# Establishment of Safety Regulation for Fuel Cell Vehicles in Japan - Hydrogen Safety -

Japan Automobile Standards Internationalization Center (JASIC)

20-21 September, 2007

UN/ECE/WP29/AC3-HFCV-SGS

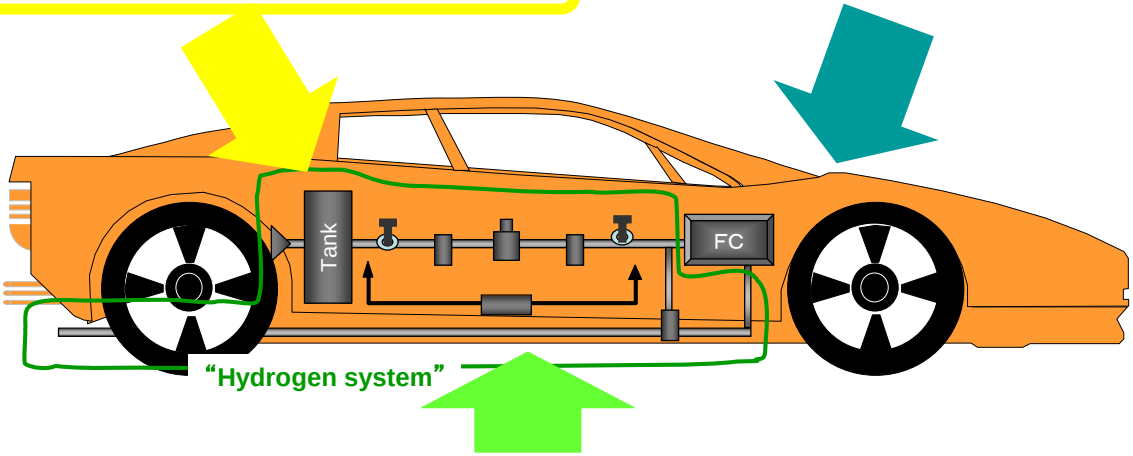
## General Concepts for Safety Regulation

**Criteria for individual components**

**Fuel Container and its attachments**

**Criteria for whole vehicle**

**Hydrogen leakage limit in collisions**




**Criteria for safety system**

**Hydrogen safety:**

- Hydrogen leak warning system
- Hydrogen gas purge amount, etc.

***High voltage safety :***

- *Protection from direct contact*
- *Protection from indirect contact, etc.*

# Items considered to establish hydrogen safety

| | | CNGV | CHG FCV | To establish safety Regulation |
|---|---|---|---|---|
| Gas leaks | Fuel gas | Natural gas | Hydrogen gas | Have no leaks<br>Which components ?<br>Hydrogen system composition ?<br>Hydrogen brittleness ? |
| | Max. operating pressure | 25MPa | 35MPa | |
| | Sensing leaks | Sense of smell | ? | Sense and shut off hydrogen gas when leakage occurs |
| | Shut off gas at the event of a leak | Manual operation | ? | |
| | Accumulation and entry of gas into the passenger compartment in the event of a leak | Sense of smell | ? | Have no accumulation and no entry of gas into the passenger compartment in the event of a leak |
| Gas discharge | Purge | ——— | ? | No discharge over the lower flammability limit |
| | Fire | PRD release | <- | Safe release method to prevent secondary disaster<br>Difference between natural gas and hydrogen gas at fire ? |
| Collision | gas leak limits | No particular test procedure (FMVSS 303) | <- | Gas leak limits is equivalent to the heat value stipulated for gasoline leak limits. |

# Concepts for technical standards regarding hydrogen gas leaks

1. Have no leaks
2. Sense and shut off hydrogen gas when leakage occurs
3. Have no accumulation and no entry of gas into the passenger compartment in the event of a leak

# 1. Measures for “Have no leaks”

- **Issues for investigation**
  - Safety measures for hydrogen gas system
    - High pressure sections: Pros and cons of conform to the High Pressure Gas Safety Law
    - Mid and low pressure sections: Contents of regulations
  - Hydrogen brittleness
    - Regulate usable or unusable materials



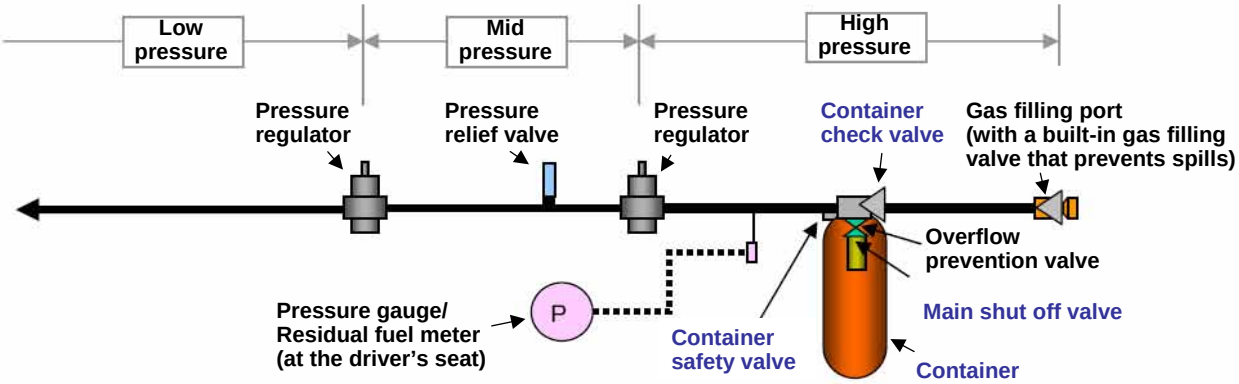
# 1. Measures for “Have no leaks”

- **Investigation results**
  - Hydrogen gas system safety measures
    - High pressure sections: Conform to High Pressure Gas Safety Law

      The few parts that cannot stop a leakage at the time of its trouble needs the certification.

      Container, Main shut off valve, Container safety valve, Container check valve

      (Main shut off valve, Container safety valve and Container check valve shall be attached directly to each gas container.)



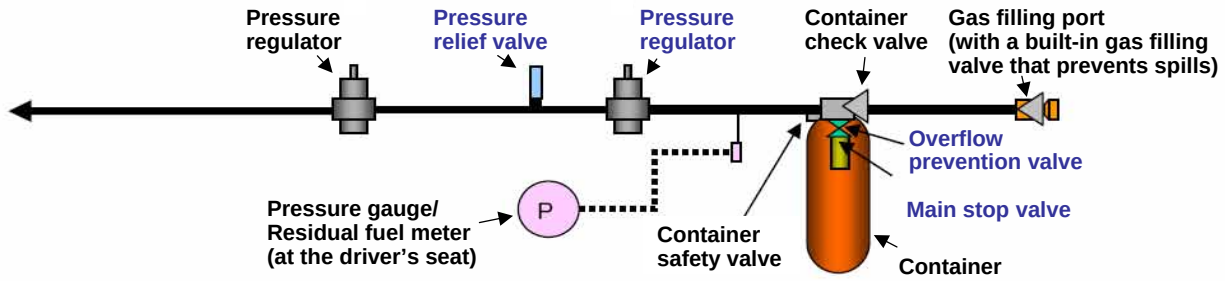
# 1. Measures for “Have no leaks”

## Investigation results

### Hydrogen gas system safety measures

- **Mid and low pressure systems: Specify performance requirements and minimum necessary structural requirements**

  - Regulator shall not be attached upstream of main stop valve.
  - Overflow shall be prevented by one of following method.
    Overflow prevention valve or Closing main stop valve by detecting abnormal pressure drop or abnormal flow raise of gas
  - Safety device shall prevent the significant rise in pressure at the downstream side of regulator by one of following method.
    Pressure reducing valve or Closing valve that shut off hydrogen supply at the primary side when pressure exceeds general-use pressure






# 1. Measures for “Have no leaks”

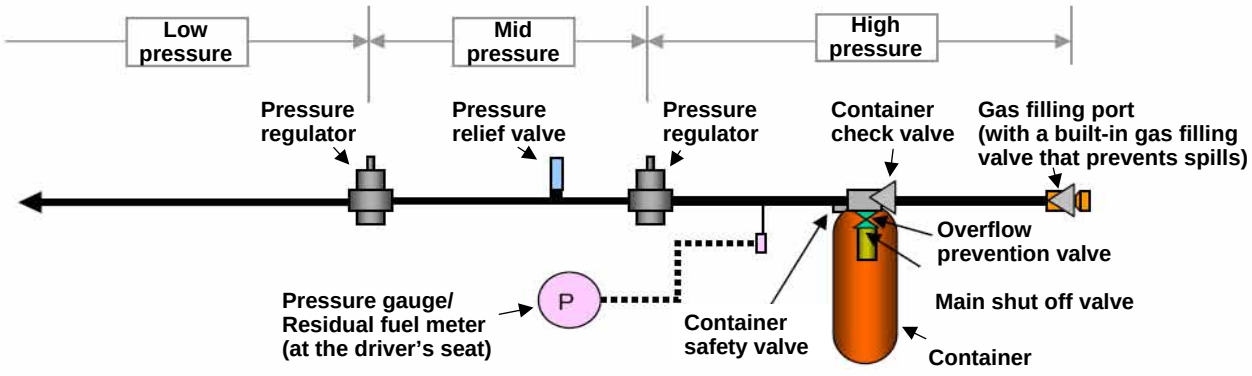
## Investigation results

### Hydrogen brittleness

- **High pressure sections: Difficult to regulate usable or unusable materials**

  - Prescribe use of materials with consideration of hydrogen brittleness

- **Mid and low pressure sections: Unnecessary if air-tightness is requisite owing to excess strength in piping**

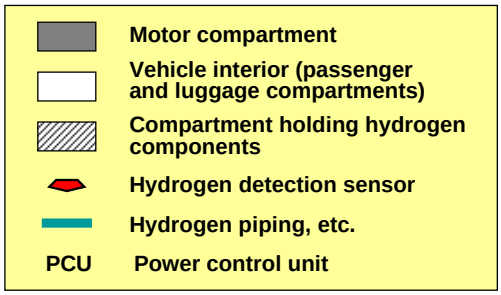


# 2. Method of “Sense and shut off hydrogen gas that occur”

- **Issues for investigation**
  - **Method of sensing leaks**
    - **Sensor**
    - **Measurement of decreases in pressure**
    - **Measurement of flow rate**
- **Investigation results**
  - **Use the method of hydrogen sensor**
  - **Detection threshold: lower flammability limit (4%)**
  - **Determine sensor location (each compartment equipped with at least 1 sensor)**

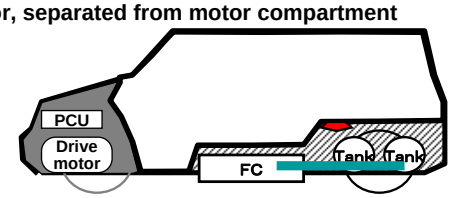


## Examples of hydrogen sensor arrangement

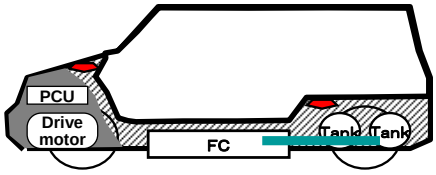



### I. With 1 compartment

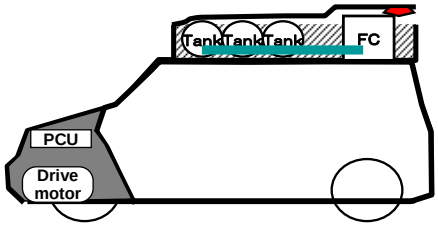
**Ex. I-1: Hydrogen components placed under vehicle interior floor, separated from motor compartment**




**Ex. I-2: Hydrogen components placed under vehicle interior floor (2 detection locations)**

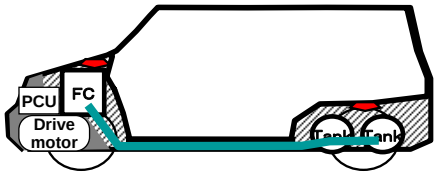



**Ex. I-3: Hydrogen components placed on roof**

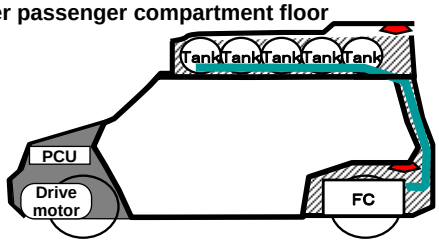



### II. With 2 compartments

**Ex. II-1: Hydrogen components placed in motor compartment and under vehicle interior floor**




**Ex. II-2: Hydrogen components placed on roof and under passenger compartment floor**

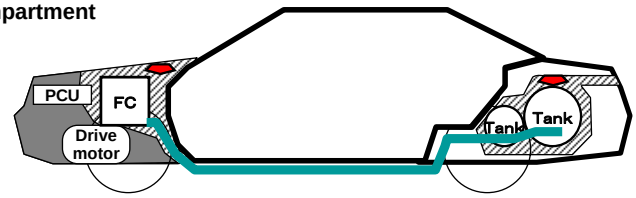


# Examples of hydrogen sensor arrangement

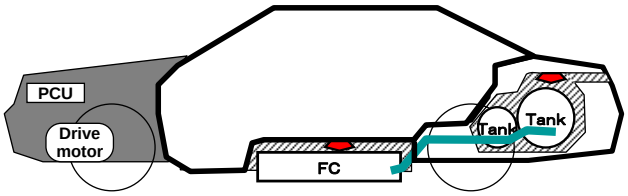
Motor compartment
Vehicle interior (passenger and luggage compartments)
Compartment holding hydrogen components
Hydrogen detection sensor
Hydrogen piping, etc.
PCU Power control unit

## III. When tank container is within vehicle interior

**Ex. III-1: Hydrogen components are placed in the motor compartment, and in tank container within luggage compartment**

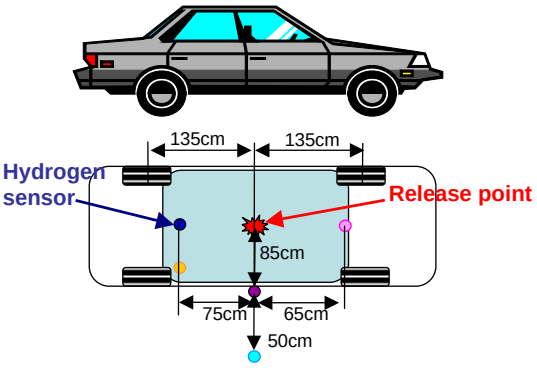



**Ex. III-2: Hydrogen components are placed under the floor, and in tank container within luggage compartment**






# Leak Detection Ability of Hydrogen Sensors



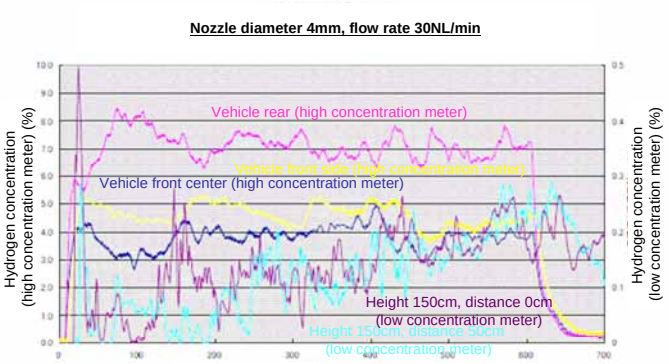
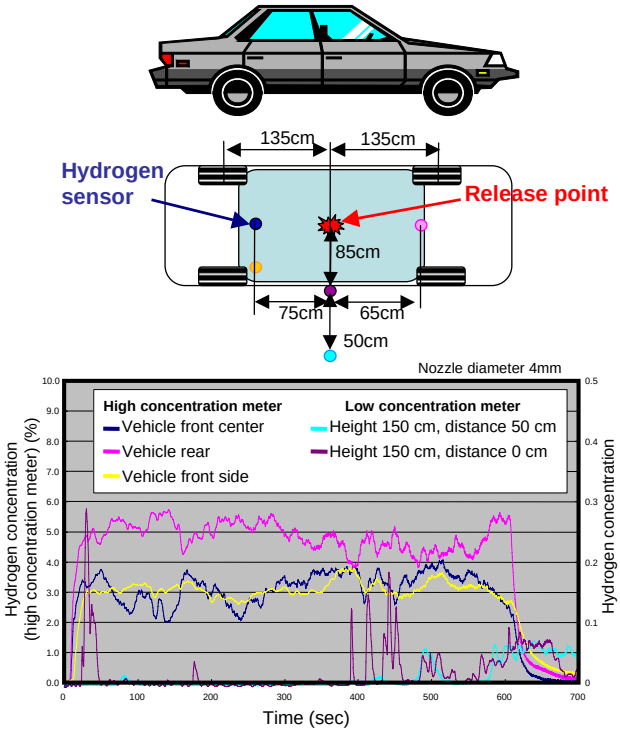




**Fig. 3-58 Hydrogen flow rate 30 NL/min**

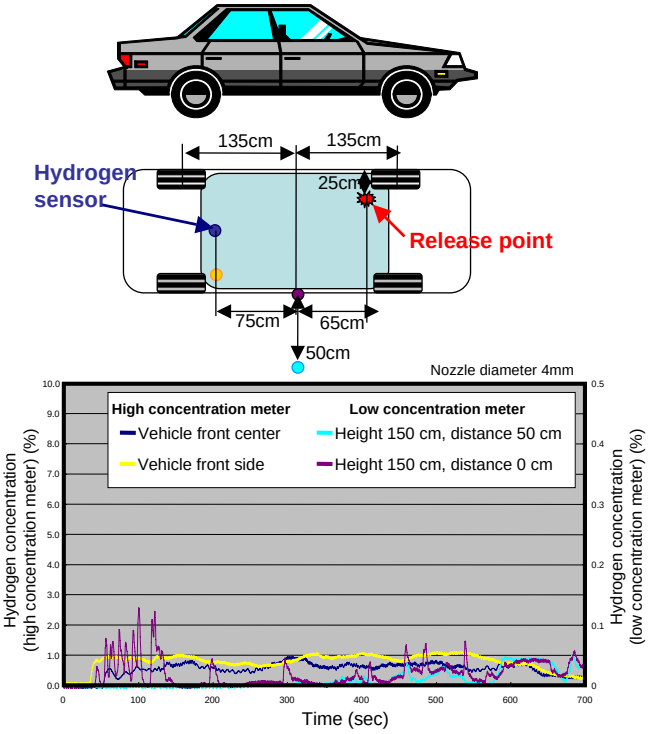
**Table 1 Hydrogen concentration with upward release from central portion of vehicle**

| Hydrogen flowrate | | Hydrogen concentration (%) | | | | |
|---|---|---|---|---|---|---|
| | | Vehicle front center | Vehicle rear | Vehicle front side | H=150cm,L=50cm | H=150cm,L=0cm |
| 10 | Maximum | 1.6 | 6.0 | 3.2 | 0.13 | 0.20 |
| | Immed. before supply cutoff | 1.2 | 4.2 | 2.8 | 0.07 | 0.10 |
| | 1 min after supply cutoff | 0.2 | 0.2 | 0.3 | 0.08 | 0.07 |
| 12 | Maximum | 3.2 | 4.9 | 3.9 | 0.11 | 0.15 |
| | Immed. before supply cutoff | 1.9 | 2.9 | 2.8 | 0.07 | 0.04 |
| | 1 min after supply cutoff | 0.2 | 0.2 | 0.4 | 0.09 | 0.05 |
| 15 | Maximum | 3.5 | 6.2 | 4.3 | 0.14 | 0.17 |
| | Immed. before supply cutoff | 1.7 | 5.7 | 3.3 | 0.08 | 0.08 |
| | 1 min after supply cutoff | 0.2 | 0.3 | 0.6 | 0.09 | 0.09 |
| 30 | Maximum | 5.0 | 8.5 | 5.3 | 0.29 | 0.50 |
| | Immed. before supply cutoff | 3.8 | 7.1 | 4.5 | 0.21 | 0.17 |
| | 1 min after supply cutoff | 0.4 | 0.3 | 0.6 | 0.22 | 0.13 |
| 131 | Maximum | 7.2 | 7.2 | 6.1 | 0.33 | 0.80 |
| | Immed. before supply cutoff | 6.7 | 6.9 | 5.7 | 0.00 | 0.04 |
| | 1 min after supply cutoff | 0.3 | 0.2 | 0.5 | 0.04 | 0.03 |

# Leak Detection Ability of Hydrogen Sensors




**Release downward from centre of vehicle,**
**(hydrogen flow rate 20NL/min)**




**Release downward from rear side,**
**(hydrogen flow rate 20NL/min)**

**An appropriately placed sensor can detect hydrogen leaks at a level equivalent to the sensitivity of the human nose in detecting gas leaks from natural gas vehicles.**

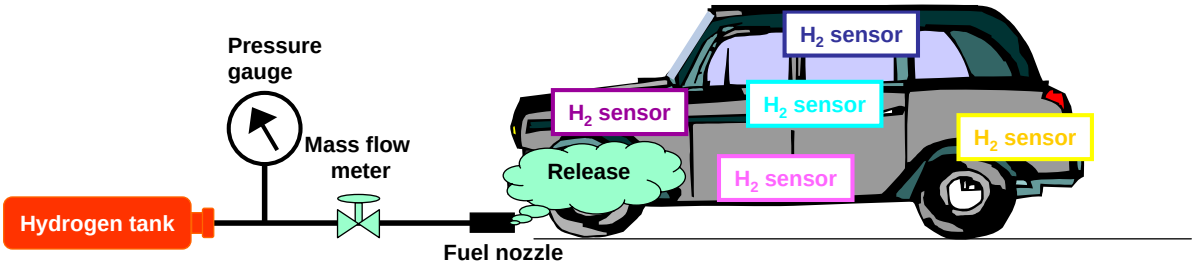


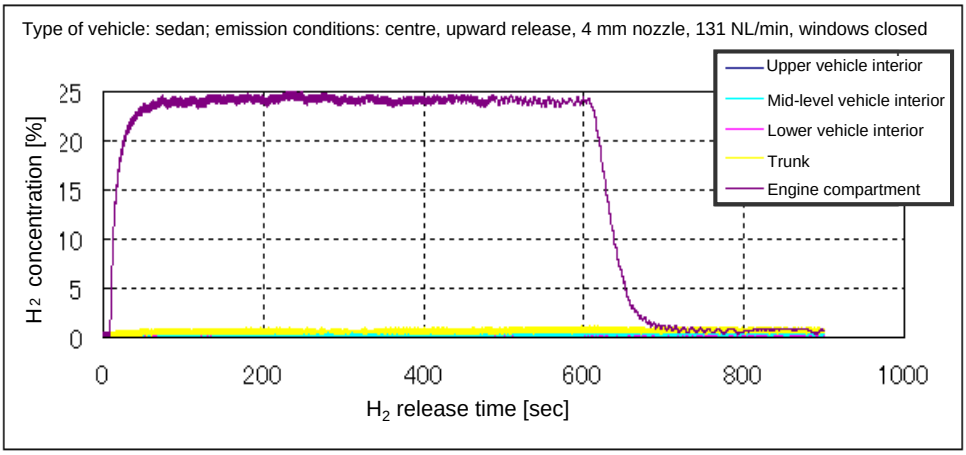
# 3. “No accumulation and no entry of hydrogen in the event of leak”

- **Issues for investigation**
  - Check whether hydrogen gas enters vehicle interior
  - Determine where hydrogen gas accumulates
- **Investigation results**
  - In a entering test, hydrogen gas did not enter the vehicle interior or trunk
  - In an accumulation test, the hydrogen gas concentration was high in the engine compartment, but fell to below 4% within 180 sec. after supply was shut off

**No particular standards prescribed**

# Verification Test on Hydrogen Gas Entering the Passenger Compartment

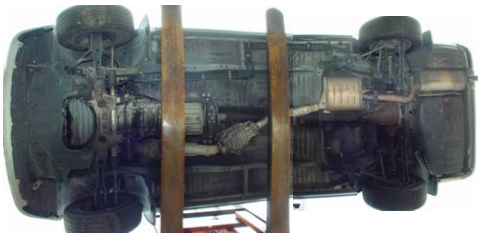



**No hydrogen gas enters vehicle interior or trunk.**



# Verification Test on Hydrogen Gas Accumulation



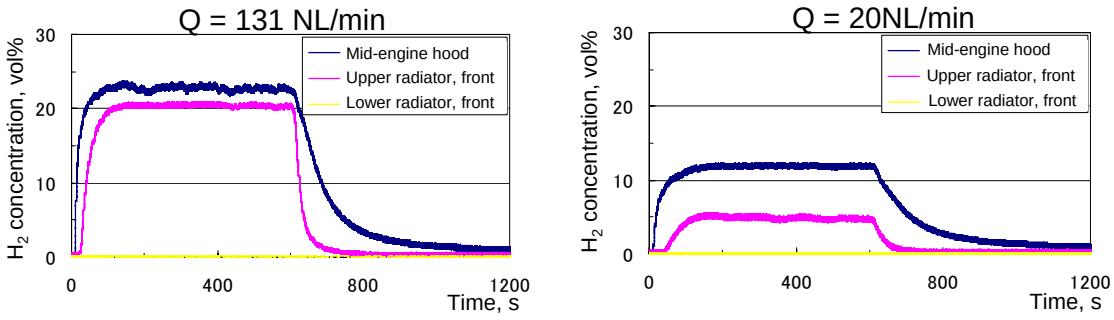
Underside of test vehicle

Concentrations within detonation range

**Standing hydrogen concentration at various locations with various flow volumes**

| Leak flow rate (NL/min) | Concentration at mid-engine hood (%) | Concentration at front side of upper radiator (%) | Concentration at front side of lower radiator (%) |
|---|---|---|---|
| 131 | 23 | 20 | 0 |
| 100 | 22 | 18.5 | 0 |
| 50 | 17 | 12 | 0 |
| 20 | 12 | 5 | 0 |
| 5 | 7 | 2 | 0 |

**Hydrogen concentration in engine compartment with different leak flow rates**




**Standing hydrogen concentration at center of hood tends increase as flow rate increases. The time required for hydrogen concentration at the mid-hood area to fall below 4% was less than 180 sec. under all test conditions.**

# Ignition Test Within the Engine Compartment



Condition of tissue paper after test

(131NL/min)

Table 2.1 Summary of flammability test results

| Leak flow rate (NL/min) | Tissue paper within engine compartment burned | | Tissue paper in front of front grille burned | Maximum thermocouple designated temperature (℃) at center of engine hood | Pressure |
|---|---|---|---|---|---|
| | Intake manifold air cleaner side | Intake manifold injector side | | | |
| 131 | A | C | D | 185.2 | N/A |
| 100 | C | A | D | 216.4 | N/A |
| 50 | C | C | D | 175.5 | N/A |
| 20 | - | - | - | - | - |
| 5 | - | - | - | - | - |

**A: Burn B: Partial burn C: Partially burned but original shape maintained**
**D: No burn**
**Hydrogen-air mixed gas does not ignite with 20, 5L/min**



# 4. Hydrogen gas discharge (hydrogen purge)

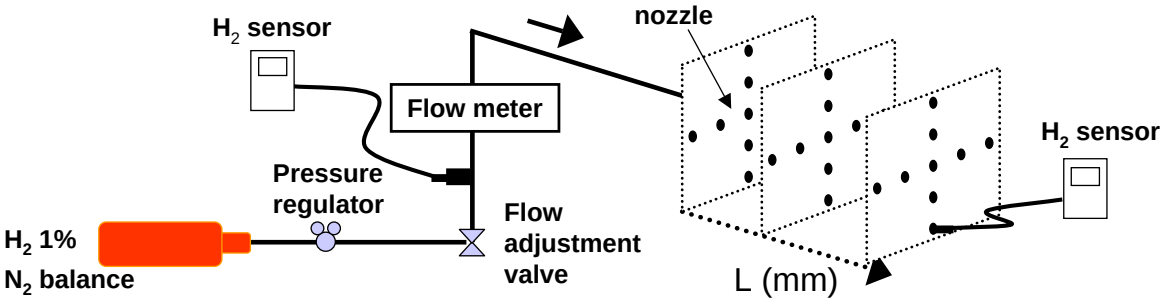
## Issues for investigation

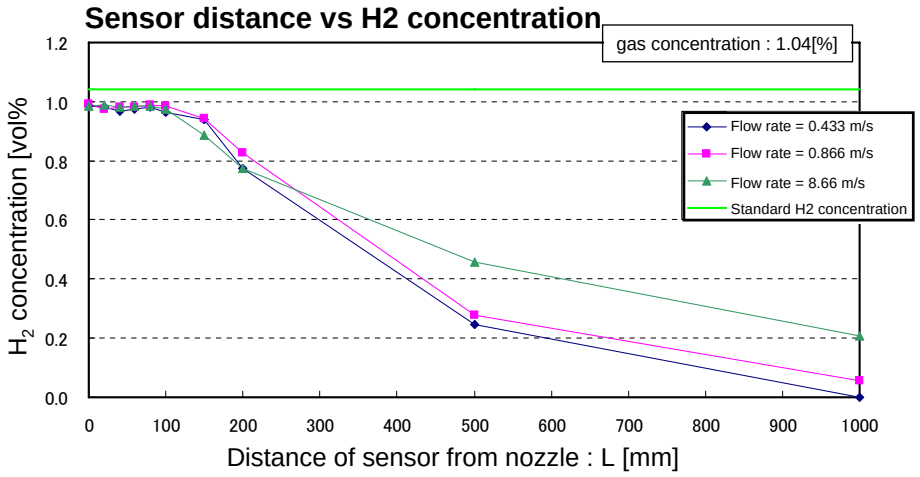
- Establish upper limit for purged hydrogen concentration
- Location for measurements of purged hydrogen

## Investigation results

- Purged hydrogen concentration is below the lower flammability limit (4%)
- Purged hydrogen measurement location: Within 100 mm of exhaust pipe end

# Location for Measurement of Purged Hydrogen Concentration



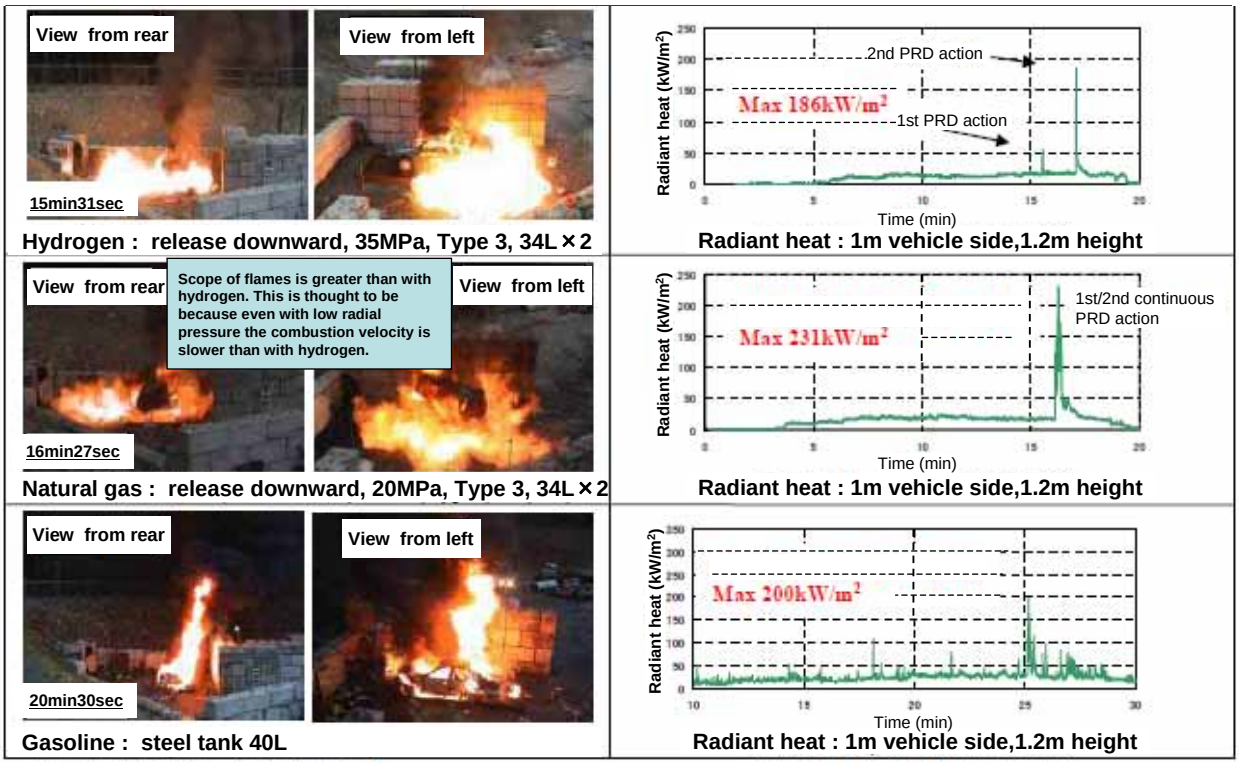






# 4. Hydrogen gas discharge (PRD release at time of fire)

- **Issues for investigation**
  - Comparison of fire with a gasoline vehicle, a natural gas vehicle and a hydrogen gas vehicle
  - Investigate safe release method to prevent secondary disaster
- **Investigation results**
  - Effect of hydrogen fire on surroundings is equivalent to or less than that of existing CNG and gasoline vehicles.
  - Prescribe direction/location in which hydrogen release cannot be allowed
    - No direct release into passenger or luggage compartments
    - No release within tire housing or toward exposed electric terminals or switches, or other sources of ignition
    - No release toward other gas containers
    - No release toward front of vehicle

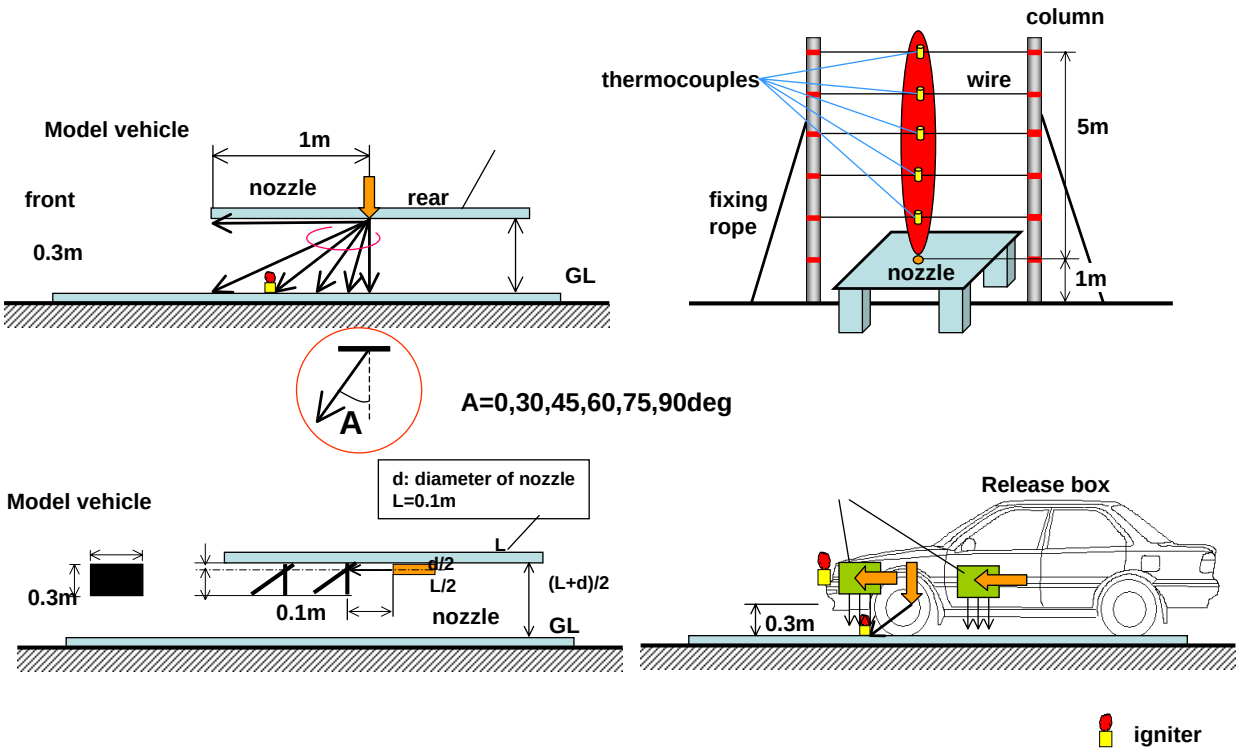
# Comparison of each fire of a gasoline vehicle, a natural gas vehicle and a hydrogen gas vehicle



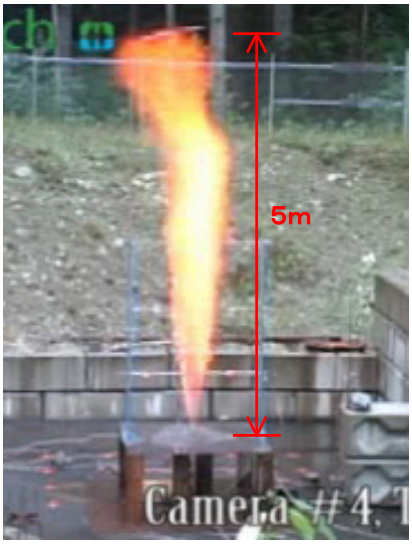

**Effect of hydrogen fire on surroundings is equivalent to or less than that of existing CNG and gasoline vehicles.**

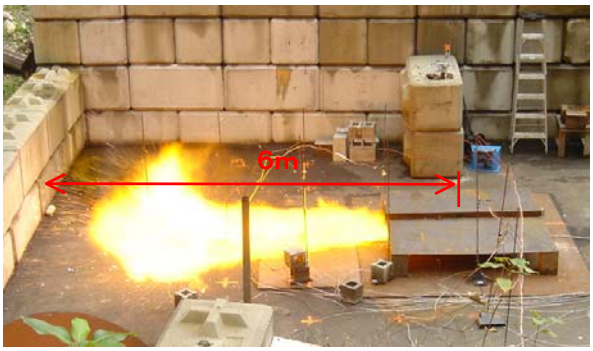


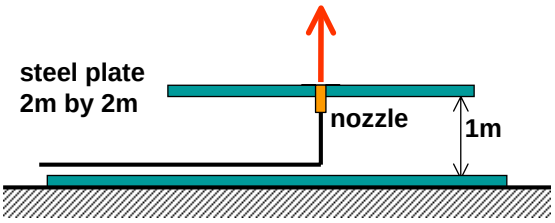
# PRD Release Combustion Test Conditions

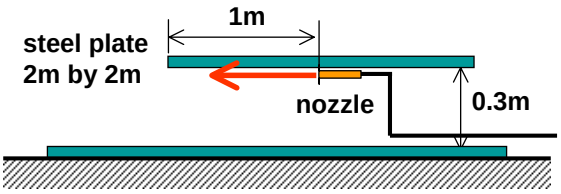


# PRD Release Combustion Test Conditions



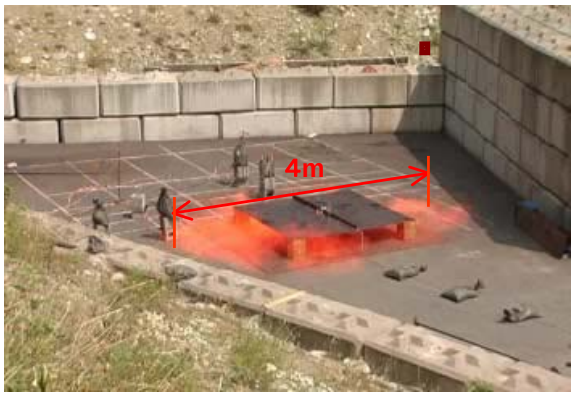



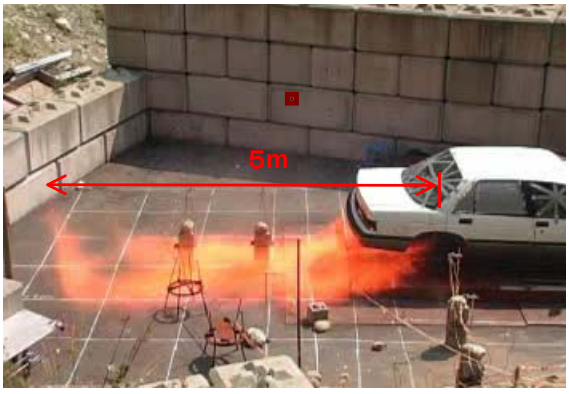



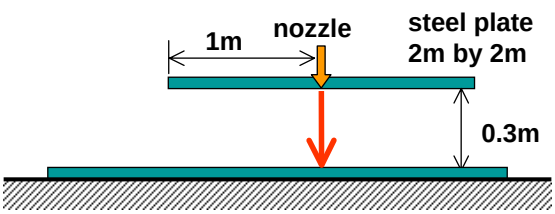



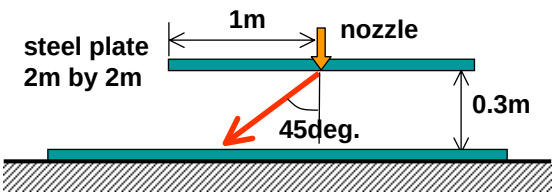



# Scenes from PRD Release Combustion Test



# Summary of PRD Release Combustion Test

1. Ignition occurred nearly simultaneously with the release of hydrogen, and the maximum spread of hydrogen flames was observed immediately after ignition.
2. In cases of direct release of hydrogen, flame length extended more than 6 m, and maximum temperature was 1400 deg.C.
3. Flames spread much to the sides when the direction of hydrogen release tended downwards and flame length was small. In cases of direct downward release, flames spread about 2 m in the front, back, and side directions.
4. This discharge combustion experiment had 2 different discharge flow rates and release upward and at a 45 deg. downward angle. No effect of differences between these two discharge flow rates was seen.
5. The results of this study indicate that direct discharge of hydrogen to the front, back, and sides should be avoided.



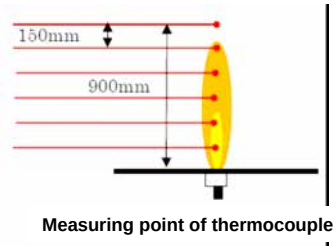
# 5. Hydrogen gas leaks in collisions

- **Issues for investigation**
  - Prescriptions for hydrogen gas leaks in collisions
    - Prescribe leak limit?
    - Shut off hydrogen supply at time of collision?
- **Investigation results**
  - Set leak limit of 131 L/min in collisions

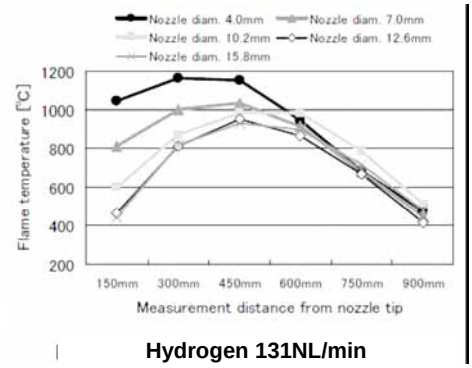
    131 L/min is equivalent to the heat value stipulated for gasoline leaks (30 g/min)
  - Conduct collision tests to confirm leak volume
    - Prescribed Helium gas instead of Hydrogen gas
    - To measure pressure down in the container is available to confirm leaks
    - Measuring Lapse time minimum 60min after collision

# Comparison of combustion
## (Flame upward release : hydrogen 131NL/min, methane 40NL/min)

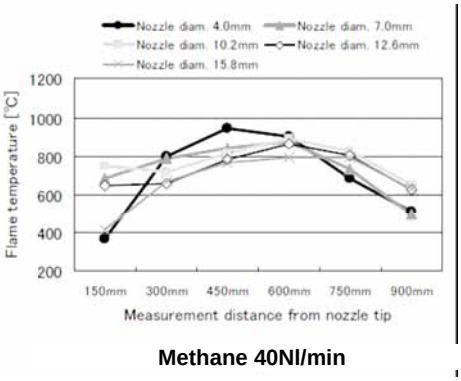
## 1. Flame temperature




Measuring point of thermocouple

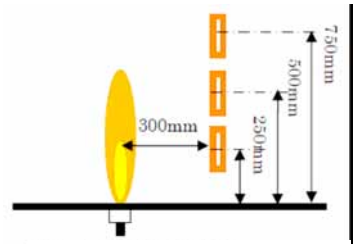



Hydrogen 131NL/min

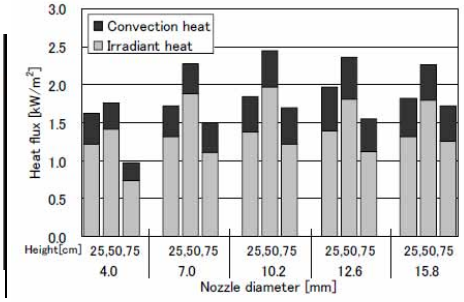



Methane 40Nl/min

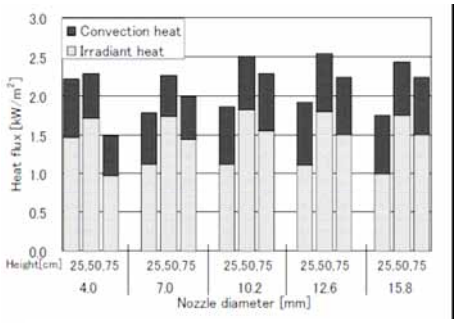
## 2. Heat flux




Measuring point of heat flux




Hydrogen 131NL/min

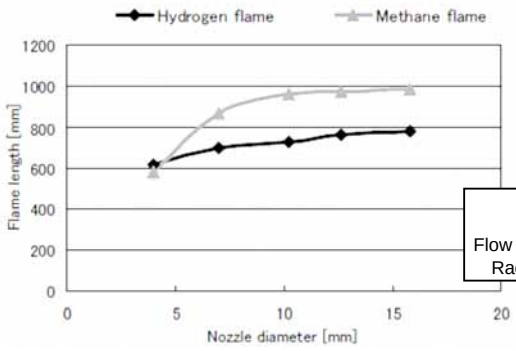



Methane 40Nl/min

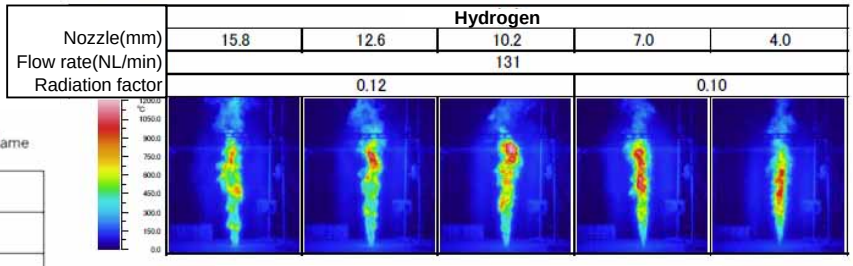


# Comparison of combustion
## (Flame upward release : hydrogen 131NL/min, methane 40NL/min)

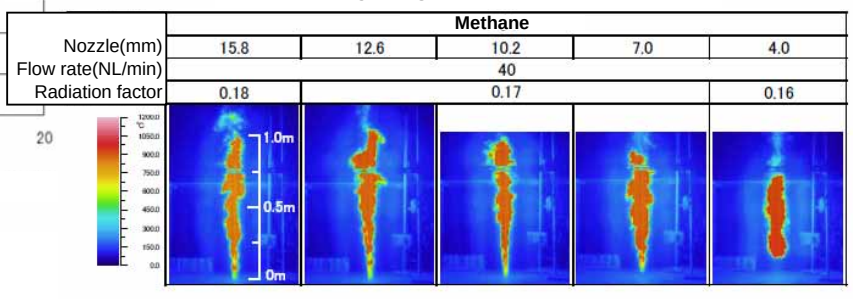
## 3.Flame length




Hydrogen 131NL/min, Methane 40Nl/min




Hydrogen 131NL/min



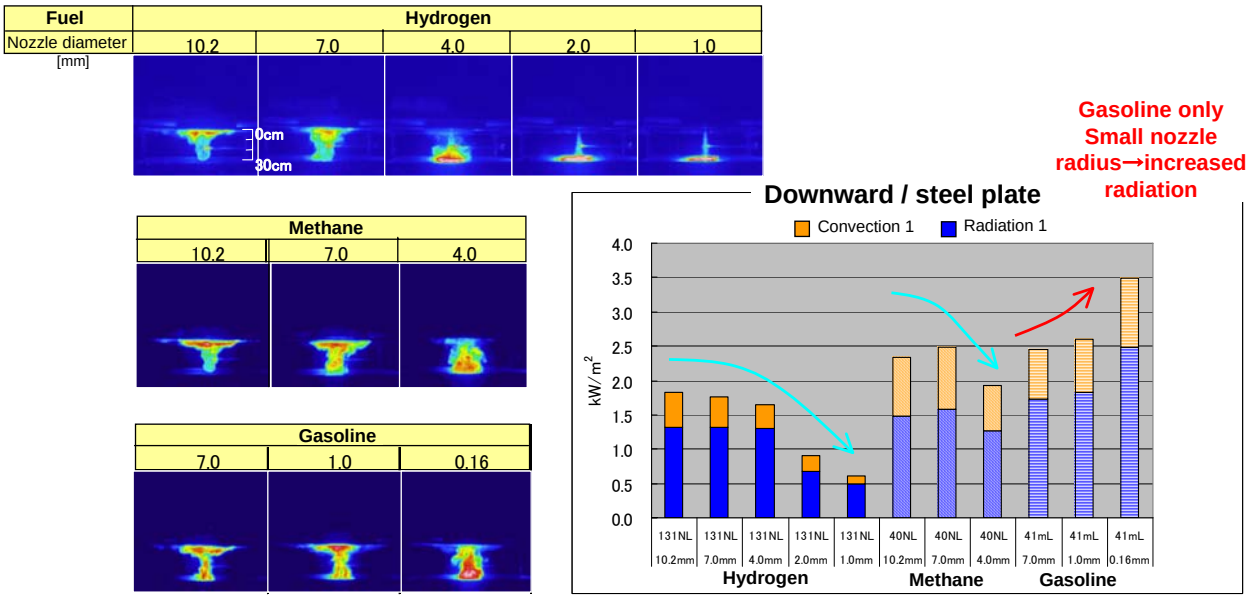

Methane 40NL/min

- No difference in distance from flame for safety regardless of flame temperature
- Similar size flames

# Comparison of combustion

**(Flame downward release : hydrogen 131NL/min, methane 40NL/min, gasoline 30g/min)**

## 4.Comparison of radiation, convection with downward release flames



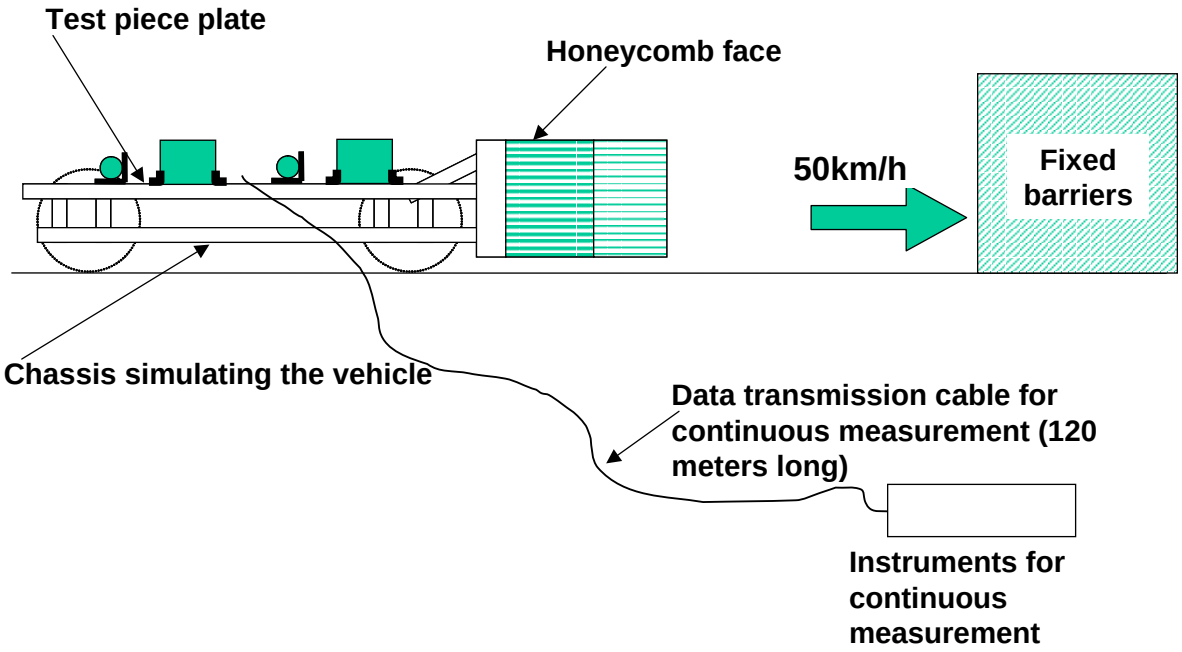

**Gasoline only Small nozzle radius→increased radiation**

- **No difference in distance from flame for safety**
- **Similar size flames**



# Appendix

# Test Conditions



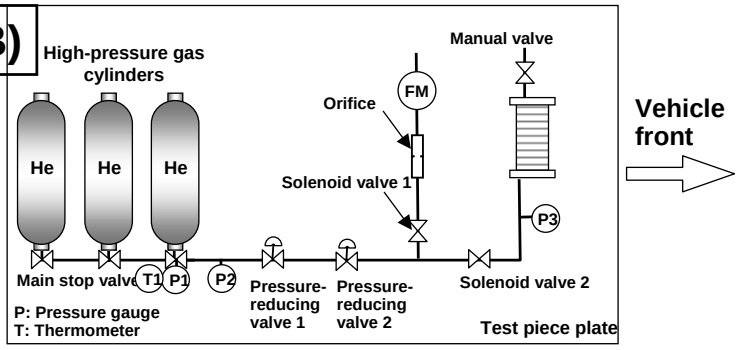



# Test Piece Conditions (A, B)

Amount of helium gas leakage (orifice design target value)
Target amount of hydrogen leakage: 131 L/min, 65 L/min
Converted to helium: 92 L/min, 46 L/min

Impact velocity: 50 km/h

All parts should be of rigid fixation
(The parts must be solidly fixed in such a way that they do not come apart under the impact)




High-pressure cylinders specifications
Type 3 composite cylinders for motor vehicles
Capacity: 34 L
Maximum filling pressure: 35 MPa
Gas type: Hydrogen only
Filling permission: Helium filled with special permission.
Number of cylinders used: 3 cylinders per test

Stack type: Solid high polymer type

Valve specifications
Main stop valve: in-tank valve for motor vehicles
Pressure reducing valve 1: Parts for motor vehicles (made by X ) (35 MPa --> Less than 1 MPa)
Pressure reducing valve 2: Industrial parts (Less than 1 MPa --> Stack supply pressure: About 0.1 MPa)
Solenoid valves 1 and 2: Solenoid valves for motor vehicles (made by X)
Sensors
Pressure gauge P1: Delivered as part of the in-tank valve (Capacity ≈ 50 MPa)
Pressure gauge P2: Sensor exclusively used for measurements (Kyowa Dengyo: 50 MPa)
Pressure gauges P3: Sensor exclusively used for measurements (Kyowa Dengyo: 2 MPa)
Temperature sensor T1: Delivered as part of the in-tank valve

Valve Operating Conditions
Main stop valve: Usually open
Solenoid valve 1: Opens after the collision
Solenoid valve 2: Closes after the collision
Manual valve: Usually closed

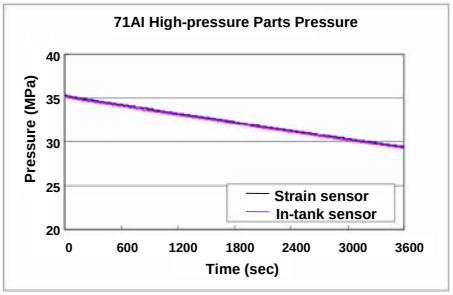
Electric measurement
Chassis simulating the vehicle
Acceleration (Front, center of gravity): Measures collisions of 500 msec in impact velocity after collision.
Valve operation: Measurement on collision, continuous measurement
Pressure, temperature: Continuous measurement (one hour after collision, wired measurement)
Event signals: Measurement on collision, continuous measurement

Measurement on collision: Short-time, high-response measurement using materials for impact test.
Continuous measurement: Low-response measurement using the data recorder.

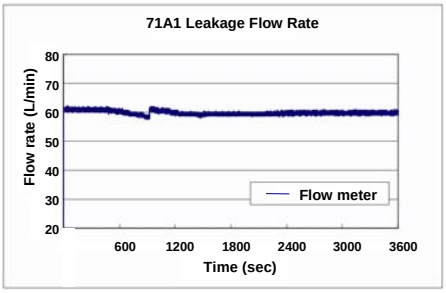
Optical Measurement: With five high-speed video cameras

# Test Results A

**Amount of Leakage Converted in Hydrogen: 131 L/min**

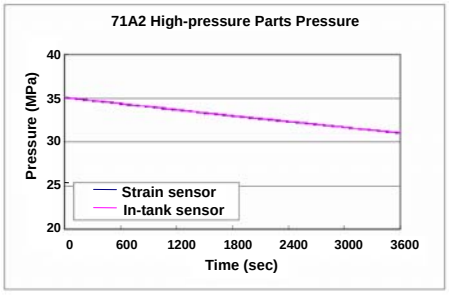



High-pressure Parts Pressure - Time Diagram

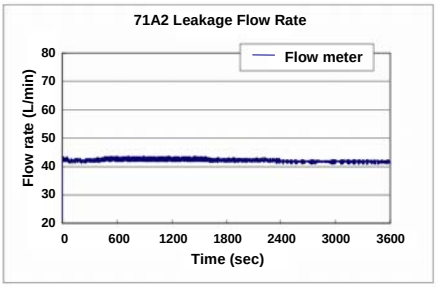



Flow Meter Flow Rate - Time Diagram

**Amount of Leakage Converted in Hydrogen: 65 L/min**




High-pressure Parts Pressure - Time Diagram




Flow Meter Flow Rate - Time Diagram

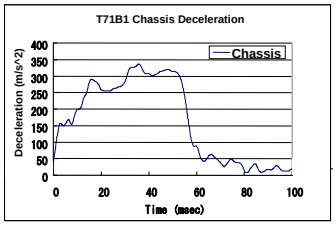
**Calculate the amount of leakage from the pressure sensor.**
**Measure the amount of leakage with the pressure sensor.**
**Validation of accuracy.**



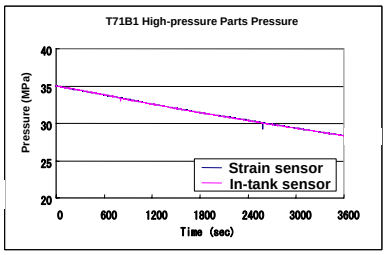
# Test Results B

**Amount of Leakage Converted in Hydrogen: 131 L/min**

**Chassis deceleration**



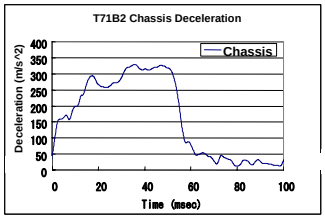

**Leakage status**



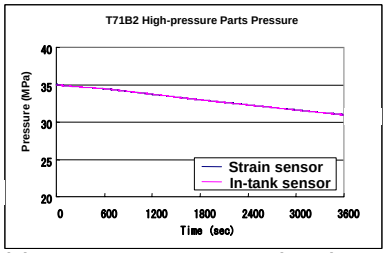

High-pressure Parts Pressure - Time Diagram

**Amount of Leakage Converted in Hydrogen: 65L/min**

**Chassis deceleration**




**Leakage status**




High-pressure Parts Pressure - Time Diagram

**Measurement: OK**
**Sensor accuracy: OK**

**Calculate the amount of leakage with the pressure sensor.**

# Reference : Comparison of hydrogen and other automobile gaseous fuels

| | Max. burn rate (m/sec) | Fuel concentration at max. burn rate (%) | Combustion heat (@$10^5$Pa, 25℃) (kJ/mol) | Flammable range (@101kPa, in air) Vol % |
|---|---|---|---|---|
| Hydrogen | 291.2 | 43 | 286 | 4.0-75 |
| Methane (main component of natural gas) | 33.8 | 9.96 | 891 | 5.0-15.0 |
| Propane (main component of LPG) | 39.0 | 4.54 | 2219 | 2.1-9.5 |
| Basis for view that hydrogen is less dangerous than other gaseous fuels | In combustion due to escaped fuel during vehicle fires, the blaze range is smaller with the same fuel release volume (flow rate) | Methane and propane reach maximum burn rate with smaller leak volumes than hydrogen (although max. burn rate is small) | Propane has the highest combustion heat when fuel is released in the same space and a combustible mixture is formed. Hydrogen is about 1/10 of propane | Propane has a lean flammability limit, and combustion (eruption of fire) occurs with a small amount |