CHAPTER 3. USER FACILITIES

The research activities described in the previous chapter of this annual report are supported by the extensive facilities of the National High Magnetic Field Laboratory. Each of the consortium partners—Florida State University (FSU), the University of Florida (UF), and Los Alamos National Laboratory (LANL)—offers outstanding resources for users. Together, the three sites offer members of the worldwide science and engineering communities unprecedented opportunities to explore science at the extremes of magnetic field, pressure, and temperature.

The portion of the laboratory located at FSU in Tallahassee includes superconducting, resistive, hybrid, and specialty magnets, along with the Magnet Science and Technology Group, the Center for Interdisciplinary Magnetic Resonance (CIMAR), the Research Program, and the administrative headquarters of the NHMFL. The NHMFL Pulsed Field Facility is located at LANL in New Mexico; and the High B/T (magnetic field/temperature) Facility and the magnetic resonance imaging/spectroscopy (MRI/S) assets of the laboratory are located at UF in Gainesville. The close proximity of visiting users to the distinguished NHMFL researchers and affiliated faculty at the three institutions sets the stage for very productive collaborations and cross-disciplinary scientific exchanges.

GENERAL PURPOSE DC FIELD FACILITIES—TALLAHASSEE

The general purpose DC magnetic field facility at the NHMFL's headquarters in Tallahassee exists to provide to the user community the strongest, quietest, steady and slowly varying magnetic fields in the world coupled with state of the art instrumentation and experimental expertise.

Several major systems provide a broad magnetic field-temperature-pressure-angle "parameter space" to researchers. Two dilution refrigerators offer 40 mK sample temperatures in fields to 33 T. Diamond anvil high pressure cells permit optical and transport measurements to 14 GPa at temperatures from 40 mK to 300 K. Magneto-optical measurements can cover wavelengths from the near ultraviolet to far infrared. Non-optical measurements of transport properties can be done at DC through audio frequency AC to millimeter and microwave frequencies. Magnetic properties of materials can be measured optically, by AC susceptibility, cantilever force and torque, and vibrating sample magnetometry. Nuclear magnetic resonance and electron magnetic resonance (both spin and cyclotron resonance) provide unique insights into materials, including many of interest to biologists and chemists. Sample rotators allow researchers to vary not only the amplitude of the applied magnetic field but also its angle with respect to the sample.

Table 1. Magnet systems available to users at the Continuous Field Facility, Tallahassee, as of January, 2001, and the kinds of experiments that can be done in them.

SUPERCONDUCTING MAGNETS		
FIELD (T), BORE (mm)	TEMPERATURE	SUPPORTED RESEARCH
18/20, 52	20 mK - 2 K	Magneto-optics–ultra-violet through far infrared, magnetization, specific heat, transport, high pressure, dependence of optical and transport properties on field orientation, etc.
17.5/19.5, 52	0.4 - 300 K	
15, 45	10 mK - 1 K	
RESISTIVE and HYBRID MAGNETS		
FIELD (T), BORE (mm)	POWER (MW)	SUPPORTED RESEARCH
20, 195	20	Magneto-optics–ultra-violet through far infrared, magnetization, specific heat, transport, high pressure, low to medium resolution NMR, temperatures from 40 mK to 800 K, dependence of optical and transport properties on field orientation, etc.
24.5, 32[1]	15	
25, 52[1]	19	
27, 32 to 50[2]	15	
30, 32	20	
33, 32	30	
42, 32	27	

1 Higher homogeneity magnet.
2 32 mm bore tube supports a coil for modulating the magnetic field

NHMFL staff often help visitors develop new instruments for unique experiments not possible with the general purpose instrumentation that is kept on hand for everyone. Eight scientists and an engineer, whose specialties cover the kinds of measurements required for much of the science commonly done at the NHMFL, work directly with users. Other members of the NHMFL's scientific staff also support the user program by developing instrumentation and collaborating with visitors.

We continue to support remote collaborators with hardware and software that allow any member of a research group to connect directly to the experimental areas at all three NHMFL sites. Remote collaborators can view data and modify experimental strategies "live" during the magnet runs.

> Further information on the facilities and services available to users of the continuous field, general purpose magnets can be obtained by contacting Bruce Brandt at *brandt@nhmfl.gov* or 850-644-4068 or by viewing *http://www.magnet.fsu.edu/users/facilities/dcfield/.*

PULSED FIELD FACILITY—LOS ALAMOS

The Pulsed Field Facility in Los Alamos is the pulsed magnet user facility of the NHMFL. Its mission is to establish magnet technologies and the experimental infrastructure to support in-house research and an international user program. To those ends, the facility offers a 20 T superconducting magnet, as well as a series of capacitor-bank-driven magnets: 50 T and 60 T short-pulse magnets (25 to 100 ms pulses) and a 40 T mid-pulse magnet (600 ms pulses). A 50 T mid-pulse magnet is under development to help mitigate the scientific impact of the loss in July 2000 of the 60 T Long-Pulse magnet.

The NHMFL–Los Alamos research staff and collaborators have developed a wide variety of experimental capabilities utilizing the short-pulse and long-pulse magnets, which are summarized in Table 2. Research proposals to utilize the facility should be submitted through the laboratory's web page *(http://www.lanl.gov/mst/nhmfl).* Magnet time is scheduled following successful review of submitted proposals. Most commonly, users visit for one to two weeks of magnet time, although longer visits and sabbatical stays are also welcome. Additional information on magnets, instrumentation, and personnel, as well as a Research Proposal Form may be obtained by contacting Alex H. Lacerda at *lacerda@lanl.gov* or 505-665-6504.

Table 2. Summary of scientific capabilities at NHMFL–Los Alamos.

FIELD, DURATION, BORE	SUPPORTED RESEARCH
Capacitor Bank Driven	Magneto-optics (IR through UV), magnetization, and magneto-transport from 350 mK to 300 K
40 T Mid-Pulse, 400 ms, 24 mm	
50 T Mid-Pulse, 400 ms, 15 mm	Dilution refrigerator is available with the 50 T, 24 mm
50 T Short-Pulse, 25 ms, 24 mm	Pressure from 10 kbar typical, up to100 kbar
60 T Short-Pulse, 25 ms, 15 mm	
Generator Driven:	
60 T Long-Pulse, 2000 msec, 32 mm	*magnet to return to service in early 2003*
Superconducting Magnet	Same as pulsed fields, plus thermal-expansion, specific
20 T magnet, 52 mm	heat, and 20 mK to 600 K temperatures.

USER FACILITIES

HIGH B/T FACILITY—GAINESVILLE

The High B/T Facility operated for the NHMFL at the University of Florida provides users with the capability for conducting experiments in high magnetic fields (up to 16.5 T) and at very low temperatures (down to 0.4 mK) simultaneously. Instrumentation for studies of magnetization, thermodynamic quantities, transport measurements, magnetic resonance and pressure is available. In addition, the facility is housed in an ultra-quiet environment with "tempest" quality electromagnetic shielding and vibration isolation of the experimental station to permit high sensitivity measurements.

Applications for the use of the facility follow the procedures as for all NHMFL facilities. The use is restricted to experiments that need the special low temperature and high field configurations available at the facility. Many of the experiments require special assemblies and direct interaction with personnel on site, as well as having need for long running times. Prospective users should contact the facility manager and resident research scientist, Dr. J.S. Xia (352-392-8871, *jsxia@phys.ufl.edu*), or the facility director, E. Dwight Adams (*adams@phys.ufl.edu*) well in advance.

CENTER FOR INTERDISCIPLINARY MAGNETIC RESONANCE (CIMAR)

The NHMFL's Center for Interdisciplinary Magnetic Resonance supports a broad range of research in the biological, chemical, and physical sciences, as well as cross-disciplinary programs in areas like environmental science. The techniques available to users include nuclear magnetic resonance (NMR), magnetic resonance imaging and spectroscopy (MRI/S), electron magnetic resonance (EMR), and Fourier transform ion cyclotron resonance mass spectrometry (ICR). Cross fertilization among the four fields is a unique feature of the Center that is facilitated by broadly based external and internal users programs.

NMR SPECTROSCOPY AND IMAGING PROGRAM

The NMR spectroscopy and imaging program has world class high magnetic fields for applications of NMR spectroscopy and imaging to chemistry, biology and material science. The unique capabilities and high field magnets at the NHMFL attract scientists from around the world to use the high field NMR

Table 3. NMR facilities in Tallahassee, as of January, 2001.

MAGNETIC RESONANCE SYSTEMS			
Frequency	**Field (T), Bore (mm)**	**Homogeneity**	**Supported Research**
1066 MHz+	25, 52	0.04 - 1 ppm	Solution NMR, structural biology, microcoils, triple resonance solution and solid state probes, including 19F capability, ultra-fast MAS, Double Rotation (DOR) spectroscopy, satellite transition MAS, PISEMA, stray field imaging, microimaging, velocimetry, GAMMA, hyperpolarized Xe-129 & He-3, RF technology development
830 MHz	19.6, 31	100 ppb	
720 MHz	16.9, 52	1 ppb	
600 MHz	14, 89	1 ppb	

\+ Under development

facility. In particular, unique user facilities in high speed magic angle spinning, double rotation (DOR) spectroscopy, stray field imaging using a 75 T/m gradient and microimaging are available. In addition unique spectroscopy above a proton frequency of 1 GHz is available both for solution and solid state NMR spectroscopy. Major application arenas in macromolecular structure determination, single cell microimaging and spectroscopy and in low gamma and quadrupole nuclei are developed. A major effort in developing RF technology is supported by the NHMFL.

NHMFL user facilities for high field magnetic resonance imaging and spectroscopy (MRI/S) are available in Gainesville. Table 4 shows the large array of instruments available. This large range of instruments offers high field NMR and MRI capabilities on a variety of biological systems ranging from biochemical solution studies, through imaging of single cells, isolated tissues and animal models, leading to human research studies. Extensive RF coil construction capabilities are available to outside users.

Table 4. MRI/S facilities at the University of Florida, as of January, 2001.

MAGNETIC RESONANCE IMAGING/SPECTROSCOPY SYSTEMS			
Frequency	**Field (T), Bore (mm)**	**Homogeneity**	**Measurements**
750 MHz	17.5, 89	1 ppb	Solution state NMR & MRI
600 MHz	14, 50	1 ppb	Solution state NMR & MRI
500 MHz	11.75, 50	1 ppb	Solution state NMR
500 MHz$^+$	11.7, 400	0.1 ppm	MRI & NMR of animals
200 MHz	4.7, 330	0.1 ppm	MRI & NMR of animals
125 MHz	3, 800	0.1 ppm	Whole body MRI & NMR

\+ Under development

The NHMFL has established strong ties with the UF Center for Structural Biology and the UF College of Medicine, and has consolidated its MRI efforts at the UF McKnight Brain Institute. For more information, see *http://www.ufbi.ufl.edu/*.

Fourier Transform Ion Cyclotron Resonance Mass Spectroscopy

During the past year the ICR program continued instrument and technique development as well as pursuing novel applications of FT-ICR mass spectrometry. These methods are made available to external users through the NSF National High-Field FT-ICR Mass Spectrometry Facility. The facility features directors for instrumentation, biological applications and environmental applications as well as a machinist, technician, and five rotating postdocs who are available to collaborate and/or assist with projects. This year, the facility added another FT-ICR mass spectrometrist to provide the first fee-for-service FT-ICR mass analysis available anywhere.

FT-ICR Magnets and Instrumentation

The **9.4 T, 220 mm bore system** continues to be the highest performance electrospray FT-ICR mass spectrometer in the world. It offers unrivaled mass resolving power ($m/\Delta m$ = 10,000,000 at mass 9,000 Da) and dynamic range (>10,000:1), as well as high mass range, mass accuracy, efficient tandem mass spectrometry (MS^n as high as MS^8), and long ion storage period.

A **7 T electrospray FT-ICR instrument** has been dedicated to high sensitivity biological analysis. HPLC and CE interfaces are available. Picomolar concentration detection limit has been demonstrated. Sample amounts as low as 300 amol loaded (in biological matrix) have been detected. The instrument is currently available for use.

9.4 and 7 T magnets have been installed. The 9.4 T magnet is currently used for ICR instrumentation development. The 7 T magnet will be optimized for volatile mixture analysis. Samples will be volatilized in a heated glass inlet system (at 200 to 300 °C) and ionized by an electron beam (0 to 100 eV, 0.1 to 10 μA). The ions will be collected in a linear multipole trap and injected into the FTICR cell. Mass resolving power ($m/\Delta m$) greater than 10^5 and mass accuracy within 1 ppm have been achieved routinely in a similar (lower field) instrument. Hundreds of components in a complex mixture (e.g., petroleum distillates) can thus be resolved and identified. This instrument should be available June 1, 2001.

Electron Magnetic Resonance Program

The continuing trend in the development of electron magnetic resonance spectroscopy toward higher field and frequency ranges is providing the advantages that can be gained from the increase in both these parameters for a broad variety of applications. The applications of high field/high frequency EMR can be roughly classified into two categories: The first one includes studies of highly concentrated spin systems, typical for material sciences. The second category of applications concerns mainly chemical, biochemical, and biological paramagnetic spin systems that are usually characterized by low spin concentrations. Low spin density systems require high spectrometer sensitivity. The high field, multifrequency spectrometers at the NHMFL were originally built for investigations of highly concentrated spin systems. The sensitivity of the spectrometers has recently been increased by orders of magnitude. Today the EMR users program spans biology, chemistry, and condensed matter physics, with an emphasis on physical chemistry and a clear trend toward more biological science.

There are two different regimes in the frequency domain for electron magnetic resonance spectroscopy, (a) from 1 to about 150 GHz, and (b) above 150 GHz. From 1 GHz up to about 150 GHz, the electromagnetic waves propagate in single-moded or over-moded waveguides, and one generally uses single mode cavities. Above 150 GHz, single mode cavities become less efficient and impracticable due to the extremely small size, and either a Fabry-Perot type cavity is used for small samples, or measurements are performed without cavity for larger samples. In EMR spectroscopy, increasing the frequency increases the absolute sensitivity in the case of single mode cavities, but as the sample size has to decrease at the same time, the concentration sensitivity is not significantly affected. Also it should be noted that pulsed techniques are only available up to 140 GHz, there are no pulse switches available for higher frequencies.

Very High Field EMR Spectrometers

The development of EMR spectrometers at the NHMFL has focused on very high field/very high frequency machines. All the instruments we develop are multifrequency. Presently there are five high field EMR spectrometers; the first three are based on a 17 T superconducting magnet, the fourth is a transient machine also with a superconducting magnet, the fifth one uses the 25 T resistive “Keck” magnet.

The first three spectrometers are built around a 17 T Teslatron magnet made by Oxford Instruments Inc. This magnet consists of a main 17 T coil with a +/- 0.1 T sweep coil.

1. **Low sensitivity CW spectrometer.** We use different sources in the 23 GHz to 3 THz range. The detector is either a Schottky diode or a "hot electron" InSb bolometer. This instrument is a direct transmission system and has very broad band capabilities. The performance specifications are:
   Sensitivity: 10^{12} spins/gauss second at room temperature.
   Averaging: up to about 100 spectra.
   Field calibration: g determination error: +/- 3.10^{-5}.
   Resolution: 1 to 10 ppm.
   Sample temperature: 1.6 to 300 K.
2. **High sensitivity CW quasi optical (QO) instrument.** The sources operate from 110 GHz up to 475 GHz for a g = 2 paramagnetic center. The system, optimized at 220 and 330 GHz, employs very low loss QO techniques; these techniques allow for phase information. The detector is an InSb mixer. The sensitivity of the QO machine is 10^{10} spins/gauss second at room temperature, all other specifications are identical to the specifications of the low sensitivity spectrometer.
3. **CW ENDOR spectrometer.** The high sensitivity QO machine is now equipped with a probe for CW Electron Nuclear Double Resonance. Concerning electron magnetic resonance, the machine operates at 220 and 330 GHz. For nuclear resonance, the RF is within the 0 to 1 GHZ range with 100 W power. The temperature of the sample is in the 4 to 300 K range.
4. **Transient EMR instrument.** The inherent time scale of an EMR experiment is inversely proportional to the measurement frequency. Thus faster measurements are possible at higher frequencies. In time-resolved EMR this enables the measurement of systems with very short lifetimes and/or fast relaxation rates. This prompted the construction of a new high field spectrometer with both fast detection as well as optical access for excitation of paramagnetic excited states and/or creation of paramagnetic reaction intermediates. The design of the spectrometer, which operates at 120, 240, and 360 GHz, combines quasi-optical techniques and a super-heterodyne detection scheme, based on Schottky diode mixers and has a 1 GHz detection bandwidth. It features both sub-nanosecond time-resolution and a high g-resolution. The room temperature sensitivity in CW-mode is of the order of 10^{11} spins/gauss second without cavity and $5x10^{8}$ spins/gauss second in a Fabry-Perot cavity. The maximum time resolution is 600 ps. The magnet is a superconducting magnet.
5. **25 T "Keck" magnet spectrometer** is built around the 25 T, high homogeneity magnet. The "Keck" magnet is perfectly poised for EMR—fast ramping to the magnetic field of interest, very convenient sweepability, homogeneity better than 10 ppm over a typical sample size (a few mm^3), and good field stability. It uses a far infrared laser for its source and an InSb "fast electron" bolometer detector with a magnetically extended response. The system performance specifications are:
   Frequency range: up to 700 GHz for a g=2 system.
   Sensitivity: 10^{13} spins/gauss second at room temperature.
   Field calibration: g determination error: +/- 3.10^{-5}.
   Resolution: better than 10 ppm.
   Sample temperature: 1.6 to 400 K.

GEOCHEMISTRY PROGRAM

The Geochemistry Program houses a mass spectrometry facility that includes a chemistry clean lab which approaches a Class 100 clean lab. This lab is used for the separation and purification of all elements that are analyzed by mass spectrometry. The facility has three mass spectrometers. The Lamont Isolab, a mass spectrometer with secondary ionization capability, is used mainly for difficult to ionize elements like Hf, Th and Hg. The Lamont Isolab, outfitted with a Daly detection system and 5 faraday cups, has TIMS, SIMS capability. The Geochemistry facility also includes a fully automated 9 collector Finnegan mass spectrometer equipped with a RPQ-system for increased abundance sensitivity and a 13 sample turret. This second mass spectrometer is used for Sr, Nd, Pb, and U isotope analyses by positive thermal ionization and Re and Os by negative ionization, as well as for most isotope dilution analyses. The third mass spectrometer is an ICP-MS Finnegan "Element" for elemental analyses. All peripheral equipment, such as mineral picking stations, atomic absorption and decay counting systems, is present.

Table 5. Types and configuration of mass spectrometers.

Name	Type of ionization	Mass analyzer configuration	Detection systems	Measurements	Sample introduction
Isolab	Thermal and Sputtering	E-M-D1-E-D2	4 faraday cups after M Daly Ion counting and faraday cup	Isotope ratios: Th, Hf and Hg	Solids and chemical separates
262/RPQ	Thermal	M-D1-E-D2	7 faraday cups, 1 electron multiplier	Isotope ratios: Pb, Sr, Nd, Os	Chemical separates
ICP-MS	Thermal-Plasma	M-E-D	Electron multiplier	Concentrations and isotope ratios	Solutions

E = energy filter
M= magnetic mass filter

LARGE MAGNET COMPONENT TEST LABORATORY

The Large Magnet Component Test Laboratory (LMCTL) was established in Cell 16 of the DC Field Facility in Tallahassee to support the continued development of a variety of cryogenic/electrical components for large superconducting magnet systems. Current is available from all four DC power supplies (up to 80 kA) and a special resistor network is provided for a single power supply (up to 20 kA). The latter provides loading for better current regulation as well as a shunt for added safety while testing components near their current limits. Magnets presently available for component tests are listed in Table 6. Apart from the dewars for magnet operation, liquid helium test dewars are available in a variety of sizes for component testing, e.g. inside diameters ranging from 320 mm to 1500 mm and inside heights ranging from 1020 mm to 3660 mm.

Table 6. Magnets available for use in the LMCTL.

Identifier	Type	Max. Field (T)	Bore (m)	Special Features
Oxford Split	Nb_3Sn/NbTi split solenoid, high-J, impregnated winding	14	0.150	30 x 70 mm^2 radial access
CWTX	NbTi split solenoid, low-J, ventilated winding	8	0.380	67-mm dia. radial access
TACL	NbTi cos θ dipole, high-J, ventilated winding	7	0.040	1-m long uniform field region
SMES CTA	NbTi simple solenoid, low-J, ventilated winding	4	2.0	Separate cryogenic test volume in bore

Access to NHMFL Facilities

As a national user laboratory, members of the worldwide science and engineering communities can access these facilities, generally without cost, through a peer-reviewed proposal process. Contact one of the people listed below for further information.

Facilities in Tallahassee, Florida

Continuous Field Facilities
http://www.magnet.fsu.edu/users/facilities/dcfield/

Bruce Brandt
Phone: 850-644-4068
Fax: 850-644-0534
brandt@magnet.fsu.edu

Electron Magnetic Resonance Facilities
http://www.magnet.fsu.edu/science/cimar/emr/

Louis-Claude Brunel (EMR)
Phone: 850-644-1647
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Nuclear Magnetic Resonance Facilities
http://nmr.magnet.fsu.edu/

Tim Cross (NMR)
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Fourier Transform Ion Cyclotron Resonance Mass Spectrometry Facilities
http://www.magnet.fsu.edu/science/cimar/icr/

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Geochemistry
http://www.magnet.fsu.edu/science/geochemistry/

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Phone: 850-644-1934
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Large Magnet Component Test Laboratory
http://www.magnet.fsu.edu/users/facilities/lmctl/

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Facilities in Gainesville, Florida

Magnetic Resonance Imaging/Spectroscopy Facilities
Gainesville, FL
http://www.ufbi.ufl.edu/
http://csbnmr.health.ufl.edu/

Steve Blackband (MRI/S)
Phone: 352-846-2854
Fax: 352-392-3422
blackie@ufbi.ufl.edu

Ultra-High B/T Facility
Gainesville, FL
http://www.magnet.fsu.edu/users/facilities/highbt/

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