Everglades National Park
500kV Underground Feasibility Study

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Prepared For:

United States Department of the Interior
National Park Service
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Executive Summary:

Placing 500kV cables underground in concrete tunnels and laying cables underwater has been done successfully during the past 30 years, primarily outside of the United States. Recently planned projects of installations up to 10 miles in length using Cross-linked Polyethylene (XLPE) cable as would be suitable for installation in a concrete duct bank are underway proving the electric utility industry accepts the fact that 500kV circuits can be satisfactorily installed in an underground system. Improved cable design and manufacture indicate that Extra High Voltage (EHV) circuits can be expected to perform reliably for 40 to 60 years, however the reliability and availability is degraded by the length of time required to accomplish a repair. Thus to have reliability and availability equivalent to overhead facilities requires the installation of redundant underground capacity. The determination of the overall feasibility of placing a 500kV circuit underground thus becomes a question of cost. Since 1990 the cost premium for Underground vs Overhead has dropped from 25X to 7X on a foot by foot comparison. While the improvement is substantial, the user continues to pay a significant penalty to go underground. For the application presented by Florida Power and Light, the premium increases by 50% in accounting for installation of a redundant circuit. Information presented in this review shows that while construction of 500kV Underground circuits is technically feasible, the process is fraught with major technical, operational, and financial challenges. As seen throughout the report, those challenges become particularly problematic when applied to a critical transmission grid making underground prohibitively expensive when the option to stay overhead exists. It also shows that using cost figures based on the most recent underground projects support a cost premium of 10-12X rather than the 20X premium indicated in the Florida Power and Light response. Not

considered as an option in this report is one where the cables would be direct buried. Such an option would greatly decrease installation costs but would not be suitable for use in a critical transmission application due to repair time and cost. An in-segment failure would likely require digging up and replacing the entire segment where the failure occurred to avoid having less reliable repair splices in an underground/underwater area.

Introduction

In the 1960's Florida Power and Light (FPL) obtained approximately 40 miles of Right-of-Way for the purpose of constructing two 500kV Transmission Lines from the Turkey Point Nuclear Generating Plant to load centers in the Miami-Dade County Area. Approximately 6.5 miles of this transmission corridor goes through the Everglades National Park (ENP) at a location now being targeted for re-hydrating and swampland restoration. The US House of Representatives has approved a bill authorizing the National Park Service (NPS) to trade land on the inside edge of the ENP for the FPL owned land that is targeted for flooding.

ENP management is currently reviewing the proposed land swap to determine the extent of any foreseeable impacts that could arise from proceeding with such a swap. The corridor of land to be potentially transferred to FPL is on the edge of the ENP adjacent to residential and commercial areas and a water canal. In looking at known and potential environmental issues, a question of the feasibility of putting the electric transmission lines underground was presented to FPL. The FPL response is that the construction of underground (UG) 500kV Transmission Lines has marginal technical feasibility and no economic feasibility. ENP desires to have the FPL response audited by a qualified independent engineering firm before making a final recommendation to the Secretary of the Department of the Interior.

Technical Feasibility

Determining the technical feasibility of installing an UG 500kV Electric Transmission Line considers the following items: 1. **Material Availability**; 2. **Installation Experience**; 3. **In-service Installations**; 4. **Reliability Factors**. Each of these is discussed below.

1. **Material Availability** – Florida Power and Light reported that three types of UG cable are technically suitable for use in a 500kV installation and this fact is not challenged. Those types are High Pressure Fluid Filled, HPFF; Self Contained – Fluid Filled, SCFF; and Cross-linked Polyethylene, XLPE. From an electrical perspective, any one of these type cables can be considered for a UG installation and each has its advantages and disadvantages. However, the improvement in the manufacture of XLPE in recent years has led to the choice of this type cable for line lengths up to 17km. Improvement of the outer sheath through the use of smooth welded aluminum to replace lead or corrugated aluminum has resulted in a smaller and lighter product resulting in longer reel lengths and easier handling. **(Attachment 1- Prysmian Cables & Systems, Pg 2 Para 4)** The most recent plan to use this product was announced in 2006 by Cable Manufacturer, Nexans, for a 17km tunnel 500kV UG installation between two substations in Shanghai, China. That project has not yet been completed, but illustrates the direction taken in the most recent selection of a UG 500kV cable installation. **(Attachment 2- Nexans Press Release, Pg1 Sect 2)** Based on the fact that UG installations of XLPE cable are currently in service and chosen for future installations it can be said that product availability is not a technically limiting factor.
2. **Installation Experience –** UG installation covers both the civil and electrical disciplines. Older installations of 138kV and 230kV UG circuits were of the HPFF design and have been installed in large cities where overhead circuits were not feasible. New York City

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with its towering buildings and dense load factor for example. Newer installations have migrated to XLPE as the reliability of the product has improved. In the US those installations have typically been in concrete encased conduit as described by the Florida Power and Light paper. Lower voltage installations have been direct buried and this could work for 500kV as well, however, the reliability of direct buried cable would be lower, and the cost of replacing a failed section would be essentially equivalent to an amount equivalent to the inflation adjusted initial cost. There have been no reported direct burial installations of any 500kV circuits and it would not be prudent to consider it for a use in a critical transmission system grid.

The UG civil construction portion of the project involving excavation/spoil removal, conduit, cement vaults, and concrete/thermal backfill is within the normal expertise of many US based construction firms. A significant portion of the UG section would be through wetlands and high water table areas and dewatering issues would be a major issue during design and construction.

UG electrical construction requires specialized expertise for making the watertight splice connections with the requisite dielectric strength. Since the maximum length of a reel of XLPE UG cable is 1500', each single conductor would require approximately 24 splices for the UG section and with 27 conductors for three lines this amounts to 648 individual splices. Quality control in the manufacturing of the cable can make the cable essentially impervious to failures from contaminants and voids in the dielectric and in the watertight quality of the metal sheath. That same quality control in the making of a splices is much more difficult to achieve thus making the splice locations more susceptible to failure. The specialized expertise needed to make the splices exists and could be acquired and

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scheduled for the initial installation, however, this expertise is limited based on current market demands. Additionally, acquiring that same expertise on short notice as would be required for repair of a failed single segment could be very difficult and could substantially lengthen the time required for return to service. In summary, qualified personnel to make splices for 500kV UG XLPE cable are a small world-wide community simply due to the fact there is not a large demand for their expertise, thus no opportunity to expand the size of the community.

3. **In-Service Installations** - There are no 500kV, XLPE UG installations in the US. Existing and planned installations overseas were covered in the Florida Power and Light response with the addition of the Shanghai project mentioned earlier in this report. Overseas experience is not directly transferable to US application since most of the overseas utilities generate power at 50 Hz compared to the US generation at 60 Hz. An UG cable in the US would have less capacitive reactance per unit length than the same cable installed overseas. This would affect power transfer but would not be expected to degrade reliability. Depending on the length of the UG cable, inductive reactance, shunt reactors, would be required to compensate for the capacitive effect of the cables. **(Attachment 3 TrAIL Co Rebuttal Statement 15, Pg 6, Lines 11-23)**

4. **Reliability Factors** - Transmission of electric power over any transmission system requires that the conductors be sized to carry the electrical amperes of the load and that the conductors be insulated from each other and from ground by a non-conductive, or dielectric medium. In overhead transmission, the air acts as the heat transfer medium to cool the conductors and as the dielectric medium to isolate the conductors from each other and from ground. In UG installations, the conductor must be isolated from ground

through dielectric or non-conductive mediums such as XLPE, high quality mineral oil, sulfur hexafluoride (SF_6) gas, or a combination of mediums such as mineral oil and paper. Mineral oil and SF_6 mediums, like air, can be used to transfer heat away from the conductors by transferring the heat to air through radiators or other cooling means. Solid dielectric mediums such as XLPE are more difficult to cool since the electrical isolation medium also acts as a heat transfer blocking insulation around the conductor. The slow transfer of heat away from the conductor through the cross-linked poly-ethylene requires larger low resistance conductor material. It is the nature of conductors, to have increasing resistance with increasing temperature thus providing a positive feedback effect that if not accounted for will lead to thermal runaway and failure. Electrical isolation and thermal insulation are major factors affecting the reliability of a UG installation. Other factors affecting the overall reliability of the installation are listed as follows:

1. Rocks/objects – in direct burial can damage the outer cover and metallic sheath causing dielectric failure.
2. Explosion potential – dielectric failure at high voltage levels will often result in catastrophic explosion that would be extremely dangerous and likely fatal to anyone within a confined area such as a tunnel or vault. Safety prudence may require that all circuits within a vault or tunnel be de-energized before workers are allowed to enter. **(Attachment 4, TrAIL Brochure, Section 3, Bullet 5)**
3. Dielectric voids/contaminants – At Extra High Voltage (EHV) levels, the electric field around the conductor is very intense. Any imperfection in the dielectric medium creates a condition for corona, ionization, and other partial discharge conditions leading to dielectric breakdown and cable failure. The

cable must come out of production in near perfect condition and must be installed with no splice imperfections.

Technical Feasibility Summary – Underground installations of circuits with voltages up to 230kV are fairly commonplace in the US and throughout the world. Cable manufacturing and installation technology has progressed to the point that reliability of those installations is comparable to the 50 year typical design life of electrical overhead systems. EHV UG cable manufacturing technology has benefitted from improvements learned with cables at lower voltage levels, and today, one would expect an EHV installation to have a 40 - 60 year life. **(Attachment 5, OLex Internet Update, Pg 2, Conclusion)** That is not necessarily true of the reliability of the multitude of splices required for a multi-mile installation. Any contamination such as moisture, dust, or air pockets in the dielectric around the splice can lead to failure and it is this risk that degrades reliability statistics for EHV cable installations. In summary, cable manufacturing for EHV applications produces a product that is sufficiently reliable to meet the demanding requirement of a critical transmission grid. Conversely, field application of EHV cables has not been demonstrated to have a reliability component equivalent to the reliability of the cable itself. Additionally, the specialized equipment and skills required to replace and reconnect a failed cable segment introduces an unacceptable time component into the recovery process thereby requiring installation of redundant facilities. However, with the spare circuit, a 500kV UG installation can be considered sufficiently reliable to meet the needs of a base load transmission line.

Economic Feasibility

Economic Feasibility of 500kV UG versus 500kV overhead is first of all a comparison of the expected or projected costs of both options. There have been numerous installations of overhead

500kV transmission lines in the US over the last decade. An 84 mile, 500kV lattice steel, triple bundled conductor line constructed in 2003-4 had a projected cost of approximately $850,000 per mile as determined during the last few weeks of the project. **(Attachment 6, Memo 84 mi line cost $74M)** That project was constructed on an existing Right-of-Way with minimal clearing and grading requirements. The FPL cost to construct 13 miles of 500kV overhead line through the ENP is estimated to cost from $2,400,000 to $3,800,000 per mile. Considering the Florida construction would involve wetland construction and has the potential for inflationary pressure on the cost of the materials, a cost of $3,000,000 per mile appears reasonable and will be the value considered for the option comparison. Two 6.5 mile segments equal 13 miles of overhead line amounting to a cost of $39,000,000 for the overhead option.

For the UG option the estimate must include the cost of the cable, duct banks, splicing vaults, and termination and switching stations at the OH/UG transitions. Those items will be looked at individually and then summed to give an overall estimate. The cost of placing EHV circuits underground has decreased dramatically since 1990 as illustrated in the attached XLPE performance article. **(Attachment 7, ABB XLPE Report, Pg 2 Chart 1)**. Prior to 1990 the cost premium for an EHV UG circuit was 25 times that of an equivalent voltage OH circuit whereas the differential is now expected to be approximately 7 times higher than overhead.

Cost of Chinese Turnkey job – The 2007 news release presented in **Attachment 2** stated that a project to manufacture and install a 17km 500kV XLPE circuit between two substations in Shanghai had been awarded to Nexans for the contract sum of 35 million Euros. The contract included the cost of constructing a 17km (10.5 miles) tunnel to house the three phase circuit. Using an approximation of $1.50 = ε1.00 this contract would be worth $52,000,000 or approximately $5,000,000 per mile (in 2007 dollars). Converting to English units yields a cost of

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approximately \$950 per circuit foot. This is for one each, three-conductor circuit, installed in a 10.5 mile tunnel. Making the conservative assumption that the majority of the cost is contained in the cable production, installation, and splicing rather than the tunnel construction, the cost per mile is tripled to \$2850 per foot to account for nine (9) conductors rather than three (3) conductors per circuit. This yields an estimated cost of \$15,000,000 per circuit mile, leading to the cost for three (3) each 6.5 mile circuits totaling 19.5 miles of \$292,000,000 which includes material and construction, including splices plus a 17 mile underground tunnel. Conservatively assuming that \$50,000,000 of that amount is for the tunnel yields an estimated amount of \$242,000,000 for the cable and installation that could be estimated for the ENP area. Estimating the cost to excavate a 20 foot wide trench to a depth of 6.5 feet for a total length of 19.5 miles through a wetland environment would require effort beyond the scope of this review. We can state this effort would include excavation and disposal of up to 500,000 cubic yards of spoil, and the installation of an equivalent amount of concrete. At an estimated average cost of \$350 per cubic yard, which would include excavation, duct fabrication, and cement product installation the cost of the duct banks would be \$175,000,000. Based on these numbers we could expect the 500kV UG to exceed \$500,000,000 which is roughly twelve times the cost of putting the equivalent transmission system on overhead facilities. This ratio is greater than the 7X presented earlier due to having three UG circuits to replace two OH circuits.

Economic Feasibility Summary

At an estimated cost of \$0.5 Billion to install UG 500kV facilities in a 6.5 mile corridor where 1/10th that amount would provide the necessary electric transmission capacity in an overhead design the use of UG technology cannot be considered as an economically feasible option from an industry (EHV) perspective. The cost of lost cultural, wildlife and viewshed preservation economic impacts are subjective and require additional data to quantify such as avian electrocution, potential adjacent real estate devaluations and lost tourist revenue. Due to the previously established parallel right-of-way easement for the planned above ground 40 mile FPL EHV transmission lines, the cultural and viewshed future impacts are of public record and although ultimate construction of such lines may upset adjacent land owners and returning visitors familiar with the affected part of the ENP, those rights have been previously established. Utilities continue to improve avian protection devises and strategies that make EHV structures more compatible with wildlife.

Future Consideration Opportunities

1. At this time it is not known exactly when the new 500kV lines reviewed in this study will be required. Recent downturns in customer demand throughout the US has delayed generation and transmission facility expansion projects nationwide and may also delay these facilities for the time necessary for new technology to develop. As an example, Gas Insulated Transmission Lines (GIL) are currently in development for applications up to 2 miles in Europe and Asia. GIL lines can be installed on the surface or direct buried in relatively shallow trenches. **(Attachment 8, Transmission & Distribution World, Gas Insulated Line Article)** Thermal performance is superior and current capacity has no limits as far as system needs are concerned.
2. An economic design of the UG option could consider the following:
   a. The selected cables have 4000 amp capacity to meet the capacity of the conductors in the overhead configuration but realistically would not be loaded above 2000 amps. Why? 2000 amps at 500kV corresponds to 1730 Mega Watts which would be more than the total output of one and one half large nuclear units. A system operating at

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this level could not sustain the loss of another line and thus would have operational constraints to back off on the generation to levels that could sustain the loss contingency. Taking this into account could reduce the amount of thermal backfill allowing the use of a portion of the excavated spoils for backfill.

b. Trench arrangements other than the proposed arrangement having three phases in one trench going into single vaults as a full three phase circuit could reduce the amount of trenching, spoils, and cement backfill. For example, eight trenches containing one phase per trench would provide six phases for two circuits and two phases for a spare. Vaults would have only two trenches terminating into them allowing two spare trenches to back stand both circuits.

List of Preparers

Donald Strickland, PE – Transmission Line Lead Engineer

Mr. Strickland has over 36 years of professional experience in engineering, construction, operation, and maintenance of utility transmission line and substation facilities. His experience includes utility construction organizational management, site construction and project management for 115kV to 500kV line and substation facilities, and standards development for transmission lines and substations. Included in this experience was serving as Construction Manager for an 84 mile 500kV Transmission Line emanating from Grand Coulee Dam. He received his BS in Electrical Engineering from North Carolina State University and is a registered Professional Engineer in North Carolina and Florida. He is a past president of the

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Raleigh (NC) Section of the IEEE and a past president of the North Carolina Society of Engineers.

Currently, Mr. Strickland is a Transmission Line Engineer for the engineering and construction of 14.4 miles of double circuit, 3000-amp capacity 345kV Transmission Lines from Oquirrh Substation to Terminal Substation for Rocky Mountain Power in Salt Lake City, Utah.

Nicholas Miller, PE – Group Leader - Patrick Energy Services – Lake Mary, Florida office

Mr. Miller brings over 17 years' experience in the field of civil/ environmental engineering. His experience includes project and construction management for civil engineering design of site layout, storm sewer, sanitary sewer, and water main projects, including LEED® certified projects.

Mr. Miller has recently worked on several projects for Progress Energy Florida including a 500-230kV Substation/T-Line Loop-in, 230kV T-Line, Baseload 500kV Design Criteria, and a Baseload GIS Program. His experience on these projects include planning, scheduling, coordination, conductor and foundation design, and overall project management.

Richard Hayes – Vice President – Federal Programs

Mr. Hayes over 22 years of operations management experience in the engineering/construction industry and with the U.S. Army Reserves. He possesses a strong track record of management of multi-discipline, complex multi-million dollar engineering/construction and contingency security operations both domestically and internationally. He is highly proficient in identifying required manpower, skills, and resources needed to meet objectives and desired end state. He has strong experience serving as a liaison between client, state and local governments, federal government, international governments, non-governmental organizations, non-profit, and for profit corporate entities. In addition, during his career he has been actively engaged in recruiting, leading, training, and mentoring of personnel.

Mr. Hayes is currently the project executive for two U.S. Army Corps of Engineers projects, Soo Locks Utility Line Replacement in Sault Ste Marie, Michigan and at Kitsap Naval Base Electrical Infrastructure upgrades in Washington. The Soo Locks Utility project will provide the necessary steam to the lock gates and the ability to shut off the system as needed for maintenance and in the event of an emergency. The tunnel construction includes connecting the steam piping and also running electric and lighting through the tunnel once the existing system is removed. The Kitsap Naval Base project includes design services for 41 critical electrical infrastructure projects at 26 common areas. The design packages will be suitable for a design/bid/build approach and will include electrical improvements to the 155kV substation equipment, 12.47/kV distribution system, 12.74 kV generator systems and associated protective equipment.

Carolyn Greenwell, PE – Transmission Line Engineer

Ms. Greenwell has over nine years of experience involving civil and structural engineering. This includes transmission line routing and alignment, structural design of transmission structures, substation civil design, foundation design, site inspection, stormwater design, civil site design, erosion and sediment control, construction inspection, and project execution documents. Her responsibilities include project management, quality control, material requirements, preparation and review of design calculations, project plan and profile, bid documents, construction drawings, and specifications for high-voltage transmission projects. She is also well-versed in PLSCADD and FAD.

Ms. Greenwell has recently performed work for Progress Energy Florida including the Central Florida South Project, KLT 230kV Line Project, and the 500kV Substation Design Criteria for the Levy Baseload Program. For these projects, Ms. Greenwell was the civil engineer responsible in-charge of civil and structural design criteria.

ATTACHMENT 1

(Prysmian Cables and Systems – Product Brochure)

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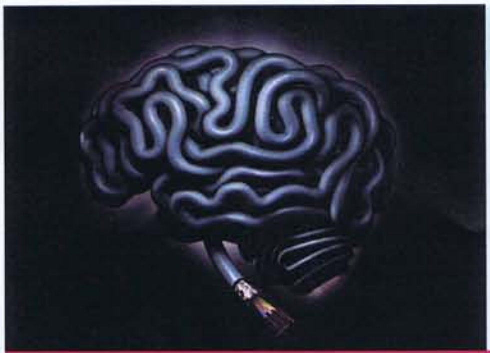

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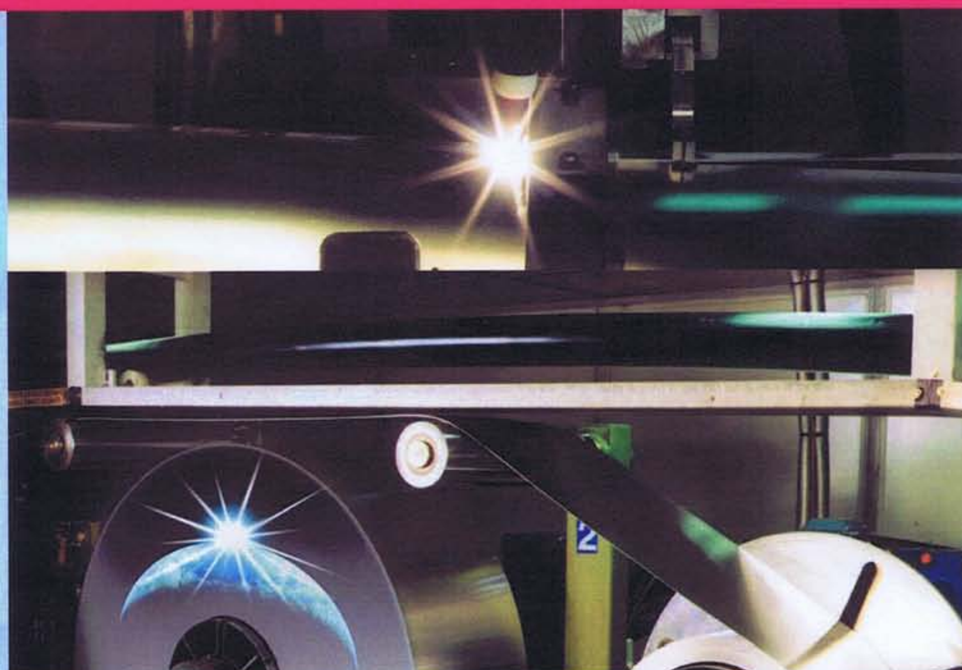


Smooth Welded Aluminium Sheath

Product
evolution

The metallic sheath plays a key role in the design of High Voltage underground cable systems, as it must satisfy essential electrical and mechanical functions to ensure the correct operation of a cable.

Cables with lead alloy sheath - the first solution adopted in the development of metallic shielding technologies - provide all necessary guarantees in terms of technical characteristics: mechanical protection, fluid and moisture tightness, and short circuit current carrying capability.

However, the main disadvantages of cables with a lead alloy sheath are weight - especially from the installation perspective – and, in specific instances, fatigue strain. Cables with Corrugated Aluminium Sheath (CAS) - the first lead substitution technique adopted in the evolution of metallic shielding technology – have a significantly reduced weight when compared with cables having a lead alloy sheath. Conversely, CAS cables have the disadvantages of not only a lower transmission capacity, due to the presence of an air gap under the corrugations; but also a larger diameter and accordingly shorter delivery lengths.

Prysmian know-how and technological competence have led to the development of a smooth welded aluminium sheath design, an innovative solution, which effectively combines the benefits of both lead and corrugated aluminium sheaths yet minimizes their disadvantages, resulting in a cable with lighter weight, reduced diameter and bending radius – with a comparative longer length.

The smooth welded aluminium sheath also guarantees excellent electrical and mechanical performance, full fluid tightness and compliance with even the strictest environmental requirements.

Industrial
process

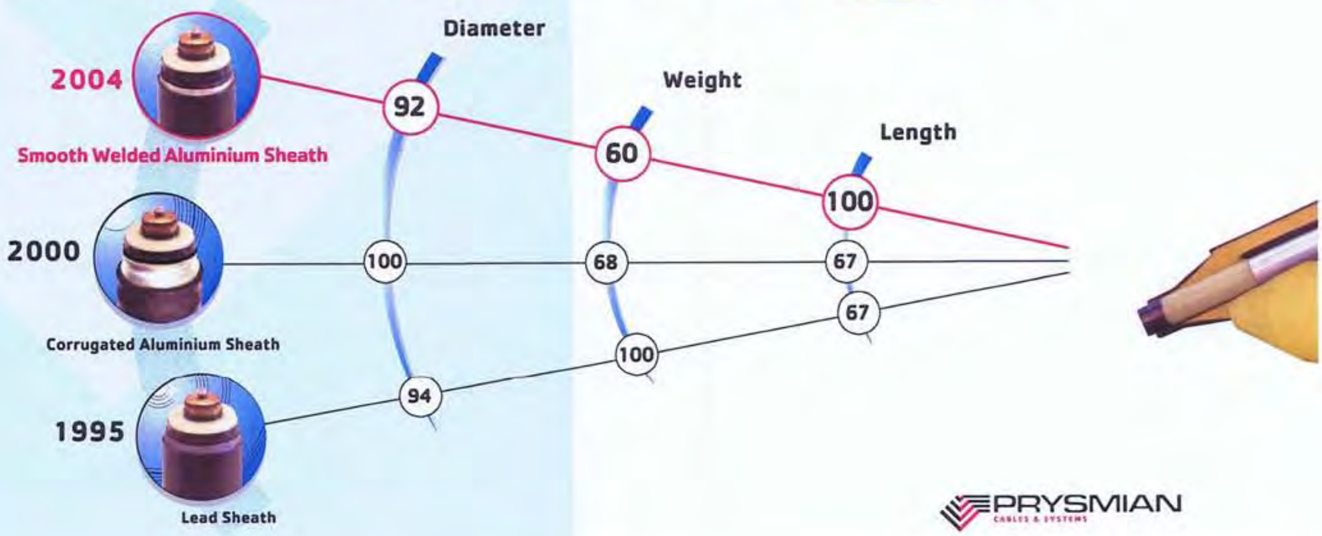
The smooth welded aluminium sheath consists of an aluminium tape, longitudinally applied over the cable core, shaped around it and welded. The outer polyethylene sheath is firmly bonded to the aluminium sheath resulting in a cable with a solid impervious water barrier and excellent resistance to fatigue strain.

The application and welding of the aluminium tape, and the extrusion of the polyethylene are carried out through a tandem process on the same line, which undergoes continuous video recorded inspection ensuring effective quality control.

Extensive tests have proven that the water-tightness and resistance to corrosion of the smooth welded aluminium sheath cable meets the most stringent standards.

Depending on the short circuit requirements, the welded aluminium sheath can be complemented with copper wires.

Benefits
Smaller Lighter Longer



Total
Quality Commitment

The Prysmian High Voltage Systems business unit is characterised by a competent and experienced approach to global turnkey solutions with improved research, engineering and manufacturing resources. Within the Pirelli Group, there are manufacturing facilities dedicated to the production of HV cables and accessories systems in 12 countries in all five continents and a single business unit, which gathers all critical functions in a co-ordinated management structure with common operative policies. The main advantages this organisation can offer are: great manufacturing flexibility, strong engineering capabilities to solve, develop and even anticipate the most innovative and demanding needs of the market, installation services with extensive experience, and **total quality commitment.**

The Prysmian brand has always been a guarantee for the supply of products and services based on worldwide common quality standards. Pirelli has a built-in multi-step quality assurance program, which covers the entire production process from cable design and raw materials purchasing, to final inspection and testing documentation.

Prysmian business locations and manufacturing sites as well as operation units are certified according to ISO 9001 and ISO 14001 Quality Management System standards for their specific activities and products, and environmental quality standards.

Standards and recommendations

National and international standards provide design guidelines for High Voltage cables, however most HV cable systems are custom designed to suit also the specific environmental parameters and operating requirements of a particular route and loading conditions, taking into account the thermal, thermo-mechanical and electrical performance necessary to ensure reliable system operation throughout service life, which naturally will vary considerably between different applications and locations.

Prysmian products are designed to meet the projected service duty and to comply with national and international testing requirements. Type approval references are given against each product type available.

Besides, international scientific bodies – like IEC and Cigré – develop relevant standards, technical recommendations and guidelines within their activities in the field of High Voltage. Prysmian relies on a long-standing tradition of participation and a strong presence within such bodies, acquired thanks to its undisputed expertise developed over scores of projects accomplished anywhere in the world.

References
Track Record

U_m (kV) up to and including	Length of cable manufactured (km, in excess of)
420	150*
245	110
170	360

Madrid-Barajas Airport	Vienna	Turbigo-Rho
400 kV - Cu 2500 mm^2	380 kV Cu 1200 mm^2	380 kV Cu 2000 mm^2
37 km	32 km	50 km
Red Electrica de España	Wienstrom GmbH	Terna SpA

*For U_m class 420 kV, an additional 80 km are under manufacture (2006)

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ATTACHMENT 2

(Nexans – Press Release)

Patrick Engineering
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Press Release

Nexans wins 35 million Euro high voltage underground power cable contract for Shanghai

World's first intra-city 500kV cable installed in a17km tunnel under the Chinese city

Paris, March 19, 2007 – Nexans, the worldwide leader in the cable industry, has received an order worth around 35 million Euro from the Shanghai Power Equipment & Materials Co. Ltd to manufacture and install a 17km, 500kV, underground power cable circuit to link Shibo and Sanlin 500kV substations in Shanghai city, China. The circuit, to be installed on behalf of the Shanghai Municipal Electric Power Co. Ltd, will establish two world records as both the first intra-city 500kV cable and the first 500kV XLPE (cross-linked polyethylene insulated) cable with a cross-sectional area of 2,500mm^2.

This contract forms part of a global infrastructure project to meet Shanghai's constantly growing demand for power, with the city's consumption estimated to reach 125 billion kWhr by 2010. The project includes the construction of a 17km underground tunnel to carry two 500kV circuits.

An innovative cable technology

Nexans will manufacture and install a total of 51km 500kV XLPE cable. The cable will be laid as three separate 17km lengths within the cable tunnel, one for each phase of the 3-phase electricity supply, and will require over 100 HV (high voltage) joints. Nexans is using an innovative cable technology for this high voltage application, with a metallic screen in smooth laminated aluminum. This is a much lighter solution than the conventional lead or corrugated aluminum sheath and this will make the cable easier to install.

The cable will be manufactured in Nexans' Charleroi factory in Belgium. The cables should be installed between the end of 2007 and 2009. The project should be completed over a 30-month period.

"The Shanghai project will provide an important customer reference for future commercial developments in China and the general Asia region, which is a particularly competitive market for HV cables. Nexans is very pleased to be breaking new ground in the installation of 500kV XLPE cable for an intra-city power link, especially as 500kV cable routes are set to increase in importance to help meet the region's growing demand for power." said Patrick Barth, Nexans' HV business group President.

About Nexans

With energy as the basis of its development, Nexans, the worldwide leader in the cable industry, offers an extensive range of cables and cabling systems. The Group is a global player in the infrastructure, industry and building markets. Nexans addresses a series of market segments from energy, transport and telecom networks to shipbuilding, oil and gas, nuclear, automotive, electronics, aeronautics, handling and automation.

With an industrial presence in more than 30 countries and commercial activities worldwide, Nexans employs 21,000 people and had sales in 2006 of 7.5 billion euros. Nexans is listed on the Paris stock exchange, compartment A of the Eurolist of Euronext. More information on http://www.nexans.com/

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ATTACHMENT 3

(TrAIL Co Rebuttal Statement No. 15)

TrAILCo Rebuttal Statement No. 15
Witness: Jay Williams

BEFORE THE
PENNSYLVANIA PUBLIC UTILITY COMMISSION

IN RE: APPLICATION OF TRANS-ALLEGHENY INTERSTATE LINE COMPANY FOR (I) A CERTIFICATE OF PUBLIC CONVENIENCE TO OFFER, RENDER, FURNISH AND/OR SUPPLY TRANSMISSION SERVICE IN THE COMMONWEALTH OF PENNSYLVANIA; (II) AUTHORIZATION AND CERTIFICATION TO LOCATE, CONSTRUCT, OPERATE AND MAINTAIN CERTAIN HIGH VOLTAGE ELECTRIC TRANSMISSION LINES AND RELATED ELECTRIC SUBSTATION FACILITIES; (III) AUTHORITY TO EXERCISE THE POWER OF EMINENT DOMAIN FOR THE CONSTRUCTION AND INSTALLATION OF AERIAL ELECTRIC TRANSMISSION FACILITIES ALONG THE PROPOSED TRANSMISSION LINE ROUTES IN PENNSYLVANIA; (IV) APPROVAL OF AN EXEMPTION FROM MUNICIPAL ZONING REGULATION WITH RESPECT TO THE CONSTRUCTION OF BUILDINGS; AND (V) APPROVAL OF CERTAIN RELATED AFFILIATED INTEREST ARRANGEMENTS	:	**Docket Nos. A-110172 A-110172F0002 A-110172F0003 A-110172F0004 G-000721229**

REBUTTAL TESTIMONY OF JAY WILLIAMS

Re: Feasibility of Placing TrAIL Underground

December 10, 2007

REBUTTAL TESTIMONY OF JAY WILLIAMS

Q. PLEASE STATE YOUR NAME AND BUSINESS ADDRESS.

A. My name is Jay Williams and my business address is 28 Lundy Lane, Ballston Lake, New York 12019.

Q. BY WHOM ARE YOU EMPLOYED AND IN WHAT CAPACITY?

A. I am employed by and a principal engineer with Power Delivery Consultants, Inc. ("PDC"). PDC provides engineering and consulting services to electric utilities, research organizations, merchant power producers, and manufacturers. Our practice areas include overhead line and underground cable design, power transformer ratings, and transmission and distribution-related engineering support for circuit uprates, operating and maintenance, failure investigation, and training.

Q. HAVE YOU PREVIOUSLY SUBMITTED DIRECT TESTIMONY IN THIS PROCEEDING ON BEHALF OF THE TRANS-ALLEGHENY INTERSTATE LINE COMPANY ("TrAILCo")?

A. No, I have not.

Q. PLEASE DESCRIBE YOUR EDUCATIONAL BACKGROUND AND PROFESSIONAL EXPERIENCE.

A. I earned a Bachelor of Science degree in engineering from Brown University and an MBA from New York University. I worked as a cable engineer at Consolidated Edison Company of New York, Inc. ("Con Edison") from 1965 until 1973, and was in charge of the transmission cable group when Con Edison was installing major amounts of 345-kV cable. I worked at Power Technologies, Inc. from 1973 until 1992 and was in charge of the cable group when I left in 1992 to form PDC with another cable specialist. At PDC, I head a group of engineering professionals, including five engineers whose entire collective workload is spent on transmission cable systems. I have developed and present several courses each year on underground power transmission, and have written more than fifty technical papers, articles, and book sections on underground transmission cables. I am a Fellow of the Institute of Electrical and Electronics Engineers, Inc. ("IEEE") and a registered Professional Engineer in New York and Ohio. My resume is attached to this testimony as TrAILCo Rebuttal Exhibit JW-1.

Q. HAVE YOU PREVIOUSLY APPEARED AS A WITNESS BEFORE ANY REGULATORY AGENCIES?

A. Yes. I testified as an expert witness on behalf of the Vermont Department of Public Service for the cable crossing at Grand Isle as part of the PV-20 line application and regarding an application by the Vermont Electric Power Company, Inc. and Green Mountain Power Company for authority to construct the Northwest Vermont Reliability Project. I have also testified as a cable expert for several utilities evaluating underground transmission lines. I am currently assisting Northeast Utilities as their expert witness on cable systems for major 345 kilovolt ("kV") installations as part of the Southwest Connecticut Reliability Project.

Q. WILL THE USE OF VARIOUS TERMS IN YOUR REBUTTAL TESTIMONY BE CONSISTENT WITH THE DEFINITIONS ASSIGNED TO THOSE TERMS IN THE TABLE OF NOMENCLATURE ATTACHED TO TrAILCo WITNESS FLITMAN'S DIRECT TESTIMONY AS TrAILCo EXHIBIT DEF-1?

A. Yes. In addition, I may define other specific terms in my rebuttal testimony.

Q. PLEASE DESCRIBE THE TOPIC AND PURPOSE FOR YOUR REBUTTAL TESTIMONY.

A. My rebuttal testimony will address and respond to the various suggestions or comments that were offered during the public input hearings in Pennsylvania regarding whether the proposed TrAIL project or any portion thereof can be placed underground.

Q. IS IT POSSIBLE TO PLACE ALL OR ANY PORTION OF TRAIL UNDERGROUND?

A. I cannot state that it would be impossible to place portions of the TrAIL project underground. However, there are numerous impediments to placing 500 kV cables underground and the disadvantages of such an installation, for all practical purposes, make the placement of any portion of the TrAIL project underground infeasible for the transmission grid reliability purposes intended for TrAIL.

Q. ARE YOU AWARE OF ANY CIRCUMSTANCES IN THE UNITED STATES OR ELSEWHERE IN WHICH 500 KV CABLES HAVE BEEN PLACED UNDERGROUND?

A. There are no current examples of the installation of 500 kV cables of any appreciable length in the United States and certainly none at the length of the route proposed for TrAIL. In fact, the only instance of cables of this voltage being placed underground of which I am aware in this country is a short length less than two miles long of 500 kV underground cables that were installed within the property of Grand Coulee Dam in the 1970s, from the generator transformers to a switchyard. Following a catastrophic failure and fire soon after installation, the replacement cables have operated satisfactorily. During that same period, a 500 kV gas-insulated line a few hundred feet long was installed on the West Coast, but it has since been abandoned. Outside of the United States, 500 kV cables have been installed underground on a limited basis in utility tunnels or under bridges for lengths of less than twenty five miles in Japan and Canada. In addition, 500 kV submarine cables of lengths limited to about 25 miles or less have been installed between Vancouver, British Columbia and Vancouver Island.

Q. WHAT ARE SOME OF THE DISADVANTAGES OF PLACING 500 KV CABLES IN A PROJECT SUCH AS TRAIL UNDERGROUND?

A. Beginning with construction-related disadvantages, placing electric cables underground requires a massive excavation of the entire length of the segments of right-of-way planned for underground installation, as compared to excavating material only at tower locations for an overhead line. To accommodate a 500 kV project with the power transfer capacity required of TrAIL, such an excavation would be particularly large in width. For example, as I explain below in my rebuttal testimony, several sets of cables would be required to provide the power transfer capability of the three-phase overhead circuit planned for TrAIL. These cables would be spliced together in fifteen hundred foot sections and would be placed into individual plastic conduits. Each set of cables could require cement vaults approximately every fifteen hundred feet, at the points of splicing, that would be approximately 35 feet long by 8 feet in width and height. The extensive excavation required to place cables underground could also severely affect streams, wetlands, and other environmentally sensitive areas along a proposed right-of-way. Finally, as compared to a relatively limited number of access roads that would be required for subsequent maintenance and repair operations along an overhead right-of-way, permanent roads would be required along the entire lengths of any underground segments for the line.

Q. ARE THERE DISADVANTAGES TO PLACING 500 KV CABLES UNDERGROUND FROM AN ELECTRICAL AND OPERATIONAL PERSPECTIVE?

A. Yes, there are several. Because they cannot dissipate heat as effectively as conductors in an above-ground open air configuration, an underground cable is able to carry far less power than a similarly-sized overhead line. Consequently, perhaps as many as four to six sets of 500 kV cables (twelve to eighteen individual cables) could be required to provide the power transfer capacity that will be required for TrAIL. As I stated above, these multiple sets of cables, and required conduit and vaults, would be a significant contributing factor to the larger excavation that would be required along the selected right-of-way segment. Additionally, the electrical capacitance for underground transmission lines is significantly higher as compared to overhead lines.

Q. WOULD YOU BRIEFLY EXPLAIN CAPACITANCE AND WHY IT IS SIGNIFICANT TO THE ISSUE OF UNDERGROUND TRANSMISSION LINES?

A. Yes. Cable capacitance is an inherent property of all cable systems, and results from the placing of insulation material between two cylindrical electrodes – the internal cable conductor and outer cable shielding. Capacitance may cause a significant increase in steady-state voltages throughout a power system as the charging current – the amount of current required to charge and discharge the cable capacitance at a frequency of 60 times per second – flows through inductive impedances such as transformers. Even without the presence of these transformers, a phenomenon known as the "Ferranti effect" causes voltage increases when the cable charging current flows through the power system itself. The flow of charging current generates heat, reducing the amount of through-current the cable is capable of carrying. This means that the charging current required for 500 kV underground cables would consume the entire power transfer capabilities of the cables beyond segment lengths of sixty miles or less, depending upon the type of cable. Finally, the cable capacitance challenges I just described could also cause unacceptably high transient over-voltage conditions on substation equipment during switching operations.

Q. DO UNDERGROUND TRANSMISSION LINES PRESENT ANY RELIABILITY DISADVANTAGES?

A. Yes. A significant example is simply the additional time required for unforeseen events and repairs to an underground facility as compared to overhead lines. A problem on a 500 kV line placed underground could require as long as a month or more to locate and repair; such emergencies on an overhead facility can be located and repaired much more quickly. There is no experience with 500-kV polyethylene-insulated cables in the duct-and-manhole system used by U.S. utilities, and no experience with 500-kV fluid-filled cables whatsoever. Researchers have expressed concern that there could be a common failure mode such as thermo-mechanical movement that could result in multiple outages on these systems. Prolonged outages of the longer durations that could be experienced with an underground facility would be counterproductive to PJM's designation of the TrAIL project as a transmission expansion necessary to maintain grid reliability.

Q. ARE THERE CABLES AVAILABLE TO THE ELECTRIC INDUSTRY THAT COULD BE PLACED UNDERGROUND AT THE VOLTAGE LEVEL AND LENGTH PLANNED FOR TRAIL?

A. Three cable types could be considered; again, however, none have been installed at 500 kV beyond the limited lengths of the installations I described above. The three possible cable types would be (i) high-pressure fluid-filled ("HPFF") cables; (ii) extruded dielectric, cross-linked polyethylene ("XLPE") cables; and, (iii) self-contained fluid-filled ("SCFF") cables. For installation at 500 kV, however, the HPFF or the XLPE cables would be the most likely candidates. Both types, however, would present significant construction and operational issues that would be disadvantageous. SCFF cables are seldom used for installations on land; they are primarily installed on long alternating current submarine crossings.

Q. PLEASE DESCRIBE HPFF CABLES AND ISSUES THIS CABLE TYPE WOULD PRESENT.

A. HPFF cable accounts for most of the limited amount of underground 345 kV transmission facilities currently in commercial service in the United States, the longest of which is a seventeen mile line. Industry-sponsored tests in this country have demonstrated the technical feasibility of these cables in a 500 kV application, but there have been no commercial installations of HPFF cables in the United States at this higher voltage. A previous short, trial installation of HPFF at 500 kV in Japan is not currently in commercial service. HPFF conductors are insulated with wrapped layers of a laminated paper/plastic tape that are factory impregnated with a dielectric liquid and shipped to the installation site on large reels. The three separate phases are then pulled at one time into a previously installed 8.625-inch (for 345 kV cables) outside diameter, coated and cathodically-protected steel pipe. 500 kV cables would probably require at least a 10.75 outside diameter pipe. The line is filled with a dielectric liquid that is pressurized to 200-250 pounds per square inch gauge ("psig"). At a minimum, a large pressurizing plant is installed at each end of the line segment to maintain this pressure while accepting fluid expansion and contraction. Assuming level terrain along the right-of-way, a pressurizing plant is installed at each end of the underground line segment to maintain pressure while accepting fluid expansion and contractions. For a right-of-way with significant terrain changes such as the preferred route for TrAIL, however, an HPFF cable system would also be segregated into multiple hydraulic (pressurizing) sections wherever elevation changes of greater than 300 feet occur along the right-of-way. The large volumes of dielectric fluids in the cable pipe (approximately 100,000 gallons for each line of a four to six line installation of a ten-mile segment) presents the potential for a large release of this fluid into the environment in the event of a major leak on even one of the cables. The entire 100,000 gallons of fluid could leak from the pipe, in the hypothetical ten-mile segment described above, depending upon the location of a leak and the time required for utility crews to find and reach that location to plug the leak. HPFF cables present the issues of reduced power transfer capability, higher electrical capacitance, and high transient over-voltages I mentioned above, and are susceptible to outages for both hydraulic and electrical problems. Finally, the installation of HPFF cables requires special training and, while there are foreign suppliers, there is only one domestic supplier for these cables, and none of these foreign or domestic suppliers have ever manufactured commercially-feasible lengths of 500 kV cables.

Q. LIKEWISE, WOULD YOU PLEASE DESCRIBE XLPE CABLE AND IDENTIFY ANY ISSUES THE POSSIBLE USE OF THIS TYPE OF CABLE WOULD PRESENT?

A. XLPE cables are conductors insulated with polyethylene, which is extruded over the conductors and then cross-linked at high temperatures. A lead, aluminum, or copper sheath is applied, and the individual conductors are configured as three XLPE-insulated cables that are pulled into individual plastic ducts in a concrete-encased duct bank or tunnel. There are only short, splice-free 345-kV XLPE lines in commercial service in this country for longer than a year (a 2.1 mile long circuit with splices that was energized in 2007), but there are significant lengths totaling more than 100 miles installed at 330-kV and higher voltages including 500 kV overseas. There are lengths totaling more than 150 miles installed at 230 kV in the United States, as well.

However, no XLPE cable has been installed at 500 kV in the United States and the limited experience elsewhere has been in utility tunnels and not in an underground installation. The manufacture and installation of XLPE cable requires extremely high levels of quality control due to the high sensitivity of dielectric materials to contaminants and voids. XLPE cables above 230 kV are available only from foreign suppliers and these cables also require special skills and equipment for splicing during installation or for repairs. The lack of domestic suppliers and the special skill requirements, while not necessarily prohibitive to the initial installation of an underground facility, are factors that can contribute to the relatively longer duration of outage repairs on underground cables if replacement cables must be shipped from overseas locations and the necessary skilled labor must be located and brought to the outage site.

Q. PLEASE DESCRIBE THE CONFIGURATION OF FACILITIES THAT WOULD BE REQUIRED TO PLACE EVEN A SEGMENT OF TRAIL UNDERGROUND.

A. First, a dead-end type transmission structure would be required at each end of an underground line segment. Transition stations would also be required at each end of the underground segment; one station to transition the overhead facility into underground and the other station to transition back to an overhead facility. The transition stations would be fenced areas, much like a traditional substation, with dimensions of approximately 160 by 320 feet. Each station would have three cable terminations for each line – 12 to 18 terminations in total, each ten or so feet tall, on substation-type structures with bases ten feet or more above the ground. Flexible conductors would be required to drop down from the overhead conductors to the cable terminations. Additional equipment within each transition station would include switches, surge arrestors, equipment for communicating with transmission control rooms, including relaying and alarms, and any circuit breakers determined to be necessary. This would be repeated at each end of each segment of the line to be placed underground. For HPPF cable systems, pressurizing plants with pumps, controls, alarms, and a large storage tank would be required at each end of an underground segment.

Q. YOU INDICATED ABOVE THAT THE CABLES REQUIRE SPECIAL SPLICING. WOULD YOU PLEASE PROVIDE SOME ADDITIONAL DETAIL ABOUT THIS PROCESS?

A. Yes. The individual cables would be provided in lengths of no more than approximately 1,500 feet for XLPE-insulated cables, and perhaps 2,000 feet for HPFF cables, on large reels that may weigh as much as 60,000 pounds or more. Consequently, splicing by factory or factory-trained splicing crews is a significant component of the construction of an underground transmission line. This splicing process requires a "clean room" environment and can take up to ten days for each individual splice. Because between four and six three-conductor lines would be required, this would mean between 12 and 18 splicing procedures would be necessary for every fifteen hundred foot length of the planned underground segment and would require the cement vaults I described earlier. This complex process not only adds significantly to the length of time for constructing underground facilities, it is the principal contributing factor to the relatively long outage periods that would result during an unforeseen event on an underground line segment. As a comparison, bare overhead transmission conductors are typically shipped in reel lengths of between 16,000 to 30,000 feet, depending on the size of conductor, and an overhead conductor splice typically takes one worker less than an hour to complete.

Q. WOULD YOU PLEASE SUMMARIZE WHY, IN YOUR PROFESSIONAL OPINION, IT WOULD BE INFEASIBLE TO PLACE ANY PORTION OF THE TRAIL PROJECT UNDERGROUND?

A. I indicated at the start of my rebuttal testimony that, while it may be technically possible to place segments of TrAIL underground, the significant construction and operational challenges I have detailed above, in my opinion, make the placement of any portion of TrAIL underground infeasible. The significantly longer time periods that would be required to respond to unforeseen outages on an underground segment would largely, if not completely, negate TrAIL's intended purpose for transmission grid reinforcement and reliability enhancement. Because there is no commercial service experience with HPFF cables at voltage levels of 500 kV or with XLPE cables in an underground environment such as for TrAIL, any segment of the line placed underground would, for all intents and purposes, be the equivalent of a research and development demonstration project for the commercial feasibility of 500 kV underground transmission facilities. In my professional opinion, such an outcome would be particularly imprudent for a new high-voltage transmission facility that is intended to maintain transmission grid reliability.

Q. DOES THIS CONCLUDE YOUR REBUTTAL TESTIMONY?

A. Yes. I reserve the right, however, to file such additional testimony as may become necessary or appropriate.

JAY A. WILLIAMS - PRINCIPAL ENGINEER

Jay A. Williams received a BS in Engineering from Brown University in 1965 and a Master of Business Administration from New York University in 1972. He joined the Consolidated Edison Company of New York in 1965, and held engineering positions in several groups at Con Edison until he joined Power Technologies, Inc. in 1973. He served in the U.S. Air Force, Base Civil Engineers, in the 1960's. He and John Cooper founded Power Delivery Consultants, Inc in 1992.

As a Senior Engineer in charge of Con Edison's Transmission Cable Group, Mr. Williams' responsibilities included system design and preparation of specifications for 138-kV and 345-kV underground transmission lines and accessory equipment; economic studies of proposed underground transmission systems; field supervision for nonstandard construction operations; and fault analysis and repair. He had responsibility for detailed design of cable bays for the Waltz Mill Cable Test Facility. He was Project Engineer for installation of the world's first underground 345-kV SF_6 - insulated transmission line, and supervised the construction of the line in 1971.

After joining PTI, Mr. Williams was responsible for experimental projects for the forced cooling of high-pressure, fluid-filled cable circuits. These projects were the first ones to undertake the installation, instrumentation, and analysis of a full-scale cable system. He was also project engineer for an EPRI-sponsored study to develop rapid and accurate leak location systems for buried cables.

Mr. Williams has conducted technical and economic studies of alternate underground systems, for voltages from 138 kV to 500 kV ac, as well as HVDC. He has prepared testimony and represented utilities and commissions in hearings. He designed and supervised the construction of an extensive uprating project for existing pipe-type cables, and has been responsible for engineering analysis, specifications, bid review, and field supervision for many underground and submarine cable projects for both utilities and architect-engineers.

In addition to utility design/installation projects, he was project engineer for the EPRI – funded development of the ACE program to perform technical and economic analyses of cable systems. He was in charge of the EPRI project to prepare the 1992 edition of the Underground Transmission Systems Reference Book; he wrote the Cable Ampacity chapter plus several other chapters of the book. He was also project engineer for the EPRI Underground Transmission Workstation project, as well as several other EPRI-funded projects — including the Distributed Fiber Optic Temperature Monitoring development. He has taught many courses and seminars for underground transmission cables, from system planning to field operation & maintenance.

Mr. Williams is a Fellow of the IEEE, and member of the Power Engineering Society and Electrical Insulation Society. He is a Voting Member of the IEEE Insulated Conductors Committee and served as Chairman of the Insulations Subcommittee. Mr. Williams has authored more than fifty technical articles and papers, and was co-author of the Underground Transmission Systems section of the McGraw-Hill Standard Handbook for Electrical Engineers. He is a registered Professional Engineer in the States of New York and Ohio.