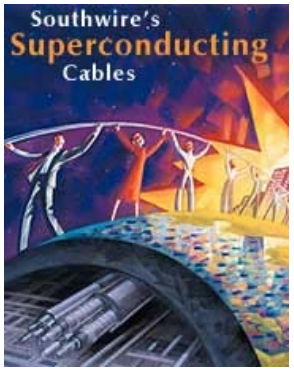
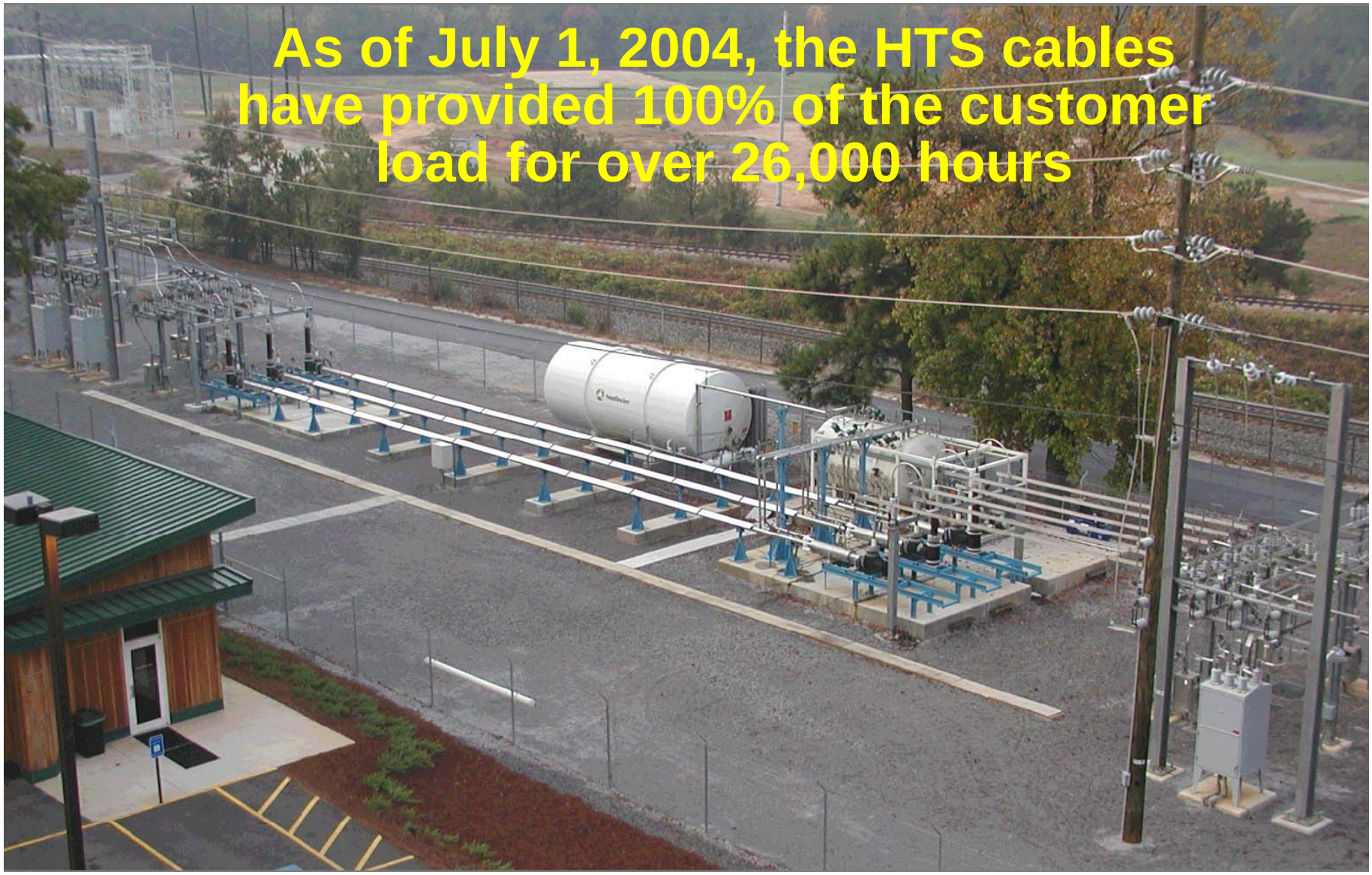
High Temperature Superconducting Cable



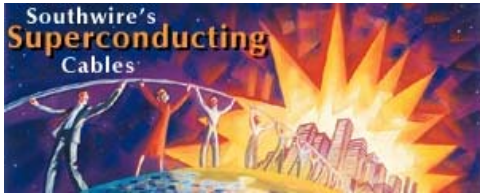
2004 Annual Peer Review

Superconductivity Program
for Electric Systems
U.S. Department of Energy

July 27-29, 2004
Washington, DC


As of July 1, 2004, the HTS cables have provided 100% of the customer load for over 26,000 hours

Southwire Project Status



- **Project history**

– Installation & Testing	Aug – Dec 1999
– Cables energized	Jan. 6, 2000
– Dedication ceremony	Feb. 18, 2000
– Continuous operation started	Feb. 21, 2000
– Unmanned operation	June 1, 2001
– Splice design and tests	FY 2000-2001
– 1.5-m tri-axial cable tests	Summer 2001
– Bend testing	FY 2001-2002
– Cable aging/partial discharge	FY 2000-2002
– 5-m tri-axial cable/terminations	FY 2002
– YBCO 1-m cable tests	FY 2003
– 5-m 3kA tri-axial cable & term.	FY2003-2004

New SPI

Presentation Outline

- **Introduction (David Lindsay, Southwire)**
  - **Overall SPI Goals & Objectives**
  - **Design Approach**
  - **Review FY 2004Milestones**
- **FY 2004 Results**
  - **30-m Cable Operation and Testing (David Lindsay, Southwire)**
  - **AEP project scope & tech requirements**
  - **Cable Research at ORNL (Jonathan Demko, ORNL)**
  - **Cryogenic Dielectrics Research (Jonathan Demko, ORNL)**
- **FY 2004 Performance**
- **Planned FY 2005 & FY 2006 Milestones**
- **Program risk mitigation strategy**
- **Research Integration**
- **Summary**

SPI Project Goals & Objectives:

- **SPI-1: 30-m Installation, Carrollton, GA**
  - **The cable system will continue to be operated and studied. Optimizations will be made to improve operating efficiencies and reliabilities.**

- **SPI-2: Bixby Substation, AEP, Columbus, OH**
  - **To complete a long length demonstration with AEP**
    - **Install 13.2 kV, 3.0 kA (69 MVA) HTS cable system in Bixby substation, about 2 times the power of the Carrollton, GA demonstration**
    - **Highest current cable project**
    - **Length would be on the order of 7 times the Carrollton, GA demonstration**
    - **Design and install a simplified and reliable cryogenic system based on prior experiences**
    - **Demonstrate pre-commercial feasibility of an underground installation.**

AEP-Southwire Project Partners

Partner		***Area of Responsibility/Expertise***
Southwire/nktc/Ultera	Ultera™ A Southwire / nkt cables Joint Venture	**Cable design, manufacturing, termination design, installation, cryo system design, systems integration, O&M, project management**
AEP	AEP®	**Installation site engineering, site civil & electrical construction, O&M**
ORNL	ornl	**Cable design, termination design, testing, cryo design**
Praxair	PRAXAIR	**Cryogenics system design, construction, operations & service**
TechCenter	TECHCENTER	**Software, controls, system integrations**

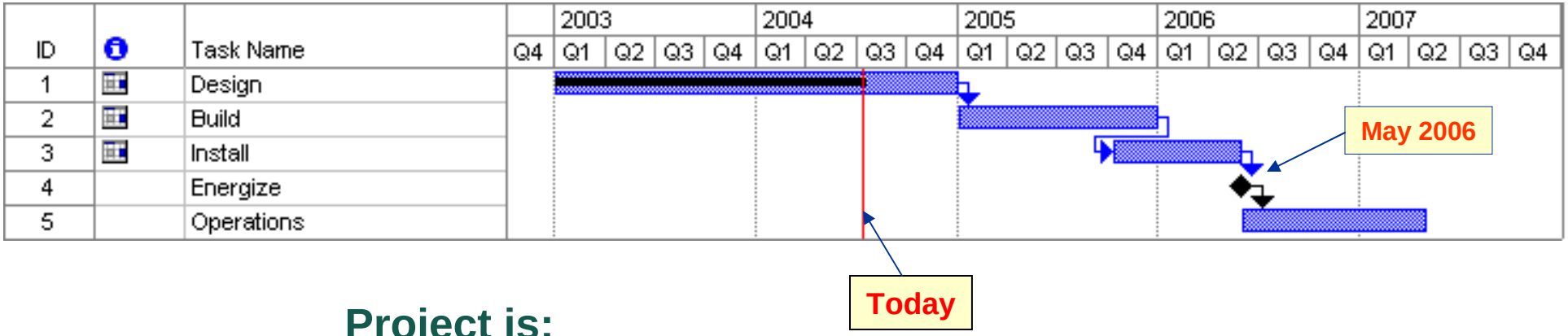
Note: The project currently has no official HTS tape partner. We have been working with AMSC on BSCCO & YBCO for more than a year.

Basic SPI Project Approach

An integrated team from Southwire, Ultera, nkt cables, ORNL and other industry partners will design, build and install a reliable cable system.

- **Cables, terminations and other component sub-systems will be proto-typed and fully tested in the lab prior to implementation**
  - **Designs evaluated by use of computer modeling**
  - **Design verification and proto-type testing is facilitated through the use of the 5-m test-bed at ORNL**
- **Where needed, expertise will be brought to the team through the use of outside contractors/consultants**
- **Ultera & ORNL will work with electric utilities to identify market applications and guide technology development to achieve a commercially viable product which meets industry needs.**

AEP-Southwire Project Timeline



Project is:

- On Schedule
- On Budget

Southwire/ORNL FY 2004 Milestones
Oct. 1, 2003 to Sept. 30, 2004

- **SPI-1: 30-m Installation, Carrollton, GA**
  - **1-3Q, FY2004 (Oct03-Jun04)**
    - **Continue operation of system with required PM and system management. - COMPLETE**
    - **SPI contract runs out 6/30/2004 – EXTENDED TO 9/30/04, NO FURTHER EXTENSION POSSIBLE. SOUTHWIRE WILL CONTINUE TO OPERATE SYSTEM.**
  - **3Q, FY2004 (Apr-Jun)**
    - **Re-test dc-Ic of cables - COMPLETE**
- **SPI-2: Bixby Substation, AEP, Columbus, OH**
  - **1Q, FY2004 (Oct-Dec03)**
    - **Electrical testing of the 5-m tri-axial, 3-phase, 3,000 Arms cable at ORNL, - COMPLETE**
    - **Testing of the YBCO cable (Additional ac loss and over-current tests) - COMPLETE**
  - **Jan2004; Go/No-Go Decision for Triax at AEP based on 5-m results - COMPLETE**
  - **Jan-Mar 2004**
    - **Completed design for cable demo at AEP Columbus and begin long lead procurements. - ONGOING**
    - **Begin civil/electrical design (ONGOING) & construction work (POSTPONED) at Bixby station**
  - **Apr-Jun 2004**
    - **Begin construction of HTS cable for AEP - POSTPONED**
    - **Test model cables and terminations to higher ac voltages (up to 69 kV), - POSTPONED**
      - **Requires upgraded dewar for the higher voltage levels.**
  - **Oct 2003 – Sept 2004**
    - **Continued research improving cryogenic system performance with industry and NASA - ONGOING**

Additional accomplishments

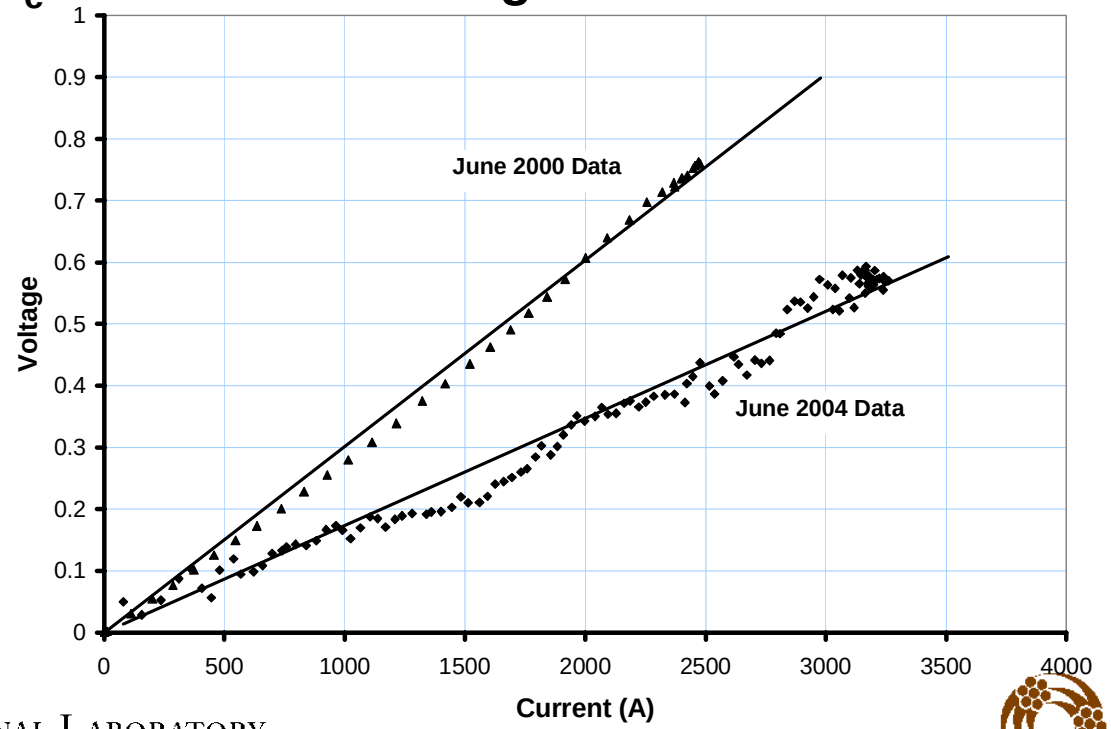
- **Setting record for longest running HTS cable installation.**
- **Tested a series 1- to 3-m cables to evaluate AMSC tape for use in AEP project.**
- **Completed testing of second generation (YBCO) conductor 1.25-m HTS cable.**
- **Completed installation and commissioning of HTS cable manufacturing line for long, continuous lengths of cable.**

Project Participants

- **Southwire/Ultera**
  - John Armstrong
  - Zack Butterworth
  - Randy Denmon
  - Terry Dyer
  - Gary Hyatt
  - Kim Knuckles
  - David Lindsay
  - Sammy Pollard
  - David Reece
  - Mark Roden
  - Jerry Tolbert
  - Nick Ware
  - Dag Willen
  - Manfred Daumling
  - Chresten Traeholt
- **AEP**
  - Doug Fitchett
  - Albert Keri
  - Dale Krummen
  - John Schneider
  - Ben Mehraban
- **Oak Ridge National Laboratory**
  - Jonathan Demko
  - Robert Duckworth
  - Alvin Ellis
  - Paul Fisher
  - Mike Gouge
  - Randy James
  - Winston Lue
  - Marshall Pace
  - Isidor Sauers
  - Bill Schwenterly
  - Dennis Sparks
  - Marcus Young
- **Praxair**
  - John Royal
  - Rick Fitzgerald
  - Nancy Lynch
  - Barry Minbiole
  - Jeff Kingsley

DC-VI test results of 30-m cables in Carrollton, GA show no change in conductor performance.

- **Voltages are measured from bus, so there is a normal resistive component.**
  - **The voltage taps and connecting bus was different for the two measurements.**
- **The main three main conductors' critical current is above the 3 kA limit of the power supply.**
- **The shield I_c remained unchanged above 2 kA.**

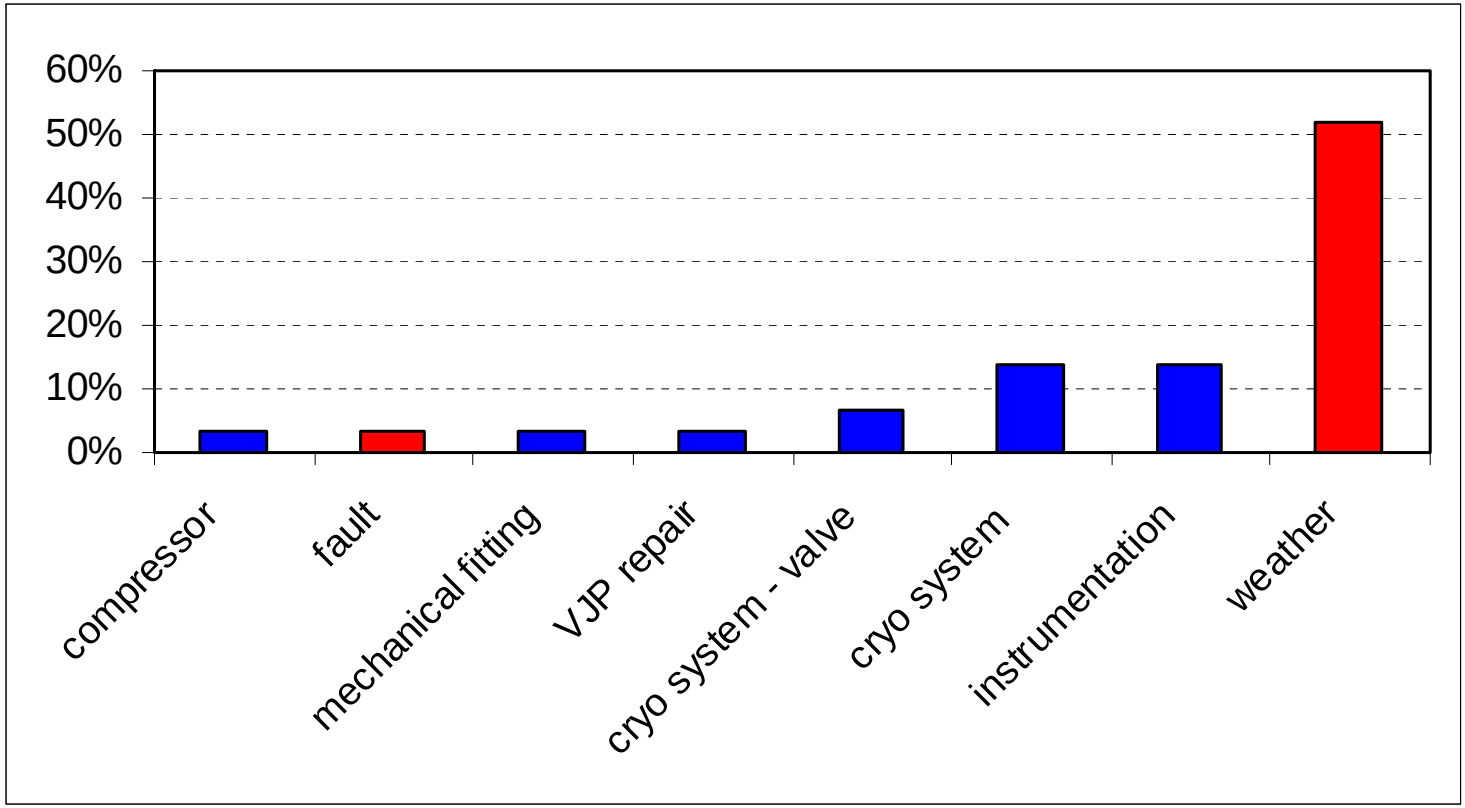


Outage Statistics

Un-Planned Outages, start-up through 30-June 2004:

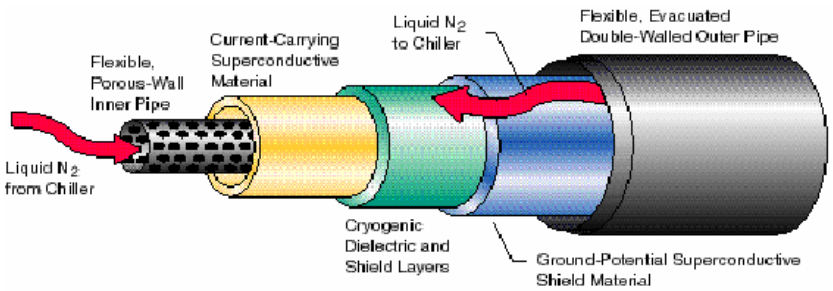
Total occurrences = 29

PM Schedule:
1 day every 9 months
(oil, filters, bearings)



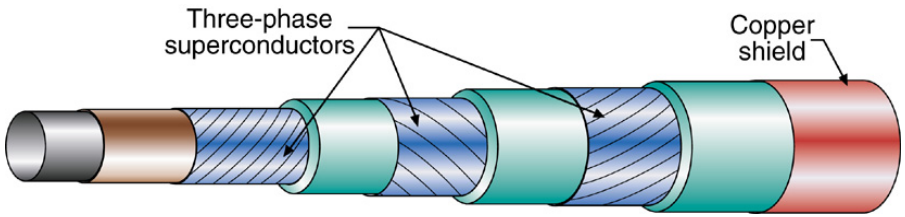
Comparison of HTS Cable Designs

30-m System
Single-Phase, Co-axial Design



- **Features of the Co-axial HTS cable**
  - **Magnetic field shielded.**
  - **Both conductor and dielectric are wrapped from tapes.**
  - **Cryogenic dielectric reduces size and increases current carrying capacity. The first cold-dielectric cable under development in US.**
  - **Flexible cable to allow reeling**

Bixby System
3-Phase, Triax Design



- **Features of the tri-axial cold dielectric HTS cable**
  - **Potential to reduce the required HTS tape by ~1/2**
  - **Potential to reduce heat loads by ~1/2**
  - **Flexible cable to allow reeling.**
  - **Southwire is fabricating 5-meter prototype 3,000 A_{rms} cable**
  - **Termination design modified for 3000 A_{rms} to meet AEP project requirement.**

‘AEP Project’

U.S. Department of Energy

SPI Phase-III

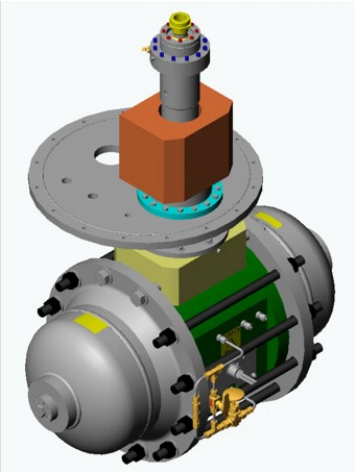
- **Utility Partner = American Electric Power**
- **Location = Bixby Substation, Columbus, OH**
- **Length = 200 meters**
- **Voltage = 13.2 kV**
- **Load Rating = 3.0 kA_{rms} AC / 69 MVA**
- **Fault Current Peak = ~56 kA**
- **Cable Design = Triax**
- **Other Features = Splice**
  Underground
  Multiple 90° Bends
- **Energize mid-2006**

Cryogenic Cooling

Experience 1: Stirling coolers
2 years operation at AMK

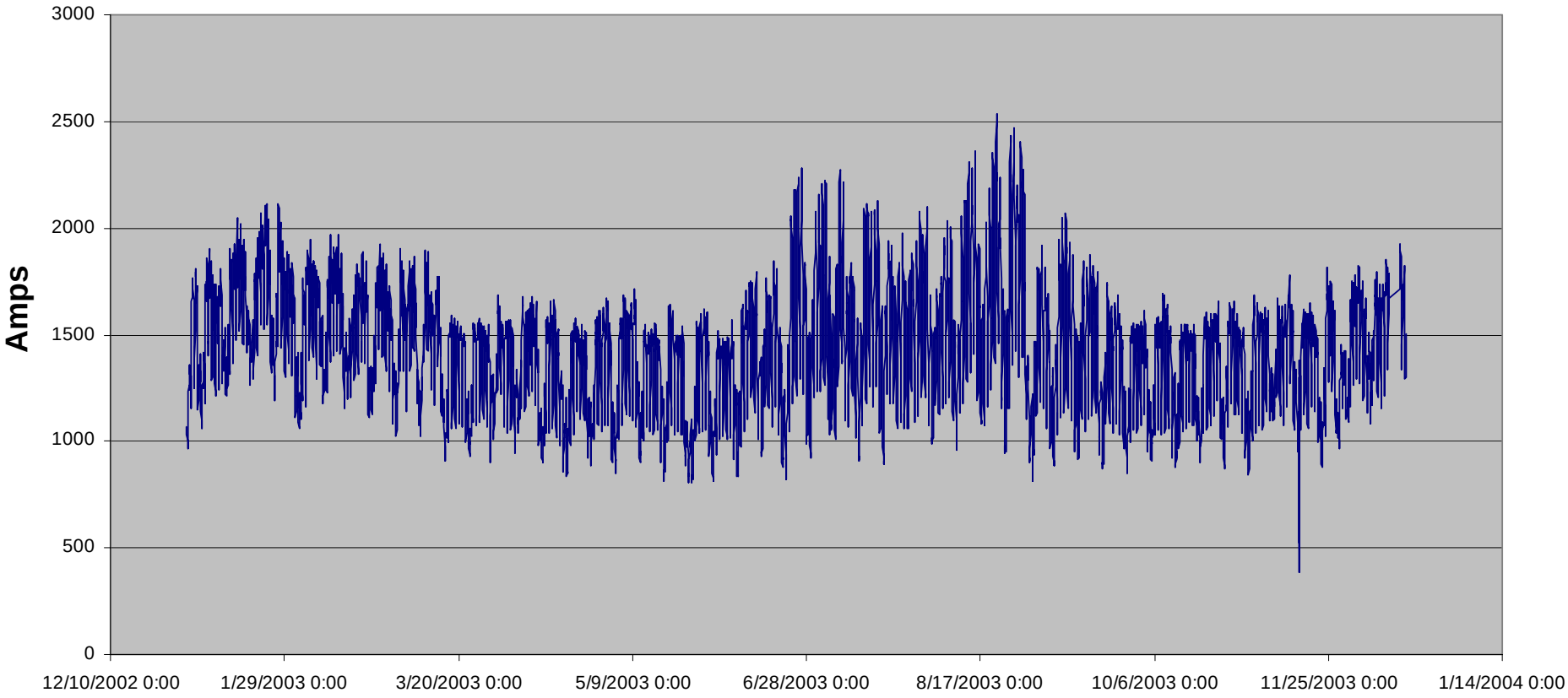
Experience 2: Open system
4+ years operation at Carrollton

New: Q-drive + pulse tube
- low vibration
- low maintenance



2003 Bixby Load Curve

Region: Columbus District: Columbus Station: BIXBY (#0071) Meter: BIXBY STATION 13 KV TOTAL Data Date Range: 01/01/2003 00:00:00 to 01/01/2004 23:59:00 Data Filter: MAX each 1 hr. period Filtered On: kVA Total Report Generated: 02/06/2004 07:40:04

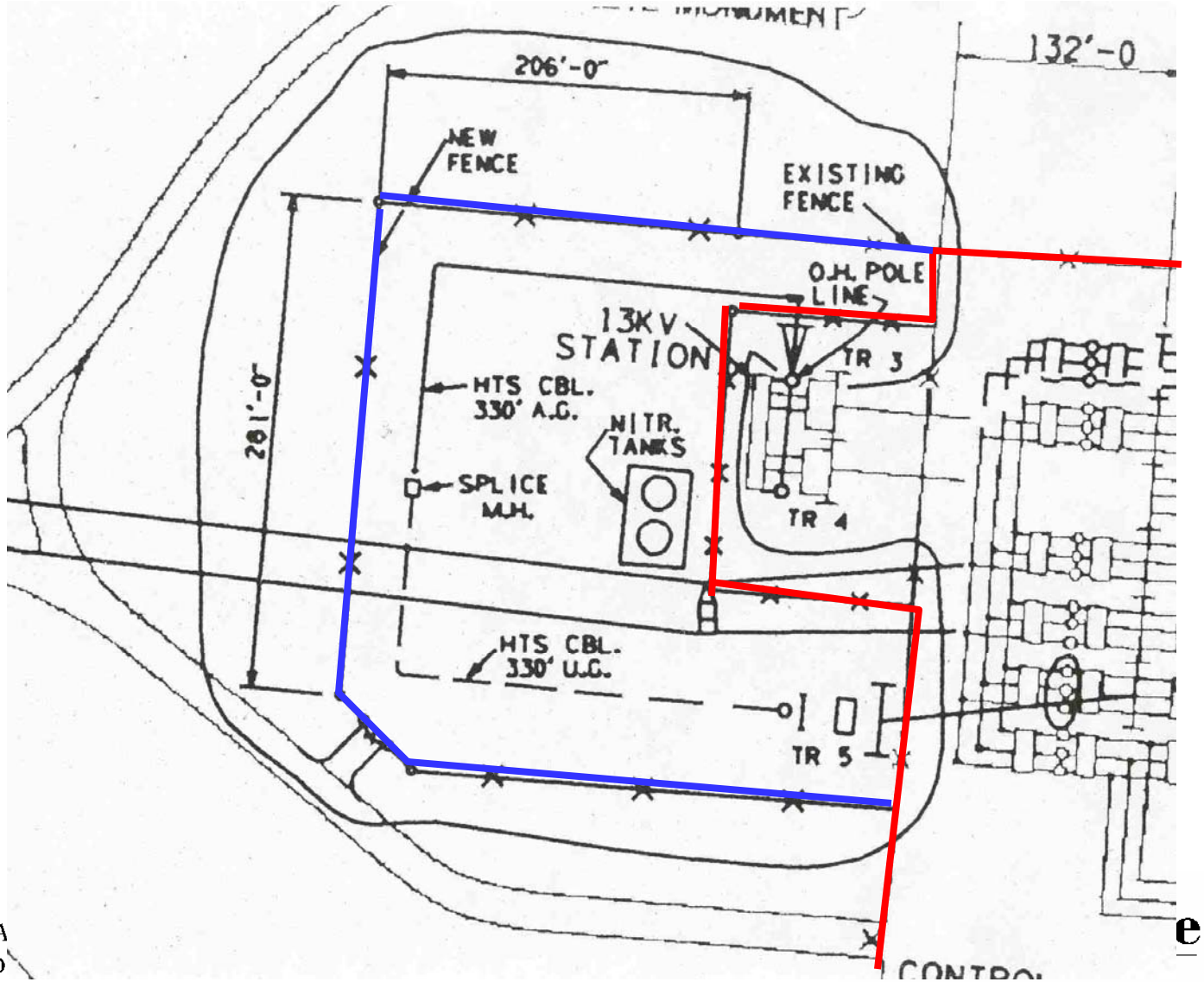


Jan – Dec 2003

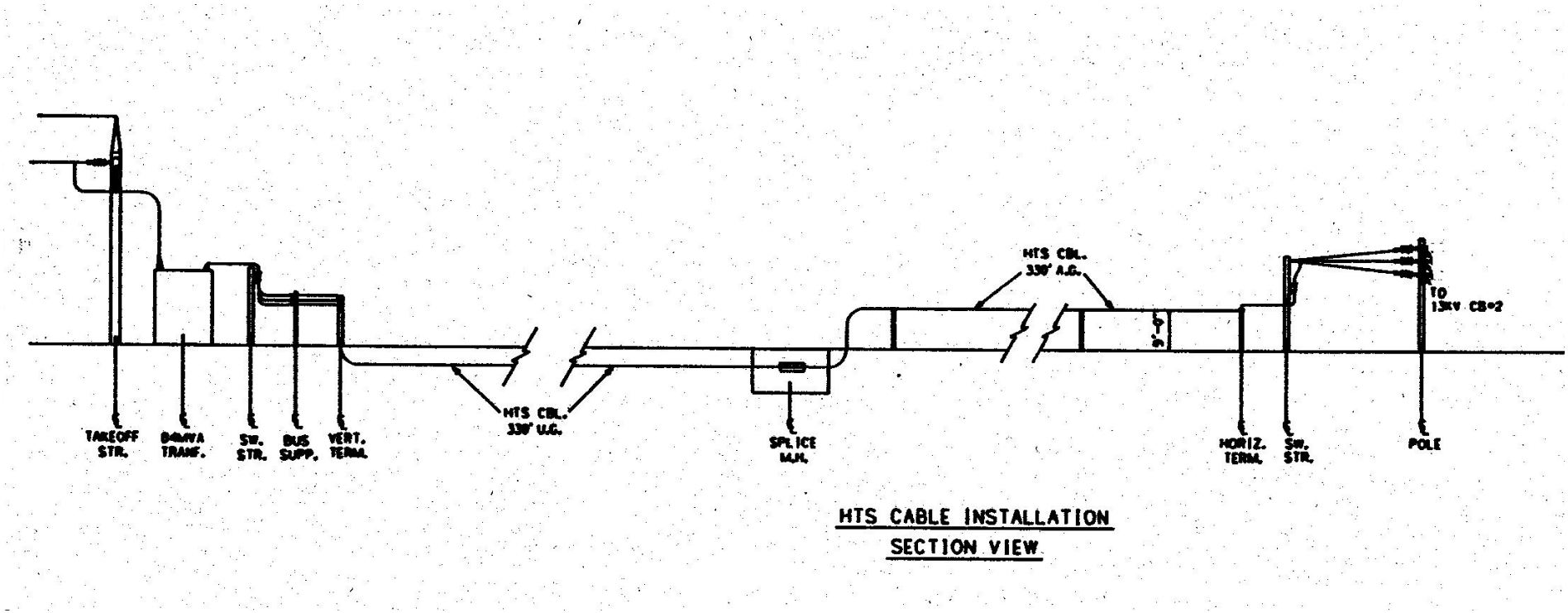
Proposed AEP Layout

Red Line = Existing Fence Line

Blue Line = New Fence Around HTS Cable System

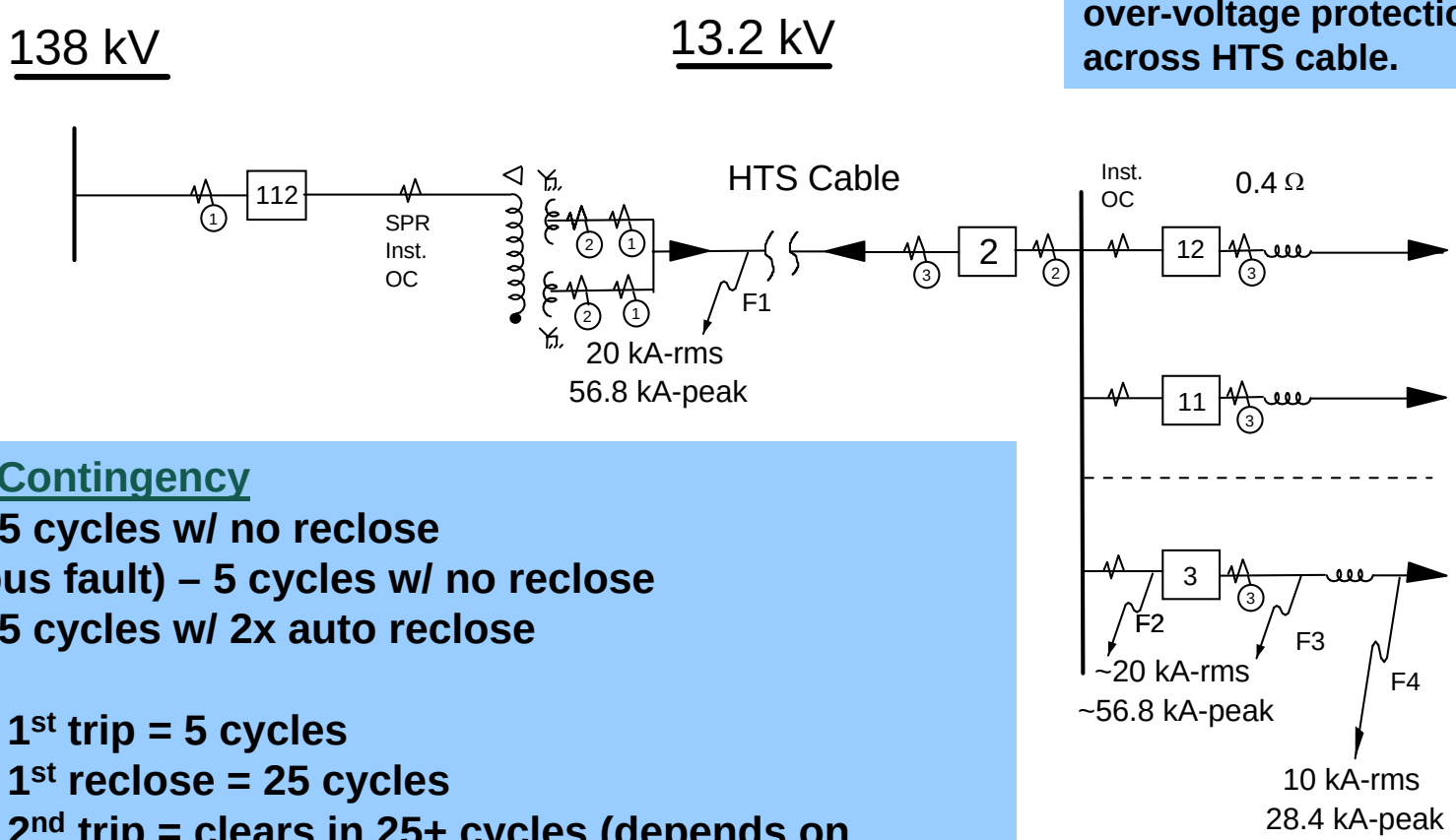


Proposed Cable Layout



Fault current / protection at Bixby 13.2 kV

Surge arrestors to provide over-voltage protection across HTS cable.

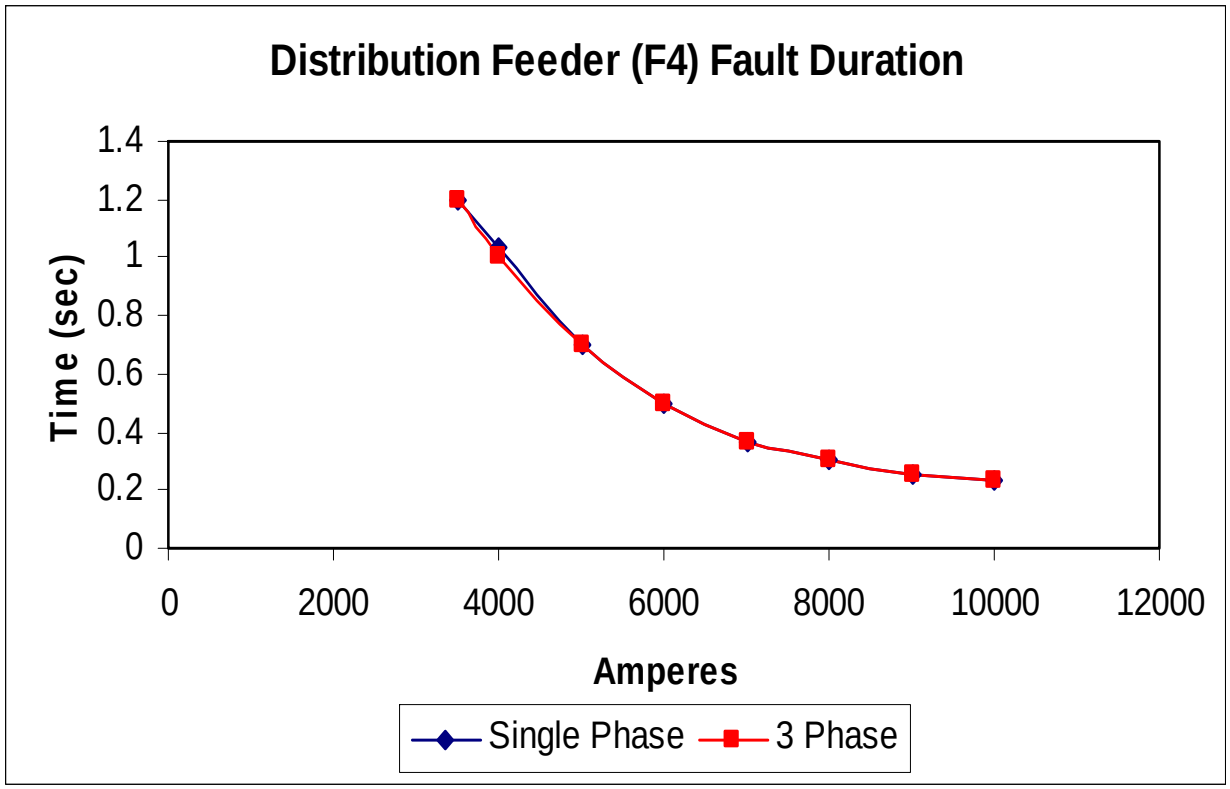


FC: 1st Contingency

- **F1 – 5 cycles w/ no reclose**
- **F2 (bus fault) – 5 cycles w/ no reclose**
- **F3 – 5 cycles w/ 2x auto reclose**
- **F4 –**
  - » **1st trip = 5 cycles**
  - » **1st reclose = 25 cycles**
  - » **2nd trip = clears in 25+ cycles (depends on current level, see next page)**
  - » **2nd reclose = 5 seconds**
  - » **3rd trip = clears in 25+ cycles, no reclose**

2nd Contingency for F1, F2, F3 is 15 cycles w/ no reclose

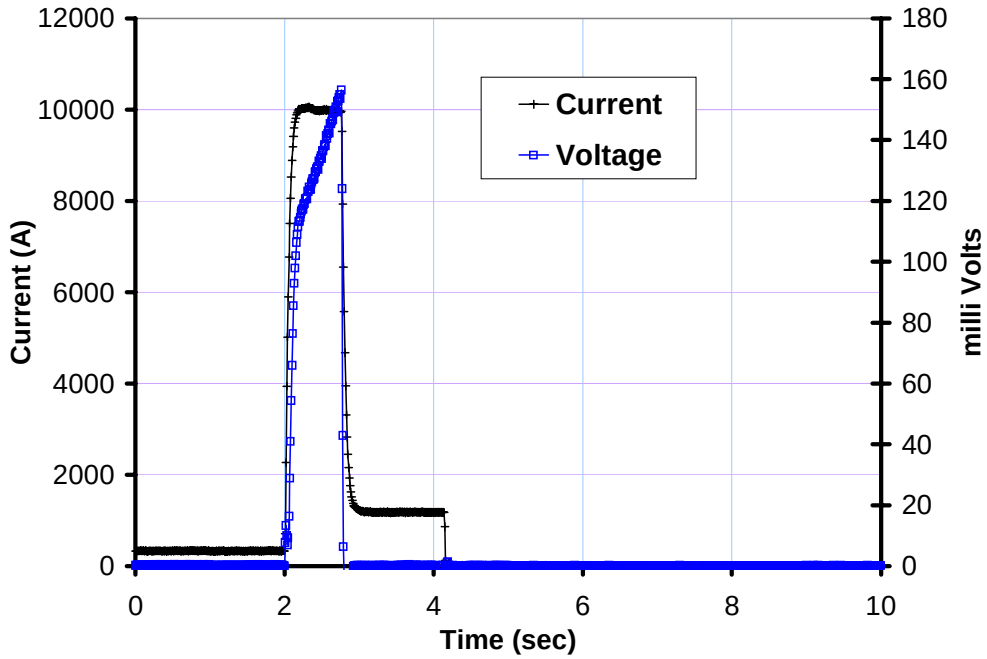
Fault Durations on Distribution Feeders (F4)



Total Fault Duration.		
Initial fault (5 cycles)		
plus two reclosings (2 x plot)		
plus breaker time (3 cycles).		
Current	(sec)	
3500	2.5333	
4000	2.1933	
5000	1.5333	
6000	1.1333	
7000	0.8733	
8000	0.7333	
9000	0.6333	
10000	0.5933	

Fault currents for the AEP triaxial cable are simulated with long duration dc over current pulses

- **Simulated 10 kA, 36 cycle (0.6 sec) fault on one distribution feeder.**
- **Current dropped to 1 kA and held for 1.5 sec – note voltage immediately back to zero after fault. Indicates cable immediately recovers to superconducting state.**
- **Test simulates fault on 1 of 7 feeders leaving 13 kV bus at Bixby while nominal current is maintained on other 6 feeders during and after fault**



In 2003, 13 kV at Bixby experienced 46 outages on distribution feeders – 'lockout' after 3 faults.

Presentation Outline

- **Introduction (David Lindsay, Southwire)**
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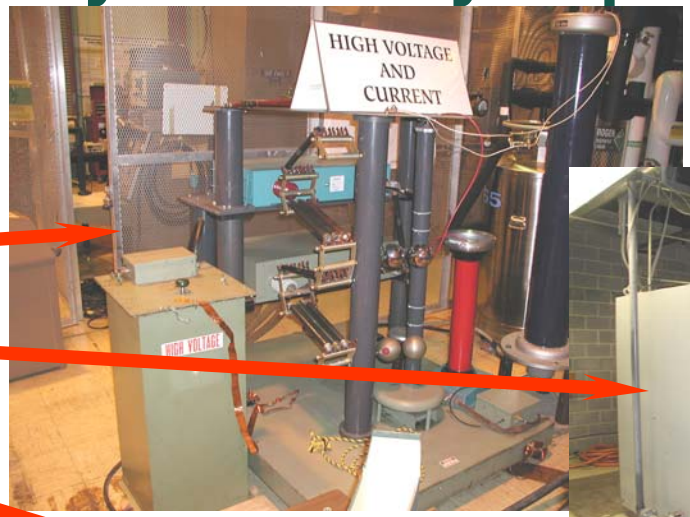
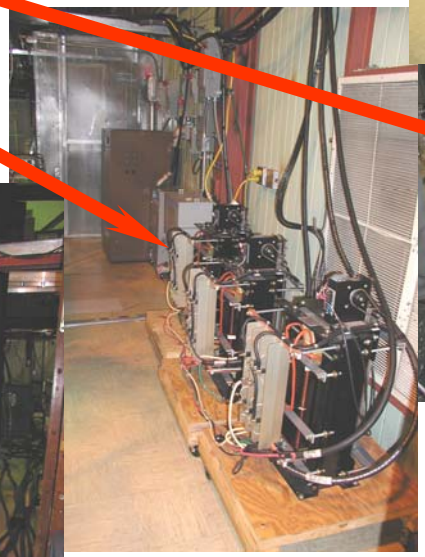
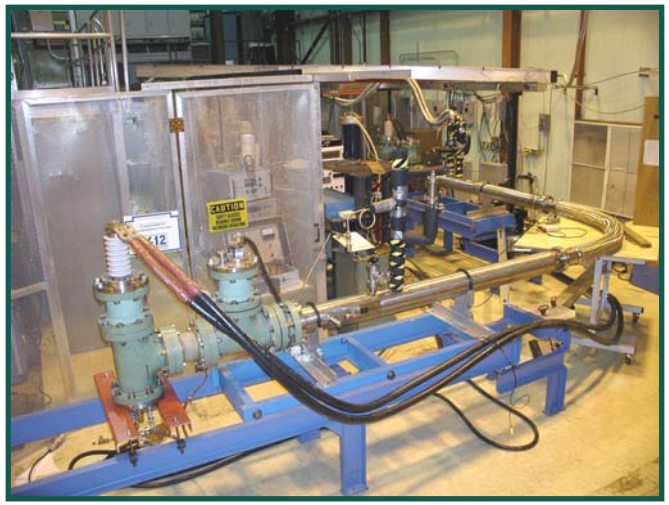
- **Planned FY 2005 & FY 2006 Milestones**
- **Program risk mitigation strategy**
- **Research Integration**
- **Summary**

HTS Cable Research Facility has many important capabilities.

- **Facility capability:**
  - Impulse power supply to 200 kV (BIL tests).
  - 25,000 A pulsed dc power supply.
  - 100 kV ac power supply
  - 3-phase, 3000 A ac power supply.
  - Subcooled liquid nitrogen.







ornl

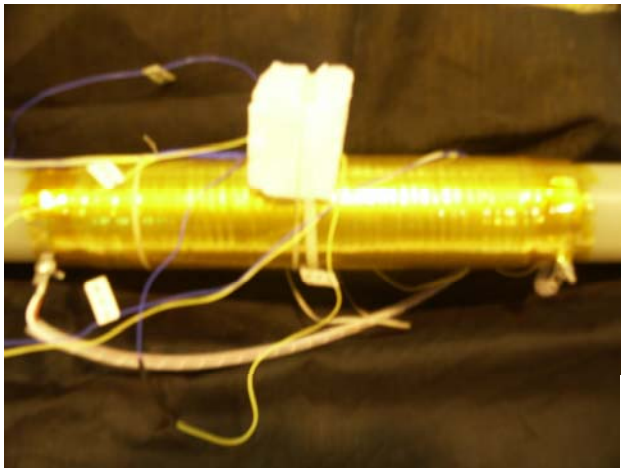
Southwire
WE DELIVER POWER

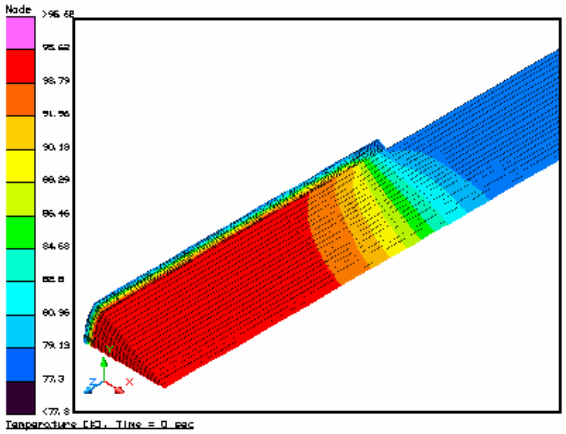
The thermal conductivity of wrapped Cryoflex™ in a liquid nitrogen bath was measured.

- **This datum is needed for design of cable cooling, particularly in the tri-axial cable design.**
- **Cryoflex™ was wrapped over a heater on a G-10 cylinder.**
- **Thermometers on either side of the Cryoflex™ provided temperature difference across a known heat load.**

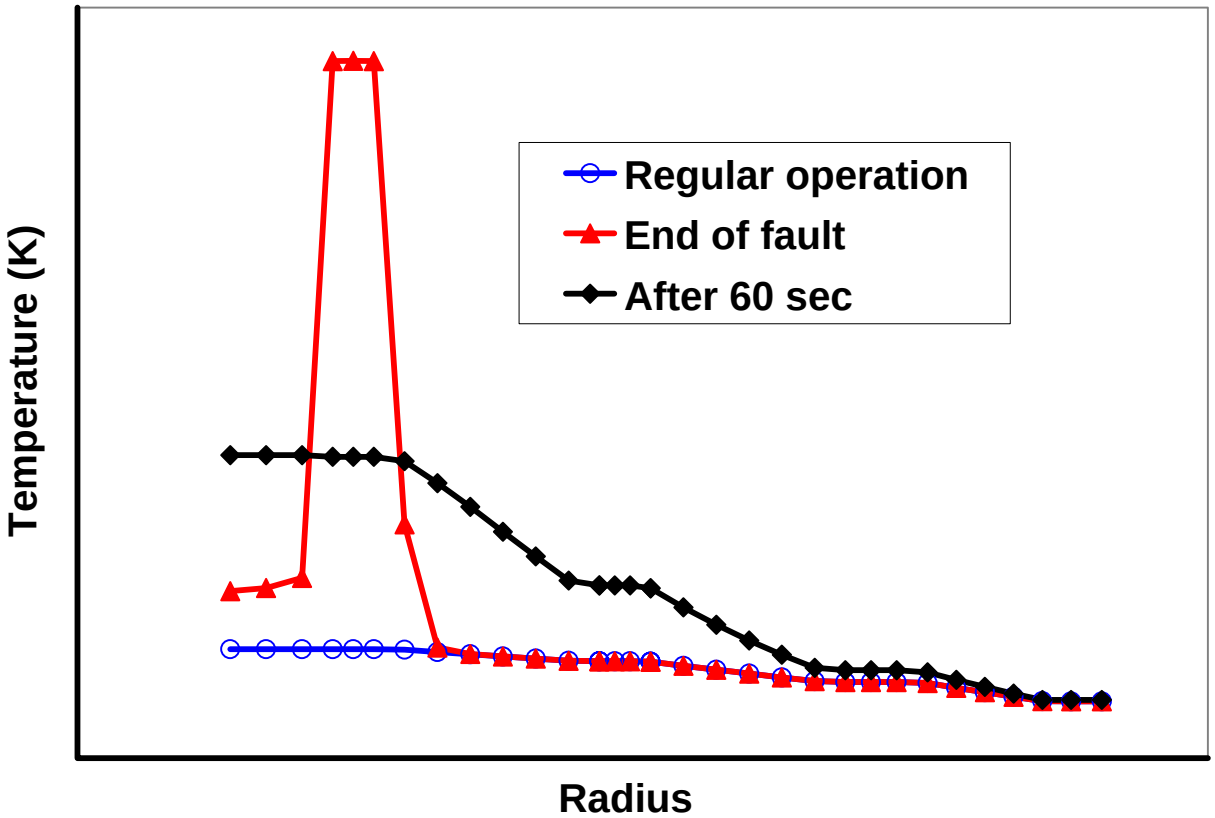
$$k = \frac{Q \ln\left(D_{out} / D_{in}\right)}{2\pi L\left(T_{out} - T_{in}\right)}$$

- **SINDA Thermal model used to verify 1-D approximation.**





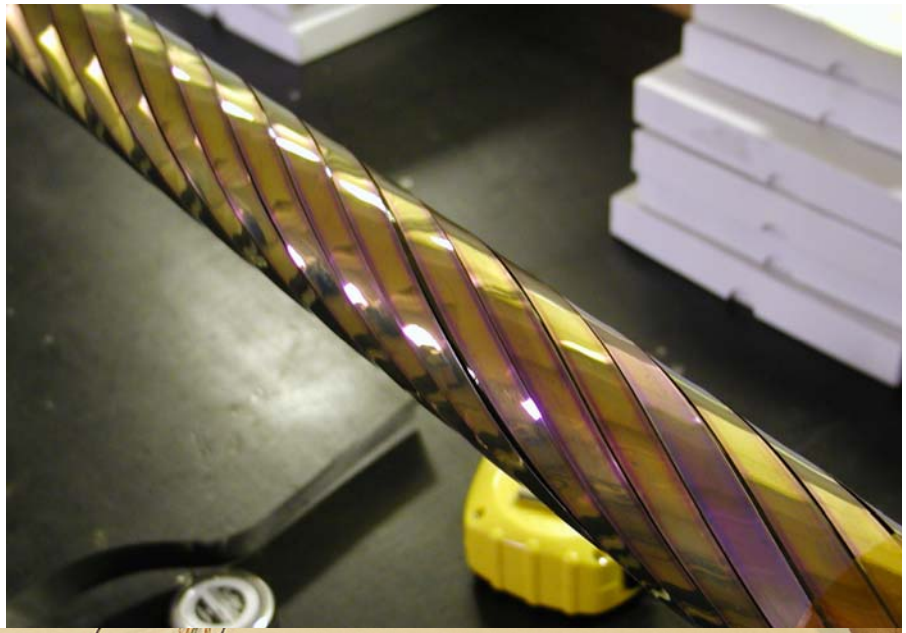
Thermal response of the triaxial cable to fault currents is under investigation.

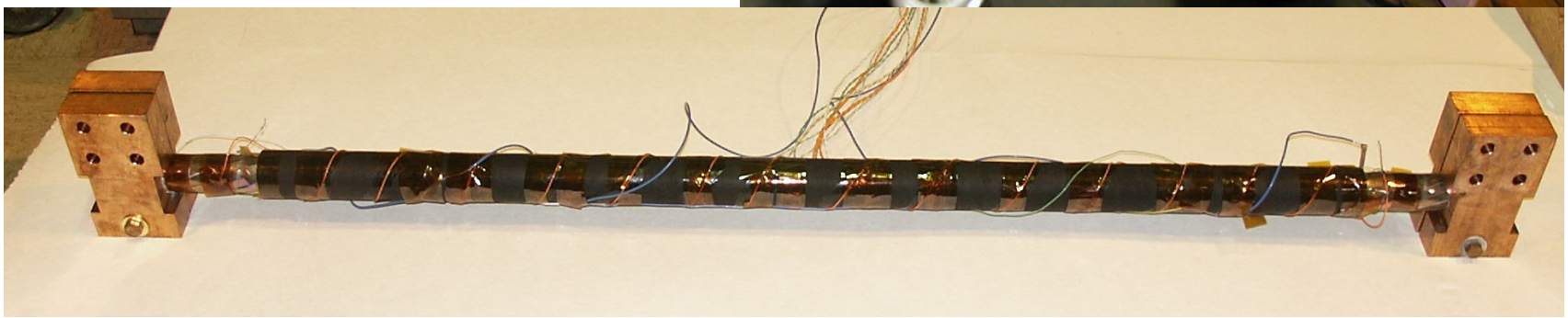


- These results are for a fault on phase 1 (innermost).
- Measurements on instrumented short sample cables will be used to develop models.

The YBCO cable was fabricated by Southwire Co. using AMSC tape and tested at ORNL

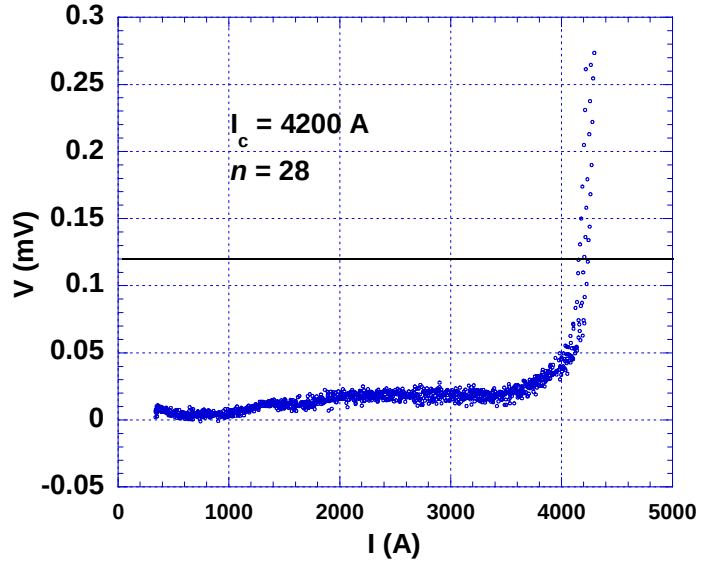
- **First commercial scale prototype from YBCO conductor.**
- **AMSC delivered 30-ea., 1.5-m 2G YBCO tapes.**
- **All tapes exceeded ORNL specifications**

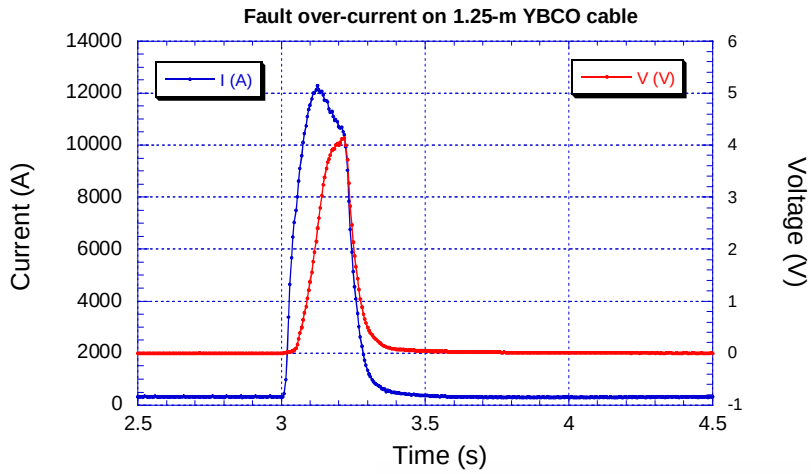




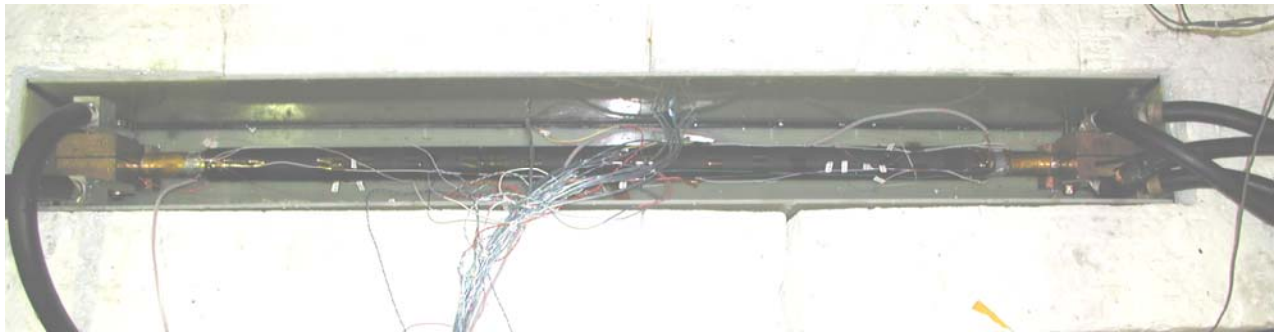
Over-current fault testing was conducted on the second generation YBCO conductor cable

- Commercial Grade demonstration YBCO cable (I_{ac} > 2 kA)
- No degradation of I_c from winding.
- YBCO conductor from American Superconductor
- Cable Specifications
  - 1.25 m long
  - 24 tapes
  - Measured I_c of 4200 A with an avg. n of 28
- A 12 kA fault current was applied.
  - The YBCO conductor did not degrade.
- New AC loss results were deferred due to damage of cable from handling.



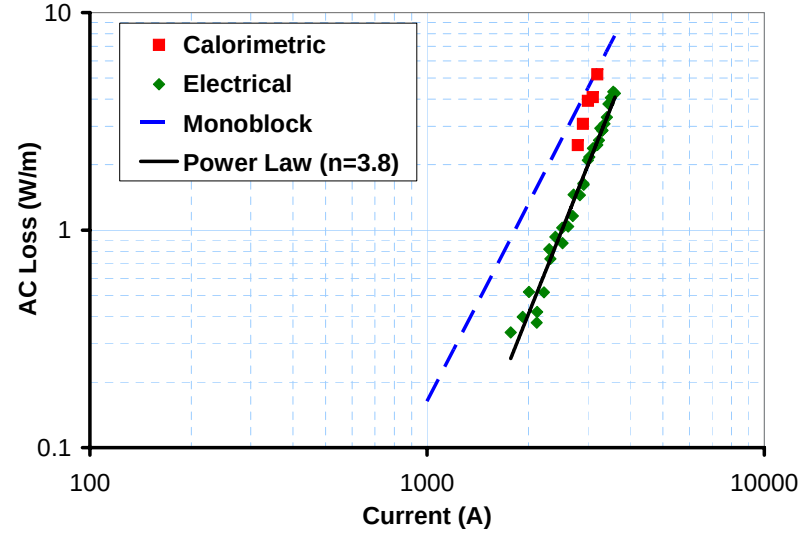


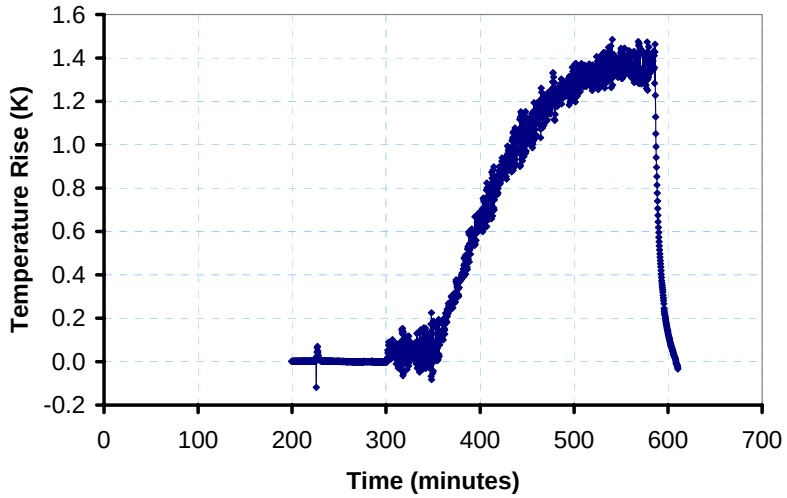
Data from a 1.5-m cable made with AMSC laminated tape will be used to compare with models.



- **1.5” OD stainless steel former with semicon layer.**
- **Two HTS layers, 27 tapes each layer.**
- **Nichrome heater tape installed length of cable over a kapton layer.**
- **Cryoflex™ layers wound to simulate tri-axial cable build.**
- **RTDs in center at 3 different radii.**

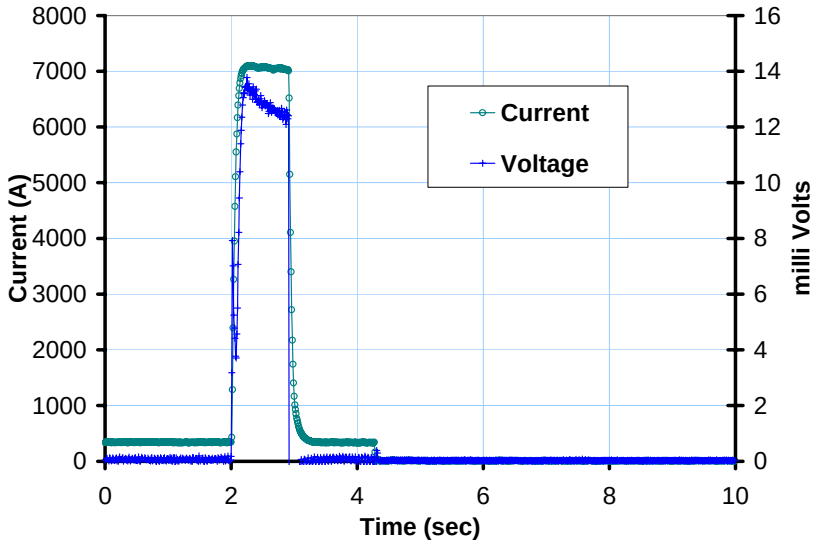
AC losses were measured on the AMSC laminated tape cable.

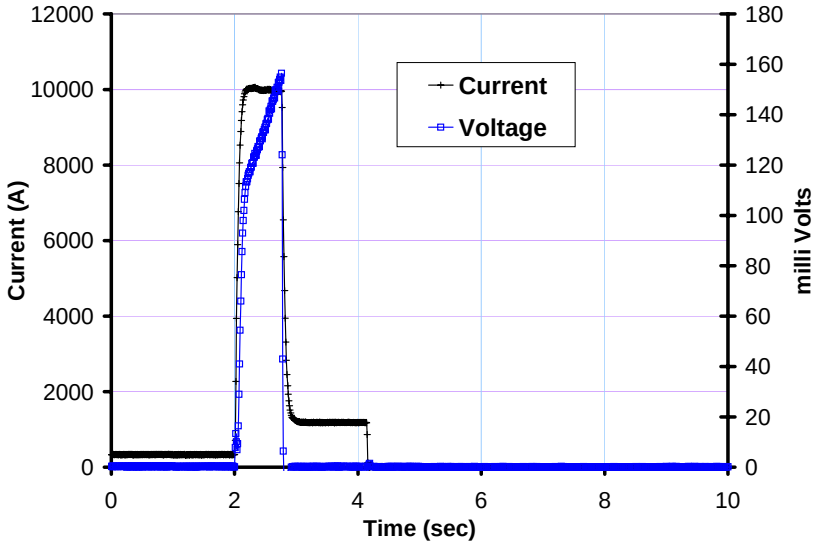




- Prototype cable with AMSC laminated BSCCO tape. Tested at ORNL.
- Wound 1.5-m cable with optimum lay angles. Cable had 54 tapes in 2 layers.
  - Cable I_c was ~4800+ A
  - AC loss of the 1.5 m cable @ 60 Hz and 77 K, slope of the dashed blue curve = 3
- AC loss at 3 kA_{rms} was ~2 watt/m electrical, ~4 W/m calorimetric.
- The conductor temperature rise was around 1.4 K for 3 kA_{rms}.

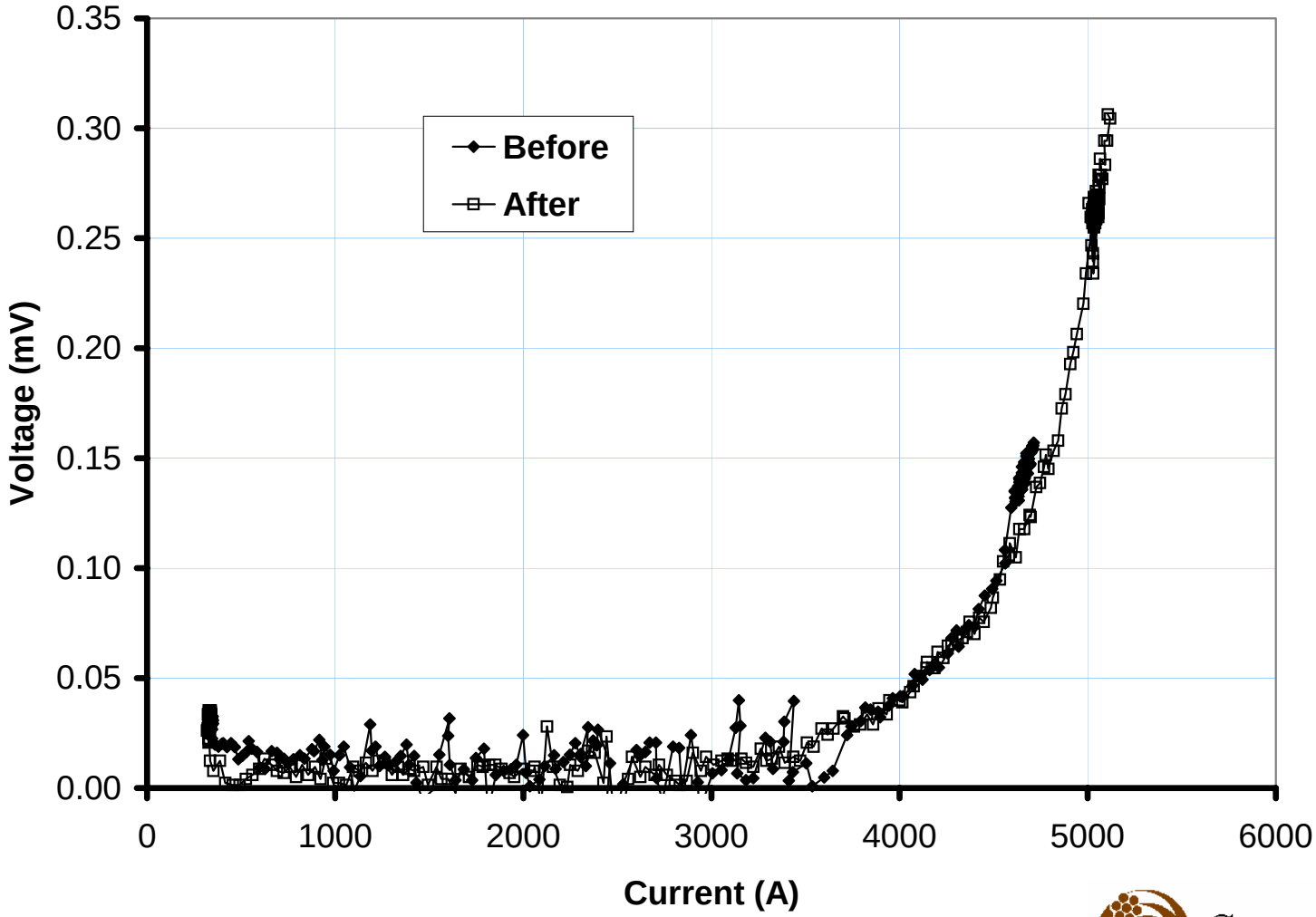
Expected fault currents were successfully withstood by the laminated cable.



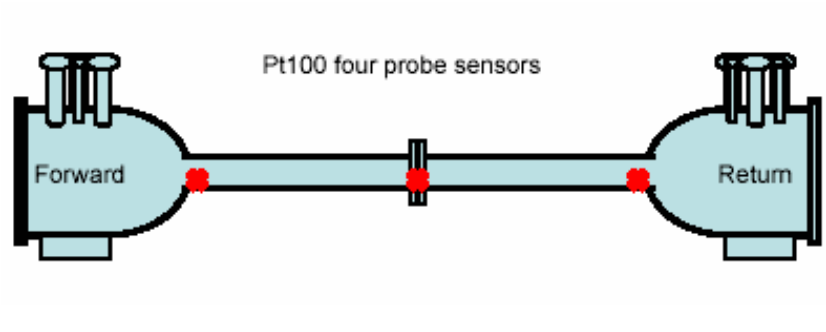


- The upper chart is a 7 kA dc pulse for ~0.9 seconds.
  - The voltage across the cable dropped during the pulse.
- The lower chart is a 10 kA dc pulse for ~0.6 seconds.
- The current was dropped after the pulse to 1 kA for 1.5 sec.
  - Voltage across the cable rose during the 10 kA pulse indicating that it heated up.
  - After dropping to 1 kA the voltage indicated it was still superconducting.

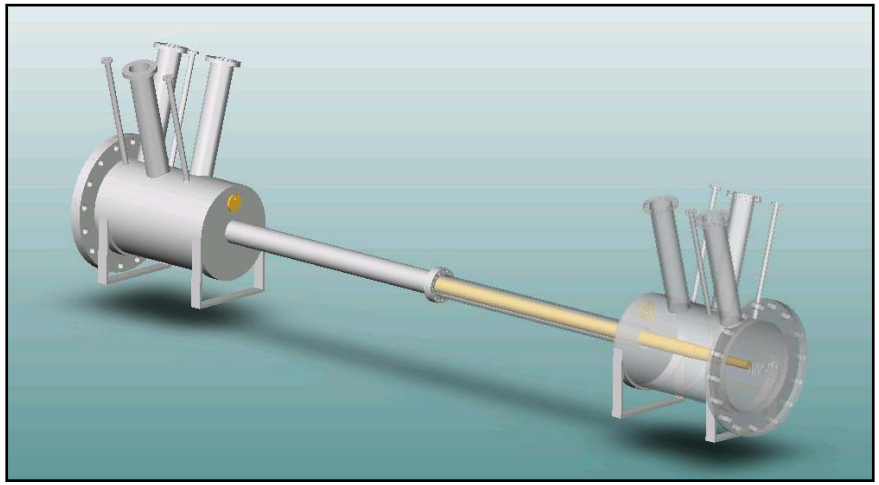
Voltage-Current characteristics were unchanged after the over-current fault simulation.

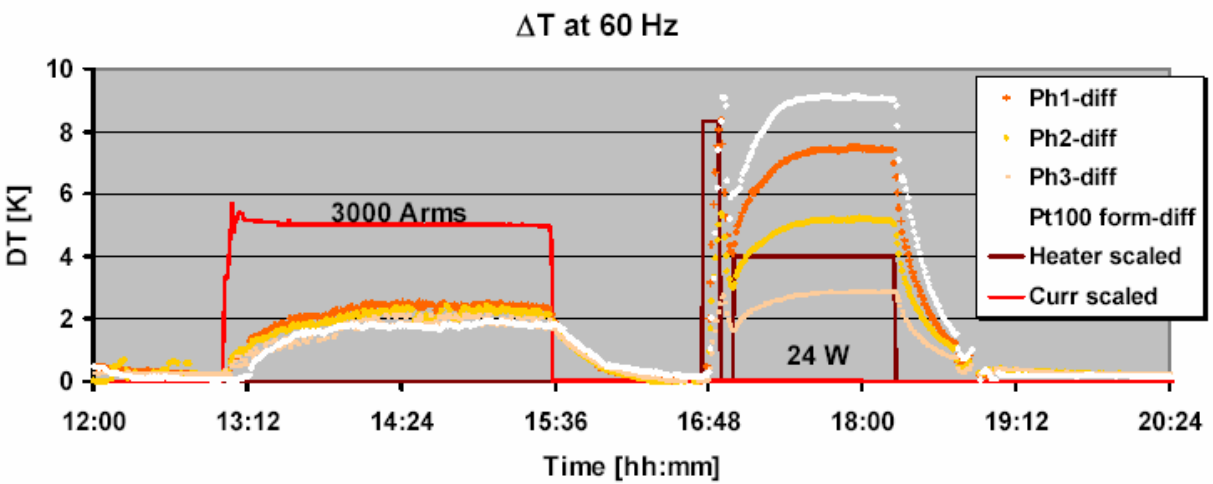


3.0 kA, 3-Phase Testing – Triax Design



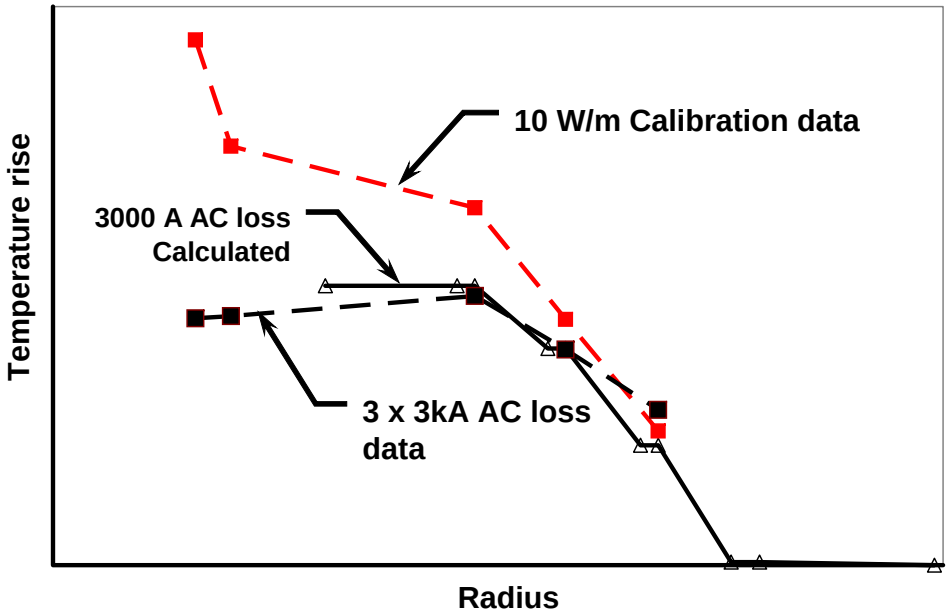
Tested in pressurized liquid nitrogen, T = 79 K





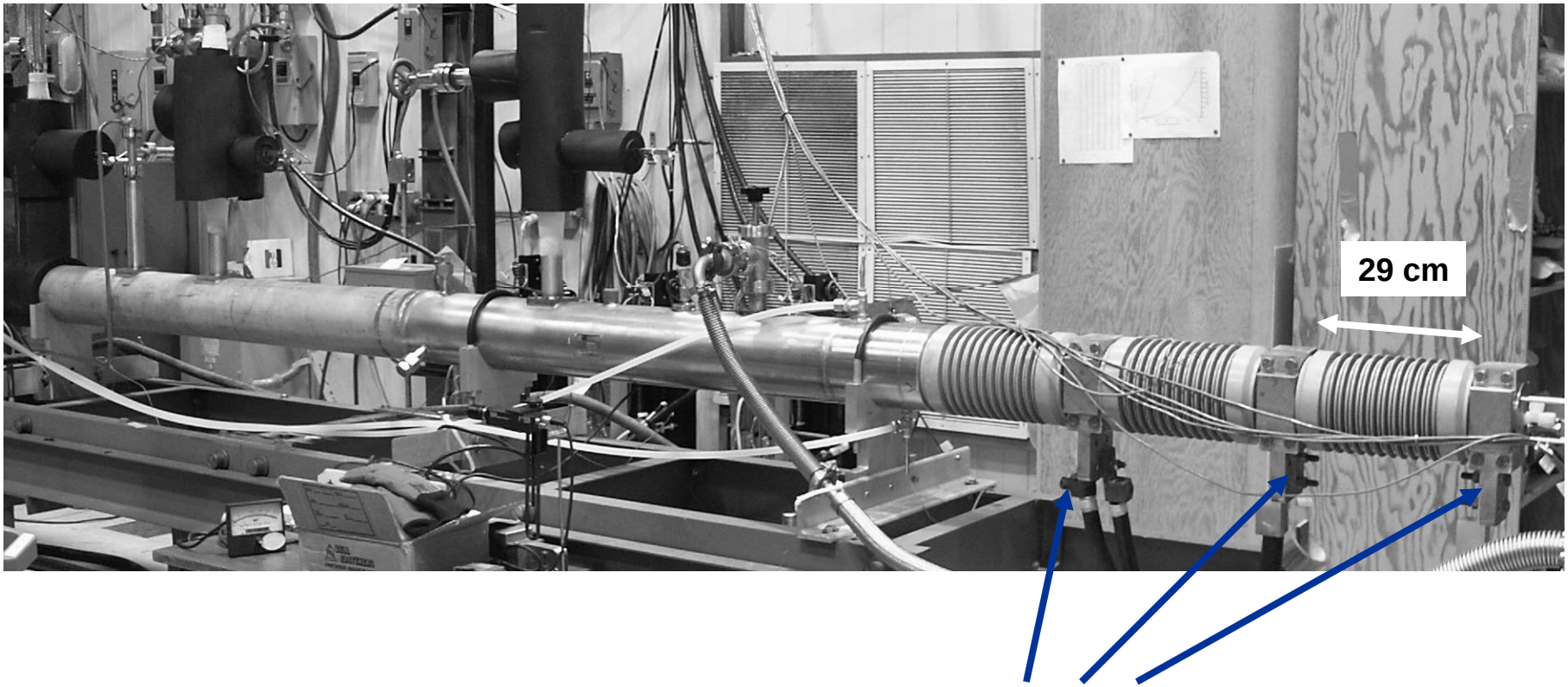
1st Proto-type:
3-Phase Triax conductor tested to 3.0 kA on all phases simultaneously. ΔT was within limits and stable. Acceptable ac loss results

Ultera in Denmark has conducted 3-phase testing of a 3-meter triaxial cable at 3 kA



- **Testing conducted in pressurized test chamber at around 2 bar.**
- **No high voltage testing was conducted.**

A 5-m, 1.3 kA cable with full-scale T3-terminations was built and tested at ORNL in FY2003.



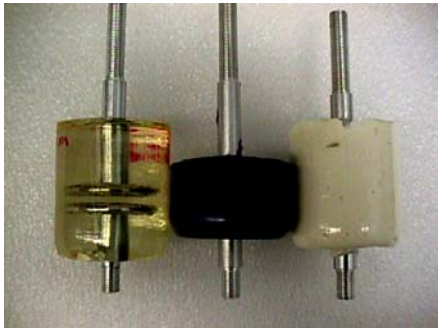
Connections for ac power

Difficulties in fabricating T3 lead to the T4 migration.

- **T3 design brought out phases concentrically making a compact configuration, however:**
  - **The required high thermal conductivity dielectric for T3 design failed to meet HV requirements**
  - **Use of conventional dielectrics as an alternate in T3 required:**
    - **Introduction of LN into the center of the termination**
      - **Limited surface area in center requires addition of heat transfer enhancement**
    - **Similar long dielectrics caused a major procurement problem for T2**
    - **T3 was too compact and would have to be modified to meet AEP standoff requirements**
- **T3 design utilized cast dielectric materials.**

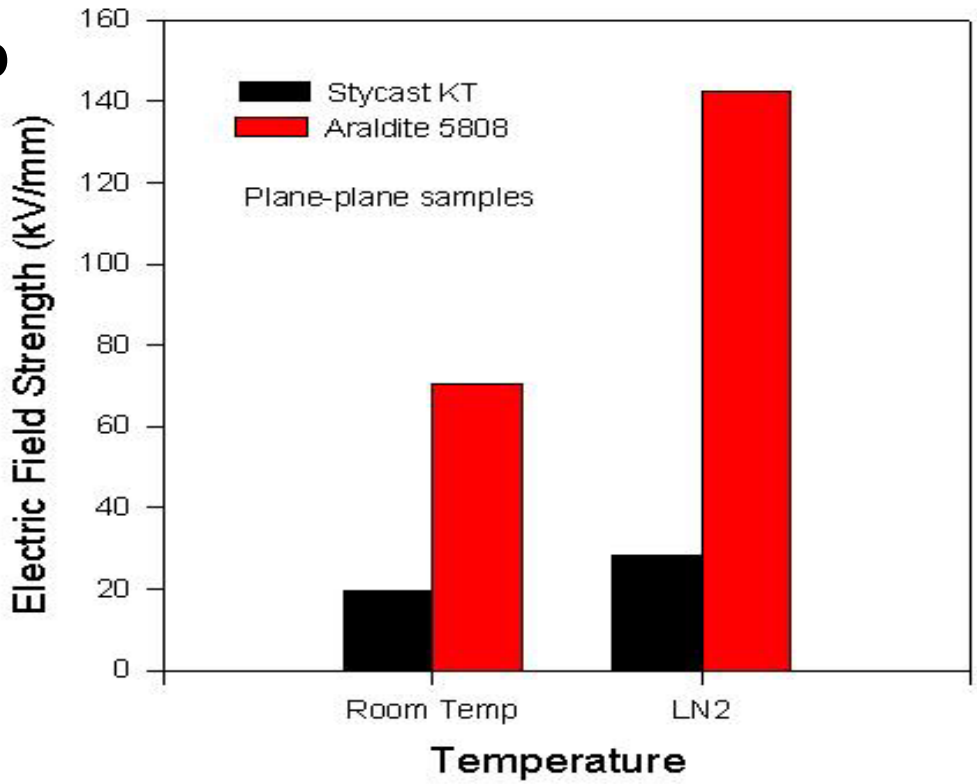
High voltage studies conducted on disk and cylindrical samples

- **Disk samples**
  - 1 to 15mm thick
  - Screened a large number of materials
  - Focused on Stycast FT and KT and
  - Araldite 5808, Filled and Unfilled
- **Small model terminations ("Baton")**
  - 1-ft length cylindrical
  - Partial discharge versus voltage
  - Aging
  - Ramp-to-BD
- **Large model terminations ("Barbell")**
  - 4-ft length
  - PD patterns
  - Breakdown strength
  - Dissection to locate cause of BD

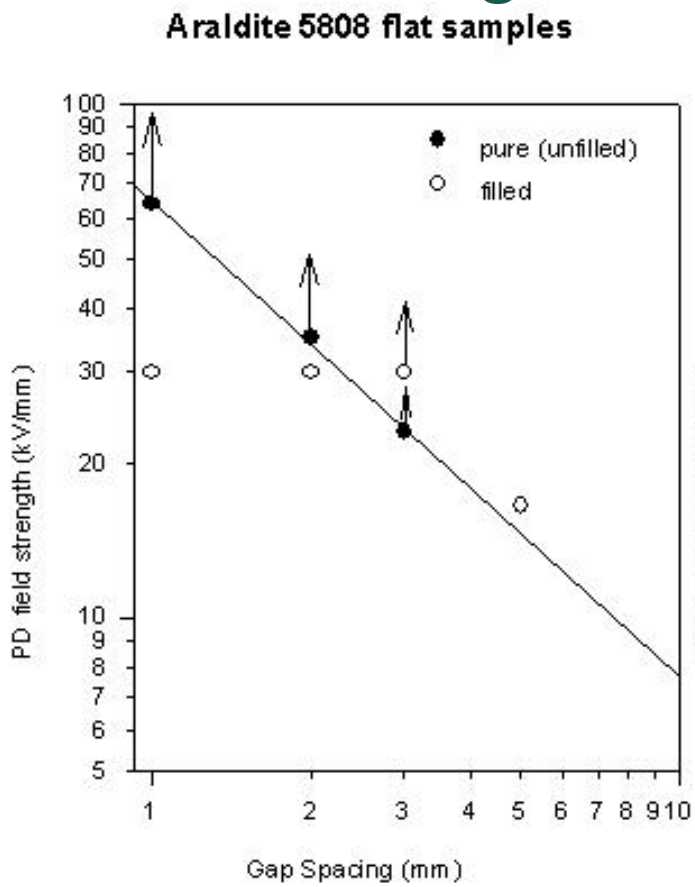


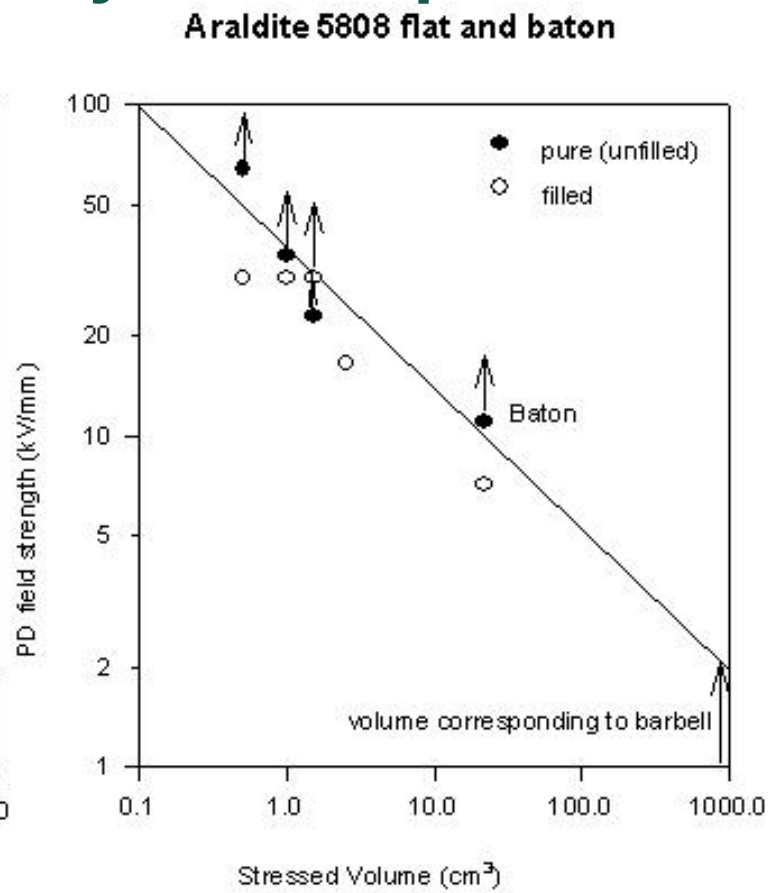
Breakdown strength depends on temperature.

- **For certain materials breakdown strength increases as the temperature decreases to LN2**
- **Stycast 2850 KT (filled) and Araldite 5808 (unfilled) shows such improvement**



Solid dielectric geometry affects performance.

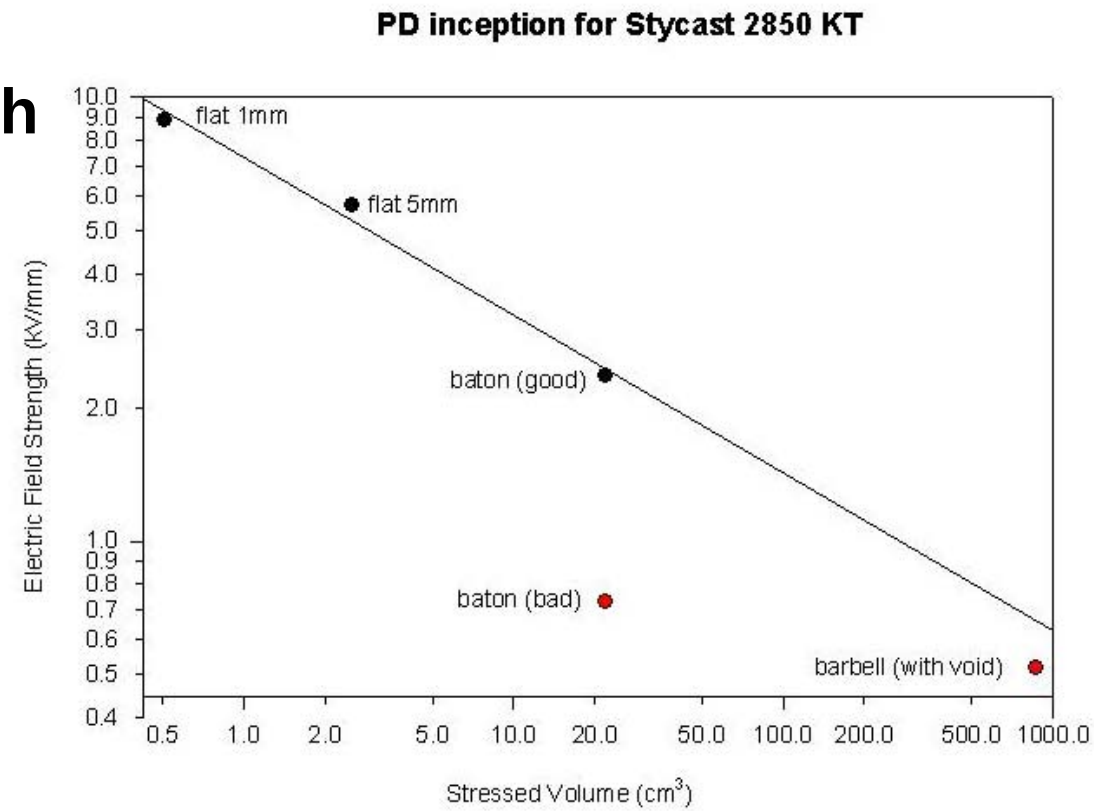




- **Pure and alumina-filled samples were tested in "flat" (plane-plane) and "baton" (cylindrical) samples**
- **PD inception voltage decreases for increasing gap and volume**

Partial discharge inception voltage in Stycast 2850 KT decreases with volume.

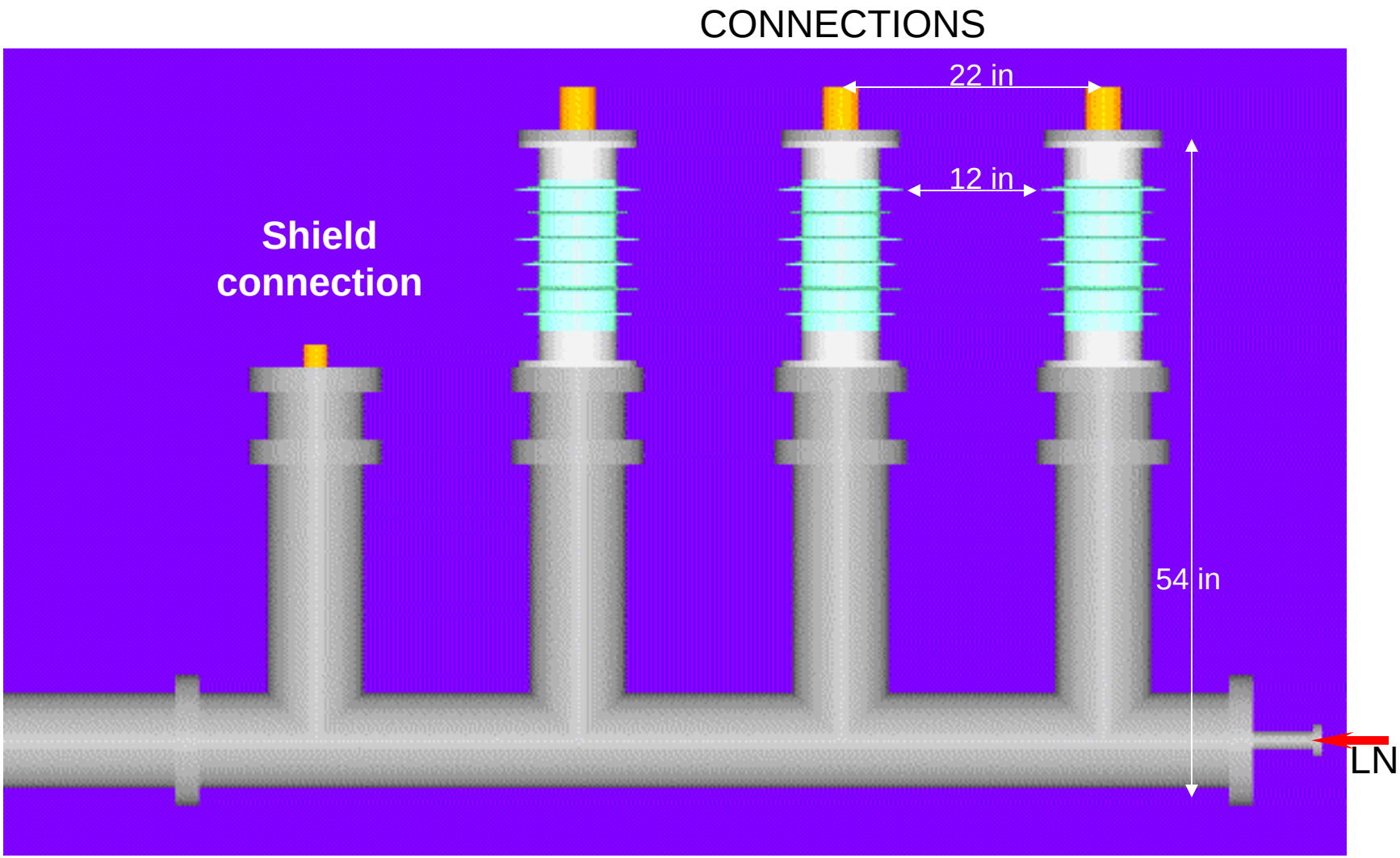
- **PD inception strength decreases as the stressed volume increases**
- **Samples with known defects show even lower strengths**



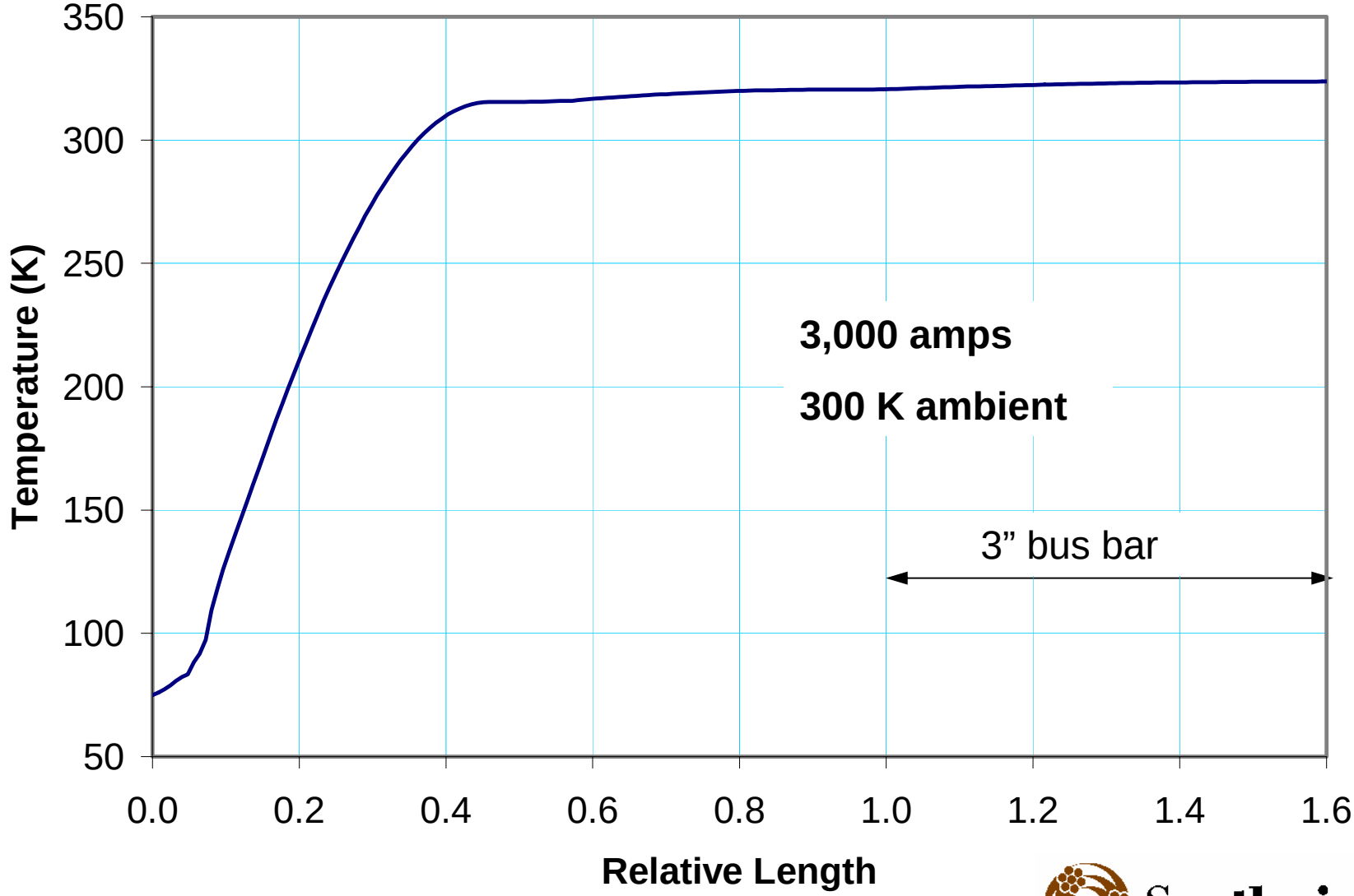
T4 design is based on successful T2 dielectric concepts

- **Differs from T3 in that phases are separated while cold thus eliminating the need for high thermal conductivity dielectric.**
- **Utilizes commercially available materials.**
- **Thermal conductivity is not a driving concern.**

T4 termination is based on compact T2 design.

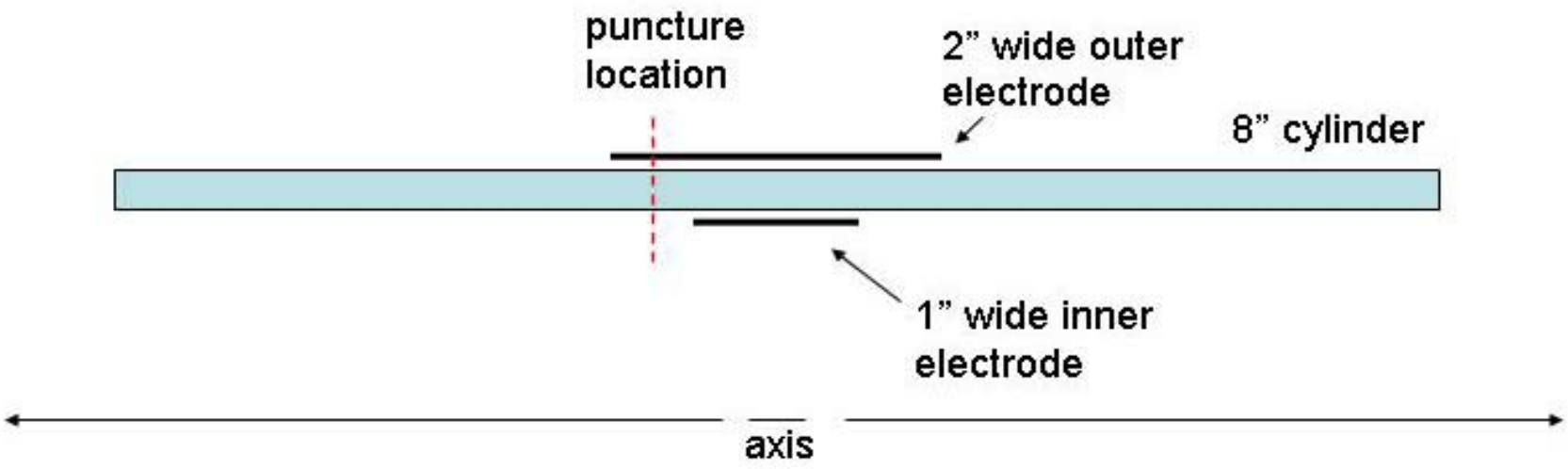


Model prediction of termination temperature along vertical centerline are acceptable.



Experiment set up to measure puncture and flashover strength of cylinders

half of longitudinal cross section of cylindrical tube showing outer and inner electrode



Impulse breakdown of cylinders

- **Flashover and puncture strength measured for cylinders of varying thickness**
- **Measurements made in air and in liquid nitrogen 1 bar and at high pressure**

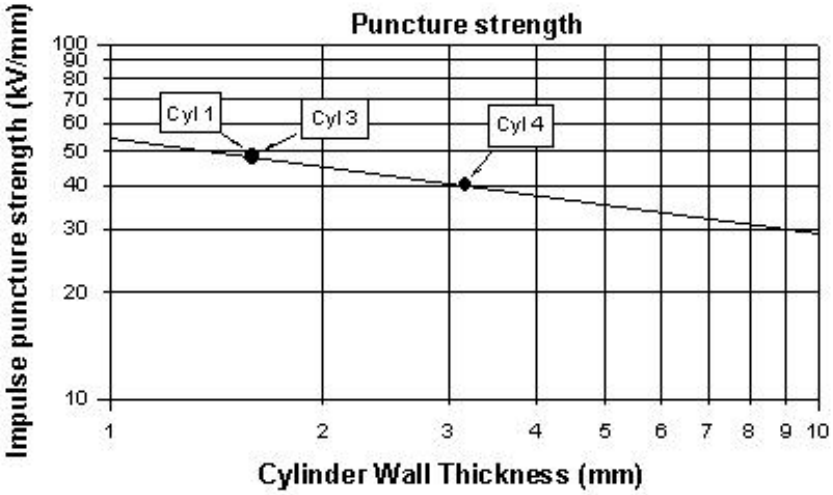
Impulse Breakdown results

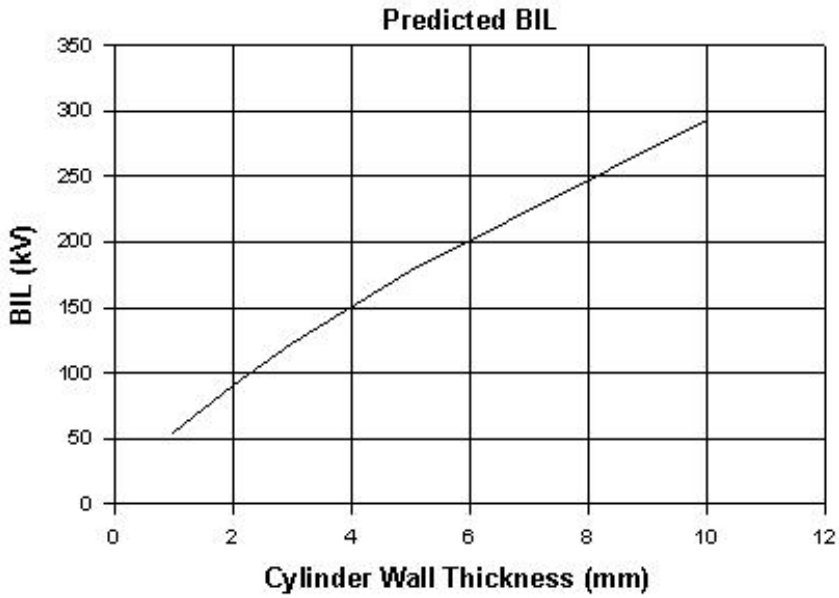
Cylinder Thickness	Air (1 atm)		LN2	
1/16" (1.6mm)	250 V/mm	Flashover	47.9 kV/mm	Puncture (1 bar)
1/16" (1.6mm)	---	---	48.5 kV/mm	Puncture (1 bar)
1/8" (3.2 mm)	---	---	40.0 kV/mm	Puncture (high press)
1/2" (12.7mm)	---	---	25.4 kV/mm	Flashover (high press)

cylinder dimensions: 8" (203 mm) long
3.5" (89 mm) inside diameter

Scaling with cylinder thickness permits estimation of BIL

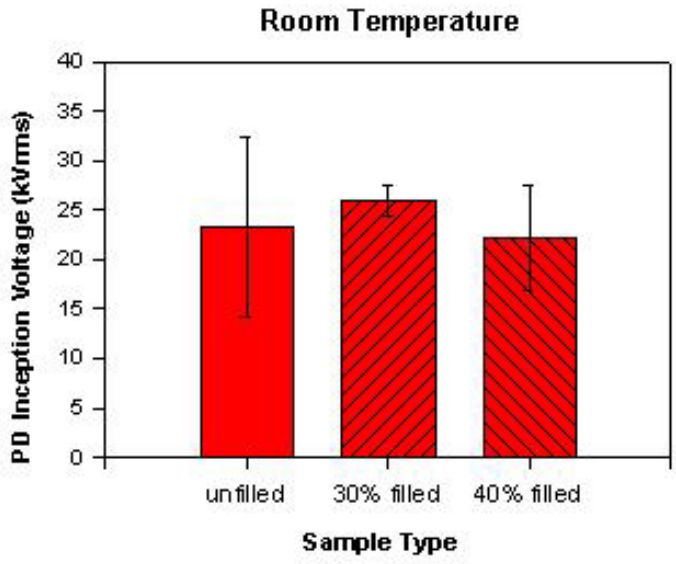
- **Puncture strength (impulse voltages) decreases with thickness for cylinders**
- **Data can be used to predict minimum thickness to BIL requirements**

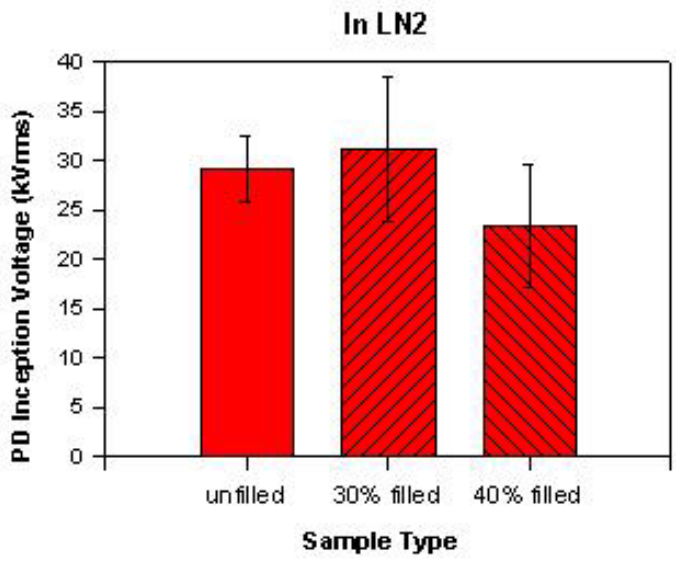




PD inception strength measured for commercial plastic disks.

- PD inception measured at room temperature and in LN2
- Three types of 3-mm thick disks studied (unfilled, 30% filled, 40% filled)
- Large statistical variation observed
- Modest increase in strength observed at low temperature
- Lower bound for PD inception: 15kV/mm





ORNL FY 2004 Performance

FY 2004 Plan

- Continue operation of system with required PM and system management. Re-test dc-I_c of cables.
- Complete electrical testing of the 5-m tri-axial, 3-phase, 3,000 A_{rms} cable at ORNL.

FY 2004 Performance

- ✓Over 26,000 hours of operation
- ✓Critical current measurements show robust superconductor
- ✓Unattended operation (since 6/01)
- ➢Deferred until the termination design is complete.
- ✓Development of a 3 kA tri-axial termination continued.
- ✓Developing dielectric materials to eliminate PD and 15 kV breakdown.

ORNL FY 2004 Performance

FY 2004 Plan

- Complete testing of the YBCO cable (Additional ac loss and over-current tests)
- Complete design for cable demo at AEP Columbus and begin long lead procurements.
- Begin civil/electrical design & construction work at Bixby station

FY 2004 Performance

✓ Measured voltage for fault currents up to 12kA.

➢ Development of a 3 kA tri-axial termination is continuing.

➢ Cable layout at site is being finalized. Ground breaking is deferred until cable system design is complete.

ORNL FY 2004 Performance

FY 2004 Plan

- Begin construction of HTS cable for AEP.
- Test model cables and terminations to higher ac voltages (up to 69 kV),
  - Requires upgraded dewar for the higher voltage levels.
- Continued research improving cryogenic system performance with industry and NASA

FY 2004 Performance

- ➢ Deferred until the termination design is complete.
- ➢ Dielectric studies have concentrated on materials for the triaxial cable terminations needed for the AEP project.
- ✓ Cryostat test plan being developed that responds to issues such as pulling forces, vacuum insulation, and cable installation.

ORNL FY 2004 Additional Tasks

FY 2004 Plan

- Tested 1- to 3-m cables to evaluate conductor architecture and minimize ac loss
- Participated in SPI Readiness Review

FY 2004 Performance

✓Measured thermal conductivity of Cryoflex™ on wrapped geometry.

✓Measured copper laminated HTS tapes for ac loss and fault tolerance.

✓Conducted design and initial testing of 3-m cable made with AMSC brass laminated HTS tapes.

✓Mitigation plans have been prepared that address the issues identified by the Readiness Review Team.

Southwire/ORNL FY 2005 Plans
Oct. 1, 2004 to Sept. 30, 2005

- **SPI-1: 30-m Installation, Carrollton, GA**
  - **SPI contract expires 9/30/2004. Final technical report due to DOE.**
  - **Disposition of system – Southwire will continue operation.**
- **SPI-2: Bixby Substation, AEP, Columbus, OH**
  - **1Q,FY2005 (Oct-Dec 2004)**
    - **Assemble and test full scale terminations for 3 kA 5-meter cable prototype.**
    - **Fault current and bend testing of 3-meter triaxial cable.**
    - **Finalize design of cryogenic system.**
  - **2Q,FY2005 (Jan-Mar 2005)**
    - **Bend test of 5-meter triaxial cable.**
    - **Splice test of 5-meter triaxial cable.**
    - **Mechanical verification test of cryostat/cable assembly.**
  - **3Q,FY2005 (Apr-Jun 2005)**
    - **Begin construction of triaxial cables for AEP project.**
    - **Begin civil/electrical work at Bixby site.**
  - **4Q,FY2005 (Jul-Sept 2005)**
    - **Ongoing system construction.**
    - **Complete construction of triaxial cable.**
  - **1Q, FY2006 (Oct-Dec 2005)**
    - **Begin on-site installation of equipment.**

Risk mitigation measures: HTS Cable

- **Risk mitigation strategy**
  - **Address risks by incremental R&D steps on models and test cables:**
    - **material tests on small scale samples (solid and tape dielectrics, HTS tapes, etc.) and on scaled model components (model cables and terminations for HV testing)**
    - **System tests on full radial scale, short-length components (1-5 m HTS cables, full-scale terminations at ORNL). Demonstrate reliable performance for moderate periods (days) and test to IEEE requirements (ac withstand, BIL, PD, fault currents)**
    - **System tests on full radial scale, moderate-length components (30-m HTS cables at Southwire). Demonstrate reliable performance for long periods (years). Periodically measure the change if any in HTS tape critical currents**
    - **Multi-year utility demonstrations with cables of length 100's of meters**
  - **Design:**
    - **Tough, comprehensive design reviews at the conceptual and final design points with participation from experts not working directly on the HTS cable project**
    - **Conducted SPI readiness review of AEP project in February 2004. Several issues identified and are being resolved.**
      - **Overcurrent fault protection**
      - **Cryostat vacuum**
      - **Cable Pulling**
    - **Perform Failure Mode and Effects Analysis (FMEA) on key sub-systems such as terminations, cryogenics and controls**

Risk mitigation measures: HTS Cable

- **Risk mitigation strategy**
  - **Assembly:**
    - **Do stringent 300 K leak testing on individual components to minimize global leak rate while cold**
    - **Extreme care in assembly so as not to introduce shorts or continuous current loops**
    - **Cleanliness, material control to reduce out-gassing**
  - **Testing:**
    - **Develop test plans up-front to ensure sufficient data for successful demonstration and for relevant standards development.**
    - **Proceed from lower risk to higher risk testing.**
    - **Key sensors are interlocked for operator warning and then automatic actions for component protection and continuity of power.**

Research Integration - Partnerships

- **Partners with expertise and funding.**
  - **Project is being conducted as a DOE SPI with equal cost sharing by Southwire and DOE. Southwire expertise includes:**
    - **Wire and cable manufacturing,**
    - **Established utility customer base,**
    - **Design and installation of turn-key systems for utilities,**
    - **Design and construction of copper rod mills world-wide,**
    - **Design and construction of manufacturing plants,**

    and now:
    - **Design, installation & operation of superconducting cables for utility customers.**
- **FY 2004 progress is evidence of well functioning team.**
  - **Triax cable research conducted jointly with Southwire/*nkt* at ORNL.**
  - **Multiple short, 1- to 3-m cables fabricated by Southwire tested at ORNL and *nkt*.**
  - **30-m cable operation and testing at Southwire**

Research Integration - Partnerships

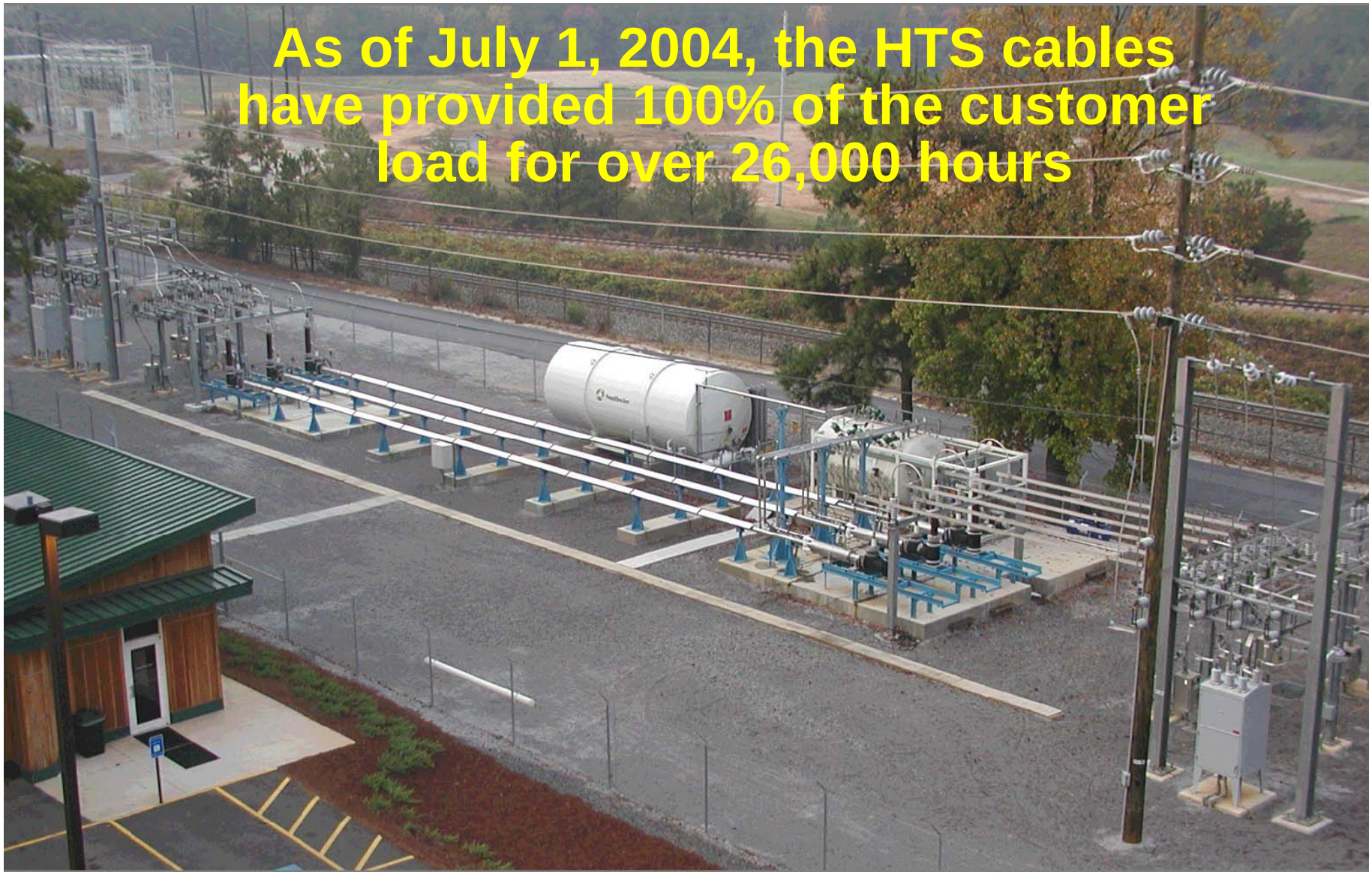
- **Cold dielectric design developed by Southwire (successful 30-m demo)**
- **Warm dielectric design developed by *nktc* (successful 30-m demonstration in Copenhagen, Denmark)**
- **Both designs available to Ultera**
- **Ultera and ORNL exchange technical information and data regularly**
  - **Teleconferences & Videoconferences**
  - **Interactive web conferencing**
  - **personnel exchanges**
  - **site visits and technical meetings**

Research Integration - Expertise and Facilities

- **Efficient use of equipment and personnel between ORNL/Ultera.**
  - **Assembly of 30-m cables has involved a team of ORNL, Southwire and subcontracted technicians.**
  - **Shared use of SW ac power supply, ORNL dc power supply, SW PD detector, fault current testing to over 56 kA in Denmark.**
- **Technical capability is being established in industry by subcontracting for subsystems and components.**
  - **Cryogenic system partner has been identified within U.S. industry (Praxair).**
  - **Components for terminations are being manufactured by U.S. industry resulting from competitive request for quotations.**
  - **Several key consultants have provided technical expertise and analysis.**

Research Integration – Publications and Outreach

- **Presentations and publications during the year**
  - **Four papers were presented at the Cryogenic Engineering Conference in September 2003 and were published in the, *Advances in Cryogenic Engineering, Vol. 49, 2004*.**
  - **Four technical papers will be presented at the 2004 ASC and submitted to *IEEE Transactions on Applied Superconductivity, 2005***
  - **One paper was presented at the 2003 Conference on Electrical Insulation and Dielectric Phenomena (CEIDP), in Albuquerque, New Mexico and was published in the proceedings.**
- **Web Sites**
  - **ORNL Superconductivity Web Site includes Annual Reports, Peer Review presentations and other project information**
    - **www.ornl.gov/HTSC/htsc.html**
  - **Southwire and Ultera Web Sites includes press releases and project information**
    - **www.mysouthwire.com, www.ultera.net**
- **ORNL participated in HTS outreach meetings with Energetics in Pennsylvania, Ohio, and New York**


As of July 1, 2004, the HTS cables have provided 100% of the customer load for over 26,000 hours