DISPERSION OF GASEOUS HYDROGEN CLOUDS
A Note to First Responders

The inadvertent release of hydrogen poses several challenges for first responders. First responders must be familiar with basic hydrogen facts to conduct safe operations.

Physical Properties Facts

Hydrogen gas is colorless and odorless. Room temperature hydrogen gas is highly buoyant, and if not confined will rise at several meters per second. It diffuses rapidly in air. Hydrogen gas at cryogenic temperatures (20 K to 23 K) is heavier than air and will stay near the ground until it warms. In the process the cold gas will condense water vapor from the air creating a cold fog.

Liquid hydrogen is colorless. It is extremely cold and only persists if maintained in a cryogenic storage vessel under pressure. If spilled on ambient temperature surfaces liquid hydrogen will rapidly boil and its vapors will expand rapidly, increasing some 845 times in volume as it warms to room temperatures. If the liquid hydrogen is confined such as between valves closing off a length of pipe and left to warm without pressure relief, pressures approaching 25,000 psia are possible. With the exception of specially designed enclosures, there is a high potential for exposed confinements to rupture under such pressures producing high pressure jets of gas and high speed shrapnel. Ignition is extremely likely under such circumstances. Should large quantities of hydrogen displace the oxygen in the air, hydrogen will act as an asphyxiant.

Combustion Properties Facts

Hydrogen mixed with air is flammable over a wide range of concentration; 4 to 75% by volume, and readily ignited by common sources of ignition such as electrical sparks or small flames. Near optimal or stoichiometric mixtures of hydrogen and air are so sensitive to ignition that initiation of combustion can be caused by miniscule friction or static discharges and hence, for practical purposes can be considered to occur spontaneously. When ignited, hydrogen flames are practically invisible to the unaided eye under artificial light or daylight. Introduction of impurities, sodium from ocean air, or other burning materials will introduce color to the hydrogen combustion. At night, hydrogen combustion produces a pale blue glow. A further consideration is that hydrogen flames radiate little IR heat, but substantial UV radiation. This means when in proximity to the flames there is little sensation of heat, making inadvertent contact with the flame a concern, as well as UV overexposure which will lead to sunburn like effects.

Should a large hydrogen cloud contact an ignition source, ignition will result in the flame flashing back to the source of the source of hydrogen. In open spaces with no confinement, flames will propagate through a flammable hydrogen-air cloud at approximately several meters per second and more rapidly if the cloud is above ambient temperatures. The result is a rapid release of heat but little overpressure. The combustion product is steam. Note that hydrogen combustion is more rapid than with other fuels and when a cloud burns it happens within a matter of seconds and all of the energy of the cloud is released.

However, should hydrogen gas mixtures swirl into confined regions such as under the hood of a running vehicle, ignition is very likely and can result in flame acceleration with the generation of high pressures capable of causing an explosion or throwing shrapnel. Flammable mixtures of hydrogen in confinements such as pipes or ducts, if ignited will readily result in accelerated flames and conditions that can lead to transition to detonation. Detonation does not occur in unconfined hydrogen unless high explosives or very strong shocks waves can act on the mixtures.

A puncture in very high hydrogen pressure storage systems (pressure greater than 200 psia) will result in a high pressure jet that may extend for some meters and may ignite.

General Recommended Practice

In the event of an inadvertent release of hydrogen the potential physical and combustion behaviors of hydrogen require caution must be observed. The spill or release area should be secured, personnel evacuated, and isolated until deemed safe. The best approach for either a gas or liquid release is to allow hydrogen to dissipate. Hydrogen gas and flame detectors in conjunction with proper personnel protective equipment are required to insure safe operations in proximity to released hydrogen due to our inability to sense the presence of gas or flames. Avoid actions that might confine hydrogen or introduce sources of ignition into a region in which hydrogen has been released. In the case of liquid spills it is not advisable to direct water streams into the pool. This will not dilute the fuel and will result in more rapid boiling and buildup of vapors.

Should ignition occur, general practice is first to isolate the source of fuel from the resulting fire. Never flare a hydrogen fire. If isolation of the source of fuel is not possible the strategy is to control the spread of flames to adjacent materials and structures while allowing the hydrogen fire to burn out. Water spray may be directed to keep nearby surfaces cool, but is generally ineffective in putting out a hydrogen fire. Extinguishing a hydrogen fire under circumstances in which the gas is still being released may result in hydrogen accumulation in the vicinity, or if there is wind, flammable mixtures being blown along the ground. Therefore, actions to put out the hydrogen fire are not recommended. With a cryogenic system caution must be taken not to direct water sprays into vent systems. Freezing of the water within a vent system may fail the relief system, cause rapid over pressurization of vessels or lines, and ultimately result in catastrophic explosion.

A Simulated Liquid Hydrogen Spill

Plume dispersion in association with the spill of 1500 gallons of liquid hydrogen was studied at the NASA White Sands Test Facility in southern New Mexico. The release rate was 1500 gallons/30 seconds into a 30 foot diameter spill pond. The observed clouds are water vapor, condensed by at least 6 to 7 percent by volume cryogenic hydrogen vapor in air. The water vapor clouds are approximately indicative of flammable regions. Hydrogen diffuses rapidly and flammable concentrations will exist around the visible water vapor. In the center of the cloud the concentration of hydrogen may be above the upper flammability limit, and hence not flammable.

Films of three tests show the effect of increasing wind speed. For a visual reference, consider that the instrumentation poles appearing in the film are 20 meters high. At 3-4 miles-per-hour cold gases spread only a small distance on the ground before warming and rising. The buoyancy of the hydrogen carries the water vapor upward as it rises. With an 8-mph breeze the cold hydrogen gas is carried further along the ground with the condensed water vapor. Eventually the hydrogen warms and becomes buoyant. More rapid wind dissipates the water vapor cloud and also more rapidly warms the cold hydrogen which now rises invisibly without its water vapor cloak.

These films give us a rough idea how a cryogenic spill might behave. However, there are limits to our knowledge. A spill of a significantly larger quantity may behave differently and form a more persistent pool. Under such conditions, air may condense into the liquid hydrogen and form a liquid-solid slurry mixture. Liquid oxygen mixed with other fuel substances such as oils form shock sensitive mixtures with explosive yields similar to solid explosives. Extreme caution should be used if confronted with a large liquid hydrogen pool. Isolate and evacuate the area. Do not expose the pool to streams of water. Wait for the pool to warm and hydrogen vapors to dissipate.