Blast Waves and Fireballs Generated by Hydrogen Fuel Tank Rupture During Fire Exposure

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5th International Symposium on Fire and Explosion Hazards

April 23-27, 2007

Background:
All Hydrogen Vehicle Fuel Tanks Have Pressure Relief Devices (PRDs) for Exposure Fire Protection

PRDs are thermally actuated, and allow complete tank blowdown when actuated, i.e. when the PRD is in the exposure fire, and PRD is not obstructed internally by debris.

Hydrogen Jet Flame from PRD Actuation during Tank Fire Exposure

Hydrogen Tank on Left and Gasoline Tank on Right

Test Series Objectives

To determine the consequences of catastrophic failure of a Type 3 tank (Test 1) and a Type 4 Hydrogen Fuel Tank (Test 2) that do not have a working PRD.

In particular to determine:

- Tank failure time and mode
- Blast wave pressures
- Hydrogen fireball size and duration
- Tank fragment distance distribution

Test 1: Type 4 Tank Test

Diameter = 41 cm

Length = 84 cm

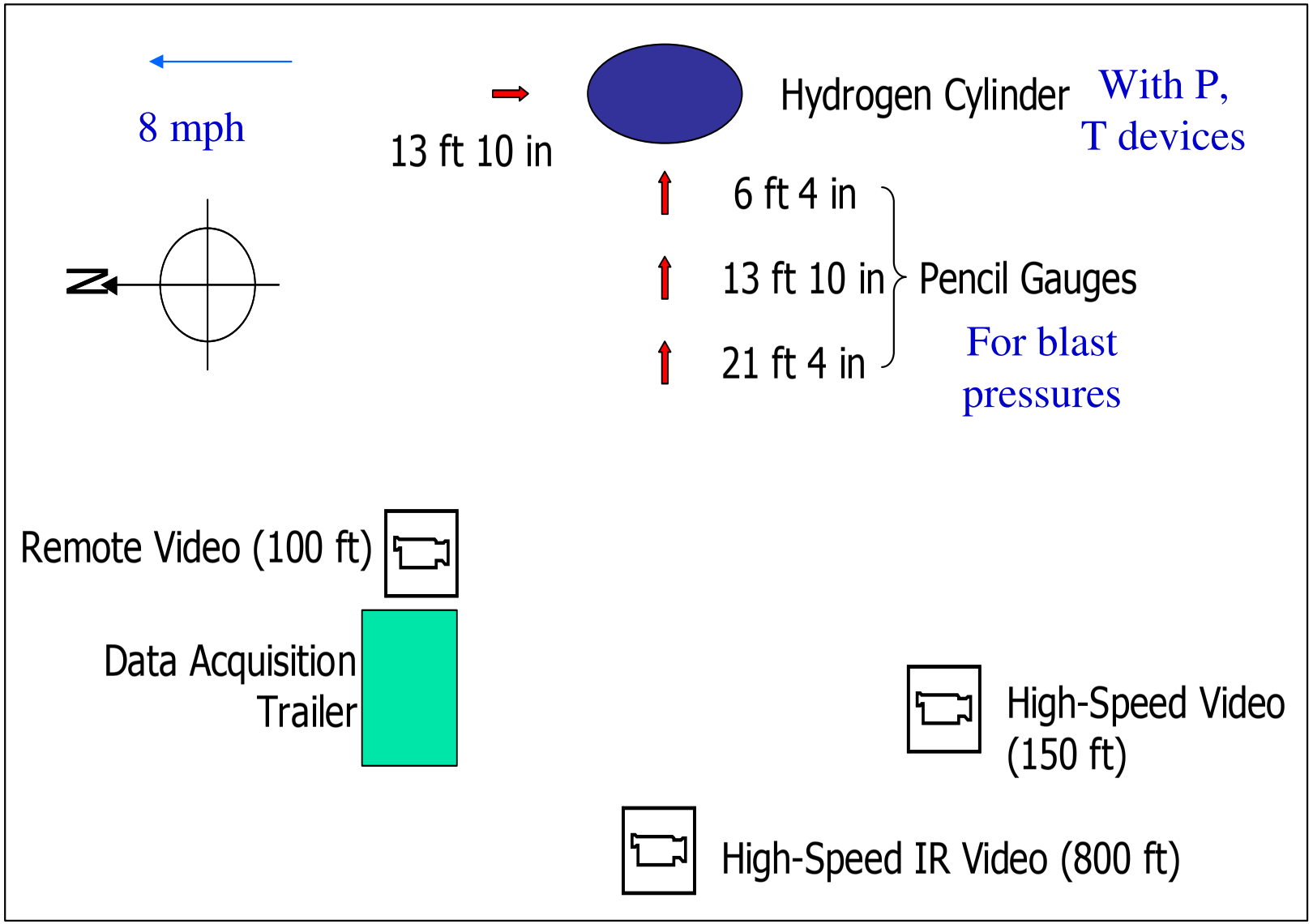
- Type 4: Fully wrapped composite with carbon fiber structural layer and resin impregnated fiberglass outer layer,
- 72.4 liter capacity, 5000 psi (34.5 MPa) Hydrogen Rated,
- **No Pressure Relief Device installed.**

Tank Exposure Fire

270 slpm propane through a 30 cm wide by
84 cm long line burner in a pan under tank;

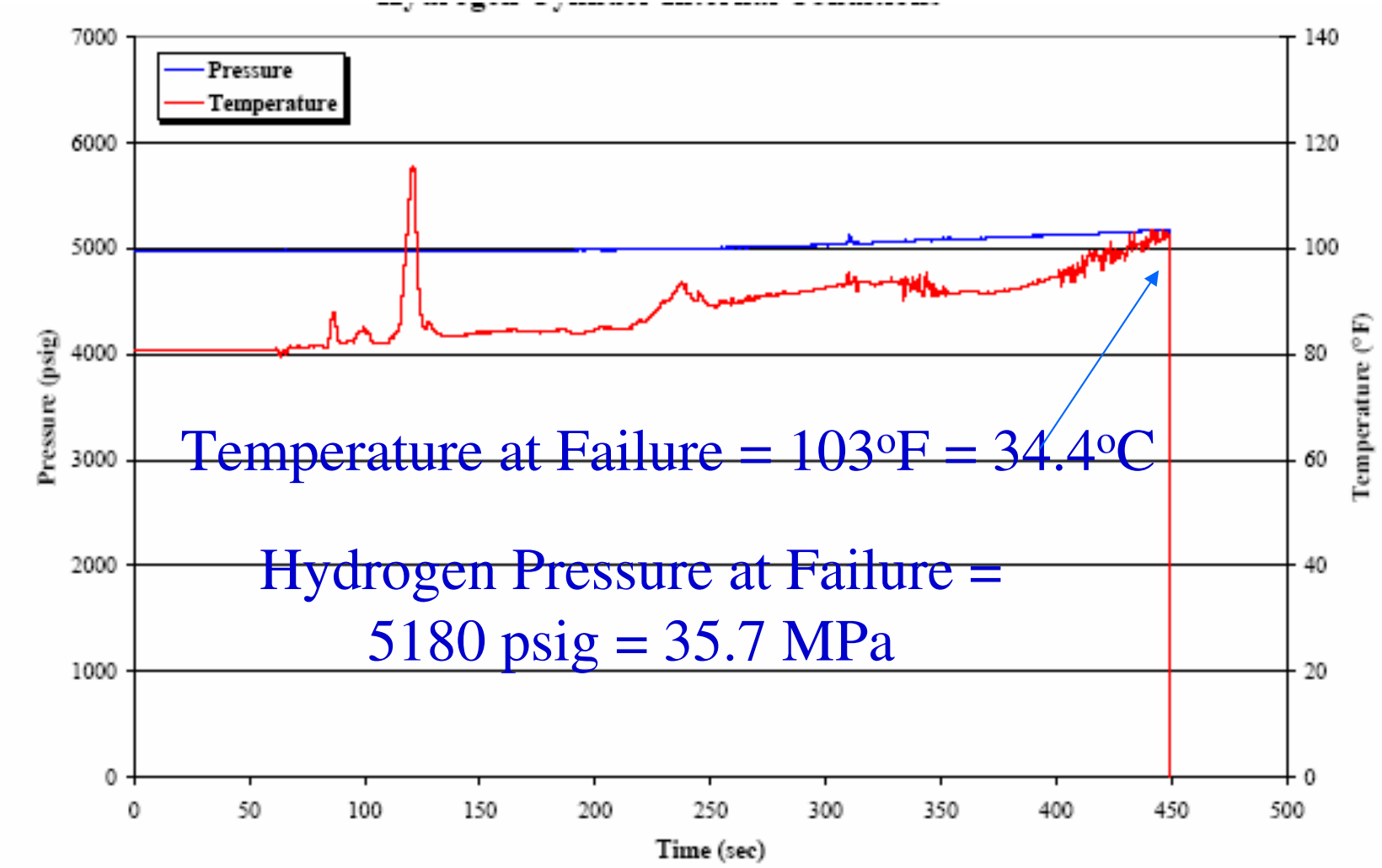
Nominal HRR = 370 kW

Instrumentation Layout

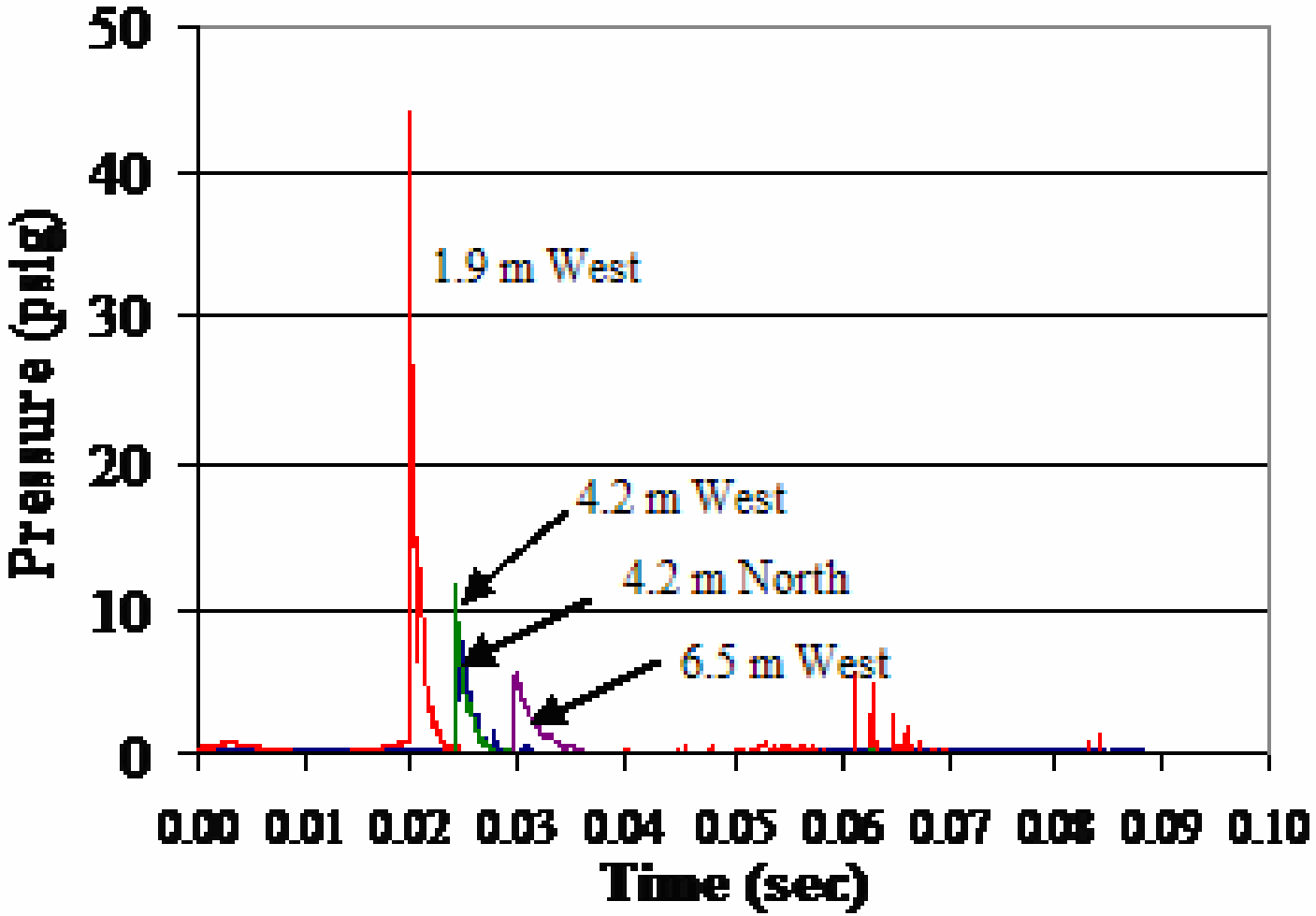


Blast Wave Transducers

Tank Gas Temperature and Pressure During Exposure Fire



Measured Blast Wave Pressures in Test 1



Test 1 Hydrogen Fireball Formation upon Tank Rupture at 6 min 28 sec

10 msec

45 msec

107 msec

Hydrogen Fireball Rise

997 msec

1240 msec

Test 2
Type 4 Tank Mounted under a Sports Utility Vehicle

Tank Volume = 88 liter;

Length = 84 cm;

P_0 = 31.8 MPa

265 kW propane pan fire under tank

Test 2 Setup with Instrumented SUV

Fire Development in Test 2

2 minutes
after ignition

4 minutes

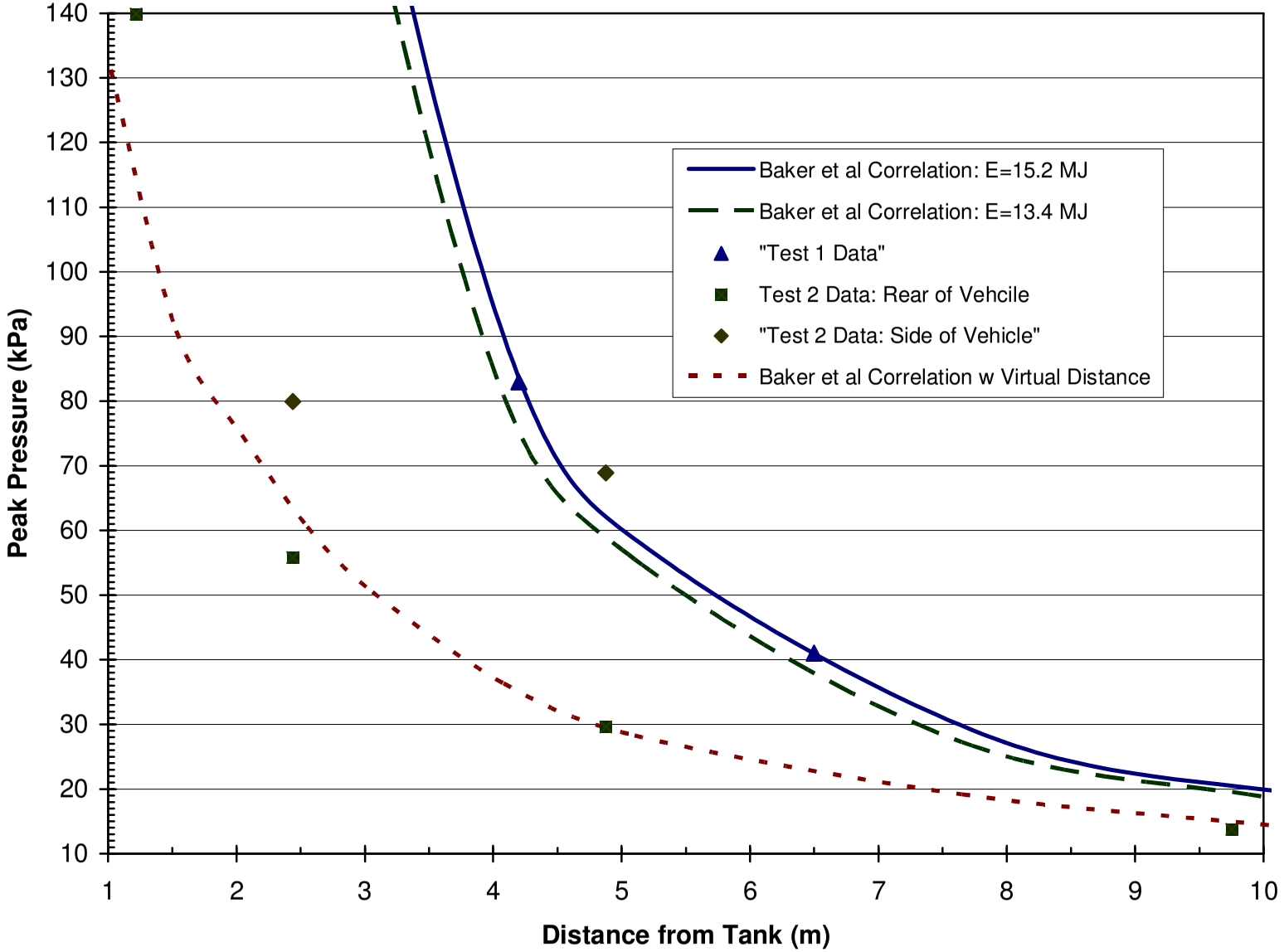
9 minutes

Tank Rupture and Fireball 12 min 18 sec after ignition in Test 2

70 msec after tank rupture

170 msec after tank rupture

Blast pressures versus distance from fuel tank center



Baker et al. Blast Wave Correlation

$$\frac{P_s}{P_a} = f\left[\left(\frac{P_b}{P_a}\right),\left(\frac{\gamma_g M_a T_g}{\gamma_a M_g T_a}\right),\left(\frac{r P_a^{1/3}}{E^{1/3}}\right)\right]$$

Blast Wave Energy

$$\int_{V_1}^{V_2} p\,dv$$

For a Able-Noble Gas Equation of State:

$$E = nRT_1 \ln\left(\frac{P_1}{P_a}\right)$$

$$n = \frac{V}{b + RT_1/P_1}$$

For hydrogen,

b = 15.84 cm^3/mol

E = 15.2 MJ for Test 1; = 13.4 MJ for Test 2

Comparison of Measured and Calculated Fireball Diameter

Measured maximum D_f = 7.7 m in Test 1; = 24 m in Test 2 (more fuel in fireball)

Correlation: $$D_f \approx 7.93 W_f^{1/3}$$

For W_f = 1.64 kg-H_2, D_f = 9.4 m

Comparison of Calculated and Observed Fireball Durations

Observed Duration ~ 2 seconds by visible range video camera, and about 4.5 seconds from IR camera

Correlation: $$t_f \approx 2.6 W_f^{1/6}$$

Calculated $t_f = 2.7$ seconds

Fireball Flame Radiation

- Measured Peak Heat Flux at 15 m in Test 2 = 210 kW/m^2
- Using Spherical Flame View Factor, calculated fireball surface emissive = 339 kW/m^2

Tank Fragments in Test 1

14 kg largest fragment found 82 m east of original tank location

Cylinder dome 2 kg end cap projectile

Found 49 m northeast

Test 2 Tank and Vehicle Fragments

Vehicle Remains

Tank Fragment 41 m away

Some SUV fragments found as far as 107 m

Conclusions:

- All composite tank failure occurred after 6 min, 27 seconds of fire exposure; composite plus metal liner tank did not fail until 12 min 18 sec
- Blast wave pressures can be calculated on basis of isothermal expansion blast wave energy, but adjustments needed for directionality, parallel or perpendicular to tank and vehicle axis.
- Hydrogen fireball maximum diameter calculated on basis of 1.64 kg hydrogen content is only 19% larger than measured diameter for tank only rupture, but is much smaller than fireball for vehicle mounted tank rupture.

Acknowledgements

- Funding provided by the Motor Vehicle Fire Research Institute
- Southwest Research Institute remote test facility and staff
- SWRI reports and many other MVFRI reports available on mvri.org Web site.

Four Types of H2 Vehicle Fuel Tanks: Rated for 350 to 700 bar

Type 1: Metal (intact after crash)

Type 2: Hoop-wrapped composite (fiber + resin) with thick metal liner

Type 3: Fully wrapped composite with thin metal liner

Type 4: Composite with non-metallic liner