HYDROGEN

HANDLER / SAFETY COURSE

Presented by

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and

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If You Have an Incident:

- Do Not Blame the Course Instructors
- Do Not Blame Anyone Else
- Get Good Video

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Thanks to all of the people at ***Stennis Space Center*** for their contributions to this class

Basics

General Description

- Highly flammable, odorless, tasteless, virtually non-toxic, a non-corrosive water (pale blue) white transparent liquid.

- Constitutes roughly 2 parts per million (PPM) of the earths atmosphere.

- Constitutes roughly 90% of the atoms found in the universe – it is the most common element.

- Constitutes roughly 3% of the earths atoms.

- Found predominantly in numerous materials and compounds including water, natural gas, gasoline, human tissue, etc.

Basics

- GH_2 is the lightest known naturally occurring gas, having a density that is only 7% (or 1/14th) that of air.
- Can exist in 4 phases or physical states: Solid (H_2), Liquid (LH_2), Gas (GH_2) and slurry (SH_2).
- A slurry, or slush, is a transition mixture of solid and liquid.
- LH_2 is chemically stable, however it is classified as a non-storable propellant because it requires venting and special insulation considerations.

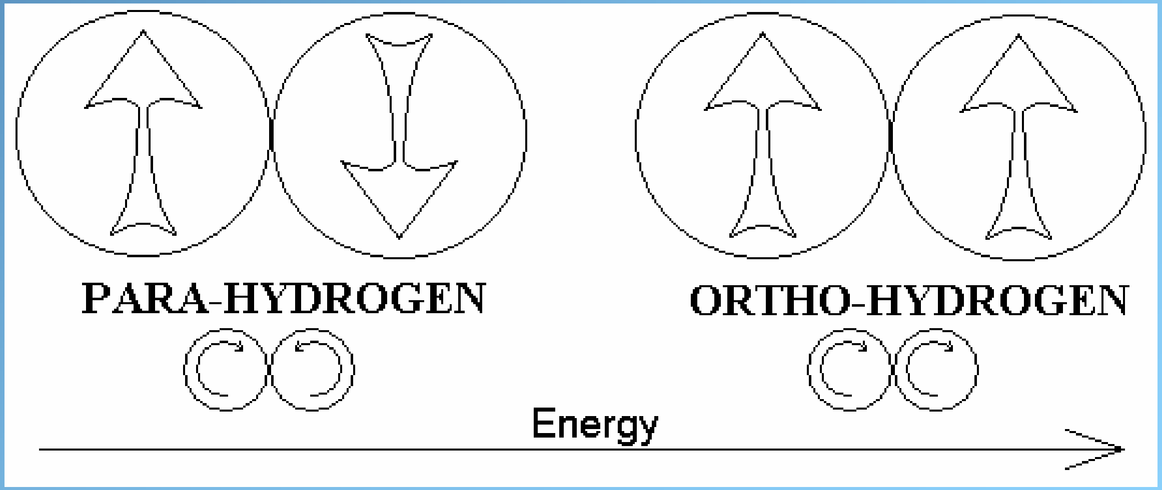
Basics

LH_2 Property	
Boiling Point (°F @ 1 atm)	-423.2
Freezing Point (°F @ 1 atm)	-434.3
Critical Temperature (°F)	-400.3
Critical Pressure (Pisa)	188
Liquid Density, lb/gal@ 1 atm (water=8.33)	0.59
Gas Density, lb/ft^3@ 70 °F (1 atm)	0.0052
Specific Gravity @ 70 °F (air=1)	0.069
Liquid/Gas Expansion Ratio (to gas @ 70 °F)	850.3:1
Flammable	Yes

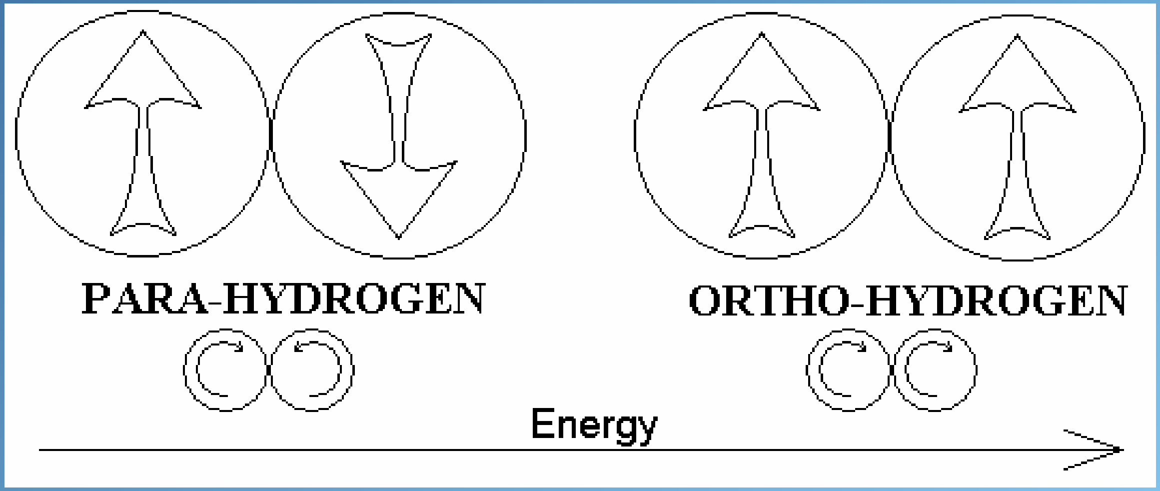
Basics

- Freely occurring Hydrogen exists as a *diatomic molecule*, meaning there are 2 individual atoms of Hydrogen bonded together to form a single molecule – H_2.

- This diatomic molecule exists in two forms distinguished by the nuclear spin orientations of the two individual atom.



Basics

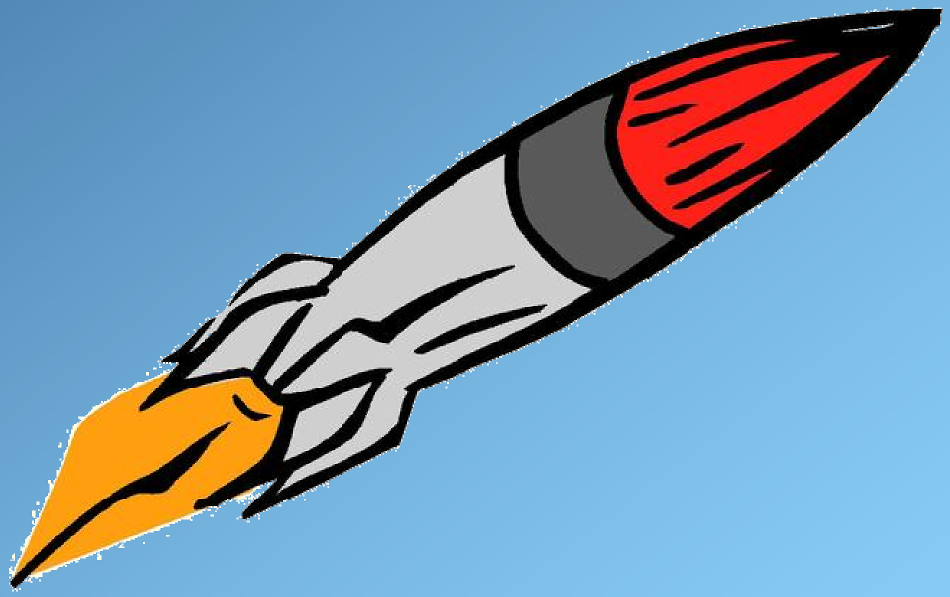


- PARA-Hydrogen - the atoms have opposite nuclear spins (i.e. the single proton nuclei of each atom of the pair spin in an anti-parallel orientation)

- ORTHO-Hydrogen - both atoms have the same nuclear spin (i.e. the single proton nuclei of each atom of the pair spin in a parallel orientation)

Basics

- Rocket engine testing uses Para-hydrogen in the liquid state.



Uses

Hydrogen is used in many industries:

- Chemicals 23%
  - Sorbitol Production
  - General Pharmaceutical
- Electronics 23%
  - Polysilicon Production
  - Epitaxial Deposition
  - Fiber Optics
- Metals 19%
  - Annealing/heat Treating
  - Powder Metallurgy
- Propulsion 17%
- Food, Float Glass, Other 18%
  - Fats/fatty Acids
  - Blanketing

Uses

Town Gas

- In towns and cities all across America, lamplighters once lit gas street lights at dusk. Inside middle class homes, gas lamps provided light and gas heaters provided warmth. The gas that fueled the lights and furnaces was not the natural gas of today, but a hydrogen-rich mixture called “town gas.” Town gas was manufactured from coal and typically contained 50% hydrogen, with the rest 50% comprised of mostly methane and CO2, with 3% to 6% of CO. (Town gas is still used extensively in some parts of the world, such as China and other Asian countries).

Uses

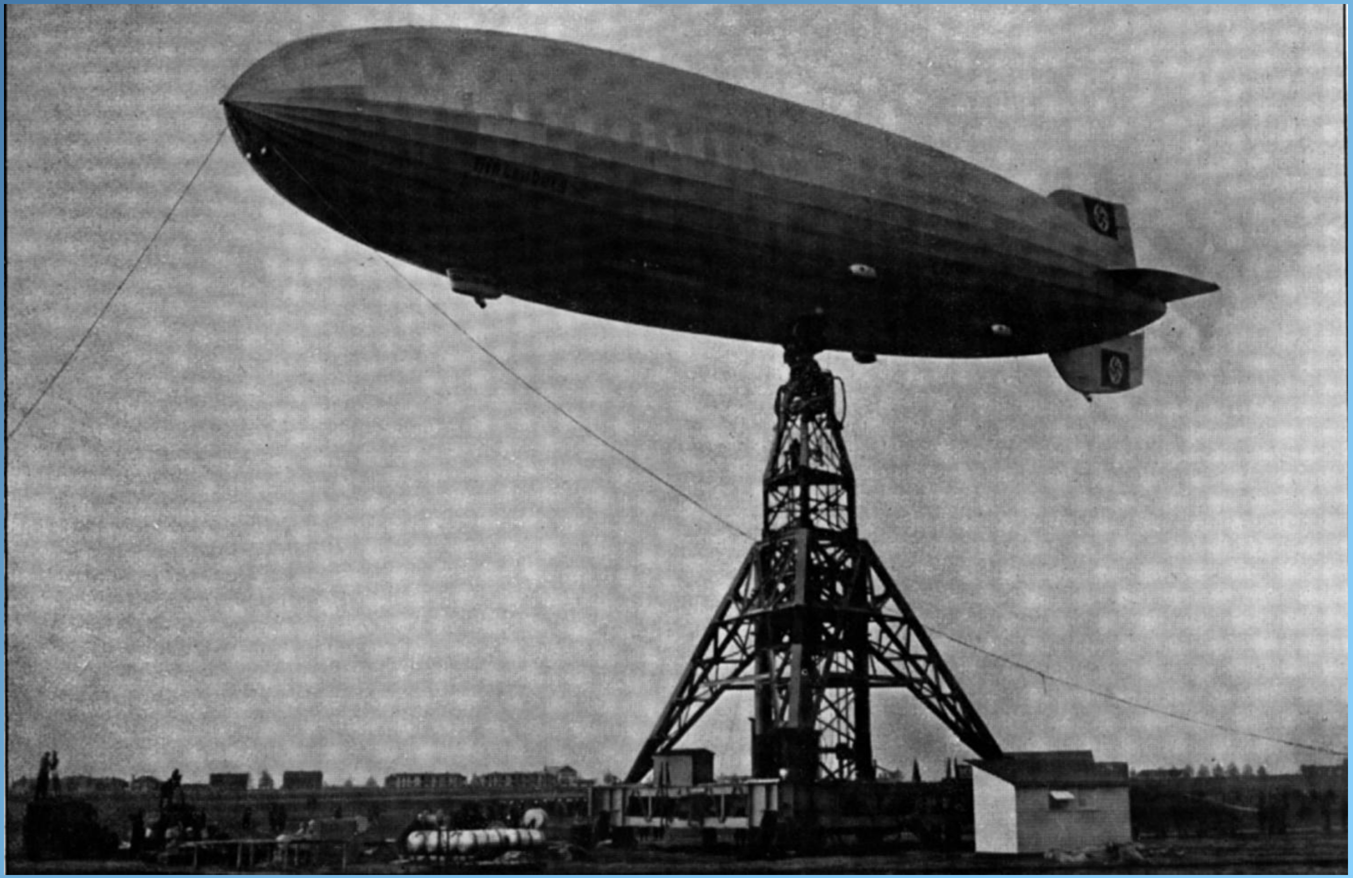
Fuel Cells

- During the month of February 2002 the first hydrogen refueling station was opened in Japan

- The University of California is requesting proposals to design, install, and supply hydrogen fuel for a hydrogen/natural gas fueling facility. Presently CNG infrastructure exists. The RFP describes work to install hydrogen storage, compression, blending (30% hydrogen by volume), and dispensing equipment for transit buses.

Uses

Misconception



Hazards

What has been seen

Hazards

Theory

- Studies by present-day researchers have concluded that hydrogen was not to blame for the disaster after all, and point to the *Hindenburg*'s skin itself as the definitive cause. Analysis of film footage shows the explosion to be inconsistent with hydrogen fire -- hydrogen only burns upward with no visible flame. Since the gasbags were coated with a gelatin concoction, and the shiny outer skin was the result of aluminum powder mixed in with the doping solution used to stretch and waterproof the hull, flammability could not be avoided. When samples of zeppelin fabric from the 1930's were extensively tested in modern laboratories, they proved to still be combustible.

Be Aware of the HAZARDS

Hazards

Balance

- We are here to help you understand the hazards that are associated with Hydrogen.

- We are also here to help understand that how to minimize the hazards with good practices.

- Having an understanding of both to help you to work safely with Hydrogen.

Hazards

Topics of Discussion

- Cryogen
- Liquid Air
- Material Incompatibility
- Leakage
- Asphyxiation
- Venting / Purge
- Relief System
- Fire
- Explosion

Hazard - Cryogen

- Cryogenics means the production of low temperatures or the study of low-temperature phenomena.

- Today the term is used as a synonym for low temperatures.

- The National Bureau of Standards set the standard as having temperatures below -240ºF (-150ºC).

- The normal boiling points of so-called permanent gases such as: hydrogen is below -240ºF. Classifying hydrogen as a cryogen.

Hazard - Cryogen

- <u>Cryogenic Burn (Frostbite)</u> – Burns similar to thermal burns on skin or other tissues produced from contact with cryogen or cold surfaces.

- Burns to the skin can result from direct contact with a cryogen or un-insulated piping containing cryogen.

- Permanent damage can occur if cryogen gets into the eye. Eyes contain fluid that is especially sensitive to cryogen exposure.

- A jet of cryogen vapor can freeze the skin or eyes faster than liquid contact, even faster than metallic contact.

Hazard - Cryogen

Third Degree Cryogen Burn (Frostbite) To Fingers & Second Degree Thermal Burn To Hand

Hazard - Cryogen

- Cryogenic burns result when tissue comes into contact with cold gases, liquid, or their containment.
- The result may be true tissue freezing to mere chilling which typically produces redness on skin.
- More significant injury is caused by true freezing, the formation of crystals within and around tissue cells.
- Frozen tissue always assumes a yellowish-white color, which persists until thawing occurs.
- Cryogenic liquid usually evaporates from the skin before freezing occurs.

Hazard - Cryogen

First Aid Emergencies

- Treatment of truly frozen tissue requires medical supervision since incorrect first aid practices invariably aggravate the injury.
- In the field it is safest to do nothing other than cover the involved area, if possible, and contact a emergency personal.
- If clothing or articles (gloves, shoes, clothing, etc.) are frozen with/to the skin, do not attempt to remove until all structures are thawed.
- Do not apply pressure to affected area except to control bleeding.
- Do not use safety showers, eyewash fountains, or other sources of water, because the temperature will almost certainly be incorrect therapeutically and will aggravate the injury.

Hazard - Cryogen

Minimize Hazard

Personal Protective Equipment

Following are minimum PPE requirements for cryogen operations where personal contact is possible:

- EYES/FACE – Safety glasses with associated side shields and face shield anytime cryogenic liquid has the potential to become exposed to the atmosphere. Goggles provide the best form of protection for the eyes.
- HANDS – Loose, insulating type gloves made for cryogenic work that can be readily tossed off.
- FEET – High-top leather shoes/boots where trousers extend over the top (shoes with fabric uppers are restricted).

Hazard - Cryogen

- BODY – Long-sleeved pocket less clothing made of impermeable and/or flame resistant/retardant material (Usually treated cotton), splash apron, etc.
- RESPIRATORY – Supplied air where oxygen deficiency or asphyxiation could occur.
- EARS – Ear plugs or muffs where excessive noise levels may occur from venting.

Hazard - Liquid Air

- Liquid Air (Condensed Air)
- Liquid Air is not a contradiction in terms – air, when cooled enough, condenses into a super cooled liquid.
- Un-insulated lines containing LH_2 or associated cold gases can condense air directly out of the atmosphere onto the outside of piping systems.
- The condensed liquid can be enriched in oxygen content to approximately 50% by volume.
- Materials not suitable for extremely low temperatures, such as carbon steel (ferrous based alloys), could become brittle and fail.

Hazard - Liquid Air

- If allowed to contact electronic equipment, sensitive or incompatible materials in systems/subsystems or moving parts, adverse effects could occur.

- Because LOX does not evaporate as rapidly as LN in liquid air, LOX can accumulate and cause chemical reactions and increase flammability with carbon based materials.

- Skin that comes in contact with liquid air can suffer serious burns.

- Asphalt that comes in contact with liquid air can become explosive

Hazard - Liquid Air

- **Ideal environment for liquid air to form**

Hazard - Liquid Air

Minimize Hazard

- Use insulated pipes
- Use good house keeping to avoid contact between organic materials and liquid air
- Restrict access to area
- Be aware of liquid air presence
- Consider using a catch pan

Material Incompatibility

- As with H_2 and most cryogenic fluids, the effect of low temperature on material properties of metal is extremely significant.
- All Ferrous alloys (iron based) except for nickel-chromium alloys, copper alloys, etc., have a loss in their ductility, tensile strength, fracture toughness when subjected to low temperatures of LH_2 and become too brittle for service.
- The absorption of and reaction with H_2 service base metals and alloys can cause hydride development and lead to a reaction embrittlement failure condition.

Material Incompatibility

3 Types Of Hydrogen Embrittlement

- Environmental Hydrogen Embrittlement
  - Observed in Metals and Alloys Plastically Deformed in H_2 Environment (Especially High Pressure)
  - Effect is Maximum in Temperature Range of -99.67 to 80.33 F

- Internal Hydrogen Embrittlement
  - Caused by Absorbed H_2
  - Effect is Maximum in Temperature Range of -99.67 to 80.33 F

Material Incompatibility

3 Types Of Hydrogen Embrittlement

- Hydrogen Reaction Embrittlement
  - Absorbed Hydrogen Chemically Combines with Metal to Form a Brittle Hydride
  - Lowers the Materials Ductility
  - Occurs More Readily at Elevated Temperature
  - Methane (CH_4) can be Formed with the Carbon in Steels

Material Incompatibility

What aids embrittlement

- Materials
  - Non-compatible Materials
  - Mechanical and Elastic Properties
  - Porosity
  - Operating Environment
  - Corrosion Effects
  - Dissimilar Materials Used Together
- Temperature
  - Thermal Conductivity
  - Temperature Effects
  - Expansion/Contraction
  - Melting Point Temperature
  - Ductility/brittleness

Material Incompatibility

Minimize Hazard

H_2 Embrittlement Commonly Addressed by:

- Increased Material Thickness
- Surface Finish
- Welding Technique
- Material Selection
- Conservative Design Stress (Avoid Yielding)
- Choosing Compatible materials

Material Incompatibility

Material	Service GH_2	Service LH_2	Service SLH	Remarks
Aluminum and its alloys	Yes	Yes	Yes	
Austenitic stainless steels with > 7% nickel (such as, 304, 304L, 308, 316, 321, 347)	Yes	Yes	Yes	Some make martensitic conversion if stressed above yield point at low temperature.
Carbon steels	Yes	No	No	Too brittle for cryogenic service.
Copper and its alloys (such as, brass, bronze, and copper-nickel)	Yes	Yes	Yes	
Gray, ductile, or cast iron	No	No	No	Not permitted for hydrogen service.
Low-allow steels	Yes	No	No	Too brittle for cryogenic service.
Nickel and its alloys (such as, Inconel® and Monel®)	No	?	?	Susceptible to hydrogen embrittlement
Nickel steels (such as, 2.25, 3.5, 5, and 9 % Ni)	No	No	No	Ductility lost at LH_2 and SLH_2 temperatures.
Titanium and its alloys	No	?	?	Susceptible to hydrogen embrittlement

Material Incompatibility

Material	Service GH_2	Service LH_2	Service SLH	Remarks
Asbestos impregnated with Teflon®	Yes	Yes	Yes	Avoid use because of carcinogenic hazard.
Chloroprene rubber (Neoprene®)	Yes	No	No	Too brittle for cryogenic service.
Dacron®	Yes	No	No	Too brittle for cryogenic service.
Fluorocarbon rubber (Viton®)	Yes	No	No	Too brittle for cryogenic service.
Mylar®	Yes	No	No	Too brittle for cryogenic service.
Nitrile (Buna-N®)	Yes	No	No	Too brittle for cryogenic service.
Polyamides (Nylon®)	Yes	No	No	Too brittle for cryogenic service.
Polychlorotrifluorethylene (Kel-F®)	Yes	Yes	Yes	
Polytetrafluorethylene (Teflon®)	Yes	Yes	Yes	

Leakage

- Hydrogen is particularly subject to leakage because of its low viscosity, small size and high mobility.

Leakage

- If a leak occurs, the higher density of the cold gas may cause it to flow horizontally or downwards immediately upon evaporation.
- GH_2 can collect in high-unventilated areas making the area unsafe for entry.
- Entry into an oxygen deficient atmosphere (below 19.5 % per volume oxygen) is not permitted without approved breathing apparatus.
- In the event of a large uncontrollable release, it is suggested the area be vacated.
- Detectors should be used in all hydrogen operations

Leakage

Leak Hazard

- December 2 1976, a special test was being conducted on to evaluate a high pressure fuel turbo-pump (HPFT) lift-off seal.
- During the test, an open air explosion took place on the test stand. There were no injuries, but nonstructural damage occurred.
- It was concluded that structures or other barriers erected for weather protection tended to minimize hydrogen dissipation and may have contributed to the extent of the damage by partial containment of the explosion to the damaged areas.

Leakage

Structure and barriers included:

- Rain shield above the engine with limited vent capability.
- Thrust drum.
- Structural walls (north and south). Structure immediately above the engine.
- Wind barriers on the west side of the engine deck

Leakage

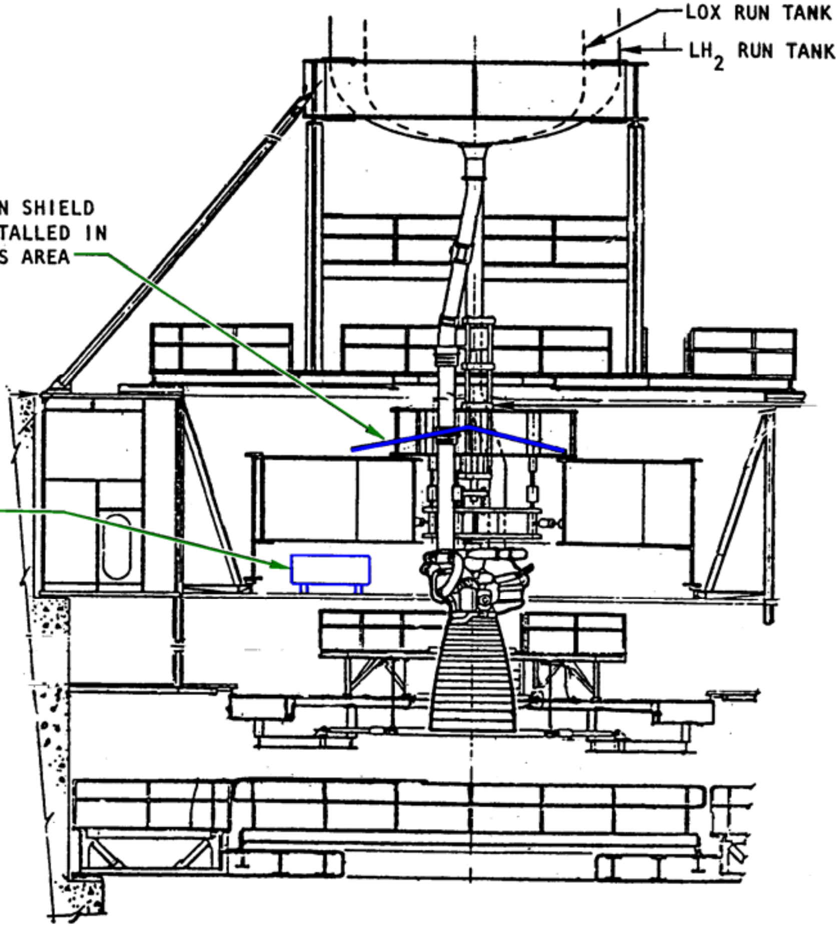


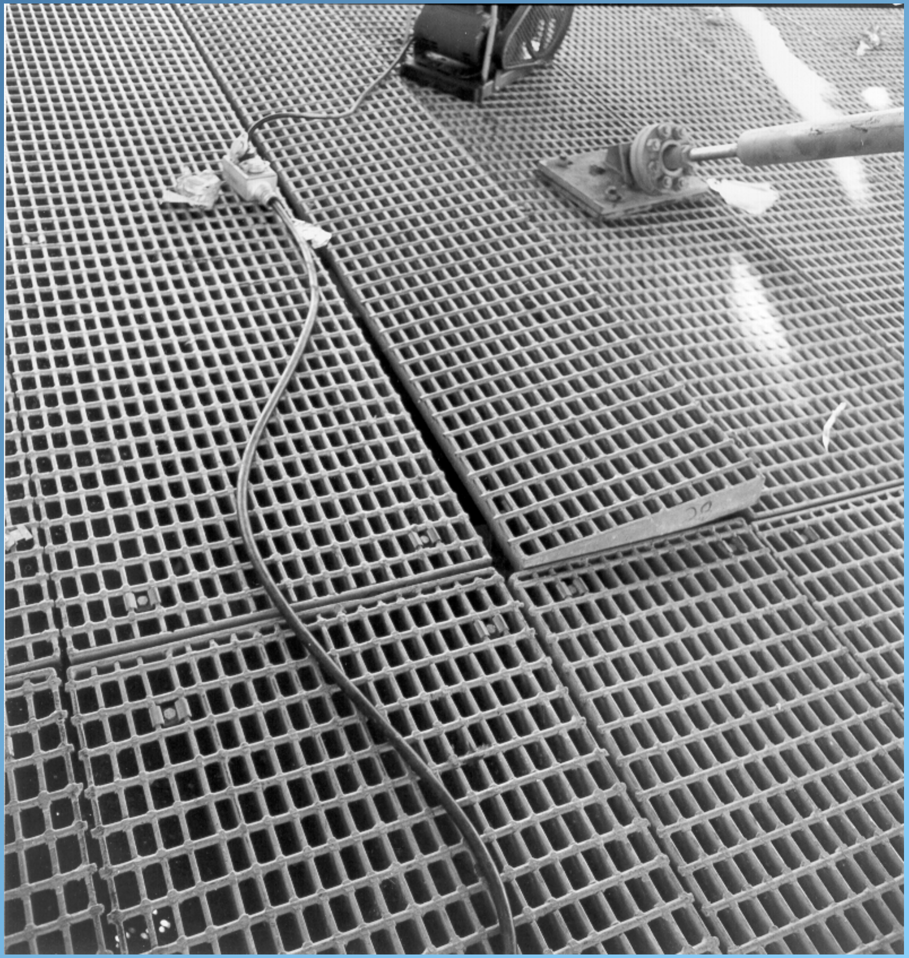
Figure 1. NSTL A-1 Engine Installation

Leakage

Resulting Damage

Leakage

Resulting Damage



Leakage

Resulting Damage

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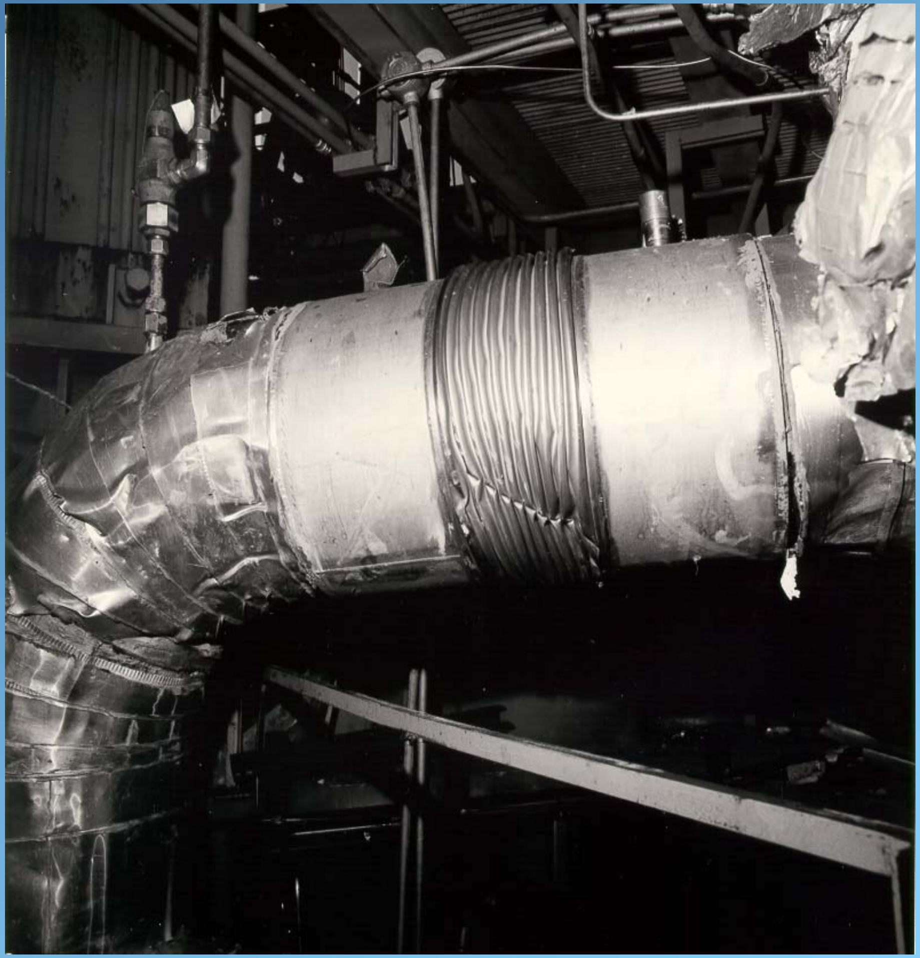

Leakage

Resulting Damage

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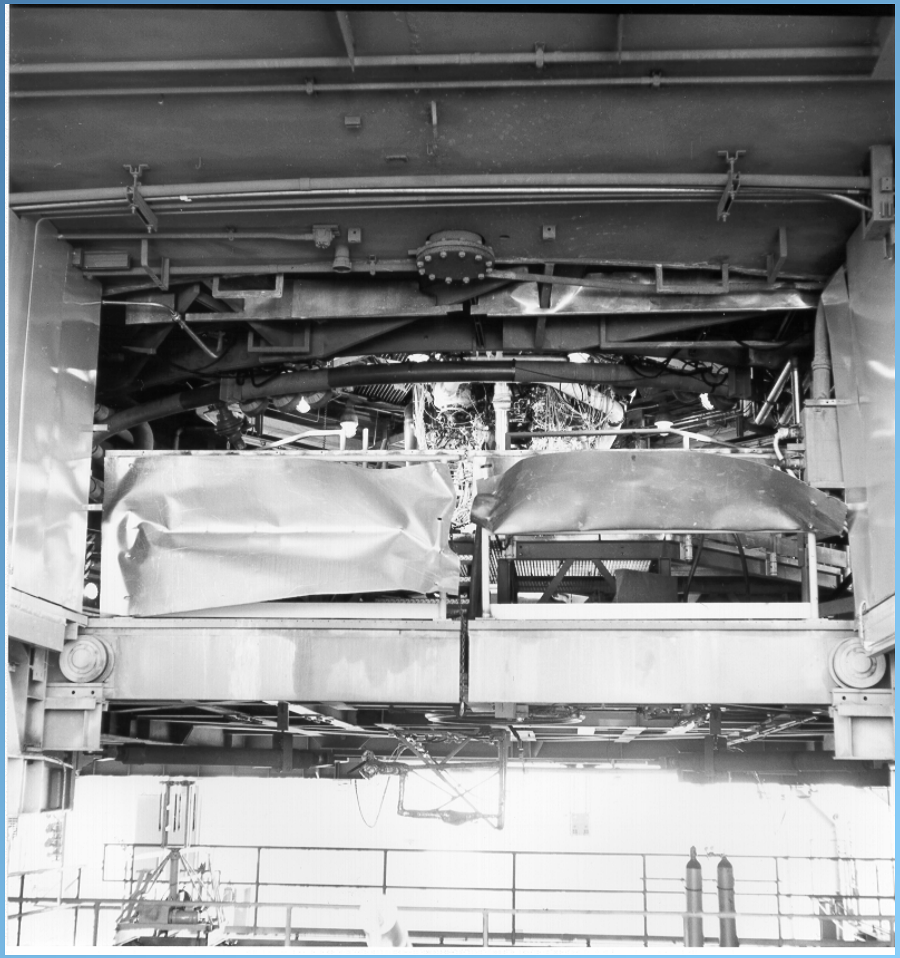
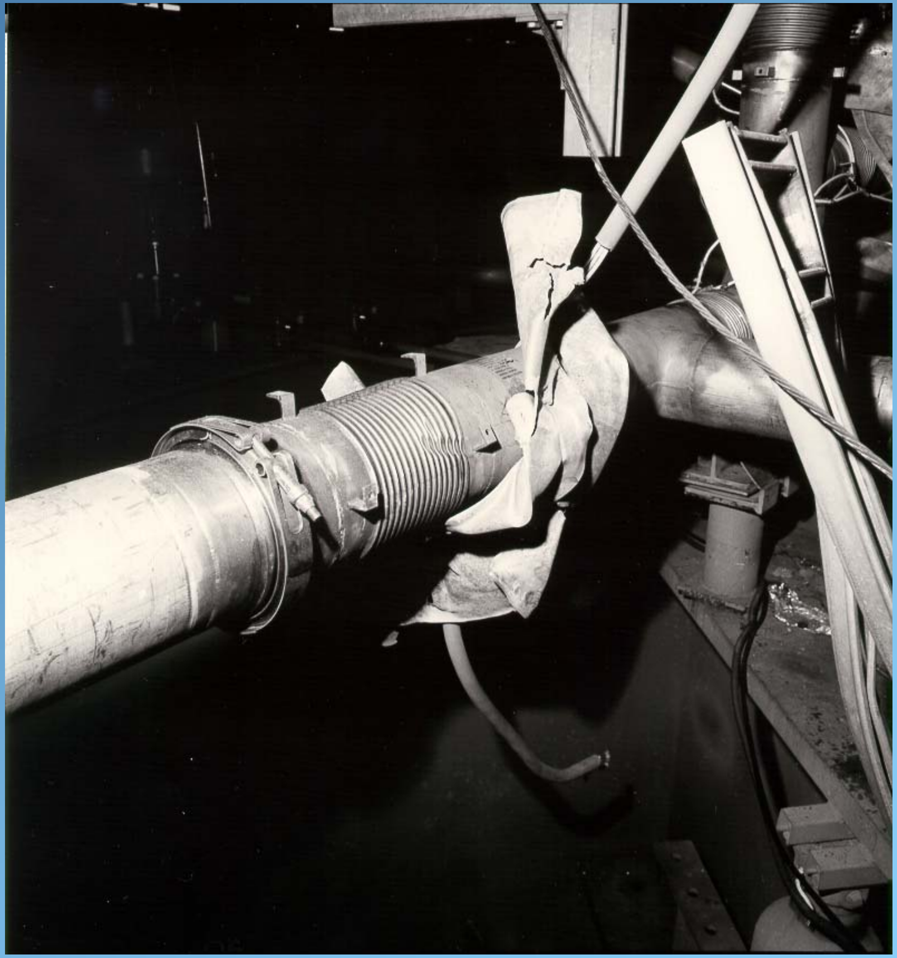
Resulting Damage



Leakage

Resulting Damage



Leakage

Some physical leak Indicators

- GH_2
  - Audible (for Large Leaks)
- LH_2
  - Vapor Cloud (we are able to see this cloud due to the moisture in the air.)
- Frost on Liquid or Cold Gas Line
  - NOTE: Could indicate poor insulation
- Because of the nature of hydrogen you can not rely on physical leak indicators.

Leakage

Possible causes

- Materials
  - Diffusion/Permeation
  - Expansion/Contraction (Different types of metals)
  - Embrittlement (caused via H_2 and temperature)

- Mechanical
  - Mechanical Stress/vibration
  - Deformation due to
    - Pressure
    - Temperature

Leakage

Minimize Hazard

- Assume leaks
- Use compatible materials
- Use welded connections when ever possible
- Use flanged connections only when necessary
- Use proper thread sealant (may be used with GH_2, but not LH_2)
- Perform Leak inspection (periodically)
- Design for leaks (try to have well ventilated areas)
- Incorporate Hydrogen detectors into system

Detectors

Catalytic

- A palladium and/or platinum catalyst is used to facilitate the combustion of hydrogen with oxygen. A sensing element detects the heat of combustion

Detectors

Electro-chemical

- Liquid or solid electrolytes surrounding a sensing electrode and a counter electrode. Reaction with hydrogen product produces a current. The gas must flow through a gas permeable membrane to reach the electrolyte.

Detectors

Optical

- The differences in the refractive index of various gases can be used for detection in sensors using optical interferometry

Detectors

Semi Conducting Oxide

- Hydrogen gas reacts with chemisorbed oxygen in a semiconductor material, such as tin oxide, and changes the resistance of the material

- **Thermal Conductivity**
- The rate of heat conduction from a heat source into the surrounding environment is dependent on the thermal conductivity of that environment

Asphyxiation

Asphyxiation

- Hydrogen leak, spills, or improper venting can result in a oxygen deficient atmosphere
- Deficiency dose not need a confined workspace to occur
- OSHA specifies a workspace cannot be occupied if it contains less than 19.5% GOX.
- You may start to experience early warning signs of oxygen deficiency or you can just pass out.

Asphyxiation

- At GOX levels between 15 - 19% symptoms may include:
  - Loss of coordination, reaction speed or energy with sense of euphoria and clumsiness.
  - Increased pulse rate and breathing.
- Between 12 - 15% symptoms may include:
  - Deeper and faster breathing with impaired judgment.
  - Physical coordination deteriorates with abnormal fatigue.

Asphyxiation

- Between 10 - 12% symptoms may include:
  - Vertigo and false judgment.
  - Collapse with inability to call out or move freely.
  - Lips turn slightly blue.
- Between 8 - 10% symptoms may include:
  - Nausea and vomiting.
  - Loss of consciousness.
- Between 8 - 6% symptoms may include:
  - Convulsive movements with respiratory gasping.
  - Respiration stops and within minutes.
  - Brain damage within 4 – 8 minutes.
  - Heart ceases action.
- Below 4%:
  - No breathing – comatose within 40 seconds.

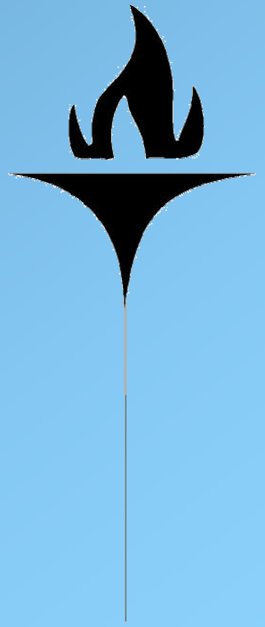
Asphyxiation

Minimize Hazard

- Monitor Oxygen levels
- Incorporate a buddy system
- Ensure a fresh air supply
- Have well design vent systems

Venting

- Venting of small amounts of GH_2 into the atmosphere is permissible.
- However, provisions must be made to provide the source does not present a hazard to personnel, confined facilities or sources of ignition.
- It is recommended to direct large quantities generated from transfer or test operations to flare stack systems for complete burn-off.
- NASA standard .5 lb/sec being vented needs to be flared
- Large amount should be evaluated by an Engineer

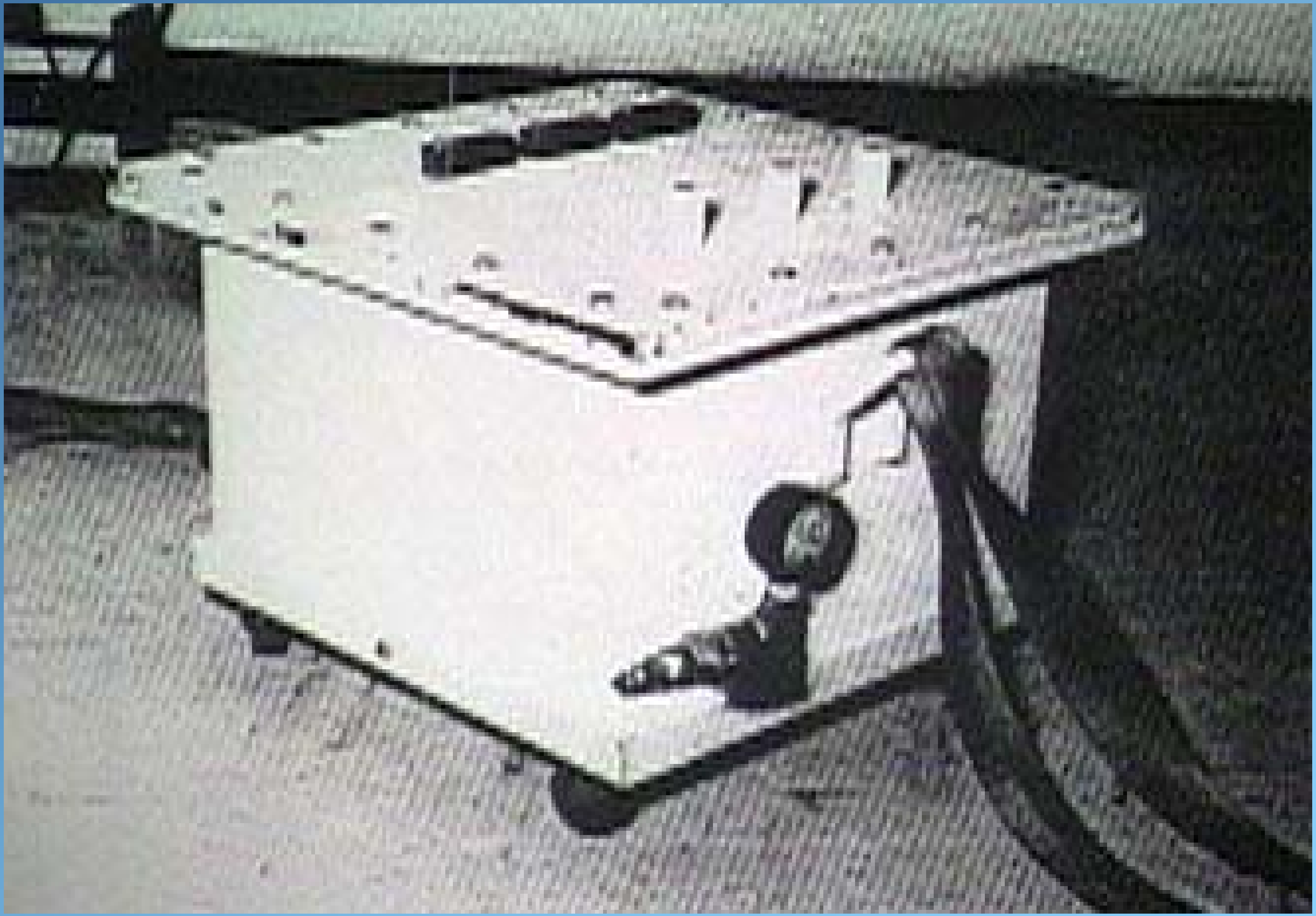


Venting

Venting gone bad

- January 29, 1972 - old JSC water immersion facility
- Water tight portable battery supply was being charged
- Hydrogen gas vent valve was closed rather than open
- The valve was installed to purge hydrogen at the direction of a previous hazards analysis

Venting



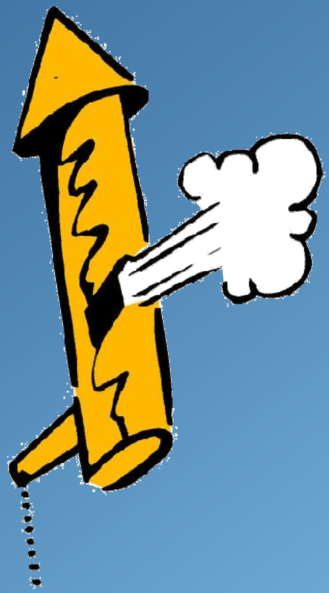
Venting

Venting

THE BOX LID KILLED ONE WORKER AND SEVERELY INJURED ANOTHER BEFORE PUNCTURING CONCRETE CEILING 35 FEET ABOVE THE FLOOR

Battery Box Test

Relief System



- Relief devices are required to permit routing of off-gassing vapors and for protecting any enclosed volume against overpressure that contains Hydrogen

- Relief device units must not be set higher than the maximum working pressure of any component in a cryogenic system.

Relief System

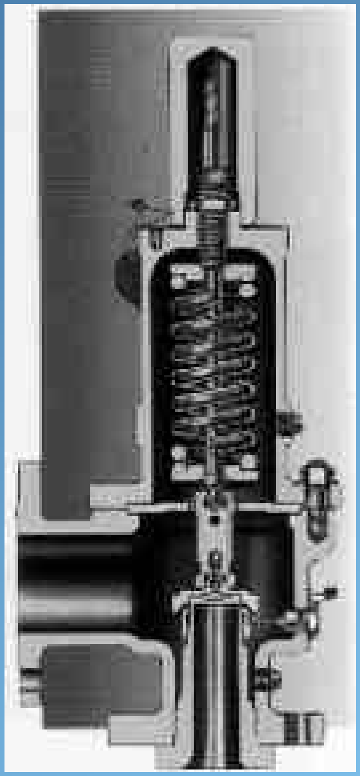
- Rupture disk are utilized as additional relief devices to account for unusual or accidental conditions.

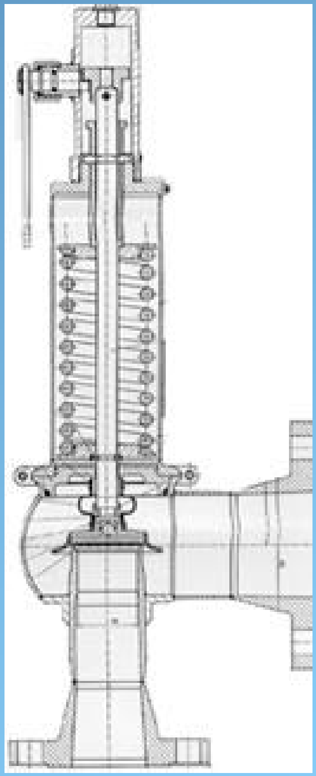
- Each and every portion of a hydrogen system must have uninterrupted pressure relief. Any part of a system that can be valved off, must have a separate means to relieve pressure.

- Systems must be designed so that the discharge from relief devices do not create a hazardous condition.

Relief System

Relief can provided by spring-loaded RV units.





Inadequate Relief

- Hydrogen warmed above critical temperatures can potentially generate extremely high pressures.

- LH_2 has a large liquid-to-gas expansion ratios (generally >700:1). Example need to consider conditions that might result in liquid lock up.

- If pressure is not adequately release via vent or relief device, the system could experience a rupture or BLEVE.

- BLEVE (Boiling Liquid Expanding Vapor Explosion) – An explosion caused by enormous pressure build up or very rapid pressure rise.

Inadequate Relief

Minimize Hazard

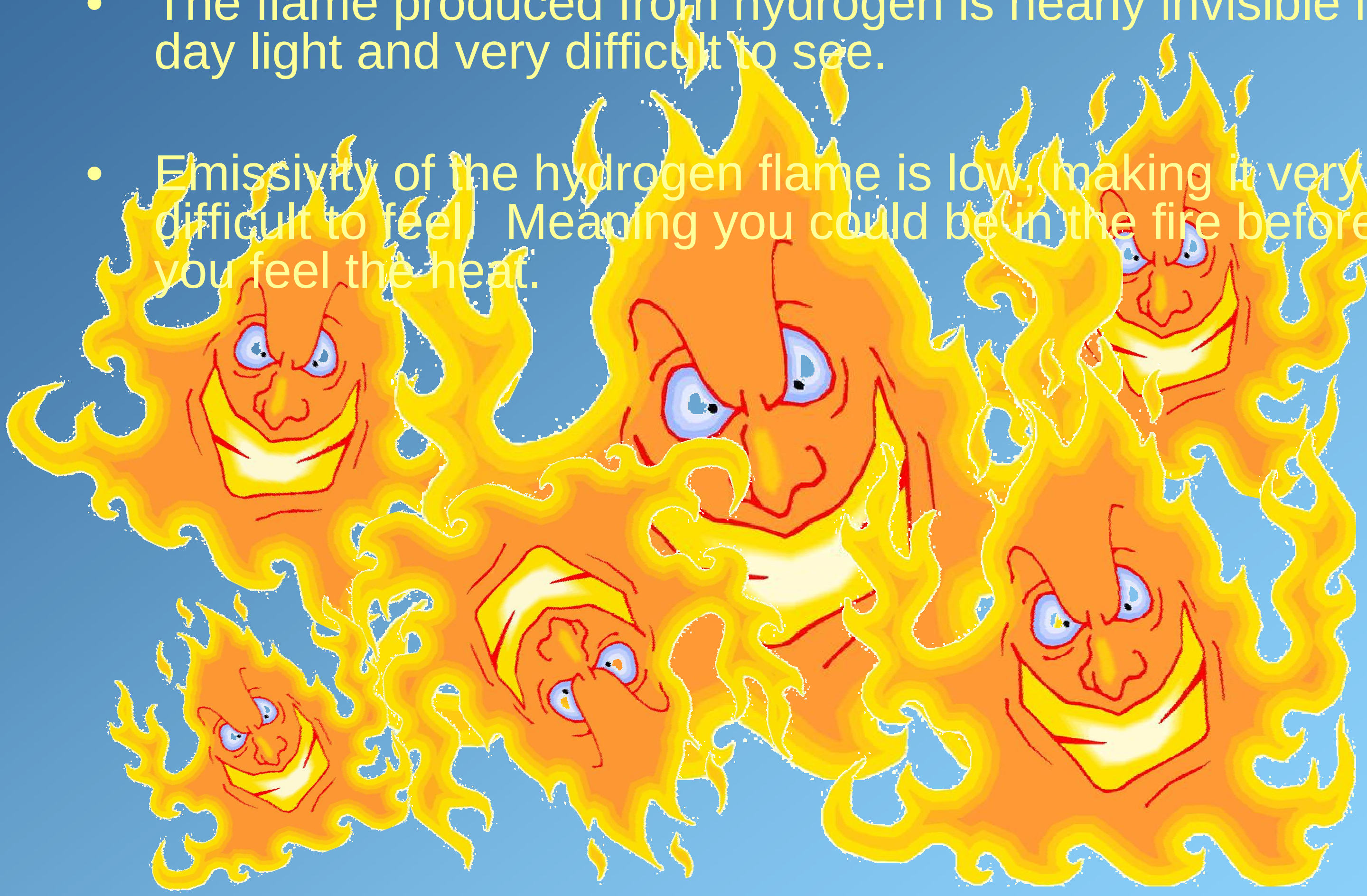
- Ensure relief devices is capable of handling the maximum volume of gas that could be produced under the most adverse condition.

- Incorporate secondary relief devices (i.e. Rupture disk)

- Have well design vent systems

Fire

- The flame produced from hydrogen is nearly invisible in day light and very difficult to see.
- Emissivity of the hydrogen flame is low, making it very difficult to feel. Meaning you could be in the fire before you feel the heat.



Fire

- Mixtures of H_2 in air and/or GOX are highly flammable in a wide range of compositions.
- The flammability limits, in % by volume of H_2, define the range over which fuel vapor will ignite when exposed to an ignition source.
- Flammability limits are dependent on the ignition energy, temperature, pressure and exposure area.
- GH_2 diffuses rapidly with air turbulence, which increases the rate of dispersion.
- Evaporation can rapidly occur in an LH_2 spill resulting in a highly flammable mixture forming over a considerable distance.
- Ignition energy for Hydrogen / Air mixture is <u>extremely</u> small

Fire

Flammability Data

Flammability Limits - Lower and Upper:………………..4% to 75% (GH_2/air mixture)

Flammability Limits - Lower and Upper……….….4% to 95% (GH_2/oxygen mixture)

Flame Temperature: ………………………………………………….……….3600°F

Auto-Ignition Temperature (GH_2 in air): …………………………………….1085°F

Auto-Ignition Temperature (GH_2 in oxygen): ………………………………1040°F

Minimum Spark Energy In Air @ 1 ATM: ……………….….…1.9×10^{-8} Btu / 0.02 mJ

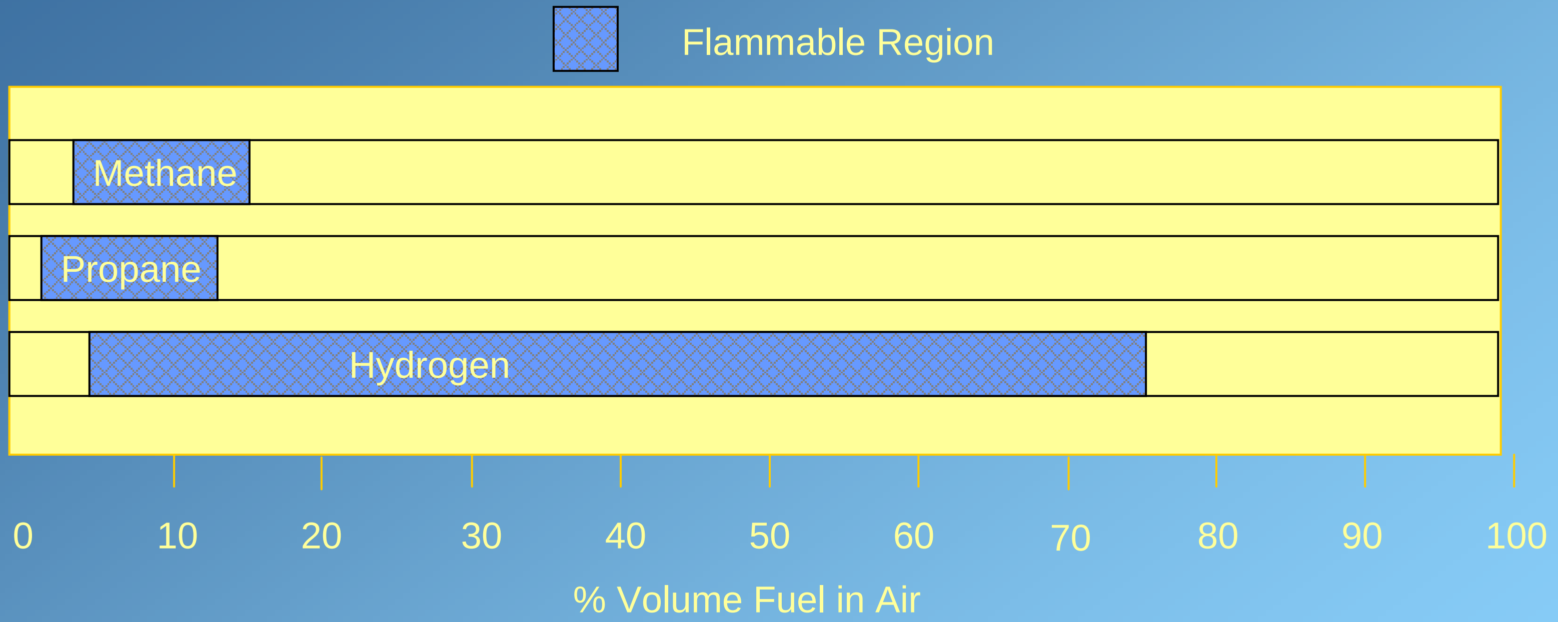
Minimum Spark Energy In Oxygen @ 1 ATM:……………..6.6×10^{-9} Btu / 0.007 mJ

Diffusion Rate: ………………………………………………..….3.8 times faster than air

Density of GH_2 ……………………………………………..….14 times lighter than air

LH_2 to GH_2 (Pressure Rise): ……………………14.7 to 28,000 Pisa (warmed to 32°F)

Flammability Limits in Air



Fire

Minimize Hazard

- Eliminate ignition sources
- Incorporate fire detection systems
- Always assume a fire can be present

Ignition Sources

What is an ignition source?

- An electrical, thermal, mechanical, or chemical event that is will supply enough energy to cause ignition to take place.

Ignition Sources/Electrical

- Short Circuits (sparks and/or arcs)
- Static Electricity (two phase – solid particle, etc.)
- Charge Accumulation
- Lightning
- Cellular phone and pagers
- Electrical Charge Generated by Equipment/Facility Operators
- Clothing (Static Electricity)

Ignition Sources / Thermal

- Open Flames
- Welding
- Personnel Smoking
- Exhaust from Thermal (Internal) Combustion Engine
- Hot Surfaces
- Explosive Charge

Ignition Sources/Mechanical

- Shock Waves or Fragments from Piping Rupture
- Friction and Galling
- Resonance Ignition (repeated shock waves in flow system)
- Mechanical Impact
- Tensile Rupture or Metal Fracture
- Mechanical Vibration

Ignition Sources / Chemical

- Flash Back; Although ignition sources may not be present at a leak or spill location, fire could occur if the movement of the flammable mixture causes it to reach an ignition source.
- Catalytic
- Mixing with reactive chemicals

Ignition Sources

Unexpected Flame

- Always anticipate the potential for a flame
- A characteristic is the ability have flash back from an ignition source from a distance
- A vent line, orifice or and k-bottle can potentially emit a flash of fire when GH_2 is suddenly released.

Fire Detection

- **Early detection of fire can prevent injury and save lives**

Fire Detection

- Test facilities throughout the complex should be provided with automatic detection systems intended to provide aural and/or visual warning in the event of fires.
- The systems should be purposely designed for precautious monitoring of suspect areas, propellant delivery systems, and pipe system components (e.g. valves, flanges, bellows, connections, etc) for immediate personnel notification.
- The warning system should be distinct and (well know)

Fire Detection

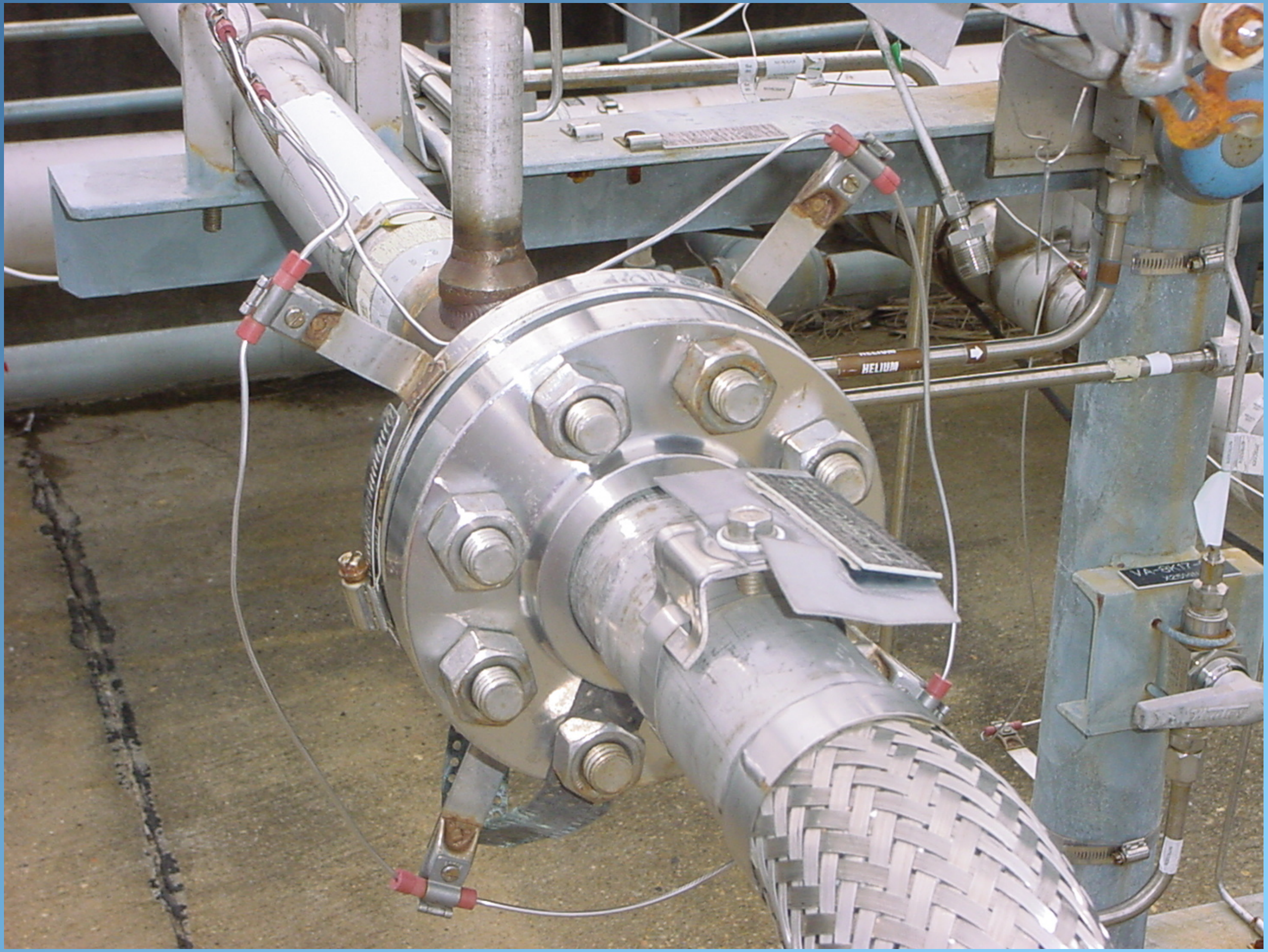
TYPICAL HYDROGEN FIRE DETECTORS

Temperature Sensor	Thermocouple or resistance temperature device (RTD) that detects the heat of the fire.
Heat Sensitive Cable	Wire or fiber-optic based cable that changes resistance or optical properties if any portion of the cable is exposed to high temperatures or is burned through.
Optical	Ultra-violet, mid/near-infrared, and thermal infrared detectors for the detection of radiation emitted by the hydrogen flame. Infrared detectors must be optimized for hydrogen flame emissions that are not the same as hydrocarbon fires.

Fire Detection

Broadband Imaging	Thermal or mid-infrared imaging systems effectively image hydrogen flames but require an operator to interpret the image for detection of fire.
Narrow band Imaging	Band-pass filters centered around the 950, 1100, and 1400 nm peaks can produce adequate images with low-cost silicon CCD cameras, image converter tubes, and vidicon systems. The filters must be carefully selected to block unwanted solar background while optimizing the imaging band for atmospheric transmission of the hydrogen fire radiation.
Brooms/Dust	Putting flammable objects or dust particles into a hydrogen flame will cause the flame to emit in the visible spectrum. Corn straw brooms, dirt, and dry fire extinguishers have been used for this purpose.

Fire Detection



Fire Detection

Fire Detection

Fire

- **How do you fight a Hydrogen fire?**

Fire

- The only sure way of handling a H_2 fire is to let it burn under control until the H_2 flow can be stopped.
- If an H_2 fire is extinguished and the H_2 flow is not stopped, a hazardous combustible mixture can begin to form immediately.
- It is very possible for an H_2 mixture to re-ignite with an explosion, causing more damage and restarting the fire.
- GN_2 is commonly used to purge out and extinguish an H_2 fire in lines and vessels.
- Stand back from the fire because person could suffer a burn from the UV rays being produced

Fire

- Water sprays can be used to extinguish any secondary fire, keep the fire from spreading, keep the systems cool to decrease the rate of H2 leakage and prevent further heat damage.
  - *CAUTION: Pressure relief devices are susceptible to becoming frozen shut from water spray during LH2 fire fighting activities.*

- Great alertness must be exercised in using water since enter into the relief device and freeze resulting in an inoperable relief device that lead to system rupture.

System Purging

Purging Techniques

- Evacuation and backfill
- Pressurization and Venting
- Flow Through

System Purging

- Hydrogen Equipment Should be Purged with an Inert Gas

- Before and after Using Hydrogen in the Equipment
  - Use Inert Gas to Purge Oxidizer (Air) before Introducing Hydrogen
  - Use Inert Gas to Purge Hydrogen before Introducing Oxidizer (Air)

- Use Nitrogen if Temperature is Above – 316 F° (-193.15 C°). If lower then the Nitrogen could liquefy.

- Use Helium if Temperature is Colder

- Turn off N_2 Purge to Vent Stack Before Venting Cold H_2

System Purging

- Solidified gases can damage systems or components due to plugging.
- Air that has not been effectively purged prior to introducing LH_2 will separate into nitrogen and oxygen.
- Air in GH_2 systems can result in explosive mixtures that could ignite from heat of compression, friction, static electricity, or other ignition sources.

Detonation

- The action of confined ignition.
- The flame and the shock wave passes through the fuel mixture at supersonic speeds.
- The hazards to personnel, structures, and nearby facilities are widely increased.
- Shrapnel

Detonation

Factors for Detonation

- Percentage of Hydrogen
  - Detonation Limits
    - In Air: 18.3-59 Vol %
    - In Oxygen: 15 To 90 Vol %
- Strength (Energy) of Ignition Source
- Degree of Confinement
  - Partial confinement (i.e. area with three vertical walls or area with absence of roof, one vertical wall/side, etc) is sufficient to produce a detonation if mixtures within the flammability limits ignite.
- Turbulence
- Diluents or Inhibitors Present
- Temperature And Pressure of Combustible Mixture

Detonation

Physiological Effects of Blast Overpressure

Maximum Overpressure (kPa)	(psi)	Effect On Personnel
7	1	Knock Personnel Down
35	5	Eardum Damage
100	15	Lung Damage
240	35	Threshold For Fatalities
345	50	50% Fatalities
450	65	99% Fatalities

Deflagration

- The ordinary unconfined mode of burning produced by the rapid expansion of blazing gases.
- A pressure wave may be produced which can travels through the mixture only at subsonic speeds.
- A loud noise may be heard and potentially damaging to nearby structures.
  - WARNING: In daylight, when H_2 burns in air it releases an invisible flame – visible flame is usually caused by impurities.

Accident

Los Alamos SFW Tube Trailer

- Hydrogen and oxygen lines modified without approval or hazards review

Accident

IN GASEOUS STORAGE, OXYGEN HAS INADVERTENTLY LEAKED INTO THIS LOS ALAMOS HYDROGEN TUBE TRAILER

Accident

THE MIXTURE, AT APPROXIMATELY 550 PSI, DETONATED

Accident

Accident

TUBES AND SHRAPNEL WERE HURLED 1,250 FEET. SEVERAL EMPLOYEES WERE BURNED.

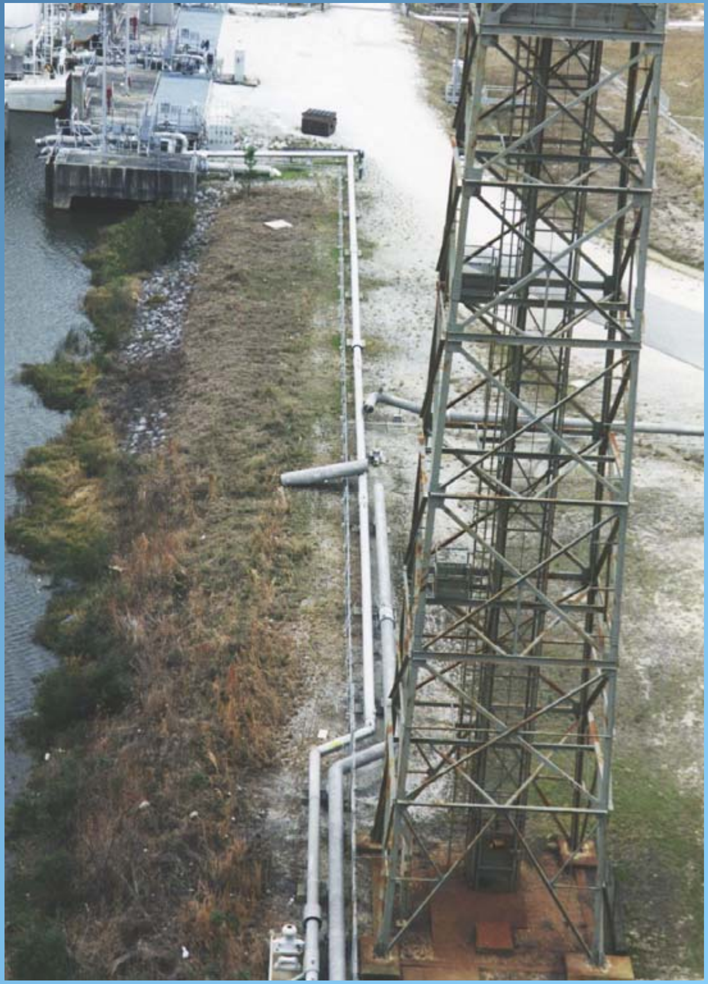
Accident

Hydrogen Balloon

- “Fire Chief Reynolds, while well-intentioned, used poor professional judgment in constructing and deploying a balloon filled with hydrogen and oxygen as an adjunct to the normal Fourth of July fireworks display, Tully said in his report. “The public was unnecessarily put at risk and one of his firefighters was injured.”

Accident

1995 Mishap
B-1 Facility
H_2 Vent Line

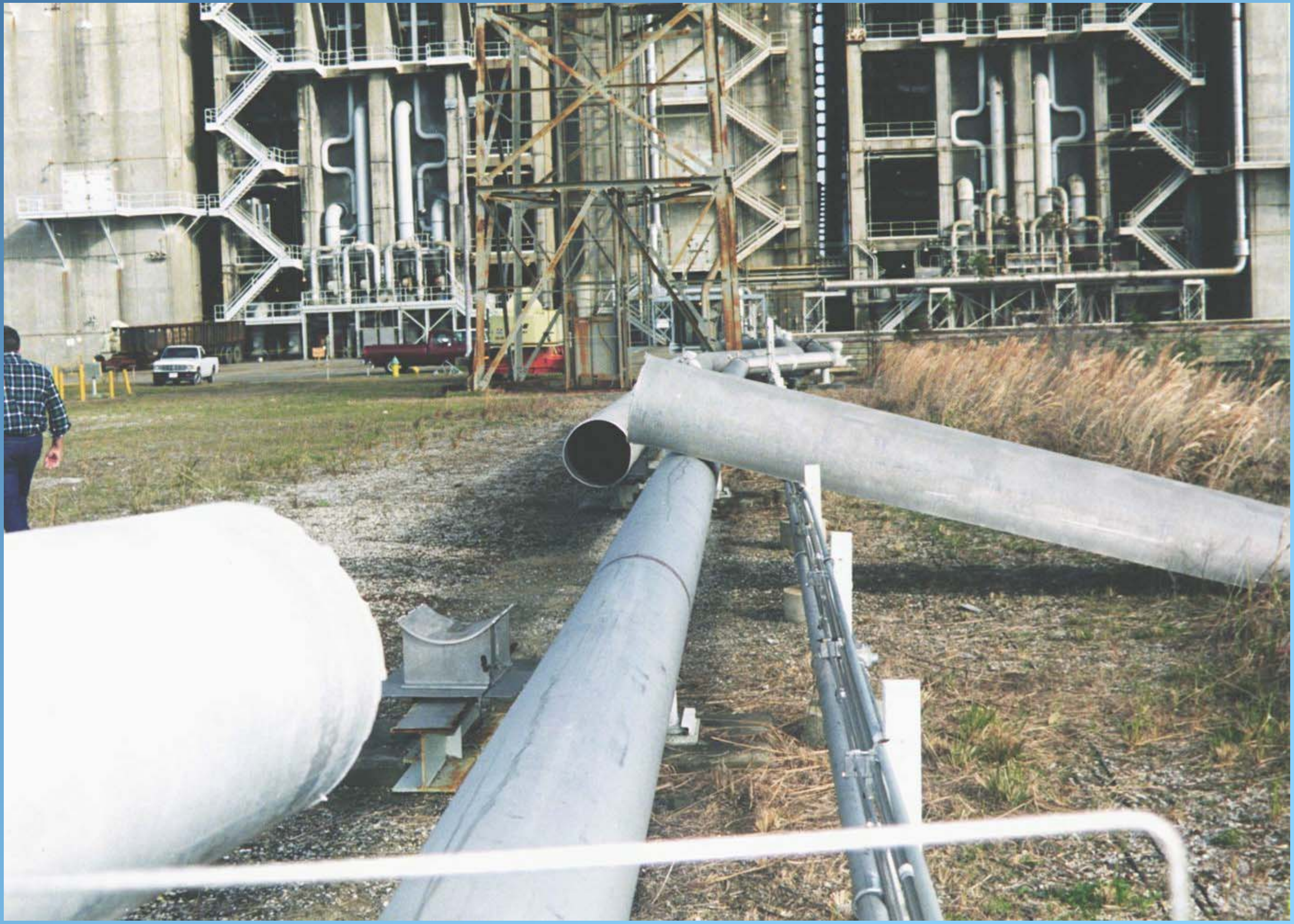


Accident

1995 Mishap
B-1 Facility
H_2 Vent Line

Accident

1995 Mishap
B-1 Facility
H_2 Vent Line



Accident

1995 Mishap
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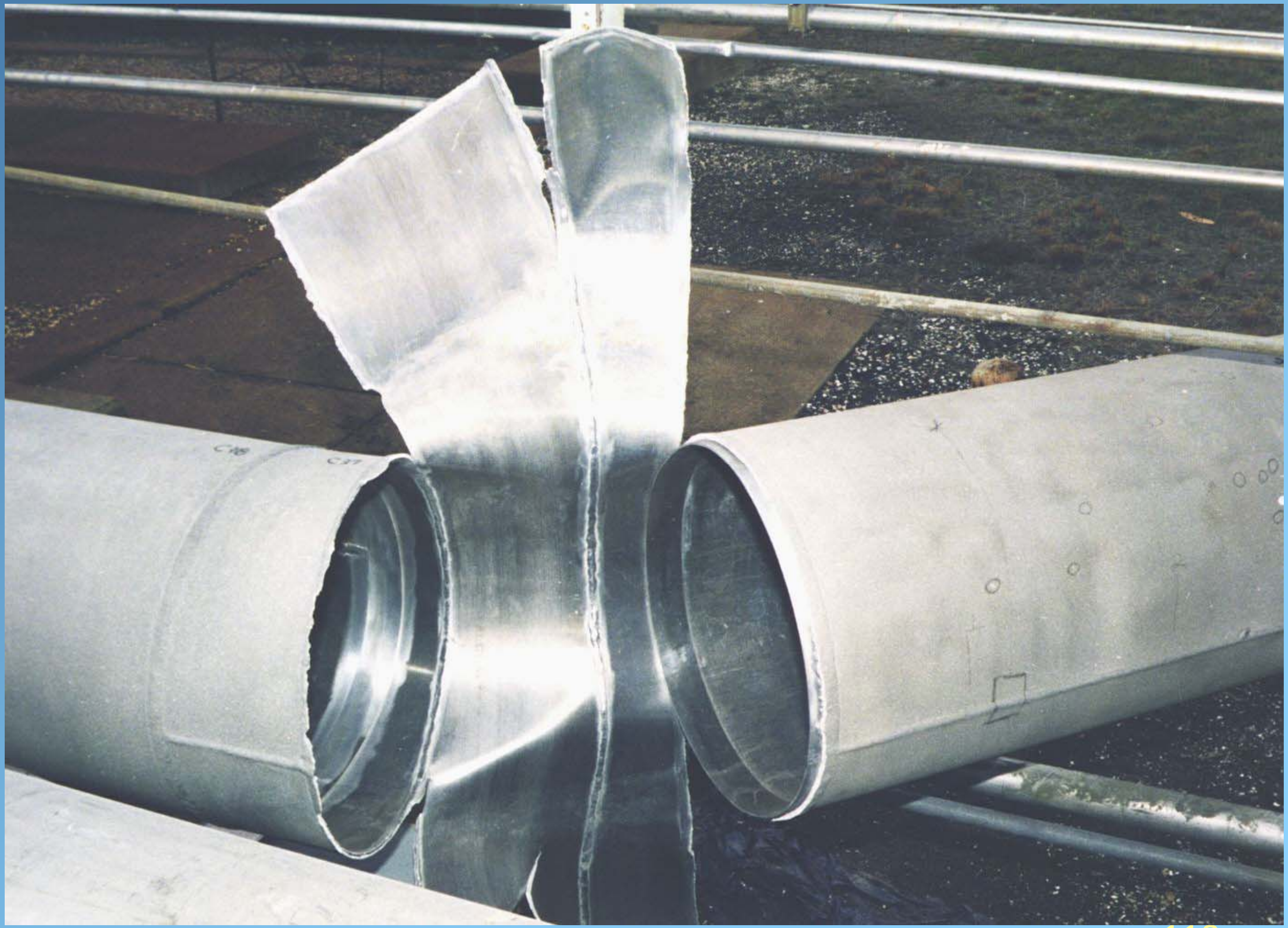

Accident

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Accident

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Testing Using Hydrogen

Testing Using Hydrogen

Group input

Help us to make this course more useful to you

- Stories
- Ideas
- Suggests
- What you would like to see
- What you did not see