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SPRINKLER DEMONSTRATIONS AT THE OAK RIDGE Y-12 PLANT

L. M. McLaughlin

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UNION CARBIDE CORPORATION
Nuclear Division

OAK RIDGE Y-12 PLANT

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SPRINKLER DEMONSTRATIONS AT THE OAK RIDGE Y-12 PLANT

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Oak Ridge, Tennessee

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SUMMARY

The demonstrations described in this report were conducted to observe the effects of applying water from a sprinkler fire fighting system onto materials generally considered too hazardous to be exposed.

Materials tested consisted of powdered uranium metal, powdered uranium hydride, powdered lithium hydride, uranium and magnesium machine turnings, and a fused salt bath. These materials were tested both inside and outside a glove box.

In the case of lithium hydride, experiments were also conducted to evaluate the use of nitrogen for purging hydrogen from the glove box to prevent the buildup of explosive mixtures. Nitrogen, argon, and Met-L-X were evaluated as to their effectiveness for smothering burning lithium hydride, uranium, and magnesium machine turnings inside a glove box.

A demonstration was also conducted to evaluate a detergent-argon-water high-expansion foam as a fire fighting agent for burning metal inside a glove box.

Auxiliary tests were made to determine if water from a typical sprinkler system impinging on empty metal containers could disturb a safe-geometry array; another test was conducted to determine if a pile of magnesium machine turnings would burn with sufficient intensity to actuate the 286° F sprinkler heads. One test was conducted to evaluate the damage to a glove box exposed to burning oil from an external source after the fire had actuated a typical sprinkler array.

The following observations are noted:

1. Uranium metal powder, uranium machine turnings, and magnesium machine turnings burned when exposed directly to water from a sprinkler head in the open, but the burning was controlled.

2. Uranium hydride powder reacted similarly to the metal powder but burned with more flame, probably because of the released hydrogen.

3. Lithium hydride powder burned when exposed directly to water from a sprinkler head in the open, but the burning was controlled.

4. Sprinkler water impinging on lithium hydride powder inside a glove box caused the powder to burn and produced flares of burning hydrogen and explosions.

5. Nitrogen introduced as a purge gas into glove boxes was effective in eliminating hydrogen explosions when sprinkler water impinged on powdered lithium hydride in the box.

6. Nitrogen and argon were effective in smothering lithium hydride, but only argon was effective on fires from uranium and magnesium machine turnings inside of glove boxes.

7. Met-L-X powder can be effective in smothering metal and lithium hydride fires inside a glove box, but the powder is difficult to apply from a fixed position.

8. Detergent-water-argon foam was partially effective in controlling metal fires; but, to be most effective, must be applied immediately after the fire starts.

9. Cans in a safe-geometry array were not disturbed by sprinkler actuation.

10. An accidental discharge of water into a fused salt bath should be avoided.

11. Automatic-sprinkler actuation was effective in controlling and extinguishing the burning of an oil-drenched glove box.

Partly as a result of the demonstrations, the following recommendations can be made regarding sprinkler and purge installations at Y-12:

1. All building areas housing and processing lithium hydride and most of the areas processing enriched uranium can be safely protected with a sprinkler system.

2. All glove boxes and machine hoods containing and processing lithium hydride can be equipped with an automatic nitrogen purge system to control the hydrogen concentration and extinguish fires.

3. Means should be provided to prevent the discharge of water into a fused-salt or molten-metal bath.

INTRODUCTION

A fire of major consequences in one of the AEC production plants has focused attention on the fact that ultimate control was achieved only through the use of water. Due to criticality considerations, water in any form for fire fighting was not permitted in the affected areas; and, although there were no significant criticality incidents reported in connection with the use of water, a principle of choice has arisen.

This principle proposes that it is better to be able to choose effective fire fighting equipment with which one is familiar than to be forced to use the equipment only as a last resort. In pursuing this premise, it is a well-established fact that automatic sprinklers generally provide a very effective fire-fighting apparatus. They have, however, usually been limited to areas that were considered to be safe if accidently discharged.

Y-12 management appointed a committee that was charged with the responsibility of reviewing and identifying those specific processing areas in the plant that were without automatic fire protection but could safely accommodate automatic sprinkler systems. The committee was composed of:

W. E. Weathersby, Chairman (Engineering)
J. T. Blackmon, Jr (Engineering)
J. R. DeMonbrun (Fire Protection Engineering)
L. M. McLaughlin (Development)
W. T. Mee (Radiation Safety)
J. B. Smith (Factory Mutual Research Corporation)

The demonstrations described in this report were conducted at the request of the committee in order to observe and become familiar with the effects of applying water from a typical sprinkler array onto certain materials and conditions that have generally been considered too hazardous to be exposed to aqueous systems. The tests were performed in Building 9817 (Fire Training Building) located in the extreme western end of the Y-12 Plant. The building is especially designed and constructed for handling and extinguishing fires.

DESCRIPTION AND DISCUSSION OF THE DEMONSTRATIONS

TEST FACILITY

For the demonstrations, an array of four sprinkler heads was mounted ten feet apart at approximately each midpoint of a square. The height of the sprinklers was ten feet from the floor. Each head was of the spray type, capable of delivering 45 gallons of water per minute under a head pressure of approximately 60 psig. The spray pattern was a solid-conical design covering an area of approximately 100 ft^2 for each nozzle. At the indicated pressure, the water was delivered as an extremely heavy shower of droplets finer than ordinary rain. All the tests were photographed on 16-mm color, silent film.

The materials and conditions of testing are described in the sections that follow, as well as a discussion of the demonstration.

INDIVIDUAL TEST PROGRAMS

Test I - Depleted Uranium Metal Powder (hydride process)

Description - The particulates of this powder average around 16 microns in diameter. Since the powder will ignite spontaneously when exposed to an ordinary atmosphere, it is normally processed and handled in glove boxes under a dry, inert gas because the powder is very sensitive to moisture as well as oxygen. Because the powder possessed these characteristics, it was predicted that it would react violently when exposed to sprinkler water. Consequently, it was decided to expose a very small quantity of the material to the sprinklers at first and then increase the amount.

For the first test, a 100-gram quantity of the powder, contained in a pint glass jar, was exposed to the air upon breaking the jar. The powder ignited almost immediately and started to burn with hardly any flare (Figure 1). After the sprinklers were turned on, the small pile of powder continued to burn as before. The water did not extinguish the flame nor add to the burning. It was noted that a vapor, probably steam, evolved from the burning mass. The powder was completely converted to the oxide in less than two minutes.

For the second test, a 200-gram portion of powder was exposed the same as for the 100-gram sample. The results were essentially the same except that burning continued for perhaps three minutes.

For the third test, 1,500 grams were exposed to the same conditions as in the preceding tests, as seen in Figures 2 and 3. Except for a brighter reaction, due to the greater amount of material, the results were the same as before. Burning continued for six to seven minutes before most of the oxide conversion had taken place.

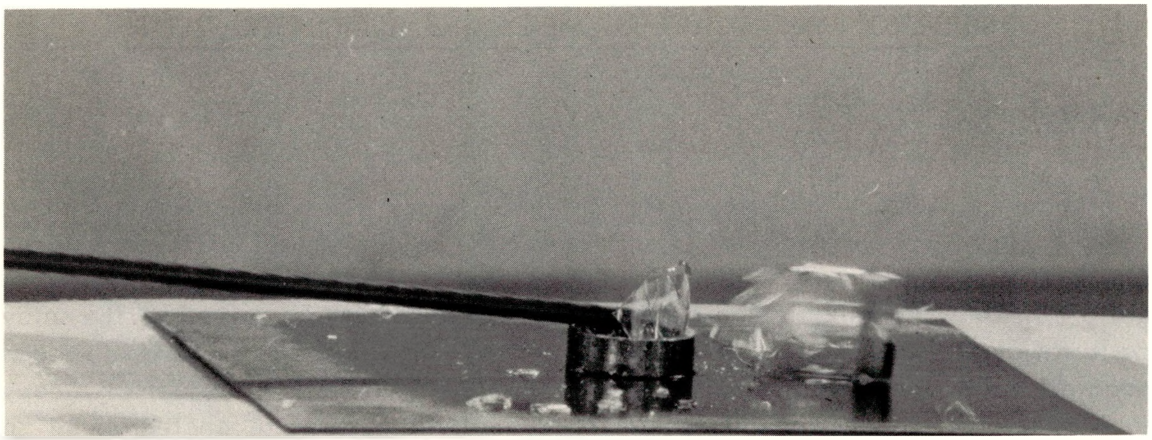

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Figure 1. URANIUM POWDER IGNITING UPON EXPOSURE.

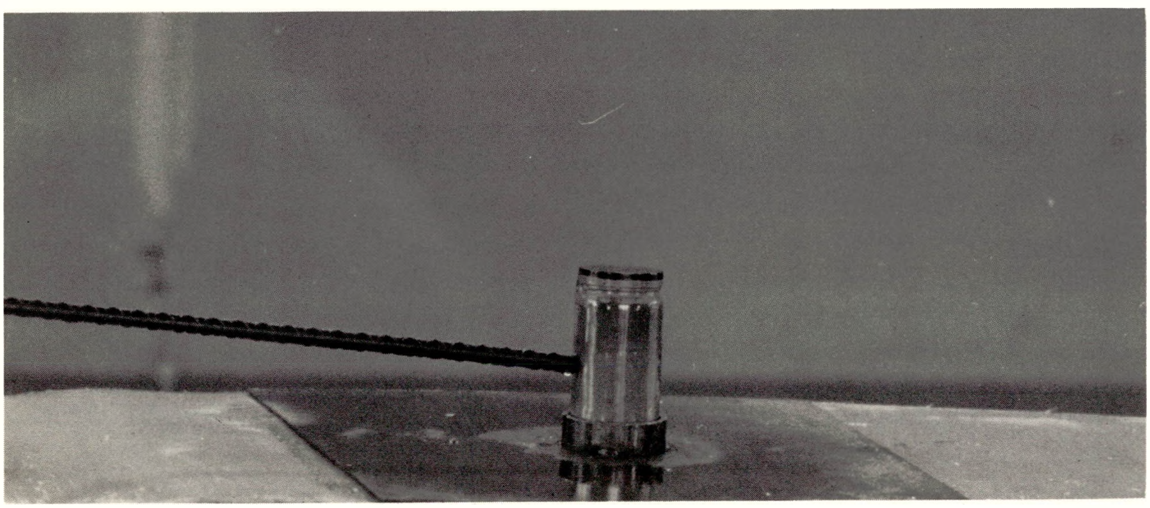

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Figure 2. GLASS JAR CONTAINING 1,500 GRAMS OF URANIUM POWDER.

Conclusions - The results of these tests would indicate that kilogram quantities of burning uranium metal powder of the type described could be effectively controlled with the application of water from a fire-sprinkler-system array similar to the one used in the test. It is possible that different sprinkler arrays could produce different results, but these tests demonstrate that, in the open system used, nothing violent occurred.

Test II - Depleted Uranium Hydride Powder

Description - This powder is a compound of uranium and hydrogen and has different chemical properties from the metal powder. The particulates, in this case, averaged

131311

Figure 3. FIFTEEN HUNDRED GRAMS OF URANIUM POWDER IGNITING UPON EXPOSURE.

eight microns in diameter, which is considered a fine material. It was speculated that contact with water would be explosive, so again only 100 grams of the material were exposed for the first test.

This test was conducted in the same manner as for the uranium metal powder in which a pint glass jar was broken and then sprayed with water from the sprinklers. When the jar was broken, ignition did not occur spontaneously; but, when the water hit the powder, ignition occurred almost immediately and burned with considerably more flare than the metal powder, perhaps because of the hydrogen being released. Steam was also noticed rising from the burning powder.

The powder was consumed in about two minutes and the addition of water from the sprinkler did not seem to cause a violent reaction; rather, the combustion continued in spite of the hydride-water reaction.

For the next test, 1,500 grams of the hydride were exposed to the sprinklers (the 200-gram sample was by passed). Except for a larger flare and the longer time needed for complete consumption of the powder (about 6 minutes), the results were the same as for the 100-gram test.

Conclusions - Again, the results of these tests indicate that kilogram quantities of powdered uranium hydride of the characterization described can be safely consumed by combustion when being exposed to water from an array of sprinklers.

This conclusion is drawn from what was demonstrated. Confinement of the powder, less water, different sprinkler patterns, presence of an inert gas, or any other variation could produce different results. The photograph of Figure 4 was taken while the material was burning after the sprinklers were turned on.

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Figure 4. BURNING URANIUM HYDRIDE DURING SPRINKLING.

Test III - Lithium Hydride Chips and Powder

Description - For this test, about 1/2 pound of lithium hydride solid chunks (1/4 inch thick and approximately two inches in diameter) were exposed to sprinklered water after breaking a glass jar. The chips reacted with the water, giving off hydrogen, but no ignition occurred.

For the next test, about 1/4 pound (1 quart) of finely ground lithium hydride powder was exposed by breaking a glass jar. The powder did not ignite when exposed to air, but did start burning when the sprinklers were actuated. The burning powder was very well contained by the water from the sprinkler, and hardly any flaring was noticed. After about half of the powder had been reacted, a stream of water from a fire hose was played on the burning material and immediately scattered the powder, causing numerous flares.

Conclusions - It was demonstrated that burning hydride powder is readily controlled by the sprinkler system, but directing a stream of water from a fire hose onto the hydride could cause a spread and intensification of the fire. The hydrogen released was apparently burned as long as the water from the sprinkler was directed on the powder.

Test IV - Filters for Lithium Hydride Powder

Description - For this test, four HEPA-CWS fire-resistant filters, used to filter the air from a lithium hydride processing area and which had been protected from moisture in the air by sealing them in several layers of polyethylene bags, were exposed to a gasoline fire and then water from the sprinkler system. Nothing happened, as predicted, since it was fairly certain that any small amount of lithium hydride dust collected on the filters had been completely reacted to the hydroxide during use and would present no fire hazard.

Test V - Sprinklers on Disarraying Hospital Cans

Description - This test was conducted to observe the effects of the sprinkler water stream on disarraying hospital cans that are used to store uranium solutions and compounds. Six each 6-inch-diameter by 12-inch-long cans and four 7-inch diameter by 7-inch-long cans were placed on a metal pan and the sprinkler system activated using 100-psig water pressure. These cans were all empty. When solutions or compounds are placed in them they would be more difficult to turn over. Also, the metal pan surface on which they were sitting was more irregular than the actual shelf surface in which these cans would be stored.

The spray did not move or turn over any of the cans. However, when a one-inch water hose spray was applied, the cans were scattered in all directions.

Test VI - Large Quantities of Lithium Hydride Powder in a Glove Box

Description - Two kilograms of lithium hydride powder were tested. A glove box was salvaged which contained Plexiglas windows (which can burn). In addition, some 1/4-inch-thick sheets of Lexan (which is supposed to be flame resistant) were placed over openings where some Plexiglas had been removed. A sheet-metal panel covered the roof. No attempt was made to make the box moisture proof. The arrangement can be seen in Figure 5.

A large glass bottle containing two kilograms of lithium hydride was placed in the glove box and arrangements were made to break the bottle through an opening in the box. A gasoline fire was started under the box, the bottle was broken, and the sprinklers actuated.

The hydride powder did not ignite when the bottle was broken even though it was exposed to some extent to the gasoline fire. Apparently, sufficient time was not allowed to get the bottle of hydride hot. After the sprinklers were turned on, the hydride powder started to burn, but the cooling effect of the water on the glove box did not permit the fire to spread to the flammable parts. The sheet-metal lid on the glove box prevented the spray from directly hitting the burning powder, and the spray of water sufficiently subdued the gasoline fire to prevent it from doing any damage. Finally, the hydride was completely consumed by playing a stream of water from a fire hose directly onto the burning powder.

The next test was designed to be conducted the same as the previous test. Four HEPA filters were placed in the glove box along with the bottle containing two

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Figure 5. SIMULATED GLOVE BOX WITH A GLASS JAR CONTAINING TWO KILOGRAMS OF LITHIUM HYDRIDE POWDER.

kilograms of powdered lithium hydride. This time the sheet-metal lid was removed. Five gallons of gasoline were poured in the pan beneath the glove box and ignited (see Figure 6). This time the bottle of hydride was given sufficient time to get hot before breakage. When the bottle was broken, the hydride ignited immediately and flared up to the same height as the flames from the burning gasoline. At this point the sprinklers were actuated manually. The fire was greatly suppressed, but the burning hydride and gasoline were never completely extinguished. It must also be noted that a great amount of dense-white caustic-laden smoke was emitted that, in a building, would greatly hamper any additional fire-fighting measures. Presumably, considerable hydrogen was emitted which, in a closed building, could pocket in ceiling areas and cause secondary fires and explosions.

In one test, a two-pound biscuit of lithium metal, measuring about 15 inches in diameter, was exposed to the sprinklers. As predicted, all that happened was a

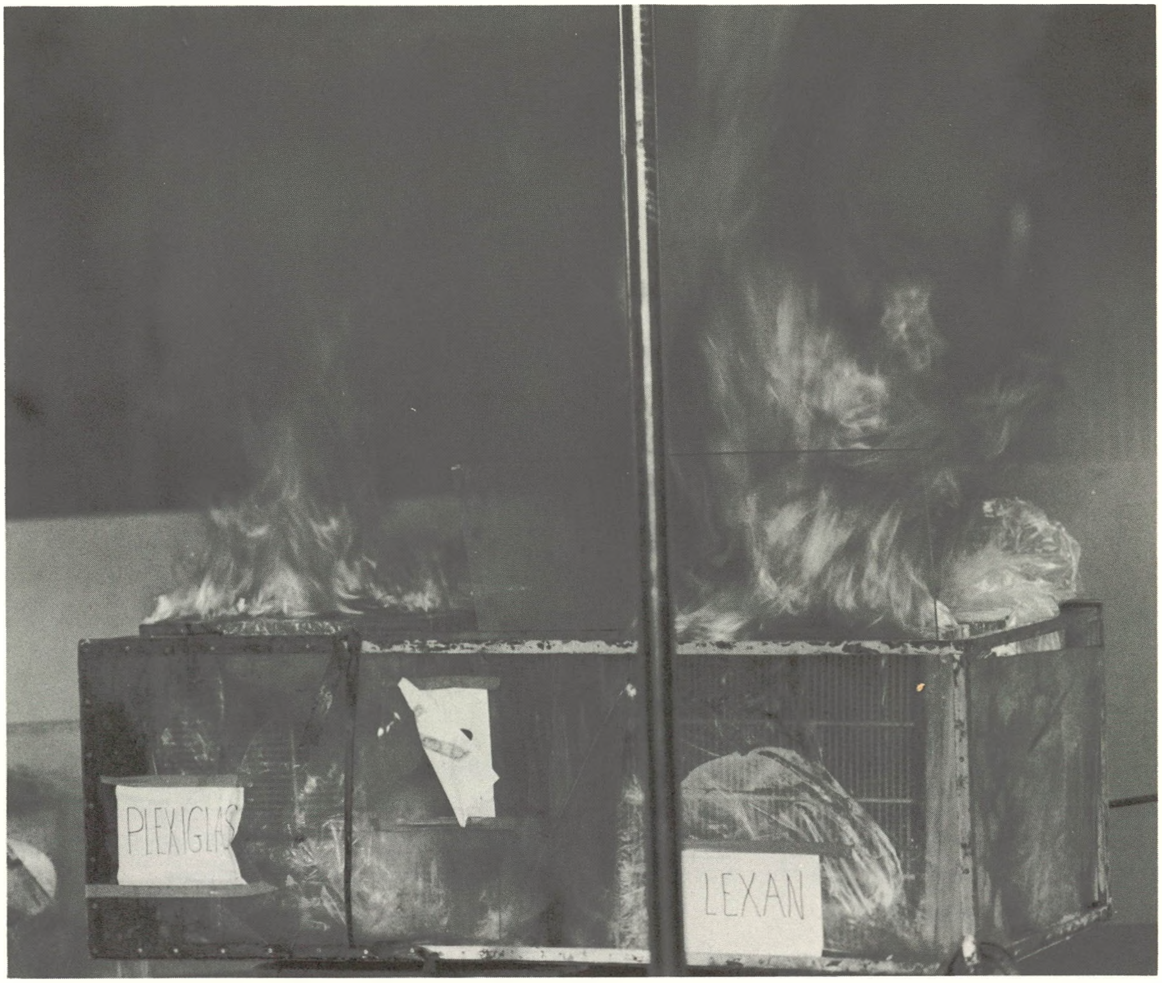

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Figure 6. TESTING BURNING LITHIUM HYDRIDE POWDER UNDER SPRINKLERS.

mild reaction of the metal with the water indicated by foaming due to the liberation of hydrogen. The hydrogen did not ignite.

Conclusions - Overall, the tests demonstrated that the burning of uranium metal and lithium hydride powders can be effectively controlled under certain conditions when sprayed with water from a fire-fighting sprinkler system. There remains, however, some uncertainty as to what other damage might be caused by the large quantity of hydrogen that could be released when these materials react with water.

Test VII - Lithium Hydride Powder in a Glove Box

Description - This demonstration was set up to expose two kilograms of powdered lithium hydride to water inside a metal-frame and Plexiglas glove box. The glove box, which measured approximately 4 feet wide by 2 1/2 feet deep by 3 3/4 feet high, was fitted with rubber gloves and, except for one open glove port, was air tight. The volume of the box was calculated to be approximately 37 ft^3. The open glove port was used to admit a long steel rod, which was used to break the glass jar containing the hydride, and a copper tube for supplying water to the exposed powder.

The objective of this demonstration was to cause the hydride to burn which, in turn, would ignite the Plexiglas and rubber gloves to the extent that a fire would be generated that could cause sprinkler activation. It was predicted that the hydride fire would be contained inside the box and that the sprinkler system would extinguish the burning Plexiglas and rubber gloves.

The demonstration proceeded as follows:

1. The jar was broken and the fine lithium hydride powder was exposed to the air inside the glove box. Nothing happened.

2. Water was then poured on the exposed powder (about one pint) and a white smoke was produced that caused a haze inside the box, but nothing else happened.

3. After about 10 minutes, it was decided to ignite the hydrogen inside the box by inserting a flaming oily rag on the end of a steel rod through the open glove port. However, before this could be done, and after a lapse of about 16 minutes from the time the water was applied, the hydrogen exploded and the hydride ignited.

   A section of the front Plexiglas panel containing the two rubber gloves was blown about 10 feet. The metal frame on the box retained sheared fragments of Plexiglas. The gloves on one side of the box were ruptured. Fingers were blown off of one glove and another glove was shredded. An observer noted a severe ballooning of these gloves at the time of the explosion. It was estimated that a force of up to 40 psig was generated on the front panel. The rubber gloves apparently acted as explosion vents, thus reducing the pressure generated inside the glove box. Had this box been equipped with glove-port covers, greater damage to the glove box might have been experienced. Two thermocouples located inside the box, one at the top and another adjacent to the hydride powder, did not register any temperature rise prior to the explosion. The Plexiglas panel on the side of the box containing the open glove port in addition to a rubber glove was bowed and cracked at the open port. The burning hydride finally set fire to a portion of the Plexiglas remaining on the front of the box.

4. The burning Plexiglas prompted a manual activation of the water sprinkler. This action created a billowing red flare which promptly died down, but was followed by another momentary billow. The hydride then proceeded to burn,

accompanied by a series of minor detonations (small pops and billows). Hydride burning continued without any other event for about 8 - 10 minutes.

5. At this point, the head pressure on the sprinkler system (4 sprinkler heads) was reduced to 7 psi. There was a slight but not drastic observable drop in the water flow, but the spray pattern was retained. This test was conducted because there is concern that with the present water supply system at Y-12, the activation of 100 sprinkler heads (design criteria) could drop the head pressure to 7 psi.

6. After observing the effect of a 7-psi head pressure on sprinkler delivery, the water was turned off and a fire directed on the remaining, almost completely reacted, mass of wet hydride. At first there was a flare and several small detonations when the water stream hit the powder, but these subsided. The water from the hose was continued until all the hydride was consumed.

Conclusions - The following conclusions can be stated:

1. Hydrogen liberated from wet lithium hydride can collect in a glove box and detonate from the heat of the reaction.

2. Installed rubber gloves can act as explosion vents, thus reducing the force of the explosion.

3. Application of sprinkler water to lithium hydride powder in unconfined spaces will cause impressive billows of fire, but otherwise will control the fire.

4. A head pressure of 7 psi appears to be sufficient to deliver a full spray pattern of water.

Test VIIIA - Lithium Hydride Powder in a Glove Box, Fire Extinguishment

Description - A second demonstration was conducted in which one kilogram of lithium hydride powder was exposed to fire and water inside a glove box. The arrangement was similar to the previous test except provisions were made to burn the hydride without the presence of moisture. Facilities were also provided to purge the box with nitrogen up to 32 ft^3 per min and to flood the bottom inside of the box with Met-L-X powder from a commercial extinguisher adapted by inserting the nozzle through the wall of the glove box. Met-L-X is simply table salt (NaCl) which has been treated with plastic and mixed with stearates to provide flowability.

The main purpose of the experiment was to determine if nitrogen could extinguish burning lithium hydride inside a glove box. The Met-L-X would be used in case the nitrogen did not work. A system was worked out using a dynamite fuse, black gun powder, and lighter fluid-soaked rags to ignite the lithium hydride powder inside the glove box after the glass jar containing the hydride powder was broken. Provisions for sampling the hydrogen in the glove box were also provided as well as thermocouples to measure and record temperatures inside the box at six places (see Figure 7).

The test proceeded by first lighting the dynamite fuse, then breaking the glass jar containing the hydride. The burning rags ignited the hydride; but, after about six

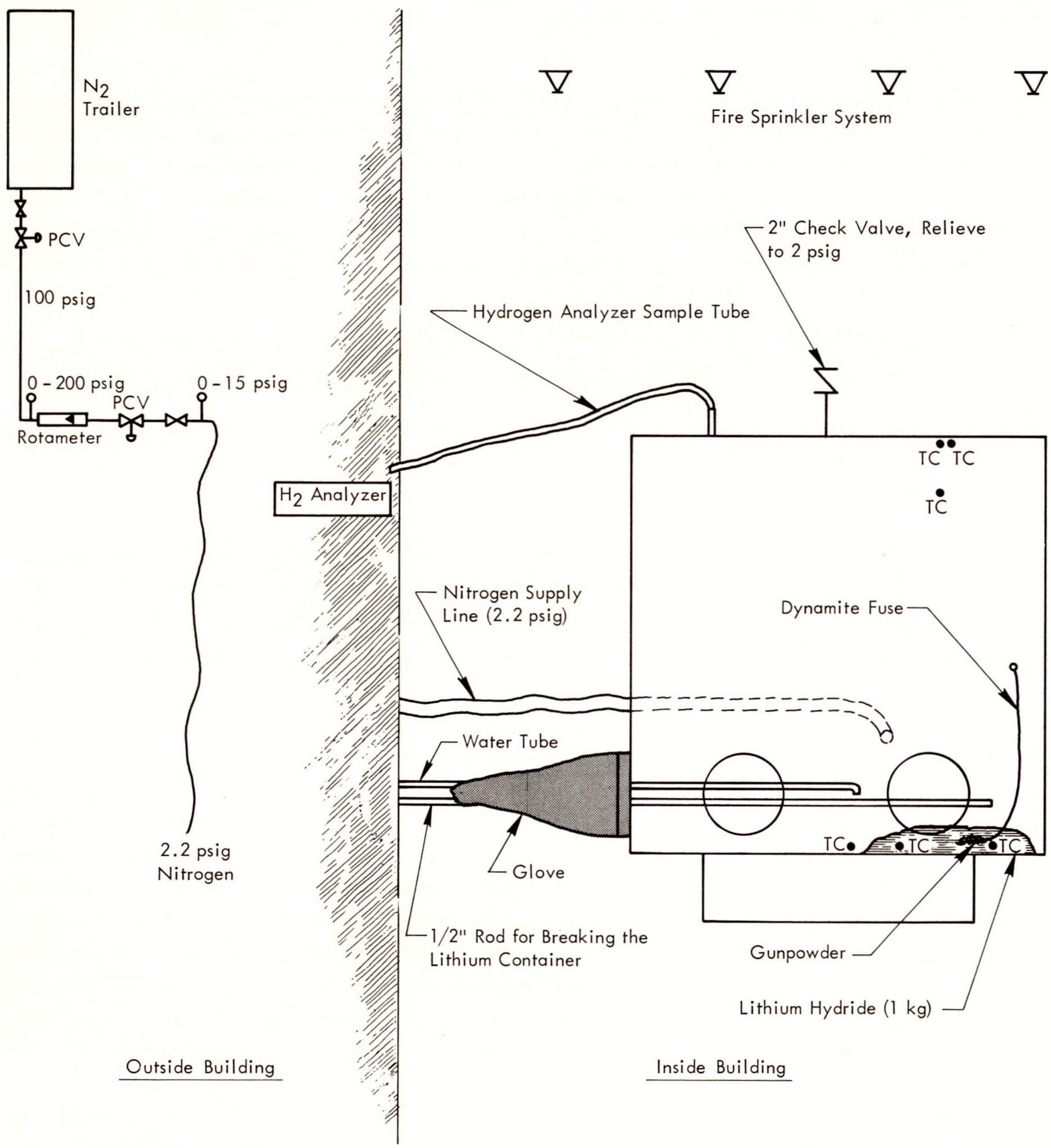

Figure 7. GLOVE BOX ARRANGEMENT FOR THE LITHIUM HYDRIDE TEST, TEST VIIIA.

minutes, the nitrogen was turned on at a maximum rate (32 cfm) and the hydride fire was extinguished.

After a total lapse of about 15 minutes, a glove was removed to let oxygen enter the box in an attempt to rekindle the hydride. The nitrogen was turned off; but, after another 10 minutes, with no apparent fire left in the box, this portion of the demonstration was abandoned.

Conclusions - It appears that a lithium hydride fire can be extinguished by the introduction of nitrogen into a glove box.

Test VIIIB - Lithium Hydride Powder in a Glove Box, Nitrogen Purge of Hydrogen

Description - In the first test with lithium hydride (Test VII, Page 13), the introduction of water onto the powdered lithium hydride resulted in an explosion of hydrogen gas and the partial destruction of the glove box. Since nitrogen was available for this test, as a purge gas for the glove box, it was decided to determine if the hydrogen generated by the addition of water to the hydride could be purged sufficiently by nitrogen to prevent an explosive mixture.

For this test, the nitrogen was introduced into the glove box at approximately 32 ft^3 per min. The glove removed in the previous experiment continued to remain off. Water was added to the hydride. A buildup of hydrogen was recorded on a portable hydrogen meter that aspirated a continuous sample through a 1/2-inch-inside diameter hose about 15 feet long. A lag time from the sample point to the instrument was estimated to be 75 seconds. The instrument used to measure the hydrogen was a portable Johnson-William Combustible Gas Indicator, Model GP, which utilizes a heated platinum filament to measure the percent of gas up to the lower explosive limit of the gas in oxygen.

After the addition of water to the hydride, about eight minutes passed before the meter indicated a maximum of about 12 percent of the range to the lower explosive limit. In another four minutes, the meter read zero and the nitrogen was turned off.

A small amount of water was again added to the hydride, this time with the nitrogen gas purge off; and, in about two minutes, the meter peaked at 80 percent of the range. In another two minutes the meter indicated about 15 percent and water was again added. In another four minutes the meter indicated an explosive mixture and the nitrogen was turned on. In an additional two minutes the meter read 40 percent and water was again added while the nitrogen was still flowing. The meter continued to indicate a decrease in the hydrogen content down to zero in another 1 1/2 minutes, at which time the nitrogen purge was turned off.

The explosive range was quickly reached in about a minute, at which time the nitrogen purge was turned on (32 cfm). This purge caused the hydrogen to drop off to less than one percent in about three minutes, and the nitrogen was turned off. The hydrogen again rose to around 35 percent where it peaked. This ended the experiment.

Conclusions - The results of the test indicated that hydrogen generated by the direct and periodic addition of small amounts of water to the powdered lithium hydride could be maintained below the explosive limits by a nitrogen purge sufficient to replace the volume of the glove box every minute. By inference it is postulated that hydrogen generated from the exposure of lithium hydride to moist air or to impinging sprinkler water inside a glove box can be controlled to below an explosive mixture by the introduction of a suitable and practical amount of dry nitrogen purge gas.

Test IX - Burning Glove Box Extinguished by Sprinklers

Description - For this test the glove box was used as set up for the previous two tests (Tests VIIIA and B). The box still contained the unreacted portion of the lithium hydride.

The objective of this test was to determine how effectively a sprinkler system can subdue and extinguish a fire fueled by burning oil that is coating the glove box. It was postulated that oil could be heated to its flash point in a malfunctioning machine-control system to the extent that it could rupture the system at some weak point and spray onto the glove box, in turn setting fire to the rubber gloves and Plexiglas.

For this test, the fire was simulated by pouring oil and gasoline over the box and by soaking rags, laid around the base of the glove box, with oil and gasoline. A nitrogen purge of approximately 5 cfm was introduced into the box since that flow rate somewhat represented the purge flow normally used to purge such a system in operation. The fire was started and almost immediately the gloves were burned off. After about seven minutes, some portions of the Plexiglas softened and fell out of the frame-metal supports, at which time the sprinkler system was turned on at a 35-psig head pressure. Prior to activation of the sprinkler it was felt that the flames were of such intensity and height that they would have actuated a fused sprinkler system long before such physical damage could have occurred to the Plexiglas. The sprinkler actuation was deliberately delayed in order to observe the effect of the water on the lithium hydride once the integrity of the box was sufficiently breached to permit water to reach the hydride. The maximum temperature recorded for the inside of the box before the water was turned on was around 380° C at the top of the box.

Exposure of the hydride to the water produced the usual flaring and billowing of flames caused by the burning hydrogen. It was noted that the hydride was burning before the addition of water from the sprinklers in spite of the 5-cfm nitrogen purge. However, the integrity of the box was lost due to burning off of the gloves which permitted the atmosphere inside the box to pick up sufficient oxygen to allow burning.

Conclusions and Recommendations - As a result of this study, certain conclusions and recommendations are noted:

1. An oil-fueled fire and burning Plexiglas can be controlled by the application of water from a sprinkler system.

2. The exposure of lithium hydride powder to water from a sprinkler system without confinement of the hydrogen gas does not appear to create a serious hazard.

3. Plexiglas panels which are secured only by the clamping action of the frame will soften and fall out of the frame.

As a result of the last conclusion, it is recommended that Plexiglas panels be secured in the frames by hanging the panels on the framing bolts running through drilled holes in the panels. This arrangement should give added support and not disturb the clamping action of the framing which is needed for sealing.

Test X - Burning Glove Box, Automatic Sprinkler Actuation

Description - This demonstration was made to test the effectiveness of a sprinkler system to extinguish a fire associated with a glove box when sprinkler actuation is automatic. At the same time, conditions were arranged to evaluate the effectiveness of a nitrogen purge to remove the hydrogen that was generated by the action of water from the sprinklers on lithium hydride powder inside the glove box since the sprinkler water can come in contact with the hydride after the rubber gloves burn off, leaving an open glove port. The glove box was set up as shown in Figures 8 and 9 except that the box was fully fitted with gloves. The Plexiglas panels placed at the sides of the glove box were provided to evaluate the propensity of the fire to spread to adjacent glove boxes and also to evaluate the ability of the sprinklers to prevent any spread.

The sheet metal ceiling over the four-sprinkler array was installed for this test to collect the hot gases that are required to melt the fusible links and actuate the sprinkler heads.

The demonstration proceeded as follows:

1. A nitrogen purge was applied to the box to effect one volume change in the box per minute ($\sim$ 37 cfm). An oxygen meter showed a reading of 5.5 percent oxygen in the box after about three minutes of purging. At this time a glass jar inside the glove box, containing one kilogram of fine lithium hydride powder, was broken to expose the powder.

2. A fire was started similar to the one set in Test IV (Page 10) to simulate a fire fueled by burning oil. In slightly less than two minutes, three of the four

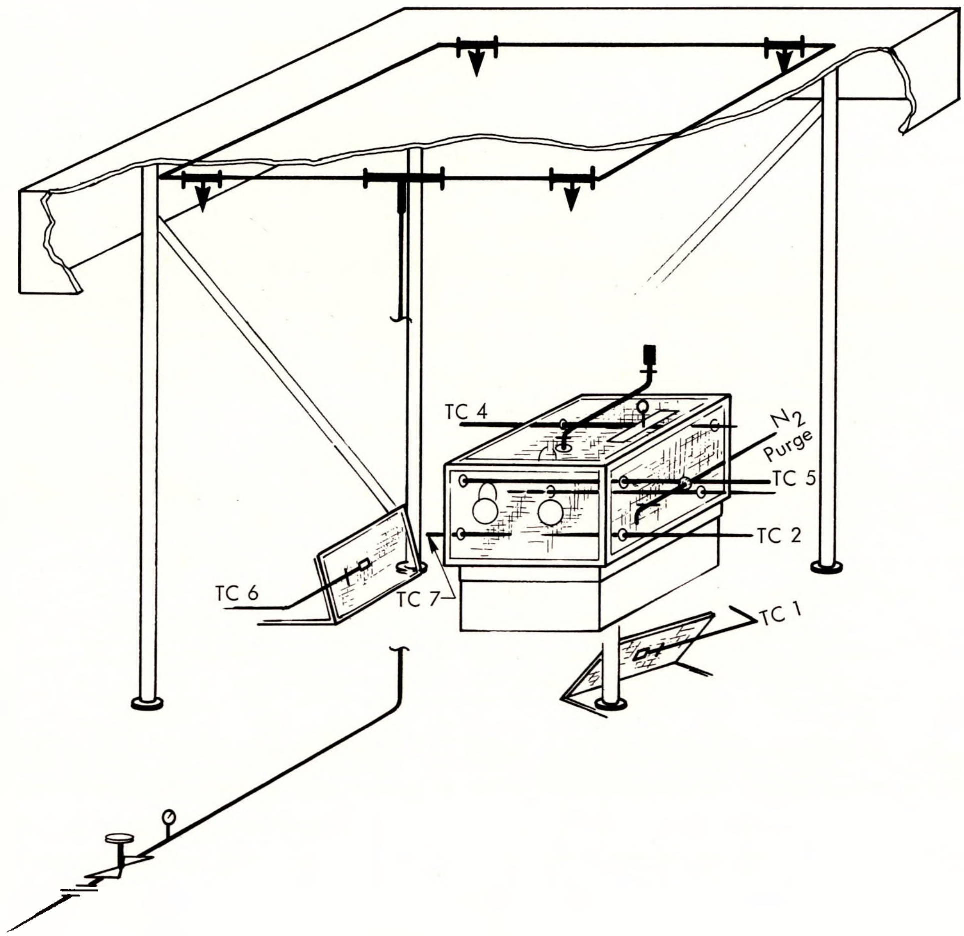

Figure 8. ARRANGEMENT FOR THE BURNING GLOVE BOX TEST, TEXT X. (Plexiglas Panels Are 4' 10" from Glove Box)

sprinkler heads were actuated, by which time the rubber gloves had been burned off. The hydrogen inside the glove box quickly rose to approximately 40 percent of the range below the lower explosvie limit after the sprinklers were actuated. A meter employing the same principle as the one used in Text IX was used to measure the hydrogen.

3. After the hydride was exposed to water through the open glove ports, the hydrogen rose to 90 percent of the lower-explosive-limit (LEL) range in a matter of four minutes after which time the hydrogen content quickly fell to 5 percent of the LEL in the next two minutes. The sprinklers at this point were turned off; the nitrogen purge was maintained at $\sim$ 37 cfm.

4. About a minute after the sprinklers were turned off, the hydrogen in the glove box (generated by the reaction of the water filling the bottom of the box with the lithium hydride) quickly rose to above the lower explosive limit. At this time a door covering an opening (approximately one square foot in area) on the

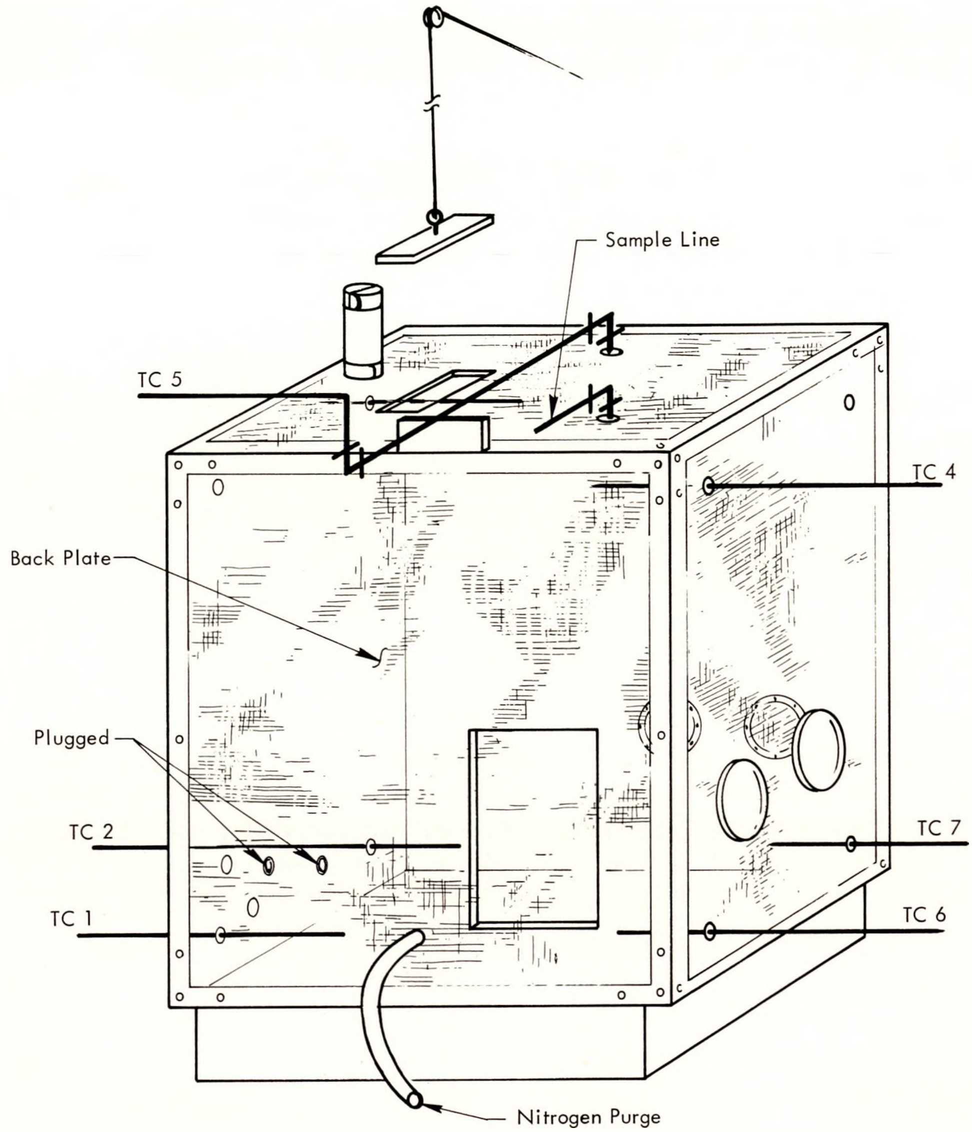

Figure 9. REAR OF THE GLOVE BOX AS ARRANGED FOR THE BURNING GLOVE BOX TEST, TEST X.

top of the box was opened to vent the hydrogen. The hydrogen fell to about 4 percent of the LEL in less than a minute.

5. With the opening in the top of the box exposed, the sprinklers were again turned on to permit more water to impinge on the remaining salt in the box to consume it.

Conclusions - A fire, fueled by gasoline, oil, and rags, actuates the sprinklers in such a short time that very little damage is done to the inside of the glove box from fire. The gloves are burned off in a few minutes and the Plexiglas is etched by the flames, but little distortion takes place. It was noted that a small length of a "two by four" lying on top of the glove box was not scorched.

Thermocouples set to detect the temperature inside the glove box and on the face of the Plexiglas side panels showed that the thermocouples on the side panels reached approximately 200° C. The bottom inside of the glove box, next to the burning gloves, was subjected to about the same temperature, while the thermocouples placed inside the box at the top-rear barely indicated any temperature rise. The side panels of Plexiglas, which were not restrained by any frame, warped slightly.

It was also observed that a nitrogen flow of one volume change per minute almost prevented any concentration of hydrogen above the lower explosive limit in spite of the poor integrity of the box caused by open glove ports. This observation prompted setting up the next test to evaluate whether increased volume changes per minute would, in fact, adequately control the hydrogen concentration.

Test XI - Glove Box Purging with Nitrogen

Description - This demonstration was prompted from the results of Test X. In that test, a nitrogen purge (1 volume change per minute) which entered through open glove ports in the glove box containing powdered lithium hydride exposed to sprinkler water, almost prevented explosive mixtures of hydrogen and air. In fact, no explosions occurred even though explosive mixtures were indicated.

For this test it was decided to use a nitrogen purge of 1 1/2 volume changes per minute to determine if explosive mixtures could be prevented. This volume change was selected as being a practical amount of nitrogen that could be supplied to the largest glove boxes contemplated in actual operation with the existing nitrogen distribution system.

The test was set up so that known volumes of hydrogen could be generated by adding specific amounts of water directly to the lithium hydride powder through an inclined copper tube extending out from the glove box to a protective barrier. Otherwise, the arrangement was essentially the same as for Test VIIIA (see Figure 7) except that: (1) no provisions were made to start a fire, (2) all glove ports were open, (3) a trap door over a one-square-foot opening in the top of the box was provided for safety venting as in Test X, and (4) the entrance nozzle of the nitrogen purge was directed more to the bottom center of the glove box.

The test proceeded as follows:

1. A nitrogen purge of 56 cfm (1 1/2 volume changes per minute) was established and the glass bottle containing one kilogram of lithium hydride powder was broken, allowing the powder to empty into a photographic tray.

2. Enough water (about 2 pints) calculated to generate approximately 37 ft^3 of hydrogen (equal to the volume of the glove box) was added to the hydride. Hydrogen started registering almost immediately and climbed to 70 percent of the LEL within 1 1/2 minutes, after which it was quickly dissipated.

3. One additional pint of water was added, but this time the hydrogen only climbed to 40 percent of the LEL which was quickly dissipated. After this, another pint of water was added and the hydrogen rose only to 20 percent of the LEL range.

4. At this time, four more pints of water were added and the hydrogen went up to 65 percent of the LEL and quickly fell to zero. Since it became obvious that adding water in such small amounts would not generate sufficient hydrogen to provide a reasonable test, it was decided to expose the hydride to sprinkler water.

5. After the sprinklers were turned on, the hydrogen rose to 75 percent of the LEL in less than two minutes; peaked; and, after several minutes, slowly fell to 50 percent. This action consumed a total of five minutes, at which time the sprinklers were turned off. The hydride was thoroughly wetted during this operation and water completely filled the photographic tray containing the hydride powder.

6. With the hydrogen reading at around 40 percent of the LEL, the nitrogen was reduced to 37 cfm (one volume change) and, with the sprinklers remaining off, the hydrogen was dissipated in about three minutes.

7. The sprinklers were again actuated with the lower (37 cfm) nitrogen flow. The hydrogen rose to about 60 percent of the LEL over a period of three minutes; and, in another two minutes, fell to 20 percent. After five minutes, the sprinklers were turned off. At this time it was decided to remove the trap door to let more sprinkler water into the box in order to consume the remaining amount of hydride. However, the door was stuck too tight and, in attempting to dislodge it, the glove box was shaken. This action apparently agitated the hydride/water mixture and the hydrogen content quickly rose into the explosive range. After the nitrogen purge was turned up to the 56-cfm rate, the hydrogen quickly fell to 30 percent of the LEL at which point the lid was finally removed. It is believed that if the full 1 1/2-volume purge rate (56 cfm) had been on at the time of agitation, the hydrogen would not have risen into the explosive range.

8. With the opening in the top of the box uncovered and the nitrogen purge at 56 cfm, the sprinklers were turned on. The lithium hydride caught on fire, then went out. A minor explosion or two occurred, but the hydrogen level stayed around 20 to 35 percent of the LEL. After about five or six minutes, the lithium hydride was dissolved.

As an adjunct to this experiment, it was felt that the amount of water that could pass through an open glove port from the sprinklers should be determined. An experiment was devised that used a front Plexiglas panel containing two glove ports. The panel was placed flat over two trash cans containing plastic bag liners so that each glove port was directly over a trash can. The sprinklers were turned on for five minutes and the amount of water collected in each plastic bag measured. The results showed that 4.8 and 5 pints were collected.

Conclusions - This experiment probably represents a worst-case situation and indicates that 1 1/2 volume changes of nitrogen per minute should be capable of purging the hydrogen that the amount of water used (~ 1 gallon in 5 minutes) could generate when reacting with powdered lithium hydride.

The demonstration, as a whole, indicated the feasibility of purging a glove box with nitrogen to dissipate the hydrogen generated by adding water to powdered lithium hydride inside a glove box from a sprinkler system.

Test XII - Extinguishing Burning Lithium Hydride in a Glove Box with Nitrogen

Description - Previous tests have indicated that burning lithium hydride inside a glove box could be extinguished by replacing the atmosphere surrounding the fire with nitrogen. Nitrogen is normally used to maintain an atmosphere of less than three volume percent oxygen in all machine hoods used for lithium hydride and has proven reliable and effective for a number of years.

Prior tests have also shown that a properly distributed nitrogen purge of approximately 1 1/2 volume changes per minute is effective in preventing explosions that can occur when hydrogen is generated inside a glove box by the reaction of water and lithium hydride.

For these tests, a nitrogen purge of 1 1/2 volume changes per minute was evaluated for extinguishing fires inside a glove box resulting from burning lithium hydride and uranium machine turnings. The glove box was equipped with rubber gloves, a 2-psi vent-relief valve, and a trap door in one side of the Plexiglas for inserting materials and lighting the fires. An air supply line was also installed to the box to provide sufficient oxygen to support combustion until the purge gas could be introduced.

Test XII with lithium hydride proceeded as follows:

1. One kilogram of lithium hydride powder was poured into a metal photographic tray inside the glove box. A handful of uranium metal turnings was also added to facilitate burning. Air was introduced into the box through a hose supplied by a portable air compressor. The powder was set afire with a propane torch and the trap door secured to make the glove box reasonably gas tight.

2. With the hydride burning, both the oxygen and hydrogen content inside the box were monitored. The nitrogen was turned on (57 cfm) and, in about a minute, evidence of burning disappeared. The nitrogen was left on for five minutes. The oxygen content dropped to 2 1/2 volume percent in about four minutes. Apparently, the burning was extinguished at about 10 volume percent oxygen. Hydrogen did not register significantly.

3. With the nitrogen off, air was introduced into the box and the hydride powder stirred. This treatment ignited the hydride. Next, the air was turned off and nitrogen introduced (57 cfm). Almost immediately the burning stopped. The nitrogen was left on for another five minutes, dropping the oxygen content to 0.4 volume percent. Finally, the hydride was stirred, but there was no evidence of burning.

4. The nitrogen was turned off, the air turned on, and the hydride rekindled. Again, the nitrogen was introduced and the burning ceased. While the nitrogen was left on (for 5 minutes), the hydride was removed from the glove box. There was no evidence of fire, but some of the uranium metal turnings caught fire after removal and, in turn, caught the hydride on fire. It was decided to repeat the experiment later without the uranium so that the hydride could be evaluated for extinguishment without the influence of the metal chips which seemed to have a greater tendency to ignite in air.

<u>Test XIII - Extinguishing Burning Uranium in a Glove Box with Nitrogen</u>

For testing the value of nitrogen for extinguishing a burning metal fire, 3 1/2 gallons of uranium machine turnings were placed in the glove box and ignited. The test proceeded as follows:

1. After the turnings were ignited, the air was turned off and the nitrogen purge started. Almost immediately there was an intensification of the burning, producing a bright orange flame which lasted about two minutes after which time the burning suddenly stopped.

2. The nitrogen was left on for five minutes. The oxygen content was reduced to less than one volume percent in less than two minutes. There was no evidence of any fire at the end of the five-minute period. Upon exposure of the turnings to the atmosphere outside the glove box, however, the turnings proceeded to burn to a black powder. Prior to this burning, the turnings had maintained their original physical form and showed no evidence of turning into a powder. Analysis of the burned powder by X-ray diffraction did not reveal any uranium nitride.

<u>Conclusions</u> - From these tests, the following conclusions were reached:

1. A repeat of Test XII, without uranium metal machine turnings, showed that the nitrogen purge used in this test was effective in extinguishing burning lithium hydride.

2. The use of nitrogen to extinguish burning uranium machine turnings is not recommended. It appeared that nitriding was taking place, although chemical analysis did not confirm the presence of a nitride. The residual oxygen in the glove box, agitated by the nitrogen, could have caused the burning turnings to flare up.

Test XIV - Met-L-X Injected into a Glove Box to Extinguish Burning Uranium

Description - This test was prepared to evaluate the effectiveness of Met-L-X as a fire extinguisher. This experiment was designed previously (see Test VIIIA), but never tested. Test XIV showed that Met-L-X is an effective extinguisher for lithium hydride fires if it can be directed to completely cover and smother the lithium hydride. This test also showed how difficult it would be to try to cover the fire automatically from a fixed position. Hand application is about the only way this material can be effectively applied.

Test XV - Burning Magnesium Turnings Exposed to a Sprinkler

Description - This test was constructed to demonstrate what would happen if burning magnesium turnings were exposed to sprinkler actuation. For this test, about three gallons of the turnings, soaked in mineral oil, were ignited. When they were burning effectively, the sprinklers were actuated. The water, impinged directly from the sprinklers onto the burning turnings, appeared to cause the turnings to burn faster at first and then some cooling seemed to take effect and the burning was reduced. The burning of the turnings, however, was never extinguished. Although the fire was intensified by the water from the sprinklers, it was evident that any adjacent property would have been protected.

Test XVI - Extinguishing Burning Uranium with Argon

Description - The objective of this test was to evaluate the effectiveness of an argon purge to extinguish a uranium metal fire. About three gallons of uranium machine turnings were ignited inside a glove box. Air was supplied to the box to support combustion. When the burning seemed sufficiently vigorous, the air was cut off and 57 cfm of argon (1 1/2 volume changes) were introduced into the glove box.

The oxygen content in the box dropped to around nine volume percent in less than two minutes, after which time the burning was reduced to a glow. In less than four minutes the glow disappeared at an oxygen level of around one volume percent.

At this time the argon was turned off and air introduced into the box. At around nine volume percent oxygen, the turnings began to glow again. Again, the air was turned off and argon started (57 cfm), after which the glowing ceased at around one volume percent oxygen. The turnings were then removed from the box where they rekindled and burned to the oxide.

Conclusions - The test demonstrated that argon can be beneficial in controlling the burning of uranium metal inside a glove box. To be most effective, the oxygen content should be purged to below one volume percent.

Test XVII - Burning Uranium in a Closed Glove Box

Description - The objective of this test was to observe the effects of burning uranium machine turnings inside a closed glove box without introducing either air or an inert gas.

For the test, about five gallons of turnings were placed directly on the metal bottom of the glove box. This arrangement was made to determine if the metal bottom would act as a heat sink and help dissipate the heat from the fire without igniting the Plexiglas or Neoprene gloves. The turnings were ignited and the glove box sealed. The turnings burned for about five minutes, turned to a bright glow; and, in another 15 minutes, only a very dull glow was detected. After a total of 50 minutes, the trap door of the glove box was opened and immediately the vapors in the box ignited. The turnings started to burn although it was difficult to detect any glow in the turnings prior to opening the door.

Heat from the burning of the turnings noticably warped the Plexiglas sides and tops of the glove box and the metal bottom, but did not ignite the Plexiglas or the rubber gloves. The bottom apparently acted to some extent as a heat sink. The concensus seemed to be that although the glove box might be warped beyond repair, no irreparable damage would have been done to a machine or fixturing.

Test XVIII - Automatic Sprinkler Actuation by Burning Magnesium

Description - The objective of this test was to determine if about five gallons of mineral oil-soaked magnesium machine turnings would burn with sufficient intensity to actuate the fused 286° F sprinkler heads when placed on the floor beneath the center of the four sprinkler array. They did not.

Test XIX - Detergent Foams on Metal Fires

Description - The literature on fire fighting systems eludes to the effectiveness of detergent foams for fighting metal fires. Since it is a simple and economical material to generate, a series of demonstrations were planned to evaluate the effectiveness of such a foam on burning uranium and magnesium machine turnings inside and outside a glove box.

For these tests, a foam generator was devised using an industrial-type DeVillibus paint-sprayer head to spray an argon/water mixture and sodium lauryl sulfate through a cheese cloth mesh (see Figure 10). The device was capable of generating a high-expansion foam (~50 to 1) at a rate of about 10 ft^3 of foam per minute. The foam was able to flow by its own accord when applied from a fixed position.

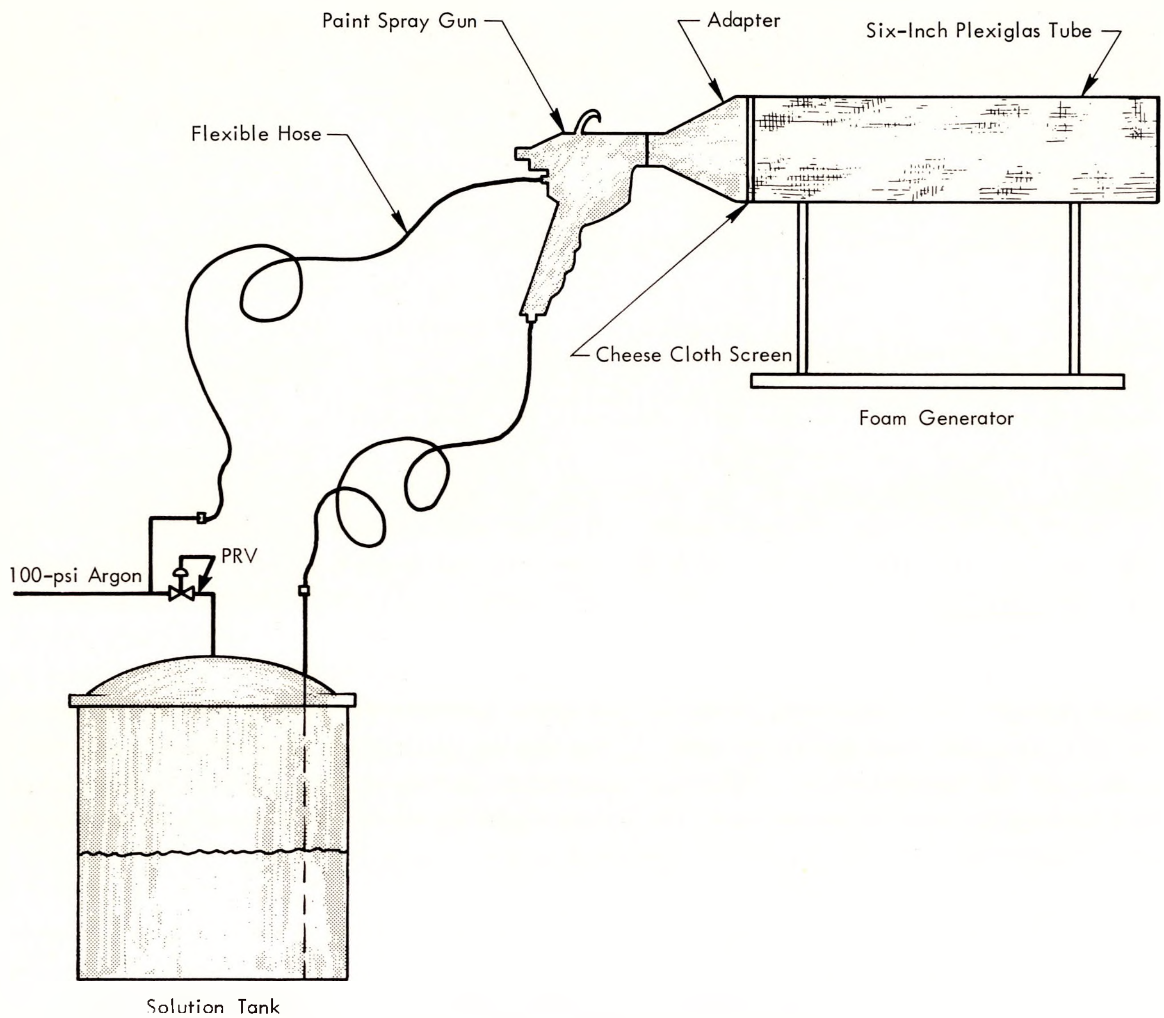

Figure 10. HIGH-EXPANSION FOAM GENERATOR.

For the first demonstration, uranium turnings were ignited inside a glove box and the foam applied from a fixed position. The application of foam, however, was far too slow and the turnings were consumed before the foam could cover the fire. Subsequent tests showed that it is a matter of great importance to attack the fire as soon as possible for foam to be fully effective. This fact was demonstrated by applying foam by holding the generator over burning uranium turnings outside the glove box. It was seen that the draft created by the flames had a tendency to deflect the stream of foam and prevent adequate coverage which permits a continued supply of air to the fire. By hand application, the foam can be applied directly to the fire by circumventing the effect of the draft, thus effectively smothering and cooling the fuel.

Similar results were noted for the demonstrations using magnesium machine turnings.

Conclusions - The following conclusions can be stated as a result of this test:

1. Detergent-inert gas foams can be effective in abating metal fires if the foam can be applied before the fire becomes intense enough to generate a draft, or if the foam can be applied sufficiently fast to form a smothering blanket to exclude all air. A draft tends to create channels of air through the foam to the fire.

2. In an enclosed space, such as a glove box, the use of a detergent-inert gas foam seems to offer no advantage over straight inert gas. In an open space, the foam, if properly applied, can be an effective fire fighting agent for burning uranium and magnesium machine turnings.

Test XX - Fused Salt Baths

Description - Considerable concern has been expressed regarding the use of a "wet" sprinkler system in areas housing fused salt baths. The concern is for the safety of personnel who might be working in the proximity of a salt bath in the event that a sprinkler head would accidently discharge water. To better understand this, a demonstration was prepared that used a small bath containing a molten eutectic mixture of approximately 35 percent lithium carbonate and 65 percent potassium carbonate at a temperature near 700° C. The molten bath was contained in an open-top steel vessel measuring about 10 inches in diameter by 18 inches deep and was placed about four feet directly beneath a sprinkler head.

This open sprinkler head was one of four mounted in the same array that was used in earlier tests. It was speculative whether the generated steam would actuate the other three sprinklers (286° F heads) which were not opened but fused.

The power to the furnace was disconnected and the sprinkler head actuated manually. Immediately, steam was generated. After about three minutes, a low-order explosion occurred which threw out a shower of molten salt in approximately a 20-foot circle. In another three to four minutes, a similar explosion occurred followed, at intermittent intervals, with 18 additional explosions at which time the water was turned off.

Post examination showed that about four inches of salt remained in the bath and that some of the salt was thrown as far as 60 feet, although most of it was thrown on and immediately around the furnace. The paint on the steel canopy above the bath was scorched as well as the paint on the furnace. The other three spray heads never actuated, indicating that steam will not normally actuate the 286° F rated heads.

One explanation for the explosions might be that the water cools the molten salt to form a crust over the remainder of the molten bath. Steam is probably trapped beneath this crust and becomes superheated at which time it expands violently and causes an eruption of the bath.

Conclusions - This demonstration showed that measures must be taken to prevent the accidental discharge of water from sprinkler heads into a molten salt bath if personnel safety is to be considered.