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EG&G Idaho
Idaho Falls, ID 83415

CAST COIL TRANSFORMER FIRE SUSCEPTIBILITY AND RELIABILITY STUDY

ABSTRACT This report investigates the fire characteristics and reliability of cast coil type transformers. A literature search was conducted and a questionnaire drafted requesting information from the manufacturers of cast coil type transformers. Abstracts from the National Fire Protection Association were reviewed to locate possible fires involving cast coil transformers. Testing was performed by the Idaho National Engineering Laboratory and independent testing firms. Results of this research and general industry usage indicate that cast coil transformers reduce risk to the user compared to liquid-filled units, eliminate environmental impacts, are more efficient than most transformer designs, and add minimal risk to the facility in a fire situation. Cast coil transformers have a long record of operation and have proven to be reliable and efficient.

NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME CALIFORNIA 93043

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 (2,000 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

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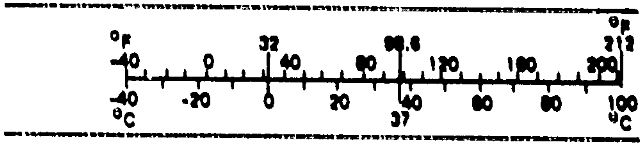
*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

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 (1,000 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



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S. A. McBride

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EG&G Idaho
P. O. Box 1625
Idaho Falls, ID 83415

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This report investigates the fire characteristics and reliability of cast coil type transformers. A literature search was conducted and a questionnaire drafted requesting information from the manufacturers of cast coil type transformers. Abstracts from the National Fire Protection Association were reviewed to locate possible fires involving cast coil transformers. Testing was performed by the Idaho National Engineering Laboratory and independent testing firms. Results of this research and general industry usage indicate that cast coil transformers reduce risk to the user compared to liquid-filled units, eliminate environmental impacts, are more efficient than most transformer designs, and add minimal risk to the facility in a fire situation. Cast coil transformers have a long record of operation and have proven to be reliable and efficient.

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SUMMARY

Cast coil transformers have been used for approximately 20 years in Europe. This technology has also been used in the United States for 15 years. Cast coil transformers offer several features that other dry-type transformers do not. These devices fill many of the needs of today's power distribution systems. Changes in the codes and regulations have made the cast coil transformer more attractive for many applications as compared to other transformers available today.

Regulations regarding the use, placement of, and restrictions on liquid-filled transformers have led to an expanding interest in the use of dry-type transformers. Banning the use of askarel as a high-fire point insulating liquid has also spawned added interest in the cast coil technology.

Cast coil transformers offer the user a high level of reliability under varied operating conditions. The transformers may be subjected to severe environments and do not experience the problems encountered by other types of transformers. For instance, the material used to insulate the transformer windings is nonhygroscopic; this allows for immediate energization of the unit after an extended period of de-energization. This material is also highly resistant to the effects of chemicals and industrial atmospheres.

Since these devices perform well under the effects of fire, the cast coil transformer is a good alternative when the possibility of fire exists. The epoxy material used to encapsulate the windings is "nonburning" according to tests performed by the Idaho National Engineering Laboratory, and the combustion products produced when one of the coils is forced to burn (i.e., where sufficient heat is applied) are within acceptable levels. The addition of a cast coil transformer to a facility does not add significantly to the fire danger of that facility and will reduce the danger if it is replacing a liquid-filled transformer.

There are several other areas in which the cast coil transformer offers increased performance characteristics. These are listed below.

1. Corona. Epoxy encapsulation of the windings without porosity provides elimination of corona generation as compared to other types of dry transformers.
2. Dielectric strength. The dielectric strength of the solid epoxy insulation is high largely due to the lack of corona and the high dielectric resistance of the epoxy.
3. Short-circuit strength. The dynamic strength of the cast coil transformer exceeds that of conventional dry-type and liquid-filled transformers. The epoxy resin provides excellent mechanical strength when the coil is subjected to the axial and radial forces that occur during a short-circuit fault.
4. BIL ratings. The cast coil transformer design offers BIL levels equal to those of standard liquid-filled devices and are superior to other dry-type transformer designs.
5. Fire protection. The materials are such that they will not support flame and are typically not a flame source.

Finally, it should be noted that the cast coil transformer is one of the most efficient available today and is attractive for use because of the increasing cost of electrical power. The following report investigates these topics further and addresses the concerns regarding the use of cast coil transformers.

CONTENTS

FIGURES

TABLES

ACRONYMS

ASTM	American Society for Testing and Materials
BPA	Bisphenol A
BIL	Basic impulse level
EC&M	Electrical Construction and Maintenance
GC	Gas chromatography
INEL	Idaho National Engineering Laboratory
HV	High voltage
IR	Infrared
LV	Low voltage
NITI	National Industry Transformer, Inc.
NFPA	National Fire Protection Association
NCEL	Naval Civil Engineering Laboratory
OSHA	Occupational Health and Safety Act
PCB	Polychlorinated biphenyl
R&D	Research and Development
TCDF	Tetrachlorodibenzofuran
TCDD	Tetrachlordinbenzodioxin
TLV	Threshold limit value
TGA	Thermogravimetric analysis

CAST COIL TRANSFORMER FIRE SUSCEPTIBILITY AND RELIABILITY STUDY

INTRODUCTION

This report investigates the fire characteristics and reliability of cast coil transformers as per NAVCOMPT Order N6830587WR70270, Amendment No. 2, Norfolk Utility Research and Development (R&D). The Naval Civil Engineering Laboratory (NCEL) requested that the Idaho National Engineering Laboratory (INEL) provide an overview of the cast coil transformer technology and include a history, overview, and fire susceptibility study for these devices.

Cast coil transformers have been used to a great extent in Europe for the last 20 years, but are only moderately used in the United States. The purpose of this report is to provide data and verification for an acceptable level of reliability and also to inform the reader about the available designs and testing procedures.

This task was accomplished in several steps. First, a literature search was conducted by the INEL technical library and available publications were obtained and reviewed. Secondly, a questionnaire was drafted requesting specific information from the manufacturers of cast coil transformers. Copies of this request along with the responses can be found in Appendix A of this report. Finally, fire reports (abstracts) from the National Fire Protection Association (NFPA) were also reviewed to locate any possible fires involving cast coil transformers. These abstracts were obtained through the NFPA's literature search system. Individual summaries of the four different types of cast coil configurations and the differences between the available designs are included in Appendix B. Descriptions of the current testing procedures are also included so that the reader will better understand the data and results. Figure 1 illustrates a typical cast coil transformer. Testing has been performed by vendors and independent testing firms. The INEL also performed their own testing, and the results are discussed in this report and included in Appendix C.

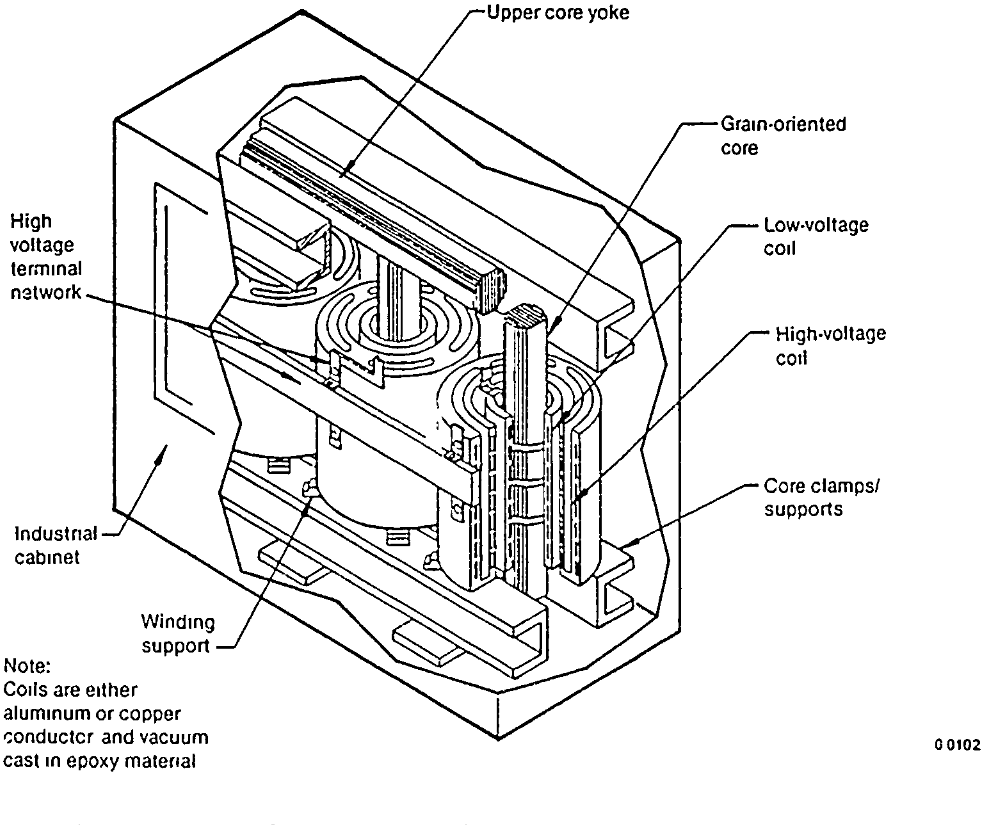

Figure 1. Typical construction of the cast coil transformer.

OVERVIEW

To best meet the requirements of this task, several issues were investigated. These issues are outlined as follows:

1. Describe the history of cast coil technology to date and provide descriptions of the available designs.
2. Discuss the "byproducts of combustion" of the epoxy used to encapsulate the coils. This includes both the research conducted by the INEL and those tests performed by other test laboratories.
3. Address the flammability of cast coil transformers. This includes testing of the epoxy material itself and also testing of the complete coil assembly. The epoxy material was tested under flame provided by an external source, but the complete coil assembly was tested for both an external flame source and an internal source (i.e., a simulated short-circuit). Testing of the epoxy material was completed by the INEL and the transformer manufacturers. Information from both the INEL and manufacturers is included in this report. Results of testing of the complete coil assembly performed by the manufacturers were not verified by the INEL as part of the scope of this report.
4. Provide available information on the coil cracking issue.
5. Discuss overall reliability of the cast coil transformer and make recommendations for their use.
6. Include background information for the reader.

HISTORY AND PRODUCT DESCRIPTION

During the last two decades there have been considerable changes in the types of fire resistant electrical distribution transformers. This was accelerated by the banning of polychlorinated biphenyls (PCBs) in the later 1970s. Before this time, PCBs were used extensively in applications where fire resistance was necessary or desired. Several new alternatives have been developed, including silicone-filled transformers, vapor-cooled transformers, RTemp-filled transformers, and cast coil transformers.

General Product Description

The cast coil transformer was developed to reduce or eliminate the deficiencies inherent in conventional open-wound dry-type transformers. The following issues were addressed:

- Basic Impulse Level (BIL)
- Short-circuit strength
- Moisture susceptibility
- Environmental considerations
- Operation in adverse environments.

The cast coil transformer is a dry-type transformer in which the primary and often the secondary windings are completely encapsulated in epoxy resin. The resin may or may not contain inert filler materials or fiberglass cloth for increased mechanical strength and fire resistance. The design philosophy of the American cast coil transformer is actually a merger of European and U.S. technology. The epoxy resin provides high dielectric and mechanical strength. It also provides superior environmental protection for the windings as opposed to dry-type transformers with open-wound construction.

The cast coil transformer is highly resistant to the effects of moisture. *All of the materials are nonhygroscopic. This allows the transformer to be immediately energized, even after an extended period of de-energization.* Dry-out time is not necessary. The epoxy resin is also extremely resistant to chemical contamination. The epoxy provides excellent protection for the windings and allows the transformer to be used in locations previously unsuitable for conventional open-wound dry-type transformers.

The epoxy encapsulation of the coils without voids or porosity eliminates corona generation. The dielectric properties of the solid insulation remain high because of the lack of corona and also because of the dielectric strength of the epoxy material itself. The epoxy also provides excellent mechanical strength during a short circuit, and the round geometry provides added strength against the axial and radial forces experienced during a short circuit. Cast coil transformers can provide BIL ratings equal to those of liquid-filled transformers. Conventional open-wound dry-type transformers can not be built effectively at these BIL levels.

With the increasing cost of producing power, the losses in transformers have become more important. The cast coil transformer is among the most efficient being used today. This transformer has slightly higher no-load losses than liquid-filled devices, but the load-losses are lower, which results in lower total losses. Appendix B describes the four types of cast coil devices evaluated for this report (Table 1).

Table 1. Types of cast coil devices

Manufacturer	Product Line
National Industri	NICAST Transformers
Square-D	Power-Cast & Power-Cast II
Elma Engineering	Cast Coil Transformers
General Electric	Geafol Transformers

In addition to those listed in Table 1, there are several other American manufacturers that build cast coil transformers such as BBC Brown-Boveri and IsoReg. However, the designs investigated for this report are typical of the available products.

CAST COIL TRANSFORMER FIRE TEST DESCRIPTION

A transformer fire typically results from one of two possible sources. A failure can occur within the transformer causing a hot spot that either exceeds the ratings of the transformer materials or creates an electric arc that ignites surrounding materials. Or, the transformer may be subjected to a source of external heat and/or flame.

Recent attention focused on the flammability of transformer cooling liquids has resulted in significant discussion on the effects of fire on cast coil transformers. An important question is whether and under what conditions will this type of transformer burn. Two conditions must occur for stable, self-sustained combustion; the temperature of the material must be raised to the fire point, and the combustion must produce an adequate supply of heat to sustain itself. This means that, after the ignition source is removed, the fire becomes an autothermal process (controlled by the balance between the heat generated by combustion and the heat carried away). This process must supply an adequate amount of heat from combustion in order to remain burning. All transformers will burn if they are subjected to sufficient temperatures, including dry, PCB, oil, RTemp, silicone, and other designs.

Several generalized tests were performed on both the transformer materials and on the complete transformer coils. The details of these tests and results are discussed in the following sections. The tests and results described include independent testing, INEL testing, and factory testing.

Epoxy Material Testing

The first fire test tested the epoxy encapsulating material itself. There are essentially two types of composite materials used in the production of cast coil transformers. The first is a bisphenol A (BPA) epoxy resin. The second is also BPA epoxy resin except that an inert filler (silica) is added to the mixture (Appendix C).

The epoxy material was tested in accordance with the Standard Method of Test for Flammability of Self–Supporting Plastics (i.e., rigid) American Society for Testing & Materials (ASTM) Designation D 634–68. This standard has recently been outdated and has not been replaced by anything to date. Testing was performed by an independent agency, and the results were taken from an Electrical Construction and Maintenance (EC&M) magazine article (Appendix D). Validation tests were performed by the INEL.

Twenty samples of the material, each 5 x 1/2 x 1/2 in., were tested using the procedure in the standard. Calibration marks were made 1 in. and 4 in. from the unclamped end of each sample. The sample under test was clamped horizontally and the flame of a Bunsen burner applied (Figure 2). If after two attempts, the specimen does not ignite, it is considered "nonburning" by this test. If the specimen continues to burn after the first or second ignition, timing is started when the flame reaches the first mark, 1 in. from the free end,

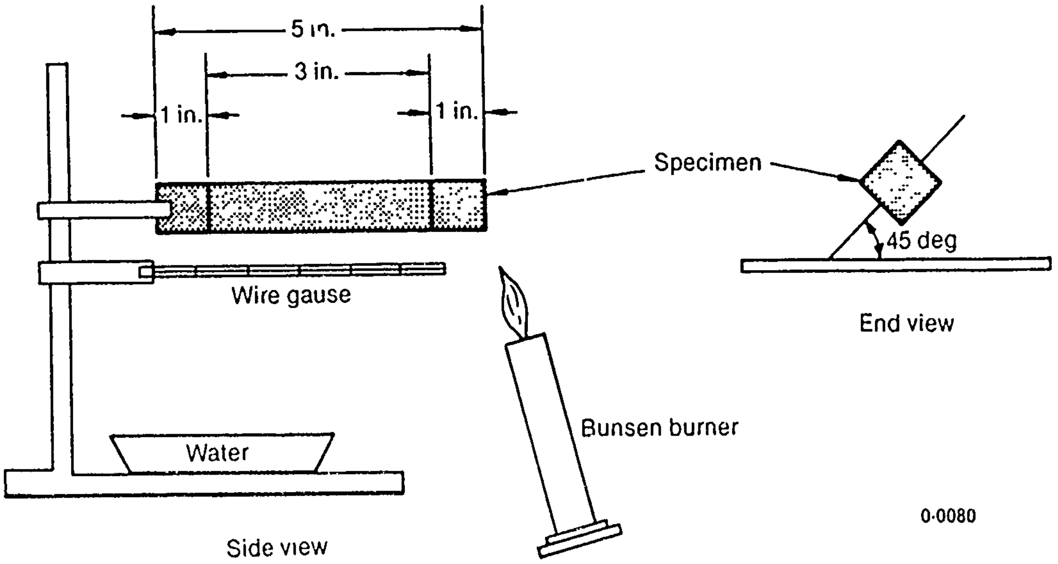

Figure 2. Apparatus for the epoxy material flammability tests performed by the INEL.

and stopped when the flame reaches the second mark, 4 in. from the free end. A specimen that burns to the 4 in. mark is considered to be "burning" by this test, and the burning rate is determined by the time it takes to burn the 3 in. between the two marks. If the specimen does not burn to the 4 in. mark, then it is determined to be "self-extinguishing" by this test, with the extent of burning being the measured length burned.

The INEL tested ten samples of the unfilled epoxy and ten samples of the filled epoxy. The results of the tests are tabulated in Table 2. The INEL tests verified the manufacturers' results that the epoxy material was nonburning. All twenty samples extinguished before they reached the first mark.

Complete Coil Assembly Testing

Currently, there are no industry or ASTM standards for testing to simulate the effects of internal faults or external flame on an epoxy encapsulated transformer coil; therefore, tests were devised by industry that represent the most severe conditions. This section is presented in four subsections. Two subsections describe the test scenarios used to simulate each of the two possible fire sources, and two subsections present typical results of a coil under each of the two test scenarios. These tests were not verified by the INEL. The testing described was performed by the manufacturers and also by an independent organization, and the results are discussed in an EC&M article, February 1986 (Appendix D).

The high voltage (HV) coil will be the most likely to be subjected to a fire situation for several reasons. It is located on the outside surface of the transformer and therefore will be the first item, excluding the cabinet, contacted by any external fire source. The high voltage placed on this coil makes it more prone to fire caused by an internal arc.

Secondary coil failures are also sources of self ignition. Secondary coils are high-current carrying conductors, and if poor joints develop or severe overloads occur, the resulting heat can cause incendiary problems. For instance, a cast coil transformer failed at Norfolk Naval Base, Virginia. Unfortunately, most

Table 2. Results from INEL flame tests of the two types of epoxy material

Sample No.	Material Filled (F) Unfilled (UF)	Total Time[a] First Burn (s)	Total Time[a] Second Burn (s)
1	NITI F	31.51	189.30
2	NITI F	0.0	8.87
3	NITI F	2.48	37.01
4	NITI F	10.79	40.34
5	NITI F	9.53	48.55
6	NITI F	20.66	28.83
7	NITI F	7.17	91.84
8	NITI F	22.08	110.48
9	NITI F	3.66	122.35
10	NITI F	46.73	20.43
1	Square-D UF	40.83	132.55
2	Square-D UF	133.80	52.49
3	Square-D UF	10.08	134.77
4	Square-D UF	199.18	24.05
5	Square-D UF	2.23	69.38
6	Square-D UF	19.27	9.96
7	Square-D UF	10.47	136.42
8	Square-D UF	3.20	287.10
9	Square-D UF	4.01	170.36
10	Square-D UF	38.78	76.59

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a. Time for flame to self extinguish after source was removed.

protection systems will not clear a low–level secondary fault and continuation of the fault can lead to catastrophic failure of the device. Possible solutions include either installation of a high–temperature alarm or smoke detection connected into the protection circuitry (Appendix E).

Coil Testing When Subjected to Arcing and a Short Circuit

To simulate an internal arcing fault, a 1 in. hole was drilled through the 1/4 in. epoxy outer coating, exposing the aluminum conductors of the winding. One end of the winding was connected to the negative lead of an arc welder, and an arc was drawn from the positive welder electrode to the aluminum winding exposed through the hole.

Under normal operation, transformers are protected by overcurrent devices that should clear the arcing fault in 30 cycles or less. To illustrate worst case conditions, the arcing test duration was extended to approximately 5 s, and a series of six tests were performed with increasing durations. The temperatures developed were sufficient to melt the aluminum wire and to establish a flame. The melting point of aluminum is 660°C during a high–energy arc between two voltage phases. The cause of the arcing can be one of many internal faults, such as turn–to–turn short circuits, coil short circuits, or phase–to–phase or phase–to–earth flashover.

Another high–energy arcing test was performed on an 800 kVA transformer of the Traffo–Union design. This test involved a three–phase HV terminal short circuit that was artificially induced. Short–circuit durations of .5 s and 2 s were used. The transformer was initially at its operating temperature of approximately 100°C. The fault level was 150 MVA.

Results of Coil Testing When Subjected to Arcing and a Short Circuit

Testing of the transformer coil under the simulation of an internal arc was performed as described in the previous subsection. The results of this test are tabulated in Table 3.

The particular coil used for this test was 36–in. high with an outside diameter of 23 in. and an inside diameter of 18 in. It consisted of multiple layers of aramid–insulated aluminum conductors covered with a fiberglass mat, placed in a metal mold, and vacuum cast in epoxy resin. The epoxy was approximately 1/4–in. thick over the winding.

Table 3. Results from the internal arc fire test simulation

Arc Duration (s)	Flame Extinction (s)
5	4.6
10	4.9
20	8.2
30	10.9
45	41.3
90	18.6

Based on the results in Table 3, a fire started by an internal fault in the transformer winding should be self–extinguishing within a short time after the fault is cleared by the system protection devices.

The second test was performed on the Traffo–Union transformer. As described in subsection, Coil Testing When Subjected to Arcing and a Short Circuit, two faults were simulated of .5 s and 2 s durations. The results of the 2 s fault were as follows. The heat caused by the arc burned a thin layer of the resin at the surface. This left a layer of soot that provided a shielding effect protecting the resin layers below. There was some melting and vaporization of the conductor material at the metal connection terminals (i.e., the root of the arc). High–speed cameras were used to verify that there was no after burning of the insulating material observed after arc extinction. Despite the visible surface damage, the transformer remained fully serviceable.

Next, the transformer was subjected to a test that simulated direct interturn and winding short circuits. Holes were drilled in the HV windings of all three phases. Six millimeter nails were placed in the holes and then connected to the short–circuit leads. The results during this test were the same as previous tests. There was no ignition and no afterburning of the resin compound or other insulating materials.

Coil Testing When Subjected to an External Flame Source

It is even more difficult to simulate how an external fire affects the coil. Fires have many variables and may be fed by many different fuels. In evaluating the risk of ignition as a result of an external fire, several factors must be considered.

The epoxy material will not contribute a large amount of heat to an existing fire. The transformer coils are a composite system of epoxy mixed with nonflammable fillers, insulating materials, and metal windings that conduct and distribute heat. Also, a fire may burn in an area that is oxygen rich or one that is relatively void of oxygen. This will have a drastic affect on the progression of the fire. The ignition temperature of the epoxy material is approximately 450°C higher than that of other construction materials such as wood; and therefore, fire protection systems should have reacted long before the epoxy of a cast coil transformer would ignite.

One typical test procedure used was application of an oxyacetylene cutting torch. The test was performed on a complete coil assembly. The coil was placed on a wooden skid and the torch flame was applied to the bottom of the coil so that the rising heated air would tend to keep the material burning. The torch flame was held in contact with the coil for 30 s. The time taken for the flame to extinguish was measured and is discussed in the following subsection. This test was informally verified by INEL personnel at the failed transformer autopsy at Norfolk, Virginia. Oxyacetylene torches were used with varying time elements and a self-sustained flame could not be produced.

Two other example tests performed to simulate external fires were (a) a wood fire that was placed underneath the coil and (b) propane gas flames applied to the side of the coil. For the wood fire test, 10 kg of untreated pinewood (5 x 2 x 100 cm) was laid on steel plates underneath the transformer and lit with shavings. The flame temperatures reached up to 1000°C. For the propane flame test, eight wide throat burners were placed evenly around the coil. The flame temperature peaked at approximately 1200°C. The burners were fired for 30 min. The results of these two tests are discussed in the following subsection.

Results of Coil Testing When Subjected to an External Source

The first external fire source test discussed was simulated by applying an oxyacetylene cutting torch to the bottom surface of the coil. The torch flame was held in contact with the coil for 30 s. The time from removal of the torch to extinction of the burning epoxy was measured. The test was repeated many times, with the torch applied for 30 s. The results in Table 4 represent the extinction times obtained.

Because of the varied range of external fires possible, it is not certain from this test that an externally caused cast-coil fire would be self extinguishing under all circumstances. However, it is highly probable that if flames of moderate size set fire to the epoxy and then were removed or extinguished, the coil fire would then self extinguish.

Table 4. Results from external fire test using an oxyacetylene cutting torch

Torch Applied (s)	Flame Extinction (s)
30	12.4
30	22.0

If the transformer was involved in a major catastrophic fire, it is possible that it would burn, but it would not add a significant amount of intensity to the fire.

Two types of external fire source tests were carried out on the Traffo-Union transformer. These two types of tests involved a wood fire and a propane gas fire. The two types of externally sourced fire simulated several different conceivable modes of attack on a transformer. The propane gas fire was considerably hotter than the wood fire and the damage more severe, although the total heat of combustion of the wood fire was actually greater.

Sixteen high-temperature nickel/chromium nickel thermocouples were fitted to the core, HV winding, and low-voltage (LV) winding of the transformer in a symmetrical arrangement with eight thermocouples for each test.

After the wood fire had been burning for some time, the insulation of the HV and LV windings ignited, and the chimney effect of the axial duct in the LV winding and of the leakage flux channel caused the epoxy to burn rapidly to the top of the transformer. However, the fire did not spread to the other limbs of the transformer.

During the propane fire test, the flame application was more intense; however, the flames still extinguished themselves shortly after the source was removed.

This same result was observed during the failure of the Norfolk Naval Base 2000 kVA unit; most of the damage was limited to the phase C coils. After electrical power was removed, the burning insulation extinguished itself.

COMBUSTION PRODUCTS

It is not possible to determine a standard set of conditions that would prevail in a hostile fire involving a cast coil transformer. There are many variables that can affect the results. These problems complicate the attempts to simulate the burning of cast coils in a laboratory. Tests have been conducted over many years with a variety of results that depend on the test conditions, parameters, and the methods of analysis of the products of combustion. Pyrolysis (decomposition of organic materials by the application of heat) has also been conducted using an ample air supply, a restricted air supply, or nitrogen only with no oxygen at various temperatures. Analysis of the products of combustion has been performed using many methods such as gas chromatography (GC) and mass spectroscopy.

Description of Testing Performed by the INEL

The results of testing performed by the INEL are summarized in the following section. The complete report containing the detailed test procedures and results is included in Appendix C.

The testing was performed on two samples of epoxy. One sample was the Square-D unfilled BPA and the other was the General Electric Company's quartz powder-filled BPA epoxy. Both of these samples were chemically evaluated for combustibility and toxic products given off during combustion or pyrolysis in an inert atmosphere.

The experiment was performed in three phases (1) chemical and physical characteristics of the two epoxies were determined, (2) temperatures at which chemical and physical changes take place in controlled air and nitrogen atmospheres were determined, and (3) the four toxic compounds previously identified from the pyrolysis of BPA were identified and quantitated for samples collected over the entire combustion process. During Phase 1, infrared (IR) spectroscopy was used to verify the chemical composition of the two materials. Phase 2 was performed under both an inert atmosphere (nitrogen) and an oxidative atmosphere (air). Thermogravimetric analysis (TGA) was used to determine the temperatures at which changes took place during heating of the polymers. Gas chromatography was used to perform Phase 3 of the analysis. During the testing, attempts to collect samples of gas from the TGA experiments for GC analysis were unsuccessful because only 10 mg of material was used for the test. Appendix C contains a detailed description of the test procedures used during these tests.

Results of Testing Performed by the INEL

Infrared spectroscopy was used to verify that the two polymers were composed of BPA epoxy. Both materials were confirmed to be BPA epoxy. The General Electric-filled sample also contained bands indicating the silica filler. Appendix C contains a summary of the testing performed by the INEL.

The TGA analysis was performed on the samples to determine their reaction under increasing temperature. Under the nitrogen atmosphere, both of the samples began to decompose at 300-350°C. The Square-D sample lost 100% of its weight at 475°C, and the General Electric sample lost 50% at 420°C. The material that remained in the General Electric sample consisted of the silica filler and was black due to the presence of elemental carbon. Under the air atmosphere, the Square-D polymer began to decompose at 250°C, and rapid oxidation occurred between 350 and 435°C. The sample had a net weight loss of 85%. Fifteen percent of the Square-D polymer remained oxidized between 535°C and 580°C. The General Electric sample began to decompose at 250°C and was followed by oxidation between 330 and 420°C. This sample had a net weight loss of 40%. Oxidation continued between 450 and 500°C with 15% more weight loss. The portion of the General Electric material left was determined to be silica filler.

Gases were collected in the impinger during the pyrolysis testing. Gas chromatograms were run on the samples. Benzene, toluene, ethylbenzene, and phenol were positively identified. Table 5 contains summary data of the quantitative information obtained.

Results of Testing from Independent Sources

Table 6 contains data taken from an EC&M article, which is included in Appendix D. The table contains actual testing data of an unknown epoxy sample as well as the acceptable Occupation Health and Safety Act (OSHA) concentrations to which humans can be exposed.

Table 5. Concentration of toxic pyrolysis products of BPA polymers

	Concentration[a] (mg/g)[b]			
	Air Atmosphere		Nitrogen Atmosphere	
Toxic Compound	Filled	Unfilled	Filled	Unfilled
Benzene	3.1	1.2	7.8	1.24
Toluene	0.65	0.26	1.9	0.86
Ethylbenzene	0.12	0.25	0.15	0.13
Phenol	12.8	4.3	10.0	—

a. Concentration: Typically 1 ppm of vapor is equal to 0.12 mg/m³ concentration in the worst case. Mg/m³: milligrams per cubic meter.

b. mg/g: Milligrams per gram.

Table 6. Products of air pyrolysis of epoxy resin as compiled in EC&M magazine

Compound Produced	Concentration[a] (mg/m³)[b]	OSHA Limits[c] (mg/m³)
Benzene	3.4 to 3.8	30
1, 3 Butadiene	0.2 to 1.0	2200
Cyclopentadiene	2.0 to 2.6	200
Naphthalene	0.36 to 0.72	50
Phenol	0.54 to 0.66	19
Styrene	0.72 to 0.96	215
Toluene	1.6 to 1.8	375

a. Concentration: Typically 1 ppm of vapor is equal to 0.12 mg/m³ concentration in the worst case.

b. mg/m³: Milligrams per cubic meter.

c. OSHA Limits: Threshold Limit Value (TLV) maximum amount in atmosphere tolerable for an 8-h period.

The results of this testing indicated that the toxic substances produced by pyrolysis of the epoxy material are in concentrations that are not harmful to humans when exposed to them for relatively long periods. The testing also indicated that cast coil transformers are not significantly hazardous to fire fighters or others near the transformer when involved in a fire.

A similar series of tests were performed on General Electric Company's Geafol transformer. The results obtained from the GC mass spectrometer indicated similar results to those discussed in the EC&M article. The discussion on the Geafol transformer contained a section that specifically discussed the production of two hazardous substances that are the results of pyrolysis of askarel. These hazardous substances [2, 3, 7, 8 tetrachlorodibenzodioxin (TCDD) and 2, 3, 7, 8 tetrachlorodibenzofuran (TCDF)] were monitored for, and the gas chromatograms of this test verified that these products were not produced by the pyrolysis of the BPA epoxy.

In Appendix C, a comment was made that the concentrations of phenol and benzene tested were above the admissible limit. This condition occurred in a small confined environment. The levels were considered safe for fire fighters and others in the areas under the normal conditions (i.e., the volume of air surrounding the transformer would be sufficient to dilute the toxic gasses, and the testing also confirmed that the cast coil transformer would not produce any significant amounts of nonbiodegradable toxic substances even if the device was completely consumed in the fire).

QUANTITATIVE MATERIAL CONCENTRATIONS OF CAST COIL TRANSFORMERS

The cast coil transformer has very little material (% by weight) that will burn in the event of a fire. As shown in Table 7, the total percentage by weight of flammable material is very small. In comparison, an oil-filled transformer contains a substantially higher amount of flammable material.

Table 7. Proportions of flammable and nonflammable materials in an 800 kVA Geafol cast-resin transformer (% by weight)

Material in Typical Cast Coil Transformer	Proportion Nonflammable (%)	Proportion Flammable (%)
Metal parts, such as core lamination, aluminum, and steel	89	
Insulating materials with flammable components		
Insulating parts of clamping structure	0.32	
LV prepreg and end encapsulation	0.70	0.47
HV resin compound and terminal link strip	4.79	2.46
HV layer insulation		1.49
Packing blocks		0.71
Transformer, complete	94.5	5.5
Total = 100%		

CAST COIL TRANSFORMER CRACKING

This section summarizes the information available to date regarding cast coil cracking.

Instances have been reported where the transformer coils have developed stress cracks. Coil cracking has been related to the compatibility of the coil electrical conductors to the epoxy resin mixture used to encapsulate the windings. The two types of conductors used today are aluminum and copper. Currently, manufactures are using more aluminum. The aluminum material does not have the same current carrying capacity of copper; therefore, the windings must be physically larger. The product descriptions, included in Appendix B, indicate those companies that use aluminum, copper, and those that use both.

Several of the manufacturers claim to use aluminum windings because of its compatibility with the epoxy. Only one company mentions the reduced cost of using aluminum windings in the transformers and states that "aluminum offers the best value for the user." Companies offering both copper and aluminum indicate that the choice is based on the loss formulas or customer preference.

Each of the manufacturers using aluminum offer their own argument as to why aluminum is the preferred choice. The arguments are summarized below.

1. Chemical resistance. The chemical resistance is the ability of the conductor to withstand the effects of chemical contaminants that may be present in the atmosphere. One consideration is to not use aluminum to increase the corrosive resistance and another is to use the conductor and design the package accordingly.

2. Joints and connections. The joints have been a problem in the past because aluminum tends to flow away from connections causing them to loosen and overheat.

3. Thermal expansion coefficients. Encapsulating the conductors rigidly in the epoxy material creates stress each time the transformer heats and cools because of different thermal expansion coefficients of the aluminum and the epoxy.

The first issue, chemical resistance of the winding material, was easily resolved. The windings are encapsulated in chemically inert epoxy resin and are not exposed to the hazardous environments or conditions that are of concern. Also, the manufacturers often use a copper bus with the aluminum windings. This way the most significant portion of exposed material is copper and may be more durable than the alternative aluminum. Therefore, the choice should not be driven by concerns about the environment.

The second issue is also addressed adequately by engineering and manufacturing techniques. The connection problems associated with aluminum have been reduced by use of several techniques. For instance, one technique is to tin plate the aluminum leads as they come out of the epoxy encapsulated winding and then mechanically couple the tin plate to a tin–plated copper pad that connects to the copper bus. This type of connection reduces the possibility of conductor movement. Another type of connection used is a special copper/aluminum explosion–bonded pad The pad consists of one plate of aluminum and one plate of copper that are explosively bonded together (e.g., DuPont–Deltaclad) to form one integral piece of material. The aluminum winding leads are then connected to the aluminum side of the pad and the copper bus to the other side. In summary, proper joints and connections should not be a factor because of the engineering solutions available.

Final issue of conductor thermal expansion compatibility to the epoxy resin mixture raises the most questions and is a sensitive area among the various manufacturers. This is further compounded because several different epoxy composite coil assembly structures are used to encapsulate the windings. Therefore, the data are not the same and difficult to assess equally.

In order to present comparative information from several of the manufacturers, a relative expansion rate will be used. The relative base will be the thermal expansion rate of pure epoxy resin, which will be 70 x 10^{-6} in./in./°C. The information available has been standardized and is presented in Table 8.

Based on this argument, the expansion coefficients of the aluminum are in fact closer to those of the composite epoxy mixtures that are used to encapsulate the windings. However, no manufactuers use epoxy without fillers and/or internal strengthening fibers or other methods of strengthening the coil assemblies. One potential problem is expansion and contraction of the materials during operation caused by changing internal transformer coil temperature and varying external

Table 8. Thermal expansion coefficient information on the different materials used in cast coil transformers

Company	Expansion Coefficients (10^{-6} in./in./°C) Aluminum	Copper	Composite[a]
Square-D	23.0	18.0	45.0
NITI	48.3	33.8	60.3
General Electric	50.0	35.0	est. 60.0

a. Square-D uses a composite mixture of glass reinforced epoxy. NITI uses a composite mixture of glass fiber reinforced silica-filled epoxy. General Electric uses a composite mixture of quartz powder-filled epoxy.

environmental temperatures. Manufacturing techniques, materials technology, and structural engineering factors all come into play in designing the composite for adequate reliability.

In summary, the transformers are designed as composite structures for strength using glass fiber reinforcements, powder filler, or a combination of both. All manufacturers have tested their coil designs under temperature tests that involve gradients of -60°C to +80°C. Many of the problems present in the coils several years ago have now been eliminated. The limits of the material are better understood, and the transformers are designed accordingly. It is sufficient to state that the manufacturers are aware of the potential problems and are actively addressing it. Additional research and investigation in stress cracking and design details can be performed upon request.

CAST COIL TRANSFORMER RELIABILITY

The specific type of transformer that best suits a given installation varies with the surrounding fire hazards, requirements of the user, and other application issues. Cast coil transformers have a proven record in Europe and other parts of the world. They have a good reliability record, are easy to maintain, and there are over 10,000 units in service ranging in kVA from 100 to 10,000, with voltages up to 34.5 kV. The initial cost of a cast coil transformer is commonly higher than costs of the other alternatives, but total ownership costs are often lower.

Based on the information obtained during this investigation, the cast coil transformer has proved to be exceptional for its intended applications. The cast coil transformer provides a high degree of fire protection for both internally and externally caused fires. At the same time, they have the capability of maintaining BIL ratings similar to liquid-filled transformers This is not true of the standard dry-type transformers.

The testing performed by the INEL during this task confirmed the available results regarding the flammability of the epoxy material and the products of combustion.

Unless ordered specifically without a cabinet, all U.S. style cast coil transformers come with an industrial grade cabinet that acts as a fire barrier. This cabinet keeps both external flame and heat away from the flammable portions of the transformer. The cabinet also serves the following functions:

- Safety
- HV isolation
- Fire protection
- Maintenance minimization.

The final concern is placing cast coil transformers in space-limited locations. The cast coil transformers are larger than standard liquid-filled units and may not fit certain applications.

In summary, cast coil transformers offer the user a high level of reliability in most environments. They are durable under fire conditions. The coil encapsulation material is "nonflammable" and self extinguishing. These types of transformers do not add any significant amount of fuel or fire danger when placed in a location where a fire might occur. If a fire should occur, the products of combustion are not sufficient to endanger the lives of fire fighters or others near the device. Cast coil transformers provide an excellent alternative for applications that are not suitable to other dry-type devices or liquid-filled units.

CONCLUSIONS

Cast coil transformers offer reduced risk to the user compared to liquid-filled units. The cast coil design eliminates the environmental impacts associated with liquid-filled designs. The threats of oil spills and catastrophic fires are reduced with the elimination of the liquid coolant. Cast coil transformers are a very attractive option when the environmental effects must be kept to a minimum. Cast coil transformers are also more efficient than most of the other transformer designs and therefore fit into the increasing trend of energy consciousness.

When a cast coil transformer is involved in a fire situation, the products of combustion consist primarily of carbon (soot) and several aromatic hydrocarbons. These concentrations are usually at acceptable levels. Overall, the cast coil transformer adds minimal risk to an installation under the worst case situation. In conclusion, cast coil transformers have a long record of operation and have proven to be reliable and efficient.

RECOMMENDATIONS

Listed below are several recommendations for the use of cast coil transformers.

1. Use near environmentally sensitive areas and areas where personnel safety is a primary concern, such as piers, waterfronts, hospitals, dormitories, cafeterias, and schools.
2. Use in areas with high power rates.
3. Use in facilities that experience cyclical loads where the transformers are or can be shut-down for long time periods.
4. Use when varying loads are experienced with high quantities of short-term overload but lower average power.
5. Use in applications where the transformers are not enclosed in vaults.

Cast coil transformers are excellent devices for many uses, but they are not the best device for all applications. Good engineering judgement and evaluations must be used to determine which design is appropriate in any given circumstance.

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APPENDIX A

INFORMATION REQUEST FORM AND RESPONSES

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INFORMATION REQUEST FORM AND RESPONSES

Information Needed From Manufacturer On Cast Coil Transformers

1. Provide description of the actual product manufactured by your company.
2. How long has your company manufactured this product?
3. What design do you use that of a parent company or your own?
4. What is the approximate number of cast coil transformers manufactured by your company to date?
5. What size and voltage ranges are available?
6. What specific applications make cast coil transformers most attractive and are there any applications where they should not be used?
7. What fire testing has been done on your company's cast coil transformers?
8. What are the combustion byproducts produced when a sample of the material used to encapsulate the core is forced to burn?
9. Are your company's cast coil transformers proven to be safe in fire situations—either from internal arcing or some other external source?
10. Provide other information that deals with the testing or reliability of your company's cast coil type transformer.

SQUARE D COMPANY
ELECTRICAL EQUIPMENT
UTILITY PRODUCTS DIVISION
MONROE PLANT
(704) 233-7411
1803 AIRPORT ROAD
P. O. BOX 5062
MONROE, NORTH CAROLINA 28110

June 3, 1988

Idaho National Engineering Laboratory
E. G. & G. Idaho Inc.
P. O. Box 1625
Idaho Falls, ID 83415

Attention: Mr. Scott McBride

Dear Mr. McBride:

In response to your letter of May 9, 1988 (copy attached), I will respond to your questions.

1. I am enclosing a copy of our bulletin MD-1, which gives a detailed description of our Power-Cast tranformer.
2. We shipped our first Power-Cast transformer from our Clearwater, FL plant in July of 1979.
3. Our Power-Cast transformer is designed and manufactured based on the May & Christe technology.
4. We have manufactured approximately 1400 Power-Cast transformers to date.
5. The Power-Cast transformers are available, three phase, over a kVA range from 300 - 10,000 kVA. The high voltage range is from 2.5kV through 34.5kV class. The low voltage range is from 1.2kV through 5.0kV class.
6. The greatest attraction for Power-Cast has been for "PCB" replacement and applications where severe environmental conditions exist (i.e. salt laden high humidity, caustic vapors, etc.). I know of no application where the product meets the kVA and voltage requirements that the Power-Cast should not be used.

7. I am enclosing a copy of a bulletin published by May & Christe which by experts examines the flammability of their technology. We use exactly the same epoxy materials as they do. We, therefore, feel that this data applies to the Power-Cast as well.

8. I am enclosing a copy of our Product Data Bulletin EIP-19, which addresses the products of combustion of cast Bisphenol "A" epoxy transformer coils in great detail. It should be noted that the data given is the results of actual testing.

9. Experience supports a non-flammable classification as defined as not being able to support combustion and will self-extinguish.

10. We have experienced a very small number of failures, approximately 3/10 of one percent, for the entire population manufactured over a 9 year period.

If we may be of further service, please advise.

Regards,

SQUARE D COMPANY

Bill Featheringill

W. E. Featheringill
Transformer Marketing Specialist

WEF:tlh

Enclosures

GE Electrical Distributio
and Control Sales Divis

[illegible]
[illegible]

May 12, 1988

Scott A. McBride
Electrical Engineer
Idaho National Engineering Lab
P. O. Box 1625
Idaho Falls, Idaho 83415

Subject: Cast Coil Transformers

Gentlemen:

In response to your May 9, 1988 letter I would like to respond as follows:

1. See attached product bulletins. We manufacture and impregnate our own transformers complete.

2. We have built our own transformers since 1982.

3. We are licensees of Trafo-Union of Germany. They have been building transformers since 1969.

4. We have manufactured over 600 units. Trafo-Union has manufactured over 20,000 units.

5. We build 34.5 KV 150 KV BiL primary to 5000 KVA, 15 KV primary to 6000 KVA, so our max. primary voltage is 34.5 KV. Our max. KVA is at 15 KV and is 6000 KVA. We have a maximum outer diameter of 40" primary cast winding. If we want lower losses, higher BiL, etc., we would sacrifice KVA or voltage to keep the diameter within 40".

6. Cast coil transformers are most attractive where there is a dirty environment, area where maintenance is very difficult. High available short circuit currents. Attractive in all applications really. Only application where they should not be used is where the ambient temperature would drop below -50°C.

7. See attached video.

8. See attached video.

9. See attached video.

10. We have an offering that no one else can match. We have 100% impregnation due to our manufacturing process. No one else does.

    We do a partial discharge test and guarantee our transformer to be partial discharge free up to 200% at 15 KV, 175% at 25 KV and 160% at 34.5 KV.

    All our transformers get impulse tests as standard.

We feel thaat with our experience, American manufactured product and superior quality we have a very good offering for you. I would like to meet with you and go over the info I have sent to you. Please allow me to be of service.

Sincerely,

Richard D. Estes

Richard D. Estes
Sales Engineer

RDE:ks

Scott,
I have a video I want to bring up and show. Can you see how many people you can get together, set something up and give me a call. It shows a lot on the fire capabilities.

Regards
Rich

ELMA ENGINEERING

ELECTRO-MAGNETIC EQUIPMENT, TRANSFORMERS
SOLID STATE CONTROL, INDUCTION HEATING AND TEST SYSTEMS

1066 EAST MEADOW CIRCLE, PALO ALTO, CALIFORNIA 94303
PHONE (415) 494-7303, TELEX 345-560

May 31, 1988

Mr. S.A. McBride
Electrical Engineer
IDAHO NATIONAL ENGINEERING LAB
P.O. Box 1625
Idaho Falls, ID 83415

Sub: Cast Coil Transformer SAM-1-88

Dear Mr. McBride:

Following up your letter of May 9, 1988, and confirming our telephone discussions, enclosed are a number of Elma Engineering documents which should address most of the questions attached to your letter.

The two-page background summary, BG-CCT, highlights features of the cast coil design, and Elma Engineering's involvement in development of the product. We have been manufacturing our own design in power distribution sizes (over 500 KVA) for about 15 years. We estimate the total number of cast coil transformers manufactured by Elma Engineering to exceed 450.

As detailed in the thirteen-page "comparison" booklet, we manufacture cast coil power transformers up to 5000 KVA and 36 KV. Please refer to the 4-page sales bulletin for standard capacities and voltage ranges. In addition, special sizes can be designed consistent with available casting molds. Elma Engineering has one of the most complete sets of casting molds available in the industry. Special arrangements of HV/LV terminations can be designed, which is frequently necessary in PCB change-out projects.

As we have discussed, flammability tests have been conducted on the epoxy resin system used in Elma cast coil transformers. The "torch" tests are documented on the enclosed film strip, which we have made available for your review. We would appreciate your returning this film when you are finished using it.

Regarding combustion by-products of the resin/insulation system, we are advised by customers who have investigated the matter that the products of combustion are non-polluting and non-toxic to humans. We have enclosed two cutaway samples of a typical casted coil for your use should you wish to conduct your own tests.

We are convinced that when properly installed on applications well-suited for cast coil transformers, and when operated within design capacities and voltages, cast coil transformers offer many features superior to liquid filled or ordinary dry-types. We hope that this material will provide you with sufficient information to enable you to reach the same conclusion.

Sincerely,

Thomas A. Beno
Vice President

Encl: (5)

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APPENDIX B

PRODUCT DESCRIPTIONS

APPENDIX B

PRODUCT DESCRIPTIONS

Square–D

Appendix B contains descriptions for the following companies: Square–D, National Industri, Inc., Elma Engineering, and General Electric Company.

Square–D manufactures their Power–Cast transformers based on the May & Christe technology. They have been building cast coil transformers in America for approximately 9 years. Their first Power–Cast transformer was shipped in mid 1979. To date, Square–D has built approximately 1400 such transformers. May & Christe has built cast coil transformers in Europe since the early 1960s.

The Power–Cast transformers are available, three phase, over a kVA range from 300 to 10,000 kVA. The high voltage range is from 2.5 kV through 34.5 kV class. The low voltage range is through 5.0 kV class.

The Power–Cast II transformer uses a bisphenol A (BPA)–based epoxy reinforced with glass cloth and small quantities of Quintex paper for insulation between the aluminum conductors. The Power–Cast transformers are equivalent to the Power–Cast II except that the Power–Cast typically incorporate copper windings instead of aluminum. The Square–D cast coil transformers are encapsulated using laminar construction with layers of fiberglass cloth impregnated with pure (unfilled) resin, unlike the silica–filled resin of the NICAST transformers. This technology uses a thinner epoxy cross section than the filled design with comparable performance and strength. However, precision molds are required.

Both the primary and secondary coils are vacuum cast with the same construction technique. This technique uses cooling vents throughout the length of the windings and a relatively thin layer of epoxy coating.

National Industri Transformers, Inc.

National Industri observed the extensive use of cast coil technology in Europe. In the 1970s, National Industri decided that it would be feasible to attack the U.S. market with "fire resistant" transformers. National Industri currently has over 7000 vacuum cast dry–type transformers in service.

National Industri's NICAST transformers utilize their own design technology, which in some ways closely resembles the Traffo–Union design. However, National Industri is not a licensee of Traffo–Union. Some of the design highlights are described in the following paragraphs.

The NICAST transformer uses a BPA–based resin, an anhydride curing agent, a flexibilizer, and a silica filler. National Industri uses a unique insulation combination that consists of NOMEX and epoxy. The coil turns are first wrapped with NOMEX insulation that is rated at 200°C and then the entire coil is encapsulated in the above epoxy resin mixture, which is reinforced with two fiberglass sheets one inside and one outside. The pure epoxy in the mixture is rated at 155°C. Silica filler is added to increase the temperature rating to approximately 200°C.

The high–voltage (HV) coils are disk wound with NOMEX turn insulation with either aluminum or copper, rectangular or foil conductor. Every other disk is upset in order to eliminate turns from crossing each other, so that internal mechanical stress concentrations are minimized during resin shrinkage. All HV coils are vacuum cast in mold.

The low–voltage (LV) coils are constructed in either a foil strip or continuous layer. These coils can be designed with or without cooling ducts and with either aluminum or copper conductor. Turn–to–turn insulation can be either NOMEX or fiberglass. Both round and oval cross sections can be constructed. The oval configuration is currently being developed in order to reduce the length dimension to make the cast coil transformer more attractive for PCB replacements. The secondary coils may be encapsulated in one of three different ways (1) vacuum cast in mold like the primary winding, (2) dip cast (Dynacast), or (3) VPI–vacuum pressure impregnated. Low precision, less costly molds are required for this design.

National Industri builds cast coil transformers from 50 kVA to 7500 kVA with voltage ratings from 2.4 kV to 35 kV. They can also build banks of single phase units to handle needs larger than 7500 kVA.

Elma Engineering

Elma Engineering is a small California–based company composed of approximately 50 employees. The company was established in 1964 and began building cast coil transformers at that time. Elma Engineering does not rely on any foreign source for transformer designs. The complete transformer is designed and built at their factory in Palo Alto, California. Their design resembles the May & Christe design. Elma has been manufacturing cast coil transformers for approximately 15 years and has approximately 350 power distribution size devices in the field to date.

Elma's cast coil tranformers are available, three phase, from 112 kVA to 5000 kVA in voltage classes of 2.4 kV to 36 kV.

Both, the HV and LV windings are separately vacuum epoxy cast in a machined metal mold, providing two rigid tubular coils with no rigid mechanical connection between their concentric arrangement. The epoxy is completely reinforced with continuous filament fiberglass to provide high mechanical strength and to prevent the epoxy from cracking. High precision molds are needed for this design.

The epoxy resin used is formulated to closely match the coefficient of expansion of the copper windings. This design utilizes pure (unfilled) epoxy.

General Electric

General Electric has manufactured Geafol cast coil transformers since 1982 under a license of Traffo-Union. They have just recently developed some new techniques and have moved away from the original licensing agreement. They now manufacture their own product. General Electric has manufactured over 600 units to date.

The Geafol transformers are available, three phase, with kVA ratings from 500 kVA to 6000 kVA (at 15 kV) at voltages of 2.4 kV to 34 kV except the maximum size of the units at the 34 kV class is 5000 kVA.

The HV windings are comprised of several individual aluminum strip coils, vacuum cast in epoxy resin with quartz powder filler. The aluminum strip windings are individual coil sections wound utilizing the aluminum foil technology. The sections are connected in a series. Multiple layers of polyester film provide the necessary turn insulation.

The LV windings are sheet windings employing a different manufacturing method from the HV windings. A foundation cylinder is first wrapped with several layers of glass fabric impregnated with ester–imide resin. Full width aluminum sheet and impregnated glass fabric insulation are then wound onto the cylinder. The full width sheet winding is then wrapped with impregnated glass fabric and cured in an oven. The ends of the windings are potted with an air dried epoxy. This technique is similar to the nonvacuum secondaries produced by National Industri.

In the past, General Electric has purchased cast type secondary coils form their competitors for their customers that require vacuum cast LV coil designs. Low precision molds are needed for this design.

APPENDIX C

INEL BYPRODUCTS OF COMBUSTION FIRE TEST REPORT

APPENDIX C

INEL BYPRODUCTS OF COMBUSTION FIRE TEST REPORT

Byproducts of Combustion of Bisphenol A Epoxy Resin

Introduction. The U.S. Navy is currently in the process of replacing their polychlorinated biphenyl (PCB) transformers with ones that are more environmentally safe. One of the proposed replacements is a transformer that uses bisphenol A (BPA) epoxy insulated coils. There is a concern over the possible health hazards associated with the combustion products of the BPA epoxy if the transformers were inadvertently subjected to high temperatures. One study has already been completed and has shown that toxic gases are produced by the combustion of BPA epoxy; however, the amount of toxic gases in air found was well below the recommended permissible exposure limit for humans.[1]

The Naval Civil Engineering Laboratory (NCEL) has provided two samples of BPA epoxy, one red in color (Square-D Company) and one brown in color (General Electric Company), to be chemically evaluated with respect to combustibility and toxic products given off during combustion or pyrolysis in an inert atmosphere. The required work needed to complete the chemical evaluation was broken into two parts. The objective of this part of the study was to develop the experimental methods to do the analysis and obtain initial results. This paper discusses the initial results of the qualitative and quantitative analysis of the combustion products of the BPA epoxy and details what further work must be done in the second part of the study. Figures C-1 through C-6 show BPA epoxy samples.

Experimental. The experimental work for this study was done along the same lines as those found in one of the articles during the literature search.[2] The analysis was carried out in three phases (1) chemical and physical characteristics of the two epoxies were determined, (2) temperatures at which chemical and physical changes take place in controlled air and nitrogen atmospheres were determined, (3) the four toxic compounds previously identified from the pyrolysis of BPA were identified and quantitated for samples collected over the entire combustion process.[1]

In phase (1) the chemical composition of the two materials was verified using infrared (IR) spectroscopy. Also, pieces (approximately 2 mm x 2 cm x 5 cm) of the two polymer samples were ignited with a bunsen burner. The heat source (the bunsen burner) was then removed to see if the plastic would support a flame.

In phase (2), the temperatures at which changes took place during heating of the polymers were determined by thermogravimetric analysis (TGA). These experiments were carried out under both an inert (nitrogen) atmosphere and an oxidative atmosphere (air). The inert atmosphere was selected to evaluate the thermal stability of the polymers in a nonoxidizing atmosphere that may undergo thermal fluctuations, such as the polymer that is located internally near the aluminum or copper coil wires of the transformers where the resistance heating is at a maximum.

Phase (3) of the analysis was done using gas chromatography (GC). Attempts to collect the gaseous products from the TGA experiments for GC analysis proved futile as only 10 mg of material could be used effectively. To collect the gaseous products from the pyrolysis of the materials under both the inert and oxidative atmospheres, a simple apparatus was constructed employing a tube furnace and an impinger containing 2 mL of emthylene chloride cooled to –78°C in an acetone/dry ice bath. The quartz furnace tube and apparatus were also rinsed with methylene chloride and the rinsate diluted to 10 mL and subsequently analyzed by GC. The resulting solutions were analyzed by GC with separation on a 10% SP 2100 packed column (Supelco Chromatography Suppliers) in a Perkin-Elmer Sigma 2 Gas Chromatograph equipped with a flame ionization detector (FID). The temperature program was as follows: isothermal for 5 minutes at 50°C, then a ramp at 8°C/minute to 230°C, and a thermal elution at 230°C for 5.0 minutes. The injector and detector were held at 270°C and the eluent (He) flow rate was 30 mL/min.

Results and Discussion.

Phase (1). While working with the two polymers during the physical evaluation, it was noted that both materials were very hard and that the "red" was much more brittle. Chemical evaluation of the two epoxy materials using IR spectroscopy confirmed that both of the samples were composed of BPA. The "brown" polymer also contained bands that were indicative of a silica-based filler, most likely the quartz powder used

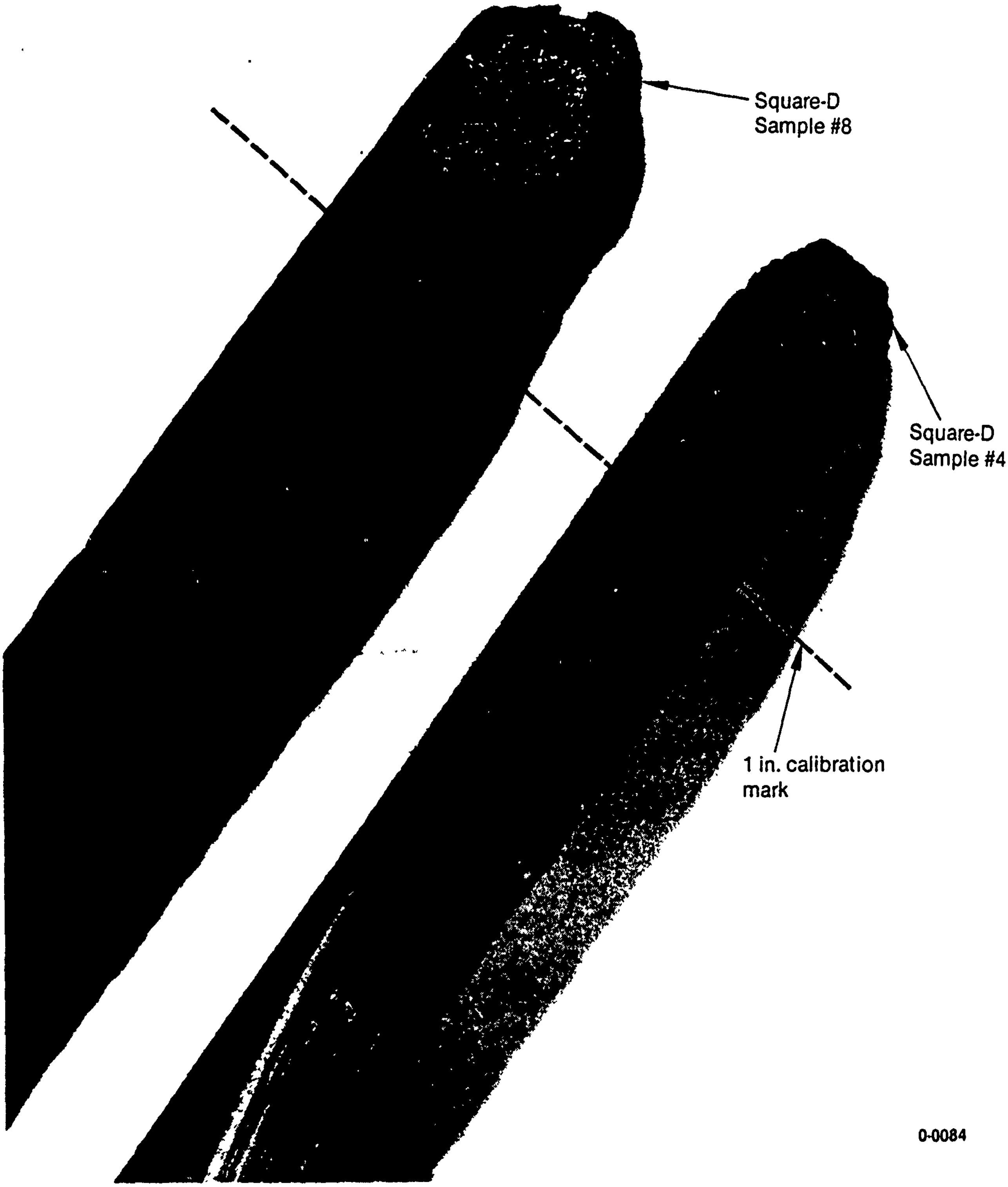

Figure C–1. This photograph is of two unfilled BPA epoxy samples (Square–D) that have been subjected to the burn tests. The flames consumed a small portion of the material, but the degradation did not reach the 1 in. mark. The material proved to be nonburning by the definition of the test procedure.

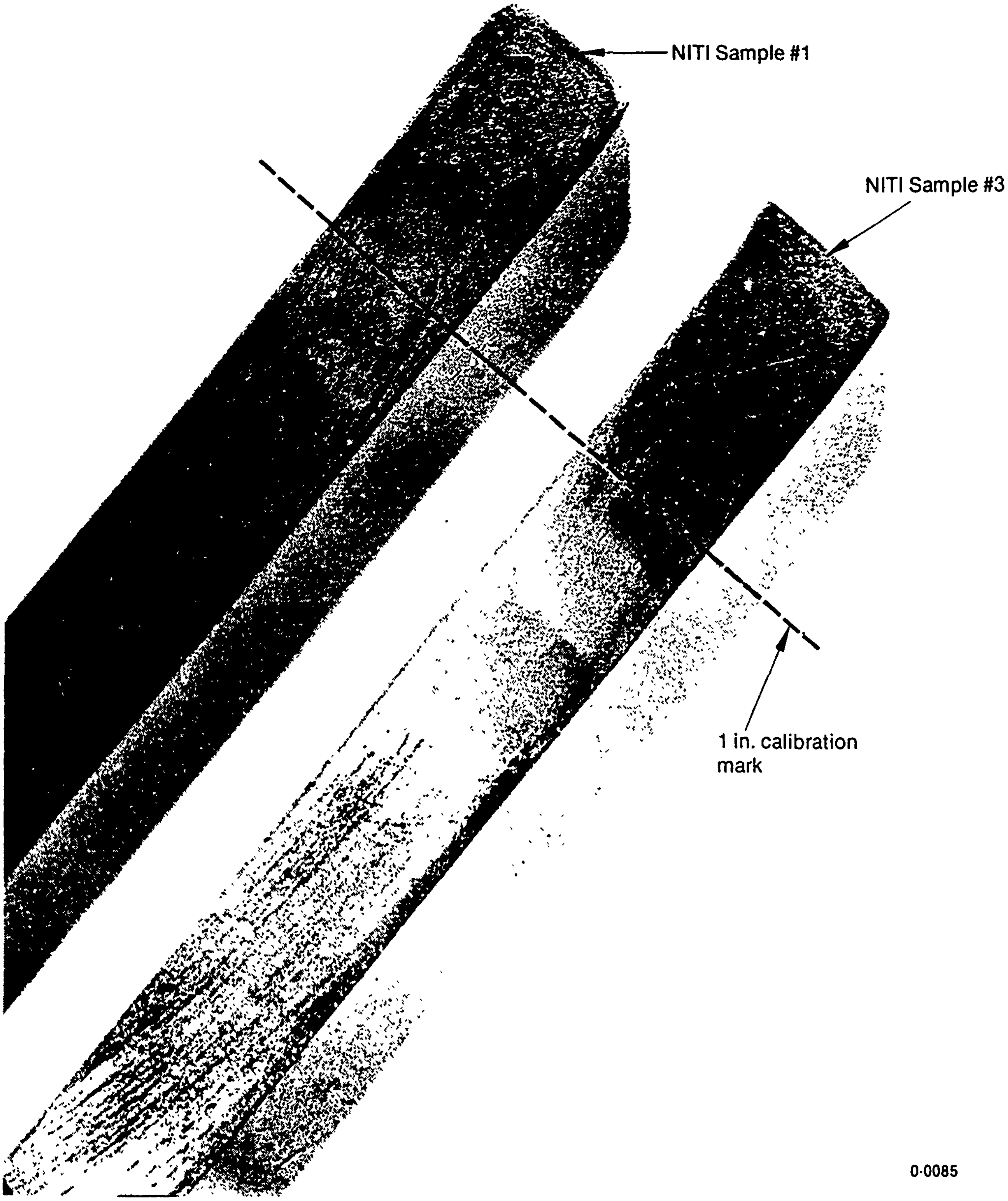

Figure C–2. This photograph is of two silica–filled BPA epoxy samples (National Industri Transformer, Inc.) that have been subjected to the burn tests. The flames caused a minimum amount of degradation of the material. In comparison to Figure C–1 the filled sample was less effected than the unfilled sample. This material also proved to be nonburning by the definition of the test procedure.

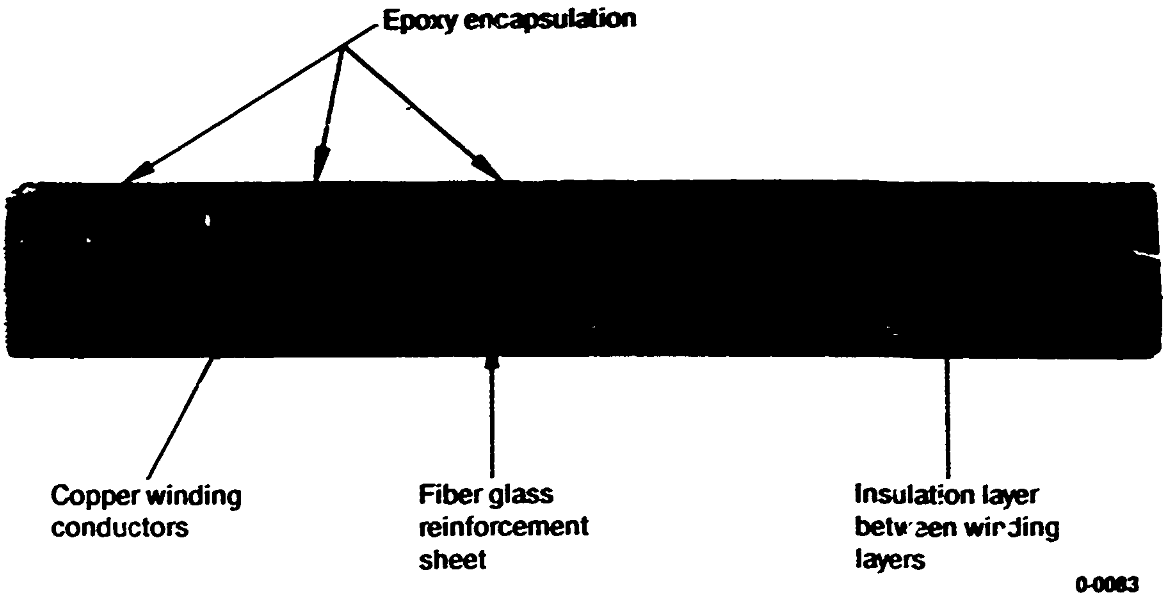

Figure C–3. This photograph shows a cross section of a cast coil taken from an Elma Engineering transformer. The section shows the coil conductors and the insulating sheets that separate the turns as well as the epoxy layer that is used to encapsulate the windings. This particular design also used a layer of fiber glass to provide reinforcement.

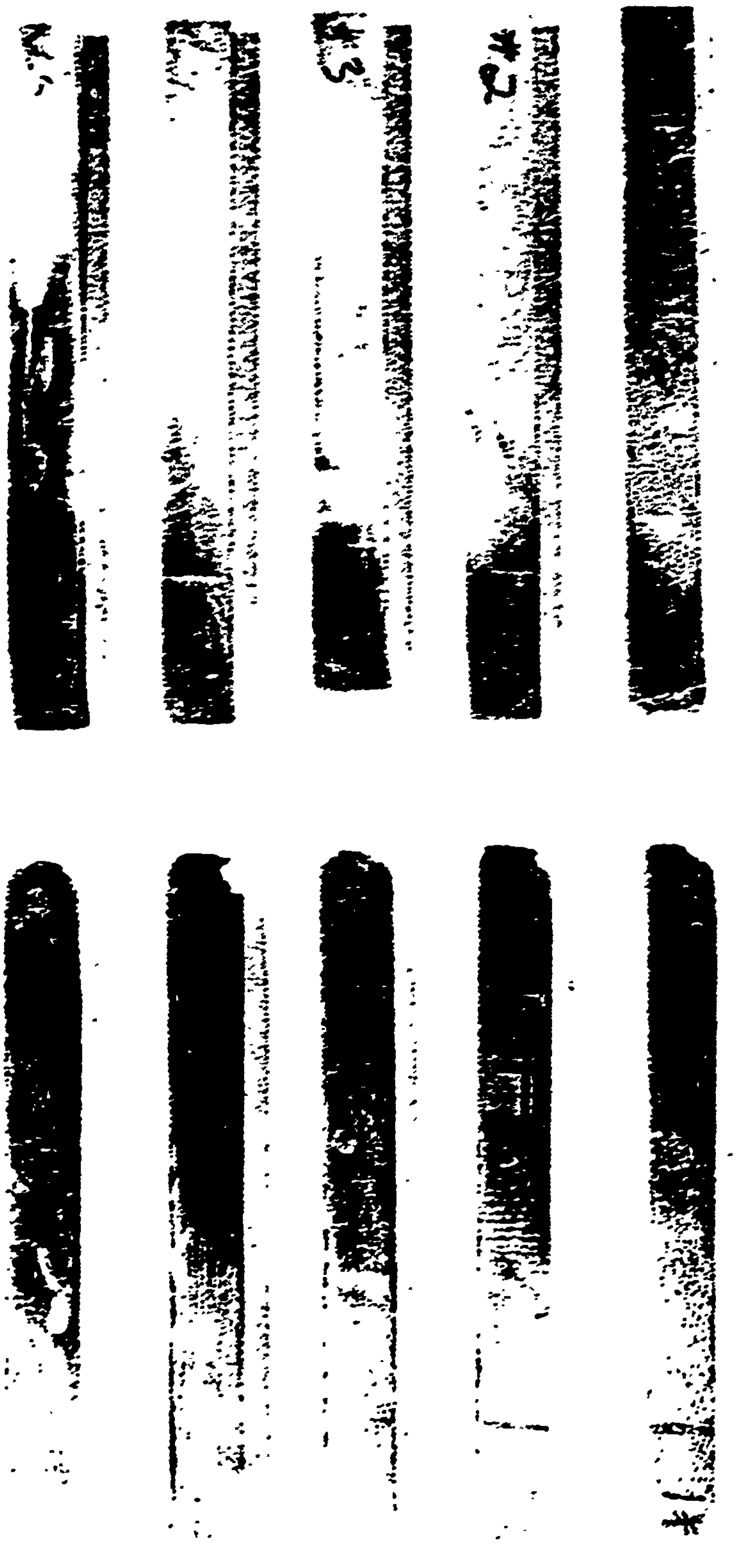

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Figure C–4. This photograph shows, starting on the top, samples 1 to 5 of the National Industri epoxy material and on the bottom, samples 1 to 5 of the Square–D epoxy.

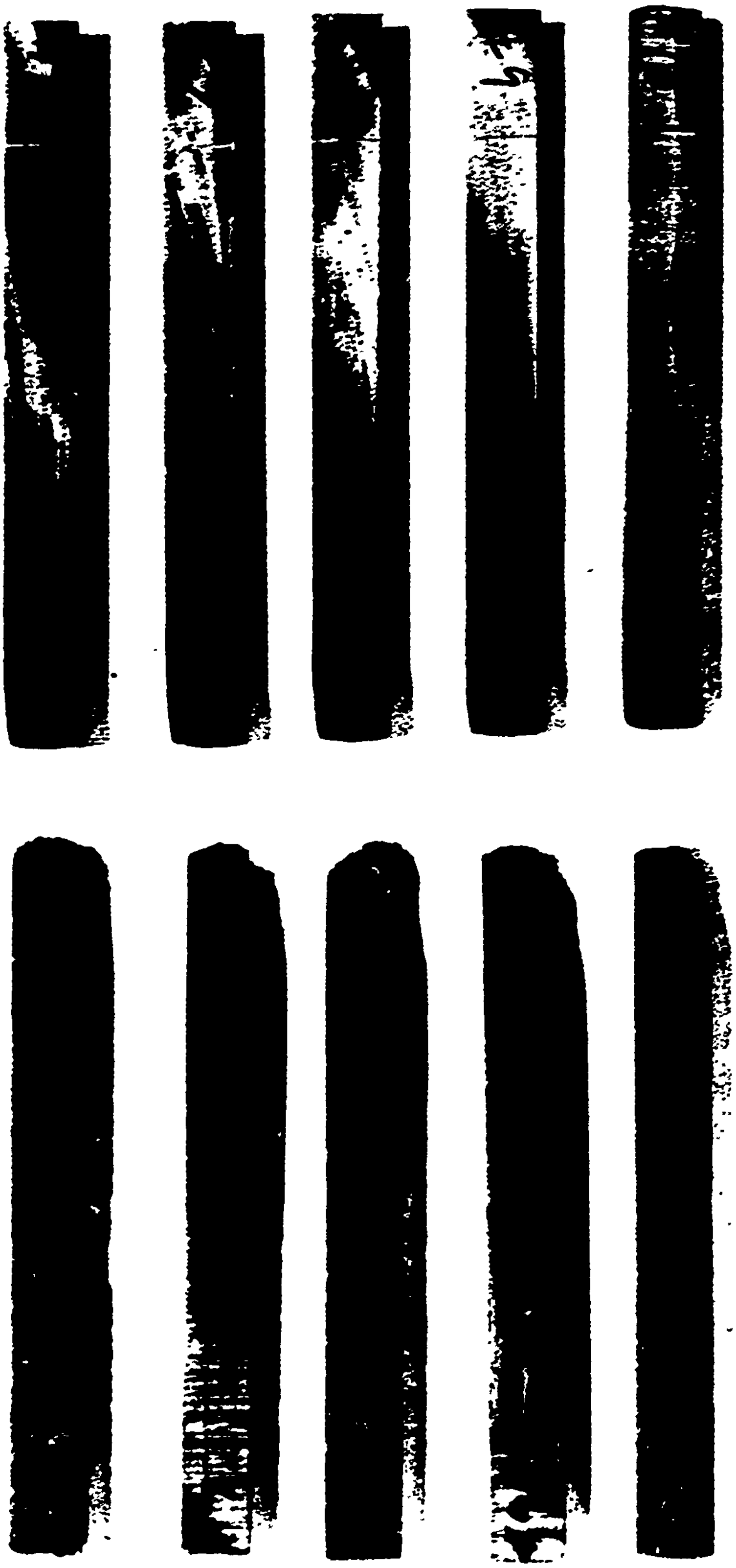

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Figure C–5. This photograph is very similar to Figure C–4 except that samples 6 to 10 are shown of each type of epoxy.

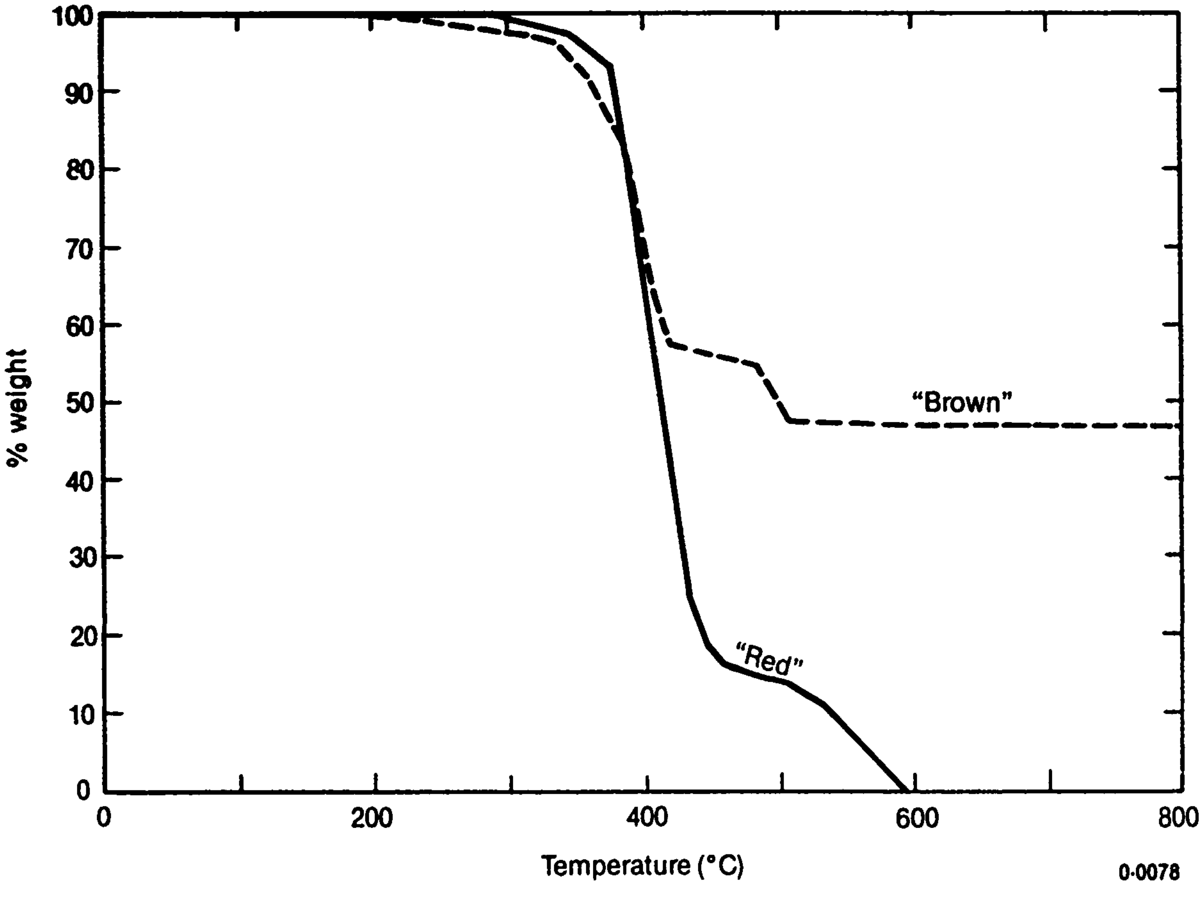

Figure C-6. Thermograms of both the brown and red polymers obtained under an air atmosphere.

as a resin hardener in the General Electric transformers.[3] The reinforcement of the resin in the Square–D transformers was done using a fiber glass filler.[4] This fiber glass filler did not show up in the spectroscopy of the "red" polymer. This absence of the filler is a possible explanation of the "red" polymer's extra brittleness. The test samples used for these tests were approximately 2 mm x 2 cm x 5 cm, which is substantially smaller than those used for the other material tests.

Phase (2). The IR analysis was followed by TGA of the epoxies to determine their characteristics with increasing temperatures (10°C/minute). Under the inert atmosphere (nitrogen) both polymers began to decompose at 300–350°C, while the "brown" (Figure C–6) polymer only lost approximately 50% of its weight by 420°C. The remaining 50% of the "brown" polymer was a black, hard solid that was determined by IR spectroscopy to be composed primarily of the silica filler. The black color was assumed to be from elemental carbon. The absence of any residue from the decomposition of the "red" polymer again shows that the Square–D samples did not contain their fiber glass filler.

Under the oxidative atmosphere (air) TGA showed that the "red" polymer (Figure C–2) began to decompose at 250°C with rapid oxidation occurring from 350 to 435°C and a net weight loss of approximately 85%. The remaining 15% was oxidized completely between 535 to 580°C. The "brown" polymer (Figure C–7) also began to decompose at 250°C with rapid oxidation between 330 to 420°C and a net weight loss of 40%. A second oxidation step was seen between 450 and 500°C with an additional 15% weight loss. The remaining 45% was a pinkish powder that was determined to be the silica filler by IR spectroscopy. These TGA curves are fairly typical for most organic polymers.[2,5,6]

Phase (3). Typical gas chromatograms of the collected gaseous pyrolysis products are shown in Figures C–8 through C–13. The chromatograms of the gases collected in the impinger contained light weight, low boiling hydrocarbons that eluted before the methylene chloride as well as many heavier hydrocarbons. Benzene, toluene, ethylbenzene, and phenol were positively identified in the impinger solutions, and phenol was also identified in the rinsate. The four toxic compounds mentioned were previously identified and quantified from the pyrolysis of BPA. Table C–1 is a brief summary of the quantitative results that were obtained in this study. These results are much higher than those previously reported (Table C–2).

If we used the same hypothetical situation that was used in the previous study of BPA[1] on the results from this study, it would indicate that both the phenol and benzene would be above the permissible exposure limit (Table C–3). These levels, however, would most likely pose no threat to fire fighters in the immediate area because of the dilution of the toxins that would occur in the area holding the transformer. Heating rates during the pyrolysis may offer one possible explanation for these results. The slower heating rates used in this study may produce larger quantities of gaseous products. The number of gaseous products and amounts of these products are greater when formed under a N_2 atmosphere primarily due to the fact that they are not able to be oxidized to CO or CO_2.

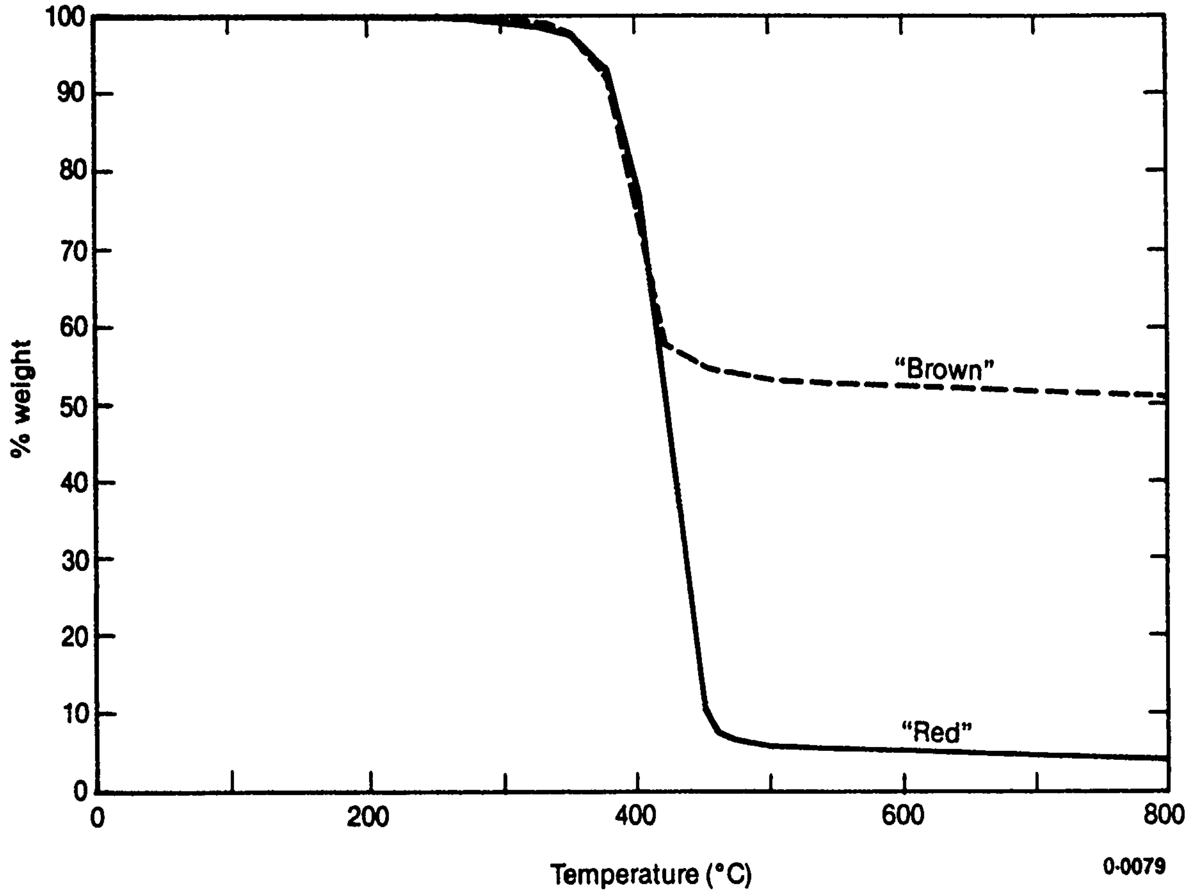

Figure C–7. Thermograms of both the brown and red polymers obtained under a N_2 atmosphere.

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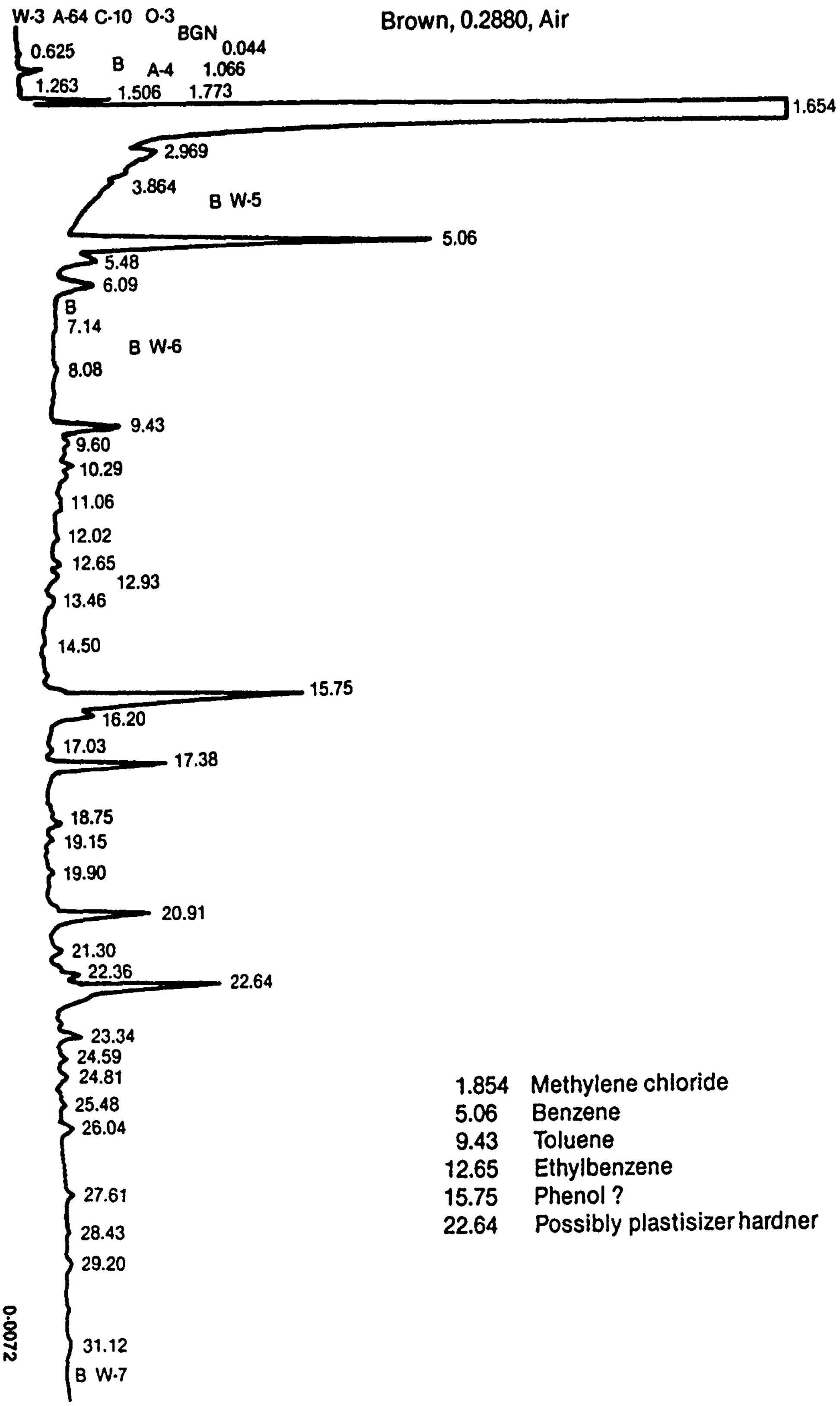
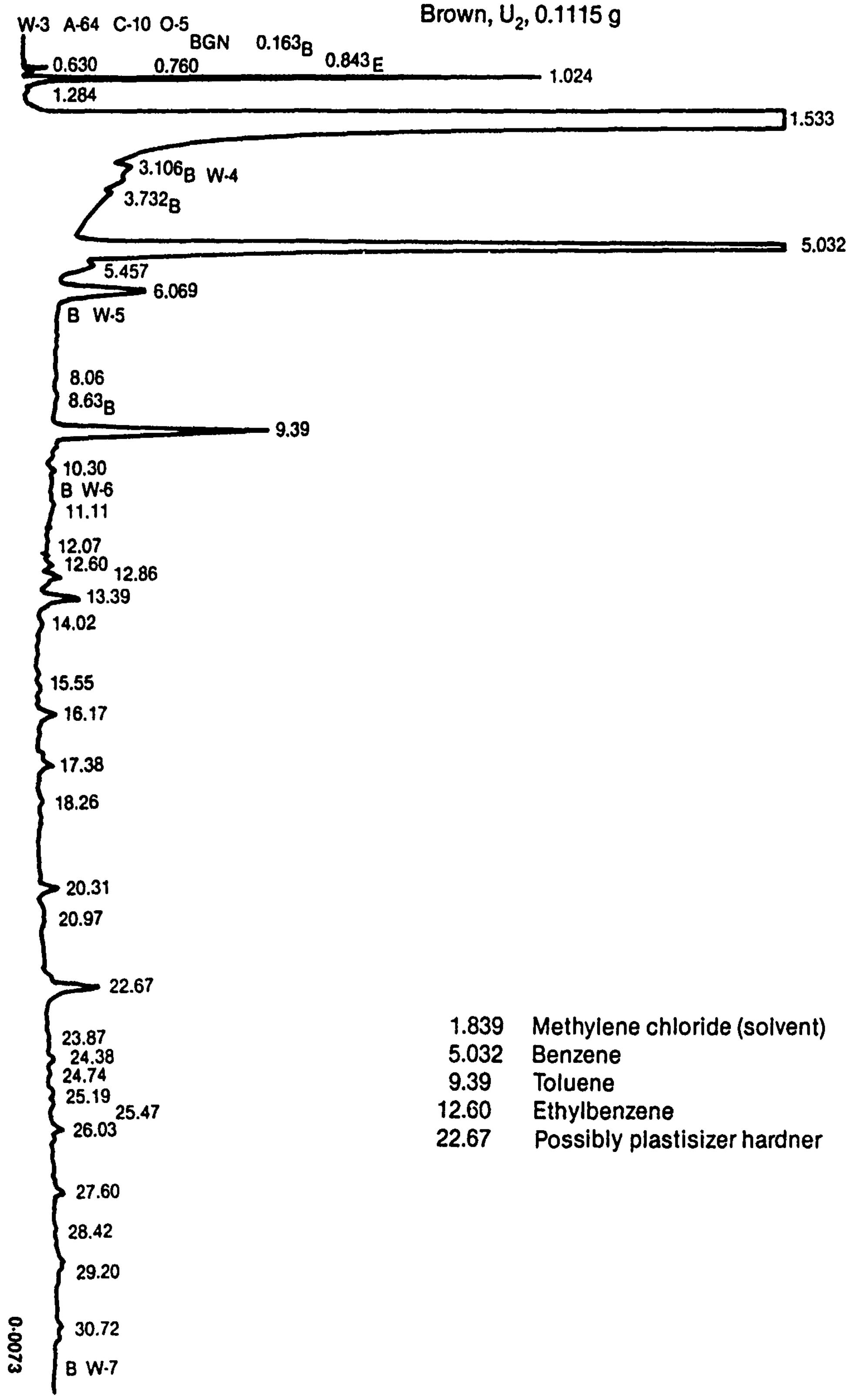
% Method 1, SP2100, Last Edited 09:19.5 87/12/01



1.854	Methylene chloride
5.06	Benzene
9.43	Toluene
12.65	Ethylbenzene
15.75	Phenol ?
22.64	Possibly plastisizer hardner

Figure C–8. Pyrolysis products of 0.2880 g of brown under an air atmosphere.

File 41, Run 9, Started 16:66.3, 87/12/01, SP2100
% Method 1, SP2100, Last Edited 09:15.5 87/12/01



1.839	Methylene chloride (solvent)
5.032	Benzene
9.39	Toluene
12.60	Ethylbenzene
22.67	Possibly plastisizer hardner

Figure C-9. Chromatogram of the pyrolysis products of 0.1331 g of brown under an N_2 atmosphere.

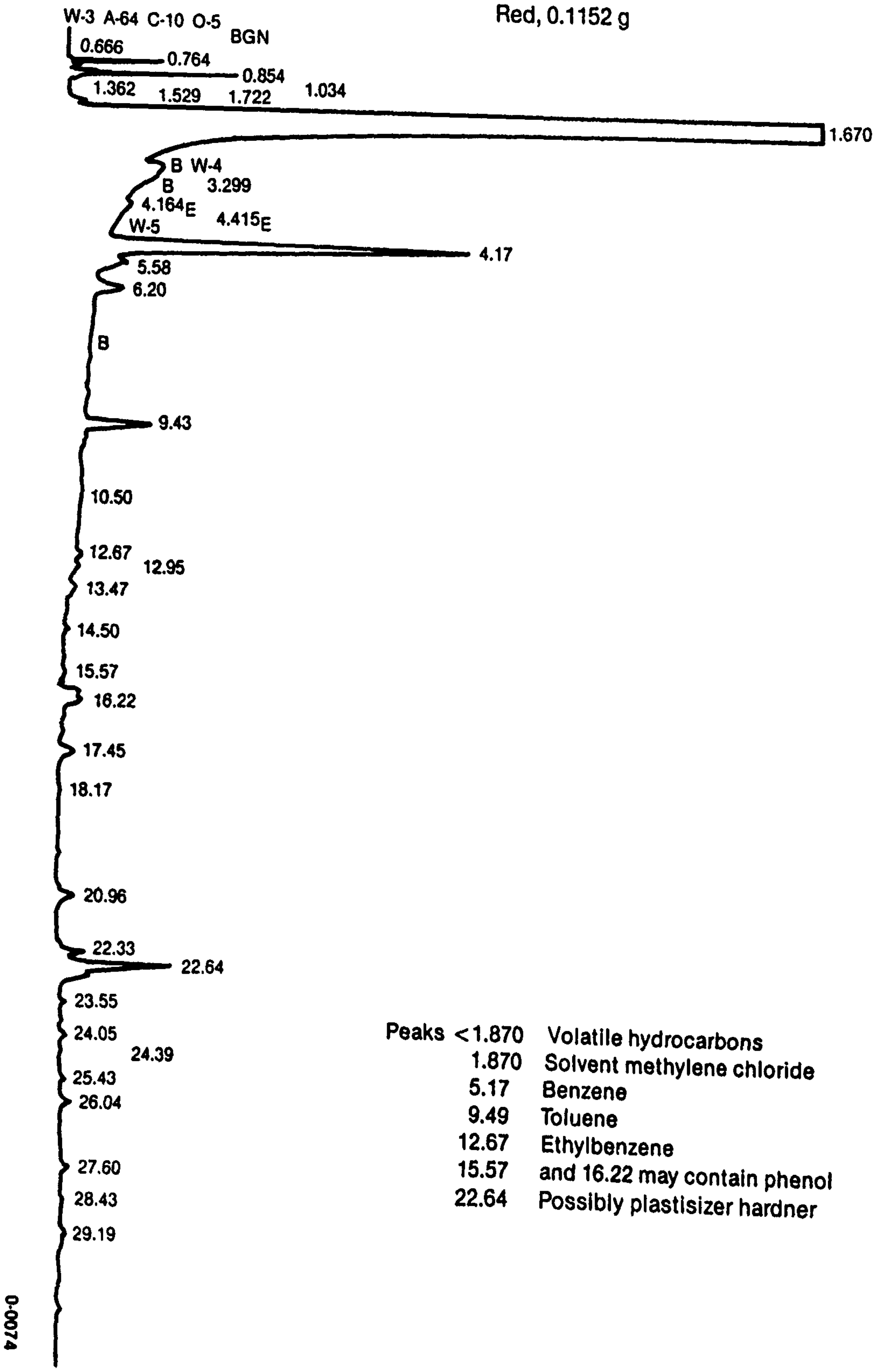
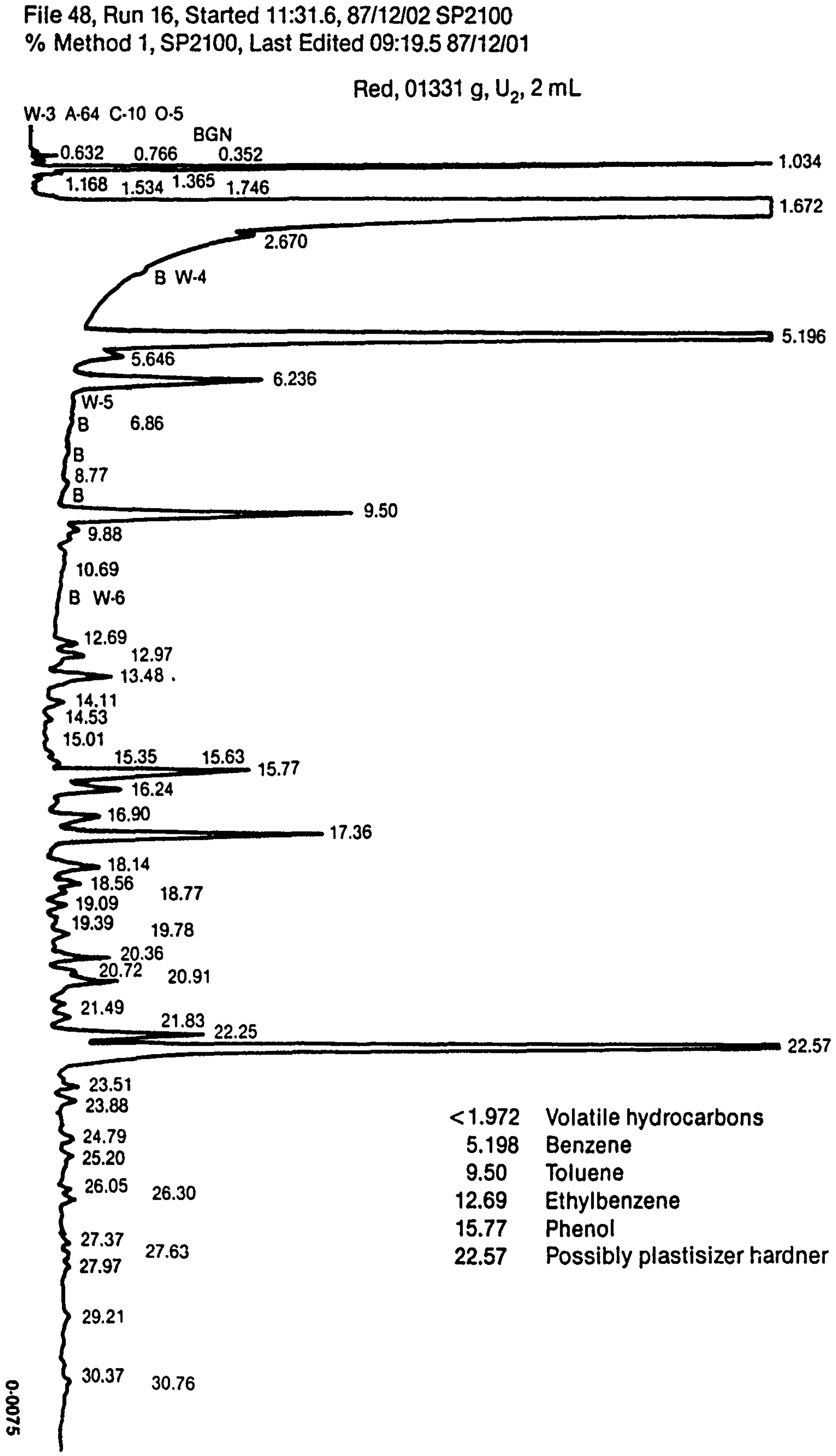
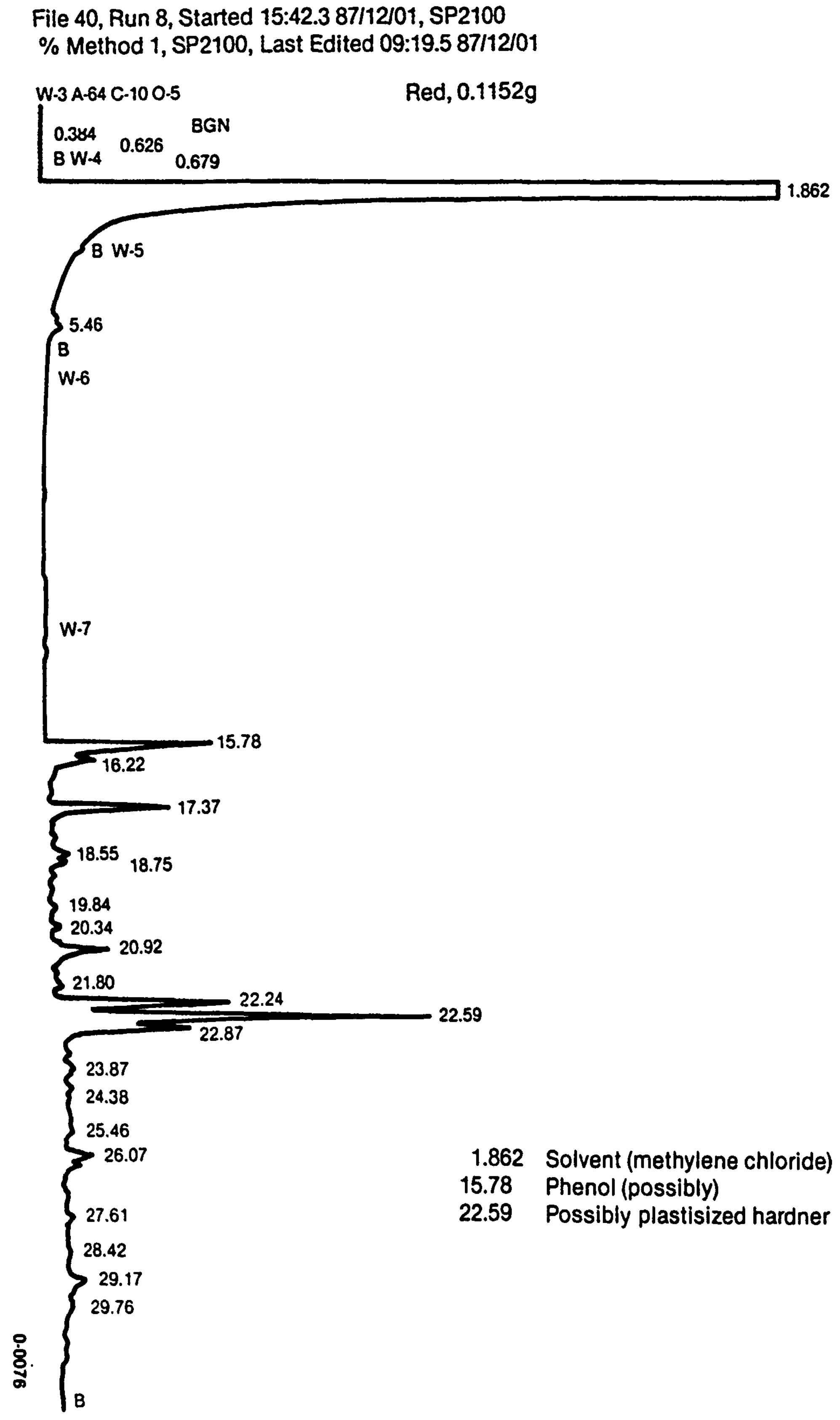


Figure C-10. Pyrolysis products of 0.1152 g of red under an air atmosphere.



<1.972	Volatile hydrocarbons
5.198	Benzene
9.50	Toluene
12.69	Ethylbenzene
15.77	Phenol
22.57	Possibly plastisizer hardner

Figure C–11. Chromatogram of products rinsed from furnace tube with methylene chloride after pyrolysis of red under an air atmosphere.



1.862	Solvent (methylene chloride)
15.78	Phenol (possibly)
22.59	Possibly plastisized hardner

Figure C-12. Chromatogram of the pyrolysis products of 0.1331 g or red under an N_2 atmosphere.

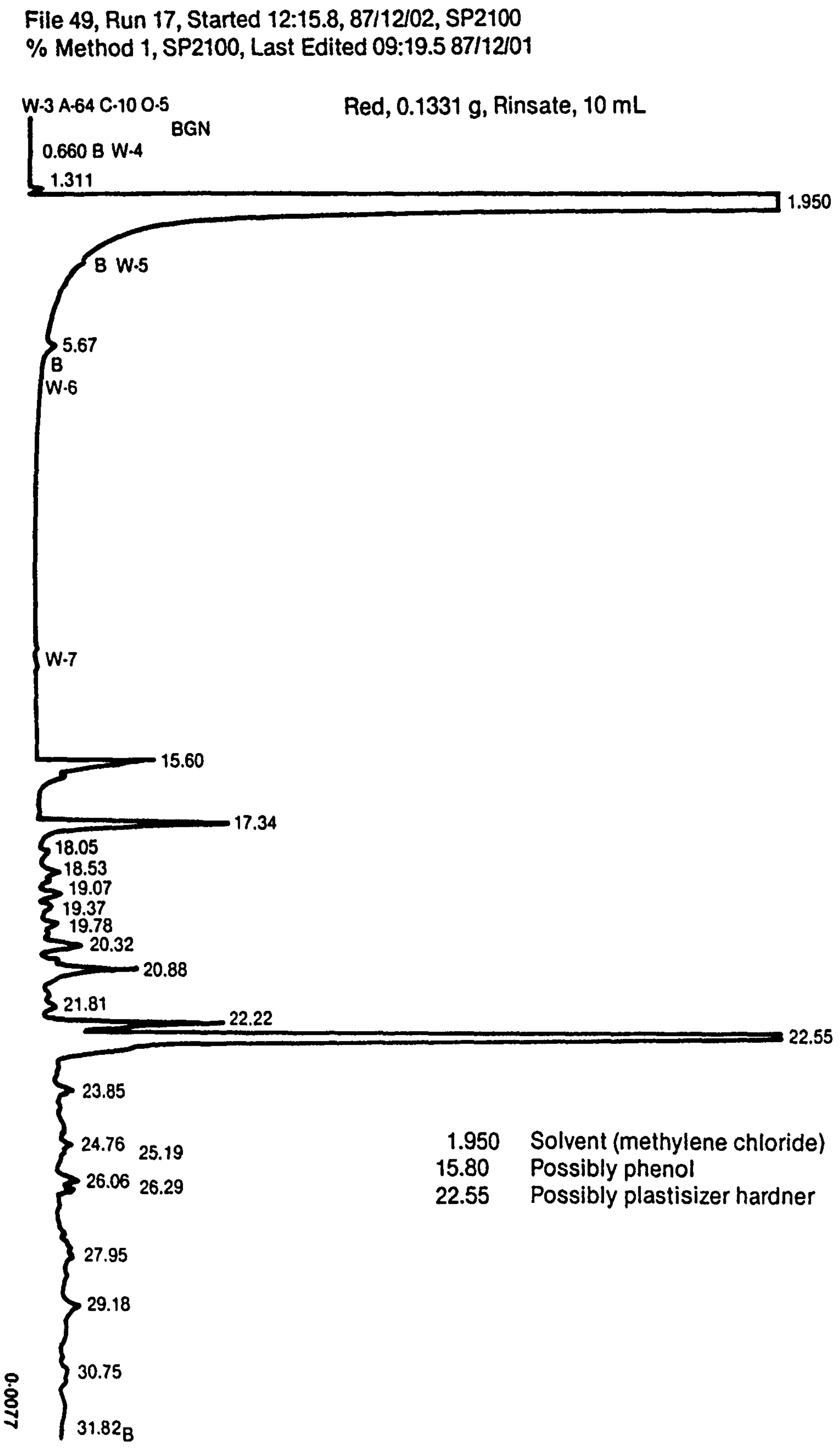


Figure C–13. Chromatogram of products rinsed from furnace tube after pyrolysis of the red under a nitrogen atmosphere.

Table C–1. Concentration of toxic pyrolysis products of BPA polymers testing preferred

	Concentration (mg/g)			
	Air Atmosphere		Nitrogen Atmosphere	
Compound	Red[a]	Brown[b]	Red	Brown
Benzene	3.1	1.2	7.8	1.24
Toluene	0.65	0.26	1.9	0.86
Ethylbenzene	0.12	0.25	0.15	0.13
Phenol	2.8	4.3	10.0	—

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a. Red is Square–D polymer.

b. Brown is General Electric polymer.

Table C–2. Comparative results of concentrations of toxic pyrolysis products of BPA polymers in air atmospheres

	Concentration (mg/g)		
	Current Study		Previous Study
Compound	Red[a]	Brown[b]	(1)
Benzene	3.1	1.2	0.0015
Toluene	0.65	0.26	0.0026
Ethylbenzene	0.12	0.25	0.002
Phenol	12.8	4.3	0.026

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a. Red is Square–D polymer.

b. Brown is General Electric polymer.

Table C–3. Concentration of toxic vapors

Toxic Vapor	Permissible Exposure Limit in Air mg/m^{-3} (ppmw)	Estimated Concentration Generated by Combustion of Red[a] BPA Epoxy in Air mg/m^3
Benzene	(25)	355.0
Toluene	375 (100)	74.2
Ethylbenzene	435 (200)	13.7
Phenol	19	1462.0

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a. Red is Square–D polymer.

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2. E. A. Boettner, Gwendolyn Ball, and Benjamin Weiss, "Analysis of the Volatile Combustion Products of Vinyl Plastics," *Journal of Applied Poly. Sci*, Vol. 13: 377, February 1969.

3. General Electric Company, *Cast/Epoxy Resin Transformers*, GEA–11501.

4. Square–D Company, Power Cast Non–Liquid Cast Resin Power Transformers," *Power Systems Engineering Date*, Vol. 1, No. 5, April 1979.

5. Gwendolyn Ball, Benjamin Weiss, and E. A. Boettner, "Analysis of the Volatile Combustion Products of Polyphenylene Oxide Plastics," *American Indust. Hyg. Assc. Journ.*, September – October.

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APPENDIX D

FIRE–TESTING CAST COIL TRANSFORMERS, EC&M, FEBRUARY 1986

FIRE-TESTING CAST-COIL TRANSFORMERS

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Do epoxy-cast-coil transformers burn or support combustion? If so, do they emit toxic combustion products? Detailed tests provide some answers.

THE EFFECTS of fire on nonflammable or less-flammable transformer fluids is a subject of considerable discussion and controversy today. Underwriters Laboratories (UL) and Factory Mutual (FM) use two entirely different standards to classify or list these fluids, each with different requirements for installing the transformers. The National Electrical Manufacturers Association (NEMA), UL, FM, NEC committees, the Electrical Power Research Institute (EPRI) and other interested parties are attempting to produce one universally accepted standard. A transformer fire can result from a failure within the transformer itself from a fault that causes a "hot spot" that exceeds the ratings of the transformer materials or creates an electric arc that ignites surrounding materials. The transformer can also be subjected to heat and flame from a fire or electric arc external to the transformer.

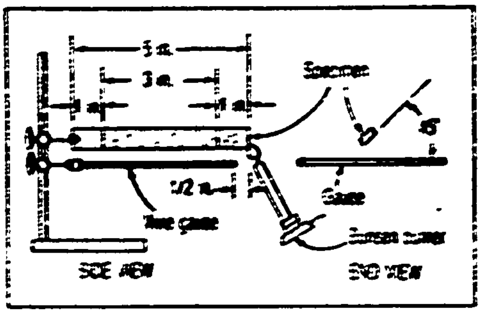
Transformer fluid exposed to fire can ignite and continue to burn, ignite and self-extinguish, or not ignite at all. Different fluids, when burning, release heat at varying rates. Products of combustion can vary from extremely toxic to completely nontoxic.

While askarel is nonflammable, when it is subjected to very high temperatures from an internal arcing fault or external fire, it produces soot that carries and deposits the PCBs far from the transformer. In addition, it produces gases and other compounds that are extremely toxic. Askarel transformer fires in several buildings have rendered them uninhabitable for years, with cleanup costing millions.

Effects of fire on cast coils

The attention focused on the effects of fire on transformer fluids has also resulted in considerable discussion on the effects of internal failure or external flames on cast-coil transformers in particular. Does the epoxy material that encapsulates the coil or coils burn? Does it sustain combustion? Are the products of combustion toxic? Because little data is available, many myths are circulating, some perhaps fostered by the competitive marketplace. One major manufacturer of cast-coil transformers felt that it would be valuable to conduct careful tests to obtain factual information.

Apparatus for flammability test



It was considered necessary to run two series of tests. One investigated the flammability of the cast epoxy material, whether it would continue to burn, and the time required for the flame to extinguish when the source of ignition was removed. The other determined the types and quantities of products of combustion of the epoxy compound, and the toxicity of these products. While some testing had been done over the years, this was a comprehensive program to obtain complete information.

All epoxy material tested was the same as is used for encapsulation of the coils in transformer production and has the following composition by weight:

Filler	200 parts
Resin	100 parts
Hardener	80 parts
Flexibilizer	60 parts
Coloring pigment	2 parts
Accelerator	0.4 parts

While the exact nature of each of the components is proprietary, the results are probably typical of materials used by several manufacturers of cast-coil transformers.

Flammability tests

Three series of tests were performed to determine the flammability of the cast coils. First, the flammability of the epoxy encapsulating material itself was measured, using a standard American Society of Testing Material (ASTM) procedure. Then a completed cast coil, as normally manufactured, was subjected to a simulated internal arcing fault. Last, the completed coil was subjected to an intense external flame.

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The epoxy material was tested in accordance with Standard Method of Test for Flammability of Self-Supporting Plastics, ASTM Designation D 635-68. The material meets the definition of "self supporting" in the standard. As required, 10 specimens of the material, each 5 × ½ × ½ in., were tested by the procedure in the standard. Calibration marks were made 1 in. and 4 in. from the unclamped end of each sample. The sample under test was clamped horizontally and the flame of a bunsen burner applied, as shown in the diagram on previous page. Testing was done under a fume hood, since some plastics emit toxic fumes. The bunsen burner was the standard 1 cm in diameter, with the flame adjusted to pure blue (highest temperature) and 1 in. high. The flame was applied for exactly 30 sec.

If, after two attempts, the specimen does not ignite, it is considered to be "nonburning by this test." If the specimen continues to burn after the first or second ignition, timing is started when the flame reaches the first mark, 1 in. from the free end, and stopped when the flame reaches the second mark, 4 in. from the free end. A specimen that burns to the 4-in. mark is considered to be "burning by this test," and the burning rate is determined by the time it takes to burn the 3 in. between the two marks. If the specimen does not burn to the 4-in. mark after the first or second ignition, it is judged to be "self-extinguishing by this test," with the "extent of burning" being the measured length burned.

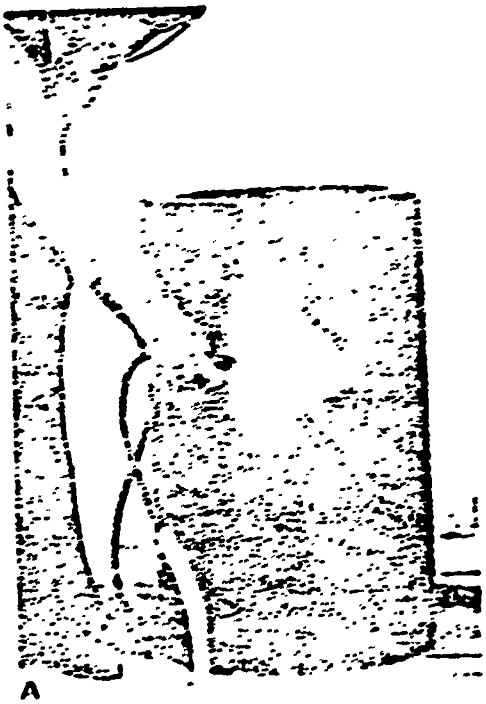
All 10 specimens under test ceased to burn in from 2 min 20 sec to 2 min 30 sec after the 30-sec application of flame, and none burned to the 4-in. mark. Therefore, the epoxy material was determined to be *"self-extinguishing* by this test."

Testing the coil

There are no industry or ASTM standards for testing to simulate the effects of internal faults or external flame on a coil, so it was necessary to devise test procedures that represented most-severe conditions and to observe the results.

For these tests, a representative cast high-voltage coil was taken from a normal production run. The coil was 36 in. high, with an outside diameter of 23 in. and an inside diameter of 18 in. It consisted of multiple layers of aramid-insulated aluminum conductors, completely covered with a fiberglass mat, placed in a metal mold, and cast in epoxy resin under vacuum to eliminate any voids. The epoxy outer layer is ¼ in. thick over the winding.

To simulate an internal arcing fault, a 1-in.-dia hole was drilled through the ¼-in. epoxy outer coating, exposing the aluminum conductors of the winding. One end of the winding was connected to the negative lead of an arc welder, and an arc was drawn from the positive welder electrode to the aluminum winding exposed through the hole.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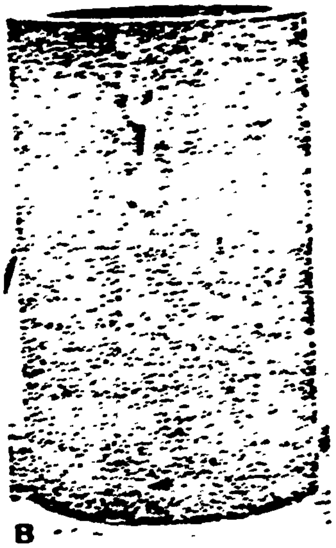
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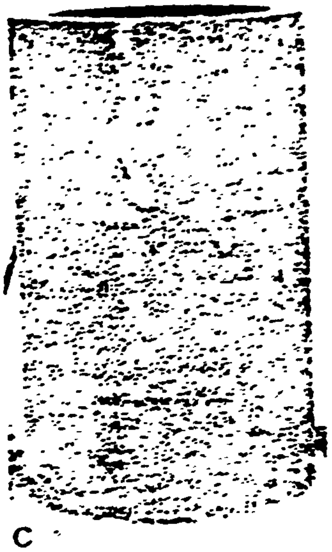
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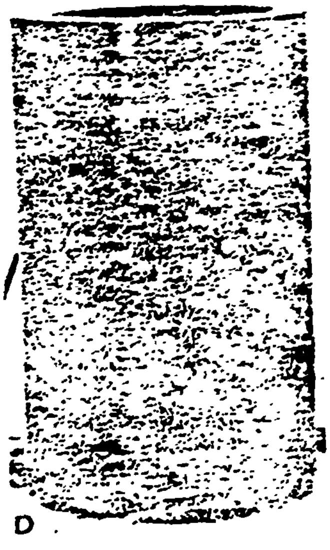
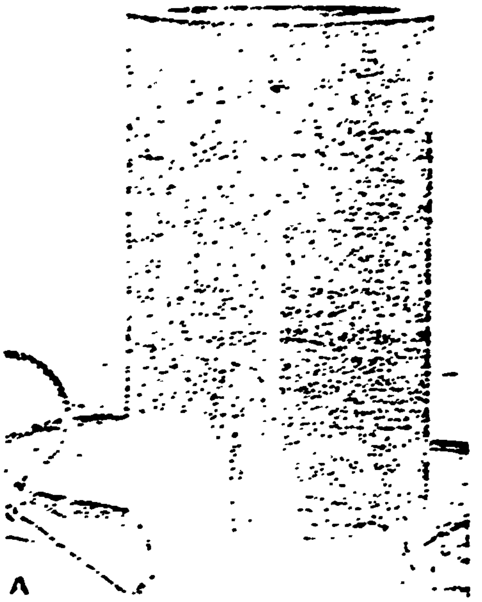

D

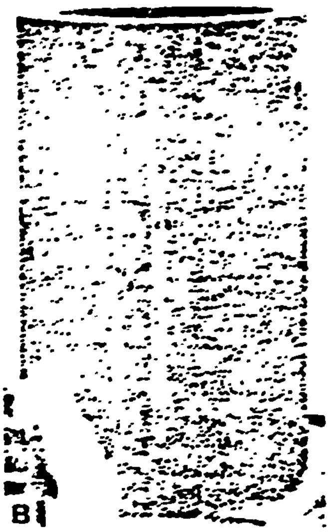
Internal arcing fault is simulated by a heliarc welding torch that creates an arc to the grounded aluminum conductor winding of the cast coil through a ½-in. cut in the epoxy, setting fire to the surrounding epoxy and melting the conductor (A). The flame of burning epoxy is maximum at the instant the welding torch is removed (B). After a few seconds, the flame has partially self-extinguished (C) and a few seconds later has completely extinguished itself (D)

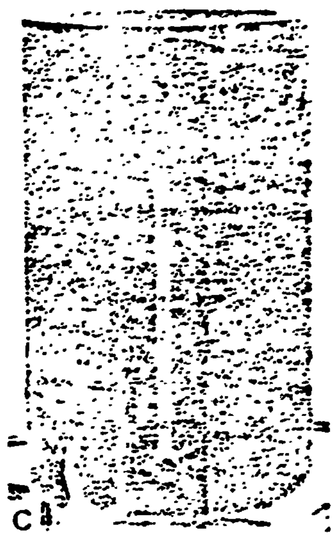
Normally, transformers are protected by overcurrent devices that should clear an arcing fault in 30 cycles (½ sec) or less. A worst-case example of a poorly protected transformer should clear in less than four seconds. To represent extreme conditions, the arcing tests started with a 5-sec. arc duration, and a total of six tests was performed, with increasing durations up to 90 sec. The temperature generated was sufficient to melt the aluminum wire and to establish a flame. (Pure aluminum melts at 660°C.) The time from the removal of the arcing electrode heat source until the flame was extinguished was measured and the sequence photographed at uniform intervals (see photos). The results were as follows:

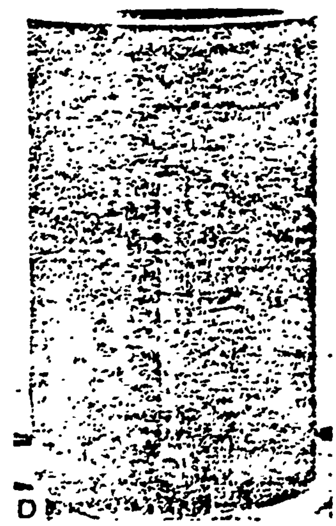
Arc duration (sec)	Flame extinction (sec)
5	4.6
10	4.9
20	8.2
30	10.9
45	41.3
90	18.6



Flame from an external fire is simulated by an oxyacetylene cutting torch, applied at the bottom of the coil so that the heat will ignite as much epoxy as possible (A). As with the arcing fault, the flame of burning epoxy is maximum as the torch is removed (B), starts to self-extinguish (C), and a few seconds later has fully extinguished itself (D).







It is clear from these results that a fire, with burning epoxy, starting from an internal failure in the coil, should be self-extinguishing within a short time after the internal electrical fault is cleared by overcurrent or other protective devices.

It was more difficult to simulate an external fire that would affect the coil. Such fires have many variables, may be fed by a wide variety of materials, and may have ample oxygen or be oxygen-starved. The results will be a large range of flame temperatures, with varying effects on the epoxy-cast coils. In evaluating the risk of ignition as a result of a hostile fire, several factors must be considered.

The ignition temperature of the epoxy material is approximately 450°C, higher than that of wood and many other common construction materials likely to be found in the building. Therefore, alarms and other protective systems should probably activate before the transformer ignites. The epoxy cast coil will not contribute a large amount of heat to an existing fire. For equivalent surface-to-mass ratios, burning epoxy yields about 12,000 Btu/lb, compared with 18,000 Btu/lb for burning transformer oil, and 8000 Btu/lb for burning pine wood. In an actual fire, the heat release rate of transformer oil would probably be higher, since it is proportional to the surface area, and burning oil would spread quickly when released from the transformer tank.

Also, the transformer coils are a composite system of epoxy mixed with nonflammable fillers, insulation and insulating materials, and metal windings that conduct and distribute heat. The entire complex mass must be elevated in temperature if there is to be any possibility of sustained combustion.

To simulate ignition from an external flame energy source, an oxyacetylene cutting torch was used. The test sample was the same representative coil used in the arcing test, rotated 180° to present a fresh surface. The coil was on a wooden skid in a draft-free enclosed area. There was no outside influence that would help to extinguish the flame. The torch flame was applied to the bottom of the coil, so that rising heated air would tend to keep the material burning, and held in contact with the specimen for 30 sec. The time from removal of the torch to extinction of the burning epoxy was carefully measured, and the sequence photographed at regular intervals (see photos). The results were as follows:

Torch applied (sec)	Flame extinction (sec)
30	12.4
30	22.0

This test was repeated many times, with the torch applied for 30 sec. and these results are representative of the extinction times obtained.

Because of the wide range of possible external fires, it is not certain from these tests that an externally caused cast-coil fire would be self-extinguishing under all circumstances. However, it is highly probable that if flames of moderate size set fire to the epoxy and then were removed or extinguished, the coil fire would then self-extinguish. If the transformer is involved in a general conflagration, it is quite possible that it would burn, but it would not add significantly to the intensity of the fire.

Products of combustion

It is not possible to determine a standard set of conditions that would prevail in a hostile fire involving a cast-coil transformer. There are many variables that can affect the results. The burning of the building materials and contents results in a complex mixture of products. The quantity of oxygen available and the different temperatures resulting from combustion of different materials acting as fuel for the fire combine to create an unpredictable variety of combustion products.

Table 1. Products of air pyrolysis of epoxy resin

Compound produced	Quantity (ppmw)	Concentration (mg/m³)	OSHA limits: TLV (ppm)	OSHA limits: TLV (mg/m³)	OSHA limits: STEL (ppm)	OSHA limits: STEL (mg/m³)
Benzene	28 to 32	3.4 to 3.8	10	30	25	75
1,3 Butadiene	2 to 8	0.2 to 1.0	1000	2200	1250	2750
Cyclopentadiene	17 to 21.5	2.0 to 2.6	75	200	150	400
Naphthalene	3 to 6	0.36 to 0.72	10	50	15	75
Phenol	4.5 to 5.5	0.54 to 0.66	5	19	10	38
Styrene	6 to 8	0.72 to 0.96	50	215	—	—
Toluene	13 to 15	1.6 to 1.8	100	375	150	560
For comparison only						
Acetic acid (vinegar)			10	25	15	37
Acetylsalicylic acid (aspirin)			—	5	—	—
Ammonia			25	18	35	27
Perchloroethylene			50	335	—	—

NOTES:

ppmw:	Parts per million by weight
ppm:	Parts per million
mg/m³:	Milligrams per cubic meter
TLV-OSHA:	Threshold Limit Value—maximum amount in atmosphere tolerable for an 8-hr period
STEL-OSHA:	Short Time Exposure Limit—maximum amount in atmosphere for no more than four 15-min exposures per day, with at least 60 min between exposures
Concentration:	Calculated estimate, based on the amount (in ppm) of toxic vapor produced, using the total volume of epoxy in a typical (2000kVA) transformer, with the total volume of air required to consume completely all the epoxy—assuming a code-minimum-sized transformer room. Typically, 1 ppmw of vapor equals approximately 0.12 mg/m³ concentration in the worst case. (For smaller transformers, larger rooms, or more air, this value would be lower.)

Unfortunately, similar problems complicate attempts to simulate in a laboratory the burning of cast coils, and tests have been conducted over many years with a variety of results, depending on the test conditions and parameters and the methods of analysis of the products of combustion. Pyrolysis (decomposition of organic materials by the application of heat) has been conducted using an ample air supply, a restricted air supply, or nitrogen only, with no oxygen, at various temperatures, such as 350°, 450°, and 900°C. Analysis of the products of combustion has been performed using many methods, such as gas chromatography and mass spectrography.

A list of possibly toxic or harmful compounds produced by pyrolysis of the epoxy casting material that have appeared consistently and in measurable concentrations in numerous tests over several years is given in Table 1. Although tests performed under different conditions produce different products of combustion, the results of separate tests performed under similar conditions are quite consistent. Also included in this table are the OSHA exposure limitations for these compounds. This table does not include harmless products of combustion, nor does it represent a list of all possible harmful products of combustion. It should be taken as an indication of what toxic compounds might be produced in an actual fire rather than as a definitive analysis of what will be produced. The OSHA limits for a few familiar substances are included for comparison purposes.

The results of combustion tests, as summed up in this table, indicate that the toxic substances produced by the burning of epoxy-cast coils for transformers are produced in concentrations to which humans can be exposed, by OSHA standards, for relatively long periods. These tests cannot include the effects of such phenomena as gas stratification that might increase the dangers of exposure. However, they do satisfy the original goal of this investigation. They demonstrate that a cast-coil transformer does not add significantly to the hazards to firefighters or others in the vicinity of a fire.

PCDD and PCDF

The investigation of possible hazards from the burning of cast-coil transformers would have ended at this point, except that there was evidence of trace amounts of chlorinated impurities in the combustion products. There is increasing public concern regarding nonbiodegradable polychlorinated compounds such as dibenzo-p-dioxins (PCDD) and dibenzofuranes (PCDF). Cancer and congenital defects are believed to be consequences of

TRANSFORMERS AND INSULATING FLUIDS

For many years, transformers used indoors and in other fire-sensitive areas were usually either askarel liquid-filled, or ventilated dry-type. Then polychlorinated biphenyls (PCBs) were determined by the Environmental Protection Agency (EPA) to be cancer-causing and not biodegradable. Askarel, sold under various trade names, consists of about 70% PCBs, and manufacture of askarel-filled transformers was prohibited. Existing askarel-filled transformers were permitted by the EPA to continue in use, but under severe restrictions intended to prevent leakage of PCBs into the environment and to eliminate human contact with the offensive PCBs.

Some existing askarel-filled transformers were retrofilled with other, more acceptable fluids, but this was seldom effective. With time, the PCBs leached out of the transformer materials and contaminated the replacement fluids to over 500 parts per million (ppm), so that the transformer was still classified as askarel-filled according to EPA standards. Many existing askarel-filled transformers are being disposed of in the manner required by the stringent EPA rules, a very costly process, and replaced with environmentally acceptable units. These replacements, and all new installations, can be either dry-type transformers or transformers filled with nonflammable or less-flammable dielectric fluids.

Dry-type transformers, with the windings immersed in air, have been used successfully for over 50 years. For over 20 years, cast-coil dry-type transformers, with either the high-voltage winding, or both the high- and low-voltage windings encapsulated in an epoxy compound have been available. A cast-coil transformer can be used in many corrosive or dirty atmospheres that rule out air-immersed windings and are much less subject to physical damage. In addition, while individual transformer designs vary widely, cast-coil units tend to have lower losses, be physically smaller, and to have greater capacity when fan-cooled than equivalent air-immersed-coil transformers.

exposure to these compounds, and the risk is so high that it was decided to conduct a specific investigation to determine whether these compounds were produced by combustion of the epoxy, and if so, in what quantity.

Extreme precision was required for this analysis because of the minute quantities and the chemical composition of the compounds involved. First, the total chlorine content of the epoxy material was determined at the Institute for Energy Research in Kjeller, Norway, using neutron activation analysis. The results showed a total chlorine content of only 0.041%. This low value indicated that polychlorinated compounds should not be a problem, but testing was continued to confirm this.

Pyrolysis of the epoxy material was performed by the Center for Industrial Research in Oslo, Norway. A sample of the epoxy weighing 275g was burned in 1.47Nm^3 (normal cubic meter—1m^3 at 20°C, 0% humidity) of air. The gaseous, solid, and liquid products of combustion were collected in a series of precision laboratory filters, condensers, and absorbent cartridges.

The actual analysis of these products of combustion was done at the Norwegian Institute for Air Research in Lillestrom, Norway. In recent years, very sophisticated techniques capable of detecting extremely small quantities of various compounds have been developed. These techniques include methane negative ion chemical ionization mass spectrometry using multiple ion detection, and electron impact ionization mass spectrometry. Using these methods, minute quantities of several PCDD and PCDF compounds were found, with the polychlorination ranging from four to eight chlorine atoms per molecule.

The results of these tests can be summarized as follows:

Compound	ng/Nm^3	ng/kg/epoxy
PCDD	0.52	1.1
PCDF	1.36	7.2
Totals	**1.88**	**8.3**

NOTE: 1 nanogram, ng, − 1 billionth of a gram.

The total of all PCDDs and PCDFs found totaled only 1.88 nanograms per cubic meter, an extremely small quantity, corresponding roughly to about 1.88 parts per *trillion*. This level is *lower by a factor of 100* than the concentration of these products in the effluents of a typical municipal incinerator. These results confirm what was expected from the low total chlorine content of the epoxy.

Conclusions

If cast coil transformers are involved in a fire, either from internal failure or external flames, they will pose no unusual hazard to firefighters or the general public.

Firefighters should use respirators when fighting a fire in an enclosed space, and no additional equipment or special precautions are required if a cast-coil transformer is involved.

The cast-coil transformer will not produce any significant quantity of nonbiodegradable toxic substances, even if the epoxy is entirely consumed in the fire. It will not produce a need for intensive detoxification of the building, and therefore there will be no resultant long-time loss of use of the facility because of the transformer.

The use of epoxy cast-coil transformers does not add to the fire risks in any significant way. ■

APPENDIX E

DESCRIPTION AND ANALYSIS OF CAST COIL TRANSFORMER FIRE AT PWC NORFOLK, VIRGINIA, NOVEMBER 1988

PWC NORFOLK CAST COIL TRANSFORMER FAILURE REPORT

S. A. McBride

Published March 1989

Prepared for the
United States Naval Civil Engineering Laboratory
By
Idaho National Engineering Laboratory
Through
DOE Contract No. DE-AC07-76ID01570

ABSTRACT

At approximately 9:00 pm on Sunday November 20, 1988, a new cast coil transformer failed. The transformer was installed in Pier 4, Vault B on Norfolk Naval Base. It has been determined that the failure occurred in the phase C low voltage coil. The fire did not spread beyond the transformer, and environmental contamination was not evident.

The transformer was removed by the manufacturer and taken to their plant where an autopsy was conducted. The shop teardown inspection concluded that there was substantial damage to both the phase C secondary coil assembly and the core leg. The rest of the device was also damaged to some extent by the heat and flame.

The actual cause of the failure has not been conclusively determined; however, the factory has determined it to be attributed to manufacturing defects. This defect is the presence of small burrs located on the coil conductors.

The manufacturer, National Industri, will replace the failed transformer under the 1 year warranty agreement. The new unit is scheduled to be installed in late May 1989.

CONTENTS

DESCRIPTION AND ANALYSIS OF CAST COIL TRANSFORMER FIRE AT PWC NORFOLK, VIRGINIA, NOVEMBER 1988

INTRODUCTION

This report details the events surrounding the recent cast coil transformer failure at PWC Norfolk on November 20, 1988. The report contains a sequence of events, a device description, analysis of the incident, manufacturers' comments, and engineering recommendations.

Two site visits have been conducted to determine as accurately as possible what the actual conditions were during the failure.

1. The first visit on November 28, 1988, was attended by G.V. Urata, NCEL, R. Culbertson, NEESA, A. Bialecki, NCEL, S.A. McBride, INEL/EG&G, and representatives from the Norfolk–based PWC. This trip was conducted to collect data and inspect the damage at the installation site.

2. The second trip was on January 25, 1989, and was attended by G.V. Urata, John Franchi, NCEL, Rod Nelson, INEL/EG&G, S.A. McBride, D. Dickerson, NAVFAC HQ, L. Steiner, NITI, I. Arsonovic, NITI, M. Haas, NITI, and T. Lanoue, NITI.

The primary objective of this second meeting was to perform an autopsy on the failed transformer in an attempt to determine the cause of failure.

SEQUENCE OF EVENTS

DATE/TIME	EVENT
October 1988	National Industri transformer #02103–B was installed in Pier 4, Vault B. This transformer replaced a PCB device of the same rating.
November 20, 1988 8:50 pm	Estimated time that the fire started.
November 20, 1988 8:59 pm	USNS Rigel (T–AF–58) reports smoke emitting from Pier 4, Vault B. Alarm received by base fire department.
November 20, 1988 9:00	Explosion #1 occurs and P–substation main breaker trips on ground fault relay (CO–8 relay type). Personnel went to P–sub and opened P–4 and P–1, 2, 3. Rolled the breakers down and tagged and locked both out. BKR P–1, 2, 3—no targets; BKR P–4—one target.
November 20, 1988 9:00	Personnel performed evacuation of pier because of the uncertainty of the transformer type (possibly PBC). Fire department injects two 150 # cylinders of halon gas into the vault through the door vents. Contact was made with the Norfolk PWC and proof was requested that the PCB transformer had been replaced with the cast coil device.
	USNS Rigel started its on board 200kW emergency generator and explosion #2 occurred.
	Suspected cause of the second resumption of the fire is backfeeding of shore transformer due to the manual operation required in this situation. Once the shore to ship link is removed the generator on board the ship stabilizes.
November 20, 1988 11:58 pm	Fire is classified as extinguished.

NOTE: For a more detailed description of the actual operations during the failure refer to the Appendix containing the Norfolk fire department report #62688, and a duty log assembled by Mr. Dave Midget of the Norfolk PWC.

DEVICE DESCRIPTION

The transformer involved in this incident has the following specifications:

SIZE	2000 kVA
PRIMARY	11.5 kV DELTA
SECONDARY	480 V GROUNDED Y
LOCATION	PIER 4 VAULT B
TYPE	CAST RESIN—HIGH PERFORMANCE
MANUFACTURER	NATIONAL INDUSTRI TRANSFORMER, INC. (NITI)

This device was installed on Pier 4 for research purposes by the Naval Civil Engineering Laboratory (NCEL) and had been loaded only a few times when the failure occurred.

FAILURE ANALYSIS

The flaw was isolated to the phase C secondary coil based on the autopsy performed on the device on January 25, 1989. The specific cause of this accident is not definitely known but is being attributed to a manufacturing error in the transformer.

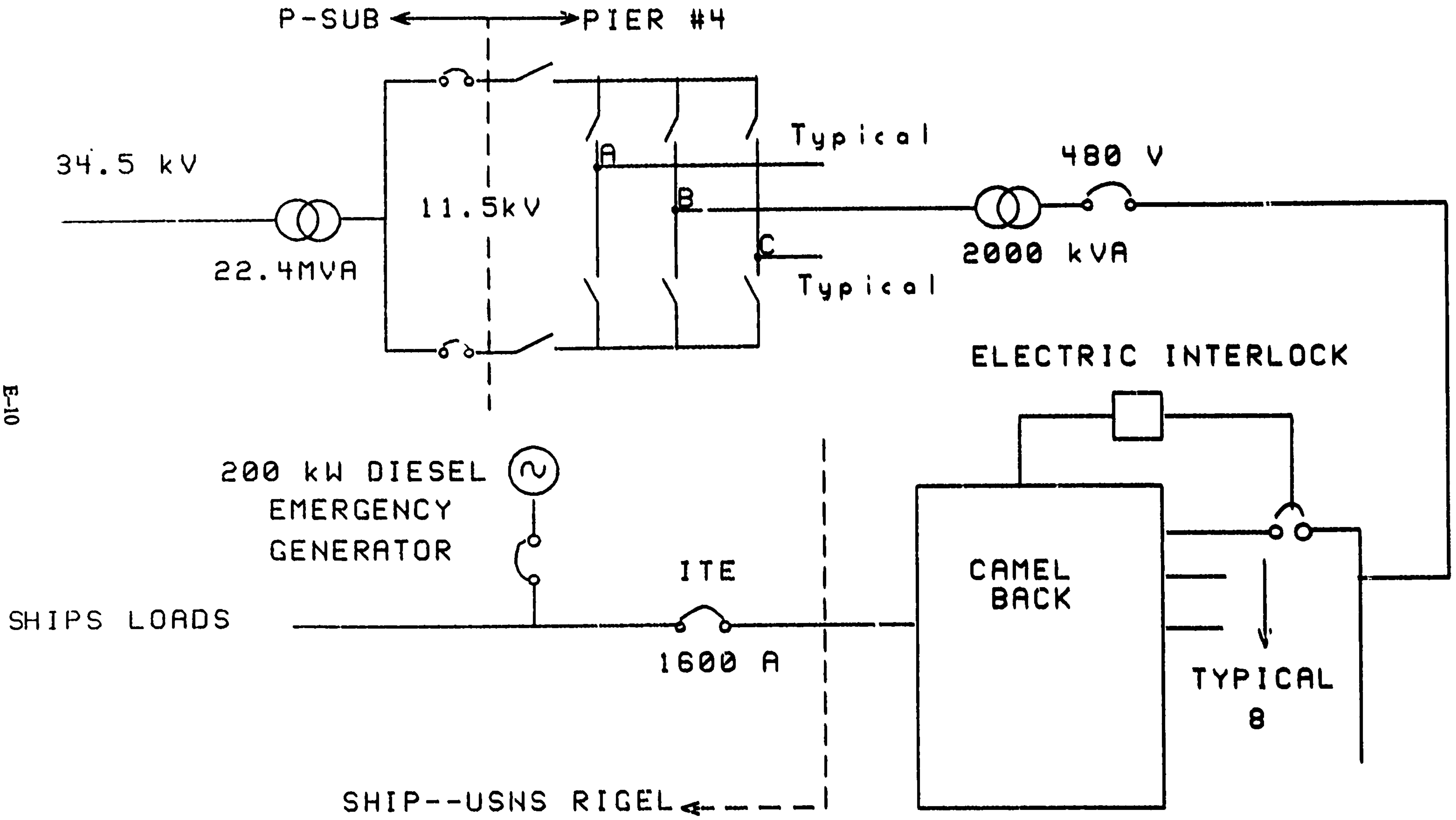
During the autopsy, several small burrs were found on the remaining sections of the low–voltage leads. These burrs were formed when the copper sections were welded together to form the lead. It is a standard procedure to remove the burrs from the leads with a grinder after the weld is made; however, they were not adequately smoothed on this device. The manufacturer indicated that burrs similar to those found could have caused the fault by penetrating the 30 mills of NOMEX turn insulation placed between the lead and the adjacent turn, which would have produced an internal turn–to–turn short circuit. The autopsy inspection revealed massive amounts of electrical arcing damage to the secondary coil assembly. The area around the arcing fault was also severely damaged by heat produced from the fault. Heat damage indicated that the fault had been in existence for a considerable time period before the start of the actual fire.

The transformer that failed successfully passed all of the standard acceptance tests before leaving the factory. The temperature rise test was, however, not performed on this particular unit. It is typical to test a typical transformer of each design to verify the design but not to test each unit individually. It is believed that the transformer was operating acceptably when it was first installed and that the few thermal cycles that the transformer was subjected to were sufficient to cause the penetration of the flawed lead through the NOMEX, creating a turn–to–turn short circuit.

The transformer was lightly loaded at the time of the fault. The primary protection activated when the heat and flame of the secondary had sufficiently degraded the primary and caused it to fault to ground. This is suspected because the primary was cleared by the ground fault relay.

The two adjacent coil assemblies were damaged by the heat and fame, but the damage was not as significant as that on the faulted coil. The fault continued for a substantial amount of time before the primary protection cleared. Estimates of the fault duration are vague and contradictory but most likely is 2 hours or more based upon the magnitude of heat damage.

After the primary protection cleared the fault, the ships 200 kW emergency generator was brought on line. Refer to the one–line diagram on the following page. The operator experienced difficulty in getting the voltage to stabilize and eventually the generator's breaker tripped off line. The operator then began to shed unnecessary loads to reduce the load level on the generator. The problem still existed and at that point it was determined that the shore to ship power feed had not been disconnected as is required. It has been estimated that approximately 30 minutes passed before the shore power cables were disconnected from the USNS Rigel. Therefore, the USNS Rigel provided both heat and arcing directly to the fault and sustained the fire for an additional 30 minutes.



System One-Line Diagram.

RECOMMENDATIONS

There are three significant problems in this system that contributed coincidentally to the failure of this transformer.

1. The manufacturing defect in the transformer
2. The lack of individual transformer protection
3. The backfeeding of the transformer by the ships' emergency generator.

On the first issue, the manufacturer has regained the problem and changed both manufacturing and quality assurance steps to address this issue.

The transformer protection was not adequate to clear the fault. There are several methods that could be employed to protect the transformer and an investigation should be conducted to determine which is the most viable option.

- Add fuses or breakers to each breakers to each primary to trip the units on individual overload.
- Add individual protection relay and interconnect to the substation or the nearest upstream breaker.
- Add a three phase secondary coil temperature sensor and connect it to an alarm alerting an operator that a high temperature condition exists and needs attention (this option would not eliminate the backfeeding capability). This sensor could be connected to the substation breaker (or primary breaker if available) and used as a control to trip the device off line upon high temperature. Use differential relay scheme to protect the transformers.

There are also several methods available to reduce the possibility of backfeeding the transformer as observed in this incident.

- A differential relay system could be configured to operate primary and secondary protection but would be quite complicated.
- The ship's on-board system or procedure could be modified to eliminate the possible backfeed. This could be accomplished by configuring the ship's shore power breaker (or tie breaker) to trip when the generator breaker is closing, either with mechanical or electrical interlock.
- Last, a reverse power relay could be installed on the main circuit breaker in the substation.

The acoustic emissions monitoring instrumentation would have detected the problems in the transformer if the device had been installed on the unit. The monitor is designed to pick up small as well as large levels of discharge (arcing). The monitor, however, would not typically alarm or trip the circuit unless designed to integrate the unit with the trip circuit.

RISK ASSESSMENT

The catastrophic failure of this transformer induced little risk to personnel on the pier or to fire fighters. If the device had been the original PCB transformer, a very great magnitude of risk would have followed a similar failure. Based on preliminary analysis of chemical swipes taken from the inside of the vault, which contained the transformer, the products of combustion from the fire were not found to be at levels dangerous to those in the vicinity of the incident. Additional soot analysis is being performed to ascertain what components are present and in what concentrations.

There was some speculation as to the type of transformer in the vault and until proof was given that the PCB transformer had been replaced by a dry-type, the fire fighters did not attempt to enter the vault. The records at the fire department had not been properly updated. The fire fighters should establish a procedure to eliminate all electrical power before entering the transformer vault with water.

The cast coil type dry transformer eliminates the risk of liquid spills that commonly occur when a typical liquid-filled transformer is involved in a fire of similar magnitude.

The fire was isolated to the transformer vault. If the device had been installed inside of a facility such as the two 750 kVA cast coil units in LF-18, it is believed that the horizontal propagation of the fire would still be at a minimum. This is not the typical case when a liquid-filled transformer is under flame. The liquid typically will spread the flame to surrounding areas when it is dispensed from the unit.

In summary, the amount of risk involved with this type of transformer in the vault installation was at a minimum in relation to the other types of devices.

CONCLUSIONS

The transformer failed because of the presence of several small burrs in the secondary coil assembly. This was termed a manufacturing error. The transformer itself was damaged substantially; however, the vault and surrounding devices were undamaged except for the buildup of soot. The transformer will be replaced by the manufacturer and is scheduled to be installed in late May 1989.

APPENDIX

DOD FIRE INCIDENT REPORT
PWC NORFOLK DUTY LOG

RCD [illegible]
1/27/89

DOD FIRE INCIDENT REPORT

Page 1 of 6 Pages

FOR OFFICIAL USE ONLY

A. Complete instructions for filling out this form are contained in DoD 6055.7-M
B. The entire form may be hand printed. Legibility is important.
C. Where blocks are provided for the individual characters of the data, follow these rules:
(1) If the entry is letters, place the first letter in the left-hand block;
(2) If the entry is a number, place it so that the last digit is in the right-hand block.

THIS SPACE FOR SAFETY CENTER ONLY

YR	MO	DAY	LINE	EXP NO.	T/C
01 02	03 04	05 06	07 08 09	10 11	80

SECTION A – GENERAL DATA

1. NAME OF FIRE DEPARTMENT
NORFOLK NAVAL STATION

2. REPORT STATUS
1. Preliminary
2. Final
3. Revised
2

3. OFF-STATION/MUTUAL AID RESPONSE
Y. Yes
N: No
N (12)

4. LOCATION
NORFOLK, VA

5. ZIP CODE (9 DIGIT / 5 DIGIT)
2 3 5 1 1 – 6 3 9 6 (13–21)

6. UIC-RUC/ IDENT. CODE
6 2 6 8 8 (22–26)

7. AFFILIATION
1. Navy 2. Marine
3. Army 4. Air Force
5. Defense Logistics Agency
6. Other
1 (27)

8. NAME OF ACTIVITY WHERE FIRE OCCURRED
PUBLIC WORKS CENTER

9. LOCATION
NORFOLK, VA

10. AFFILIATION
1. Navy 2. Marine
3. Army 4. Air Force
5. Def. Log. Agency
6. Other
1 (28)

11. UIC-RUC/ IDENT. CODE
0 0 1 8 7 (29–33)

12. DATE OF FIRE
YR 8 8 MO 1 1 DAY 2 0

13. DAY OF WEEK
1. Sun 5. Thu
2. Mon 6. Fri
3. Tue 7. Sat
4. Wed
1 (36)

14. INCIDENT NUMBER
0 1 4 9 (37–40)

15. MUTUAL AID RECEIVED
Y. Yes
N. No
N (41)

16. METHOD OF ALARM FROM PUBLIC
TELEPHONE
1 0 (42–43)

17. TYPE OF SITUATION FOUND
STRUCTURE FIRE
1 1 (44–45)

18. FIXED PROPERTY USE
STORAGE PROPERTY
9 9 9 (46–48)

19. MOBILE PROPERTY TYPE (Auto., Mobile Home, Ship, Aircraft)
(49–50)

20. IF MOBILE PROPERTY (Auto., Mobile Home, Ship, Aircraft)	YEAR	MAKE	MODEL/OR ACFT. MODEL	SERIAL NO./OR BUREAU NO.	LICENSE NO.

SECTION B – ORIGIN AND IGNITION DATA

21. AREA OF FIRE ORIGIN
TRANSFORMER VAULT
6 3 (51–52)

22. LEVEL OF ORIGIN
GRADE LEVEL TO 9' ABOVE
1 (53)

23. TERMINATION STAGE
1. HEAT TERMINATED IN THE OVERHEAT STAGE BEFORE SMOLDER OR FLAME
2. FIRE TERMINATED IN THE SMOLDER STAGE, BEFORE ANY FLAME
3. FIRE TERMINATED IN OR AFTER THE FLAME STAGE
4. NOT APPLICABLE
3 (56)

24. EQUIPMENT INVOLVED IN IGNITION (IF ANY)
TRANSFORMER
4 2 (54–55)

25. IF EQUIPMENT INVOLVED IN IGNITION	YEAR	MAKE	MODEL	SERIAL NO.	VOLTAGE
	1988	EBA NATIONAL INDUSTRI CORP		02103-1	11,500 TO 480

MATERIAL FIRST IGNITED *(26 and 27 only)*

26. TYPE
PLASTIC
4 0 (57–58)

27. FORM
CABLE AND INSULATION
6 1 (59–60)

28. FORM OF HEAT OF IGNITION
UNSPECIFIED SHORT CIRCUIT ARC
2 4 (61–62)

29. IGNITION FACTOR
SHORT CIRCUIT
5 4 (63–64)

CARD NO.
8 1 1 8 (77–79)

DD Form 2324, 84 JAN

S N 0102-LF-002-3240

DOD FIRE INCIDENT REPORT

FOR OFFICIAL USE ONLY

SECTION C – STRUCTURE AND FIRE DATA

30. STRUCTURE TYPE (If not structure proceed to 46) WAREHOUSE 1 12	31. STRUCTURE NO. 4 13 14 15 16 17 18	32. YEAR CONSTR 19 20 21 22	33. NUMBER OF STORIES 0 0 1 23 24 25

34. GROUND FLOOR AREA 26 27 28 29 30 31 32	35. CONSTRUCTION TYPE NONCOMBUSTABLE 4 33	36. CONSTRUCTION METHOD SITE BUILT 1 34

37. EXTENT OF FLAME DAMAGE	38. EXTENT OF SMOKE DAMAGE	39. EXTENT OF WATER DAMAGE	40. EXTENT OF FIRE CONTROL DAMAGE
1. CONFINED TO THE OBJECT OF ORIGIN	1. CONFINED TO OBJECT OF ORIGIN	1. CONFINED TO OBJECT OF ORIGIN	1. CONFINED TO OBJECT OF ORIGIN
2. CONFINED TO PART OF ROOM OR AREA OF ORIGIN	2. CONFINED TO PART OF ROOM OR AREA OF ORIGIN	2. CONFINED TO PART OF ROOM OR AREA OF ORIGIN	2. CONFINED TO PART OF ROOM OR AREA OF ORIGIN
3. CONFINED TO ROOM OF ORIGIN	3. CONFINED TO ROOM OF ORIGIN	3. CONFINED TO ROOM OF ORIGIN	3. CONFINED TO ROOM OF ORIGIN
4. CONFINED TO THE FIRE-RATED COMPARTMENT OF ORIGIN	4. CONFINED TO THE FIRE-RATED COMPARTMENT OF ORIGIN	4. CONFINED TO THE FIRE-RATED COMPARTMENT OF ORIGIN	4. CONFINED TO THE FIRE RATED COMPARTMENT OF ORIGIN
5. CONFINED TO FLOOR OF ORIGIN	5. CONFINED TO THE FLOOR OF ORIGIN	5. CONFINED TO THE FLOOR OF ORIGIN	5. CONFINED TO THE FLOOR OF ORIGIN
6. CONFINED TO BUILDING OF ORIGIN	6. CONFINED TO BUILDING OF ORIGIN	6. CONFINED TO BUILDING OF ORIGIN	6. CONFINED TO BUILDING OF ORIGIN
7. EXTENDED BEYOND BUILDING OR ORIGIN	7. EXTENDED BEYOND BUILDING OF ORIGIN	7. EXTENDED BEYOND BUILDING OF ORIGIN	7. EXTENDED BEYOND BUILDING OF ORIGIN
8. NOT A STRUCTURE FIRE	8. NOT A STRUCTURE FIRE	8. NOT A STRUCTURE FIRE	8. NOT A STRUCTURE FIRE
9. NO DAMAGE OF THIS TYPE	9. NO DAMAGE OF THIS TYPE	9. NO DAMAGE OF THIS TYPE	9. NO DAMAGE OF THIS TYPE
1 35	3 36	9 37	9 38

41. AT TIME OF FIRE, BUILDING WAS:
1. OCCUPIED BY AWAKE PERSONS
2. OCCUPIED BY SLEEPING PERSONS
3. OCCUPIED BY CHILDREN OR AGED PERSONS ONLY
4. NOT OCCUPIED
5. VACANT
6. NONE OF ABOVE (Explain in narrative)

4
39

42. IF FLAME SPREAD BEYOND ROOM OF ORIGIN: TYPE OF MATERIAL GENERATING MOST FLAMES. 40 41	43. AVENUE OF FLAME TRAVEL 42 43
44. IF SMOKE SPREAD BEYOND ROOM OF ORIGIN: TYPE OF MATERIAL GENERATING MOST SMOKE: 44 45	45. AVENUE OF SMOKE TRAVEL 46
46. METHOD OF DETECTION UNDETERMINED NOT REPORTED 0 0 47 48	47. METHOD OF EXTINGUISHMENT (2) 150# HALON EXTINGUISHERS 2 0 49 50

48. AGENT AND QUANTITY USED (CIRCLE AGENTS USED & CODE AGENTS AND QUANTITY)

0 WATER – SPRAY/FOG
1 WATER – SOLID STREAM
2 WATER – BOTH 0 AND 1
3 AFFF
4 OTHER FOAMS (PROTEIN, HIGH EXPANSION FOAM AGENTS)
5 DRY CHEMICAL
6 CARBON DIOXIDE
7 HALOGENATED AGENTS (HALON 1211, 1301)
8 WATER WITH ADDITIVES (WET WATER, ETC)
9 OTHER (COMBUSTIBLE METAL EXTINGUISHING AGENTS, ETC)

	AGENT	QTY.		AGENT	QTY.
1	7 54	3 0 0 55 56 57 58 59 60	2	61	62 63 64 65
3	66	67 68 69 70	4	71	72 73 74 75

49. MOST EFFECTIVE EXTINGUISHING AGENT USED HALON
7
51

50. NUMBER OF PEOPLE RESCUED BY FIRE DEPT. (Explain in narrative)
52 53

51. DEFICIENCIES OR PROBLEM AREAS
If problems existed in any of the following areas, indicate and further explain in narrative:
1. ALARM TRANSMITTAL
2. FIRE DEPARTMENT RESPONSE
3. PUMPER, HOSE, LADDERS, ETC.
4. MANPOWER
5. BREATHING APPARATUS, PROTECTIVE CLOTHING, ETC.
6. EXTINGUISHING AGENTS, WATER SUPPLY, ETC.
7. VENTILATION, FORCIBLE ENTRY, SALVAGE
8. WEATHER
9. ITEMS OF NON-COMPLIANCE (OSHA)
10. OTHER

76

CARD NO.
8 7 8
77 78 79

DoD FIRE INCIDENT REPORT

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SECTION D – FIRE PROTECTION FACILITIES (IN STRUCTURES ONLY)

52. AUTOMATIC SPRINKLERS PROVIDED? (IF NO,PROCEED TO 53)	Y. YES N. NO	12	Y
PERCENT COVERED?		13 / 14 / 15	/ 9 / 9
IF LESS THAN 100%, WERE SPRINKLERS IN FIRE AREA?	Y. YES N. NO	16	N
OPERATED AT FIRE?	Y. YES N. NO	17	N
CONNECTED TO FIRE ALARM HEADQUARTERS?	Y. YES N. NO	18	Y
WAS SPRINKLER OPERATION FIRST INDICATION OF FIRE?	Y. YES N. NO	19	N
NUMBER OF SPRINKLER HEADS OPERATED?		20 / 21	

TYPE OF SPRINKLER SYSTEM

1. WET
2. DRY
3. DELUGE-WATER
4. DELUGE-FOAM
5. PRE-ACTION DELUGE

22: 2

SPRINKLER PERFORMANCE

1. SPRINKLERS OPERATED SATISFACTORILY – EXTINGUISHED FIRE
2. SPRINKLERS OPERATED SATISFACTORILY – HELD FIRE IN CHECK
3. NO SPRINKLER OPERATION; FIRE TOO SMALL
4. NO SPRINKLER OPERATION; NO SPRINKLERS IN FIRE AREA
5. SPRINKLER OPERATION UNSATISFACTORY (EXPLAIN IN NARRATIVE).
6. PERFORMANCE OF AUTOMATIC EXTINGUISHING EQUIPMENT NOT CLASSIFIED ABOVE
7. PERFORMANCE OF AUTOMATIC EXTINGUISHING EQUIPMENT UNDETERMINED OR NOT REPORTED

23: 4

53. AUTOMATIC FIRE ALARM PROVIDED? (IF NO,PROCEED TO 54)	Y. YES N. NO	24	N
PERCENT COVERED?		25 / 26 / 27	
IF LESS THAN 100%, WERE DETECTORS IN FIRE AREA?	Y. YES N. NO	28	
OPERATED AT FIRE?	Y. YES N. NO	29	
CONNECTED TO FIRE ALARM HEADQUARTERS?	Y. YES N. NO	30	
WAS DETECTOR OPERATION FIRST INDICATION OF FIRE?	Y. YES N. NO	31	

TYPE OF ALARM SYSTEM

1. FIXED TEMPERATURE
2. RATE OF RISE
3. COMBINATION FIXED TEMP/RATE OF RISE
4. SMOKE/SMOKE COMBINATION
5. OTHER

32:

PERFORMANCE OF FIRE DETECTION EQUIPMENT

1. DETECTOR(S) IN THE ROOM OR SPACE OF FIRE ORIGIN, AND THEY OPERATED
2. DETECTOR(S) NOT IN THE ROOM OR SPACE OF FIRE ORIGIN, AND THEY OPERATED
3. FIRE TOO SMALL TO ACTIVATE DETECTORS
4. DETECTOR PERFORMANCE UNSATISFACTORY (EXPLAIN IN NARRATIVE)
5. NO DETECTORS PRESENT
6. PERFORMANCE OF FIRE DETECTION EQUIPMENT NOT CLASSIFIED ABOVE
7. PERFORMANCE OF FIRE DETECTION EQUIPMENT UNDETERMINED OR NOT REPORTED

33:

54. MANUAL FIRE ALARM SYSTEM PROVIDED? (IF NO,PROCEED TO 55)	Y. YES N. NO	34	Y
OPERATED AT FIRE? (IF NO,PROCEED TO 55)	Y. YES N. NO	35	N
CONNECTED TO FIRE ALARM HEADQUARTERS?	Y. YES N. NO	36	Y
IF OPERATED DID SYSTEM PERFORM SATISFACTORILY?	Y. YES N. NO	37	

55. INSTALLED PORTABLE EXTINGUISHERS (NOT F.D. CARRIED)

1. EXTINGUISHERS NOT PROVIDED
2. PROVIDED BUT NOT USED
3. OPERATED SATISFACTORILY
4. OPERATED UNSATISFACTORILY (EXPLAIN IN NARRATIVE)
5. OPERATION N/A

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56. OTHER FIXED SPECIAL EXTINGUISHING SYSTEMS IN FIRE AREA (IF NONE, PROCEED TO SECTION E) 1. NONE 2. BUILT-IN CARBON DIOXIDE FLOODING SYSTEMS PROVIDED 3. BUILT-IN CARBON DIOXIDE - HAND HOSELINE PROVIDED 4. BUILT-IN "HALON" FLOODING SYSTEM PROVIDED 5. BUILT-IN DRY CHEMICAL SYSTEM PROVIDED 6. BUILT-IN FOAM SYSTEM PROVIDED 7. OTHERS 1 (39)	FIXED SPECIAL EXTINGUISHING SYSTEMS OPERATED 1. AUTOMATIC 2. MANUAL 3. NOT OPERATED (40)	SPECIAL SYSTEM PERFORMANCE 1. FIRE TOO SMALL FOR SYSTEM OPERATION 2. OPERATED SATISFACTORILY – EXTINGUISHED FIRE 3. OPERATED SATISFACTORILY – HELD FIRE IN CHECK 4. OPERATED UNSATISFACTORILY (EXPLAIN IN NARRATIVE) 5. OPERATION N/A (41)

SECTION E – LOSSES

PROPERTY DAMAGED	ESTIMATED $ VALUE	ESTIMATED $ LOSS
57. STRUCTURE OR MOBILE PROPERTY (GOVERNMENT)	(42-49)	(50-57)
58. CONTENTS (GOVERNMENT)	25000 (12-19)	35000 (20-27)
59. NON-GOV PROPERTY (IF NONE PROCEED TO 61)	(34-41)	(42-49)

60. IF NON-GOV. LOSS, GIVE PROPERTY TYPE
1. PRIVATE
2. CONTRACTOR
3. SPECIAL SERVICES
4. EXCHANGE, PX
5. GOV LOSS, REIMBURSED
6. OTHER ______
(58)

CARD NO. 0 3 0 (77 78 79)

61. NO. INCIDENT-RELATED INJURIES (28 29 30)

62. NO. INCIDENT-RELATED FATALITIES (31 32 33)

SECTION F – TIMES (24-HR CLOCK)

63.

ESTIMATED TIME FIRE STARTED	FIRE DETECTED	ALARM RECEIVED
2050 (50-53)	2050 (54-57)	2053 (58-61)

F. D. ARRIVED	EXTINGUISHED	CARD NO.
2054 (62-65)	2358 (66-69)	0 4 0 (77 78 79)

SECTION G – BRIEF NARRATIVE OF FIRE

ON 20 NOVEMBER 1988 AT 2053 HOURS EMERGENCY COMMUNICATIONS CENTER RECEIVED A PHONE CALL REPORTING A FIRE AT PIER #4. ENGINE ONE AND TWO, TRUCK ONE AND DISTRICT CHIEF CAR 1-1 WERE DISPATCHED. ON ARRIVAL FOUND SMOKE EMITTING FROM TRANSFORMER VAULT "B" DOOR ON NORTHSIDE OF PIER. ENGINE ONE AND CAR 1-1 ATTEMPTED FORCEABLE ENTRY OF VAULT DOOR UNTIL HEARD EXPLOSION TAKE PLACE INSIDE OF VAULT. CAR 3 WAS NOTIFIED OF EXPLOSION AND RESPONDED. CAR 1-1 CALLED FOR PWC ELECTRICIAN THEN MADE ENTRY INTO WAREHOUSE TO CHECK FOR FIRE EXTENSION IN WAREHOUSE SECTION. CAR 3 ARRIVED ON SCENE AND SET UP COMMAND POST, ALSO STARTED TAKING MEASURES AND HANDLING AS A PCB FIRE. PIERS AND STREETS WERE BLOCKED OFF BY BASE POLICE. CAR 3 CALLED FOR TWO 150# HALON CARTS FROM AIRFIELD WHICH FIRE WAS EXTINGUISHED WITH. THE SOURCE OF SMOKE WAS FOUND TO BE A TRANSFORMER FIRE LOCATED IN VAULT "B". PWC ELECTRICIAN SECURED POWER TO PIER 4. FIRE WAS EXTINGUISHED IN TRANSFORMER. FIRE DEPARTMENT PERSONNEL VENTILATED WAREHOUSE AND COOLED DOWN TRANSFORMER CORES. INVESTIGATION REVEALED THAT FIRE WAS CAUSED BY A MALFUNCTIONED TRANSFORMER WHICH WAS INSTALLED ONE MONTH AGO. THE TRANSFORMER DID NOT CONTAIN PCB'S. TWELVE FIREFIGHTERS RESPONDED WITH DISTRICT CHIEF WILSON AND ASSISTANT CHIEF DAVIS IN COMMAND OF FIRE SCENE.

EQUIPMENT: ENGINE ONE: 1000 GPM PUMPER   TRUCK ONE: 100' AERIAL
ENGINE TWO: 1000 GPM PUMPER

D L Butler
BUTLER, D. L. DEPUTY CHIEF
NAVBASE FIRE DEPARTMENT, NORFOLK, VA

CUTHRIELL, A. L. FIRE CHIEF
NAVBASE FIRE DEPARTMENT, NORFOLK, VA.

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FOR ADDITIONAL INFORMATION PHONE NO.______ (CHECK ONE) ☐ AUTOVON ☐ FTS ☐ COMMERCIAL

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S/N 0102-LF-002-3240

11/30/88
DPMC
610.E1

11/20/88

DUTY LOG

Rcd
2100
(9pm)

(T. Lewis)

"Firecall Pier 4. Vault B
found transformer or switchgear on fire.
Went to P-Sub and opened P-4 &
P-2,3,4, rolled both breakers down
tagged and locked both breakers. The 5kv
on Pier is still hot"

"No surge on chart P-Sub = NO INK

P-2,3,4 no targets
P-4 one target

comp. 2330
(11:30)

→ Virginia was on Pier 7 ← (ON Pier 234
MUSE unit)

D. Midgett Home

I was called 10:30-1100 asked about Pier 4 PCB
according to J. W who made call
Fire Dept was not entering vault till knew
for sure XFMR was not PCB - he said
the unit was still burning. I told him
it was ① new ② dry. He wanted proof
finally decided to go down & look at
next vault for proof.

9-920 J W was called

Ships affected

Riegale - Pier 4 Pier 4 VHB (still there) ← on Muse

Virginia - Pier 7 (Muse) (still there)

V N-3570 OTR D ENG officer 4-5238 ENG 4-3169

R 4-4948 4-4108

at 2pm assist Chief Davis

Davis - fire department took photos (not avail yet)

(Fire station 2) 4-7352 4-7326 ← fire dept.

end of Gilbert

station across from supply Piers answer call

→ said blew after response ←

Riegal → Lost shore power → 2100 on 20th
4-4108 accord To Eng officer

Virginia → Lost shore power → 2120 on 20th
4-5238
4-3169

W-146

Fire STA 1

copy of report

Chief Wilson → Sta Chief
4- 7264

LOG has 2053
out ~~[illegible]~~ 2059
ret 0200 (21st)

DID RIEGAL open their on board Bkr?

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