<u>Summary of past SMD projects and contributions to the development of superconducting magnet technology</u>.

BNL's development of superconducting magnets for use in accelerators began about 40 years ago. The first conference on this topic was held at BNL in 1968. Among the early accomplishments were the construction of a NbTi dipole that was used in the High Energy Extracted Beam at the AGS and a R&D quadrupole wound with Nb_3Sn tape. Much of this R&D was carried out by William Sampson.

This and other work formed the basis for BNL's proposal in the 1970's to build a proton-proton collider, Isabelle, based on magnets made with a wide NbTi cable. To achieve the desired width, the cable was braided. During the R&D program, the performance goals of the magnets were increased in order to double the machine energy. When it became uncertain whether the magnets could reach the new goals, BNL started an alternate magnet R&D program using a narrower cable that was not braided. The cable, initially developed at Rutherford Lab, was then in use at Fermilab. The new R&D group, under Robert Palmer, developed a magnet design based on cable made using Fermilab's specifications. These magnets met the Isabelle performance goals. Nonetheless, on the advice of a HEPAP subpanel, the DOE halted construction of the accelerator in 1983 in favor of the construction of the SSC.

Because of the success of the cable magnet, BNL was included with Fermilab and Berkeley in the development of magnets for the SSC. For the better part of ten years, about 90% of the magnet R&D effort was focused on SSC dipoles. By 1993, when the SSC was canceled, BNL and Fermilab had produced ten dipoles at each lab that met specifications for the SSC main ring. Both laboratories had developed strong capabilities in the areas necessary for success, including magnet design, superconductor qualification, magnetic field measurement, and the full range of necessary engineering disciplines.

Following the cancellation of the proton-proton collider, BNL focused on the design of a heavy ion collider, RHIC. BNL was able to develop a collider design that met the physics goals of the heavy ion community (100 GeV/amu for fully stripped gold) and used the infrastructure completed for the proton-proton collider (tunnel and helium refrigerator). The Magnet Division developed prototypes of the principal magnets as a "background" activity during the years of SSC R&D.

By 1993, BNL had handed off the magnets to the SSC staff, approval for RHIC had been obtained, and all efforts were directed to R&D for RHIC, which yielded cost-effective designs for the moderate field magnets that were needed. The Magnet Division supplied about 2,000 magnet elements for RHIC, many from industrial vendors, the remainder made at BNL. Magnet installation in RHIC was completed in 1999. In the six years of RHIC operations, only three magnets have been removed for repair. One was repaired in place. About 180 people were on the Magnet Division staff during peak production.

The Magnet Division's capabilities for magnetic field measurement were built up substantially during the SSC program and augmented as needed for measurements of the series production of magnets for RHIC and SNS. The measurements are used for qualifying magnets for accelerator use. When coupled with magnet design codes, the measurements have also been quite useful in identifying magnet construction errors. Most measurements are carried out with rotating coils, which provide accurate measurements of field harmonics in constant and slowly varying magnetic fields and field angles with respect to gravity. For RHIC, the Division developed two novel methods for relating magnetic centers to external fiducials.

In 1997, the Magnet Division began work on 20 dipoles for the insertion regions of the LHC, made as part of the U.S. contribution to the construction of the collider. Four versions (corresponding to each of four positions in the lattice) were developed, based on the RHIC arc dipole. This program was completed in September 2005. All of these magnets are now at CERN.

In parallel with the work for the LHC, the Magnet Division improved a CAD/CAM automatic winding machine first developed for the helical dipoles to the point where magnets with the complexity and precision needed for a collider's final focus region could be made. This "direct wind" process was first used to produce six magnets in cryostats for an upgrade of the HERA e-p collider at DESY. The magnets and have operated successfully since2002. More recently, the Magnet Division has delivered two magnets to IHEP in Beijing for an upgrade of the BEPC electron-positron collider there. These magnets are now undergoing acceptance testing. Currently, the Magnet Division is working on R&D for the wide-angle final focus magnets for the International Linear Collider's Beam Delivery System. In addition to the hardware, an important suite of skills has been developed for the "direct wind" projects, ranging from accelerator physics to the use of ultrasound for setting the epoxy used to hold the conductor precisely.

The Magnet Division has carried on a conductor development program from its beginning. The Division tests material supplied by vendors and keeps them informed of the performance needs for materials used in accelerator magnets. The Division works closely with staff in the BNL Materials Science Department, which performs R&D on the materials. The Division's program now focuses on Nb_3Sn and high temperature superconductors (HTS).

The development work on Nb_3Sn has led to the construction of magnets using cable before reaction (when it is ductile) and after reaction (when it is brittle). Magnets wound with unreacted Nb_3Sn are being made as part of BNL's collaboration with Fermilab, LBNL, and SLAC in the LHC Accelerator Research Program (LARP). The goal of the magnet work in LARP is to qualify Nb_3Sn magnets for use in an upgrade of the LHC by demonstrating successful operation of a 4 m quadrupole in 2009. Several years of work on magnets wound with reacted Nb_3Sn came to fruition this year with the successful test of a 10 T common coil dipole.

The Magnet Division is working with HTS in both tape and cable forms. HTS tape is being used for R&D on the "fragmentation region" quadrupole that would be located immediately downstream of the target at the planned Rare Isotope Accelerator (RIA). A short model mirror quadrupole has been successfully tested. The Magnet Division is working with the BNL NSLS to design HTS tape coils that would be part of NSLS II. HTS cable is being used to wind demonstration coils.

BNL's expertise in superconductors was a key to the development of a fast-pulsed model dipole. The magnet was made to demonstrate the viability of such magnets, which are part of GSI's proposal for a new facility (FAIR). The dipole was made using RHIC cable and other components, modified to reduce cyclic energy losses. The successful test included measurements of both energy loss and field quality using instrumentation developed to make measurements in fast-pulsed magnets. CERN is also considering the use of fast-pulsed for an upgrade.