Project Title:	**Applied R&D of 1st and 2nd Generation HTS Conductors**
Organization(s):	**Oak Ridge National Laboratory**
Presenters:	M.J. Gouge (ORNL)
FY 2004 Funding:	$150 K

Project Purpose and FY 2004 Objectives: The purpose of this R&D project is to investigate the performance of prototype HTS conductors with a goal of design optimization for a broad range of practical ac and dc applications. For HTS transmission cables and other T&D devices, this involves examining the performance of single tapes and prototype cables with respect to AC loss and quench and stability when applying short-circuit fault currents of different magnitude and duration. Emphasis in 2004 was on over-current testing of HTS tapes with various stabilizer configurations, completion of HTS tape burn-out experiments, ac loss characterization of 2nd generation HTS tapes and the impact of magnetic substrate materials on the inductance of 2nd generation HTS cables.

FY 2004 Performance: From the 2003 peer review the following plans were projected for FY 2004:

- Impact of various YBCO conductor substrates and stabilization layers on ac losses and over-current tolerance will be studied. Status: Over-current and burn-out tests were conducted on BSCCO and YBCO tapes with various stabilizers and bare and insulated surfaces. AC losses were measured in 4- and 10-wide YBCO tables with different metal substrates.
- Normal zone propagation and stability margins will be measured in a series of copper-stabilized, YBCO coated conductors with different copper thicknesses and joining techniques. Status: not done due to R&D equipment in use by a higher priority SPI project.
- A 1-Tesla HTS coil will be made with YBCO conductor and tested to determine operating envelope and stability margins. Status: deferred to FY 2005 due to program funding reductions in FY 2004.
- Plan to make a YBCO cable with ~4-mm wide 2G tape. Status: not done due to higher priority, prerequisite work on impact of ferromagnetic substrates on 2G cable inductance and ac losses.

FY 2005 Plans: Normal zone propagation and stability margins will be measured in a series of copper-stabilized, YBCO coated conductors with different copper thicknesses and joining techniques. A 1-2-m-long 2G power cable will be made from 4-mm-wide, stabilized YBCO tapes. A 1-Tesla HTS coil will be made from YBCO conductor and tested at 30-80 K to determine the operating envelope as a function of (I, B, T), stability margins and quench propagation characteristics.

FY 2004 Results: A series of over-current experiments were performed with BSCCO and YBCO tapes. The 20-cm-long HTS tapes were covered with layers of Cryoflex™ dielectric tapes (thickness from ~0.1-1 mm) and bath-cooled in liquid nitrogen. Over-currents were supplied by pulsing a 3-kA, 30-V dc power supply. Electromechanical and thermal limitation of over-current pulses were measured on BSCCO and YBCO tapes. With pulse lengths as short as 35 ms, it is found that the BSCCO and YBCO tape made by AMSC can be pulsed to at least 1 to 1.2 kA range without being damaged electromechanically. Longer pulses at moderate over-currents indicated that both HTS tapes can be heated above room temperature (300 K) range without suffering from degradation. However, severely degraded HTS or burn-out of the tapes were observed when the pulse duration was further lengthened by as short as 10 ms which produced peak temperatures significantly above room temperature. The heating of the tapes accelerates as the temperature and the resistivity of the tape gets higher. Thus, a prudent design peak temperature of the HTS tape for short-circuit fault over-current could be 200 K or lower. When an additional Cu strip of about the same dimension was added to the HTS tape both the over-current magnitude and duration limitations were found to be about doubled. This is apparently due to the shunting function and the added heat capacity of the Cu strip. On the other hand, for ac applications one should be careful in adding Cu to the HTS tape, as the additional ac loss could be excessive. Thermal analysis of the heat absorption during the over-current pulse and the cooldown after the pulse indicates that the heat dissipation from the HTS conductor to its surroundings via the Cryoflex™ insulation in the simulated cable construction is a slow diffusion process. The time constant is on the order of 1-2 s during the pulse and 8-15 s after the pulse. Thus, there may not be vapor formation in the liquid nitrogen even if the HTS is heated to 150-200 K range during the over-current pulse. In a related experiment, burn-out measurements were performed on 1st and 2nd generation HTS wires in a liquid nitrogen bath to test their stability; dc heating pulses of 1 minute duration were applied. Tests were performed on bare wires and with up to ten layers of Cryoflex™. These tests were conducted by applying current above the critical current and holding it constant for up to one minute. If during this period of time the voltage remained constant, the tape was considered stable under that operating condition. At some applied current, the surface cooling of the tape by the liquid nitrogen bath was not sufficient to balance the heat generation at the conductor, which results in a voltage rise and an unstable condition is reached. The measurements showed that while a single layer can have a significant effect on the thermal stability of both 1st and 2nd generation wires, additional insulating layers have little effect on stability. Simulations performed on 1st generation wire, using the flux flow method to model the current transition within the conductor, resulted in theoretical burn-out measurements that coincided with experimental results. Electrical measurement of ac transport losses of 10-mm and 4-mm-wide YBCO on NiCrW substrates (with a nominal I_c of 100 A per cm width) found that the total ac loss scales inversely with the square of the total conductor critical current. When the contribution of the ferromagnetic losses of the substrate are considered, the influence of the NiCrW substrate is not as significant as that seen in YBCO samples with Ni-5at%W substrates. The measured loss was compared to ac loss models. From the testing of the 1.25-m copper-laminated YBCO cable, the impact of NiW substrates on cable ac losses and inductance was examined through the construction of a pair of prototype cables made from 4.8-mm-wide stainless-steel BSCCO and with/without 4.8-mm-wide NiW substrates. Finite element modeling and experimental measurements will be compared. Modeling shows that the cable inductance increases by 10% at low currents <1 kA and approaches a lower asymptotic limit as the current approaches operating values >3 kA.

Research Integration: There is also a close interaction with AMSC and SuperPower staff working on 2nd generation conductor under CRADAs with ORNL. Tapes with different substrates and stabilizers as well as support components like low temperature solder are provided by CRADA partners. SPI CRADA partners like Southwire are leveraged to wind prototype cables. Results from the HTS burn-out experiments with BSCCO and YBCO tapes were presented last fall at the 2003 Cryogenic Engineering Conference and will be published in 2004. Papers on the HTS tape over-current testing, magnetic substrate impact on the inductance of YBCO cables and substrate material impact on YBCO conductor ac losses are in preparation to be presented at the 2004 Applied Superconductivity Conference. Results are also communicated to peers working in the DOE SPI projects so conductor performance can be optimized for the particular constraints of a given application.