# Evaluation of Hazards Associated with $H_2$ Combustion

## Mid-Term Assessment Workshop

**Brussels**
**02 October 2002**

**Presentation by**
**S. Dorofeev**

**FZK,**
**Germany**

# Hazards associated with $H_2$ combustion



## Introduction

- For introduction of $H_2$ as a retail fuel quantitative safety and risk assessment is needed
- This requires quantitative methodology for evaluation of hazards associated with $H_2$ combustion or explosion
- The following issues should be addressed for hazard evaluation
  - Combustion regime (slow flames, fast supersonic flames, detonations)
  - Pressure and thermal loads inside the mixture
  - Air blast waves and thermal radiation outside
  - Missiles

# Hazards associated with $H_2$ combustion



## Background

- Straightforward solution - **fully resolved simulation of turbulent reactive flows with multi-species chemistry** – will stay out of reach for quite some time to come

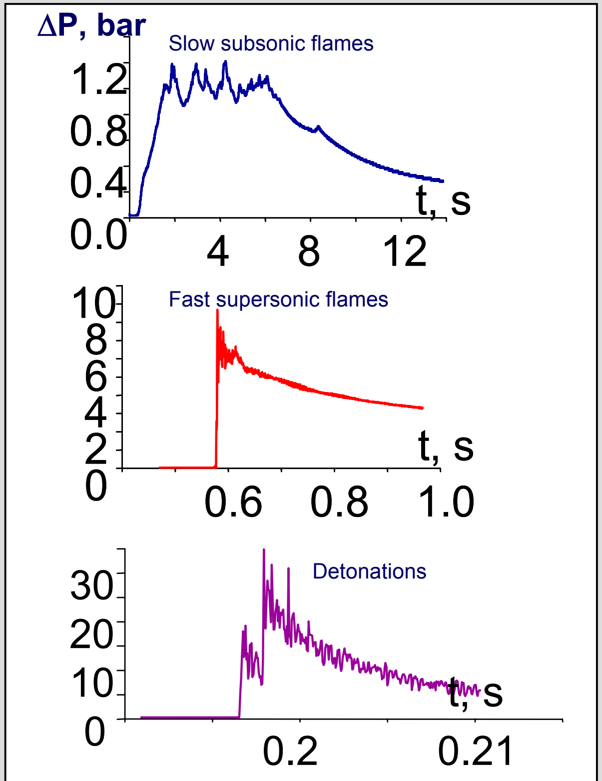
- Approach for evaluation of hazard potential from combustion events that has been explored so far is largely empirical
  - Address key issues experimentally
  - Develop analytical and engineering models for hazard evaluation
  - Validate "under-resolved" numerical tools for explosion simulation

- Most of activities have been focused on
  - Unconfined and confined explosion of CH fuels (chemical/fuel industry)
  - Hydrogen combustion behavior under confined conditions (nuclear energy)

# Hazards associated with $H_2$ combustion

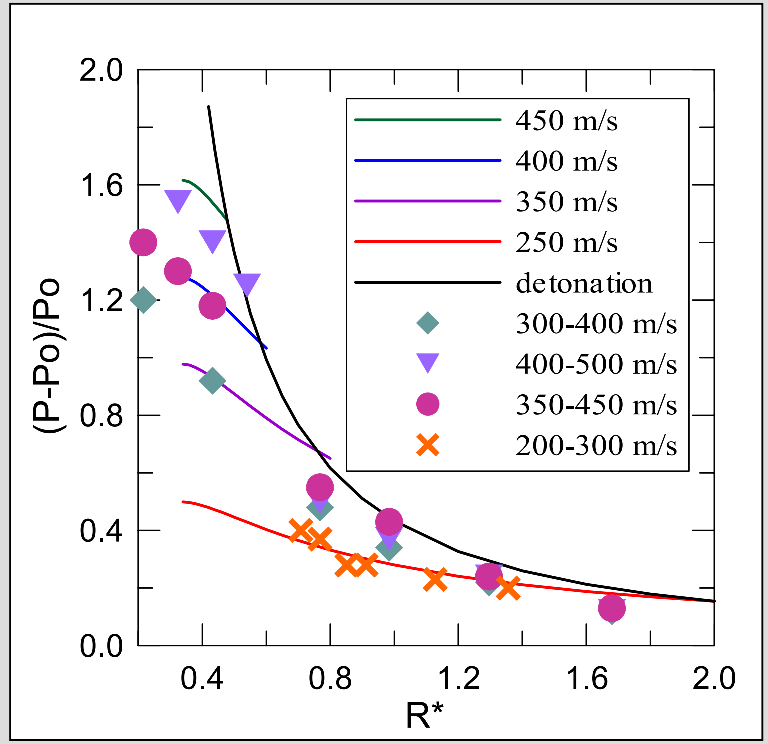
## Key issue: How fast can it burn?

- Combustion regime is important. Hazards from various explosion events depends significantly on the flame speed




Pressure loads typical for various combustion regimes in confined explosions

Air blast overpressure as a function of flame speed

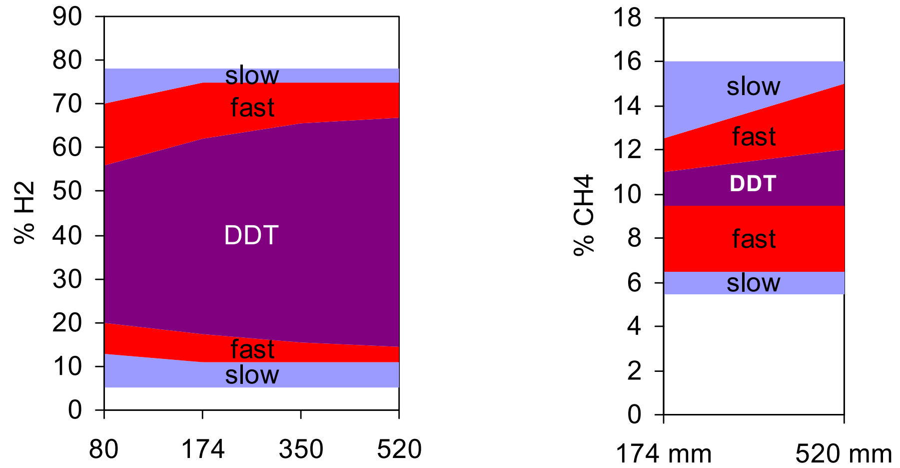


# Hazards associated with $H_2$ combustion

## Criteria for FA and DDT

- Critical conditions for strong FA and DDT were studied extensively, especially for **confined explosions**
- Limits for fast flames and DDT depend not only on composition but also on geometry, scale, and initial thermodynamic state
- Criteria were formulated for FA ($\sigma>\sigma^*$) and DDT ($L>\alpha\lambda$) and tested against wide variety of experimental data

Composition limits for fast flames and DDT in tubes (BR=0.6) versus tube diameter for $H_2$ and $CH_4$

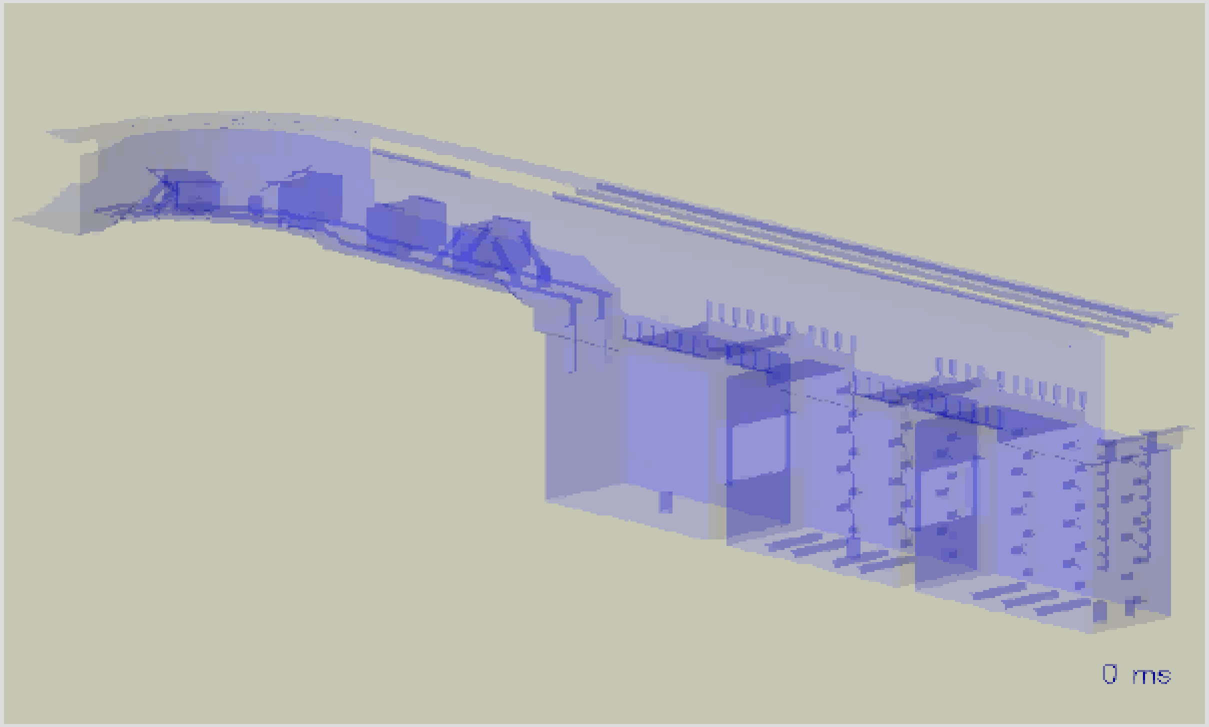


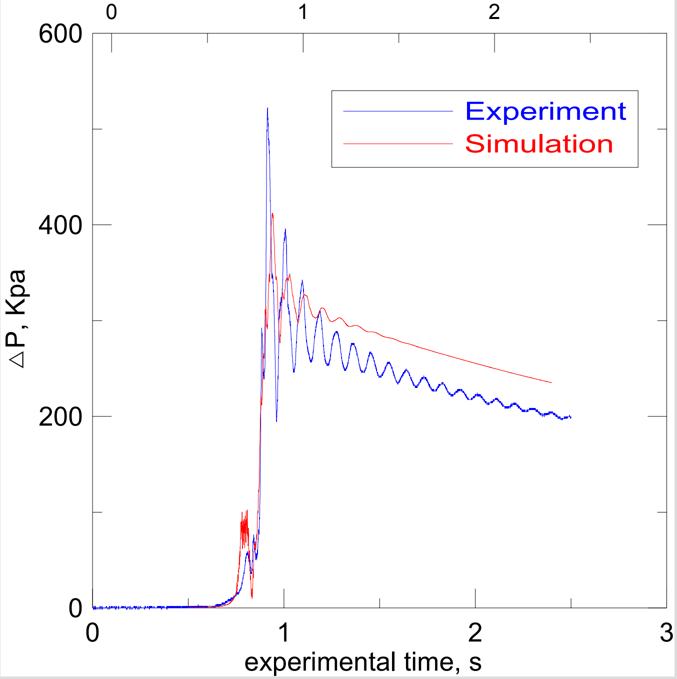
# Hazards associated with $H_2$ combustion



## Validation of combustion codes

- Example of code validation against large-scale experimental data (RUT facility). Blind simulation of $H_2$-air deflagration with B0X code (CREBCOM package, KI)



# Hazards associated with $H_2$ combustion

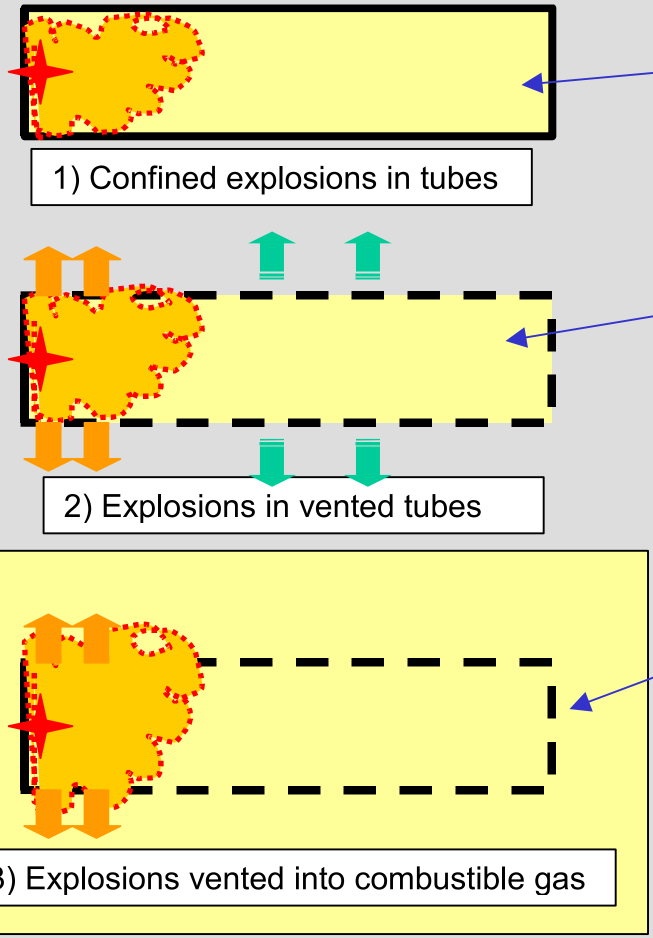


## Approach

- Safety and risk studies of $H_2$-fuel involve accidental releases of hydrogen into a partially vented, partially confined geometry
- These cases are relatively less understood compared to cases of confined geometry
- To take advantage of data and understanding available
- Experimental data should be useful to provide quantitative methodology for safety and risk studies

# Hazards associated with $H_2$ combustion

## Approach




- Case 1): relatively well understood
- Case 2): can be related to some accident situations, and serves as a bridge between case 1) and the main problem case 3)
- Case 3) is directly related to real applications involving the geometry of vehicles/infrastructure

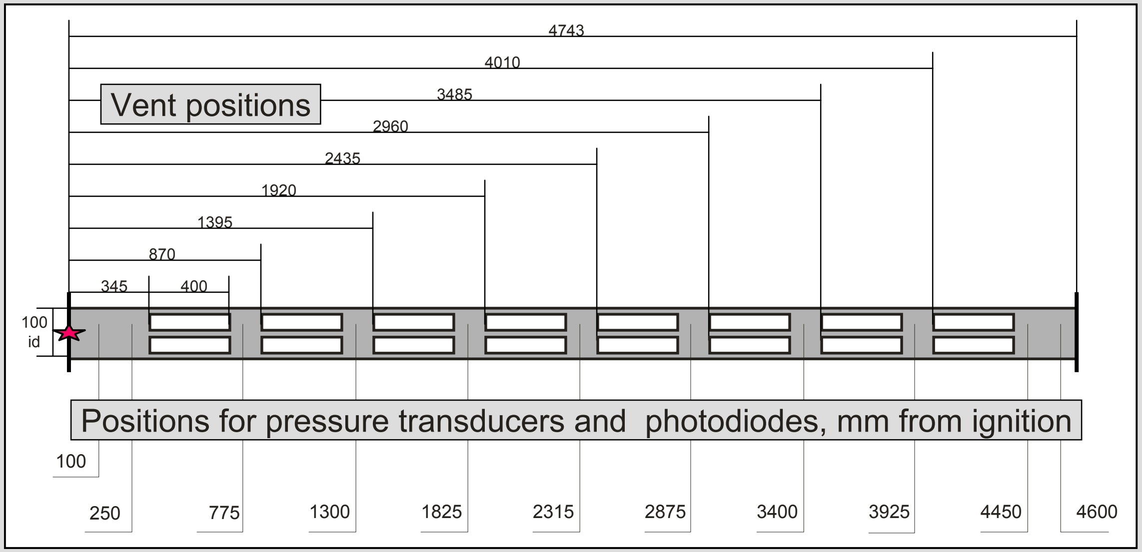
# Hazards associated with $H_2$ combustion

## Objectives of EIHP 2 experimental program

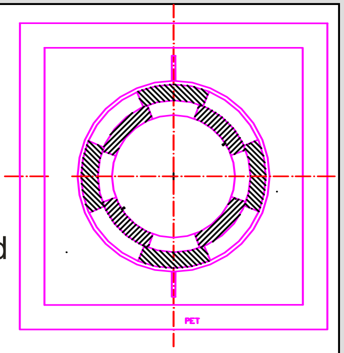
- Study of critical conditions for strong Flame Acceleration and DDT in vented tubes and semi-confined geometry;
- Comparison of explosion properties of hydrogen and typical hydrocarbon fuels in semi-confined geometry
- Generation of the data necessary for validation of computer codes for simulation of gaseous explosions in semi-confined geometry.

# Hazards associated with $H_2$ combustion

## Tests in vented tube



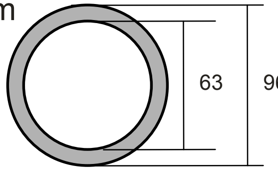

Mutual position of inner tube, outer tube, and frame



Orifice plate obstacles

Spacing: 100 mm

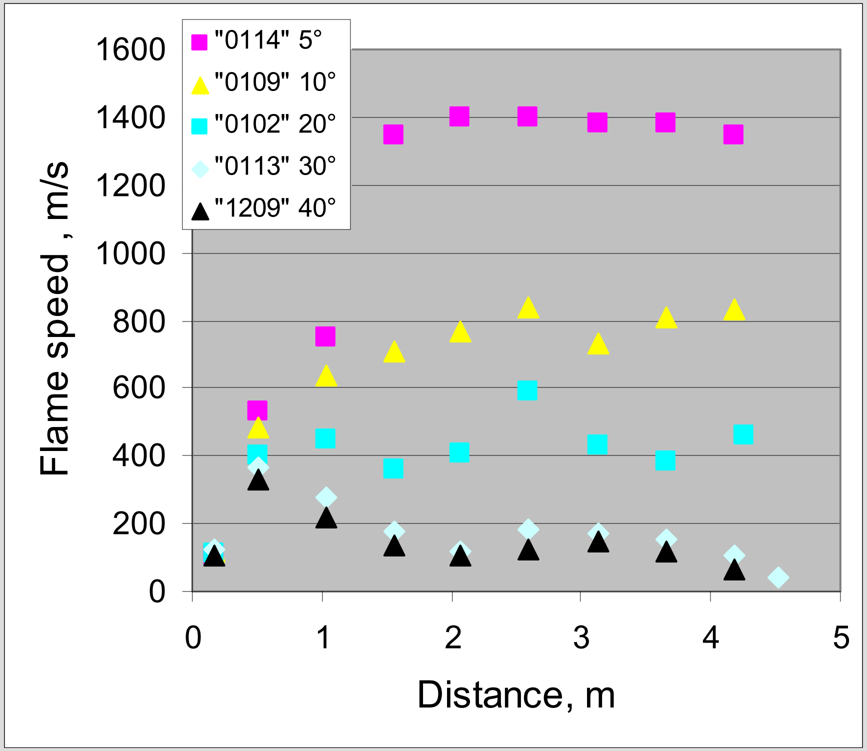
Thickness of the plates: 10 mm



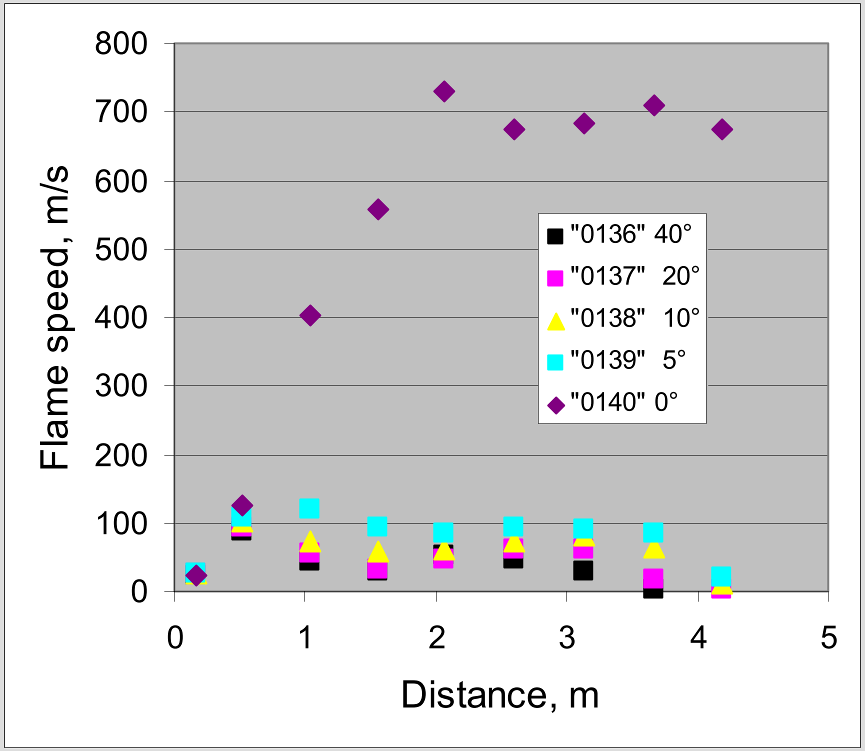
# Hazards associated with $H_2$ combustion

## Tests in vented tube

- Results: flame speeds versus distance




25% $H_2$



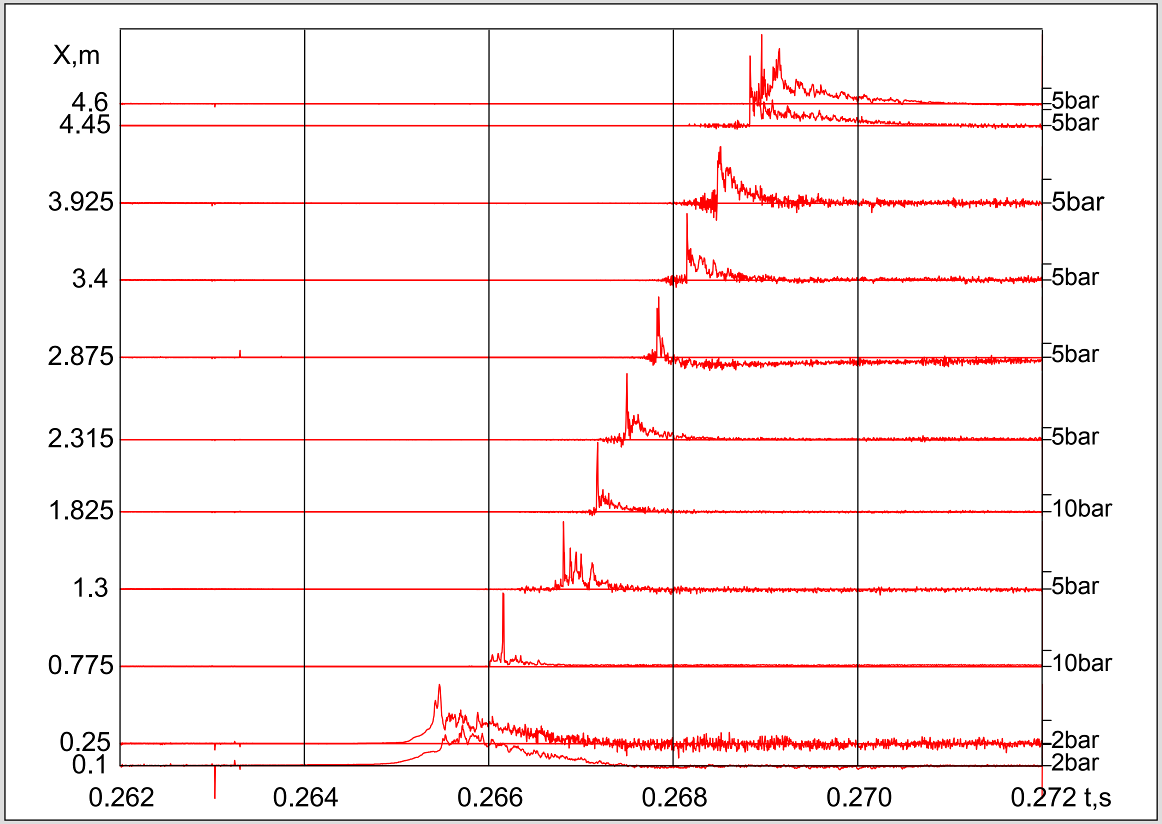

9.5% $CH_4$

# Hazards associated with $H_2$ combustion



## Tests in vented tube

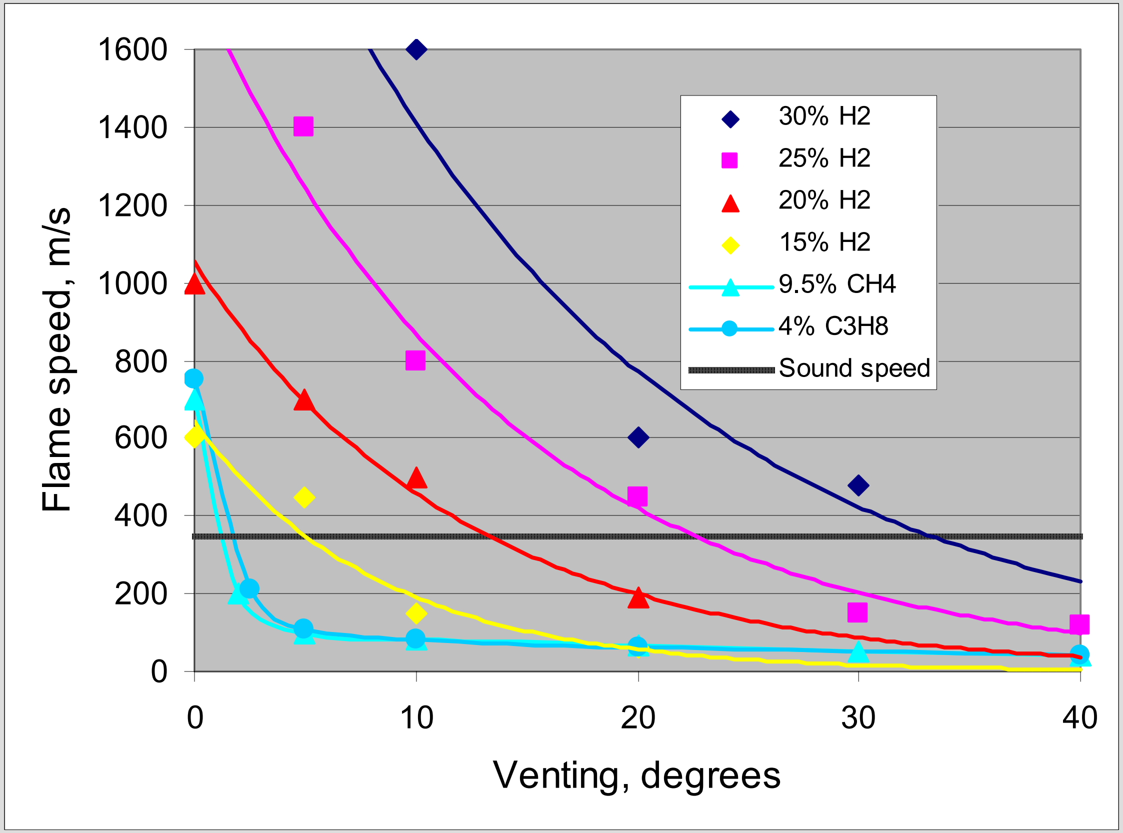
- Results:
  - pressure records inside the tube
  - data necessary for code validation



# Hazards associated with $H_2$ combustion

## Tests in vented tube

- Final flame speeds
  - effect of venting
  - effect of mixture composition
- $H_2$ shows wider range of compositions for fast flames
- Potential for $H_2$ – flames to accelerate is less affected by geometry constrains

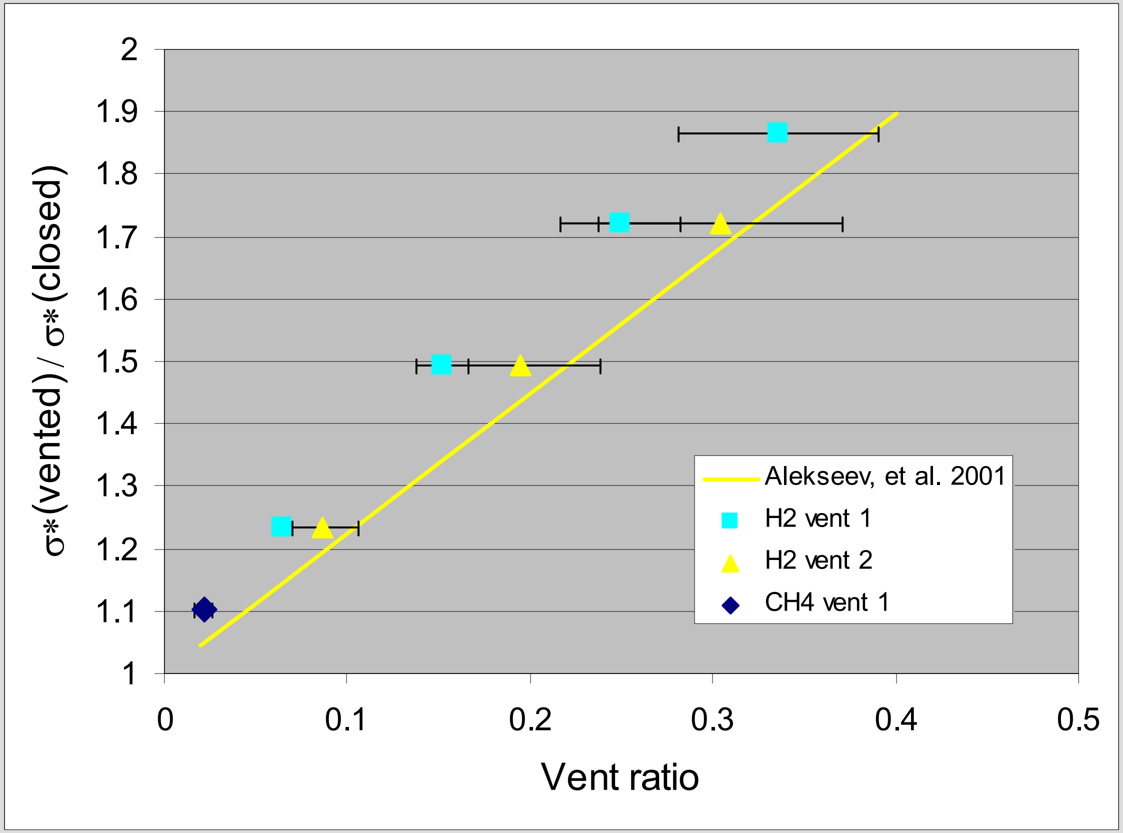


# Hazards associated with $H_2$ combustion



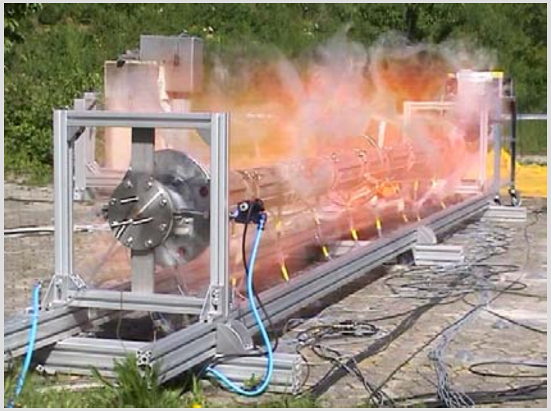
## Tests in vented tube

- Critical conditions for strong FA
- Minimum expansion ratio of a mixture $\sigma^*$, necessary for strong FA increases with venting

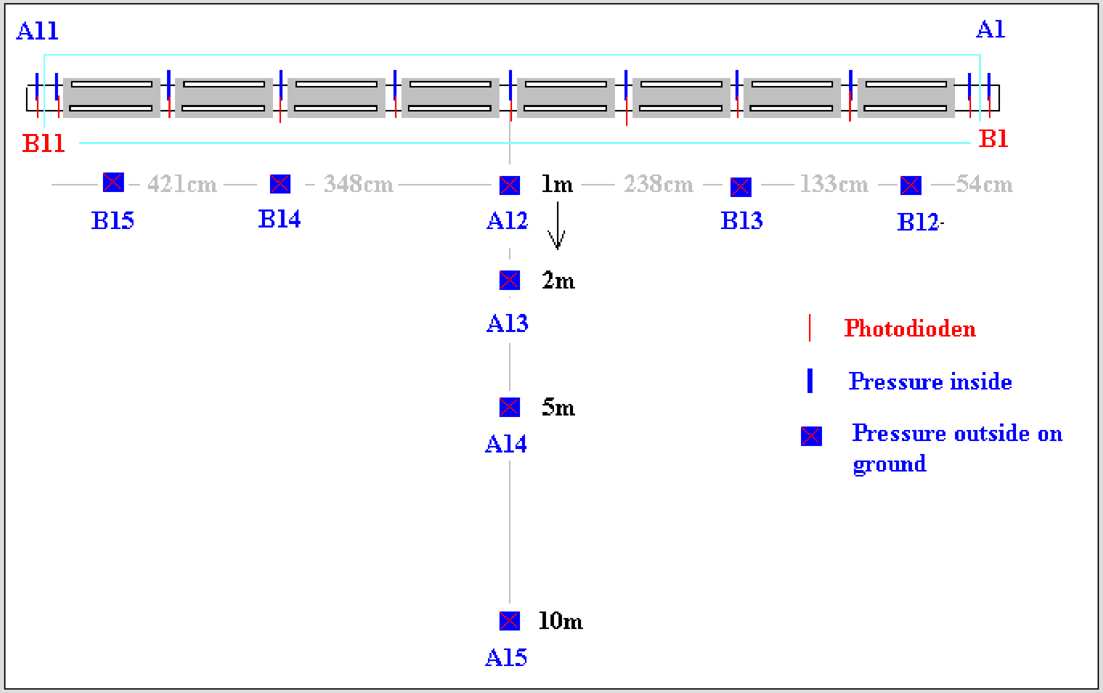


# Hazards associated with $H_2$ combustion

## Tests in semi-confined geometry



Positions for pressure transducers and photodiodes. Top view.

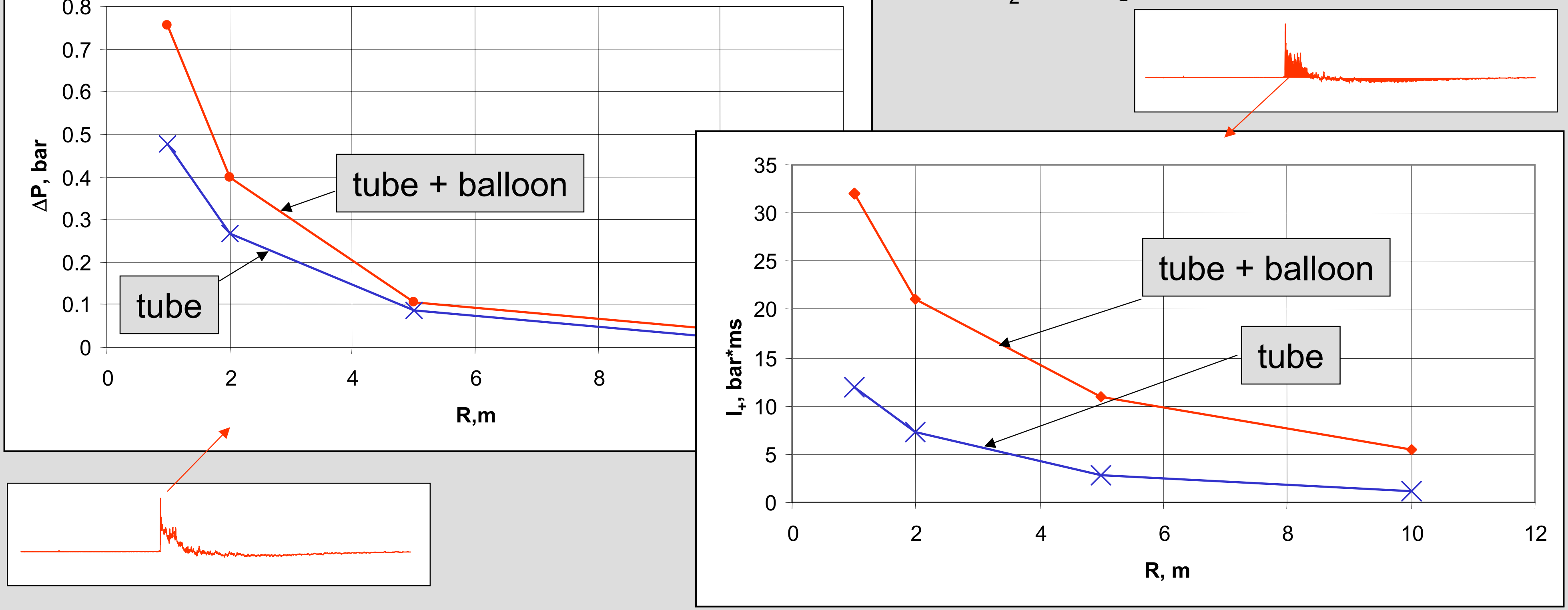


# Hazards associated with $H_2$ combustion

## Tests in semi-confined geometry

- Results: overpressure and impulse in air blast wave versus distance

30% $H_2$, venting 15°



# Hazards associated with $H_2$ combustion

## Summary

- Experimental data, models, and computer codes are available for evaluation of hazards associated with $H_2$ combustion
- Most of these tools are validated for confined hydrogen explosions
- EIHP experimental program have provided an important extension on the role of venting and semi-confined geometry on FA and DDT
- Tests on semi-confined $H_2$ explosions are in progress to provide data for code validation

# Hazards associated with $H_2$ combustion



## Issues

- More experimental data are necessary to cover wider variety of applications
  - Free plums and jets
  - Stratified layers
  - …
- All these should give a basis for development of methodology for evaluation of hazards from hydrogen explosions
- Extensive code development and validation work should be made to provide reliable input for quantitative safety and risk studies