Organization:	**Oak Ridge National Laboratory**
Project Title:	**High-Temperature Superconducting Power Cable**
Presenters:	**David Lindsay (Southwire Company) and Michael Gouge (ORNL)**
FY 2002 Funding:	**$1.4 million (DOE to ORNL)**

Project Purpose and FY 2002 Objectives: Southwire Company and ORNL have jointly developed, built and demonstrated a series of cold-dielectric, high-temperature superconducting (HTS) power cables for this Superconductivity Partnership Initiative (SPI) project. The 30-m cable at Southwire's wire manufacturing complex in Carrollton, GA, continues to run, accumulating over 15,000 hours at full load to date and running unattended over the last 12 months. This cable is rated at 12.4-kV, 1,250-A, 3-phase, 60-Hz, and 27-MVA. The cable was placed into full service in April 2000 for an extended testing period under industrial conditions, highlighting Southwire's expertise in HTS cables and field testing this viable technology for the electric utility industry. In FY 2002, ORNL has worked with Southwire to research and improve the overall design and capabilities of the HTS cable system including:

- Completion of bend testing of a 5-m HTS cable with a flexible vacuum cryostat,
- Design, construction, initial testing and analysis of an innovative, 5-m tri-axial HTS cable including 3-phase terminations,
- Continued development of the pressurized termination concept,
- Continued development and testing of cryogenic dielectric materials,
- Cable aging studies,
- Continued research improving cryogenic system performance with industry and NASA,
- Initial design of cable subsystems for a long-length cable installation at Columbus, OH, in partnership with Southwire Company and American Electric Power (AEP).

FY 2002 Performance and FY 2003 Plans: Bend testing in the flexible cryostat was successfully completed for a 5-m cable; cable performance was maintained at bend angles of 0, 30, 60 and 90 degrees. The cable successfully passed the 110 kV BIL test at the 90-degree bend position. The design of the 5-m tri-axial cable and associated 3-phase terminations was completed in the 2nd quarter of the fiscal year. The 3-phase cable was manufactured by Southwire and delivered to ORNL in late May 2002. Final assembly of the terminations is in progress and initial cooldown and electrical dc/ac testing is scheduled for the last quarter of FY 2002. The component R&D completed for the tri-axial cable terminations, especially in the dielectric and heat transfer areas, will directly benefit the pressurized termination concept. R&D on aging of model HTS cables immersed in liquid nitrogen is continuing with an emphasis on correlating the aging with partial discharge signals. The Southwire team is working closely with national laboratory staff conducting the Cryogenics Assessment Study to ensure cable cryogenic issues are addressed in this planned FY 2003 initiative; they are also working on cryostat performance and reliability issues with international vendors and via a collaboration with NASA-Kennedy Space Center (NASA-KSC).

Plans for FY 2003:

1. Complete electrical testing of the 5-m tri-axial, 3-phase cable at ORNL,
2. Design (in FY-2002), fabricate and install (in FY-2003) a 30-m tri-axial, 3-phase cable system at Southwire Company's HTS demo site,
3. Test model cables and terminations to higher ac voltages (up to 66 kV in FY 2003),
4. Complete design of the long length cable demo at AEP Columbus and begin long lead procurements.

FY 2002 Results: Significant progress has been made towards the project objectives during the year:

30-m HTS Cable. In April 2000, the cable was placed into extended service and has logged over 15,000 hours of full power operation since that time. The performance of the superconductor was tested in April 2001 and there has been no measurable change in the critical current of the superconductor providing further credence to the viability of this promising technology. There have been several cable outages due to the cryogenic system and this experience is being used in specifying technical requirements for the SPI project with AEP.

5-m Test Cables and Improved Terminations. A 5-m-long superconducting splice cable was constructed and successfully tested at the ORNL/Southwire Cable Test Facility located at ORNL. An improved pressurized termination (T2) design with a lower heat loss and higher impulse breakdown strength was tested. The 5-m cable enclosed in a flexible cryostat was successfully tested at bend angles from 0 to 90 degrees (the bend radius was 1.2 m). Tests included dc V-I, operation at rated ac voltage and current, ac withstand and impulse (BIL).

Cryogenic Dielectric Aging Tests. Experiments to assess the expected life of the cable dielectric system are in progress. When a high-voltage stress, V, is applied to a cable, the time-to-breakdown, t, is generally related to the stress by the power law relation, $t\ V^{n}$ = constant, where *n* depends on the thickness and type of dielectric. A determination of *n* from aging experiments conducted at different voltage stresses is being used to determine the expected life of a cable at its operating stress. Partial discharge (PD), considered to be the aging mechanism of cryogenic cable dielectrics, is being studied using a state-of-the art partial discharge detection system which provides phase and amplitude resolved PD data. Development was conducted on potential materials for the dielectric insulation in the 3-phase terminations that require high breakdown strength and good thermal conductivity at 77 K and 300 K.

Tri-axial Cable. A tri-axial cable design that compacts all three phases into one concentrically wound cable offers efficient use of superconducting tape and the minimum cable cross-sectional area. A 1.5-m-long, tri-axial cable was built and tested in the summer of 2001. The critical current of this tri-axial cable was measured and the ac losses were quantified in a variety of configurations. A 5-m tri-axial cable with 3-phase terminations has been designed and is near the end of the assembly phase. Testing will be conducted in the 4th quarter of this fiscal year.

Research Integration: The design, assembly, and operation of the cable test facilities at ORNL and the 30-m demonstration cable at Southwire Company have been totally integrated efforts drawing upon scientists, engineers, and technicians from Southwire, ORNL, and private industry. Private consultants, cryogenic equipment manufacturing firms, and superconducting materials suppliers have been used extensively during the project. Major components of the 5-m and 30-m cable systems were procured via competitive subcontracts. An initial program has been completed with NASA-KSC to investigate improvements in the thermal insulation performance of flexible cryostats for HTS cables.

Four HTS cable technical papers were presented at the *Cryogenic Engineering Conference* in July 2001 and three technical papers are planned for the *Applied Superconductivity Conference* in August 2002. A technical paper on cable aging at cryogenic temperatures is planned for the Conference on Electrical Insulation and Dielectric Phenomena in October 2002. An invited paper on this cable SPI project was presented at the IEEE Winter Power Meeting in New York in January 2002. An invited review paper on HTS cables was given at the TMS Conference held in Seattle, Washington in February 2002. A paper on thermal management of HTS cables was presented at the Space Technology Applications International Forum in February 2002. A paper on HTS cables was presented at a DARPA workshop on superconducting devices coupled with cryogenically-cooled power electronics held in January 2002. ORNL supported a technical assessment by Anteon Corporation (for ONR) of HTS cables on all-electric ships.