

# **Assessment and Testing of High-Pressure Fluid-Filled (HPFF) Cables**

*New York Power Authority Niagara Power Project*

**1014696**

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# **Assessment and Testing of High-Pressure Fluid-Filled (HPFF) Cables**

New York Power Authority Niagara Power Project

**1014696**

Technical Update Report, March 2007

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# ABSTRACT

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The Niagara Power Project of the New York Power Authority (NYPA) includes the Robert Moses Power Plant (RMPP), the Lewiston Pumping Generation Plant (LPGP) and a substation that connects the output of these facilities to the NYPA transmission system. Both of the power plants were built in 1961. The high-pressure fluid-filled (HPFF) cable systems at these two facilities have been in operation for more than 40 years. NYPA required an assessment of the condition and life expectancy of the HPFF cable systems at RMPP, LPGP, and the substation.

This report describes the results of diagnostic tests that were performed on the 115 kV and 230 kV HPFF cable systems at the NYPA RMPP and LPGP facilities that were performed by Power Delivery Consultants, Inc (PDC), Detroit Edison Company (DECO), DTE Energy Technologies (DTE), and Quality Inspection Services, Inc.(QIS).

The diagnostic tests that were performed on the seven, 115 kV and ten, 230 kV HPFF cable systems indicate that there has been very little thermal aging of the cable insulation during the past 45 years of operation and that the quality of the pipe dielectric fluid is good with the exception of the dissipation factor.

The DGA tests performed by DECO indicate that there has been little or no thermal aging of the cable insulation and all of the cable systems are in good condition with the exception of a fluid sample from the switchyard end trifurcator for Unit #4. Low levels (1 ppm) of acetylene were detected at this location which may be an indication of electrical discharges in one of the adjacent cable terminations.

The rated-voltage insulation dissipation factor measurements, which were performed on RMPP Unit #3 and Unit #13 cables, also indicate that the high voltage insulation of the 115 kV (Unit #3) and 230 kV (Unit #13) cables have experienced very little thermal aging.

The X-ray images of the cable riser pipes, trifurcators, and joint casings provided by QIS did not reveal any areas of concern with the possible exception of LPGP Unit #2 cable system. The images of the joint casing for this 230 kV cable system indicate that there is a significant amount of cable bending between one end of the joint casing and the splices when the cable system is loaded. Thermo-mechanical bending of the cable in this area may result in displacement of the insulating tapes at some time in the future.

The PD measurements performed by DTE on RMPP 230 kV cable #9 detected high frequency signals emanating from two of the switchyard end riser pipes. These signals detected by DTE are of concern. DTE recommends repeating the measurements at some time in the future to determine if there is a trend of increasing PD signals. However, the X-ray inspection of this area did not show any abnormalities.



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Dr. Nirmal Singh of Detroit Edison was responsible for working with NYPA Niagara Power Project personnel in collecting dielectric fluid samples as well as for performing dissolved gas analysis of the fluid samples.

Dr. Nagu Srinivas of DTE Energy Technologies was responsible for planning and conducting partial discharge measurements on the Niagara Power Project HPFF cable systems.

Mr. Brian Caccamise of Quality Inspection Services, Inc. was responsible for performing Digital Radiography inspection of the HPFF cable systems.

Mr. George Stranovsky and Tom Moody of the New York Power Authority were responsible for coordinating the efforts of NYPA personnel in conducting the tests reported in this document.



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# 1

## INTRODUCTION

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The New York Power Authority (NYPA) Niagara Power Project includes the Robert Moses Power Plant (RMPP), Lewiston Pumping Generation Plant (LPGP) and a substation that connects the output of these facilities to the NYPA transmission system. Both of the power plants were built in 1961. The HPFF cable systems have been in operation for more than 45 years. NYPA required an assessment of the condition and life expectancy of the HPFF cable systems at RMPP, LPGP for maintenance and planning purposes.

Although these HPFF cable systems have a good operating history, they have exceeded their design life, which is generally taken to be 40 years. Although forty years is a common assumption for the useful life of HPFF cable systems there are both laboratory test results and operating experience that indicate that these cable systems will operate significantly longer than forty years depending on their operating conditions, maintenance, and other factors.

This report describes the results of radiographic inspections, partial discharge (PD) measurements, and dissolved gas analysis (DGA) that were performed on several of the 115 kV and 230 kV HPFF cable systems in 2004 and 2005. Cable insulation dissipation factor measurements were performed on 115 kV and 230 kV cable systems in 2006 by Power Delivery Consultants, Inc. (PDC). These diagnostic measurements were performed by subcontractors of the Electric Power Research Institute (EPRI). Analysis of the test results were performed by PDC, Detroit Edison (DECO) and DTE Energy (DTE).



# 2

## HPFF CABLE SYSTEM LIFE – LIMITING FACTORS

---

There are several factors which are known to limit the useful life of HPFF cable systems<sup>1</sup>. The most important of these factors are summarized in the following sections. Note that electrical failures can also be caused by other sources such as installation damage, poor workmanship in splices, or defects in the cable. These conditions would have resulted in cable problems earlier in the cable life, so are not addressed here. Another failure cause, dig-in, is not relevant to the NYPA cables. Operating errors cannot be predicted, so are not addressed in our evaluation.

### ***2.1 Thermal Deterioration***

It is well known that impregnated paper high voltage insulation deteriorates more rapidly as the operating temperature of the insulation is increased. This deterioration is a result of several factors. First, the paper loses mechanical strength as a result of chemical changes in the paper that are accelerated with increasing temperature. More specifically, the paper loses fold endurance, tear strength, elongation to break, and tensile strength. Another property related to cellulose chain length, degree of polymerization also decreases.

Another form of deterioration of the impregnated paper insulation results from the generation of moisture from the paper. This moisture results from the chemical loss-of-life of the paper and to some extent release of moisture which was adsorbed by the paper prior to impregnation. Some of this moisture is eventually released to the pipe filling fluid, but the majority of the moisture is initially absorbed by the paper. The increased moisture levels result in higher dielectric losses which will increase the rate of thermal deterioration, and can eventually lead to thermal-electric instability.

### ***2.2 Thermal Mechanical Forces***

HPFF cable system operating experience has shown that cable system failures sometimes result from mechanical forces which bend the cables adjacent to the splices in the joint casings. This thermal-mechanical bending (TMB) may be caused by expansion and contraction of the cable system as a result of temperature variations caused by load cycling. Mechanical damage has also been experienced in some instances as a result of the cables sliding down the pipe due to elevation changes. Actually, the mechanical damage that has occurred due to sliding of the cable in the line pipe usually is a result of the combined ratcheting effect of load cycling and gravitational forces.

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<sup>1</sup> IEEE Std 1425-2001, “IEEE Guide for the Evaluation of the Remaining Life of Impregnated Paper-Insulated Transmission Cable Systems”, 29 March 2002.

Although TMB problems could occur at any point in the cable system, experience to date has indicated that it is primarily a problem in joint casings. Most TMB problems have occurred with 345 kV cable systems due to the greater thickness of insulating tapes; however, there have been several 230 kV HPFF cable systems that have exhibited TMB failures.

A similar problem is the failure of HPFF cable terminations due to the mechanical deformation of their electrical stress relief components. This problem has resulted from movement of the cable inside of the termination due to sliding of the cable down inclines or shifting of the stress cone relative to the cable due to differential hydraulic pressure. The shifting due to hydraulic pressure can be caused during fluid filling or as a result of fault initiated pressure transients.

### ***2.3 Corrosion of the Steel Pipe***

A fundamental requirement for the operation of an HPFF cable system is maintaining the pressure of the pipe filling fluid at a nominal pressure of at least 200 psig (values range between 170 and 275 psig during normal operation). In order to accomplish this, the integrity of the steel pipe must be maintained. There are several HPFF cable systems where the economic life of the system has been limited by corrosion problems with the steel pipe. These situations are most severe where stray currents related to DC transportation systems are present. However, there have also been problems with above ground installations where salt corrosion combined with deterioration of the pipe corrosion coating led to leaks and in some cases loss of pressure.

### ***2.4 Contamination of the Dielectric Fluid***

Most experience indicates that there is little deterioration of the pipe filling fluid under normal operating conditions. However, there have been some instances where contamination of the pipe dielectric fluid from external sources has resulted in replacement of the cable.

### ***2.5 Other Localized Electrical Problems***

Other localized problems such as termination problems have resulted in system failures or system outages, but these problems generally have not been a limiting factor in the life of the entire cable system. Any uniform deterioration of the impregnated paper insulation due to rated voltage power frequency stress is insignificant compared to thermal and mechanical aging provided that the pipe pressure is maintained within the usual recommended limits.

### ***2.6 Pipe Fluid Pressure***

If the cables are operated for any length of time at pressures below about 100 psig, ionization could be initiated, especially in the terminations. This ionization could lead to long term degradation even after full pressure is restored. In a few cases, HPFF cable terminations have failed within minutes or hours, after a complete pressure loss. This is due to reduced dielectric strength of the oil-impregnated insulating tapes and pockets of nitrogen gas that accumulate in at the top of the cable terminations.

## **2.7 Transient Overvoltages**

Transmission cables are almost always protected by surge arresters mounted in close proximity to the potheads. However, many cable engineers are suspicious that a number of unexplained cable failures may have been initiated by transient overvoltages. Unfortunately, there is little data that would confirm or dispel the suspicion that HPFF cable life is significantly affected by system overvoltages.

## **2.8 Relative Importance of Life Limiting Factors**

The relative importance of the above factors is system dependent. The following paragraphs summarize what is known about the relative importance of the above factors.

The amount of thermal decomposition of the impregnated paper insulation depends on the loading history of the cable system and the temperature profile along the length of the cable system. One of the underlying thermal design principles for impregnated paper transmission cables is that mechanical properties of the cable insulation will hold up for forty years of operation if they are operated continuously at a temperature of 85 °C. Conversely, the insulation in an HPFF cable system may be expected to have a life of greater than 40 years if it is operated at temperatures of less than 85 °C. Laboratory tests indicate that cable life decreases by a factor of two each time that the continuous operating temperature is increased by 8 to 10 °C. This loss of insulation life is a result of deterioration of mechanical properties of the cellulose. Test results from Waltz Mill<sup>2</sup> indicate that the thermal deterioration of the cables without motion lies somewhere between the 8 degree rule and 10 rules, and that the 10 degree rule is probably optimistic for cables that are subjected to thermal-mechanical bending.

The physical geometry of the cable system, primarily elevation changes, and mechanical restraints in the cable system determines to a large extent the probability that mechanical stresses will significantly limit the life of a specific cable system.

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<sup>2</sup> EPRI TR-111712, “Transmission Cable Life Evaluation and Management”, December 1998.



# 3

## NIAGARA POWER PROJECT HPFF CABLE SYSTEMS

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The Niagara Power Project is composed of the Robert Moses Power Plant (RMPP), the Lewiston Pump-Generating Plant (LPGP), and the switchyard that connects the output of these facilities to NYPA'S transmission system.

Water from the Niagara River above Niagara Falls flows via large underground conduits to the forebay, located 300 feet above the Robert Moses Power Plant. From the forebay the water can either flow through the turbines in the Robert Moses Power Plant or it can be pumped by the turbines at the Lewiston Pump-Generating Plant into Lewiston Reservoir. When RMPP and LPPG are generating at full output, the water from Lewiston Reservoir flows through the LPGP turbines and then through the RMPP turbines.

### 3.1 RMPP Electrical System

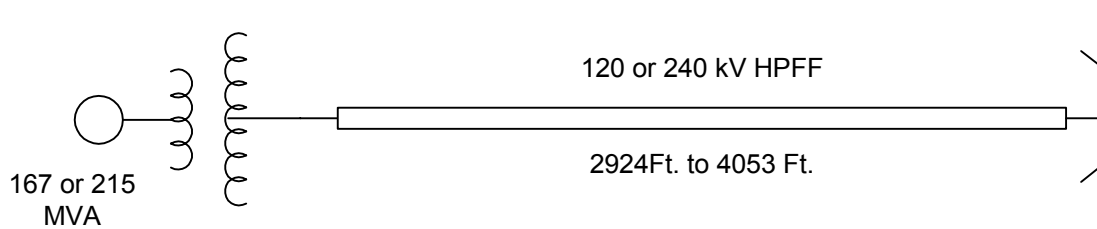
There are a total of 13 generators at RMPP with a maximum output of 2,315 MVA. The nameplate rating of the generators at RMPP are 167 and 215 MVA. Seven of these generators are connected to the switchyard via 115 kV HPFF cable and six are connected to the switchyard via 230 kV HPFF cable systems. All of the HPFF cable systems were commissioned at the time that the RMPP was completed in 1961.

Figure 3-1 is a simplified schematic showing how the HPFF cables are connected to the hydro generators and the Niagara Power Project switching yard. Each of the 167 or 215 MVA generators is connected by a dedicated HPFF cable to the switchyard as shown in the following sketch. In the past there were no circuit breakers at the power dam which means that some cables are de-energized when the electrical load for RMPP drops below a certain level. Water flow to the turbines can only be cut back by approximately 30% from full throttle, which in turn means that some generators and cables are disconnected from the power system rather than trying to throttle back on all the generators. Circuit breakers are now installed at the bottom of the power dam.

The HPFF pipe-type cables are installed in tunnels between the power plant and the 115 kV and 230 kV switchyards. The 115 kV HPFF cables systems are identified as circuits 1 through 7 and vary in length from 2924 to 3734 feet. The 230 kV circuits are identified as circuits 8 through 13 and vary in length from 4053 to 4728 feet.

Each of the 115 kV and 230 kV cable circuits was installed in three lengths, with splices located in tunnel section 29 and in the trifurcation joints at the power plant end trifurcator casings. There is a 300 feet elevation difference between the potheads located at the transformers at the RMNPP

and the potheads located in the switchyards. This elevation change is achieved by a slope in the cable tunnels of approximately 40 degrees.



**Figure 3-1**  
**Simplified Electrical Schematic of the RMPP Hydro Generators and HPFF Cables**

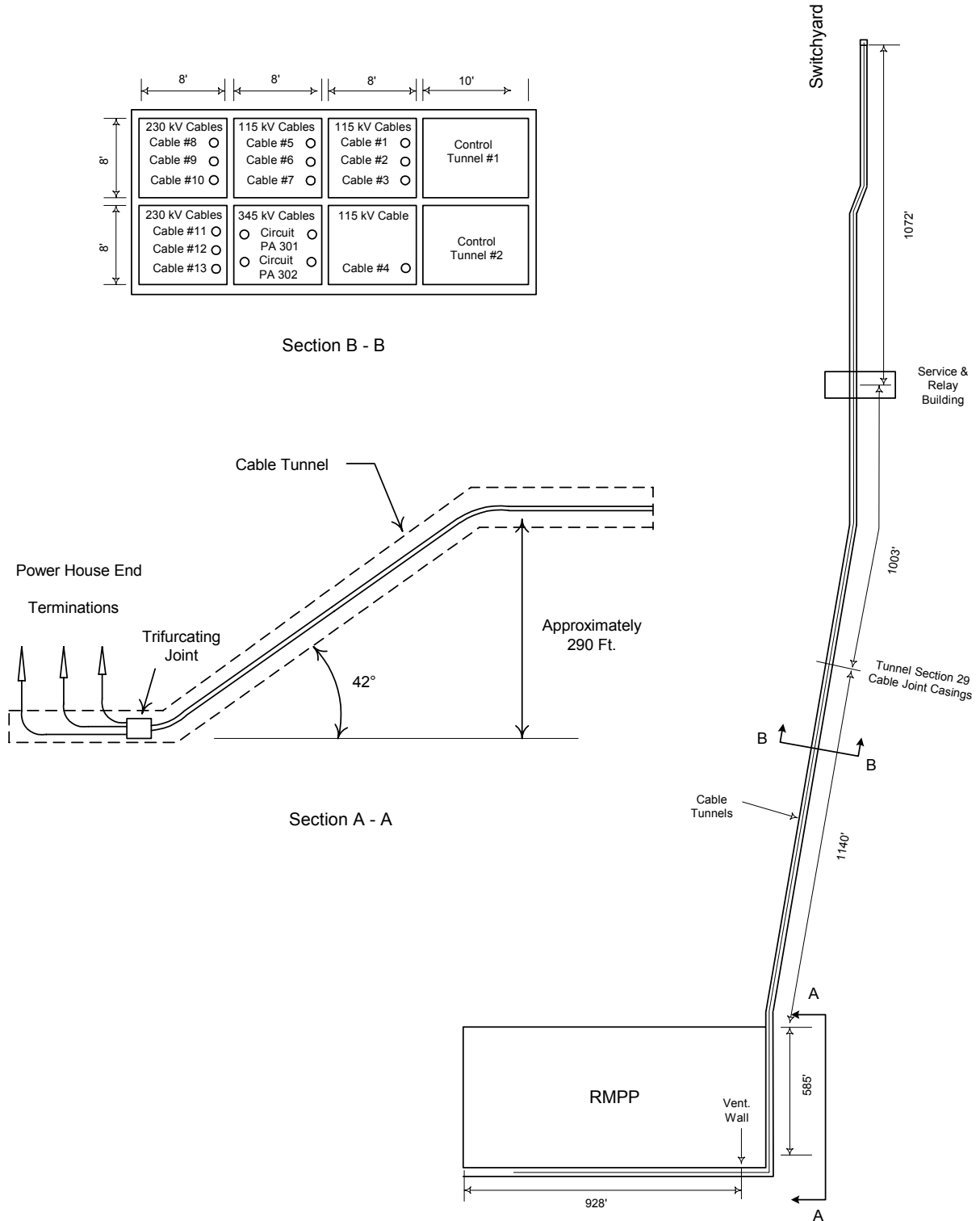
### 3.2 RMPP Tunnels

The air in the six RMPP cable tunnels is circulated by forced draft fans and cooled by air refrigeration equipment. Air refrigeration equipment was part of the original construction and has been upgraded in recent years when the output capacity of several of the hydro generators were increased from 167 MVA to 215 MVA. The original design criterion for the tunnel cooling systems was to maintain the tunnel air temperature to 40 °C or lower. Plant personnel reported that the present system was designed to maintain an ambient air of 70 °F (21 °C) or cooler. A cross section of the cable tunnels that contain the RMPP HPFF cable pipes is shown in Figure 3-2.

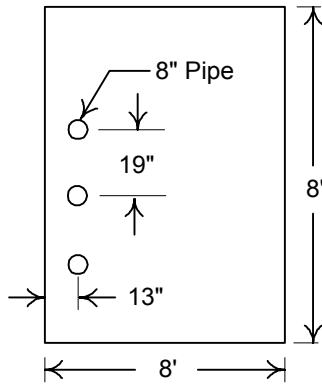
Tunnel 5	Tunnel 3	Tunnel 1
230 kV ○ Circuit 8 ○ Circuit 9 ○ Circuit 10	115 kV ○ Circuit 5 ○ Circuit 6 ○ Circuit 7	115 kV ○ Circuit 1 ○ Circuit 2 ○ Circuit 3
230 kV ○ Circuit 11 ○ Circuit 12 ○ Circuit 13	345 kV Cables ○ Circuit PA 301 ○ Circuit PA 302	115 kV ○ Circuit 4
Tunnel 6	Tunnel 4	Tunnel 2

**Figure 3-2**  
**Cross Section of RMPP Cable Tunnels**

The two, 345 kV cable circuits shown in Figure 3-2 carry power from a transmission line that crosses the Niagara River from Canada. They are not part of this analysis. Approximate dimensions of the pipes in relation to the tunnel are shown in Figure 3-4.



**Figure 3-3**  
**Plan and Profile Drawing for RMPP HPFF Cable Systems**



**Figure 3-4**  
**RMPP cable tunnel cross section**

### 3.3 RMPP Cable Data

The parameters of the HPPF cable manufactured by The Okonite Company are summarized in Table 3-1. These cables were constructed to the first edition of AEIC CS2.

The NYPA cable system specifications required that the cable conductors be sized such that conductor temperatures not exceed 70 °C for a tunnel ambient air temperature of 40 °C for unity loss factor.

**Table 3-1**  
**RMPP Cable System Parameters**

Parameter	115 kV	230 kV
Conductor Size (kcmil)	1750 Cu	750 Cu
Type Of Conductor	Copper, 4 segments	Concentric
Conductor Diameter	1.526	0.998
Conductor Resistance ( $\mu\Omega$ /ft.) @ 25 C	6.19	14.4
Insulation Thickness (mils)	450	880
Insulation Shield	5 mil Cu Tape	5 mil Cu tapes
Skid Wire	Single, 0.1 x 0.2 Brass	Single, 0.1 x 0.2 Brass
Impregnating Fluid	Mineral Oil	Mineral Oil
Pipe Filling Fluid	Sun #6	Sun #6
Pipe Size (IPS)	8	8
Dissipation Factor (%) @ 25 C	0.3	0.3

### 3.4 RMPP Pipe Filling Fluid and Cable Hydraulic Systems

The pipe filling fluid is Sun #6 mineral oil for all circuits. There has never been an occasion to remove the dielectric fluid from the pipes or treat the dielectric fluid other than that for pothead repairs.

Dissolved Gas Analysis (DGA) and other routine dielectric fluid measurements have been were once every 5 years in recent times. Samples are taken from the cable pipe at the midpoint splice casing or from the trifurcation joint casings.

There are two pressurization units for the RMPP cables that are connected to the cable pipes at a location near the switch yard end of the circuits. There is no intentional circulation of the pipe filling fluid.

During normal operation, one pressurization unit feeds the 115 kV cables and the second unit feeds the 230 kV cables. The reservoir capacities for the RMPP 115 kV and 230 kV circuits are both 3500 gallons. High and low pressure alarms are set at 270 and 150 psig respectively.

### 3.5 RMPP Cable System Problems

Plant personnel were aware of only one significant problem that had occurred with the RMPP HPFF cables. In 1966, five, 230 kV cable potheads in the switchyard experienced an internal fault that resulted in explosions of the porcelain. These termination failures were a result of loss of system pressure that occurred when a valve was incorrectly closed. This operating error resulted in the loss of pipe pressure for all of the RMPP 230 kV cable systems.

The following table lists the 230 kV pothead failure history.

**Table 3-2**  
**RMPP Pothead Failures**

Circuit	Phases	Year
9	A	1966
11	B	1966
12	A, B, C	1966
9	B	1974

Maintenance records indicated that all of the 115 kV potheads on Circuit #6 had been replaced at the power dam in 1969, but there was no indication of why they were replaced. No records were found that documented the reason for replacing the phase B pothead in 1974.

### 3.6 LPGP Cable Systems

The LPGP has twelve motor-generators that are connected to the Niagara switchyard by means of four, 230 kV HPFF cable systems as shown in Figure 3-5. Maintenance procedures and diagnostic testing for these HPFF cable systems are similar to those described in the preceding sections for the RMPP cables.

### 3.7 LPGP Electrical System

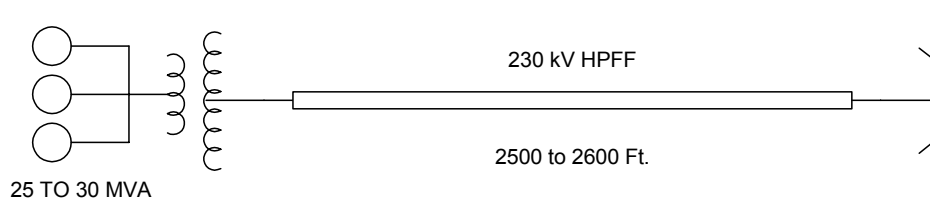
There are a total of twelve motor-generators at LPGP that are used to pump water from the forebay to the Lewiston Reservoir during light load conditions. The water in the reservoir is then used to generate electric power during high load conditions. The original name plate rating of the motor-generators was 25 MVA, but the ratings of the units were increased to 28 for some machines to 30 MVA for others in 1980.

As indicated by Figure 3-5, the HPFF cable systems carry the current for one to three motor-generator units depending on system conditions.

### 3.8 LPGP Tunnels

The Lewiston Plant 230 kV HPFF cables traverse the distance between the reservoir and the Niagara switchyard in two tunnels with dimensions similar to those for the RMPP tunnels.

The primary difference between the RMPP tunnels and the LPGP tunnels are that the LPGP tunnels are relatively level and there are only two pipes per tunnel. The air in the two LPGP tunnels is circulated by forced draft fans, but the air is not refrigerated. Two temperature transducers monitor air temperature at the supply and discharge points of the air circulation system.



**Figure 3-5**  
**Simplified Electrical System Schematic for LPGP HPFF Cable Systems**

### 3.9 LPGP Cable Parameters

The cable parameters for the 230 kV HPFF cable, manufactured by The Okonite Company, are summarized in the following table. These cables were constructed to the first edition of AEIC CS2.

**Table 3-3**  
**LPGP Cable Parameters**

<b>Parameter</b>	<b>Value</b>
Conductor Size (kcmil)	500 Cu, Concentric
Conductor Resistance ( $\mu\Omega/\text{ft.}$ ) @ 25 C	21.6
Insulation Thickness (mils)	870
Insulation Shield	5 mil Cu tapes
Skid Wire	0.1 x 0.2 Brass
Cable OD	2.780
Impregnating Fluid	Sun XX
Pipe Filling Fluid	Sun 6
Pipe Size (IPS)	8
Dissipation Factor (%) @ 25 C	0.3

### **3.10 LPGP Pipe Filling Fluid and Cable Hydraulic Systems**

The pipe filling fluid is Sun #6 mineral oil for all circuits. There has never been an occasion to remove the dielectric fluid from the pipes or treat the dielectric fluid. Similar to the RMPP cables, DGA and other routine pipe fluid measurements have been made once every 5 years in recent times.

### **3.11 LPGP Cable System Problems**

LPGP personnel were not aware of any problems with the HPFF cable systems at this facility.



# 4

## DIAGNOSTIC TESTS

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The following diagnostic test results are presented in this report.

Radiographic inspection of RMPP 115 kV HPFF cable system #3 operating at no-load and under-load operating conditions

Radiographic inspection of RMPP 230 kV HPFF cable system #9 at no-load and under-load operating conditions

Radiographic inspection of LPGP 230 kV HPFF cable system #2 at no-load and under-load operating conditions

Partial discharge measurements performed on RMPP 230 kV HPFF cable system #9 under normal operating conditions (350A to 450A)

Pipe fluid dissolved gas analysis performed on pipe fluid samples taken from all of the 115 kV, 230 kV, and 345 kV cable systems

Pipe fluid tests (moisture, power factor, electrical breakdown, peroxide content, furan content, and neutralization number)

Rated-voltage cable insulation dissipation factor measurements

The following sections describe the results of the above diagnostic tests.

### 4.1 Radiographic Inspection

Radiographic (X-ray) inspection has been one of the most commonly used, non-invasive inspection methods to look for signs of thermal mechanical bending in HPFF cable systems. Radiographic inspections were performed at the NYPA RMPP and LPGP facilities by Quality Inspecton Services (QIS) using radioactive sources (iridium 192 and cobalt 60) and a digital X-ray imaging technique developed by Kodak. The iridium source was primarily used for the riser pipe radiographic inspection and the initial trifurcator and joint casing inspections. The cobalt 60 source was used for radiographic inspection of the trifurcator casings and joint casings.

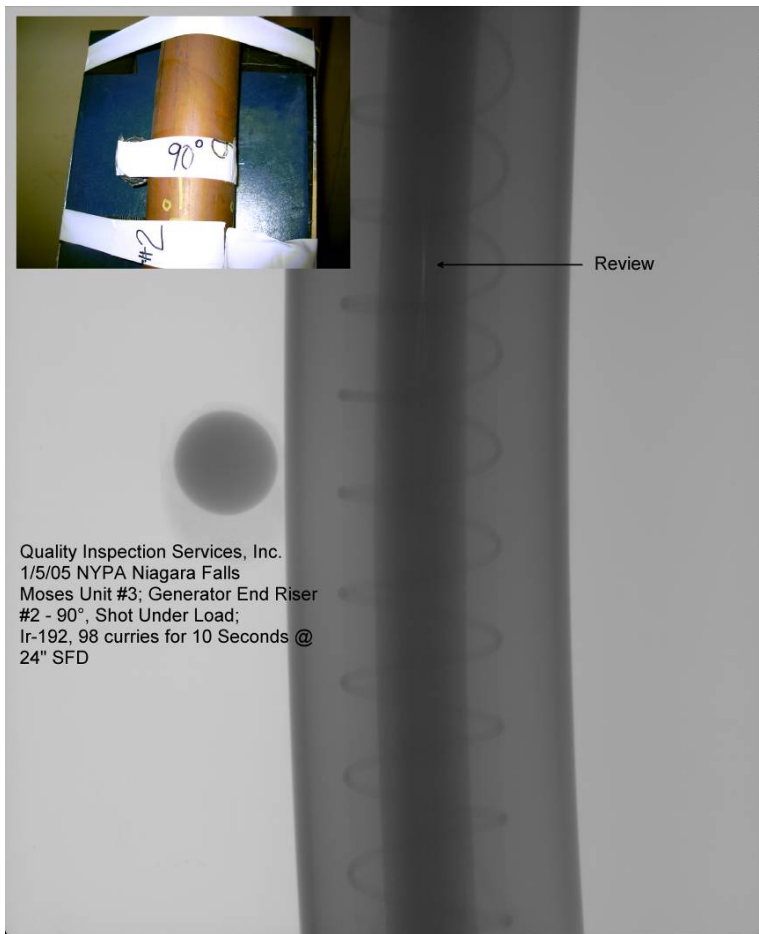
#### 4.1.1 Radiographic Digital Imaging Process

The digital imaging method employed by QIS produces high definition digital images in a proprietary format (xry) that must be viewed by a personal computer program called Starlight. Two versions of the Starlight program are available. The full version of the program was used

by QIS to view the images and convert some of the images to JPEG format, a widely used image compression format. The JPEG format files are significantly smaller (approximately 500 kbytes) than the proprietary xry format with a typical file size of (8,000 kbytes). However, the definition of the JPEG file images are not as good as the proprietary xry format. A reduced capability version of the Starlite program is distributed at no cost with the xry image files to facilitate viewing with a personal computer; however, the manipulated image files cannot be exported, saved, or printed.

The quality of the JPEG digital images were suitable for initial viewing and were useful to understand the location of the images with respect to the outside pipe or casing as a result of the photographic images inserted by QIS (see Figure 4-1).

The quality of the xry format images varied significantly. The clarity, contrast, and sharpness of most of the riser copper pipes were good. The conductor, edges of the cable core, and skid wires were clear in most cases.



**Figure 4-1**  
**Example JPEG File Image with Inserted Photographic Image**

The clarity, contrast, and sharpness of the digital images of the cables and joints in the trifurcator and normal joint casings varied from good to marginal in a few cases depending on the source

used (iridium 192 or cobalt 60), the distance from the radioactive source to the cables, and the exposure time. In most cases the quality of the images must be fine tuned with the Starlite viewing program to compensate for various levels of exposure in a given image. In most cases the edges of the cable high voltage conductor, and skidwires could be seen. The edges of the cable core, including the metal shielding tapes, were relatively clear in some images and “fuzzy” in other images.

It is PDC’s opinion that similar quality images of HPFF cables in steel pipes are obtained using the conventional photographic film and the newer digital radiographic imaging process. The primary advantages of the digital imaging process are:

1. Significantly shorter exposure times are required compared to conventional photographic film (typically 2.5 minutes vs. 30 minutes). The time savings for the digital imaging process is not very significant if radiographic inspection is performed at only one location. However, the shorter exposure time is a significant advantage when approximately 140 images are required.

The images can be manipulated with the Starlite computer program to compensate for under or over exposure. Adjustment of the image on photographic film is not possible other than changing the intensity of the viewing light.

Accurate dimension measurements can be made using the computer image viewing/manipulation software. A metal ball of known diameter (1.6875”) is placed in each of the images (see Figure 4-1) that is used to calibrate the measurement option of the image viewing software.

PDC recommends purchasing the full capability Starlite software if this inspection method is to be used in the future because it facilitates saving and printing of image files that have been enhanced with the tools in the program. A trial and error process is required to maximize the clarity of each of the images and this must be repeated each time that the image is viewed with the reduced capability software. This is because the modified images cannot be saved with the reduced capability software.

#### **4.1.2 Radiographic Inspection Locations**

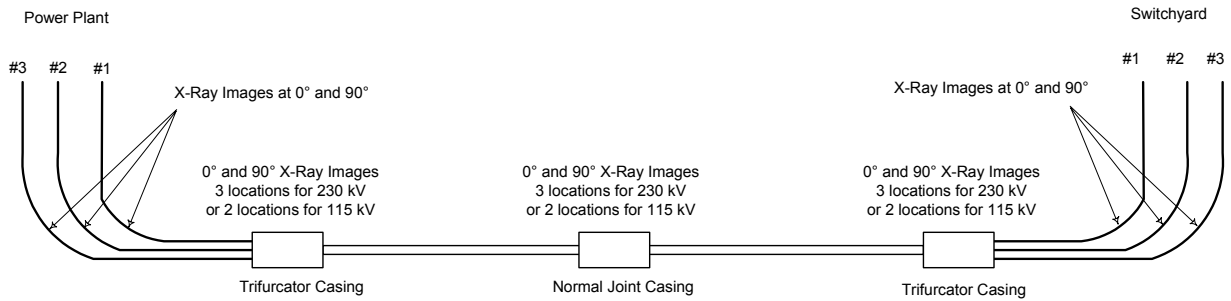
Table 4-1 contains a list of the radiographic inspections that were completed at the time that this report was prepared.

**Table 4-1  
Summary of RMPP and LPGA Radiographic Inspections Dates**

HPFF Cable Circuit	Under Load Operation	No-Load Operation
--------------------	----------------------	-------------------

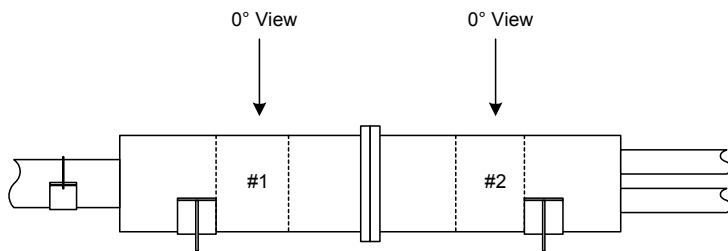
RMPP Circuit #3, 115 kV	1/5/05 – 1/6/05	6/5/06 6/6/06
RMPP Circuit #9, 230 kV	1/3/05 – 1/5/05	6/14/05 & 6/15/05
LPGP Circuit #2, 230 kV	1/7/05 – 1/10/05	3/16/05 & 3/17/05

The radiographic inspection process was performed at one location for each of the six riser pipes for RMPP #3, RMPP #9, and LPGP #2 cable circuits as shown in Figure 4-2. Two images were obtained at each of the six riser pipe locations. One image was taken in line with the main cable pipe (0°) and perpendicular to the main cable pipe (90°). The distances along the riser pipe from the trifurcator casing to the location of the image were noted in all cases.

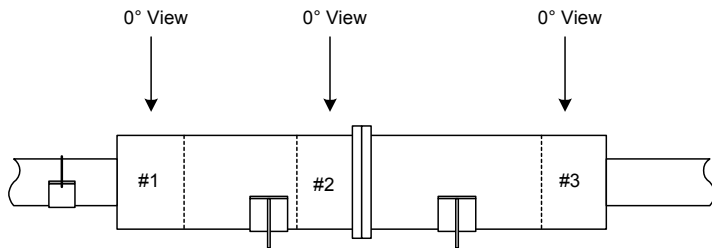


**Figure 4-2**  
**Radiographic Inspection Locations for Riser Pipes**

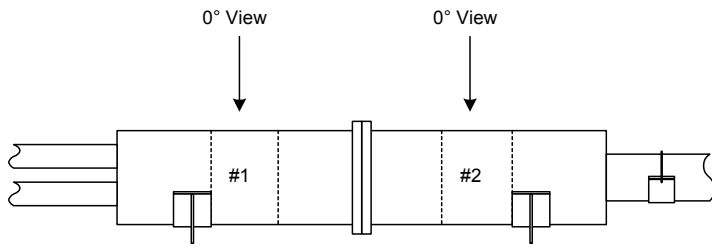
Radiographic inspections were performed at the ends and middle of the 7-foot long 230 kV joint and trifurcator casings. Radiographic inspections were performed at two locations of the shorter 115 kV casings. Figures 4-3 through 4-11 show the locations of the radiographic inspections for RMPP #3, RMPP #9, and LPGP #2 joint and trifurcator casings.



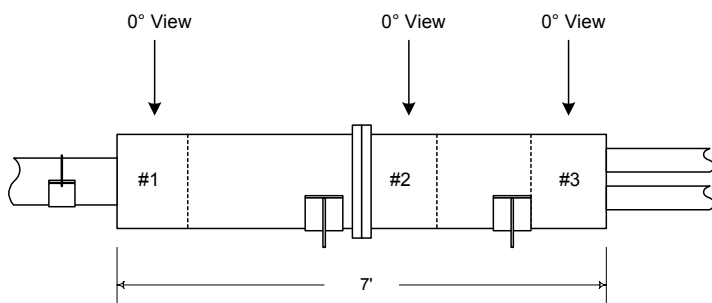
**Figure 4-3**  
**Radiographic Inspection Locations for RMPP #3 Generator End Trifurcator Casing**



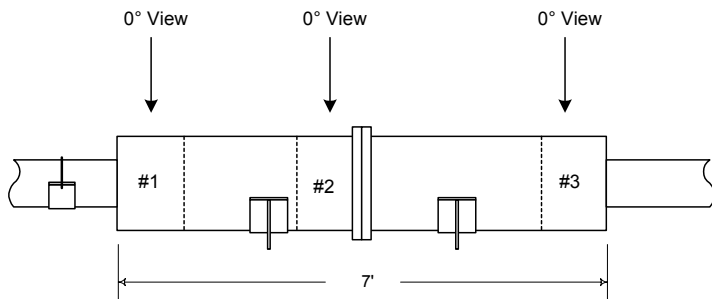
**Figure 4-4**  
**Radiographic Inspection Locations for RMPP #3 Normal Joint Casing**



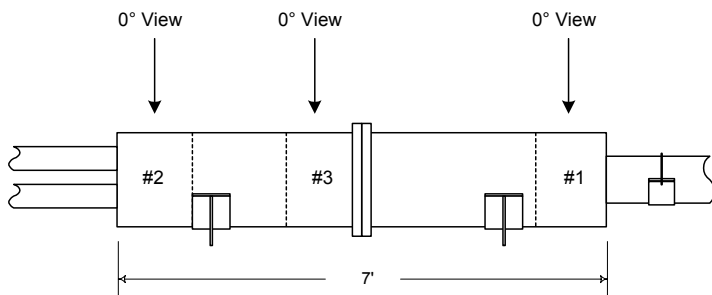
**Figure 4-5**  
**Radiographic Inspection Locations for RMPP #3 Switchyard End Trifurcator Casing**



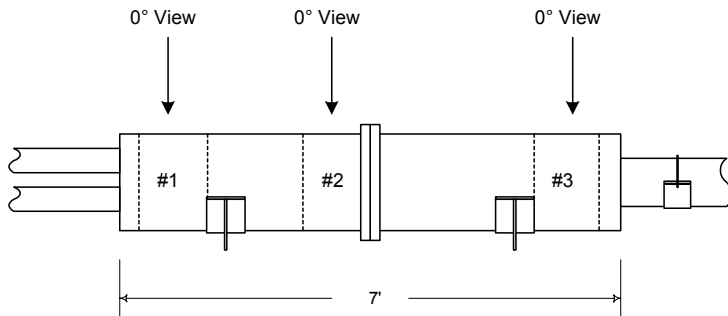
**Figure 4-6**  
**Radiographic Inspection Locations for RMPP #9 Generator End Trifurcator Casing**



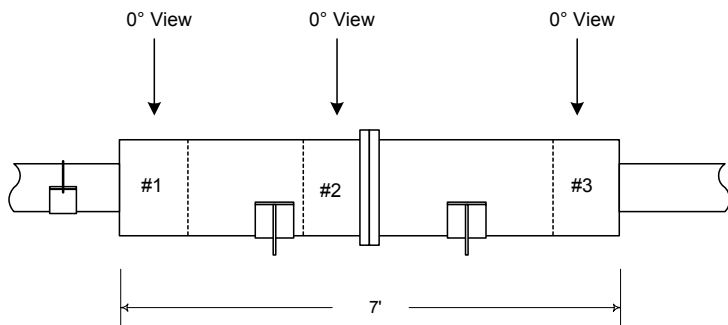
**Figure 4-7**  
**Radiographic Inspection Locations for RMPP #9 Joint Casing**



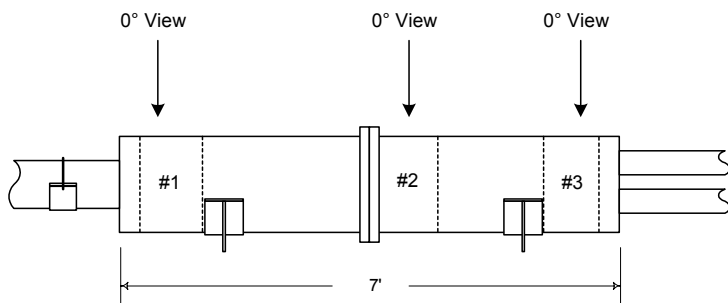
**Figure 4-8**  
**Radiographic Inspection Locations for RMPP #9 Switchyard End Trifurcator Casing**



**Figure 4-9**  
**Radiographic Inspection Locations for LPGP #2 Generator End Trifurcator Casing**



**Figure 4-10**  
**Radiographic Inspection Locations for LPGP #2 Joint Casing**



**Figure 4-11**  
**Radiographic Inspection Locations for LPGP #2 Switchyard End Trifurcator Casing**

### 4.1.3 Image Evaluation and Analysis Procedure

The following process was used to analyze the HPFF cable system digital images.

An initial pass was made through all of the digital images to learn to use the features of the software for viewing the xry format images, to become familiar with the locations where the

images were taken, and to resolve several inconsistencies between the annotations on the images and the images.

Each of the images was then viewed in more detail to check for:

Bending of the cables in the large diameter casings

Longitudinal movement of the cables within the joint and trifurcator casing.

Uneven spacing of the factory applied skid wires

Unintended objects in the riser pipes and casings

Roughness of the inside of the riser pipes

Displacement of the cable and joint metal shielding. Note: It was not possible to determine if the cable shielding tape or joint tinned braid has been displaced in a number of the joint and trifurcator casings because of low image quality.

Any other abnormalities

#### **4.1.4 Summary of Radiographic Image Analysis**

The following paragraphs summarize the results of the radiographic image analysis. Appendix A contains a complete listing of the digital images that were taken as of 8/24/05 including comments about observations and image quality.

##### Cable riser pipes

The primary objectives of the riser pipe radiographic inspections were to determine:

If there are any foreign objects in the riser pipes that may have damaged the cable during thermal expansion and contraction of the cables. The failure analysis of a recent 345 kV cable fault at the NYPA Blenheim-Gilboa facility indicated that the most likely cause of failure was the presence of metal fragments in the riser pipe from a previous termination repair.

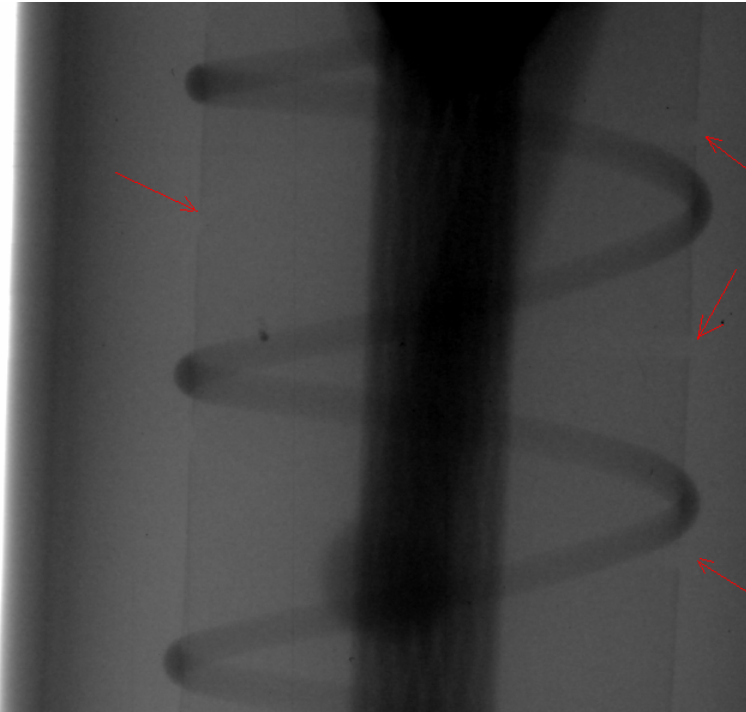
If there was any mechanical damage to the cables when they were pulled into the vertical bend of the riser pipes. Higher than normal pulling tensions may result in skidwire displacement and in some cases displacement of the shielding tapes.

If there are any signs of skidwire or pipe abrasion as a result of thermal expansion and contraction.

No abnormalities were observed at the locations where the radiographic inspections were performed.

The butgaps between the metal shielding tapes could be observed in some of the digital images (see Figure 4-12). The edges of the metal shielding tape (indicated by the arrows) are visible after image enhancement is performed. The butgap spacings were measured to be 0.1" with the

viewing software which is somewhat larger than typical (0.08"). However, the butt gap spacings were reasonably uniform in the area where they are visible indicating that there has not been any displacement of the tapes. The dark semi-circular object adjacent to the cable high voltage conductor in the lower part of the image and the dark area to the right of the cable conductor at the top of the image are portions of a metal C-clamp used to hold the image plate in place.



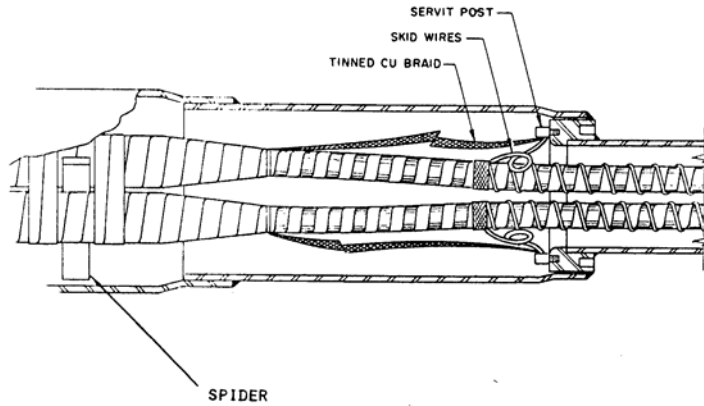
**Figure 4-12**  
**Image from LPGP Feeder #2 Generator Side Riser #2**

### Trifurcator and Joint Casings

The x-ray images show that the joints and cables are supported and mechanically restrained in their casings by binding the three joints or cables to a single spider located near the midpoint of the casings. Although this was standard practice for restraining the cable joints at the time that the cables were installed, current practice is to use multiple spiders to minimize flexing of the cables between the ends of the casings and the ends of the joints. The multiple joint restraints are to prevent thermal-mechanical bending (TMB) cable failures that were observed on 345 kV HPFF cable systems in the late 1970's. Most of the TMB failures occurred in 345 kV cable systems; however, TMB failures have been reported for 230 kV HPFF cable systems by Public Service Electric and Gas and the Los Angeles Department of Water and Power (LADWP).

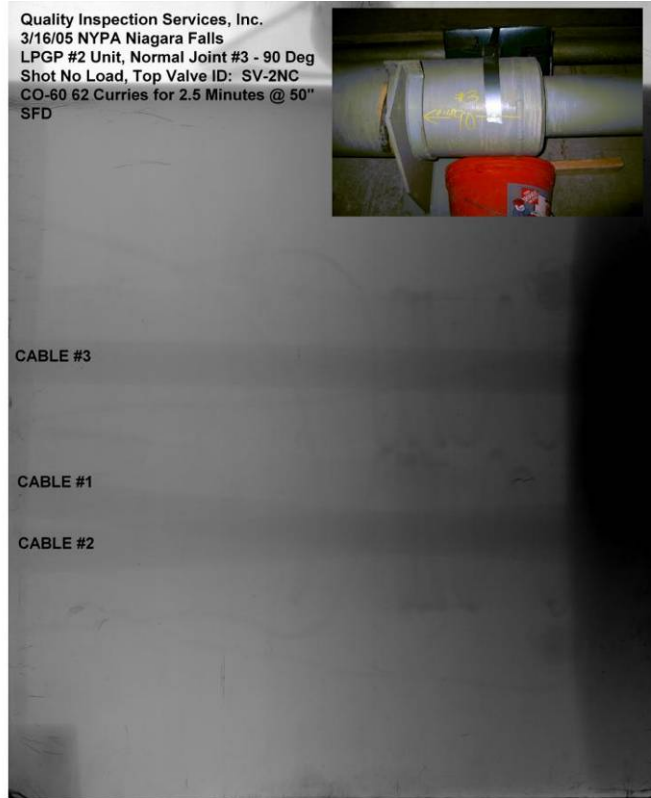
The cable skidwire termination and grounding in the normal and trifurcator joint casings for the RMPP and LPGP cable circuits are somewhat unusual at RMPP and LPGP. Figure 4-13 shows the most common method for terminating the cable skid wires in HPFF transmission cables. As shown in Figure 4-13, the skidwires are typically connected to a servit post located on the face of the closest pipe reducer. Figure 4-13 shows an x-ray image of the RMPP #9 generator side (joint) trifurcator casing. The x-ray images for all of the joint casings indicate that the skid wires are

connected to servit posts located on the pipe reducers at the opposite end of the joint casing. There is a considerable amount of slack in some of the skidwires as they run from one end of the joint casings to the opposite end. It appeared during the first pass review of the digital images that some of the cable skid wires are loose and unrestrained in the casings; however, further review of the images indicated that the skid wires are not loose in the casing.

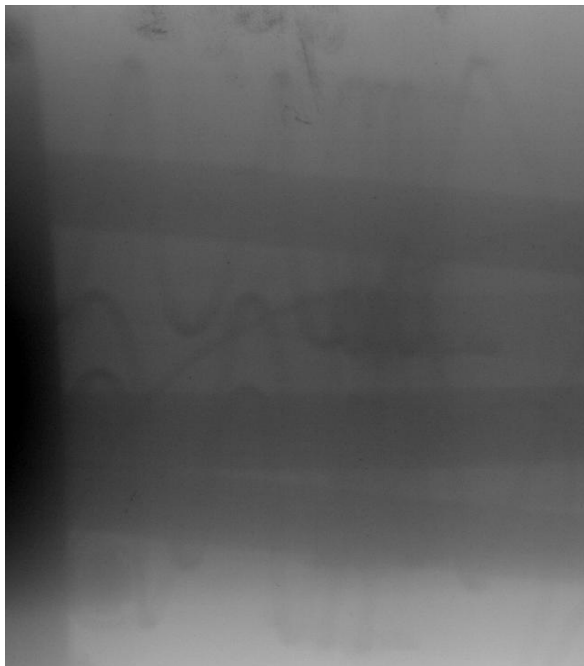


**Figure 4-13**  
**Typical Details of HPFF Cable Skidwire Termination**

The cables should be gradually bent in the areas where there are transitions between the end of the casing and the end of the joint or spider. This appeared to be the case for all locations except for the LPGP #2 joint casing at location #1 (See Figure 4-15) and the trifurcator casing #3 (See Figure 4-17).



**Figure 4-14**  
LPGP #2 230 kV HPFF, Normal Joint Casing, Location #3



**Figure 4-15**  
LPGP #2, 230 kV, Normal Joint Casing, Location #1 (Under Load)



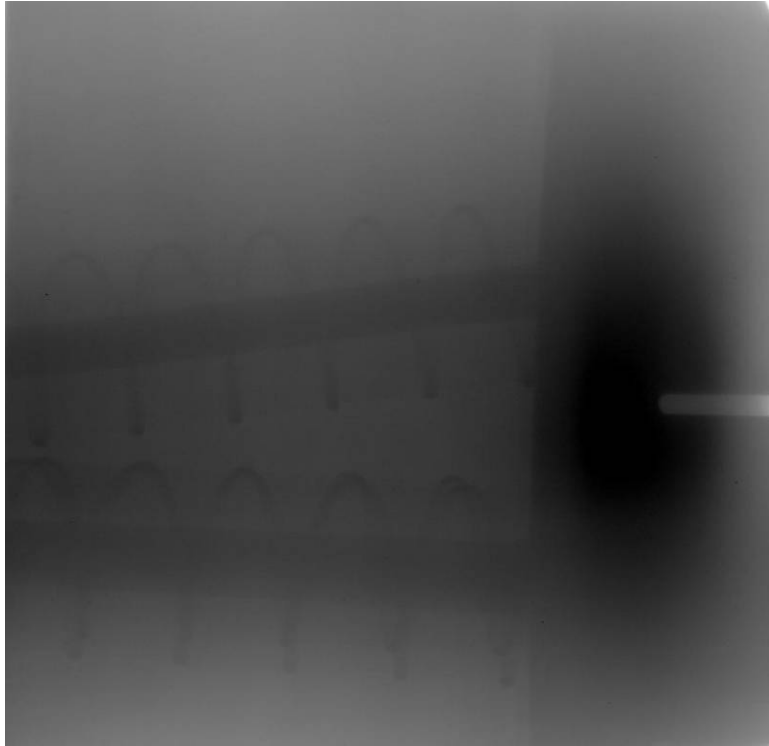
**Figure 4-16**  
**LPGP #2, 230 kV, Normal Joint Casing, Location #1 (No Load)**

A comparison of Figures 4-15 and 4-16 show that a significant amount of bending occurs in the cables at one end of the LPGP#2 normal joint casing when the operating condition goes from no load to normal load condition. PDC recommends repeating the under load radiographic inspection for four LPGP 230 kV normal joints when the corresponding hydro motor/generator units are operating at full load (motoring) to determine if there is significant cable bending in the joint casing.

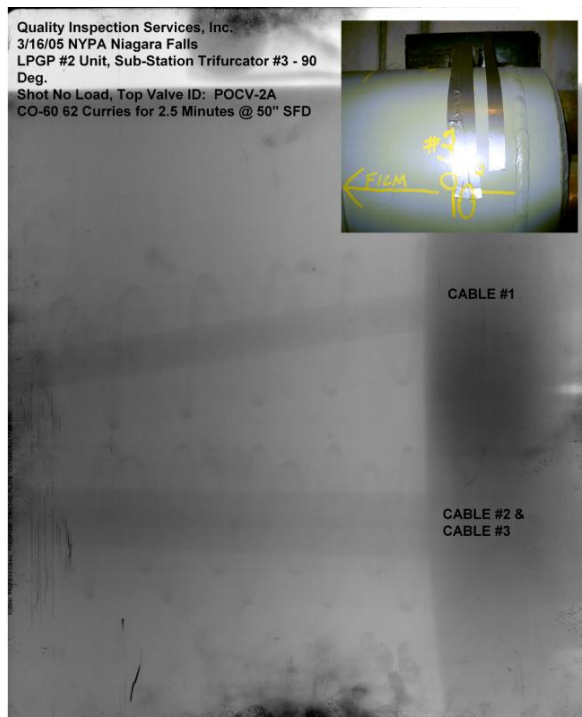
One of the cables in the LPGP substation end trifurcator casings has a significant amount of bending; however, the cable appears to be little difference between the hot (under load) and cold (no load) operating conditions. This being the case, there is a relatively small amount of thermal mechanical bending as the cable expands and contracts.

Intermittent gaps were observed in many images for RMPP cable #3 (see figure 4-19) that appear to be the interface between adjacent conductor segments. The gap does not appear to be continuous in the images because of the spiraling of the segments.

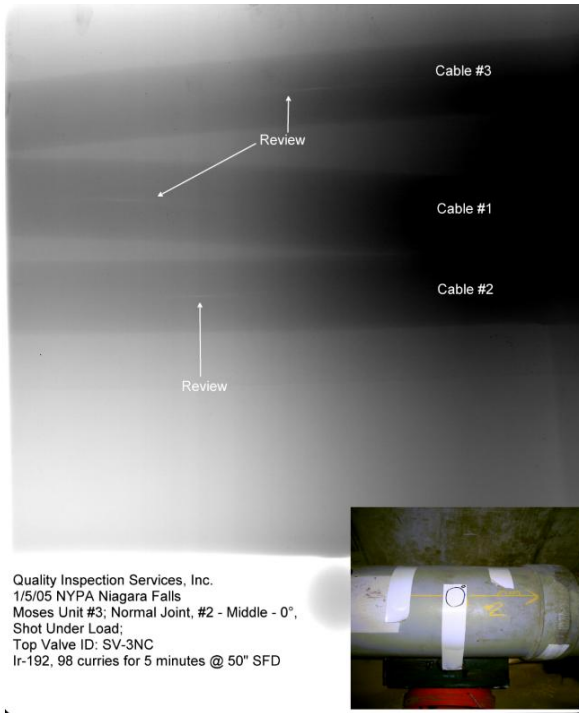
All of the cable joints appeared to be approximately centered in the casings indicating that there has not been a significant amount of movement from the time that the splices were completed.



**Figure 4-17**  
**LPGP #2, 230 kV, Substation Trifurcator Casing, Location #3 (Under Load)**



**Figure 4-18**  
**LPGP #2, 230 kV, Substation Trifurcator Casing, Location #3 (No Load)**



**Figure 4-19**  
**RMPP #3 Gaps in Conductor Segments**

## 4.2 DGA and Fluid Tests

Detroit Edison (DECO) performed DGA and other pipe filling fluid condition assessment tests on each HPFF cable circuit at the Niagara Power Project to assess their condition. Initial sampling of the HPFF transmission cables was performed under the direction of DECO and subsequent sampling was by NYPA personnel using equipment provided by DECO.

The initial plan was to collect samples of the dielectric fluid at the joints, trifurcators, and terminations of all of the RMPP 120 and 230 kV circuits and the LPGP 230 kV circuits. However the following modifications were made to the planned fluid sampling program.

It was discovered during the initial dielectric fluid sampling on December 13 and 14, 2005 that none of the 115 kV and 230 kV HPFF terminations are fitted with sampling valves at the top of the terminations. Since valves are necessary to dielectric fluid samples from the top of the cable terminations, the sampling program had to be modified until valves can be installed on the terminations. At the present time the termination sampling has been limited to two of the generator end terminations on RMPP #9.

NYPA personnel collected fluid samples from the 345 kV HPFF cable systems and DECO performed DGA testing of these samples.

Dielectric fluid sampling, with the exception of the terminations, was performed with cable circuits energized.

The DGA testing and dielectric fluid quality testing on Niagara Power Project circuits consisted of the following tests:

1. Measurement of the dissolved gas content of 14 gases using gas chromatography
2. Perform laboratory testing of the dielectric fluid samples to measure the following parameters
  - Moisture content
  - Dielectric breakdown strength
  - Dissipation factor at 100 °C
  - Furfural content
  - Peroxide content
  - Acidity

DECO's report describing the details of HPFF cable system dielectric fluid sampling using the EPRI EDOSS method, fundamentals of HPFF cable aging, dissolved gas analysis, results of DECO's laboratory tests, and DECO's evaluation of the test results are contained in Appendix B of this report. The following sections summarize the results of the DGA and dielectric fluid test results.

#### **4.2.1 RMPP 115 kV and 230 kV Trifurcator Casings**

Tables 4-2 and 4-3 show the DGA test results for the RMPP HPFF cable systems for samples taken at the switchyard and generator end trifurcator casings. Of all the 26 trifurcators, both with and without a splice, acetylene was observed only at cable #4 switchyard trifurcator. The acetylene content of the sample from this trifurcator was 1 ppm. This is a 115 kV trifurcator, and it has no splice. Acetylene comes solely from the dielectric fluid and is the result of electric arcing. It is noteworthy that cables per se rarely yield acetylene, and this trifurcator has no splice. The source of this acetylene likely lies in the termination located close by or the riser pipe (s). This underscores the need for fluid sampling and DGA testing of RMPP cable #4 terminations. The sampling of this termination will also take care of the status of the cable in the riser. It should be pointed out that 115 kV HPFF terminations have experienced more problems than their splices and even cables based on industry record.

The concentration of carbon monoxide is extremely low, demonstrating that the cable paper has hardly experienced any aging thus far, and the conductor temperatures involved have been modest. Likewise, the observed levels of carbon dioxide are also quite low. The high ratio of carbon dioxide to carbon monoxide also supports lack of aging, the higher this ratio, the better it is; a ratio of around 10 or more is excellent. Such a high ratio also indicates that there is no paper trouble and the cellulose insulation is sound. The relationship of the carbon dioxide concentration to the EPRI Waltz Mill findings shows that the life of these cables would exceed 100 years at the present loading conditions from the standpoint of the aging of paper insulation, a

critical consideration. It is assumed that no unusual or sudden problems will arise. Such problems are not generally expected in 115 kV HPFF cables.

A higher ethane to ethylene ratio is desirable, higher the better; it is implicit that these two gases are evolving from the insulating system. Of all the ratios associated with the 26 trifurcators, the smallest ethane to ethylene ratio was observed at RMPP cable #4 switchyard trifurcator (4.2/2.1 = 2), the only trifurcator that showed acetylene. This is in accord with EPRI investigations at DECO laboratories that ethylene generation is associated with acetylene.

The type, distribution and concentration of other gases are in order, except the case for RMPP cable #11 switchyard trifurcator. However, the high levels of hydrocarbon gases shown in column 12 of Table 4-2 have not evolved from the insulation system. The relatively high concentrations of saturated hydrocarbon gases (methane, ethane, propane, even isobutene and n-butane) are due to the contamination of the original fluid for 230 kV cables through the nitrogen blanket containing these saturated hydrocarbons, readily available at refineries. DECO has countered this situation at a handful of utilities where several earlier cables manufactured in the 1960s were involved. In a few such instances DECO also observed high levels of unsaturated hydrocarbon gases such as isobutylene and propylene. In earlier days, the purity of nitrogen blanket was not specified. The high solubility of such gases does not permit ready elimination under degassing conditions. The observed levels of these gases are too low in relation to their solubilities to present any problems during inadvertent loss of pressure.

The effect of this fluid in RMPP cable #11 switchyard trifurcator is also present for cables 9, 10, 12 and 13 for the 230 kV system, as shown by relatively higher gas contents compared to the rest of cables. It is noteworthy that the RMPP cable #11 trifurcator at the other end is completely free of such gases. This demonstrates that this fluid volume was confined to the switchyard end of RMPP cable #11.

**Table 4-2**  
**Dissolved Gas Content (ppm) RMPP Switchyard End Trifurcators**

Gas	RMPP Cable System												
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
Methane	9.2	12	12	15	11.5	10	13	16	199	140	9,343	124	28
Ethane	4.2	6.6	7.5	4.2	4.5	3.6	5.3	5.5	97	67	5,058	59	35
Ethylene	0.8	1.8	1.3	2.1	1.2	1.0	1.5	3	28	52	1,226	14	4.2
Acetylene	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propane	6.5	10	13	5.0	5.1	8.1	9	4.5	111	54	7,491	77	83
Propylene	2.5	4.0	4.3	3.1	2.6	3.5	2.8	3.1	71	49	4,001	43	15
Isobutane	0.0	0.0	0.0	2.4	1.8	0.0	0.6	0	20	8.9	1,273	12	5
n-Butane	0.6	0.7	1.0	1.2	0.8	0.6	1.6	0	13	6.6	909	9.1	6.6
t-2-Butene	0.2	1.1	0.6	0.4	0.4	0.7	0.3	0.9	20	15	1,259	14	4.2
1-Butene	0.0	0.0	0.0	0.5	0.4	0.0	0.0	0	1.8	0.9	116	1.2	0
Isobutylene	0.0	1.1	1.0	2.9	2.2	1.6	1	3.5	168	109	13,133	127	27
Hydrogen	185	225	188	139	233	121	135	158	141	211	414	110	121
C. Monoxide	12	17	6.9	3.9	11	4.4	7.3	9.7	16	9.5	28	14	19
C. Dioxide	108	250	208	245	295	105	100	147	163	183	144	171	142

**Table 4-3**  
**Dissolved Gas Content (ppm) RMPP Generator End Trifurcators**

RMPP Cable System													
Gas	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
Methane	9.8	7.9	11	14	14	16	11	19	13	13	9.9	12	51
Ethane	9.7	3.8	4.4	4.1	4.9	13	3.9	8.9	5.5	5.8	3.7	4.5	31
Ethylene	2.4	1.3	1.3	1.2	1.3	1.9	1.1	1.1	1.1	1.2	0.7	0.8	5
Acetylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propane	27	8.6	7.2	5.2	8.1	31	5.1	13	7.4	8.3	4.7	5.2	52
Propylene	5.4	3.5	3.2	2.6	3.1	8.3	2.0	6.6	3.5	3.2	1.6	2.0	22
Isobutane	1.9	0	0	0	0	0	0	1.8	2.6	0	0	0.0	8.6
n-Butane	2	0.6	0	0	0.5	1.8	0	1.6	0.8	0	0	0.0	6.8
t-2-Butene	1.3	0	0	0	0	1.4	0	2.1	0.8	0.7	0	0.0	7.4
1-Butene	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0
Isobutylene	7.2	2.9	2.7	3	3	4.3	2.3	16	8.2	3.4	2.4	2.7	73
Hydrogen	96	134	348	278	248	116	370	124	146	192	195	205	73
C. Monoxide	5.6	8.3	6.5	12	17	16	14	18	13	11	12	13	15
C. Dioxide	150	169	176	455	126	297	155	201	110	137	133	128	142

#### 4.2.2 RMPP 115 kV and 230 kV Normal Splice Casings

Table 4-4 shows the DGA test results for the RMPP HPFF cable systems for samples taken at the normal joint casings. Of all the 13 RMPP splices, only the splice associated with RMPP cable #1 shows some acetylene, at 0.5 ppm. Normally operating splices should not show any acetylene. This low level of acetylene does not pose a concern, particularly at 115 kV operation. However, considering the importance of these cables, associated as they are with a power plant, it is recommended to move a small amount of fluid (no more than 10 gallons) to establish if this acetylene is originating away from the middle of the splice (sampling port) toward the end of the splice, where the cable-splice interface is located. The remaining gases for cable system #1 and the remaining splices are in sound order. Because of the presence of a small amount of acetylene at cable #1, the ethane to ethylene ratio effect discussed in Table 4-2, holds here too. It is one of the two highest ratios.

**Table 4-4  
Dissolved Gas Content (ppm) RMPP Normal Joint Casings**

RMPP Cable System													
Gas	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
Methane	8.6	14	13	10	10	13	8.7	7.3	9.4	12	8.8	14	10
Ethane	4.0	6.2	5.1	4.0	3.0	6.2	2.3	2.1	4.5	5.8	3.2	9.4	6.7
Ethylene	1.5	1.5	1.3	1.8	1.0	2.2	1.0	0.4	0.9	1.1	0.9	1.5	0.8
Acetylene	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propane	7.4	8.9	8.0	5.9	4.2	14	3.5	2.6	7.4	9.6	4.4	17	10
Propylene	2.1	4.0	2.3	2.4	1.9	3.8	1.3	1.2	2.3	2.6	1.3	3.1	2.4
Isobutane	0.0	0	0	1.3	0	0	0	0	0	0	0	0	0
n-Butane	0.6	1	0.5	0.7	0.5	0.7	0.4	0	0.5	0.7	0	1.0	0.6
t-2-Butene	0.0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	0.0	0	0	0	0	0	0	0	0	0	0	0	0
Isobutylene	0.4	6.4	2.4	3.6	3.1	2.9	2.7	1.7	2.6	1.5	2.1	2.5	2
Hydrogen	87	68	61	65	66	76	83	149	215	192	279	155	109
C. Monoxide	4.2	16	19	20	22	17	19	32	68	29	22	75	36
C. Dioxide	116	172	158	188	185	218	158	115	152	141	149	172	112

### 4.2.3 LPGP 230 kV Cable Systems

Table 4-5 shows the DGA test results for the samples taken from the LPGP cable systems. As shown in this table, acetylene, the single most diagnostic gas is not present in the trifurcators or splices. The type, distribution and concentration of all other gases demonstrate that the 230 kV LPGP cables and splices are operating satisfactorily, not posing any concern. The low values of hydrogen and all hydrocarbon gases are particularly noteworthy. It would be better to see higher carbon dioxide to carbon monoxide ratios for splices, similar to the case of LPGP Unit #1 splice (column 10). Combined with the levels of other gases, the relatively poor ratio of carbon dioxide to carbon monoxide does not cause any concern. However, it is recommended to re-sample cable #2 and cable #3 splices in the future.

The high levels of saturated and unsaturated hydrocarbon gases (column 4, cable #3) are due to the original contamination of the original pipe fluid, as discussed for Table 4-2.

**Table 4-5**  
**Dissolved Gas Content (ppm) LPGP 230 kV Cable Systems**

Gas	LPGP Cable System											
	Generator End Trifurcator Casings				Switchyard End Trifurcator Casings				Joint Casings			
	#1	#2	#3	#4	#1	#2	#3	#4	#1	#2	#3	#4
Methane	120	11	2793	3.3	67	5.4	16	17	6.8	5.6	32	6.9
Ethane	79	7.6	2363	3.2	43	3.9	13	11	3.4	2.6	25	2.5
Ethylene	4.5	2.9	574	0.5	8.7	0.8	5.3	3.3	0.7	0.8	6.3	0.4
Acetylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propane	127	14	3108	4.5	83	6.1	19	18	9.2	4.6	33	4.5
Propylene	36	6.8	2199	1	20	2.2	7.0	8.3	2.3	1.5	23	1.1
Isobutane	15	0	486	0	6.4	0	1.2	2.2	0	0	5.1	0
n-Butane	16	1.1	423	0	7.4	0	1.6	2	0.6	0	3.8	0.7
t-2-Butene	17	0	643	0	5.2	0	0	0	0	0	6.1	0
1-Butene	0	0	0	0	0	0	1.5	1.7	0	0	0	0
Isobutylene	83	1.1	3022	1.9	19	1.7	5.7	12	2.5	2.2	26	1.9
Hydrogen	109	116	185	121	69	69	140	63	101	62	131	92
C. Monoxide	31	73	25	10	23	56	67	47	27	58	48	47
C. Dioxide	119	143	140	104	162	144	109	166	173	160	126	135

### 4.2.4 115 kV Trifurcators Associated with Auto Transformer

Table 4-6 shows the DGA results on additional 115 kV HPFF cables. The absence of acetylene and the very low concentrations of other gases show that these four cables are operating satisfactorily. The samples taken at Bay 19 (columns 2 and 3) showed relatively high hydrogen concentrations at 652 ppm and 930 ppm, as compared to any other 115 kV cable at the Niagara Power Project. A hydrogen concentration of a few thousands ppm is deemed acceptable, particularly when all the other gases have low concentrations. This indicates that the cables are operating satisfactorily.

**Table 4-6**  
**Dissolved Gas Content (ppm) 115 kV Trifurcators Associated with Auto Transformer**

Gas	Trifurcator		Pressure Switch	
	Auto 2A	Auto 2B	Auto 2A	Auto 2B
Methane	9.7	9.9	12	10
Ethane	6.6	5.4	12	8
Ethylene	2.7	2.3	2.8	2.4
Acetylene	0.0	0.0	0.0	0.0
Propane	9	6.3	18	10
Propylene	4.6	3.5	6.9	5.1
Isobutane	0	0	1.2	0
n-Butane	0.5	0	1.2	0.7
t-2-Butene	0	0	0	1
1-Butene	0.9	0	1.2	0
Isobutylene	7.6	1.9	15	3.7
Hydrogen	652	930	143	154
C. Monoxide	17	26	16	19
C. Dioxide	230	248	175	164

#### 4.2.5 345 kV Cables

Table 4-7 shows the DGA data for the 345 kV cable systems. The DGA data for the three phases of the 345 kV cable associated with autotransformer #3 are provided in columns 2, 3 and 4. The absence of acetylene is noteworthy. While all the gases are in sound order, the ratio of carbon dioxide to carbon monoxide is not desirable. As pointed out earlier, the concentration of carbon dioxide should be much higher than that of carbon monoxide. It is seldom reversed in cables, as is the case. The low concentrations of all hydrocarbon gases reduces the concern posed by the behavior of carbon monoxide and carbon dioxide. We have observed quite high levels of hydrogen in riser pipes but not the reverse carbon oxides ratio. The present hydrogen concentration is quite small. Nevertheless, the highest hydrogen level (519 ppm) observed in the three phases corresponds to the case of the lowest carbon dioxide to carbon ratio (0.66). It is recommended to resample these three 345 kV locations, including the terminations.

The DGA data for the 345 kV circuit related to autotransformer #5 (column 5) and the two 2-piped circuits (columns 6 to 9) indicate that all the 345 kV cables, which have circulating fluid, are operating satisfactorily. It is also recommended to sample these circuits, if the circulation is stopped for some reason. The associated terminations should also be sampled. The high carbon dioxide-to-carbon monoxide ratios are noteworthy in columns 5 to 9.

**Table 4-7**  
**Dissolved Gas Content (ppm) 345 kV Cables Associated with Auto Transformers 3 & 5**

	Generator End Trifurcator Casings				Pressure Switches (PA) 538			
	#1	#2	#3	#4	#1	#2	#3	#4
Gas	Auto #3			Auto #5	301-1	301-2	302-1	302-2
Methane	13	20	19	23	9.9	9.2	11	11
Ethane	20	26	18	20	18	18	21	21
Ethylene	3.2	4.1	3.1	2.4	1.4	1.2	1.5	1.3
Acetylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propane	60	73	53	47	57	57	62	65
Propylene	9.5	13	9.8	7.5	6.9	6.9	7	7.1
Isobutane	2.9	2.9	2.2	2.5	2.4	3.3	2.9	3
n-Butane	2.8	3.5	2.5	2.2	2.7	2.7	3	2.7
t-2-Butene	0	1	1.1	0	0	0	0	0
1-Butene	0.7	0.2	0	0	0	0	0	0
Isobutylene	3.7	1.4	4.6	13	3.8	4.2	3.9	3.9
Hydrogen	519	441	233	253	80	89	98	103
C. Monoxide	291	363	418	13	14	13	13	13
C. Dioxide	194	285	314	172	191	182	189	178

#### 4.2.6 RMPP Cable Terminations

DGA results on 115 kV Phase A and Phase B terminations at RMPP cable #9 generator end were excellent. However, it is essential to take 2-3 samples, as the fluid is drawn to take care of the entire termination length. This procedure should be adopted for the missing Phase C and all other terminations.

**Table 4-8**  
**Dissolved Gas Content (ppm) RMPP Cable System #9 Generator End Cable Terminations**

Gas	Phase A	Phase B
Methane	15	35
Ethane	8.5	21
Ethylene	1.8	3.0

Gas	Phase A	Phase B
Acetylene	0.0	0.0
Propane	11	28
Propylene	4.1	10
Isobutane	0.0	1.8
n-Butane	1.0	2.0
t-2-Butene	0.0	0.0
1-Butene	0.9	1.6
Isobutylene	6.6	13
Hydrogen	150	129
C. Monoxide	11	18
C. Dioxide	208	269

#### 4.2.7 Dielectric Fluid Condition Assessment Tests

Table 4-9 shows the results of the dielectric fluid condition assessment tests on the RMPP 115 kV switchyard end trifurcators (cable #1 to cable #7) and RMPP cable #1 splice from 2004. Table 4-10, 4-11, and 4-12 contains the results of the remaining dielectric fluid condition test results for the RMPP cables that were performed in 2006. Table 4-13 contains the results of the dielectric fluid quality tests for the LPGP 230 kV HPFF cable systems performed in 2006.

The moisture data is excellent. The non-detectable (nd) or low furan levels, indicating a lack of thermal aging of the cable insulating paper tapes. The non-detectable peroxide content also supports the earlier comments that the quality of the original oil was excellent. The neutralization number, which is a measure of fluid oxidation through the formation of oxidizing species during operation, is even well below the specified value (0.03) for new mineral oil. The excellent value of neutralization number obviates the need for IFT (interfacial tension).

The pipe dielectric fluid dissipation factor values for most of the RMPP and LPGP cables are somewhat higher than recommended by most industry guides and specifications. AEIC CS31-95 (Specification for Electrically Insulating Low Viscosity Pipe Filling Liquids for High-Pressure Pipe-Type Cable) specifies a maximum DF at 100 °C is 0.1 percent is for new low and high viscosity dielectric fluids. This specification does not include the medium viscosity type utilized at NYPA. However, ASTM 1819, 1971, specifies a maximum DF of 0.6 percent at 100 °C for the medium viscosity oil (750 to 800 SUS). Since it is easier and cost-effective to treat low viscosity oils (50-60 SUS) than higher viscosity oils (750-800 SUS), lower DF values are readily attainable with the former. It is noteworthy that some leading utilities have specified a higher maximum value than 0.6 percent at 100 °C medium viscosity oils.

DECO considers the observed dissipation factor values at 100 °C to be acceptable for in-service mineral oils. Such values have been sometimes observed for satisfactorily operating HPFF cable systems. It would be desirable to have lower DF values than those reported for the NYPA RMPP and LPGP cable systems, as typical values for both polybutene/polubutene-alkylbenzene blends and mineral oils range from 0.4 to 0.7 percent at 100 °C. Nevertheless, it is DECO's opinion that oil treatment is not necessary for many reasons, such as quality of other fluid tests, nature of relatively high viscosity mineral oil and industry experience. It should be kept in mind that DF of the much higher viscosity impregnant is expected to be higher than that of typical pipe fluids. In fact, DF data presented in Sun Oil's publications are always about twice the corresponding values of its pipe fluids. The limited volume of pipe fluids in power plants HPFF cables, unlike what is available on the transmission grid, tends to accentuate the DF value; it was also observed at St. Lawrence Hydro Plant. It should be added that the carbon-loaded insulation shielding acts as a good filter to trap many impurities and the mixing of the pipe and impregnating fluids is confined primarily to outer layers.

**Table 4-9**  
**Dielectric Fluid Condition Assessment Tests for RMPP Switchyard End Trifurcators (2004)**

	#1	#2	#3	#4	#5	#6	#7	Pressure Switch
Moisture(ppm)	3.01	2.32	2.64	2.59	2.93	nd	2.69	2.635
Dielectric Strength (kV) ASTM(D877)	31.0	35.8	46.9	35.3	46.4	44.9	37.1	29.5
% DF@100 °C	0.844	1.381	1.291	1.037	1.342	1.367	1.316	1.157
Peroxide Content (ppm)	nd	nd	nd	nd	nd	nd	nd	nd
Neutralization No.(mg/g)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Furans (ppb)	nd	nd	nd	nd	nd	nd	nd	nd

**Table 4-10**  
**Dielectric Fluid Condition Assessment Tests for RMPP Switchyard End Trifurcators (2006)**

	#8	#9	#10	#11	#12	#13
Moisture(ppm)	2.5	4.78	3.21	4.01	2.31	3.91
Dielectric Strength (kV) ASTM(D877)	43.4	47.8	40.9	44.5	45.6	43.7
% DF@100 °C	1.580	2.108	1.896	1.962	2.055	1.669
Peroxide Content (ppm)	nd	nd	nd	nd	nd	nd
Neutralization No.(mg/g)	0.01	0.01	0.01	0.01	0.01	0.01
Furans (ppb)	nd	1.3	nd	nd	1.2	nd

**Table 4-11**  
**Dielectric Fluid Condition Assessment Tests for RMPP Generator End Trifurcators (2006)**

	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
Moisture(ppm)	5.37	3.51	3.30	4.01	5.34	3.89	5.27	5.21	3.45	2.92	3.88	2.71	3.22
Dielectric Strength (kV) ASTM(D877)	44.3	42.1	42	44.3	43.6	42	44.9	47.5	47.8	42.1	46.6	40.8	46.7
% DF@100 °C	1.104	1.078	1.223	1.037	1.241	1.500	1.117	0.932	1.210	1.210	1.712	1.949	1.421
Peroxide Content (ppm)	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Neutralization No.(mg/g)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Furans (ppb)	1.2	nd	1.1	nd	nd	nd	nd	1.1	nd	nd	nd	1.1	nd

**Table 4-12**  
**Dielectric Fluid Condition Assessment Tests for RMPP Pressure Switch Location (2006)**

	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
Moisture(ppm)	2.94	3.01	2.44	3.56	2.96	3.62	3.06	3.61	2.94	4.01	3.25	3.49	3.07
Dielectric Strength (kV) ASTM(D877)	55.2	53.7	55.2	52.8	53.3	51.3	49.8	54.0	48.6	50.1	47.7	44.0	45.4
% DF@100 °C	0.932	0.893	0.972	0.893	0.893	1.17	0.919	0.715	1.210	1.447	1.381	1.685	2.319
Peroxide Content (ppm)	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Neutralization No.(mg/g)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Furans (ppb)	1.2	nd	nd	1.4	nd	nd	1.3	1.1	1.2	nd	nd	1.3	1.4

**Table 4-13**  
**Dielectric Fluid Condition Assessment Tests for LPGP Cable Systems (2006)**

	Switchyard End Trifurcators				Generator End Trifurcators				Switchyard End Pressure Test			
	#1	#2	#3	#4	#1	#2	#3	#4	#1	#2	#3	#4
Moisture(ppm)	3.30	3.52	2.94	4.79	3.02	2.91	4.01	3.12	3.45	3.91	3.42	3.61
Dielectric Strength (kV) ASTM(D877)	42.9	47.2	55.2	49.0	52.8	49.3	59.2	56.6	57.9	53.1	57.0	54.5
% DF@100 °C	1.104	1.019	0.735	1.170	1.024	1.154	1.21	0.919	0.418	0.629	0.497	0.435
Peroxide Content (ppm)	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Neutralization No.(mg/g)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Furans (ppb)	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

The breakdown values for RMPP cables #2 through cable #7 are well above the specified (30 kV) level for new mineral oil of this vintage. The values for RMPP cable #1 trifurcator, particularly the cable #1 splice, are somewhat marginal compared to the specified value for new oil. However, it should be pointed out that these values are acceptable for in-service fluid.

The dielectric fluid breakdown values for all of the LPGP 230 kV HPFF cable systems (Table 4-13) are excellent.

#### 4.2.8 Conclusions and Recommendations

DECO's recommendations and conclusions based on the results of the DGA tests are:

1. Based on the carbon oxides and furfural contents, it is concluded that the sampled cables and the splices (115 kV, 230 kV and 345 kV) per se have not experienced any aging. The generated DGA and Fluid data show that the sampled cable systems are operating in a satisfactory manner. However, some follow-up action is needed to ensure continued trouble-free operation.
2. The low value of acetylene at RMPP cable #1 115 kV splice does not pose a concern. At a convenient time, this acetylene should be followed up to establish its maximum level along the splice through limited fluid drainage (5-8 gallons) in 2-3 installments and corresponding gas measurements. This was done at the B-G plant to locate the source of acetylene at Feeder #3, Generator end, with success.

3. The acetylene situation at RMPP unit #4 trifurcator (115 kV) calls for relatively faster resolution. The sampling of unit #4 switchyard terminations will not only resolve the observed acetylene at this trifurcator but also establish the condition of the termination.
4. It is essential to employ a pipe fluid that has minimum dissolved gases and avoid high saturated hydrocarbon gases, as observed in two RMPP units. The presence of such gases in the original fluid can complicate the DGA interpretation process. The measurement of original gas content is recommended.
5. It is recommended to resample LPGP splices at units #2 and #3. While they do not pose any concern, it will be prudent to resample them at a convenient date.
6. Because of reverse ratio of carbon dioxide to carbon monoxide, it is recommended to resample the riser pipes of 345 kV cable associated with Auto-Transformer #3.
7. It is recommended to remove the corona dome at Phase C termination at RM Unit #9, generator end so that this termination can be sampled for DGA, like the other terminations (Phases A and B) at this location.
8. Of all the recommended actions, the sampling of all terminations is the most important one. It is essential to take three samples from each termination, as the fluid is drained, to take care of the entire termination through DGA.
9. The fluid sampling of the terminations for oil quality tests would also shed light on the higher dissipation factor values that were observed.

It should be noted that there are varying opinions concerning acceptable limits for the 100 °C dissipation factor for HPFF transmission cable pipe filling fluids. DECO considers the 100 °C dissipation factor values shown in Tables 4-9 through 4-13 to be acceptable for in-service mineral oils based on DECO's experience. However, IEEE Standard 1406-1998 (Guide to the Use of Gas-In-Fluid Analysis for Electric Power Cable Systems) contains the following recommendation in (Section 9.4 - Dielectric Tests).

“If the dissipation factor gets too high, the dielectric properties of the insulation system may be affected and ultimately lead to service failures. A maximum value of 0.5% at 100 °C is thought to be a prudent limit for satisfactory operation. If the dissipation factor is higher than this value, fluid treatment should be considered.”

It is PDC's experience that some utilities<sup>3</sup> have used a degassing and hot-clay (Fuller's Earth) treatment when the pipe fluid 100 °C dissipation factor exceeds 1 percent. This is particularly true for new cable systems with system voltages 230 kV and higher. Consequently, it is PDC's opinion that it would be prudent to treat the dielectric fluid to reduce the 100 °C dissipation factor in the NYPA RMPP HPFF cable circuits at some time in the future when other maintenance is being performed.

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<sup>3</sup> J. W. McCourt, “Contamination of Pipe Filling Oil For Pipe-Type Cable”, Minutes of the IEEE Insulated Conductors Committee, 1974.

## **4.3 Partial Discharge Measurements**

Partial discharge (PD) measurement is a diagnostic method that detects the onset and magnitude of discharges in cable insulation and evaluates the electrical and thermal performance of the cable systems. Although, field PD measurements have not been normally been performed on pipe-type cable systems, PD measurements were performed on RMPP 230 kV cable system #9 to evaluate the effectiveness of this diagnostic tool for HPFF cable system condition assessment.

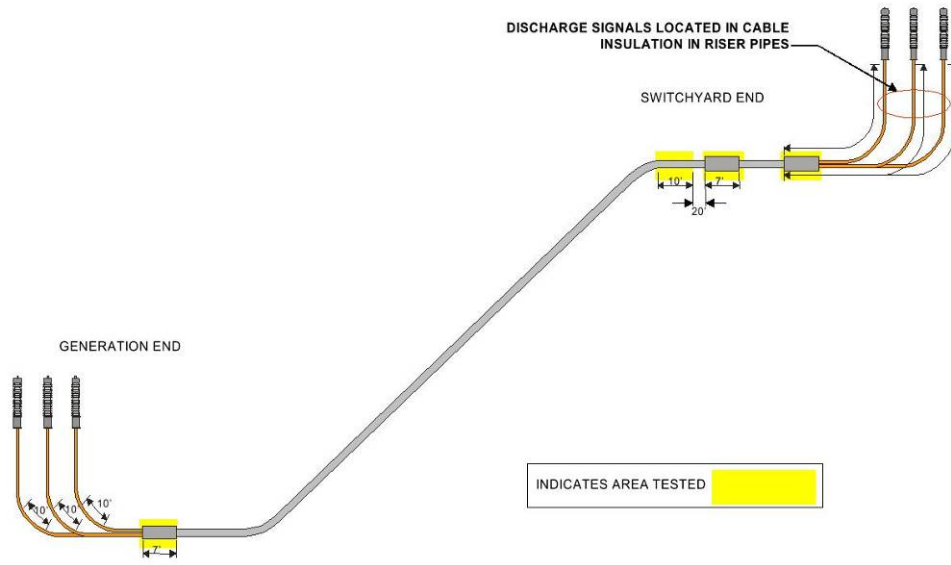
### **4.3.1 Locations of PD Measurements**

Condition assessment of cable system #9, a 230 kV, 750 kcmil Cu conductor, high pressure fluid-filled (HPFF) cable, was carried out by DTE Energy Technologies (DTE) on January 5 and 6, 2005. The assessment was performed in selected sections (see Figures 4-20 and 4-21) of the cable system which included six riser pipes, two trifurcators, one normal splice and a 10-foot section of pipe. Data for the assessment were taken with the line energized and under normal operating conditions.

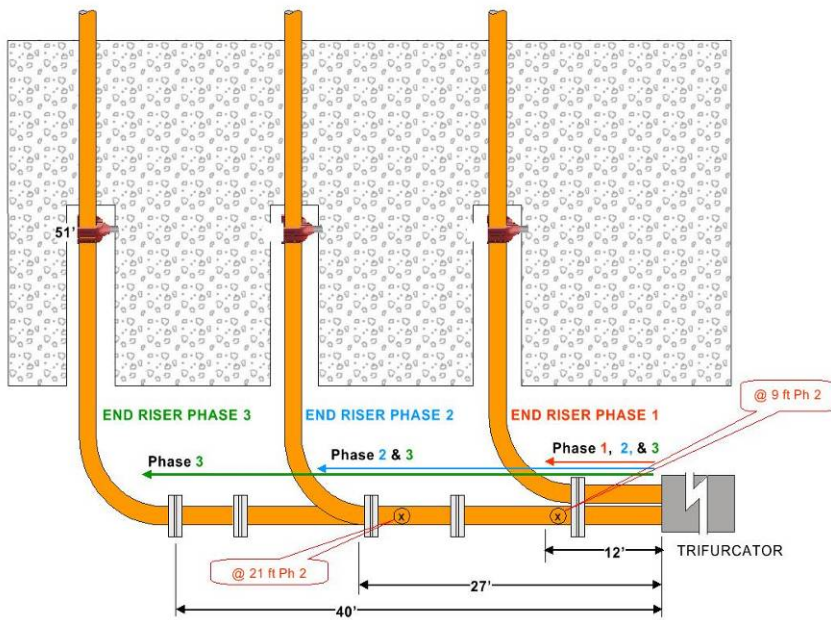
### **4.3.2 Measurement Procedure**

The PD measurement procedure consisted of placing a high frequency signal transducer around the cable pipe, riser pipe, or casings to measure the presence of signals on the cable pipe between 30 MHz and 140 MHz, and determining the total discharge signal within four frequency windows (ranges). Integration of the signal strength in each of the frequency windows allowed comparisons to be made at one foot intervals along the selected area. Plots of signal strength (mV) versus frequency were plotted representing the results as a function of longitudinal location of the measurement. Only signals having the appropriate 60 Hz modulation, which indicates signals generated within the electrical system, were considered.

DTE then utilized a signature or fingerprint method of signal recognition; signals emanating from substation equipment external to the cable insulation were identified. A schematic diagram of RMPP cable #9 is presented in Figure 4-20. The sections of RMPP cable #9 selected for testing were obtained from the EPRI statement of work. Accordingly, this included six riser pipe sections, three at the Switchyard Station end and three at RMPP end and the two respective trifurcators. Tests were performed on a normal joint casing and ten feet of line pipe toward the power plant about 500 ft from the switchyard termination riser pipes. Measurements were taken during a two-day working period. Markings were made over the pipe a foot apart in the sections selected for sampling to help locate the sensor.



**Figure 4-20**  
Locations of the PD measurements on RMPP cable system #9



**Figure 4-21**  
PD measurement locations, cable system #9 riser pipes

### 4.3.3 Conclusions

DTE's detailed report describing the PD measurements is contained in Appendix C of this report. PDC is not qualified to comment on the DTE PD measurement procedure and results because:

DTE's PD measurement method is a proprietary measurement procedure that is primarily based on laboratory tests performed by DTE.

The measurement results cannot be directly related to picoColumbs (pC) which are the units used to quantify the results of other electrical PD measurement methods.

DTE's conclusions concerning the PD measurements on RMPP 230 kV cable #9 were:

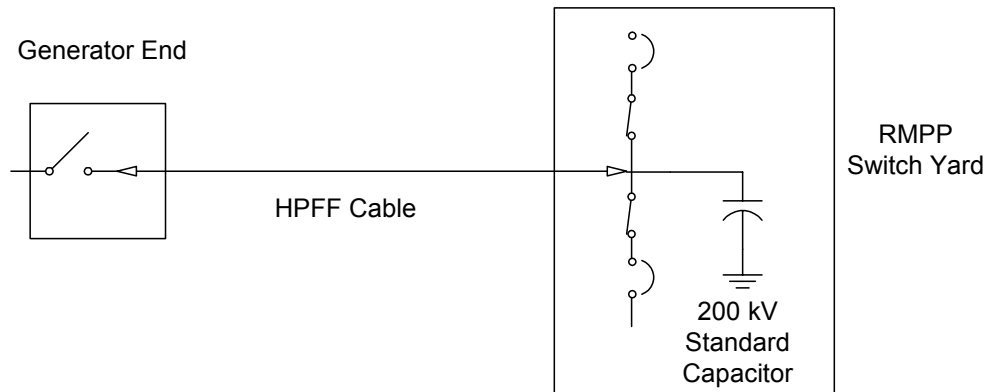
1. Measurements at the switching yard end of RMPP Cable #9 detected signals emanating from the cable insulation in some locations along the riser pipes in phases 2 and 3 at the Switchyard Station end of the cable. Signals were also detected when the PD instrumentation was connected to the Phase 2 riser pipe, but these were of lesser concern to DTE's engineer that evaluated the measurement results. The rest of the equipment tested from the Switchyard Station end, namely, the trifurcator, normal splice, and line pipe section showed no signals of concern.
2. The PD measurements detected exceedingly high interference was encountered from aerial components associated with the terminations of Feeder #9 at the generator end of the circuit. These signals completely mask signals from any other source and could be an indication of problem equipment external to the cable in question.

#### **4.4 Cable Insulation Dissipation Factor Measurements**

Rated voltage cable insulation dissipation factor measurements were performed by PDC on the RMPP 115 kV Unit #3 and RMPP Unit #13 230 kV cable systems on 6/12/06 and 3/1/2006 respectively.

Insulation dissipation factor measurement is a method of assessing the condition of high voltage insulation that is routinely performed on transmission cables before they are shipped for installation. Performing dissipation factor measurements on HPFF transmission cables in the field requires specialized equipment because of two reasons. First, it is not possible to temporarily disconnect the cable shield from ground, as required by conventional laboratory measurements. Second, a high capacity, high voltage source is required to perform the measurements due to the relatively high cable capacitance. Specialized test equipment was developed by the EPRI in 1992 that makes use of a high voltage fiber optic link and that energizes the cable from the power system.

The dissipation factor measurements were performed at the NYPA RMPP switching yard, as shown in the one-line diagram in Figure 4-22. Dissipation factor measurements were performed for each of the three cable phases sequentially by energizing the cables from the switchyard bus with the opposite (generator) end of the line open.



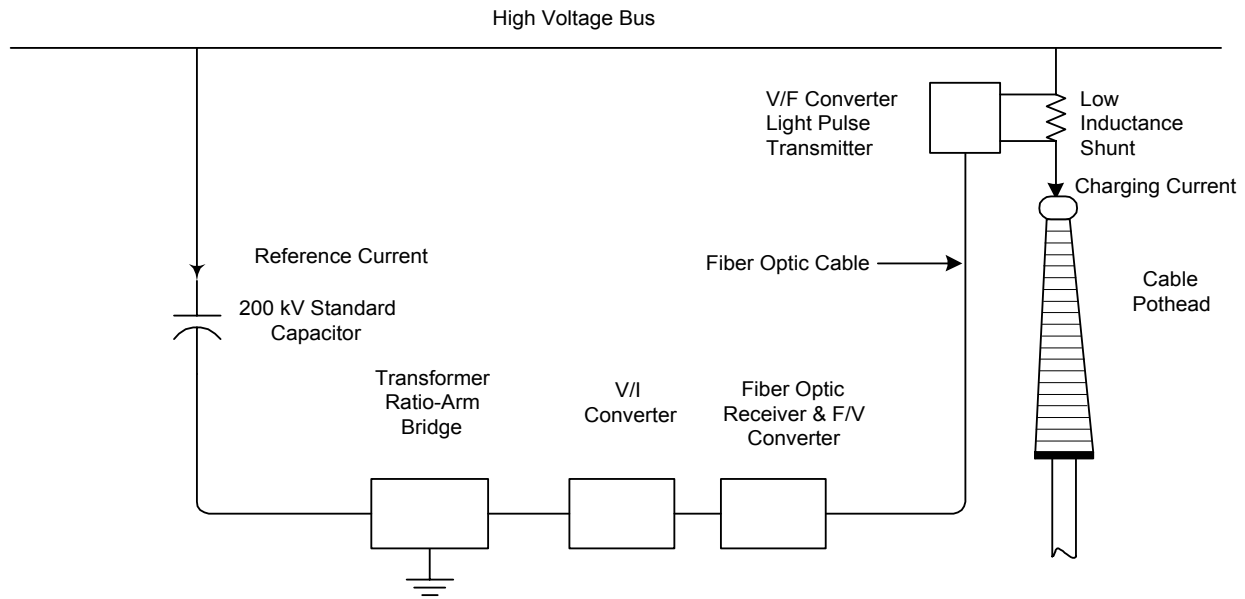
**Figure 4-22**  
**Connection diagram for cable insulation dissipation factor measurements**

Dissipation factor measurements (also called tangent delta measurements or sometimes referred to as insulation power factor measurements) give an indication of the dielectric losses in high voltage insulation. The dissipation factor of a high voltage cable is initially measured in the manufacturer's factory to give an indication of the quality of the manufacturing process. This nondestructive electrical measurement is also of use as an in-service measurement to give an overall indication of the cable insulation. A higher than normal dissipation factor value for the cable insulation is usually an indication that either the high voltage insulation has been contaminated with some polar compound, such as water, that the cable insulation has deteriorated due to thermal decomposition of the cellulose insulation. Dissipation factor measurements give an indication of the average condition of the cable insulation.

The cable insulation dissipation factor is also of significance because it is an important parameter in determining the current carrying rating of a transmission cable. If a transmission cable's dissipation factor increases significantly above the as-manufactured or nominal value, then the maximum normal current rating (ampacity) of the cable must be decreased to avoid operating the cable insulation at temperatures above the maximum operating temperature (typically 85 °C for oil impregnated paper ac transmission cables) for the high voltage insulation.

#### **4.4.1 Measurement Procedure**

Dissipation factor measurements are routinely performed on several different types of power systems equipment as a diagnostic test, but equipment for making dissipation factor measurements on transmission cables was just recently developed due to the high capacitance and charging KVA requirements of most cable circuits. A schematic of the equipment that was used to perform these measurements is shown in Figure 4-23.



**Figure 4-23**  
**Dissipation factor measurement schematic diagram**

As indicated by Figure 4-23, the high voltage cable is energized by the power system (NYPA 115 kV or 230 kV switchyard bus in this case) at rated voltage and the cable insulation's dissipation factor is measured by a modified transformer ratio-arm bridge.

The transformer ratio-arm bridge measures the phase angle difference between the charging current flowing through the cable's high voltage insulation and the charging current that flows through a standard capacitor (a capacitor with very low dielectric losses). Commercially available transformer ratio-arm bridges or Schering bridges are commonly used in high voltage laboratories or manufacturing plants to measure the cable dissipation factor. However, the bridge circuit must be modified for the field measurement of cable systems. This is because all of the cable charging current must flow through one winding of the bridge, and this is not possible in most transmission cable systems because of their grounding at multiple points. The EPRI developed dissipation factor instrument measures the charging current flowing into the cable that is energized from one end at the cable's termination and then transmits this information to the bridge at ground potential via an analog fiber optic data link.

Figure 4-24 shows the high voltage standard capacitor (left) connected to the switchyard bus and the charging current transmitter connected in series with one of the 230 kV cable terminations (right).



**Figure 4-24**  
Dissipation factor measurement equipment connected to NYPA high voltage bus

The RMPP #3 and #13 cables were out of service for a number of days preceding the dissipation factor measurements for maintenance. Consequently, the lines were at ambient earth temperature (approximately 20 °C) at the time of the measurements.

#### **4.4.2 Measurement Results**

The values of the dissipation factor which are read from the EPRI instrumentation must be corrected for errors associated with the measurement circuit and errors that are associated with the charging current losses in the cable high voltage conductor. The charging current correction factor, which increases with the square of the length of the transmission line, compensates for the joule losses in the high voltage conductor produced by the capacitive charging current. The uncorrected and corrected values of the cable dissipation factor measurements for RMPP Unit #3 and Unit #13 are shown in Table 4-14 and Table 4-15 respectively.

**Table 4-14  
Results of RMPP #3 Dissipation Factor Measurements (6/12/06)**

Phase	Uncorrected Dissipation Factor (%)	Corrected Dissipation Factor (%)
Phase A	0.402	0.382
Phase B	0.415	0.395
Phase C	0.401	0.381

**Table 4-15  
Results of RMPP #13 Dissipation Factor Measurements (3/1/06)**

Phase	Uncorrected Dissipation Factor (%)	Corrected Dissipation Factor (%)
Phase A	0.246	0.226
Phase B	0.257	0.237
Phase C	0.246	0.226

#### **4.4.3 Interpretation of Measurement Results**

The Association of Edison Illuminating Companies (AEIC) specification CS2 for high-pressure fluid filled cable systems contains maximum values for the cable dissipation factor that can be used as basis for evaluating the field dissipation factor measurements. In the case of 230 kV class HPFF cables manufactured before 1967 the maximum allowable dissipation factors at 20 °C was 0.30 percent and the maximum allowable dissipation factor for 115/138 kV class HPFF cables was 0.6 percent. Although AEIC CS2 dissipation factor limits provide an upper limit for comparison, the most suitable basis for interpreting the results of the dissipation factor measurements is to compare the field measurement results with the initial factory dissipation factor measurements at the same temperature. This is because the dissipation factor of oil-impregnated paper insulation depends on the moisture content of the paper at the time of impregnation and on the density of the paper tapes. Higher density paper tapes have higher impulse breakdown strength, but the dissipation factor increases with the density of the tapes. Consequently, the dissipation factor of new HPFF cables will vary from one manufacturer to the next and to a lesser extent on the manufacturing process. A review of factory test reports (including test reports for the NYPA St. Lawrence Power Project) for HPFF cables manufactured before 1967 indicates that typical room temperature insulation dissipation factors for new 115 kV HPFF cables were 0.35 to 0.40 percent. The dissipation factor for older 230 kV cables ranged from 0.25 percent to 0.3 percent.

Dissipation factor measurement for RMPP Unit #3 and Unit #13 cables indicate that their dissipation factors after more than 40 years of operation are in the range of typical values for new cables. This is another indicator that there has been very little thermal aging of the cable insulation.

# 5

## SUMMARY

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Radiographic inspection, cable insulation dissipation factor, pipe fluid DGA and quality assessment tests, and partial discharge measurements were performed by QIS, PDC, DECO, and DTE Energy to determine the condition of the NYPA RMPP and LPGP 115 kV and 230 kV HPFF cable circuits.

Results of the diagnostic tests indicate:

1. The radiographic inspection performed on RMPP cable #3, RMPP #9 and LPGP #2 revealed only one abnormality that is of concern. The images for LPGP #2 normal joint indicate that there is a significant amount of cable bending between one end of the joint casing and the splices that occurs when the cable operation changes from no load to normal load. PDC recommends that additional radio graphic inspection be performed at this joint and other LPGP cable joints.
2. The cable insulation dissipation factor tests indicate that 115 kV RMPP #3 and 230 kV RMPP #13 are in the range expected for new cable systems manufactured prior to 1967. This indicates that there has been no uniform deterioration of the cable insulation during the past 45 years of operation.

The pipe dielectric fluid DGA and furfural content measurements performed by DECO indicate that the aging of the RMPP and LPGP cables has been negligible during the past 45 years of operation.

The DGA measurements detected low acetylene levels in RMPP cable #1 splice and the RMPP unit #4 trifurcator. The acetylene level in cable #1 splice does not cause immediate concern; however the acetylene level in the cable #4 trifurcator calls for prompt resolution.

The RMPP pipe fluid 100 °C dissipation factor values ranged from slightly less than 1% to 2% (See Tables 4-9 through 4-12). IEEE Standard 1406 recommends that actions be taken to reduce the pipe dielectric fluid dissipation factor when it exceeds 0.6%. Many utilities have used a Fullers Earth filter to reduce the dissipation factor of HPFF dielectric fluid when it exceeds recommended levels. PDC recommends heating (40 °C to 60 °C) and circulating the pipe fluid for the RMPP HPFF cable systems through a Fullers Earth filter to improve the dissipation factor when the units are out of service for routing maintenance. This dielectric fluid treatment could be accomplished by interconnecting two the pipes for HPFF circuits in a common tunnel as shown in Figure 5-1.

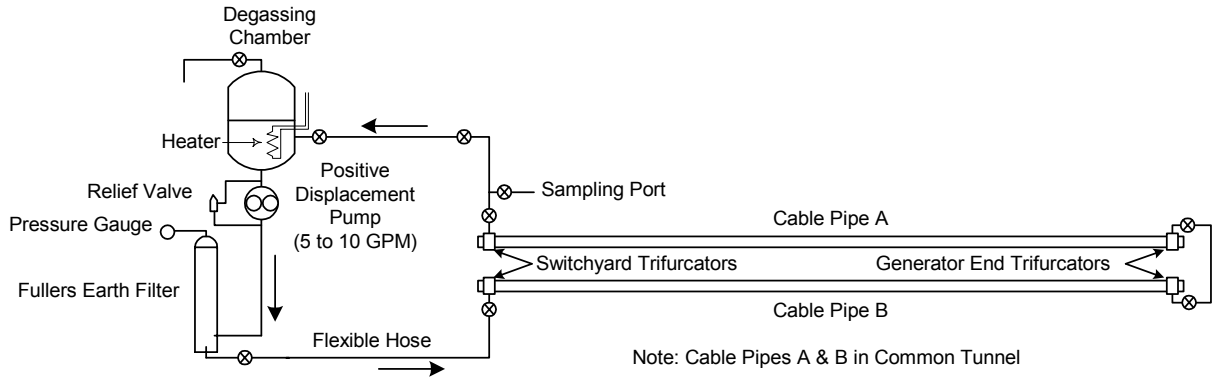
With the exception of the dissipation factor, the remaining fluid quality tests (dielectric breakdown, moisture content, peroxide content) for the RMPP and LPGP cable systems indicate that the pipe fluid is in good condition.

The PD measurements performed by DTE on RMPP 230 kV cable #9 detected high frequency signals emanating from two of the switchyard end riser pipes. These signals detected by DTE

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Summary

are of concern. DTE recommends repeating the measurements at some time in the future to determine if there is a trend of increasing PD signals.



**Figure 5-1**  
**Hydraulic schematic of pipe fluid treating equipment**

# A

## RADIOGRAPHIC INSPECTION IMAGE SUMMARY

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This appendix contains a listing of the images of the NYPA RMPP and LPGP HPFF transmission cable systems that were taken by QIS. The lists also contain comments concerning any abnormalities that were observed as well as PDC's assessment of the relative quality of the images for the purpose of assessing the condition of the HPFF cables.

Radiographic Inspection Image Summary

Table A-1. RMPP HPFF Cable System #9 Radiographic Images (Under Load and No Load)

NYPA RMPP Feeder #9 230 kV 750 KC MIL HPFF Cable Feeder X-Ray Analysis											
Images taken during Hot and Cold (Loaded and Unloaded)						Edges of	Edge of				
						Conductor	Insulation	Skidwires	Cables		
Component	Location	Angle	Hot/ Cold	Source	Image Qual	Visible (Y/N)	Shield Visible	Visible (Y/N)	Bent? (Y/N)	Comments	File Location – DVD 1
											<b>Folder: \Feeder 9 Cold (JPG files in subfolder: \JPEG Images)</b>
Generator riser pipe #1 (center)	1	0	C	Ir	7	Y	Y	Y	N	Cable centered (side-to-side in riser pipe)	Generator Side Riser, Shot 1-00.xry Generator Side Riser, Shot 1-00.jpg
Generator riser pipe #1 (center)	1	90	C	Ir	7	Y	Y	Y	N	Cable against outside bend of riser pipe	Generator Side Riser, Shot 1-90.xry Generator Side Riser, Shot 1-90.jpg
Generator riser pipe #2	2	0	C	Ir	7	Y	Y	Y	N	Skid wires appear to open near bottom of image	Generator Side Riser, Shot 2-00.xry Generator Side Riser, Shot 2-00.jpg
Generator riser pipe #2	2	90	C	Ir	7	Y	Y	Y	N	Skid wires appear to open near top of image	Generator Side Riser, Shot 2-90.xry Generator Side Riser, Shot 2-90.jpg
Generator riser pipe #3	3	0	C	Ir	7	Y	Y	Y	N	Skid wires appear to open top of image	Generator Side Riser, Shot 3-00.xry Generator Side Riser, Shot 3-00.jpg
Generator riser pipe #3	3	90	C	Ir	7	Y	Y	Y	N	Cable centered (side-to-side in riser pipe)	Generator Side Riser, Shot 3-90.xry Generator Side Riser, Shot 3-90.jpg
Generator trifurcator	1	0	C	Co	6	Y	Y	Y	Y	no abnormalities visible	Generator Side Trifurcator, Shot 1-00.xry Generator Side Trifurcator, Shot 1-00-PDC.jpg Generator Side Trifurcator, Shot 1-00-QIS.jpg Generator Side Trifurcator, Shot 1-00.jpg
Generator trifurcator	1	90	C	Co	7	Y	Y	Y	top cable up	no abnormalities visible	Generator Side Trifurcator, Shot 1-90.xry Generator Side Trifurcator, Shot 1-90.jpg
Generator trifurcator (mid)	2	0	C	Co	3.5	Y	N	NA	Y	xry and jpg images look significantly different	Generator Side Trifurcator, Shot 2-00.xry Generator Side Trifurcator, Shot 2-00.jpg
Generator trifurcator (mid)	2	90	C	Co	4.5	Y	Barely	NA	N	Significantly different exposure levels left to right	Generator Side Trifurcator, Shot 2-90.xry Generator Side Trifurcator, Shot 2-90.jpg

Radiographic Inspection Image Summary

NYPA RMPP Feeder #9 230 kV 750 KC MIL HPFF Cable Feeder X-Ray Analysis											
Images taken during Hot and Cold (Loaded and Unloaded)						Edges of	Edge of				
			Hot/		Image	Conductor	Insulation	Skidwires	Cables		
Component	Location	Angle	Cold	Source	Qual	Visible	Shield	Visible	Bent?		
						(Y/N)	Visible	(Y/N)	(Y/N)	Comments	File Location – DVD 1
											<b>Folder: \Feeder 9 Cold (JPG files in subfolder: \JPEG Images)</b>
Generator trifurcator	3	0	C	Co	7	Y	Y	Y	N		Generator Side Trifurcator, Shot 3- 0ø.xry Generator Side Trifurcator, Shot 3- 0ø.jpg
Generator trifurcator	3	90	C	Co	4.5	Y	Y*	Y*	slightly	Cable in casing not clear	Generator Side Trifurcator, Shot 3- 90ø.xry Generator Side Trifurcator, Shot 3- 90ø.jpg
Normal Joint (left end)	1	0	C	Co	4.5	Y	Y	Y	N	Skid wires and "loose skid wires" visible	Normal Joint, Shot #1- 0ø.xry Normal Joint, Shot #1- 0ø.jpg
Normal Joint (left end)	1	90	C	Co	5	Y	Y	Y	N	Skid wires and "loose skid wires" visible	Normal Joint, Shot #1- 90ø.xry Normal Joint, Shot #1- 90ø.jpg
Normal Joint (mid)	2	0	C	Co	3	Y	N		N		Normal Joint, Shot #2- 0ø.xry Normal Joint, Shot #2- 0ø.jpg
Normal Joint (mid)	2	90	C	Co	3	Y	Fuzzy		N	Spider visible	Normal Joint, Shot #2- 90ø.xry Normal Joint, Shot #2- 90ø.jpg
Normal Joint (right end)	3	0	C	Co	4	Y	N	NA	N	4 skid wires going diagonal across	Normal Joint, Shot #3- 0ø.xry Normal Joint, Shot #3- 0ø.jpg
Normal Joint (right end)	3	90	C	Co	3	Y	Fuzzy	NA	N	"loose skid wires" diagonal across visible	Normal Joint, Shot #3- 90ø.xry Normal Joint, Shot #3- 90ø.jpg
Substation riser pipe	1	0	C	Ir	7	Y	Y	Y	N	Cable centered (side-to-side in riser pipe)	Sub Station Riser, Shot 1- 0ø.xry Sub Station Riser, Shot 1- 0ø.jpg
Substation riser pipe	1	90	C	Ir	7	Y	Y	Y	N	Cable pulled up against inside of pipe bend	Sub Station Riser, Shot 1- 90ø.xry Sub Station Riser, Shot 1- 90ø.jpg
Substation riser pipe	2	0	C	Ir	7	Y	Y	Y	N	Cable centered (side-to-side in riser pipe)	Sub Station Riser, Shot 2- 0ø.xry Sub Station Riser, Shot 2- 0ø.jpg
Substation riser pipe	2	90	C	Ir	7	Y	Y	Y	N	Cable pulled up against inside of pipe bend	Sub Station Riser, Shot 2- 90ø.xry Sub Station Riser, Shot 2- 90ø.jpg
Substation riser pipe	3	0	C	Ir	7	Y	Y	Y	N	Cable centered (side-to-side in riser pipe)	Sub Station Riser, Shot 3- 0ø.xry Sub Station Riser, Shot 3- 0ø.jpg
Substation riser pipe	3	90	C	Ir	7	Y	Y	Y	N	Cable pulled up against inside of pipe bend	Sub Station Riser, Shot 3- 90ø.xry Sub Station Riser, Shot 3- 90ø.jpg
Substation trifurcator	1	0	C	Co	6	Y	Y	Y	slightly	no abnormalities visible	Sub Station Trifurcator, Shot 1- 0ø.xry Sub Station Trifurcator, Shot 1- 0ø.jpg
Substation trifurcator	1	90	C	Co	6.5	Y	Y	Y	slightly(top)	no abnormalities visible	Sub Station Trifurcator, Shot 1- 90ø 50 inches.xry Sub Station Trifurcator, Shot 1- 90ø reshoot.xry Sub Station Trifurcator, Shot 1- 90ø.xry Sub Station Trifurcator, Shot 1- 90ø reshoot.jpg
											<b>Folder: \Feeder 9 Cold (JPG files in subfolder: \JPEG Images)</b>

Radiographic Inspection Image Summary

NYPA RMPP Feeder #9 230 kV 750 KCMIL HPFF Cable Feeder X-Ray Analysis											
Images taken during Hot and Cold (Loaded and Unloaded)						Edges of	Edge of				
						Conductor	Insulation	Skidwires	Cables		
Component	Location	Angle	Hot/ Cold	Source	Image Qual	Visible (Y/N)	Shield Visible	Visible (Y/N)	Bent? (Y/N)	Comments	File Location – DVD 1
Substation trifurcator	2	0	C	Co	6.5	Y	Y	Y	slightly	no abnormalities visible	Sub Station Trifurcator, Shot 2-00.xry Sub Station Trifurcator, Shot 2-00.jpg
Substation trifurcator	2	90	C	Co	7	Y	Y	Y	slightly	No abnormalities visible	Sub Station Trifurcator, Shot 2-90.xry Sub Station Trifurcator, Shot 2-90.jpg
Substation trifurcator (mid)	3	0	C	Co	6.5	Y	Y	Y	yes	No abnormalities	Sub Station Trifurcator, Shot 3-00.xry Sub Station Trifurcator, Shot 3-00.jpg
Substation trifurcator (mid)	3	90	C	Co	4.5	Y	?	Y	yes	Spider visible	Sub Station Trifurcator, Shot 3-90.xry Sub Station Trifurcator, Shot 3-90.jpg
											<b>Folder: \Feeder 9 Hot (JPG files in subfolder: \JPEG Images)</b>
Generator riser pipe #1 (center)	1	0	H	Ir	8	Y	Y	Y	N	Cable centered (side-to-side in riser pipe)	Generator End Riser #1 00.xry Generator End Riser #1 00.jpg
Generator riser pipe #1 (center)	1	90	H	Ir	8	Y	Y	Y	N	Cable against outside bend of riser pipe.	Generator End Riser #1 90.xry Generator End Riser #1 90.jpg
Generator riser pipe #2	2	0	H	Ir	8	Y	Y	Y	N	Cable centered (side-to-side in riser pipe)	Generator End Riser #2 00.xry Generator End Riser #2 00.jpg
Generator riser pipe #2	2	90	H	Ir	8	Y	Y	Y	N	Cable against outside bend of riser pipe	Generator End Riser #2 90.xry Generator End Riser #2 90.jpg
Generator riser pipe #3	3	0	H	Ir	8	Y	Y	Y	N	Cable against of riser pipe.	Generator End Riser #3 00.xry Generator End Riser #3 00.jpg
Generator riser pipe #3	3	90	H	Ir	8	Y	Y	Y	N	Cable against of riser pipe.	Generator End Riser #3 90.xry Generator End Riser #3 90.jpg
Generator trifurcator	1	0	H	Ir	3.5	Y	Fuzzy	Y	Y	Skid wires going diagonal across	Generator End Trifurcator Left Side 00.xry Generator End Trifurcator Left Side 00.jpg
Generator trifurcator	1	90	H	Ir	3.5	Y	Fuzzy	Y	Y	Skid wires going diagonal across	Generator End Trifurcator Left Side 90.xry Generator End Trifurcator Left Side 90.jpg
Generator trifurcator (mid)	2	0	H	Ir	4.5	Y	Y	NA	Y	Spider visible	Generator End Trifurcator Middle Side 00.xry Generator End Trifurcator Middle Side 00.jpg
Generator trifurcator (mid)	2	90	H	Ir	4	Y	Fuzzy	NA	slightly	Spider visible	Generator End Trifurcator Middle Side 90.xry Generator End Trifurcator Middle Side 90.jpg
											<b>Folder: \Feeder 9 Hot (JPG files in subfolder: \JPEG Images)</b>

Radiographic Inspection Image Summary

NYPA RMPP Feeder #9 230 kV 750 KCMIL HPFF Cable Feeder X-Ray Analysis											
Images taken during Hot and Cold (Loaded and Unloaded)						Edges of	Edge of				
			Hot/		Image	Conductor	Insulation	Skidwires	Cables		
Component	Location	Angle	Cold	Source	Qual	Visible	Shield	Visible	Bent?	Comments	File Location – DVD 1
						(Y/N)	Visible	(Y/N)	(Y/N)		
Generator trifurcator	3	0	H	Ir	5	Y	Y	Y	slightly	No abnormalities visible	Generator End Trifurcator Right Side 0ø.xry Generator End Trifurcator Right Side 0ø.jpg
Generator trifurcator	3	90	H	Ir	7	Y	Y	Y	slightly	Good image, no abnormalities	Generator End Trifurcator Right Side 90ø.xry Generator End Trifurcator Right Side 90ø.jpg
Normal Joint (left end)	1	0	H	Ir	6.5	Y	Y	Y	N	no abnormalities visible noted	Normal Joint, Shot #1 0ø.xry Normal Joint, Shot #1 0ø.jpg
Normal Joint (left end)	1	90	H	Ir	4.5	Y	Fuzzy	Y	slightly	Image exposure varies significantly	Normal Joint, Shot #1 90ø.xry Normal Joint, Shot #1 90ø.jpg
Normal Joint (mid)	2	0	H	Ir	5	Y	Y	NA	slightly	no abnormalities visible noted	Normal Joint, Shot #2 0ø.xry Normal Joint, Shot #2 0ø.jpg
Normal Joint (mid)	2	90	H	Ir	4.5	Y	Barely	NA	slightly	no abnormalities visible noted	Normal Joint, Shot #2 90ø.xry Normal Joint, Shot #2 90ø.jpg
Normal Joint (right end)	3	0	H	Ir	4.5	Y	Barely	NA	N	no abnormalities visible noted	Normal Joint, Shot #3 0ø.xry Normal Joint, Shot #3 0ø.jpg
Normal Joint (right end)	3	90	H	Ir	4.5	Y	Barely	NA	N	no abnormalities visible noted	Normal Joint, Shot #3 90ø.xry Normal Joint, Shot #3 90ø.jpg
Substation riser pipe	1	0	H	Ir	8	Y	Y	Y	N	Cable centered (side-to-side in riser pipe)	Sub-Station End, Left Side of Trifurcator 0ø.xry Sub-Station End, Left Side of Trifurcator 0ø.jpg
Substation riser pipe	1	90	H	Ir	8	Y	Y	Y	N	Cable pulled up against inside of pipe bend	Sub-Station End, Left Side of Trifurcator 90ø.xry Sub-Station End, Left Side of Trifurcator 90ø.jpg
Substation riser pipe	2	0	H	Ir	8	Y	Y	Y	N	Cable centered (side-to-side in riser pipe)	Sub-Station End, Middle Side of Trifurcator 0ø.xry Sub-Station End, Middle Side of Trifurcator 0ø.jpg
Substation riser pipe	2	90	H	Ir	8	Y	Y	Y	N	Cable pulled up against inside of pipe bend	Sub-Station End, Middle Side of Trifurcator 90ø.xry Sub-Station End, Middle Side of Trifurcator 90ø.jpg
Substation riser pipe	3	0	H	Ir	8	Y	Y	Y	N	Cable centered (side-to-side in riser pipe)	Sub-Station End, Right Side of Trifurcator 0ø.xry Sub-Station End, Right Side of Trifurcator 0ø.jpg
Substation riser pipe	3	90	H	Ir	6	Y	Y	Y	N	Significantly different exposure levels	Sub-Station End, Right Side of Trifurcator 90ø.xry Sub-Station End, Right Side of Trifurcator 90ø.jpg
Substation trifurcator	1	0	H	Ir	5	Y	Fuzzy	Y	slightly	no abnormalities visible noted	Sub-Station End, Riser #1 0ø.xry Sub-Station End, Riser #1 0ø.jpg
											<b>Folder: \Feeder 9 Hot (JPG files in subfolder: \JPEG Images)</b>
Substation trifurcator	1	90	H	Ir	5	Y	Fuzzy	Y	slightly	no abnormalities visible noted	Sub-Station End, Riser #1 90ø.xry Sub-Station End, Riser #1 90ø.jpg

*Radiographic Inspection Image Summary*

NYPA RMPP Feeder #9 230 kV 750 KCMIL HPFF Cable Feeder X-Ray Analysis						Edges of	Edge of				
Images taken during Hot and Cold (Loaded and Unloaded)						Conductor	Insulation	Skidwires	Cables		
Component	Location	Angle	Hot/ Cold	Source	Image Qual	Visible (Y/N)	Shield Visible	Visible (Y/N)	Bent? (Y/N)	Comments	File Location – DVD 1
Substation trifurcator	2	0	H	Ir	5	Y	Fuzzy	1Cable	slightly	Skid wires visible 1 cable only	Sub-Station End, Riser #2 00.xry Sub-Station End, Riser #2 00.jpg
Substation trifurcator	2	90	H	Ir	5	Y	Barely	1Cable	slightly	Appears that only one cable has skid wires	Sub-Station End, Riser #2 90.xry Sub-Station End, Riser #2 90.jpg
Substation trifurcator (mid)	3	0	H	Ir	4.5	Y	Barely	1Cable	slightly	Image of top cable iunder exposed	Sub-Station End, Riser #3 00.xry Sub-Station End, Riser #3 00.jpg
Substation trifurcator (mid)	3	90	H	Ir	5	Y	Barely	1Cable	slightly	No abnormalities visible	Sub-Station End, Riser #3 90.xry Sub-Station End, Riser #3 90.jpg

Table A-2. RMPP HPFF Cable System #3 Under Load Radiographic Images

NYPA RMPP Feeder #3 115 kV 1750 KCMIL HPFF Cable Feeder X-Ray Analysis											
Component	Location	Angle	Hot/ Cold	Source	Image Qual	Edges of Conductor	Edge of Insulation Shield	Skidwires	Cables	Comments	File Location – DVD 1 <b>Folder: \Feeder 3 Hot (JPG files in subfolder: \JPEG Images)</b>
						Visible (Y/N)	Visible (Y/N)	Visible (Y/N)	Bent? (Y/N)		
Generator riser pipe Cable #1	1	0	H	Ir	7	Y	One	Y	N	Cable off center in pipe. No visible abnormalities	Generator Side Riser #1 0ø.xry Generator Side Riser #1 0ø.jpg
Generator riser pipe Cable #1	1	90	H	Ir	7	Y	Y	Y	N	Cable off center in pipe. No visible abnormalities	Generator Side Riser #1 90ø.xry Generator Side Riser #1 90ø.jpg
Generator riser pipe Cable #2	2	0	H	Ir	7	Y	Y	Y	N	Cable off center in pipe. No visible abnormalities	Generator Side Riser #2 0ø.xry Generator Side Riser #2 0ø.jpg
Generator riser pipe Cable #2	2	90	H	Ir	7	Y	Y	Y	N	Cable off center in pipe. No visible abnormalities	Generator Side Riser #2 90ø.xry Generator Side Riser #2 90ø.jpg
Generator riser pipe Cable #3	3	0	H	Ir	7	Y	Y	Y	N	Cable in center of pipe. No abnormalities noted.	Generator Side Riser #3 0ø.xry Generator Side Riser #3 0ø.jpg
Generator riser pipe Cable #3	3	90	H	Ir	7	Y	Y	Y	N	Cable off center in pipe. No visible abnormalities	Generator Side Riser #3 90ø.xry Generator Side Riser #3 90ø.jpg
Generator trifurcator casing (left)	1	0	H	Ir	4.5	Y	top only	Y	Y (normal)	Gap in HV conductor (between segments)?	Generator Side Trifurcator, #1 - Left Side 0ø.xry Generator Side Trifurcator, #1 - Left Side 0ø.jpg
Generator trifurcator casing (left)	1	90	H	Ir	4.5	Y	N	Y	Y (normal)	Spider visible on right	Generator Side Trifurcator, #1 - Left Side 90ø.xry Generator Side Trifurcator, #1 - Left Side 90ø.jpg
Generator trifurcator casing (right)	2	0	H	Ir	3.5	Y	N	Fuzzy	Y (normal)	No abnormalities visible	Generator Side Trifurcator, #1 - Right Side 0ø.xry Generator Side Trifurcator, #1 - Right Side 0ø.jpg
Generator trifurcator casing (right)	2	90	H	Ir	4.5	Y	Fuzzy	Y	Y	Top 2 cables in line. Segment gaps visible	Generator Side Trifurcator, #1 - Right Side 90ø.xry Generator Side Trifurcator, #1 - Right Side 90ø.jpg
Normal Joint Casing (left)	1	0	H	Ir	4.5	Y	Y	Y	N	Top 2 cables in line. Segment gaps visible	Normal Joint Location #1 Left - 0ø.xry Normal Joint Location #1 Left - 0ø.jpg
Normal Joint Casing (left)	1	90	H	Ir	4	Y	Y*	Y*	Slightly	*Poor image top cables. Segment gaps visible	Normal Joint Location #1 Left - 90ø.xry Normal Joint Location #1 Left - 90ø.jpg
Normal Joint Casing (mid)	2	0	H	Ir	4.5	Y	N	NA	Y (normal)	Segment gaps visible Edge of spider on right of image.	Normal Joint Location #2 Middle - 0ø.xry Normal Joint Location #2 Middle - 0ø.jpg

Radiographic Inspection Image Summary

NYPA RMPP Feeder #3 115 kV 1750 KCMIL HPFF Cable Feeder X-Ray Analysis											
						Edges of Conductor Visible	Edge of Insulation Shield Visible	Skidwires Visible	Cables Bent?		
Component	Location	Angle	Hot/ Cold	Source	Image Qual	(Y/N)	(Y/N)	(Y/N)	(Y/N)	Comments	File Location – DVD 1
Normal Joint Casing (mid)	2	90	H	Ir	4.5	Y	1 joint	NA	Slightly	Edge spider on left of image. Segment gaps visible	Normal Joint Location #2 Middle - 90ø.xry Normal Joint Location #2 Middle - 90ø.jpg
Normal Joint Casing (right)	3	0	H	Ir	3	Y	N	N	N	Skid wires around cable are not visible at reducer	Normal Joint Location #3 Right - 0ø.xry Normal Joint Location #3 Right - 0ø.jpg
Normal Joint Casing (right)	3	90	H	Ir	4.5	Y	Fuzzy	N	N	No skid wires visible around cables at reducer.	Normal Joint Location #3 Right - 90ø.xry Normal Joint Location #3 Right - 90ø.jpg
Substation riser pipe Cable #1	1	0	H	Ir	7	Y	Y	Y	N	Cable against inside bend of pipe. No visible abnormalities	Sub-Station Side Riser #1 0ø.xry Sub-Station Side Riser #1 0ø.jpg
Substation riser pipe Cable #1	1	90	H	Ir	7	Y	Y	Y	N	Cable in center in pipe. No visible abnormalities	Sub-Station Side Riser #1 90ø.xry Sub-Station Side Riser #1 90ø.jpg
Substation riser pipe Cable #2	2	0	H	Ir	7	Y	Y	Y	N	Cable in center in pipe. No visible abnormalities	Sub-Station Side Riser #2 0ø.xry Sub-Station Side Riser #2 0ø.jpg
Substation riser pipe Cable #2	2	90	H	Ir	7	Y	Y	Y	N	Cable against inside bend of pipe. No visible abnormalities	Sub-Station Side Riser #2 90ø.xry Sub-Station Side Riser #2 90ø.jpg
Substation riser pipe Cable #3	3	0	H	Ir	7	Y	Y	Y	N	Cable in center in pipe. No visible abnormalities	Sub-Station Side Riser #3 0ø.xry Sub-Station Side Riser #3 0ø.jpg
Substation riser pipe Cable #3	3	90	H	Ir	7	Y	Y	Y	N	Cable against inside bend of pipe. No visible abnormalities	Sub-Station Side Riser #3 90ø.xry Sub-Station Side Riser #3 90ø.jpg
Generator trifurcator casing (left)	1	0	H	Ir	4	Y	Fuzzy	Y	N	Segment gaps. Lower left of image "washed out"	Sub-Station Side Trifurcator - #1 Left 0ø.xry Sub-Station Side Trifurcator - #1 Left 0ø.jpg
Generator trifurcator casing (left)	1	90	H	Ir	4	Y	N	Y	N	Top 2 cables in line.	Sub-Station Side Trifurcator - #1 Left 90ø.xry Sub-Station Side Trifurcator - #1 Left 90ø.jpg
Generator trifurcator casing (right)	2	0	H	Ir	4	Y	Fuzzy	Y	Y (normal)	Horizontal gaps in two of HV conductors?	Sub-Station Side Trifurcator - #2 Right 0ø.xry Sub-Station Side Trifurcator - #2 Left 0ø.jpg
Generator trifurcator casing (right)	2	90	H	Ir	4	Y	Fuzzy	Y	Y (normal)	No abnormalities visible	Sub-Station Side Trifurcator - #2 Right 90ø.xry Sub-Station Side Trifurcator - #2 Left 90ø.jpg

Table A-3. LPGP HPFF Cable System #2 Radiographic Images (Under Load and No Load)

NYPA LPGP Feeder #2 230 kV 500 KCMIL HPFF Cable Feeder X-Ray Analysis											
							Edge of Insulation				
							Shield	Skidwires	Cables		
			Hot		Relative Image Qual	Conductor Visible	Visible	Visible	or Joints Bent?		
Component	Location	Angle	Cold	Source	Image Qual	Visible	(Y/N)	(Y/N)	(Y/N)	Comments	File Location – DVD 2
											<b>I. Folder: \Feeder 2 Cold\LPGP #2 Generator Side Risers JPEGS</b> <b>II. Folder: \Feeder 2 Cold\Photos (Jpeg of location photo)</b>
Generator riser pipe #1	1	0	C	Ir	7.5	Y	Y	Y	N	Cable centered in riser pipe, no abnormalities	I. LOCATION 1 0 DEG.jpg II. Generator Riser #1 - 0ø.JPG
Generator riser pipe #1	1	90	C	Ir	5.5	Y	Y*	Y*	N	*Cable against outside bend of riser pipe, 1/3 of Cable over exposed	I. LOCATION 1 90 DEG.jpg II. Generator Riser #1 - 90ø.JPG
Generator riser pipe #2	2	0	C	Ir	7	Y	Y	Y	N	Cable centered in riser pipe, no abnormalities	I. LOCATION 2 0 DEG.jpg II. Generator Riser #2 - 0ø.JPG
Generator riser pipe #2	2	90	C	Ir	7.5	Y	Y	Y	N	Cable against outside bend of riser pipe, no abnormalities visible	I. LOCATION 2 90 DEG.jpg II. Generator Riser #2 - 90ø.JPG II. Generator Riser #2 Dimensions.JPG
Generator riser pipe #3	3	0	C	Ir	7.5	Y	Y	Y	N	Cable centered in riser pipe, no abnormalities	I. LOCATION 3 0 DEG.jpg II. Generator Riser #3 - 0ø.JPG
Generator riser pipe #3	3	90	C	Ir	7.5	Y	Y	Y	N	Cable against outside bend of riser pipe, no abnormalities visible	I. LOCATION 3 90 DEG.jpg II. Generator Riser #3 - 90ø.JPG II. Generator Riser #3 Dimensions.JPG
											<b>I. Folder: \Feeder 2 Cold\LPGP #2 Generator Side Trifurcator JPEGS</b> <b>II. Folder: \Feeder 2 Cold\Photos (Jpeg of location photo)</b>
Generator trifurcator (right)	1	0	C	Co	4.5	Y	Barely	Y	Slightly	No abnormality visible	I. LOCATION 1 0 DEG.jpg II. Generator Trifurcator #1 Left - 0ø.JPG
Generator trifurcator	1	90	C	Co	4.5	Y	Barely	Y	Slightly	No abnormality visible. Cables 2 & 3 in line.	I. LOCATION 1 90 DEG.jpg II. Generator Trifurcator #1 Left - 90ø.JPG
Generator trifurcator	2	0	C	Co	4.5	Y	Barely	Y	N	Spider Visible, No Abnormalities	I. LOCATION 2 0 DEG.jpg II. Generator Trifurcator #2 Middle - 0ø.JPG
Generator trifurcator	2	90	C	Co	4.5	Y	Barely	Y	N	Spider Visible, No Abnormalities, Bottom 2 cables inline with each other	I. LOCATION 2 90 DEG.jpg II. Generator Trifurcator #2 Middle - 90ø.JPG
Generator trifurcator	3	0	C	Co	6.5	Y	Barely	Y	N	Skid wires around cable visible for the entire width of film	I. LOCATION 3 0 DEG.jpg II. Generator Trifurcator #3 Right - 0ø.JPG
Generator trifurcator	3	90	C	Co	5	Y	Barely	Y	N	Spider Visible, No Abnormalities, Bottom 2 cables inline with each other	I. LOCATION 3 90 DEG.jpg II. Generator Trifurcator #3 Right - 90ø.JPG
											<b>I. Folder: \Feeder 2 Cold\LPGP #2 Normal Joint Pegs</b> <b>II. Folder: \Feeder 2 Cold\Photos (Jpeg of location photo)</b>
Normal Joint Casing (left)	1	0	C	Co	5	Y	Barely	Y	Y	Cables 1&2 in line, Skidwires "bunched" at reducer	I. LOCATION 1 0 DEG.jpg I. LOCATION 1 0 DEG.xry II. Normal Joint #1 - 0ø.JPG
Normal Joint Casing (left)	1	90	C	Co	4.5	Y	N	Y*	Slightly	Skidwires visible on cables 1 and 2 only. Cable 3 image very "fuzzy"	I. LOCATION 1 90 DEG.jpg I. LOCATION 1 90 DEG.xry II. Normal Joint #1 - 90ø.JPG
Normal Joint Casing (mid)	2	0	C	Co	4	Y	N	NA	Y	"Ghost" of spider visible. Cable 2 bent	I. LOCATION 2 0 DEG.jpg I. LOCATION 2 0 DEG.xry II. Normal Joint #2 - 0ø.JPG

Radiographic Inspection Image Summary

NYPA LPGA Feeder #2 230 kV 500 KCMIL HPPF Cable Feeder X-Ray Analysis											
						Edge of Insulation			Cables		
						Edges of	Shield	Skidwires	or Joints		
			Hot		Relative	Conductor	Visible	Visible	Bent?		
Component	Location	Angle	Cold	Source	Image Qual	Visible	(Y/N)	(Y/N)	(Y/N)	Comments	File Location – DVD 2
Normal Joint Casing (mid)	2	90	C	Co	4	Y	N	NA	N	"Ghost" of spider visible on left side of image. Cables 1 & 3 in line.	I. LOCATION 2 90 DEG SHOT 2.xry I. LOCATION 2 90 DEG.jpg I. LOCATION 2 90 DEG.xry II. Normal Joint #2 – 90ø.JPG
Normal Joint Casing (right)	3	0	C	Co	5	Y	Barely	Y	Y**	**Significant bending of cable 1at right side of image	I. LOCATION 3 0 DEG.jpg I. LOCATION 3 0 DEG.xry II. Normal Joint #3 - 0ø.JPG
Normal Joint Casing (right)	3	90	C	Co	5	Y	Barely	Y	Y**	**Significant bending of cables 1 & 2 at left side of image	I. LOCATION 3 90 DEG.jpg I. LOCATION 3 90 DEG.xry II. Normal Joint #3 - 90ø.JPG
											<b>I. Folder: \Feeder 2 Cold\LPGA #2 Substation Side Risers JPEGS (Jpeg of Xray)</b> <b>II. Folder: \Feeder 2 Cold\Photos (Jpeg of location photo)</b>
Substation riser pipe #1	1	0	C	Ir	7	Y	Y	Y	N	Cable near center in riser pipe	I. LOCATION 1 0 DEG.jpg II. Sub-Station Riser #1 - 0ø.JPG
Substation riser pipe #1	1	90	C	Ir	7.5	Y	Y	Y	N	Cable on one side of riser pipe	I. LOCATION 1 90 DEG.jpg II. Sub-Station Riser #1 - 90ø.JPG II. Sub-Station Riser #1 - Dimensions.JPG
Substation riser pipe #2	2	0	C	Ir	7.5	Y	Y	Y	N	Cable against inside bend of riser pipe, no abnormalities	I. LOCATION 2 0 DEG.jpg II. Sub-Station Riser #2 - 0ø.JPG II. Sub-Station Riser #2 - 0ø Best.JPG
Substation riser pipe #2	2	90	C	Ir	7.5	Y	Y	Y	N	Cable centered in riser pipe, no abnormalities	I. LOCATION 2 90 DEG.jpg II. Sub-Station Riser #2 - 90ø.JPG
Substation riser pipe #3	3	0	C	Ir	7.5	Y	Y	Y	N	Cable near center in riser pipe, no abnormalities	I. LOCATION 3 0 DEG.jpg II. Sub-Station Riser #3 - 0ø.JPG
Substation riser pipe #3	3	90	C	Ir	7.5	Y	Y	Y	N	Cable on one side of riser pipe, no abnormalities	I. LOCATION 3 90 DEG.jpg II. Sub-Station Riser #3 - 90ø.JPG
											<b>I. Folder: \Feeder 2 Cold\LPGA #2 Substation End Trifurcator JPEGS</b> <b>II. Folder: \Feeder 2 Cold\Photos (Jpeg of location photo)</b>
Substation trifurcator	1	0	C	Co	5	Y	Barely	Y	N	No abnormality visible	I. LOCATION 1 0 DEG.jpg II. Sub-Station Trifurcator #1 - 0ø.JPG
Substation trifurcator	1	90	C	Co	5	Y	Barely	Y	N	Two cables in line. No abnormalities visible	I. LOCATION 1 90 DEG.jpg II. Sub-Station Trifurcator #1 - 90ø.JPG
Substation trifurcator	2	0	C	Co	4.5	Y	Barely	Y	Y	All cables bent slightly. Spider visible	I. LOCATION 2 0 DEG.jpg II. Sub-Station Trifurcator #2 - 0ø.JPG
Substation trifurcator	2	90	C	Co	5	Y	Barely	Y	Y*	Cable #1 (only) bending.	I. LOCATION 2 90 DEG.jpg II. Sub-Station Trifurcator #2 - 90ø.JPG
Substation trifurcator	3	0	C	Co	5	Y	Barely	Y	N	No abnormality visible	I. LOCATION 3 0 DEG INVERTED.jpg I. LOCATION 3 0 DEG.jpg II. Sub-Station Trifurcator #3 - 0ø.JPG
Substation trifurcator	3	90	C	Co	5	Y	Barely	Y	Y	Cable #1 (only) significantly bent. Cables 2 & 3 in line.	I. LOCATION 3 90 DEG.jpg II. Sub-Station Trifurcator #3 - 90ø.JPG

Radiographic Inspection Image Summary

NYPA LPGA Feeder #2 230 kV 500 KCMIL HPFF Cable Feeder X-Ray Analysis											
							Edge of Insulation				
							Edges of Shield	Skidwires	or Joints		
			Hot		Relative Image Qual	Conductor	Visible	Visible	Bent?		
Component	Location	Angle	Cold	Source	Image Qual	Visible	(Y/N)	(Y/N)	(Y/N)	Comments	
File Location – DVD 2											
<b>Folder: \Feeder 2 Hot (JPG files in subfolder: \JPEG Images)</b>											
Generator riser pipe	1	0	H	Ir	5*	Y	Y	Y	N	*Tearing of image, difficult for analysis	Generator Side Riser #1 - 0ø.xry Generator Side Riser #1 - 0ø.jpg
Generator riser pipe	1	90	H	Ir	7*	Y	Y	Y	N	*Some "tearing" of image Cable on outside of riser pipe bend.	Generator Side Riser #1 - 90ø.xry Generator Side Riser #1 - 90ø.jpg
Generator riser pipe	2	0	H	Ir	8	Y	Y	Y	N	Gaps in shield tapes visible	Generator Side Riser #2 - 0ø.xry Generator Side Riser #2 - 0ø.jpg
Generator riser pipe	2	90	H	Ir	8	Y	Y	Y	N	Cable against outside of pipe. No abnormalities visible	Generator Side Riser #2 - 90ø.xry Generator Side Riser #2 - 90ø.jpg
Generator riser pipe	3	0	H	Ir	8	Y	Y	Y	N	Gaps in shield tapes near top of image visible	Generator Side Riser #3 - 0ø.xry Generator Side Riser #3 - 0ø.jpg
Generator riser pipe	3	90	H	Ir	8	Y	Y	Y	N	Gaps in shield tapes visible	Generator Side Riser #3 - 90ø.xry Generator Side Riser #3 - 90ø.jpg
Generator trifurcator (left)	1	0	H	Ir	4.5	Y	Y*	Y*	N	*Image of bottom Cable poor. No abnormalities visible	Generator Side Trifurcator #1 Left - 0ø.xry Generator Side Trifurcator #1 Left - 0ø.jpg
Generator trifurcator	1	90	H	Ir	4.5	Y	Y*	Y*	N	*Image of bottom Cable poor. Two top cables in line.	Generator Side Trifurcator #1 Left - 90ø.xry Generator Side Trifurcator #1 Left - 90ø.jpg
Generator trifurcator	2	0	H	Ir	4.5	Y	Y*	Y*	Slightly	*Spider is visible. Image of bottom Cable poor.	Generator Side Trifurcator #2 Middle - 0ø.xry Generator Side Trifurcator #2 Middle - 0ø.jpg
Generator trifurcator (right)	2	90	H	Ir	5	Y	Y	Y	Slightly	Top two cables in line.	Generator Side Trifurcator #2 Middle - 90ø.xry Generator Side Trifurcator #2 Middle - 90ø.jpg
Generator trifurcator	3	0	H	Ir	5	Y	Y*	Y*	N	*No abnormality visible. Image of top Cable poor.	Generator Side Trifurcator #3 Right - 0ø.xry Generator Side Trifurcator #3 Right - 0ø.jpg
Generator trifurcator	3	90	H	Ir	5	Y	Y*	Y*	N	Top two cables in line	Generator Side Trifurcator #3 Right - 90ø.xry Generator Side Trifurcator #3 Right - 90ø.jpg
Normal Joint Casing (left)	1	0	H	Ir	5	Y*	Y*	Y*	Y	*Image of bottom splice is underexposed	Normal Joint #1 Left - 0ø.xry Normal Joint #1 Left - 0ø.jpg
Normal Joint Casing (left)	1	90	H	Ir	5.5	Y	Y	Y*	Y	No abnormalities visible	Normal Joint #1 Left - 90ø.xry Normal Joint #1 Left - 90ø.jpg
Normal Joint Casing	2	0	H	Ir	4.5	Y*	N	N	Slightly	*Only two of 3 splices are visible.	Normal Joint #2 Middle - 0ø.xry Normal Joint #2 Middle - 0ø.jpg
Normal Joint Casing	2	90	H	Ir	4	Y*	N	N	Slightly	*Only two of 3 splices are visible.	Normal Joint #2 Middle - 90ø.xry Normal Joint #2 Middle - 90ø.jpg
Normal Joint Casing (right)	3	0	H	Ir	5	Y	Fuzzy	Y	Y	Significant bending of all 3 cable at mid of image	Normal Joint #3 Right - 0ø.xry Normal Joint #3 Right - 0ø.jpg
Normal Joint Casing (right)	3	90	H	Ir	5	Y*	Fuzzy	Y	Y	Significant bending of all 3 cable at mid of image	Normal Joint #3 Right - 90ø.xry Normal Joint #3 Right - 90ø.jpg
Substation riser pipe	1	0	H	Ir	8	Y	Y	Y	N	Gap in shield tape visible. Cable centered in pipe.	Sub-Station Riser #1 - 0ø.xry Sub-Station Riser #1 - 0ø.jpg
Substation riser pipe	1	90	H	Ir	8	Y	Y	Y	N	Gaps in shield tape visible, cable against outside bend of pipe.	Sub-Station Riser #1 - 90ø.xry Sub-Station Riser #1 - 90ø.jpg
Substation riser pipe	2	0	H	Ir	7.5	Y	Y	Y	N	Gap in shield tape (right side of cable?). Cable centered in pipe	Sub-Station Riser #2 - 0ø.xry Sub-Station Riser #2 - 0ø.jpg
Substation riser pipe	2	90	H	Ir	8	Y	Y	Y	N	No abnormality visible	Sub-Station Riser #2 - 90ø.xry Sub-Station Riser #2 - 90ø.jpg

Radiographic Inspection Image Summary

NYPA LPGP Feeder #2 230 kV 500 KCMIL HPFF Cable Feeder X-Ray Analysis											
							Edge of Insulation		Cables		
						Edges of	Shield	Skidwires	or Joints		
			Hot		Relative	Conductor	Visible	Visible	Bent?		
Component	Location	Angle	Cold	Source	Image Qual	Visible	(Y/N)	(Y/N)	(Y/N)	Comments	File Location – DVD 2
Substation riser pipe	3	0	H	Ir	8	Y	Y	Y	N	Gaps in shield tape visible, cable centered in pipe.	Sub-Station Riser #3 - 0ø.xry Sub-Station Riser #3 - 0ø.jpg
Substation riser pipe	3	90	H	Ir	8	Y	Y	Y	N	Gaps in shield tape visible, cable against outside bend of pipe.	Sub-Station Riser #3 - 90ø.xry Sub-Station Riser #3 - 90ø.jpg
Substation trifurcator (left)	1	0	H	Ir	4.5	Y	N	Y	N	No abnormality visible. Top cable difficult to see.	Sub-Station Trifurcator #1 Left - 0ø.xry Sub-Station Trifurcator #1 Left - 0ø.jpg
Substation trifurcator (left)	1	90	H	Ir	5	Y	Barely	Y	N	Only two cables visible	Sub-Station Trifurcator #1 Left - 90ø.xry Sub-Station Trifurcator #1 Left - 90ø.jpg
Substation trifurcator (mid)	2	0	H	Ir	4.5	Y	1 cable	Y	N	No abnormalities visible. Spider visible	Sub-Station Trifurcator #2 Middle - 0ø.xry Sub-Station Trifurcator #2 Middle - 0ø.jpg
Substation trifurcator (mid)	2	90	H	Ir	5.5	Y	1 cable	Y	Y	2 cables in line.	Sub-Station Trifurcator #2 Middle - 90ø.xry Sub-Station Trifurcator #2 Middle - 90ø.jpg
Substation trifurcator (right)	3	0	H	Ir	4.5	Y	1 cable	Y*	Slightly	*Image quality of bottom Cable poor.	Sub-Station Trifurcator #3 Right - 0ø.xry Sub-Station Trifurcator #3 Right - 0ø.jpg
Substation trifurcator (right)	3	90	H	Ir	5	Y	2 cables	Y	Y	Significant bending of top cable. Other 2 cables in line.	Sub-Station Trifurcator #3 Right - 90ø.xry Sub-Station Trifurcator #3 Right - 90ø.jpg

Table A-4. RMPP HPFF Cable System #3 No Load (No Load-) Radiographic Images

NYPA RMPP Feeder #3 120 KV 1750 KCMIL HPFF Cable Feeder X-Ray Analysis						Edges of	Insulation				
			Edge of			Conductor	Shield	Skidwires	Cables		
			Hot/			Visible	Visible	Visible	Bent?		
Component	Location	Angle	Cold	Source	Image Qual	(Y/N)	(Y/N)	(Y/N)	(Y/N)	Comments	File Location – DVD 2
											<b>D:\Feeder 3 Cold\Generator End</b>
Generator riser pipe Cable #1	1	0	C	Ir	8	Y	Y	Y	N	Cable off center in pipe. No visible abnormalities	Generator End Riser #1 0ø.jpg Generator End Riser #1 0ø.xry
Generator riser pipe Cable #1	1	90	C	Ir	8	Y	Y	Y	N	Cable centered in pipe. No visible abnormalities	Generator End Riser #1 90ø.jpg Generator End Riser #1 90ø.xry
Generator riser pipe Cable #2	2	0	C	Ir	8	Y	Y	Y	N	Cable off center in pipe. No visible abnormalities	Generator End Riser #2 0ø.jpg Generator End Riser #2 0ø.xry
Generator riser pipe Cable #2	2	90	C	Ir	8	Y	Y	Y	N	Cable against pipe. No visible abnormalities	Generator End Riser #2 90ø.jpg Generator End Riser #2 90ø.xry
Generator riser pipe Cable #3	3	0	C	Ir	8	Y	Y	Y	N	Cable off center in pipe. No visible abnormalities	Generator End Riser #3 0ø.jpg Generator End Riser #3 0ø.xry
Generator riser pipe Cable #3	3	90	C	Ir	8	Y	Y	Y	N	Cable against pipe. No visible abnormalities	Generator End Riser #3 90ø.jpg Generator End Riser #3 90ø.xry
Generator trifurcator casing (left)	1	0	C	Ir	4.5	Y	N	Y	Y (normal)	Gap in HV conductor (between segments)	Generator End Trifurcator #1 0ø.jpg Generator End Trifurcator #1 0ø.xry
Generator trifurcator casing (left)	1	90	C	Ir	3	Y	N	Y	Y (normal)	Spider visible on right	Generator End Trifurcator #1 90ø.jpg Generator End Trifurcator #1 90ø.xry
Generator trifurcator casing (right)	2	0	C	Ir	3	Y	N	Y	Y (normal)	No abnormalities visible	Generator End Trifurcator #2 0ø.jpg Generator End Trifurcator #2 0ø.xry
Generator trifurcator casing (right)	2	90	C	Ir	4	Y	N	Y	Y	Bending similar to hot condition	Generator End Trifurcator #2 90ø.jpg Generator End Trifurcator #2 90ø.xry
											<b>D:\Feeder 3 Cold\Normal Joint</b>
Normal Joint Casing (left)	1	0	C	Ir	4	Y	N	Y	N	Top 2 cables in line. Segment gaps visible	Normal Joint #1 0ø Left.jpg Normal Joint #1 0ø Left.xry
Normal Joint Casing (left)	1	90	C	Ir	4	Y	N	Y	Slightly	Segment gaps visible	Normal Joint #1 90ø Left.jpg Normal Joint #1 90ø Left.xry
Normal Joint Casing (mid)	2	0	C	Ir	5	Y	N	N	Y (normal)	Cable #1 bending	Normal Joint #2 0ø Middle.jpg Normal Joint #2 0ø Middle.xry
Normal Joint Casing (mid)	2	90	C	Ir	5	Y	N	N	Y (normal)	Cable #3 bending	Normal Joint #2 90ø Middle.jpg Normal Joint #2 90ø Middle.xry
Normal Joint Casing (right)	3	0	C	Ir	4.5	Y	N	Y	N	"Loose" skid wires visible	Normal Joint #3 0ø Right.jpg Normal Joint #3 0ø Right.xry
Normal Joint Casing (right)	3	90	C	Ir	4.5	Y	N	Y	N	"Loose" skid wires visible	Normal Joint #3 90ø Right.jpg Normal Joint #3 90ø Right.xry
											<b>D:\Feeder 3 Cold\Substation</b>
Substation riser pipe Cable #1	1	0	C	Ir	8	Y	Y	Y	N	Cable centered in pipe. No visible abnormalities	Sub-Station Riser #1, 0ø.jpg Sub-Station Riser #1, 0ø.xry
Substation riser pipe Cable #1	1	90	C	Ir	6	Y	Y	Y	N	Cable against pipe. No visible abnormalities	Sub-Station Riser #1, 90ø.jpg Sub-Station Riser #1, 90ø.xry

Radiographic Inspection Image Summary

NYPA RMPP Feeder #3 120 KV 1750 KCMIL HPFF Cable Feeder X-Ray Analysis											
			Edge of			Edges of	Insulation				
			Hot/			Conductor	Shield	Skidwires	Cables		
						Visible	Visible	Visible	Bent?		
Component	Location	Angle	Cold	Source	Image Qual	(Y/N)	(Y/N)	(Y/N)	(Y/N)	Comments	File Location – DVD 2
Substation riser pipe Cable #2	2	0	C	Ir	8	Y	Y	Y	N	Cable centered in pipe. No visible abnormalities	Sub-Station Riser #2, 0ø.jpg Sub-Station Riser #2, 0ø.xry
											<b>D:\Feeder 3 Cold\Substation</b>
Substation riser pipe Cable #2	2	90	C	Ir	8	Y	Y	Y	N	Cable against inside bend of pipe. No visible abnormalities	Sub-Station Riser #2, 90ø.jpg Sub-Station Riser #2, 90ø.xry
Substation riser pipe Cable #3	3	0	Cold	Ir	7.5	Y	Y	Y	N	Cable centered in pipe. No visible abnormalities	Sub-Station Riser #3, 0ø.jpg Sub-Station Riser #3, 0ø.xry
Substation riser pipe Cable #3	3	90	Cold	Ir	8	Y	Y	Y	N	Cable against inside bend of pipe. No visible abnormalities	Sub-Station Riser #3, 90ø.jpg Sub-Station Riser #3, 90ø.xry
Generator trifurcator casing (left)	1	0	Cold	Ir	4	Y	N	N	N	No abnormalities visible	Sub-Station Trifurcator #1 0ø.jpg Sub-Station Trifurcator #1 0ø.xry
Generator trifurcator casing (left)	1	90	Cold	Ir	5	Y	N	Y	N	Bottom 2 cables in line.	Sub-Station Trifurcator #1 90ø.jpg Sub-Station Trifurcator #1 90ø.xry
Generator trifurcator casing (right)	2	0	Cold	Ir	5	Y	N	Y	Y (normal)	Horizontal gaps in one of HV conductors	Sub-Station Trifurcator #2, 0ø.jpg Sub-Station Trifurcator #2, 0ø.xry
Generator trifurcator casing (right)	2	90	Cold	Ir	4.5	Y	N	Y	Y (normal)	No abnormalities visible	Sub-Station Trifurcator #2, 90ø.jpg Sub-Station Trifurcator #2, 90ø.xry

***B***

**DECO DGA REPORT**

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Condition and Life assessment of High Pressure Fluid-Filled Cable  
Systems at NYPA's Niagara Power Project through Dielectric  
Fluid Testing

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**Introduction:** The condition and remaining life of a High Pressure Fluid-Filled (HPFF) cable are basically governed by the condition of the laminar dielectric system composed of cellulosic paper and the dielectric fluid, provided the integrity of the cable pipe and the pressure are maintained. Based on the EPRI-sponsored investigations at Detroit Edison (1,2) and the erstwhile EPRI Waltz Mill Cable Testing Facility (3), it has been demonstrated that the dual goals of condition and life assessment can be achieved through pipe fluid testing. The fluid testing consists of Dissolved Gas-Analysis (DGA) and several fluid tests. While DGA (4) provides a sound assessment of the condition of the cable and its accessories aided by other fluid tests, it offers a rough estimate of the remaining cable life based on the concentrations of carbon oxides and furfural content in the pipe fluid, per EPRI results obtained at Waltz Mill (3).

This report addresses the condition and life assessment of 115 kV and 230 kV HPFF Cable systems at NYPA's Niagara Power Project through DGA and related fluid testing. The Niagara Project is comprised of The Robert Moses (RM) and The Lewiston Pump Generating Plant (LPGP). The former plant (RM) has 13 cables, each with one trifurcator, one trifurcating joint (splice) and a single splice in the middle, the latter (LPGP) has 4 cables, each with 2 trifurcators and a single splice. While all cables associated with LPGP operate at 230 kV, the first seven RM cables operate at 115 kV, with the remaining (8-13) operating at 230 kV. The lack of valves limited termination sampling. However, all 115 kV and 230 kV trifurcators and splices were covered. In addition, DGA was performed on the 345 kV cables to generate a baseline for future activity.

All the DGA sampling and analysis were performed according to EDOSS (EPRI Disposable Oil Sampling System) that has been specifically developed (5) for HPFF cable systems. Several Niagara personnel were trained to take samples by the EDOSS method during DECo's December 13-14, 2004 visit.

While the previous report issued on August 19, 2005 contained the DGA data on all trifurcators and terminations with available sampling valves, a significant portion of the fluid data were missing for lack of related sampling. Subsequent to this report, the remaining fluid samples were taken both by Detroit Edison and NYPA personnel in the July-August, 2006 period to complete the entire effort.

**General DGA Comments:** Since DGA is central to the present investigations, it is advisable to make general comments on DGA, as applied to HPFF cable systems, before the results generated at NYPA, are discussed.

Following the success of DGA to power transformer toward condition assessment, DGA has been increasingly considered for HPFF cable systems. While the transformer experience dating back to the mid-1960s in the US is useful, particular attention has to be paid to HPFF cable DGA with respect to sampling and subsequent gas analysis due to distinct differences in the operating conditions, materials and constructions involved in these two vital electrical products. Such marked differences include types and viscosity of insulating fluids, operating pressures, electrical stresses, nitrogen blankets in HPFF pressurizing reservoirs, general gas contents and constructional details. This calls for proper field sampling and analysis procedures that take into account the peculiarities of HPFF cable systems, ensuring that the sample faithfully represents the fluid in the equipment and nothing is lost from and added to the sample content. It is also important to keep sample handling to a minimum in the laboratory, avoiding any transferring step(s).

Some of the challenges associated with the sampling of pipe fluids (100 SUS to 775 SUS @100 °F) can be overcome by means of the EPRI method, where the same field vial serves both as the sampling and analysis vessel.

## **1. Generation of Gases:**

During the operation of an HPFF cable, a number of gases such as carbon dioxide, carbon monoxide, hydrogen and lower (C1s) as well as higher hydrocarbons (C2s, C3s, C4s....) are generated in the fluid-paper system under electrical and thermal stresses. Such gases remain dissolved in the dielectric fluid and are in a liquid state, hence the name dissolved gases. In other words, the dissolved gases lose all semblance of gas. Once these gases are formed, they remain in place, even if, the cause of generation has ceased. Partial discharges disappear, once the source causing them becomes inactive or subsides, due to the many factors such as modifications of the internal surface of the cavity and changes in its pressure, shape or temperature. It should be noted that the various gases remain in solution unless the saturation levels, which are related to the gas solubility, are exceeded, leading to bubble formation.

Paper yields carbon oxides, moisture and minute amounts of methane and hydrogen, the latter two can be neglected for practical purposes. Besides the generation of carbon oxides and moisture under thermal stresses, paper also loses its physico-chemical properties (tensile strength, folding endurance, burst strength and degree of polymerization). Accordingly, the yield of carbon oxides also serves as a rough indicator of the paper aging brought about by thermal stresses, both prolonged and elevated. The life of a cable is determined by the condition of the paper insulation. This aging refers to normal aging, in other words, a kind of “graceful” aging and is different from localized and strong action involving electrical activity on both fluid and paper; in-service cables can be exposed to both such actions. The pipe fluid yields lower and higher hydrocarbon gases, hydrogen, and even carbon oxides, depending on its peroxide content.

The type, concentration and distribution of gases are governed by the specific nature of the problem faced by a cable. Certain gases can be associated uniquely with either electrical or thermal activity. Dissolved gases do not only lend themselves to accurate measurements with proper instrumentation but their generation is also more sensitive to thermal and electrical stresses, compared to other diagnostic techniques. Moreover, such gases can be detected at extremely low levels with relative ease, given proper instrumentation, sampling and analysis procedures.

Whereas hydrogen is related to low level electrical activity, acetylene is associated with strong electrical action, invariably involving a visible discharge, however, faint. The thermal generation of acetylene requires temperatures in excess of 600 C. Ionization activity leads to partial discharges, leading to acetylene and carbonized fluid along with unsaturated species such as ethylene, propylene and butene. Acetylene is considered to be the single, most important gas. The generation of isobutylene is primarily connected with the thermal decomposition of the dielectric fluid, particularly polybutenes, for which isobutylene is the starting material.

Both the levels and ratios of gases are important. It is important to consider the entire pattern of gases rather than rely on a few individual gases, however important, for proper data interpretation and future follow-up. The concentrations of the generated gases are related to the energy released during the electrical (and hence or otherwise thermal) activity involved. While sound DGA experience can readily distinguish between a sound and an unsatisfactory cable, periodic monitoring to establish gas generation trends and rates is essential for cases posing

concern. Nevertheless, the gas generation rates should periodically be determined to establish whether or not a particular cable is maintaining dielectric integrity or deteriorating. Such periodic monitoring also confirms, if any previous unusual electric or thermal activity has ceased. The cable per se, splices and terminations are sources of gases, and each component, particularly HPFF terminations, behaves very differently from the standpoint of DGA – an important HPFF cable system DGA lesson.

While an unusual activity occurring in the dielectric medium (or media) will give rise to gases, it should be kept in mind that some location (s) are more deleterious than others. This calls for a keen understanding of the equipment and its various components, including operation. It follows that the DGA (and related fluid data) generated on particular equipment being addressed should be carefully looked into its entirety, without undue reliance on any available historical data – such previous data are useful but cannot resolve many situations.

## **2. HPFF Terminations**

It should be pointed out that the terminations of 115 kV HPFF (high-pressure fluid-filled) cables seem to have experienced more problems than the cables and splices. The reverse holds for the 345 kV class, with the 230 kV experience closer to the 345 kV level. We identified several impending HPFF termination problems since 1989, particularly in the 115-138 kV class, e.g., MLG&W, HL&P, AEP, OUC and HECO. These serious problems were caught in time because of timely DGA, a diagnostic tool that is highly effective in revealing HPFF cable problems, all the more for their terminations.

The hazards posed by flying porcelain pieces resulting from the shattering of porcelain - under high pressures associated with pipe-type cable systems - during faults have to be taken seriously. Keeping this hazard in mind, two porcelain housings were utilized in the earlier terminations before high-pressure porcelain was developed and accepted. The sampling of a termination could also take care of the status of the cable in the riser pipe; problems have been related to the riser pipe section cable have been encountered. The mechanical stresses and any attendant movements experienced by cables in risers have led to gases, particularly excessive hydrogen, in a few cases.

The ideal way to sample a termination is from the top, and a few samples should be taken, as limited fluid is drained, to take care of the entire termination length associated with the narrow annular space formed by the termination porcelain housing and insulated cable assembly. However, if there is a bottom valve, it might be sufficient to take a single sample at the bottom, followed by two at the top to cover the top half by draining some fluid as DGA sample is taken.

## **3. Quality of Original Pipe Fluid**

The original pipe fluid that is invariably degassed at the shipping or the receiving site should be free of dissolved gases. The pipe fluid is always shipped under a nitrogen blanket to avoid contamination via moisture or air. Accordingly, high nitrogen levels are generally observed in pipe fluid, particularly in splices near the pumping plant reservoir. However, the blanketing nitrogen medium have been found to be contaminated with saturated hydrocarbons (methane, ethane, propane; even propylene in one previous case) in some cases, particularly older cables. Since these saturated gases are readily available in Oil Refineries, such a situation can occur. As the industry became more knowledgeable, the users insisted on high quality nitrogen, resulting in

the absence of saturated hydrocarbons in original oils. It is essential to keep such a situation in mind while interpreting DGA data, otherwise confusion and poor interpretation would follow.

#### **4. Quality of Sampling**

The importance of proper sampling cannot be overemphasized. The sample being taken should faithfully represent what is inside the equipment. It must not lose its contents or be contaminated in any way during shipment or handling by external agents. Particular attention should be paid to the sampling process, as the field environment is seldom easy. The tagging of the samples is evidently important.

#### **5. Transformers versus Cables**

DGA is widely used to assess the condition of Power Transformers. However, there are marked differences in the materials and operating conditions for the two products. These differences include: fluid pressure, electrical stresses, fluid characteristics, fluid movement, geometry, insulation tightness, cellulosic materials, and gas diffusion/permeation. Thus the DGA of various cables and their differing components should not be confused with that of transformers.

#### **EDOSS Sampling Procedure**

The procedure to perform DGA sampling by the EDOSS method is described below:

The EDOSS sampling vial is under vacuum, with a shelf life of about 8 weeks from the date of preparation. The date of preparation is inscribed on the vial and is represented by the leftmost 4 digits. Two digits for the month, and two digits for the day.

- Connect the sampling device as shown in Figure A-1 at a.
- With the valve handle pointing toward the ground, open the equipment valve to flush about one quart of fluid. This operation cleans all the connecting fittings and pipes.
- Point the valve handle toward the needle by rotating it 180° and allowing a few cc of fluid to flush through the hollow needle, Figure A-1 at b.
- While fluid slowly drains out of the needle, install a glass vial in the vial holder, Figure A-1 at c. This is accomplished by pulling down the outer ring of the vial holder with a spring-loaded mechanism, inserting the vial and then releasing the outer ring. The spring-loaded mechanism should close by itself and hold the vial firmly in place.
- As shown in Figure A-1 at d, push the vial holding unit with the secured vial into the needle housing. Fluid will rush into the vial as soon as the needle passes through the rubber stopper.
- Allow fluid to reach the center blue line as shown in Figure A-1 at e and pull from the glass vial until it is released from the vial holder. You can leave the valve open until the next sample, or close the valve as the proper level of fluid is reached.
- Two samples should be taken at every location.

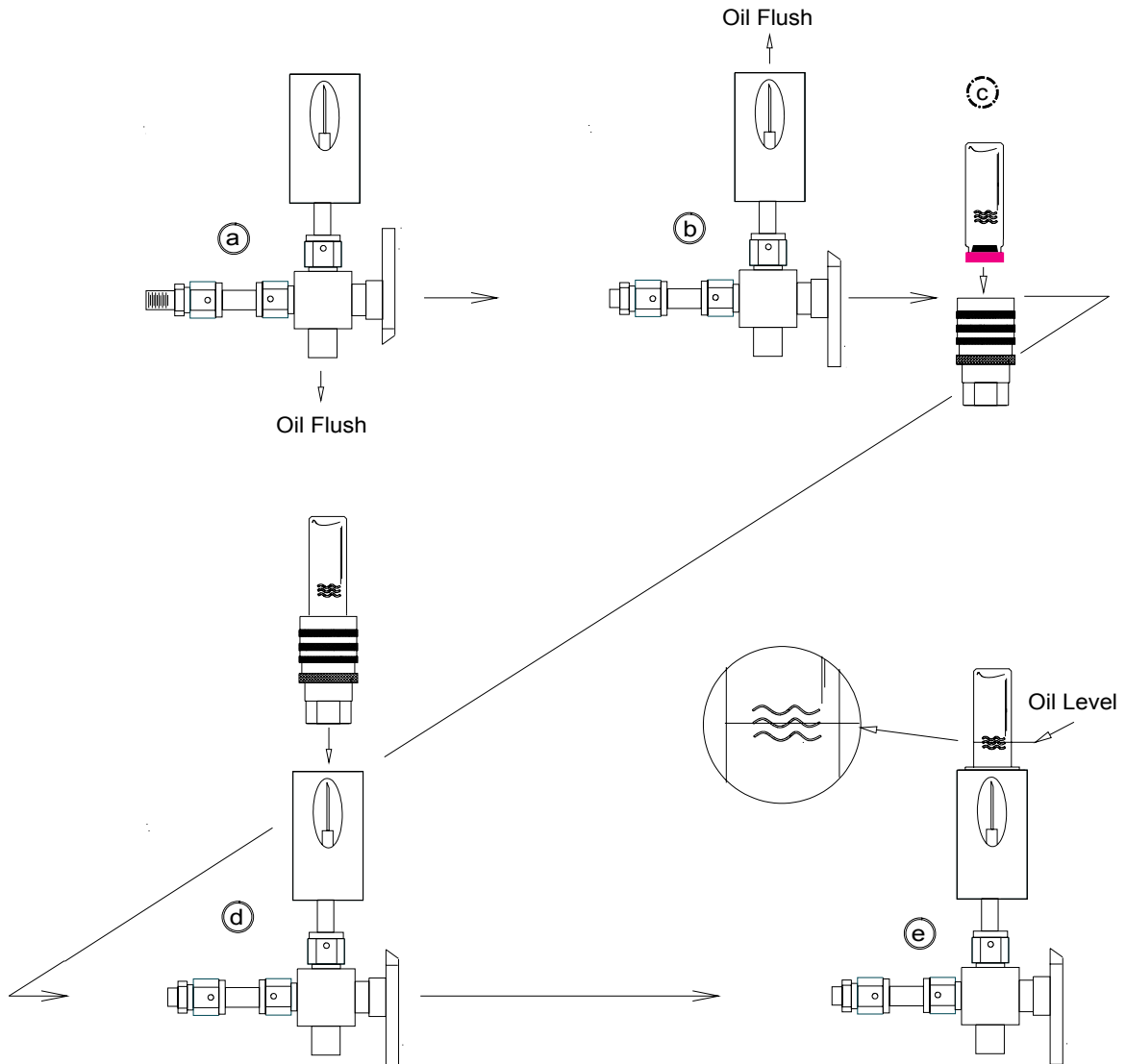


Figure A-1. Diagram showing the steps involved in fluid sampling with EDOSS

### A.1.2 Disassembling

Once the two samples are taken, close the valve connecting to the equipment being sampled and rotate the valve handle to the drain position allowing the release of pressure buildup. Drain as much oil as possible and disassemble the unit.

“Zep Break Wash” spray works well to clean the fittings. CAUTION this fluid does not contain CFC’s but is extremely flammable.

Against this general background, the results are discussed as follows:

**Discussion of Results:** The DGA and Fluid results are shown in Tables 1 through 9, including the sampling dates.

Table 1 shows the DGA data for switchyard and generator end trifurcators of the thirteen RM HPFF cables; the voltage level is indicated in the Table, depending on the Unit number . The term PT refers to Power Tunnel housing the cable, and the designations such as YD1NC, YV13NC and BD1NC (row 3, Table 1) are used to identify the sampling valves.

Table 2 shows the DGA results for the 13 RM splices, with the indicated voltage levels and the customary sampling designations in row 3. Table 3 shows the results on the 230 kV - eight trifurcators and four splices for the other plant, namely, LPGP - at the Niagara Power Project. Table 4 shows the DGA results on additional 115 kV cables. The samples were taken from each trifurcator (columns 2 and 3) in Bay 19. A2-1A and A2D-1B are sample valve designations at the trifurcators. Likewise, columns 4 and 5 show the data generated at each trifurcator in Bay 14 with the designated valves, A2VV-1A and A2VV-1B. The combination of the auto-transformer, dual 115 kV HPFF cable circuits and overhead line was devised to overcome the difficulty of overhead routing from Bay 14 to Bay 19.

Table 5 illustrates the DGA data on 345 kV cables, which are required to connect the Niagara Switchyard to Canadian Switchyard by overhead lines across the river. The DGA data for the three riser pipes of the 345 kV cable circuit associated with autotransformer #3 are shown in columns 2 to 4 of Table 5. This autotransformer has a similar configuration to autotransformer #2 that utilizes a HPFF cable circuit and overhead line. The results on the 345 k V cable connected with autotransformer #5 are shown in column 5; this cable has circulating fluid. The last four columns of Table 5 show the DGA data on two 345 kV HPFF circuits, namely 301 and 302; each circuit consists two parallel pipes that are specified as 301-1, 301-2, 302-1 and 302-2. These four cables are also circulating types. The terms CV301-1, CV301-2, CV302-1 and CV302-2 refer to the sampling valves that are part of the circulating pump assembly located near the trifurcator at the 538 ft. level of the dam. The DGA results on 115 kV Phase A and Phase B terminations for RM #9 at the generator end are presented in Table 6. The NYPA personnel were not able to remove the corona dome at the top of Phase C, which should be addressed in the future.

The DGA and Fluid samples for RM units #1 through #7 at the Switchyard Trifurcators and Unit #1 splice were taken by Detroit Edison during December 13-14, the rest of the sampling relating to DGA was done by NYPA's personnel. A detailed report with due recommendations on the sampling done by Detroit Edison was forwarded to Mr. Ying Shen on December 22, 2004.

The fluid was identified to be mineral oil, with a viscosity of 757 SUS @ 100 oF, shown as a bottom note in Table 1. This viscosity could present difficulties in sampling by syringes, even in tunnels, and all the more if the cable is de-energized. The syringes are meant for transformers, whose viscosity is only 50-60 SUS @ 100 °F.

The DGA data, presented in Tables 1 through 6 have been compared to the extensive field and laboratory data generated by Detroit Edison Company (DECo) for EPRI and many domestic and foreign utilities, with focus on EPRI Guidelines for the Interpretation of DGA (4) and on Selection, Handling and Maintenance of Cable Fluids (6) together with several EPRI INNOVATORS (7,8,9) relating to HPFF cable systems.

Each of the six DGA Table is addressed as follows:

**Table 1:** Of all the 26 trifurcators, both with and without a splice, acetylene was observed only at Unit #4 Switchyard Trifurcator; its level being 1 ppm. This is a 115 kV trifurcator and it has no splice. It should be added that acetylene is seldom found in satisfactorily operating cable systems. As mentioned earlier, acetylene comes solely from the dielectric fluid and is the result of some electric arching. It is noteworthy that cables per se rarely yield acetylene, and this trifurcator has no splice. The source of this acetylene likely lies in the termination located close by or the riser pipe (s). This underscores the need for DGA of Unit #4 terminations all the more. The sampling of this termination will also take care of the status of the cable in the riser. Because of high operating pressures that could result in the shattering of porcelain into flying pieces during a termination failure, HPFF terminations should be taken seriously, as mentioned earlier. In addition, it should be pointed out that 115 kV HPFF terminations have decidedly experienced more problems than their splices and even cables based on industry record.

The concentration of carbon monoxide is extremely low, demonstrating that the cable paper has hardly experienced any aging thus far, and the conductor temperatures involved have been modest. Likewise, the observed levels of carbon dioxide are also quite low. The high ratio of carbon dioxide to carbon monoxide also supports lack of aging, the higher this ratio, the better it is; a ratio of around 10 or more is excellent. Such a high ratio also indicates that there is no paper trouble and the cellulosic insulation is sound. The relationship of the carbon dioxide concentration to the EPRI Waltz Mill findings shows that the life of these cables would exceed 100 years at the present loading conditions from the standpoint of the aging of paper insulation, a critical consideration. It is assumed that no unusual or sudden problems will arise. At any rate, such problems are not generally expected in 115 kV HPFF cables.

A higher ethane to ethylene ratio is desirable, higher the better; it is implicit that these two gases are evolving from the insulating system. Of all the ratios associated with the 26 trifurcators, the smallest ethane to ethylene ratio was observed at RM Unit #4 switchyard trifurcator (4.2/2.1 = 2), the only trifurcator that showed acetylene. This is in accord with EPRI investigations at DECo Laboratories that ethylene generation is tied up with acetylene.

DECO DGA Report

Table 1: DGA data for 115 kV (1-7) & 230 kV (8-13) Switchyard and Generator end Trifurcators for the Robert Moses (RM) Plant

Location	Switchyard Trifurcator (RM Units)													Trifurcator (RM Units)												
	PT1			PT2	PT3			PT5			PT6			PT1			PT2	PT3			PT5			PT6		
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
YD1NC	YD2NC	YD3NC	YD4NC	YD5NC	YD6NC	YD7NC	YD8NC	YD9NC	YD10NC	YD11NC	YV12NC	YV13NC	BD1NC	BD2NC	BD3NC	BD4NC	BD5NC	BD6NC	BD7NC	AD8NC	AD9NC	AD10NC	AD11NC	AD12NC	AD13NC	
Date	12/13/04			12/13/04			1/1/05						1/1/05			1/1/05	1/1/05	1/1/05								
Methane	9.2	12	12	15	11.5	10	13	16	199	140	9,343	124	28	9.8	7.9	11	14	14	16	11	19	13	13	9.9	12	51
Ethane	4.2	6.6	7.5	4.2	4.5	3.6	5.3	5.5	97	67	5,058	59	35	9.7	3.8	4.4	4.1	4.9	13	3.9	8.9	5.5	5.8	3.7	4.5	31
Ethylene	0.8	1.8	1.3	2.1	1.2	1.0	1.5	3	28	52	1,226	14	4.2	2.4	1.3	1.3	1.2	1.3	1.9	1.1	1.1	1.1	1.2	0.7	0.8	5
Acetylene	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propane	6.5	10	13	5.0	5.1	8.1	9	4.5	111	54	7,491	77	83	27	8.6	7.2	5.2	8.1	31	5.1	13	7.4	8.3	4.7	5.2	52
Propylene	2.5	4.0	4.3	3.1	2.6	3.5	2.8	3.1	71	49	4,001	43	15	5.4	3.5	3.2	2.6	3.1	8.3	2.0	6.6	3.5	3.2	1.6	2.0	22
Isobutane	0.0	0.0	0.0	2.4	1.8	0.0	0.6	0.0	20	8.9	1,273	12	5.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	1.8	2.6	0.0	0.0	8.6	
n-Butane	0.6	0.7	1.0	1.2	0.8	0.6	1.6	0.0	13	6.6	909	9.1	6.6	2	0.6	0	0	0.5	1.8	0	1.6	0.8	0.0	0.0	6.8	
t-2-Butene	0.2	1.1	0.6	0.4	0.4	0.7	0.3	0.9	20	15	1,259	14	4.2	1.3	0.0	0.0	0.0	0.0	1.4	0	2.1	0.8	0.7	0.0	7.4	
1-Butene	0.0	0.0	0.0	0.5	0.4	0.0	0.0	0.0	1.8	0.9	116	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Isobutylene	0.0	1.1	1.0	2.9	2.2	1.6	1	3.5	168	109	13,133	127	27	7.2	2.9	2.7	3	3	4.3	2.3	16	8.2	3.4	2.4	2.7	73
Hydrogen	185	225	188	139	233	121	135	158	141	211	414	110	121	96	134	348	278	248	116	370	124	146	192	195	205	73
C. Monoxide	12	17	6.9	3.9	11	4.4	7.3	9.7	16	9.5	28	14	19	5.6	8.3	6.5	12	17	16	14	18	13	11	12	13	15
C. Dioxide	108	250	208	245	295	105	100	147	163	183	144	171	142	150	169	176	455	126	297	155	201	110	137	133	128	142

Pipe Fluid Viscosity: 757 SUS @100°F

The type, distribution and concentration of other gases are in order, except the case for RM Unit #11 switchyard trifurcator. However, the high levels of hydrocarbon gases shown in column 12 of Table 1 have not evolved from the insulation system. The relatively high concentrations of saturated hydrocarbon gases (methane, ethane, propane, even isobutene and n-butane) are due to the contamination of the original fluid for 230 kV cables through the nitrogen blanket containing these saturated hydrocarbons, readily available at Refineries. We have countered this situation at a handful of utilities (Houston Light & Power, AEP, Oroville Pumped Storage Dam in California, Virginia Electric Power and Wisconsin Electric), where several earlier cables manufactured in the 1960s were involved. In a few such instances (Wisconsin Electric), we have also observed high levels of unsaturated hydrocarbon gases such as isobutylene and propylene. In earlier days, the purity of nitrogen blanket was not specified. The high solubility of such gases does not permit ready elimination under degassing conditions. The observed levels of these gases are too low in relation to their solubilities to present any problems during inadvertent loss of pressure.

The effect of this fluid in RM #11 switchyard trifurcator is also felt for Units 9, 10, 12 and 13 for the 230 kV system, as shown by relatively higher gas contents compared to the rest of cables. It is noteworthy that the RM Unit #11 trifurcator at the other end is completely free of such gases. This demonstrates that this fluid volume was confined to the switchyard end of RM Unit #11.

**Table2:** Of all the 13 RM splices, only the splice associated with RM Unit #1 shows some acetylene, at 0.5 ppm. Normally operating splices should not show any acetylene. This low level of acetylene does not pose a concern, particularly at 115 kV operation. . However, considering the importance of these cables, associated as they are with a power plant, it is recommended to move a small amount of fluid (no more than 10 gallons) to establish if this acetylene is originating away from the middle of the splice (sampling port) toward the end of the splice, where the cable-splice interface is located.

Rest of the gases at Unit #1 and the remaining splices are in sound order. Because of the presence of a small amount of acetylene at Unit #1, the ethane to ethylene ratio effect discussed in Table 1, holds here too; it is one of the two highest ratios.

Table 2: DGA Data on 115 kV Splices (1-7) and 230 kV Splices (8-13) for RM

Location	Pressure Switch Junction (RM)								Power Switch Junction (RM)				
	PT1			PT2	PT3			PT5			PT6		
	SV-1NC	SV-2NC	SV-3NC	SV-4NC	SV-5NC	SV-5NC	SV-7NC	SV-8NC	SV-9NC	SV-10NC	SV-11NC	SV-12NC	SV-13 NC
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
Date	12/14/04	1/12/05					1/13/05		1/13/05				
Methane	8.6	14	13	10	10	13	8.7	7.3	9.4	12	8.8	14	10
Ethane	4.0	6.2	5.1	4.0	3.0	6.2	2.3	2.1	4.5	5.8	3.2	9.4	6.7
Ethylene	1.5	1.5	1.3	1.8	1.0	2.2	1.0	0.4	0.9	1.1	0.9	1.5	0.8
Acetylene	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propane	7.4	8.9	8.0	5.9	4.2	14	3.5	2.6	7.4	9.6	4.4	17	10
Propylene	2.1	4.0	2.3	2.4	1.9	3.8	1.3	1.2	2.3	2.6	1.3	3.1	2.4
Isobutane	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
n-Butane	0.6	1.0	0.5	0.7	0.5	0.7	0.4	0	0.5	0.7	0	1.0	0.6
t-2-Butene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1-Butene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Isobutylene	0.4	6.4	2.4	3.6	3.1	2.9	2.7	1.7	2.6	1.5	2.1	2.5	2
Hydrogen	87	68	61	65	66	76	83	149	215	192	279	155	109
C. Monoxide	4.2	16	19	20	22	17	19	32	68	29	22	75	36
C. Dioxide	116	172	158	188	185	218	158	115	152	141	149	172	112

**Table 3:** The DGA results on the 8 trifurcators and 4 splices at 230 kV for LPGP are given in Table 3. As shown in this Table, acetylene, the single most diagnostic gas is not present in the trifurcators or splices. The type, distribution and concentration of all other gases demonstrate that the 230 kV LPGP cables and splices are operating satisfactorily, not posing any concern. The low values of hydrogen and all hydrocarbon gases are particularly noteworthy. We would have preferred to see higher carbon dioxide to carbon monoxide ratios for splices, similar to the case of LPGP Unit #1 splice (column 10). Combined with the levels of other gases, the relatively poor ratio of carbon dioxide to carbon monoxide does not cause any concern. However, it is recommended to re-sample Unit #2 and Unit #3 splices in the future.

The high levels of saturated and unsaturated hydrocarbon gases (column 4, Unit #3, PD3NC) are due to the original contamination of the original pipe fluid, as discussed in Table 1.

**Table 4:** This Table shows the DGA results on additional 115 kV HPFF cables. The absence of acetylene along with the very low concentrations of other gases show that these 4 cables are operating satisfactorily. The samples taken at Bay 19 (columns 2 and 3) showed relatively high hydrogen concentrations at 652 ppm and 930 ppm, as compared to any other 115 kV cable at the Niagara project. A hydrogen concentration of a few thousands ppm is deemed acceptable, particularly when all the other gases have low concentrations. This indicates that the cables are operating satisfactorily.

**Table 5:** This Table shows the DGA data on 345 kV cables. The DGA data for the three phases of the 345 kV cable associated with autotransformer #3 are provided in columns 2, 3 and 4. The absence of acetylene is noteworthy. While all the gases are in sound order, the ratio of carbon dioxide to carbon monoxide is not desirable. As pointed out earlier, the concentration of carbon dioxide should be much higher than that of carbon monoxide. It is seldom reversed in cables, as is the case. The low concentration of all hydrocarbon gases reduces the concern posed by the behavior of carbon monoxide and carbon dioxide. We have observed quite high levels of hydrogen in riser pipes but not the reverse carbon oxides ratio. The present hydrogen concentration is quite small. Nevertheless, the highest hydrogen level (519 ppm) observed in the three phases corresponds to the case of the lowest carbon dioxide to carbon ratio (0.66). It is recommended to resample these three 345 kV locations, including the terminations.

The DGA data for the 345 kV circuit related to autotransformer #5 (column 5) and the two 2-piped circuits (columns 6 to 9) indicate that all the 345 kV cables, which have circulating fluid, are operating satisfactorily. It is also recommended to sample these circuits, if the circulation is stopped for some reason. The associated terminations should also be sampled. The high carbon dioxide-to- carbon monoxide ratios are noteworthy in columns 5 to 9.

Table 3: DGA Data on 230 kV on Generator & Switchyard Ends Trifurcators and Splices for the Lewiston Pumped Generating Plant (LPGP)

Location	Trifurcator (LPGP Units)				Trifurcator Switchyard (LPGP Units)				Pressue Switches (LPGP)			
	PT1		PT2		PT1		PT2		PT1		PT2	
	#1	#2	#3	#4	#1	#2	#3	#4	SV-1NC	SV-2NC	SV-3NC	SV-4NC
	PD1NC	PD2NC	PD3NC	PD4NC	OD1	OD2	OD3	OD4	#1	#2	#3	#4
Date	1/13/2005				1/13/2005				1/14/2005			
Methane	120	11	2793	3.3	67	5.4	16	17	6.8	5.6	32	6.9
Ethane	79	7.6	2363	3.2	43	3.9	13	11	3.4	2.6	25	2.5
Ethylene	4.5	2.9	574	0.5	8.7	0.8	5.3	3.3	0.7	0.8	6.3	0.4
Acetylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propane	127	14	3108	4.5	83	6.1	19	18	9.2	4.6	33	4.5
Propylene	36	6.8	2199	1.0	20	2.2	7.0	8.3	2.3	1.5	23	1.1
Isobutane	15	0.0	486	0.0	6.4	0.0	1.2	2.2	0.0	0.0	5.1	0.0
n-Butane	16	1.1	423	0.0	7.4	0.0	1.6	2.0	0.6	0.0	3.8	0.7
t-2-Butene	17	0.0	643	0.0	5.2	0.0	0.0	0.0	0.0	0.0	6.1	0.0
1-Butene	0.0	0.0	0.0	0.0	0.0	0.0	1.5	1.7	0.0	0.0	0.0	0.0
Isobutylene	83	1.1	3022	1.9	19	1.7	5.7	12	2.5	2.2	26	1.9
Hydrogen	109	116	185	121	69	69	140	63	101	62	131	92
C. Monoxide	31	73	25	10	23	56	67	47	27	58	48	47
C. Dioxide	119	143	140	104	162	144	109	166	173	160	126	135

Table 4: DGA Data on 115 kV Trifurcators Associated with Auto Transformer, 2A (Bay 19) & 2B (Bay 14)

Location	Trifurcator (Access Bldg-1)		Pressure Switchyard (Access Bldg-1)	
	PT1			
	Auto 2A	Auto 2B	Auto 2A	Auto 2B
	A2D-1A	A2D-1B	A2VV-2A	A2VV-2B
Date	1/14/2005			
Methane	9.7	9.9	12	10
Ethane	6.6	5.4	12	8
Ethylene	2.7	2.3	2.8	2.4
Acetylene	0.0	0.0	0.0	0.0
Propane	9	6.3	18	10
Propylene	4.6	3.5	6.9	5.1
Isobutane	0.0	0.0	1.2	0
n-Butane	0.5	0.0	1.2	0.7
t-2-Butene	0.0	0.0	0.0	1.0
1-Butene	0.9	0.0	1.2	0
Isobutylene	7.6	1.9	15	3.7
Hydrogen	652	930	143	154
C. Monoxide	17	26	16	19
C. Dioxide	230	248	175	164

Table 5: DGA Data on 345 kV Cables Associated with Auto Transformers 3 & 5, including the Dual Line at the 538 ft Level of the Dam

Location	Pressure Switch			Pressure Switch Pit by Auto#5	Pressure Switches (PA)			
	Auto #3				538			
	SG-AT3			Auto #5	301-1	301-2	302-1	302-2
	A	B	C	SVAT 5 - ANC	CV301-1	CV301-2	CV302-1NC	CV302-2NC
Date	2/1/2005			2/1/2005	1/18/2005			
Methane	13	20	19	23	9.9	9.2	11	11
Ethane	20	26	18	20	18	18	21	21
Ethylene	3.2	4.1	3.1	2.4	1.4	1.2	1.5	1.3
Acetylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Propane	60	73	53	47	57	57	62	65
Propylene	9.5	13	9.8	7.5	6.9	6.9	7.0	7.1
Isobutane	2.9	2.9	2.2	2.5	2.4	3.3	2.9	3
n-Butane	2.8	3.5	2.5	2.2	2.7	2.7	3	2.7
t-2-Butene	0.0	1.0	1.1	0.0	0.0	0.0	0.0	0.0
1-Butene	0.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Isobutylene	3.7	1.4	4.6	13	3.8	4.2	3.9	3.9
Hydrogen	519	441	233	253	80	89	98	103
C. Monoxide	291	363	418	13	14	13	13	13
C. Dioxide	194	285	314	172	191	182	189	178

**Table 6:** The DGA results on 115 kV Phase A and Phase B Terminations at RM Unit #9 generator end are excellent. However, it is essential to take 2-3 samples, as the fluid is drawn to take care of the entire termination length. This procedure should be adopted for the missing Phase C and all other terminations.

Table 6: DGA Result on 115 kV Phase A & Phase B Terminations at RM Units #9 Generator End

Location	RM #9 Generator End	
	Phase A	Phase B
Date	6/7/2005	
Methane	15	35
Ethane	8.5	21
Ethylene	1.8	3.0
Acetylene	0.0	0.0
Propane	11	28
Propylene	4.1	10
Isobutane	0.0	1.8
n-Butane	1.0	2.0
t-2-Butene	0.0	0.0
1-Butene	0.9	1.6
Isobutylene	6.6	13
Hydrogen	150	129
C. Monoxide	11	18
C. Dioxide	208	269

**Table 7, 8 and 9:** These three tables show the results of various fluid tests (moisture, breakdown, dissipation factor, peroxide, neutralization number and furfural content) on NYPA's Niagara electrical system.

Table 7 covers the fluid results on the all the 13 switchyard-end and generator-end trifurcators of the RM (Robert Moses) plant. While RM trifurcators, numbers 1 through 7, are associated with the 115 kV HPFF cable system, the rest of the trifurcators (8 through 13) relate to the 230 kV HPFF cable system.

The fluid results relating to all the 13 RM splices are shown in Table 8, with splices, numbered 1 through 7 and 8 through 13 corresponding to the 115 kV and 230 kV HPFF system, respectively. Table 9 shows fluid data on the generator- and switchyard-end trifurcators along with the four splices for the 230kV LPGP (Lewiston Pumped Generating Plant) HPFF cable system.

The moisture data is excellent throughout, as shown in the 4th row for the three fluid data tables. This demonstrates that well-degassed fluids have been employed. The specified maximum moisture level is 30 ppm, and the observed values ranged from about 2 to 5 ppm. Out of 51 cases, furans were undetectable for 37 instances, for the rest below 1.5 ppb. The furan measurements demonstrate lack of any paper aging, even a 100 years, according to Waltz Mill findings (3). The non-detectable peroxide content also supports the earlier comments that the quality of the original oil was excellent. The neutralization number, which is a measure of fluid oxidation through the formation of oxidizing species during operation, is well below the specified value (0.03) for new mineral oil. The excellent value of neutralization number obviates the need for IFT (interfacial tension).

Before the dissipation factor results are discussed, it will be beneficial to understand the behavior of this fluid parameter as regards mineral oil versus synthetic fluids, considering the 45-year age of the Niagara HPFF cables.

While HPFF cables with mineral oil, both as an impregnant and a pressurizing medium, have served the industry well, the main reason for the introduction of polybutene fluid was its lower dissipation factor (DF) and its stability over time and temperature compared to mineral oil. The composition of mineral oil is complex, and it depends on the crude stock, geographical location, including the degree and method of refining. However, the choice of a few starting materials involved along with the controllable chemical processing for the manufacture of a synthetic hydrocarbon like polybutene (or alkylbenzene ) imparts stability and makes the realization the desired property levels possible.

Table 7: Fluid Data on RM 115 kV Trifurcators (1-7) & 230 kV Switchyard End and Generator End Trifurcators for the Robert Moses (RM) Plant

Date	12/13/04		12/13/04		07/10/06																					
Location	Switchyard Trifurcator (RM Units)													Generator end Trifurcator (RM Units)												
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
Moisture(ppm)	3.01	2.32	2.64	2.59	2.93	nd	2.69	2.50	4.76	3.21	4.01	2.31	3.91	5.37	3.51	3.30	4.01	5.34	3.89	5.27	5.21	3.46	2.92	3.88	2.71	3.22
Dielectric Strength (kV) ASTM(D877)	31.0	35.6	46.9	35.3	46.4	44.9	37.1	43.4	47.6	40.9	44.5	46.6	43.7	44.3	42.1	42	44.3	43.6	42	44.9	47.6	47.8	42.1	46.6	40.8	46.7
% DF@100C	0.644	1.381	1.291	1.037	1.342	1.367	1.316	1.580	2.108	1.896	1.962	2.056	1.659	1.104	1.076	1.223	1.037	1.241	1.500	1.117	0.932	1.210	1.210	1.712	1.949	1.421
Peroxide Content (ppm)	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Neutralization No.(mg/g)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Furans (ppb)	nd	nd	nd	nd	nd	nd	nd	nd	1.3	nd	nd	1.2	nd	1.2	nd	1.1	nd	nd	nd	nd	1.1	nd	nd	nd	1.1	nd

Table 8: Fluid Data on 115 kV Splices (1-7) and 230 kV Splices (8-13) for the Robert Moses (RM) Plant

Date	7/11/2006							7/12/2006					
Location	Pressure Switch (Switchyard)												
	RM#1	RM#2	RM#3	RM#4	RM#5	RM#6	RM#7	RM#8	RM#9	RM#10	RM#11	RM#12	RM#13
Moisture(ppm)	2.94	3.01	2.44	3.56	2.96	3.62	3.06	3.61	2.94	4.01	3.25	3.49	3.07
Dielectric Strength (kV) ASTM(D877)	55.2	53.7	55.2	52.8	53.3	51.3	49.8	54.0	48.6	50.1	47.7	44.0	45.4
% DF@100C	0.932	0.893	0.972	0.893	0.893	1.17	0.919	0.715	1.210	1.447	1.381	1.685	2.319
Peroxide Content (ppm)	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Neutralization No.(mg/g)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Furans (ppb)	1.2	nd	nd	1.4	nd	nd	1.3	1.1	1.2	nd	nd	1.3	1.4

Table 9: Fluid Data on 230 kV on Switchyard End & Generator End Trifurcators and Splices for the Lewiston Pumped Generating Plant (LPGP)

Date	7/10/2006				7/11/2006				7/12/2006			
Location	Trifurcators (Switchyard End)				Trifurcators (Generator End)				Pressure Test Switch (Splices)			
	LPGP #1	LPGP #2	LPGP #3	LPGP #4	LPGP #1	LPGP #2	LPGP #3	LPGP #4	LPGP #1	LPGP #2	LPGP #3	LPGP #4
Moisture(ppm)	3.30	3.52	2.94	4.79	3.02	2.91	4.01	3.12	3.45	3.91	3.42	3.61
Dielectric Strength (kV) ASTM(D877)	42.9	47.2	55.2	49.0	52.8	49.3	59.2	56.6	57.9	53.1	57.0	54.5
% DF@100C	1.104	1.019	0.735	1.170	1.024	1.154	1.21	0.919	0.418	0.629	0.497	0.435
Peroxide Content (ppm)	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Neutralization No.(mg/g)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Furans (ppb)	nd	nd	nd	nd	nd	1.4	nd	nd	nd	nd	nd	nd

Per the AEIC Specifications for Electrically Insulating Low Viscosity Pipe Filling Liquids for High-Pressure Pipe-Type Cables, 1984 Edition, the specified maximum %DF @ 100 oC is 0.3 is for low viscosity mineral oil. These Specifications exclude the medium viscosity type mineral oil utilized at NYPA. However, ASTM 1819, 1971, on which the AEIC specifications are essentially based, specifies a maximum %DF of 0.6 at 100 o C for the medium viscosity mineral oil (750 to 800 SUS). Since it is easier and cost-effective to treat low viscosity oils (50-60 SUS) than higher viscosity oils (750-800 SUS), lower %DF values are readily attainable with the former. It is noteworthy that some leading utilities have specified even a higher maximum value than 0.6% at 100 oC) for medium viscosity mineral oils. Synthetic hydrocarbon fluids such as polybutene, alkylbenzenes and blends thereof are characterized by relatively low dissipation factor values (0.1% or below at 100 C) and stability over time. In fact, this was the main reason for the replacement of mineral oils by synthetic fluids, whose properties can be better controlled in man-made processing environment.

Accordingly, the observed dissipation factor values @100 oC, are considered acceptable for in-service mineral oils. Such values (even higher) have been sometimes observed at satisfactorily operating HPPF cables. It would be desirable to have lower DF values than those observed (Table 7, row 4), as typical values for both polybutene/polubutene-alkylbenzene blends and mineral oils range from 0.4%-0.7% @ 100 C. Nevertheless, any oil treatment is not deemed necessary for many reasons, such as quality of other fluid tests, nature of relatively high viscosity mineral oil and the industry experience. It should be kept in mind that DF of the much higher viscosity impregnant is expected to be higher than that of typical pipe fluids. In fact, DF data presented in Sun Oil's scientific publications are always about twice the corresponding values of its pipe fluids. The limited volume of pipe fluids in power plants HPPF cables, unlike what is available on the transmission grid, tends to accentuate the DF value; it was also observed at St. Lawrence Hydro Plant. It should be added that the carbon-loaded insulation shielding acts as a good filter to trap many impurities and the mixing of the pipe and impregnating fluids is confined primarily to outer layers.

The breakdown values at Unit#2 through Unit#7 are well above the specified (30kV) level for new mineral oil of this vintage. The values at Unit#1 trifurcator, particularly the Unit#1 splice, are somewhat marginal compared to the specified value for new oil. However, it should be pointed out that these values are quite acceptable for in-service fluid.

### **Conclusions and Recommendations:**

1. Based on the carbon oxides and furfural contents, it is concluded that the sampled cables and the splices (115 kV, 230 kV and 345 kV) per se have not experienced any aging. The generated DGA and fluid data show that the sampled cable systems are operating in a satisfactory manner. However, some follow-up action is needed to ensure continued trouble-free operation.
2. The low value of acetylene at RM unit#1 115 kV splice does not pose a concern. However, at a convenient time, this acetylene should be followed up to establish its maximum level along the splice through limited fluid drainage (5-8 gallons) in 2-3 installments and corresponding gas measurements. This was done at the B-G plant to locate the source of acetylene at Feeder #3, Generator end, with success.
3. The acetylene situation at RM unit #4 trifurcator (115 kV) calls for relatively faster resolution. The sampling of unit #4 switchyard terminations will not only resolve the observed acetylene at this trifurcator but also establish the condition of the termination.

4. It is essential to employ a pipe fluid that has minimum dissolved gases and avoid high saturated hydrocarbon gases, as observed in two RM units. The presence of such gases in the original fluid can complicate the DGA interpretation process. The measurement of original gas content is always recommended.
5. It is recommended to resample LPGP splices at units #2 and #3. While they do not pose any concern, it will be prudent to resample them at a convenient date.
6. Because of reverse ratio of carbon dioxide to carbon monoxide, it is recommended to resample the riser pipes of 345 kV cable associated with Auto-Transformer #3.
7. It is recommended to remove the corona dome at Phase C termination at RM Unit #9, generator end so that this termination can be sampled for DGA, like the other terminations (Phases A & B) at this location.
8. Of all the recommended actions, the sampling of all terminations is the most important one, and should be addressed. The failure of a termination can pose physical hazard due to porcelain shattering under high pressure conditions. Compare to 230 kV and 345 kV HPFF terminations, 115-138 kV HPFF terminations have presented more problems. It is essential to take three samples from each termination, as the fluid is drained, to take care of the entire termination through DGA.
9. The fluid sampling of the terminations for oil quality tests would also shed light on the higher dissipation factor values observed.

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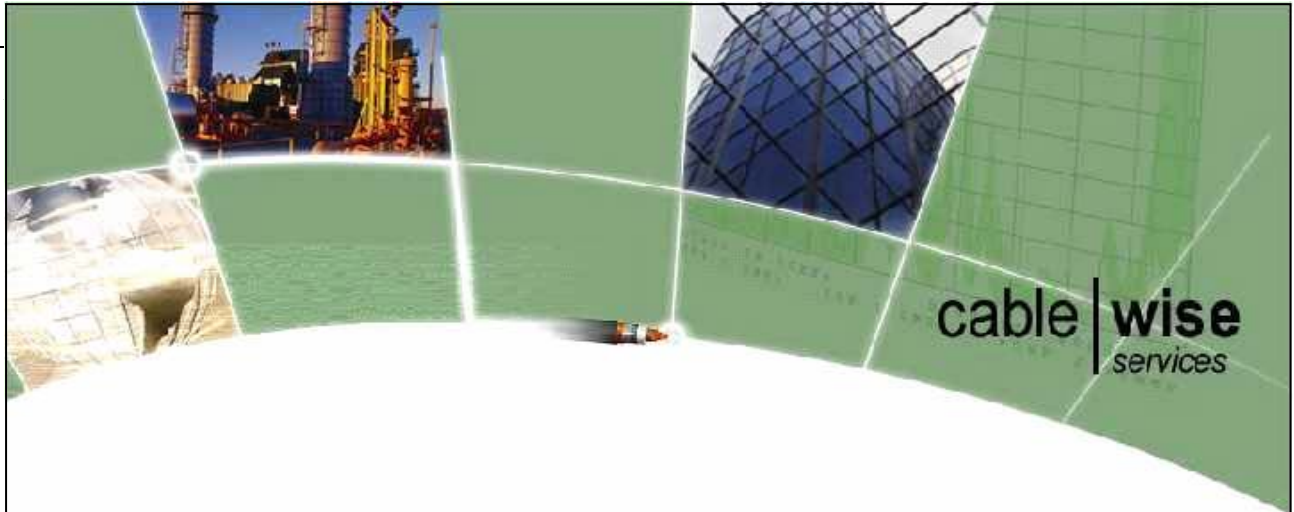
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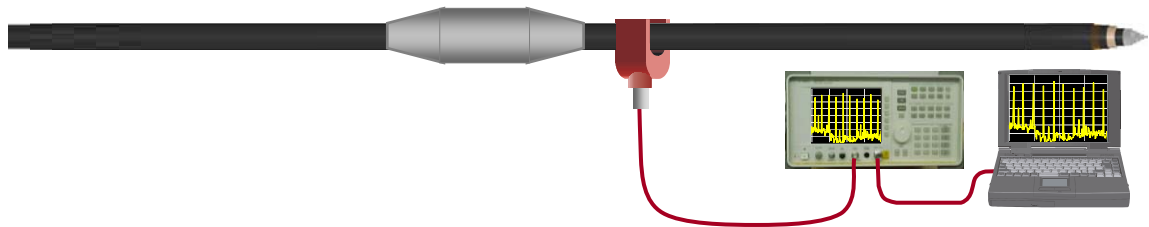
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## **DTE PARTIAL DISCHARGE MEASUREMENT REPORT**

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**Condition Assessment**  
**Of**  
**Feeder #9, 230 kV HPFF Cable System**  
**for**  
**New York Power Authority**  
***R. Moses (RMPP)***  
**New York**  
**February 8, 2005**



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**Condition Assessment  
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for  
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Niagara Falls, New York  
February 8, 2005  
Report # 2005-**

**SUMMARY ..... C-3**

**INTRODUCTION ..... C-4**

**RESULTS ..... C-5**

**CONCLUSIONS ..... C-7**

**Summary**

Condition assessment of Feeder #9, a 230 kV, 750 kcmil Cu conductor, high pressure fluid-filled (HPFF) cable belonging to the New York Power Authority (NYPA) R. Moses Generation Plant (RMPP) in Niagara Falls, state of New York, was carried out by DTE Energy Technologies on January 5 and 6, 2005. This feeder, which is installed in a tunnel, connects the RMPP with a Switchyard Station. The assessment was performed in selected sections of the system which included six riser pipes, two trifurcators, one normal splice and a 10-foot section of pipe. Data for the assessment were taken with the line energized and under normal operating conditions.

Of all Feeder #9 sections included in this report, signals originating from the cable insulation were only observed in the riser pipe sections at the Switchyard end. The trifurcator, normal joint, and pipe section showed no signals of concern. In the case of the RPMM end of the feeder, very strong discharges propagating from the terminations were observed in the tunnel area along the three riser pipes. The intensity of the discharges was observed to decrease at increasing distance from the terminations. Very strong corona-type discharges in the termination area were confirmed with a parabolic pinpointter which indicated above normal discharge activity in the overhead trainers to the cable terminations. It is believed that the icy weather conditions could have exaggerated emission of high frequency discharge signals from the substation.

## **Introduction**

Details of Feeder # 9 construction and operation are given in the table below:

### **Feeder #9, RMPP**

Rated Voltage	230 kV
Conductor Size	750 kcmil, copper
Insulation Thickness	880 mils
Cable Diameter	2.973 in
Pipe ID	8 in
Pipe Filling Fluid	Sun #6
Cable Manufacturer	Okonite
Load	350 to 450 A
Load Cycle	Continuous initially, peaking plant lately
O & M Practice	Routine maintenance: monitoring of pressurization units, pipe pressure and temperature. Excessive pump operation, high /low pressure. DGA annually
Failures	Phase A 1966 Phase B 1974

## **Results**

The results from this test are shown graphically on figures 1 through 11. The calculation procedure consisted of determining the total discharge signal within a variety of frequency windows, and then graphically representing the results as a function of longitudinal location of the measurement. Only signals having the appropriate 60 Hz modulation which indicates signals generated within the electrical system were considered. Consequently, utilizing a signature or fingerprint method of signal recognition, signals emanating from substation equipment external to the cable insulation were identified.

A schematic diagram of Feeder #9 is presented in Figure 1. The sections of Feeder #9 selected for testing were obtained from the original Statement of Work (attached). Accordingly, this included six riser pipe sections, three at the Switchyard Station end and three at RMPP end and the two respective trifurcators. Tests were performed on a normal joint casing and ten feet of line pipe toward the power plant about 500 ft from the switchyard termination riser pipes. Measurements were taken during a two-day working period. Markings were made over the pipe a foot apart in the sections selected for sampling to help locate the sensor. A summary of the results for each of the test points are given as follows.

### **Feeder # 9 Riser Pipes at Switchyard Station End**

Analysis of data from the riser pipe sections under the Switchyard Station was carried out at four frequency bands covering the range from 40 to 130 MHz. A typical frequency domain scan is shown in Figure 2. The selected frequency bands are highlighted in this figure. A number of different signals were isolated within these four narrow frequency windows. Integration of the signal strength in each of the frequency windows allowed comparison to be made at one foot intervals along the selected area. Due to the presence of high frequency noise (spark or arcing discharges) from the Switchyard Station, it was decided to test along the entire length of the riser pipes for all three phases. The pipe lengths for each riser are 21 ft, 34 ft and 51 ft for phases 1, 2 and 3, respectively. Phases 1, 2 and 3 are close together for the first 9 ft, at which point phase 1 riser separates. Consequently, phases 2 & 3 continue close together up to a point 27 ft from the edge of the trifurcator, where Phase 2 riser separates. This situation is depicted in the graphs showing the results of total signal as function of distance from the trifurcator edge in figures 4 through 7. It should be noted, that the y-axis in this graphs, represents the square of the total signal for a given frequency band and it is represented as a function of distance to the edge of the trifurcator.

Squaring the total signal increases the signal to noise ratio facilitating the visualization of weak signals whose intensity are slightly above background level. The findings are summarized by phase as follows:

#### ***Phase 1***

The pipe containing phase 1 is the shortest of the three. Low frequency signals, refer to figures 4 and 5, had a signature identifiable as discharge activity originating in the substation from components connected to the cable terminations and propagating down the riser pipe. These discharges are intense and showed a decreasing intensity at increasing distance to the terminations; refer to the trend lines showed in Figure 4, thus confirming the

location of the source. Among the different phases, phase 1 show in average a higher intensity of substation noise when compared to the other phases, with Phase 3 showing the least intensity. Data for higher frequency have significantly lower intensity, however, the signature stills indicates presence of substation noise. It should be noted that the riser pipe for Phase 1 is shorter than the other two and therefore, closer to the termination area where most of the noise is originating.

### **Phase 2**

Low frequency signals in this phase show a decreasing trend, refer to Figure 4, corresponding to substation noise. In the next frequency windows data for this phase shows a signature not observed near the termination end, thus indicating presence of cable insulation noise. Cable insulation signals for Phase 2 seem to peak at 9 feet and 25 feet from the edge of the trifurcator. Both of these signals were observed at several data points within one area. Although the signals are not very intense, there is an element of concern and retesting is necessary to establish trending as a function of time and cable load if possible.

### **Phase 3**

Low frequency data indicates decreasing total signal intensity at increasing distance from terminations for signals showing the signature of substation noise. The trend line in Figure 3 shows this distance effect. This in an indication that signals in this specific frequency belong to substation noise from air gap discharge activity external to the cable and/or cable terminations. Signals attributable to the cable insulation are shown at points 13 ft and 22 ft from the edge of the trifurcator. These signals are small in intensity and characterized with a low repetition and therefore not of immediate concern. Trending of these signals is recommended before action is taken.

### **Trifurcator Switchyard Station End**

The data for this trifurcator is shown in Figure 8. Measurements were made directly over the trifurcator casing with a large diameter sensor at one foot intervals. The signals observed along the trifurcator correspond to substation noises with no specific peaks indicating the lack of any discharge sources inside the trifurcator.

### **Normal Joint**

Data from the normal joint are shown in Figure 9. The two traces in Figure 9 which corresponds to a much broader bandwidth of 100 to 200 MHz and 50 to 100 MHz show no signals. It should be noted that frequency range selected in to calculate the data in this joint and in the pipe sections that follow are much wider than those selected in the previous part of this report and cannot be compared. The total signal intensity observed in the normal joint is exceedingly small.

### **10-foot Pipe Section**

Data from 10-foot pipe section are shown in Figure 10. No signals were observed in this pipe section. Total signal intensity was exceedingly small.

### **Trifurcator at Generation End**

Data from the trifurcator are presented in Figure 11. A high level of background noise was observed at all locations along the trifurcator. Based on the data taken from the riser pipes, it is expected that all the signals captured in the trifurcator are external to this cable and originating above ground in the area where this cable is terminated. The background noise is very strong and was not attenuated fast enough to show a decreasing trend toward the farther end of the 7-foot long trifurcator.

### **Riser Pipes at Generation End**

Extremely high intensity discharges were observed from this end of the cables. The observed signals, which are believed to have originated external to the cable from equipment connected aerially to the cable terminations and originating in more than one phase. Riser pipe signals from the three phases were equally strong and only the signal in phase 1 showed a decreasing trend with increasing distance from the end of cable. The signals were significantly higher in intensity when measured at the point where the riser pipes meet the ceiling, which is the closer point to the termination. With this in consideration, in addition to the magnitude of the signal, it is concluded that the discharges must be external to the cable system but present in equipment in electrical contact with the cable terminations. To confirm the presence of this activity, the feeder #9 terminations area was visited and a parabolic antenna was used to scan for corona-type and air gap discharges in the aerial equipment connected to the cable terminations. At this time, extremely high intensity discharges were detected from more than one source. This confirms the findings made from measurements inside the tunnel area underneath the substation.

## **Conclusions**

### **Switchyard Station End**

Signals emanating from the cable insulation were observed in some locations along the riser pipes in phases 2 & 3 at the Switchyard Station end of the cable, being of more concern those signals from Phase 2. The rest of the equipment tested from the Switchyard Station end, namely, the trifurcator, normal splice, and line pipe section showed no signals of concern.

### **RMPP End**

An exceedingly high interference was encountered from aerial components associated with the terminations of Feeder #9. These signals completely mask signals from any other source and could be an indication of problem equipment external to the cable in question.

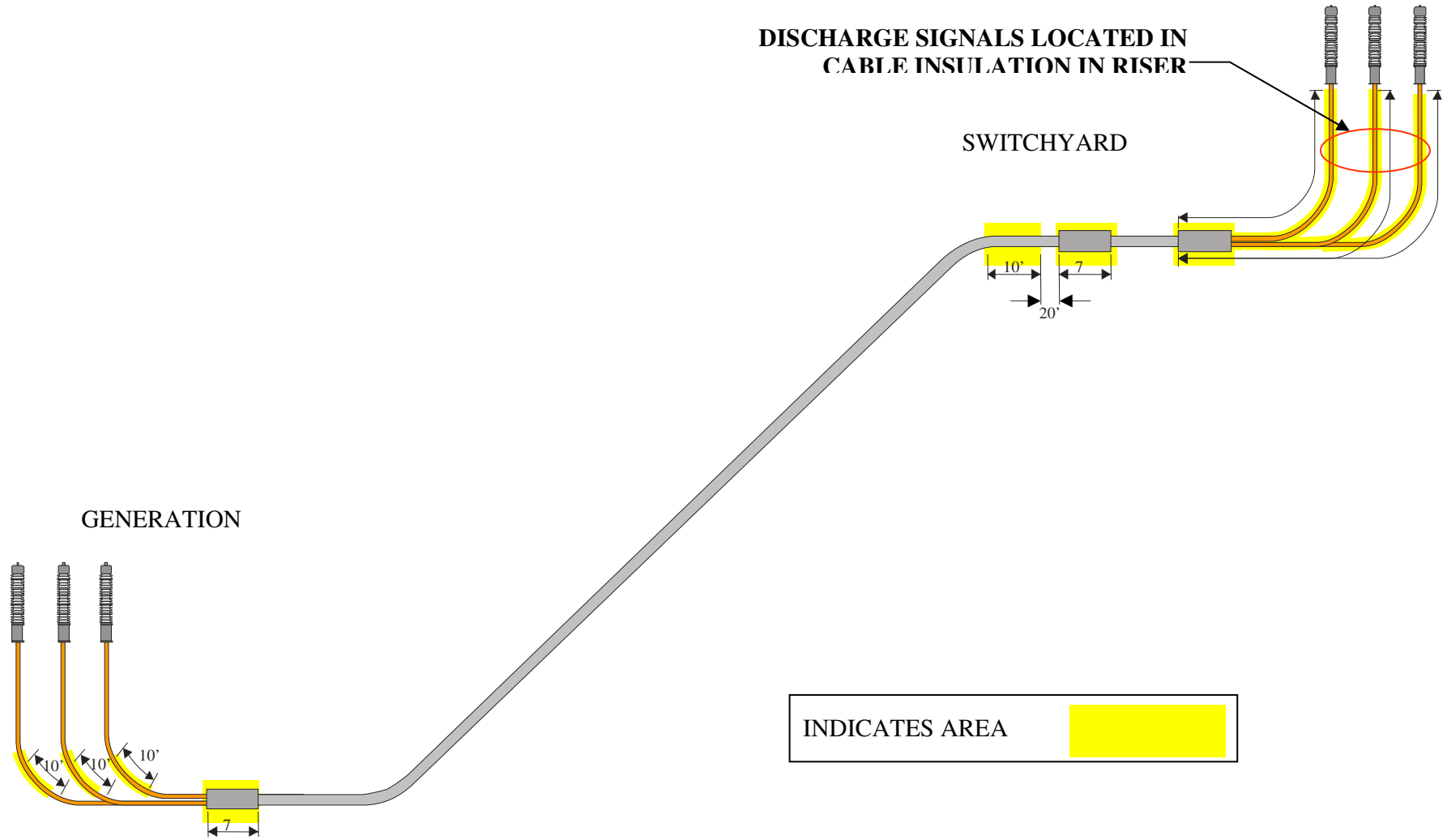
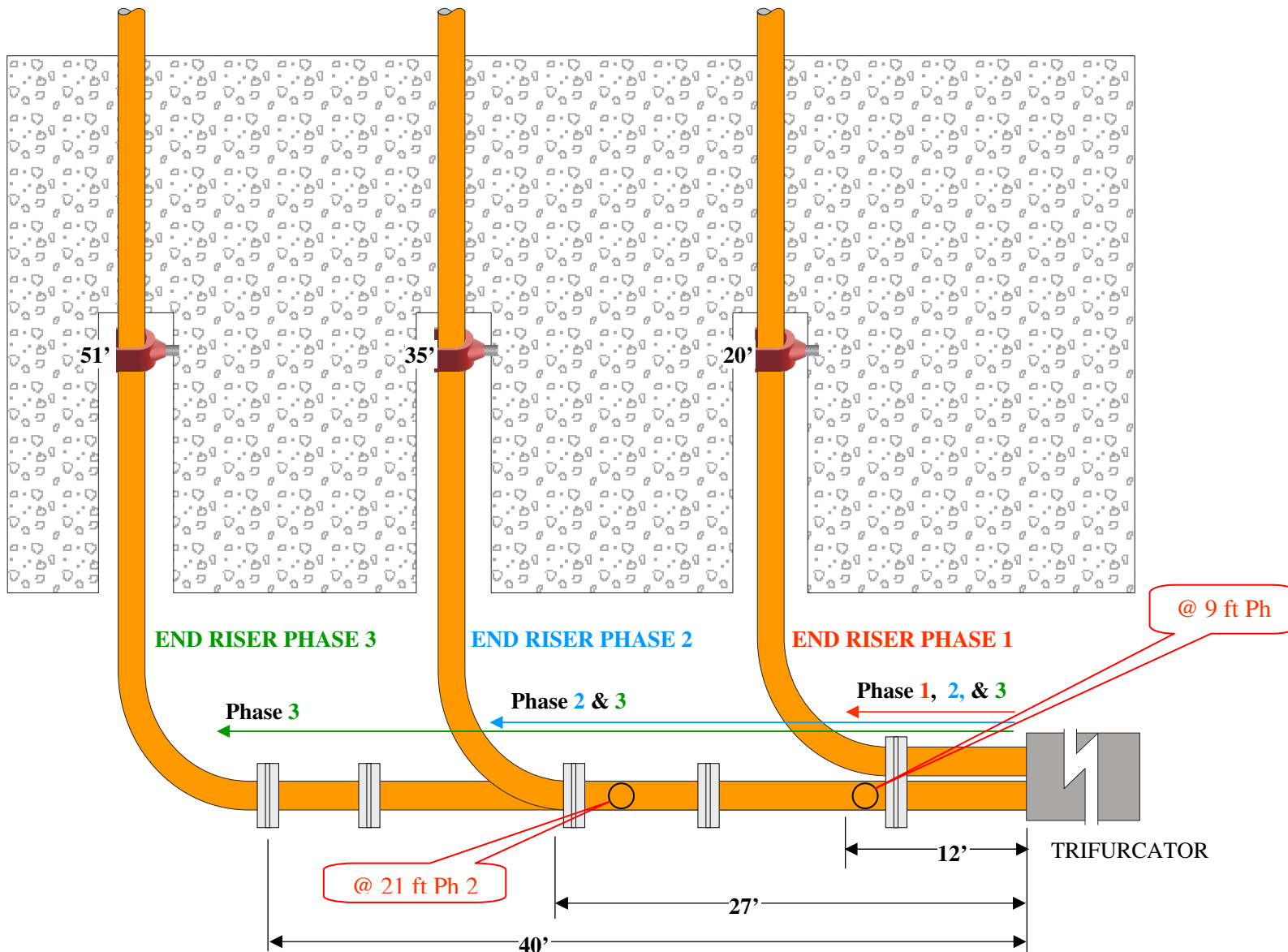
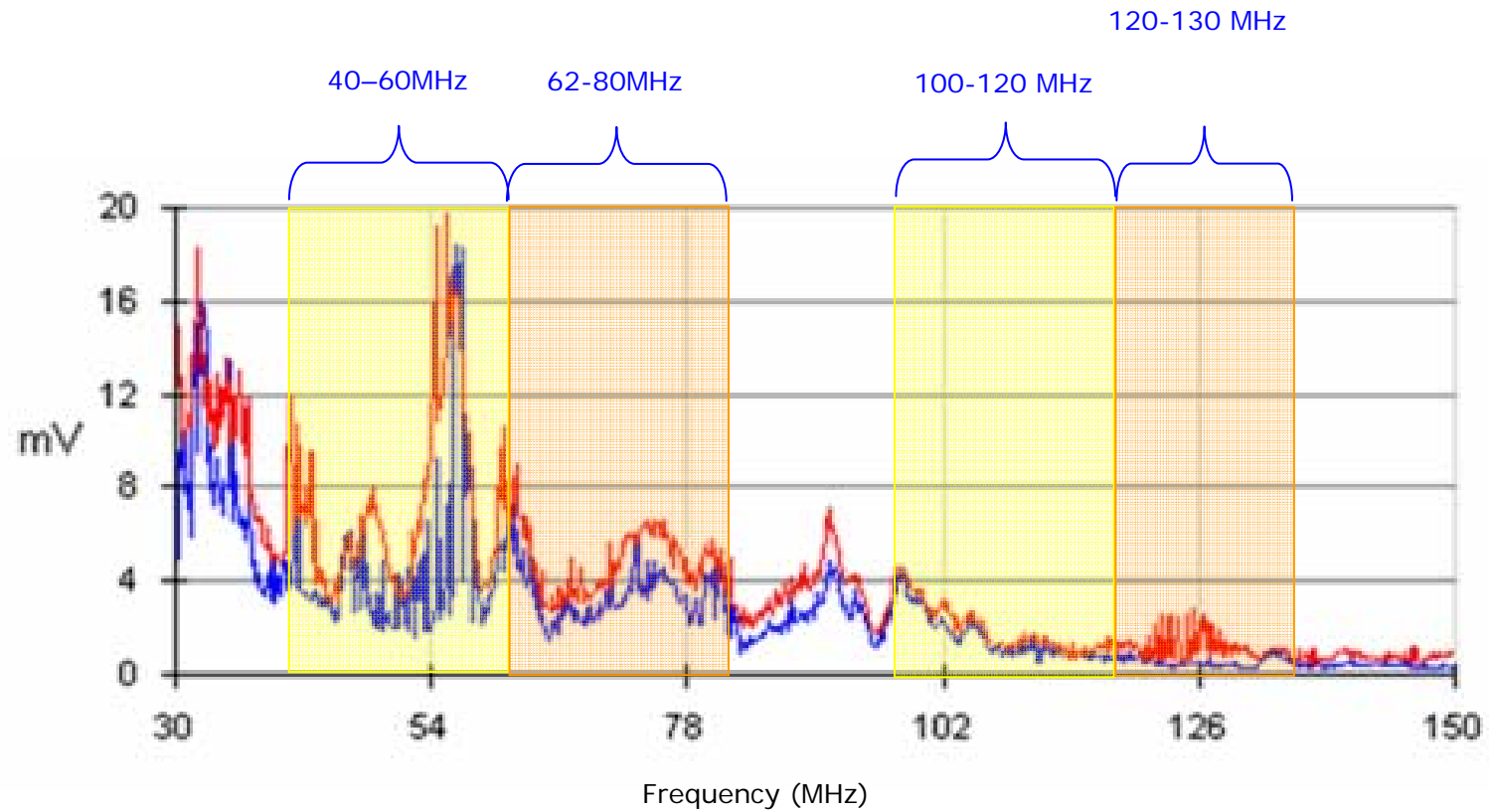


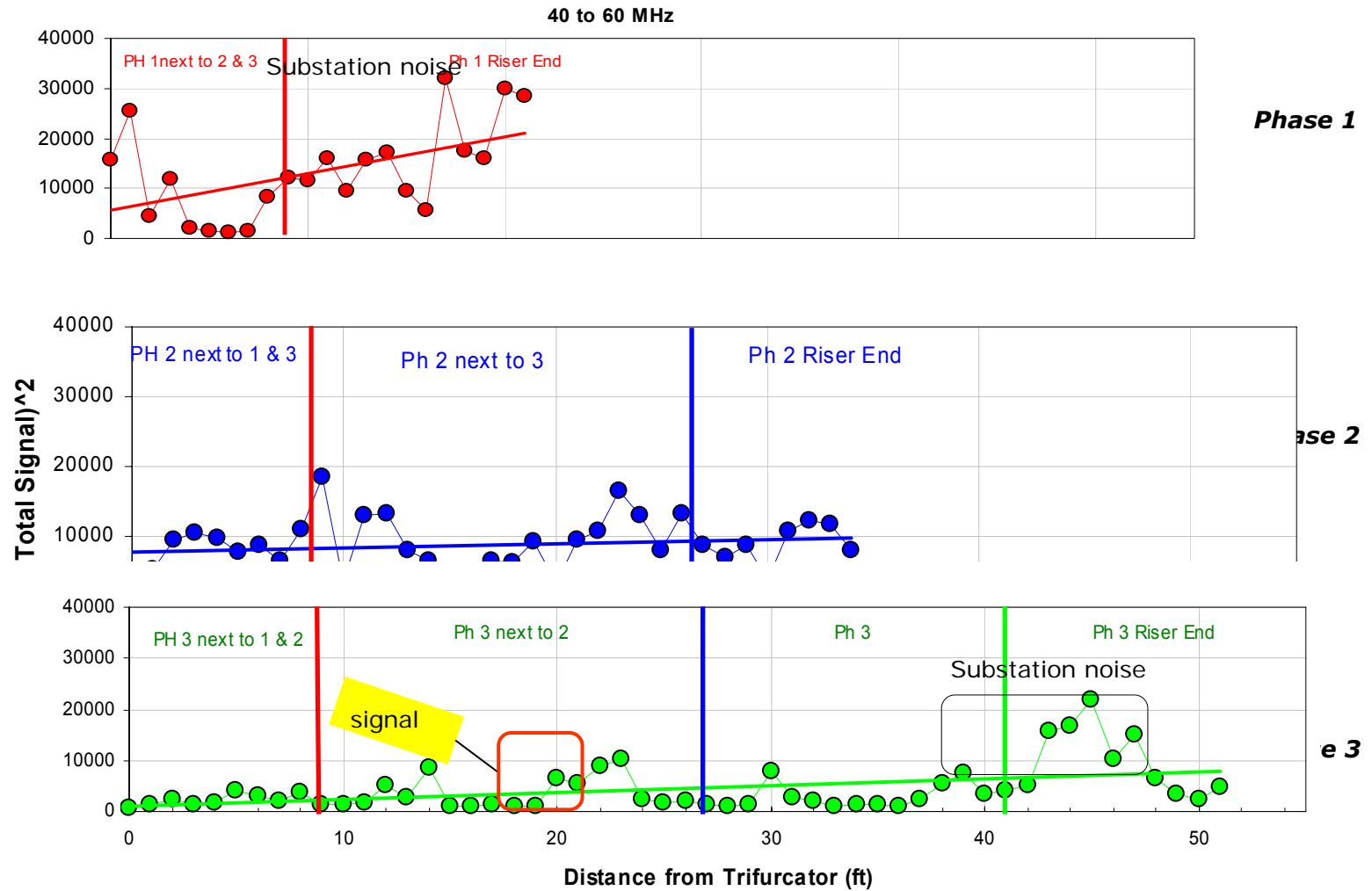
Figure 1: Schematic diagram of Feeder #9, R. Moses Generation Station.



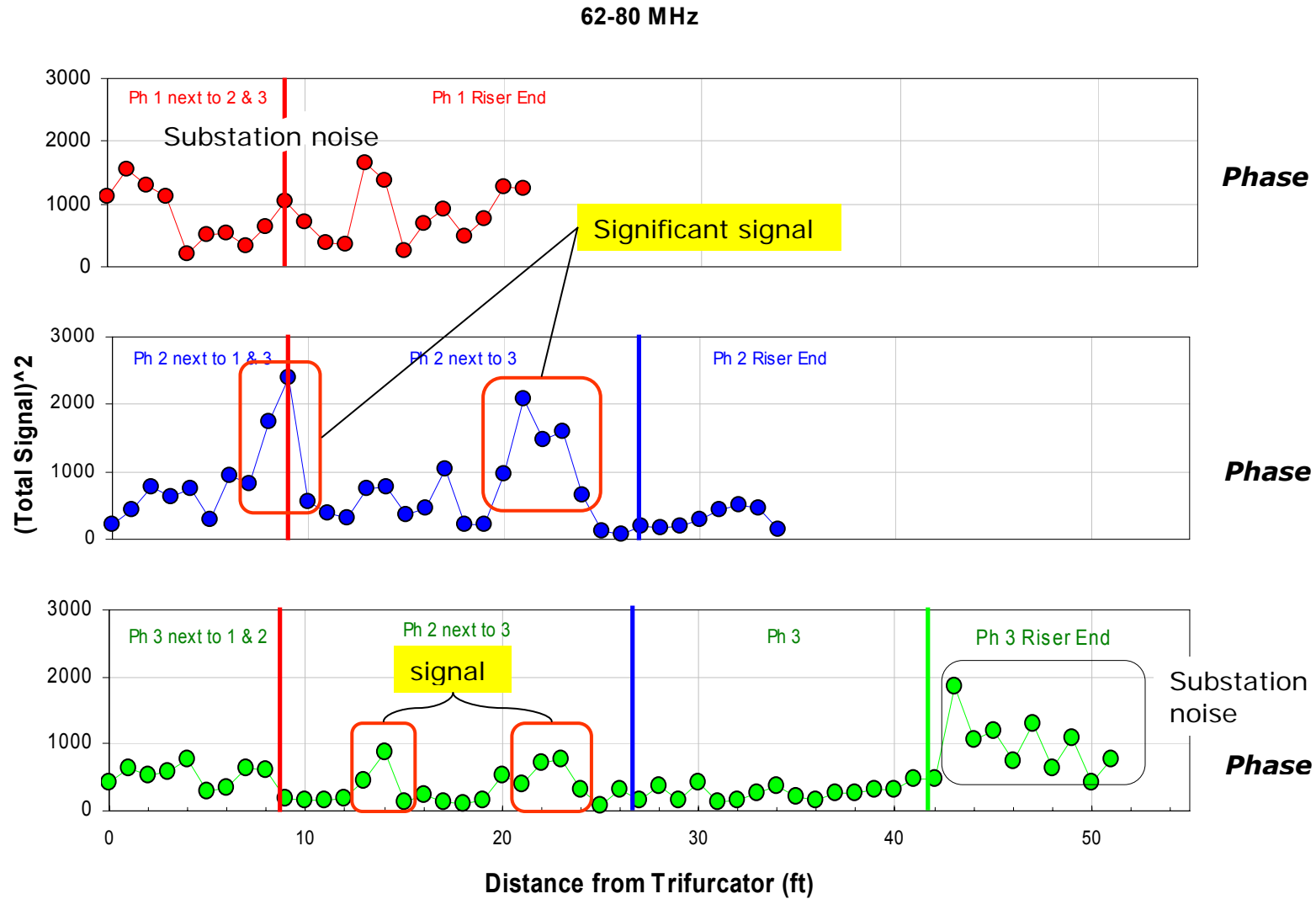
**Figure 2** Schematic diagram of riser pipes for feeder #9 under the terminations at R. Moses Substation end. Footage shown indicates distance in feet from the edge of the trifurcator to the end of the exposed riser pipe at the ceiling of the tunnel. When multiple phases were together, measurements were made at the same foot



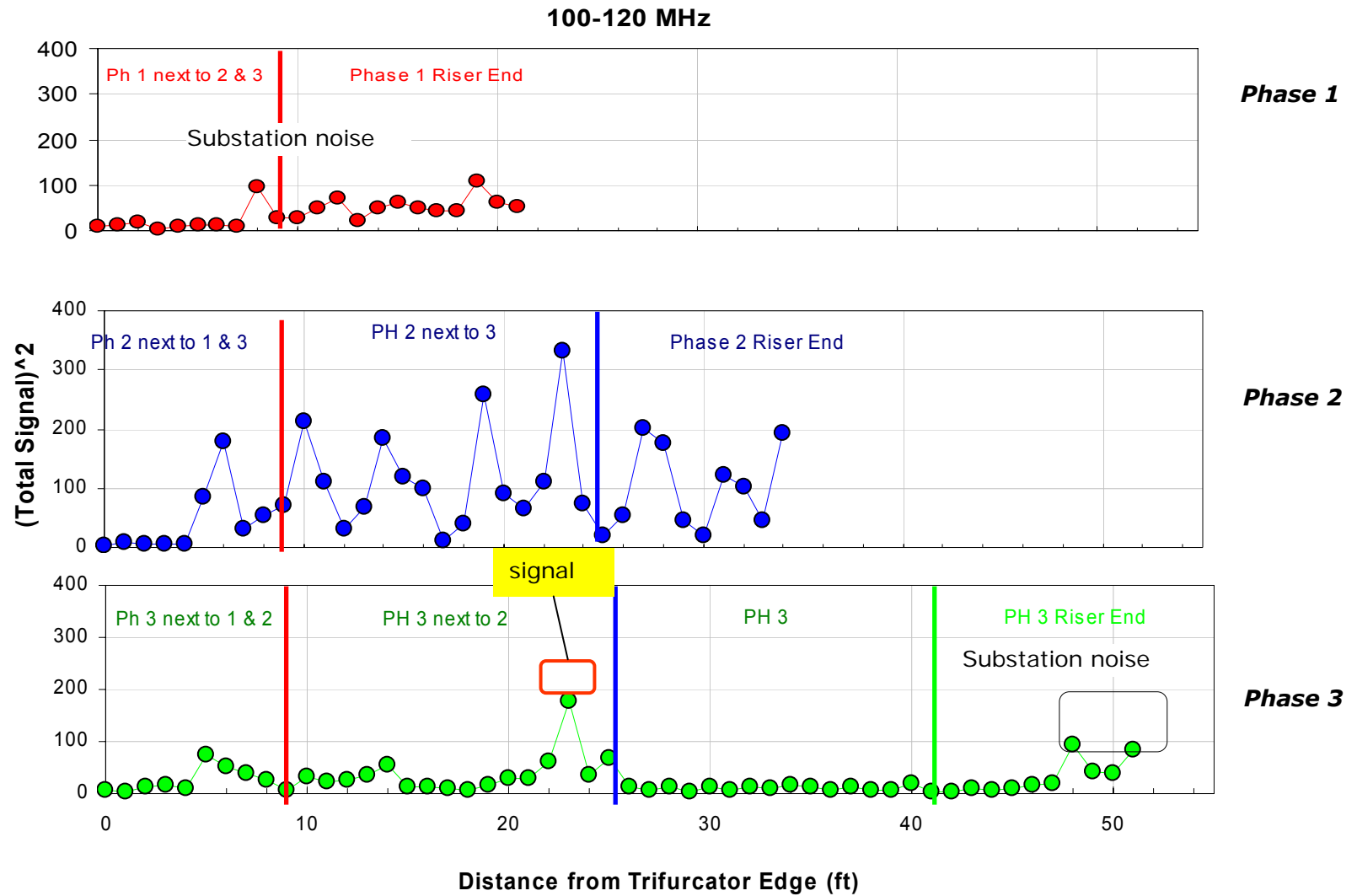
**Figure 3:** Typical frequency scan from a test point at the R. Moses end of feeder #9 showing frequency windows where integration of total signal was carried out as a function of distance from trifurcator



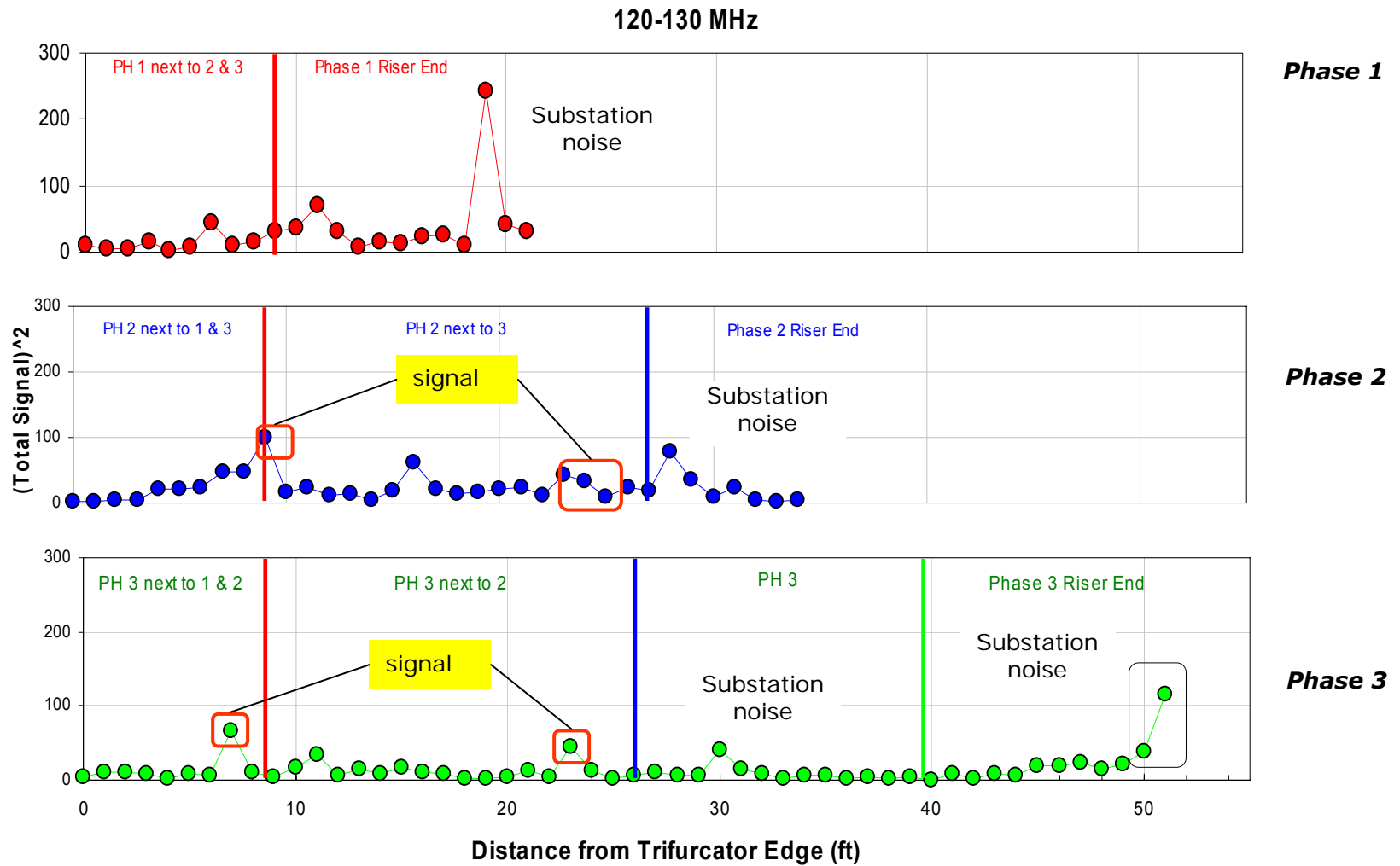
**Figure 4:** The square of the total signal as a function of distance to trifurcator for frequency window 40 to 60 MHz for all three cable phases. Note that the level of total signal is higher for Phase 1 and lower for Phase 3.



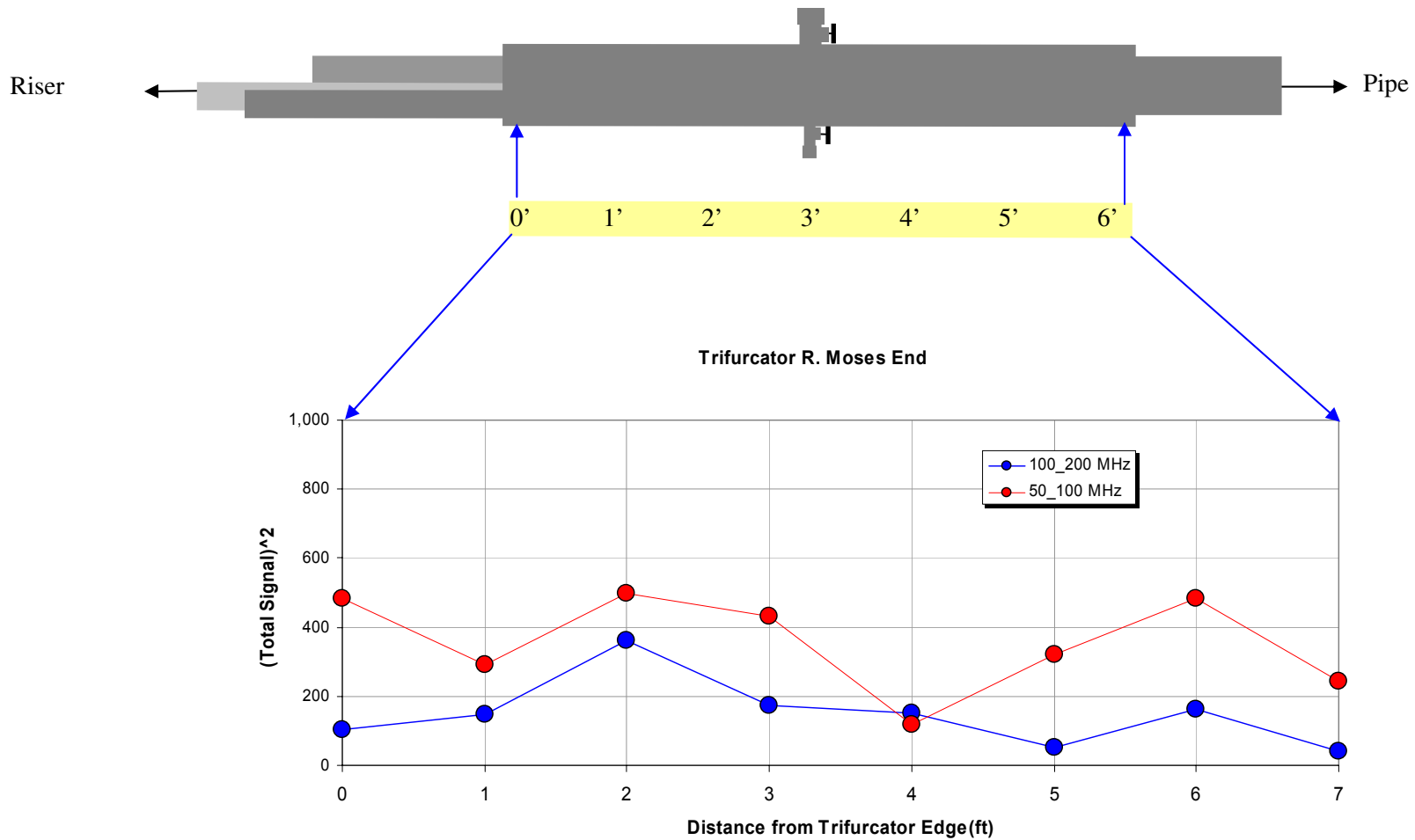
**Figure 5:** The square of the total signal as a function of distance to trifurcator for frequency window 62 to 80 MHz for all three cable phases. Note that the signal level is lower for Phase 3, while distinctive signals were observed at two points in Phase 2.



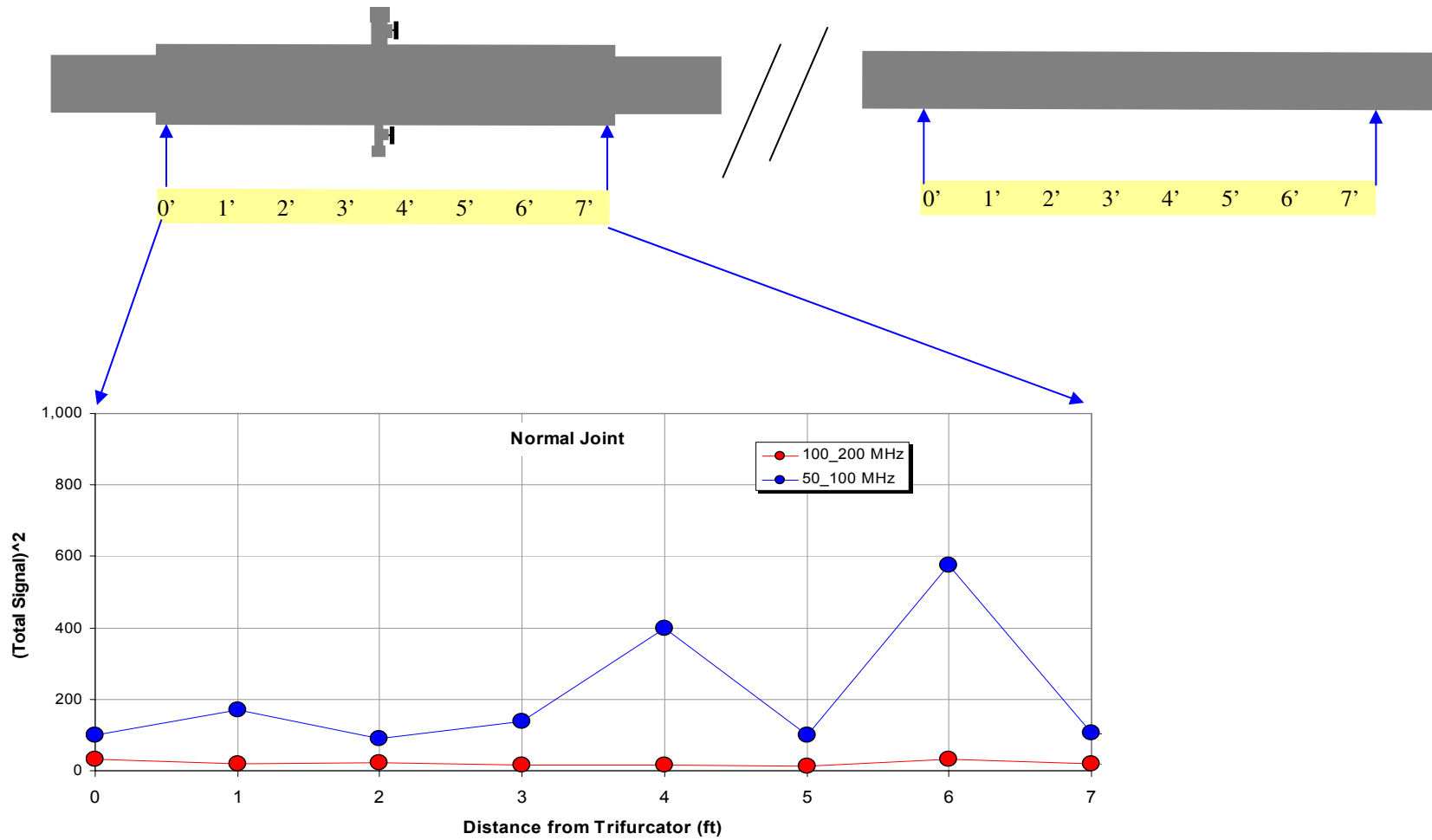
**Figure 6:** The square of the total signal as a function of distance to trifurcator for frequency window from 100 to 120 MHz for all three cable phases. Note that the signal level is higher in Phase 2 compared to phases 1 and 3



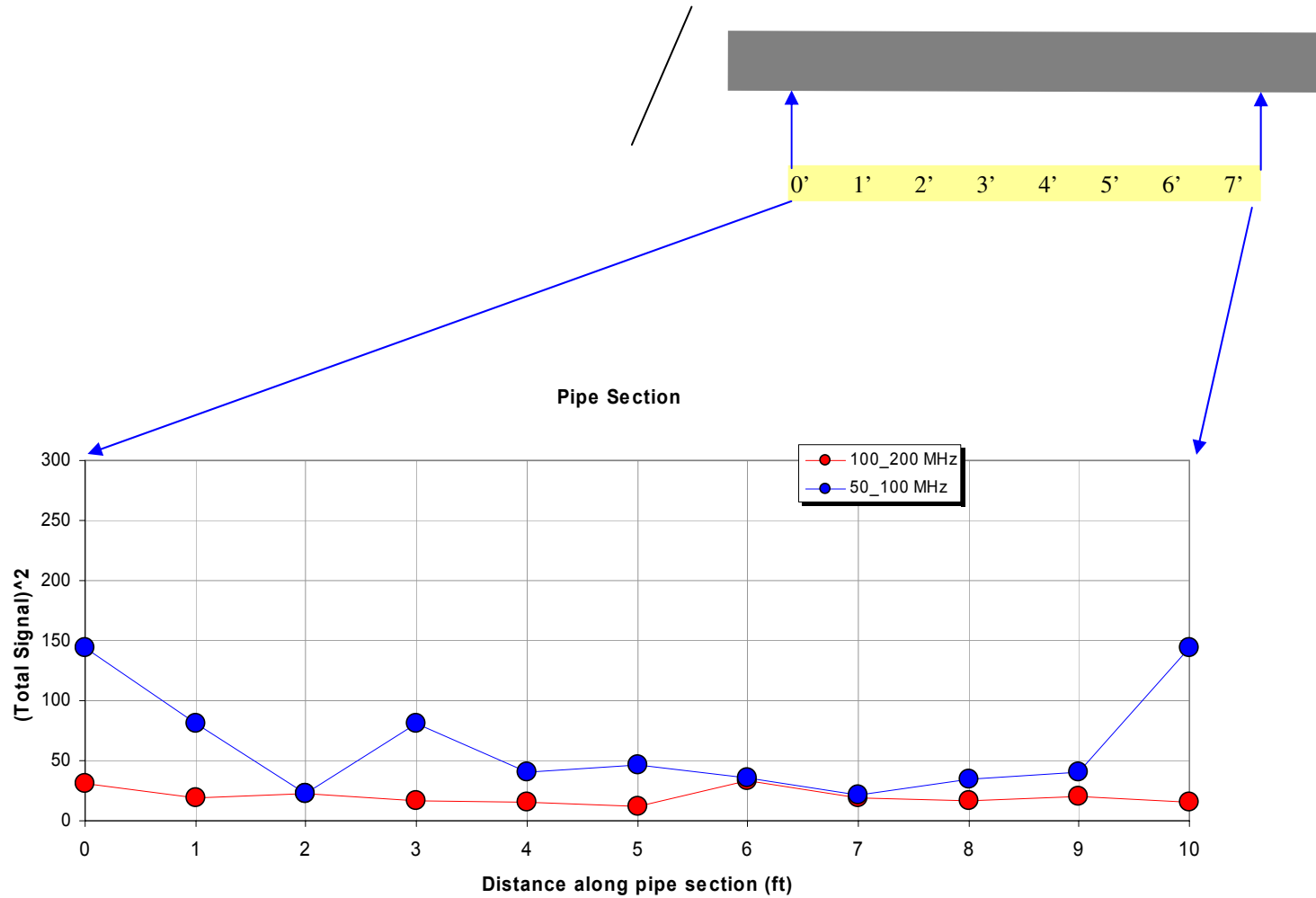
**Figure 7:** The square of the total signal as a function of distance to trifurcator for frequency window from 120 to 130 MHz for all three cable phases. Note that besides the large peak in Phase 1, several small peaks can be observed in all three phases.



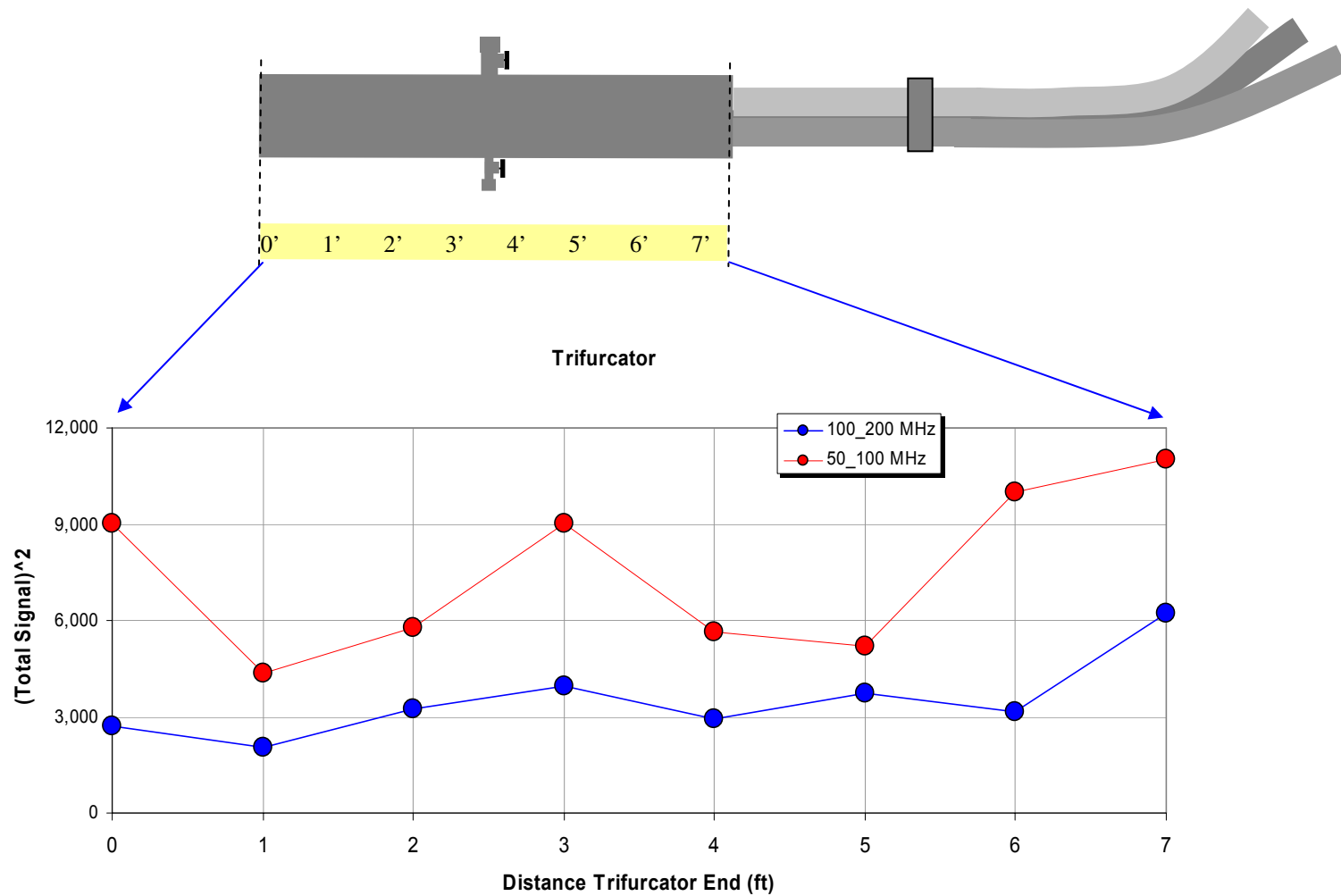
**Figure 8:** Diagram showing Feeder #9 trifurcator, R. Moses end, location of test points and data for two wide frequency ranges, 100 to 200 MHz and 50 to 100 MHz.



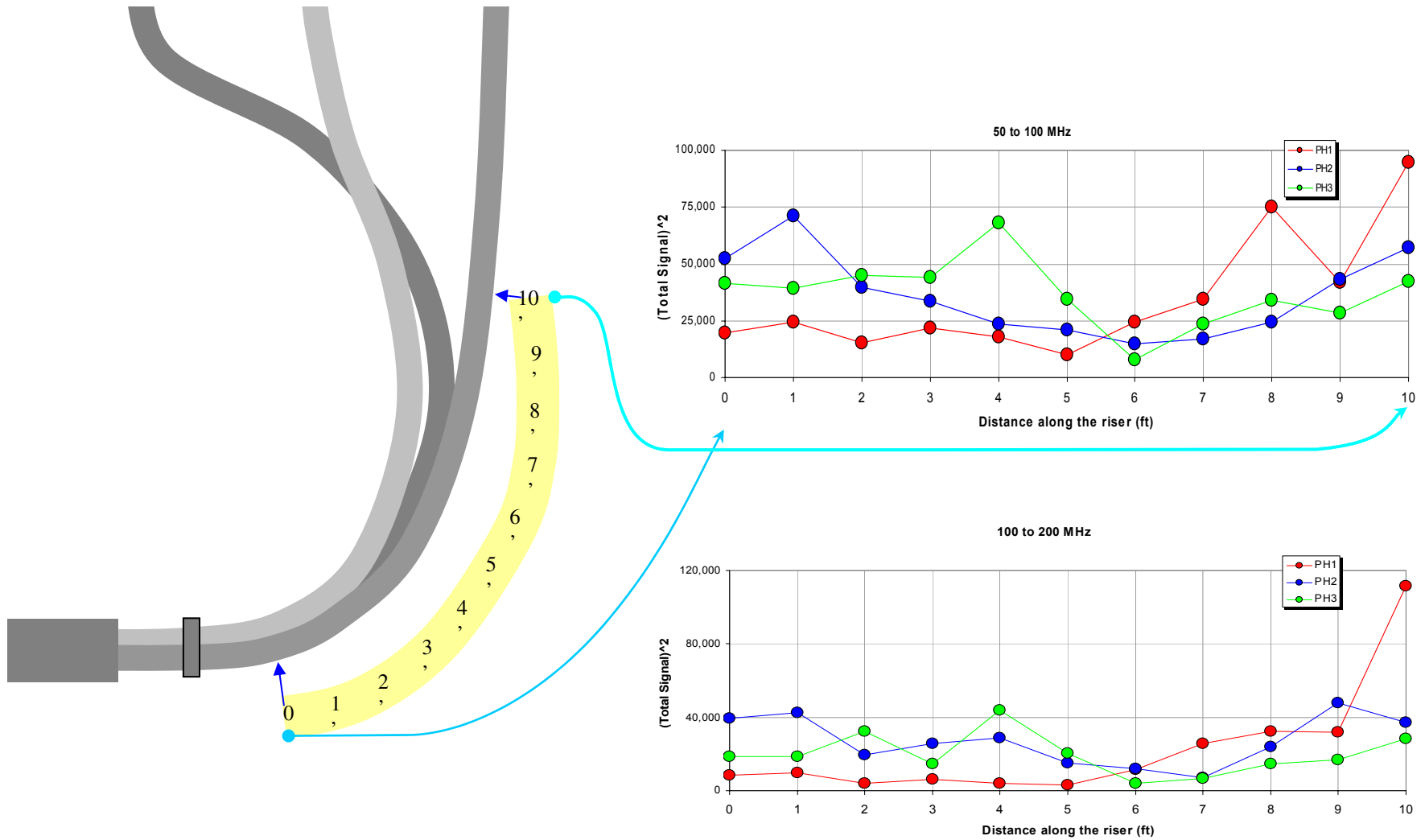
**Figure 9:** Diagram showing Feeder #9 data from a normal joint pipe. The two traces show the square of the total signal for 50 to 100 MHz and 100 to 200 MHz



**Figure 10:** Square of total signal from 10-foot pipe section. Notice that the small intensity of signals and the lack of well defined peaks



**Figure 11:** Schematic diagram of Feeder #9 trifurcator at generation end. Test locations on both portions of the cable system are shown by the foot marks.



**Figure 12:** The square of the total signal as a function of location along the 10' section of riser pipe from feeder #9 at generation end of the cable at two different frequency windows.





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