LIQUID NITROGEN FIRE EXTINGUISHING SYSTEM TEST REPORT

May 4, 1972

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**Special Materials and Services Division
ARGONNE NATIONAL LABORATORY**

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TEST REPORT

OBJECTIVE

The objective of this test series was to demonstrate the feasibility of using liquid nitrogen as a fire-extinguishing agent for certain types of metal fires. It was intended to provide data and experience appropriate to the design of a second series which will test the applicability of this technique to plutonium fires and which will develop more detailed operating information and permit more precise measurement of test parameters - oxygen depletion rates and equilibrium concentrations, temperature effects, and nitrogen pressures, flow rates, spray methods and patterns, etc. The test series was directed specifically toward extinguishment of metal fires occurring in well-confined areas and was not intended to be representative of any larger classification.

TEST PROCEDURE

Fires of several types were constructed -- magnesium, mixed magnesium and zirconium, sodium and cerium. Generally, pairs of similar arrangements were constructed. One arrangement of each type was ignited and allowed to burn to completion without the application of any extinguishing agent. After the second fire was well established, the liquid nitrogen spray system was activated. Burning times were measured and atmospheric temperature and oxygen concentration were measured during the liquid nitrogen application. Time lapse motion pictures were taken of one fire couple to further document its extinguishment and permit detailed comparison. For the sodium fires and some of the magnesium fires, no control tests were considered necessary.

TEST FACILITY DESCRIPTION

Test Cell. The room in which the tests were conducted was 27 x 18 x 14 feet (L,W,H). The floor and ceiling were reinforced concrete. Two walls were brick and the other two were metal (steel and

aluminum). Laminated safety glass windows were provided in one of these metal walls for direct observation of room conditions during the fires. Doors, windows and other openings were sealed during the fires.

Nitrogen Supply System. Liquid nitrogen was stored in a 600 gallon dewar equipped with an evaporator and a pressure regulation system which maintained tank pressure at 40 psi. This vapor pressure served to deliver the liquid nitrogen through a 50 foot insulated, one inch diameter line to 6 spray heads located on a 9 foot grid approximately 12 feet above the floor of the test cell. Except for line size and nozzle type, this system closely resembled water spray extinguishing systems. The nozzles used were Spraying Systems Company Model 1/2HI135WSQ which provided a square spray pattern. A single manual cryogenic valve in the supply line was used to control flow. The flow rate was held constant throughout the series at approximately 600 SCF/M. This rate was determined by measuring the decrease in total dewar weight over an extended period. Due to the relatively long and initially relatively warm delivery lines, during the first 1-1/2 minutes of each test only nitrogen vapor reached the spray heads. Thereafter, however, liquid was sprayed directly into the cell.

Cell Ventilation. During the test, approximately 600 SCF/M of cell atmosphere was withdrawn; no make-up air was provided. All room openings were sealed prior to the test to prevent any inleakage of air and the actual exhaust rate was adjusted to provide a very slight positive pressure (approximately 1 mm. of water) within the room during nitrogen admission. The exhaust system inlet was near the cell ceiling above the level of the spray system. Although prefilters and HEPA filters already existed in the ventilation system, an auxiliary blower and filter system - exhausting into the primary system - was used to collect smoke from immediately above some of the fires as an attempt to improve the visibility during the test.

Instrumentation. The installed instrumentation for this test series was limited. Thermocouples and a multipoint recorder were provided to measure the temperature of the room atmosphere at locations 1, 3, 5, 7,

9 and 11 feet above the floor. A valved tubing system permitted collection of gas samples at each of these same locations. An in-line oxygen analyzer permitted direct observation of the oxygen concentration of any single sampling station. A secondary oxygen analysis system had its single detector located at the 5 foot level. The primary oxygen sample system included the ability to withdraw atmospheric samples for off-line analysis. The cell windows permitted direct observation of all fires and time-lapse photography of one pair of fires.

RESULTS

Temperature and Oxygen Depletion Effects. Figures 1 and 2 present data on the oxygen data concentration and temperature of the cell atmosphere during the period of liquid nitrogen flow. The temperature information in Figure 2 is representative of a rather small fire. Heat produced by a larger fire (approximately 3 pounds of magnesium) raises the initial points of this curve but after about 4 minutes, temperatures approximate those shown in Figure 2. The oxygen depletion measurements indicate no significant difference between the several sampling stations. This tends to indicate that oxygen depletion takes place by a mixing/diffusion rather than a stratification process; however, measured depletion rates are higher than would be expected without some contribution from stratification. Direct observation of the cold vapor indicates that thorough mixing is achieved. Concern for adverse effects for exposed concrete, brick, paint and other surfaces to liquid nitrogen was unfounded; none were observed. No liquid was observed beyond 3 to 4 feet from the nozzles.

Magnesium - Zirconium Fires. Fires composed of magnesium and zirconium turnings and magnesium punchings (approximately 20% zirconium) on a sand bed are extinguished by the described liquid nitrogen system in about 12 minutes. * For magnesium-zirconium fires, time was measured to the absence of any well-defined flame and a decrease in the observed color to a dull red. Atmospheric oxygen concentration at extinguishment was

* Determination of all extinguishment times involves a measure of subjectiveness; times determined by several observers occasionally differed by 2 minutes or more.

~ 7.5%. A similar control fire burned for 72 minutes in the absence of any extinguishing media. Magnesium fires exhibited about the same characteristics as the magnesium-zirconium fires and similar extinguishment times (same criteria) were measured. Larger fires involving 2 pounds and 3 pounds of mixed magnesium turnings, punchings, flakes and plates were tested. The 2 pound fire was extinguished in 14 minutes (~ 7% O₂) with unconsumed metal remaining. The 3 pound fire was ignited in a manner which resulted in a higher reaction rate than any of the other fires. Although no flames were evident after 14 minutes (~ 6% O₂) the fire bed continued to glow bright red for approximately 10 additional minutes. No unconsumed metal was found after this fire. No controls were run for these larger fires. The initial addition of liquid nitrogen caused the magnesium and possibly the magnesium-zirconium fires to exhibit more rapid burning rates for a period of up to 3 minutes. This was attributed to turbulence effects which provided increased oxygen availability in the combustion area. No re-ignition of any of these fires occurred after suspension of the liquid nitrogen supply.

Sodium. Approximately 3/4 pound of sodium was ignited in a graphite crucible by heating externally until all the sodium was molten and ignition occurred. Burning time was measured from the application of the liquid nitrogen to the point where no red glow was present and agitation of the ashes and molten metal produced only occasional sparks. This occurred at 20 minutes (~ 4% O₂). The liquid nitrogen flow was then stopped. Re-ignition occurred 8 minutes later with continued operation of the external heat source and at 12 minutes without the heat source. Re-extinguishment by further nitrogen application was achieved in approximately 13 minutes (~ 4% O₂). An observable increase in reaction rate was noted during the early stage of liquid nitrogen introduction.

Cerium. Cerium was selected as a test material because of the similarity of its burning characteristics - relatively slow reaction and propagation rates - to those of plutonium. Only a limited amount of material - two, 3 ounce plates - was available for these tests. The time from liquid nitrogen application to the point of complete absence of any visible redness was 15 minutes (~ 7% O₂). In a control test, the other plate burned in

excess of 40 minutes. No re-ignition occurred even with rapid re-establishment of near normal oxygen concentrations. No increased reaction rate was noted during the early stage of nitrogen addition.

CONCLUSIONS AND COMMENTS

Liquid nitrogen fire extinguishing systems may, under certain conditions, offer an effective alternate to conventional metal fire extinguishing media. These conditions are:

1. That the area is relatively air-tight,
2. That this containment will not be violated during the early phase of the fire prior to the nitrogen application and,
3. That compatible ventilation systems are provided.

These conditions generally exist (or are coming into existence) in storage vaults for plutonium. For such vault protection service additional benefits from the use of liquid nitrogen would accrue:

1. No immediate vault entry for fire fighting would be necessary. Security and nuclear material safeguards standards would not be compromised.
2. Containment control problems would be reduced substantially. Delayed entry would permit application of appropriate protective systems - isolation rooms, protective clothing, clothing change and survey, etc. - to prevent the spread of contamination beyond the vault area; decontamination costs would therefore be reduced. The fire extinguishing media itself would not add to the cleanup burden and cost.
3. The interaction between criticality control procedures and fire-fighting techniques would become more straight forward. No moderating material would be added as extinguishing media. No dislocation of stored items would result from the extinguishment process.

While the present test has served to demonstrate that the use of liquid nitrogen for combatting metal fires has merit under certain conditions, further work is necessary before this system can be applied to nuclear materials storage vaults. This work includes the determination of:

1. The effectiveness of liquid nitrogen for extinguishing plutonium and uranium fires,
2. The relative functioning of the two extinguishing mechanisms - cooling and oxygen depletion,
3. The actual oxygen depletion mechanism - mixing, diffusion, or stratification,
4. Optimal or acceptable delivery systems parameters - spray patterns, pressures, flow rates, etc., and
5. Operational and safety factors - manually-operated valving, automatic valving, failsafe requirements, personnel hazards, etc.

FIGURE 1

FIGURE 2

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