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HEALTH PHYSICS AND SAFETY DIVISION
Informal Report

FINAL REPORT
FIRE TESTS OF HALON 1301 EXTINGUISHING SYSTEMS
FOR USE IN INSTRUMENT TRAILERS

John B. Deitz
March 13, 1973

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ABSTRACT

A series of six fire tests was conducted of a prototype Halon 1301 fire extinguishing system for use in Brookhaven National Laboratory instrument trailers. Test fires included methyl alcohol, kerosene, a wood crib, and electrical equipment. The test trailer volume was 3200 cubic feet. Of primary interest was the effectiveness of the system in limiting fire loss potentials, and the levels of Halon 1301 decomposition products (primarily HF) produced by the various test fires. As a result of the tests, the prototype system was judged effective as a fire extinguishing system. Halon 1301 concentrations were about 8%. Using a 12-second discharge time, on a 4 sq. ft. methyl alcohol fire, a peak concentration of approximately 550 ppm HF was produced. When the discharge time was reduced to 8 seconds, with the same methyl alcohol fire, the peak HF concentration was approximately 350 ppm. The kerosene and electrical fires produced HF concentrations of less than 10 ppm. A peak of approximately 40 ppm was produced from the wood crib fire. When a risk-benefit analysis was conducted, the recorded levels of Halon 1301 decomposition were not considered a serious personnel hazard for most BNL trailer installations.

[†]A preliminary report, BNL 16942, was issued June 16, 1972 describing the first two of the series of tests. The preliminary report contains some inaccurate data, which has been revised in this final report. (1)

SUMMARY

During the Spring and Summer of 1972, a series of six fire tests was conducted on a prototype Halon 1301 fire extinguishing system installed in an instrument trailer at Brookhaven National Laboratory. The tested system was the first installed system of approximately fifty systems that are being provided for high value instrument trailers and portable houses at the Laboratory.

Originally, only one test had been planned. The principal objective of this test was to confirm that the system design specifications were met, and to demonstrate system operation to BNL personnel. For this first test, a methyl alcohol fire was set and allowed to be extinguished by the Halon 1301 system in a normal automatic manner, that is, the system was allowed to function as it would if an unfriendly fire had actually occurred in the trailer. The Halon 1301 system functioned as intended, promptly extinguished the fire, and appeared to satisfactorily meet the system design specifications, including compliance with the current applicable fire protection standards.

However, observers experienced what were felt to be unexpectedly high concentrations of Halon 1301 decomposition products, concentrations which might be hazardous to personnel. Because of this disturbing side effect, an additional series of five tests (numbered 2 through 6 in this report) was conducted. The principal purpose of these tests was to investigate further the levels of Halon 1301 decomposition that could occur from a fire in a trailer, and to evaluate whether the levels of decomposition were indeed hazardous to personnel.

Test 2 duplicated as closely as possible the conditions of the first methyl alcohol test fire, except that air samples were collected.

Test 3 also duplicated as closely as possible the methyl alcohol fires of the previous two tests, but the Halon 1301 discharge time was reduced by approximately a factor of 2, since there was strong evidence in the literature to suggest that decreasing the discharge time would significantly reduce the amount of decomposition.*

In Test 4 kerosene was used for the test fire instead of methyl alcohol, in order to observe the decomposition levels from a greatly different type of flammable liquid fire.

*The first editions of the National Fire Protection Association Standards on Halon 1301 Systems specified a discharge time of 30 seconds or less⁽²⁾. Apparently in recognition that decomposition could be reduced by reducing the discharge time, the standard was changed in 1971 to 10 seconds or less⁽³⁾.

For Tests 5 and 6 a wood crib and a simulated electrical fire, respectively, were used, in order to observe the decomposition levels from more typically to be expected trailer fires involving ordinary combustibles and electrical equipment.

The only tests that produced high concentrations of Halon 1301 decomposition products (as evidenced by the concentration of hydrogen fluoride in the air) were the two methyl alcohol fires, although when the agent discharge time was reduced from 12 seconds to 8 seconds (Tests 2 and 3, respectively) the HF concentration levels appear to have been reduced by at least 18% (peaks of about 550 ppm and 350 ppm HF, respectively, were observed). With the kerosene and simulated electrical fires, HF concentration levels were less than 10 ppm. With the wood crib fire, a peak HF concentration of about 40 ppm was observed.

After evaluating the risks to personnel and the benefits gained in the context of the specific trailer/Halon 1301 system arrangement, it was concluded that hazards to personnel from potential decomposition products were not serious.

HALON 1301 SYSTEM DESIGN

Background

Trailer and trailer-type structures have long been used at Brookhaven National Laboratory experimental facilities. In the past, dollar values and mission interruption potentials concentrated in a trailer were relatively small, and the number of trailers located within buildings was limited. In recent years, however, due to the changing needs of experimenters and increased sophistication of equipment, equipment values within an individual trailer have often increased to levels of several hundred thousand dollars, and a trailer or a trailer complex may control experiments that have taken months to set up, with total investments ranging as high as several million dollars.

As a result, an area of priority fire safety interest at the Laboratory for a number of years has been improved fire protection for trailers. One area of attack has been in the area of trailer design specifications, which have greatly improved the fire safety of the trailer as a structure. Parallel with improved design (which is effective primarily on new trailer purchases) has been the extensive installation of automatic extinguishing systems and improved early warning fire detection services.

Automatic extinguishing systems are being installed in all BNL trailers according to a priority schedule. The first priority includes all trailers or similar portable structures within BNL buildings containing high value equipment (> \$100,000), or containing highly flammable materials such as flammable liquids, gases, etc. The second priority includes all other trailers or similar portable structures within BNL buildings where the presence of the trailer presents significant exposure hazards to the building. The third priority is all trailers or similar temporary structures outside of buildings which contain BNL high value equipment (greater than \$100,000), or which contain highly flammable material which seriously exposes a BNL structure (generally within 20 feet). The fourth priority includes all other combustible trailers or temporary structures which provide moderate or severe exposure hazards to BNL structures. At the present time, nearly all trailers in priorities one and two have been equipped with automatic extinguishing systems, and substantial inroads have been made into priority groups 3 and 4.

Two types of automatic extinguishing systems are being used in trailers -- automatic sprinkler systems and Halon 1301 systems. Automatic sprinkler systems have been installed in locations where an ample water supply is available, where the trailer is not expected to be relocated for a substantial period of time, and where the costs of installation are less than the Halon 1301 system. These locations have all been trailer complexes, involving four or more adjoining trailers. Eighteen trailers have been equipped with sprinkler systems, with an additional seven scheduled.

However, by far the greater majority of trailers are being equipped with Halon 1301 systems. Halon 1301 systems were selected because of a number of advantages:

1. The adaptability of Halon 1301 as an automatic extinguishing system for trailer type structures^(4,5).
2. The ease of installation and flexibility of the systems, enabling their application to a wide variety of trailer sizes and occupancies with minimal interruption to occupants.
3. Their small space requirement, enabling their installation even in trailers with space limitations.
4. The mobility of the system. When a trailer is moved, there needs to be only minimal interruption of fire protection, as the system

can operate for greater than 24 hours off battery power. The only utility connections required are electrical power and fire alarm.

5. The low toxicity of the undecomposed Halon 1301, vitally important in the case of accidental discharges.
6. The full supervision and reliability that could be obtained with the system as compared to the cost of obtaining corresponding levels of supervision and reliability with other systems.

Other types of automatic extinguishing systems were considered. Automatic sprinkler systems were ruled out for most applications primarily because of the difficulties and costs involved in maintaining an adequate and reliable water supply to trailers in exterior locations, and the recurring costs whenever trailers are relocated. Secondary negative factors with respect to sprinkler systems were the somewhat greater potentials for cleanup costs and downtime.

High expansion foam systems were considered but were ruled out, again primarily because of the difficulties and cost of a reliable water supply in exterior locations and potential maintenance problems. Of secondary negative importance was the limited experience with high expansion foam systems for electronic equipment, and the potentials for greater downtime and cleanup costs.

Carbon dioxide total flooding systems were ruled out primarily because of the risks to personnel. While CO₂ itself is generally considered nontoxic, in the concentrations used as a fire extinguishment (at least 40%), it acts as a simple asphyxiant. A secondary negative factor was the greater space requirements for a CO₂ system.

Design

Because of the large number of trailers to be equipped with Halon 1301 fire extinguishing systems, and the presence of many variables such as trailer size, configuration, and occupancy, flexibility and ease of installation were basic design requirements. As a result, a modular arrangement was decided upon, with the principal variables between systems being the quantity of Halon 1301 being provided. Five system sizes were decided upon, covering the range of trailer sizes at BNL with the provision that the nominal Halon 1301 concentration in the trailer be not less than 6% nor more than 8%. These systems were as follows:

TABLE I. BNL Halon 1301 Trailer Systems

<u>System No.</u>	<u>Min. Vol. Trailer c.f.</u>	<u>Max. Vol. Trailer c.f.</u>	<u>Halon 1301 Req. lbs.</u>	<u>Theoretical Conc. @ Min. Vol.*</u>	<u>Theoretical Conc. @ Max. Vol.*</u>
1	880	1200	30	8.0%	6.8%
2	2060**	2800	70	8.0%	6.8%
3	2801	3600	90	8.9%	6.8%
4	3601	4200	105	8.0%	6.8%
5	4201	5000	125	8.0%	6.8%

* at 70°F (from NFPA 12A, ¶2520)

** a survey revealed no trailers in range 1201 c.f. to 2060 c.f.

The specifications also called for the Halon 1301 systems to conform to the provisions of National Fire Protection Association Standard No. 12A, "Standard on Halogenated Fire Extinguishing Agent Systems--Halon 1301", latest edition. Specific reference was made to ¶2621, which calls for the agent discharge to be "substantially completed in a nominal 10 seconds or a shorter time if practicable"⁽⁶⁾.

Other design features of the Halon 1301 system included:

1. Two levels of automatic detection -- a Fire Alert FT200 products-of-combustion detector arranged to give only an alarm (sound local bells and call the BNL Fire Department) but not discharge the Halon 1201 system; and two or more Fenwal 140°F Detect-A-Fire rate-compensated heat sensors, each arranged to discharge the Halon 1301.
2. An exterior manual station for manual activation of system.
3. Complete supervision of the electrical systems.
4. Backup battery power (24+ hours capacity).
5. Interlocks to kill fresh air intake and noninstrument power.
6. An interface panel to tie in to the BNL fire protective signaling system.

Test Trailer System

The test trailer had a volume of 3200 c.f. (see Fig. 1 for trailer dimensions). For this volume, System 3 (90 lbs. Halon 1301) was installed. The theoretical Halon 1301 concentration was therefore 7.7%. The trailer was closed, with almost no ventilation to the outside.

Figures 2 and 3 show control panel, cylinder and piping arrangement for the test trailer which, except for minor variations in placement, is typical for all trailers.

TEST 1 - METHYL ALCOHOL

The first test was conducted to confirm that the system functioned as intended and satisfactorily met the design specifications, including compliance with the NFPA Standard 12A requirements for Halon 1301 systems.

The primary objective of this test was to simulate, as closely as possible, a reasonable fire situation -- with observations noting speed of detector operation, rate of Halon 1301 discharge, concentration distribution of Halon 1301 in the trailer, and speed of fire extinguishment. Because of the past performance of Halon 1301 systems recorded both in the literature and from limited tests conducted by BNL, Halon 1301 decomposition was not expected to be significant, and therefore no air analysis was to be conducted.

The Fire

Within the trailer, a 2' x 2' metal pan containing one pint of methyl alcohol and several balls of tightly wadded newspaper was ignited as a test fire. The pan was located at one end of the trailer (see Fig. 1 for pan, detectors and discharge nozzle locations). Methyl alcohol was selected because it is clean burning, i.e., not soot-producing. The wadded paper was included to give a three-dimensional effect to the fire, to include some Class A combustible materials, and to simulate a fire situation more closely related to an actual flammable liquid spill fire in a trailer.

At approximately 20 seconds after ignition, the nearest 140°F temperature sensor, located approximately 4 feet horizontally from the center of the pan at ceiling, initiated discharge of the Halon 1301. While there was conflicting testimony from observers, some thought that the fire continued to burn for a short period of time after the completion of discharge; because of the poor visibility in the trailer due to a large amount of fogging, the actual time of extinguishment was not confidently determined. Figure 4 shows the pan contents after the fire. There was no "deep-seated" burning of the paper, only surface charring. Some methyl alcohol liquid remained in the pan after the fire was extinguished, estimated to be 1/4 to 1/2 pint*.

* After all the flammable liquid fires, the pan and charring appeared substantially the same.

Halon 1301 Discharge

The Halon 1301 discharge was completed in about 12 seconds. While the discharge time was greater than 10 seconds, consultation with the NFPA fire extinguishing systems specialist indicated that 12 seconds is within the limits of a "nominal 10 seconds".

At the time of the test there were four observers in the trailer standing near an exit door -- one from the system supplier, one from the AEC, one from the Health Physics and Safety Division, and one from a BNL operating group. Immediately after discharge, the observers within the trailer experienced a strong acrid odor, later thought to be hydrogen fluoride and hydrogen bromide. They immediately exited the trailer and were exposed to the fumes for less than one minute. While there was some irritation of the respiratory tract which continued for several hours after the incident, none suffered any lasting ill effects, nor required specific medical attention.

When the system discharged, visibility was substantially impaired. The relative humidity at the time of the test was approximately 92%, accounting for the high fogging on system discharge; the high relative humidity would not normally exist in an air-conditioned occupied trailer. The fog remained in the trailer for several minutes, and did not dissipate until after the doors of the trailer were left opened for several minutes, at which time the fog "rolled" out across the ground.

Halon 1301 Concentration

A maximum concentration of 8% Halon 1301 was measured, close to the 7.7% theoretical concentration calculated. A Gow-Mac 1301 analyzer was used, designed and calibrated for Halon 1301 in air. Other contaminants, such as HF and HBr , interfere with the accuracy of the instrument; however, consultation with the Gow-Mac engineers indicate that this interference would be small at the levels of contaminants up to several thousand parts per million.

Review of Test 1

In reviewing this first test, it was theorized that the hot methyl alcohol flame, the relatively large flame envelope in relation to the relatively small volume of the trailer, and the discharge time of the system, combined to create much higher than expected levels of decomposition. Although the system extinguished the fire, a number of disturbing questions on the side effects were raised, and a decision was made to conduct further, more fully documented tests.

In order not to delay the Halon 1301 system installations in other trailers, a decision was also made to increase the size of the discharge pipe and the nozzle orifice in these other trailers to achieve a more rapid discharge time (calculated at 6-7 seconds), since there was strong evidence in the literature to suggest that decreasing the discharge time would significantly reduce the decomposition levels.

TEST 2 - METHYL ALCOHOL

The second test was intended to duplicate as closely as possible the first test, but with much greater documentation, especially with respect to the levels of HF and HBr produced.

The Fire

The fire was as closely identical to the fire of Test 1 as possible, consisting of a 2' x 2' metal pan containing one pint of methyl alcohol and several wads of tightly wadded newspaper, positioned as in Test 1. When ignited, the fire flashed immediately, and appeared characteristic of the first test fire. Flames were observed to rise 3 to 4 feet above the pan surface, and fill the entire pan at the base. Two chromel-alumel thermocouples, positioned 2 feet and 3 feet above the pan surface*, recorded a temperature rise to approximately 620°C and 270°C, respectively, in approximately 7 seconds. The lower thermocouple recorded a maximum temperature of approximately 670°C at 16 seconds, the time of Halon 1301 discharge. The thermocouples then recorded a rapid temperature drop to approximately 300°C (lower) and 50°C (upper) in 2 seconds. A small flame in one corner of the pan was visually observed for approximately 25 seconds after the discharge was completed, and a fluctuating pattern was recorded on the thermocouples for the same period. Figure 5 represents graphically the fire history.

Air Samples

Both BNL and the E.I. DuPont de Nemours took air samples during this test for analysis.

The DuPont samples were taken through a copper tube into evacuated Teflon sample bottles located exterior to the trailer, containing a small quantity of

* The thermocouple temperatures should not be interpreted as an indication of flame temperature; but only for comparison purposes with respect to fire development. A third thermocouple, of a heavier type, proved to be too slow in response to be of use for comparison purposes; even though located closer to the pan than the other two thermocouples.

ion-free water. The end of the tube was positioned approximately 18 feet from the fire pan, and approximately 4 feet off the floor. The samples were analyzed by DuPont.

The BNL samples were taken by uncorking wax-coated evacuated glass bottles containing a small quantity of NaOH water solution in an area 17 to 20 feet from the fire, 3 to 4 feet from the floor. Personnel with personal protective equipment were used for this operation. The samples were analyzed by the Analytical Chemistry Group, BNL Chemistry Department by the Zirconium Quercetin method*.

Concentration of HF and HBr

Analysis of the decomposition products, HF and HBr, is shown in Tables II, III and IV, and is shown graphically in Figure 5. A maximum concentration of 590 ppm HF was recorded at 71 seconds, which decreased to about 170 ppm at 533 seconds after discharge.

TEST 3 - METHYL ALCOHOL

The third test duplicated as closely as possible the fires of Tests 1 and 2, changing only the rate of Halon 1301 discharge.

Piping and Nozzle Changes

The discharge piping was increased in size to 1-1/2" nominal, and the nozzle increased to 7/8" nominal orifice diameter. This configuration was being used in the other trailers where installation of the Halon 1301 systems was continuing. Calculations had indicated that this configuration should reduce the discharge time by approximately one-half to between 6 and 7 seconds.

*Following the distribution of the June 16, 1972 preliminary report (BNL Informal Report No. 16942)⁽¹⁾, a factor of 2 mathematical error was noted in the calculations of HF concentration using the Zirconium Quercetin method, resulting in corrected HF concentration by the Z-Q method greatly in disagreement with both BNL and DuPont concentration analyses made using fluoride electrode method. Since the Test 2 samples were no longer available, the samples could not be reanalyzed. When the Test 3 samples were analyzed, it was observed that the fluoride electrode initially gave a high reading which, when observed for a short period of time, appeared to be stable. However, if the electrode were allowed to remain immersed in the sample solution for one hour or longer, the initial reading slowly declined to a stable reading in substantial agreement with the Z-Q method. It was therefore concluded that the Test 2 fluoride electrode readings were in error. The Z-Q method was used in the subsequent analyses because of the shorter time required for analysis.

The Fire

The fire remained as closely identical to the fires of Tests 1 and 2 as possible, consisting of the same 2' x 2' metal pan containing one pint of methyl alcohol and several balls of tightly wadded newspaper; the pan was positioned as in Tests 1 and 2.

The fire flashed immediately and appeared characteristic of the first two test fires; the flame height was again 3 feet to 4 feet above the pan surface, and filled the entire pan at the base. The two thermocouples positioned (as with Test 2) 2 feet and 3 feet above the pan surface, recorded a temperature rise to approximately 790°C and 670°C, respectively, in 4 to 5 seconds. The lower thermocouple recorded a maximum temperature of 840°C at 12 seconds after ignition, the time of the Halon 1301 discharge. Both the rate of fire development and the maximum thermocouple temperatures were somewhat higher than Test 2. The thermocouples then recorded a rapid temperature drop to approximately 350°C (lower) and 200°C (upper) at 2 seconds after the beginning of discharge. While observers did not notice any continued flaming after the completion of the discharge, the thermocouples recorded a fluctuating pattern similar to Test 2 (including a slight increase in temperature at 10 seconds after the end of the discharge), indicative of possible unobserved continued flaming for approximately 23 seconds after the Halon 1301 discharge was completed. Figure 6 shows graphically the fire history.

Halon 1301 Discharge

The discharge was complete in 8 seconds. As with Tests 1 and 2, there was air turbulence in the room sufficient to disturb papers and other loose light objects, but not significantly more than was observed during the slower discharge of Test 2. There was a slight fogging on discharge but this was not sufficient to impair visibility in the trailer.

A maximum Halon 1301 concentration of 7.8% was recorded on the Gow-Mac, which decreased slowly to approximately 6% at 5 minutes after completion of discharge, and 5% at 8 minutes -- similar to the observed results of the other tests.

Air Samples

Air samples were collected in evacuated 1 liter polypropylene flasks containing a small quantity of NaOH water solution, by means of a stainless steel

tube extending into the trailer. The end of the tube was positioned approximately 16 feet from the fire pan, and approximately 4 feet above the floor. The samples were analyzed for HF only by the Analytical Chemistry Group, BNL Chemistry Department, by the Zirconium Quercetin method, although 3 samples were also analyzed by a fluoride electrode to crosscheck the results, with substantially the same results*.

The analysis is as shown in Table II, and represented graphically by Figure 6.

TEST 4 - KEROSENE

For the fourth test, the Halon 1301 system piping and nozzle configuration of Test 3 remained unchanged, but the fire fuel was changed from methyl alcohol to kerosene.

Fuel Change

In an attempt to see the effect of a different fuel on the amount of Halon 1301 decomposition, 1 pint of Laboratory grade kerosene was substituted for methyl alcohol in the test fire. Kerosene was selected because it is a pure hydrocarbon with different burning characteristics from methyl alcohol. The kerosene was placed in the same 2' x 2' metal pan, along with several wads of newspaper. The pan was positioned as in previous tests.

Halon 1301 System

There was no change in the Halon 1301 system configuration from Test 3.

The Fire

As expected, the fire developed somewhat slower than the methyl alcohol fires of the previous tests, there being no instant flash-over. The two thermocouples, positioned (as in Tests 2 and 3) 2 ft. and 3 ft. above the pan surface, recorded a temperature rise to approximately 970°C and 720°C at 18 seconds after ignition, with both thermocouples recording a temperature of about 1100°C at discharge of the Halon system, 21 seconds after ignition. The thermocouples then recorded a rapid smooth drop in the temperature to approximately 650°C (lower) and 280°C (upper) in two seconds, and 280°C (lower) and 80°C (upper) in 5 seconds. There was no evidence of continued burning, either from the thermocouple readings, or by the observers. Figure 7 shows graphically the fire history.

*See footnote, page 9

Halon 1301 Discharge

The discharge was complete in 7 seconds. Other observed discharge effects were as with Test 3. The Halon 1301 concentration was again about 8% maximum, dropping to approximately 6% at 5 minutes.

Air Samples

Air samples were collected and analyzed as in Test 3. All twelve samples taken at times from 15 seconds to 6 minutes after discharge showed no HF concentrations in excess of 10 ppm, the lower limit of confident HF concentration from the analysis method used.

TEST 5 - WOOD CRIB

For the fifth test, the Halon 1301 system was unchanged from Tests 3 and 4; the fire fuel consisted of a wood crib.

The Wood Crib

The wood crib consisted of 50 pieces of 1-1/2" x 3/4" x 12" long seasoned white pine, laid 5 to a tier, 10 tiers high. Crib overall dimensions were 12" x 12" x 15-1/2" high. The crib was placed on steel channel supports so that it was 4" off the base of the 2' x 2' pan. A 4" diameter cup, containing a few milliliters of methyl alcohol, was positioned in the bottom center beneath the crib and ignited (the quantity of methyl alcohol was determined so that it would burn out in 1.5 to 2 minutes, and therefore did not interact with the Halon 1301 discharge).

The Fire

The fire, as expected, developed very slowly in comparison with the flammable liquid fires of the previous tests. A thermocouple located approximately 6" above the top of the crib recorded a temperature rise to approximately 430°C in approximately 90 seconds, a decline to approximately 320°C at approximately 105 seconds, and then a rise to a plateau of approximately 850°C at 135 seconds until the Halon 1301 discharge at 151 seconds after ignition. The thermocouple then recorded a rapid smooth drop to 380°C at 2 seconds and 270°C at 5 seconds after discharge. Active flaming appeared to stop about 4 seconds after Halon discharge was initiated. Some slight smoldering continued for about a minute after discharge, and then ceased. Examination of the wood after the fire indicated substantial involvement of all the pieces in the fire, although there

was no deep charring, the maximum being about 1/8" near the bottom of the crib. Figure 8 shows graphically the fire history.

Halon 1301 Discharge

The Halon 1301 system discharged at 151 seconds after ignition. The discharge was complete in 7 seconds. Other discharge effects were substantially as observed in Tests 2 and 3. The discharge did not affect the integrity of the wood crib. The Halon 1301 concentration was again approximately 8%, dropping to approximately 4% at 5 minutes.

Air Samples

Air samples were collected and analyzed as in Tests 3 and 4. The analysis is as shown in Table II. The maximum concentration was 39 ppm HF, recorded in a sample taken 60 seconds after discharge.

TEST 6 - SIMULATED ELECTRICAL

For the sixth test, the nozzle was increased in size to 1-1/2" orifice diameter and a simulated electrical fire was used.

The Fuel and Fire

A 12" diameter, 2' high plywood drum, open on both ends, was filled with a wide variety of electrical components such as wiring, circuit boards, resistors, etc. in a random fashion, simulating a piece of experimental electrical equipment. The cylinder was placed 4 inches off the floor of the pan and ignited as in Test 5. The fire, as expected, developed very slowly; however, soon after ignition large quantities of thick black smoke issued from the cylinder, and the trailer would have quickly become untenable by personnel (estimate about 1 - 1.5 minutes). The two thermocouples, one located at the top of the cylinder, the other about 8 inches above the cylinder, had only recorded a temperature of 100°C at 2 minutes, 30 seconds after ignition, although the trailer was well charged with smoke and visibility was greatly impaired at this point. At about 2.5 minutes, balls of flame were issuing out of the top of the cylinder and climbing the smoke column like a ladder at intervals of about every 5-10 seconds. At 3 minutes, the flames issuing from the cylinder became more constant. At about 3 minutes, 10 seconds, the thermocouples recorded a temperature of 200°C. At 3 minutes, 20 seconds, the lower thermocouple recorded a temperature of about 380°C, while the upper remained constant at about 200°C. A sudden increase

in the temperatures recorded by both thermocouples then brought the temperature to a maximum of 600°C (lower) and 270°C (upper) at 3 minutes, 22 seconds, when the Halon 1301 system discharged. At the time of discharge, the trailer was so heavily charged with smoke that exterior observers on one side of the 10 foot wide trailer could see no evidence of light from windows on the other side; and the fire was only visible as a faint orange glow. The temperature as recorded by the thermocouples immediately dropped to 340°C (lower) and 80°C (upper) in 2 seconds and 300°C (lower) and 120°C (upper) in 5 seconds. Cooling was much slower with this fire, indicative of the greater heat capacity of the fire mass, and possible continued internal smoldering. There was, however, no visible evidence of continued flaming after the discharge although visibility made any significant observations impossible. Figure 9 shows graphically the fire history.

Examination of the material after the fire revealed that the major contributor to the fire was phenolic in the form of boards and tubes. It probably has the lowest ignition temperature of all the items present. Plastic (vinyl) and rubber covered wires in an amount of several pounds were charred to a considerable extent. The remaining material consisted of discrete electronic components, resistors, capacitors, transformers, connectors and coils which contributed very little to the fire.

Halon 1301 Discharge

The discharge was completed in 4 seconds. Because of the heavy charge of smoke at discharge, any turbulence effects of the more rapid discharge were not observed. There was no significant observed tendency for the Halon 1301 discharge to clear the smoke from the atmosphere. The Halon 1301 concentration was again about 8%, and dropped to approximately 4% in 5 minutes.

Air Samples

Air samples were collected and analyzed as in previous Tests 3-5. All samples, taken from 15 seconds to 6 minutes after discharge, analyzed at less than 10 ppm HF. See Table II.

EFFECTIVENESS OF THE TRAILER HALON 1301 SYSTEM AS A FIRE EXTINGUISHING SYSTEM

From the results of the tests, we conclude that the Halon 1301 system as installed in the BNL trailers is an effective fire extinguishing system which reasonably can be expected to extinguish a fire and to limit damage to equipment

and trailer to within acceptable levels under most normal circumstances. In all cases, system response as measured by observed fire size, was sufficiently fast to prevent generalized fire damage, although there is little doubt significant localized fire damage could occur, particularly with respect to electrical and electronic equipment.

Where there is compact equipment of unusually high localized value, supplemental local fire detection, such as the placement of a discharge initiating fire detector within the equipment, may be desirable. Such supplement detection would appear to be highly desirable whenever the monetary loss from a fire prior to expected extinguishing system operation might exceed \$100,000. Other situations where this supplemental detection might be required are equipment having long replacement times, the loss of which would have severe mission interruption potentials; and equipment vital to safety systems.

EFFECT OF FASTER HALON 1301 DISCHARGE TIMES

One particular interest in these series of tests was the difference in HF concentration between Tests 2 and 3, where the Halon 1301 discharge time was decreased by approximately a factor of 2.

It seemed obvious in looking at the HF concentration data from Tests 2 and 3 that the concentrations were different, i.e., that Test 3, with the 8 second discharge time, had lower concentrations of HF than Test 2, with a discharge time of 12 seconds. However, to confirm that the apparent difference was not likely to be by chance, a statistical comparison of the data was performed.

The data was first normalized to the same time = 0 at the approximate maximum HF concentration for each test. Then, for each set of data, curves were fitted using the least squares method of the form.

$$C = Ae^{-Bt}$$

where C = HF concentration (ppm), t = time (secs.) after maximum HF concentration, A and B are constants.* For Test 2, A = 562. and B = .00248; while for Test 3, A = 351. and B = .0163. These resultant curves are plotted in Figures 5 and 6 (with t corrected to the time scale of the graph).

*The data of Test 2 was also fitted to a third order polynomial. Over the range of data, the more general polynomial curve closely agreed with the exponential form.

Using these curves, and assuming that the curve reasonably represented the HF concentration decay relationship, the sample data was further normalized to a common time, $t = 0$. That is, a grouping of data points, X_n , for each test was developed from the relationship:

$$C_n = X_n e^{-Bt_n}$$
$$X_n = C_n / e^{-Bt_n}$$

where C_n = recorded HF concentration at time t_n , and B = the calculated constant, for each test, obtained from the least squares exponential curve fit. X_n then represents the normalized C_n data points at $t = 0$, and can be thought of as a sample data grouping if all the samples were collected at the time of maximum HF concentration.

The two normalized data groups of X_n were then compared using an F test. At a confidence level of 99.5%, the null hypothesis that the data groups were the same was rejected. Further, at a confidence level of 90%, the null hypothesis that the difference in the X_n means of the two groups was less than 100 ppm was rejected.

It was therefore concluded, with near certainty, that the HF concentration of Test 3 was less than the HF concentration of Test 2; and further, it was concluded, with reasonable certainty that the reduction in HF concentration from Test 2 to Test 3 was at least 18%, and probably more.

It should be noted, however, that this analysis does not necessarily mean that reducing Halon 1301 discharge time reduces the quantity of decomposition products produced. Many tests at different discharge rates need to be conducted to be confident that this is so.

HALON 1301 DECOMPOSITION HAZARDS WITH RESPECT TO TRAILER HALON 1301 SYSTEMS

Toxicology of HF

The principal decomposition products of Halon 1301 are hydrogen bromide (HBr) and hydrogen fluoride (HF), with some free halogens (Br_2), and small amounts of carbonyl halides (COF_2 , $COBr_2$)⁽⁷⁾. The highest concentration of HF that can be tolerated by man for 1 minute is about 100 ppm. This causes a definite smarting of the skin, a definite sour taste, and some degree of conjunctival and respiratory irritation. In air containing 55 ppm, the taste is apparent and there is irritation of the eyes and nose, but no smarting of the skin. The concentration

of 30 ppm can be tolerated for several minutes, but the taste becomes evident after a short time, and there is mild smarting of the nose and eyes⁽⁸⁾. Some authorities consider concentrations of 50 to 250 ppm to be dangerous, even for brief exposures⁽⁹⁾.

High concentrations, in the range of 500 to 1000 ppm, produce extreme burning pain in the eyes and upper respiratory tract, and smarting of the skin. Coughing and gasping occur and breathing becomes difficult. Pulmonary edema (exudation of fluid into the lungs) may result from significantly long exposures as a result of HF being absorbed by moist surfaces in the respiratory tract⁽¹⁰⁾.

Information on the toxicology of HBr is less available. HBr irritation to the skin and nose becomes noticable at about 3 ppm⁽¹¹⁾, about the same threshold level as HF.

Both HF and HBr have the same Threshold Limit Value (TLV) of 3 ppm, as given by the American Conference of Governmental Industrial Hygienists. TLV values refer to airborne concentrations of substances, and represent conditions under which it is believed that nearly all workers can be exposed day after day without adverse effect. The permissible short-term excursion above the TLV for HF and HBr respectively, is approximately 6 ppm. For mixtures of toxic substances, the American Conference of Governmental Industrial Hygienists considers the effects to be additive, unless there is clear evidence to the contrary⁽¹²⁾.

The approximate lethal concentration values for 15-minute exposures to HF and HBr respectively, are 2500 ppm and 4750 ppm⁽¹³⁾. LC₅₀ values for rats receiving single short exposures range from 4970 ppm (5-minute exposure) to 1310 ppm (10-minute exposure)⁽¹⁴⁾.

ACTUAL HALON 1301 DECOMPOSITION EXPERIENCED IN TEST FIRES

A generalized model to predict Halon 1301 decomposition levels is not available. Although a number of fire tests have been conducted in which decomposition levels have been measured (primarily HF and HBr), the published data is generally not in sufficient detail to arrive at more than the most qualitative generalizations. HF concentrations of only a few parts per million to several hundred parts per million have been reported (excluding those tests where deliberately high Halon 1301 decomposition was encouraged)⁽¹⁵⁻²⁰⁾. Unfortunately, the published data often does not include such basic information as enclosure volume, fire size,

or materials burned. In other cases, time-average HF concentrations are reported, and not peak values, or the sample times are so far apart that peak values may have been missed, resulting in decomposition concentration values which may be biased to the low side; this may be accounted for in that many of the studies were designed for equipment corrosion evaluation, with lesser emphasis on hazards to personnel.

Since the BNL tests were not designed to evaluate Halon 1301 decomposition for a wide variety of system applications, care should be taken in making generalized conclusions from the results.

One of the primary objectives of the tests was to evaluate Halon 1301 decomposition from real fire situations extinguished by a specific prototype Halon 1301 system. No attempt was made to standardize preburn time, fire size at time of Halon 1301 discharge, rate of fire development, etc. Rather, the concern was with a fire which develops and is extinguished in a "normal" manner by a specific Halon 1301 system. The items that remained essentially the same in all the tests were the trailer volume, fire location, fire detector location and temperature setting, the discharge nozzle location, and, with the flammable liquids, the fire surface area. In this sense, the test results relate to a specific set of conditions and application.

Within this context, the following observations are made:

- While the HF levels produced by the methyl alcohol test fires were not as high as originally reported⁽¹⁾, personnel could have tolerated the HF concentration levels for only a few brief moments; rapid evacuation of the trailer would have been forced upon the occupants.
- The HF levels produced by the kerosene, the wood crib, and the simulated electrical fires were not high enough to produce significant threats to personnel.
- There is evidence to suggest that the amount of Halon 1301 decomposition varies depending upon the material involved in the fire.
- There is evidence to confirm that the relative decomposition of Halon 1301 from a fire can be reduced by decreasing the agent discharge time.

Hazards to Personnel

In analyzing the risk to personnel from potential Halon 1301 decomposition, the following factors are considered:

1. The most likely type of fire in a BNL experimental trailer is one involving ordinary combustibles or electrical equipment. There is strong evidence from tests by others and from BNL Tests 5 and 6, that the level of decomposition products from these fires, of a magnitude corresponding to the detection capabilities of the trailer systems, is not significant (16,19). In the case of fires involving electrical and electronic equipment, the trailer would have been uninhabitable from the fire products long before the Halon 1301 system would have discharged.
2. There is evidence that among flammable liquids, the level of Halon 1301 decomposition varies significantly with the material, and that the materials which are suspected of producing the highest decomposition, while certainly not atypical of materials found in trailers, likewise they are not among the most commonly found, nor are they usually regularly needed.

While little is known about differences in potential Halon 1301 decomposition from fires involving different flammable liquids, empirical data on the relative differences could be obtained from relatively simple tests, and administrative controls could be placed on the use of flammable liquids likely to produce high decomposition concentrations in a fire.

Until further information becomes available, however, materials which are suspected of producing high decomposition levels, such as short-chained alcohols, ketones, and aldehydes, should be used with special caution in locations equipped with Halon 1301 systems.

It should be noted that these flammable liquids rarely need to be used on a regular basis in personnel occupied locations equipped with Halon 1301 systems, and where used, they are primarily used as solvents. There are many less flammable solvents that can be substituted for their use.

3. For the more probable fire situations (i.e. fires involving ordinary combustibles or electrical equipment), it is unlikely that the Halon 1301 systems installed in BNL trailers will automatically discharge on the fire when the trailer is occupied by personnel, or at least it will not discharge on a fire without some prior warning to occupants.

The principal design consideration for the systems was the prevention of major damage to trailer contents, and prevention of an interior trailer fire developing to the point where exterior exposures are threatened. The system was designed anticipating a series of prior actions, with Halon 1301 discharge the final step when other actions had failed.

Because of the small area of a trailer, if personnel are in a trailer, they would reasonably be expected to detect a fire in the early stages, well before automatic Halon 1301 system discharge, and either extinguish the fire with portable fire extinguishers, or manually initiate Halon 1301 system discharge (in which case the fire would be of a smaller size than at automatic detection).

If the trailer was unoccupied by personnel, or if the fire continued to develop in an occupied trailer, the BNL Fire Department is automatically signalled by the products-of-combustion detector, with response to the trailer in 2 to 3 minutes. Only if these prior steps fail to control the fire will the Halon 1301 system automatically discharge.

4. Even if personnel are present in a trailer when a Halon 1301 system discharges, and decomposition occurs with concentrations to the levels of the tests, prompt personnel evacuation from trailers rarely poses a problem, and there is little reason why occupants cannot immediately and safely exit. In fact, a fire of sufficient magnitude to automatically initiate Halon 1301 system discharge probably poses as much, and often more of a threat to continued occupancy from its combustion by-products (especially carbon monoxide or hydrochloric acid) than a Halon 1301 discharge/decomposition.

The Halon 1301 decomposition products HF and HBr are readily detectable at concentrations well below levels that are considered dangerous. The vapor has such a sharp and penetrating odor that the inhalation of seriously toxic quantities is unlikely unless the victim is trapped in such a location that escape from the vapor is impossible. The experience of those exposed to the Halon 1301 decomposition of Test 1 confirms this to be true. In most trailers, exit from the trailer is unencumbered--normally two exits from the trailer are provided. However, in the event that someone does become trapped because of a fire, there is likely to be greater hazard to the individual from the unchecked fire than from Halon 1301 decomposition.

Occupants of the trailer during the first test experienced no difficulty in promptly leaving the trailer, even with poor visibility. Clear aisles and readily accessible exits should, however, always be maintained.

Special consideration needs to be given to those locations where continued occupancy is claimed to be necessary or desirable. One of the important potential advantages of Halon 1301 is high personnel tolerance, which could conceivably enable continued personnel occupancy. At the present time, however, there is not sufficient data available to the design engineer to predict the level of Halon 1301 decomposition that will be produced with a specific Halon system design. Therefore, no guarantees can be made that continued personnel occupancy will be possible.

Some contend that if there is any chance a Halon 1301 system discharge will result in decomposition products concentrations high enough to pose risks to continued personnel occupancy, than automatic Halon 1301 systems should not be installed. However, the fact of the matter is that the fire itself, and its combustion by-products, is much more likely to pose risks to personnel than is Halon 1301 decomposition. Without the Halon system, personnel evacuation is much more likely from the unchecked fire. If a condition is so important or hazardous that controlled shutdown must be effected, this should be arranged to proceed automatically or be capable of being controlled from a second remote location, and not be dependent upon continued personnel occupancy.

Conclusion

Within the context of the Halon 1301 system design in use in the BNL instrument trailers, the potential for Halon 1301 decomposition poses little risk to trailer occupants:

- Excessive decomposition appears to occur with only specific materials.
- These materials are not the most likely materials to be involved in a trailer fire.
- Even if these materials are involved, excessive levels of decomposition are readily apparent, prompt personnel evacuation is normally possible, and personnel exposures would be limited.

TABLE II. BNL SAMPLES, HF ANALYSIS, ALL TESTS

Time after start of discharge, seconds Before discharge, but after fire start	Analysis by Zr-Quercetin Method HF Concentration in ppm by Volume in Air				
	TEST NO.				
	2	3	4	5	6
	<15	<10	<10	<10	<10
15		60	<10	20	<10
22	405				
30		374	<10	30	<10
34	405				
45		304	<10	32	<10
47	565				
60		164	<10	39	<10
62	575				
71	590				
90		230	<10	32	<10
111	405				
120		120	<10	15	<10
136	490				
150		16	<10	<10	<15*
180		24	<15*	<10	<10
185	390				
225	390				
240		19	<15*	<10	<10
254	230				
286	375				
300		<10	<10	<10	<10
313	295				
360		<10	<10	<10	<10
372	190				
435	260				
497	190				
533	170				

*With these samples, the HF concentration could only be determined confidently to be less than 15 ppm, although there is no reason to believe that they were not also less than 10 ppm.

TABLE III. DU PONT SAMPLES, HF & HBr ANALYSIS, TEST 2

<u>Time/Seconds</u>	<u>PPM HF</u>	<u>PPM HBr</u>
0 (at start of discharge)	18	33
60	773	20
120	721	18
180	722	14
240	696	17
360	541	13
480	412	14
555" door opened - personnel left room		
600	309	20

TABLE IV. ENL SAMPLES, HBr ANALYSIS, TEST 2

<u>Time after start of discharge, seconds</u>	<u>HBr Conc. PPM</u>
Before discharge, after fire start	<10
34	200
62	240
111	200
185	220
230	130
313	160
435	170
533	120

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TRAILER ISOMETRIC

Figure 1.

Scale: $3/16" = 1'$

Fig. 2 Trailer Halon 1301 System Control Panel, Battery Cabinet & Cylinder Supply

Fig. 3 Trailer Salon 1301 System
Piping & Discharge Nozzle, Ceiling
Detectors

Fig. 4 Fire Pan, Test 1, Methyl Alcohol
(similar for all flammable liquid
tests)

FIG. 5 TEST 2 METHANOL

FIG. 6 TEST 3 METHANOL

FIG. 7 TEST 4 KEROSENE

FIG.8 TEST 5- WOOD CRIB

FIG. 9 TEST 6 - SIMULATED ELECTRICAL