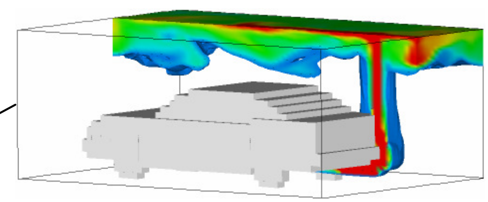
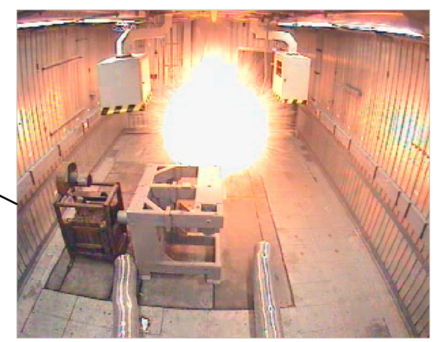
INVESTIGATION OF HYDROGEN DISTRIBUTION AND COMBUSTION IN ACCIDENT SCENARIOS

Applications

- Introduction
- Analysis steps
  1. Mixture generation
  2. Hazard evaluation
  3. Combustion simulation
  4. Consequence analysis
  5. Experimental research
- Summary





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OBJECTIVES

- Explosions of large amount of combustible gases mixed with air are responsible for the major part of losses and damages among many industrial accidents
- Growing utilization of hydrogen as future energy carrier requires better understanding of hydrogen related safety aspects
- The outcome of a hydrogen related accident depends on many parameters and complex physics
- Need to develop a mechanistic understanding and complete modeling procedure

  - to predict accident progress and consequences

  - to develop efficient mitigation measures

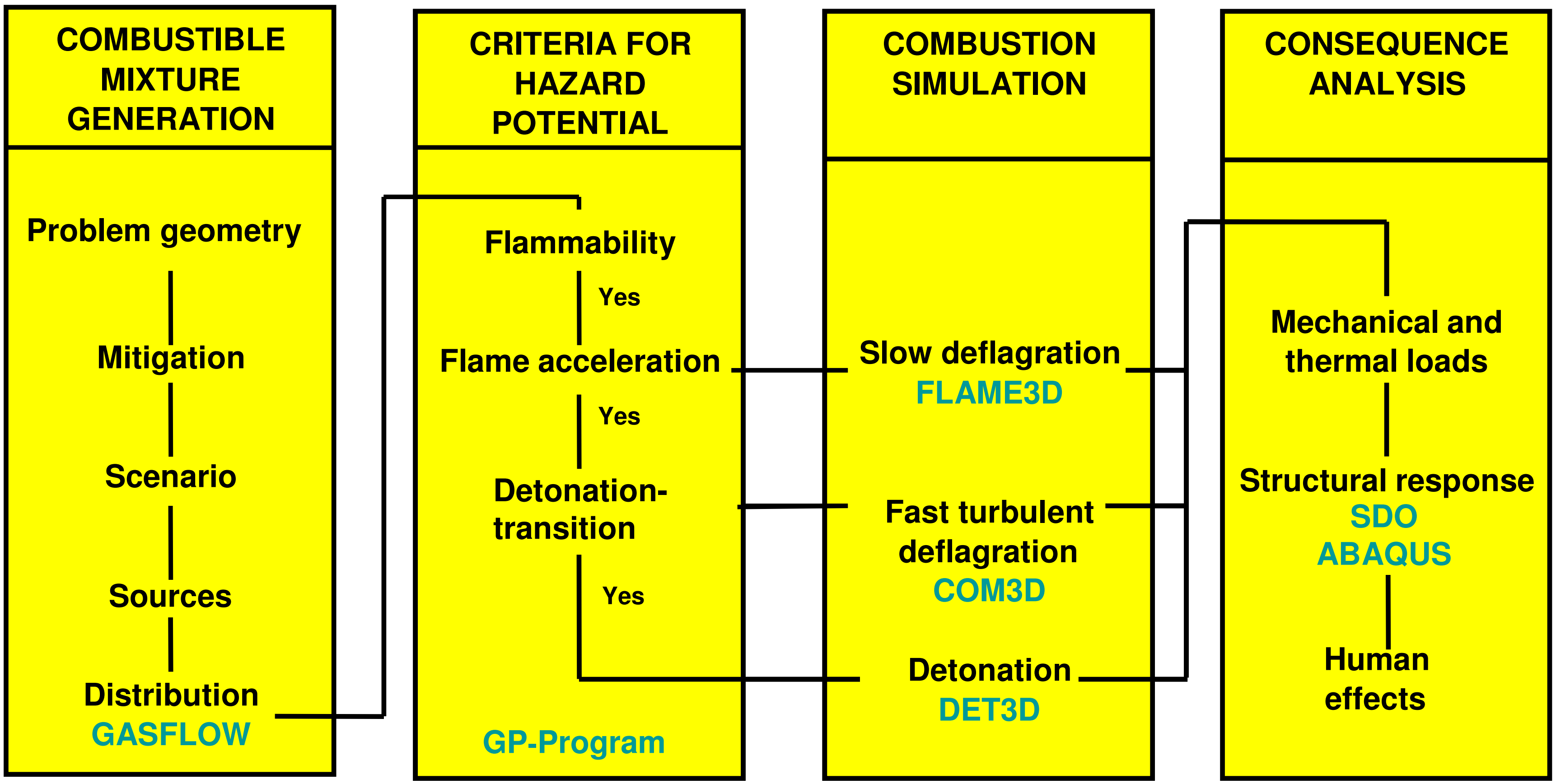
  - to support development of safe hydrogen technologies

  - to provide reliable data base for rules, codes and standards

- The presentation describes approach and current status of FZK analysis methodology

ANALYSIS METHODOLOGY

- FZK develops numerical codes and methods for consistent analysis of hydrogen behavior in accident scenarios, four main steps:



- More than 150 person-years of experience

1. MIXTURE GENERATION

- Release of cold GH_2 (22K) from LH_2-tank at bottom of vehicle in garage
- 1 W energy deposition, 170 g GH_2/d, 5 x 34g H_2 releases, effect of release rate on risk?

COMBUSTIBLE MIXTURE GENERATION

Problem geometry

Mitigation

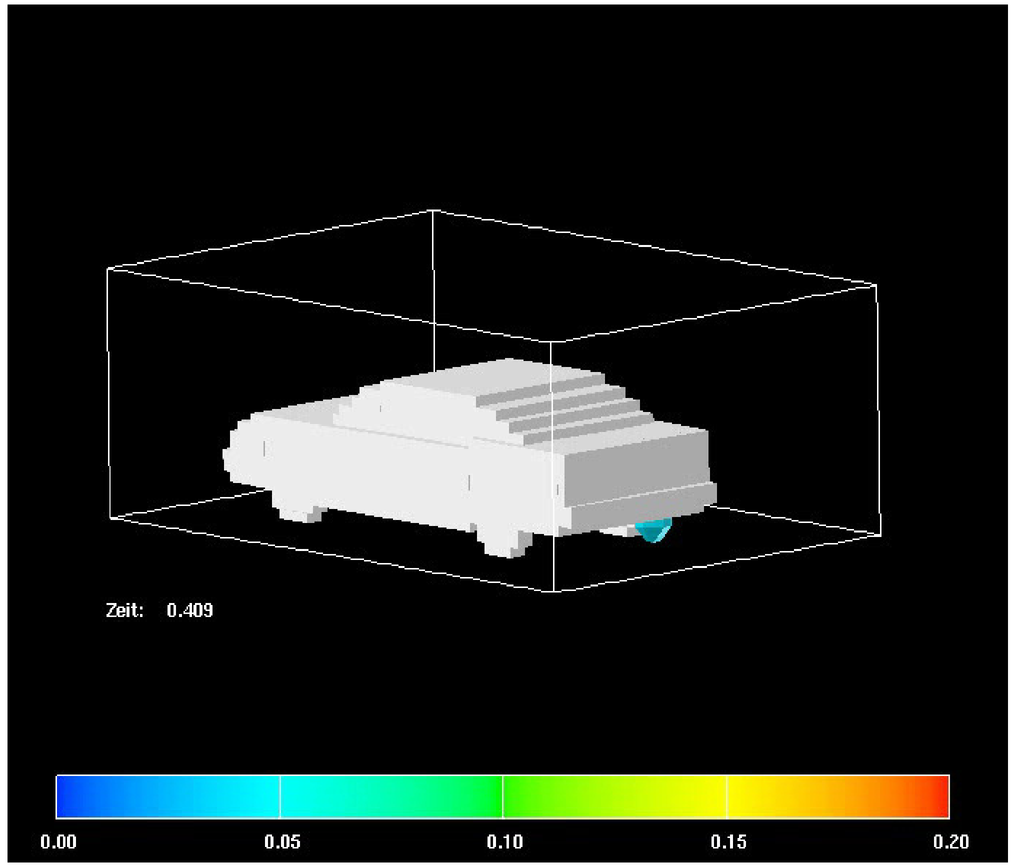
Scenario

Sources

Distribution
GASFLOW

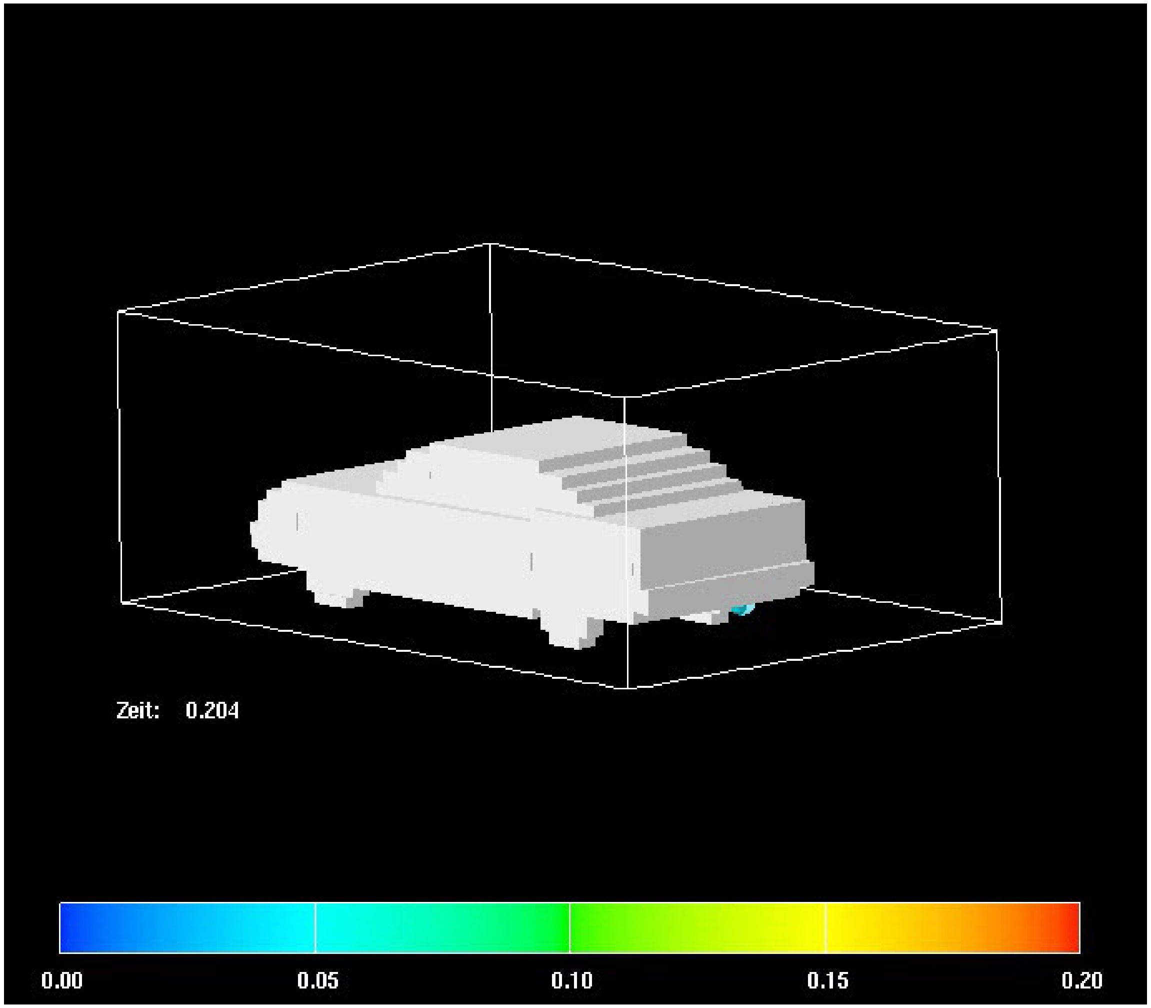
Case1:

3,4 g H_2/s
For 10 s



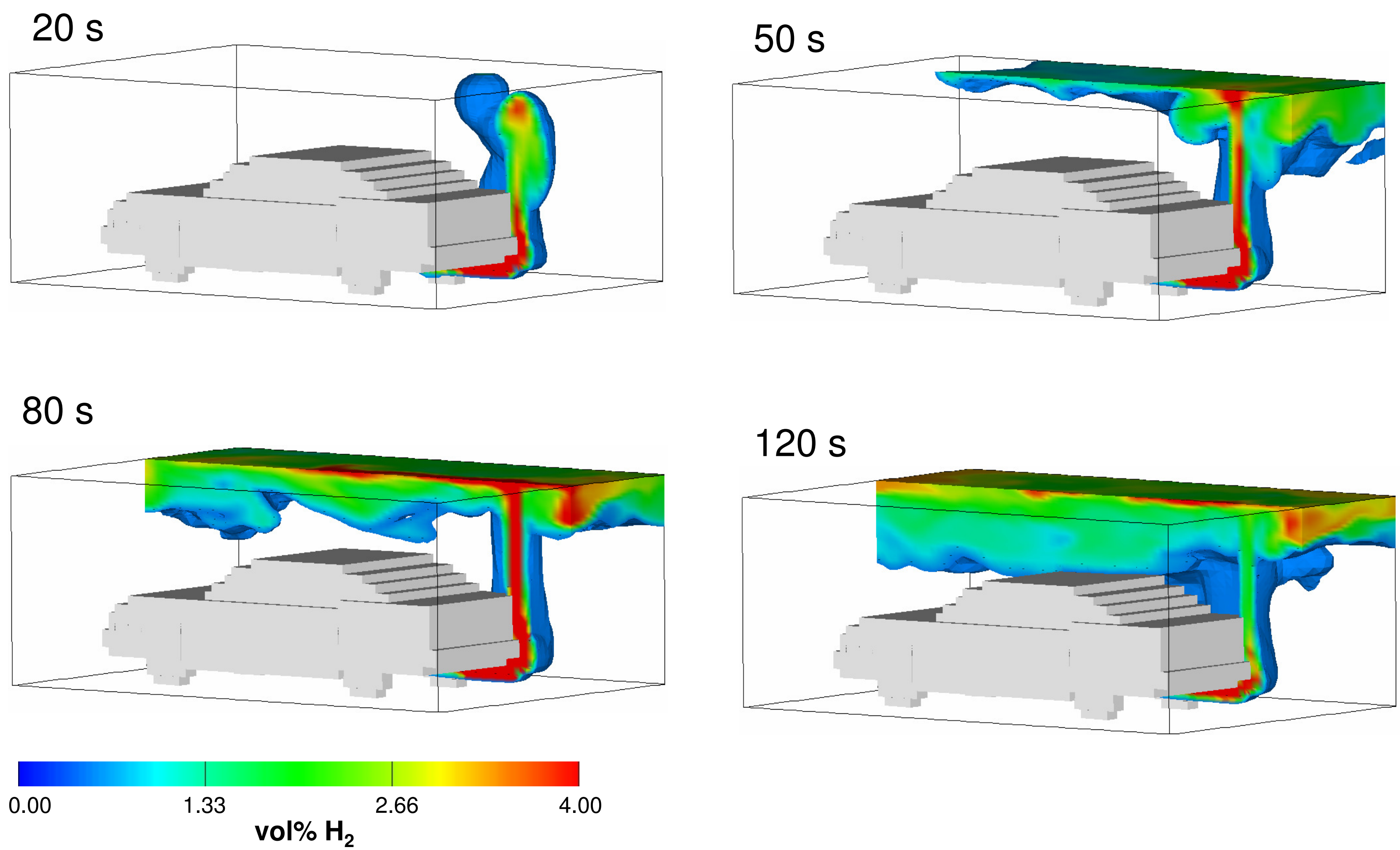
MIXTURE GENERATION : Case 2

- GH_2 source of 0,34 g H_2/s for 100s duration



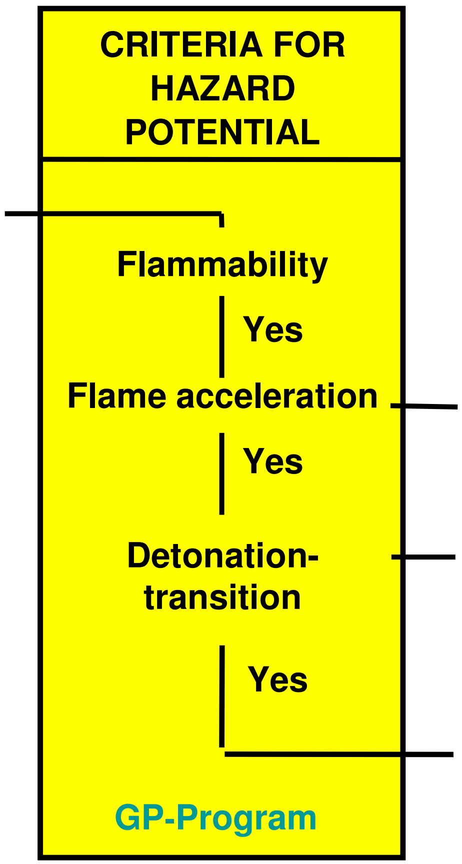
MIXTURE GENERATION :Case 2

- Calculated H_2-concentration field for 0.34 g H_2/s release in a garage, $\bar{x}$ = 0,6 vol%



II. HAZARD POTENTIAL

- What hazard is actually presented by the calculated H_2-air distribution ?



- Hydrogen hazard is mainly determined by the fastest possible combustion regime of the mixture
  - slow deflagration
  - fast turbulent deflagration
  - detonation

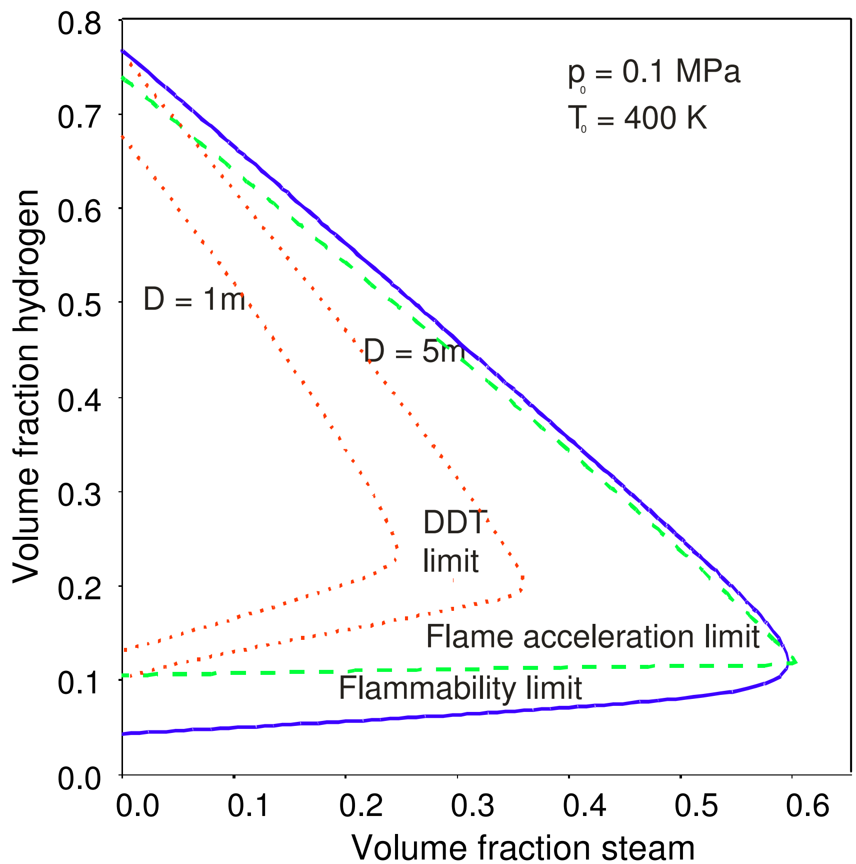
- Transition criteria were developed to estimate conservative (fastest) combustion regime possible for a given H_2-air mixture and geometry
  - inert /slow
  - slow/fast
  - deflagration/detonation

GP-CODE

- All criteria implemented in interactive GP-code
  $f(p_0, T_0, x_{H2}, x_{O2}, x_{H2O}, x_{N2}, D)$

- Example for H_2-air-steam mixtures

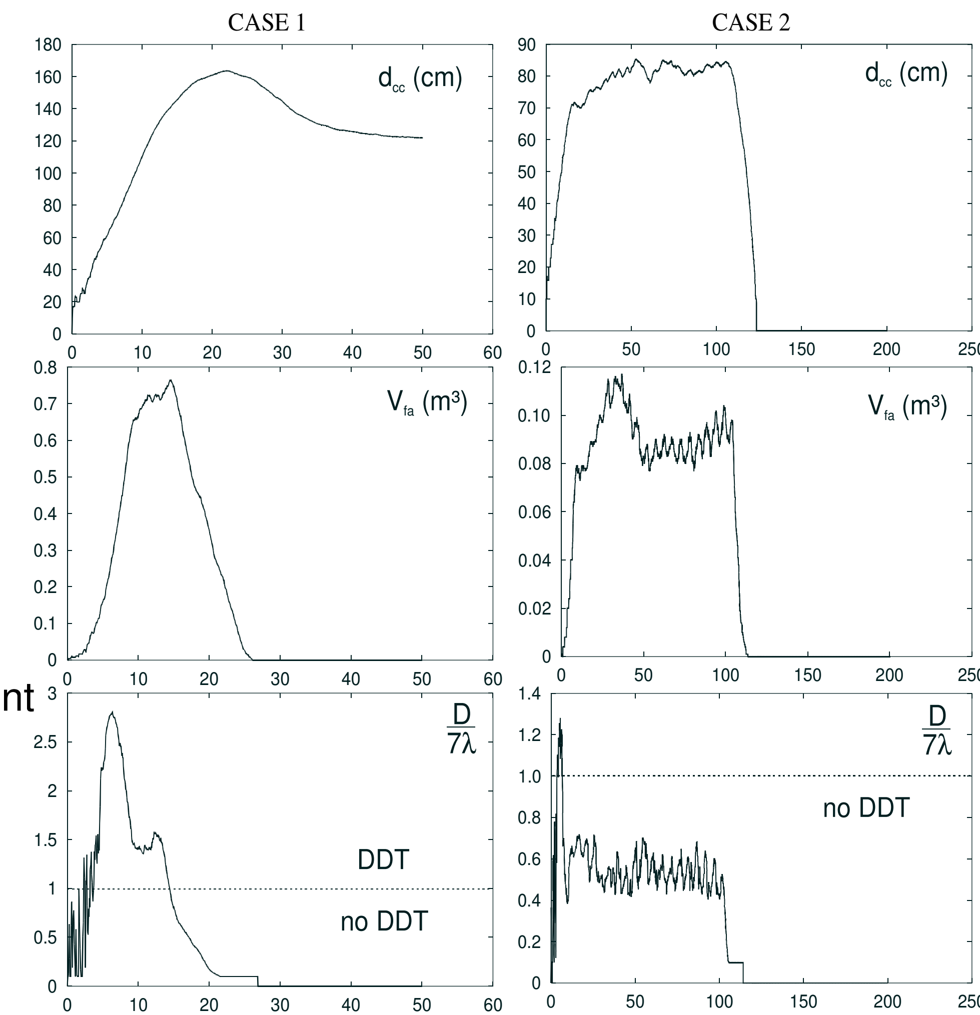
- mixtures above 60 vol% are inert
- flammability and flame acceleration limits nearly coincide on the rich side
- the DDT limit is scale dependent, in larger system (D) leaner mixtures can undergo a deflagration-to-detonation transition



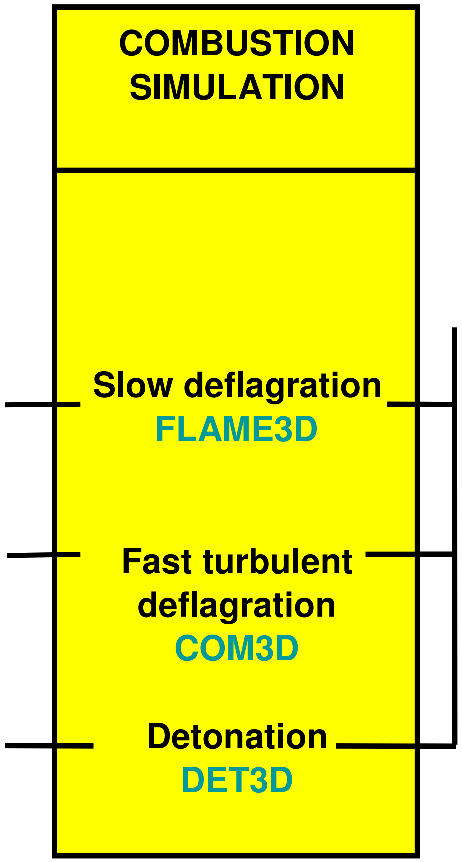
HAZARD FOR GARAGE EXAMPLE

- Criteria are evaluated on-line in GASFLOW from known H_2-distribution
- CASE 1:
  - significant and stable volume of combustible mixture
  - potential for flame acceleration and DDT exists during and shortly after release
- CASE 2:
  - only small volume is able to support deflagrations, disappears shortly after end of release
  - no DDT hazard
  - inherent mixing mechanisms sufficient to dilute source
- H_2 release in confined spaces above a certain critical rate (here 0.3 g/s) requires additional measures for hazard control

3.4 g H_2/s, 10s | .34 g H_2/s, 100s

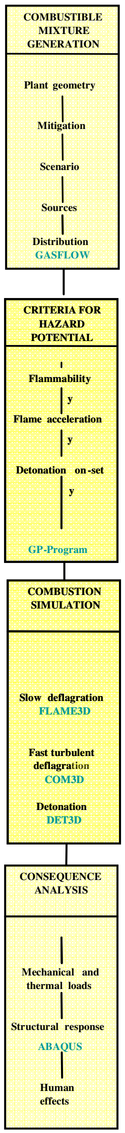


III. COMBUSTION SIMULATION



- Different physics involved in different combustion modes
- Three CFD codes under development and in use at FZK
- Codes model stable combustion regimes, while transition phenomena are covered by criteria

LOCAL EXPLOSION IN CONFINED VOLUME

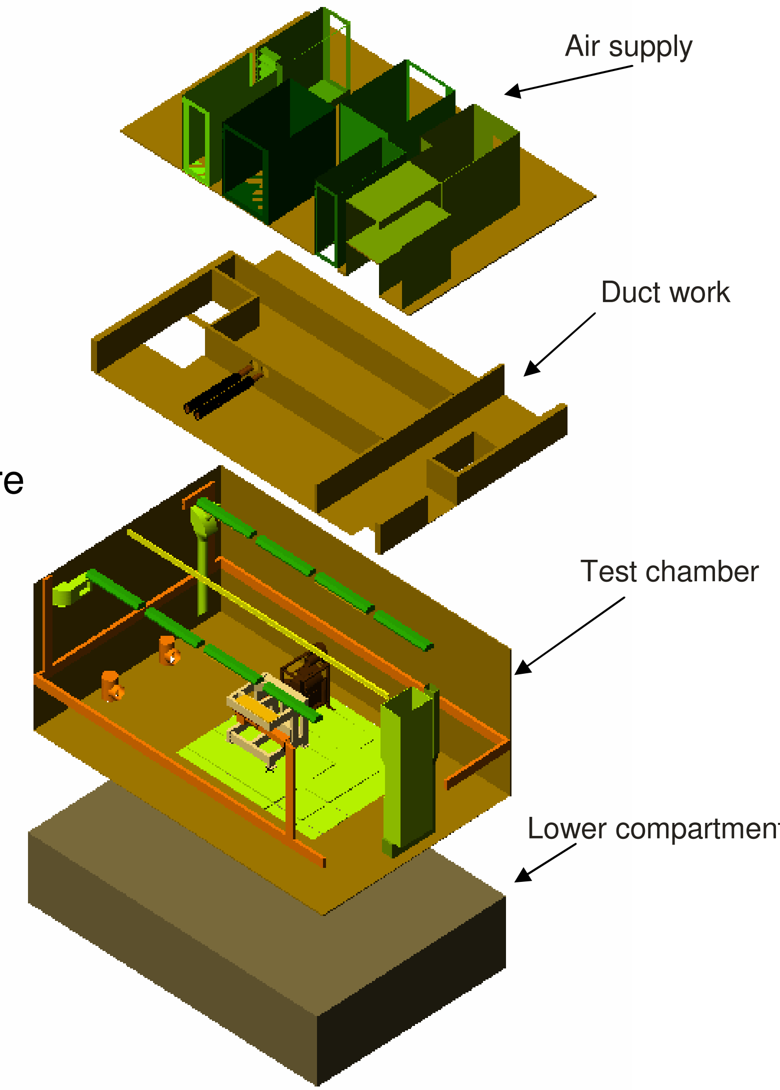


- Test chamber at FZK for hydrogen release and local explosion experiments in confined spaces under controlled flow conditions

  - volume 160 m^3
  - air ventilation up to 24,000 m^3/h

- Structural stability against dynamic pressure loads tested under conservative conditions

  - stoichiometric, homogeneous mixture
  - locally concentrated (2-16g H_2)
  - obstacles to reach high flame speeds

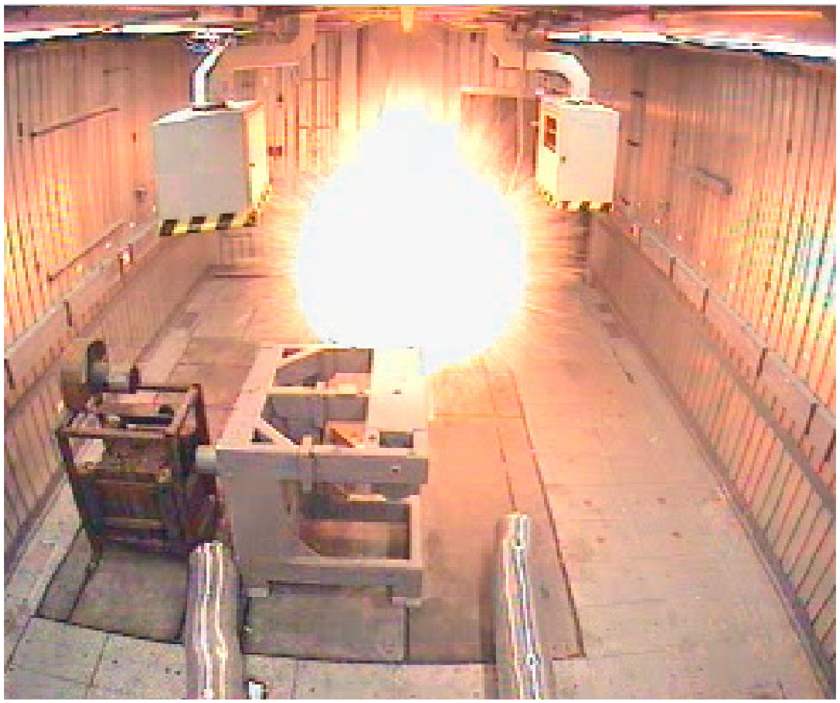


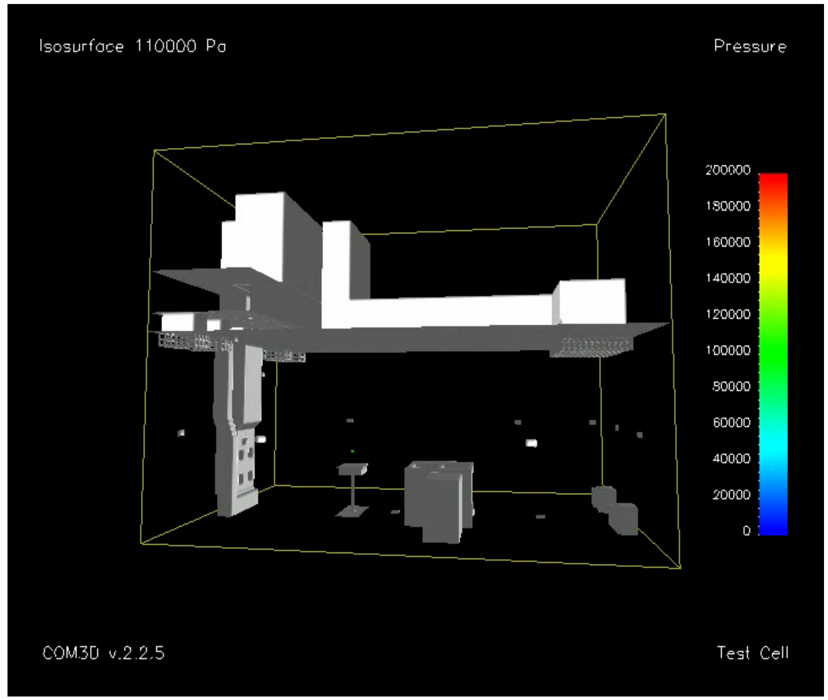
COM3D SIMULATION FOR FZK TEST CHAMBER

- Fast local turbulent H_2-air deflagration in FZK test chamber
  - 8 g H_2
  - p_0 = 0.1 MPa
  - x_{H2} = 29.8 vol%

- Numerical simulation

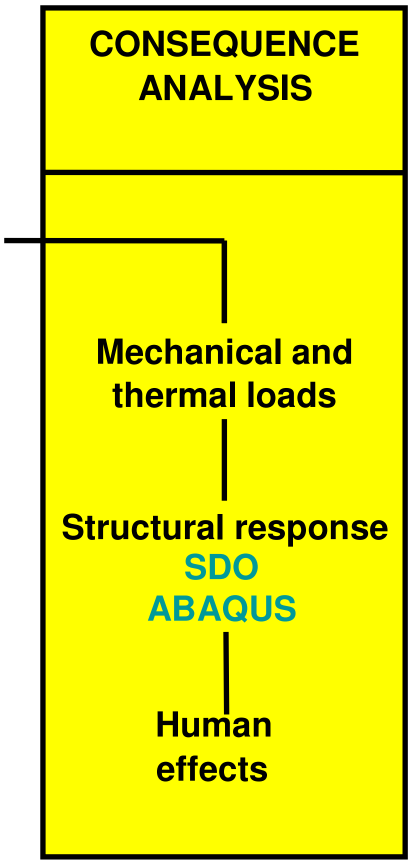
COM3D: Δx = 3.45 cm, total ~ $7 \cdot 10^6$ cells
Fast combustion followed by detonation of 8 g H_2 in stoichiometric mixture in cube 69 x 69 x 69 cm

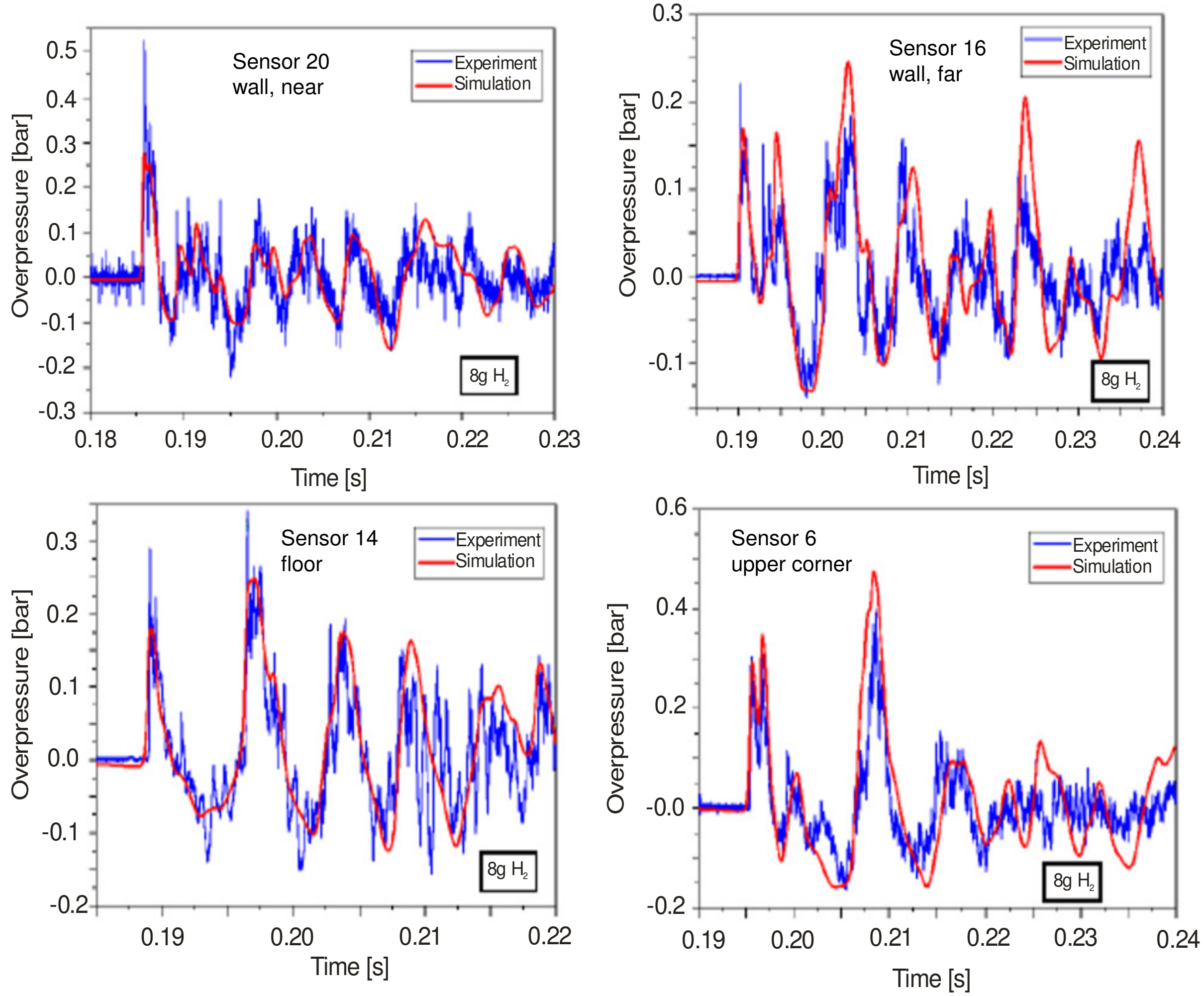




IV. CONSEQUENCE ANALYSIS

- Output of CFD combustion calculation allows to estimate the consequences



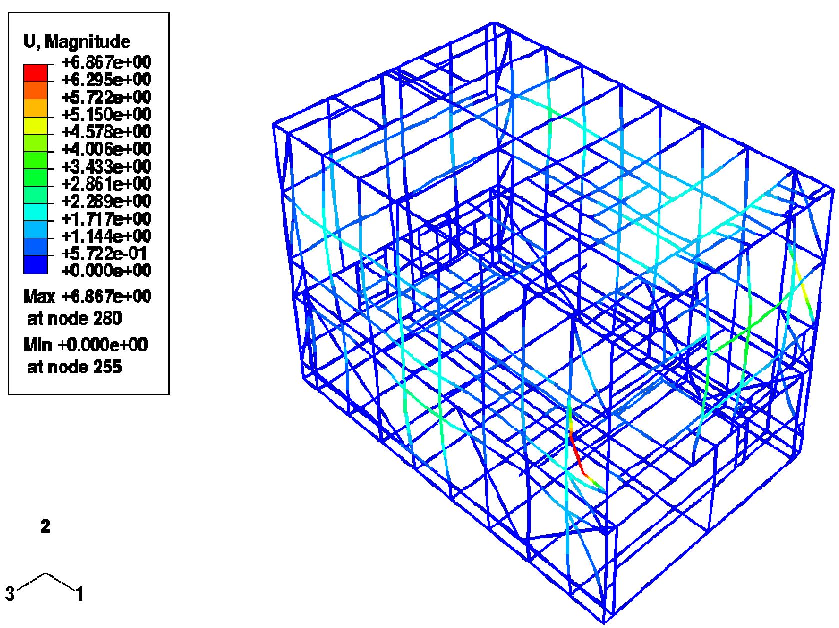


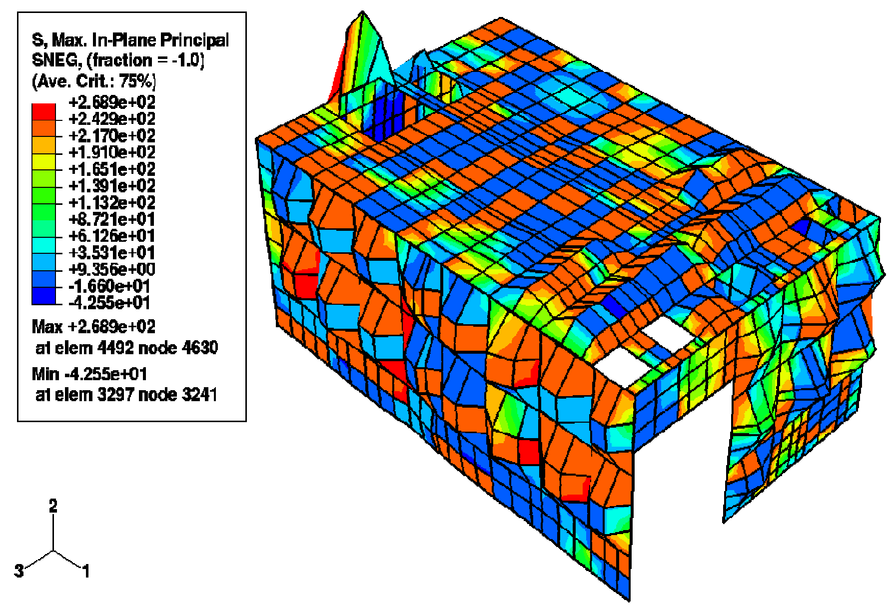
- Example: Pressure loads of 8g H_2 test in FZK facility

STRUCTURAL RESPONSE: Test chamber results

- Response of FZK test chamber simulated with ABAQUS
  - input : P(t) at 8000 locations (COM3D → ABAQUS)
  - output: stress and strain

- Maximum displacement in frame (mm)
- Maximum stress in inner wall (MPa)

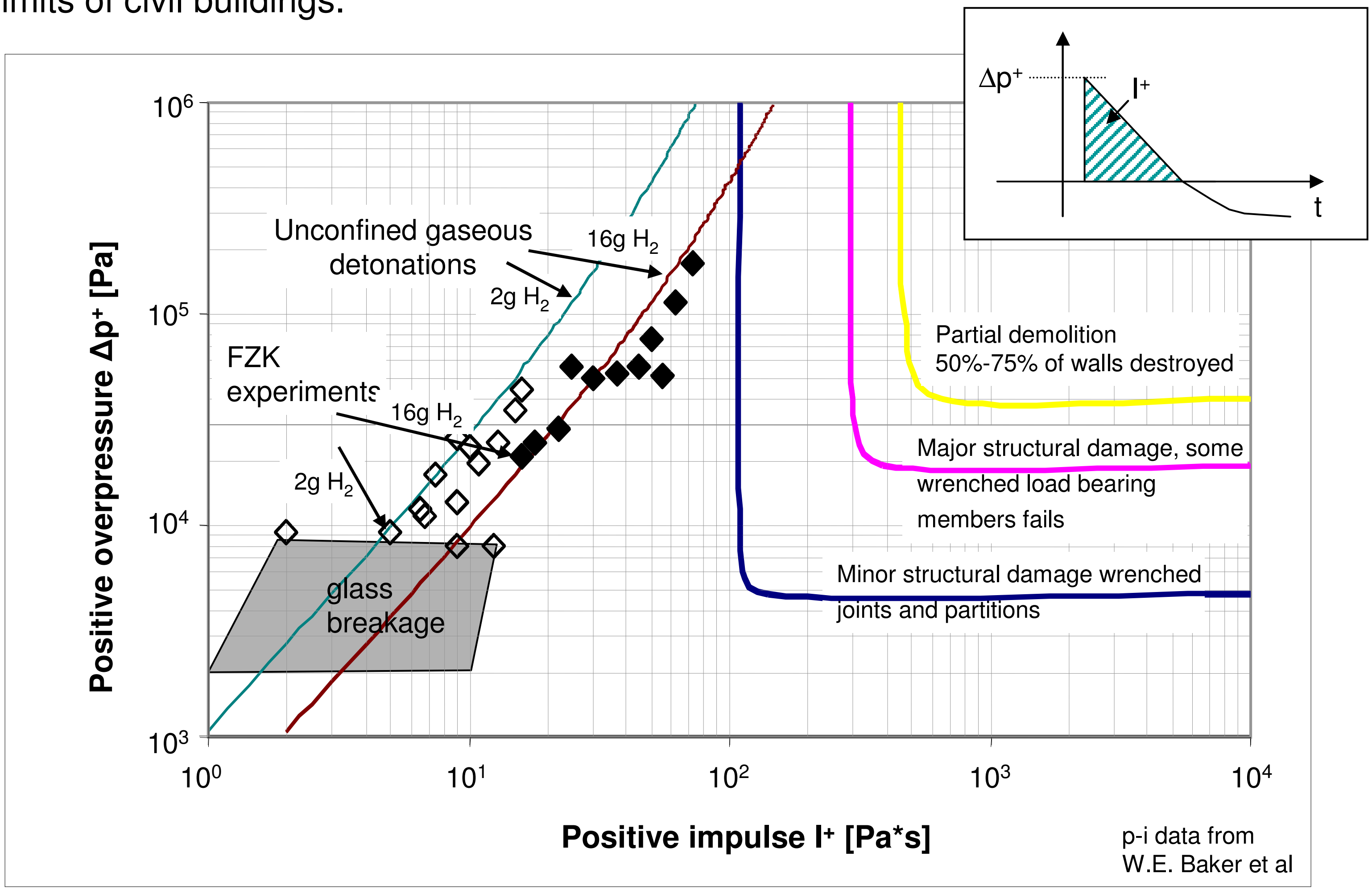




- Result: Walls and framework structure can confine tested fast local combustions, limiting H_2 mass estimated with model

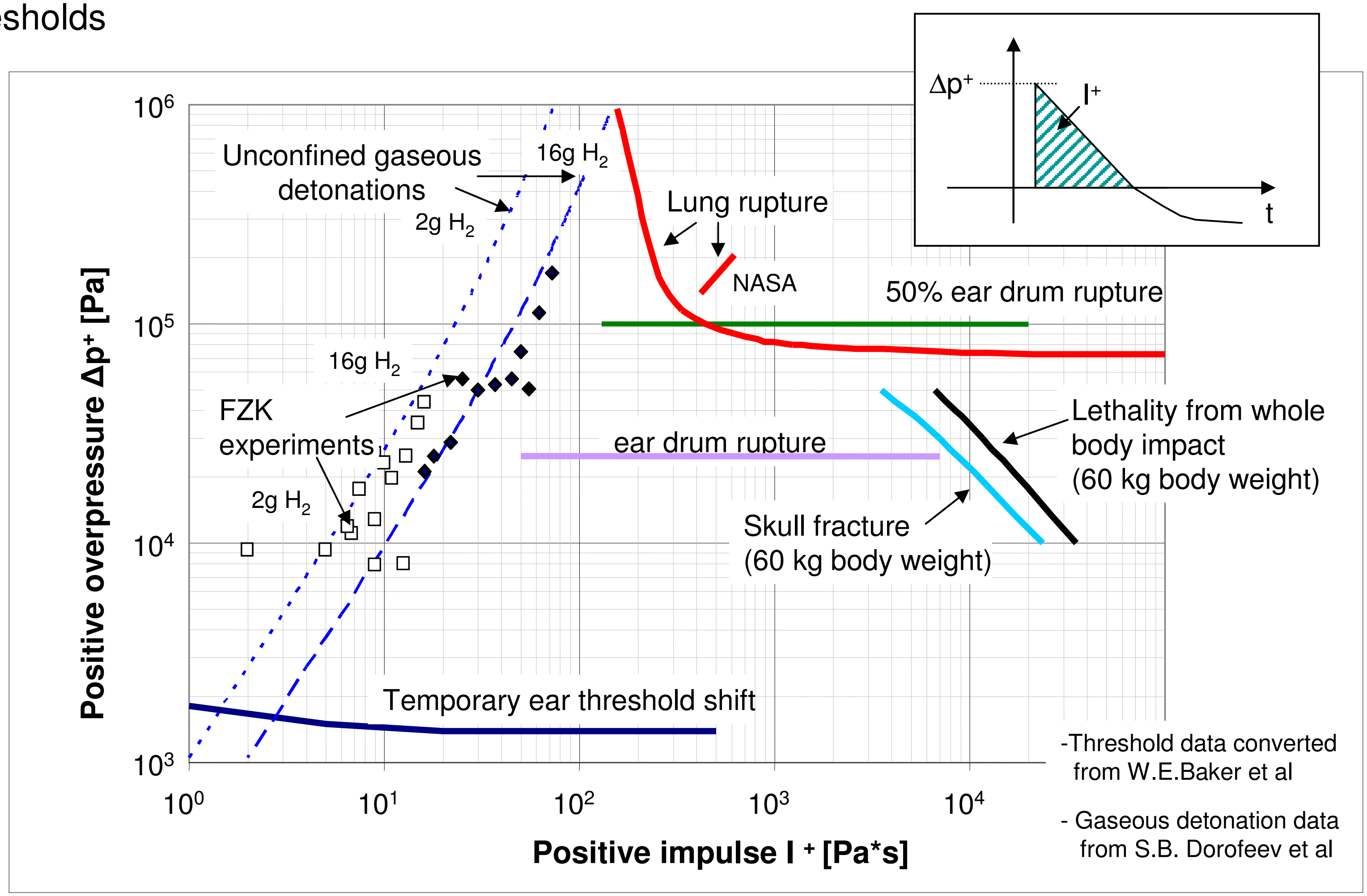
STRUCTURAL RESPONSE: Damage thresholds for civil buildings

- Comparison of measured blast wave parameters in FZK test chamber to known damage limits of civil buildings.



HUMAN EFFECTS: Injury thresholds

- Comparison of measured blast wave parameters in FZK test chamber to known injury thresholds

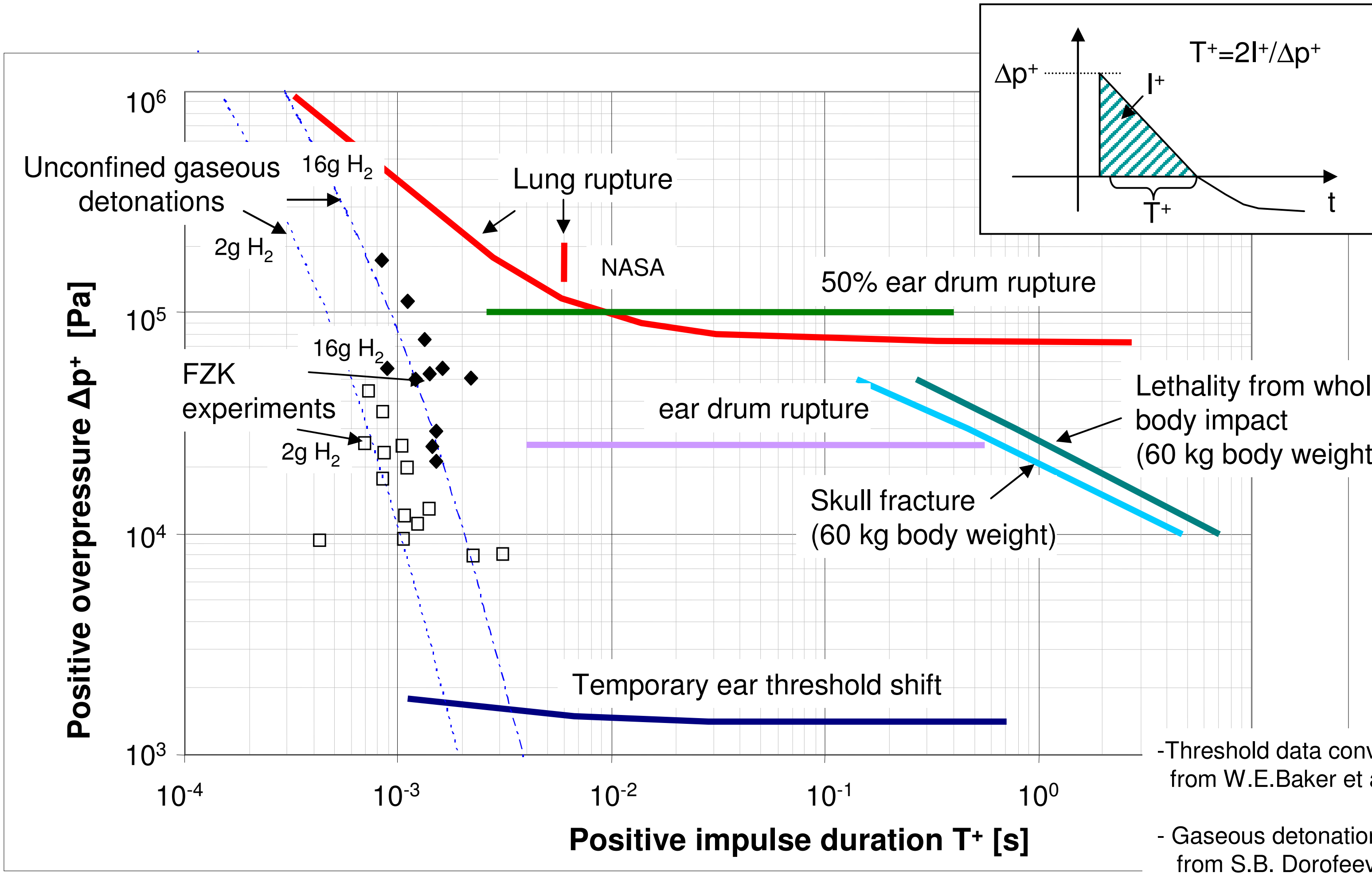


-Threshold data converted from W.E.Baker et al

- Gaseous detonation data from S.B. Dorofeev et al

HUMAN EFFECTS: Injury thresholds

- Comparison of measured blast wave parameters Δp^+ and T^+ in FZK test chamber to known injury thresholds



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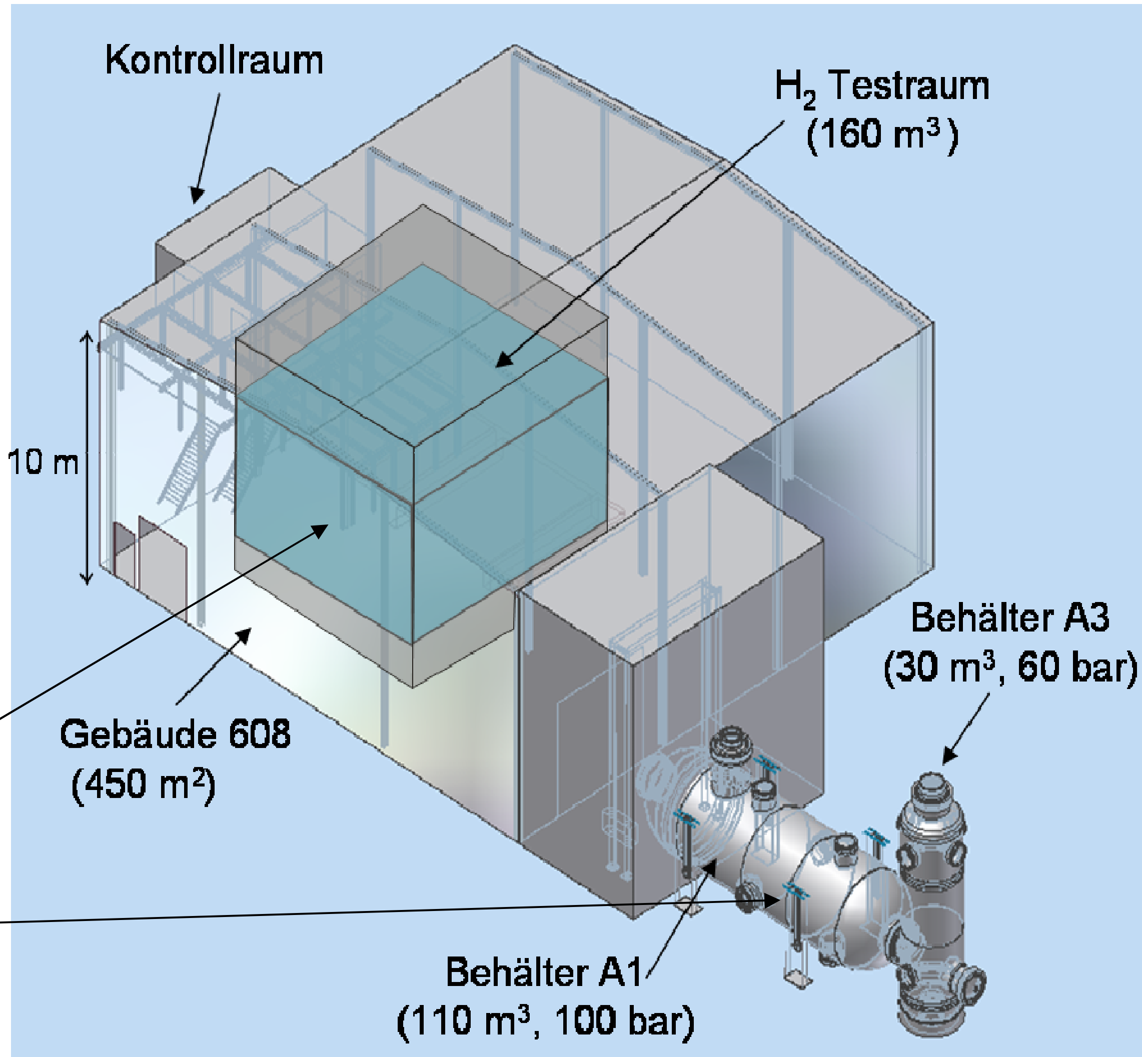
TEST SITE AT FZK FOR HYDROGEN EXPERIMENTAL RESEARCH

Experimental studies:

- Development of transition criteria
- Validation of CFD tools
- Development of scaling methodology

- Facility for H_2 release and distribution studies under controlled flow conditions
- Large-scale facilities for combustion studies
- Combustion tubes



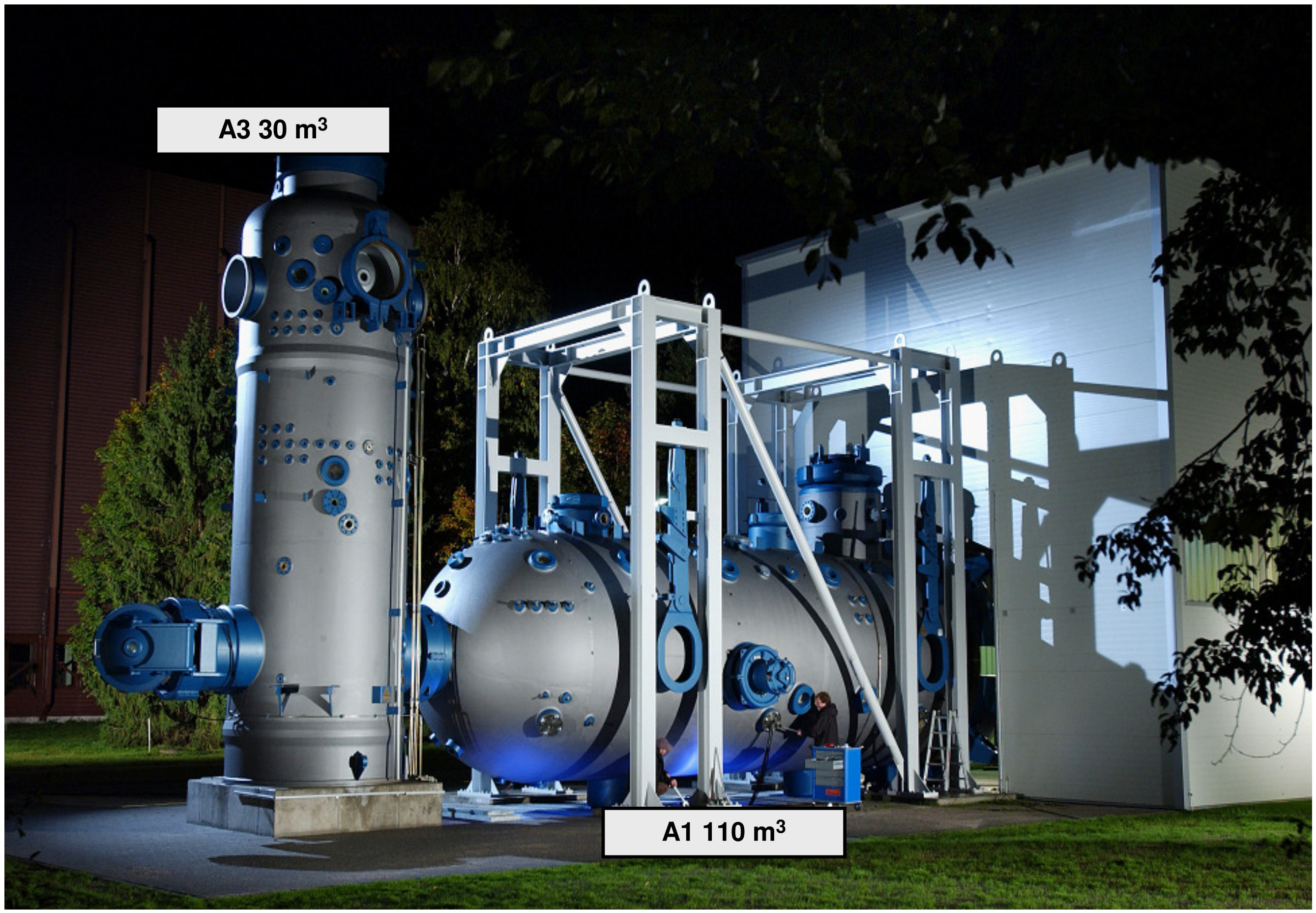
LARGE-SCALE COMBUSTION EXPERIMENTS

Facilities of scales relevant to industrial dimensions

Multipurpose vessels for research connected with combustion processes in large scales

A1 - 100 bar

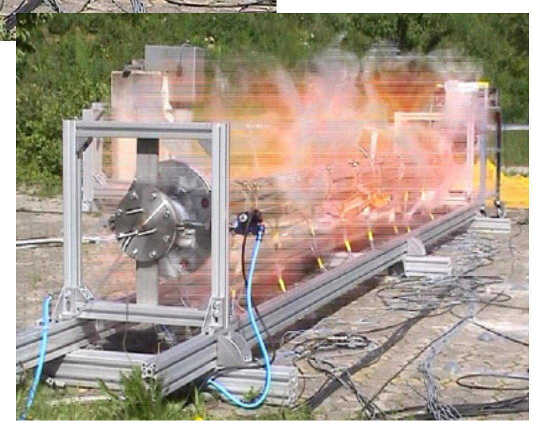
A3 - 60 bar



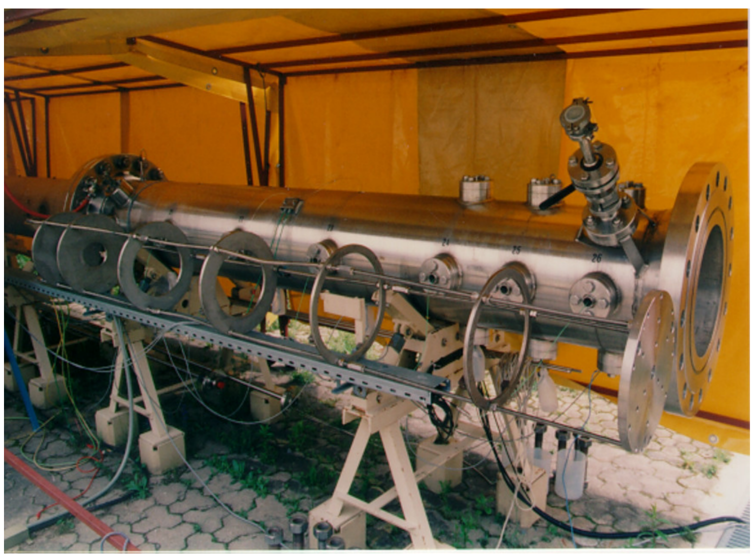
MEDIUM-SCALE COMBUSTION EXPERIMENTS

Study of combustion,
turbulent deflagration,
DDT and detonation

Partially vented geometry



Confined geometry



SUMMARY

- A mechanistic procedure for analysis of hydrogen behavior was developed. The methodology is based on 3D CFD tools.

- It addresses:
  - prediction of accident consequences
  - development of efficient mitigation measures
  - support of safe use of hydrogen technologies

- Two examples for hydrogen behavior in confined spaces were presented
  - hydrogen release is safe up to a critical release rate, which depends on details and which can be evaluated
  - structural damage of the enclosure can be modeled (ABAQUS)
  - combustion of up to 16 g hydrogen can cause :
    - glass fraction but no structure damage to normal civil buildings
    - ear damage but no lung rupture
  - blast effects from local explosions (2-16g H_2) are restricted to ear damage