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PROJECT ROVER
LIQUID HYDROGEN SAFETY
-A FIVE YEAR LOOK-

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T. E. Ehrenkranz
Los Alamos Scientific Laboratory

MASTER

ABSTRACT

Large scale use of liquid hydrogen has been associated with Project Rover at Jackass Flats, Nevada since 1959. There have been misadventures; these, together with the advice of specialists led to continuing improvements in procedures and equipment. Main components of the liquid hydrogen system are described; incidents and the lessons learned are related and the gradual refinement of safety devices and procedures are traced. It is felt today that standing operating procedures, control over incompatible operations, room inerting, remote control of high hydrogen flow rates and proven equipment reliability make the main contributions to carrying out large scale liquid hydrogen operations with confidence.

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INTRODUCTION

Liquid hydrogen has been used by the Los Alamos Scientific Laboratory on Project Rover since 1959. An early involvement in liquid hydrogen safety was the preparation of a set of instructions to drivers hauling liquid hydrogen to Jackass Flats. By the end of 1960 over 70,000 gallons of liquid were received at Test Cell "A" at Jackass Flats. This liquid was vaporized by a stationary Linde pump vaporizer installation and stored at 3,500 psi in the tank farm. The first dewars for liquid hydrogen storage were constructed in 1961, and the following shows the trend in dewar capacity and usage of LH₂.

	LASL dewar capacity	LASL usage, gallons	Turnover	
1961	56,000 gallon	90,000	1.6	At Test Cell "A"
1962	156,000 "	350,000	2.2	*Test Cell "C" also went into operation
1963	156,000 "	1,300,000	8.3	
1964	100,000 "	1,450,000	14.5	Test Cell "A" vacated by LASL
1965 (6 months)	100,000 "	930,000 (6 months)	9.3	

Note, under "Turnover," the ratios of usage to storage capacity.

Loss through boil-off being only about 1/2% per day these turnovers indicate the actual amount of liquid handling operations; receiving, transferring, cooldown, and usage as coolant, during reactor tests.

*There is no Test Cell "B"

THE SYSTEM

The liquid hydrogen systems at both test cells consist of the following principal components:

Fill Stations - where LH_2 is received in over-the-road transport dewars.

Vaporizers and Pumps - for filling the hydrogen gas-tank farm.

Dewars - two horizontal cylindrical dewars at Test Cell "A", 28,000 gallons each. Two spherical dewars at Test Cell "C", 50,000 gallons each. These dewars' inner shells are of AISI type 304 stainless steel and are insulated with three feet of "Perlite," normally evacuated to about 50 microns. There are two safety relief valves on each dewar set at 105 and 110 psig and one rupture disk set at 155 psig. (The vacuum annulus is also protected from internal pressure by one or more rupture disks.) These devices have sufficient relieving capacity to care for loss of vacuum. When the dewars are pressurized during operations, the rupture disks are valved off but the safety reliefs remain operative. Diking is not used in the dewar areas, but advantage is taken of sloping terrain. The two 28,000 gallon dewars at Test Cell "A" were protected by sprinklers from a single automatic deluge valve, and the two 50,000 gallon dewars at Test Cell "C" are sprinklered from an individual deluge valve for each dewar; the valves activate automatically and have manual shut-off. It is planned to separate the sprinklers on these dewars into two zones: top and bottom, and to provide manual activation of the sprinklers to cool the dewars during high power reactor runs.

Turbine - and Electrically-Driven Pumps. These are used to propel liquid hydrogen to the reactor or to cryogenic test equipment, respectively.

Piping. Vacuum jacketed piping of type 304 stainless steel. The vacuum space is protected by spring loaded relief devices. The discharge piping immediately adjoining the dewars, during quiescent periods, contains helium at 3-5 psig above dewar pressure to prevent hydrogen leaks into the piping.

Hydrogen Monitoring. J and W monitors are used in all indoor spaces which contain hydrogen piping. Each room has 4-5 units and they are set up to alarm when two or more units (in one room) indicate two per cent or more hydrogen. If the system becomes inoperative due to power failure or other reasons, places where hydrogen may exist are monitored by personnel using approved hand held analyzers.

INCIDENTS

The following incidents played a part in pointing up deficiencies and resulted in improved operations.

- A. A serious accident occurred in 1961; it did not involve liquid hydrogen, but the resulting changes in our way of life probably significantly improved the safety of our liquid hydrogen operations. The reactor had been coupled to the test cell face. For our purposes, the reactor was an extension of the hydrogen piping. This is so because the hydrogen (coolant) is forced through longitudinal holes in the reactor until it exits through a

nozzle on top of the reactor. At the time of the accident a movable sheet metal shed was over the reactor.* Ten people were inside and three nearby, engaged in a variety of last minute tasks to prepare for a reactor run. Due to a leaky valve in the piping hydrogen gas issued from the nozzle with an audible rush and was ignited by an unknown source, perhaps metal particles carried in the gas stream. The resulting explosion blew out the sheet metal side panel of the shed and most of the occupants suffered bruises, fractures and ruptured eardrums and the severest injury was a fractured heel-bone. The eardrum damage suggests overpressure of more than 10 psi and the fact that some were blown several feet indicates that it was more like 25 psi, but not much more, because over about 35 psi fatalities may be expected. Just before the explosion, a valve, found later to be leaking, had been opened and it is presumed that the gas that issued pushed into the shed the gas that had earlier leaked into about 500 feet of downstream piping. As a result of this accident more rigid controls were instituted over operations at the test cell. Specifically, test cell managers were appointed for day-in day-out control and a Status Board was set up to schedule operations on days preceding major

*The shed is weather protection for the reactor and for personnel.

In this instance it was in place to duplicate a previous arrangement during some instrument calibration.

experiments. Block and bleed systems were installed to insure that piping outside the tank farm was free of gas. Thus there is now less possibility of performing incompatible operations at the same time.

- B. At the time of the incident, the cryogenic system incorporated two 28,000 gallon liquid hydrogen dewars and a large central vent system into which all vents from individual pieces of equipment were vented. Each dewar was protected from over-pressure by two safety valves and a rupture disk, all of which exhausted into the central vent system. There was a hand valve in series with each safety valve or rupture disk.

The dewars had been filled just prior to the incident and the boil-off gas was being vented into the central vent. The flare stack was lit, as it was customary to burn all vented hydrogen. Workmen in the Flow Control Room then removed a flange covering a port in the central vent. As the vent was filled with low density hydrogen gas, a chimney effect was created, and air was aspirated into the stack. The air mixed with the hydrogen, eventually producing a combustible mixture which was ignited by the flare stack and resulted in a low order explosion.

An alert technician immediately deduced the cause of the explosion and closed the vent valve on the dewars. However, the explosions continued, spaced about 5 minutes apart. An oxygen analyzer attached to the central vent showed oxygen

concentration to increase linearly to about six per cent, and then the mixture would explode and the O_2 concentration would drop to 0 per cent only to build up again. It was surmised that the rupture disks which were in parallel with the vent had been damaged, thus accounting for the continuing explosions. The hand valves in series with the rupture disks were closed, and the explosions stopped. The central vent was then purged, the flange replaced, and the rupture disks removed for inspection.

It was found that the rupture disks had been blown in backwards by the first explosion. Water droplets were found in the pipes to the dewars, and about three per cent O_2 was found in the dewar pressurization piping. The contents of the dewars were then emptied, the dewars warmed above the boiling point of O_2 , and the gas analyzed. No objectionable contaminants were found, so the dewars were returned to service.

As a result of this experience, the dewars have been equipped with small local stacks to take care of normal boil-off. These stacks exhaust to the atmosphere above the dewars and are not flared. These stacks are equipped with a remotely controlled shut-off valve and a spring loaded check valve set to maintain 7 psig to insure the exclusion of air. Also, the wisdom of a hand valve in series with a rupture disk was seen. The valve is normally open and sealed in place.

This incident was somewhat unique in that an explosion

occurred as the upper explosive limit was reached in an initially over-rich mixture.

- C. On one occasion, a "hat" containing instrumentation had to be removed from the top of an LH_2 dewar. This was mounted on a flange which, in turn, was secured to another flange; this latter flange was under dewar pressure. A set of short bolts and a set of long ones on the same bolt circle were used to retain these two components; the bolt heads were identical. Not only the short bolts were removed, but all bolts were loosened resulting in a gaseous hydrogen leak from the ullage space. Pressure was then vented to atmospheric, and while monitoring for a combustible atmosphere the assembly was secured. This incident emphasized the need for accurate as-built drawings and the presence of technicians who are familiar with all the systems involved, in this case, dewar piping and dewar instrumentation.
- D. While vaporizing LH_2 from a transport dewar, a leak was noted. System was shut down and the area was cleared. It was found that a "Kel-F" O-ring in a bayonet flange had cracked. As frost had been observed earlier it was established that in the future frost on such joints shall be regarded as a sign of impending leakage and the need for immediate preventive maintenance.
- E. A Bourdon tube ruptured in a pressure gauge which was in liquid hydrogen service after 528 hours of operation. By the time the alarm sounded the valve was isolated, the system vented and secured. It was found that the tube was of 403 stainless steel

which is subject to hydrogen embrittlement. Instructions were given to replace all such Bourdon tubes with 300 series stainless steel tubes, and to note that all Bourdon tubes that are magnetic are certain to be unsuitable for such service. Later we had a similar failure; the earlier search for 400 series stainless Bourdon tubes didn't uncover this one.

- F. Manual sprinkler system shutoffs were installed for dewars after inadvertent operation due to heat radiated by a reactor during a test run.

To date we have had no cases of frostbite from LH_2 . Our people are advised, however, in the event of spillage to use the emergency showers as first aid.

With respect to incidents, it may be interesting to list the reasons for entering the test cell and dewar area during remote operations. This covers about one year:

Cryogenic valve leak	(1) time
Cryogenic pump trouble	(1) time
Cryogenic line leak	(2) times
Fires	(2) times
Flare troubles	(2) times
Closures for inerted spaces	(3) times
Other: Cameras, hydraulic system, electronics, gas leaks, etc.	(18) times

Preventive maintenance of pumps, safety valves, gauges, filters, flexible hoses and motors is on a 6 monthly schedule.

LASL-AEC-OFFICIAL

Valves and pressure regulators are checked before each experimental run. This means an interval of about one week to two months.

CONSULTANTS

In the Fall of 1961 a group of cryogenic specialists met at Jackass Flats at the request of Dr. Keith Boyer of LASL. These men were from NASA, APCI, Aerojet General, NBS and LASL's Cryogenic Engineering and Safety Groups. Here follows a list of this group's recommendations of general interest - all accomplished.

Rupture Disks

Dewars should be protected by rupture disks which are set above the safety valve settings. The disks should be backed to prevent undue flexing, and should be equipped with a normally open hand valve upstream, and with a purge tap between the disk and this valve. Replacement of disks should be made, based upon experience.

Room inerting

Indoor spaces containing hydrogen piping to be inerted during experimental runs with nitrogen to bring oxygen concentration below 5 per cent.

Hydraulic oil

Compatibility of hydraulic fluid with hydraulic components to be verified to reduce leaks.

Helium zone

At dewar outlets, between two valves in series, a monitored

helium block at slightly higher than dewar pressure was provided upon the recommendation of this group of people. This zone extends from the dewar outlet to a block valve located outdoors.

Safety valves

Hand valves under safety valves and provisions for purging this volume of air were recommended.

Shutoff valves for safety devices

These items, referred to above are to be locked open, and a procedure established to govern their operation.

Dewar vacuum insulation

Continuous monitoring was recommended.

Flare stack

Purging before flaring was recommended.

In the summer of 1962 the LASL Safety Director, together with Group CMF-9 made the following general recommendations:

1. Controlled access in hazardous areas.
2. Establishment of emergency procedures for fires and spills.
3. Safety training of all persons.
4. Determine speed of response of hydrogen detectors.
5. A search for places where air can condense and drip on such combustibles as asphalt, and remedy such conditions by insulating cold pipes and vessels.
6. Heat resistant coating for dewar structural-support.
7. Insulate water deluge pipes to prevent accidental cold-shock.

8. Check relief valves periodically.
9. Verify that discharge piping of pressure reliefs are directed safely away from people.
10. Search for non-obvious areas where hydrogen may collect.

Special fire department instruction and emergency procedures were carried out at the beginning. It has been considered wise to reexamine these procedures from time to time. To date we have not had hydrogen fires requiring fire department response. An interesting practice evolved over the years through the wishes of the operators of the test cell. When a transport dewar arrives with LH_2 the fire department is called to stand by when connections are made to the manifolds. Then they go away but leave charged hoses available. They return again, to stand by, while the dewars are disconnected. The water spray is often used routinely by test cell personnel to warm up leaky joints. Originally, fire department personnel stood by during the entire transfer operation. In other facilities the practice has been merely to have the charged hoses available but without special standby personnel.

SAFETY ORGANIZATION

A local safety committee composed of senior members of each organization and a representative of the LASL Safety Office was established early in the project. It first met monthly. After much urgent business had been taken care of and reliable procedures had been established the tendency has been to meet about quarterly. The transactions of the safety committee are widely distributed.

LASL-ALC-OFFICIAL

A representative of the LASL Safety Office on a rotating basis is in residence at Jackass Flats about 48 weeks a year. These people are no strangers to the area and to the operation, yet, in a way they are visitors and represent an "outside" viewpoint.

A Rover Test Site Safety Manual was written in 1960 and revised in 1962. It contained general industrial safety material, and provisions of special interest to Jackass Flats including cryogenic safety.

When the LASL Health and Safety Manual was published in 1964 - this contained a quite complete collection of generally applicable safety requirements for LASL operations - the Test Site Safety Manual was superseded by a set of locally written Rover Safety Procedures, covering the principal operations. The prevailing tone of these procedures is positive rather than restrictive and they are at once a guide to technical requirements and safety.

Safety training on the test site is provided by the LASL Safety Office in several ways, ranging from distribution of data sheets, safety newsletters and the like, short talks on specific subjects at the jobsite, to fairly elaborate seminars for professional employees.

SAFETY PHILOSOPHY

On Project Rover we rely very heavily on the Test Cell Managers. These people always know, in effect, what's going on and through their control incompatible operations cannot go on at the same time. A few days before a run, all activities are scheduled by a Status

Board. Experiments and operations which require a high degree of coordination are governed by checklists. Hazardous operations are carried out remotely.

Regarding the engineering controls for prevention of accidental ignition perhaps the most important one is inerting all spaces where hydrogen exists under pressure (Reference: Item 1, Bibliography.) We try to utilize Class I Group B electrical equipment in true Division 1 locations, but we also try to locate most electrical equipment in non-hazardous areas, or at least we try to upgrade locations into Division 2. The hydrogen detection systems are frequently reviewed and simplified.

As far as hydrogen quantity-distances are concerned, rather than using very conservative distances and long, expensive runs of pipe there is increasing dependence upon the reliability of dewars. Rather than protecting occupied areas by relying on distance, we try to protect the dewars themselves. The 1944 East Ohio liquefied methane disaster which is almost forgotten today first led to excessive conservatism which later gave way to a rational development of standards governing site selection, material selection for cryogenic service, over-pressure protection devices and procedures for maintenance and for emergency action, which give us confidence in our present day operations.

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