MEMORANDUM

TO: Dennis Schwehr

FROM: Roberta Straub

RE: Damages

DATE: July 6, 1993

Here is another document which I came across and that may have implications for the damages calculations. I don't know if you've seen it or if you already have a copy. I realize this is not the best copy, but our original is no better. If you do already have a copy, please disregard this. I would be interested to know your thoughts on whether you believe this document is important or useful (or not) after you have read it. Thank you.

rjs\nvpower\damages.mm9

FILE
NEMA/DOE/NBS
PROJECT

cc:
cc:
cc:

NEMA TRANSFORMER PCB REPLACEMENT STUDY

Submitted by:

NATIONAL ELECTRICAL
MANUFACTURERS ASSOCIATION
2101 L Street, N.W.
Washington, D.C. 20037

INTRODUCTION

The demise of the use of PCBs in transformers has resulted in the need for the industry to develop substitutes. Because of the fact that flammability is one of the primary criteria for the acceptance of these substitutes, studies of the flammability have been initiated by the industry. The studies have been found to be more complex than anticipated and extensive additional investigations will be required before fire safe transformers can be approved using appropriate materials. The purpose of this proposal is to provide short-range screening data to develop a basis for subsequent in depth studies that will lead to industry standards that will protect the public and limit property damage and personal injury.

OVERALL PURPOSE

To conduct an evaluation of transformers containing dielectric substitutes to establish fire safety standards performance criteria and approved tests.

SOE PROGRAM

To conduct an experimental program to screen possible PCB substitutes with respect to flammability and develop correlations with forthcoming standards proposed by Factory Mutual. In addition, catastrophic transformer failures will be simulated and related to fluid properties, gas content of fluids, and transformer operating temperature. A few representative transformers will be "exploded" to confirm fire safety requirements. Obviously, additional studies will be required in order to achieve the

overall purpose of the program as stated above. The DOE program would provide the technical basis for the subsequent transformer studies.

PROGRAM BACKGROUND

For more than 40 years the transformer industry used Askarels (polychlorinated biphenyls, PCBs) as an insulating and heat transfer liquid in equipment that was required to be fire safe. Since the early 1970's, environmental concerns mounted concerning the use of PCBs and ultimately the Toxic Substances Act mandated the cessation of manufacture and use of these materials. The search by industry for substitute materials ultimately led to the need for some form of industry approval for fire safety, particularly when these substitute materials were used in transformers in indoor installations. In addition, further governmental regulations (NIOSH, etc.) must be satisfied. Since the industry is now without a liquid insulated transformer that has been shown to be fire safe, efforts and financial support have been applied to an experimental program conducted by Factory Mutual Research Corporation (FMRC) directed to the establishment of standards for fire safety. The technical difficulties associated with the quantitative evaluation of transformers insulated with substitute materials have been much greater than anticipated and it is clear that extensive additional experimental work must be done before suitable standards may be established.

The cost of full-scale transformer tests involving disruptive failure of the unit is very high. The costs are prohibitive when

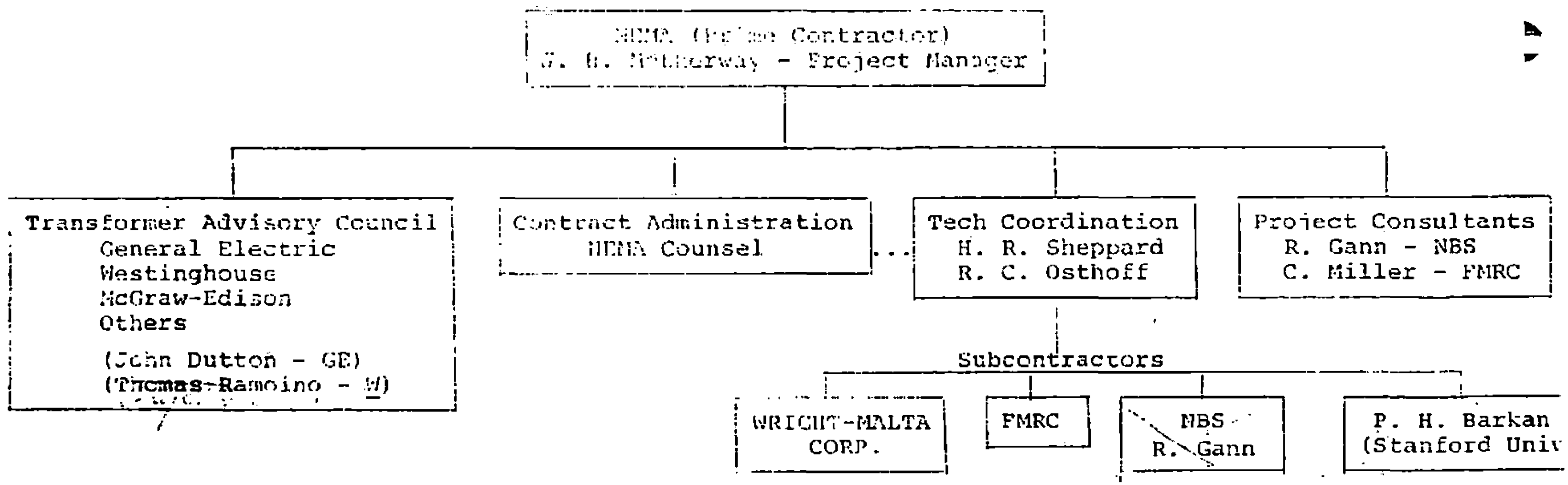
one is employing the technique to qualify the fire safety of transformers incorporating PCB substitutes. We have found that explosive charges can be used to simulate transformer arc-faults. The purpose of this proposal is to relate the explosive disruptive failure to arc-induced failure to be employed as a flammability criterion for transformers filled with PCB substitutes.

PROGRAM ORGANIZATION

It is proposed that the National Electrical Manufacturers Association (NEMA) ~~would~~ be the prime contractor. The program organization is shown on the following page.

The Transformer Advisory Council will provide transformer oriented inputs and guidance to NEMA on the overall program. Technical coordination of the subcontractors will be carried out by Mr. W. R. Sheppard of Westinghouse and Dr. R. C. Ostheff of General Electric. Mr. C. Miller of Factory Mutual Research Corporation and Mr. R. Gann of the National Bureau of Standards will act as technical consultants to NEMA on the overall program

PROGRAM ORGANIZATION



TECHNICAL PROPOSAL

TASK I Analytical Studies

The amount of energy involved in the arc-induced disruptive failure of transformers can be translated to equivalent explosives (in terms of total energy release and time duration). Dr. P. H. Barkan of Stanford University has extensively studied arc faults in distribution transformers.(1) It is proposed to employ Dr. Barkan to work with Malta-Wright Corporation (Ballston Spa, New York where the initial explosion studies were conducted), to relate electrical fault behavior in transformer tanks to that of the use of an explosive charge. Included in these studies will be the velocity of the fluid (and/or cover), the energy release, the time duration, the pressure generated, and the temperature of the fluids to be evaluated. Although the initial studies will be concentrated on cylindrical distribution transformer tanks without cores and coils, mathematical correlations for oil filled transformers in rectangular tank configurations will be developed in conjunction with the efforts of Dr. T. A. Alverson of Westinghouse Transformer Medium Power Division.

These studies will be made to establish the relevancy of these testing methods to transformer credibility of failure modes and to support the use of explosives for the simulation of electric arc-induced catastrophic transformer failures. The

(1) P. H. Barkan, B. L. Damsky, L. F. Ettlinger and E. J. Kotsky, IEEE Transaction on Power Apparatus and Systems, Vol. PAS-95, No. 1, Jan.-Feb. 1976, p 17 et seq.

similarity of explosive and electrical failures will be evaluated.

Drs. Barkan and Alverson will recommend instrumentation for the explosive tests, review the procedures, and aid in correlation of the data.

TASK II - Ignition Technique Investigation

The large scale burn tests conducted at Factory Mutual Research Corporation (FMRC) employed an annular structure that contained n-heptane (approximately 1 inch of heptane on top of about 2 inches of water) for ignition of test liquids. The heptane was ignited and burned for about 15 minutes. The heptane flame heated the fluid by both conduction and radiation until the fluid under test was ignited.

Unfortunately, the heptane continued to burn after the test fluid was ignited, and this distorted the heat release measurements. In addition, the physical act of adding water and heptane annulars may easily have resulted in contamination of the fluid under test. Furthermore, once the heptane was ignited it burned in cellular (also called polyhedral or disturbed) flames. This can result in "distillation" of the heptane into the test liquid, again causing possible errors in the heat release measurements. It has been observed by R. Gann of the National Bureau of Standards that an improved ignition technique should

(2) G. H. Markstein and L. M. Sommers, 4th International Symposium on Combustion, 1953, p 527 et seq.

be developed, e.g. an annular propane burner, annular electrical resistance heaters, etc. in order to eliminate the above-mentioned possible sources of error in the heat release measurements. The improved ignition source will be designed and built by NBS under the direction of R. Gann.

TASK III - Large-Scale Burns

It is proposed that Factory Mutual Research Corporation (FMRC) conduct a series of large-scale burn tests at the FMRC West Gloucester, R.I. test site. These tests would employ the ignition technique developed by NBS and replicate burns would be conducted. The data developed in these tests would be utilized to categorize the various fluids for use in indoor transformers for buildings with various ceiling heights. In addition, an attempt will be made to correlate the heat release data from the large-scale burns with similar data obtained in the laboratory scale tests at FMRC.

It is proposed that the following categories of liquids be measured at the West Gloucester facility:

2 - silicones of different flammabilities

3 - hydrocarbons of different flammabilities

It is proposed that the heat-release for each fluid be measured three times to determine the reproducibility of the test method. All tests will be conducted with R. Gann of NBS providing consultation to FMRC personnel.

TASK IV - Wright-Malta Tests

The actual tests involving explosives will be carried out at Wright-Malta Corporation (Ballston Spa, N.Y.). Mr. Tod Butler, the principal investigator of the Malta site, has extensive experience with explosives. In addition, the Wright-Malta Corporation site is ideally situated and equipped to carry out such experiments.

Extensive studies have been made of arc-fault failures in transformers. The work of Barkan et al contains experimental data which shows the basic energy release vs. time characteristics of arc-faults. Several concepts of arc fault simulation were considered; the most promising concept for simulation of the energy release was the propellant charge technique.

The arc-fault energy release vs. time quickly determines that a slow burning black powder propellant used commercially with an ignition compound would be desirable. Black powder is commercially available in a large number of energy grades, burning rates, and combustion temperatures. By proper blending of the grades the desired energy release rates can be achieved. In preliminary studies, the charge was designed using the basic information contained in the Engineering Design Handbook on Propellant Actuated Devices. Graph #1 shows the approximate charge requirements for steel piston actuators. Under oil propellant actuators the heat loss to the transformer fluid is not clearly defined. The first powder charge tested was a 2F grade black powder. The combustion burning rate was slower

than desired in the water tests. Therefore, a 50-50 mixture of 1F and 2F black powder was used. Barkan had taken Fastax motion pictures of the top surface of the transformer oil during arc-fault failures. The energy release rate in the initial experiment was slower than desired, so that the charge was modified to 42.5 g. of 3F grade black powder. Further measurements of the pressure time curve in the initial phases of the proposed program may show that further charge modification may be necessary.

Extensive data were available with an arc-fault failure approximately 7" from the bottom of the 10 kVA transformer can.

The propellant charge is located at the same location as the arc-fault. Fastax motion pictures of the transformer can cover without the restraining band installed were used to verify the kinetic energy imparted to the liquid. Graph #2 shows the general area of kinetic energy release that was desirable. The motion pictures will be used to confirm that the proper kinetic energy is being imparted to the transformer oil.

We have shown that explosives may be used to simulate arc induced faults with accompanying cover-blowing on 10 kVA distribution transformer tanks. In these cases where ignition of the oil occurred, the photographic records showed a good analogy to arc-induced cover-blowing experiments carried out by General Electric at its High Power Laboratory in Philadelphia. The explosive charge simulated the arc energy and duration in the Philadelphia tests.

Two other measurements of significance will be conducted during each transformer cover-blowing experiments. In each case, shallow (ca. 1" deep) discrete pans of combustible materials, e.g. transformer oil, cardboard, etc. will be placed in 5-foot increments up to about 18 feet away from the transformer. Three arrays of such pans will be placed at 120° around the experimental unit in order to eliminate the effects of low level winds. Such observations will provide an indication of capability of the expelled dielectric to ignite adjacent combustibles. Furthermore, an array of temperature measurements above each tank will be made during the expulsion of the fluid. The array of temperature measurements will be made in the region of 10-30 feet above the tank in order to help correlate the temperature data needed for the FMRC heat release criteria.

Only very meager data exist concerning the flammability characteristics of various dielectric fluids as a function of their temperatures at the time of tank rupture. Therefore, we propose to utilize explosives to produce cover-blowing type failures on 10 KVA tanks containing the following fluids:

Transformer Oil - for a comparison standard

3 Hydrocarbon oils - e.g. RTEmp, a PAO, and a bright stock

2 silicones of different viscosities, e.g. 50 cs and 100 cs.

Each of these would be tested at initial liquid temperatures of 60°C, 100°C, and 135°C. In addition there are no data concerning the effects of the gases dissolved in the dielectric fluid (that may be generated in the transformer) on

the flammability. It is proposed two fluids be selected for testing in which combustible gas is dissolved. We have chosen a gas composition consisting of 80% H_2, 10% CH_4, and 10% C_2H_4 to be roughly representative of gas compositions that could be generated from the fluids in this test program. These tests will be run with fluid saturated with the gas mixture. An assessment of the change in flammability caused by the pressure of the gases will be made based upon these tests.

Replication of the "blow-up" tests will be conducted on the fluids that yield significant information. At the present, the reproducibility of these tests has not been established.

To this point in the proposed program only cylindrical tanks with the covers held on by retaining rings will have been tested. It is proposed to evaluate the effect of rectangular tank geometry with welded covers. The experiments will involve the use of small scale models in which the geometry will be representative of load center transformer geometry. The same measurements as described above for the cylindrical tanks will be conducted. Four model tanks will be tested.

Based in the data and observations of the disruptive failure of the cylindrical and rectangular tanks, as well as predictive calculations, a selection of actual transformers (up to 4 cylindrical tanked units and up to 4 single-phase pad-mounted transformers) will be failed-up explosive charges. In these cases, the explosive charges would be placed in an artificial cavity in the high voltage windings. Again, the same measuremcnts described above would be included in the disruptive failure

experiments. On the other hand, should the analytical studies provide the mathematical basis for including several 3Ø transformers, these would be substituted for the 1Ø units alluded to above. Again, with the 3Ø transformers the same measurements will be made as on the 10 kVA can blow-up tests.

NEMA TRANS

	TASK	JUNE
I	Analytical Studies	
	A. Single Ø 50 kVA Dist.	
	B. Three-Ø 5000 kVA Load Center	
II	Ignition Technique	
	A. Method Devel.	
	B. Equip.Design	
	C. Equip.Constr.	
III	Large-Scale Burns	
	A. FMRC Tests	
	B. Data Analysis	
IV	Wright-Malta Tests	
	A. Single-Phase 10 kVA Tank Tests	
	B. Three-Phase Rectangular Load Center Models Tests	
	C. 1Ø & 3Ø Transformer Tests	
	D. Data Consolidation	

TONNER PCB REPLACEMENT STUDY