AD-A015 003

ELECTROSTATIC HAZARDS PRODUCED BY CARBON DIOXIDE IN INERTING AND FIRE-EXTINGUISHING SYSTEMS

J. T. Leonard, et al

Naval Research Laboratory
Washington, D. C.

28 August 1975

NRL Report 7920

Electrostatic Hazards Produced by Carbon Dioxide in Inerting and Fire-Extinguishing Systems

J. T. LEONARD AND R. C. CLARK

Chemical Dynamics Branch
Chemistry Division

August 28, 1975

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
US Department of Commerce
Springfield, VA. 22151

NAVAL RESEARCH LABORATORY
Washington, D.C.

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Report 7920	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ELECTROSTATIC HAZARDS PRODUCED BY CARBON DIOXIDE IN INERTING AND FIRE-EXTINGUISHING SYSTEMS		5. TYPE OF REPORT & PERIOD COVERED Final report on one phase of the NRL problem. 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J.T. Leonard and R.C. Clark		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, D.C. 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NRL Problem C05-19 Project N-65197-75-WR-55185
11. CONTROLLING OFFICE NAME AND ADDRESS Department of the Navy Naval Ship Engineering Center Hyattsville, Md 20782		12. REPORT DATE August 28, 1975 13. NUMBER OF PAGES 22
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Static electricity
Carbon dioxide
Fire suppression
Inerting systems
Ignition hazards

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In tests of the possible electrostatic hazard resulting from the discharge of CO_2 by the hatch-snuffing (inerting) system of gasoline tankers, measurements were made of the field strength developed in a full-scale model of a tanker hatch when a 22.7-kg CO_2 cylinder was discharged via the nozzles of the hatch-snuffing system. A camera employing high-speed film and, in some runs, an instrumented probe were used to detect discharges. The field strength in the center of the hatch reached a maximum value of 50 to 170 kV/m about 40 to 60 s after the CO_2 began to enter the hatch and then fell to zero near the

20. Abstract (Continued)

end of the run (120 s). No evidence of electrostatic discharges was found on the photographs or on the oscilloscope traces from the probe circuit. Shipboard tests confirmed the conclusions reached in the model tests.

Companion experiments were also conducted using a 6.8-kg CO_2 fire extinguisher, since this device was involved in a fatal accident. Field strengths of the order of 1300 kV/m were observed when this extinguisher was discharged into a simulated hatch area. Photographs and oscilloscope traces confirmed the presence of electrical discharges. The characteristics of the electrostatic charge generated by the CO_2 hatch-snuffing system differed from the characteristics of the charge generated by the fire extinguisher due to a plastic horn on the extinguisher. The hatch-snuffing system employs eight metal orifices but no horn or similar funneling device. When the plastic horn was removed and the fire extinguisher was discharged through the remaining metal orifice, the field strength was reduced by a factor of 100, clearly demonstrating the charging characteristics of the plastic horn.

CONTENTS

INTRODUCTION 1

EXPERIMENTAL PROCEDURE 1

- Ship's CO_2 Hatch-Snuffing System 1
- Simulated-Hatch With CO_2 Hatch-Snuffing-System Nozzles 4
- Simulated-Hatch and a Portable CO_2 Fire Extinguisher ... 5
- Shipboard Hatch 5

RESULTS AND DISCUSSION 7

- Simulated-Hatch With CO_2 Hatch-Snuffing-System Nozzles 7
- Simulated-Hatch and a Portable CO_2 Fire Extinguisher ... 7
- Shipboard Hatch 12
- Comparison With the Bitburg Incident................ 16

SUMMARY AND CONCLUSIONS 17

REFERENCES.................................... 18

ELECTROSTATIC HAZARDS PRODUCED BY CARBON DIOXIDE IN INERTING AND FIRE-EXTINGUISHING SYSTEMS

INTRODUCTION

On October 23, 1973, two Navy firemen were killed while attempting to use a portable CO_2 fire extinguisher to *inert* the tank of an 18.9-m^3 (5000-gal) Air Force type F-6 aircraft refueler [1]. The tank, which previously had been in JP-4 service, was being inerted prior to painting and minor electrical repairs. After one of the firemen had introduced a short burst of CO_2 into the tank, he remarked that the extinguisher horn was sparking. Having been advised to hold the horn against the side of the tank, he introduced another burst of CO_2 into the tank, whereupon the fatal explosion occurred.

Following this incident a message went out to the fleet warning of the dangers of static electricity generated by high-velocity streams of CO_2 containing solid particles (CO_2 snow). These particles can generate potentials as high as 50,000 volts as they slide down the horn of an extinguisher [2]. Voltages of this magnitude are sufficient to produce sparking from the horn as was observed just before the above accident. Furthermore the snow particles can produce a charged cloud inside the tank, which can also lead to spark discharges. In view of these hazards the use of CO_2 fire extinguishers to inert tanks containing or that previously contained hydrocarbon vapors was prohibited at naval installations.

Subsequently concern was expressed by the fleet over the safety of the CO_2 hatch-snuffing system which is installed in the aviation-gasoline (AVGAS) tanks of fleet oilers (AO's and AOG's). These systems do not discharge sufficient CO_2 to extinguish a fire in the tank, merely enough to inert the hatch area. Since in this application CO_2 is discharged into a fuel/air mixture which, though not burning, could be in the flammable range, the generation of static electricity by CO_2 in such systems is of particular importance. To investigate the possible electrostatic hazards of these systems, field strengths were measured aboard a fleet oiler as well as on a full-scale model of the ship's CO_2 hatch-snuffing system. To obtain a comparison, the charge-generating characteristics of portable 6.8-kg (15-lb) CO_2 fire extinguishers employing a variety of delivery horns were also investigated.

EXPERIMENTAL PROCEDURE

Ship's CO_2 Hatch-Snuffing System

The ship selected for this study, the USS *Truckee* (AO-147), has five AVGAS tanks midships (Fig. 1) which are tied into the CO_2 hatch-snuffing system. When activated, the system discharges 16 cylinders of CO_2 (with a total weight of 363 kg, or 800 lb) into the five tank hatches (Fig. 2). A second 16-cylinder shot may be delivered if necessary. The No. 4 AVGAS tank hatch (Fig. 3) was chosen for the present study. The capacity of this tank is 1589 m^3.

Manuscript submitted June 25, 1975.

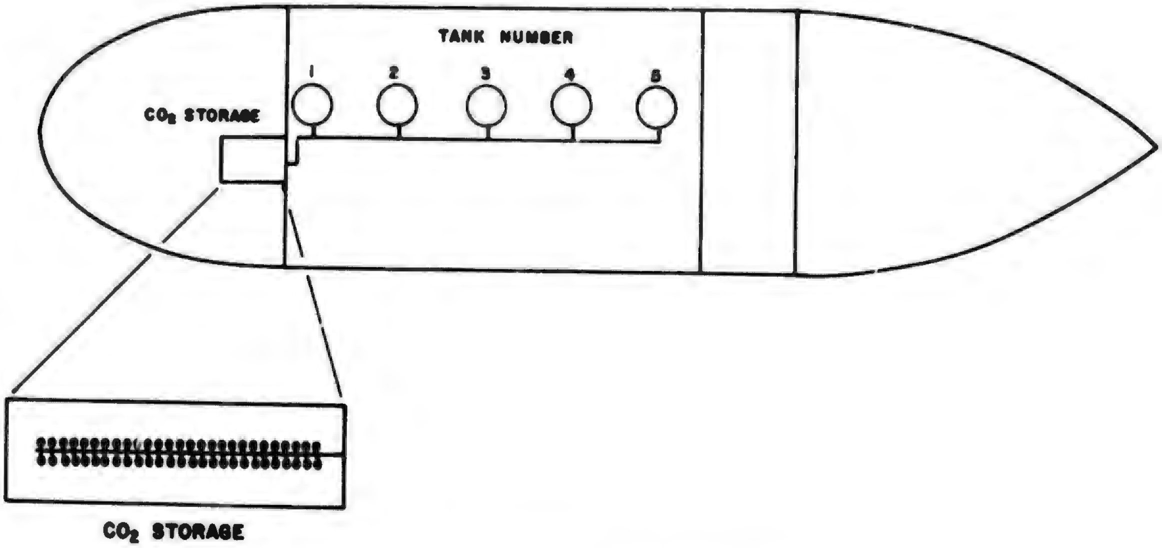


Fig. 1—Layout of the tanker's CO_2 hatch-snuffing system. (Some of the storage cylinders on the manifold are part of another system.)

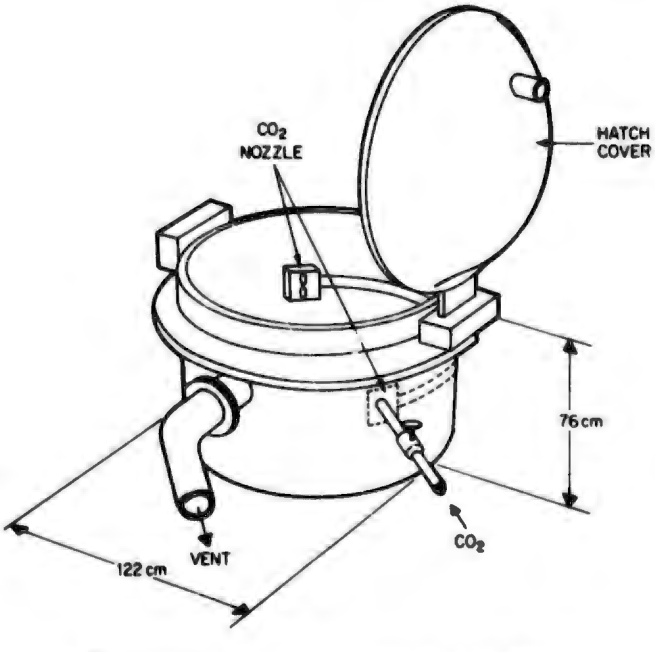
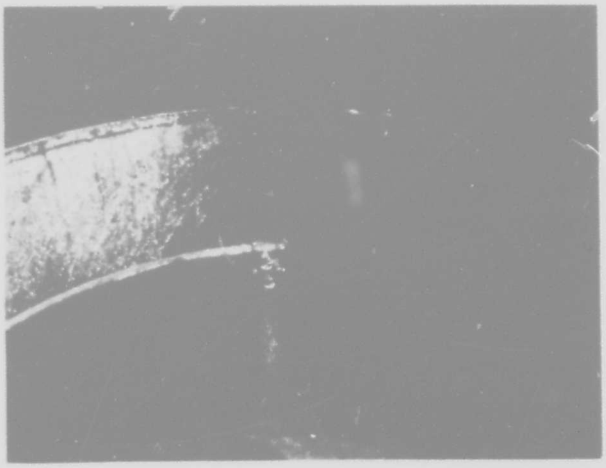
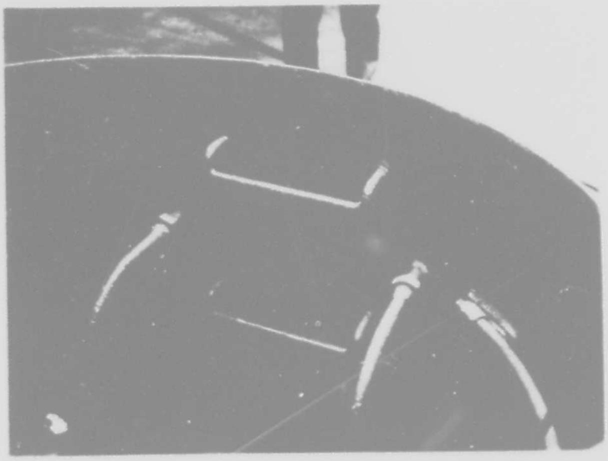


Fig. 2—CO_2 nozzles in a typical AVGAS hatch

(a) No. 4 AVGAS hatch



(b) CO_2 nozzle 1



(c) CO_2 nozzle 2 (at right)

Fig. 3—Placement of CO_2 nozzles in the AVGAS hatch studied

Simulated Hatch With CO_2 Hatch-Snuffing-System Nozzles

Prior to the shipboard studies, tests were conducted in a full-scale model of the hatch area (Fig. 4). The CO_2 nozzles installed in the simulated hatch were the type approved for the hatch-snuffing system. Each nozzle has two sets of 2.38-mm-diameter counter-impinging orifices (Fig. 5); one set directs CO_2 in a horizontal plane and the other set directs CO_2 in a plane 30° into the tank. Two 15-cm holes were cut into a plywood hatch cover to accommodate the electrostatic field meter, used to measure the strength of the electrical field generated by the discharge of CO_2, and the camera, used to photograph discharges.

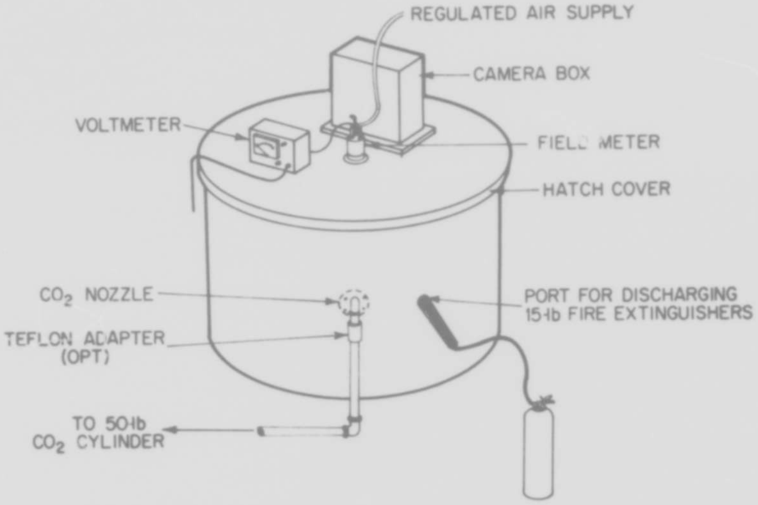


Fig. 4—Simulation of hatch and CO_2 hatch-snuffing system

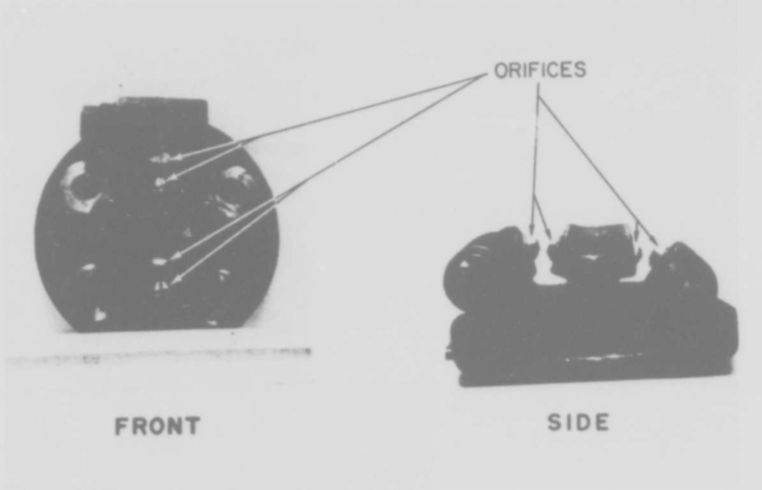


Fig. 5—CO_2 nozzles used in the hatch-snuffing system

The field meter (designed for shipboard use by Chevron Research Co., Richmond, California, and provided for these studies by Mobil Research and Development Laboratory, Paulsboro, N.J.) consists of an insulated, butterfly-shaped metal plate with a similarly shaped grounded plate rotating in front of it. The rotor, driven at a constant speed by an air motor, alternately exposes and shields the insulated plate from the electric field, causing the charge induced on the insulated plate by the field to cycle between zero and maximum. When the insulated plate is connected to ground through a low-impedance meter, the alternating charge results in an alternating current which is indicated by the meter (a Hewlett Packard Model 403A ac transistorized voltmeter (Fig. 4) modified to read out directly in terms of field strength).

A Polarioid Model 110B camera with Polaroid Type 410 film (ASA = 10,000) was used to photograph discharges. The camera was placed in a light-tight box 46 cm above the plane of the nozzles. At this distance, the field of view is 20 by 28 cm. The camera shutter was held open for the entire period while CO_2 was being discharged into the hatch.

The camera was selected to detect discharges since it can do so without disturbing the electrical field in the hatch. Discharges with energies as low as 0.2 mJ, the minimum ignition energy for hydrocarbon vapors [3], were detected in earlier tests with this system. For some experiments, a probe was placed directly below either opening in the hatch cover and also at various positions within the tank itself to serve as a lightning rod to intentionally attract discharges. The probe consisted of a 2.5-cm spherical electrode connected to a Tektronix Type 535A oscilloscope. An RC network with an RC time of 1 ms was shunted across the input of the oscilloscope.

In the simulated-hatch tests CO_2 from a 22.7-kg (50-lb) cylinder was discharged through the nozzle system in the form of either a gas or when the cylinder was inverted, a liquid. Field strengths were measured while the camera was positioned directly above either CO_2 nozzle, midway between the two nozzles, or in the center of the hatch. To measure charging currents, the entire simulator was electrically isolated by inserting a Teflon adapter in the CO_2 line (Fig. 4) and placing the simulator on Teflon blocks.

Simulated-Hatch and a Portable CO_2 Fire Extinguisher

Along with the simulated-hatch studies using the CO_2 hatch-snuffing system, a 6.8-kg CO_2 fire extinguisher was discharged into the hatch through a hole in the plane of the discharge nozzles (Fig. 4). Three plastic horns and a metal horn (Fig. 6) were compared for charge-generation capabilities. The conical and elliptical plastic horns were fabricated from cloth-reinforced Bakelite, and the model H plastic horn was made of polyethylene. The metal horn was galvanized steel. Usually field-strength measurements and photographic exposures were made continuously throughout these runs.

Shipboard Hatch

The same equipment (field meter, camera, hatch cover, probe, and oscilloscope) used in the simulated-hatch studies was installed in the hatch of the No. 4 AVGAS tank aboard the tanker (Fig. 7). Measurements were also made through the Butterworth opening

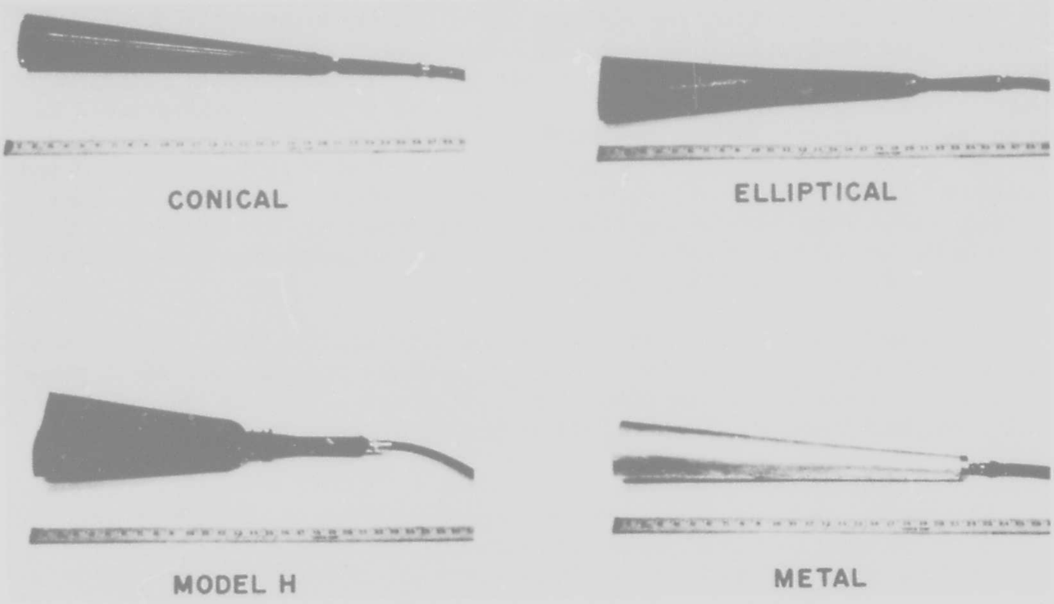


Fig. 6—CO_2-delivery horns used in fire-extinguisher tests

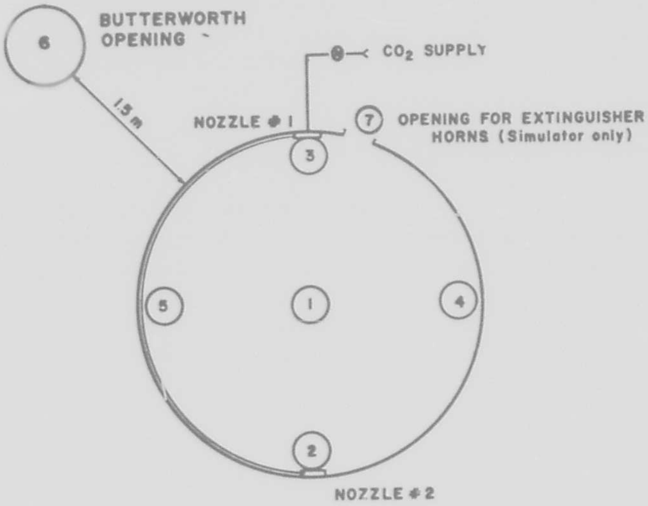


Fig. 7—Numbering of test positions of the field meter, camera, and probe for both the shipboard and simulated-hatch studies

closest to the No. 4 hatch to determine the field strength at a point 4.5 m below deck level. Ladders and structural members prevented making readings at other points without entering the tank. Since the tank would have to be ventillated and certified safe for man after each run, tests were not made at other levels.

The procedure for the shipboard tests was similar to that for the simulated-hatch studies except that two 22.7-kg CO_2 cylinders were used instead of only one as in the simulator. Field-strength measurements were made when the CO_2 began to enter the hatch and continued as long as a detectable signal was obtained. The camera shutter was fully opened during the entire test. A few tests were also performed using the 6.8-kg fire extinguisher.

RESULTS AND DISCUSSION

Simulated-Hatch With CO_2 Hatch-Snuffing-System Nozzles

A summary of the results obtained when discharging a 22.7-kg CO_2 cylinder into the simulator through the nozzles of the hatch-snuffing system is given in Table 1. A plot of the field strength developed in the simulated hatch while discharging liquid CO_2 is shown in Fig. 8. As shown in the figure, the field strength in the hatch increases during the run, reaching a maximum value as the CO_2 supply is depleted. The results confirm that appreciable field strengths occur only when CO_2 is discharged as a liquid. Upon leaving the cylinder, the liquid is converted to both a solid (CO_2 snow) and a gas. Gaseous CO_2 does not generate much static electricity (Table 1). Thus it is the separation of the solid CO_2 particles from the metal nozzle which generates charge. The highest field-strength reading obtained was 170 kV/m (run 40). Variations in field strength are probably due to impurities such as moisture and rust in the liquid CO_2, since Heidelberg et al. [4] have shown that such contaminants can alter the charge-generating characteristics of CO_2.

No discharges were detected in any of the photographs taken or by the probe when the simulated hatch-snuffing system was fired. It was concluded from the simulated-hatch studies that field strengths in the range 100 to 200 kV/m could be expected when the shipboard system was activated, but that spark discharges probably would not occur.

Simulated-Hatch and a Portable CO_2 Fire Extinguisher

The results obtained when a portable CO_2 fire extinguisher was discharged into the simulated hatch through a hole in the plane of the hatch-snuffing-system nozzles are given in Table 2. The horns were grounded to the hatch for the tests. Of the three commercially available types of horns investigated, the conical type gave consistently higher results in all tests except run 22, which involved the model H horn. In addition to the effect of impurities, variations in charge generation with a given type of horn were also attributed to differences in the liquid CO_2 content of the individual cylinders, a fact that was not appreciated in early tests. After several nearly empty CO_2 cylinders were en-

Table 1 — Summary of Field-Strength Measurements When the CO_2 Hatch-Snuffing System Was Discharged into the Simulated Hatch

Run	Position*		Max Field Strength (kV/m)	Discharges Detected	Remarks
	Field Meter	Camera			
CO_2 Discharged as a Liquid					
2	1	2	20	No	—
5	1	2	100	No	—
7	1	2	90	No	—
40	1	2	170	No	Partial cylinder discharged
41	1	2	140	No	—
48	1	4	18	No	Partial cylinder; no snow formed
49	1	4	35	No	Partial cylinder; no snow formed
50	1	4	60	No	Little snow
CO_2 Discharged as a Gas					
6	1	2	15	No	—
8	1	2	5	No	—

*Position 1 = center of hatch; position 2 = above CO_2 nozzle; position 4 = midway between CO_2 nozzles (see Fig. 7).

countered, the practice of weighing the cylinders before and after testing was initiated. Weights of supposedly full cylinders varied considerably (Table 2).

The lowest field strengths were obtained with a specially made galvanized metal horn. The maximum values shown in Table 2 were peak values obtained as initial spikes. Following the peak, the field strength dropped rapidly to a value in the range 10 to 40 kV/m. A comparison of the field strengths developed by the standard conical horn and the metal horn (Fig. 9) reveals that CO_2 generates far less static electricity on the metal horn. In a separate test it was shown that removal of the conical horn and discharging the extinguisher through the metal orifice reduced the field strength by a factor of 100 (Fig. 9). Thus the plastic material (Bakelite or polyethylene) in the horn is responsible for the high field strengths when CO_2 fire extinguishers are discharged. Removing the horn or replacing it with metal greatly reduces static charge generation.

Attempts were made to photograph discharges while the 6.8-kg CO_2 extinguishers were being fired. During these tests, in which the extinguisher was resting on a metal

Table 2 — Summary of Field Strength Measurements When the Portable (6.8-kg) CO_2 Fire Extinguisher Was Discharged into the Simulated Hatch

Run	Type of Horn	Position*		Discharges on Photographs	Max Field Strength (kV/m)	Weight of CO_2 (kg)	Remarks
		Field Meter	Camera				
10	Conical†	1	2	Yes	1000	—‡	Many discharges
18	Conical	1	2	No	>1000	—‡	—
31	Conical	1	7	No	>1000	6.4	—
26	Elliptical	1	2	No	630	5.9	—
27	Elliptical	1	7	Yes	470	4.1	—
29	Elliptical	1	7	Yes	650	4.8	—
22	Model H	1	2	No	1300	—‡	Discharges seen at hatch opening
23	Model H	1	2	No	400	—‡	Discharge seen at hatch opening
24	Model H	1	2	No	450	—‡	Low yield of snow
25	Mddel H	1	2	No	750	5.4	—
28	Model H	1	7	Yes	600	5.0	—
19	Metal	1	2	No	150	—‡	—
20	Metal	1	2	No	10	—‡	All gas; no snow
21	Metal	1	2	No	115	—‡	—
32	Metal	1	7	No	250	6.6	—

*Position 1 = center of hatch; position 2 = above CO_2 impact area; position 7 = above horn (Fig. 7).
†Horn insulated from extinguisher by a Teflon adapter.
‡Not available.

deck and the horn was in contact with the grounded hatch, no discharges were found at the impact point on the opposite side of the hatch (position 2). However discharges were seen and photographed both on the inside and outside of the hatch (positions 3 and 7) at the point where the horn passed through the hatch (Fig. 10). The test conditions are similar to the circumstances at the time of the fatal accident described in the Introduction [2] wherein ignition occurred when the horn of the extinguisher was placed in contact with the hatch opening. The only time that discharges were detected at the impact point of the CO_2 on the opposite side of the hatch (position 2) was when the horn was insulated from the hatch and the extinguisher (by a Teflon adapter) for a measurement of the charging current. During these tests multiple discharges occurred at the impact point, almost completely overexposing the film (Fig. 11). Apparently these were cloud-to-ground discharges, although the exact nature could not be discerned from the film record. The maximum field strength developed in this test was 1000 kV/m.

As indicated, it is difficult to compare the charge-generating characteristics of various types of horns due to the differences in impurities and liquid CO_2 content of as-received CO_2 fire extinguishers. In an attempt to circumvent these difficulties, a series of tests was conducted wherein the horns were connected to a single 22.7-kg CO_2 cylinder. The field

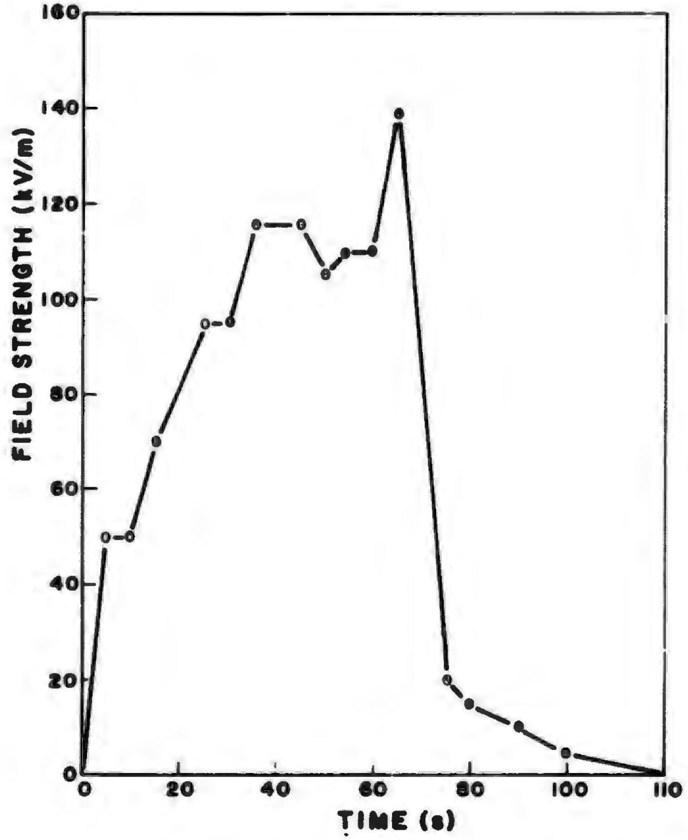


Fig. 8—Field Strength in the simulated hatch during discharge of 22.7 kg of CO_2 as a liquid (run 41 in Table 1)

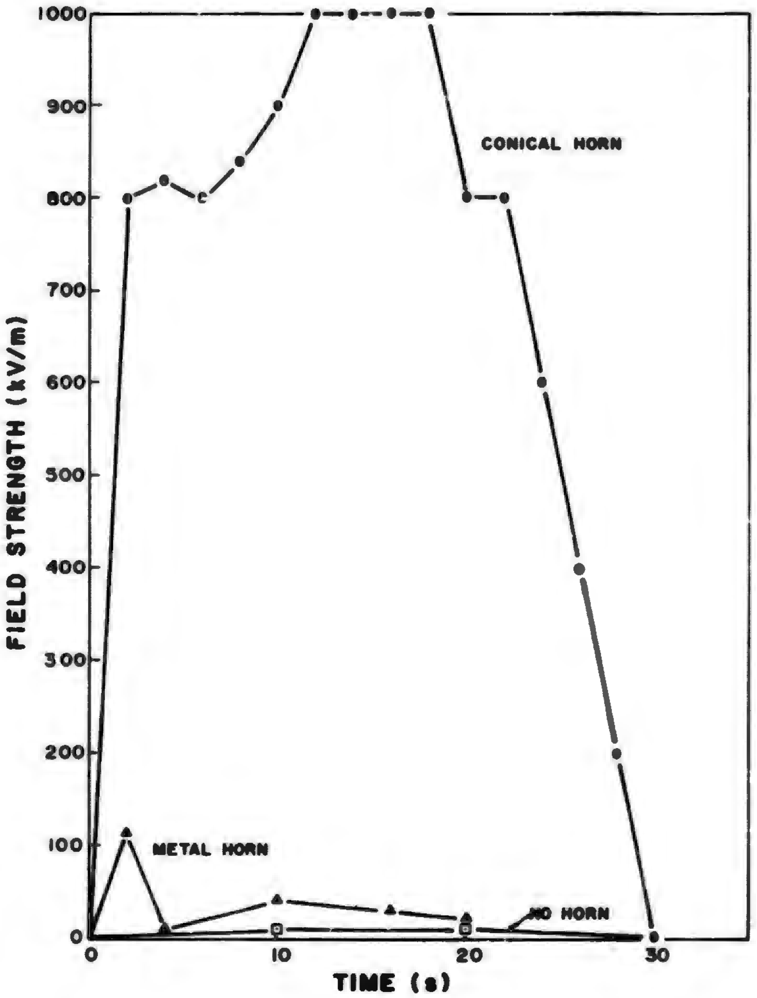


Fig. 9 — Comparison of electrostatic-charge generation characteristics of conical and metal CO_2-fire-extinguisher horns

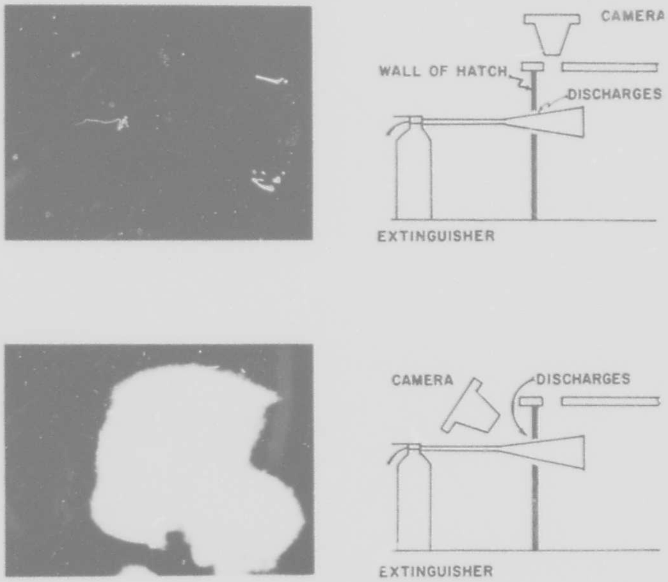
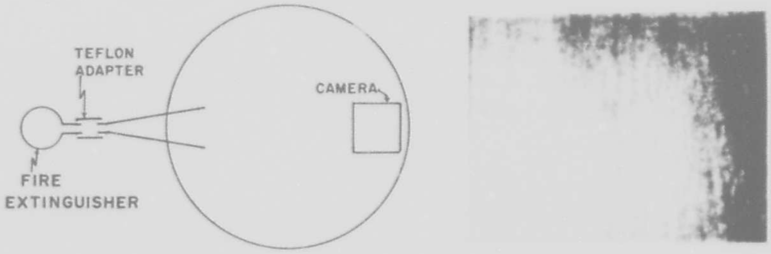


Fig. 10 — Discharges between fire-extinguisher horn and hatch opening



SIMULATOR

DISCHARGES

Fig. 11 — Multiplicity of discharges at CO_2-impact area during firing of a portable fire extinguisher through a horn insulated from the hatch and the extinguisher

strength was recorded in the simulated hatch as the CO_2 passed through the horn for 30 s, the time required to almost empty a completely filled 6.8-kg cylinder. The results of this comparison (Fig. 12) confirmed the high charging characteristics of the model-H horn (run 22, Table 2) and the low charging tendency of the metal horn.

The model-H horn has greater surface area and contains four orifices as opposed to the single orifice in the other horns. Thus in 30 s considerably more CO_2 snow passes over the model H horn than over any of the other horns. When attached to a full 6.8-kg cylinder, the model-H horn discharges its CO_2 in 26 s as opposed to 32 s for the other horns. The higher field strengths developed by the model-H horn are attributed to the faster release of CO_2 snow from this horn as well as to differences in materials of construction.

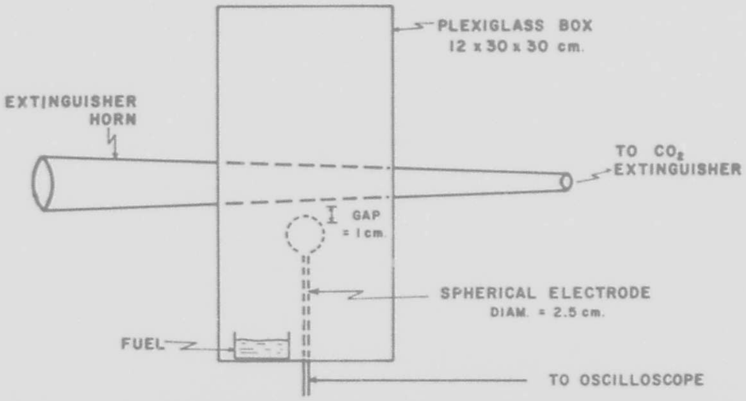
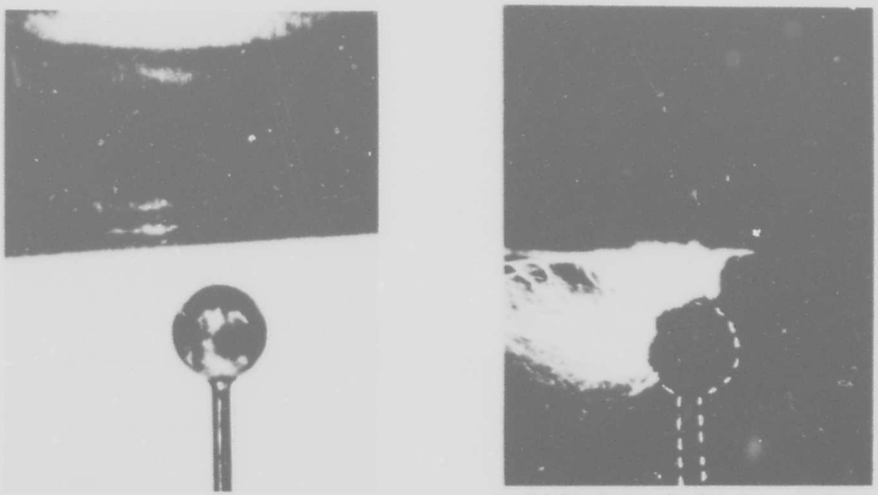


Fig. 13 — Apparatus for studying discharges in flammable atmospheres



(a) Electrode diagrammed in Fig. 14

(b) Discharges in the absence of a flammable atmosphere

Fig. 14 — Discharges from a CO_2-fire-extinguisher horn

general the field strength in the hatch increased to a maximum of 50 to 110 kV/m in 20 to 40 s and then rather quickly fell off to zero near the end of the run (in 80 to 120 s). The peak field strengths were sustained for only 10 to 20 s. In addition to impurities in the CO_2, variations in field strength were attributed to the differences in the amount of liquid CO_2 discharged during a given run, since leakage of some CO_2 at the manifold was inevitable.

The comparison in Fig. 15 of the field strength developed by the hatch-snuffing system aboard ship with the values obtained in the simulated hatch shows that although the maximum values obtained with either system are comparable, the simulated-hatch system maintains a high field strength for a longer time than the shipboard system. The difference is probably because aboard ship the CO_2 has to travel through approximately 82 m of 19-mm-diameter pipe before reaching the hatch, whereas with the simulated hatch the

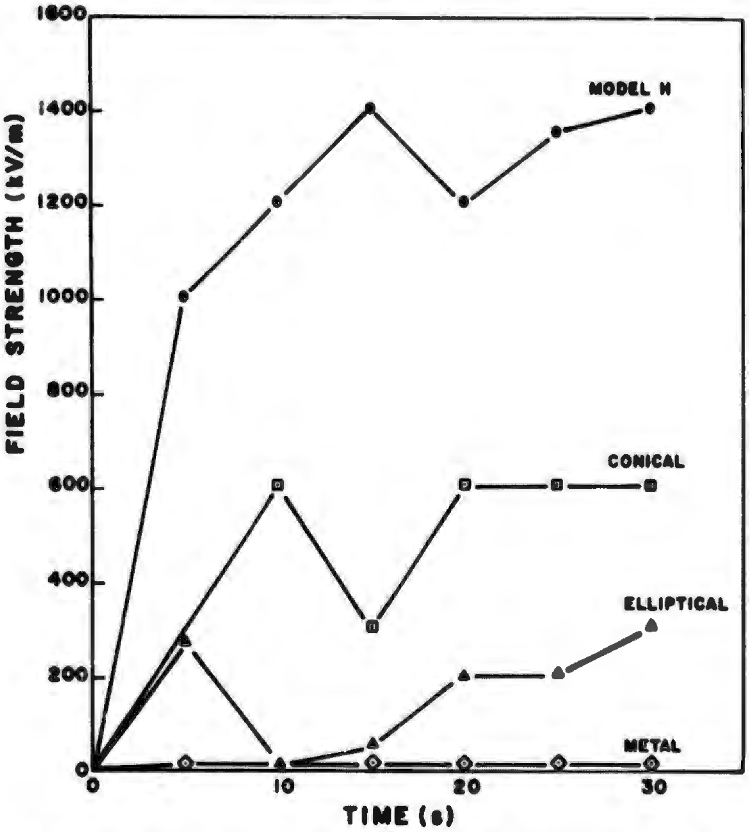


Fig. 12 — Comparison of charging tendencies of various types of horns discharging CO_2 from a single 22.7-kg cylinder

The conical and elliptical horns did not charge as highly when discharging CO_2 from the 22.7-kg cylinder as when 6.8-kg cylinders were fired, probably because the maximum values obtained with the 6.8-kg cylinders usually occurred when the CO_2 discharged in an initial, strong blast. The 22.7-kg cylinder had a needle valve, so that the CO_2 was released gradually until the valve was fully opened, resulting in no initial surge and no peak field strengths.

To establish that discharges can take place between the horn and some grounded object, the center 12-cm section of the horn was encased in a plexiglass box containing a grounded electrode 1 cm from the horn (Fig. 13). A Petri dish containing n-heptane was used whenever a flammable atmosphere was required. When a 6.8-kg fire extinguisher was discharged through the horn *in the absence of a flammable atmosphere*, multiple discharges occurred (Fig. 14). When the chamber was filled with a flammable mixture and the extinguisher was fired, a mild explosion occurred, clearly demonstrating the incendiary nature of the horn-to-probe discharges.

Shipboard Hatch

The results of the shipboard studies are summarized in Table 3, and a plot of the field-strength readings obtained during a typical run (run 9) is given in Fig. 15. In

Table 3 — Summary of Field-Strength Measurements During Shipboard Tests

Run	Position*			Max Field Strength (kV/m)	Discharges Detected		Remarks
	Field Meter	Camera	Probe		Camera	Probe	
Probe Not Installed							
1-7	1	3	—	50-95	No	—	Some leakage in CO_2 room
8	1	5	—	100	No	—	—
9	1	3	—	110†	No	—	Highest field strength obtained.
10	3	1	—	95	No	—	—
Probe Installed in Hatch							
11	1	3	3	65	No	No	Probe directly below camera, 10 cm from CO_2 nozzle
12	1	3	3	85	No	No	—
13	3	1	1	95	No	No	—
Field Meter and Probe Lowered 6.8 m Below Deck Through Butterworth Opening							
15	6	6	6	14	No	No	Field strength is considerably lower at this point.
6.8-kg Extinguisher (Conical Horn) Discharged Through Camera Port in Hatch Cover							
14, 17, 20	1	—	1	200-700	—	Yes	Field strength lower than in simulator studies

*Position 1 = center of hatch; position 3 = above CO_2 nozzle; position 5 = midway between CO_2 nozzles; position 6 = Butterworth opening (Fig. 7).

†Estimated-meter off scale.

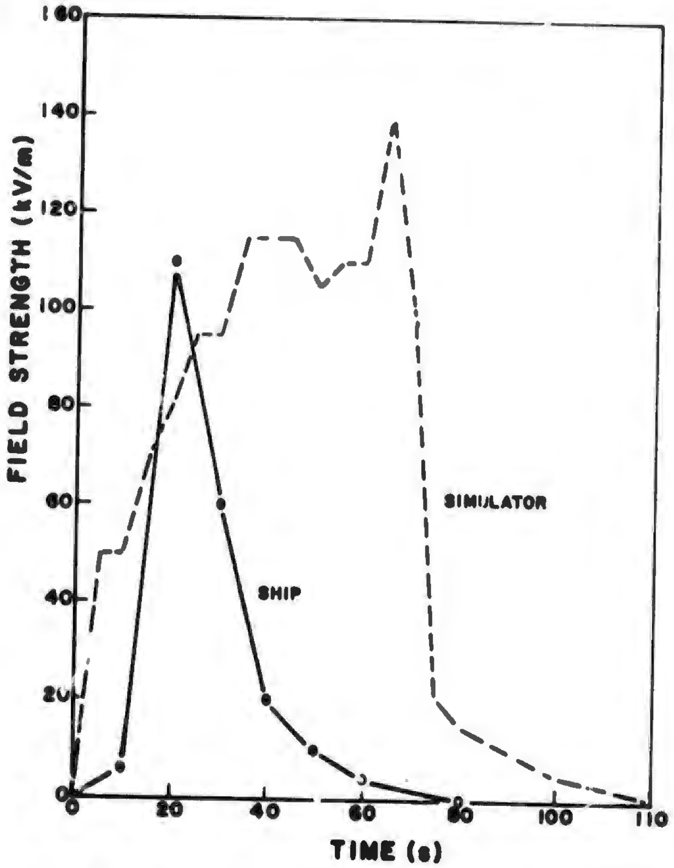


Fig. 15 — Field-strength data for the CO_2 hatch-snuffing system from a shipboard run in comparison with simulated-hatch data (Fig. 8)

distance between the CO_2 cylinder and the nozzle is only 3 m. During this travel aboard ship, considerable liquid CO_2 is converted to gas, which, as was shown in the simulator studies, does not generate much static electricity.

The maximum field strength obtained in these runs (110 kV/m) is comparable to the maximum values obtained when loading tank trucks and refuelers with hydrocarbon fuels [5,6]. In this case the charge is generated by the fuel as it passes through the pumps, filters, and piping of the fuel-handling system. Often the fuel/air mixture in the tank truck or refueler is in the flammable range when such loading operations are performed. Field strengths in the range 50 to 400 kV/m are also attained during tanker-washing operations [7]. In these instances the fuel/air mixture in the tanks may also be in the flammable range. Over a 10-year period there have been approximately 120 *known* fires or explosions attributed to static electricity during loading of tank trucks and refuelers [8], 35 incidents during fueling of piston-engine and jet aircraft [9], and a number of incidents during tanker-washing operations, including three severe explosions of large crude carriers in one month [10]. Considering the total number of fuel loadings and tanker washings that were carried out safely during this period, the incidence of electrostatic ignitions during the same period is extremely small. Apparently when electrostatic ignitions occur, the field strengths exceed the "normal" values given above.

The field strength required to produce spark breakdown in air between two parallel-plate electrodes is 3000 kV/m. If one of the electrodes has a small radius of curvature, then the field will be concentrated around this point and discharges will occur when the overall field strength is less than 3000 kV/m. Thus Schonland [11] in discussing long sparks states that two field-strength conditions must be met for the advance of the spark pilot streamer: the field strength in front of the tip must exceed 3000 kV/m, and the mean field strength inside its channel must be greater than 600 kV/m. In addition Bruinzeel [12] has reported that spark discharges occurred during loading of jet fuel into a simulated aircraft fuel tank at a field strength of 500 kV/m. In the present study spark discharges were obtained from CO_2 fire extinguishers, which often developed field strengths in the range 500 to 1300 kV/m, but not from the CO_2 hatch-snuffing system, which produced field strengths in the range 50 to 170 kV/m in both the shipboard and simulated-hatch tests. No discharges were detected on any of the photographic exposures that were made during the shipboard tests, nor were any discharges detected when the probe was used. Thus it would appear that the maximum field strengths developed by this CO_2 hatch-snuffing system are below the minimum value required to produce spark discharges.

Comparison With the Bitburg Incident

In 1954 29 persons were killed and nine injured while witnessing the demonstration of a newly installed CO_2 fire-extinguishing system in Bitburg, Germany [13]. The victims were standing on a partially filled 5000-m^3 underground tank containing JP-4-type jet fuel when 360 kg of CO_2 was discharged into the tank through a pipe 70 m long and 100 mm in diameter. An explosion occurred which was attributed to an electrostatic discharge from the CO_2 snow as it was being released into the tank. Heidelberg et al. [4], in the course of investigating the cause of this accident, studied the charge-generating characteristics of CO_2 in a system which simulated the Bitburg installation: employing a 100-mm pipe. They also investigated the charging characteristics of a variety of CO_2 delivery systems (gas and fog nozzles and snow pipes) which differed in number and size of orifices and in expansion volumes. These workers found that high charging and luminous phenomena (brush and spark discharges) occurred when CO_2 was discharged through the 100-mm pipe and the snow pipes but not through the fog or gas nozzles. Apparently the production of CO_2 snow and consequently the generation of static electricity is limited by the low-expansion characteristics of the gas and fog nozzles.

To relate the results of the present investigation to that of Heidelberg et al., current measurements were made by electrically isolating the entire simulated-hatch system and discharging 22.7 kg of CO_2 via the hatch-snuffing-system nozzles. The charge on the CO_2, as calculated from the resulting current trace (Fig. 16), was 1.8 μC/kg of CO_2. Heidelberg et al. [4] reported luminous phenomena using snow pipes when the charge level was 26 to 29 μC/kg of CO_2 but observed none at 11 μC/kg. No discharges were detected with either the gas or fog nozzles, which generated charge levels in the range 0.01 to 0.1 μC/kg. The lowest charge level at which discharges were reported by Heidelberg was 4.5 μC/kg when CO_2 was released through a 100-mm-diameter pipe. However, as explained by Heidelberg et al., the charging characteristics of the 100-mm pipe are quite different from the gas or fog nozzles. For example, in the 100-mm pipe liquid CO_2 can expand and form snow which generates static charge as it traverses the length of the pipe. Thus significant charging currents were recorded on isolated sections of the 100-mm pipe. By

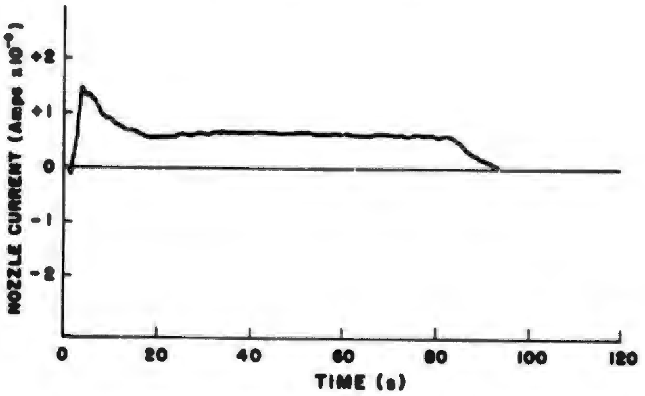


Fig. 16 — Charging current for CO_2 hatch-snuffing-system Nozzles

contrast the currents measured on the 19-mm pipe used with the gas and fog nozzles were negligible. In the latter systems, which are similar to the hatch-snuffing system, the charge is generated primarily at the nozzle.

Among the more significant findings reported by Heidelberg et al. [4] was the effect of impurities on the magnitude of charge generated by CO_2. Thus replacing the standard CO_2 (dew point of 13°C) with technically pure CO_2 (dew point of 44°C) reduced the charge from 28 μC/kg to 11 μC/kg or less. Further drying of the CO_2 to a dew point of -48°C caused the charge to fluctuate between 0.1 and 10 μC/kg, with the higher values predominating. Addition of 17 g of water per kg of CO_2 increased the charge to 25 μC/kg. Iron oxide, at a level of 0.03 g/kg CO_2 produced nearly the same level of charge as water, 17 μC/kg. Thus from the standpoint of reduction of hazard in inerting systems there is a clear advantage to reducing impurities in CO_2.

SUMMARY AND CONCLUSIONS

To conclude:

- The field strengths developed by discharging 22.7-kg cylinders of CO_2 into the simulated hatch as a liquid are of the same order (80 to 170 kV/m) as were found in the shipboard studies.

- Field strengths developed by discharging gaseous CO_2 into the simulated hatch are about 1/10 the values obtained with liquid CO_2.

- No spark discharges were detected when CO_2 was discharged into the simulated hatch via the hatch-snuffing-system nozzles or aboard ship.

- Field strengths in the range 400 to 1300 kV/m were obtained when firing 6.8-kg CO_2 extinguishers into the simulated hatch. Under these conditions spark discharges were obtained from the horn of the extinguisher to the wall of the hatch. When the horn was insulated from the hatch and also from the CO_2 cylinder, spark discharges were also detected in the area where the CO_2 impacted on the opposite side of the hatch.

- In view of the demonstrated capability of these devices to produce incendive discharges, the use of portable CO_2 fire extinguishers to inert tanks containing flammable atmospheres should be strictly forbidden. None of the safety literature on the use of CO_2 fire extinguishers reviewed by the present authors contained any warnings regarding the possible spark hazards in flammable atmospheres. Since the present authors are aware of at least three explosions which occurred while these extinguishers were being used to inert fuel tanks, there is ample evidence that such warnings are overdue.

- Removal of the plastic horn and discharging of the extinguisher through the remaining metal orifice reduced the field strength by a factor of 100.

- In view of the comparatively low field strengths obtained during the shipboard tests (110 kV/m maximum vs 1300 kV/m for the CO_2 fire extinguisher) and in the absence of any evidence of spark discharges on the photographs or the probe, it is concluded that CO_2 hatch-snuffing systems which employ gas-type nozzles present only minimal electrostatic hazard. However, since Heidelberg et al. [4] have demonstrated that other types of delivery systems (snow nozzles and a 100-mm pipe) can produce spark discharges, the results of this study cannot be intepreted as a blanket approval of all types of CO_2 inerting systems. Each system must be evaluated on its own merits.

REFERENCES

1. Lifeline—*The Naval Safety Journal* 3 (No. 2), 18 (1974).
2. W.H. Haessler, NFPA Quarterly 221, 1963.
3. B. Lewis and G. von Elbe, *Combustion, Flames and Explosions of Gases*, Academic Press, New York, 2nd edition 1961, p. 334.
4. E. Heidelberg, K. Nabert, and G. Schön, Arbeitsschutz, Fachteil des Bundesarbeitsblattes, Nr. 11, 221, 1958.
5. "Jet Fuel Static Electricity Refueler Variables Study," Socony Mobil Oil Co., Paulsboro, N.J., Sept. 1964.
6. J.T. Leonard and H.W. Carhart, "Static Electricity Measurements During Refueler Loading," NRL Report 7203, Jan. 5, 1971.
7. J.M. van de Weerd, "Electrostatic Charge Generation During The Washing of Tanks With Water Sprays—II: Measurements and Interpretation," in *Static Electrification, 1971*, Institute of Physics, London, 1971, p. 158.
8. K.C. Backman and A.H. Popkin, "Tank Truck Incidents Attributed to Static Electricity, 1960-69," Report RL-72M-69, Esso Research and Engineering Co., Lindon, N.J., Sept. 30, 1969.
9. J.T. Leonard, "Principles of Electrostatics in Aircraft Fuel Systems," in "Lightning and Static Electricity Conference Papers," Air Force Avionics Laboratory, Wright-Patterson AFB, Ohio, Dec. 19, 1972, p. 415.
10. D. van de Meer, "Electrostatic Charge Generation During Washing of Tanks With Water Sprays—I: General Introduction," in *Static Electrification—1971*, Institute of Physics, London, 1971, p. 153.

11. B.F.J. Schonland, *Proc. Roy. Soc.* **A220**, 25 (1953).

12. C. Bruinzeel, *J. Inst. Petroleum* 49, 125 (1963).

13. G. Schön, Arbeitsschutz, Fachteil des Bundesarbeitsblattes, 37, 1956.