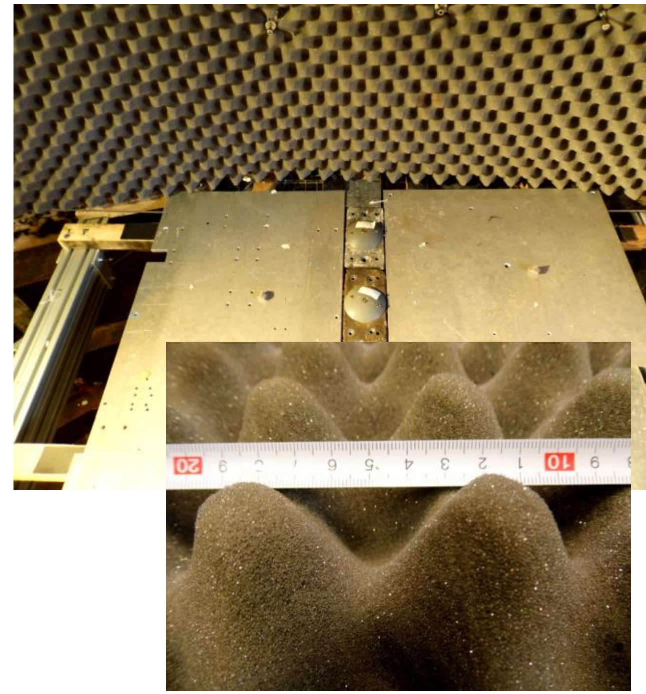
Glass wool

Density: 12.8 kg/m³

Open surface structure

(acoustic glass wool)

Acoustic structured foam 50 mm



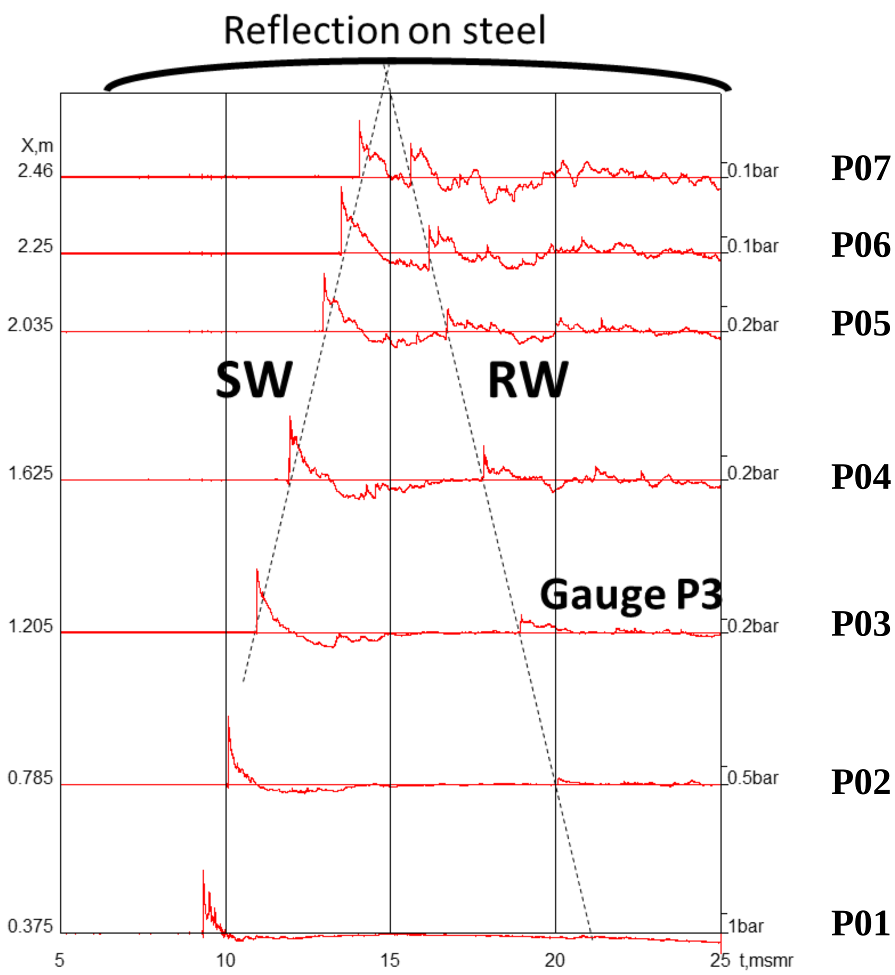
Design: acoustic wave attenuation

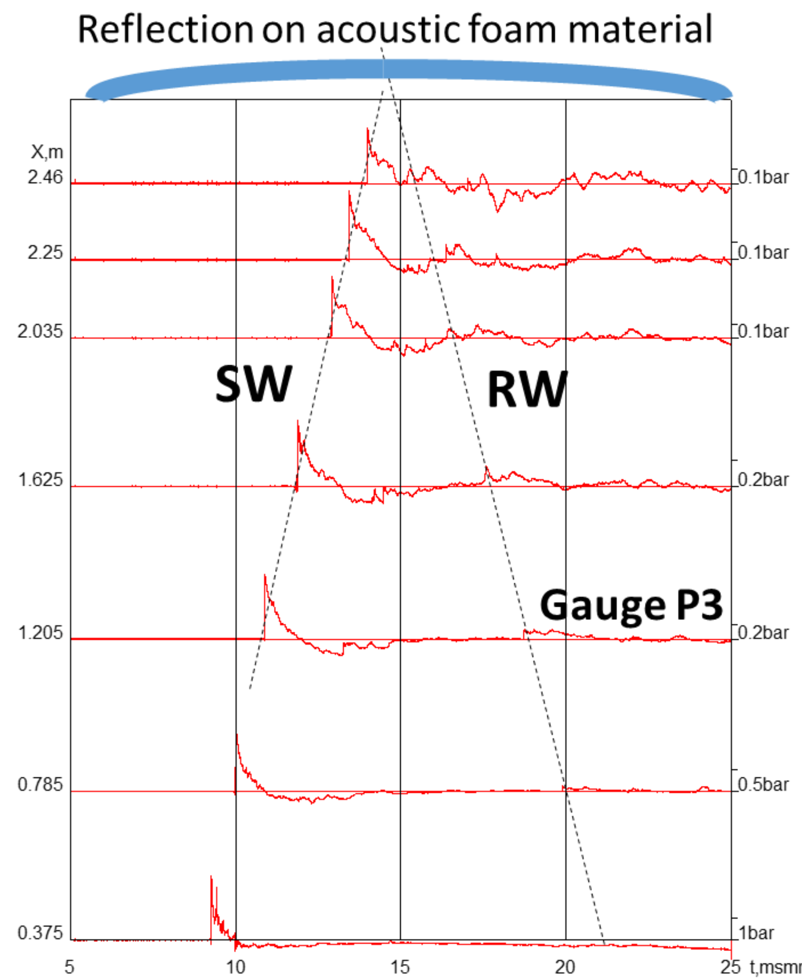
Density: 28 kg/m³

Open surface structure

Compression hardness: 4 kPa (40 % deformation)

Shock wave propagation

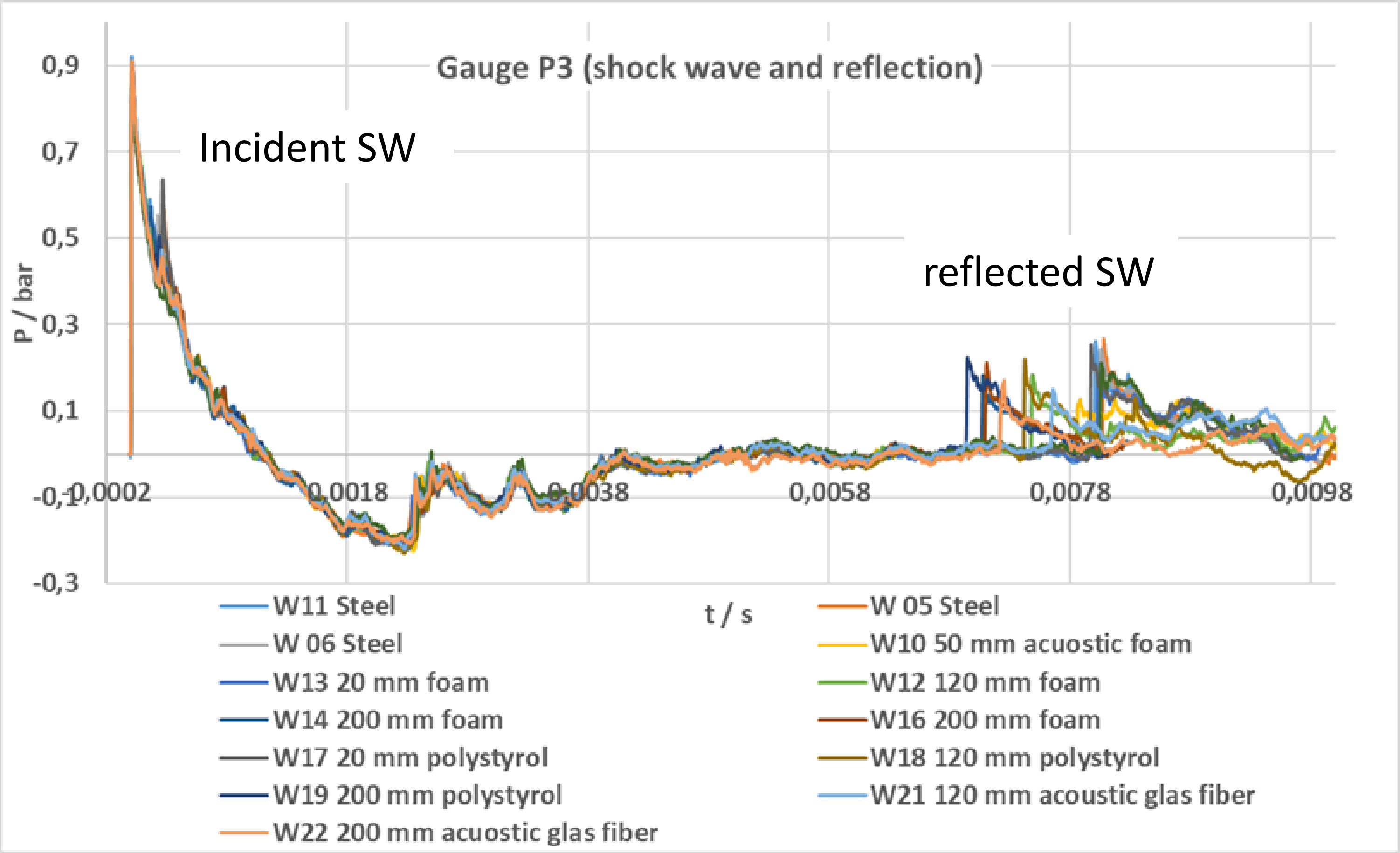




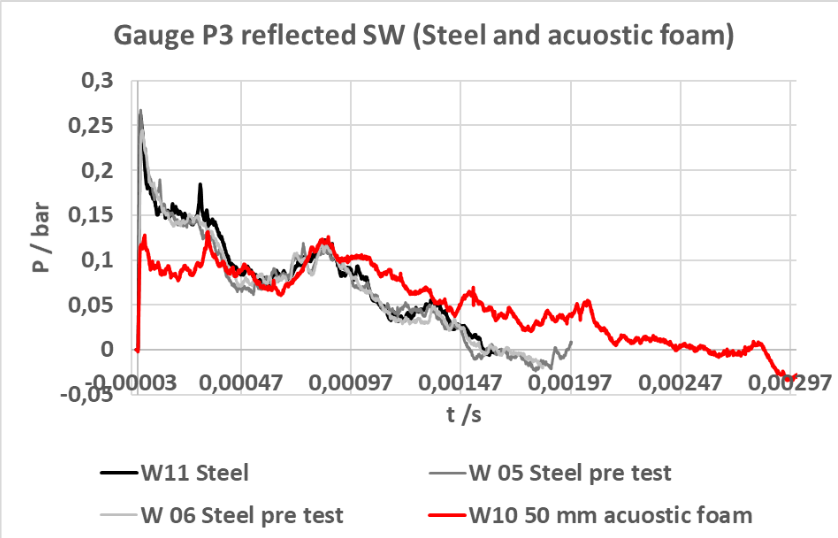
Pressure history gauge P3

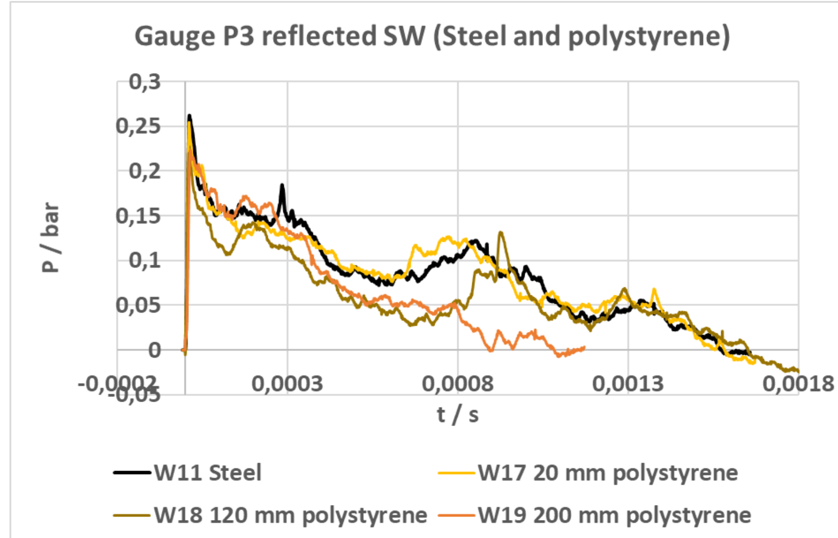
Combustion unit produces an highly reproducible SW.

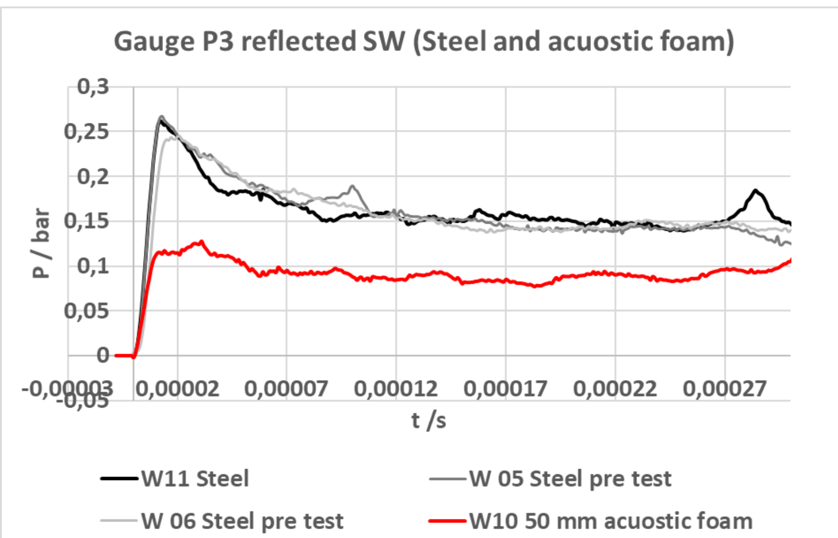
Due to the different thickness of the tested absorbed material, the arrival time of the reflected SW differs.

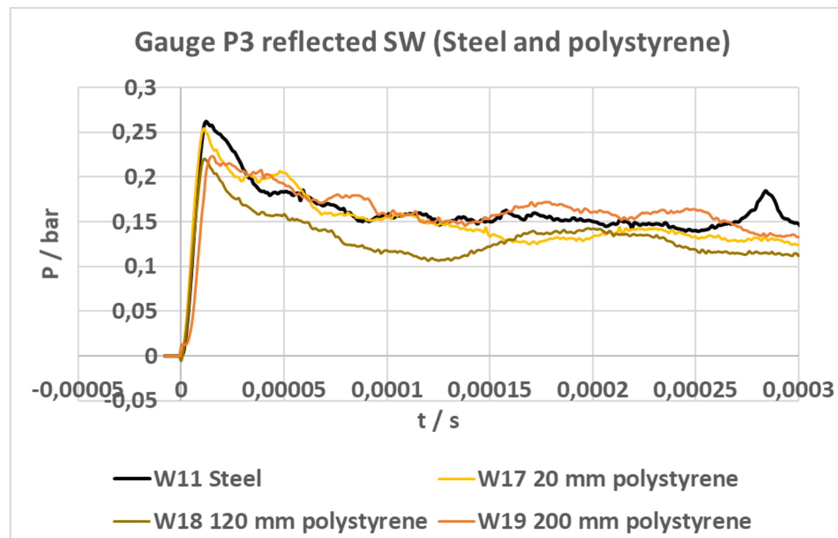


Reflected pressure history gauge P3: steel vs. soft material

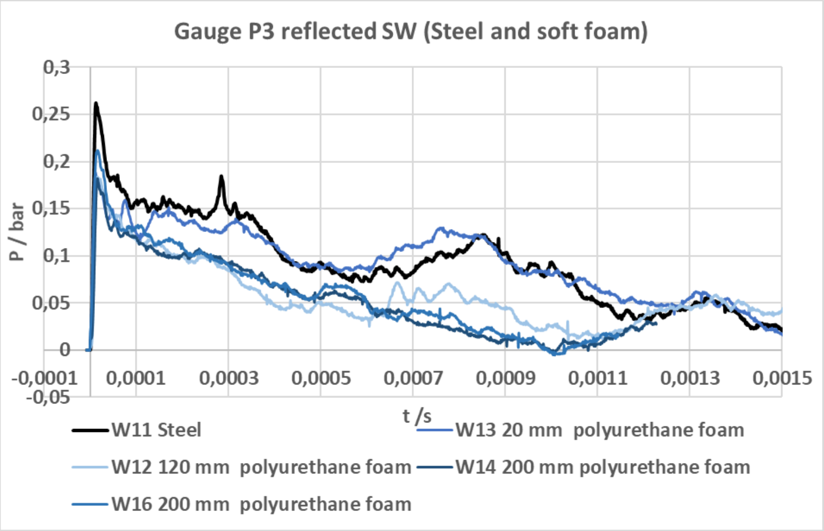


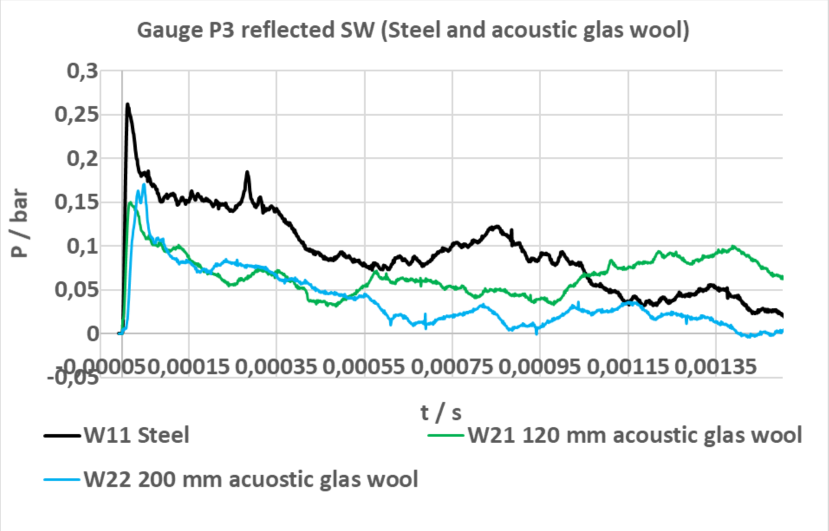


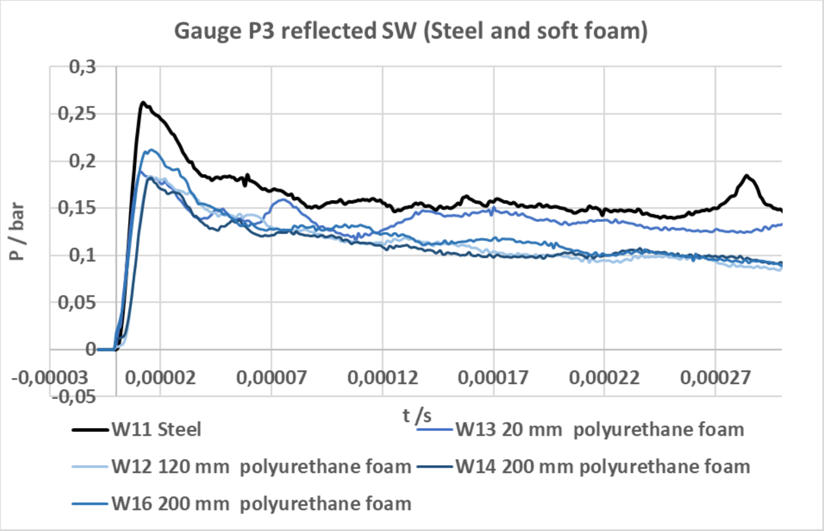


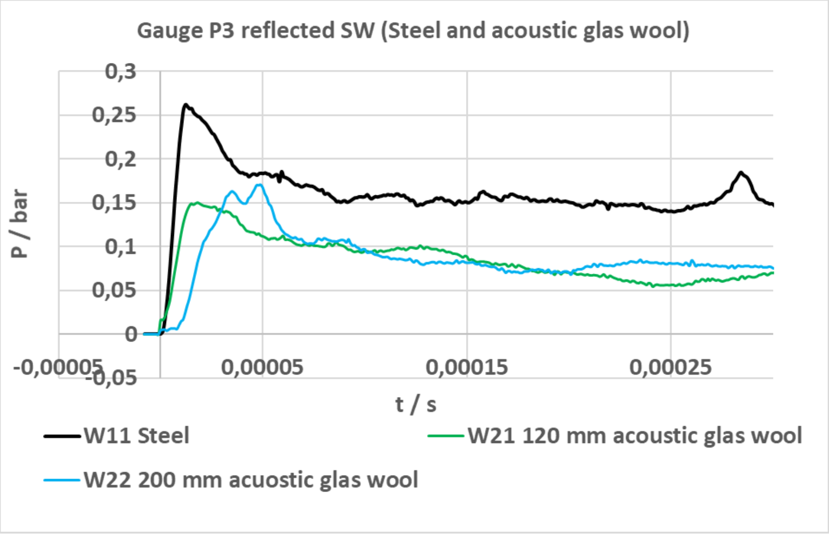


Reflected pressure history gauge P3: steel vs. soft material

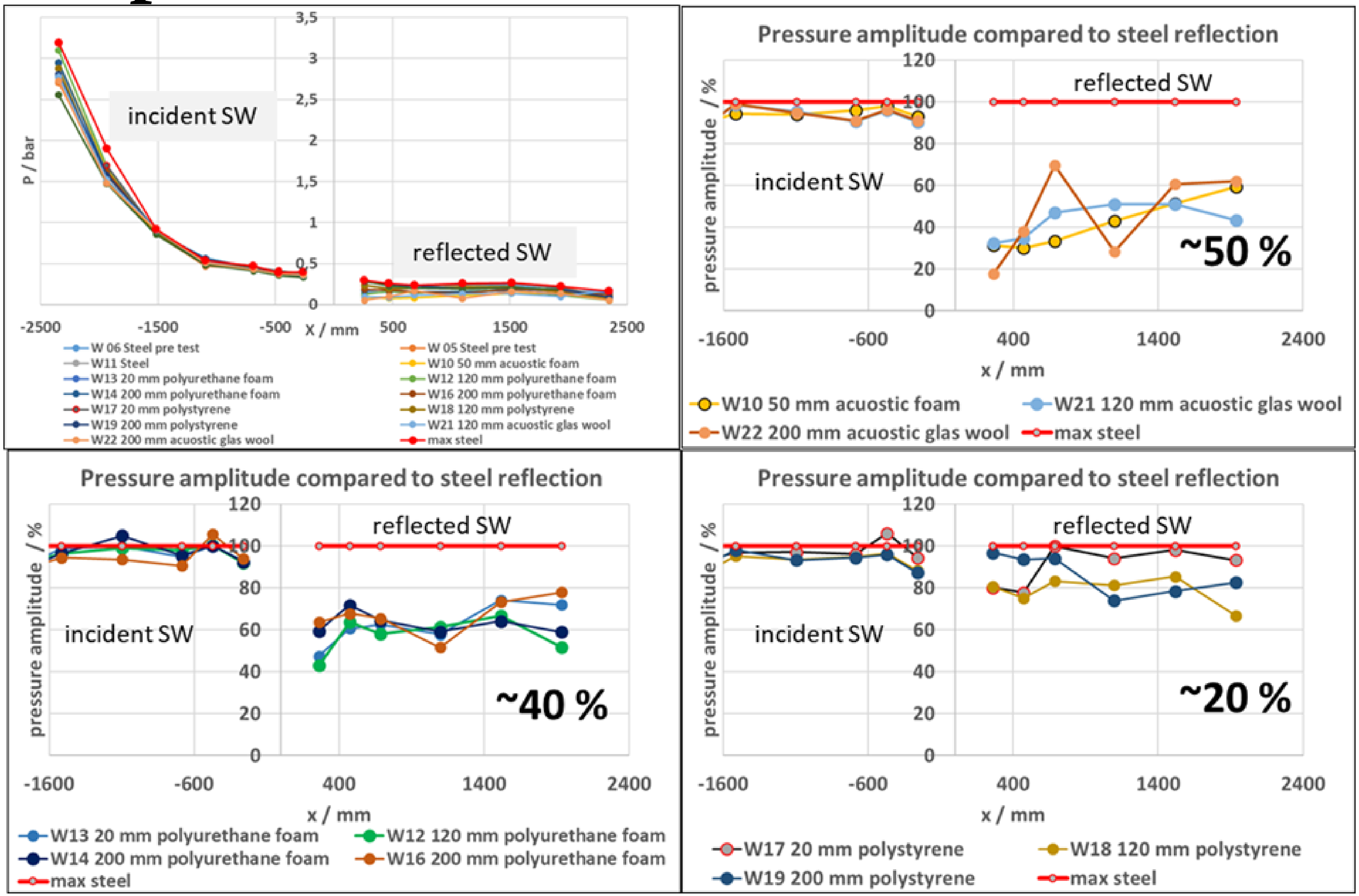








Amplitude attenuation



No clear influence of foam thickness on shock wave amplitude is observed.

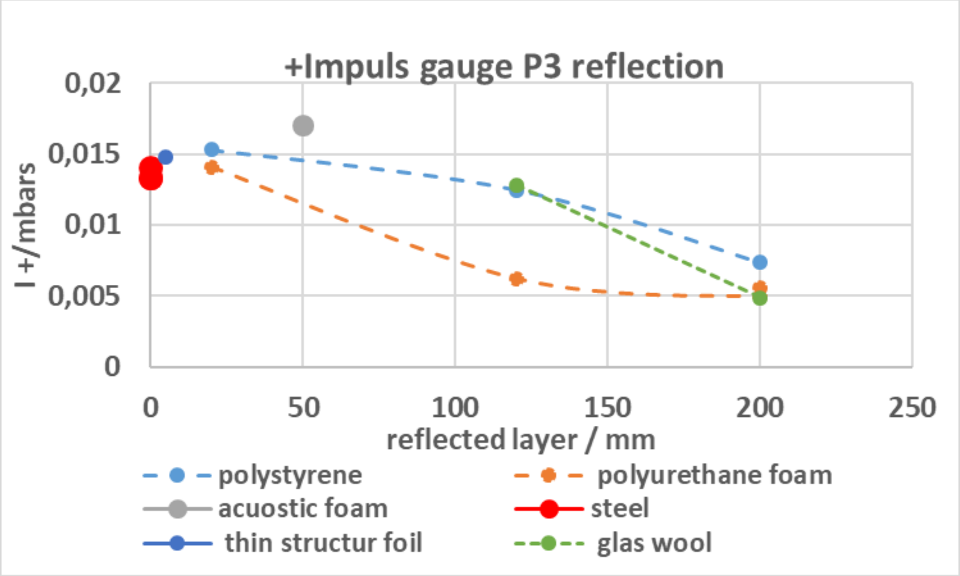
Positive impulse attenuation

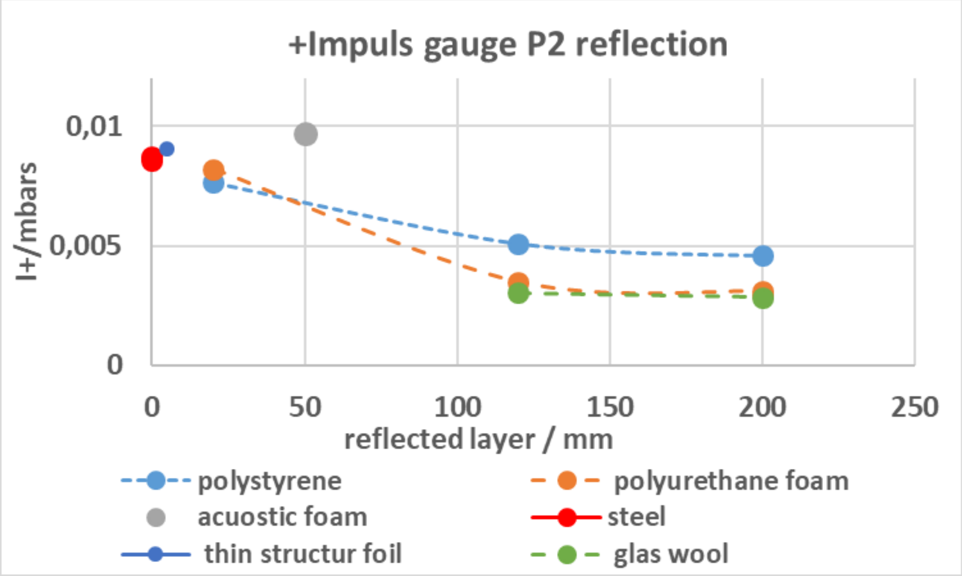
A proper evaluation of the positive impulse of the reflected shock wave is possible only for pressure gauge P2 and P3.

- **A clear trend of an influence of the thickness of the absorbing material on impulse+ is observed.**

- With increasing thickness of the absorbing material, the impulse+ attenuation due to reflection increases.

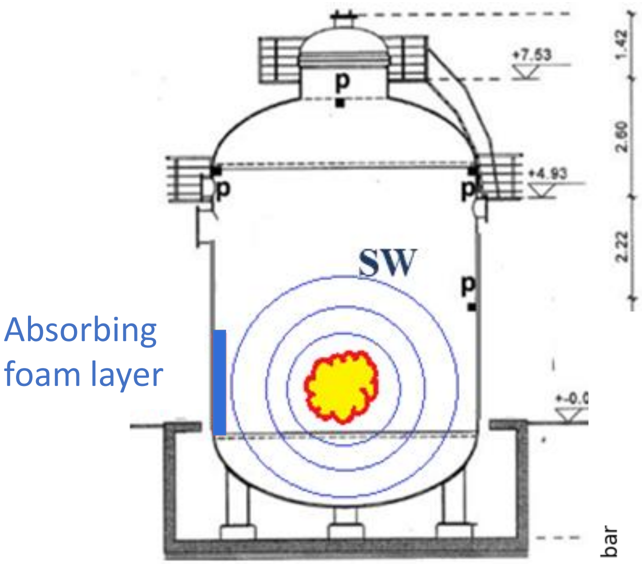
- Exception is the acoustic polyurethane foam, the reflected positive SW impulse is higher than that from the steel wall.



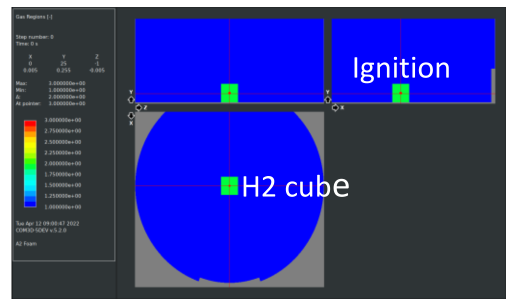


Simulation of shockwave attenuation by soft foam layer

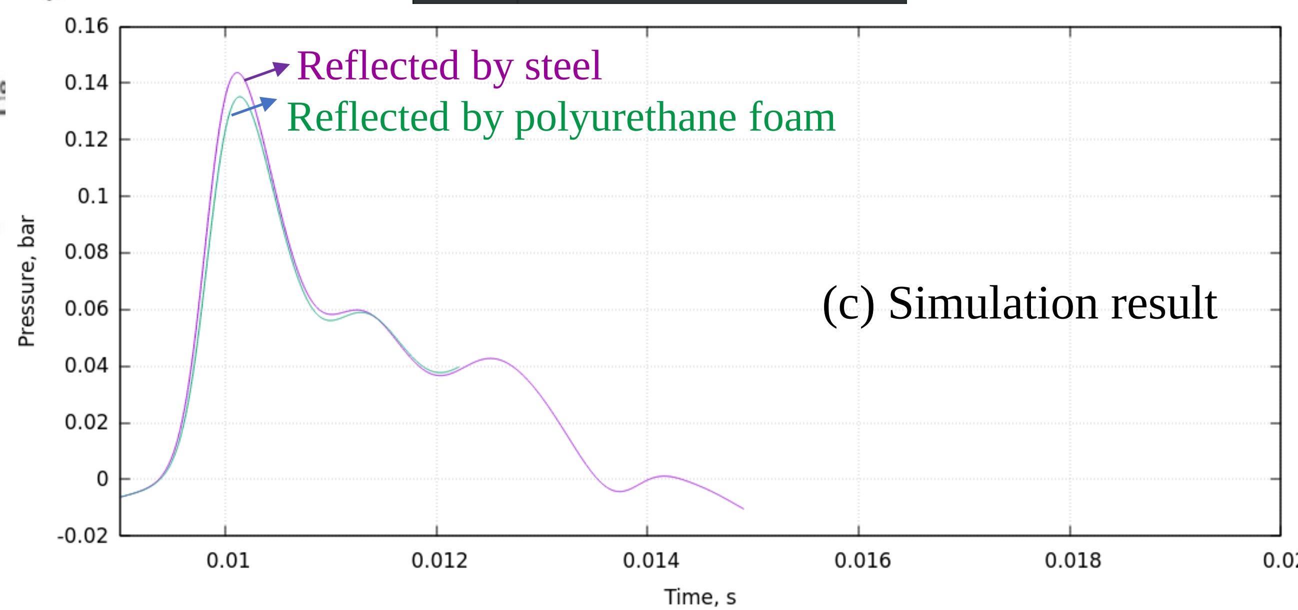
- Geometry model – HYKA A2 vessel
- Coupled COM3D-ABAQUS codes
- On the reflection foam surface:
  - thermal-dynamic boundary condition is determined by shockwave simulation in COM3D;
  - moving boundary condition is determined by crushable foam model calculation in ABAQUS
- Simulation results: foam can indeed mitigate the shockwave pressure amplitude



(a) Geometry



(b) CFD model



(c) Simulation result

Summary (SW absorbing materials)

- The SW attenuation due to reflection on soft materials was investigated inside a vessel of 220 m^3 volume. A cube sized (0.55 m) combustion unit filled with 4 g H_2 was used to provide reproducible SW from a unconfined H_2/air detonation.

- Comparing to the reflected SW amplitude from the steel wall, the reflected SW amplitude is reduced by,

~50 % Glass wool (fiber) and acoustic (structured) polyurethane
~40 % Polyurethane foam (soft foam):
~20 % Polystyrene

- For the SW amplitude attenuation, no clear trend of an influence of the thickness of the absorbing material was observed.

- For the SW impulse+ attenuation, an influence of the thickness of the absorbing material was observed. The impulse+ attenuation increases with increasing thickness of the absorbing materials.

Summary (water spray)

- The SW attenuation due to propagation in water spray charged atmosphere was investigated inside a vessel of 220 m^3 volume. A cube sized (0.55 m) combustion unit filled with 4 g H_2 was used to provide reproducible SW from a unconfined H_2/air detonation.

- Comparing to the reference dry case, a shock wave attenuation effect was found when water is injected.

- SW amplitudes are reduced by,

  droplet water spray, 10 ~ 15 %,
  mist water spray, 10 ~ 30 %.

- SW impulse+ are reduced by,

  droplet water spray, slightly,
  mist water spray, 10~20 %.

The general conclusion is that water spray has a positive effect on SW attenuation.

The investigated water spray density, used in fire extinguisher systems shows a moderate effect on SW attenuation. It is expected that high density water sprays, like a curtain or waterfall, shows higher effect on SW attenuation.

tunnel HP

Clean Hydrogen Partnership

Acknowledgements

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