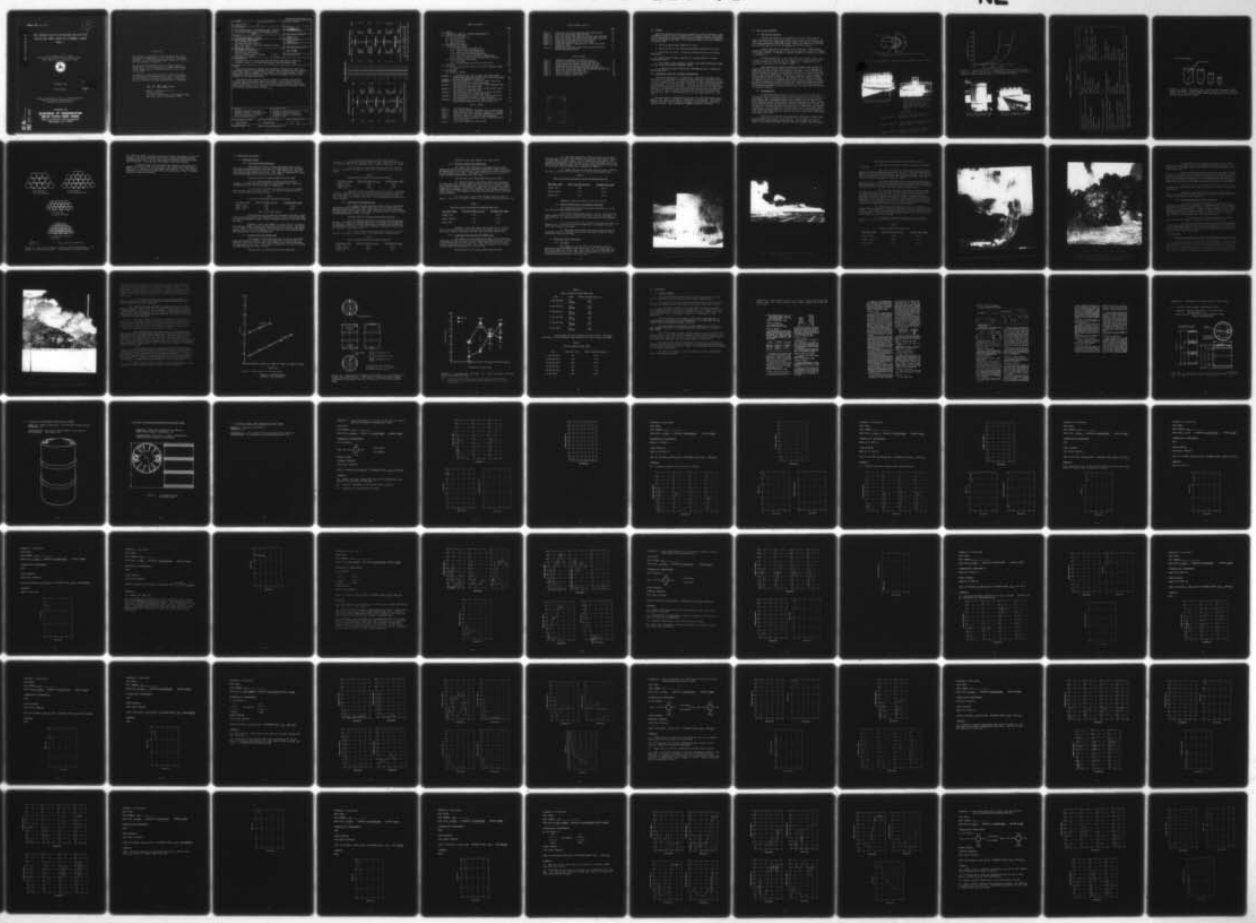
AD-A043 803 COAST GUARD RESEARCH AND DEVELOPMENT CENTER GROTON CONN F/G 13/4
FIRE EXPOSURE TESTS OF POLYETHYLENE AND FIFTY-FIVE GALLON STEEL--ETC(U)
SEP 76 R C RICHARDS, K T WHITE

UNCLASSIFIED CGR/DC-16/76 USCG-D-116-76 NL

1 OF 2
AD A043803



Report No. CG-D-116-76

14

FIRE EXPOSURE TESTS OF POLYETHYLENE AND FIFTY-FIVE GALLON STEEL DRUMS LOADED WITH FLAMMABLE LIQUIDS PHASE I

R. C. Richards and K. T. White
U.S. Coast Guard Research and Development Center
Avery Point, Groton, Connecticut 06340

September 1976

FINAL REPORT

Prepared for

DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD
Office of Research and Development
Washington, D.C. 20590

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

The contents of this report reflect the views of the Coast Guard Research and Development Center, which is responsible for the facts and accuracy of data presented. This report does not constitute a standard, specification or regulation.

D. L. Birkimer

DONALD L. BIRKIMER, Ph.D., P.E.
Technical Director
U.S. Coast Guard Research and Development Center
Avery Point, Groton, Connecticut 06340

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
USCG-D-116-76		

4. Title and Subtitle	5. Report Date
FIRE EXPOSURE TESTS OF POLYETHYLENE AND FIFTY-FIVE GALLON STEEL DRUMS LOADED WITH FLAMMABLE LIQUIDS PHASE I	September 1976
	6. Performing Organization Code
7. Author(s) R. C. RICHARDS and K. T. WHITE	8. Performing Organization Report No. CGR&DC-16/76
9. Performing Organization Name and Address United States Coast Guard Fire and Safety Test Facility Bldg. 108, Brookley Airport and Industrial Complex Mobile, AL 36615	10. Work Unit No. (TRAIS) 763800G.06 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Department of Transportation United States Coast Guard Office of Research and Development Washington, DC 20590	13. Type of Report and Period Covered FINAL REPORT 14. Sponsoring Agency Code

15. Supplementary Notes

Performed at the U.S. Coast Guard Fire and Safety Test Facility under the technical control of the Coast Guard Research and Development Center.

16. Abstract

Tests were conducted to compare the performance (resistance) of steel and polyethylene drums to fire exposure both singly and in arrays using JP-4 (aviation fuel) and Acetone as flammable liquid cargoes. The internal pressure, internal temperature, external temperature, time to failure and method of failure were recorded for each drum type tested.

Polyethylene drums failed by melting, burning or softening and then discharging their liquid cargoes under load pressure. Steel drums failed due to increased temperature of the steel and increased internal pressure causing the double rolled seam at top or bottom to unroll resulting in catastrophic failure of the drum by jetting and/or explosion.

17. Key Words	18. Distribution Statement
hazardous materials containers, flammable liquids, drum fires, ship fires, marine safety, hazardous materials transportation	Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	145	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

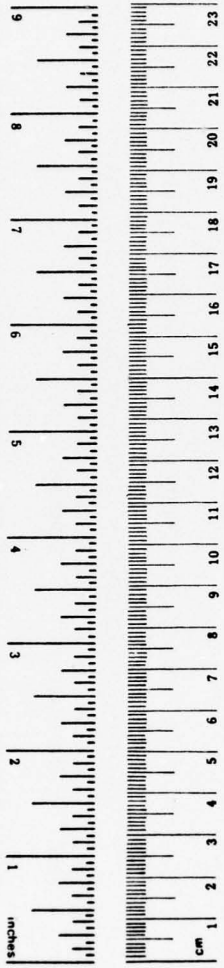
408 730

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

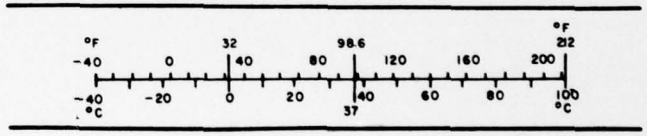
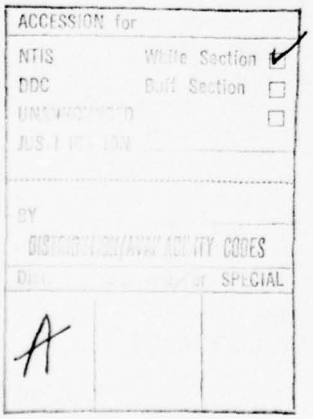


TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF TABLES



1.0 PURPOSE

Many drum producers and users have requested that they be permitted to use polyethylene drums for marine transportation of flammable liquids. The purpose of this testing was to determine whether the polyethylene drums are sufficiently safe in fire exposure situations. The questions answered on the fire endurance of drums include:

a. How do 55 gallon steel drums fail in fire?

b. How do 55, 30, 15, and 5 gallon polyethylene drums fail in a fire?

c. Which will fail first, a 55 gallon polyethylene drum or a 55 gallon steel drum?

d. Which failure is most dangerous, the 55 gallon steel or 55 gallon polyethylene drum?

e. Is it safer to ship flammable liquids in many small polyethylene drums or a few large (55 gallon) polyethylene drums?

f. Is there any relation between wall thickness and time to failure for blow molded drums?

2.0 BACKGROUND OF DRUM USE IN MARINE TRANSPORTATION

Present DOT (Department of Transportation) regulations imply that steel drums are the standard means of packaging small quantities of flammable liquids for marine transportation. Questions with regard to these regulations have been raised in light of the superior impact resistance of the 55 gallon polyethylene drum compared to its steel counterpart. The National Bureau of Standards and the Navy have demonstrated this impact resistance in drop tests and other experimentation. Why then are 55 gallon polyethylene drums used only by exemption? One reasons is that at temperatures between 75°C and 180°C polytheylene will melt and burn. This is a problem which would not be experienced with a steel drum.

The whole matter is complicated by the fact that when steel drums are exposed to heat, some of this heat is transferred to the contents. The contents absorb it and the internal pressure increases to the point where a bursting failure can occur. This releases the flammable contents to the fire.

3.0 TESTING AND PROCEDURES

3.1 The Fire Pan and Fire

The Test Pan (Figure 1) was constructed so that a Table, made of angle iron which could accept 2"x4" wooden slats, could be placed inside. The legs of the table sit on diaphragms in the bottom of the tank and are supported by a weight determining (load cell) system. Water was placed in the pan level with the table and the fire fuel was pumped onto the water surface.

Aviation fuel, JP-4, was chosen for its lower cost, known physical properties, specified mixture and the fact that it provides a volatility similar to toluene or octane. In addition, no special equipment or chemicals are needed to extinguish it.

Acetone based products (e.g., inks, dyes, and cleaning fluids), which a survey of shippers showed was the most common liquid presently being shipped in drums, is much more volatile than JP-4 (Figure 2). A comparison of the properties of acetone and JP-4 is made in Table 1.

Since pressure can accelerate failure, the higher vapor pressure of acetone could cause a shorter time to failure than JP-4. For the purposes of these tests the time to failure is defined as the amount of time (minutes and seconds) between the ignition of the pan fire and failure. Failure occurs when there is any loss of weight due to discharge of cargo. This loss in weight is evident using a load cell system. A five pound or sudden decrease in weight was regarded as failure of the drum. The reaction of JP-4, should be similar to Figure 2, and if so, the temperature data can be used to predict the resulting internal pressure if acetone (or some other liquid whose temperature versus pressure curve is known) were the liquid cargo. A few tests using acetone as the cargo were performed to verify the above curve for acetone and its relation to the time to failure.

3.2 Instrumentation

To determine weight changes, a system of four load cells was used. This system had a 20,000 pounds capacity and was accurate to ± 3 pounds when read graphically. Type K thermocouples were used to measure internal and external drum temperatures. A pressure transducer was connected to the inside of the drum to measure internal drum pressure. These and secondary data were recorded in the Coast Guard Fire and Safety Test Facility's instrumentation trailer. The secondary data included wind speed and direction, air temperature, and barometric pressure. By these means, the failure (greater than 5 pound weight loss or steep loss of internal pressure) of the test drum and the resulting release of cargo liquid were documented. To reinforce this data, movies and/or photographs were taken of all tests.

Entry into the drum for the thermocouple and pressure transducer piping was made through the bung (see Figure 3). For steel drums, the original bung was drilled and tapped to permit mounting. For polyethylene drums, a special teflon adaptor was made to protect the drum and bung. This was needed

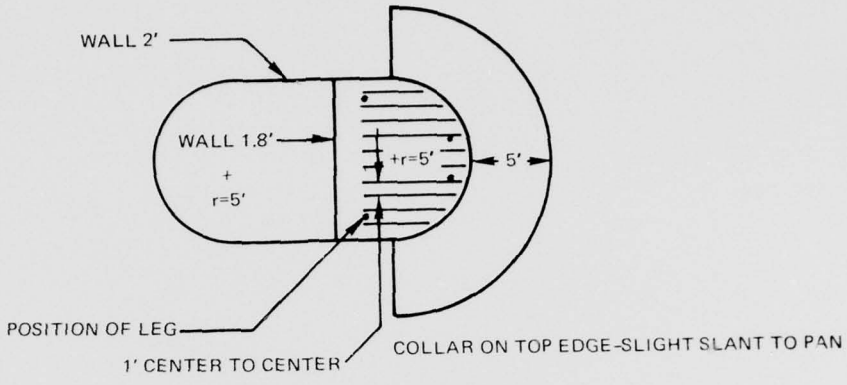
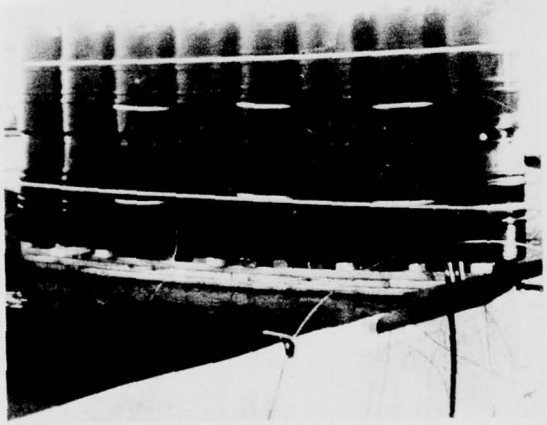
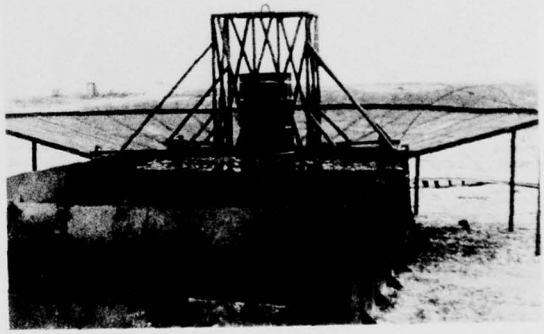


Figure 1. Fire Pan Table. The pan is constructed of steel plate.



View of fire pan and table set up for 55 gal array.



View of fire pan and table set up for test of 55 gal steel drum. Cage was added for safety after explosion of initial test drum.

ERRATA SHEET

Page 3, Figure 1. Picture in lower left belongs in the lower right of Figure 2, page 4.

Page 4, Figure 2. Caption should read "Internal" vice "Vapor" Pressure vs Temperature...

Page 4, Figure 2. Picture in lower right belongs in the lower left of Figure 1, page 3.

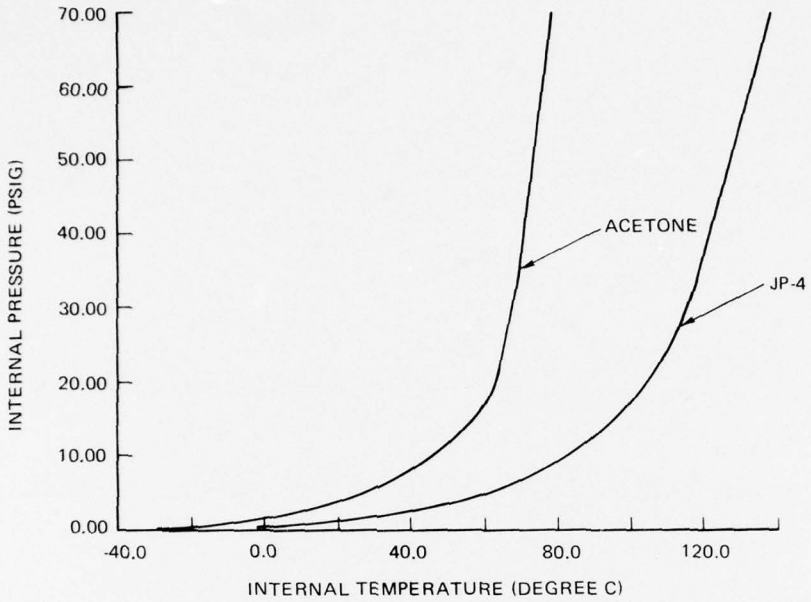
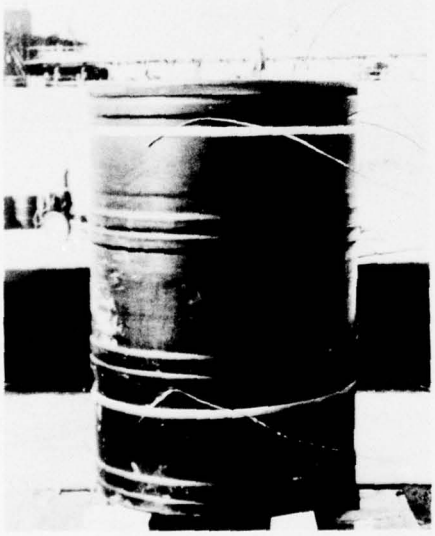
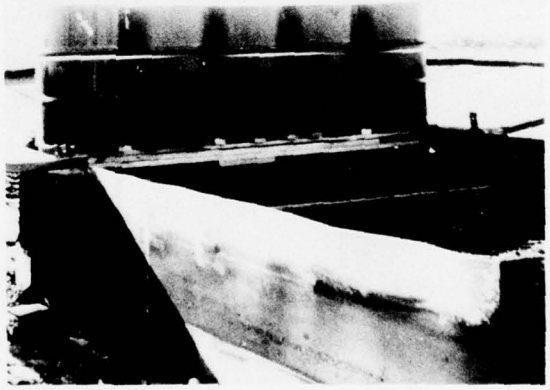


Figure 2: Vapor Pressure vs. Temperature for JP-4 and Acetone (Source: MIL-T-5624 for JP-4 and Physical Chemistry, 3rd Edition, Gordon M. Barrow, McGraw Hill, 1973, P.542 for Acetone)



Single polyethylene drum (55 gal) wired for test



Array of polyethylene drums (15 gal) wired for test

TABLE 1

COMPARATIVE INFORMATION ON ACETONE AND JP-4

	ACETONE	JP-4
Physical State	Liquid	Liquid
Explosive Limits (by volume in air)	Lower 2.6%, Upper 12.8%	Lower 1.3%, Upper 8.0%
Flash Point	-17.8°C (0°F)	-23.3°C to -1.1°C (-10°F to +30°F)
Autoignition Temperature	+560°C (+1040°F)	+240°C (+464°F)
Boiling Point	+56.1°C (+133°F)	+176°C to +287°C (+349°F to +549°F)
Color	Colorless	Colorless to light brown
Corrosivity	Non-corrosive	Non-corrosive
Liquid Density (lb/cu ft) @ 40°F (Linear Over Range) @ 100°F	50.4 48.1	48.4 46.5
Heat of Vaporization at Boiling Point	7.092 kilocalories/mole	78 cal/g (140 BTU/lb)
Melting Point (Freezing Point)	-93.9°C (-137°F)	<-48°C (<-54°F)
Molecular Weight	58.08	Mixture
Odor	Sweetish	Like fuel oil
Vapor Pressure at +20°C (+68°F)	181.7 mm Hg	72.4 mm Hg
Water Solubility (miscibility)	Soluble in all proportions in water	Not soluble
Threshold Limit (toxicity)	1000 ppm.	200 ppm.

(Source: Chemical Safety Data Sheet SD-87-Acetone-Manufacturing Chemists Association; CHRIS Hazardous Chemical Data, CG-446; Specification MIL-T-5624.)

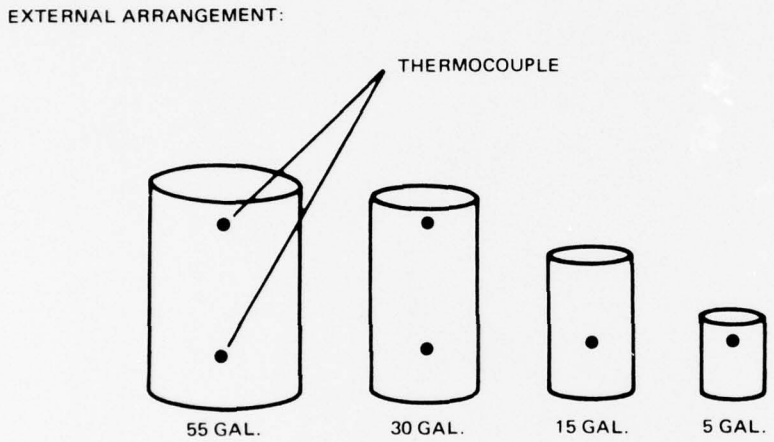


Figure 3: Single Drum Fire Test, External and Internal Thermocouple Placement. Thermocouples were placed 10.5 inches (and 31 inches for 55 and 30 gal drum) above the base and at 0, 90, 180 and 270 from the main seam.

to eliminate a false failure due to heat absorption by the metal fittings or sensors causing a softening or melting of the plastic in contact with them. Since Teflon melts at a higher temperature than the polyethelene, it can therefore insulate the drum from the sensors.

External thermocouples were held in place using steel banding. The banding also absorbed heat but since drums are banded together as part of the standard procedure in shipment, it was felt that this would provide a condition for testing similar to that found in the field.

3.3 Single Drum Tests

Steel drums conforming to 46 CFR (Code of Federal Regulations) 146.05-10(a) and 49 CFR 178.116 (DOT 17E) (Appendix A) were used in a comparison study with two types of polyethelene drums; one blow molded, the other rotationally molded. Steel drums conforming to DOT specification 17E were chosen because of their consistency and high standard of production. Each type was tested separately and the results compared.

The general test sequence was as follows. The test drum was filled to rated capacity with the cargo liquid. Regulations (49 CFR 178.19-3(a) and 178.116-2(a)) require an air space above the liquid in the drum. Care was taken to comply. The drum was then instrumented as required for the different tests. (See Sections 3.2 and Figure 3.) The filled and instrumented drum was placed on wooden slats near the center of the fire pan. The bottom of the drum was approximately 3 inches above the surface of the fuel and the wooden slats were at least 8 inches apart. From the time the drum was filled to the time of the tests was between 3 and 4 minutes which would in no way allow the cargo to interact with the polyethylene drums. The fuel in the pan was ignited and allowed to burn until drum failure occurred and the weight recording system returned to the "table only" weight. The failed drum (if any remained) was examined after the pan fire went out.

This test sequence was followed using the 55 gallon steel drum, 55 gallon rotationally molded polyethylene drum, and the 5, 15, 30, and 55 gallon blow molded polyethylene drums. This was necessary since shape, wall thickness, size, construction, etc., change as the capacity changes. Detailed information on the polyethylene drums used can be found in Appendix B.

3.4 Drum Array Tests

The chances of shipping a single drum of flammable liquid are remote. The more likely situation is to find a cluster of array of drums. To simulate this practice, fire tests were performed on arrays of drums. The arrays, Figure 5, show the closest-packing arrangement of drums normally used by the shipping industry. The arrays were instrumented (Figures 4 and 5) and located at pallet height above the fuel. The fire was ignited and allowed to burn until failure and the return to "table only" weight occurred.

"Table only weight" is defined for the purpose of these tests, as the load cell reading of the fire pan table and empty test drum. This weight value is recorded before the test and then the drum is filled with cargo. During the

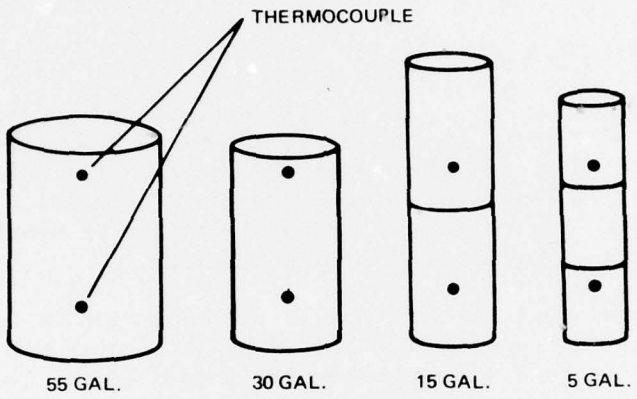
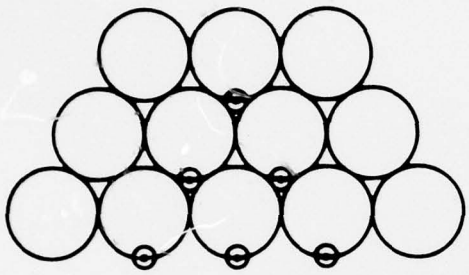
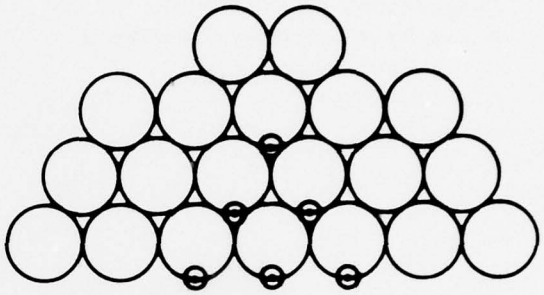


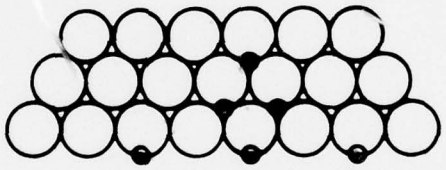
Figure 4: Drum Array Fire Tests, Exterior Thermocouple Placement. Thermocouples were placed 10.5 inches and 31 inches above the base on drums in the positions given in Figure 6.



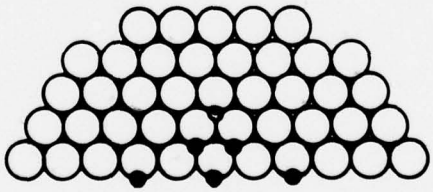
55 GAL DRUM ARRAY
TOTAL CARGO WAS 660 GAL



30 GAL DRUM ARRAY
TOTAL CARGO WAS 600 GALLONS



15 GAL DRUM ARRAY
TOTAL 630 GAL IN 42 DRUMS



5 GAL DRUM ARRAY TOTAL 645 GAL
IN 129 DRUMS

= DRUM

= LOCATION OF 2 THERMOCOUPLES

Figure 5: Top view of Drums in Closet-packing Arrangement. All drums were filled and sealed. Thermocouple placement shown.

test, when this weight is reached, the drum has failed, discharged the cargo and is empty. One array of 55 gallon steel drums, 55 gallon rotationally molded polyethylene drums and 5, 15, 30, and 55 gallon blow molded polyethylene drums were fire tested. The arrays were held together using steel banding.

The smaller drums (5 and 15 gallon) were stacked to approximate the height of a 55 gallon drum. This was done to get similar fire loading (600 to 660 gallons of cargo per array) and similar fire exposure. Heat, and therefore temperature, is a function of height above a burning liquid. Thus, the heights should be as similar as possible.

4.0 OBSERVATIONS AND RESULTS

4.1 Polyethylene Drums

4.1.1 Five Gallon Blow Molded Drum

Test numbers 1-3 and 17-19 were made using single 5 gallon blow molded polyethylene drums conforming to DOT Specification 34. For these tests the drums were loaded with JP-4 as cargo. Test numbers 20-22 used the same drums but used acetone as the cargo. Test number 35 consisted of an array of 129 drums loaded with 645 gallons of JP-4 for cargo.

From the tests the following observations were made:

(a) The drums failed when the sides burned, melted or softened. The cargo left the drum under its head pressure only. There was no detectable rise in interior pressure or temperature.

(b) The times to failure and discharge rates for the single drum and array tests are shown in Table 2. The data is the mean for three tests of each type unless otherwise noted.

TABLE 2

FIVE GALLON BLOW MOLDED POLYETHELENE DRUM DATA

TYPE TEST, CARGO	TIME TO FAILURE (min-sec)	DISCHARGE RATE (gpm)*
Single, JP-4	0-39	14.5
Single, Acetone	1-16	27.5
Array, JP-4	0-30	212.6

*gpm = gallons per minute

The discharge rate is defined as the number of gallons of cargo in the test drum divided by the difference of time to failure and the time when the table only weight is reached. This is expressed in units of gallons of cargo per minute.

Appendix C covers test numbers 1-3, 17-22, and 35. In each of the tests the interior pressure and temperature rose after failure. The results of test number 22 were discarded when the discharge rate for Acetone was determined for Table 2, due to the abnormal type of failure of this particular drum. This failure gives a very low discharge rate.

4.1.2 Fifteen Gallon Blow Molded Drum

Test numbers 4-6 were made using single 15 gallon blow molded polyethylene drums conforming to DOT Specification 34. For these tests the drums were loaded with JP-4 as cargo. Test numbers 23-25 used the same drums but used Acetone as the cargo. Test number 42 consisted of an array of 42 drums contained 630 gallons of JP-4 for cargo.

From the tests the following observations were made:

(a) The drums failed when the sides burned, melted or softened. The failures were observed between 5 and 15 inches from the bottom of the drum. There was no observable rise in internal temperature or pressure.

(b) The times to failure and discharge rates are shown in Table 3. The data is the mean for three tests of each type unless otherwise stated.

TABLE 3

FIFTEEN GALLON BLOW MOLDED POLYETHYLENE DRUM DATA

TYPE TEST, CARGO	TIME TO FAILURE (min-sec)	DISCHARGE RATE (gpm)
Single, JP-4	0-54	20.8
Single, Acetone	2-03	47.1
Array, JP-4	1-12	65.6

Appendix D covers test numbers 4-6, 23-25, and 42. Once again in each of these tests the rise in internal temperature and pressure occurred after the failure of the drum. The failure of the bottom layer of drums in array test number 42 caused the top layer to fall and apparently decreased their time to failure.

4.1.3 Thirty Gallon Blow Molded Drum

Test numbers 7-9 were made using single 30 gallon blow molded polyethylene drums conforming to DOT Specification 34. For these tests the drums were loaded with JP-4 as cargo. Test numbers 26-28 used the same drums but used Acetone as the cargo. Test number 43 consisted of an array of 20 drums containing 600 gallons of JP-4 for cargo.

From the tests the following observations were made:

(a) The failures occurred 15 to 24 inches from the bottom of the drum. The side of the drum burned, melted or softened to allow discharge of the cargo. Changes in internal temperature and pressure were recorded but are believed in error due to fluctuation caused by a transducer failure, which was corrected for subsequent tests.

(b) Time to failure and discharge rates are given in Table 4. The data is the mean for three tests of each type unless otherwise noted.

TABLE 4

THIRTY GALLON BLOW MOLDED POLYETHYLENE DRUM DATA

TYPE TEST, CARGO	TIME TO FAILURE (min-sec)	DISCHARGE RATE (gpm)
Single, JP-4	1-27	50.4
Single, Acetone	2-00	54.0
Array, JP-4	1-42	53.1

Appendix E covers test numbers 7-9, 26-28, and 43.

4.1.4 Fifty-Five Gallon Blow Molded Drum

Test numbers 10-12 were made using single 55 gallon blow molded polyethylene Special Permit (Exemption) drums which closely conform to DOT Specification 34, except for size. Test numbers 29-31 used the same drums but used Acetone as the cargo. Test number 44 consisted of an array of 12 drums loaded with 660 gallons of JP-4 for cargo.

From the tests the following observations were made:

(a) Failure resulted from burning, melting or softening of the drum sides 15 to 24 inches above the base of the drum. The cargo flowed out of the drum under head pressure only. There was no real rise in internal temperature or pressure. The pressure readings from test number 10 were discarded due to instrument failure. The temperature rise occurred very near the failure time and it is believed that the drum failed earlier than recorded but was not detected.

(b) The times to failure and discharge rates are given in Table 5. The data is the mean for three tests of each type unless otherwise noted.

TABLE 5

FIFTY-FIVE GALLON BLOW MOLDED POLYETHYLENE DRUM DATA

TYPE TEST, CARGO	TIME TO FAILURE (min-sec)	DISCHARGE RATE (gpm)
Single, JP-4	1-40	152.8
Single, Acetone	1-31	131.2
Array, JP-4	1-33	212.9

Appendix F covers test number 10-12, 29-31 and 44. Through most of the tests there was no increase in internal temperature or pressure until after failure. Once again the cargo left under head pressure only.

4.1.5 Fifty-Five Gallon Rotationally Molded Drum

Test numbers 13-15 were made using single 55 gallon rotationally molded polyethylene Special Permit (Exemption) drums which closely conform to DOT Specification 34, except for size. Test numbers 32-34 used the same drums but used Acetone as the cargo. Test number 45 consisted of an array of 12 drums loaded with 660 gallons of JP-4 for cargo.

From the tests the following observations were made:

(a) Observable discharge of cargo occurred 15 to 40 inches from the base of the drum. The sidewall burned, melted or softened to release the cargo under its head pressure. Figure 6 shows this quite clearly. For purposes of photography, a hand line was used to almost extinguish the pan fire. Since this was taken just after failure the mode of failure can be clearly seen. No increase in internal temperature or pressure was observed.

(b) Times to failure and discharge rates are given in Table 6. The data is the mean for three tests of each type unless otherwise noted.

TABLE 6

FIFTY-FIVE GALLON ROTATIONALLY MOLDED POLYETHYLENE DRUM DATA

TYPE TEST, CARGO	TIME TO FAILURE (min-sec)	DISCHARGE RATE (gpm)
Single, JP-4	2-04	161.0
Single, Acetone	2-27	118.1
Array, JP-4	1-44	95.7

Appendix G covers test numbers 13-15, 32-34 and 45.

4.1.6 General Observations of Polyethylene Drum Tests

The following observations were made encompassing all of the fire tests involving polyethylene drums:

(a) Failure occurred with side wall failure. Failure of the smaller drums may have at first occurred very high on the side wall similar to test number 22. The remaining side wall then failed giving the low discharge rate.

(b) Upon failure the drums released the cargo liquid under head pressure only. No real rise in internal temperature (or pressure) occurred until after failure of the drums.

(c) Discharge rates increase with drum capacity and this is to be expected due to the higher head pressure and greater volume of liquid available as drum size increases.

4.2 Fifty-Five Gallon Steel Drums

4.2.1 The Tests

Test numbers 16, 36, and 38-41 were made using single 55 gallon steel drums conforming to DOT Specification 17E. For these tests the drums were loaded with JP-4 as cargo. Test number 37 used the same type drum but used Acetone as the cargo. Test number 46 consisted of an array of 12 drums loaded with 660 gallons of JP-4 for cargo.

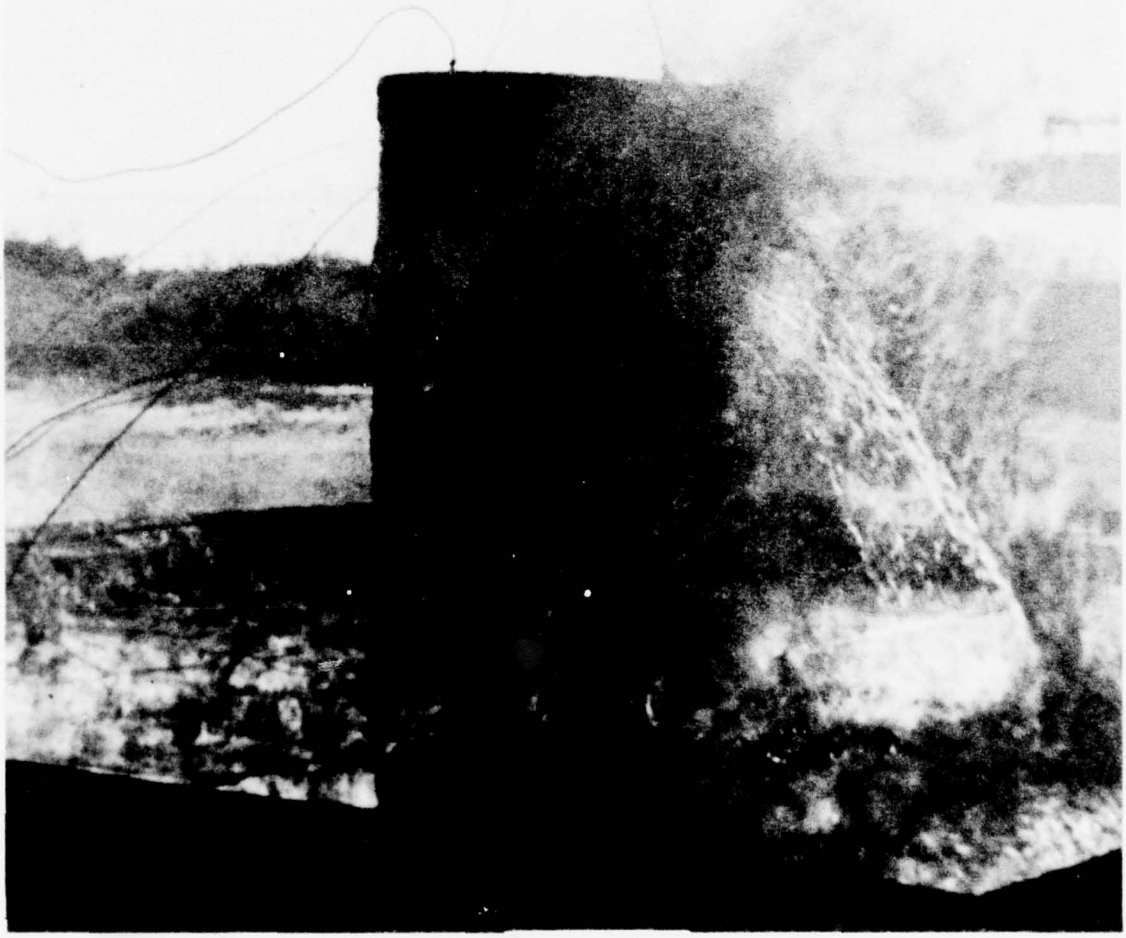


FIGURE 6 - FIFTY-FIVE GALLON ROTATIONALLY MOLDED POLYETHYLENE DRUM JUST AFTER FAILURE

Pan fire nearly extinguished by handline for photo purposes.

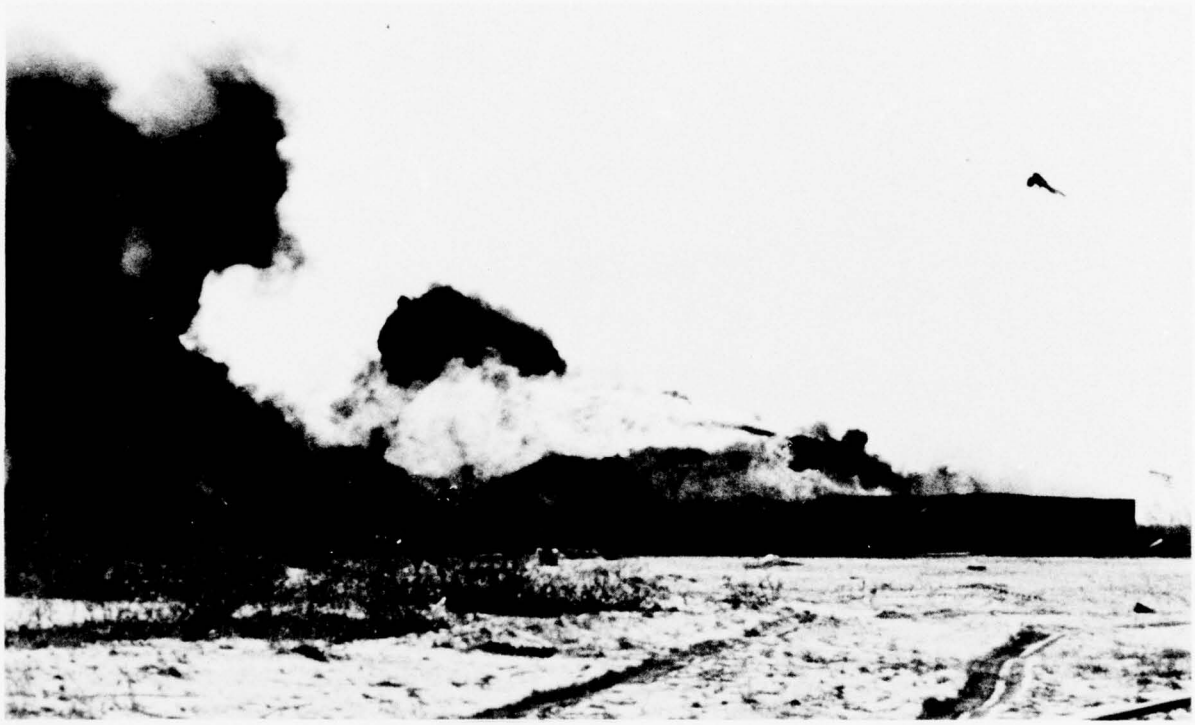


FIGURE 7 - A FIFTY-FIVE GALLON STEEL DRUM JETTING CARGO VAPOR

The cargo is JP-4.

From these tests the following observations were made:

(a) There were three modes of failure as the drum is exposed to the fire:

(1) The first mode occurred when the rolled seam would soften and unroll allowing the vapor to vent in a jet. This is clearly seen in Figure 7 which shows a 55 gallon steel drum jetting cargo vapor. The cargo in this test is JP-4. This mode of failure may relieve the pressure sufficiently so that the drum will continue to vent until empty.

(2) The second mode of failure occurs when the internal pressure continues to rise even after venting and the drum explodes, blowing the top or bottom out. This type of failure is shown in Figure 8. In this instance the top blew off and the JP-4 cargo was thrown out under pressure.

(3) The third and most violent mode of failure is when an entire top or bottom rolled seam fails without jetting. The internal pressure rises and upon failure the fuel is thrown out as a fire ball and the remainder of the barrel becomes a projectile. Figure 9 shows the effects of this mode of failure. This picture shows a 55 gallon drum, which had a bottom seam fail, and the remainder of the drum went 150 to 200 feet into the air over a fire ball, itself over 65 feet across. In the left of the picture the smoke trail and instrumentation leads can be seen trailing the drum.

(b) Throughout the test series no failure of the vertical welded seams were observed. Jetting occurred when the interior pressure reached 8 psig. The maximum interior pressure observed was 71 psig, immediately prior to an explosion. Of the 19 steel drums tested (including the array), with JP-4 as the cargo, 12 (63 percent) exploded.

(c) The times to failure and discharge rates are shown in Table 7. The data is the mean for three tests of each type unless otherwise noted.

TABLE 7

FIFTY-FIVE GALLON STEEL DRUM DATA

TYPE TEST, CARGO	TIME TO FAILURE (min-sec)	DISCHARGE RATE (gpm)
Single, JP-4	4-48	8.9
Single, Acetone	1-25	40.2
Array, JP-4	∿8 min	23.6

FIGURE 8 - A FIFTY-FIVE GALLON STEEL DRUM EXPLODES (blowing the top off) AFTER VENTING

FIGURE 9 - A FIFTY-FIVE GALLON STEEL DRUM EXPLODING

A 55 gallon steel drum loaded with JP-4 has a bottom failure. The drum went 150 to 200 feet into the air over a fire ball over 65 feet across. Note the white smoke trail left by the drum and the instrumentation leads trailing the drum.

The discharge rate of the single drum JP-4 tests excludes the data from test number 16 due to the explosive failure of that drum. This failure gave an extremely high rate of discharge and therefore skewed the data on the other tests.

The Acetone single drum test data is from test number 38 only. The data on the 55 gallon array loaded with JP-4 is from test number 46, which was not instrumented. This was done to allow sufficient time for personnel to clear to a safe distance and to protect the instrumentation readout from any damage from the fire and explosion. The times for this test were determined by observation of the drums. The observation times are accurate to $\pm$10 seconds.

Due to the lack of instrumentation the time between the first explosion and last explosion was taken as the time to be used to calculate the discharge rate.

Appendix H covers test numbers 16, 36, 37, 38-41 and 46. In each of the tests the rolled seam failed due to increasing internal pressure caused by increasing internal temperature.

4.2.2 General Observations of Steel Drum Tests

(a) Steel drums fail explosively, or by jetting, or by a combination of jetting and an explosion. The tendency is for them to explode (63 percent with JP-4 as cargo). Figure 10 shows a 55 gallon steel drum with Acetone as cargo exploding after a 2 minute 47 second exposure to fire. This drum began jetting at 1 minute 25 seconds. The white area at the top of the flaming geyser is unburned Acetone. Figure 11 shows the same test seconds later after the fire has caught up to the unburned Acetone.

In these tests all the failures occurred at a rolled seam, either top or bottom. The welded, vertical seam did not fail.

(b) Steel drum failures result in large discharge rates due to the tendency for these containers to fail explosively. As the volatility of the cargo liquid increases, the time to failure decreases. The more volatile the liquid the faster the rise in interior pressure, which results in an increase in the tendency to explode.

5.0 DISCUSSION

5.1 Failure of Fifty-Five Gallon Steel and Polyethylene Drums in a Fire

(a) DOT Specification 17E - Steel drums exposed to a fire will fail by jetting and/or exploding. Explosion is the far more common failure mode on interior drums of an array (8 or 9 of the 12 drums exploded in the array test number 46; 6 of these did not jet prior to exploding). The time to failure of this drum was longer than polyethylene when JP-4 was used as the cargo. With JP-4 this drum averaged 4 minutes 48 seconds until failure versus an average

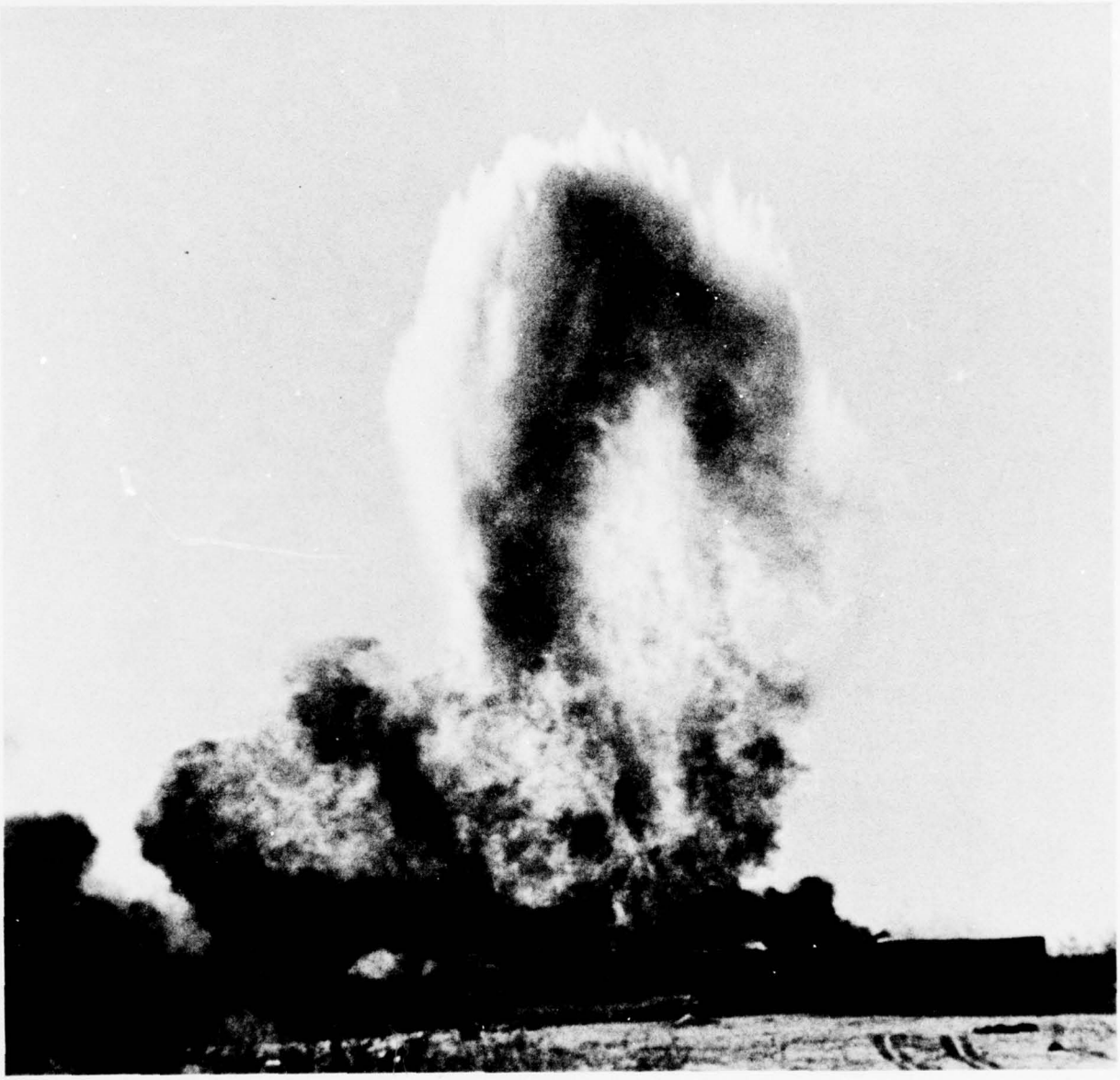


FIGURE 10 - FIFTY-FIVE GALLON STEEL DRUM WITH ACETONE CARGO EXPLODING

This 55 gallon steel drum loaded with Acetone began jetting at 1 minute 24 seconds and exploded, as seen here, after 2 minutes 47 seconds. Note the unburned Acetone at the top of the flaming geyser.

FIGURE 11 - FIFTY-FIVE GALLON STEEL DRUM WITH ACETONE CARGO EXPLODING

View of aerial fire ball (from 1/4 mile away from the test pad). The Acetone, yet unburned in Figure 10, burns in midair.

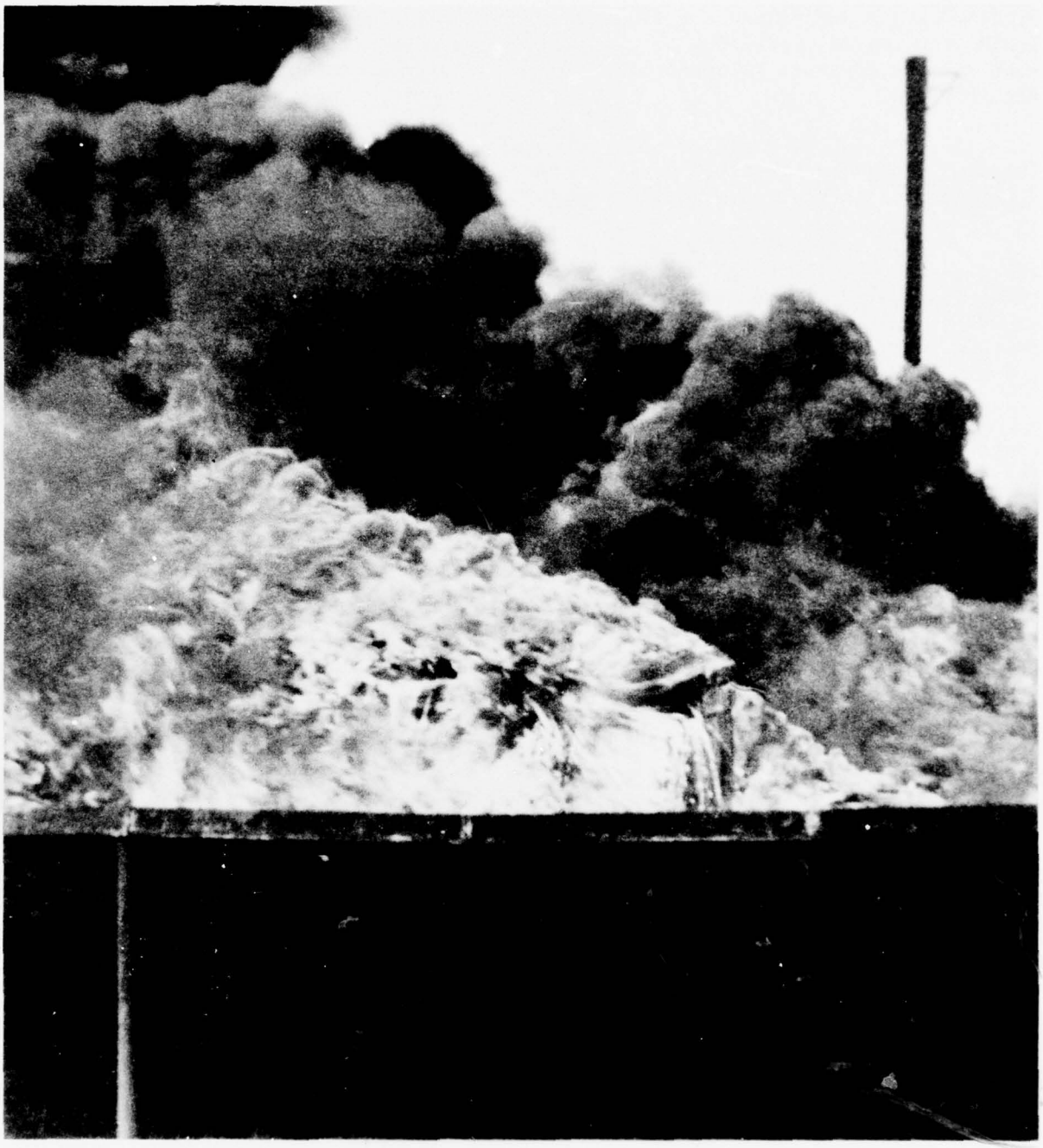


FIGURE 12 - THIRTY GALLON POLYETHYLENE TEST ARRAY FAILURE

The drums in the 30 gallon array test melted, burned or softened to release the JP-4 cargo. The cargo is released under head pressure only.

of 1 minute 54 seconds with the polyethylene drums. This time period could give fire fighters sufficient time in which to extinguish a blaze. The disadvantage of the steel drum lies in the pressure buildup. The cause of the buildup was not determined but is probably due to the vapor pressure over the liquid, the thermal expansion of the liquid or a combination of the two. The result of the pressure is drum failure with the drum's contents thrown over a large area.

In the range of volatility of the cargo liquids tested, the time to failure for the steel drums loaded with flammable liquids decreases as the volatility of the cargo increases.

(b) Polyethylene drums loaded with flammable liquids melt, burn or soften to release the cargo under only the cargo head pressure for the range of liquids tested. This is illustrated in Figure 12 which shows the drums in the 30 gallon array test failing. The JP-4 cargo is being released under head pressure only as the drums melted, burned or softened. There was no fire ball or explosion to hamper personnel.

The time to failure for polyethylene drums, in the range of volatility of these tests, does not decrease (it increases or remains the same) with increasing volatility. This is explained by the different liquid heat capacities of JP-4 and acetone which are shown in Figure 13. Since acetone can absorb more heat then JP-4, it will insulate the drum for a longer period of time, thus increasing the time to be expected to failure.

Due to production and resin differences in polyethylene drums, exact failure times and modes cannot be predicted. Figure 14 shows a 55 gallon blow molded drum. The figure would be typical for blow molded drums as the thinnest area is located 90° from the parting line. The sharp radii in this area would be the thinnest areas. This fact alone could influence the time to failure. The 55 gallon blow molded drum used in this test was made of a high density polyethylene with a melting point of 135°C (275°F) and a decomposition temperature range of 335°C to 450°C.

At best then, these facts, combined with the rather indefinite change of state of polyethylene, make it difficult to predict a time to failure as with steel drums. A plot of test data on times to failure was made versus the minimum wall thickness called for by specifications (Figure 15). As can be seen, there appears to be little relation between time to failure and minimum wall thickness. The increase in failure time for acetone is again explained by the difference in liquid heat capacity between JP-4 and Acetone (Figure 13).

(c) Table 8 gives the time to failure of the single drum tests. With polyethylene drums as size increases, the time to failure increases.

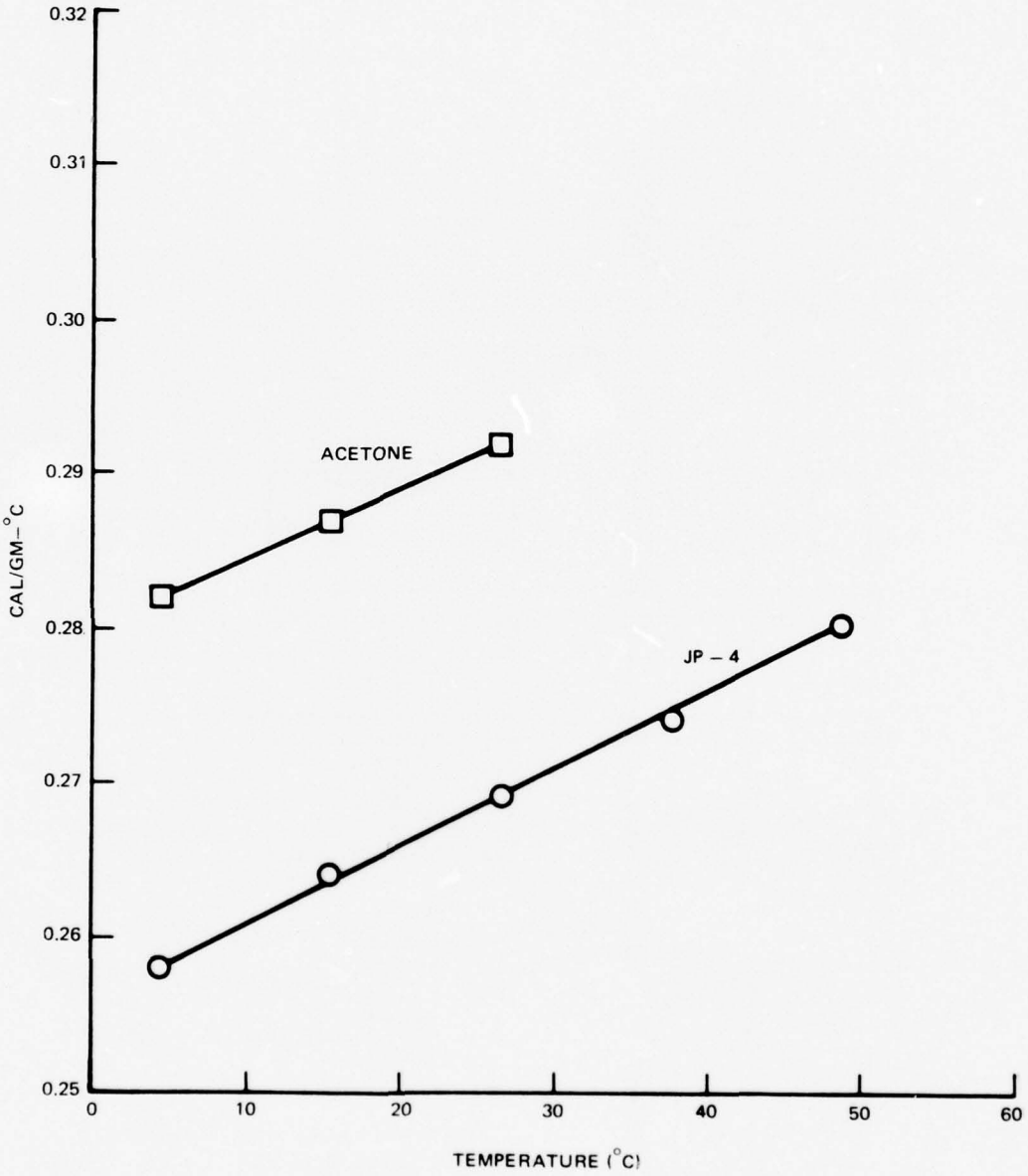


FIGURE 13. Heat Capacity of JP-4 and Acetone

Source: CHRIS Hazardous Chemical Data-CG-446-2

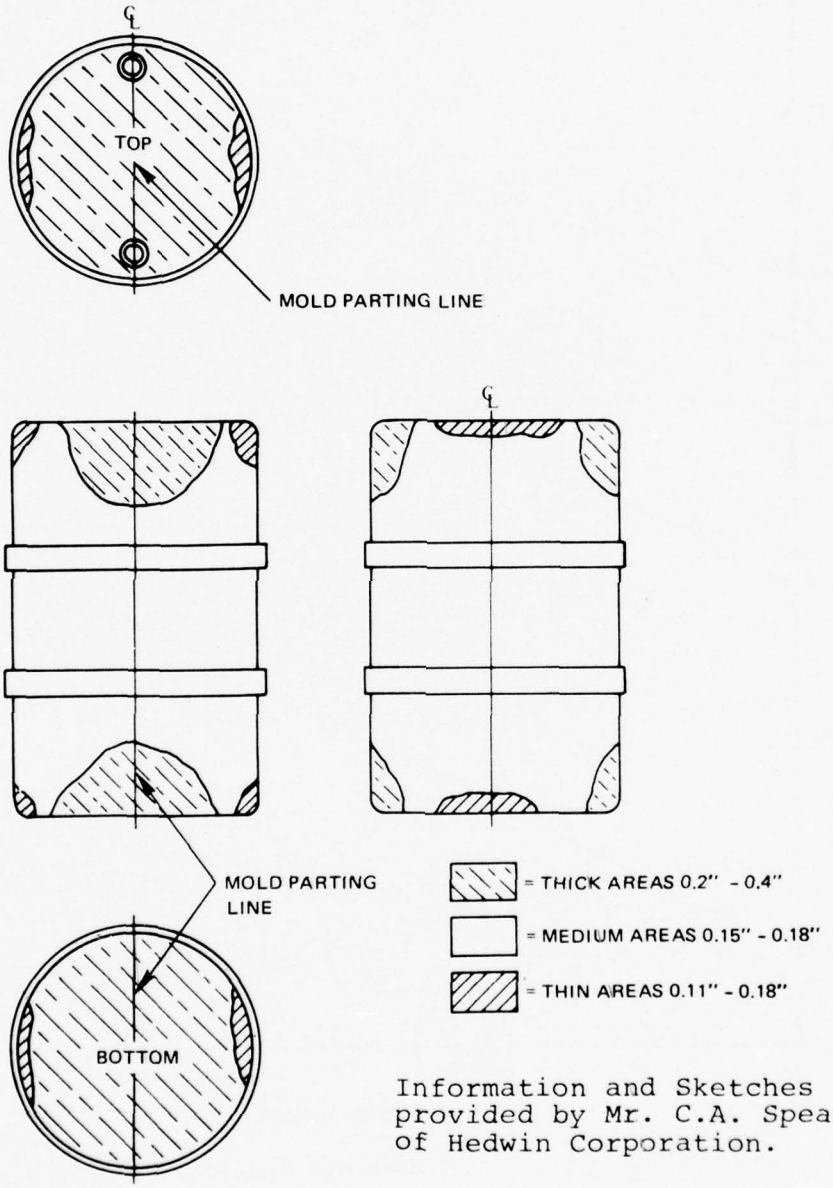


Figure 14. Distribution of Material Thickness in a Blow Molded 55 Gallon Polyethylene Drum. Drum shown is manufactured by Hedwin Corporation, Baltimore, MD, but is typical of other blow molded drums.

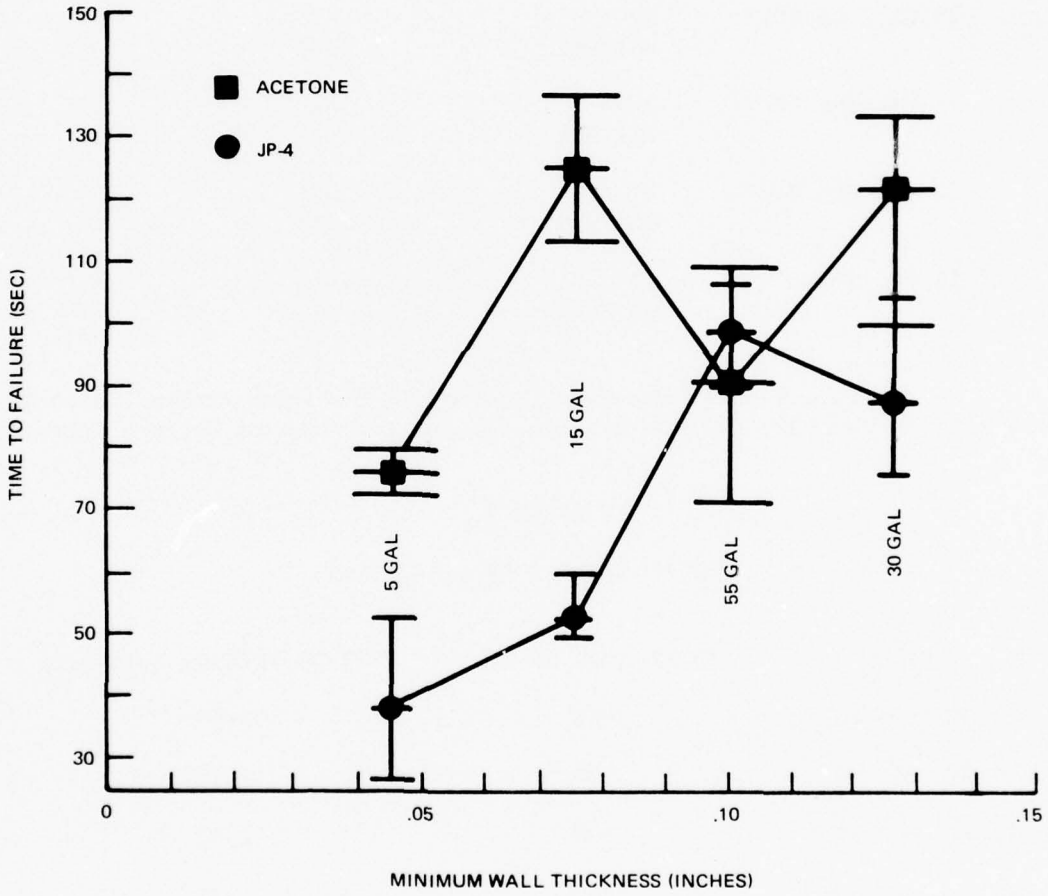


Figure 15: Minimum Wall Thickness vs. Time to Failure for Blow Molded Polyethylene Drums.

NOTE: The vertical lines indicate the range of the data for each drum. The intersection of the vertical and horizontal lines is an actual data point.

TABLE 8

TIME TO FAILURE OF SINGLE DRUM TESTS

SIZE	CARGO	TIME TO FAILURE (min-sec)
5 GAL BLN POLY	JP-4	0-39
	ACETONE	1-16
15 GAL BLN POLY	JP-4	0-54
	ACETONE	2-03
30 GAL BLN POLY	JP-4	1-27
	ACETONE	2-00
55 GAL BLN POLY	JP-4	1-40
	ACETONE	1-31
55 GAL ROT POLY	JP-4	2-04
	ACETONE	2-27
55 GAL STEEL	JP-4	4-48
	ACETONE	1-25

Table 9 gives the same information for drum arrays. Once again, as the size of the polyethylene drum increases, the time to failure increases.

TABLE 9

TIME TO FAILURE OF ARRAY TESTS

SIZE	CARGO (GAL JP-4)	TIME TO FAILURE (min-sec)
5 GAL BLN POLY	645	0-30
15 GAL BLN POLY	630	1-12
30 GAL BLN POLY	600	1-42
55 GAL BLN POLY	660	1-33
55 GAL ROT POLY	660	1-44
55 GAL STEEL	660	∿8 min

6.0 CONCLUSIONS

6.1 Specific Comments

(a) Fifty-five gallon steel drums fail by jetting and/or exploding when the rolled top or bottom seam fails from internal drum pressure.

(b) The 55, 30, 15, and 5 gallon polyethylene drums fail by melting, burning or softening and then releasing the cargo liquid under head pressure.

(c) The time to failure of a specification 17E steel drum appears to be dependent on the volatility of the liquid cargo. The higher the volatility of the two liquids tested, the shorter the time to failure. On the other hand, the polyethylene drums' fire endurance appears to be independent of cargo volatility.

(d) The failure of the 55 gallon steel drum is more dangerous, as the tendency of this container to fail explosively will spread the fire and create a hazard for personnel exposed to the fire.

(e) The results of this series of tests indicate that it is safer to ship flammable liquids in a few large polyethylene drums than in a cluster of small drums.

(f) In the range of liquids covered by these tests, polyethylene drums should be used to carry very volatile flammable liquids, since no explosive failures can occur. (Note that the time to failure may or may not be longer than for steel drums which depends on the liquid heat capacity of the cargo.)

(g) Steel drums should be preferable for transport of low volatility flammable liquids since the chances of explosive pressure being reached decreases and the time to drum failure should be longer. This allows more time to extinguish the fire before drum failure.

(h) There is a range of volatility where both steel or polyethylene can be used without preference.

Appendix A: Specifications for 5, 15, and 30 gallon polyethylene drums (Spec 34) and 55 gallon steel drums (Spec 17E) Title 49 U.S. Code.

§ 178.19 Specification 34; reusable molded polyethylene container for use without overpack. Removable head not authorized.

[Order 71, 31 F.R. 9073, July 1, 1966]

§ 178.19-1 Compliance.

(a) Required in all details.

[Order 71, 31 F.R. 9073, July 1, 1966]

§ 178.19-2 Material.

(a) Containers shall be made of polyethylene which shall have the following properties, as determined by the American Society for Testing Materials (ASTM) methods designated. Tests shall be performed on resin with additives included:

Property	Specification	ASTM method
Melt index	1.2 maximum	D 1238 (62T).
Density range	0.941-0.965	D 1505 (63T).
Tensile strength	3,000 p.s.i. minimum.	D 638 (61T).
Percent elongation.	75 percent minimum.	D 638 (61T).

(b) Ultraviolet light protection shall be provided by impregnation of polyethylene with carbon black or other equally efficient pigments or inhibitors These additives must be compatible with lading and must retain their effectiveness for the life of the container.

(c) Other materials may be added provided they do not adversely affect the physical properties specified in paragraph (a) of this section or the performance specified in § 178.19-7.

[Order 71, 31 F.R. 9073, July 1, 1966]

§ 178.19-3 Construction and capacity.

(a) Container must be constructed in accordance with the following table:

Marked (rated) capacity not over (gallons)[1]	*Minimum thickness (inches) measured on any point of container*
2½ thru 6½	0.045
15	.075
30	.125

[1] Minimum actual capacity shall not be less than rated capacity plus 4 percent. Maximum actual capacity shall not be greater than rated capacity plus 15 percent for containers up to 15 gallons and shall not be greater than rated capacity plus 10 percent for containers 15 gallons and over.

[Order 71, 31 F.R. 9073, July 1, 1966]

§ 178.19-4 Closure.

(a) Openings shall not exceed 2.7 inches in diameter.

(b) Closures shall be of material resistant to lading and adequate to prevent leakage under tests prescribed in § 178.19-7 and under conditions incident to transportation.

(c) Vented closures where specified in Part 173 of this chapter are authorized

[Order 71, 31 F.R. 9073, July 1, 1966]

§ 178.19-5 Defective containers.

(a) Containers with repaired bodies not authorized.

[Order 71, 31 F.R. 9073, July 1, 1966]

§ 178.19-6 Marking.

(a) Each container must be permanently marked by embossment in letters and figures at least ½ inch in size as follows:

(1) DOT-34**; stars to be replaced by the rated capacity of the container (for example, DOT-34-5). These marks shall be understood to certify that the container complies with all specification requirements

(2) Month and year of manufacture; name of maker or maker's symbol (symbol, if used, must be registered with the Bureau of Explosives). For example, DOT-34-5-6/65 to indicate a container of 5 gallons capacity made in June 1965.

[Order 71, 31 F.R. 9073, July 1, 1966]

§ 178.19-7 Tests.

(a) At least three samples taken at random, filled and prepared as specified and closed as for use, shall be capable of withstanding the tests in subparagraphs (1), (2), and (3) of this paragraph without leakage. These tests shall be performed at the start of initial production and at 4-month intervals and shall be repeated on any change of type, size, materials, or process method. No single container shall be expected to withstand more than one of the following tests:

(1) The container filled to 98 percent capacity with water shall be dropped from a height of 4 feet onto solid concrete so as to drop diagonally on top edge or any part constructed to a lesser strength.

(2) The container filled to 98 percent capacity with a solution compatible with polyethylene and which remains liquid at 0° F. shall be dropped from a height of 4 feet onto solid concrete on any part of the container when container and contents are at or slightly below 0° F. Filled container shall be stored at 0° F. or lower temperature for at least 4 hours immediately preceding test.

(3) The container shall be tested by retaining for 5 minutes hydrostatic pressure of at least 15 pounds per square inch at equilibrium without showing pressure drop or evidence of leakage.

(b) At least three containers taken at random from each continuous production lot of no more than 1,000 containers of each given type and size shall withstand without leakage or failure the test prescribed in § 178.19-7(a)(2).

(c) At least three containers of each size and type taken at random at start of initial production, and upon any change in materials, design, or process method shall withstand without failure or leakage the following tests. No single container shall be expected to withstand more than one test:

(1) The container filled to 98 percent of capacity with water shall be capable of withstanding a vibration test by placing the container on the vibration table anchored in such manner that all horizontal motion shall be restricted and only vertical motion allowed. The test shall be performed for one hour using an amplitude of one inch at a frequency that causes the test container to be raised from the floor of the table to such a degree that a piece of paper or flat steel strap or tape can be passed between the table and the container.

(2) The container filled to 98 percent capacity with water shall withstand the following static compression test without buckling of the side walls sufficient to cause damage, but in no case shall the maximum top to bottom deflection be more than one inch. Compression shall be applied to the load bearing areas of the top of the container for a period of not less than 48 hours.

Marked (rated) capacity (gallons)	*Compression test (pounds)*
2½ thru 6½	600
15	1,200
30	1,800

(d) Records of test results to be maintained in current status and retained by each manufacturer at each producing plant.

[Order 71, 31 F.R. 9073, July 1, 1966]

§ 178.116 Specification 17E; steel drums.

Single trip container. Removable head containers not authorized.

§ 178.116-1 Compliance.

(a) Required in all details.

§ 178.116-2 Rated capacity.

(a) Rated capacity as marked, see § 178.116-10(a)(3). Minimum actual capacity of containers shall be not less than rated (marked) capacity plus 4 percent. Maximum actual capacity shall not be greater than rated (marked) capacity plus 5 percent or rated (marked) capacity plus 4 percent plus 1 quart whichever is the greater.

§ 178.116-3 Composition.

(a) Sheets for body and heads to be low carbon, open hearth or electric steel.

§ 178.116-5 Seams.

(a) Body seams welded.

§ 178.116–6 Parts and dimensions.

(a) Parts and dimensions as follows:

Marked capacity not over (gallons)	Type of container	Minimum thickness, uncoated sheets (gauge)		Rolling hoops		
		Body sheet	Head sheet	Type	Minimum	
					Size (gauge or inch)	Weight (pounds per foot)
5	Straight side	24	24	None		
10	do	22	22	do		
30	do	[2] 19	[2] 19	(1)		
55	do	[2] 18	18	(1)		

[1] Rolled or swedged in hoops.
[2] 20 gauge authorized.

(b) Steel sheets of specified gauges shall comply with the following:

Gauge No.	Nominal thickness [1] (inch)	Minimum thickness [1] (inch)
18	0.0478	0.0428
19	.0418	.0378
20	.0359	0324
22	.0299	0269
24	.0239	0209

[1] Thickness shall be measured at any point on the sheet not less than ⅜ inch from an edge.

[29 FR 18893, Dec. 29, 1964. Redesignated at 32 FR 5606, Apr. 5, 1967 and amended by Amdt. 178–31, 39 FR 10910, Mar. 22, 1974; 39 FR 11891, Apr. 1, 1974]

§ 178.116–7 Convex heads.

(a) Convex (crowned) heads, not extending beyond level of chime, required for drums of 25 gallons capacity or over. Convexity to be minimum of ⅜".

§ 178.116–8 Closures.

(a) Adequate to prevent leakage; gaskets required.

(b) Closing part (plug cap plate etc., see Note 1) must be of metal as thick as prescribed for head of container: *Provided,* That thinner metal closures or closures of other material are authorized for containers of 12 gallons capacity or less when opening to be closed is not over 2.7 inches in diameter and closures, except threaded metal closures, are fitted with outside sealing devices which cannot be removed without destroying the closure or sealing device (see paragraph (d) of this section).

NOTE 1: This does not apply to cap seal over a closure which complies with all requirements.

(c) For closure with threaded plug or cap, the seat (flange, etc.) for plug, or cap, must have 3 or more threads; two drainage holes of not over 5/16 inch diameter are allowed. Plug, or cap, must have sufficient length of thread to engage 3 threads when screwed home with gasket in place: *Provided,* That for containers having a capacity of 12 gallons and less the seat (flange, etc.) for plug, or cap, must have two or more complete threads and plug, or cap, must have sufficient length of thread to engage two threads when screwed home with gasket in place.

(d) Closures of screw-thread type or closed by positive means, of any material or design, may be authorized by the Bureau of Explosives for use, upon satisfactory proof of efficiency.

§ 178.116–9 Defective containers.

(a) Leaks and other defects to be repaired by method used in constructing container, not by soldering.

§ 178.116–10 Marking.

(a) Marking on each container by embossing on head with raised marks, or by embossing or die stamping on footring on drums equipped with footrings, or on metal plates securely attached to drum by brazing or welding not less than 20 percent of the perimeter as follows:

(1) DOT–17E. The letters STC; located near the DOT mark to indicate "single-trip container." In addition, when the container is of stainless steel, the type of steel used in body and head

sheets as identified by American Iron and Steel Institute type number, and also the letters HT following steel designation on containers subjected to stress-relieving or heat-treatment during manufacture (for example, DOT-17E-304 or DOT-17E-304 HT as applicable) shall be shown. These marks shall be understood to certify that the container complies with all specification requirements.

(2) Name or symbol (letters) of maker; this must be recorded with the Bureau of Explosives.

(3) Gauge of metal in thinnest part, rated capacity in gallons, and year of manufacture (for example, 12-55-50). When gauge of metal in body differs from that in head, both must be indicated with slanting line between and with gauge of body indicated first (for example 14/12-55-50 for body 14 gauge and head 12 gauge).

[29 F.R. 18893, Dec. 29, 1964, as amended by Order 66, 30 F.R. 5755, Apr. 23, 1965]

§ 178.116-11 Size of markings.

(a) Size of markings (minimum): ½" high for 33-gallon or less, ¾" for over 33 and not over 55 gallons.

§ 178.116-12 Type tests.

(a) Samples taken at random and closed as for use, shall withstand prescribed tests without leakage. Tests to be made of each type and size by each company starting production and to be repeated every 4 months. Samples last tested to be retained until further tests are made or for 1 year, whichever period is shorter. The type tests are as follows:

(1) Test by dropping, filled with water to 98 percent capacity, from height of 4 feet onto solid concrete so as to strike diagonally on chime, or when without chime seam, to strike on other circumferential seam; also additional drop test on any other parts which might be considered weaker than the chime. Closing devices and other parts projecting beyond chime or rolling hoops must also be capable of withstanding this test.

(2) Hydrostatic pressure test of 15 pounds per square inch sustained for 5 minutes.

[29 F.R. 18893, Dec. 29, 1964, as amended by Order 66, 30 F.R. 5755, Apr. 23, 1965]

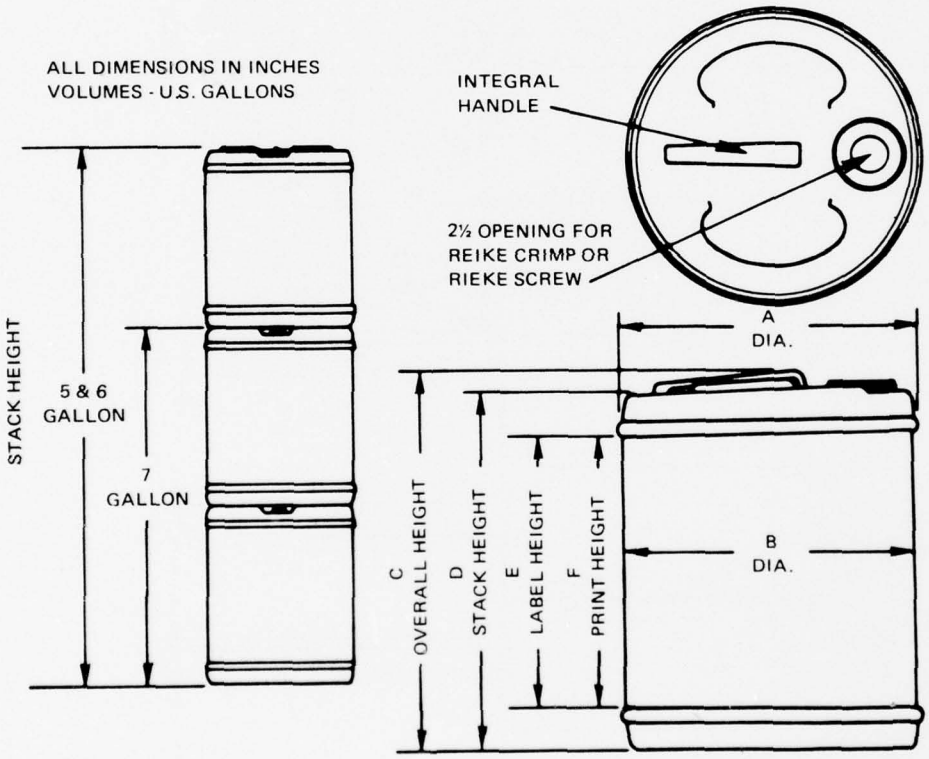
§ 178.116-13 Leakage test.

(a) Each container shall be tested, with seams under water or covered with soapsuds or heavy oil, by interior air pressure of at least 7 pounds per square inch for containers over 12 gallons capacity and at least 5 pounds for others. Equally efficient means of testing are authorized upon demonstration and proof of satisfactory tests to representative of Bureau of Explosives. Leakers shall be rejected or repaired and retested

Appendix B: Information on drums used in these tests.

1. 5 Gallon, Blow Molded, Polyethylene Drum.

   Supplier: Harley Corporation, P.O. Box 5497, Spartanburg, S.C.
   Construction: One piece, blow molded of high density polyethylene.

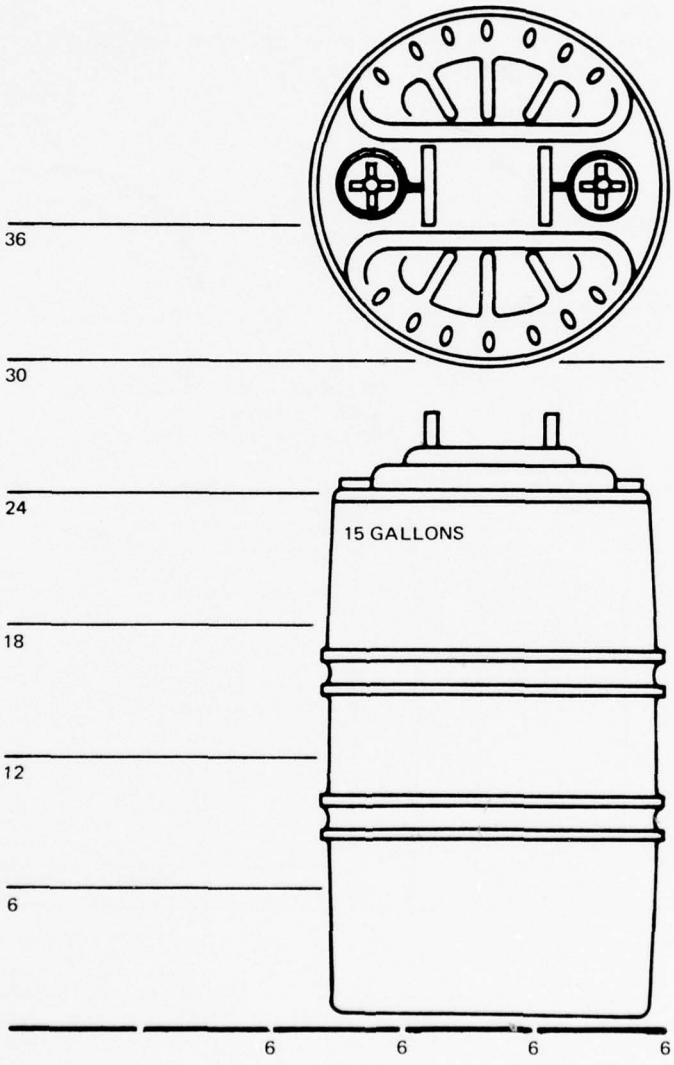


SIZE	A	B	C	D	E	F	STACK HEIGHT
5 GAL.	11 23/32	11 1/2	14 3/4	14 1/8	10 1/8	9	43

2. 15 Gallon, Blow Molded, Polyethylene Drums.

Supplier: Container Corporation of America, 1205 E. 12th Street, Wilmington, Del.

Construction: One piece, blow molded of high density polyethylene.

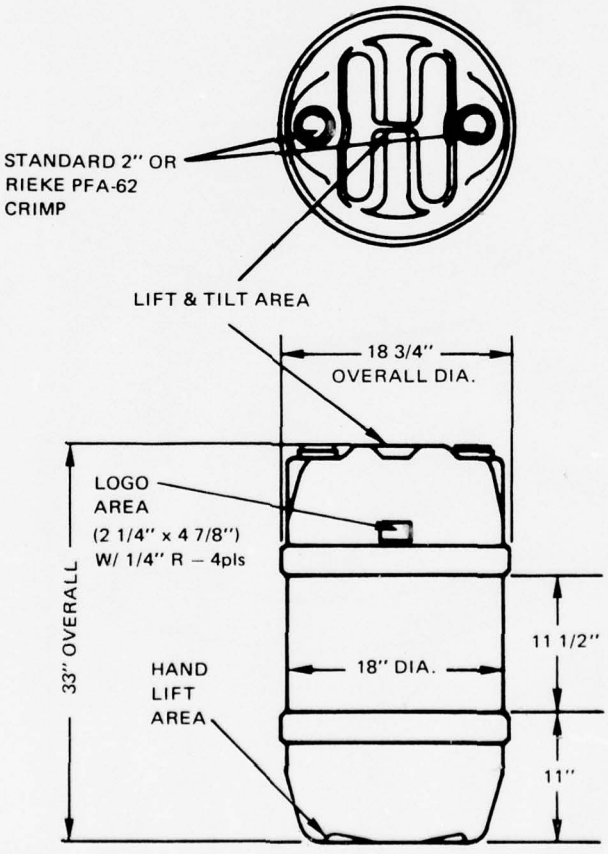


DIMENSIONS "ALL DIMENSIONS ARE NOTED APPROXIMATE IN INCHES."

3. 30 Gallon, Blow Molded, Polyethylene Drum

Supplier: Harley Corporation, P.O. Box 5497, Spartanburg, SC

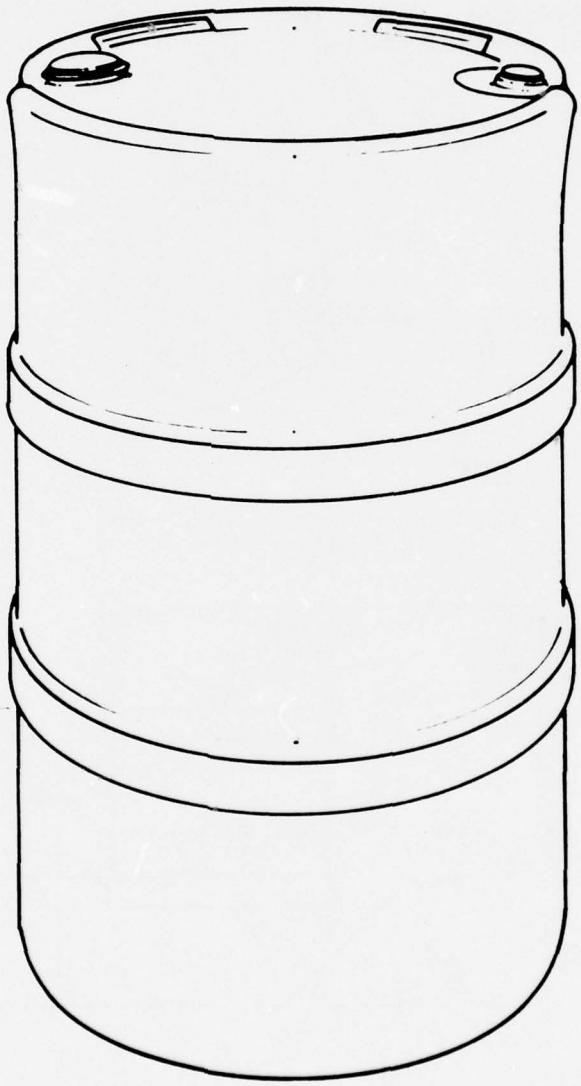
Construction: One piece blow molded of high density polyethylene.



4. 55 Gallon, Blow Molded, Polyethylene Drums.

Supplier: Hedwin Corporation, 1600 Roland Heights Avenue, Baltimore, MD

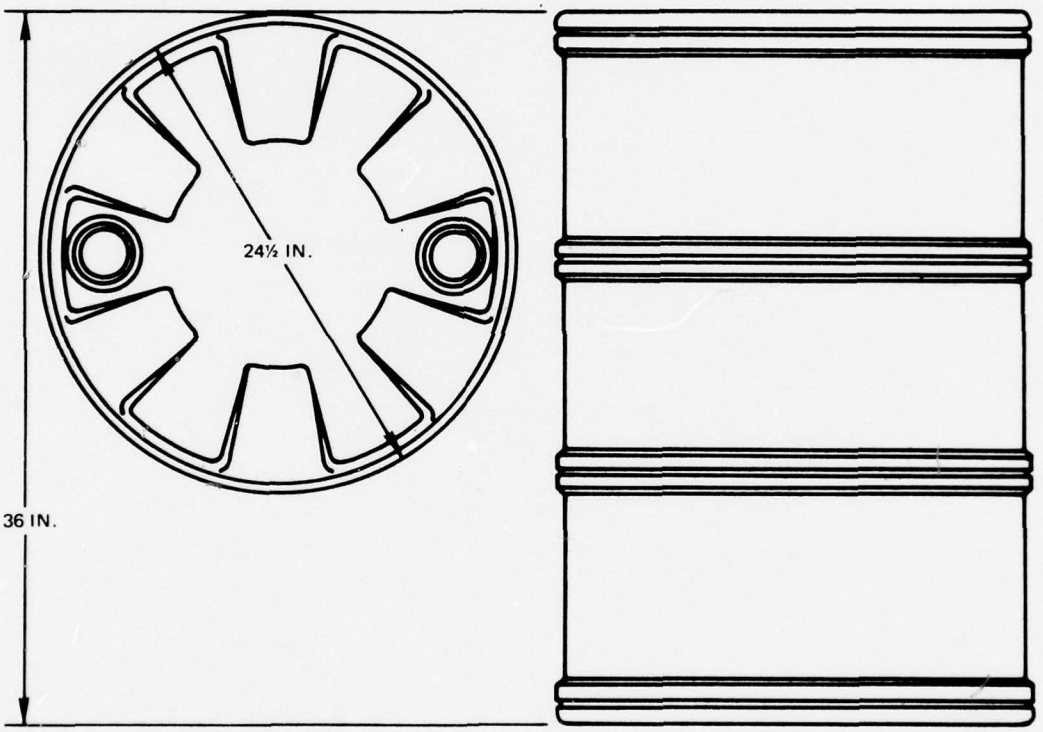
Construction: One piece, blow molded of high density polyethylene. (See Figure 14).



5. 55 Gallon, Rotationally Molded Polyethylene Drum

Supplier: Container Corporation of America, 1205 E 12th Street, Wilmington, DE

Construction: One piece, 3 layer, rotationally molded of high density polyethylene.



DIMENSIONS "ALL DIMENSIONS ARE NOTED APPROXIMATE IN INCHES."

6. 55 Gallon, Steel, DOT Specification 17E Drum.

Supplier: Florida Drum Company,
Pensacola, FL

Construction: All 18 gage steel with welded side seam and rolled device in accordance with DOT Specification 17E.

APPENDIX C: Data from Tests 1-3, 17-19, 20-22, and 35, using 5 gallon blow-molded polyethylene drums.

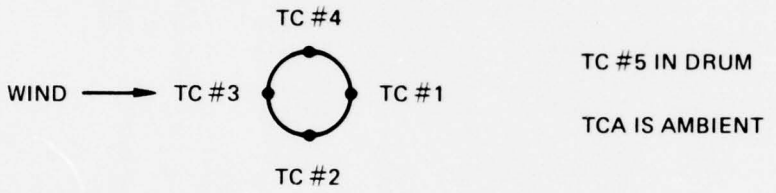
DATA FROM:

TEST NUMBER 1

DRUM SIZE 5 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

AS IN FIGURE 4



OTHER SENSORS.

INTERNAL PRESSURE

LOAD CELLS (WEIGHT)

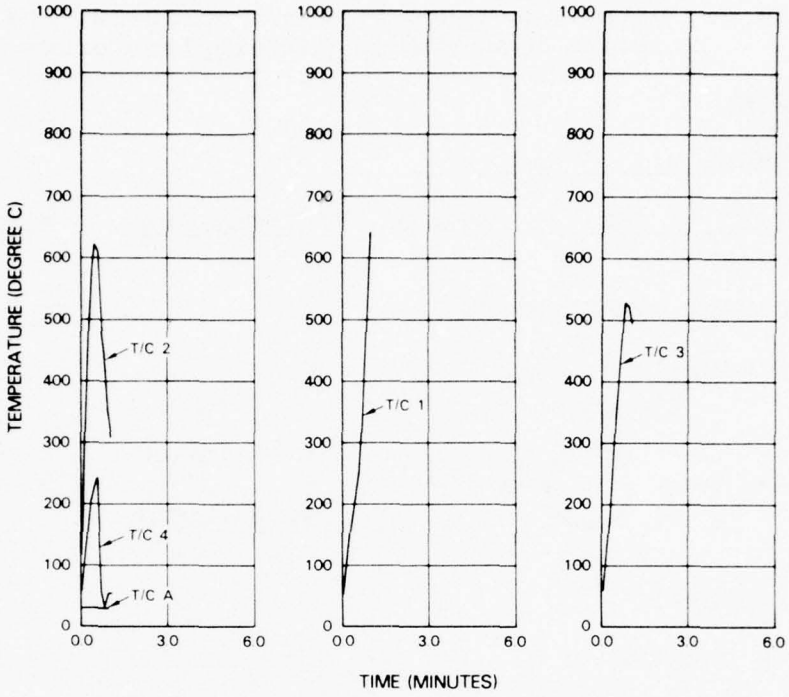
TIME TO FAILURE: 0 MIN 43 SEC; DISCHARGE RATE: 13.0 GPM JP-4

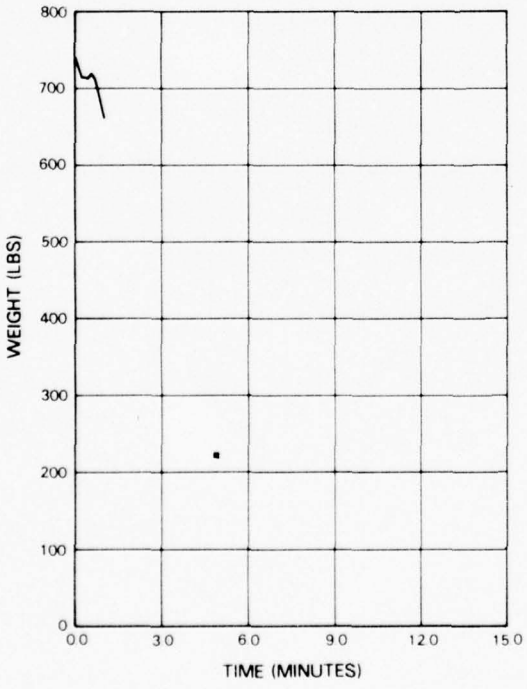
COMMENTS:

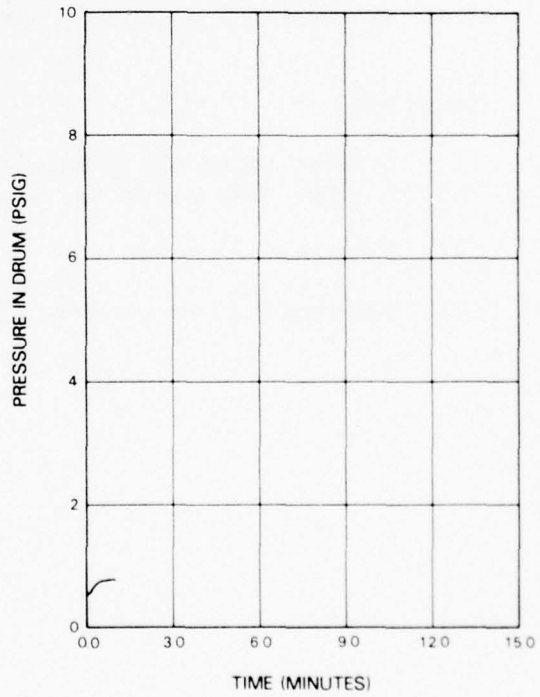
(1) Sudden external temperature drop means thermocouple has fallen into the water in the pan.

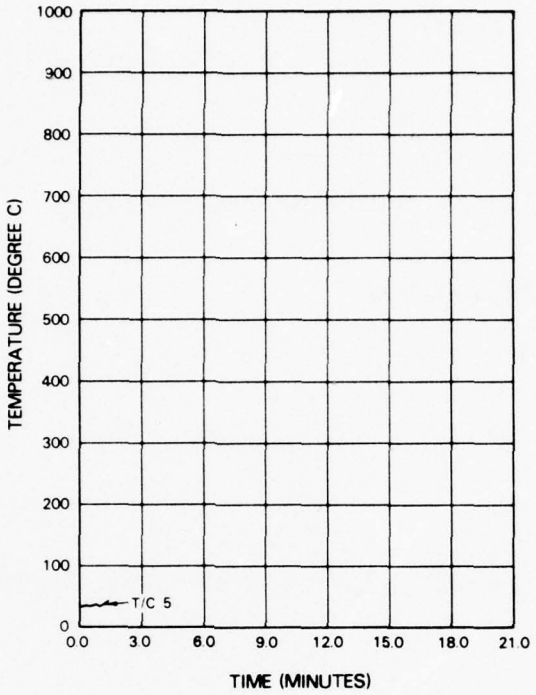
(2) Internal temperature rise occurs after failure.

(3) Pressure rise occurs after failure.


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 2
T/C 4
T/C A
T/C 1
T/C 3
00
30
60
TIME (MINUTES)


WEIGHT (LBS)
800
700
600
500
400
300
200
100
0
00
30
60
90
120
150
TIME (MINUTES)


PRESSURE IN DRUM (PSIG)
10
8
6
4
2
0
00
30
60
90
120
150
TIME (MINUTES)


1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (DEGREE C)
T/C 5
0.0
3.0
6.0
9.0
12.0
15.0
18.0
21.0
TIME (MINUTES)

APPENDIX C (Continued)

DATA FROM:

TEST NUMBER 2

DRUM SIZE 5 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

SAME AS IN TEST #1

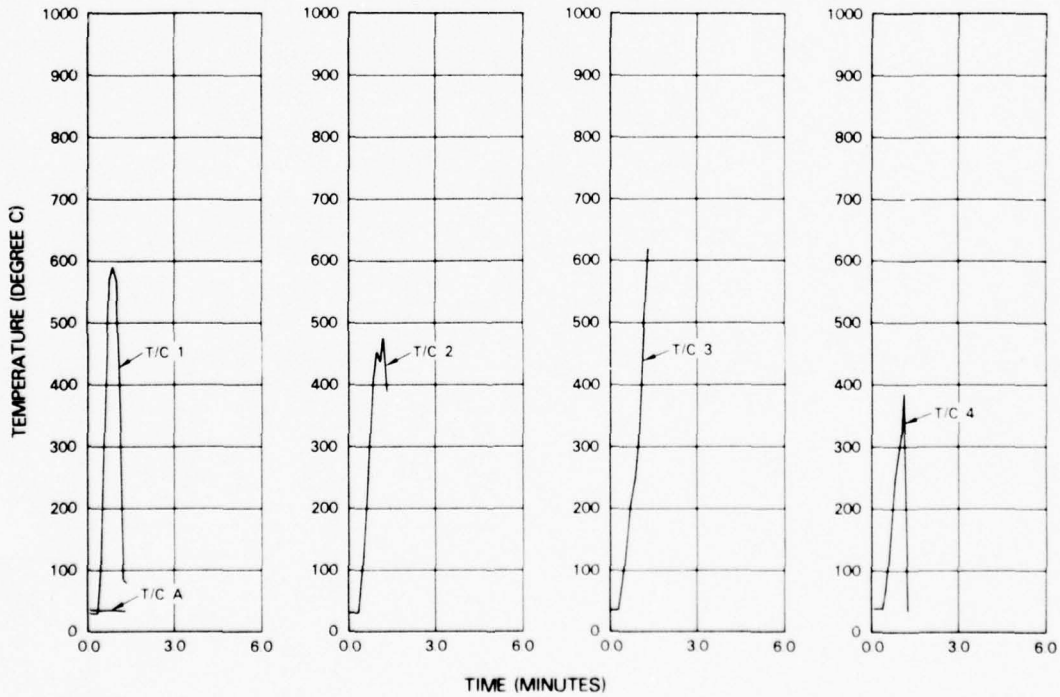
OTHER SENSORS:

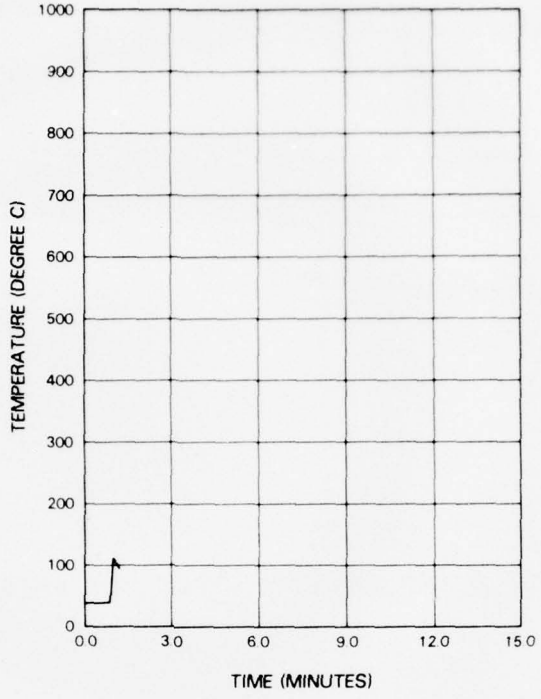
SAME AS IN TEST #1

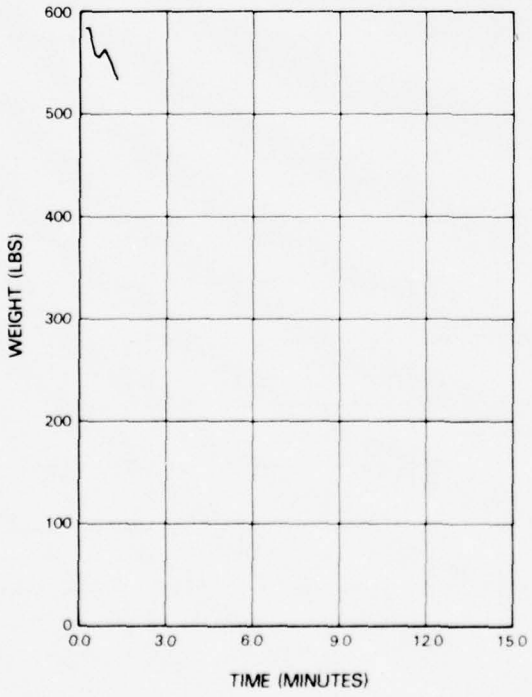
TIME TO FAILURE: 0 MIN 39 SEC; DISCHARGE RATE: 83 GPM JP-4

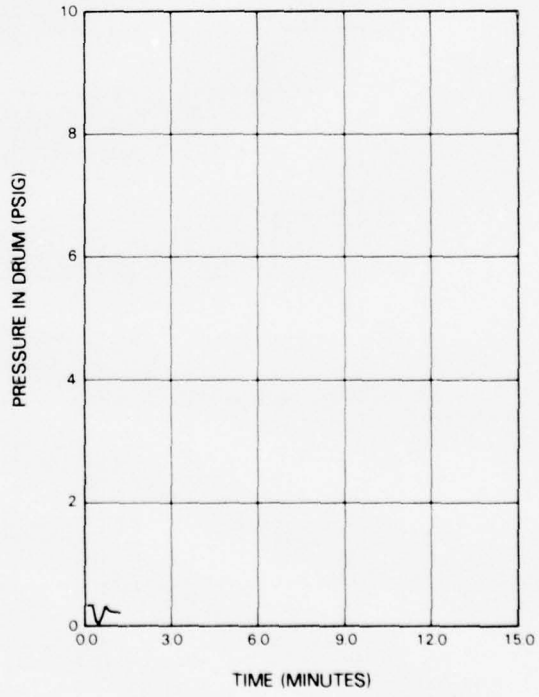
COMMENTS:

(1) Internal pressure fall occurs at failure.




TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
00
30
60
90
120
150
TIME (MINUTES)


WEIGHT (LBS)
600
500
400
300
200
100
0
00
30
60
90
120
150
TIME (MINUTES)


PRESSURE IN DRUM (PSIG)
10
8
6
4
2
0
00
30
60
90
120
150
TIME (MINUTES)

APPENDIX C (Continued)

DATA FROM:

TEST NUMBER 3

DRUM SIZE 5 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

SAME AS IN TEST #1

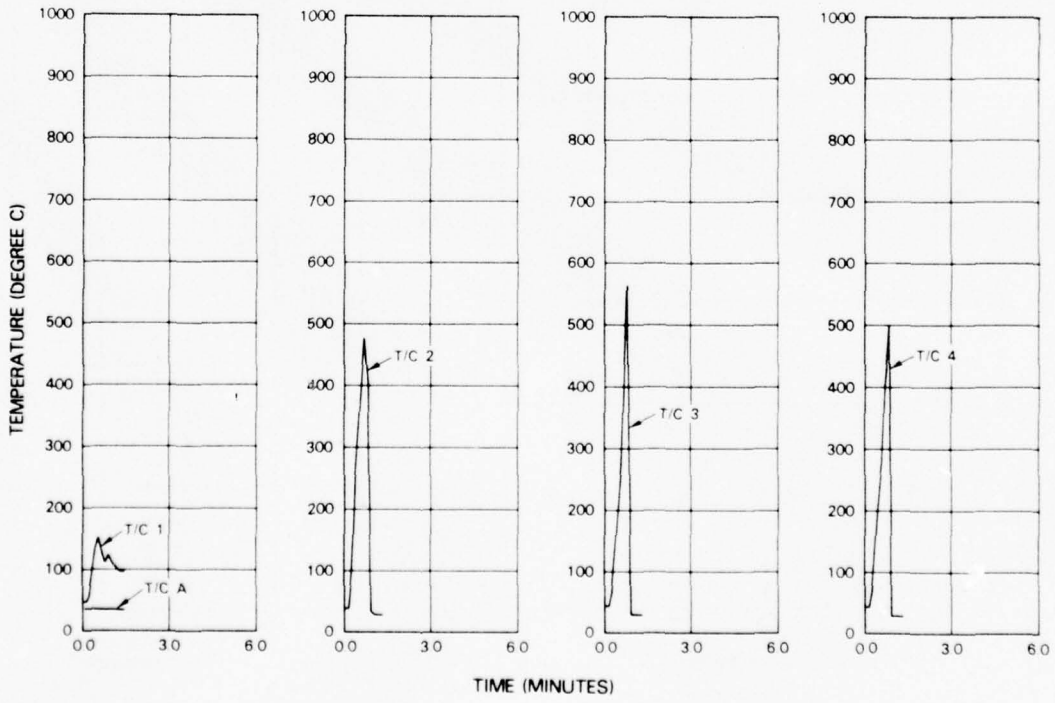
OTHER SENSORS:

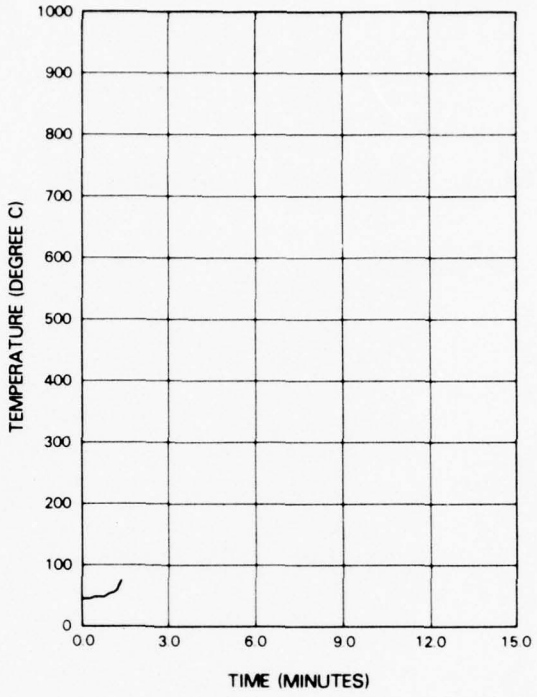
SAME AS IN TEST #1

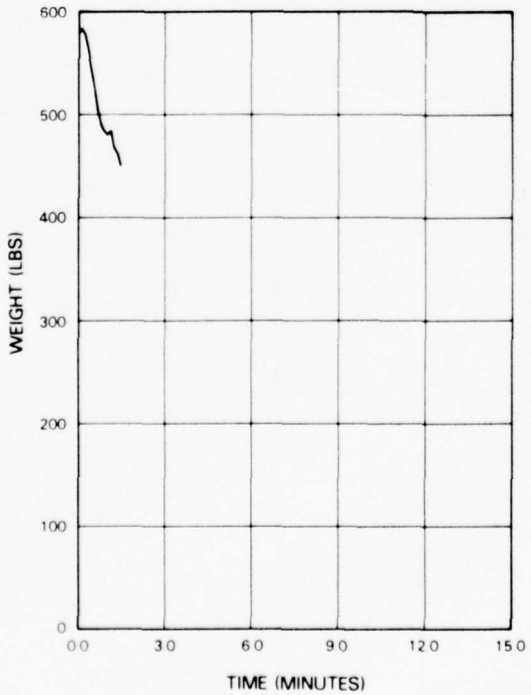
TIME TO FAILURE: 0 MIN 24 SEC; DISCHARGE RATE: 8.1 GPM JP-4

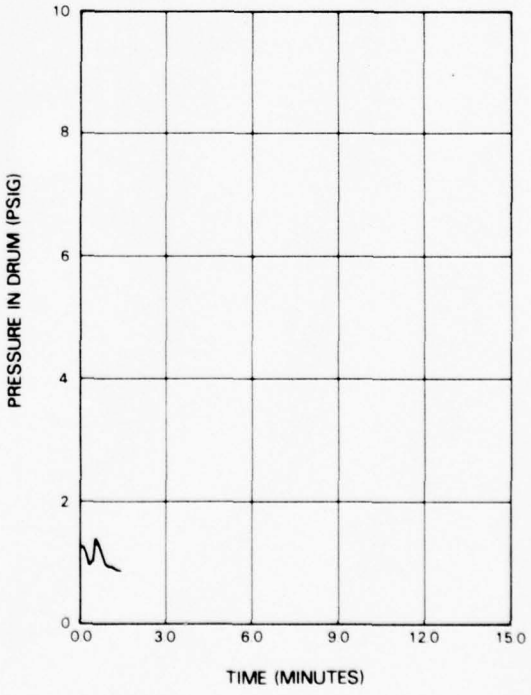
COMMENTS:

(1) Internal pressure changes occur after failure.




1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (DEGREE C)
00
30
60
90
120
150
TIME (MINUTES)


600
500
400
300
200
100
0
WEIGHT (LBS)
00
30
60
90
120
150
TIME (MINUTES)


10
8
6
4
2
0
PRESSURE IN DRUM (PSIG)
00
30
60
90
120
150
TIME (MINUTES)

APPENDIX C (Continued)

DATA FROM:

TEST NUMBER 17

DRUM SIZE 5 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

NONE

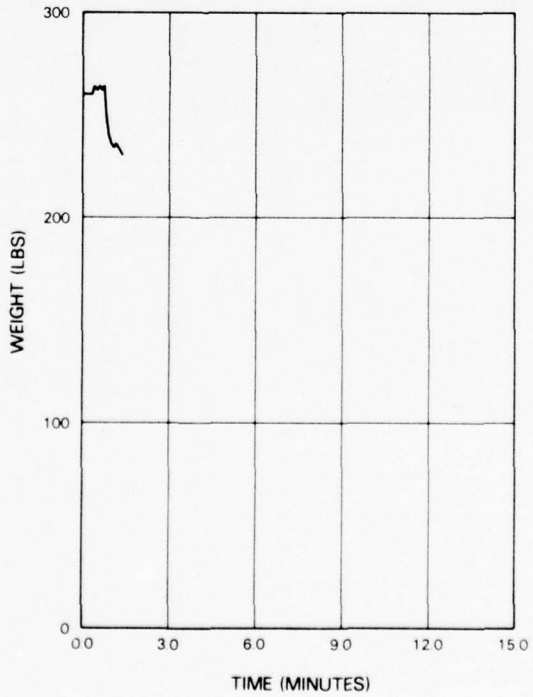
OTHER SENSORS:

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 0 MIN 48 SEC; DISCHARGE RATE: 20.0 GPM JP-4

COMMENTS:

This test was run to verify the discharge rates and very short times to failure seen in Tests #1, 2 and 3.



APPENDIX C (Continued)

DATA FROM:

TEST NUMBER 18

DRUM SIZE 5 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

NONE

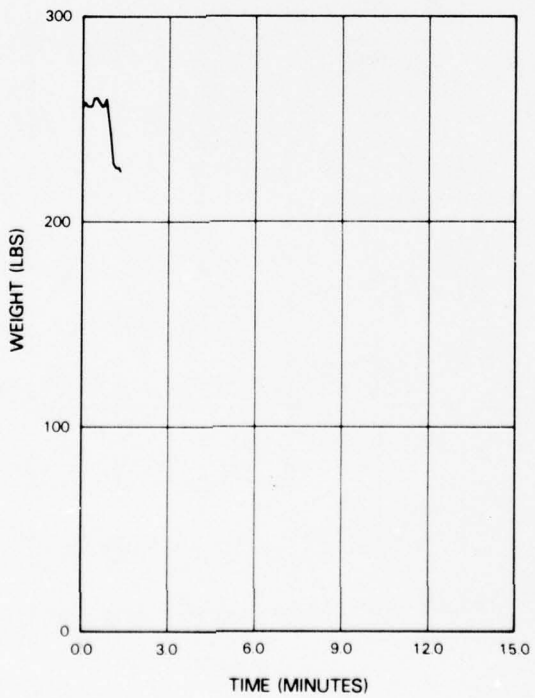
OTHER SENSORS:

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 0 MIN 54 SEC; DISCHARGE RATE: 25.0 GPM JP-4

COMMENTS:

SAME AS TEST #17



APPENDIX C (Continued)

DATA FROM:

TEST NUMBER 19

DRUM SIZE 5 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

NONE

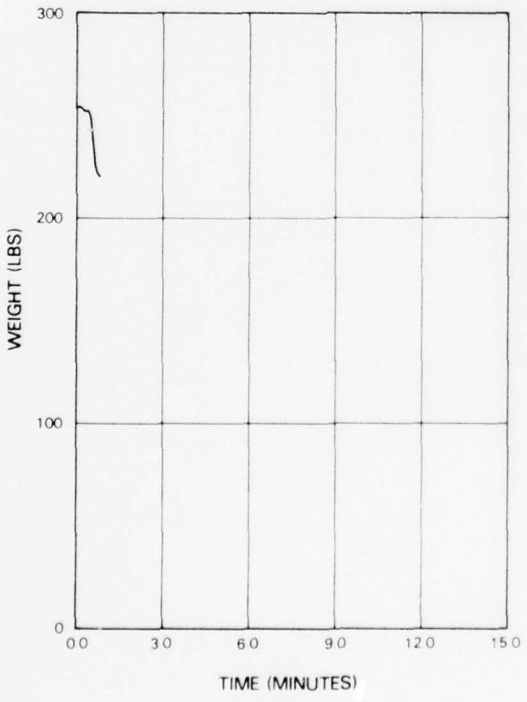
OTHER SENSORS:

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 0 MIN 24 SEC; DISCHARGE RATE: 12.5 GPM JP-4

COMMENTS:

SAME AS TEST #17



APPENDIX C (Continued)

DATA FROM:

TEST NUMBER 20

DRUM SIZE 5 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

NONE

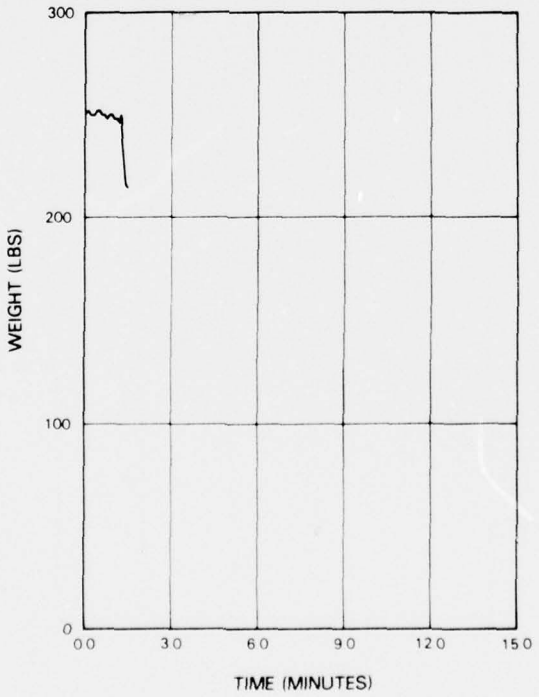
OTHER SENSORS:

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 1 MIN 18 SEC; DISCHARGE RATE: 25.0 GPM ACETONE

COMMENTS:

This test was run to determine the time to failure and discharge rate for a cargo other than JP-4.



APPENDIX C (Continued)

DATA FROM:

TEST NUMBER 21

DRUM SIZE 5 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

NONE

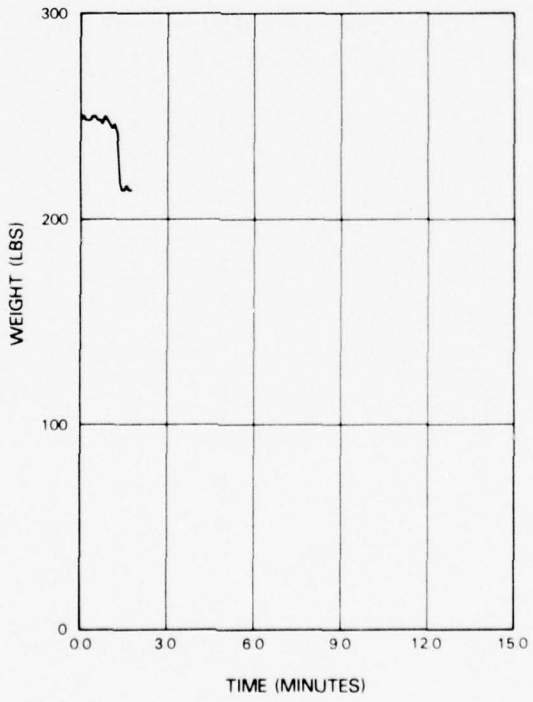
OTHER SENSORS:

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 1 MIN 17 SEC; DISCHARGE RATE: 30.0 GPM ACETONE

COMMENTS:

SAME AS TEST #20



APPENDIX C (Continued)

DATA FROM:

TEST NUMBER 22

DRUM SIZE 5 GAL, MATERIAL POLYETHYLENE, METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

NONE

OTHER SENSORS:

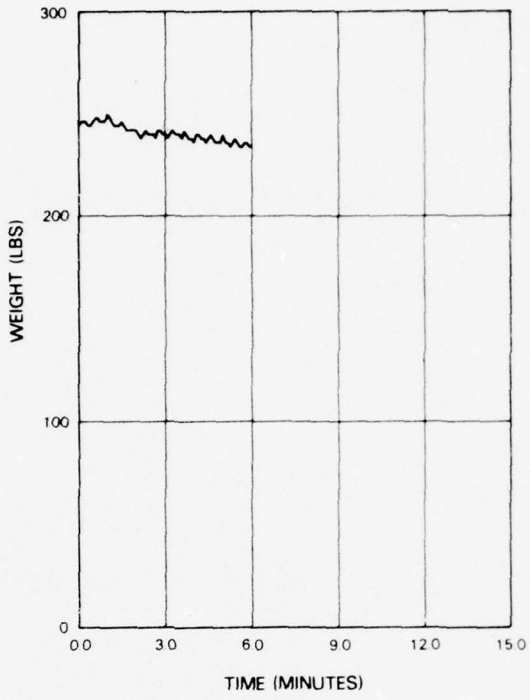
LOAD CELLS (WEIGHT)

TIME TO FAILURE: 1 MIN 12 SEC; DISCHARGE RATE: 2 (SEE NOTE) GPM ACETONE

COMMENTS:

(1) SAME AS IN TEST #20

(2) As can be seen in Figure 15a, the discharge rate is abnormally low compared to Tests #20 and #21. The top melted in for failure as the side melted/burned down. This flowing of the side wall made a plug of polyethylene under the drum, among the wood slats. The bottom was thus protected from fire exposure. The drum burned like a candle for a long time after the pan fire burned out.


300
200
100
0
WEIGHT (LBS)
00
30
60
90
120
150
TIME (MINUTES)

APPENDIX C (Continued)

DATA FROM:

TEST NUMBER 35

DRUM SIZE 5 GAL (ARRAY), MATERIAL POLYETHYLENE, METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

AS IN FIGURE 5

```
    #6              #12
  #4  #5          #10  #11
#1  #2  #3      #7  #8  #9
  LOWER           UPPER
```

OTHER SENSORS:

LOAD CELLS (WEIGHT)

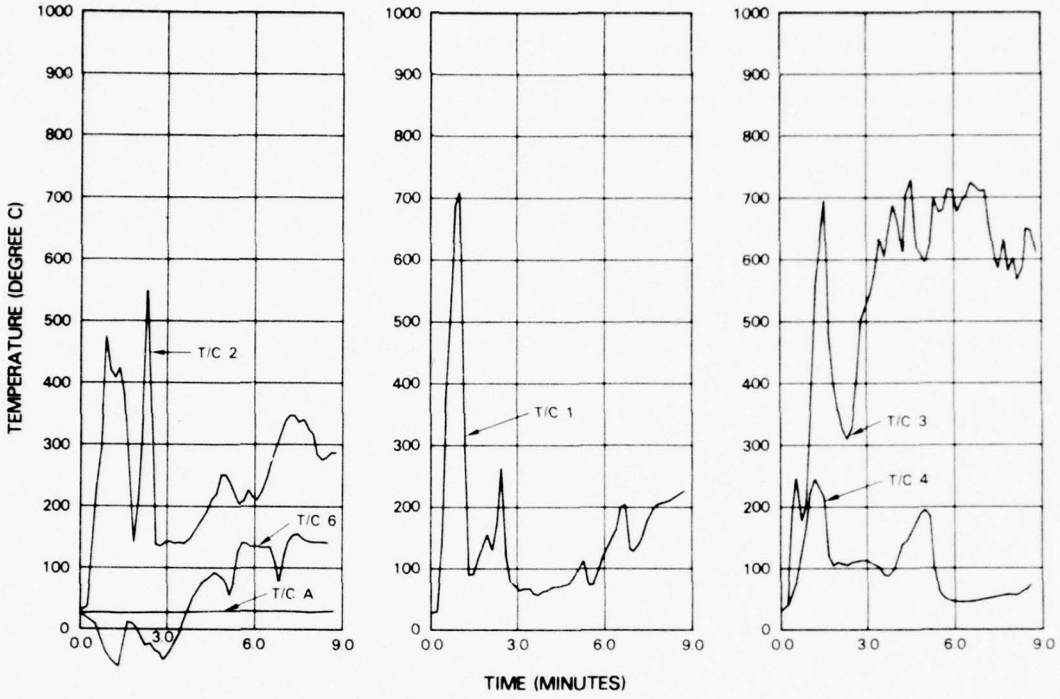
TIME TO FAILURE: 0 MIN 30 SEC; DISCHARGE RATE: 212.6 GPM JP-4

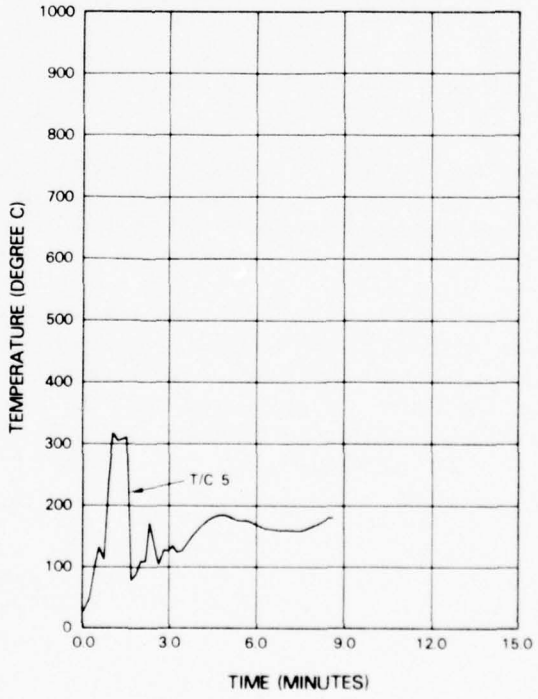
COMMENTS:

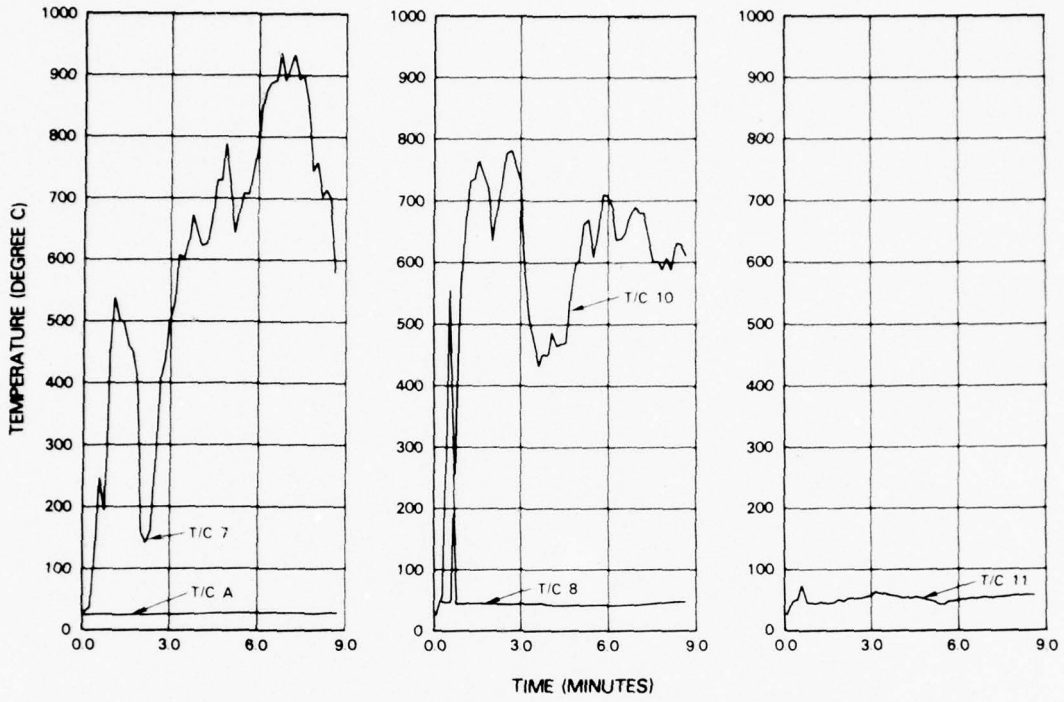
(1) This test was a fire test of an array of 129 drums containing 645 gal of JP-4. See Figure 8.

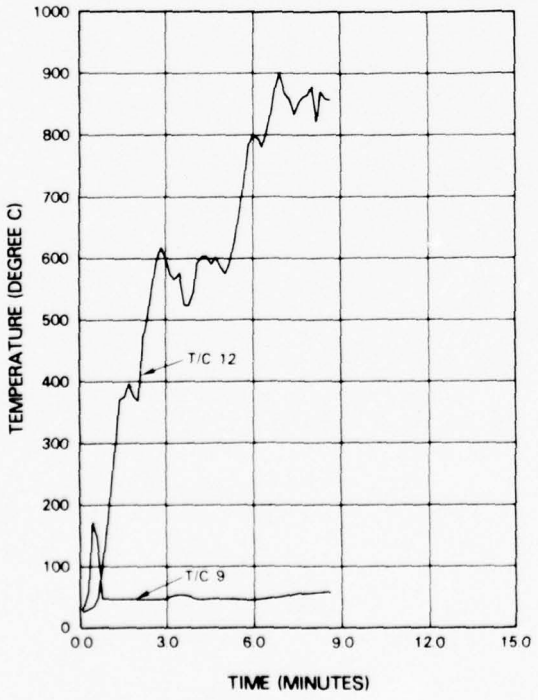
(2) Fluctuations of external temperature were due to wind gusting and contact with cool cargo liquid from failed drums. Later in the test, some thermocouples fell into the water in the fire pan while others were melted into chunks of polyethylene.

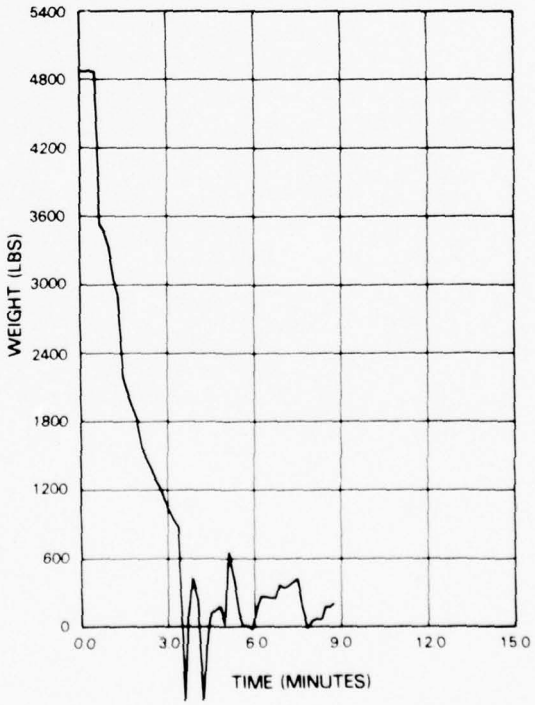
(3) The lower level of drums near thermocouples #1 and 2 failed first. The drums above them then fell into the fire. Some fell off the table and out of the pan. The resulting ground fire caused load cell failure at about 3 min 20 sec. By this time, most of the drums had already failed. At 8 min 45 sec, all power was lost due to short circuits in the generator.


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 2
T/C 6
T/C A
T/C 1
T/C 3
T/C 4
0.0
3.0
6.0
9.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 5
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
00
30
60
90
T/C 7
T/C A
T/C 10
T/C 8
T/C 11
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
00
30
60
90
120
150
T/C 12
T/C 9
TIME (MINUTES)


WEIGHT (LBS)
5400
4800
4200
3600
3000
2400
1800
1200
600
0
00
30
60
90
120
150
TIME (MINUTES)

APPENDIX D: Data from Tests 4-6, 23-25, and 42, using 15 gallon blow-molded polyethylene drums.

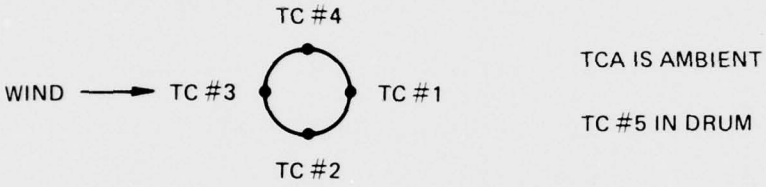
DATA FROM:

TEST NUMBER 4

DRUM SIZE 15 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

AS IN FIGURE 4



OTHER SENSORS:

INTERNAL PRESSURE

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 0 MIN 49 SEC; DISCHARGE RATE: 13.8 GPM JP-4

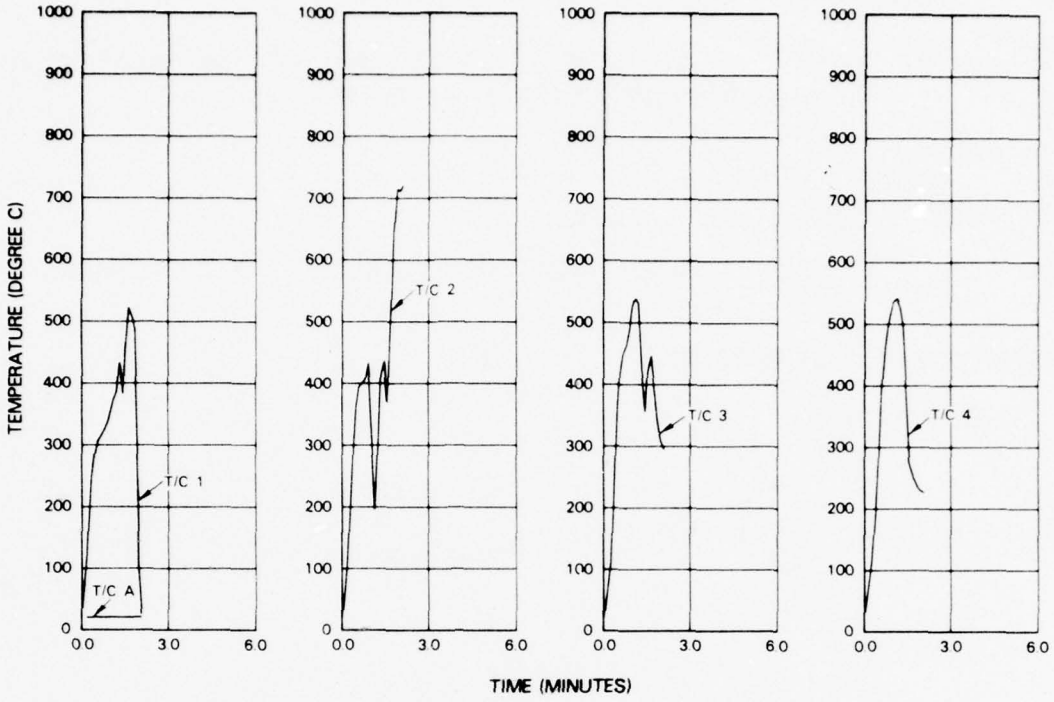
COMMENTS:

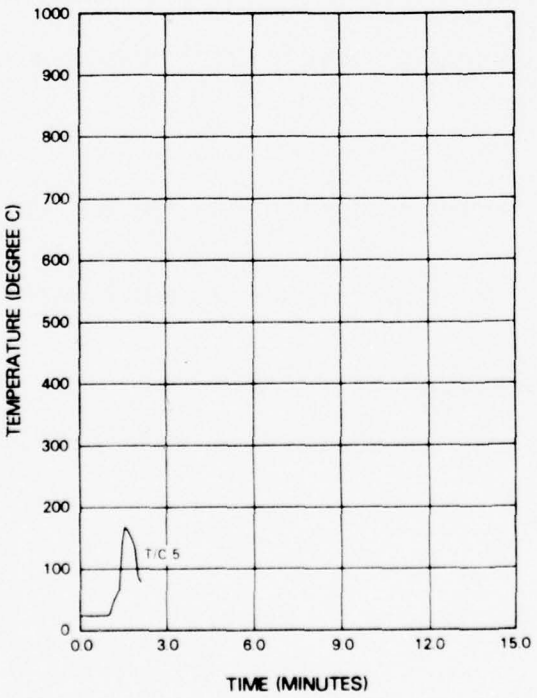
(1) Sudden temperature drop means thermocouple has fallen into the water in the pan.

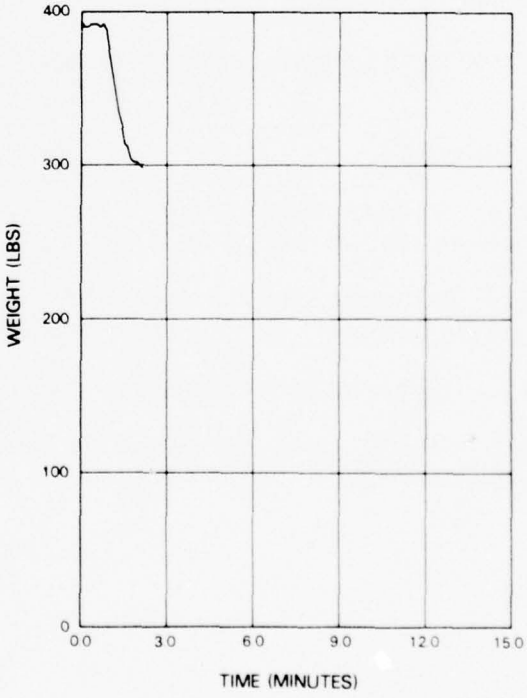
(2) Fluctuations in temperature could be caused by wind gusts or cargo hitting the thermocouple.

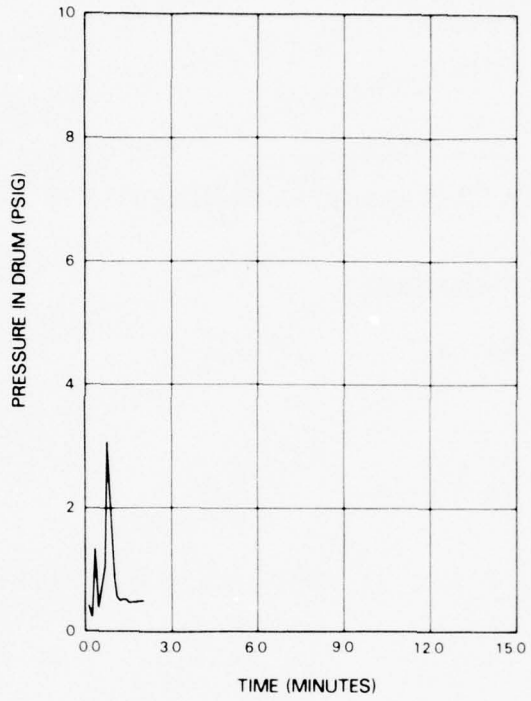
(3) Internal temperature rise occurred after failure.

(4) The 1 psig increase in internal pressure seen before failure was blamed on calibration.


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C A
T/C 1
T/C 2
T/C 3
T/C 4
0.0
3.0
6.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 5
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


WEIGHT (LBS)
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


10
8
6
4
2
0
PRESSURE IN DRUM (PSIG)
00
30
60
90
120
150
TIME (MINUTES)

APPENDIX D (Continued)

DATA FROM:

TEST NUMBER 5

DRUM SIZE 15 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

SAME AS IN TEST #4

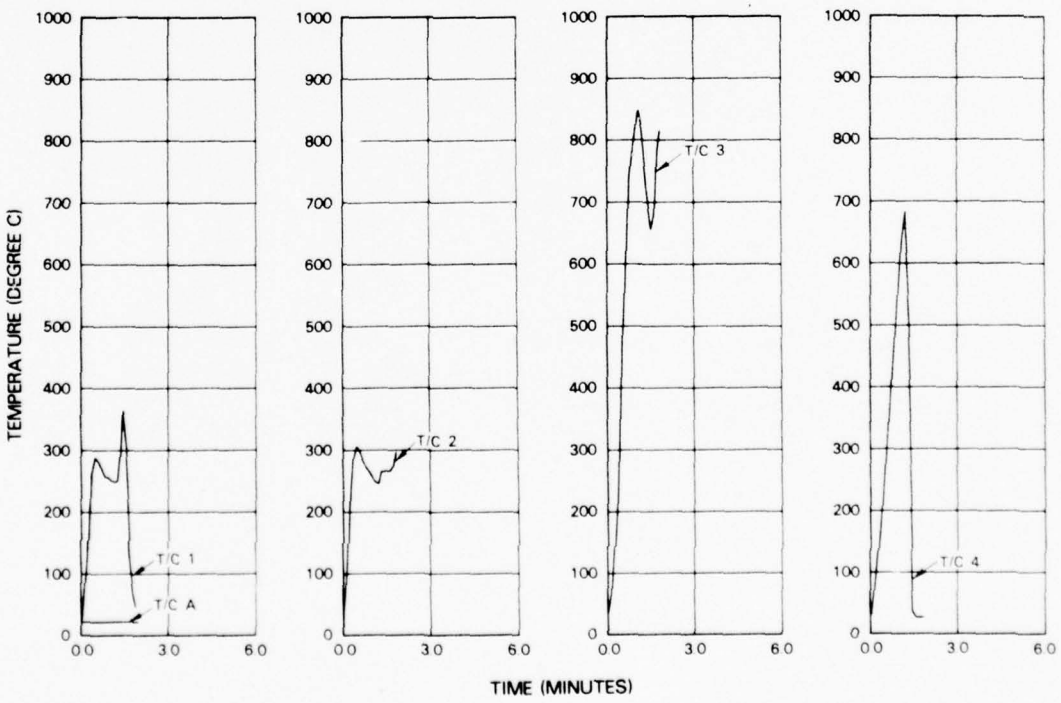
OTHER SENSORS:

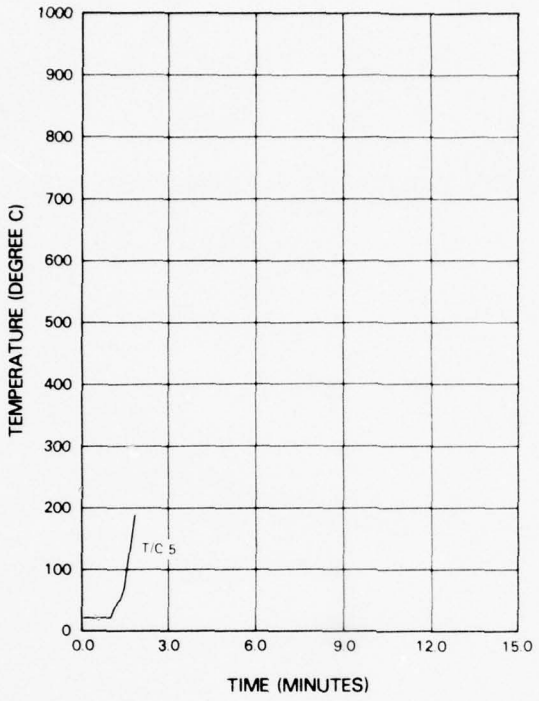
SAME AS IN TEST #4

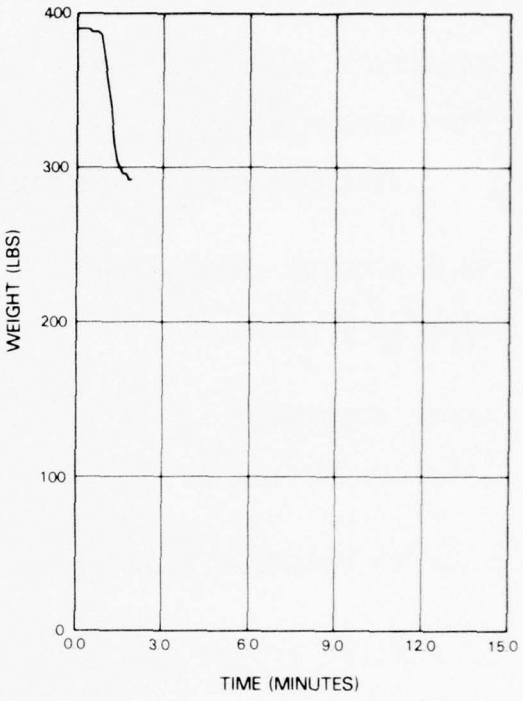
TIME TO FAILURE: 0 MIN 54 SEC; DISCHARGE RATE: 25.0 GPM JP-4

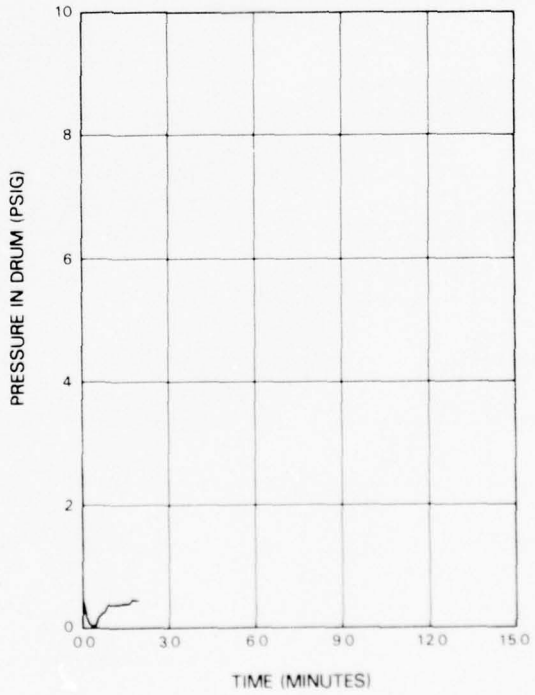
COMMENTS:

(1) Internal pressure decrease with time is unreal. Probably due to calibration or transducer error.




TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 5
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


WEIGHT (LBS)
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


PRESSURE IN DRUM (PSIG)
10
8
6
4
2
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

APPENDIX D (Continued)

DATA FROM:

TEST NUMBER 6

DRUM SIZE 15 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

SAME AS IN TEST #4

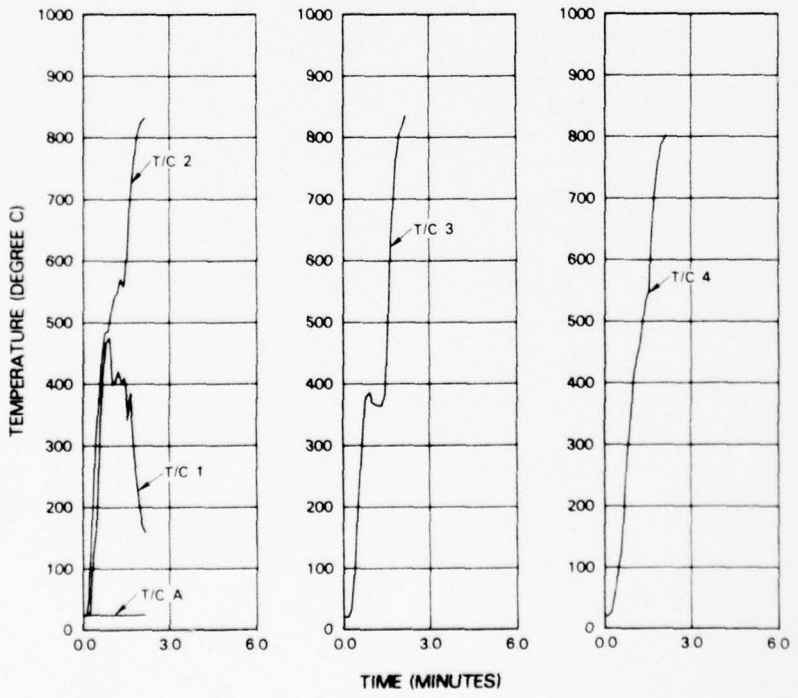
OTHER SENSORS:

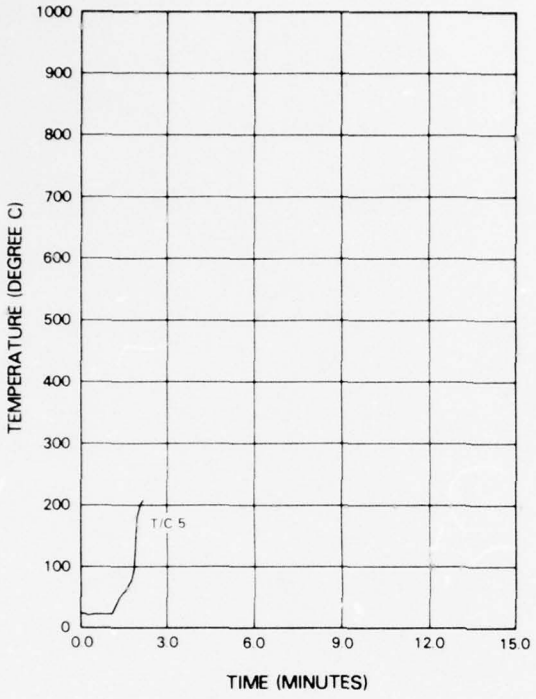
SAME AS IN TEST #4

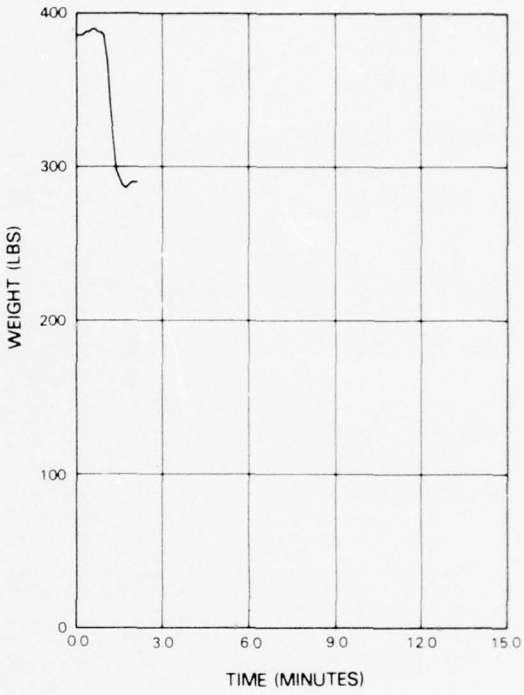
TIME TO FAILURE: 1 MIN 0 SEC; DISCHARGE RATE: 23.7 GPM JP-4

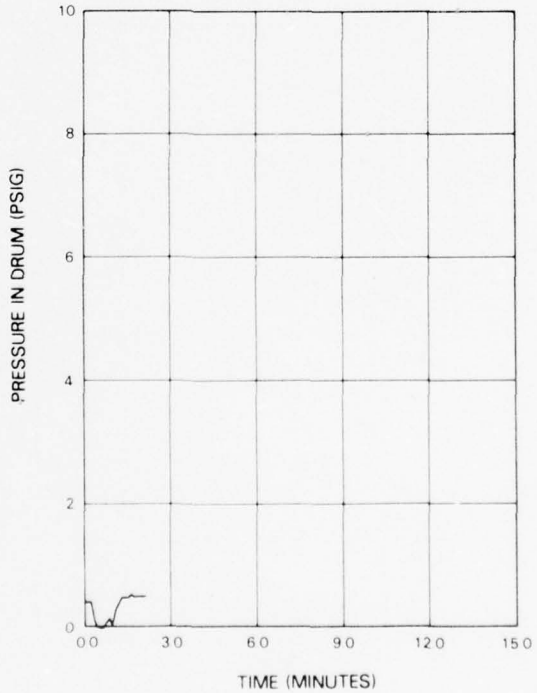
COMMENTS:

NONE




TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 5
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


WEIGHT (LBS)
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


PRESSURE IN DRUM (PSIG)
10
8
6
4
2
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

APPENDIX D (Continued)

DATA FROM:

TEST NUMBER 23

DRUM SIZE 15 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

NONE

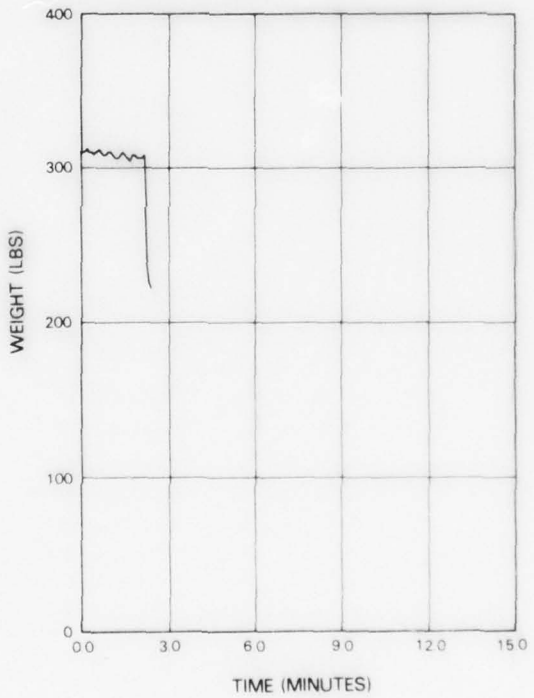
OTHER SENSORS:

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 2 MIN 17 SEC; DISCHARGE RATE: 90.0 GPM ACETONE

COMMENTS:

This test was run to determine the time to failure and discharge rate for a cargo other than JP-4.



APPENDIX D (Continued)

DATA FROM:

TEST NUMBER 24

DRUM SIZE 15 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

NONE

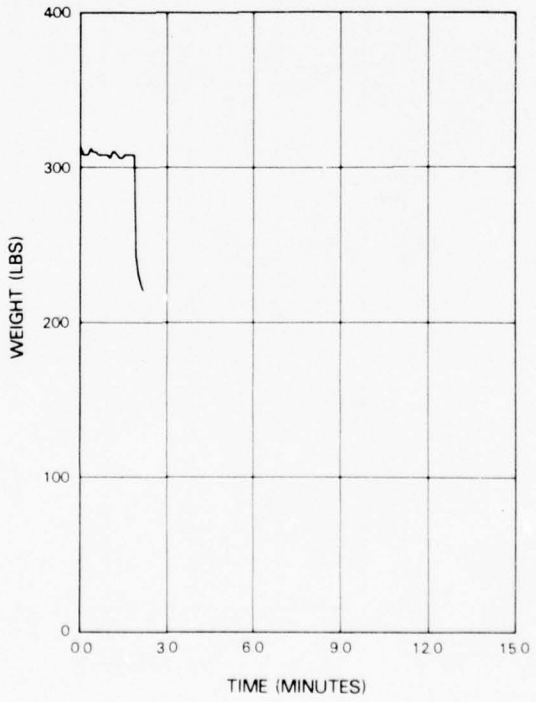
OTHER SENSORS:

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 1 MIN 57 SEC; DISCHARGE RATE: 21.4 GPM ACETONE

COMMENTS:

NONE



APPENDIX D (Continued)

DATA FROM:

TEST NUMBER 25

DRUM SIZE 15 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

NONE

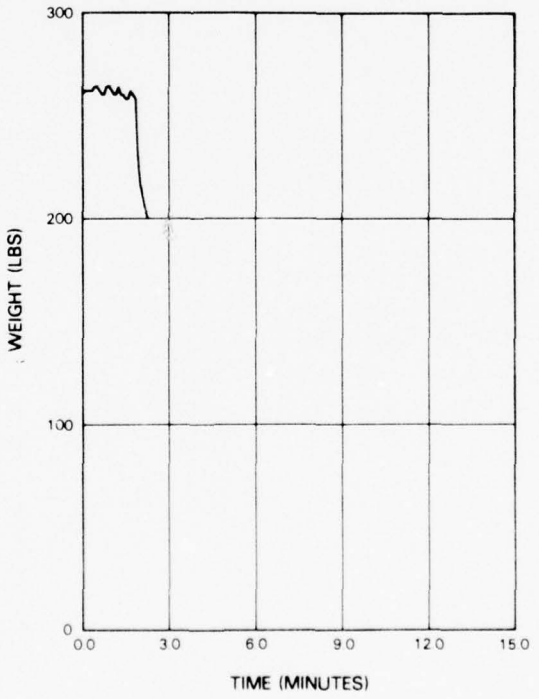
OTHER SENSORS:

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 1 MIN 54 SEC; DISCHARGE RATE: 30.0 GPM ACETONE

COMMENTS:

NONE



APPENDIX D (Continued)

DATA FROM:

TEST NUMBER 42

DRUM SIZE 15 GAL (ARRAY), MATERIAL POLYETHYLENE METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

AS IN FIGURE 12

OTHER SENSORS:

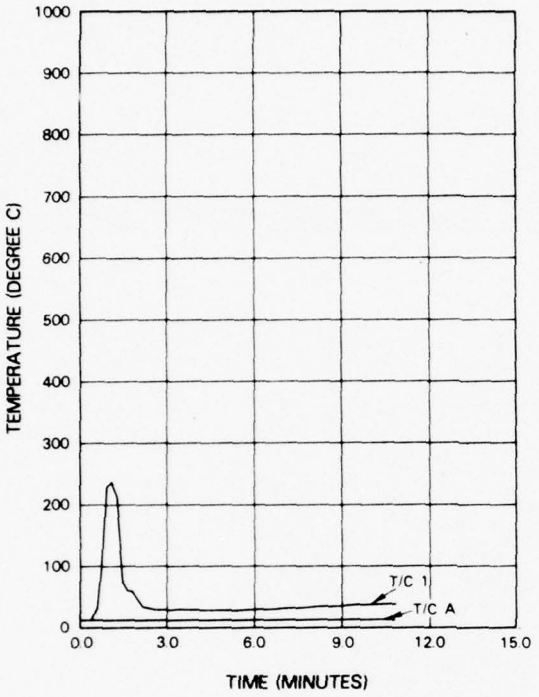
LOAD CELLS (WEIGHT)

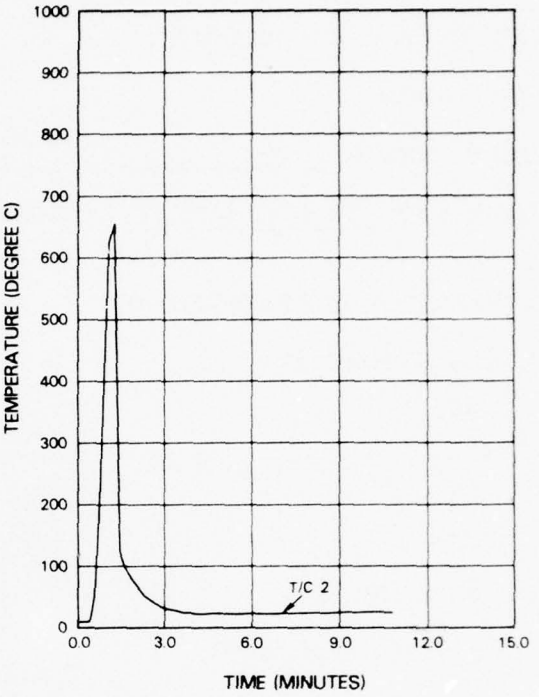
TIME TO FAILURE: 1 MIN 12 SEC; *DISCHARGE RATE*: 65.6 GPM JP-4

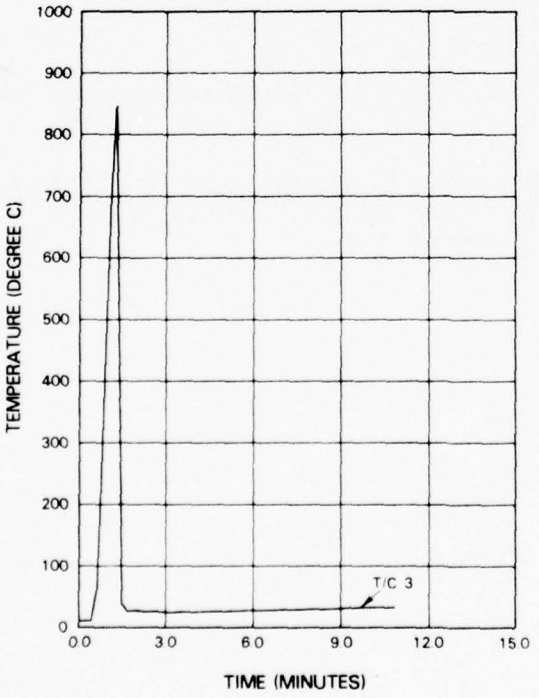
COMMENTS:

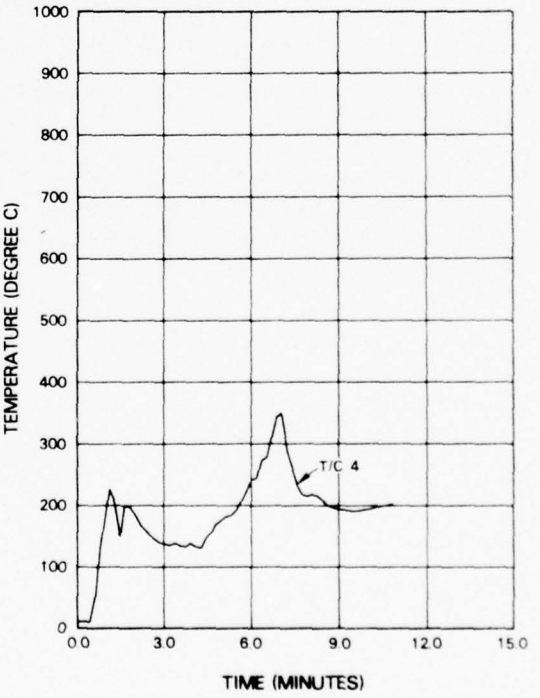
(1) This test is a fire test of an array of 42 drums leaded with 630 gal of JP-4.

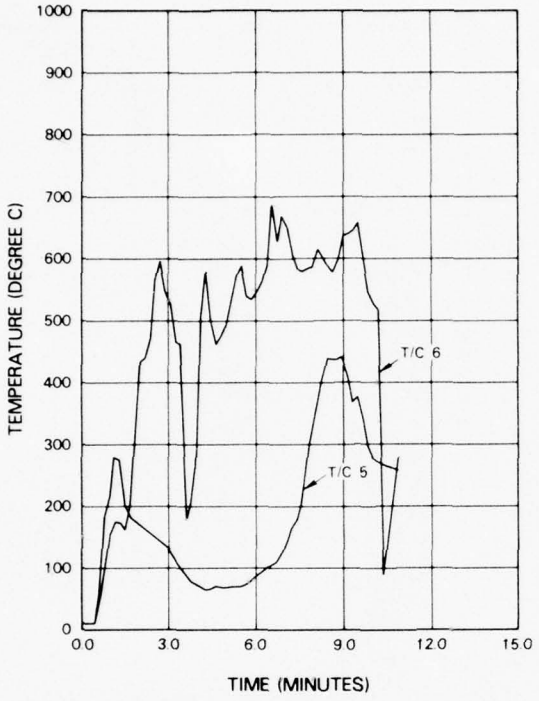
(2) The drums on the bottom layer near thermocouple #2 failed first. The layer above then fell. The array finally looked like a pile of deformed and deforming drums.

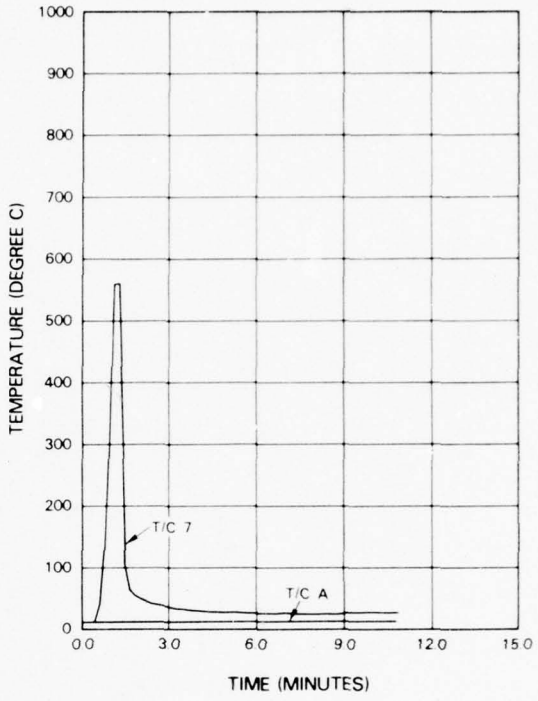

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)
T/C 1
T/C A

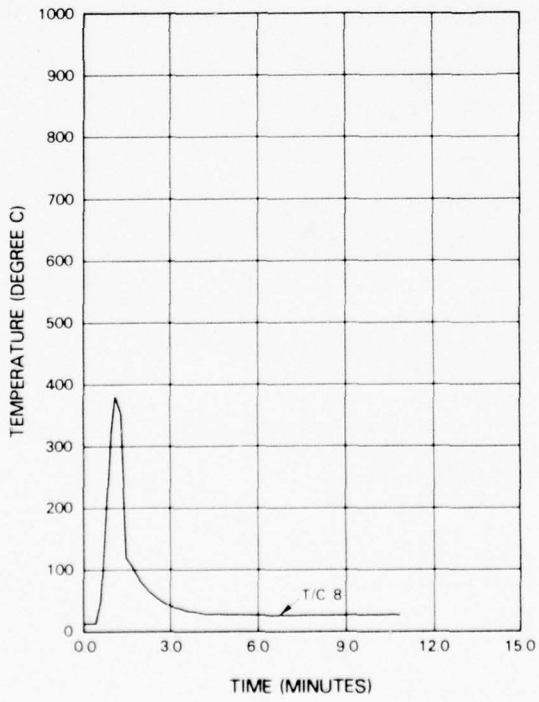

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)
T/C 2

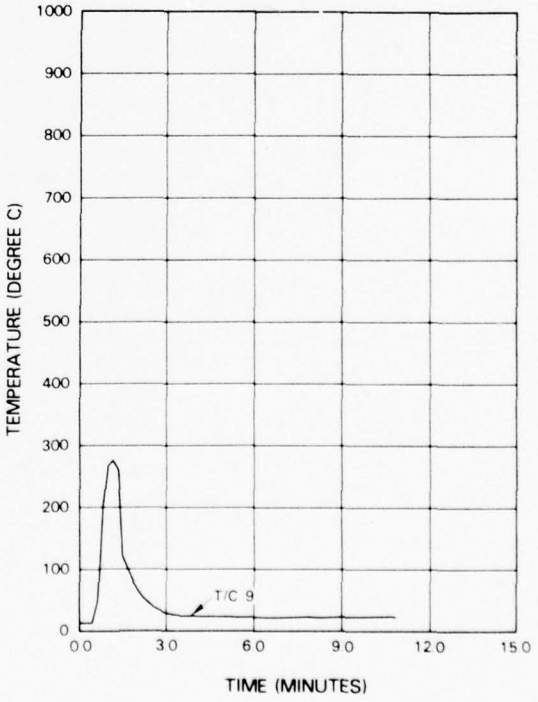

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)
T/C 3

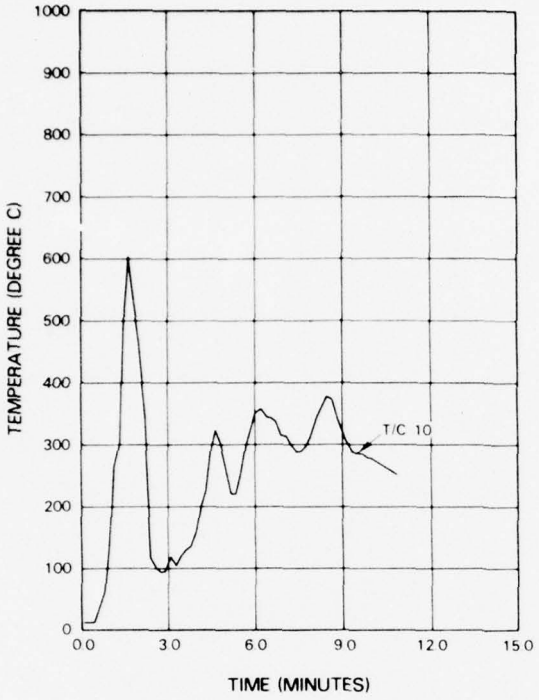

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)
T/C 4

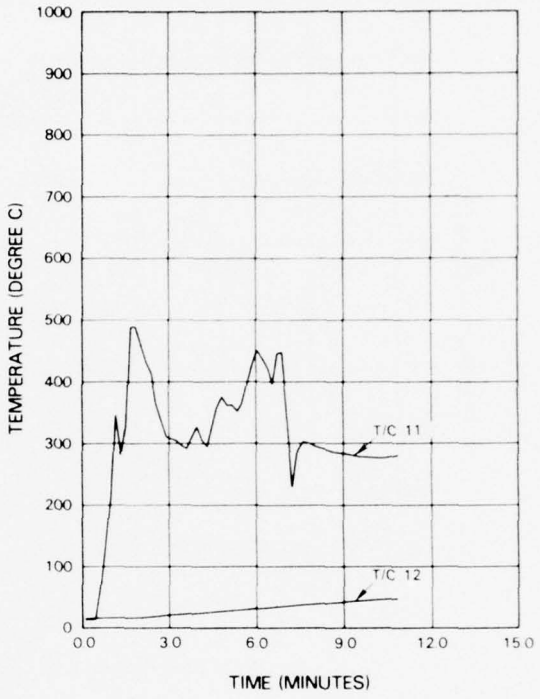

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
30
60
90
120
150.0
TIME (MINUTES)
T/C 6
T/C 5

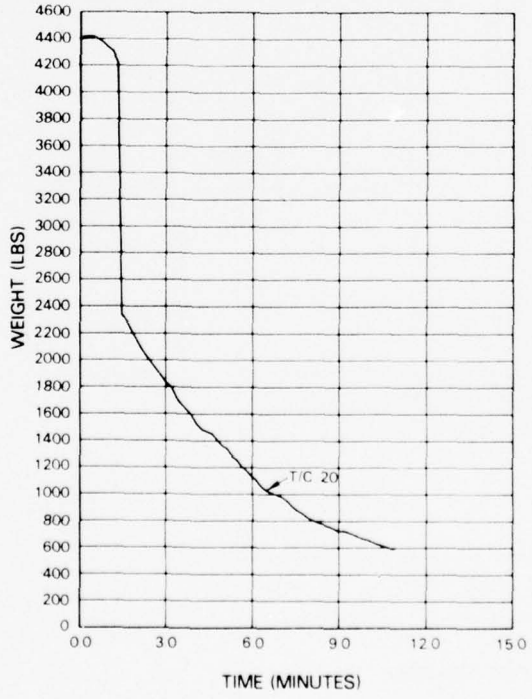

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
30
60
90
120
150.0
TIME (MINUTES)
T/C 7
T/C A


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
30
60
90
120
150.0
TIME (MINUTES)
T/C 8


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
30
60
90
120
150.0
TIME (MINUTES)
T/C 9


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
00
30
60
90
120
150
TIME (MINUTES)
T/C 10


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
00
30
60
90
120
150
TIME (MINUTES)
T/C 11
T/C 12


WEIGHT (LBS)
4600
4400
4200
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
00
30
60
90
120
150
TIME (MINUTES)
T/C 20

APPENDIX E: Data from Tests 7-9, 26-28 and 43 using 30 gallons blow-molded polyethylene drums.

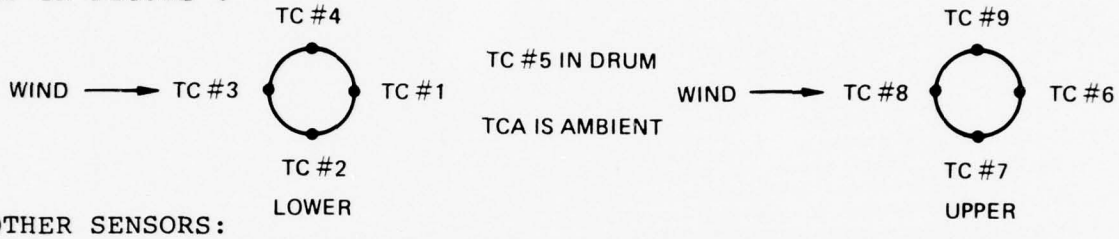
DATA FROM:

TEST NUMBER 7

DRUM SIZE 30 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

AS IN FIGURE 4



OTHER SENSORS:

INTERNAL PRESSURE

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 1 MIN 45 SEC; DISCHARGE RATE: 45.0 GPM JP-4

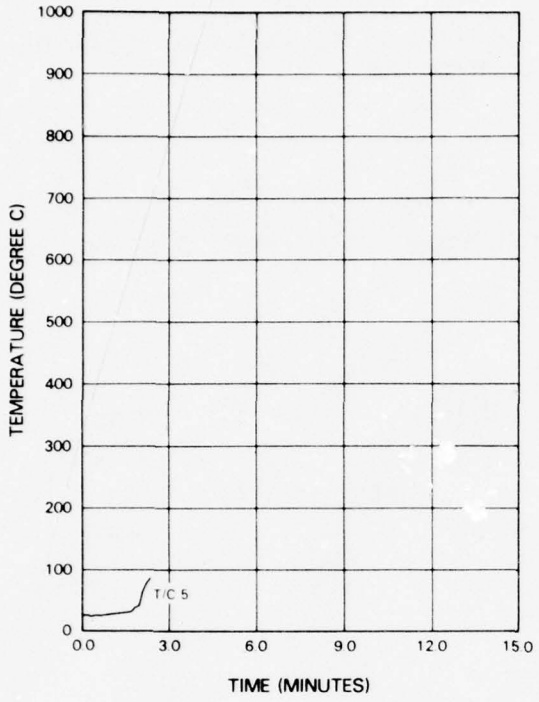
COMMENTS:

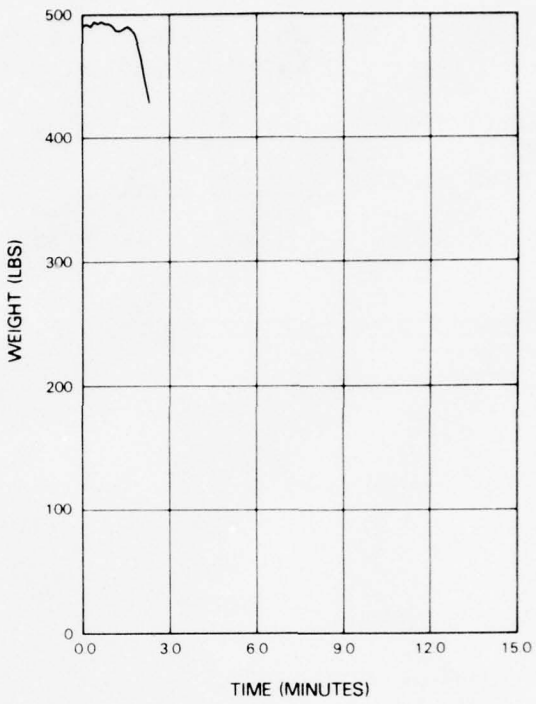
(1) Sudden drops in external temperature are due to the thermocouple falling into water in the fire pan.

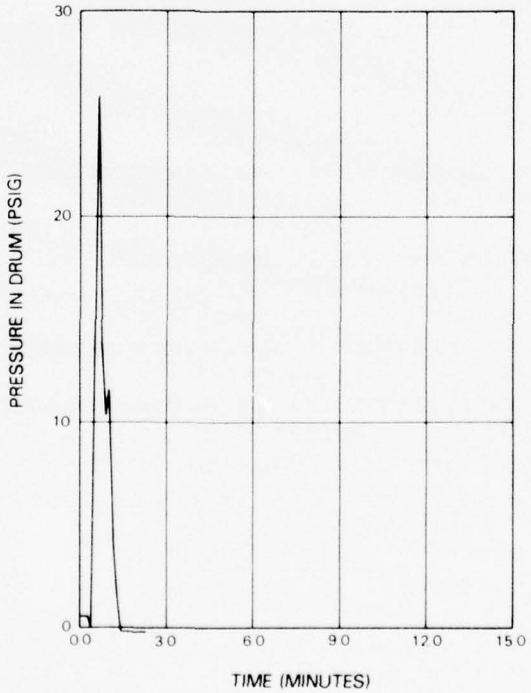
(2) Fluctuations in external temperature may be due to wind gusts or cargo hitting the thermocouple.

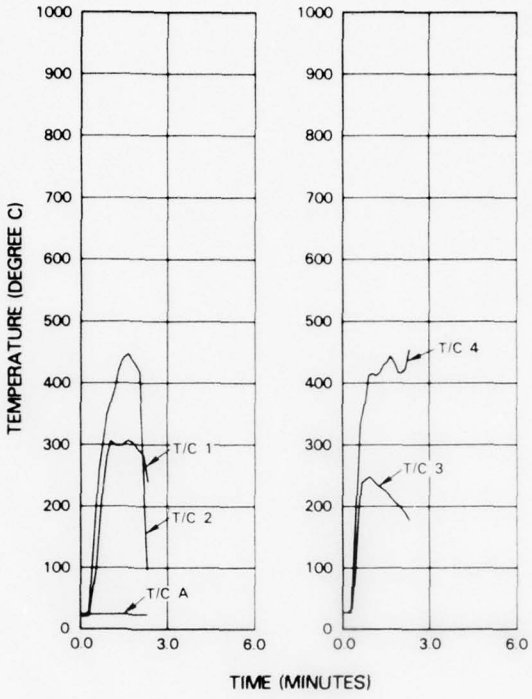
(3) Sharp rise of internal temperature occurs after failure.

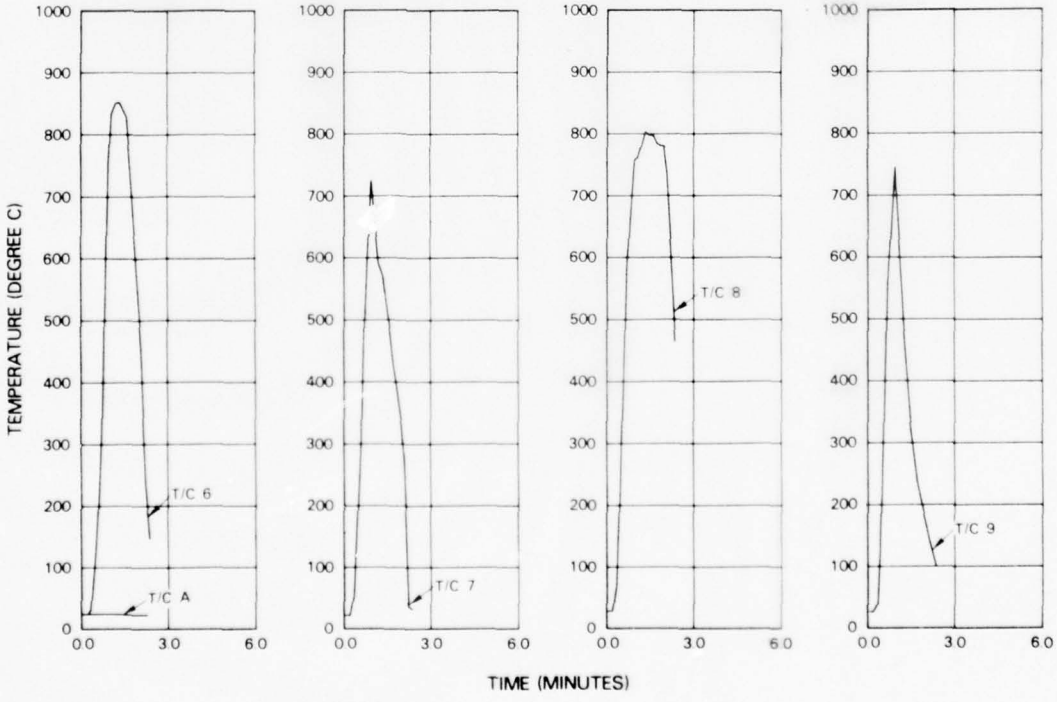
(4) Rise in internal pressure is unreal considering internal temperature. A 26 psig rise cannot occur for a maximum possible 5^{o}C rise in temperature when working at the lower end of the vapor pressure vs temperature curve (Figure 3, JP-4). Error introduced due to transducer failure.


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 5
00
30
60
90
120
150
TIME (MINUTES)


WEIGHT (LBS)
500
400
300
200
100
0
00
30
60
90
120
150
TIME (MINUTES)


PRESSURE IN DRUM (PSIG)
30
20
10
0
00
30
60
90
120
150
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 1
T/C 2
T/C A
T/C 4
T/C 3
0.0
3.0
6.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 6
T/C A
T/C 7
T/C 8
T/C 9
0.0
3.0
6.0
TIME (MINUTES)

APPENDIX E (Continued)

DATA FROM:

TEST NUMBER 8

DRUM SIZE 30 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

SAME AS IN TEST #7

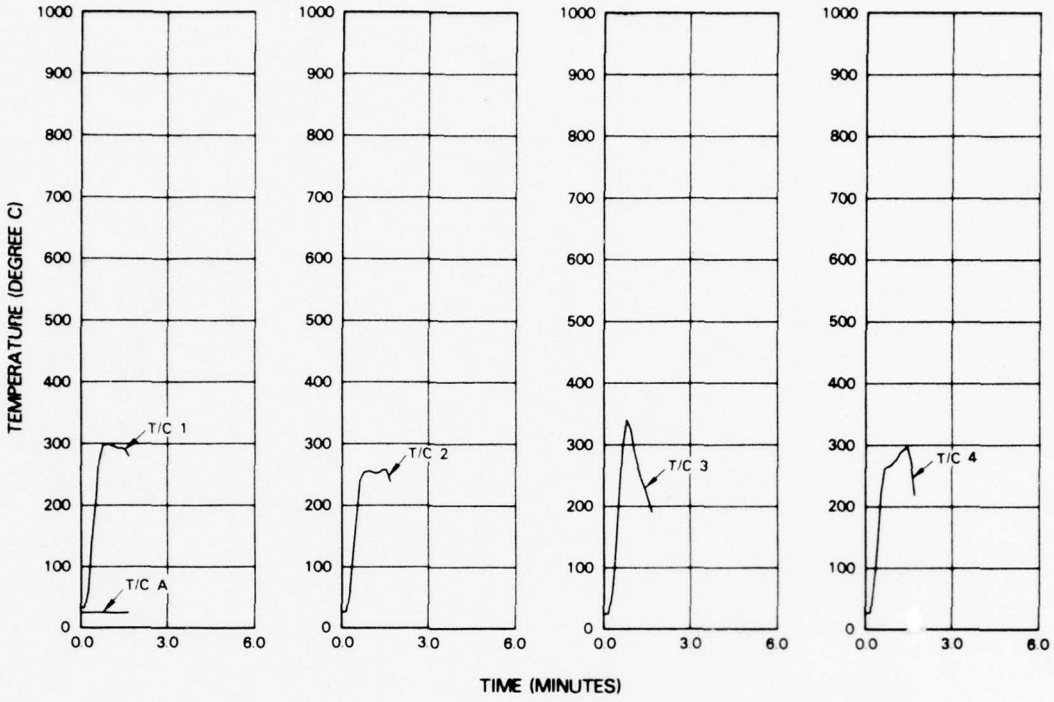
OTHER SENSORS:

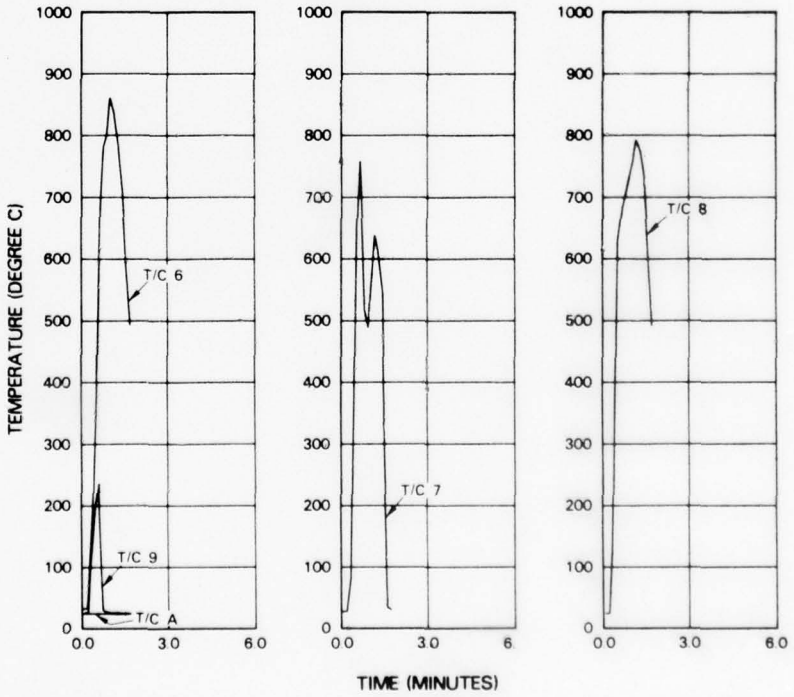
SAME AS IN TEST #7

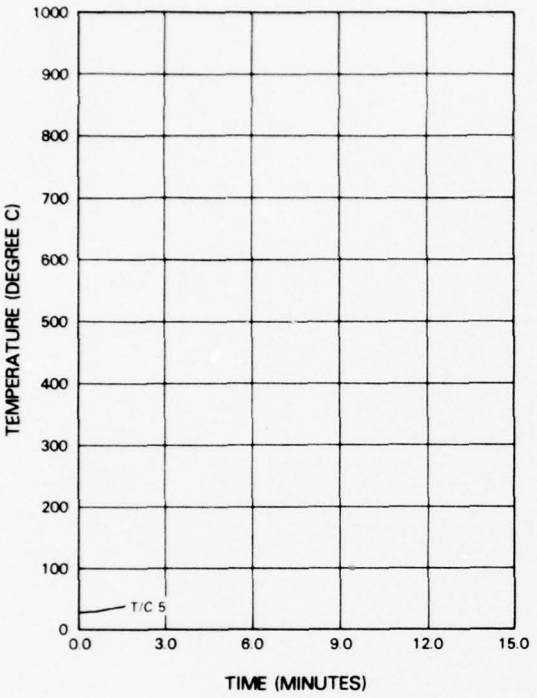
TIME TO FAILURE: 1 MIN 18 SEC; DISCHARGE RATE: 60.0 GPM JP-4

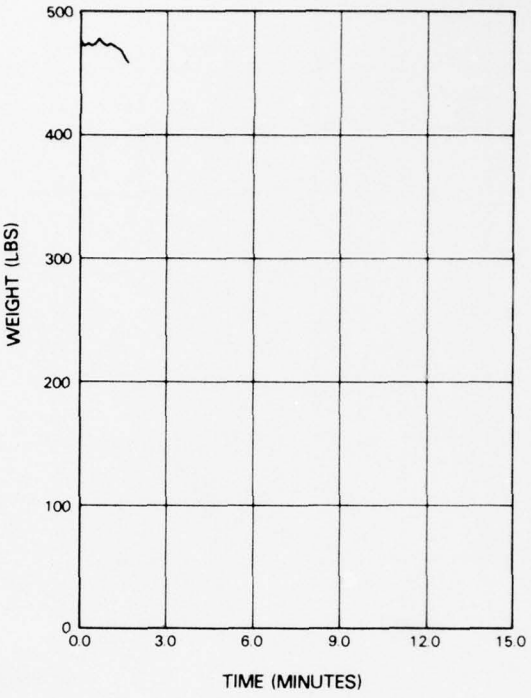
COMMENTS:

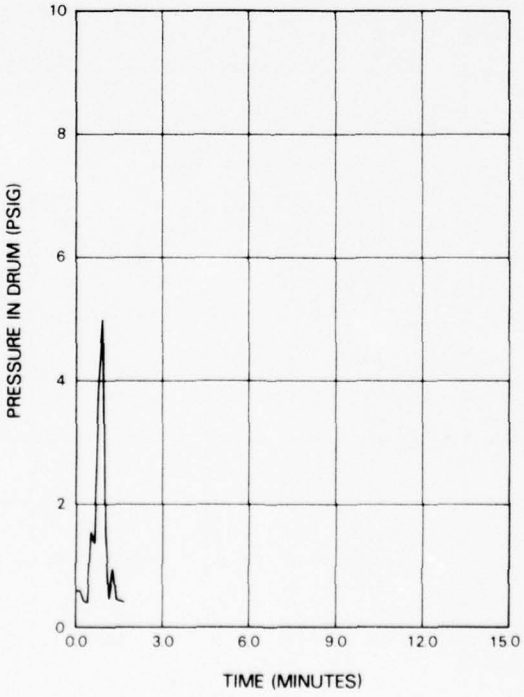
(1) Possible internal temperature and pressure build up. Not observed in any other polyethylene drum test. Bubble or burst not observed in this test.


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 1
T/C A
T/C 2
T/C 3
T/C 4
0.0
3.0
6.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 6
T/C 9
T/C A
T/C 7
T/C 8
0.0
3.0
6.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 5
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


WEIGHT (LBS)
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


PRESSURE IN DRUM (PSIG)
10
8
6
4
2
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

APPENDIX E (Continued)

DATA FROM:

TEST NUMBER 9

DRUM SIZE 30 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

SAME AS IN TEST #7

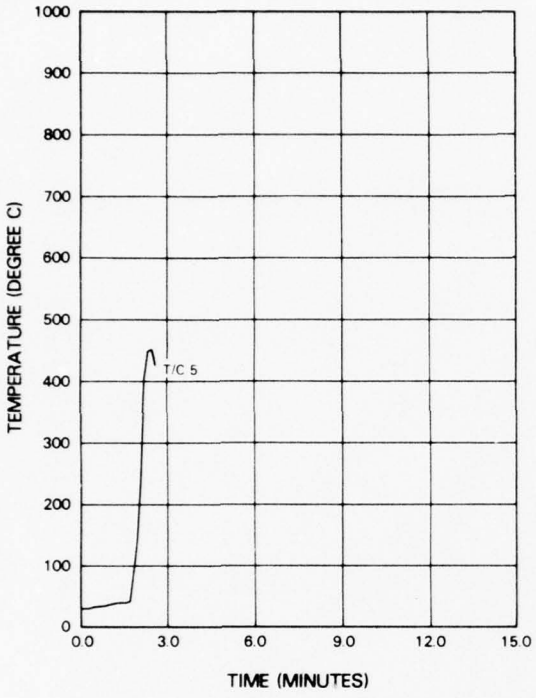
OTHER SENSORS:

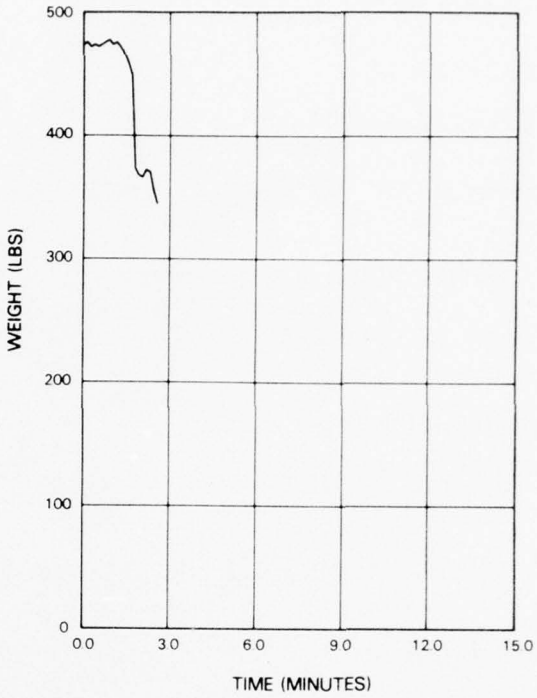
SAME AS IN TEST #7

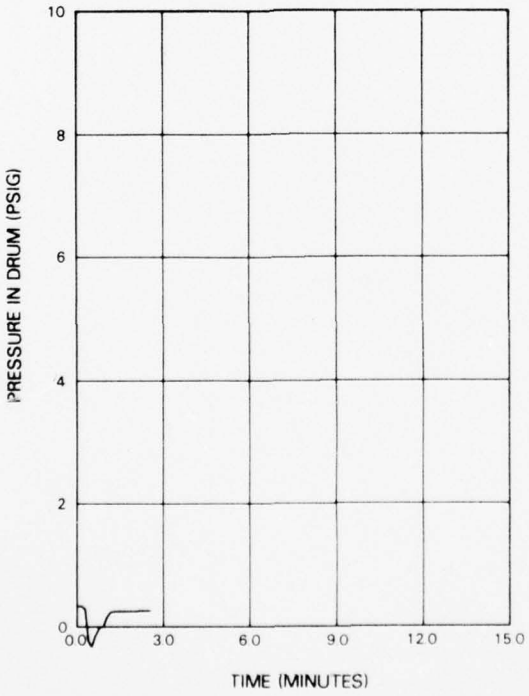
TIME TO FAILURE: 1 MIN 18 SEC; DISCHARGE RATE: 46.2 GPM JP-4

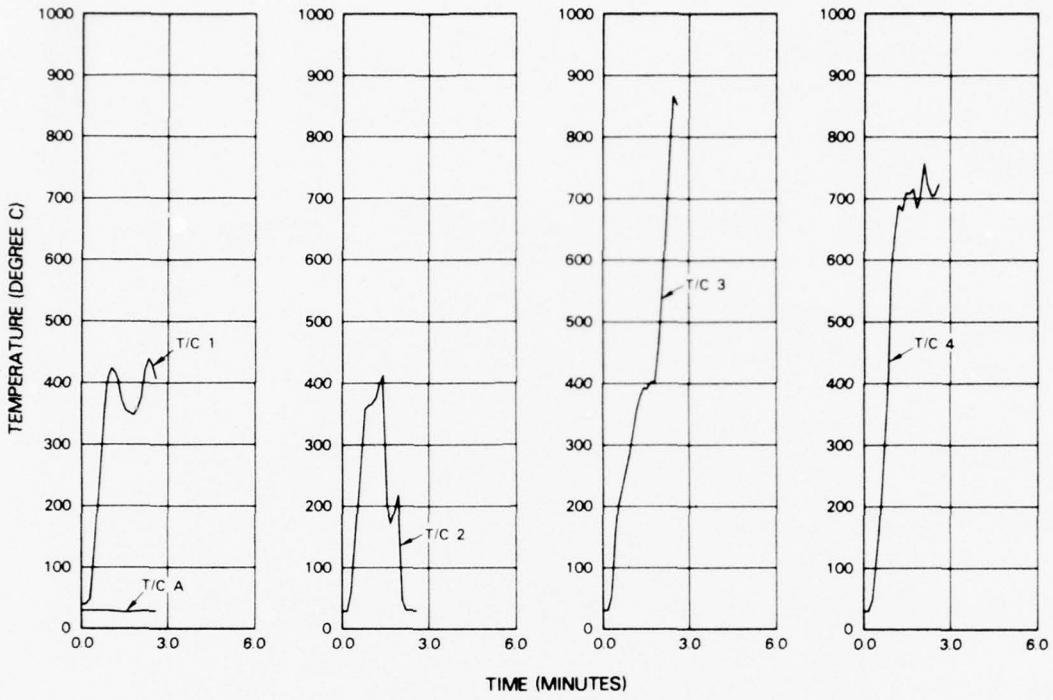
COMMENTS:

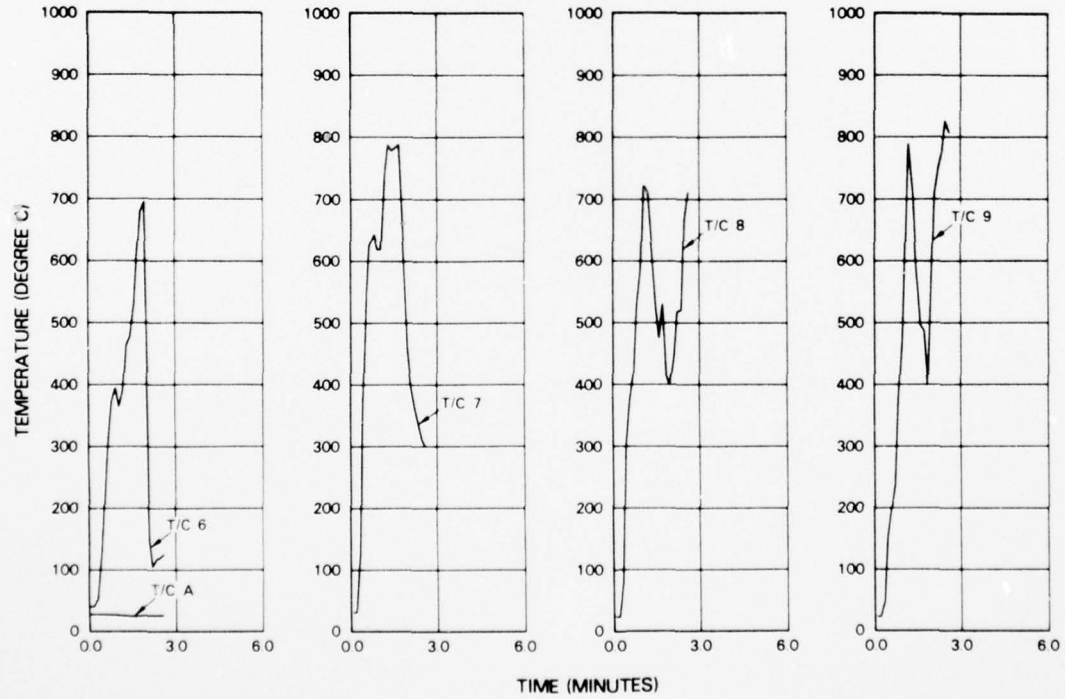
(1) No pressure rise in the drum to accompany the upward internal temperature drift shown. Internal temperature rise may be just instrument drift.


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 5
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


WEIGHT (LBS)
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


PRESSURE IN DRUM (PSIG)
10
8
6
4
2
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
T/C 1
T/C A
T/C 2
T/C 3
T/C 4
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
T/C 6
T/C A
T/C 7
T/C 8
T/C 9
TIME (MINUTES)

APPENDIX E (Continued)

DATA FROM:

TEST NUMBER 26

DRUM SIZE 30 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

NONE

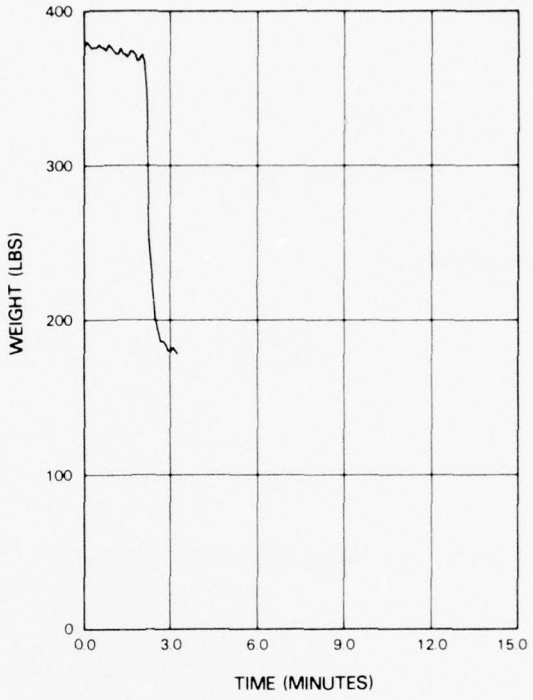
OTHER SENSORS:

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 2 MIN 12 SEC; DISCHARGE RATE: 56.3 GPM ACETONE

COMMENTS:

NOTE: This test was run to determine the time to failure and discharge rate for a cargo other than JP-4.


400
300
200
100
0
WEIGHT (LBS)
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

APPENDIX E (Continued)

DATA FROM:

TEST NUMBER 27

DRUM SIZE 30 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

NONE

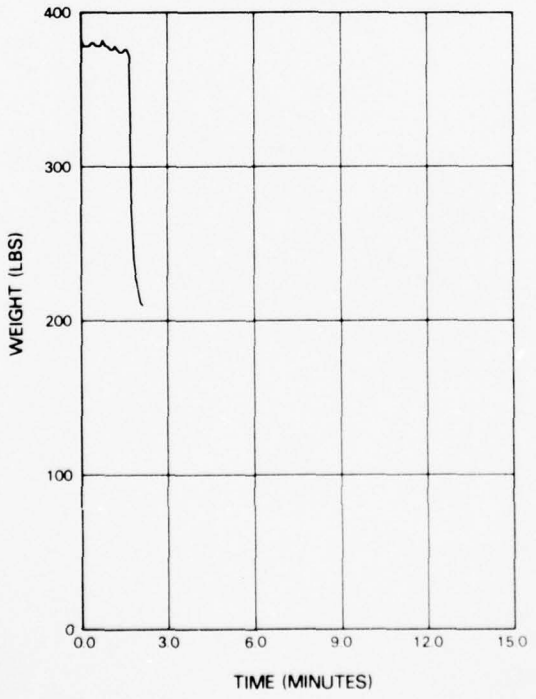
OTHER SENSORS:

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 1 MIN 42 SEC; DISCHARGE RATE: 20.0 GPM ACETONE

COMMENTS:

NONE



APPENDIX E (Continued)

DATA FROM:

TEST NUMBER 28

DRUM SIZE 30 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

NONE

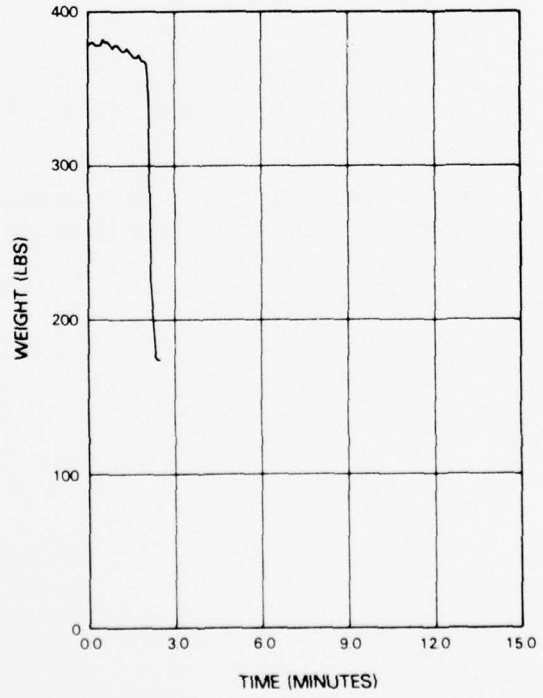
OTHER SENSORS:

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 2 MIN 6 SEC; DISCHARGE RATE: 85.7 GPM ACETONE

COMMENTS:

NONE



APPENDIX E (Continued)

DATA FROM:

TEST NUMBER 43

DRUM SIZE 30 GAL (ARRAY), MATERIAL POLYETHYLENE METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

AS IN FIGURE 11

#6		#12
#4 #5	TCA IS AMBIENT	#10 #11
#1 #2 #3		#7 #8 #9
LOWER		UPPER

OTHER SENSORS:

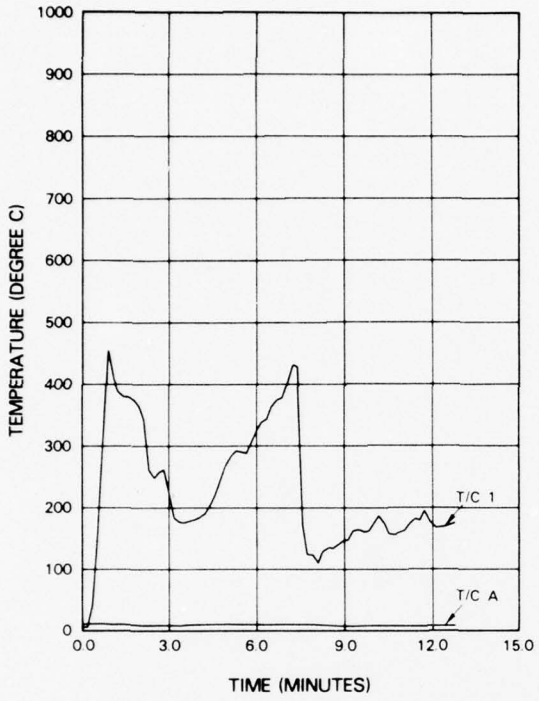
LOAD CELLS (WEIGHT)

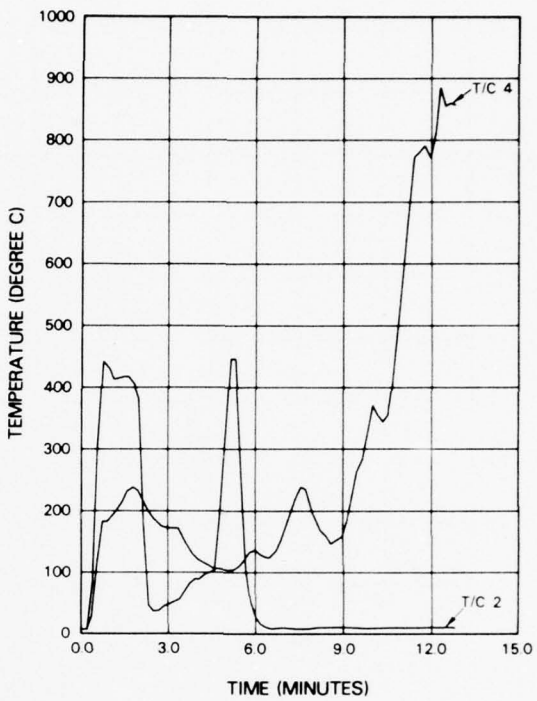
TIME TO FAILURE 1 MIN 42 SEC; DISCHARGE RATE: 53.1 GPM JP-4

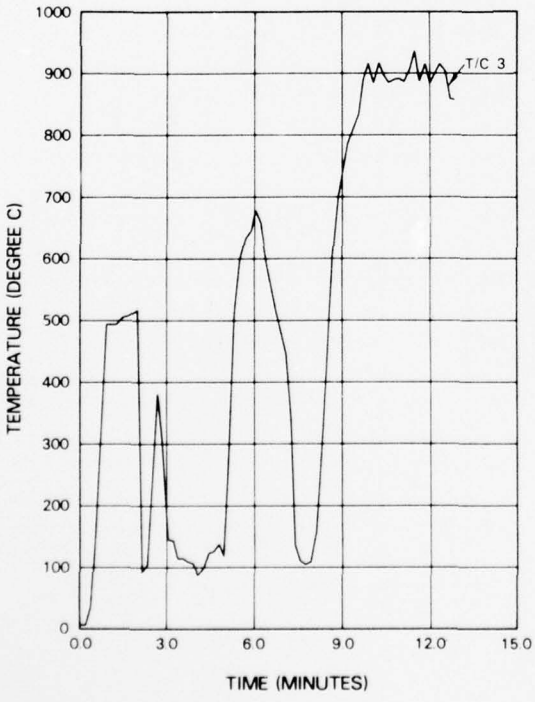
COMMENTS:

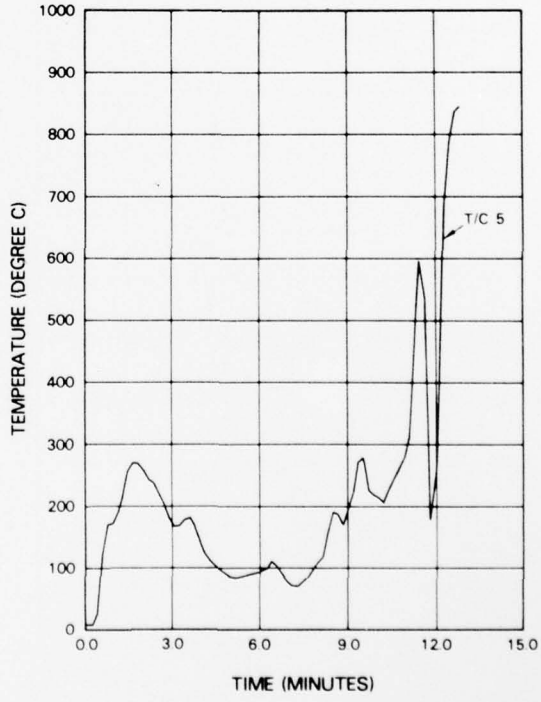
(1) This test was a fire test of an array of 20 drums loaded with 600 gal of JP-4.

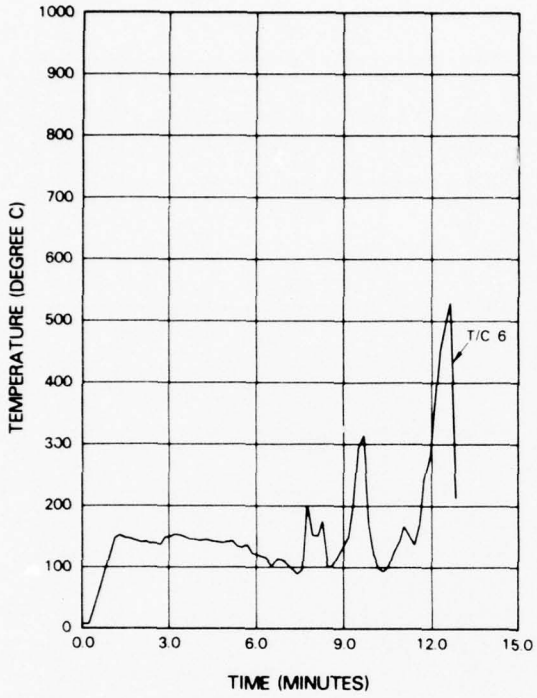
(2) The drums in the first row failed, bent toward the fire and fell. The second row played a similar role and so on, until all had failed and were empty.

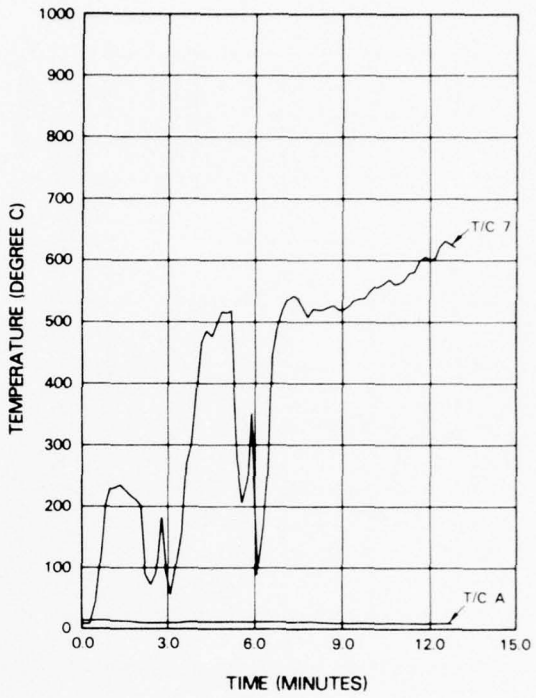

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)
T/C 1
T/C A

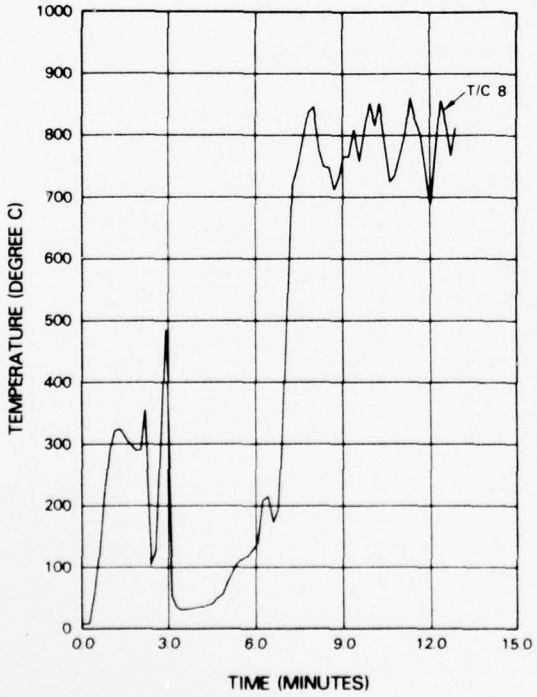

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)
T/C 4
T/C 2

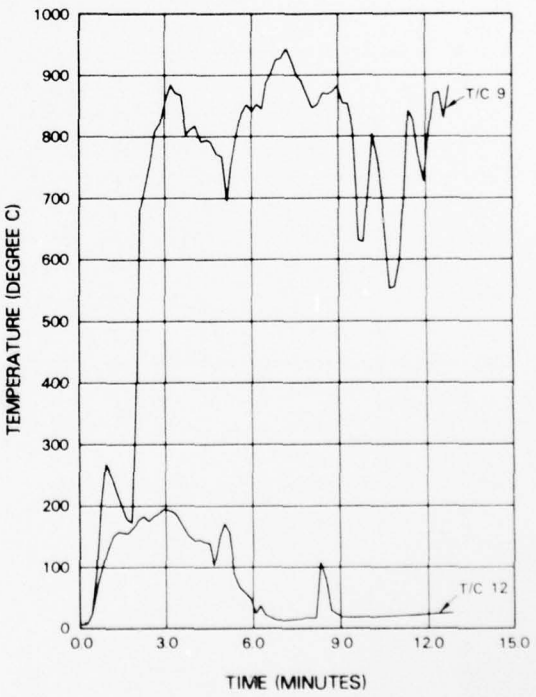

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)
T/C 3

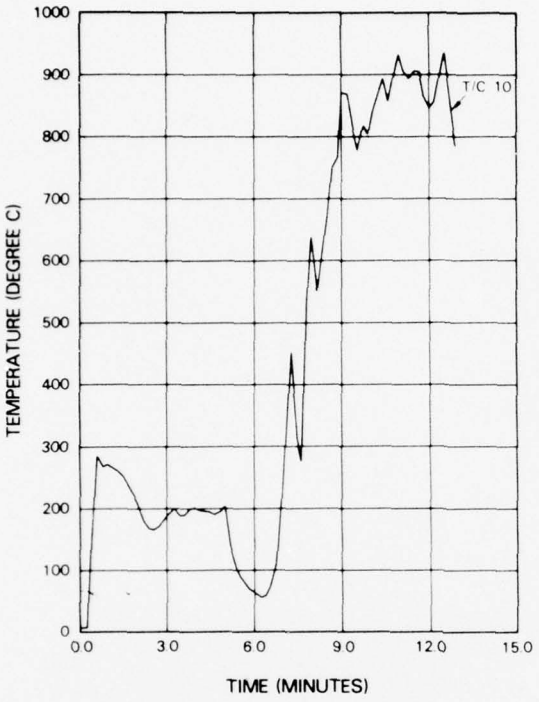

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)
T/C 5

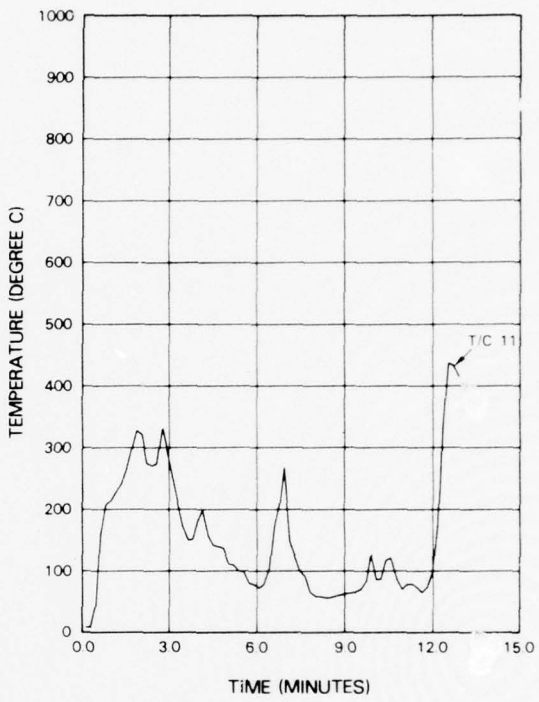

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)
T/C 6

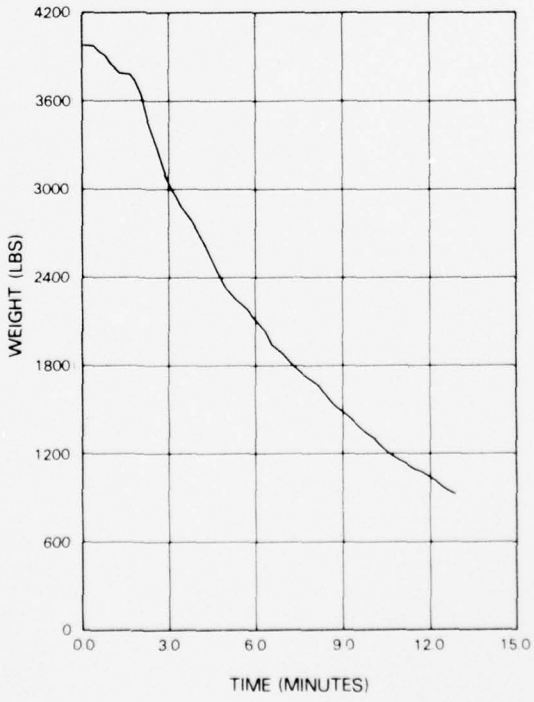

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)
T/C 7
T/C A


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)
T/C 8


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)
T/C 9
T/C 12


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 10
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 11
0.0
3.0
6.0
9.0
12.0
15.0
TiME (MINUTES)


WEIGHT (LBS)
4200
3600
3000
2400
1800
1200
600
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

APPENDIX F: Data from Tests 10-12, 29-31, and 44 using 55 gallon blow-molded polyethylene drums.

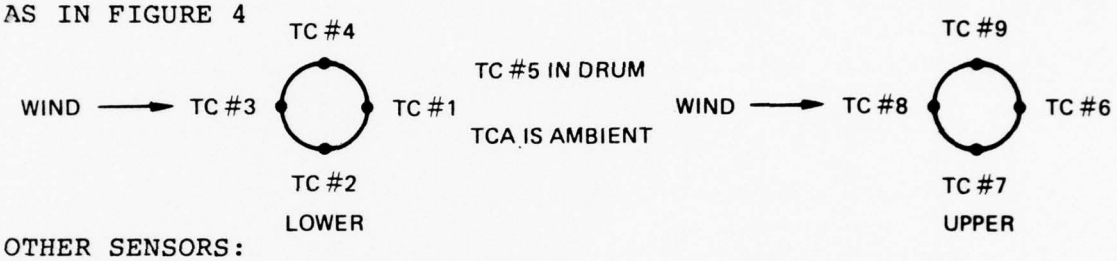
DATA FROM:

TEST NUMBER 10

DRUM SIZE 55 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

AS IN FIGURE 4



OTHER SENSORS:

INTERNAL PRESSURE

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 1 MIN 42 SEC; DISCHARGE RATE: 91.7 GPM JP-4

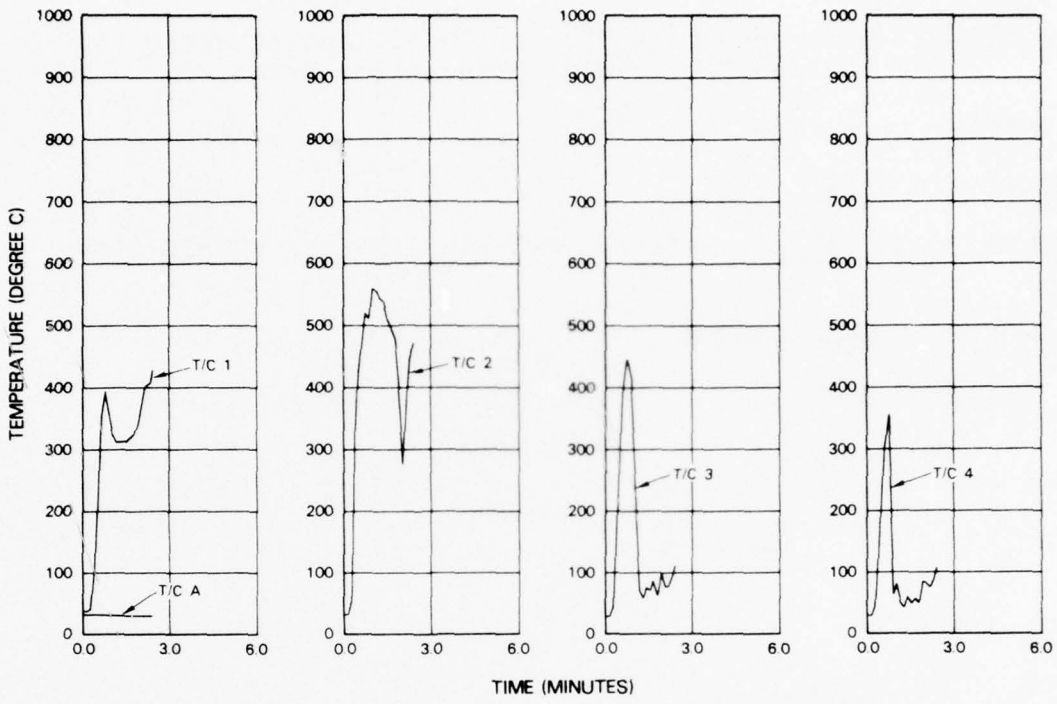
COMMENTS:

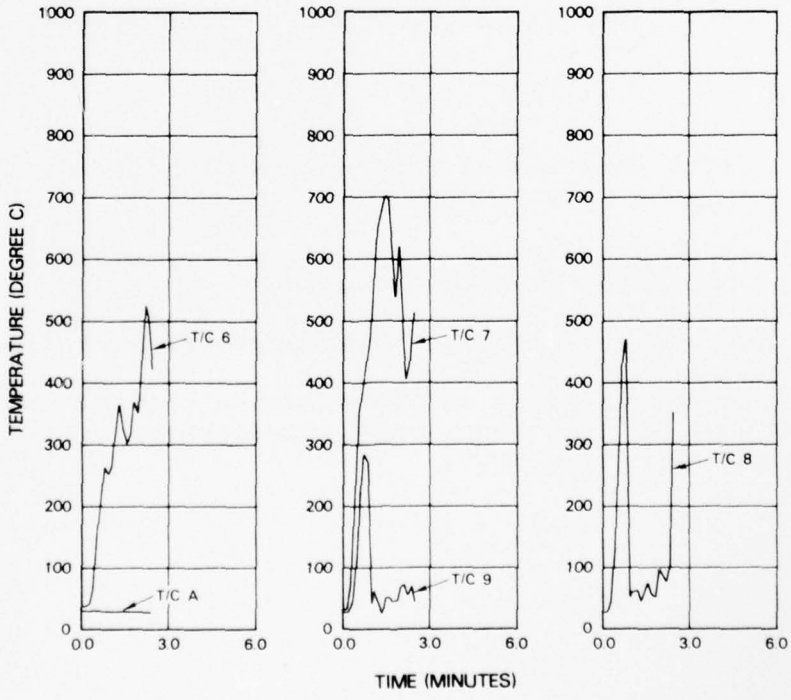
(1) Sudden drops in external temperature are due to the thermocouple falling into water in the pan.

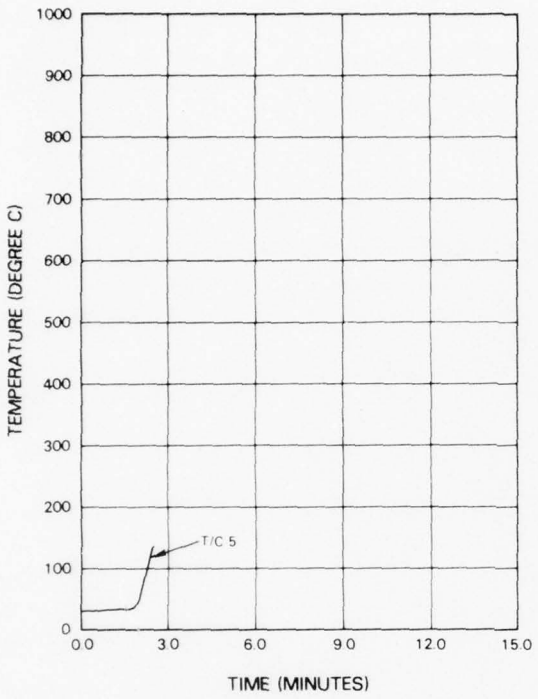
(2) Fluctuations in external temperature may be due to wind gusts or cargo hitting the thermocouple.

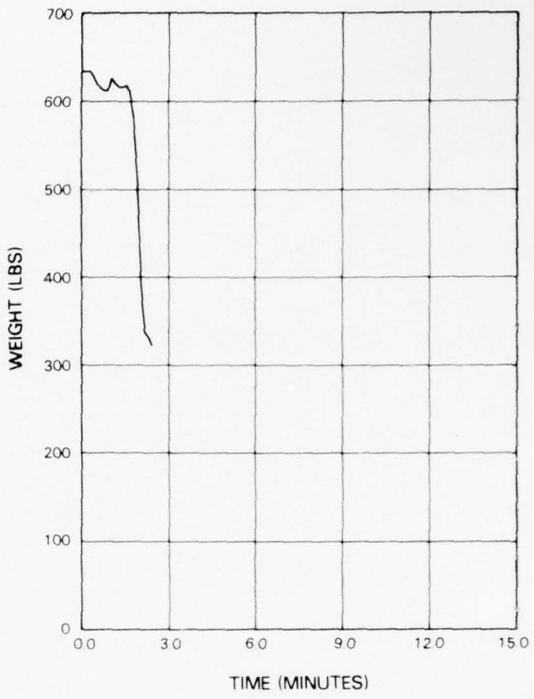
(3) Sharp internal temperature rise occurs after failure.

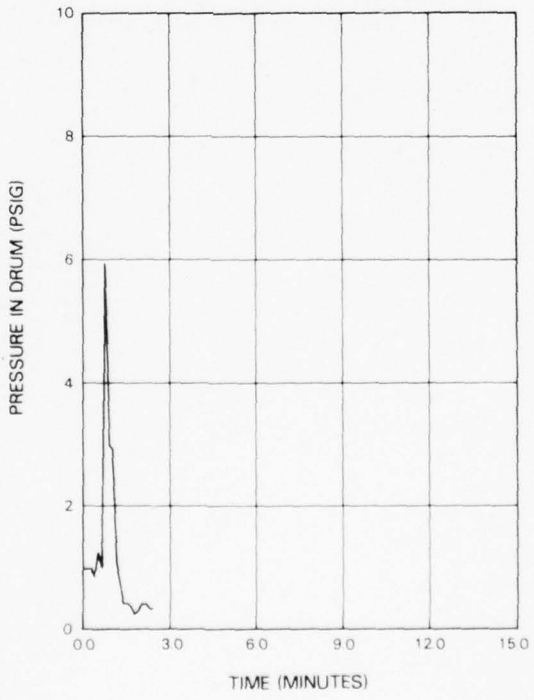
(4) Real internal pressure and temperature change. No bubbling or bursting seen at failure. Temperature/pressure rise not seen in other tests with this drum.


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
T/C 1
T/C A
T/C 2
T/C 3
T/C 4
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
T/C 6
T/C A
T/C 7
T/C 9
T/C 8
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 5
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

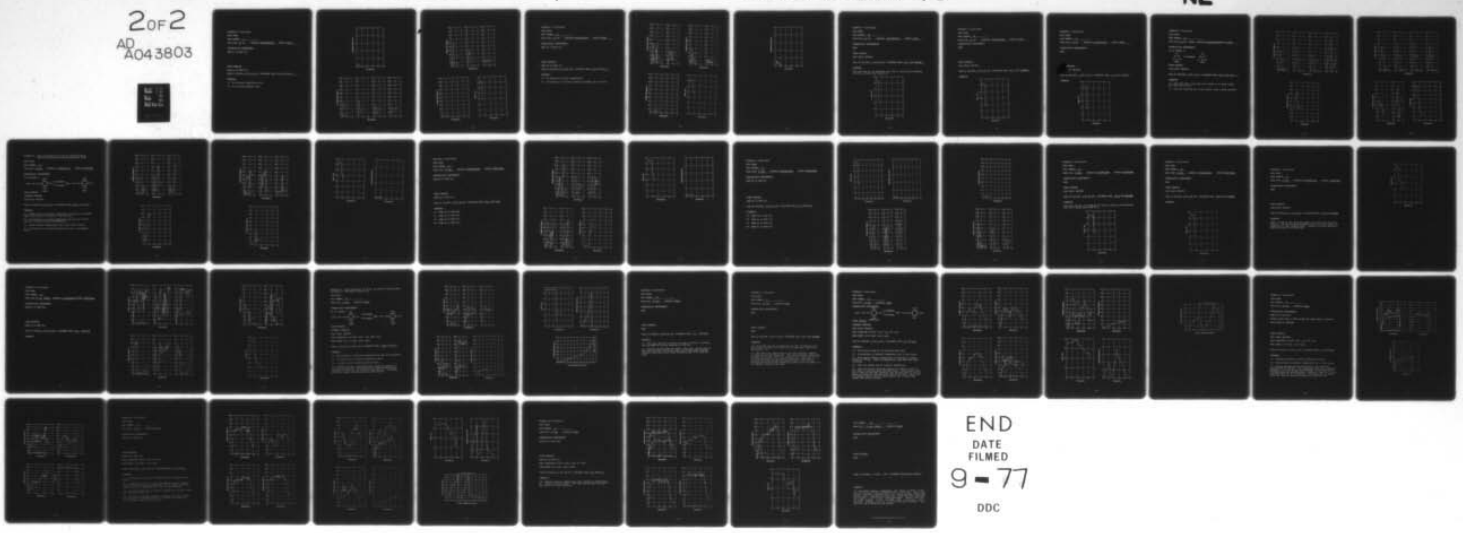

WEIGHT (LBS)
700
600
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


PRESSURE IN DRUM (PSIG)
10
8
6
4
2
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

AD-A043 803 COAST GUARD RESEARCH AND DEVELOPMENT CENTER GROTON CONN F/G 13/4
FIRE EXPOSURE TESTS OF POLYETHYLENE AND FIFTY-FIVE GALLON STEEL--ETC(U)
SEP 76 R C RICHARDS, K T WHITE

UNCLASSIFIED CGR/DC-16/76 USCG-D-116-76 NL

2 OF 2
AD A043803



END
DATE FILMED
9-77
DDC

APPENDIX F (Continued)

DATA FROM:

TEST NUMBER 11

DRUM SIZE 55 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

SAME AS IN TEST #10

OTHER SENSORS:

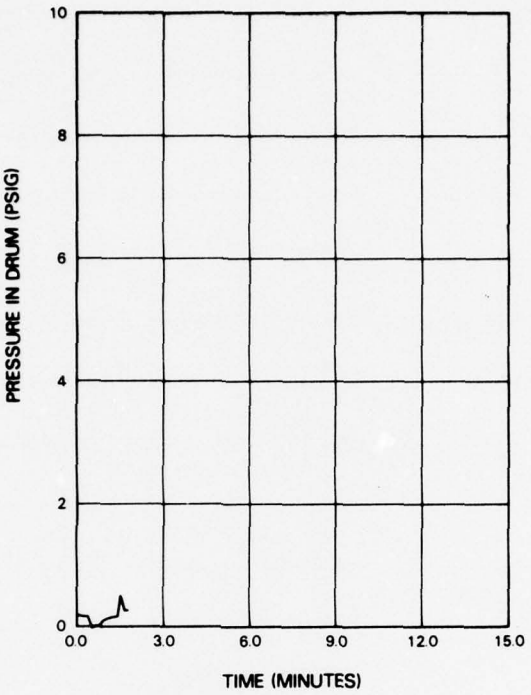
SAME AS IN TEST #10

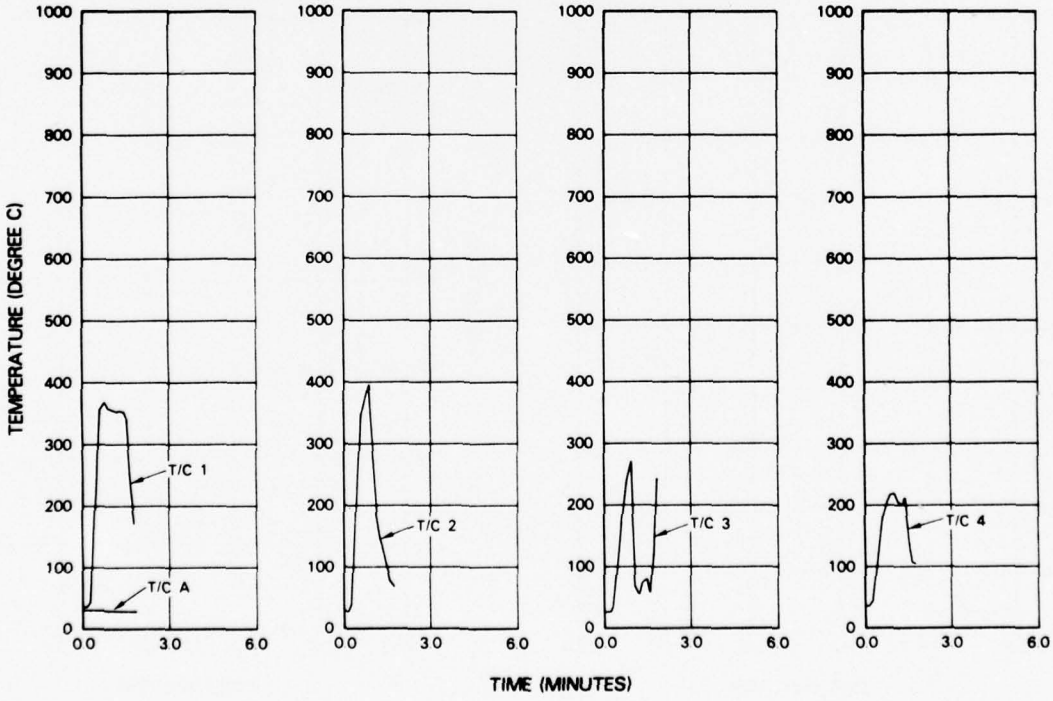
TIME TO FAILURE: 1 MIN 30 SEC: DISCHARGE RATE: 275.0 GPM JP-4

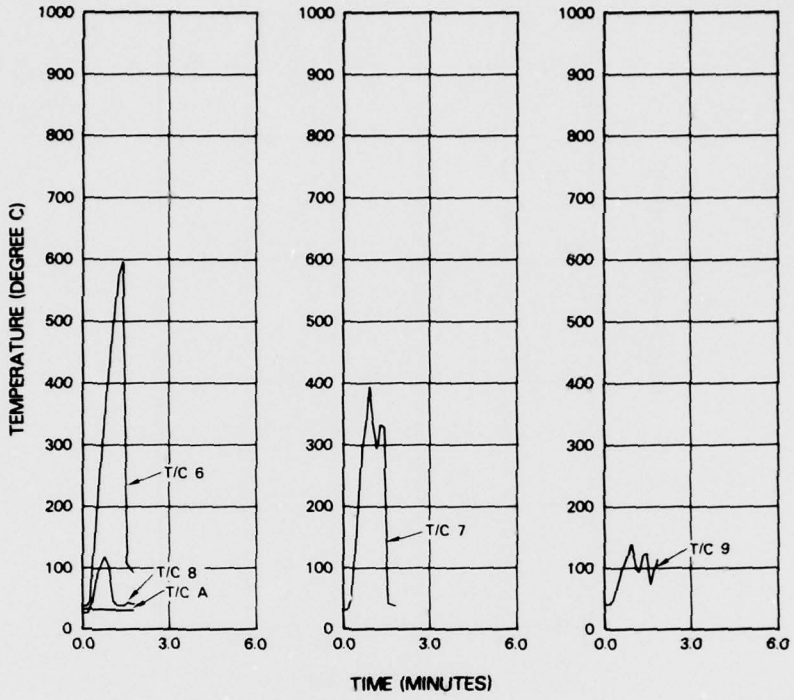
COMMENTS:

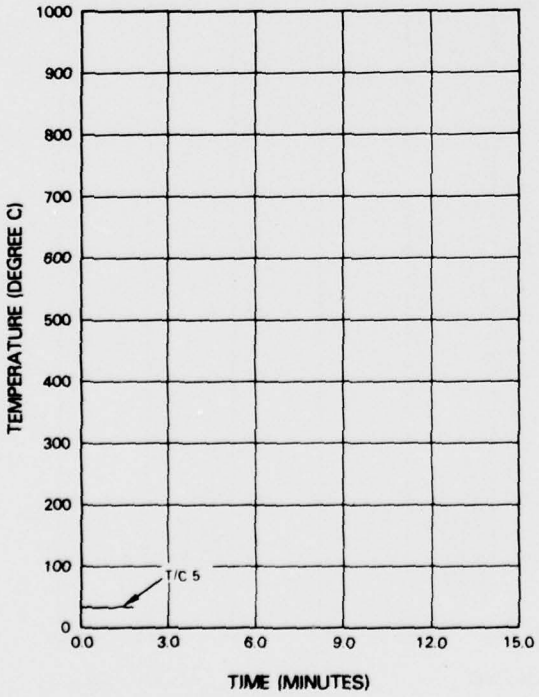
(1) No internal temperature rise.

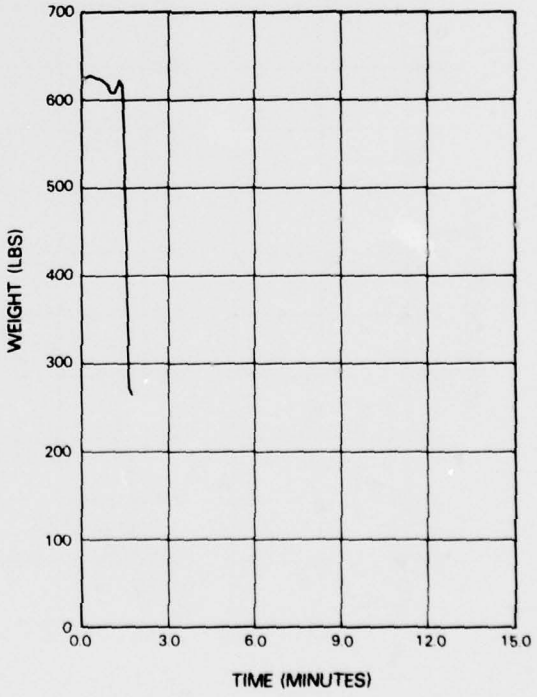
(2) No internal pressure rise.


PRESSURE IN DRUM (PSIG)
10
8
6
4
2
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 1
T/C A
T/C 2
T/C 3
T/C 4
0.0
3.0
6.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 6
T/C 8
T/C A
T/C 7
T/C 9
0.0
3.0
6.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 5
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


WEIGHT (LBS)
700
600
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

APPENDIX F (Continued)

DATA FROM:

TEST NUMBER 12

DRUM SIZE 55 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

SAME AS IN TEST #10

OTHER SENSORS:

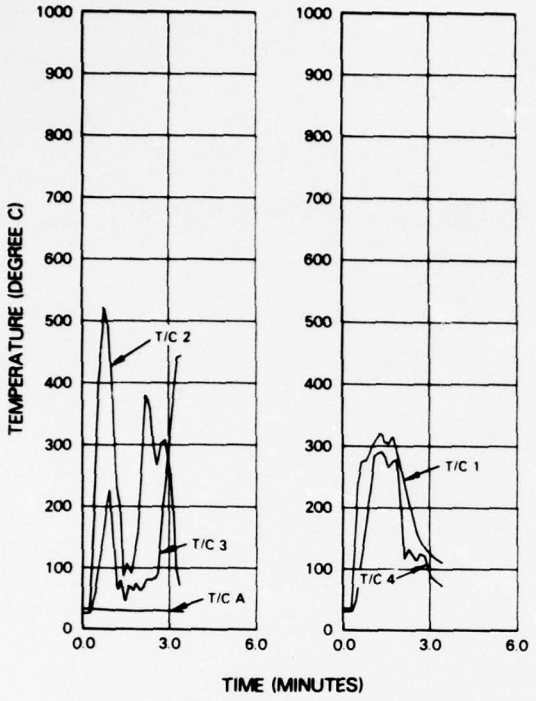
SAME AS IN TEST #10

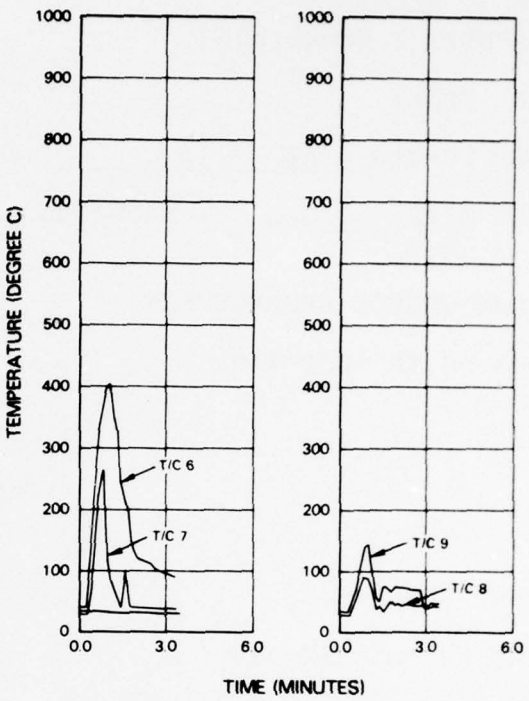
TIME TO FAILURE: 1 MIN 48 SEC; DISCHARGE RATE: 91.7 GPM JP-4

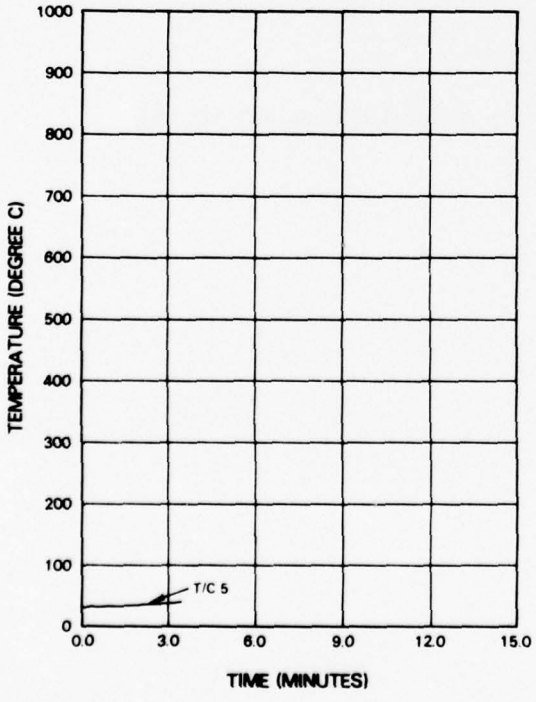
COMMENTS:

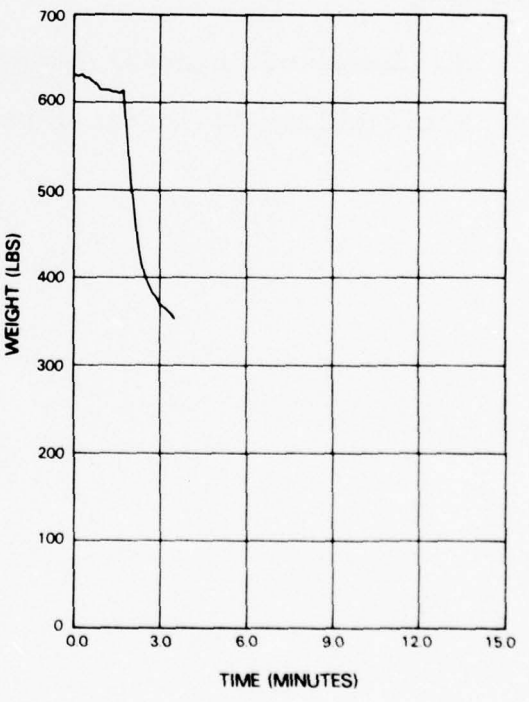
(1) No change of internal temperature.

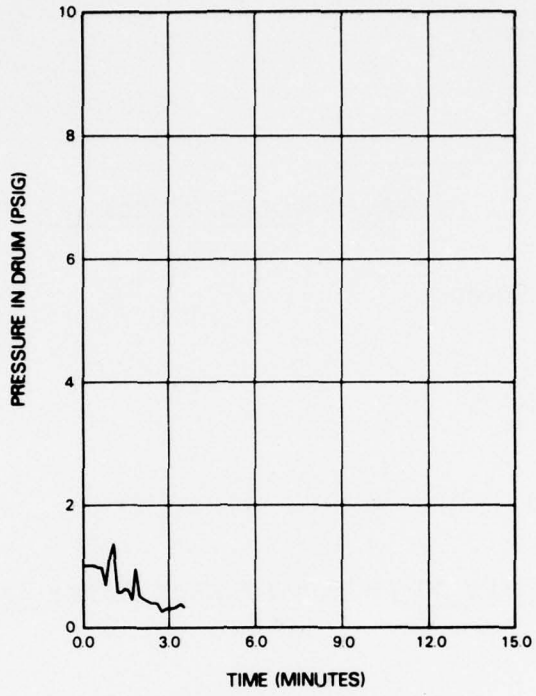
(2) Fluctuations of internal pressure probably due to drift.


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 2
T/C 3
T/C A
T/C 1
T/C 4
0.0
3.0
6.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 6
T/C 7
T/C 9
T/C 8
0.0
3.0
6.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 5
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


WEIGHT (LBS)
700
600
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


10
8
6
4
2
0
PRESSURE IN DRUM (PSIG)
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

APPENDIX F (Continued)

DATA FROM:

TEST NUMBER 29

DRUM SIZE 55 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

NONE

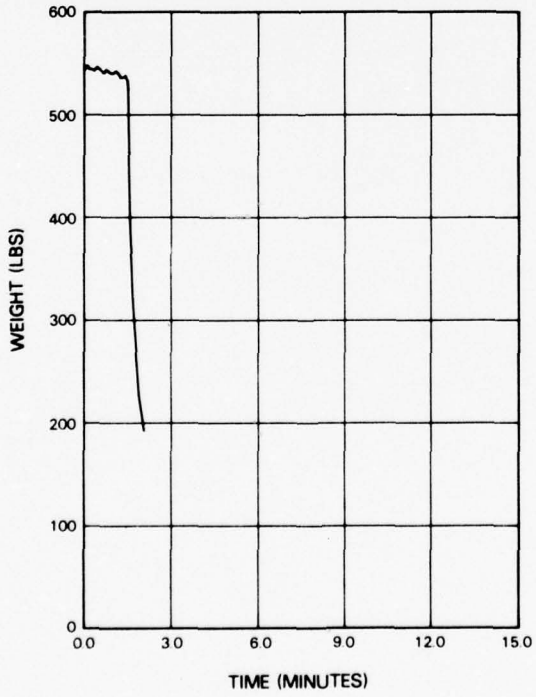
OTHER SENSORS:

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 1 MIN 30 SEC; DISCHARGE RATE: 110.0 GPM ACETONE

COMMENTS:

This test was run to determine the time to failure and discharge rate for a cargo other than JP-4.



APPENDIX F (Continued)

DATA FROM:

TEST NUMBER 30

DRUM SIZE 55 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

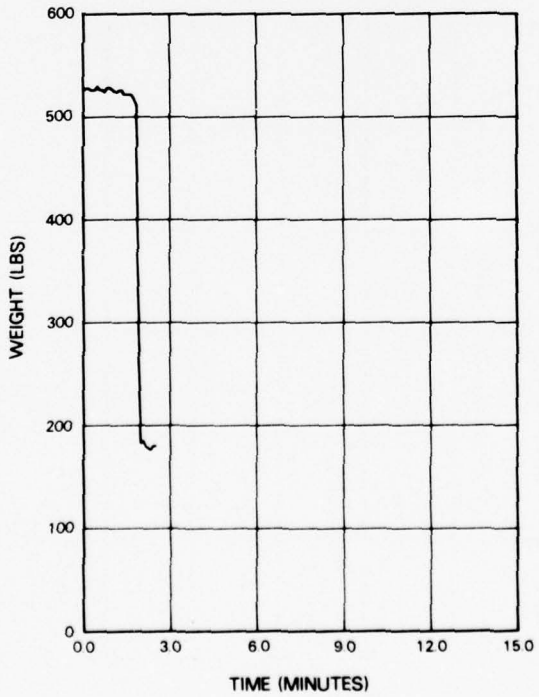
NONE

OTHER SENSORS:

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 1 MIN 51 SEC; DISCHARGE RATE: 235.7 GPM ACETONE

COMMENTS:



APPENDIX F (Continued)

DATA FROM:

TEST NUMBER 31

DRUM SIZE 55 GAL , MATERIAL POLYETHYLENE , METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

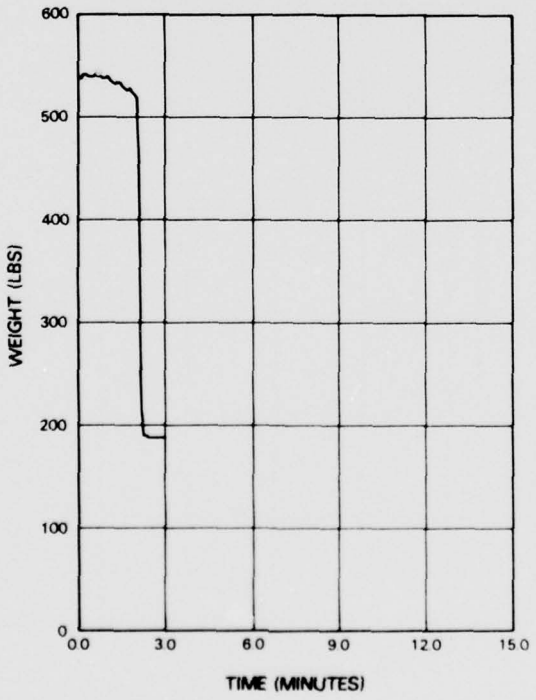
NONE

OTHER SENSORS:

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 1 MIN 12 SEC; DISCHARGE RATE: 47.8 GPM ACETONE

COMMENTS:



APPENDIX F (Continued)

DATA FROM:

TEST NUMBER 44

DRUM SIZE 55 GAL (ARRAY) MATERIAL POLYETHYLENE METHOD BLOWN

THERMOCOUPLE ARRANGEMENT:

AS IN FIGURE 10

OTHER SENSORS:

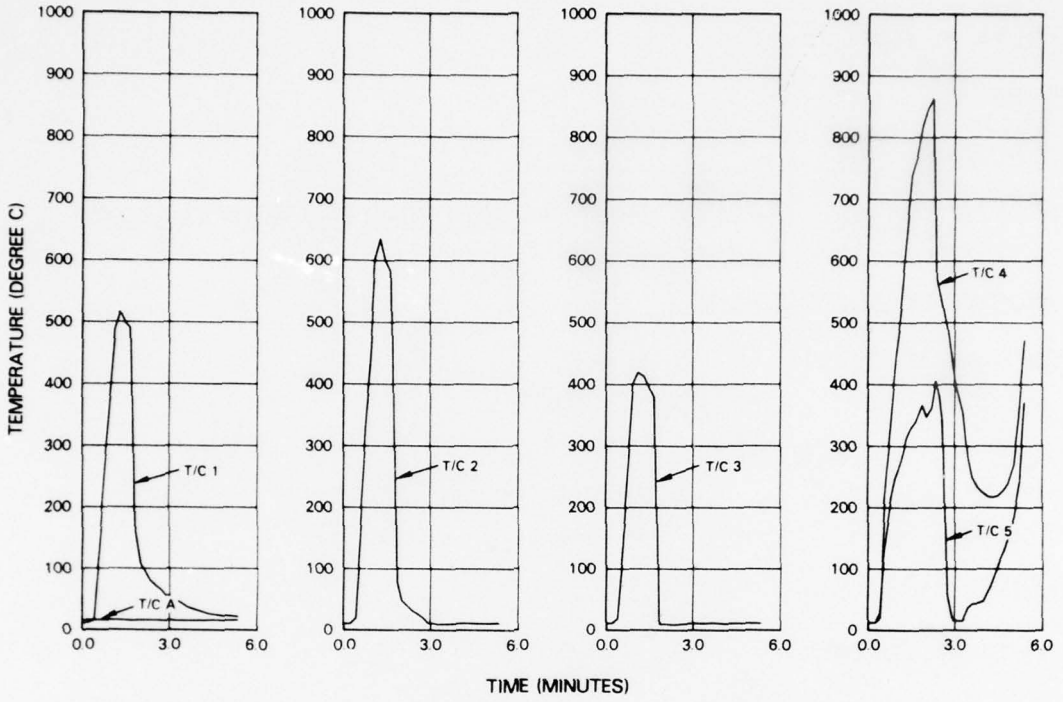
LOAD CELLS (WEIGHT)

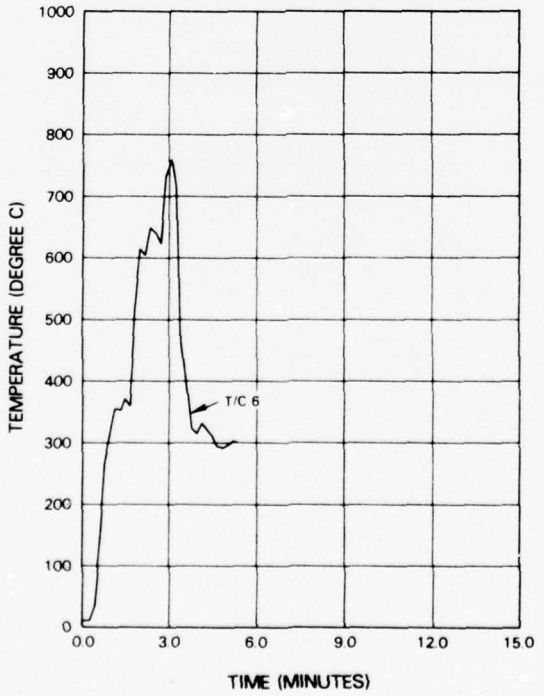
TIME TO FAILURE: 1 MIN 33 SEC; DISCHARGE RATE: 212.9 GPM JP-4

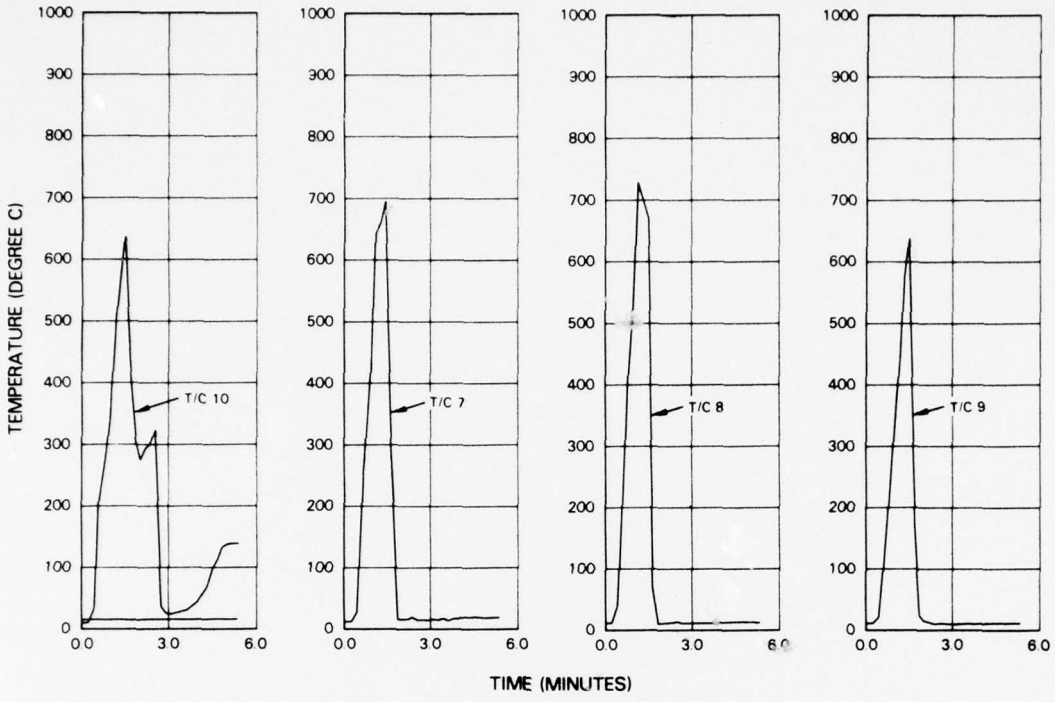
COMMENTS:

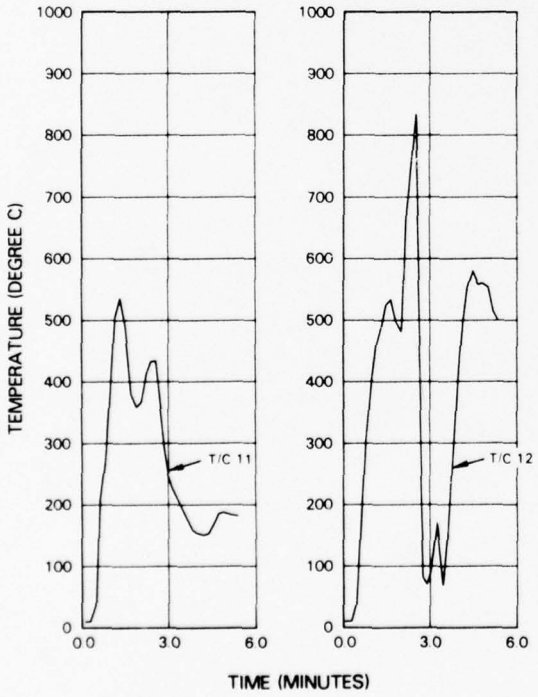
(1) This test was a fire test of an array of 12 drums loaded with 660 gal of JP-4.

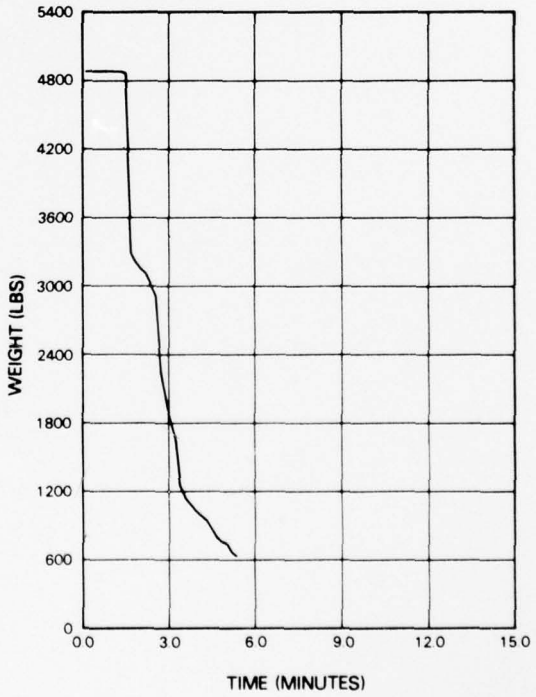
(2) Note the leveling off of the weight, then a sharp decrease.


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
T/C 1
T/C A
T/C 2
T/C 3
T/C 4
T/C 5
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
T/C 6
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 10
T/C 7
T/C 8
T/C 9
0.0
3.0
6.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 11
T/C 12
0.0
3.0
6.0
TIME (MINUTES)


WEIGHT (LBS)
5400
4800
4200
3600
3000
2400
1800
1200
600
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

APPENDIX G: Data from Tests 13-15, 32-34, and 45 using 55 gallon rotationally molded polyethylene drums.

DATA FROM:

TEST NUMBER 13

DRUM SIZE 55 GAL , MATERIAL POLYETHYLENE , METHOD ROTATIONAL

THERMOCOUPLE ARRANGEMENT:

AS IN FIGURE 4

OTHER SENSORS:

INTERNAL PRESSURE

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 2 MIN 5 SEC; DISCHARGE RATE: 253.8 GPM JP-4

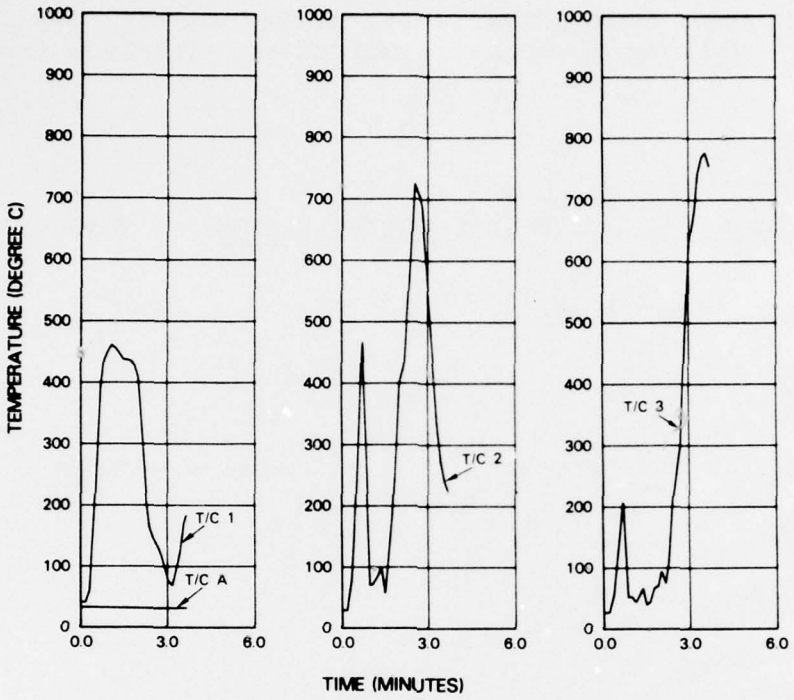
COMMENTS:

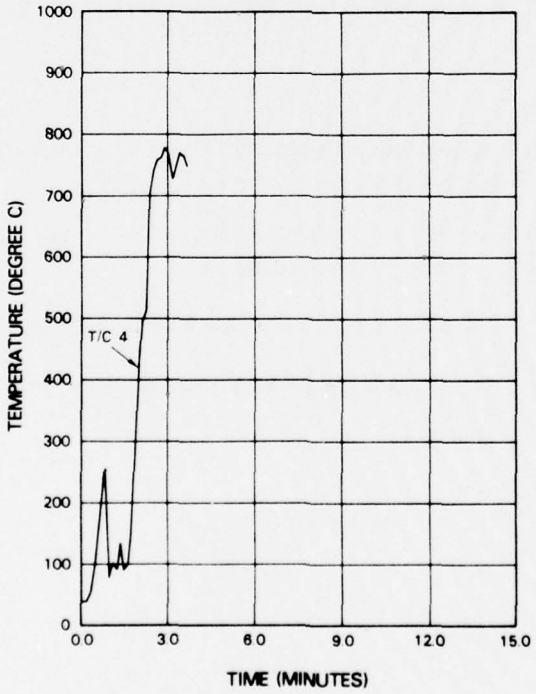
(1) Sudden drops in external temperature are due to the thermocouple falling into the water in the fire pan.

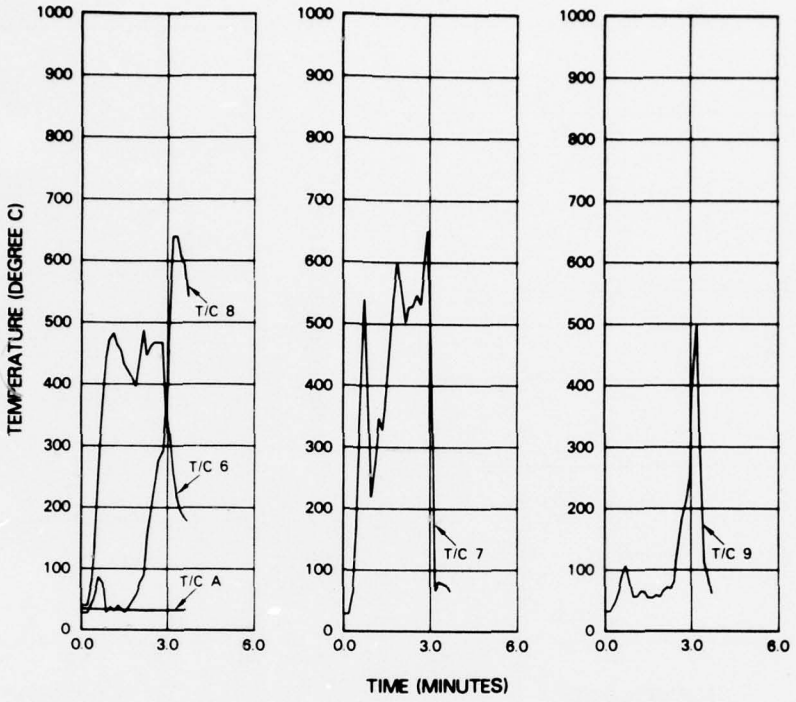
(2) Fluctuations in external temperature may be due to wind gusts or cargo hitting the thermocouple.

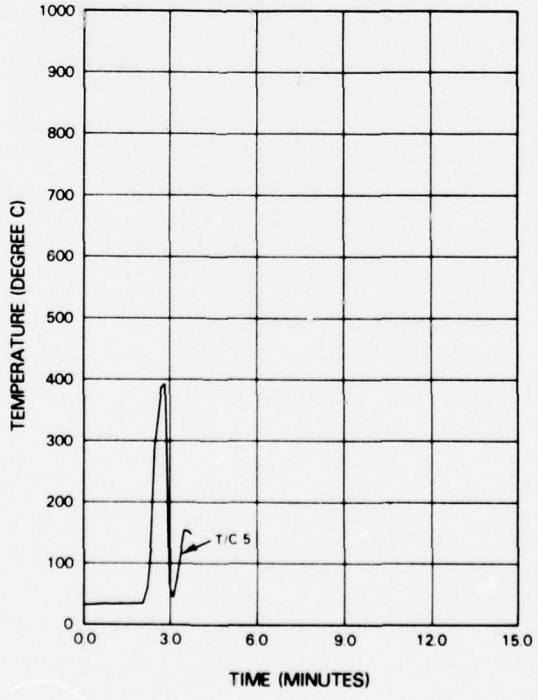
(3) Sharp internal temperature rise occurs after failure.

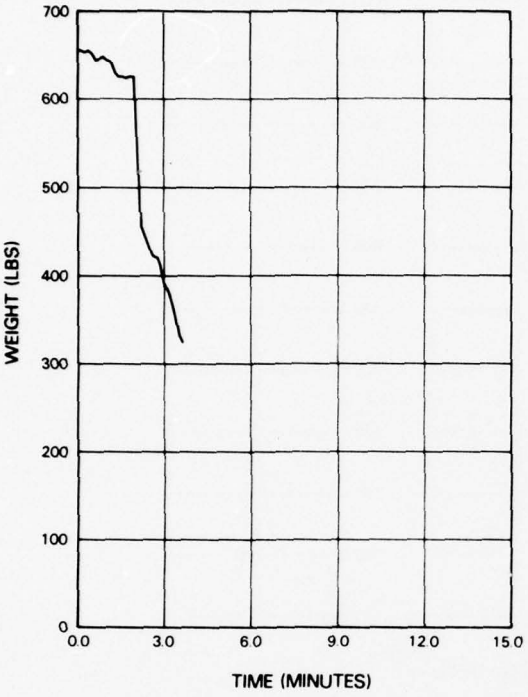
(4) Fluctuations of internal pressure are due to instrument drift.

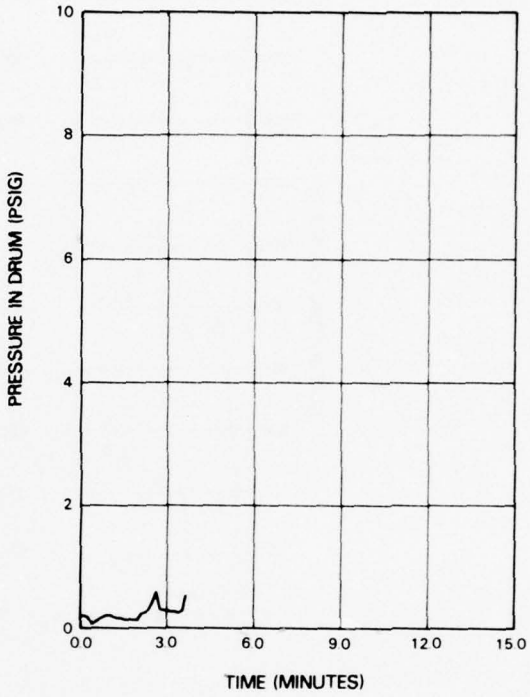

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
T/C 1
T/C A
T/C 2
T/C 3
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
T/C 4
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
T/C 8
T/C 6
T/C A
T/C 7
T/C 9
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
T/C 5
TIME (MINUTES)


WEIGHT (LBS)
700
600
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


PRESSURE IN DRUM (PSIG)
10
8
6
4
2
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

APPENDIX G (Continued)

DATA FROM:

TEST NUMBER 14

DRUM SIZE 55 GAL , MATERIAL POLYETHYLENE , METHOD ROTATIONAL

THERMOCOUPLE ARRANGEMENT:

SAME AS IN TEST #13

OTHER SENSORS:

SAME AS IN TEST #13

TIME TO FAILURE: 2 MIN 36 SEC; DISCHARGE RATE: 137.5 GPM JP-4

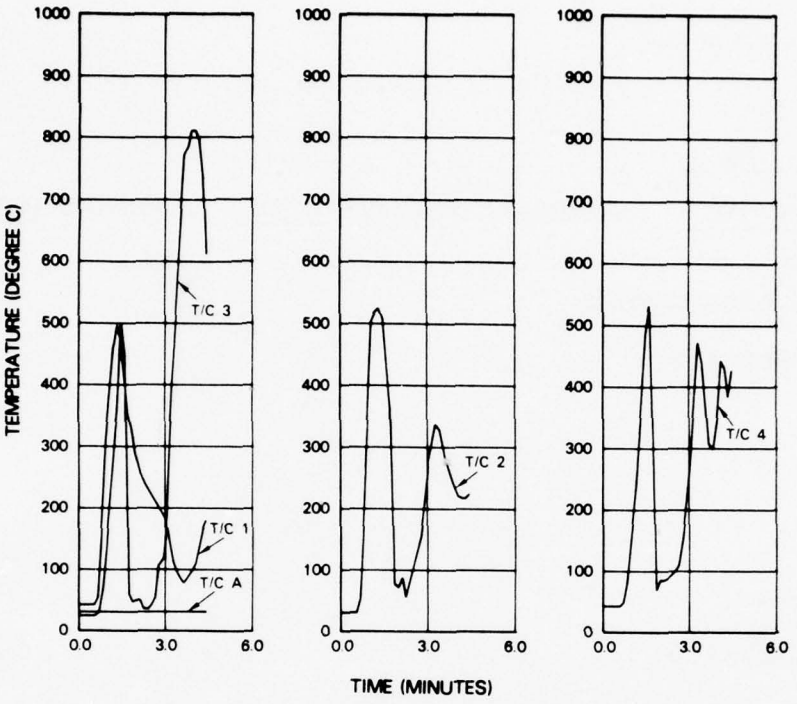
COMMENTS:

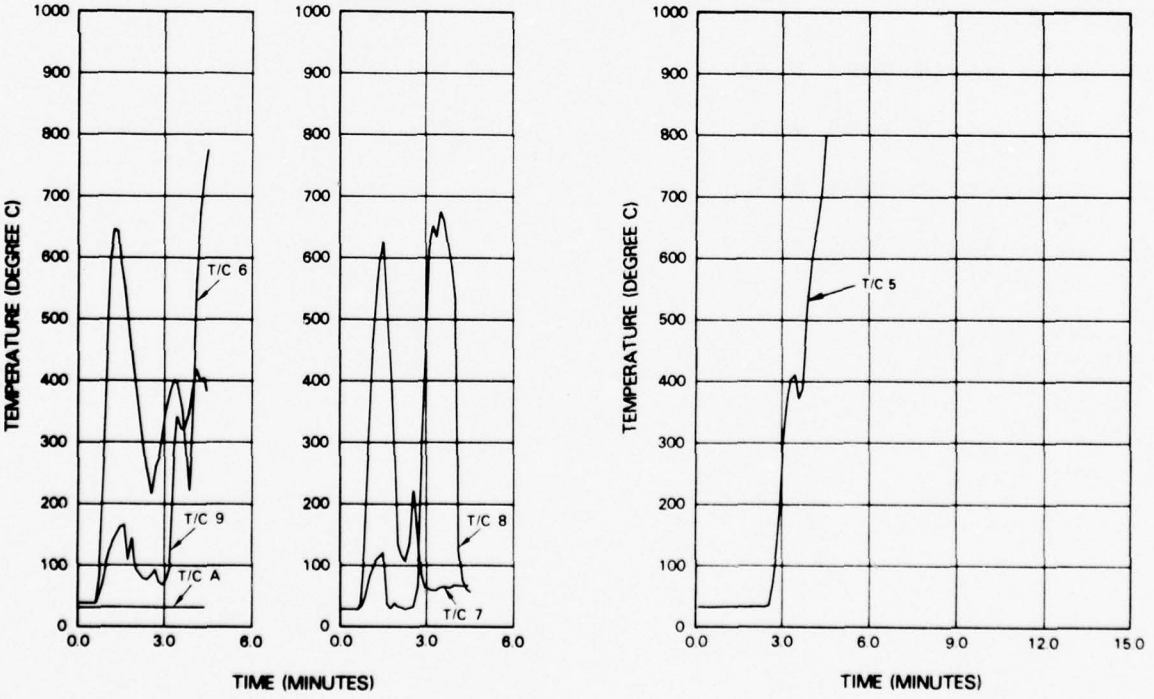
(1) Same as in Test #13

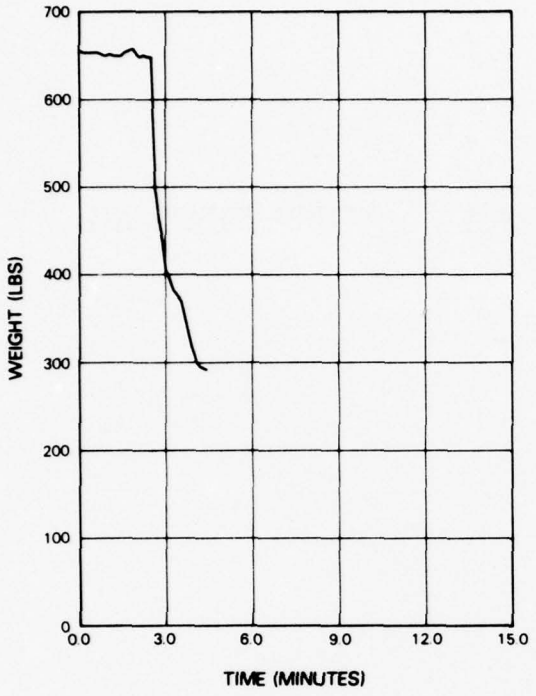
(2) Same as in Test #13

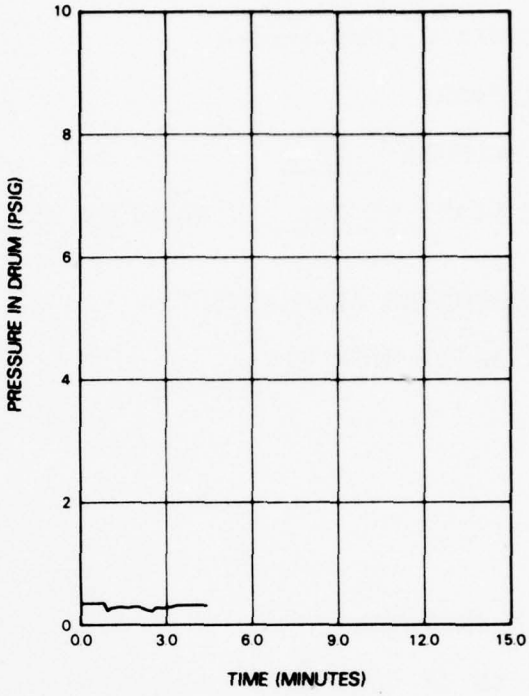
(3) Same as in Test #13

(4) Same as in Test #13


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
T/C 3
T/C 1
T/C A
T/C 2
T/C 4
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
0.0
3.0
6.0
T/C 6
T/C 9
T/C A
T/C 8
T/C 7
TIME (MINUTES)
9.0
12.0
15.0
T/C 5


700
600
500
400
300
200
100
0
WEIGHT (LBS)
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


10
8
6
4
2
0
PRESSURE IN DRUM (PSIG)
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

APPENDIX G (Continued)

DATA FROM:

TEST NUMBER 15

DRUM SIZE 55 GAL , MATERIAL POLYETHYLENE , METHOD ROTATIONAL

THERMOCOUPLE ARRANGEMENT:

SAME AS IN TEST #13

OTHER SENSORS:

SAME AS IN TEST #13

TIME TO FAILURE: 1 MIN 30 SEC; DISCHARGE RATE: 91.7 GPM JP-4

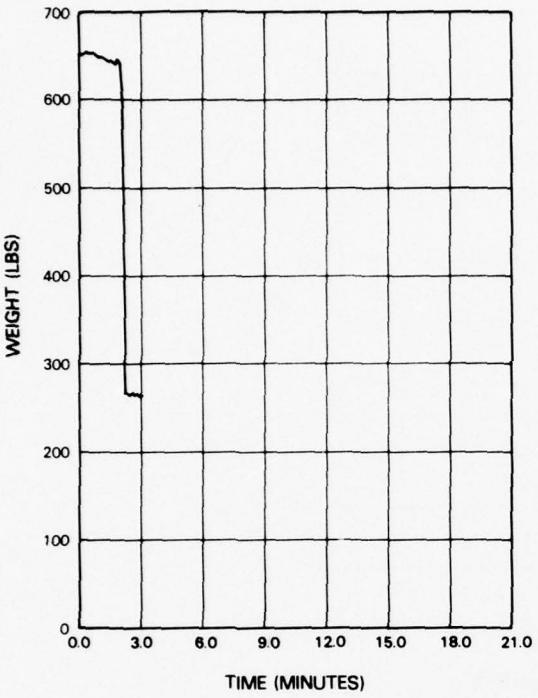
COMMENTS:

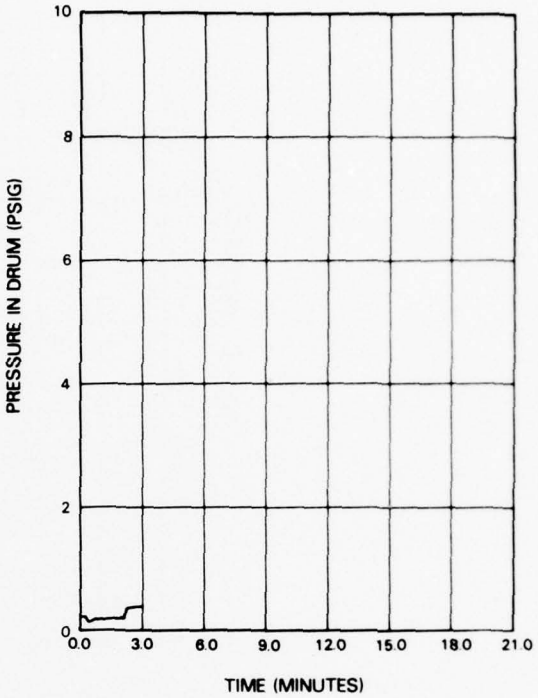
(1) Same as in Test #13

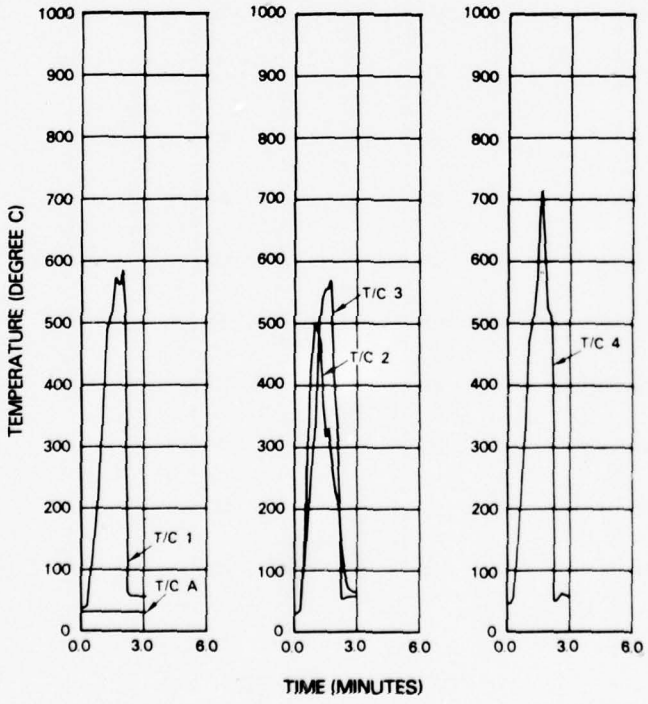
(2) Same as in Test #13

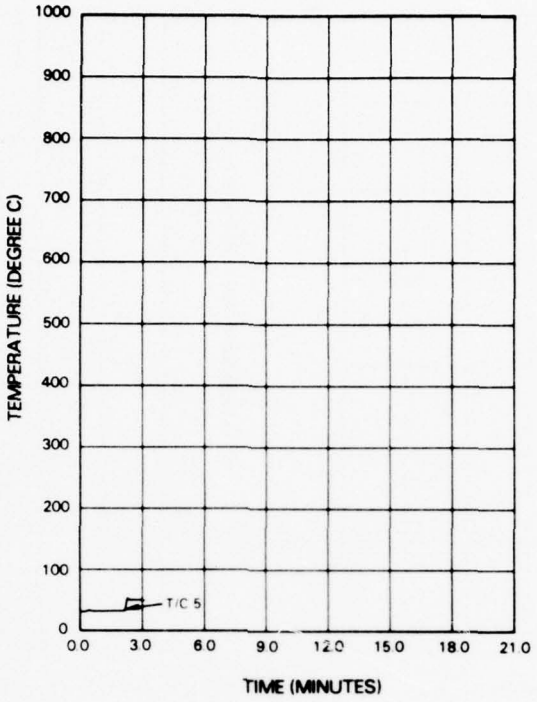
(3) Same as in Test #13

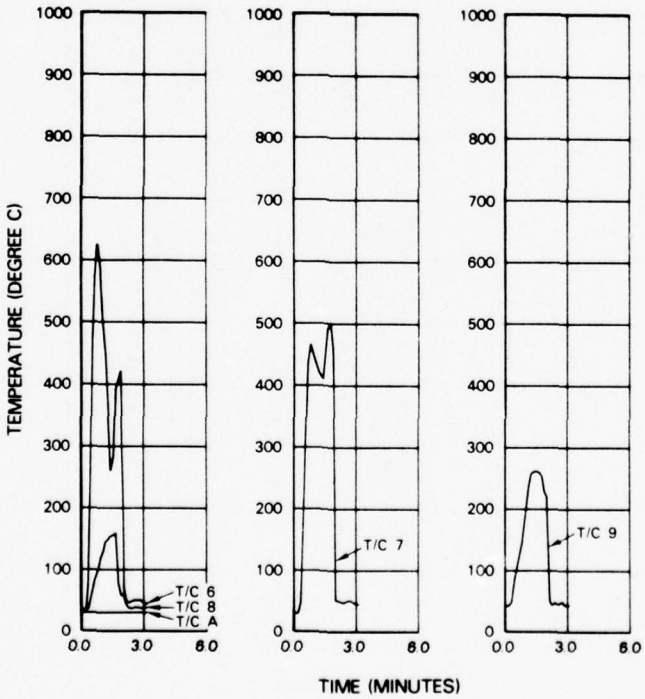
(4) Same as in Test #13


WEIGHT (LBS)
700
600
500
400
300
200
100
0
0.0
3.0
6.0
9.0
12.0
15.0
18.0
21.0
TIME (MINUTES)


PRESSURE IN DRUM (PSIG)
10
8
6
4
2
0
0.0
3.0
6.0
9.0
12.0
15.0
18.0
21.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 1
T/C A
T/C 3
T/C 2
T/C 4
0.0
3.0
6.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 5
0.0
3.0
6.0
9.0
12.0
15.0
18.0
21.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 6
T/C 8
T/C A
T/C 7
T/C 9
0.0
3.0
6.0
TIME (MINUTES)

APPENDIX G (Continued)

DATA FROM:

TEST NUMBER 32

DRUM SIZE 55 GAL , MATERIAL POLYETHYLENE , METHOD ROTATIONAL

THERMOCOUPLE ARRANGEMENT:

NONE

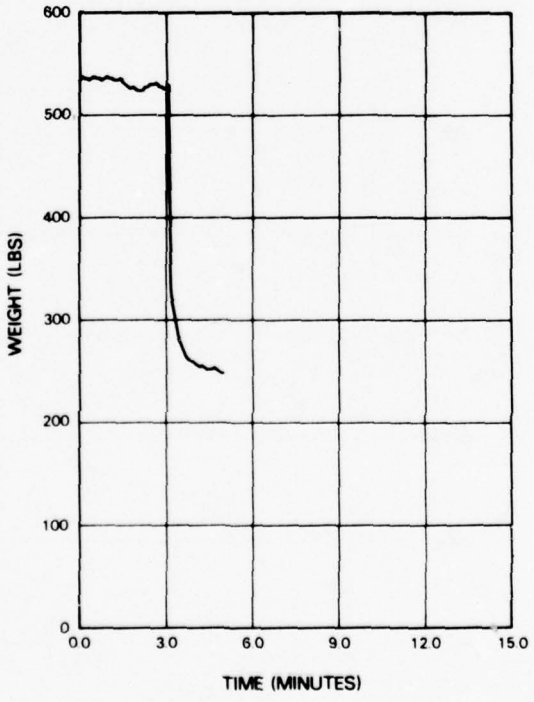
OTHER SENSORS:

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 3 MIN 14 SEC; DISCHARGE RATE: 150.0 GPM ACETONE

COMMENTS:

This test was run to determine the time to failure and discharge rate for a cargo other than JP-4.



APPENDIX G (Continued)

DATA FROM:

TEST NUMBER 33

DRUM SIZE 55 GAL , MATERIAL POLYETHYLENE , METHOD ROTATIONAL

THERMOCOUPLE ARRANGEMENT:

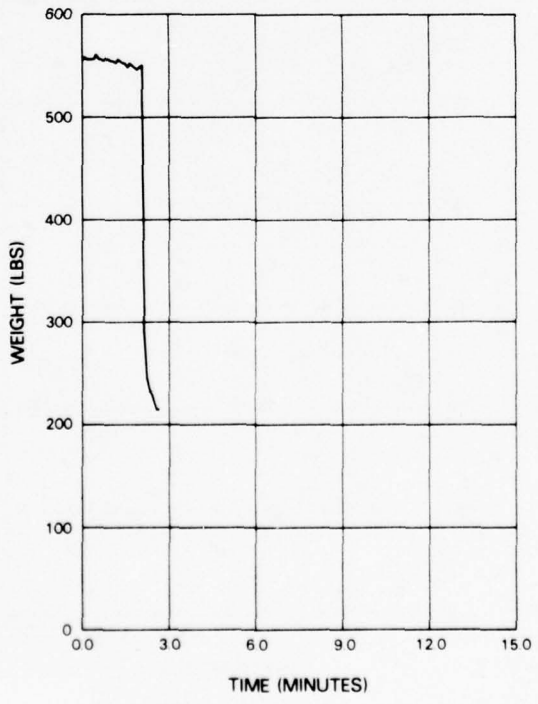
NONE

OTHER SENSORS:

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 2 MIN 36 SEC; DISCHARGE RATE: 183.3 GPM ACETONE

COMMENTS:



APPENDIX G (Continued)

DATA FROM:

TEST NUMBER 34

DRUM SIZE 55 GAL , MATERIAL POLYETHYLENE , METHOD ROTATIONAL

THERMOCOUPLE ARRANGEMENT:

NONE

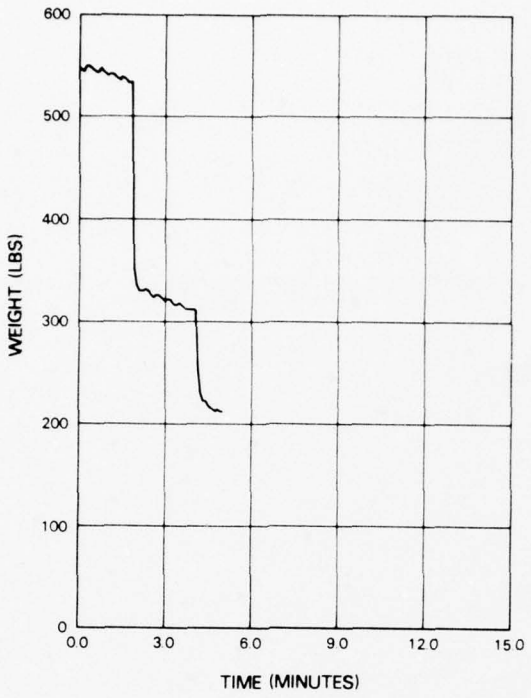
OTHER SENSORS:

LOAD CELLS (WEIGHT)

TIME TO FAILURE: 1 MIN 55 SEC; DISCHARGE RATE: 20.9 GPM ACETONE

COMMENTS:

NOTE: As can be seen from the graph, this drum had a two step failure. The first step discharged about 2/3 of the cargo; the remaining 1/3 was released later. Failure initially occurred about half way up the drum side.


600
500
400
300
200
100
0
WEIGHT (LBS)
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

APPENDIX G (Continued)

DATA FROM:

TEST NUMBER 45

DRUM SIZE 55 GAL (ARRAY), MATERIAL POLYETHYLENE METHOD ROTATIONAL

THERMOCOUPLE ARRANGEMENT:

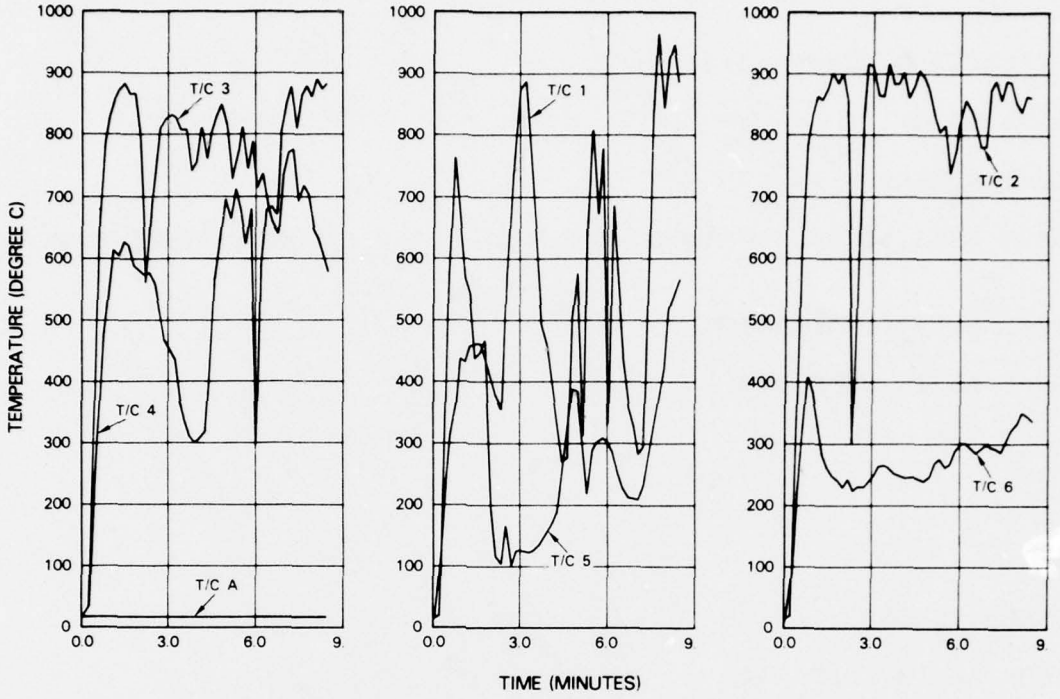
SAME AS IN TEST #44

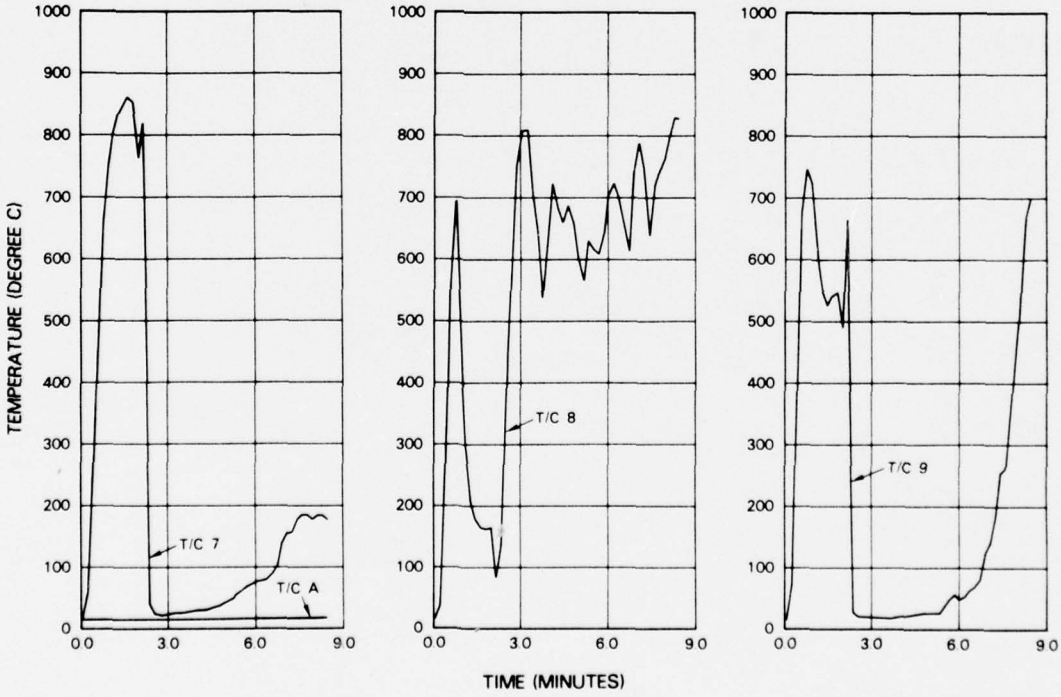
OTHER SENSORS:

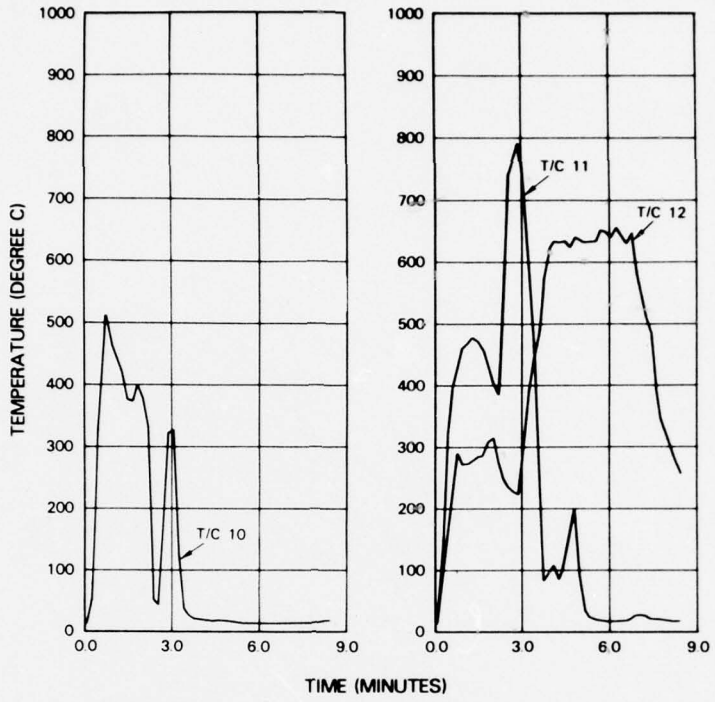
SAME AS IN TEST #44

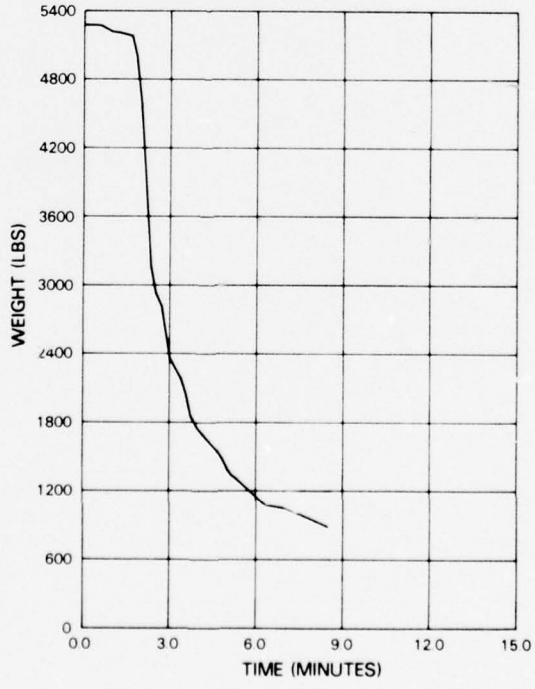
TIME TO FAILURE: 1 MIN 44 SEC; DISCHARGE RATE: 95.7 GPM JP-4

COMMENTS:


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 3
T/C 4
T/C A
T/C 1
T/C 5
T/C 2
T/C 6
0.0
3.0
6.0
9
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 7
T/C A
T/C 8
T/C 9
0.0
3.0
6.0
9.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 10
T/C 11
T/C 12
0.0
3.0
6.0
9.0
TIME (MINUTES)


WEIGHT (LBS)
5400
4800
4200
3600
3000
2400
1800
1200
600
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

Appendix H: Data from tests 16, 36-41, 46 using 55 gallon drums conforming to DOT Specification 17E.

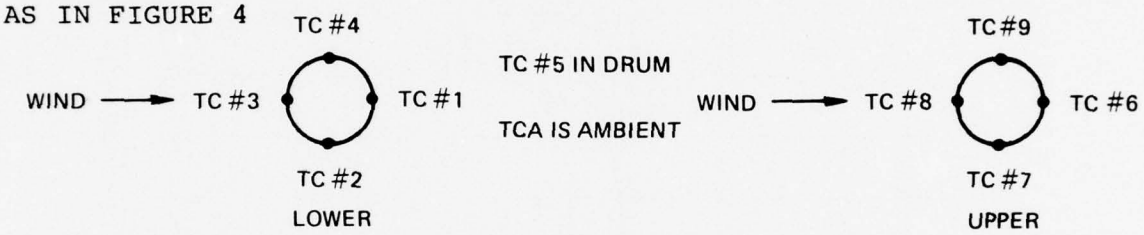
DATA FROM:

TEST NUMBER 16

DRUM SIZE 55 GAL , MATERIAL STEEL

THERMOCOUPLE ARRANGEMENT:

AS IN FIGURE 4



OTHER SENSORS:

INTERNAL PRESSURE

LOAD CELLS (WEIGHT)

WIND DIRECTION (317-325° true) (ave 320° true)

WIND SPEED (2.5-5.5 mph) (ave 3 mph)

TIME TO FAILURE: 8 MIN 0 SEC; DISCHARGE RATE: 3300.0 GPM JP-4

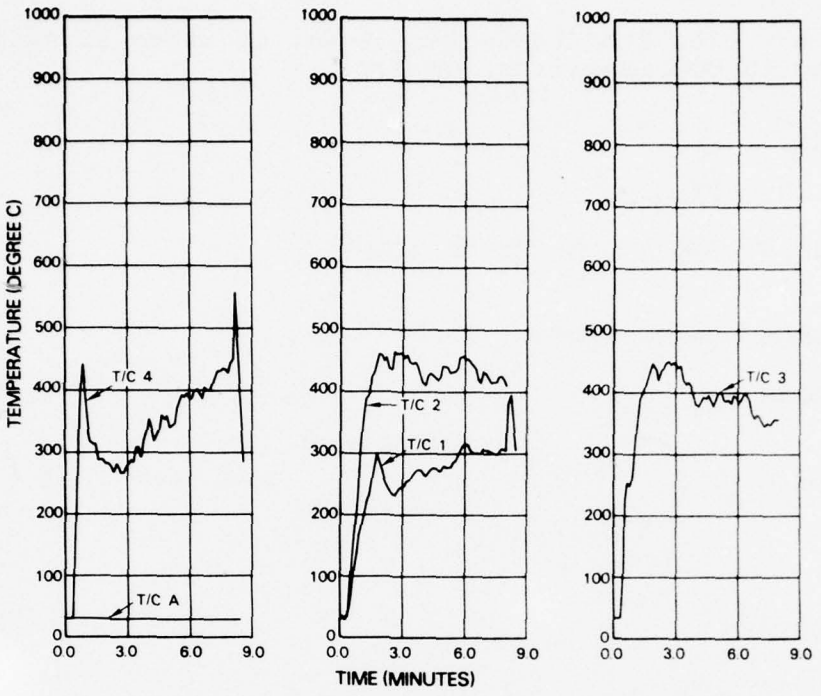
COMMENTS:

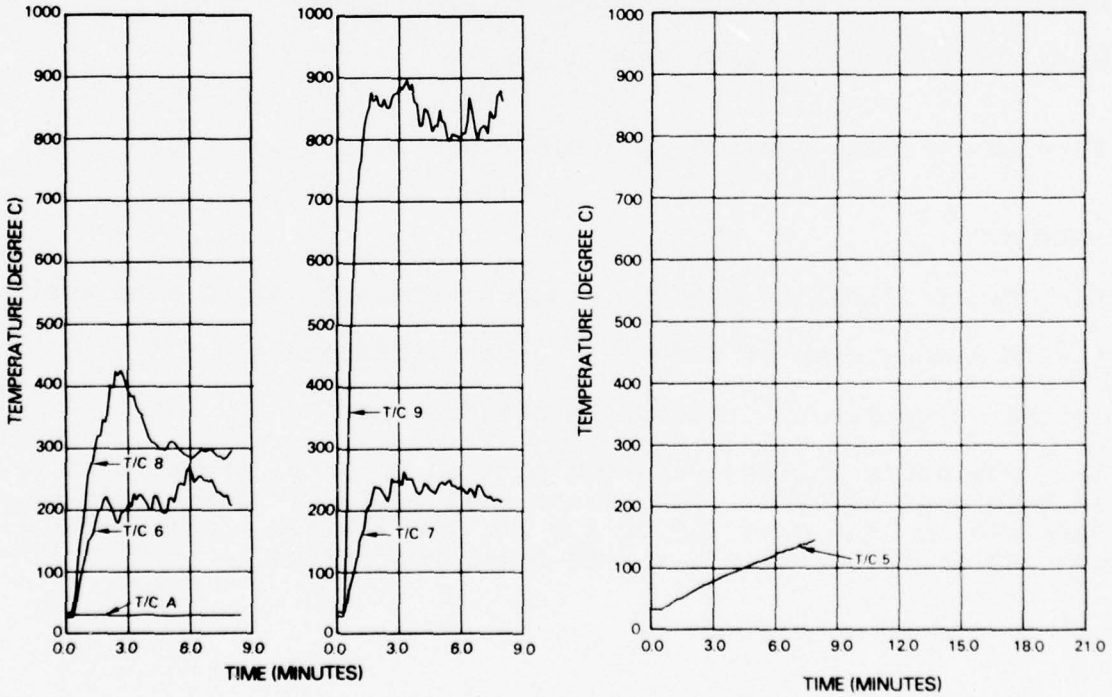
(1) Fluctuations in external temperature are due to wind gusts.

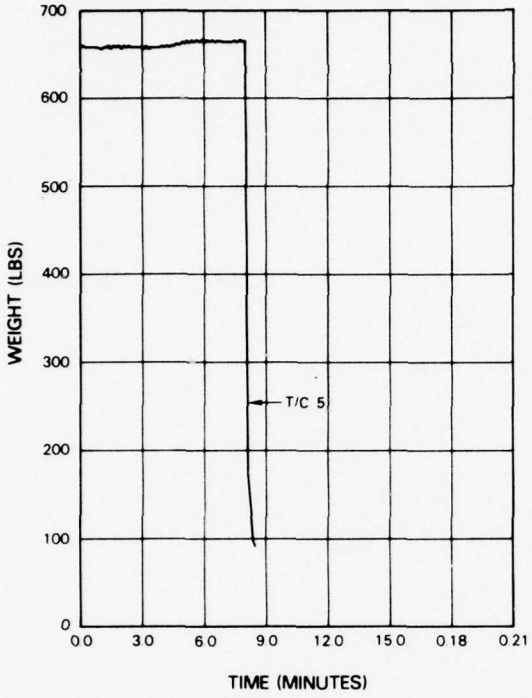
(2) A steady rise of internal temperature seen.

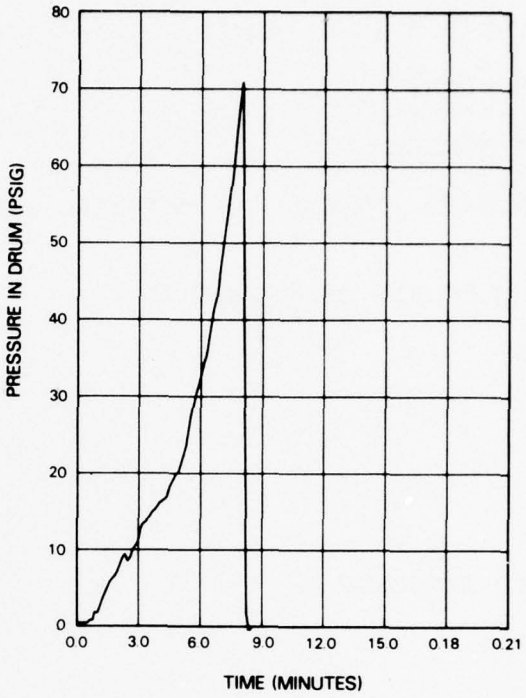
(3) A steep rise of internal pressure seen.

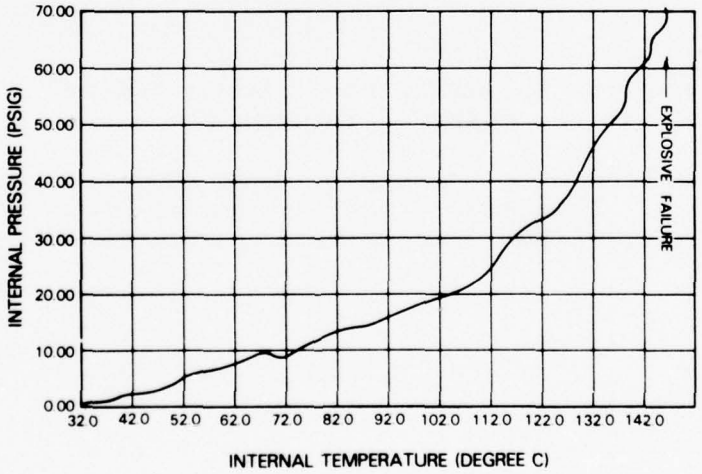
(4) Explosive failure occurred with an internal pressure of 70.9 psig at 146.0°C. The bottom seal failed launching the remainder of the drum 150 to 200 ft into the air. A fireball over 63 ft across also resulted from the failure.


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 4
T/C A
T/C 2
T/C 1
T/C 3
0.0
3.0
6.0
9.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 8
T/C 6
T/C A
T/C 9
T/C 7
T/C 5
0.0
3.0
6.0
9.0
12.0
15.0
18.0
21.0
TIME (MINUTES)


WEIGHT (LBS)
700
600
500
400
300
200
100
0
T/C 5
00 30 60 90 120 150 018 021
TIME (MINUTES)


PRESSURE IN DRUM (PSIG)
80
70
60
50
40
30
20
10
0
00 30 60 90 120 150 018 021
TIME (MINUTES)


INTERNAL PRESSURE (PSIG)
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
EXPLOSIVE FAILURE
320 420 520 620 720 820 920 1020 1120 1220 1320 1420
INTERNAL TEMPERATURE (DEGREE C)

APPENDIX H (Continued)

DATA FROM:

TEST NUMBER 36

DRUM SIZE 55 GAL , MATERIAL STEEL

THERMOCOUPLE ARRANGEMENT:

NONE

OTHER SENSORS:

NONE

TIME TO FAILURE: 4 MIN 30 SEC; DISCHARGE RATE: 5.5 GPM JP-4

COMMENTS:

(1) This test was run to verify the time to failure, discharge rate and mode of failure observed in Test #16.

(2) Failure resulted when the upper, down wind, rolled seam of the drum unrolled. The cargo vapor was vented under pressure forming a blow torch-like flame extending some 25 ft from the drum.

APPENDIX H (Continued)

DATA FROM:

TEST NUMBER 37

DRUM SIZE 55 GAL , MATERIAL STEEL

THERMOCOUPLE ARRANGEMENT:

NONE

OTHER SENSORS:

NONE

TIME TO FAILURE: 1 MIN 25 SEC; DISCHARGE RATE: 40.2 GPM ACETONE

COMMENTS:

(1) This test was run to determine the time to failure, discharge rate and mode of failure for a cargo other than JP-4. See Section 3.1.

(2) The down wind, upper seam of the drum unrolled, similar to Tests #36 and 38 through 41. The blow torch-like flame grew to about 20 ft long. At 2 min 47 sec of test time, the top of the drum was blown off by internal pressure. This sent a column of burning and unburned acetone 100 ft into the air. The unburned acetone then formed an airborne ball of flame 53 ft in diameter, trailing down wind.

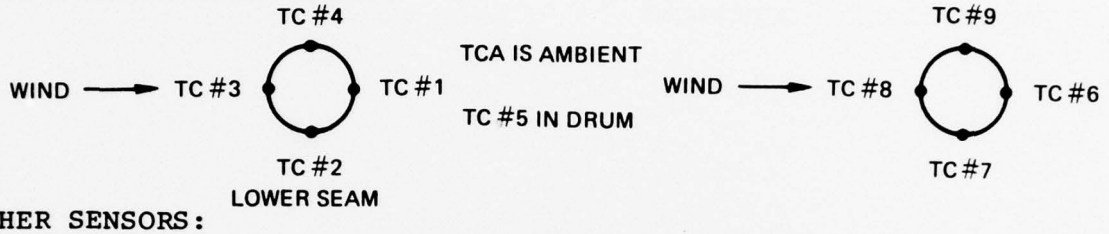
APPENDIX H (Continued)

DATA FROM:

TEST NUMBER 38

DRUM SIZE 55 GAL , MATERIAL STEEL

THERMOCOUPLE ARRANGEMENT:



OTHER SENSORS:

INTERNAL PRESSURE

LOAD CELLS (WEIGHT)

WIND DIRECTION (0-160° true) (ave 35° true)

WIND SPEED (1-9.5 mph) (ave 8 mph)

TIME TO FAILURE: 3 MIN 12 SEC; DISCHARGE RATE: 5.4 GPM JP-4

COMMENTS:

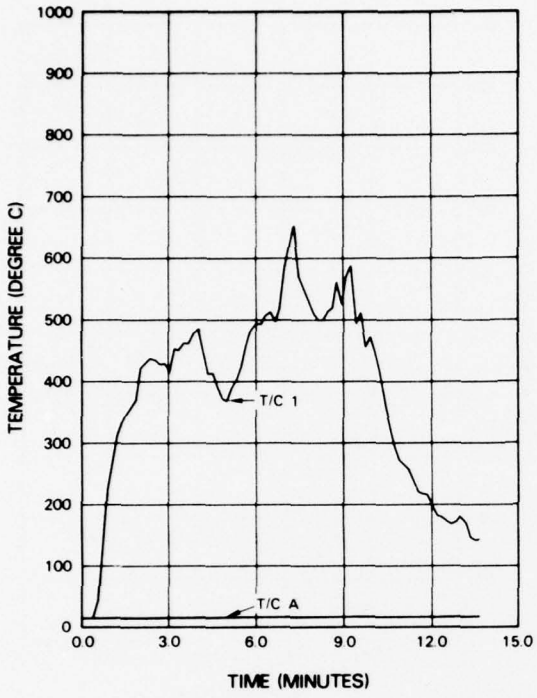
(1) The vertical seam of the drum was down wind.

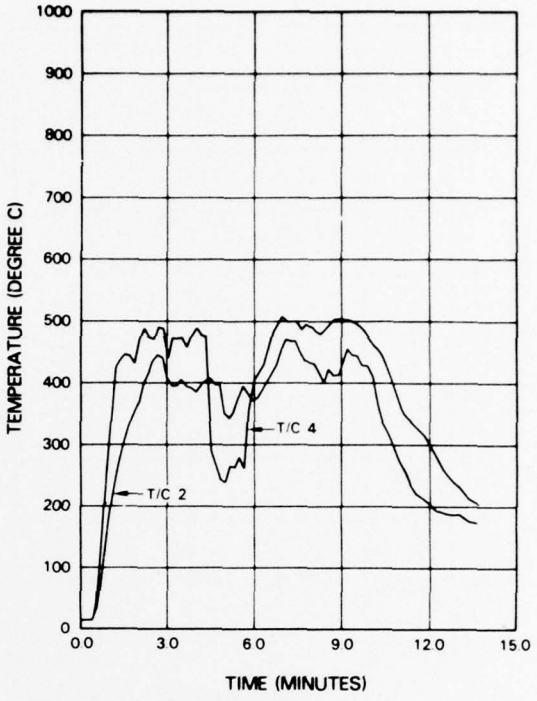
(2) Fluctuations in external temperature due to wind gusts.

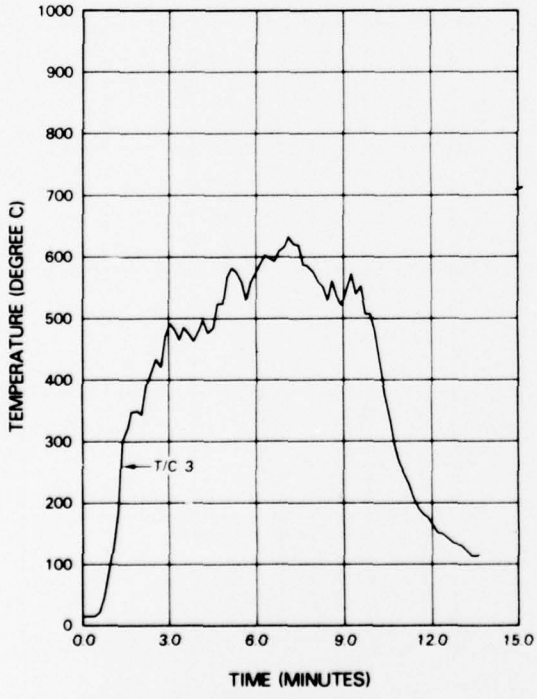
(3) The highest external temperature is recorded by thermocouple #6 (TC #6). Note the temperature drop when cool cargo is vented.

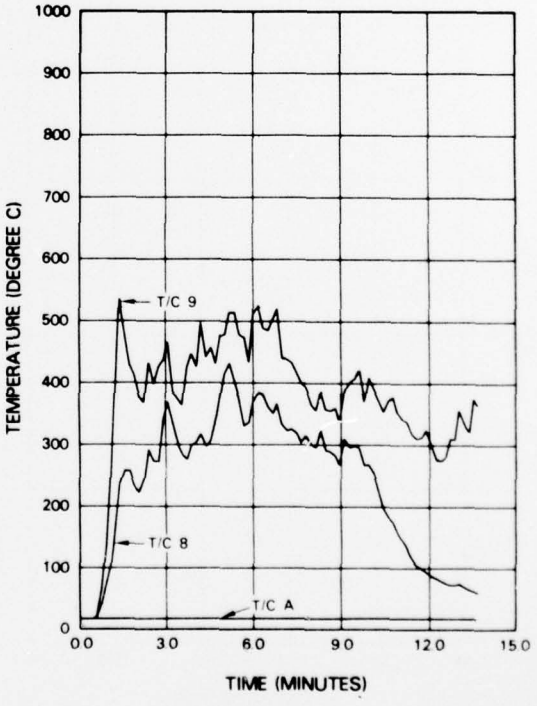
(4) Note the steady rise of internal temperature.

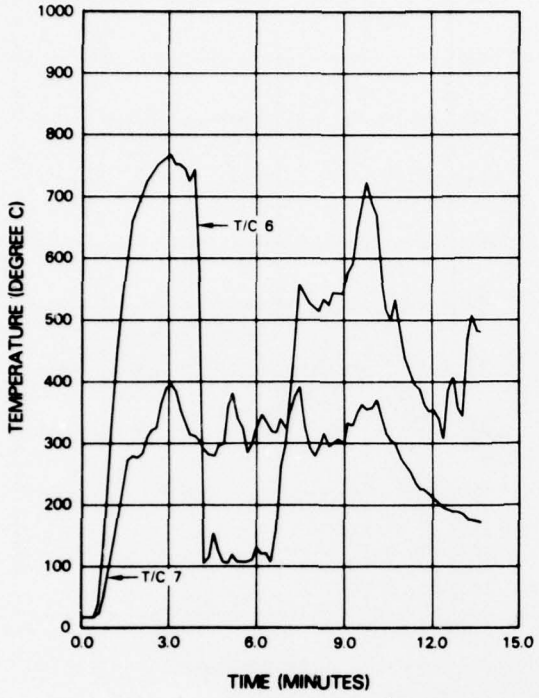
(5) Note the rise of internal pressure to failure (3 min 12 sec) then a rise even while the drum vents. The failure, similar to that in Test #36, resulted from the unrolling of the top seam, at a point on the down wind side of the drum. Note that the pressure after failure builds beyond the 7.1 psig that caused the initial failure.

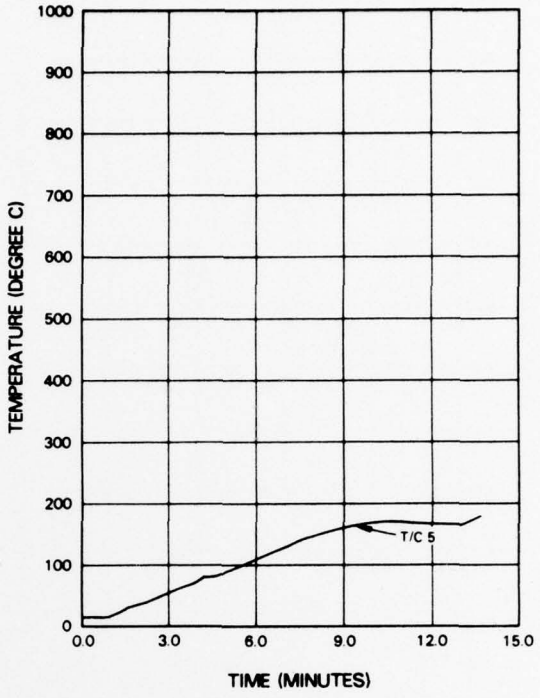

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 1
T/C A
00
30
60
90
120
150
TIME (MINUTES)

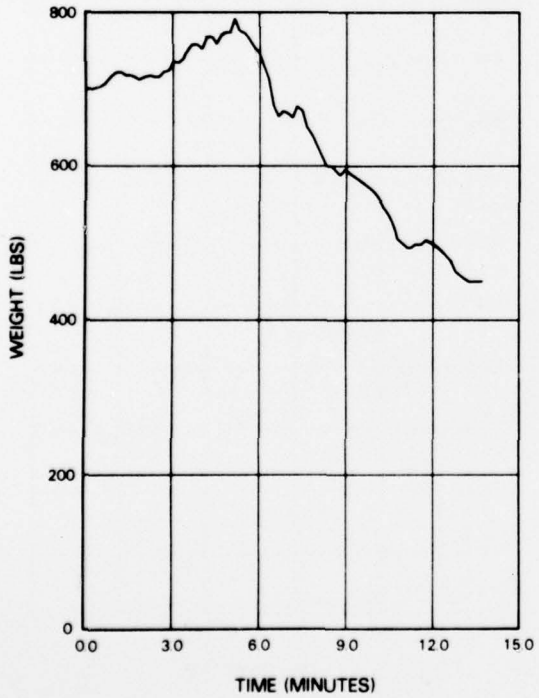

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 4
T/C 2
00
30
60
90
120
150
TIME (MINUTES)

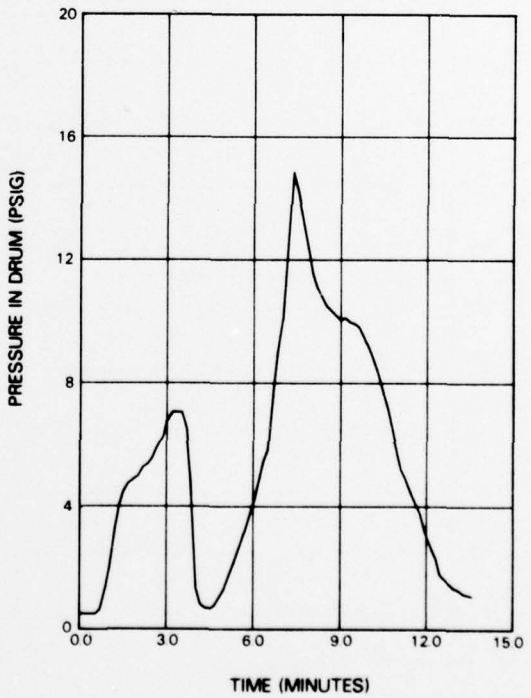

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 3
00
30
60
90
120
150
TIME (MINUTES)

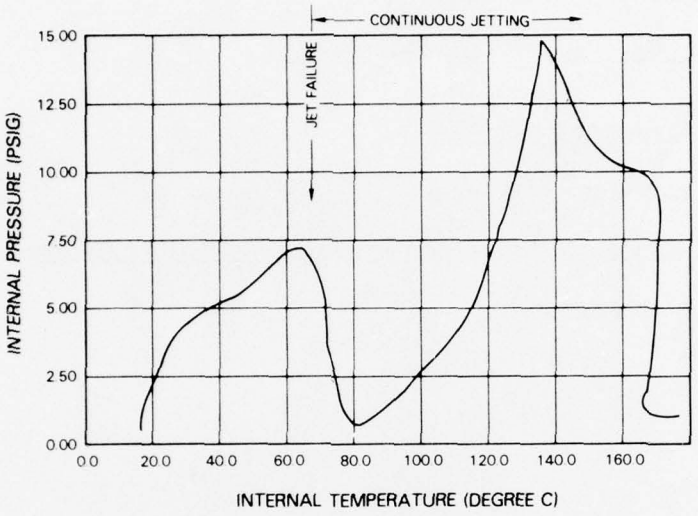

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 9
T/C 8
T/C A
00
30
60
90
120
150
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 6
T/C 7
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 5
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


WEIGHT (LBS)
800
600
400
200
0
00
30
60
90
120
150
TIME (MINUTES)


PRESSURE IN DRUM (PSIG)
20
16
12
8
4
0
00
30
60
90
120
150
TIME (MINUTES)


CONTINUOUS JETTING
JET FAILURE
INTERNAL PRESSURE (PSIG)
15.00
12.50
10.00
7.50
5.00
2.50
0.00
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
INTERNAL TEMPERATURE (DEGREE C)

APPENDIX H (Continued)

DATA FROM:

TEST NUMBER 39

DRUM SIZE 55 GAL , MATERIAL STEEL

THERMOCOUPLE ARRANGEMENT:

SAME AS IN TEST #38

EXCEPT UPPER SEAM IS DRUM BOTTOM AND LOWER SEAM IS DRUM TOP

SINCE DRUM IS INVERTED.

OTHER SENSORS:

LOAD CELLS (WEIGHT)

WIND DIRECTION (0-200^{o} true) (ave 35^{o} true)

WIND SPEED (1-10 mph) (ave 8 mph)

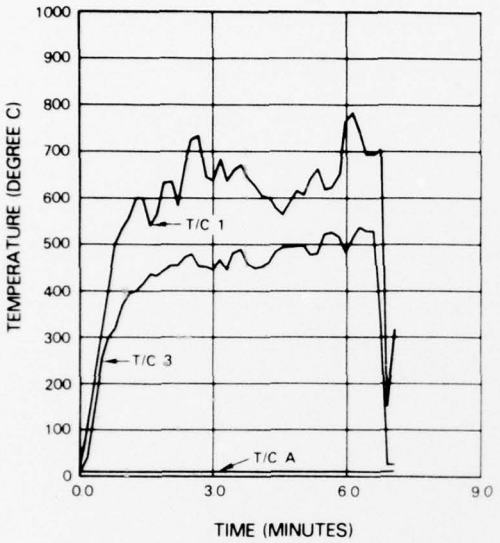
TIME TO FAILURE: 3 MIN 37 SEC; DISCHARGE RATE: 17.5 GPM JP-4

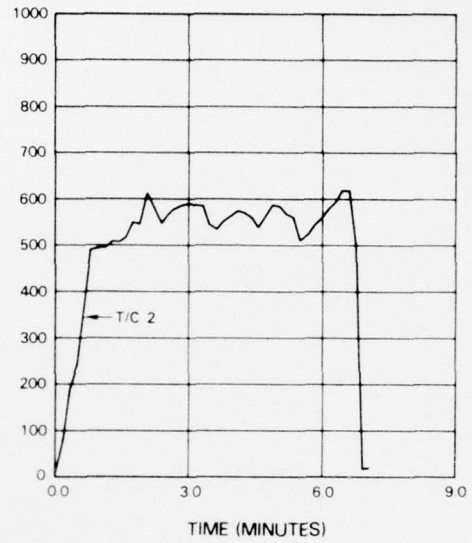
COMMENTS:

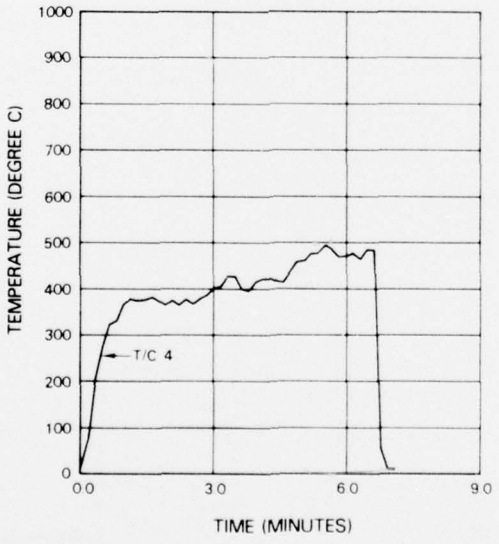
(1) Drum was inverted to study orientation effects.

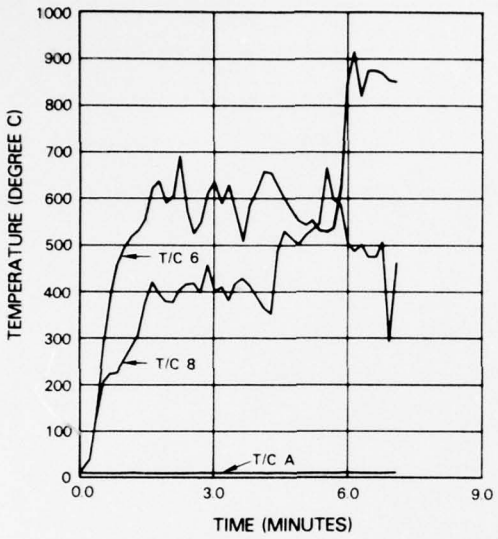
(2) Fluctuations in external temperature due to wind gusts.

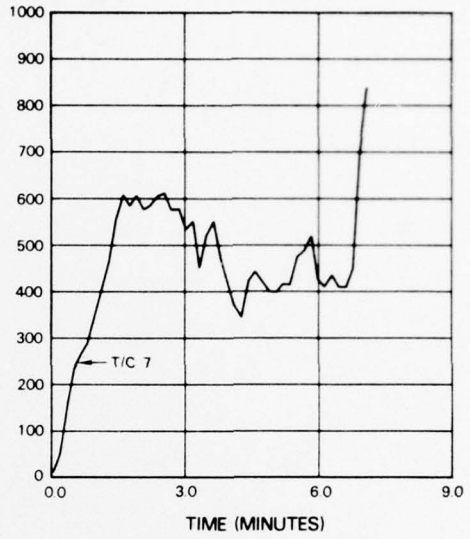
(3) Failure occurred by the unrolling of the seam near thermocouple #6 (TC #6). The drum began venting the internal pressure. At 6 min 40 sec the remainder of the seam failed. The explosion that resulted sent a column of flame 40 ft up to a balloon about 50 ft in diameter. The sharp loss in weight shows the speed at which the remaining cargo was lost.

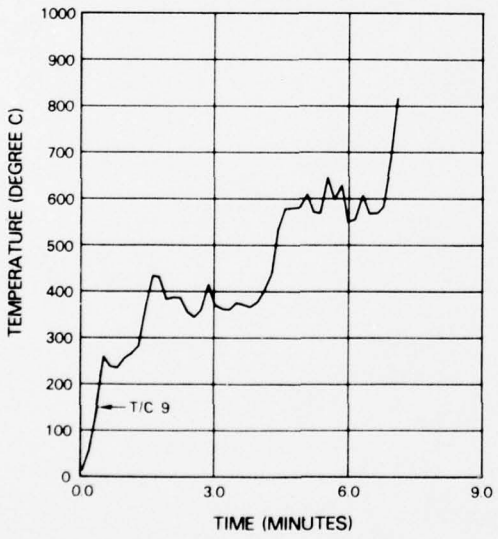

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 1
T/C 3
T/C A
0.0
3.0
6.0
9.0
TIME (MINUTES)

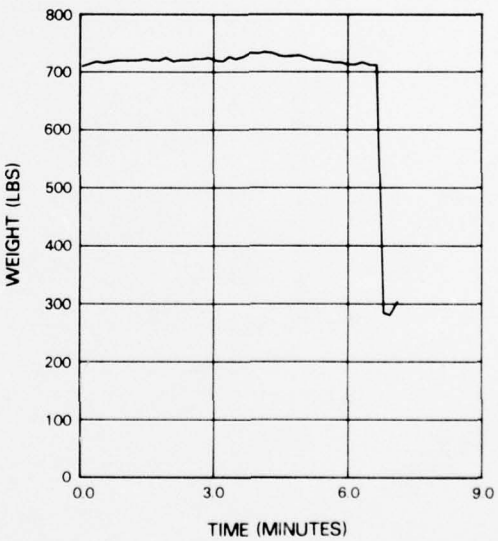

1000
900
800
700
600
500
400
300
200
100
0
T/C 2
0.0
3.0
6.0
9.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 4
0.0
3.0
6.0
9.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 6
T/C 8
T/C A
00
30
60
90
TIME (MINUTES)


1000
900
800
700
600
500
400
300
200
100
0
T/C 7
00
30
60
90
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 9
00
30
60
90
TIME (MINUTES)


WEIGHT (LBS)
800
700
600
500
400
300
200
100
0
00
30
60
90
TIME (MINUTES)

APPENDIX H (Continued)

DATA FROM:

TEST NUMBER 40

DRUM SIZE 55 GAL , MATERIAL STEEL

THERMOCOUPLE ARRANGEMENT:

SAME AS IN TEST #38

OTHER SENSORS:

SAME AS IN TEST #38

WIND DIRECTION (VARY) (ave 35^{o} true)

WIND SPEED (1-10 mph) (ave 8 mph)

TIME TO FAILURE: 3 MIN 12 SEC; DISCHARGE RATE: 6.6 GPM JP-4

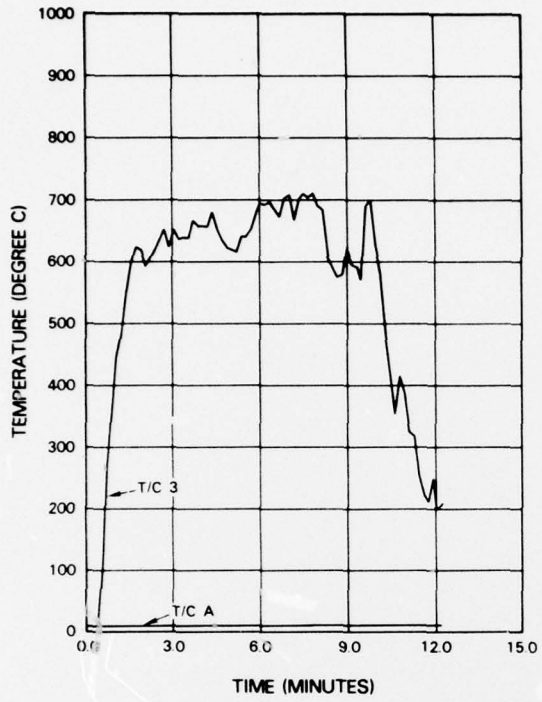
COMMENTS:

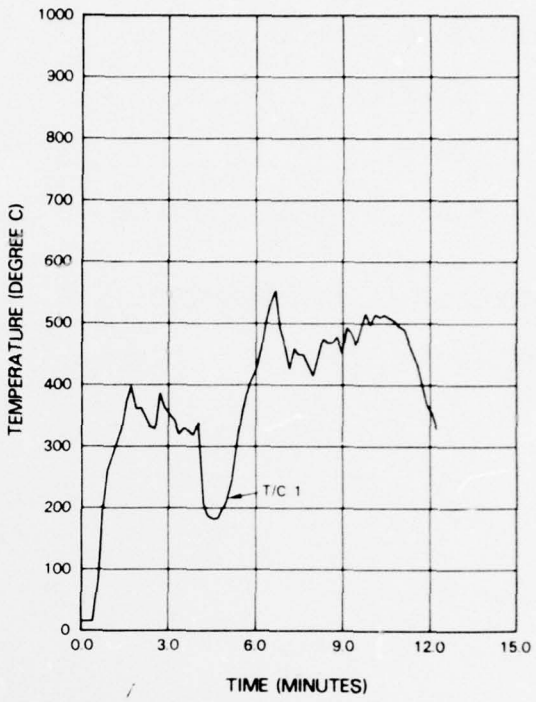
(1) Fluctuations in external temperature were caused by wind gusts.

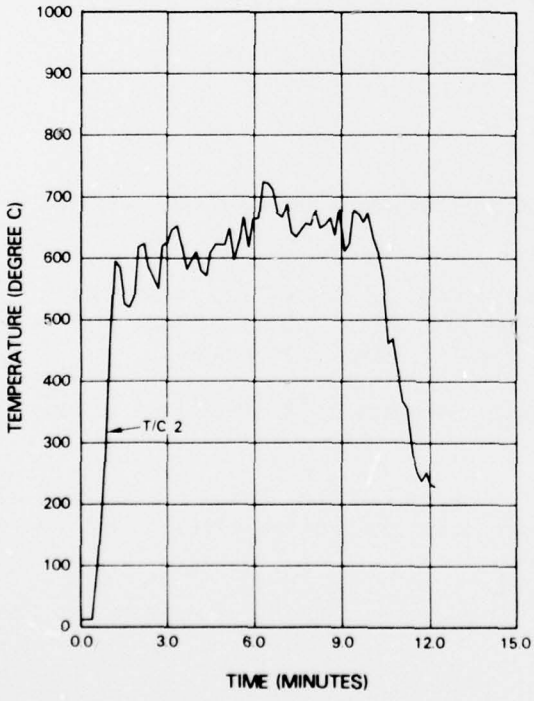
(2) Thermocouples #6 and 7 show the highest exterior temperatures. Failure occurred between them, at the upper seam, and caused the dip in temperature at 3 min 12 sec (failure).

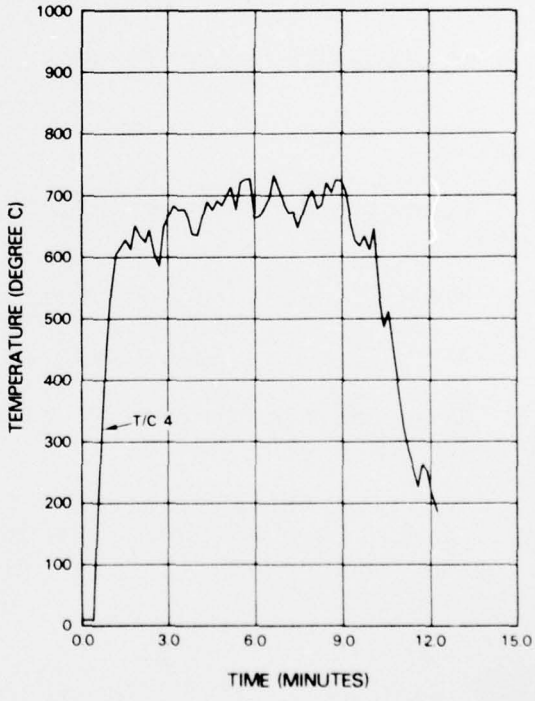
(3) Note the steady rise of internal temperature similar to the rise in Tests #16 and 38.

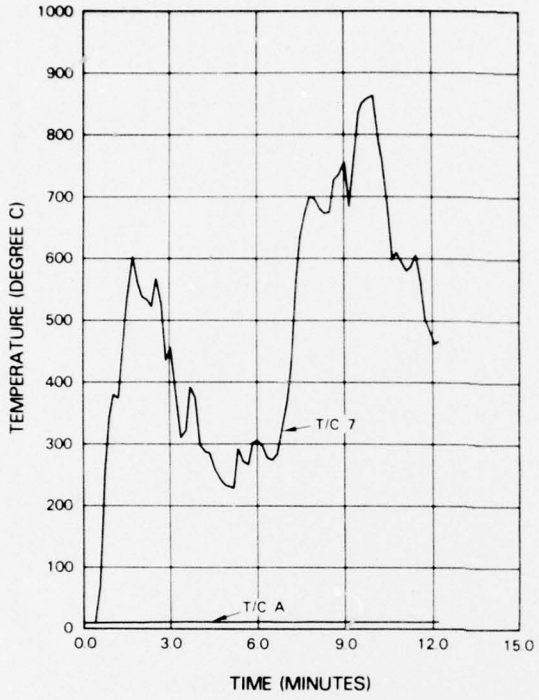
(4) The rise of internal pressure is similar to that of Test #38. Again, the pressure builds to a higher value than the 8.2 psig that caused initial failure.

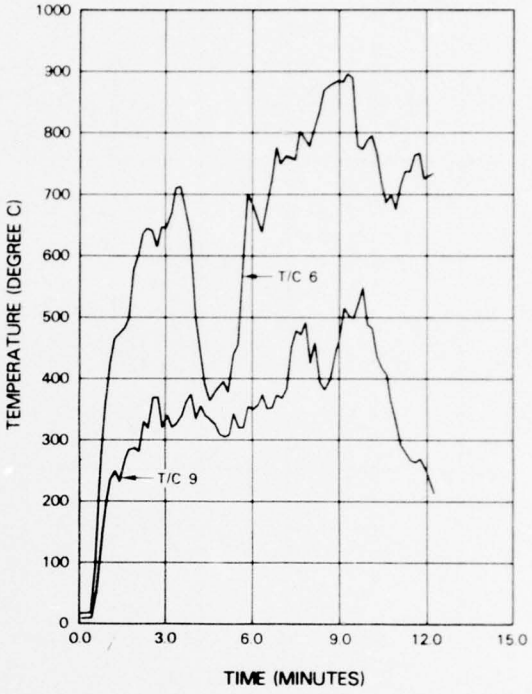

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 3
T/C A
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

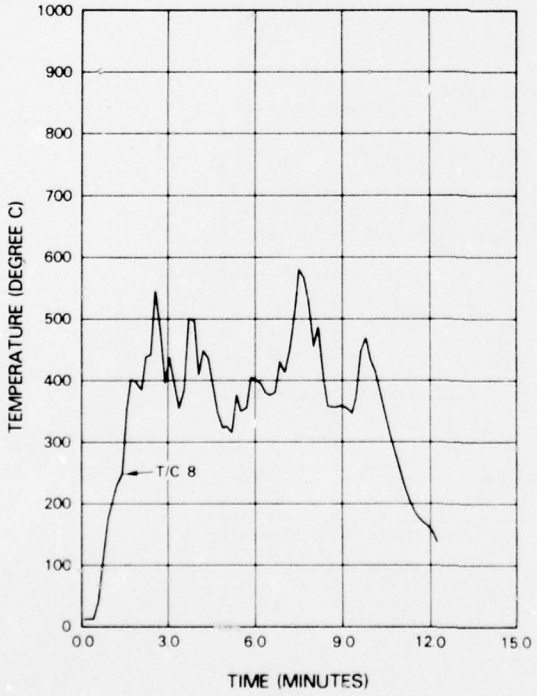

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 1
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

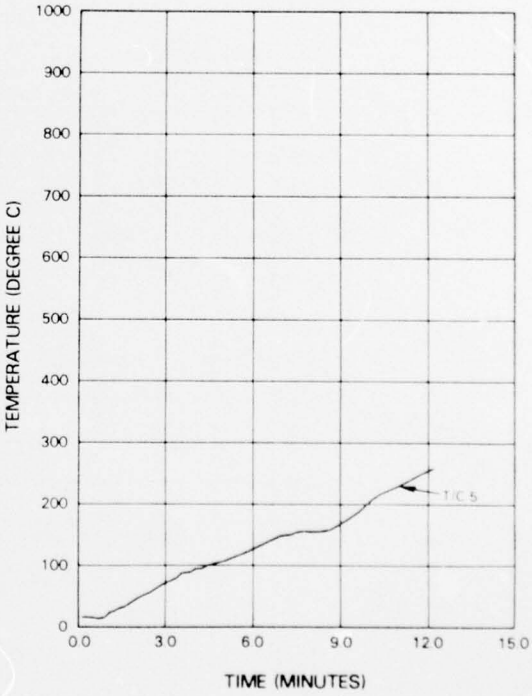

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 2
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

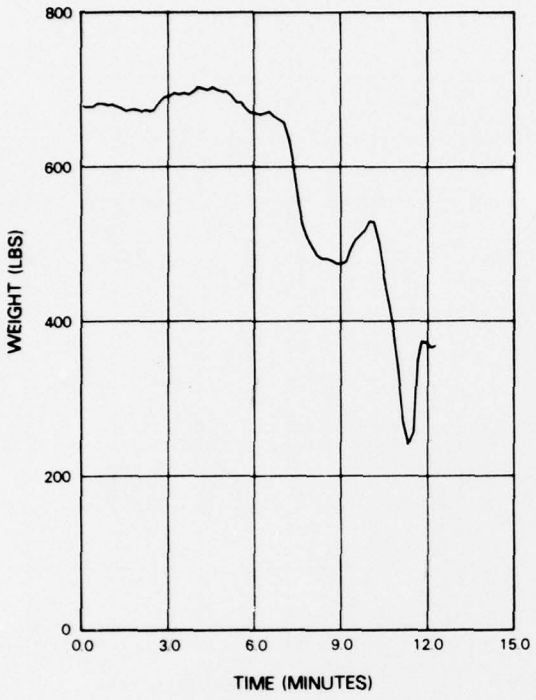

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 4
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

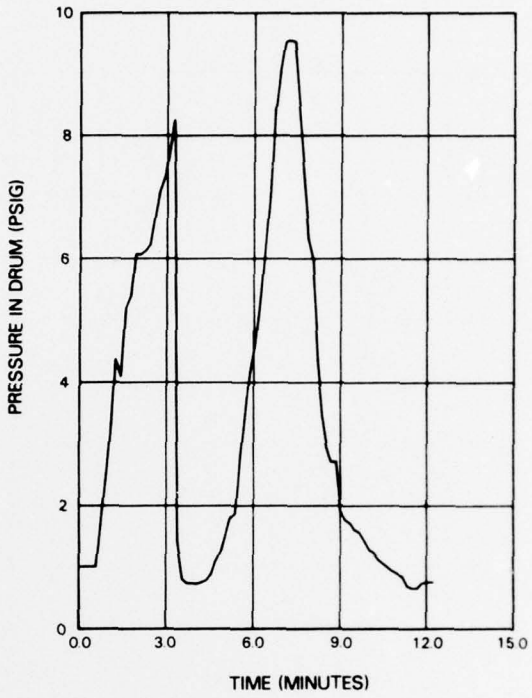

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 7
T/C A
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

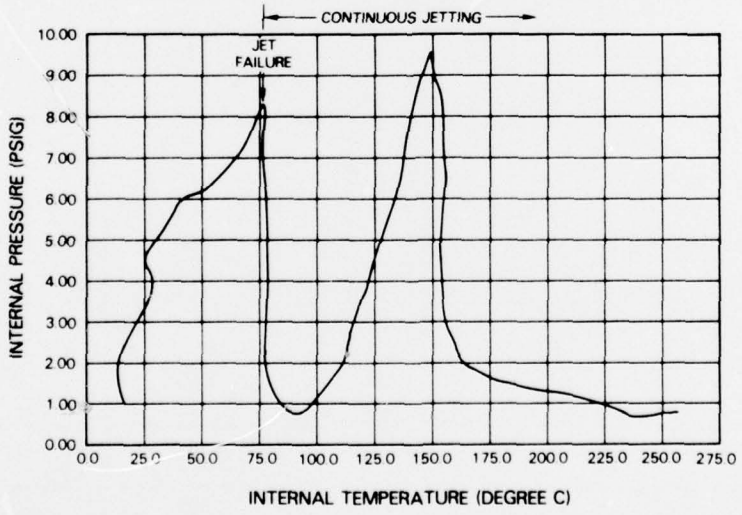

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 6
T/C 9
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 8
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 5
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


800
600
400
200
0
WEIGHT (LBS)
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


10
8
6
4
2
0
PRESSURE IN DRUM (PSIG)
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


CONTINUOUS JETTING
JET FAILURE
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
INTERNAL PRESSURE (PSIG)
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
200.0
225.0
250.0
275.0
INTERNAL TEMPERATURE (DEGREE C)

APPENDIX H (Continued)

DATA FROM:

TEST NUMBER 41

DRUM SIZE 55 GAL , MATERIAL STEEL

THERMOCOUPLE ARRANGEMENT:

SAME AS IN TEST #38

OTHER SENSORS:

SAME AS IN TEST #39

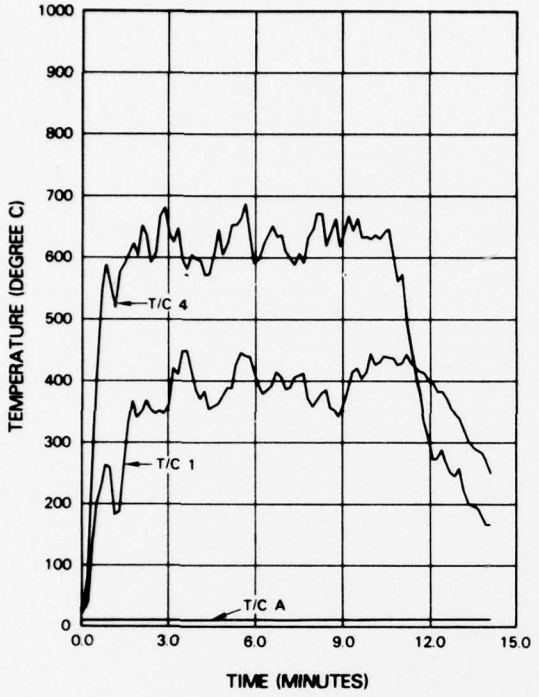
WIND DIRECTION (0-100° true) (ave 35° true)

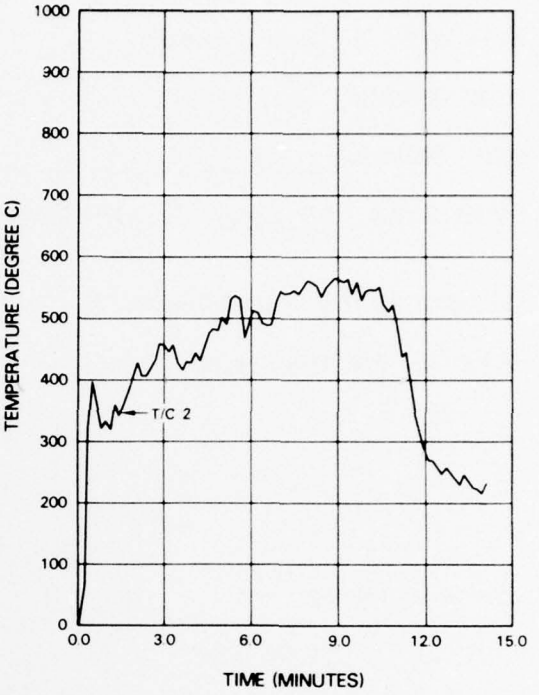
WIND SPEED (2-10 mph) (ave 8 mph)

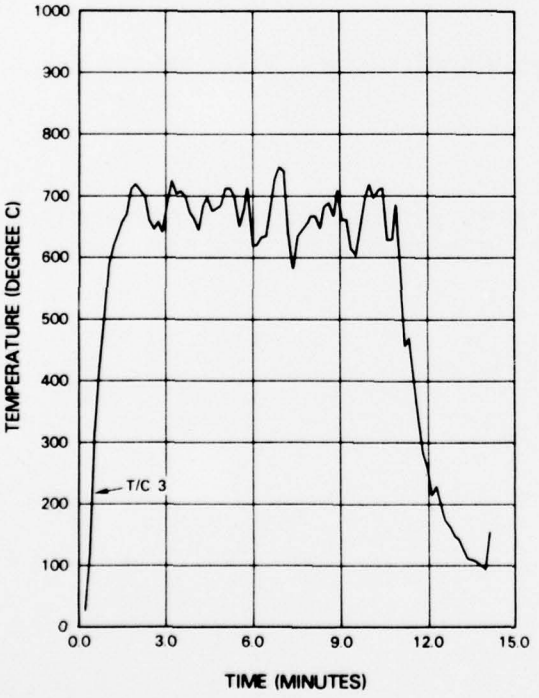
TIME TO FAILURE: 6 MIN 18 SEC; DISCHARGE RATE: 9.6 GPM JP-4

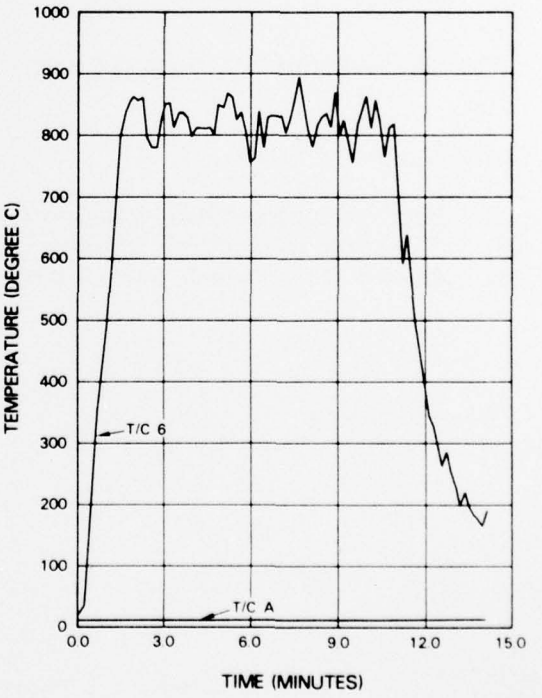
COMMENTS:

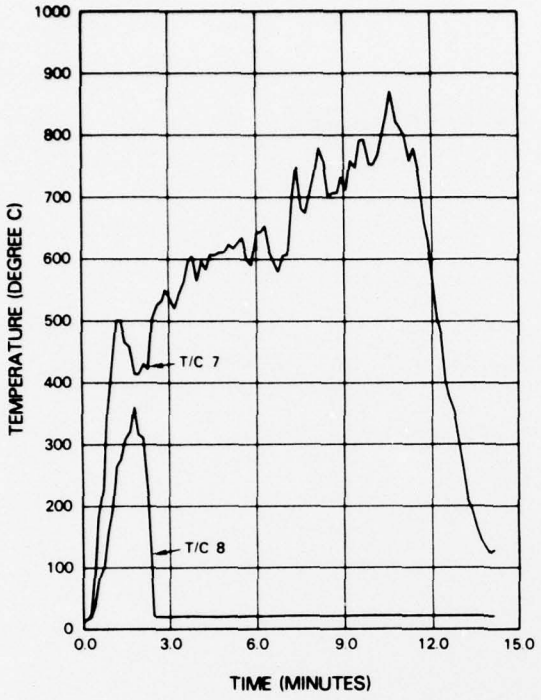
(1) Highest external temperatures were reached at thermocouple #6. Failure occurred there. The seam unrolled and the vapor was jetted out under pressure.

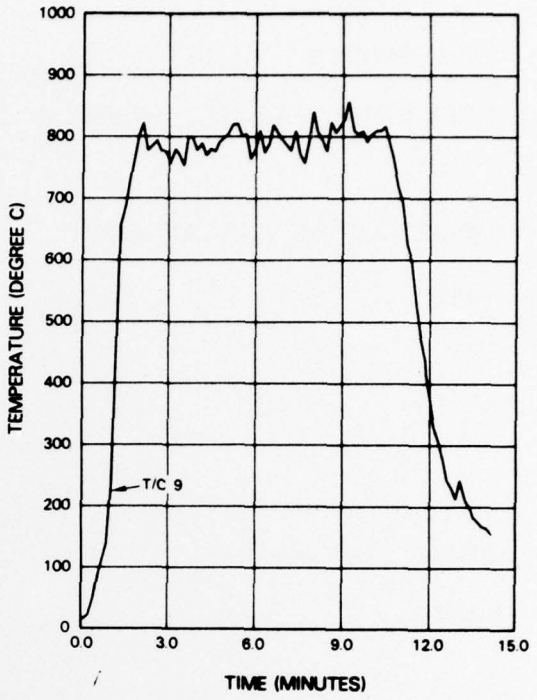

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 4
T/C 1
T/C A
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

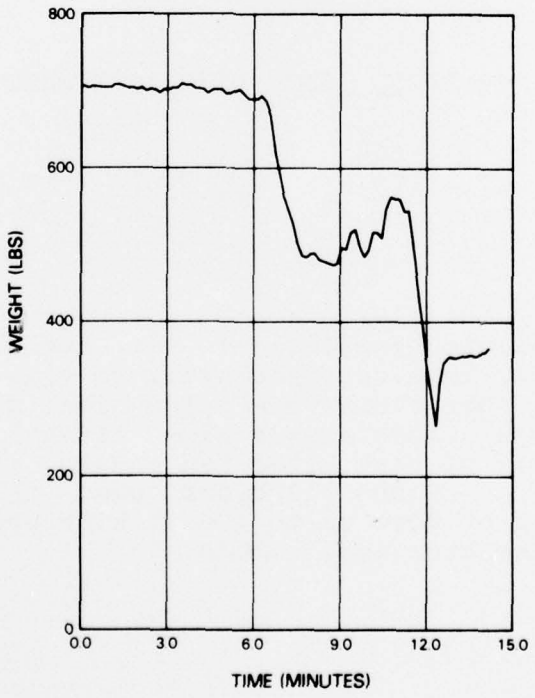

TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 2
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 3
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 6
T/C A
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 7
T/C 8
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


TEMPERATURE (DEGREE C)
1000
900
800
700
600
500
400
300
200
100
0
T/C 9
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)


WEIGHT (LBS)
800
600
400
200
0
0.0
3.0
6.0
9.0
12.0
15.0
TIME (MINUTES)

TEST NUMBER 46

DRUM SIZE 55 GAL (ARRAY) MATERIAL STEEL

THERMOCOUPLE ARRANGEMENT:

NONE

OTHER SENSORS:

NONE

TIME TO FAILURE: ~8 MIN SEC: DISCHARGE RATE: (23.6) GPM JP-4

COMMENTS:

(1) The first failure (explosion) was noted at about 8 min. Initial failure may have occurred prior to this time. Due to the dangers involved, observers were at a great distance away from the test pan. Explosions and/or blow torch-like jets continued until about 36 min of test time had passed. Within this time, all drums failed. Of the 12 drums used in the test, 8 or 9 exploded. Columns of fire up to 150 ft high were observed. Fire balls of 100 ft diameter were common.

☆U.S. GOVERNMENT PRINTING OFFICE: 1977—701-314/81