

# THE NATIONAL HIGH MAGNETIC FIELD LABORATORY: A NATIONAL RESOURCE IN SUPPORT OF BIO-MEDICAL SCIENCE AND TECHNOLOGY

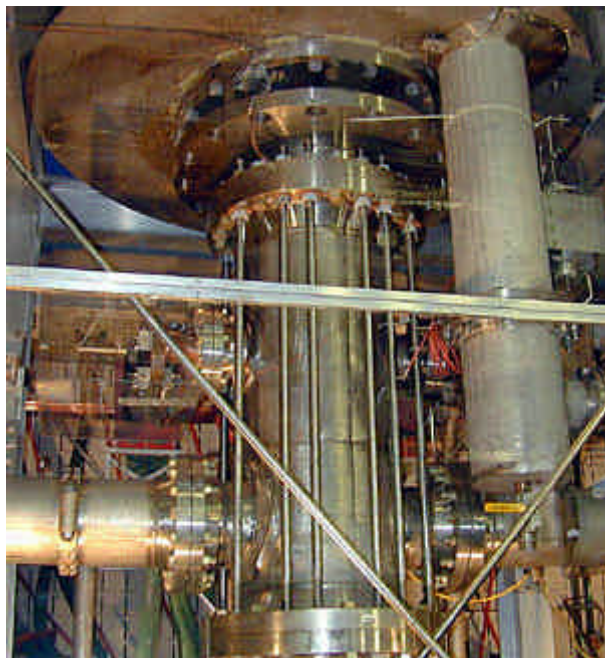
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**INTRODUCTION:** The National High Magnetic Field Laboratory (NHMFL) is an international user facility supported by the United States National Science Foundation and the State of Florida. The laboratory is operated by Florida State University, the University of Florida, and Los Alamos National Laboratory and charged to develop and maintain facilities in support of magnet-related research that are open to all qualified scientists and engineers through a peer-review proposal process. The laboratory has developed and supports unique facilities responding to the scientific challenges in biology, biomedicine, chemistry, engineering, geochemistry, materials science, and physics. In addition to supporting magnet-related science, the NHMFL has established unique capabilities in nearly all areas of magnet science and technology that respond to the wide and varied challenges from the diverse communities served by the laboratory. There are only a limited number of facilities similar to the NHMFL worldwide and the NHMFL is the only magnet laboratory in the western hemisphere. The NHMFL is the largest and highest powered magnet laboratory in the world and provides access to the highest magnetic field in almost all magnet areas including continuous powered, resistive magnets; pulsed magnets; and specialized superconducting magnets. Unique magnets are only one of the components required to drive new science and technology at high magnetic fields. The faculty and staff of the NHMFL in collaboration with users from other institutions have been committed to the development of new approaches to measurement science. These efforts have led to high field magnetometry with sensitivities approaching and often exceeding that available with commercial magnetometers, e.g., superconducting quantum interference devices, and novel high pressure cells for high pressure research that are compatible with the high magnetic fields and the small volumes often associated with reaching the highest magnetic fields.

In response to the challenges in biology, biomedicine, chemistry, and environmental sciences, the laboratory has established magnetic resonance programs in electron magnetic resonance (EMR), nuclear magnetic resonance (NMR), magnetic resonance imaging (MRI) and in Ion Cyclotron Resonance Mass Spectroscopy (ICRMS). The NHMFL is the only laboratory in the world that supports such a diverse approach to magnetic resonance and the complementary and synergistic nature of these techniques has helped to drive new research areas. This paper will provide an overview of the NHMFL current capabilities followed by a more detail discussion of some of the areas where the NHMFL is going to respond more effectively to new scientific challenges that may be of interest in biological, medical, chemical and environmental sciences areas. A much fuller summary of the research accomplishments of the users of this national facility is presented in the *NHMFL Annual Research Review* which is available on the NHMFL web site ([www.magnet.fsu.edu](http://www.magnet.fsu.edu)). In addition, the NHMFL publishes the *NHMFL Annual Programs Report* that is also available on the web and provides an overview of the programs, user activities, and outreach programs for the NHMFL.

**NHMFL-OVERVIEW:** The main facilities of the NHMFL are located in Tallahassee, Florida and are housed in a 330,000 sq. ft complex dedicated to magnet-related research and technology. Additional facilities are located at two other sites including the High B/T Facilities and Advanced Magnetic Resonance Imaging and Spectroscopy (AMRIS) facilities located at the University of Florida in Gainesville, Florida, and the NHMFL Pulsed Field Facility located at Los Alamos National Laboratory, Los Alamos, New Mexico. The NHMFL in Tallahassee provides user access to continuous fields in resistive ( $B \leq 33$  T), hybrid ( $B \leq 45$  T) and superconducting ( $B \leq 20$  T) magnets. At the center of the continuous field facilities is a very low ripple, 40 MW DC power supply and a high pressure, high



*Fig. 1: 45 T Hybrid magnet at the NHMFL.*

volume cooling system. Shown in Fig. 1 is the 45 T Hybrid. This magnet provides user access to field up to 45 T in a 32 mm warm bore and is composed of a superconducting magnetic capable of providing 14 T with a powered resistive magnet at the center providing the balance of the field. This is the highest continuous field system in the world. In addition to the Hybrid, the NHMFL also operates several resistive magnets configured to meet a variety of needs including a 25 T, 52 mm warm bore magnet with a homogeneity approaching 10 ppm. In the near future this magnet's homogeneity will be improved with a target of  $\sim 1$  ppm. This coupled with a NMR field lock on the DC power and compensation coils will permit research with both temporal and spatial homogeneities approaching and, in some cases, exceeding 1 ppm. Such a system opens new opportunities unique in the world for high field NMR at and beyond 1 GHz. The NHMFL is currently studying a new design for the next generation hybrid, which will place the superconducting outsert and resistive insert in series. This system may offer much greater stability and hopefully will open new research

opportunities in the 30 T to 35 T range for high field NMR with temporal and spatial homogeneities exceeding 1 ppm.

At the NHMFL Pulsed Magnet Facilities located at Los Alamos National Laboratory, the laboratory provides higher magnetic fields approaching 75 T for short durations, i.e., for a few 10's milliseconds. Within the next few years, the NHMFL hopes to offer short-pulsed fields approaching 100 T. Under redevelopment is a new powered magnet that can provide controlled pulses up to 60 T with a variety of pulse shapes. The controlled waveform for this pulsed magnet includes a nearly constant 60 T for 100 msec. and represents an absolutely unique capacity in the world. The High B/T Facility at the University of Florida combines low temperatures, i.e.,  $\sim$  few 100  $\mu$ K, and high magnetic fields,  $B \leq 16$  T. The upper limit on the magnetic field will soon be increased to  $\sim 20$  T with the procurement of a new superconducting magnet for this facility.

In addition to the powered and pulsed magnets, the NHMFL provides a variety of specialty systems to support magnetic resonance including EMR, ICRMS, NMR and MRI. Because of the demanding requirements for homogeneity and stability for most of these systems, superconducting technology is exclusively used here. For all the magnetic resonance techniques, increased magnetic field increases resolution and signal to noise with the details of the resonance technique dictating the level of improvement.

Under development testing at the NHMFL is a 21.1 T (900 MHz), high-resolution, NMR magnet, i.e., a homogeneity  $\sim 1$  ppb and a warm bore of 100 mm. This magnet is shown in Fig. 2 as it is prepared to be installed in a test dewar for high field testing prior to installation in its final cryostat and commissioning for users. This system will be one of the world's highest field, largest bore, high-resolution NMR systems.

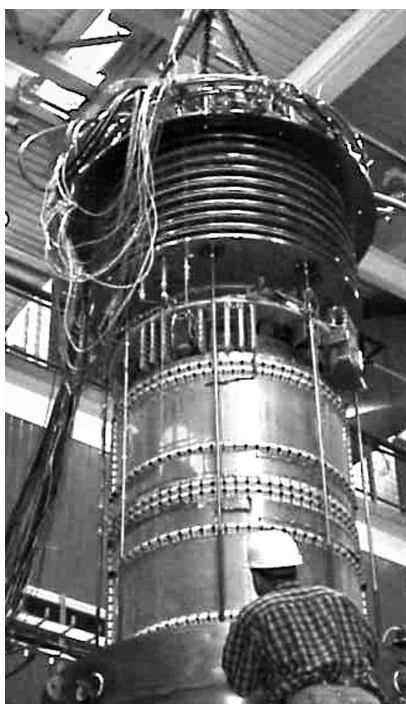


Fig. 2: NHMFL 900 MHz magnet system.

In addition to the high field NMR facilities, the NHMFL in collaboration with the McKnight Brain Institute at the University of Florida also provides access to a 12 T, 400 mm warm bore, small animal imaging system. In mass spectroscopy, the NHMFL offers the highest precision mass spectrometers in the world. The unique ICRMS facilities will soon be augmented by the highest field ICRMS system in the world, i.e., a 15 T, 100 mm bore magnet that is under development. The EMR facilities offer unique capabilities including a Bruker W-band and X-band spectrometer with many unique features along with a high field, time resolved, EMR spectrometer permitting time resolved EMR spectroscopy with solution approaching nanoseconds. Most of these facilities have been developed specifically to open new research opportunities in the biological and chemical sciences.

**BIOLOGY AND CHEMISTRY AT HIGH MAGNETIC FIELDS:** High magnetic fields enhance all the magnetic resonance techniques but nowhere is the drive to high magnetic field stronger than in NMR. Here the quest for high fields is driven by improved resolution and reductions in signal to noise. Much of this attention is focused on structural biology where the commercial sector is aggressively

pushing systems to the 900 MHz range. It is anticipated that soon this drive may even extend to efforts to produce a 1 GHz high resolution NMR system. New probe development focused at cryo- and superconducting probes will also have a significant impact on improved sensitivity for the future. Much of this effort will continue to be driven by structural biology and drug development.

ICRMS offers unparalleled precision along with the capability to analyze unknown mixtures. Diesel fuel is a very good example of an unknown mixture where there is a keen interest in having more detailed knowledge about those components that negatively impact the environment, e.g., sulfur bearing compounds. Show in Fig. 3 is a trace of abundance vs. mass to charge ratio for a typical diesel fuel. Capitalizing on the two key aspects of ICRMS, researchers can examine very complex unknown mixtures and because of the extremely high resolutions of this approach, a unique chemical identification is often possible. It is quite clear that these two features of ICRMS can be extended to a

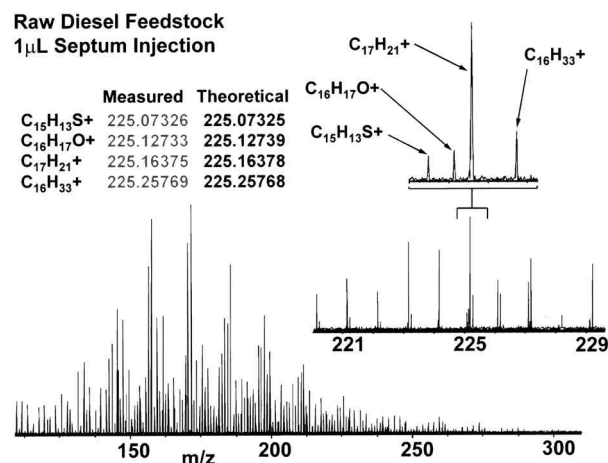


Fig. 3: ICRMS analysis of diesel fuel.

host of interesting problems in both the biological and chemical sciences, including environmental analysis, forensics, and protein sequencing.

The background information presented above is only a very brief glimpse into the vast impact that high magnetic fields can have on the biological and chemical sciences. There are other areas where magnetic fields are making an impact, e.g., processing and growth of biological systems which take advantage of the ability to use high magnetic fields to levitate diamagnetic materials and also to

provide a preferred direction for growth due to the anisotropy in the magnetic susceptibility. The impact of higher magnetic fields on MRI, e.g., increased spatial resolution with increase fields, and the extension of MRI to functional brain imaging and non-invasive chemical diagnosis has not even been mentioned. The presentation will explore these areas along with an overview of the NHMFL capabilities and examples of applications of high magnetic fields to various scientific challenges in the biological and chemical sciences.