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Overview of Sandia's Hydrogen Safety, Codes and Standards Program Area

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Introduction to Hydrogen for Transportation

- Hydrogen Fuel Cell Powered Electric Vehicles (FCEV)
  - Electric vehicles which use a hydrogen fuel cell to convert hydrogen to electricity
- Fuel Cell
  - "Battery with a gas tank"
  - Electrochemical device to convert chemical energy to electrical energy
- Fueling
  - High pressure hydrogen (5,000 or 10,000psi)
  - Fueling Time is 3-5 min

More information:

University of Washington Program

US Department of Energy Program

Sandia Safety, Codes and Standards


Introduction to Hydrogen for Transportation

<u>Common uses of hydrogen:</u>

- 9 million tons annual in US (56 Bkg global)

-Oil Refinery

 - 60% of current hydrogen use

 -“Sweetens” and removes sulfur

 -21 Million Fuel Cell Vehicles (FCVs) equivalent

- Food – partially-hydrogenated fats

- Electrical power equipment coolant

- Ultra-clean heating ovens – metals, silicon wafers, etc.

<u>Not yet common use:</u>

- Personal vehicles, private residences

- 12,000 hydrogen stations would put hydrogen within two miles of 70 percent of the U.S. population

Sandia's Role

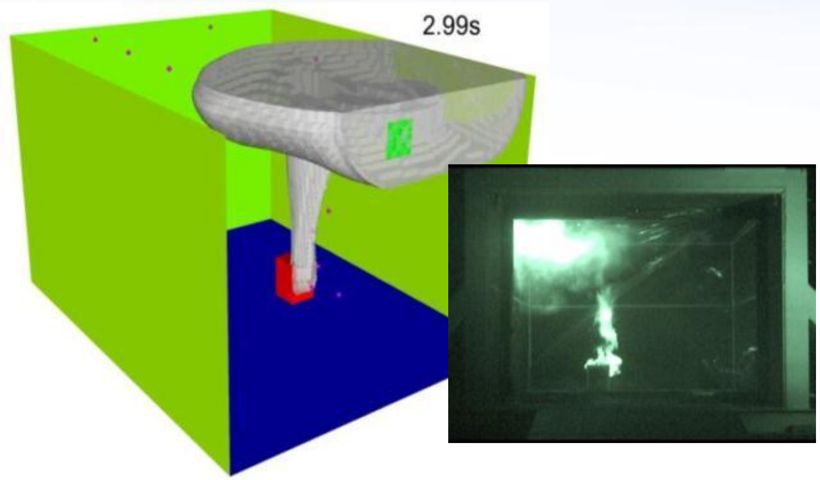
- Laboratory Mission Area: Energy, Climate & Infrastructure Security
  - Transportation Energy Center
    - Combustion and Technology Branch
      - Hydrogen & Combustion Technology Program
        - Hydrogen Safety, Codes and Standards R&D

Hydrogen Safety, Codes and Standards R&D Goals:

- Eliminate barriers to access and availability of safety data and information.
- Enable market development with consistent regulations, codes and standards.
- Provide technical data for creation and revision of regulations, codes and standards.

R&D program for Safety, Codes and Standards

Hydrogen behavior



Simulation and experimental validation of release during indoor refueling

H2 effects in materials, components, and systems

Technical Reference

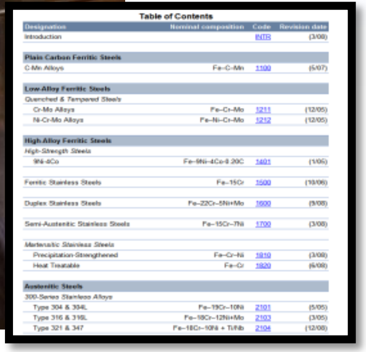


Table of Contents

Designation	Nominal composition	Code	Revision date
Introduction		INTR	(3/08)
Plain Carbon Ferritic Steels			
C-Mn Alloys	Fe–C–Mn	1100	(5/07)
Low-Alloy Ferritic Steels			
Quenched & Tempered Steels			
Cr-Mo Alloys	Fe–Cr–Mo	1211	(12/05)
Ni-Cr-Mo Alloys	Fe–Ni–Cr–Mo	1212	(12/05)
High-Alloy Ferritic Steels			
High-Strength Steels			
9Ni-4Co	Fe–9Ni–4Co–0.20C	1401	(1/05)
Ferritic Stainless Steels	Fe–15Cr	1500	(10/06)
Duplex Stainless Steels	Fe–22Cr–5Ni+Mo	1600	(9/08)
Semi-Austenitic Stainless Steels	Fe–15Cr–7Ni	1700	(3/08)
Martensitic Stainless Steels			
Precipitation-Strengthened	Fe–Cr–Ni	1810	(3/08)
Heat Treatable	Fe–Cr	1820	(6/08)
Austenitic Steels			
300-Series Stainless Alloys			
Type 304 & 304L	Fe–19Cr–10Ni	2101	(5/05)
Type 316 & 316L	Fe–18Cr–12Ni+Mo	2103	(3/05)
Type 321 & 347	Fe–18Cr–10Ni + Ti/Nb	2104	(12/08)

Mechanical load-frame used to characterize H2 effects in materials

Quantitative Risk Assessments

Quantitative Risk Assessment helps establish requirements for hydrogen installations

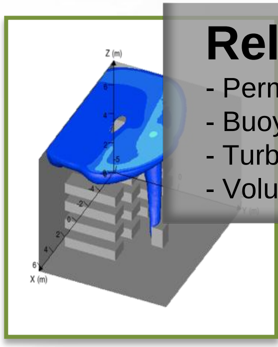
C&S development support

NFPA® SAE® UL ISO ICC INTERNATIONAL CODE COUNCIL® ASME SETTING THE STANDARD

Regulations Codes and Standards Advocacy

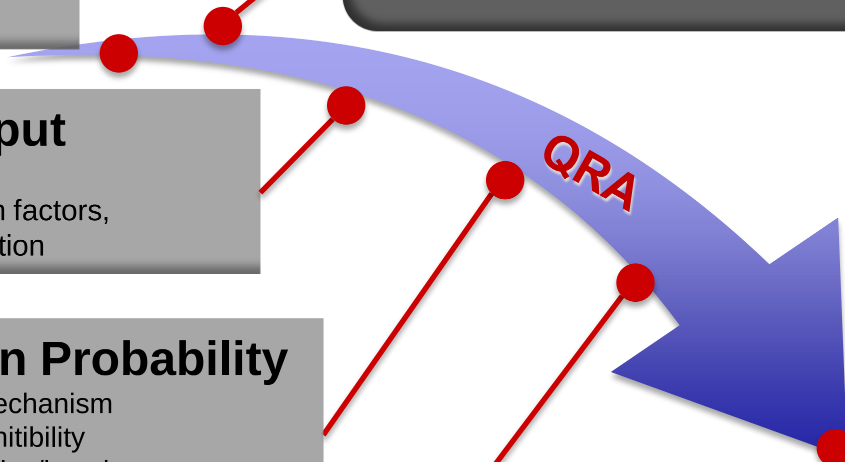
Risk-Informed Approach

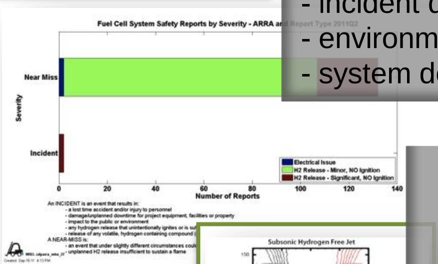
Use validated simulations, field data and expert input to determine risk through quantitative risk assessment.



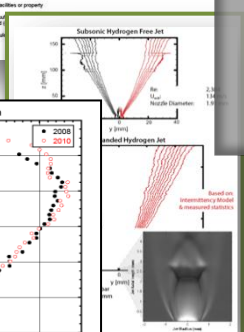
Release Probability
- Permeation
- Buoyant creeping flow
- Turbulent jet
- Volumetric rupture

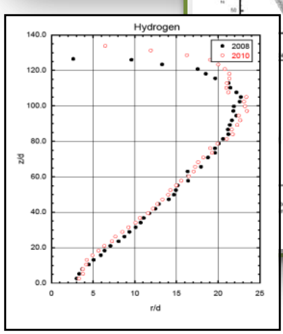
Informed Input
Code development groups, industry, regulators and code enforcers



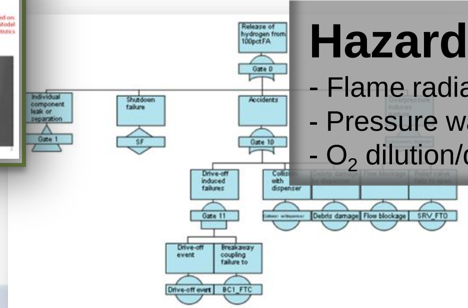


Field Data Input
- incident data,
- environmental/human factors,
- system design/mitigation





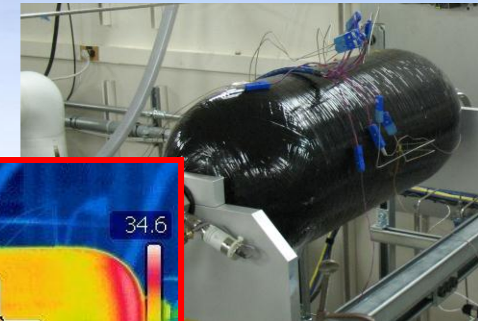
Ignition Probability
- Ignition mechanism
- Mixture ignitibility
- Ignition delay/location
- Sustained light-up



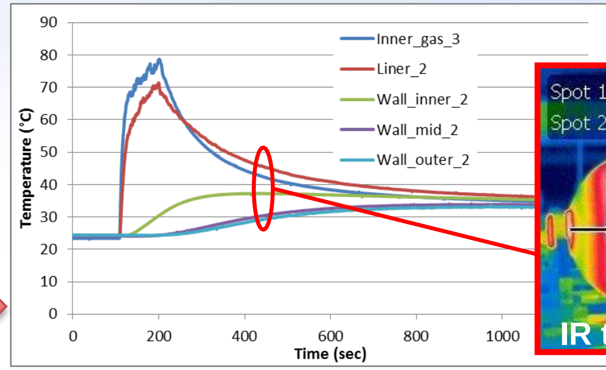
Hazard Probability
- Flame radiation
- Pressure wave (deflagration/detonation)
- O_2 dilution/depletion

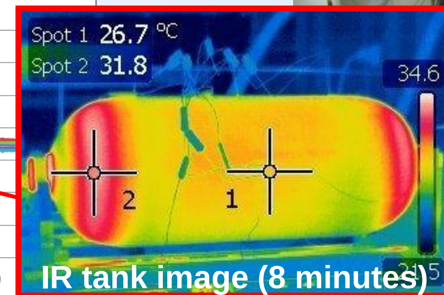
Harm Probability
- Burns
- Lung damage
- Shrapnel wounds
- Building collapse

Simulation and Experimental Validation

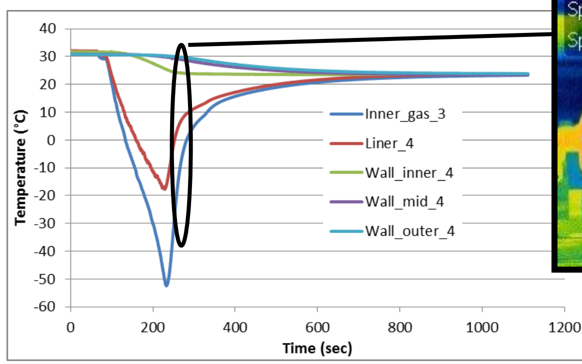


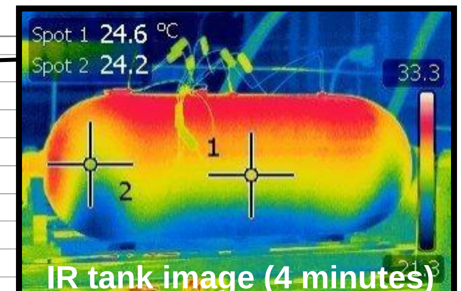
Test #	Initial pressure (psi)	Final pressure (psi)	Fill time (sec)
1	20	1500	60
2	20	1500	90
3	20	1500	150
4	20	1500	300
5	20	1000	90
6	**20**	**2000**	**90**
7	145	2000	90
8	290	2000	90
9	725	2000	90

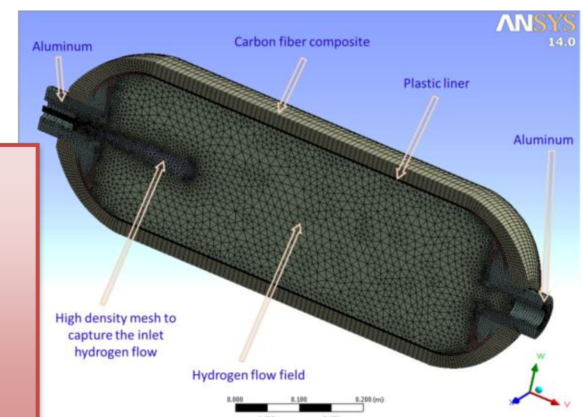




Test #	Initial pressure (psi)	Final pressure (psi)	Release rate (g/sec)
1	1300	20	1.5
2	1300	20	0.75
3	1300	20	1.0
4	**1300**	**20**	**1.9**
5	1700	20	0.4
6	1700	20	1.5
7	1700	20	0.75





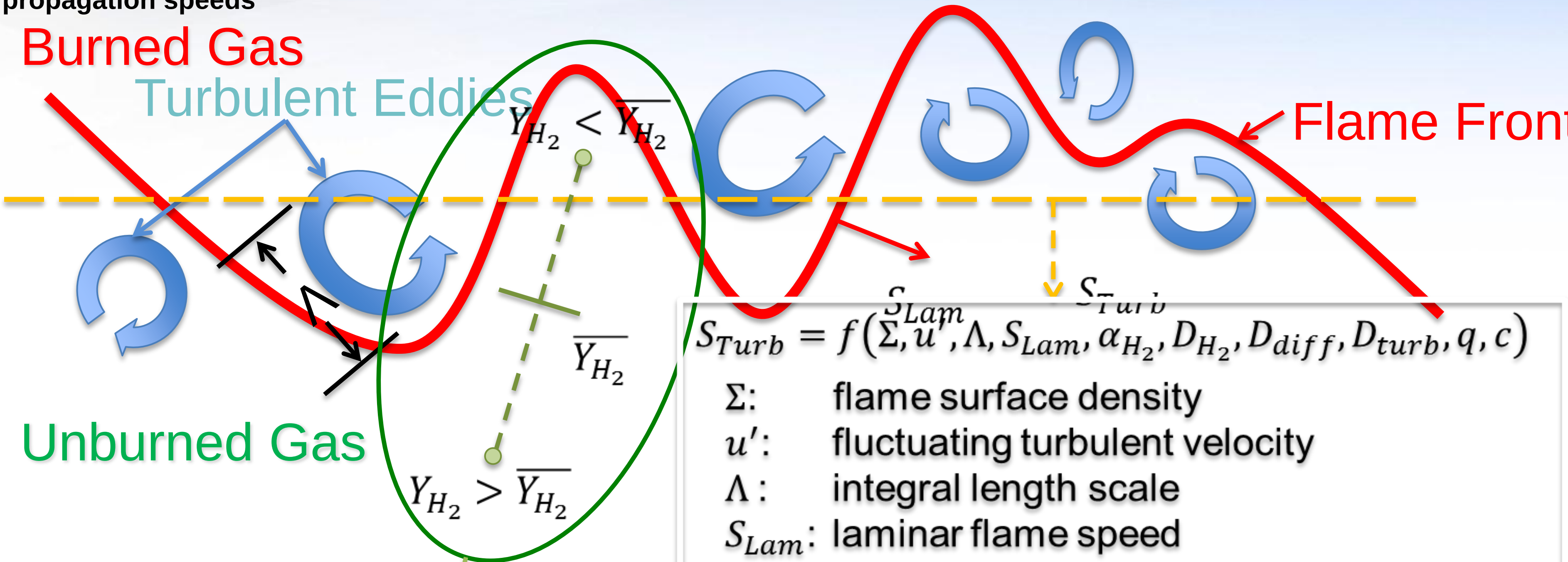


<u>Model Results:</u>

- ✓ Model completed, currently in validation
- ✓ *Goal:* results available for SAE Interface Group (J2601) discussion; Sept 2012
- ✓ *Goal:* Comparison with other research and industrial datasets in support of 2015 vehicle deployment

Improve Mixture Measurement

Flamelet models can be used to predict these turbulent flame front propagation speeds



H_2 preferentially diffuses toward reaction front (differential diffusion)
- Increased flame front distortion

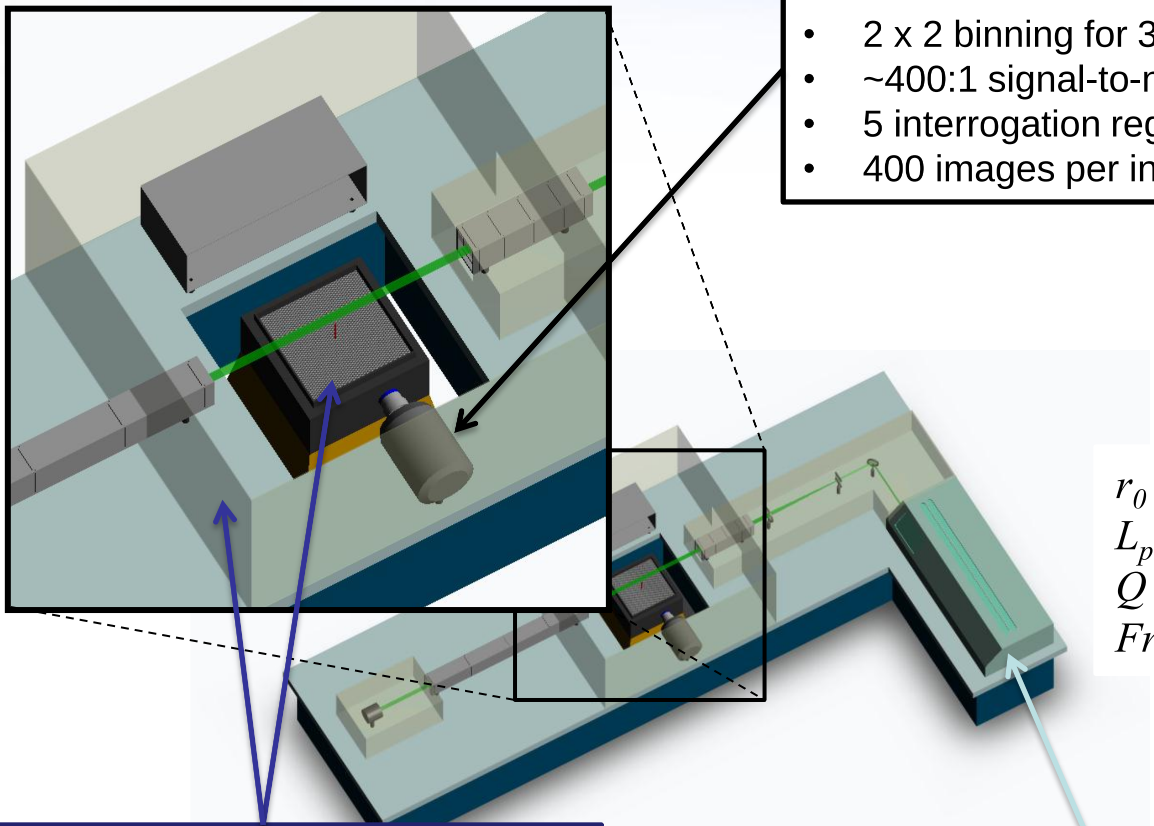
Driscoll, 2007

$$S_{Turb} = f\left(\Sigma, u', \Lambda, S_{Lam}, \alpha_{H_2}, D_{H_2}, D_{diff}, D_{turb}, q, c\right)$$

- Σ: flame surface density
- u': fluctuating turbulent velocity
- Λ: integral length scale
- S_{Lam}: laminar flame speed
- α_{H_2}: thermal diffusivity
- D_{H_2}: molecular diffusivity
- D_{diff}: differential diffusion
- D_{turb}: turbulent diffusivity
- q: heat release
- c: reaction progress variable

Turbulent Jet Experiment

Scalar field of a momentum driven, turbulent H_2 jet was examined via high-resolution Planar Rayleigh Scatter Imaging (PLRS).



PIXIS 400B low noise CCD Camera

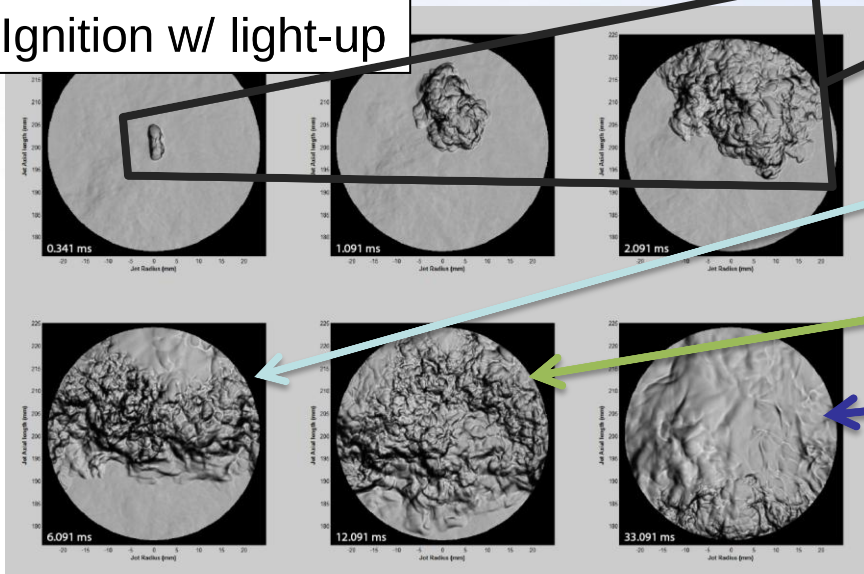
- 2 x 2 binning for 3.94 pix/mm resolution
- ~400:1 signal-to-noise
- 5 interrogation regions (37 x 125 mm^2)
- 400 images per interrogation region

$$r_0 = 0.95\ mm$$
$$L_{pipe} = 250\ mm$$
$$Q = 100\ lit/min$$
$$Fr_{den} = 1170$$

Additional diagnostics include Particle Image velocimetry (PIV), Laser Doppler Velocimetry (LDV) and OH Laser Induced Fluorescence (LIF).

Flame Light-Up Imaging

Ignition w/ light-up



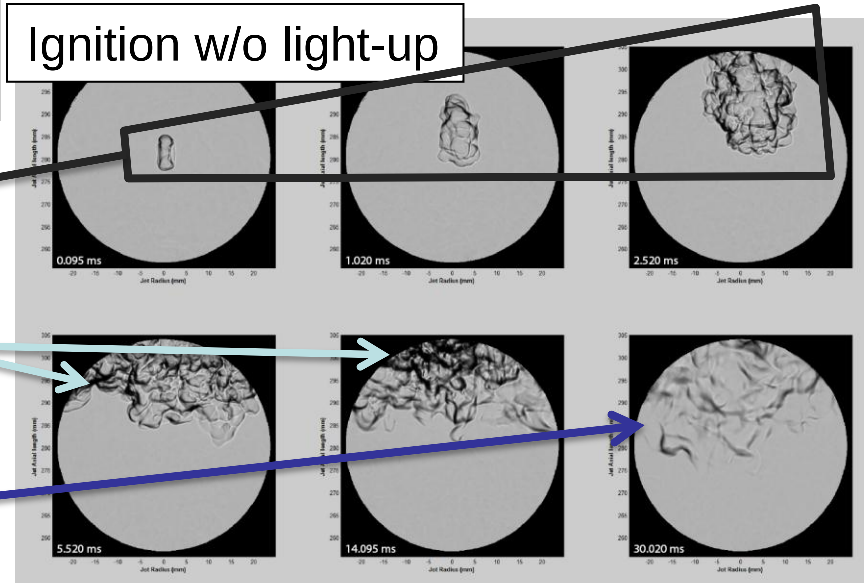
Rapid volumetric ignition kernel growth

Kernel forms into turbulent flame front

Flame front broadens

Front **overcomes** flow convection

Ignition w/o light-up



Slower kernel growth

Thinner, less turbulent flame front

Front **overcome** by convection

✓ Imaging observations indicate sustained flame light-up correlates with 1D flame front propagation speeds.

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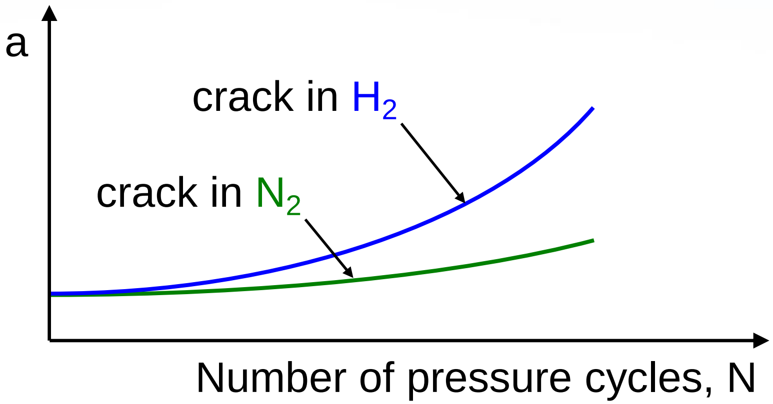
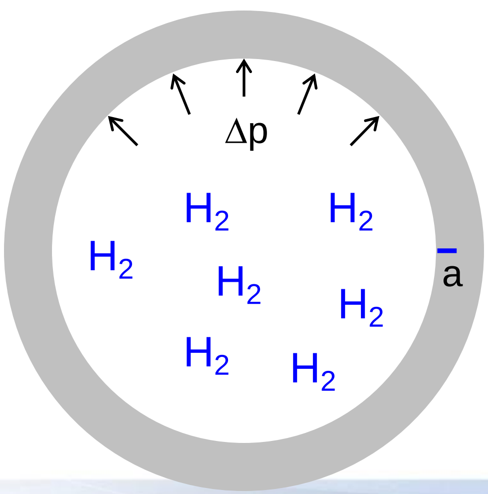
Safety qualification must consider hydrogen embrittlement of metal components

Hydrogen embrittlement accelerates fatigue cracking





$N_f = N_{initiation} + N_{growth}$

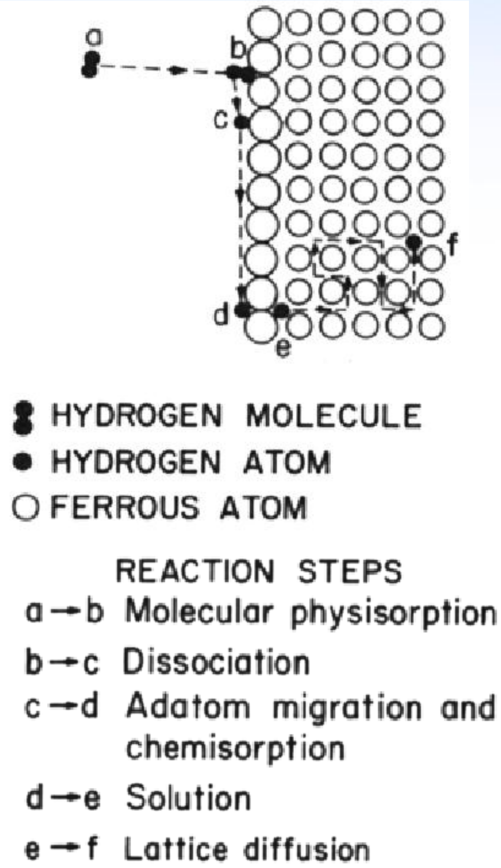
Barthélémy, 1st ESSHS, 2006

Hydrogen Embrittlement

- Hydrogen is the smallest element
- Hydrogen ‘interrupts’ the metal structure
- Material becomes more brittle
- Hydrogen affects are different for different types or classes of metals

- Sandia has an enduring program in hydrogen effects in materials for the national defense mission area

- This expertise was used to provide assistance to this investigation



AC Transit Emeryville, CA
Incident Summary

- Hydrogen release and subsequent jet fire from vent system
- No significant damage, injuries or fatalities
  - Root Causes – improper material and poor quality control
  - Contributing factor – inadequate communication of critical data
  - Contributing factor – inadequate communication of design changes (canopy)
  - Contributing factor – lack of sub-system isolation and inadequate communication of vulnerabilities during safety reviews

Thank You

Questions?