Mitigation of hydrogen-air detonations

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Outline

- Flame quenching, MSEG
- Deflagration arresters
- Detonation arresters
- Detonation quenching – new ideas
  - by inert gas zone
  - by foams and meshes
  - by air gaps
- Testing of arresters

Flame quenching by walls

- **Cooling – dominant effect**
- Chemical effect (destruction of radicals)
- Quenching distance:

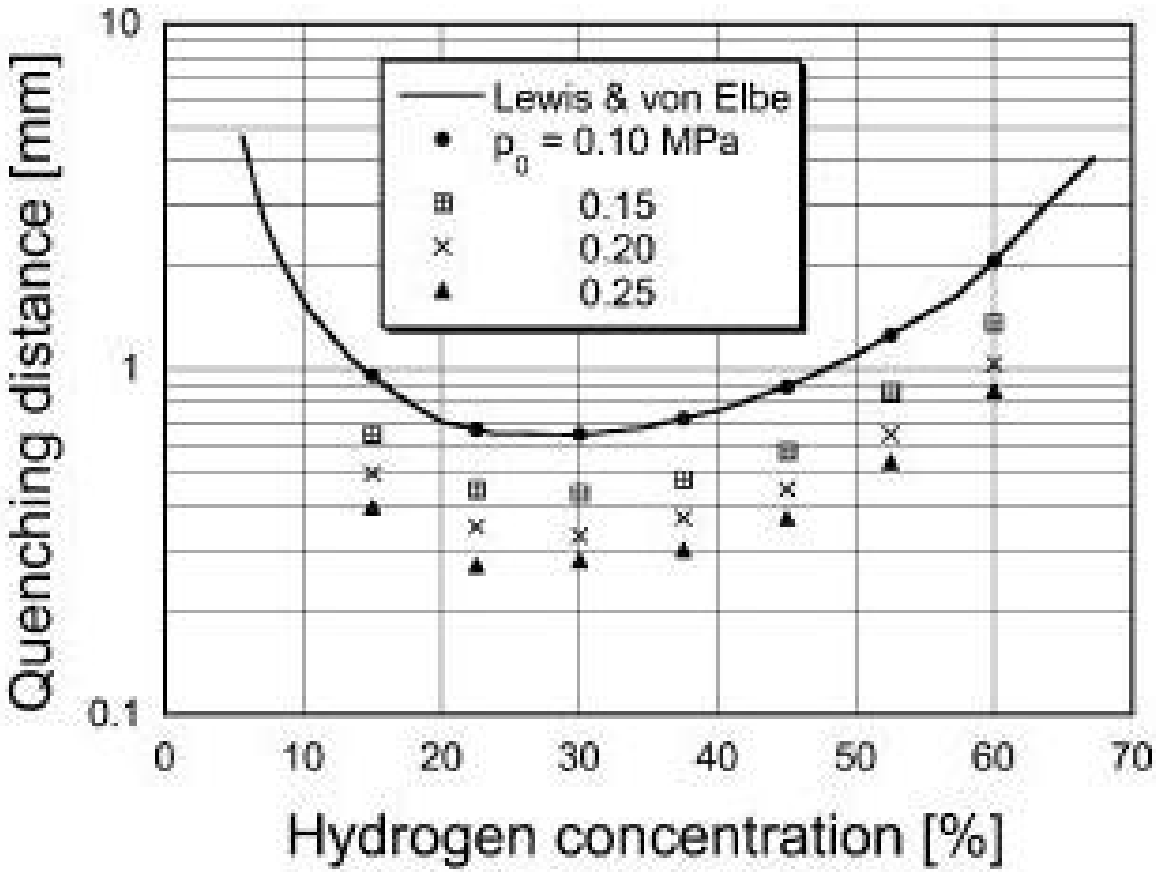
$$d_q \propto \delta \propto \frac{\lambda}{c_p \rho_u S_L} \propto \frac{\lambda T_u}{c_p \overline{M}} \frac{1}{p_0} \frac{1}{S_L}$$

S_L – laminar burning velocity

δ - flame thickness

- only about 22% of the heat generated by the flame per unit surface must be removed in order to quench the flame

Flame quenching by walls



(Yang et al., 2003)

Maximum experimental safe gap (MESG)

Forced flow conditions parameter – in explosions, fast deflagrations

Fuel in stoichiometric mixture with air	**Pressure after explosion p_e (atm)**	**MESG for a partition of 25 mm thick (mm)**	**Quenching distance at p = 1 atm (mm)**	**Quenching distance at $p = p_e$ (mm)**
Hexane	7.8	0.95	3.56	0.5
Benzol	8.7	0.95	2.0	0.4
Hydrogen	9.3	0.15	0.2	0.07
Acetylene	6.9	0.02	0.76	0.05

MESG – dynamic parameter (depends on the direction of the flow relative to flame)

(Chomiak, 1990)

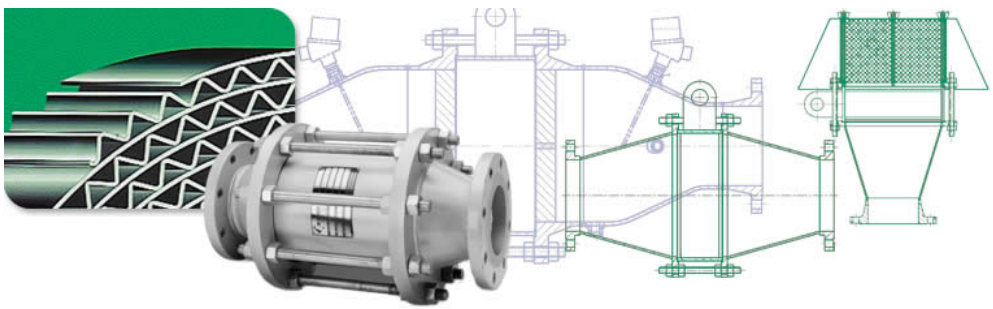
Deflagration arresters

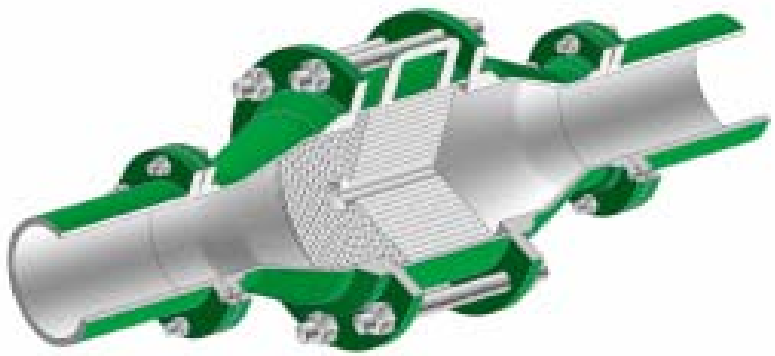
- Devices to prevent the passage of flame along a pipe
- Three types:
  - Type 1 – with multiple small channels (planar sheet metal, crimped ribbon, wire gauze, perforated plate, perforated block, sintered metal, parallel plate, wire pack, packed bed);
  - Type 2 – hydraulic devices;
  - Type 3 – velocity flame stoppers.

Deflagration arresters

Type1

- Mechanism of operation: flame quenching and heat loss
- Diameter of the aperture of an arrester should be smaller than the quenching diameter by at least 50%.
- Desirable properties
  - high free cross-sectional area available for flow
  - low resistance to flow
  - high capacity to absorb the heat of the flame
  - ability to withstand mechanical shock





Deflagration arresters

Type 2

- Contain a liquid, usually water, which serves to break up the gas stream into bubbles and so prevents passage of the flame

Deflagration arresters

Type 3 – velocity stoppers

- Used in end-of-line applications to prevent a flame passing from downstream to the upstream side
- Principle of operation: to assure that the velocity of the upstream gas passing through the arrester is sufficiently high to prevent a flame propagating through the arrester from the downstream side.
- Velocity necessary to prevent flashback through apertures larger than those which would give quenching:

$$u_T = 0.2015 g_L D$$

D – internal pipe diameter (m)
g_L – laminar velocity gradient (s^{-1}); a function of the gas and its concentration; for hydrogen its maximum value is equal to 10 000 s^{-1}
u_T – turbulent flashback velocity (m/s)

Deflagration arresters

On the market:

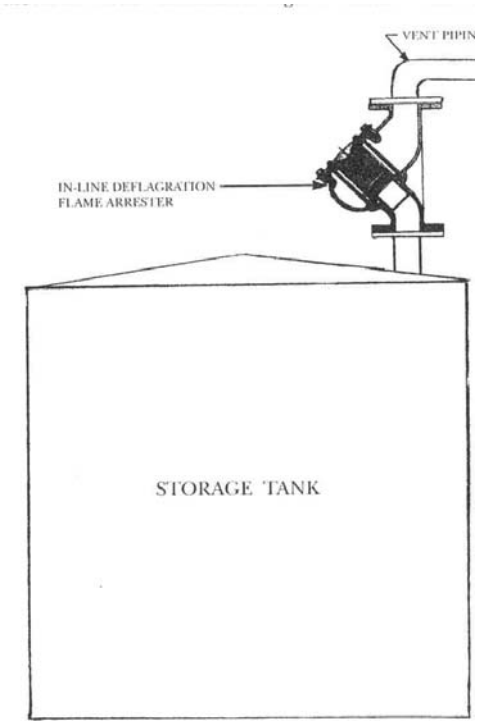
PROTEGO - ranging in size from 10 mm to 400 mm, approved in Germany for mixtures of hydrogen and air in all ranges of concentration

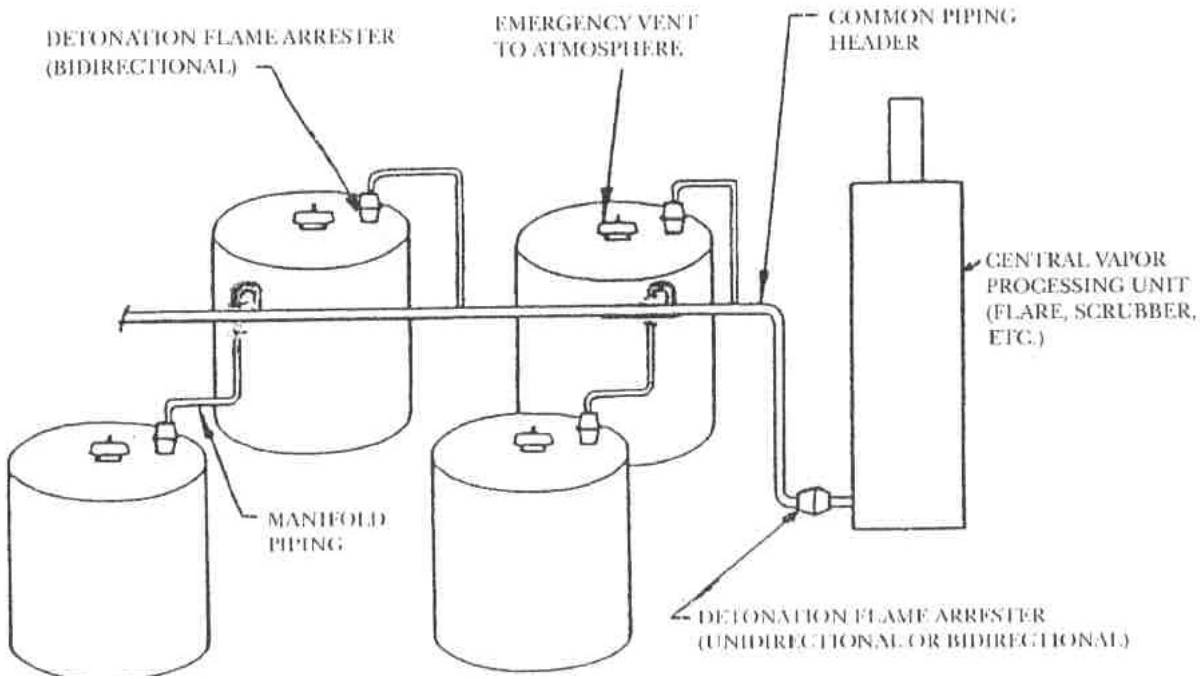
ENARDO - arresters for hydrogen-air mixtures

WESTECH Ltd.

Others ……..

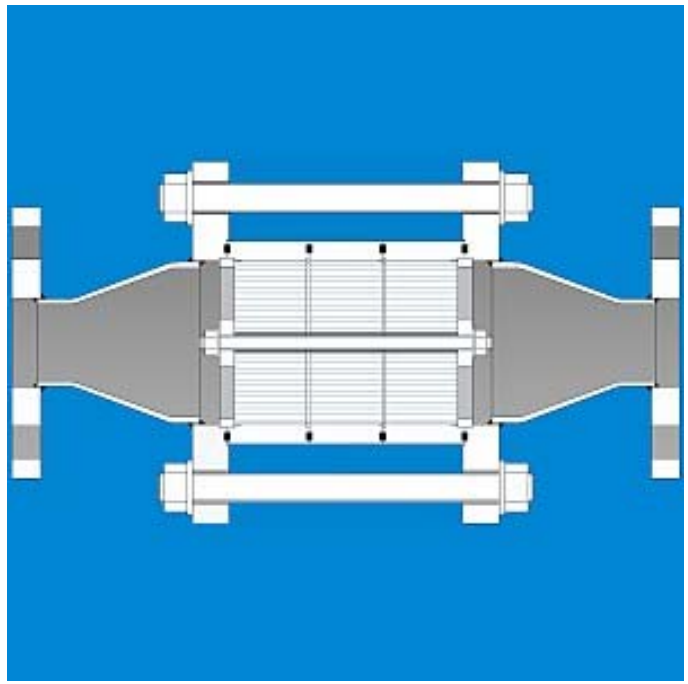
Detonation arresters



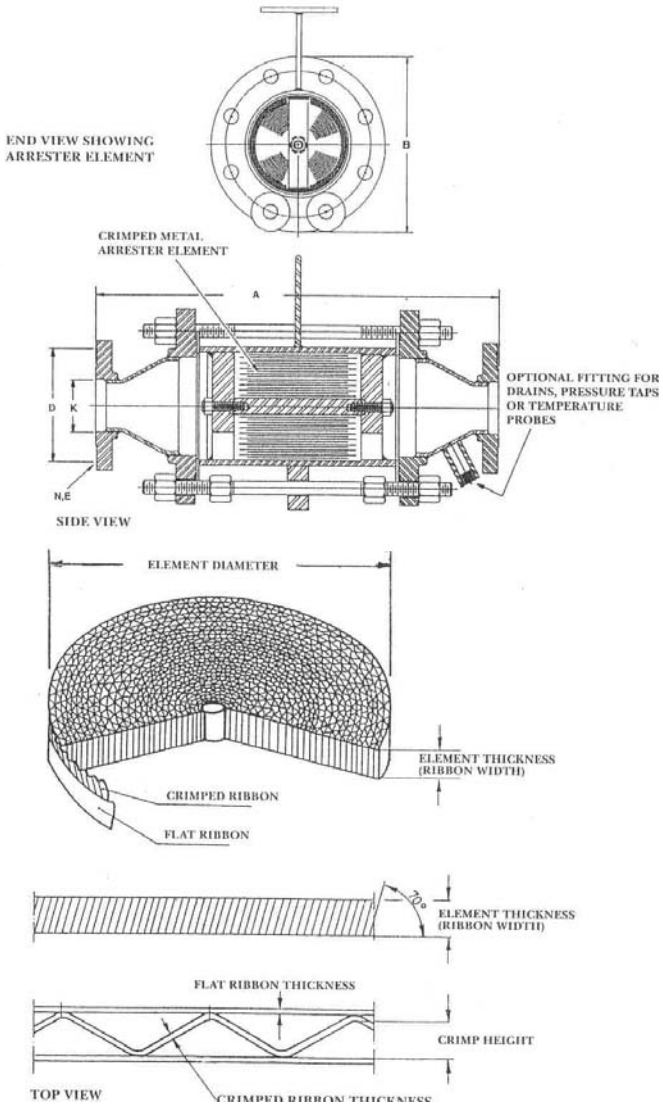


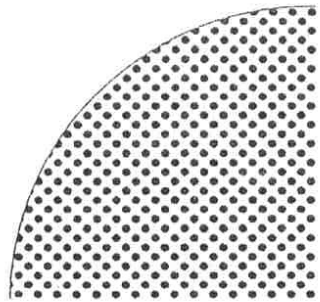
Detonation arresters

1. Same as for deflagration – just longer channels and stronger

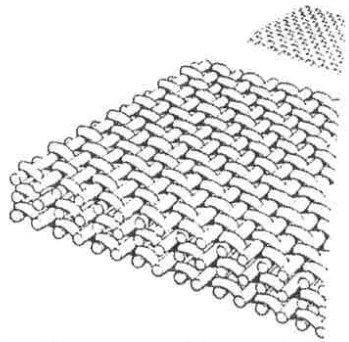


Detonation arresters

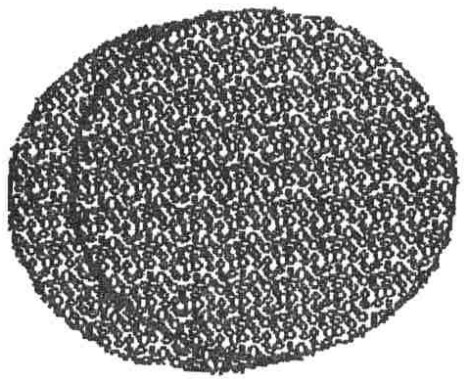




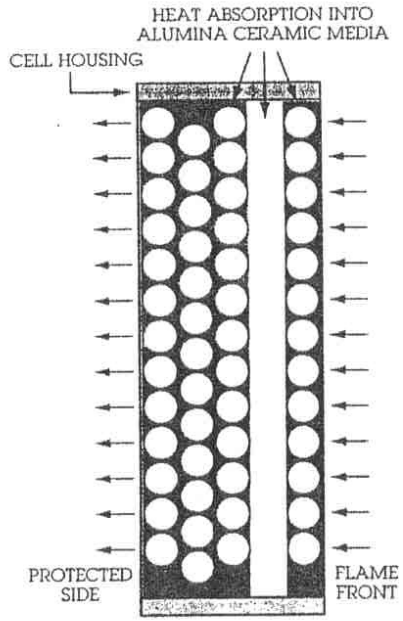
(a) Perforated plate



(b) Wire gauze and gauze packs

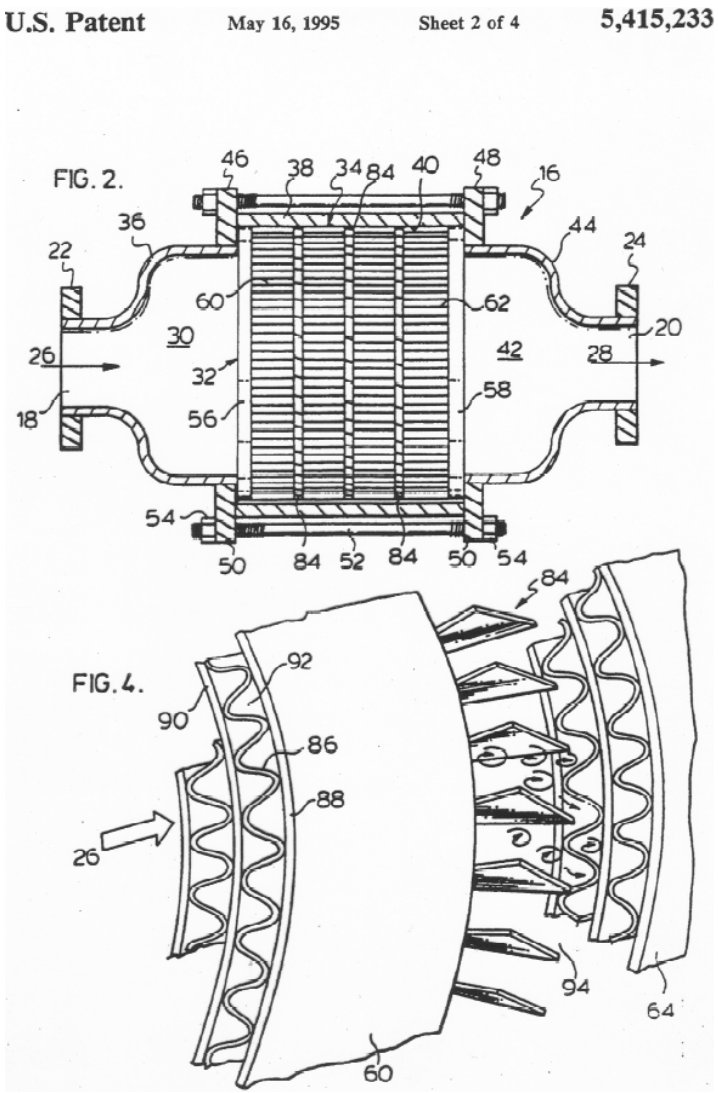


(c) Sintered metal



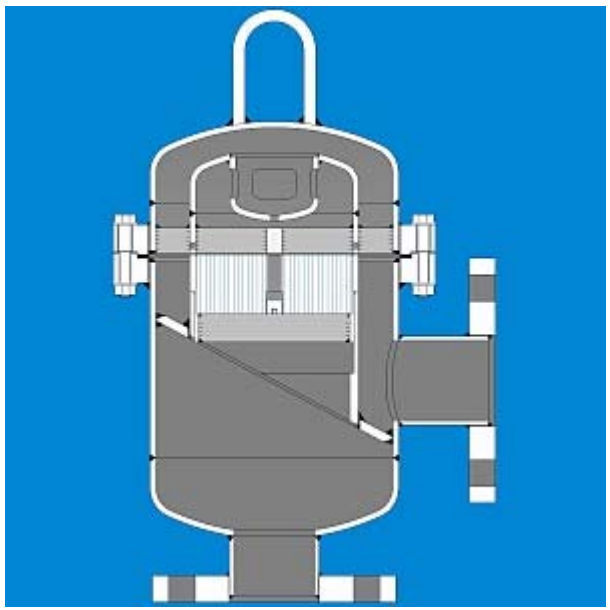
(d) Ceramic balls

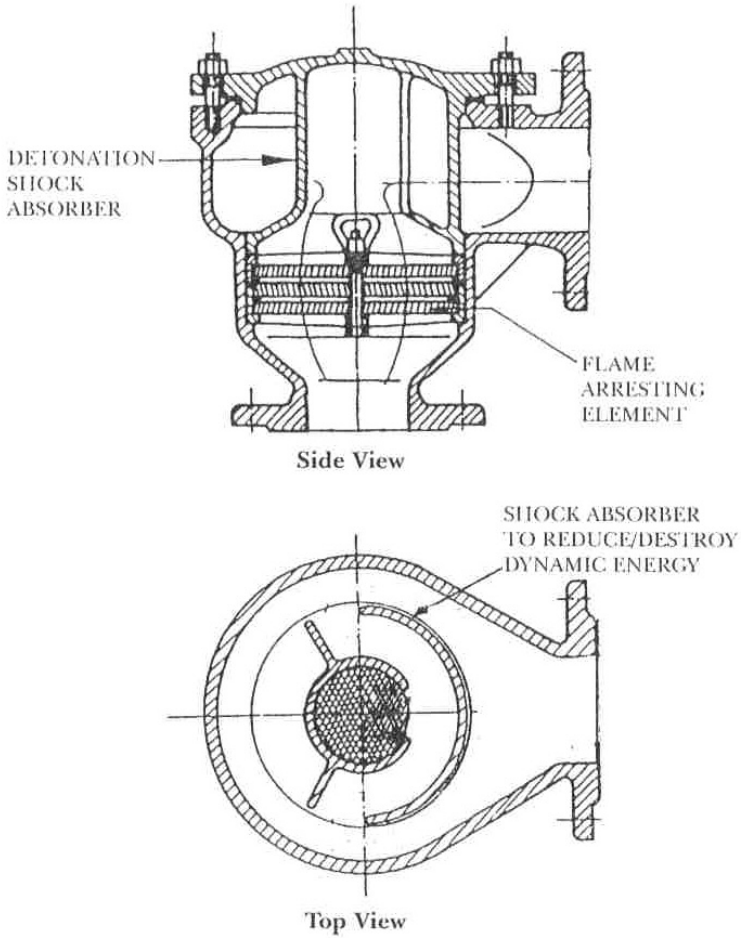
Detonation arresters



Detonation arresters

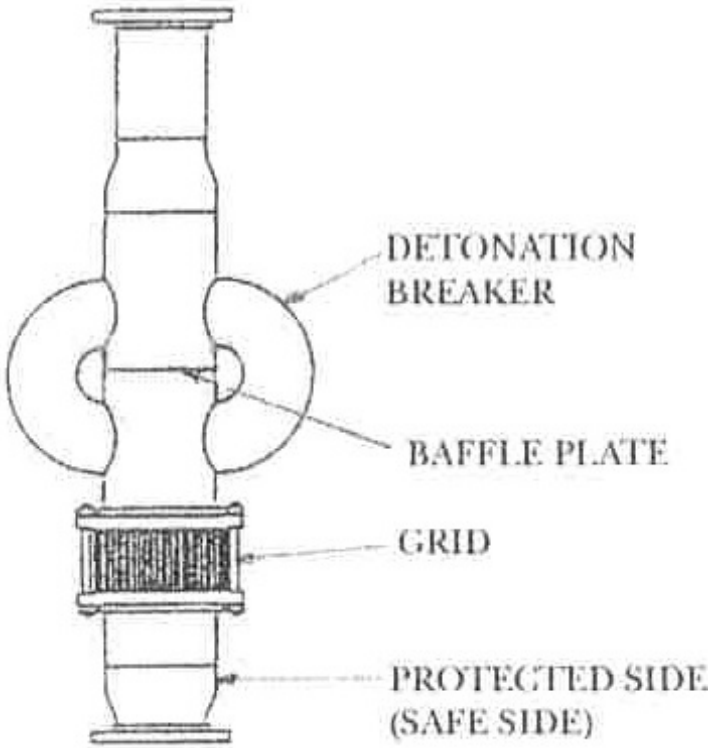
2. With a "shock absorber"





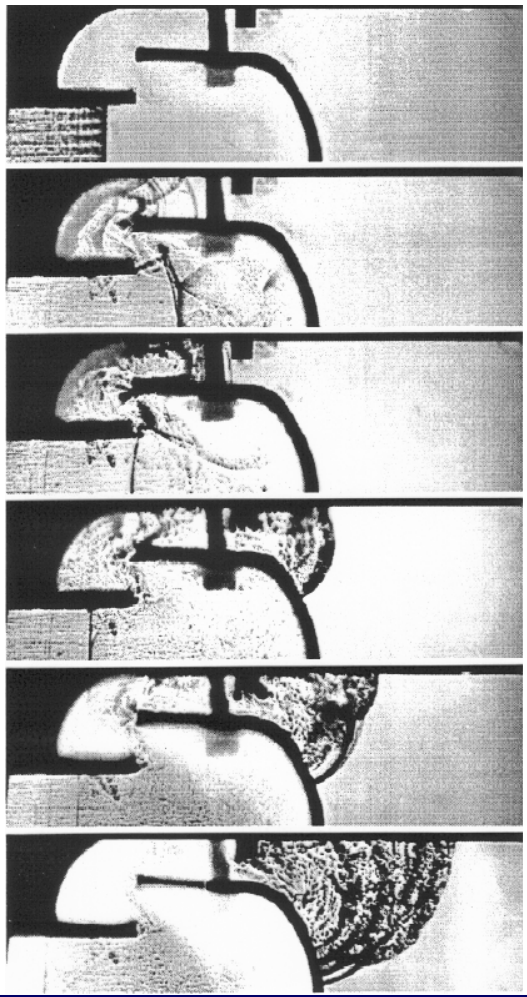
Detonation arresters

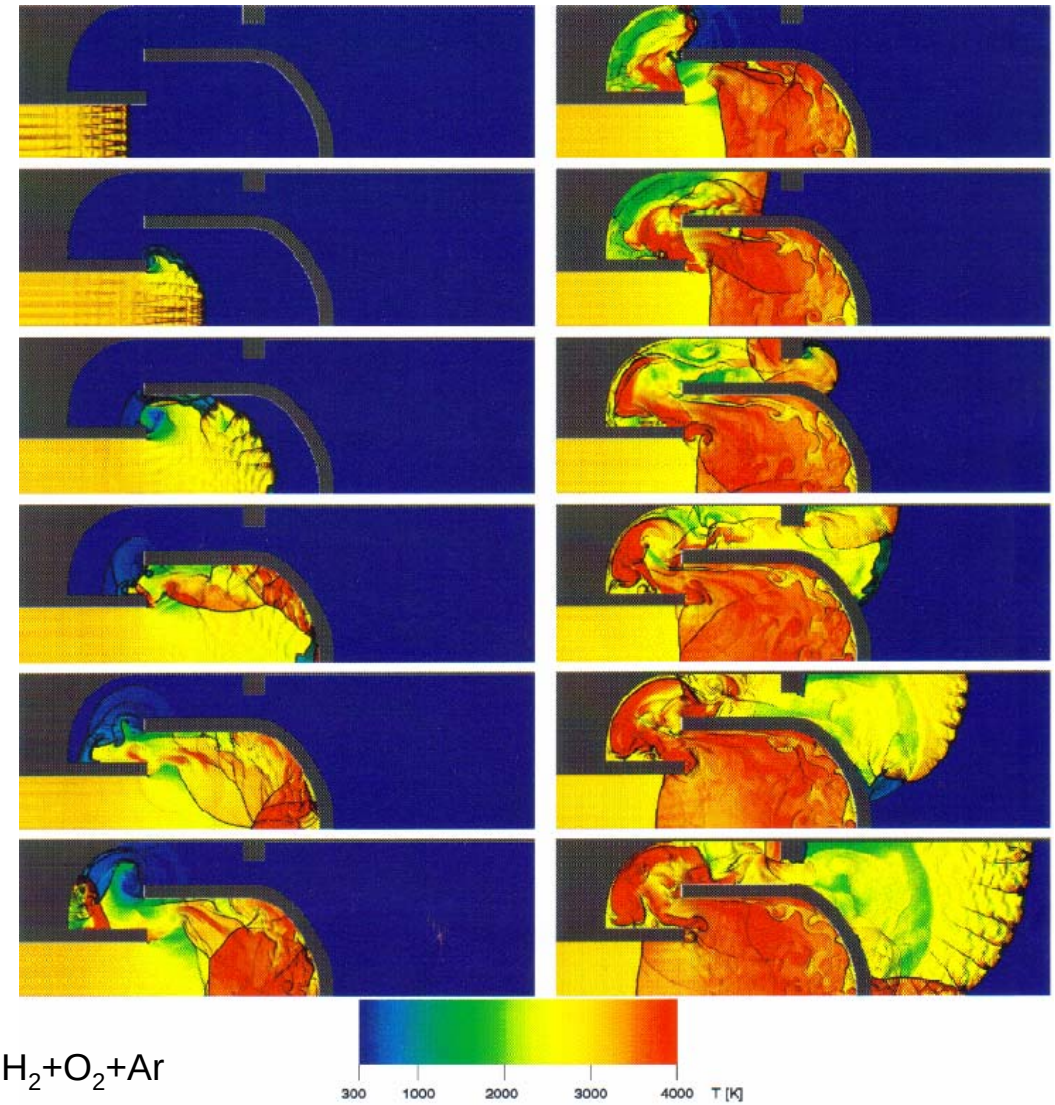
3. With a "detonation momentum attenuator"



Detonation arresters

Detonation propagating through detonation arrester with "detonation momentum attenuator„

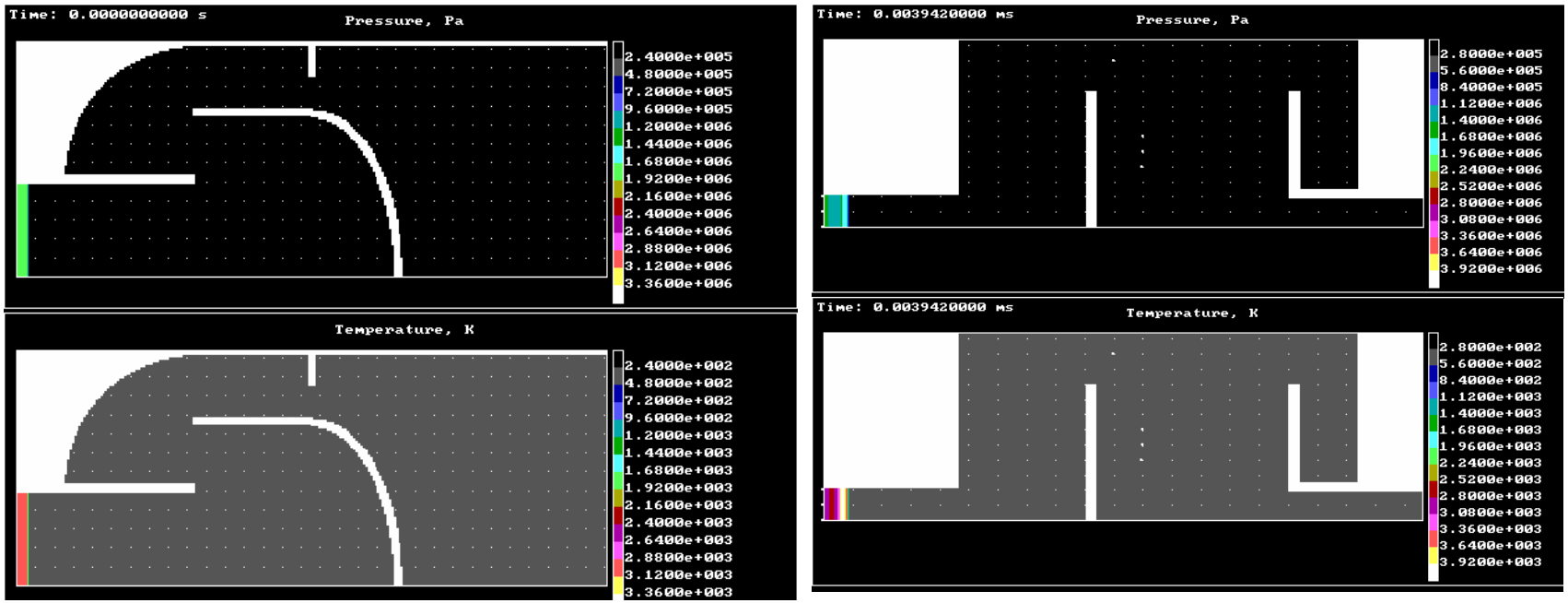




$2H_2+O_2+Ar$

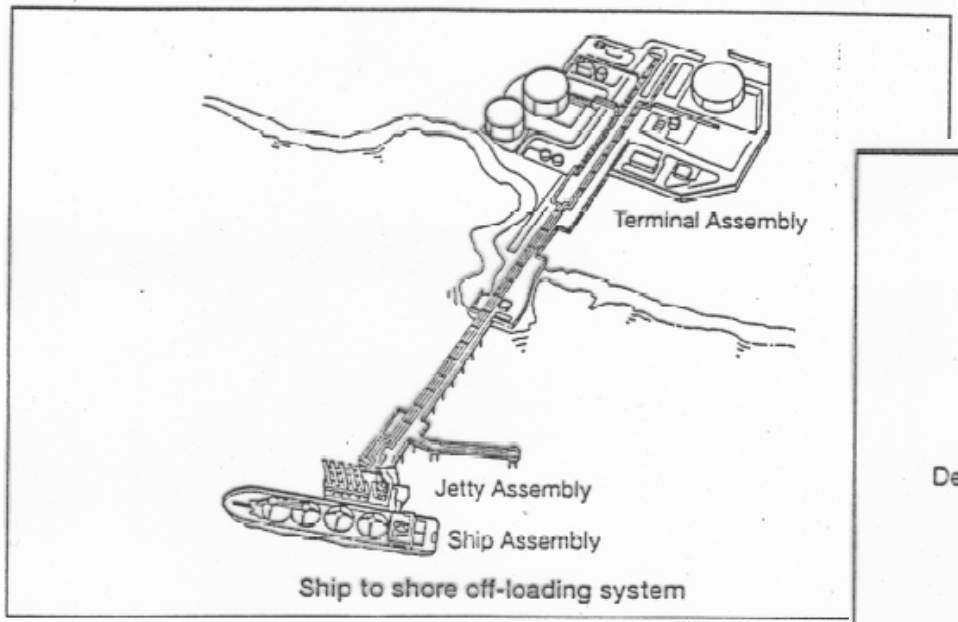
Detonation arresters

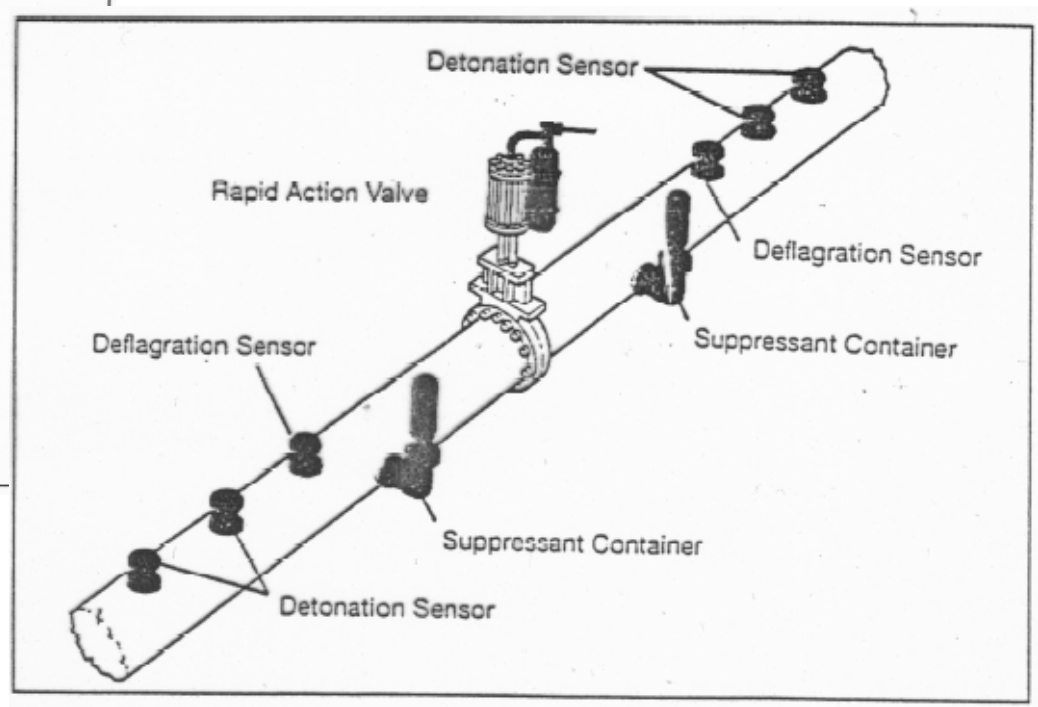
Simulation of detonation propagating through detonation arrester with "detonation momentum attenuator„ - DETO2D code



Detonation quenching

Active arresters for waste gas recovery processes
(Kidde Graviner Ltd.)





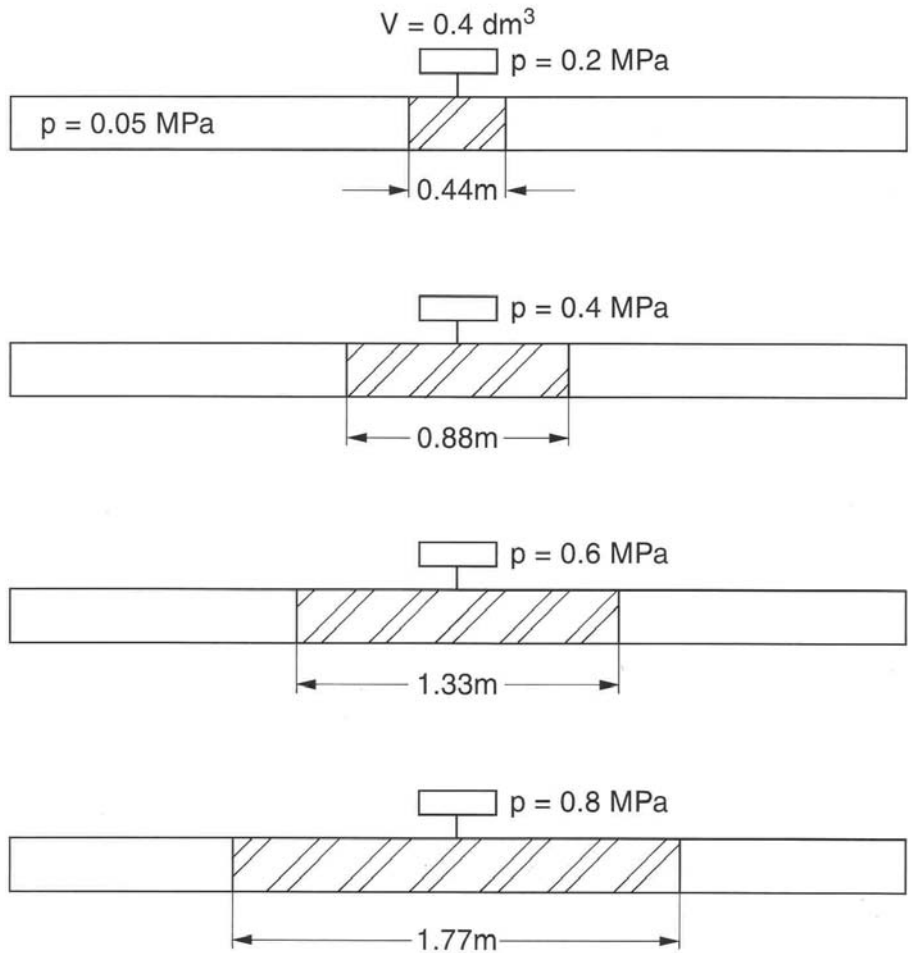
Detonation quenching by inert zone

$2H_2+O_2$ mixture

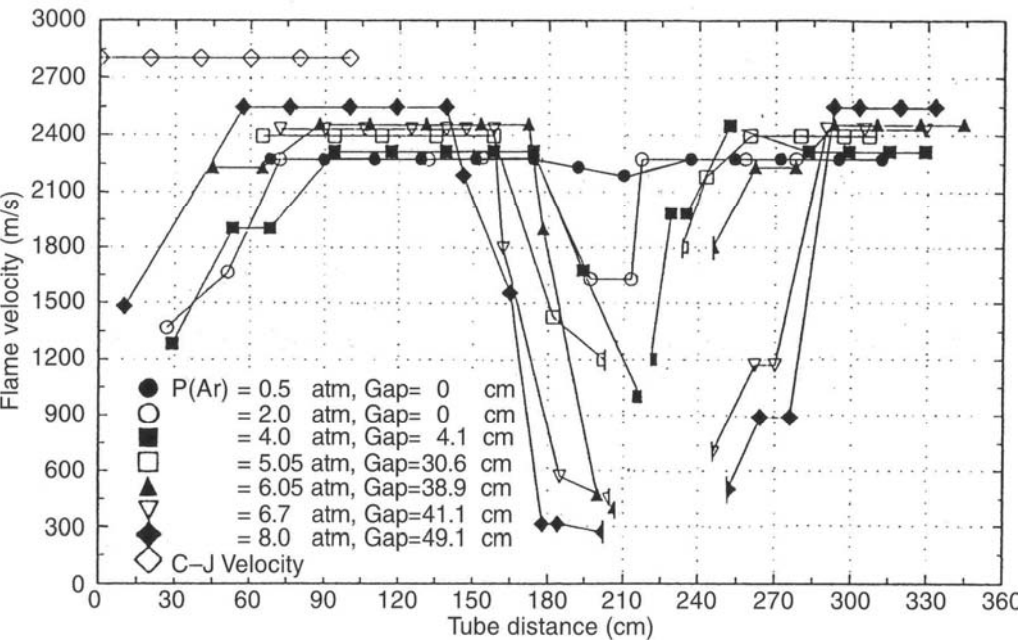
P_0 = 0.3MPa and 0.5MPa

3.6m x 60mm x 60mm channel

Inerts: Ar, He, N_2, CO_2



Detonation quenching by inert zone



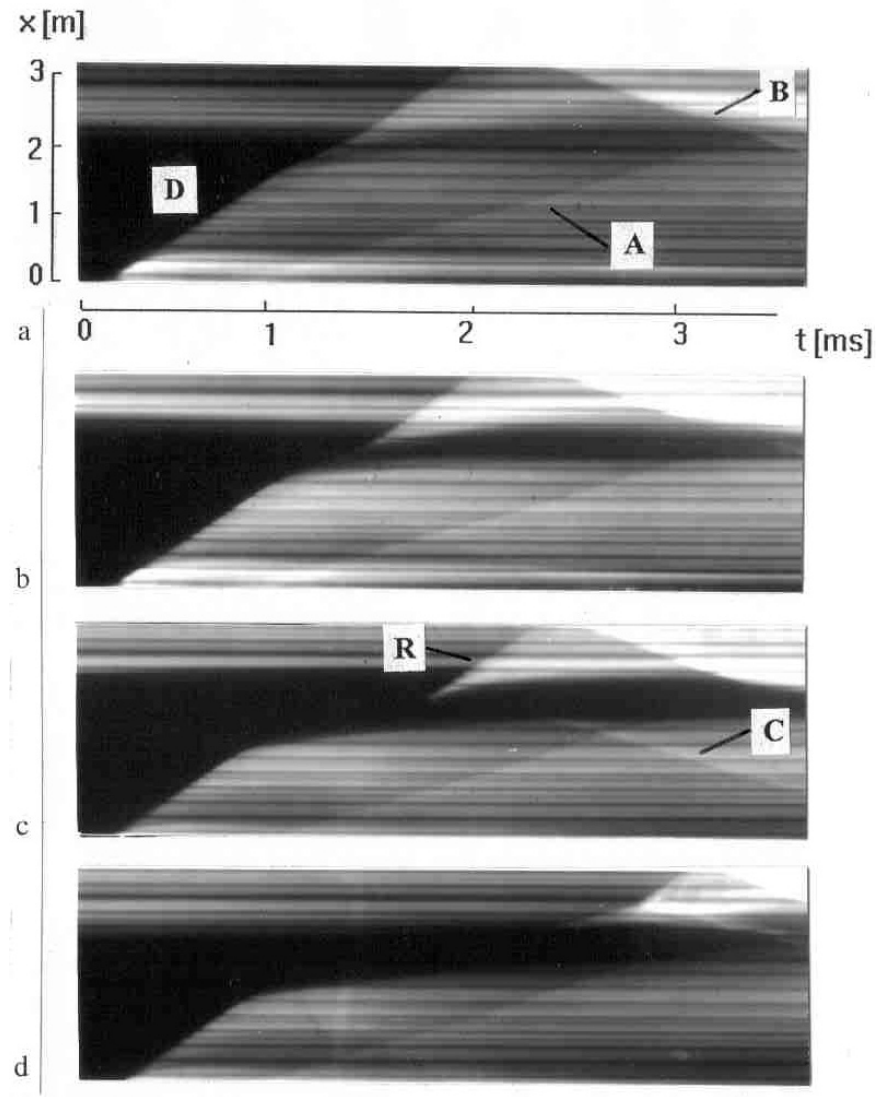
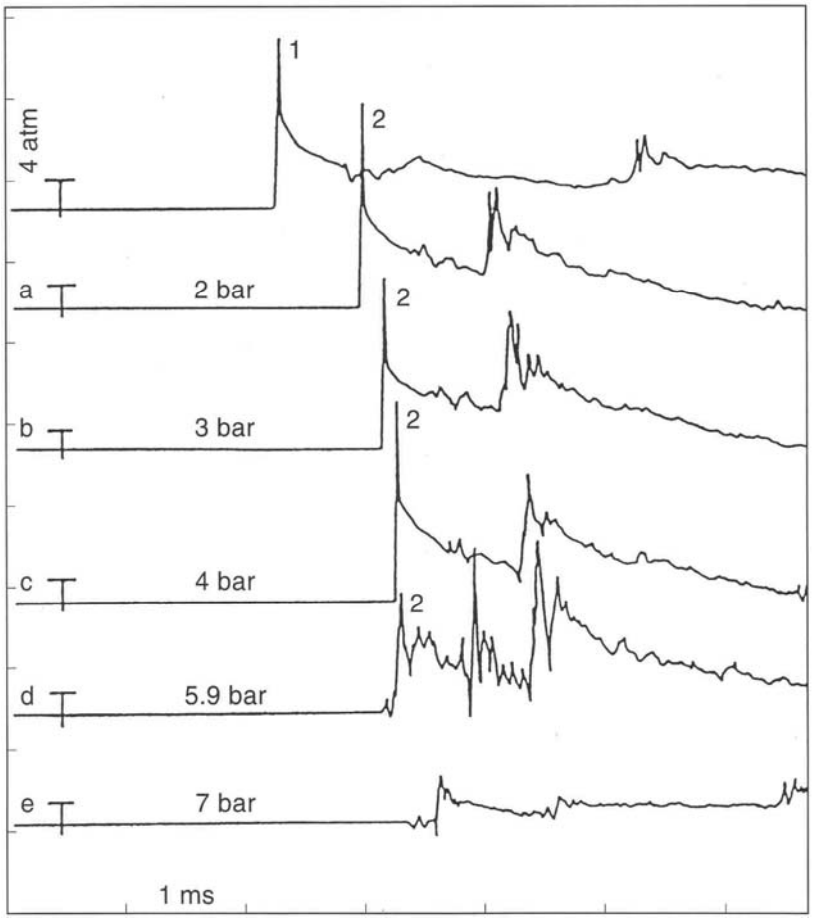
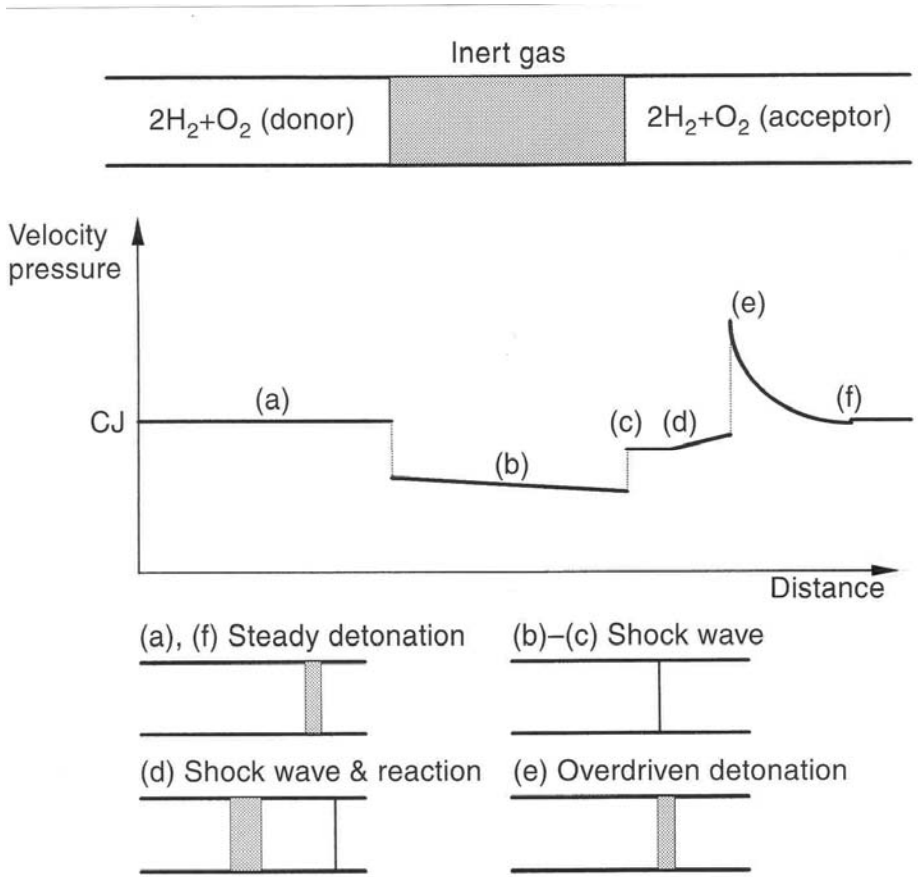


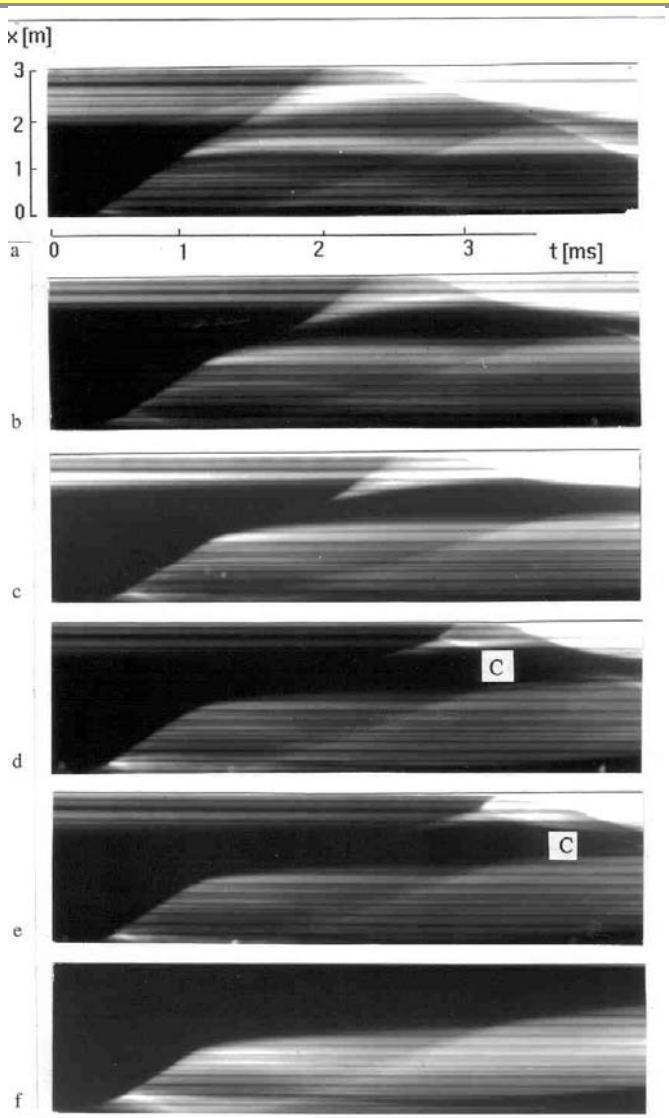
Fig. 3a–d. Streak photographs of $2H_2+O_2$ detonation interaction with Ar zone; initial mixture pressure p_0=0.5 bar; Ar injection pressure: **a** 2 bar, **b** 4 bar, **c** 6 bar, **d** 8 bar; A – primary retonation wave reflected from ignition end; B shock wave after detonation reflection from channel end; C – retonation wave from reinitiated detonation; D – primary detonation wave; R – reinitiated detonation wave

Detonation quenching by inert zone





Detonation quenching by inert zone



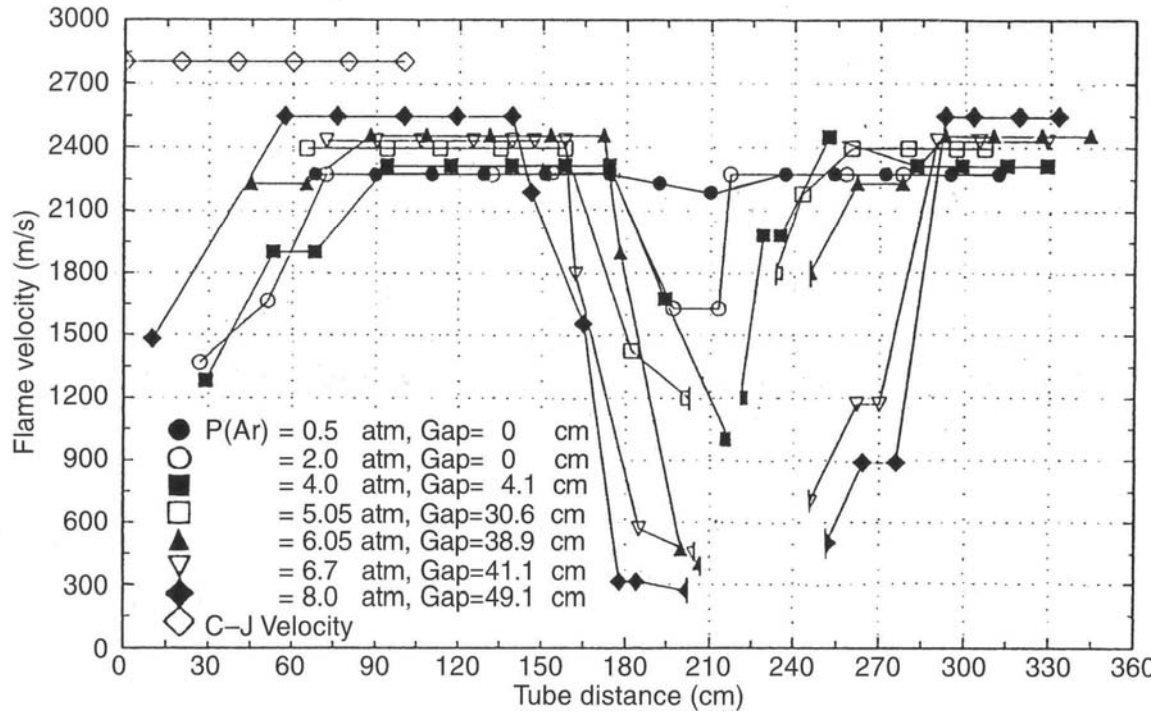


Fig. 6a–f. Streak photographs of $2H_2+O_2$ detonation interaction with Ar zone: p_0=0.3 bar; Ar injection pressure: **a** 0.5 bar, **b** 3 bar, **c** 5 bar, **d** 5.9 bar, **e** 6.6 bar, **f** 7 bar; C - retonation wave from strong DDT

Detonation quenching by inert zone

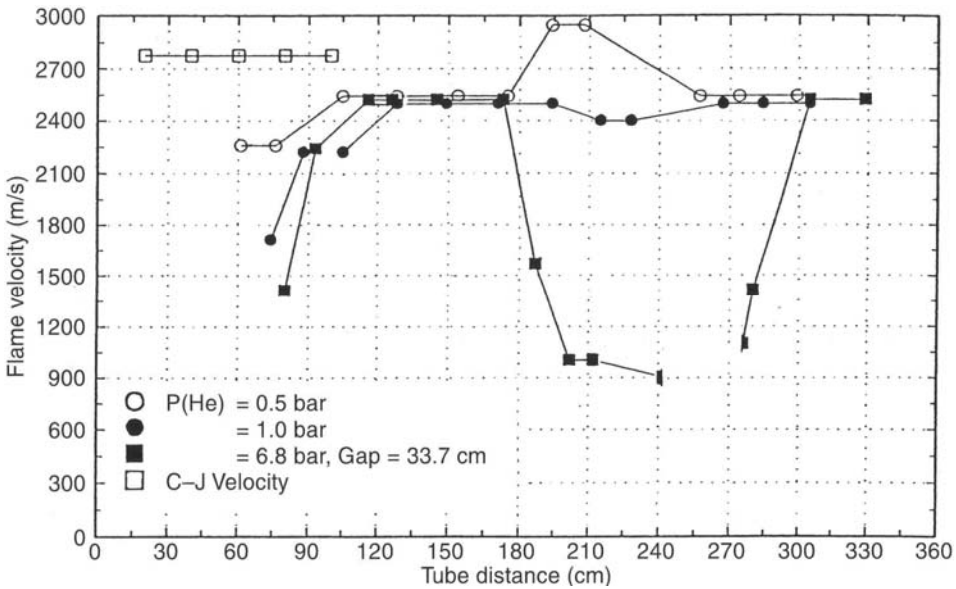


Fig. 14. Flame velocity vs. distance in $2H_2+O_2$ at p_0=0.3 bar for different He injection pressures

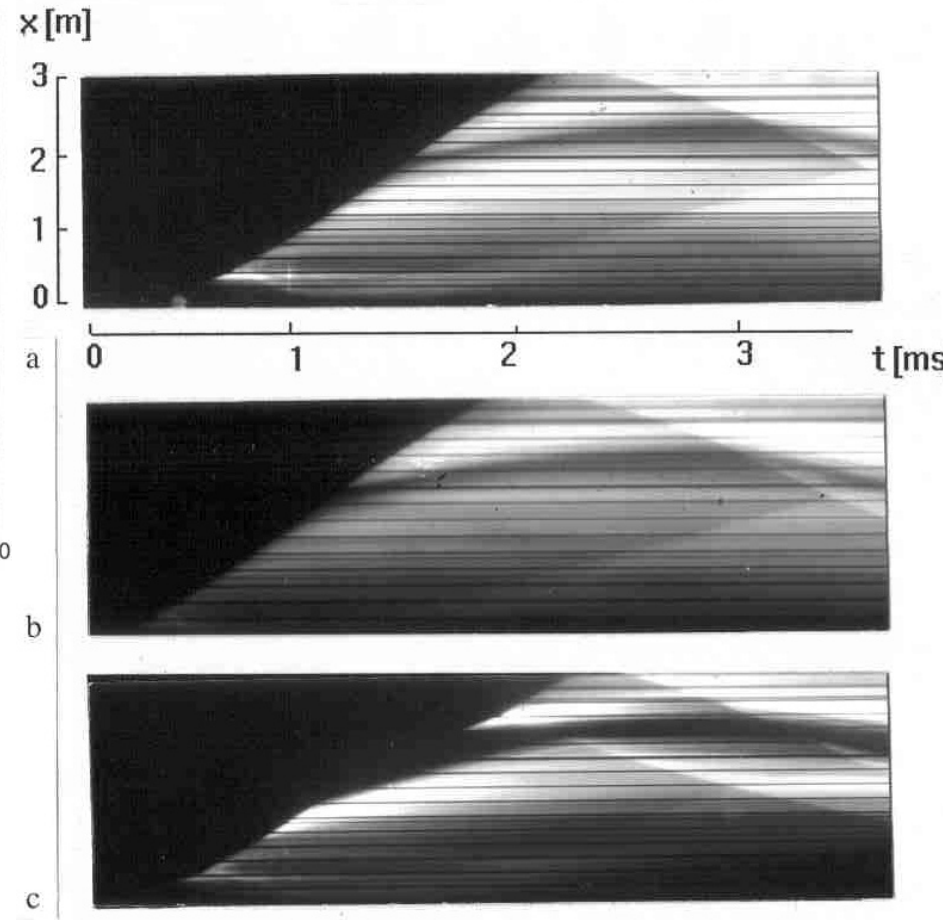
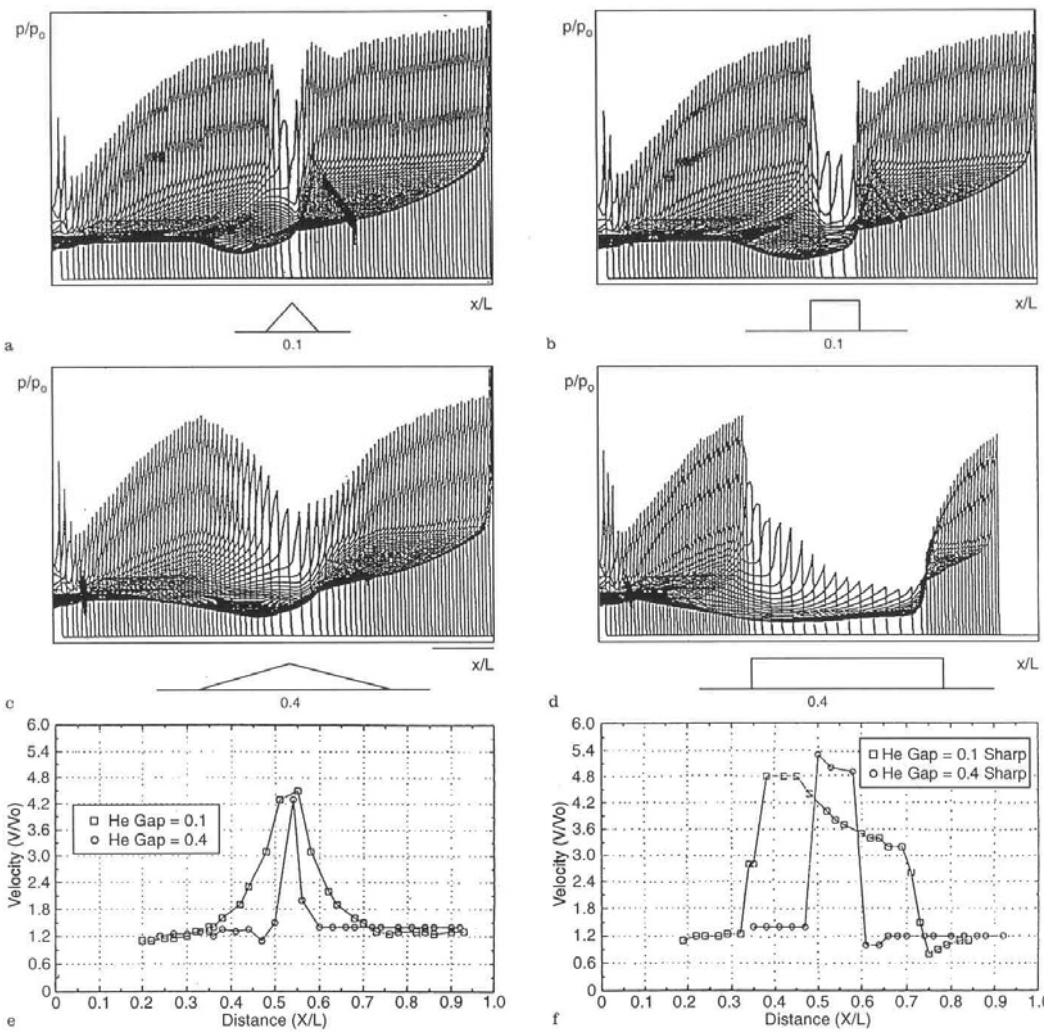


Fig. 13a–c. Streak photographs of $2H_2+O_2$ detonation interaction with He zone; p_0=0.3 bar; He injection pressures: **a** 0.5 bar, **b** 1 bar, **c** 6.5 bar

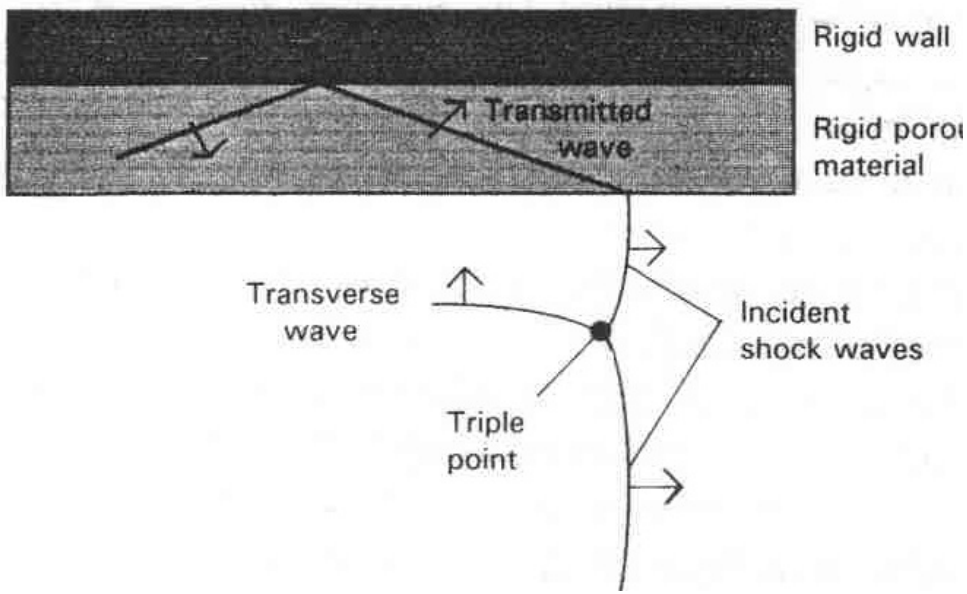
Detonation quenching by inert zone

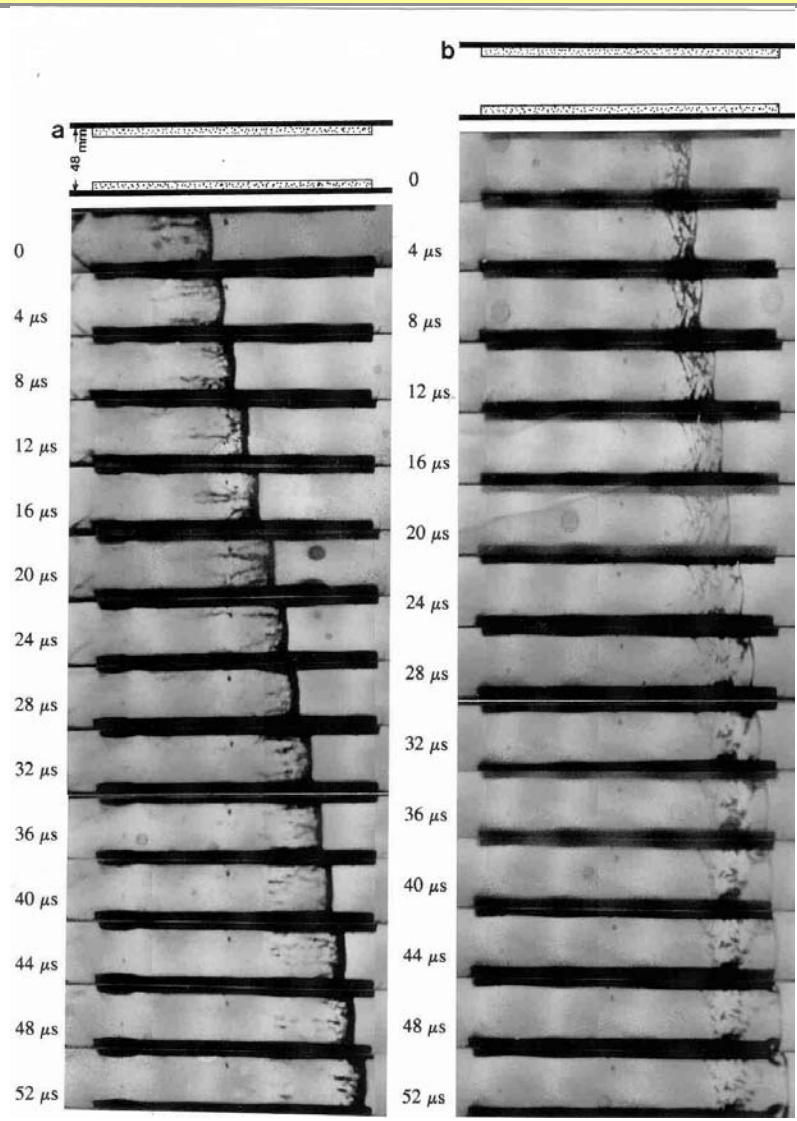


1D numerical simulation – DL code

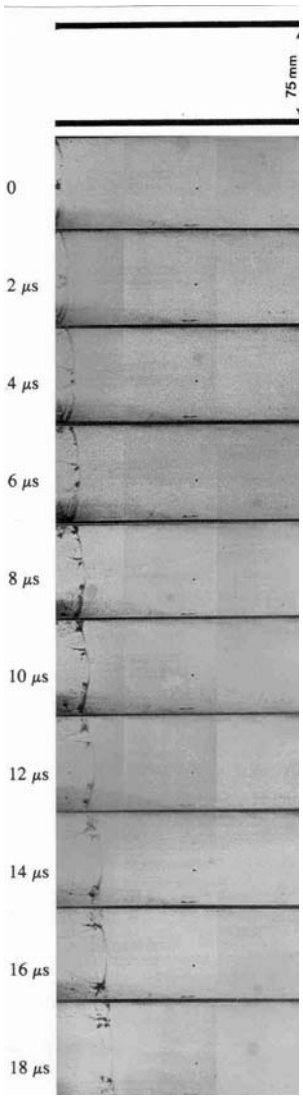
Detonation quenching by meshes

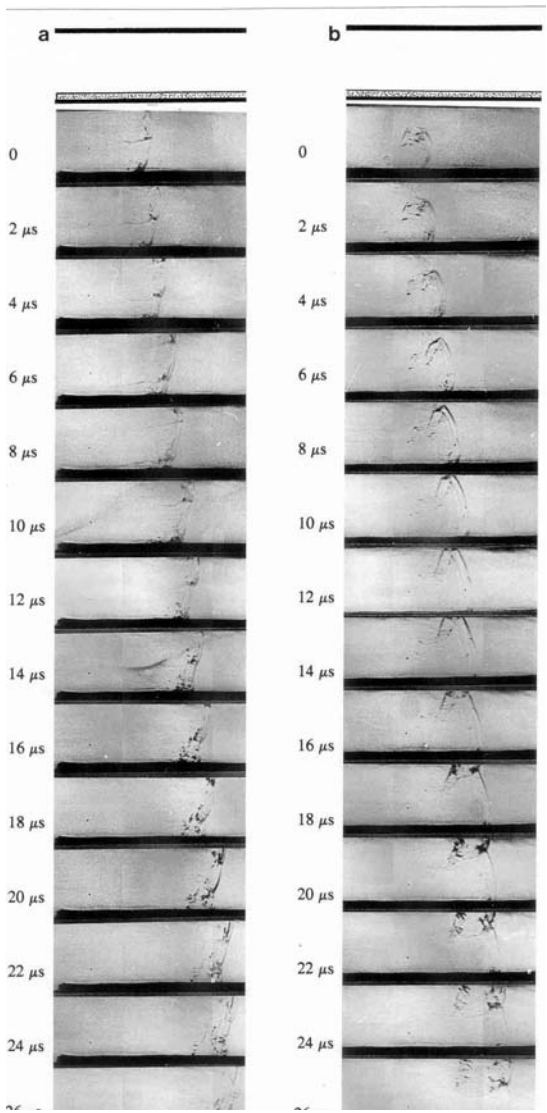
Detonation interaction with the mesh lining the wall



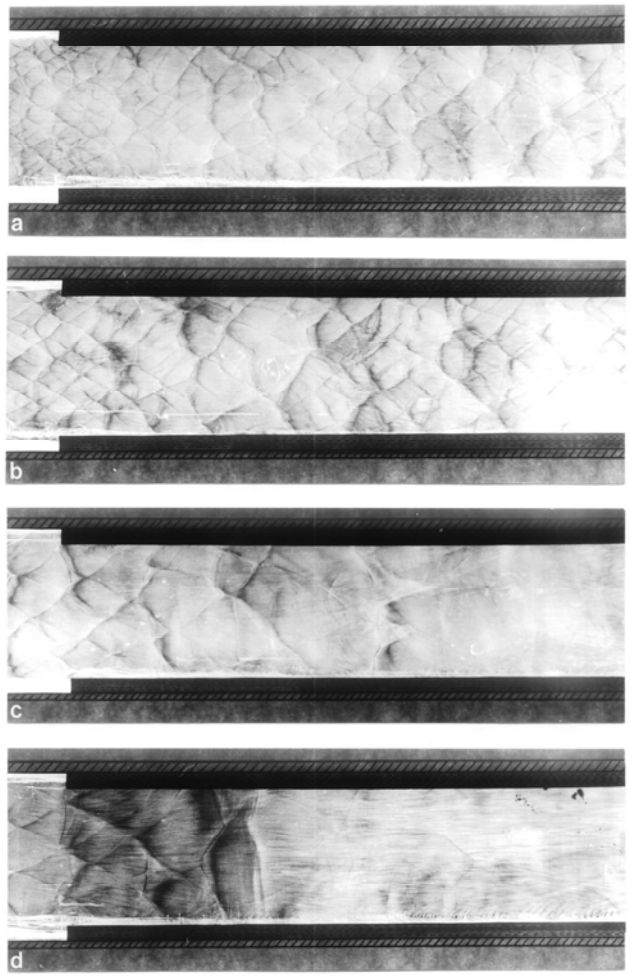


Detonation quenching by meshes

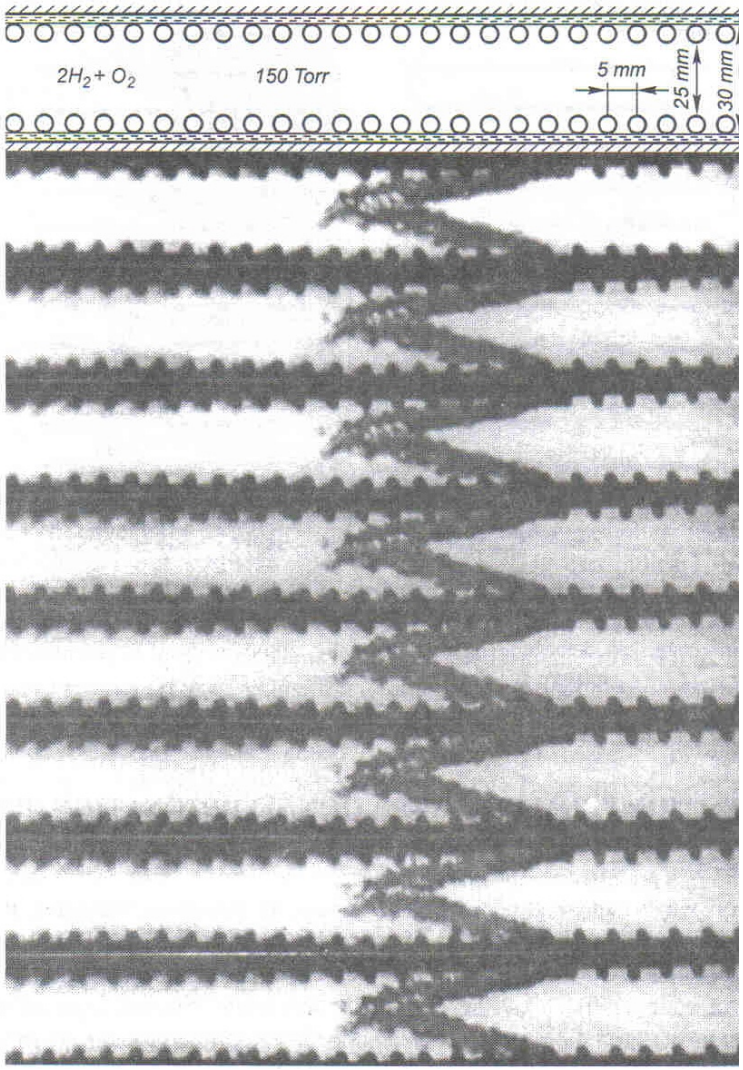




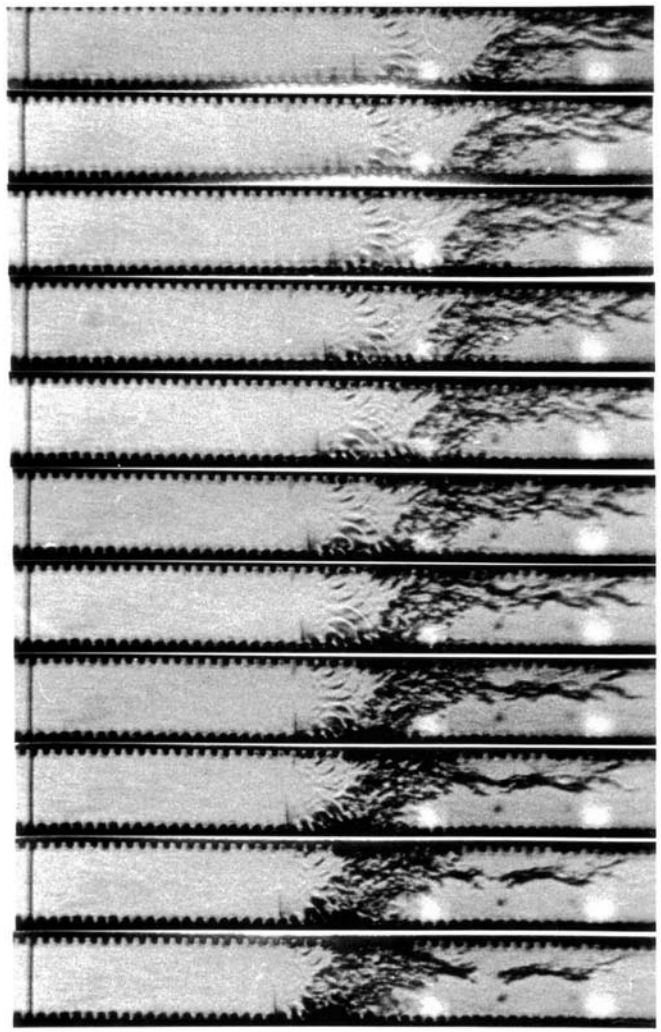
Detonation interaction with the wire mesh lining the wall



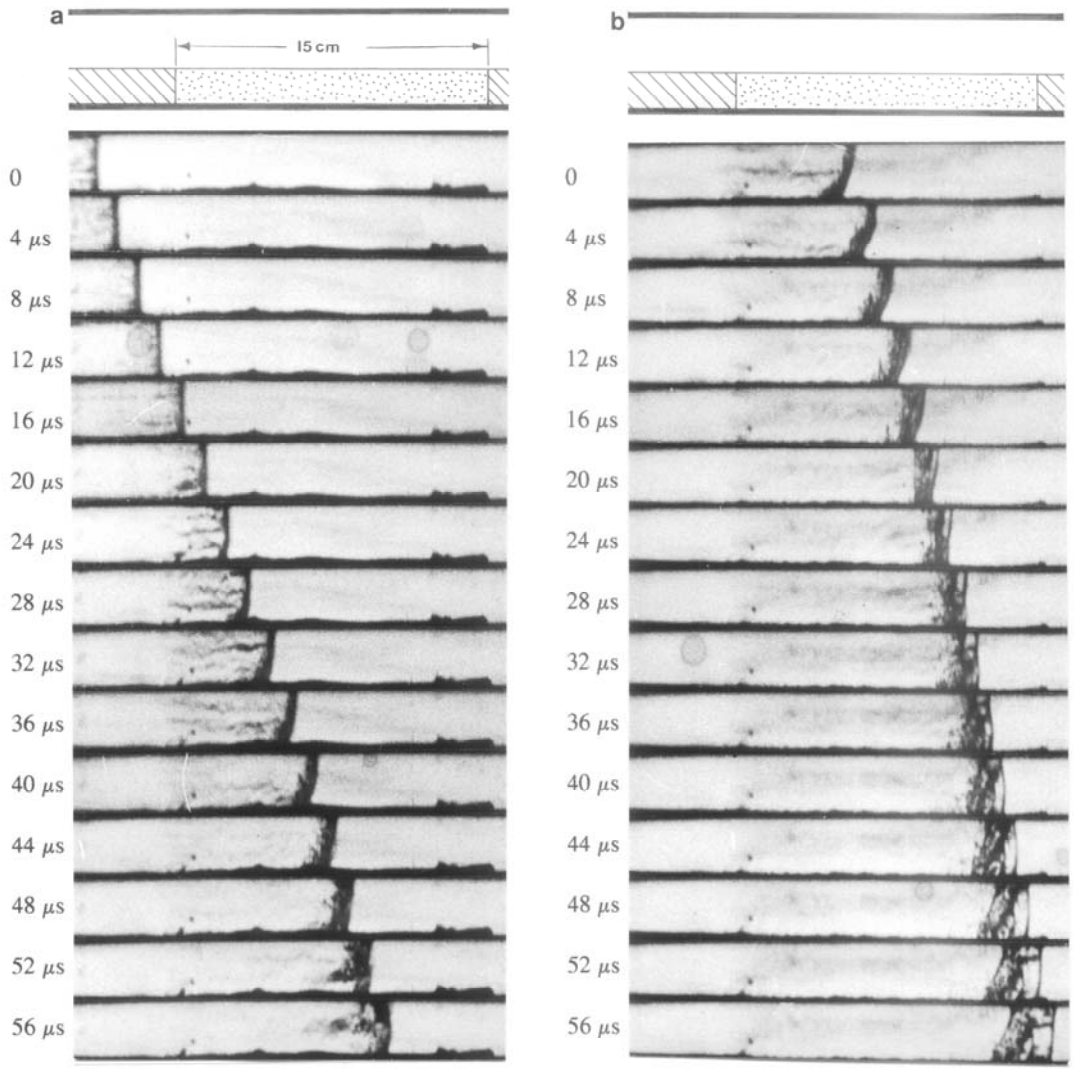
Detonation quenching by meshes



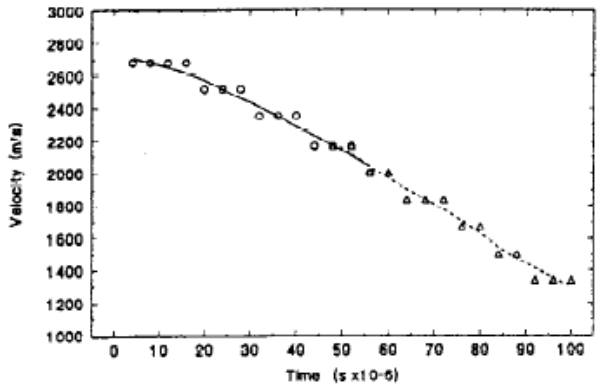
No meshes



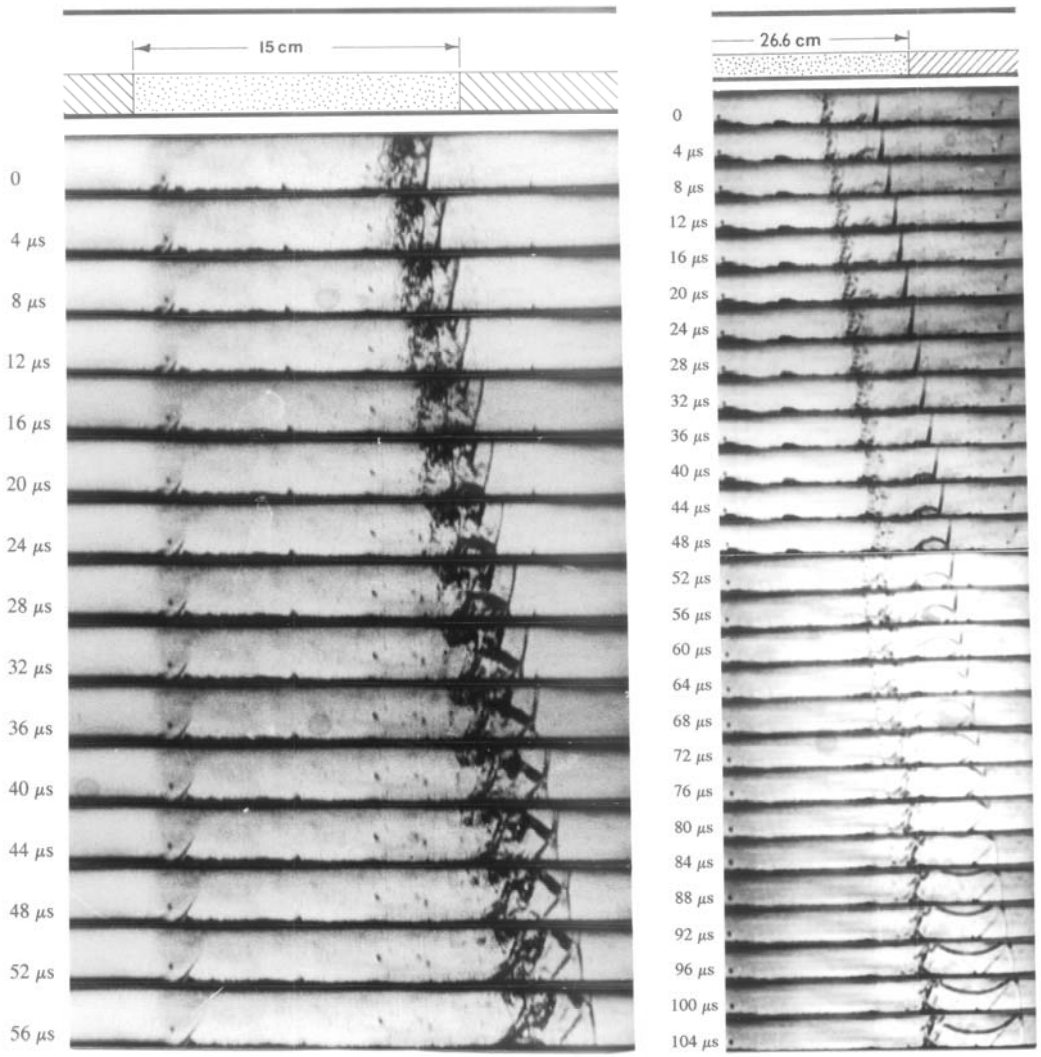
Detonation quenching by fiberglass



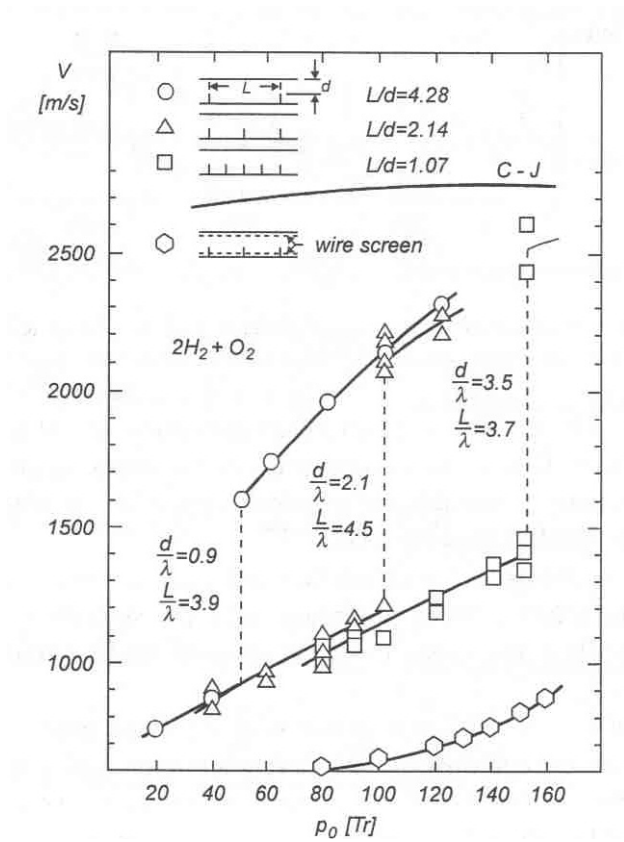
Detonation propagation over the fiberglass section



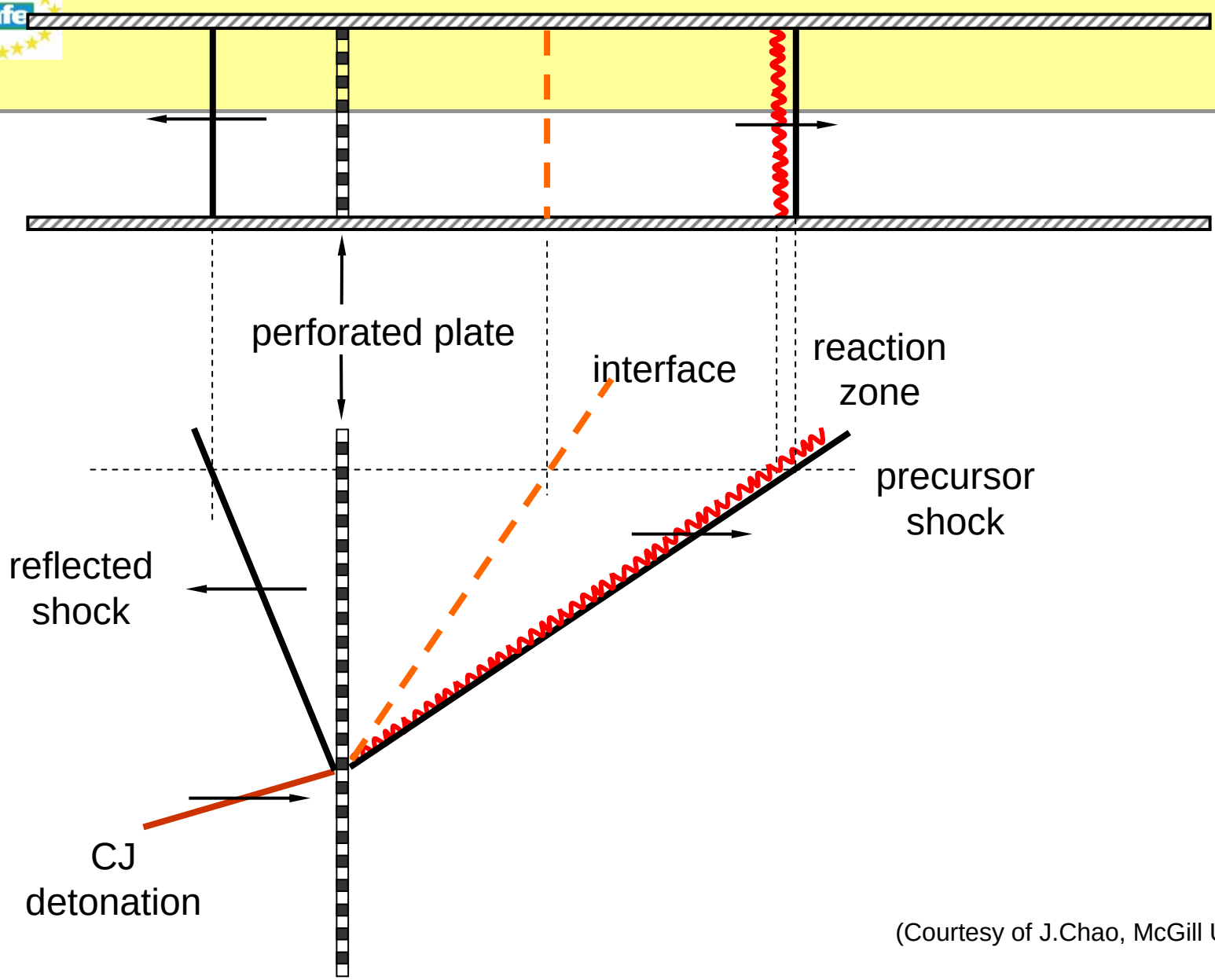
Detonation quenching by fiberglass



Detonation propagation over the fiberglass section

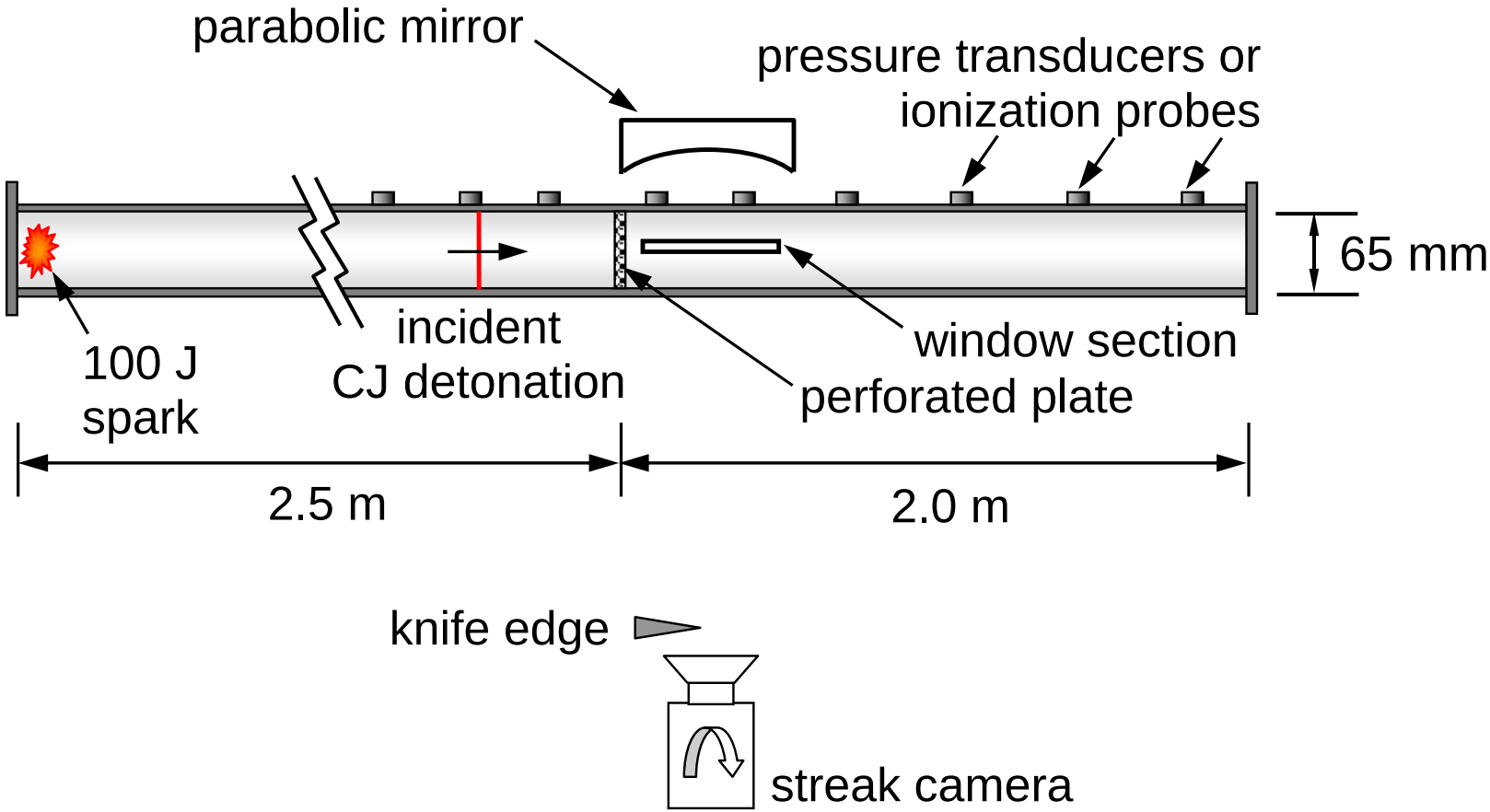


Detonation quenching by perforated plate



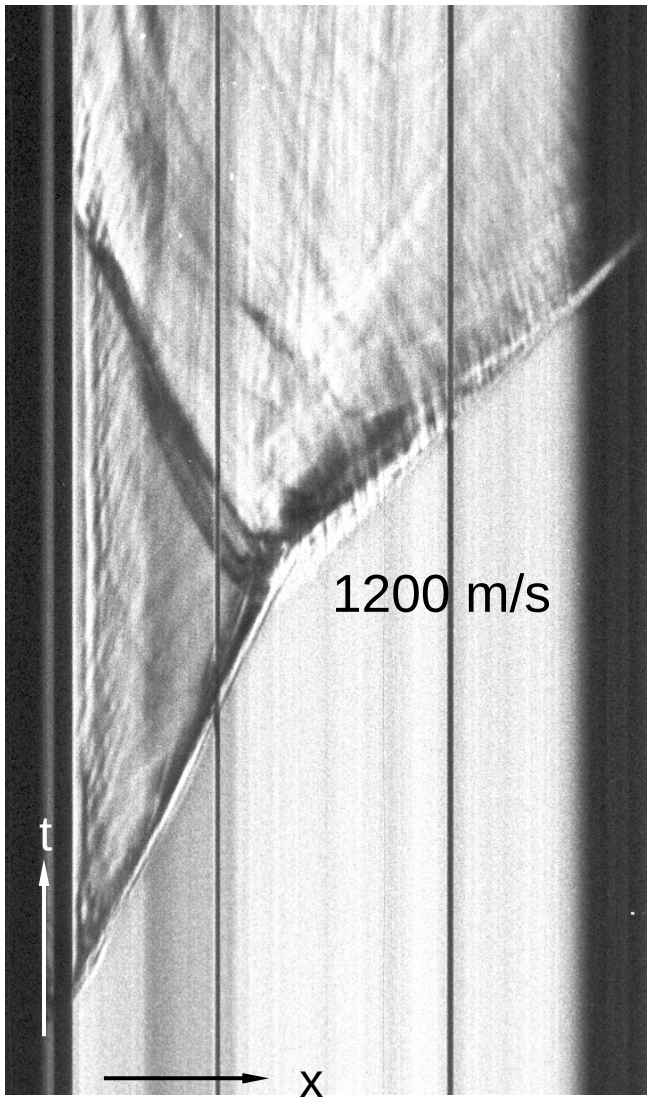
(Courtesy of J.Chao, McGill University)

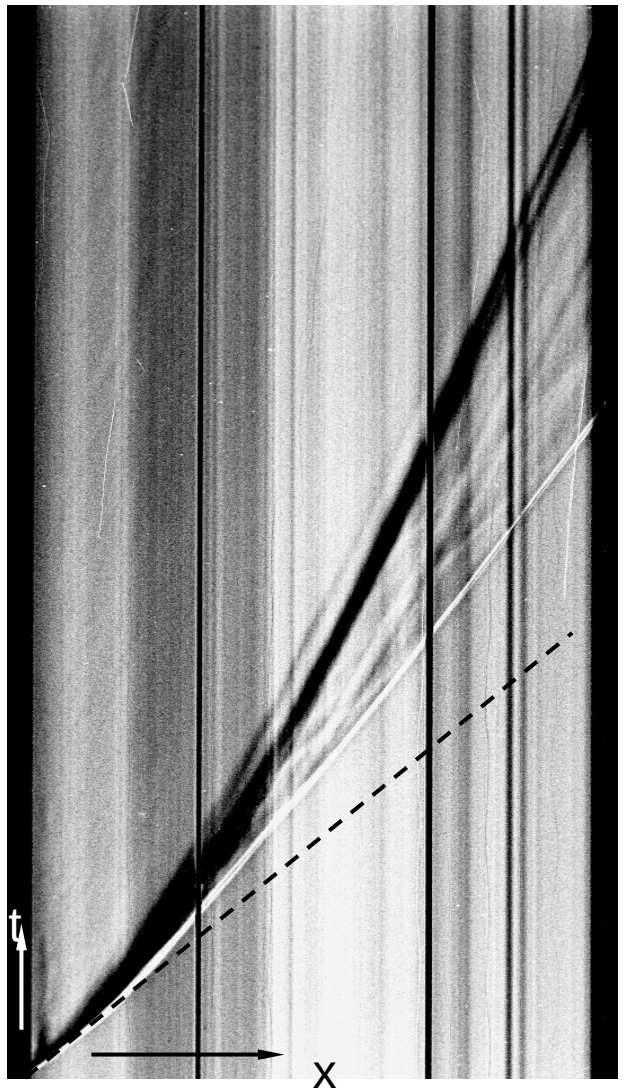
Detonation quenching by perforated plate

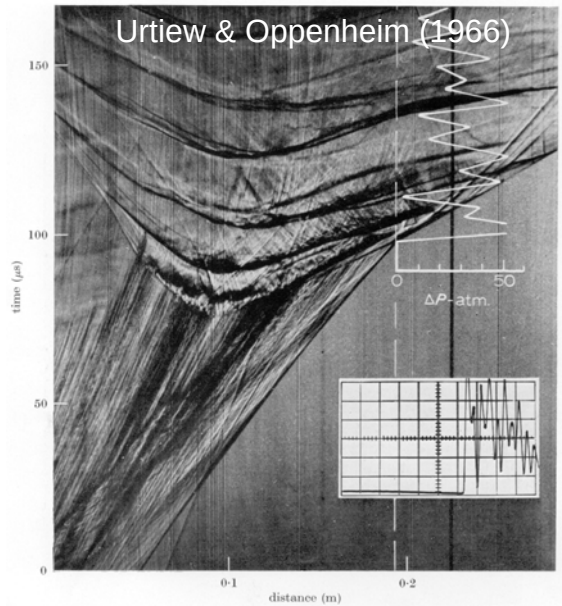


(Courtesy of J.Chao, McGill University)

Detonation quenching by perforated plate



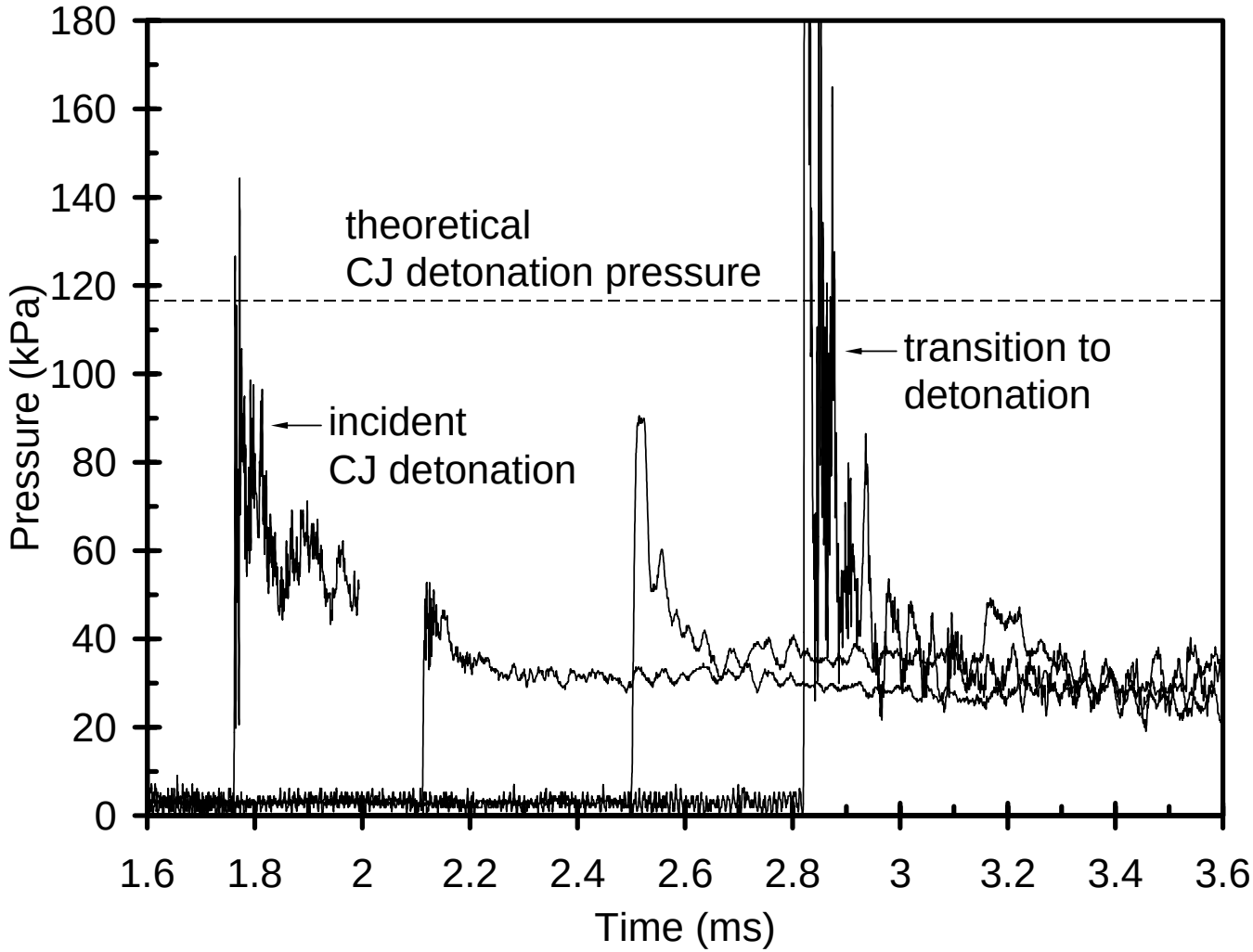




1200 m/s

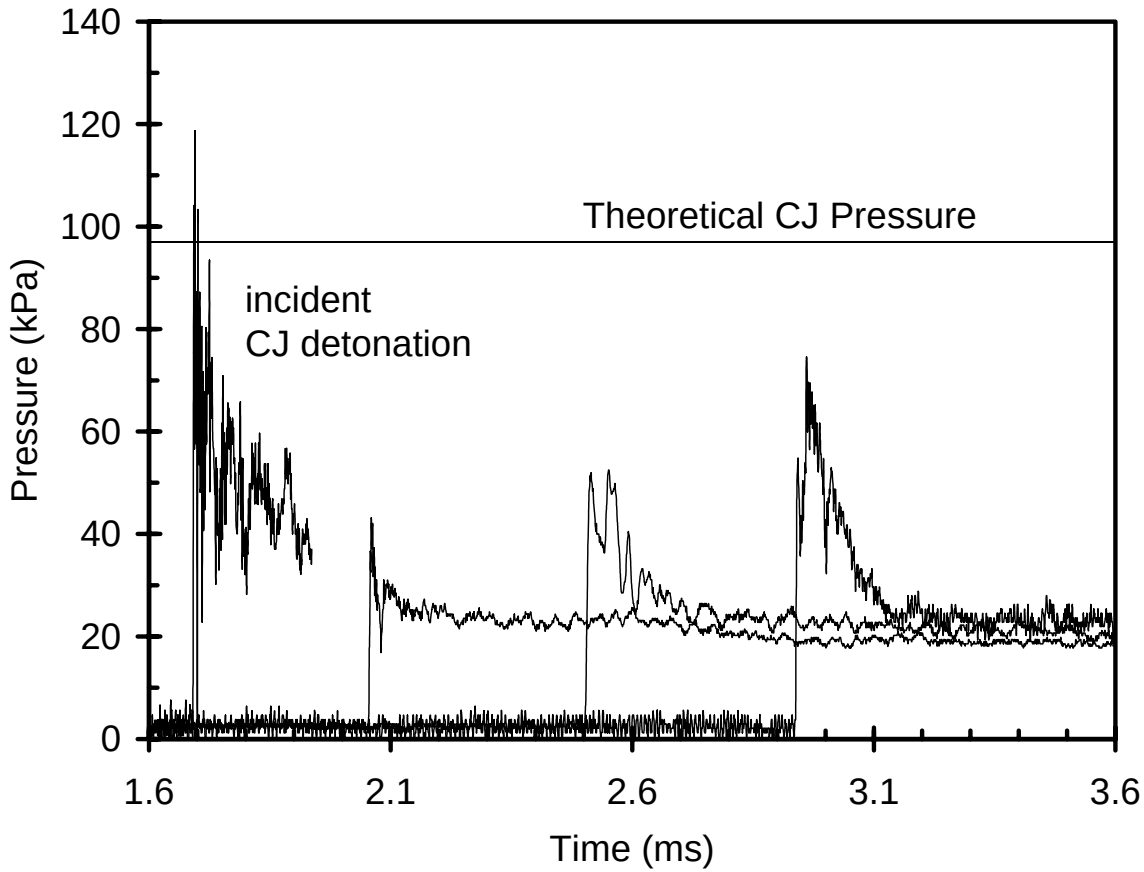
(Courtesy of J.Chao, McGill University)

Detonation quenching by perforated plate



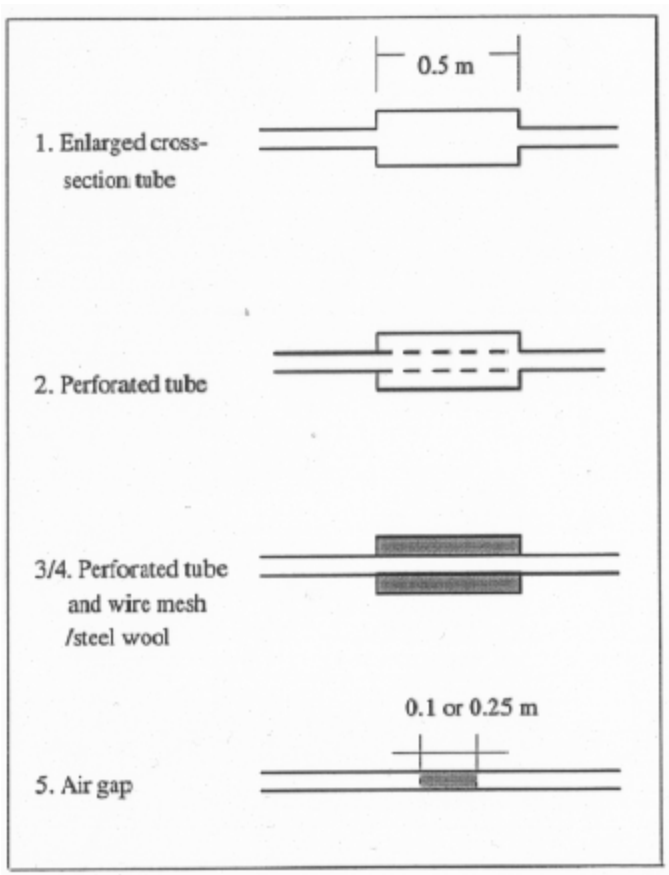
(Courtesy of J.Chao, McGill University)

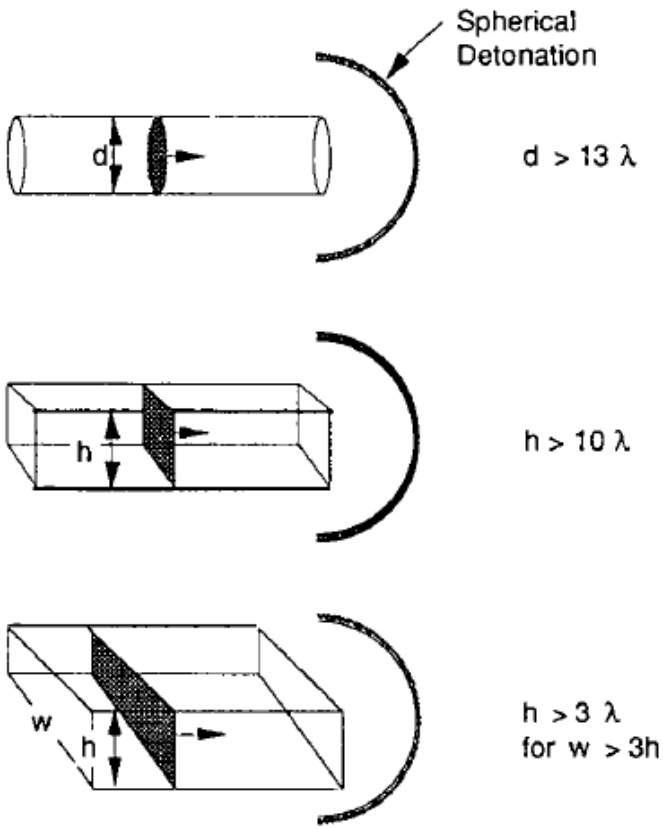
Detonation quenching by perforated plate

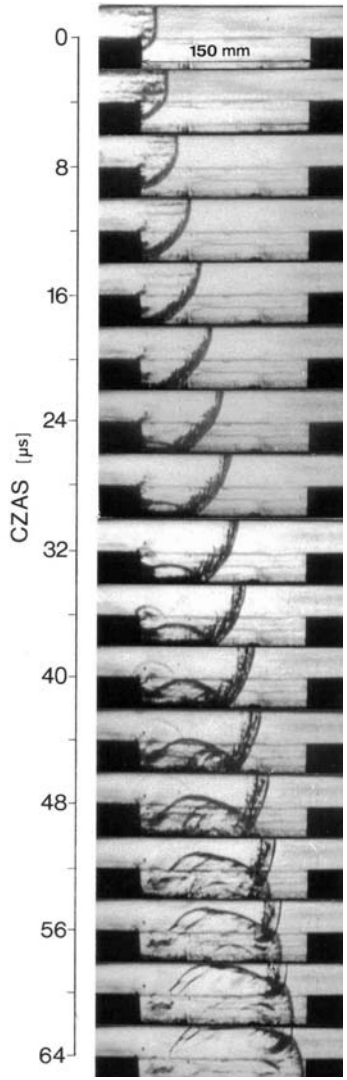


(Courtesy of J.Chao, McGill University)

Detonation quenching by diffraction

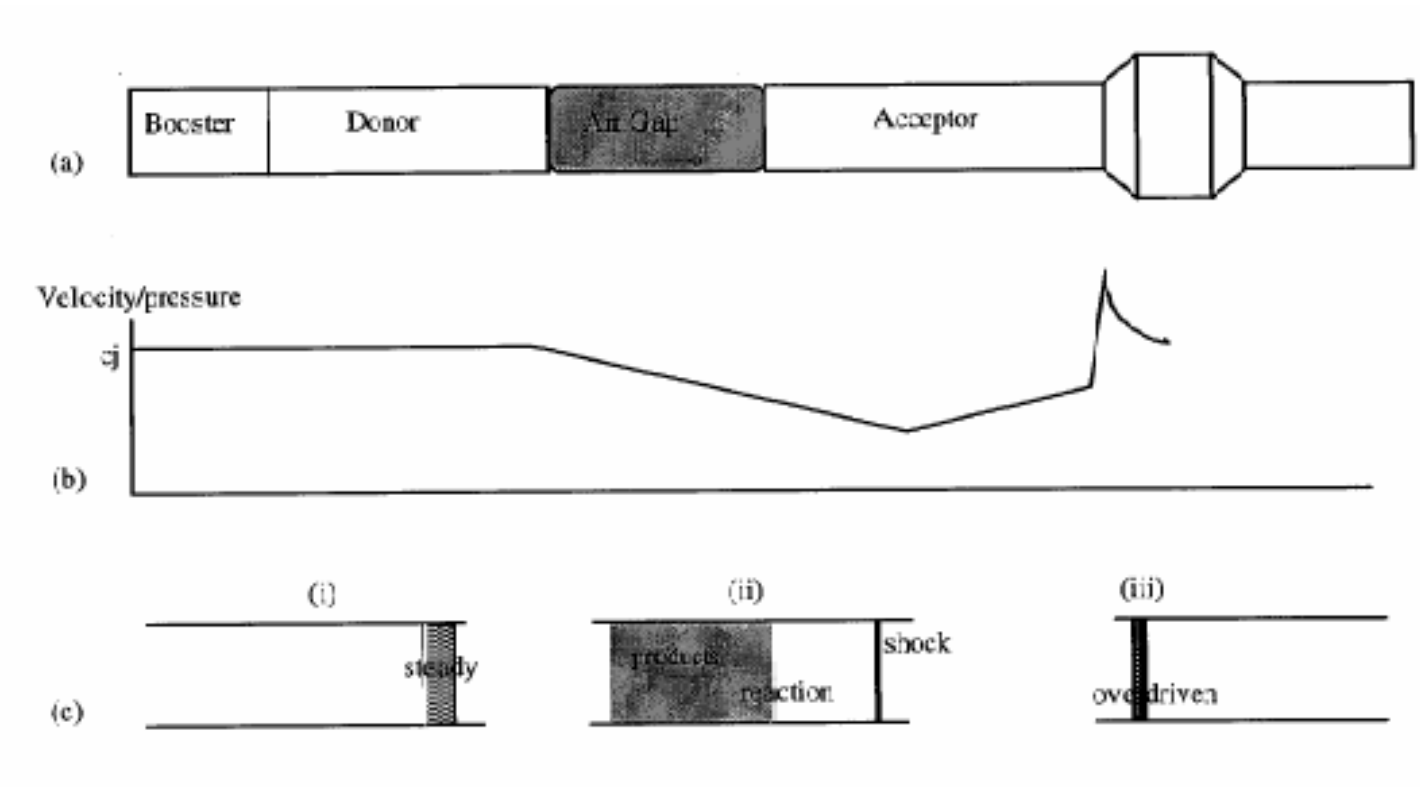






Detonation quenching by air gap

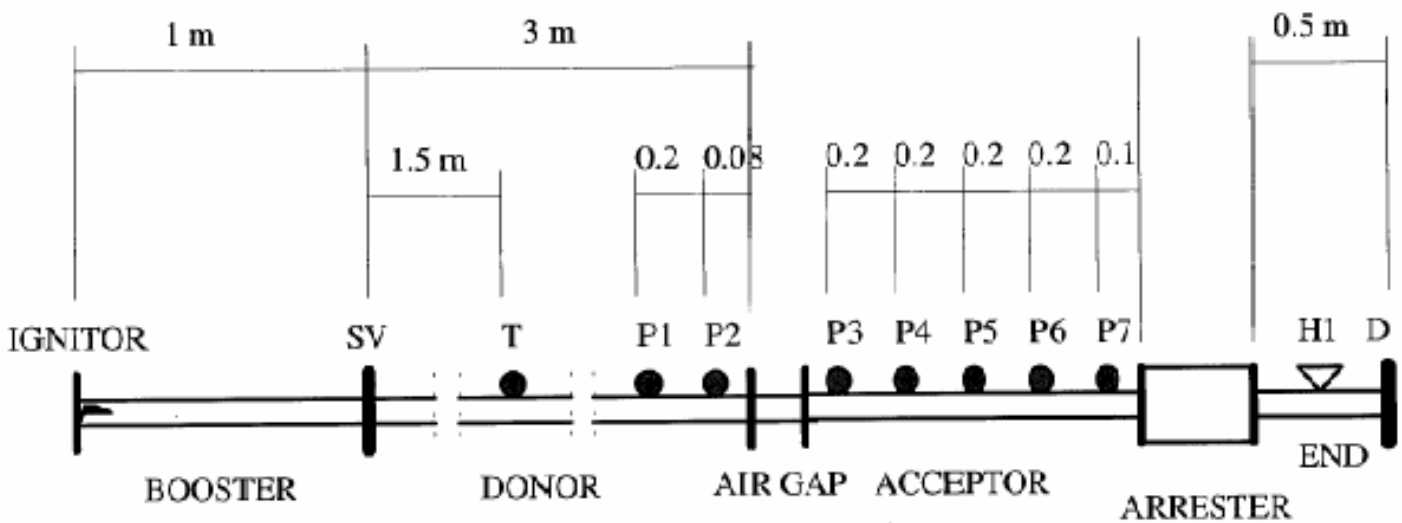
Objective: controlled DDT for testing arresters



Detonation quenching by air gap

Experimental setup

- 50 mm tube
- 0.1MPa initial pressure



P - pressure transducer

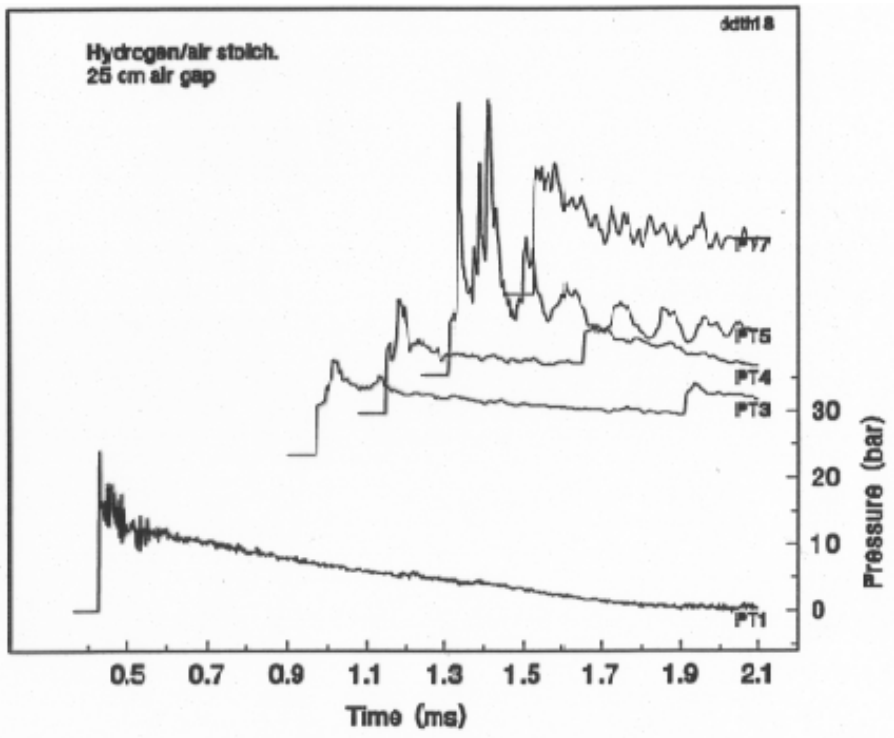
H - photodiode

T - trigger transducer

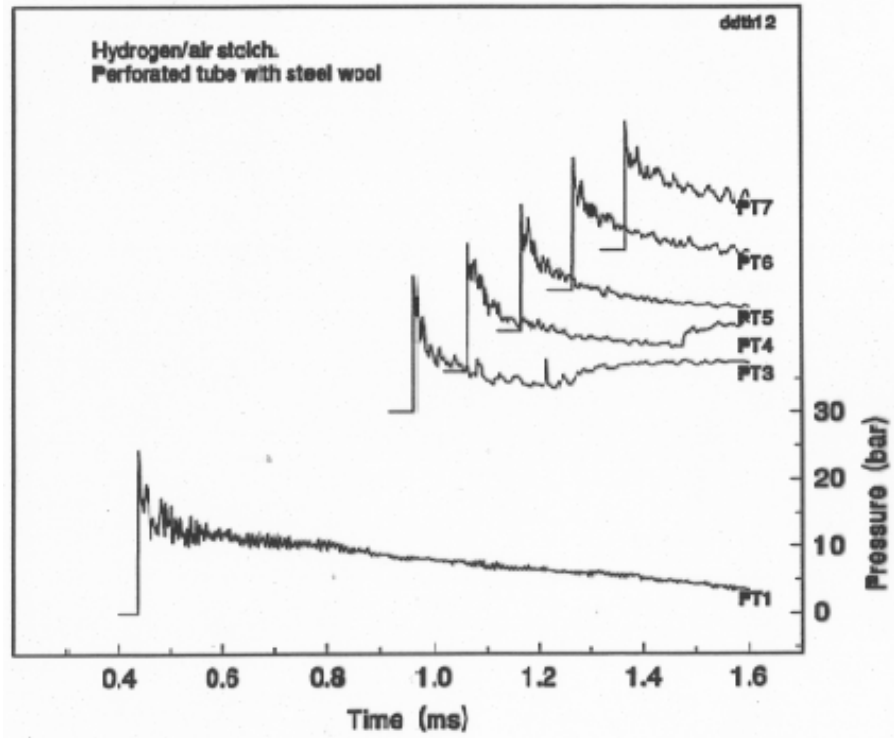
SV - slide valve

D - diaphragm

Detonation quenching by air gap

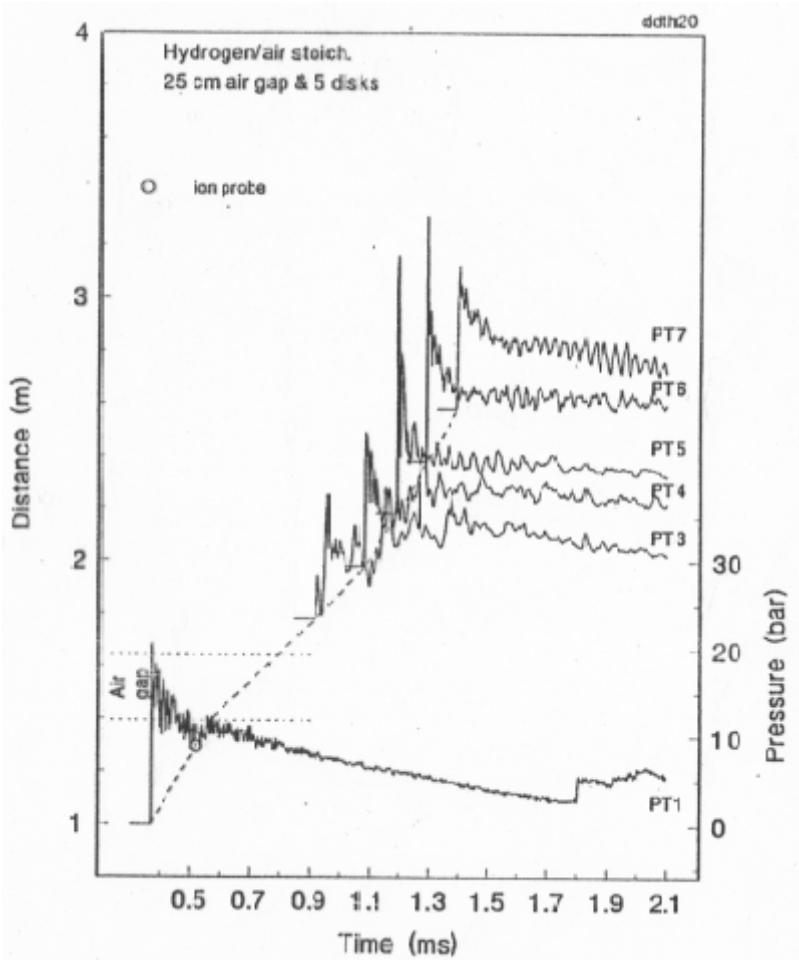


Quenching and DDT

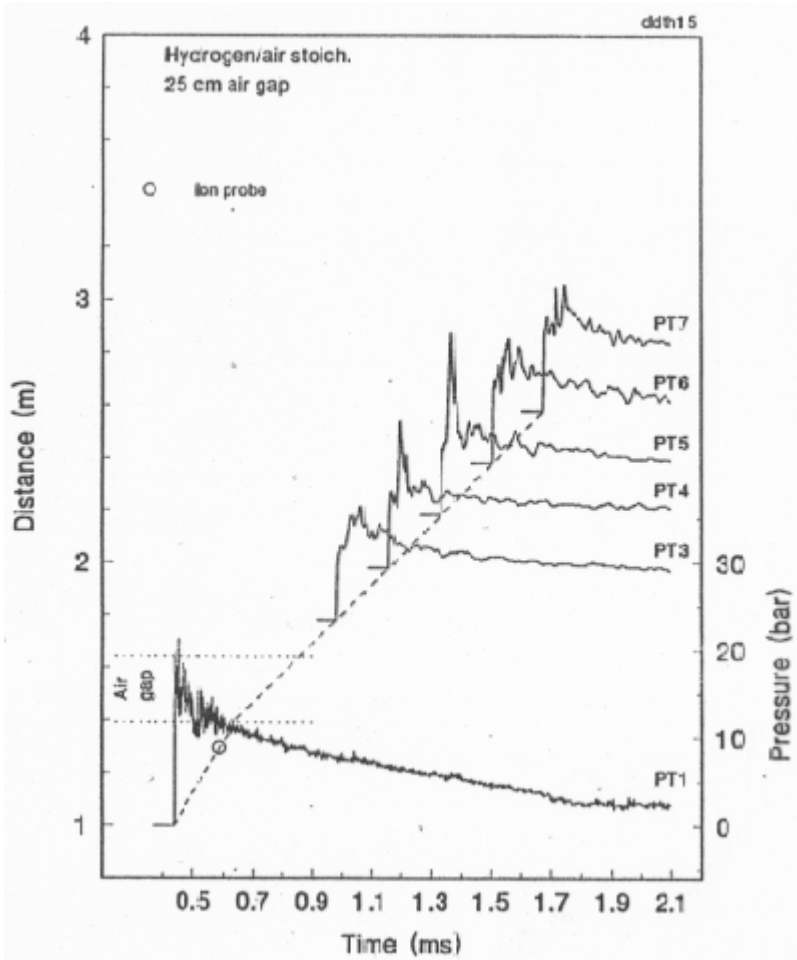


No quenching

Detonation quenching by air gap

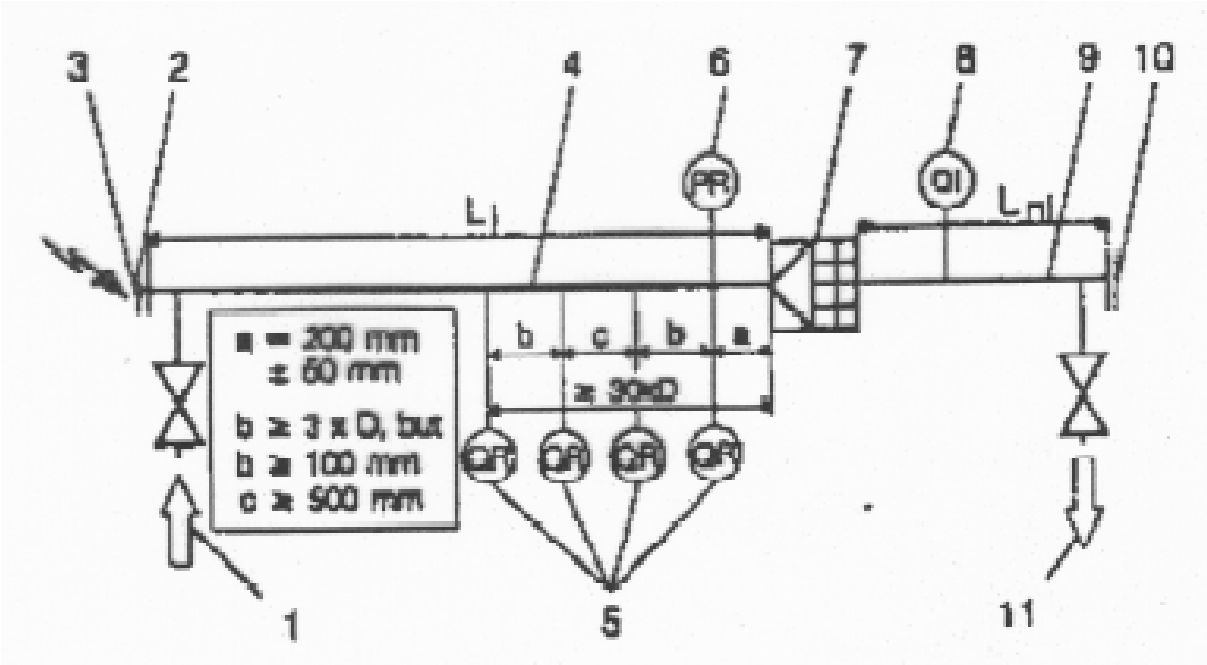


Quneching and DDT



Quenching

Testing of arresters



1 Mixture inlet
2 Explosion proof container or pipe end
3 Ignition source
4 Unprotected pipe (length L_i, diameter D)
5 Flame detectors for flame velocity measurement
6 Pressure transducer
7 Detonation flame arrester
8 Flame detector
9 Protected pipe (length L_{ni}, diameter D)
10 Pipe end
11 Mixture outlet

BRITISH STANDARD

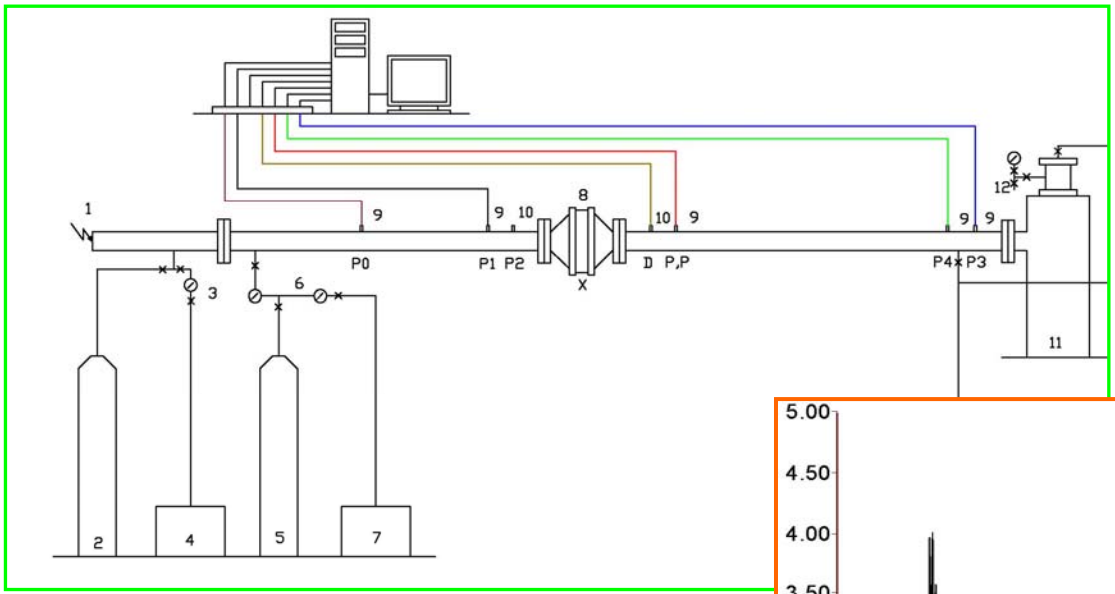
BS EN 12874:2001

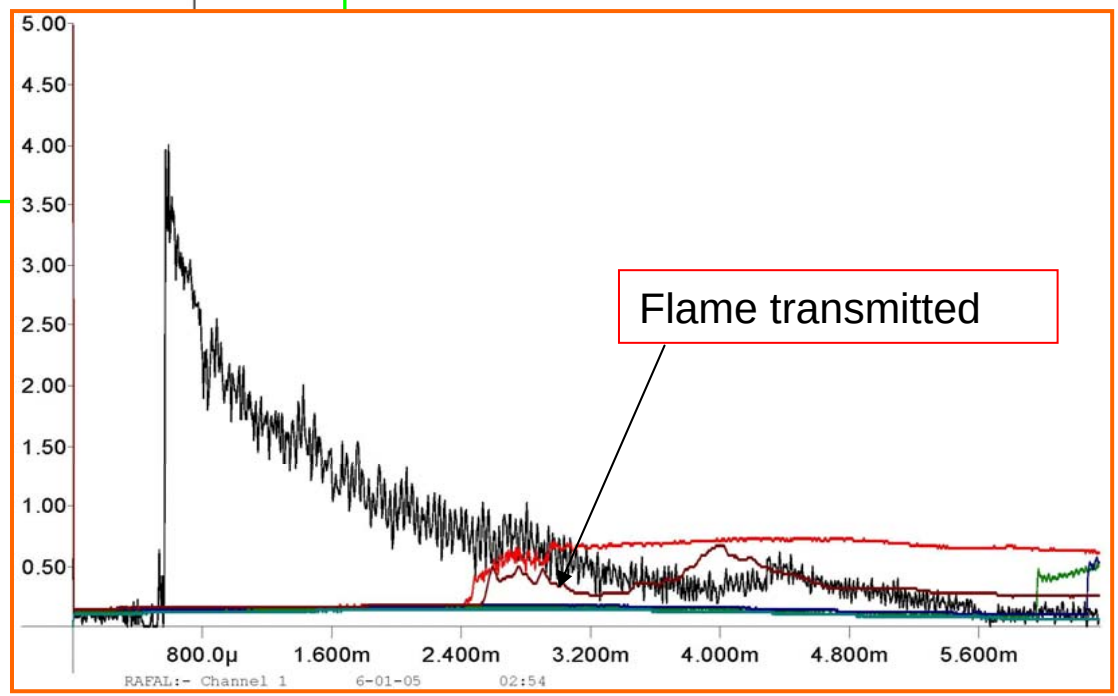
Flame arresters — Performance requirements, test methods and limits for use

The European Standard EN 12874:2001 has the status of a British Standard

ICS 13.220.99; 13.230

Testing of arresters





8 - arrester

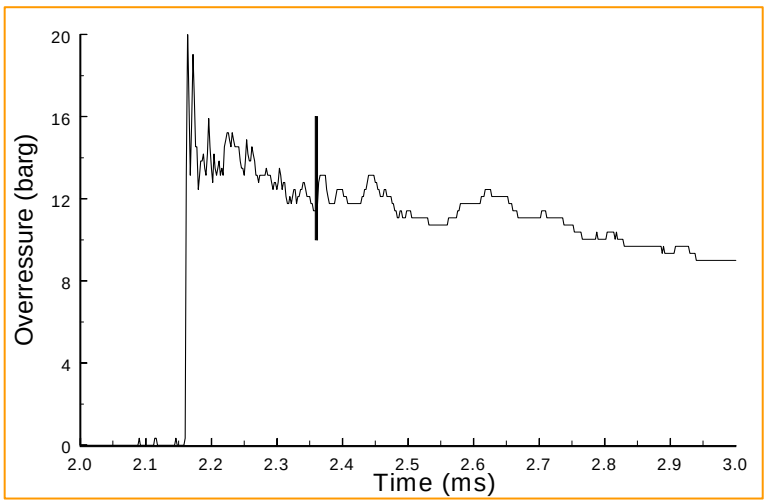
9 – pressure transducer

10 – photodiode

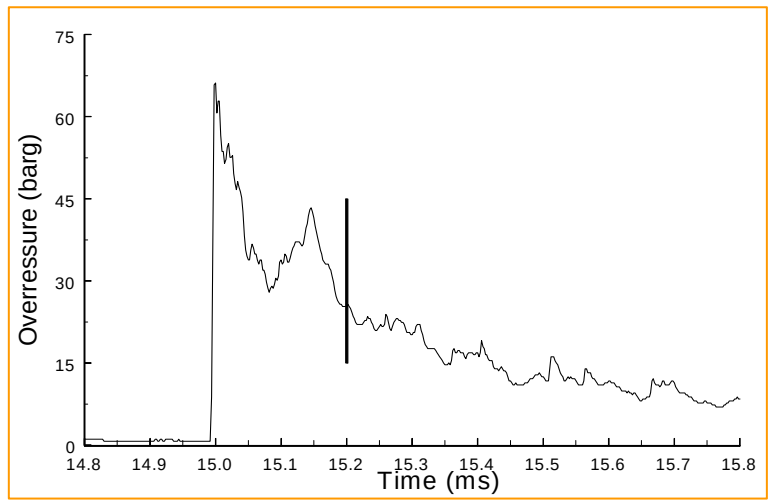
Testing of arresters

Problems:

- existing protocols for testing arresters differ from country to country
- unsteady detonations – DDT, overdriven
- fast deflagration vs CJ detonation
- tests are subject to misinterpretation



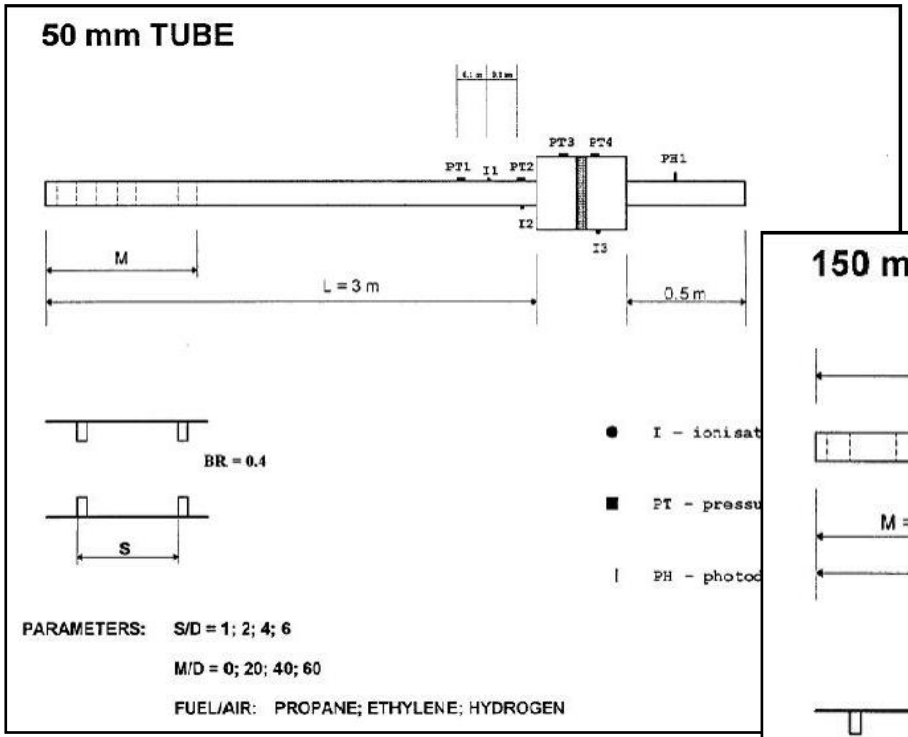
CJ detonation

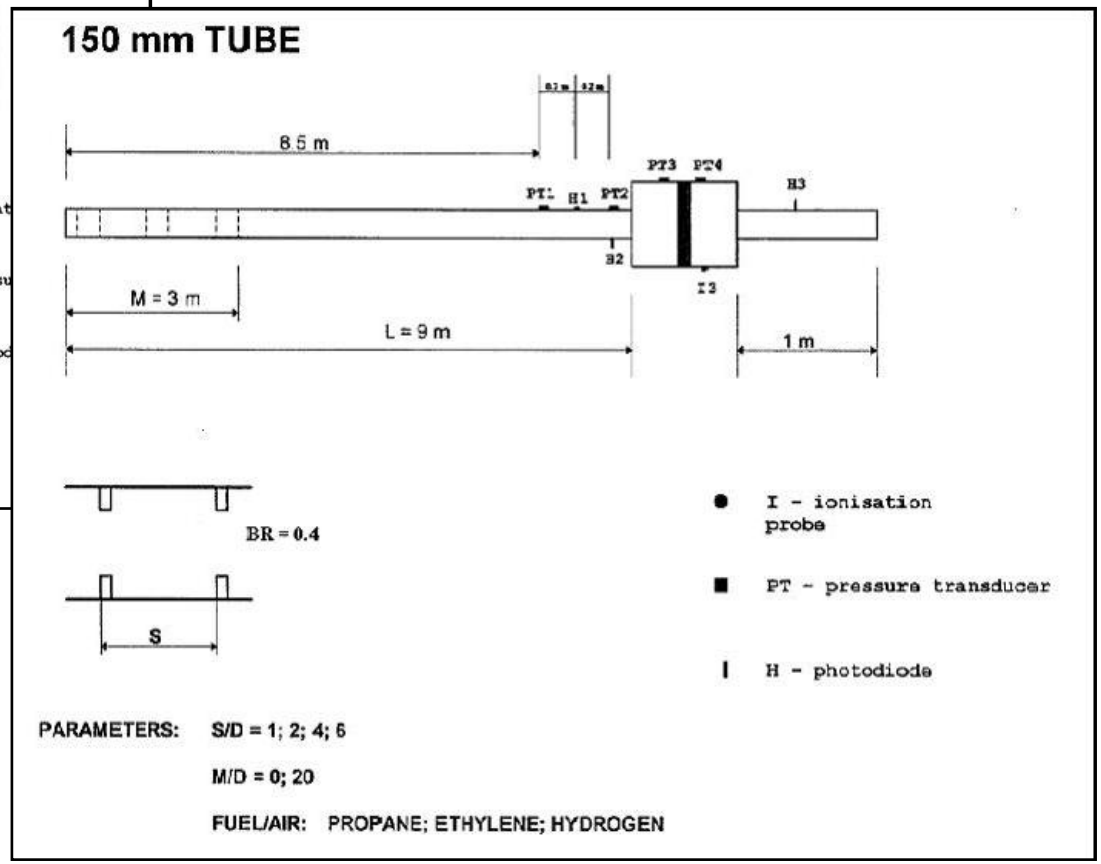


Overdriven detonation

Testing of arresters

Scaling effect

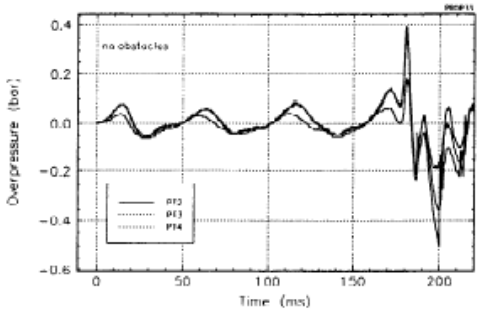




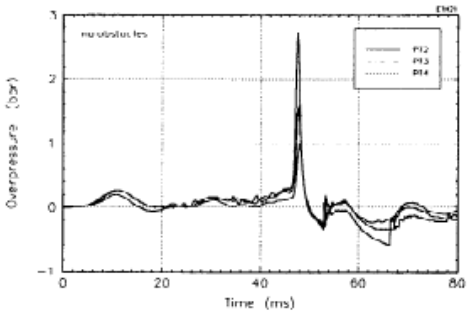
Summary of the tests for 50 mm and 150 mm tubes showing arrester responce: (+) succesesful, flame stopped; (-) failure, flame passed; and the type of combustion wave achieved at the end of flame tube: DF - deflagration, DT - detonation, QDT - quasidetonation, DDT - deflagration to detonation transition, ODT - overdriven detonation

S/D	Mixture	50 mm				150 mm
		M/D				
		0	20	40	60	M/D=20
1	Propane-air	(+) DF	(+) DF	(+) DF	(+) DF	(+) DF
	Ethylene-air	(+) DF	(-) DF	(+-) DF	(+) DF	(-) DT
	Hydrogen-air	(-) DF	(-) DT	(-) DT	(-) QDT	(-) DT
2	Propane-air		(+) DF	(+) DF	(+) DF	(+) DF
	Ethylene-air		(-) DF	(-) DT	(+) QDT	(-) DF, DT
	Hydrogen-air		(-) DT	(-) DT	(-) DT	(-) DT
4	Propane-air		(+) DF	(+) DF	(+) DF	(+) DF
	Ethylene-air		(-) DF	(-) DF, QDT	(-) DT	(-) DF, DT
	Hydrogen-air		(-) DT, DDT	(-) DF, DT	(-) DT	(-) DT
6	Propane-air		(+) DF	(+) DF	(+-) DF, DDT	(+) DF
	Ethylene-air		(-) DF	(-) DF, DT	(-+) DF, DDT	(-) DT
	Hydrogen-air		(-) DDT, DT	(-) DT	(-) DT	(-) DT

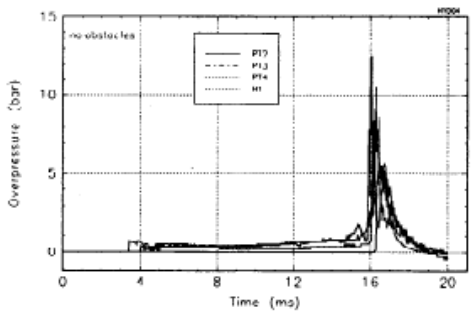
Pressure histories without obstacles



Propane-air

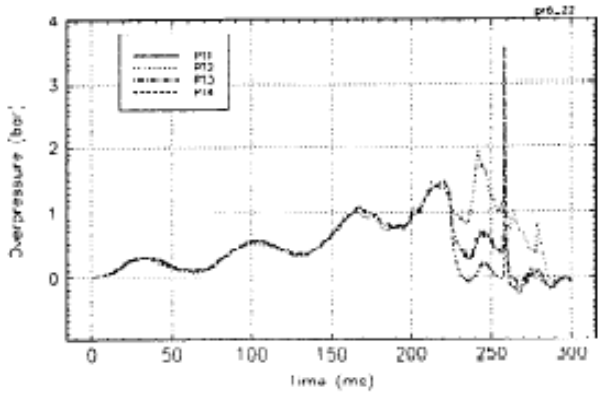


Ethylene-air

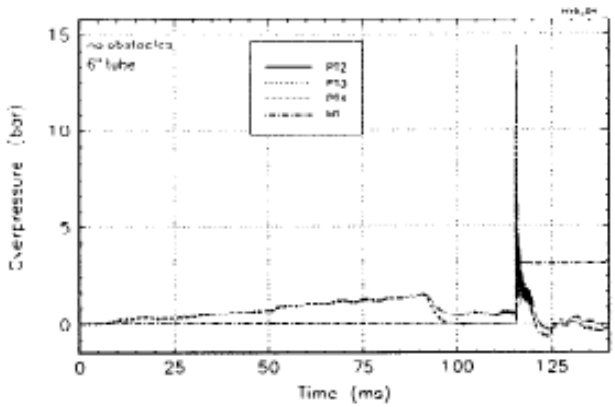


Hydrogen-air

50 mm tube



Propane-air

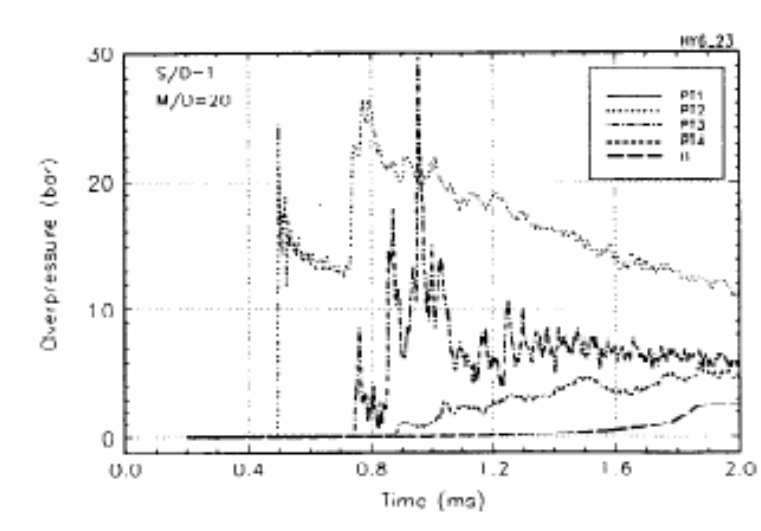


Hydrogen-air

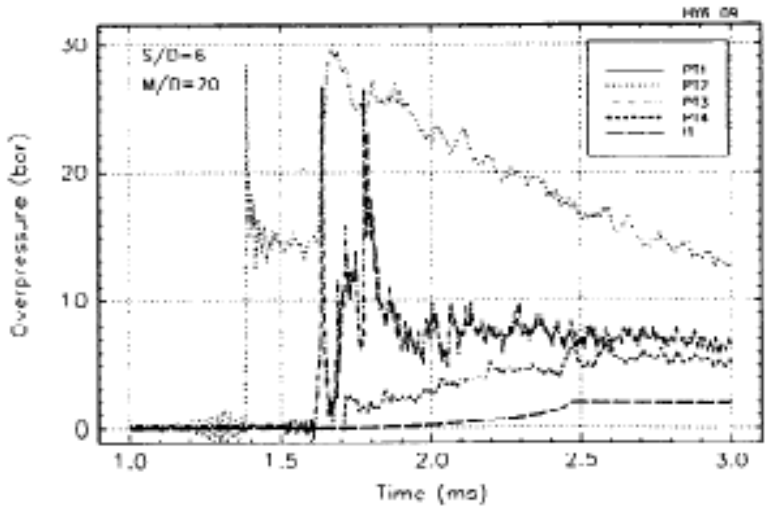
150 mm tube

Pressure histories with obstacles

150 mm tube



Hydrogen-air



Hydrogen-air