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REPORTS
The National High Magnetic Field Laboratory

Operated by: FLORIDA STATE UNIVERSITY • UNIVERSITY OF FLORIDA • LOS ALAMOS NATIONAL LABORATORY

World's Most Powerful Magnet Tested — *Ushers in New Era for Steady High Field Research*

The first phase of the commissioning tests of the 45 Tesla Hybrid magnet at the NHMFL was completed December 17, 1999, with the magnet achieving 44 T and experiments being conducted at fields to 45 T. Read the article by James Brooks on page 3 for an exposition of the experiments done. Another article by John Miller and Mark Bird, page 12, places the outsert and insert in the context of similar magnets, and Bruce Brandt describes the systems that keep the two magnets operating together safely (page 15).

The 45 T Hybrid magnet consists of two behemoth magnets. The total magnet system weighs 34 metric tons and stands 22 feet tall. A superconducting magnet forms the outer section and provides a background

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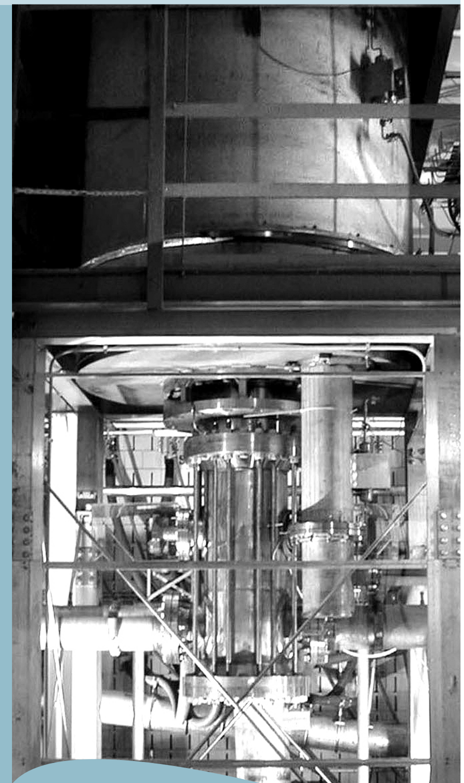

45 T Hybrid

Advanced Magnetic Resonance Imaging and Spectroscopy (AMRIS) Facility
Progress and Research Report #3, April 2000

11.7 T, 40 cm MRI system being delivered to the University of Florida, November 1999.

Steve Blackband, Associate Professor, University of Florida Neuroscience Department

In this issue we are fortunate to report three big developments at the AMRIS facility—I doubt one of these reports will ever be as eventful!

1. BIG NEWS: Since our last report in the fall 1999 newsletter, the 750 MHz wide bore NMR/MRI instrument has been delivered and installed. Unfortunately there has been an initial problem cryoshimming the magnet. When cooled down fully to 2 K (this is a pumped magnet system), contact was lost with one of the cryoshims. It is thus not clear if the magnet will achieve high resolution specification. The instrument has been capable of imaging, however, and we have obtained our first 2 and 3D data sets on the machine which appear to be of high quality. We hope to present

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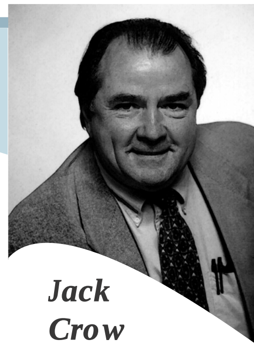
From the Director's Desk



Jack Crow

The National Science Foundation conducted its Renewal Site Review of the laboratory on April 16-18. Based on the comments made by many of the external reviewers, the committee was impressed by our progress and our vision for the future, as presented in the renewal proposal and during presentations.

During the coming weeks and months, the committee's report will be reviewed by NSF at several levels. We expect that throughout this time there will be a dialogue between the National Science Foundation and the NHMFL with regard to priorities and funding issues. Ultimately, NSF Director Rita Colwell will make a recommendation to the National Science Board, which will consider it, we anticipate, at its October meeting.

I want to take this opportunity to publicly recognize and thank the members of the External Advisory Committee and the Users' Committee for their critical guidance and assistance over the last year. The members participated in special meetings, conference calls, and e-mail discussions about the proposal; and many came to the laboratory in March to help us polish our presentations. In addition, EAC Chair George Crabtree and Users' Committee Chair Chuck Agosta attended the site visit and met with the committee.

We were also extremely pleased to have several distinguished guest speakers who gave outstanding presentations to the Review Committee on behalf of the laboratory:

- Dante Gatteschi, University of Florence, who talked about opportunities in EMR
- Horst Störmer, Columbia University and Lucent Technologies, who spoke on high magnetic field science opportunities in semiconductors and quantum wells
- Warren Warren, Princeton University, who discussed his perspectives on the next very exciting frontiers in high field NMR science.

The site visit was further strengthened by the support of a group of guests who represented the laboratory's institutional and private sector collaborations:

- Phil Ingram, Training Solutions Interactive
- Jan Kees Maan, High Field Magnet Laboratory, University at Nijmegen, The Netherlands
- Steve McQuillan, Oxford Instruments Research Instruments
- Bill Simonsick, DuPont Marshall Laboratory
- George Srajer, Advanced Photon Source, Argonne National Laboratory.

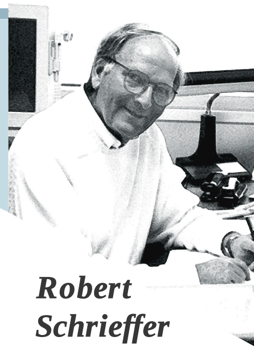
Their discussions with committee members and NSF panel members helped to show the broad range of science and engineering outreach activities that have been established by the laboratory—and how these interactions will be even more important during the decade ahead.

Certainly, the most critical group of people during the site visit and throughout the development of the renewal proposal represented the NHMFL partner institutions—Florida State University, the University of Florida, and Los Alamos National Laboratory—and the State of Florida. In addition to the leaders of FSU, UF, and LANL, we were particularly gratified to have Florida Lieutenant Governor Frank Brogan and Vice Chancellor of the State University System James Mau support the laboratory by welcoming the committee during the opening session. The state and institutional support for the NHMFL in the renewal proposal is very significant and demonstrates their strong, continued commitment to this federal-state effort.

Many of the people recognized here came great distances and took time away from very important responsibilities to support the laboratory during the site visit. We are sincerely grateful. Now we need to ask *all* of our users, supporters, and readers to do one more thing: communicate to Congress the importance of fully funding science and engineering at NSF and the other departments and agencies that drive research and technology in the United States. If you are unsure how to do this, see the AIP Science Policy web site (*www.aip.org/gov*) for information and guidance and we would be happy to assist you. If you have any questions, contact Ms. Janet Patten, NHMFL Director of Governmental and Public Relations (patten@magnet.fsu.edu).

Jack Crow

From the Chief Scientist's Desk



Robert Schrieffer

The following article shows the results from the first experiments on the NHMFL Hybrid magnet. Three types of materials are studied, an organic solid, an intermetallic material, and a semiconducting quantum well structure. Each of these materials is at the forefront of condensed matter physics and the results are of great importance.

The results of the organic material show that a ground state in a strong magnetic field is complex rather than a simple metal predicted from lower field experiments. It is possible that above 23 T a charge density wave occurs below 2 K.

In the intermetallic compound CeNiSn, high magnetic field shows that the resistance is not that of a simple metal expected from low field measurements. Rather one finds a negative curvature of the magnetoresistance for fields about 43 T whose origin is to be determined.

Preliminary experiments on the quantum well structure GaAs/AlGaAs exhibit the traditional quantum Hall effect magnetoresistance minima at filling factor 1/3 and 2/3. More refined experiments are necessary to reveal new minima in the resistance at other filling factors.

The importance of these experiments is clear and we congratulate Professor Brooks and his group for these pioneering experiments on the 45 T Hybrid magnet.

First Experiments in the NHMFL Hybrid Magnet

J.S. Brooks, L. Balicas, J. Matson, I. Rutel, FSU/NHMFL, the Scientific Team+, and the Technical Team*

We report measurements on several different condensed matter systems as a function of temperature in fields to 46 T in the recently commissioned Hybrid magnet[1] at the NHMFL. The scientific mission of the experiment was three fold:

- To examine in DC fields the high magnetic field state of the organic conductor system α-(BEDT-TTF)$_2$KHg(SCN)$_4$,
- To test the notion that the high field state of the Kondo semiconductor CeNiSn is metallic, and third,
- To measure the fractional quantum Hall effect in the high electron density limit.

The technical mission was to determine the parameters of a "typical" user run in the Hybrid where He-3 temperatures and standard electronic instrumentation would be used. The samples were mounted for electrical transport measurements, using standard techniques, in the 1 mm gap region between dysprosium pole pieces on a He-3 insert probe. The He-3 pumping station had to be maintained at 3 m away from the cryostat, due to the large fringing field (of order 100 Gauss), to avoid interference with the pressure gauges and pumps. The instrumentation was 6 m from the cryostat. LCD displays were mandatory to monitor computer operations. The results below were obtained in a six-hour run in the Hybrid magnet on December 12, 1999.

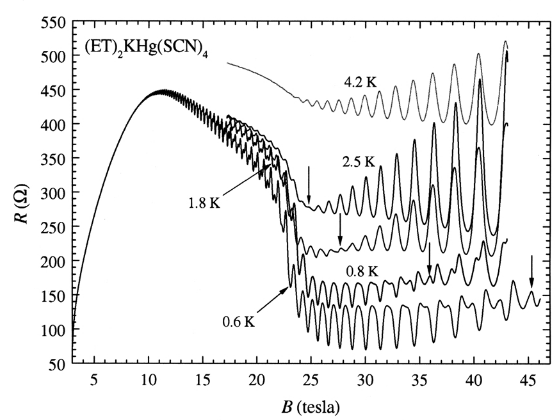


Figure 1. Magnetoresistance as a function of magnetic field B for a α-(ET)$_2$ KHg(SCN)$_4$ single crystal at several temperatures. Two Shubnikov de Haas (SdH) type oscillations are observed with a difference of phase of $\Delta\phi = \pi$. At certain fields, indicated by vertical arrows, $\Delta\phi$ changes from π to values close to 0. This effect, observed in transport but not in magnetization measurements points towards some kind of unusual scattering mechanism.

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In Figure 1 we show the magnetoresistance of the organic conductor α-(BEDT-TTF)$_2$KHg(SCN)$_4$ as a function of magnetic field and temperature.[2] The lowest temperature trace serves to define the operation of the Hybrid with dysprosium pole pieces. The dysprosium quickly saturates to 3 T for a small applied field[3] as the superconductor outsert is swept up to 14 T (corresponding to 17 T at the sample position). The resistive magnet is then varied systematically from zero to over 40 T (43 T in the highest field trace, which corresponds to 46 T for the samples) for different temperatures for the duration of the run, and only at the end of the run is the total field brought to zero. The data in Figure 1 show some very striking manifestations of the high field phase of α-(BEDT-TTF)$_2$KHg(SCN)$_4$. (The entrance to the high field phase of this material is indicated by a sharp decrease in the resistivity of the sample above B_k=22.5 T.) First, the DC fields give very high quality data that show how the Shubnikov de Haas effect evolves above the electronic transition at B_k. Not only are the amplitudes of the oscillations not monotonically increasing with lower temperature, but a dramatic shift in the phase of the wave forms develops below about 2 K. We further note the appearance of a node in the wave forms (see arrows) which moves to higher fields at lower temperatures.

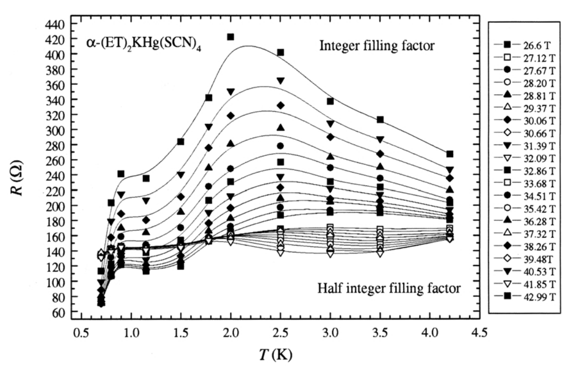

Figure 2. Dependence on temperature T(K) of the magnetoresistance obtained from the field scans shown in Figure 1. Below a certain T dependent maximum the resistance decreases sharply as a function of T, which is suggestive of a phase transition. The position of this maximum depends on the Landau filling factor. The magnetoresistance is more pronounced and the "transition temperature" is relatively higher at each SdH oscillation maximum.

In Figure 2 we further explore this high field phase by plotting the temperature dependence of the maxima and minima of the wave forms (corresponding to different fields), and in Figure 3 we show the phase diagram that

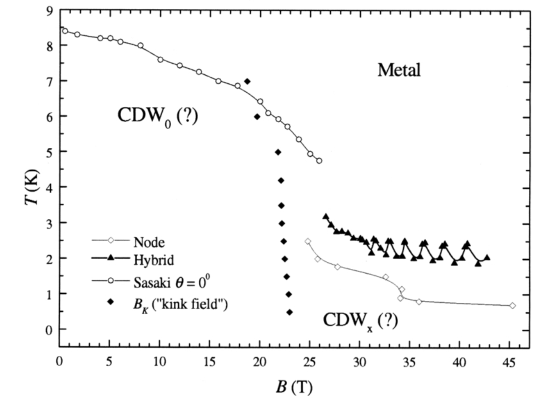

Figure 3. Proposed T - B phase diagram for α-(ET)$_2$KHg(SCN)$_4$. Opened circles are points from previous transport measurements. Solid diamonds indicate the position of the so-called kind field BK at which a first order phase transition takes place. Opened diamonds are the positon of the "node" seen in Figure 1. Solid triangles suggest the phase boundary obtained from the onset of the resistivity drop shown in Figure 2. The transition temperature seems to slightly increase when the Fermi level is in the middle of the gap between two consecutive Landau levels.

is suggested by the dramatic changes in temperature dependence shown in Figures 1 and 2.

- These results clearly show that the high field ground state of α-(BEDT-TTF)$_2$KHg(SCN)$_4$ is complex (not a simple metallic phase) and that this phase extends above 46 T. The general features seen in this phase diagram can be described by models for charge-denisity waves (CDW) in high magnetic fields.[2] **In this respect DC fields play a crucial role where complex ground states exhibit hysteretic, first order behavior that may be magnetic field sweep dependent.**

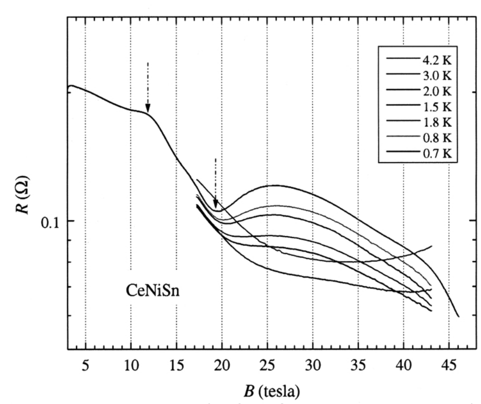

Figure 4. Magnetoresistance of a CeNiSn single crystal as a function of magnetic field B (current is along the b-axis, and the field is applied along the easy a-axis) at several temperatures. At low temperatures two anomalies (inflection points) are seen and indicated by vertical arrows. The anomaly at 13 T that was associated to a weak meta-magnetic transition has been suggested to reflect the disappearance of the pseudogap due to the overlap of spin-up and spin-down bands due to the Zeeman effect.

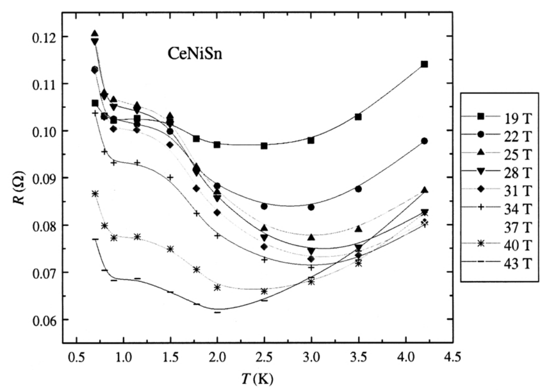

Figure 5. Magnetoresistance as a function of temperature T at several field values (extracted from the field scans previously shown in Figure 4). At 43 T a semiconducting type behavior is still present below 2.0 K although the system is "more-metallic." This observation contradicts the claims of a complete suppression of the quasiparticle gap (or pseudogap) along the a-axis for B≥13 T. Both inflection points could be indications of two subsequent metamagnetic transitions characterized by energy gaps Δ_1 and Δ_2 respectively. This would be consistent with a Fermi liquid theory of heavy fermions, based on the periodic Anderson model, which suggests a density of states exhibiting two characteristic energy scales Δ_1 and Δ_2 for the CeNiSn compound. Each transition would correspond to the suppression of each pseudogap at Δ_1 and Δ_2 respectively. Nevertheless, the semiconducting like behavior seen at low temperatures for fields as high as 43 T, clearly indicates the presence of a gap or pseudogap at the highest fields, in contradiction with any explanation in terms of field-induced pseudogap suppression that is frequently used to explain the unusual properties of CeNiSn under field.

In Figure 4 we show the magnetoresistance of CeNiSn, a high quality single crystal from the Takabatake group. Here the field is in the **a**-axis direction, and the current is perpendicular to the field. At low T, the sample resistance is only about 0.2 Ω. This system is considered to be semiconducting at low temperatures due to the presence of a pair of small pseudo-gaps (Δ_1 and Δ_2) at the Fermi energy at low temperatures.[4] In a magnetic field, it has further been reported that the zeeman splitting of this small gap structure will smear out the pseudo-gaps and produce a metallic phase.[5] The results of the present study are quite surprising. Although the two main signatures at 14 T and 19 T may indeed be correlated with the closing of successive gaps, the behavior of the resistance in the range 20 T to 40 T exhibits an unusual temperature dependence, given previous expectations for a high field metallic state. This is shown in Figure 5 where the presence of a gap or pseudogap is apparent in the activated nature of the high field resistance. It is however important to note that the resistance at 46 T is lower by over a factor of two at the lowest temperatures, and there is some indication of a new behavior above 43 T. With a base field of 45 T, the dysprosium method will allow us to explore this regime to 48 T, and further investigation of this material is planned in the future to resolve these issues.

- Our results on CeNiSn at very high fields show that the Kondo semiconductor nature of the material does not evolve in into metallic state in any simple manner. Other factors may come into play, based on the activated nature of the high field resistance, and its field-dependent structure. In particular, the intriguing downturn of the resistance above 43 T deserves further investigation. **Here again, DC fields play a crucial role since in this case the resistance of the material is very small, and good signal-to-noise is essential.**

In Figure 6 we show the quantum and fractional quantum Hall effect in a GaAs/AlGaAs single quantum well structure with a relatively high electron density (n = 3.8 x $10^{11}/cm^2$). One can see the "usual" integer quantum Hall behavior at low magnetic fields, and the last two signatures are the 2/3 and 1/3 fractional quantum Hall states. As the temperature decreases, the fractional states become more apparent. This sample was used not for the purpose of a new scientific result, but to simply represent a 2DEG measurement in this first run. The sample suffered from some ground-loop and carrier density difficulties, as the details of the R_{xx} minima and R_{xy} plateaus clearly show.

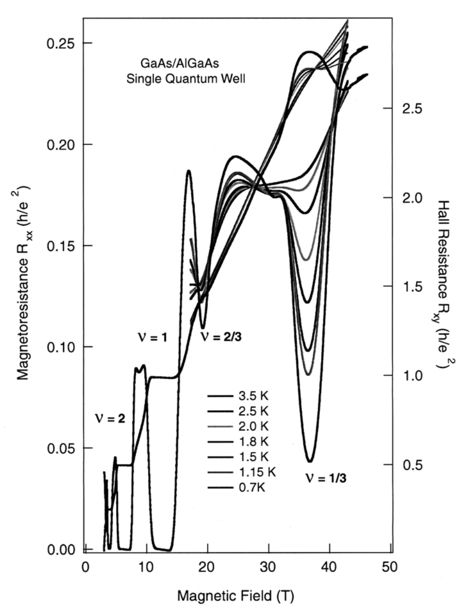

Figure 6. Magnetoresistance (right axis) and Hall effect (left axis) in units of h/e2 for a single GaAs/AlGaAs quantum well.

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Nevertheless, the temperature dependence of the 2/3 and 1/3 R_{xx} minima gave us an independent indication of the local temperature within the 1 mm gap of the dysprosium pole pieces.

We summarize by noting that the experiments in the first Hybrid run gave us new insight into the high magnetic field ground states of several materials in very different areas of condensed matter physics. We further note that experiments involving temperatures below pumped He-4 temperatures and with magnetic flux enhancement can be performed in the Hybrid magnet at the NHMFL in a scheduled, user-oriented mode of operation.

This work is supported in part by NSF DMR-99-71474 (JSB) and NSF-DMR-95-27035 through a cooperative agreement with the State of Florida (NHMFL).

+The Scientific Team: N. Biskup, T. Stalcup, J. Qualls, B. Ward, S-Y. Han, M. Tokumoto (Electrotechnical Labs, Japan), J Simmons and J. Reno (Sandia National Labs), T. Terashima (NRIM, Japan), H Aoki, Y. Echizen, and T. Takabatake (Tsukuba Univ., Japan).

*The Hybrid Team: The Hybrid Team comprises far too many people from the NHMFL and elsewhere to be credited here. The authors are greatly indebted to them for their efforts in the design, construction, and testing of the NHMFL Hybrid magnet.

1 M. Bird, NHMFL Site Visit Poster Session, April 17, 2000.
2 See also J. S. Qualls, L. Balicas, J. S. Brooks, N. Harrison, L. K. Montgomery, and M. Tokumoto, NHMFL Site Visit Poster Session, April 17, 2000, and to be published.
3 J. S. Brooks, Z. Fisk, S. Hill, J. Sarrao, T. Szabo, S. Uji, P. Sandhu, S. Valfells, and L. D. Seger, Int'l. Workshop on High Magnetic Fields: Industry, Materials & Technology, Tallahassee, Feb. 28 -Mar 1, 1996 **World Scientific Press**, 30 (1996).
4 H. Ikeda and K. Miyake, J. Phys. Soc. Jpn. **65**, 1769 (1996).
5 T. Ekino, T. Takabattake, H. Tanaka, and H. Fujii, Phys. Rev.

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field of 14 T. It is held at 1.7 K so that heat can be removed from the superconducting cable by superfluid helium. A water-cooled "Florida Bitter" magnet sits in the center of the superconducting magnet and provides a variable field that reached 30 T during the December tests, and is expected to run routinely to at least 31 T for user research following some just completed improvements.

Commissioning a new major magnet facility as complex as the Hybrid is a challenging and sometimes frustrating process. Each system in the facility has to be tested by itself as much as possible, but all must be made to work together. Some systems, like the cryogenic refrigeration system, were tested extensively and improved over the two years between their completion and system tests. Each system had features and components that could not be tested under the proper conditions of load and interactions until the whole thing was available. Problems arose with almost every system as its untested functions were probed. Each time testing would stop or shift to another component until the problem was fixed. Some problems required days to solve, which added to the test team's anxiety level as the deadline for shutting down the whole system for the lab's annual maintenance period loomed. People would scatter to other tasks until time to gather again on the user platform to set off toward the next milestone.

Finally, the test crew was convinced that the outsert protection system was able to discriminate between a noisy fluctuation in an outsert segment voltage and an incipient quench, and would discharge the 100 MJ of outsert stored energy into the external dump resistor. Furthermore, the outsert protection system would satisfactorily ignore the transient voltages associated with an insert magnet trip without unnecessarily discharging the outsert magnet. It was time to ramp the whole magnet to full field. The outsert was first ramped up in two kiloampere steps, the field measured, and all systems were observed for a few minutes for signs of trouble. It reached full field without incident; the insert had done likewise months before; and now was the time for the real test of both – would they work together? The resistive insert was ramped up in two kiloampere steps while the outsert was held at full field, the total field was measured, coil voltages were measured, and coil temperatures were calculated. Insert coils were running hot for most of the test ramp. At 44 T the temperature was too high to continue. The decision was made to stop the testing at this point to avoid damaging the insert, let people get

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some sleep, and let the cryogenic system recover. The resistive magnet crew inspected the insert in the morning and reported that interaction of the insert and outsert had caused one of the insert coils to shift and reduce the flow of cooling water. The problem was fixed temporarily, the system was run up again and turned over to local researchers for experiments at up to 42 T. Everyone involved in the design, building, and testing of the Hybrid magnet system was tired, relieved, and triumphant—it worked!

An official commissioning ceremony and symposium on high field research is planned for the early fall to officially acknowledge the engineers and corporate partners who made this significant achievement possible.

Thanks to Bruce Brandt, director of the DC Field Facility, for contributing this article.

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a potpourri of these images in the next newsletter. A detailed quantitative test is still required.

The Bruker engineer returned in April to begin assessing the homogeneity problem. In any event, many congratulations and thanks to Bruker.

2. BIG NEWS: The **11.7 T/40 cm MRI instrument** made field in February 2000. Although there were several small crisises on the way up, it did this without a quench. Many thanks to the Magnex engineers and also our own Ben Inglis, especially for sorting out the cryogenics. There has been a problem shimming the magnet in that the Z2 cryoshim is not strong enough, but a relatively simple solution of winding an additional room temperature Z2 shim on the large gradient set has been proposed and will be tested. A first attempt to interface the large gradient coil with the new shim was unsuccessful because the gradient coil was, unfortunately, manufactured too short. The gradient has been shipped back to be lengthened and should be returned in six to eight weeks. In the meantime the smaller 12 cm diameter gradients were placed in the magnet and the first unshimmed (but surprisingly good) images of a phantom were obtained on April 25th. Fingers crossed, touch wood, but we are close. Even so, many congratulations and thanks to Magnex.

3. BIG NEWS: We have obtained the first phased array images on a **4.7 T research instrument**. Phased array coils are now commonly available on clinical instruments. We have purchased the first phased array on a research animal instrument in the United States. Bruker engineers recently got the receiver hardware functioning (thanks to Mark Mattingly) and our NHMFL-supported AMRIS rf engineer, Barbara Beck, tested her first four channel 4.7 T (200 MHz) phased array coil. It worked the first time. Many congratulations to all concerned. We will be evaluating the signal-to-noise ratio (SNR) gains the coil provides and evaluating coil developments in the near future.

In additional news:

The 500 MHz spectrometer magnet had a faulty quenching cryoshim and was consequently dysfunctional. Bruker rapidly exchanged the magnet, and after the usual shakedown, the magnet is now behaving satisfactorily. Its spectroscopic capabilities are being evaluated.

The 3 T/80 cm instrument has been upgraded and appears to be functioning well, at least for imaging. The echo planar images (EPI) especially are quite wonderful for a “routine” instrument. Unfortunately spectroscopy has taken a hit and is not yet functional—the engineers at GE are “working on it.” It is not clear to the author if the desire to get good EPI images has compromised the instrument such that the resultant gradient performance (eddy currents) precludes good spectroscopy. This remains to be seen—fingers crossed again!

Sadly, we must say goodbye to David Peterson, one of our NHMFL-employed rf engineers. Dave has taken a position in industry in Gainesville. Good luck Dave, and thanks.

Our own Barbara Beck chaired the rf coil session at the ISMRM in Denver this year and did a great job. Her new design for a high field MR coil (the ReCav coil) was also received well—a summary of the coil follows in this issue’s AMRIS Research Report.

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AMRIS Research Report #3

Large Volume High Frequency RF Coils: The ReCav Coil

Barbara L. Beck, University of Florida Brain Institute and NHMFL
H. Ralph Brooker, University of South Florida
Stephen J. Blackband, UF Departments of Neuroscience and the UF Brain Institute, NHMFL, and the University of South Florida

This work was presented at the ISMRM in Denver, March 2000.

Introduction. To achieve improved SNR and spectral resolution, MR systems continue a drive toward higher magnetic field strengths, and consequently higher resonant frequencies. Traditional rf coil design techniques used at lower field strengths begin to break down at higher frequencies as the coil dimensions approach significant portions of a wavelength. The coils can become far field radiators, compromising the near field performance, or they may become inhomogeneous due to significant phase shifts around the coil. New designs to reduce these problems involve the use of resonant cavities,[1-5] with the TEM resonator[1,3] the most widely applied. In this work we explored the utility of the coaxial reentrant cavity as a simple and effective alternative high frequency volume rf coil.

Theory. Cavity resonators are used widely in microwave engineering where device dimensions and wavelengths are the same order of magnitude. One type of cavity resonator is the reentrant cavity, in which the walls of the cavity fold into, or reenter, the center of the cavity. The coaxial reentrant cavity (dubbed ReCav coil), displayed in Figure 1, is one in which the electromagnetic fields can be MR compatible.[1]

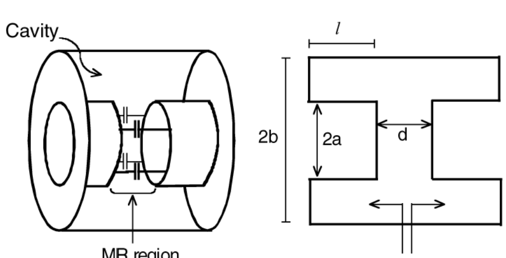

Figure 1. Schematic of the ReCav coil (left) with a cross-sectional equivalent (right).

Methods. A ReCav coil was made for use on a 4.7 T Bruker Avance system. The ReCav was made from two coaxial cylinders, the outer cylinder of O.D. 7 5/8", the inner cylinder of I.D. 3", total length of cavity 7", and length of MR useful region 2" (Figure 1). The outer cylinder was covered with a thin copper sheet that was segmented to break up gradient induced eddy currents. The inner cylinder was covered with the same copper sheet, leaving a 2" gap in the center. The outer and inner cylinders were shorted at the ends with copper covered end plates. The capacitance of the cavity was controlled with four capacitors attached across the 2" center gap, spaced at azimuth angles 30°, 150°, 210°, and 330°. The ReCav was excited by inserting, from one end, a small loop between the inner and outer cavities, oriented in the ZX plane. A shielded 8-element lowpass birdcage with equivalent dimensions as the ReCav coil was built for comparison. The birdcage was excited by capacitively coupling across one of the distributed capacitors in a leg. SNR comparisons were made on the 4.7 T instrument with a cylindrical loading phantom filling 70% of the useable coil volume, and a rat brain *in vivo*. A standard spin echo imaging sequence was used for SNR measurement.

Results. The loaded and unloaded Q measurements and SNR with the loading phantom are shown in the following table.

Coil	QEmpty	QLoaded	Qe/Ql	SNR
CoRC	563	83	6.8	151
Birdcage	120	82	1.5	145

Q damping is much greater for the ReCav than the birdcage, resulting in equivalent Q when loaded. The SNR is similar for the coils on the loaded phantom. Animal images are shown in Figure 2 and are virtually identical.

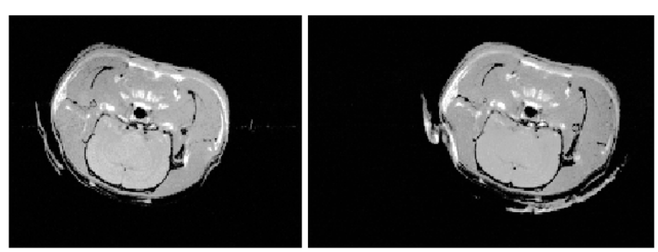

Figure 2. Rat head images using the ReCav (left) and birdcage (right) coils and identical imaging sequences.

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Conference & Workshop Activity

Electrospray Ionization FT-ICR Mass Spectrometry Tutorial Workshop

November 8-10, 2000
NHMFL, Tallahassee, Florida

The NSF National High-Field FT-ICR MS Facility will offer a hands-on tutorial workshop this fall. The program will consist of five half-day sessions, divided between oral presentations and hands-on sessions on electrospray FT-ICR MS.

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Discussion. These results demonstrate a close performance equivalence of the ReCav coil and a birdcage coil at 200 MHz and 3” internal diameter. In comparison to other designs in the literature, the ReCav coil is very simple to construct and control. The coil has just six capacitors, with tuning controlled by one of the capacitors across the 2” gap and matching controlled by a capacitor attached to the excitation loop. At higher frequencies, as the coil sizes approach significant portions of a wavelength, the ReCav efficiency may be better than the birdcage because of its ability to contain the electromagnetic fields. We are investigating larger ReCav coils at 500 MHz and quadrature versions of the same coil design in expectation of the completion of the 11.7 T/40 cm Magnex/Bruker system, and exploring a theoretical model of the coils characteristics. This work is presently being written up for full publication.

Acknowledgements. The authors thank Dr. J. Fitzsimmons, Dr. R. Duensing, D. Peterson, and Dr. T. Vaughan for stimulating discussions, and support from the NHMFL and the UFBI.

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4 Griswold, M., *et al.*, SMR Proc., #995 (1995).
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This workshop is designed to introduce the participant to the principles, instrumentation, hands-on operation, and selected applications of this technique. More advanced topics will be included as time permits.

The program will be presented by Alan Marshall (overview and principles), Christopher Hendrickson (FT-ICR instrumentation) and Mark Emmett (electrospray and applications). Provided reference materials will include review articles and handouts of overheads. A unique feature of the program will be hands-on access (groups of no more than five participants) to gain familiarity with sample preparation/introduction and instrument operation/optimization. Instrument operation will be presented in general terms, and will not be limited to any particular vendor.

The fee for this workshop will be $1,200.00; enrollment will be very limited to ensure individual attention during the hands-on sessions. To register or for further information, contact Alan Marshall, director of the NHMFL ICR Program, 850-644-0529, fax 850-644-1366, marshall@magnet.fsu.edu.

US-Japan Joint Seminar on Innovative Measurement Techniques in Cryogenics

December 3-6, 2000
NHMFL, Tallahassee, Florida

There has been considerable progress in this field over recent years, some of which has been driven by applications such as superconducting magnet systems and space-based technology. Other major applications and opportunities are in the development of refrigeration, particularly small-scale cryocoolers. This three-day seminar will bring together researchers involved in making cryogenic measurements and developing instrumentation to discuss new techniques, devices, and their use in measurements and applications.

The small workshop environment, with approximately 30 attendees, is expected to provide a very effective forum for focused exchange. Some of the contributions will be of a tutorial nature and given by world leaders in the field.

CONFERENCE & WORKSHOP ACTIVITY continued on page 10

CONFERENCE & WORKSHOP ACTIVITY continued from page 9

Shorter contributions on more narrowly defined topics will be sought from junior scientists and graduate students.

The NHMFL, NSF International Programs Division, and the Japanese government are co-sponsoring this event that will be held at the NHMFL in Tallahassee. For further information, contact Steve Van Sciver, director of NHMFL Magnet Science and Technology Program, 850-644-0998, fax 850-644-0867, *vnsciver@magnet.fsu.edu.*

Third North American FT-ICR Conference

Mid-March 2001
Austin, Texas

The NHMFL ICR Program is busy organizing this biennial conference that it initiated in 1997. The inaugural meeting was in Tallahassee, followed by the second conference in San Diego in 1999. Interest and attendance at the second meeting was very high, so prospective participants should stay tuned. For updated information, contact Alan Marshall, program director, 850-644-0529, fax 850-644-1366, *marshall@magnet.fsu.edu*.

Physical Phenomena at High Magnetic Fields (PPHMF-IV)

October 19-25, 2001
Santa Fe, New Mexico
Hotel Headquarters: Hilton of Santa Fe

Planning continues for this major international conference initiated by the NHMFL in 1991 and held every three years. For updated information, see the conference web site: *http://www.lanl.gov/mst/nhmfl/PPHMF4/.*

Applied Superconductivity Conference (ASC04)

October 4-8, 2004
Site: TBD

This major conference is held every two years. In September 2000, ASC00 will be held in Virginia Beach, Virginia; ASC02 will be in Houston, Texas, in August; and in October 2004 ASC04 comes to Florida. Planning continues for this important international meeting that typically attracts over 1,800. For information, contact Conference Chair Justin Schwartz, associate professor of mechanical engineering and NHMFL Magnet Science & Technology group leader, 850-644-0874, fax 850-644-0867; *schwartz@magnet.fsu.edu.*

NHMFL in the Spotlight at ENC Meeting

This year's Experimental NMR Conference or ENC meeting showcased the NHMFL. Held on the beautiful state-run conference grounds of Asilomar on the Monterey Peninsula, nearly 1,500 spectroscopists met in early April to discuss new experiments, new hardware, and new applications. More than a quarter of the attendees were from outside the United States. The conference offered 73 plenary talks and more than 600 posters.

Two of the NHMFL's staff scientists, Drs. Zhehong Gan and Nagarajan Murali, presented talks. Dr. Gan's presentation focused on a new method recently published in the *Journal of Magnetic Resonance* for obtaining high resolution spectra of odd-halves quadrupole nuclei by correlating the central and satellite transitions in a two-dimensional approach. Dr. Murali presented the collaborative work performed with Professor Warren Warren from Princeton University on developing high resolution NMR spectroscopy using the 25 T Keck magnet through intermolecular Zero Quantum Coherence Spectroscopy.

Two external users of NHMFL-NMR facilities also presented their work. Dr. Ago Samosan from the Estonian National Institute of Chemical Physics

MT-16 Chair H. Schneider-Muntau (front row center), with Chair of MT-15, Prof. Y.X. Wan (left) and Chair of MT-17, Dr. R. Perin (right).

and Biophysics discussed high speed magic angle spinning in the 25 T Keck magnet and in the 19.6 T (833 MHz 1H frequency) superconducting magnet. Dr. Sam Grant from the University of Chicago discussed work done in collaboration with Steve Blackband and Tom Mareci at the University of Florida on the observation of ^{1}H spectra from a selected volume inside a living neuronal cell.

Finally, Tim Cross, the NHMFL's NMR Spectroscopy and Imaging program director gave a talk on using solid state NMR to characterize membrane proteins (see page 19 for further information).

The meeting was a great success, not only for the NHMFL, but also for high field NMR research. In a special session organized by NSF, NIH, DOE, and the Office of Science and Technology Policy, the NMR community made it very clear that a great deal of exciting new science awaits the next generation of very high field NMR instruments. The input provided to the agency representatives by the ENC participants hopefully will fuel additional interagency discussions leading to the development of a coordinated national effort to provide adequate resources to support the numerous scientific opportunities awaiting high field NMR capabilities.

Hans Schneider-Muntau, *NHMFL Deputy Director*

The 16th International Conference on Magnet Technology (MT-16) was held in Ponte Vedra Beach, Florida, at the Marriott Sawgrass Resort, during September 26 to October 2, 1999. The NHMFL was very proud to garner this prestigious conference for the United States—for the first time after 12 years—and to host it.

Our invitation to MT-16 had an overwhelming response: a 25 percent increase in abstracts and an equal increase in number of participants in comparison to earlier MT conferences, making it the largest conference in this series. We registered more then 510 participants (and nearly 50 companions), representing over 90 different companies, 91 universities, and 70 governmental institutions. This growth demonstrates the ever increasing importance of magnet technology. The impressive participation from the private sector indicates the progress that is being made in industrial applications of magnetic fields, and its enormous future potential.

Many highlights in the program underlined the outstanding quality of the invited and submitted contributions. I list here a few lasting impressions from the conference.

- The opening speech by Congressman Vernon J. Ehlers, on "The Political Future of Science and Technology" with an impressive overview on the importance of the role of science and technology in modern civilization (the text is available at *http/ www.house.gov/science/science_policy_study.htm*).

MT-16 FOLLOW-UP REPORT continued on page 12 continued from page 11

- The truly international character of this magnet technology conference. About equal numbers of the participants represented the United States, Europe, and the Far East.
- The uniquely important role of magnet technology in the field of high energy physics. The many contributions from and for the Large Hadron Collider, and accelerators and detectors in general, demonstrated this very clearly. The development of the next generation of accelerators will require new ideas, better materials, and more cost-effective manufacturing procedures. Twenty-five percent of the papers dealt with magnets for the high energy physics community.
- The importance of materials, conductors, and insulators for advanced magnet design. Impressive progress has been made in low and high temperature superconductors. Special interactive sessions on insulations were organized, and a summary with conclusions was included at the end of these contributions. One-fourth of all papers concerned material questions.
- The strong interaction with the private sector. Fifteen percent of all conference papers dealt with industrial applications, such as NMR and MRI magnets, magnets for Fourier Transform Ion Cyclotron Resonance (FT-ICR), energy storage, magnetic separation, levitation, HTS transformers, current limiters, etc.
- The magnet laboratories in their worldwide role as originator of new ideas, applications and technologies. A special session was organized for a presentation of their development programs, and test and user facilities.
- The vibrant atmosphere during the poster sessions. Traditionally, posters play a significant role at MT conferences as they facilitate exchange and interactions. Combined with the industrial exhibition to ease the establishment of contacts, the poster sessions were a true source of intense discussion and communication.

The scientific contributions were peer reviewed and have already appeared in printed form. Volume 10 of *IEEE Transactions on Applied Superconductivity* came out in March 2000, and is entirely dedicated to MT-16 (almost 1,600 pages).

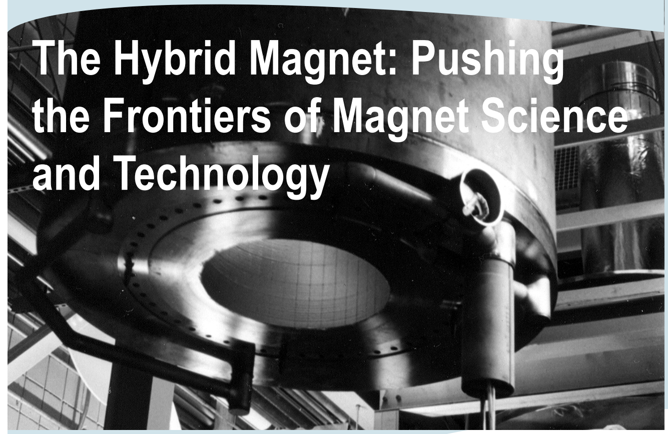
Many, many people contributed to the success of the conference, and to make it such a memorable and positive experience. The conference would not have happened without the numerous people from the staff of the NHMFL, too many to list them all by name, with their professional and enthusiastic participation.

Very special thanks also go to 13 conference sponsors, whose generous support was applied principally to the printing cost of the special volume of *IEEE Transactions on Applied Superconductivity*.

As chair of MT-16, I wish to thank the members of the International Organizing Committee, the Program Committee, and the National Advisory Committee for their competent advice.

The International Organizing Committee met on Wednesday, September 29, 1999. Geneva was confirmed as the site of the next International Conference on Magnet Technology, MT-17. The conference will be hosted by the European Organization for Nuclear Research (CERN).

The Hybrid Magnet: Pushing the Frontiers of Magnet Science and Technology



John Miller, *NHMFL Hybrid Outsert Project Leader*
Mark Bird, *NHMFL Hybrid Insert Project Leader*

Much has been said to try to quantify the performance of the 45 T Hybrid (for example, it produces almost a million times the Earth's field, it stores over 100 MJ of energy in its magnetic field, the system weighs over 34 metric tons, etc.). Sometimes, these descriptions are not very satisfying. After all, pulsed magnets can produce higher field, there's more energy stored in two quarts of gasoline, and a locomotive weighs more. Perhaps more satisfying comparisons can be made to other similar systems upon which people (and funding agencies) have seen fit to expend significant resources. Since such projects are generally the subject of careful scrutiny, it is reasonable to expect that they give a useful perspective of the "state of the art" for the technology in question. In Figures 1 and 2, we try to make such comparisons for the superconducting outsert of the 45 T Hybrid. In Table 1, we provide a list of systems included with references. This list is not exhaustive but it is certainly representative of the highest achievements in recent years for a variety of applications; we arbitrarily limit consideration to magnets with maximum field greater than 5 T.

Among the many parameters that measure the difficulty of building a superconducting magnet, field production is the most often mentioned. To the magnet designer, however, the maximum field at the windings is the more directly meaningful parameter. Of course, field alone does not fully measure the difficulty. As with many things, size matters. In Figure 1, we present our group of systems with a simultaneous comparison of maximum field at the windings and inner diameter of the high field windings. The level of difficulty increases as we move up and to the right on this graph, and the 45 T Hybrid outsert is clearly on the frontier.

Stored energy is another very real measure of superconducting magnet performance. It directly impacts the design through its relation to mechanical stresses in the windings and to requirements for protecting the magnet should it be necessary to extract or dissipate that energy suddenly. Typically, design features to accommodate the stored energy (for example, distributed structure or integral shunt material in the conductor) result in lower current densities in the windings than would otherwise be achievable. In Figure 2, the systems are displayed for simultaneous comparison of stored energy and winding pack current density. Note that many of these systems have "graded" windings, wherein several levels of windings

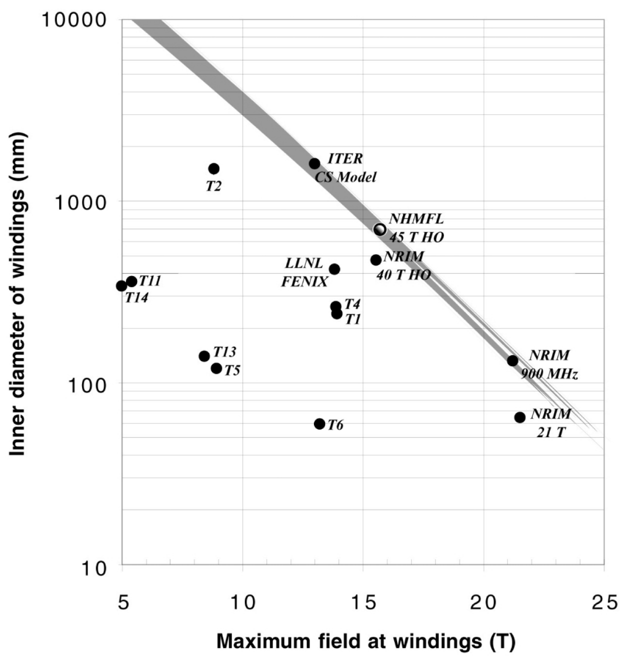


Figure 1. A comparison of recent high field superconducting magnets on the basis of maximum field and inner diameter of the windings.

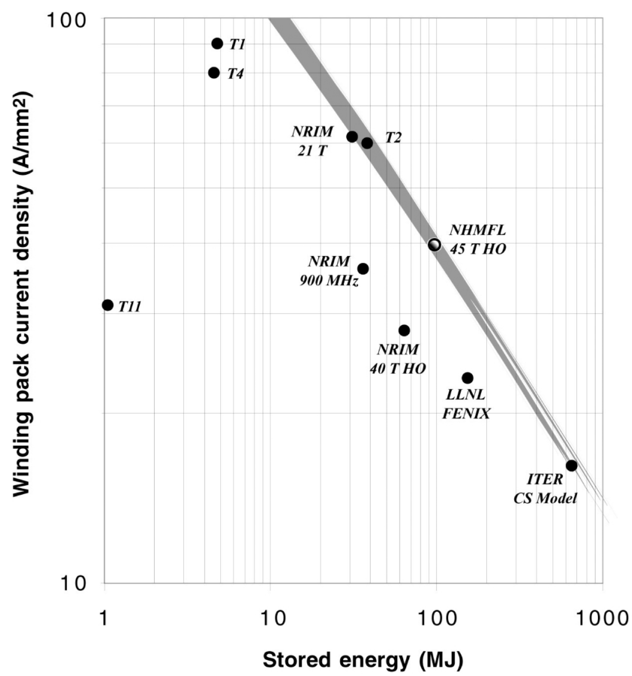


Figure 2. A comparison of recent high-field magnets on the basis of stored energy and winding-pack current density (in the case of magnets with graded windings, the current density of the high-field windings is displayed).

HYBRID FRONTIERS continued on page 14

Table 1. High field magnet systems and references for Figures 1 and 2.

Item	Description/Intended Use	Reference
T1	DC solenoid/Conductor testing	Tsukamoto *et al*., IEEE Trans. Applied Superconductivity, Vol 9, no. 2, p. 547 (1999).
T2	DC solenoid/Conductor testing	*ibid*
T4	DC solenoid/Conductor testing	*ibid*
T5	DC split solenoid/Conductor testing	*ibid*
T6	DC solenoid/Conductor testing	*ibid*
T11	DC pancake module/SMES development	*ibid*
T13	DC solenoid/SMES development	*ibid*
T14	Pulsed pancake module/SMES development	*ibid*
NRIM 40T HO	DC solenoid/Research facility	Morita *et al*., in High Magnetic Fields: Applications, Generation, and Materials, Schneider-Muntau ed., World Scientific, Singapore, p. 333 (1997)
NHMFL 45T HO	DC solenoid/Research facility	
FENIX	DC split solenoid/Conductor testing	Slack *et al*., IEEE Trans. Magnetics, Vol. 27, no. 2, p. 1835 (1991).
CS Model Coil	Pulsed solenoid/Technology demonstration	H. Tsuji, JAERI, private communication, 19 April 2000.
NRIM 21T	DC solenoid/Research facility	Hirose *et al*., Proceedings of the 15th International Conference on Magnet Technology (MT15), Beijing, Peoples Republic of China, October 20 - 24, 1997.
NRIM 900 MHz	DC solenoid/Research facility	Kiyoshi *et al*., IEEE Trans. Applied Superconductivity, Vol. 9, no. 2, p. 559 (1999) and T. Kiyoshi, NRIM, private communication, 6 March 2000.

are included—with different conductor choices or different structural content, etc. In these cases, the winding pack current density in the innermost or high field winding was chosen to represent the system. As in Figure 1, the more difficult domain is up and to the right, and again the 45 T Hybrid outsert is at the frontier.

Comparing the resistive insert to other magnet projects is more difficult, as there are few similar systems to which one can compare it. It is easier to compare purely resistive magnets. For example, the NHMFL provides users 30 T in a 32 mm bore using 15.3 MW of power. The High Magnetic Field Laboratory in Grenoble provides its users with 30 T in a 34 mm bore but uses about 21.3 MW of electric power (approximately 40 percent more) and a set of coils that weighs roughly 2.5 times more to do it.[1] Of course, our 30 T magnet is now obsolete, 33 T is now our state-of-the-art magnet using only 17 MW. The Hybrid insert is then another major step beyond our stand-alone resistive systems.

What is also unique about the NHMFL Hybrid insert is that it was designed as a stepping stone to still higher fields and other interesting developments. For example, during the next five years we expect to upgrade the system from 45 T to 50 T by making very minor changes to the insert coil set during regular maintenance activities. Furthermore, we plan to build a new insert running on two power supplies (20 MW) that would provide over 42 T and allow another (36 T) magnet to run at the same time. In addition, we could build the new two power supply insert as a high homogeneity insert and provide users with 40 T and field uniformity of 10 ppm or better over a 10 mm diameter spherical volume. Such a system would have substantial appeal to the NMR community.

Another point worthy of notice is that the Florida-Bitter magnet technology developed at the NHMFL and used in the Hybrid insert is now being adopted by other laboratories around the world. The NHMFL is very pleased with the cooperative program that has been established between the NHMFL and the laboratories at Nijmegen, The Netherlands; Tsukuba, Japan; and Grenoble, France, where sharing of new technologies and ideas will continue to benefit the worldwide magnetic research communities.

1 Aubert, G., *et al.* "The 20 MW-50 mm Bore Diameter Magnet of the Grenoble High Magnetic Field Laboratory," *IEEE Transactions on Applied Superconductivity*, **10** (1), 455-457 (March 2000).

Hybrid Control & Protection Systems: Critical for Magnet Operation & Safety

***Bruce Brandt,** Director of NHMFL DC Field Facility*

This article focuses on the controls and support systems that make it possible to operate safely the two coupled magnets that make up the 45 T Hybrid magnet system. Design and construction of the control system was a collaborative effort of engineers, scientists, and technicians from the NHMFL's Instrumentation and Operations, Physical Plant, and Magnet Science and Technology Groups. It drew on the experience gained with previous hybrid magnets at the Francis Bitter Magnet Lab and the Grenoble High Magnetic Field Lab, as well as other large magnet systems. Its purposes are to provide the desired magnetic fields to experimenters, detect problems inside each magnet in time to prevent damage, and protect experimenters and equipment from failure of a component. Problems that must be protected against range from failure of all power to the laboratory to having a control computer stop functioning smoothly.

The Hybrid insert's power supplies are controlled by the same system that controls all the water cooled magnets in the DC high field facility; the outsert power supplies use a similar system. The user interface is different in that the user communicates verbally with the Hybrid magnet operator to set the desired field and ramp rate, and the user's data acquisition system records voltages proportional to the currents in the two magnets and calculates the total field. One Apple computer running LabVIEW® software controls and monitors both the insert and outsert magnet power supplies via a serial interface.

The computer hard- and software system that Scott Hannahs developed to deal with problems with the resistive magnet is similar to what he developed for the other water cooled magnets, with the addition of a few unique tests to make sure, for example, that the insert and outsert fields have the same polarity. Protecting the superconducting outsert magnet is a rather different process. Any superconducting magnet must be protected from a quench, which occurs when a local region of the superconducting cable rises and remains above its current-sharing temperature. The current-sharing temperature is determined by the operating conditions (current and field) of the magnet. Above this temperature, the region becomes resistive and there is heat generated. The resistive zone grows inexorably if the heat is not removed quickly enough, and, if the magnet current is high, will rise quickly to quite dangerous temperatures unless the magnet is discharged. The Hybrid quench protection system is designed to detect a quench and disconnect the power supply so that the magnet current discharges through a shunt resistor. In less than five seconds the 100 megajoules of energy stored in the magnet is dumped into the shunt resistor, the magnet, and the liquid helium. This is an exciting event, with smoke arising from the dust and paint on the resistor, the whoosh of helium vapor passing through the vent pipe, and various exclamations of surprise, amazement, and disappointment by the people present.

A power supply is used to ramp the superconductor, and to maintain the field. The voltage across the magnet terminals when ramping is up to about 25 volts, and very nearly zero when the field is constant. A quench can be detected as a voltage across the length of superconductor that has become resistive. This can occur when ramping, so a scheme must be used to separate the resistive voltage associated with a superconducting to normal transition from the inductive voltages resulting from changes in the magnetic field. A standard technique is to compare the voltage across one segment of the magnet with the average voltages of two adjacent or otherwise comparable segments. The voltages must be brought to the outside of the magnet cryostat, isolated, amplified, filtered, and fed to a computer that does the calculations fast enough to make a decision about whether or not to discharge the magnet before it destroys itself. The quench detection computer system was developed by Scott Hannahs using Apple and National Instruments hardware and LabVIEW® software.

One of the more dramatic complications of the quench detection system is that the voltage across the entire magnet during a quench can reach 5 kV, with the maximum voltage to ground being about 2.5 kV. The quench detection computer, operators, and experimenters are protected from this voltage by the connecting wire

HYBRID CONTROLS continued on page 16

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insulation, conduit, isolation amplifiers, fiber-optic signaling, and NEMA-rated enclosures surrounding high-voltage components. Also, access to areas of risk is tightly controlled and alarmed. A worst case magnet discharge resulting from certain situations such as a break in a magnet current lead would produce much higher voltages to ground. In this case, the system breaks the connections to the amplifiers with fuses and discharges the voltages to ground via controlled paths in order to protect people and save the voltage tap wires and isolation electronics. The isolation amplifier boards and the general scheme for getting the voltage signals safely to the computer input points were designed and built by Peter Murphy, Andy Powell, Lee Bonninghausen, and Joel Piotrowski.

Much of the rest of the magnet control and protection system is designed to discharge the magnet at various controlled rates and thus prevent damage or injury if a variety of other problems occur. An eight page table lists every condition that the design group considered a potential threat, the signal that indicates that the condition exists, the action to be taken, and the actor. The "actor" can be an automatic valve or switch, a computer, or a person. The action can prevent operation of the magnet until a requirement has been met or an improper situation cleared. It can also shut down the magnet slowly, to avoid warming up the magnet or creating a potentially dangerous transient; or quickly, as in the case of a quench. The highest priority was given to personnel safety. Equipment was protected depending on the cost and difficulty of repairing or replacing it.

The control and protection system was important and complex enough to require considerable time during the commissioning tests (see elsewhere in this issue) for tuning its components and verifying its proper operation. It worked well, with one exception that provided an unplanned test of the quench detection system. Two signals were supposed to show that the two magnets had the same polarity. One used strain gauges on part of the magnet support structure; the other read the magnet current polarities provided by the power supplies. The strain gauges turned out to be affected too much by the fringe fields of the magnets to be useful. When one of the power supplies got the polarity wrong following a field reversal, the insert was ramped up with the wrong polarity and caused the magnetic field at the innermost outsert windings to go high enough to cause the conductor to go normal. The magnet quenched but the quench detection and magnet discharge systems worked as needed. The power supply manufacturer has developed a way to prevent future polarity errors, and the strain gauges will be replaced with a Hall sensor that will read the sum of the insert and outsert fields so that the operator can check for problems. Both will be installed before the next series of tests and will be in place when the magnet is next run.

Attention: Prospective Hybrid Users

The Hybrid Magnet should be available to users again in early fall following a new series of tests. Proposal process information is available online:
www.magnet.fsu.edu/user/facilities/proposal/index.html.

For forms and further information, contact:
Bruce Brandt
850-644-4068
fax: 850-644-0534
brandt@magnet.fsu.edu)

or

Merry Ann Johnson
850-644-6257
johnson@magnet.fsu.edu

Attention Users

Alex Lacerda

We are slowly getting back to normal after the terrible wildfire that consumed 47,000 acres around Los Alamos and displaced 400 families. One NHMFL family had their home completely destroyed, one home was condemned, one had extensive smoke damage, and most other people who lived in Los Alamos suffered losses of some sort. We are all back to work, healthy, and grateful for all the support. See the next issue of *NHMFL Reports* for a complete story.

As many of you know, in the months preceding the fires, we were busy relocating the Pulsed Field Facility into a new building (see *NHMFL Reports*, Fall Issue). This relocation was accompanied by an extensive redesign of the user support infrastructure. In the new building, the NHMFL Pulsed Field Facility is configured for future growth by fully exploiting the freedom to time-multiplex pulsed magnet experiments. The Long-Pulse and Short-Pulse User programs are now located in separate buildings and, for the first time, short-pulse experiments can operate completely independently of one another.

A 15 mm bore, 50 T, capacitor-bank-driven, long-pulse magnet has been successfully trained and is ready for use. The total pulse duration is 500 ms with 40 ms risetime. The new 50 T magnet is expected to be particularly useful for high field optical spectroscopies of highly reflective or brightly luminescing materials, and as an initial testbed for further higher-field, higher-resolution experiments in the 60 T Long-Pulse magnet.

The Proposal Request Form to utilize the NHMFL–Los Alamos Facilities may be found at the following web address:
http://www.lanl.gov/mst/nhmfl/

We hope to hear from you soon. Should you have any questions or comments, please contact me: Alex H. Lacerda, NHMFL–Los Alamos Users Program director, 505-665-6504, fax 505-665-4311, *lacerda@lanl.gov*.

Physical Phenomena at High Magnetic Fields IV
October 19-25, 2001
Santa Fe, New Mexico

This conference will bring together experts to discuss recent advances in areas of science and applications in which high magnetic fields play an important role.

The program will consist of invited and contributed papers as well as posters, covering a broad range of materials, superconductivity, organic solids, the quantum Hall effect, chemical and biological systems, and the technological use of high magnetic fields.

For deadlines and updated information, see the conference web site:
http://www.lanl.gov/mst/nhmfl/PPHMF4/

Geochemistry at the NHMFL—*An Update*

Visitors to the laboratory in Tallahassee may hear an unusual new sound on the third floor: the loud cracks emanating from an **Electric Pulse Disintegrator** (EPD, or "zapper"). The zapper is an instrument that discharges a large potential, 130 to 150 kV, on a sample (rock in our case). The zap is like hitting the rock by lighting and results in disintegration of the sample. Compared to mechanical crushing disintegration by EPD results in more breaks along grain boundaries. Therefore, individual mineral grains are liberated in a larger grain size fraction than through mechanical crushing. *This instrument can be used to separate a gold leaf intact from quartz crystals or whole fossils out of a rock*. It is thought that the difference in dielectric constant between the minerals results in breakage along grain boundaries but the exact mechanism is unknown. An early instrument was first built in the Soviet Union in the early 1960s and was originally developed to disintegrate mined materials after which the ore minerals could be separated from the rest. As far as we know, it was never developed past the prototype stage. With this new instrument, minerals can now be separated out of larger size fractions and less material is needed; this is a great advantage for analyses of minerals when *in-situ* analyses are not possible. The instrument at the NHMFL is one of only three zappers at universities in the United States.

Last December a **new electronic journal in Earth Sciences was launched: *Geochemistry, Geophysics, Geosystems*, G-cubed or *G*^{3} for short**. The journal is housed at the NHMFL (*http://gcubed.magnet.fsu.edu*) and its timely launching was due in large part to the original web design and support provided by Mike Davidson's Optical Microscopy Group in the laboratory. The journal is published by APS's sister organization the American Geophysical Union (AGU). The journal was founded with support from Scripps Institution of Oceanography, Harvard University, Lamont-Doherty Earth Observatory of Columbia University, Florida State University, and the NHMFL. *One of the goals of the journal is to provide the earth science community with a journal that can take advantage of the innovations possible through electronic, web-based publication*. These include electronic dissemination of data sets both large and small, illustrations and graphics formats such as movies, virtual reality images, sound, mathematical models, etc. Another goal of the journal is to keep individual and institutional subscription rates as low as possible and to avoid escalating prices.

The Geochemistry Group recently received a program enhancement grant (PEG) from the FSU Foundation Cornerstone Program for interdisciplinary research that is a collaboration between Alan Marshall (NHMFL-ICR Program), Jurek Krzystek (NHMFL-EMR Program), and Vincent Salters (PI, NHMFL-Geochemistry), as well as Bill Cooper and Gregg Choppin in FSU Chemistry and Bill Landing in FSU Oceanography. The project "Determining the speciation of nutrients, radionuclides and metals in natural waters" will use Fourier Transform Ion Cyclotron Resonance Mass Spectrometry (FT-ICR-MS)

GEOCHEMISTRY continued on page 19

Imaging Helical Wheels of Membrane Proteins by Solid State NMR

The cover story for the May issue of the *Journal of Magnetic Resonance* describes a new finding in the solid state NMR of membrane proteins. In the two-dimensional PISEMA spectra that correlate ^{15}N-^{1}H dipolar and ^{15}N chemical shift interactions of samples aligned with respect to the magnetic field axis of the NMR spectrometer, a pattern of resonances is observed when helical proteins are present. In biochemistry textbooks helices are often illustrated by a diagram known as a helical wheel, formed by looking down the helical axis ($\mathbf{h_Z}$) and marking the position of amino acids every 100° around a circle reflecting 3.6 amino acids per helical turn. The observed pattern of resonances in the PISEMA spectrum represents such a helical wheel. This results from realizing that it is possible to draw the laboratory frame of reference directly in the NMR spectrum, albeit somewhat distorted. Consequently, the helical wheel in the spectrum is also somewhat distorted from its ideal circular shape.

This pattern provides two unique pieces of information for the characterization of membrane proteins. First, the position of the wheel in the spectrum of a uniformly ^{15}N labeled sample can be directly interpreted in terms of the tilt or slant (τ) of the helix with respect to the membrane normal and the magnetic field axis. This led to the name of these patterns, as Polar Index Slant Angles or PISA wheels. In addition, it is possible to determine the rotational orientation (ρ) about the helical axis ($\mathbf{h_Z}$) by using an amino acid specific labeled sample. For instance, all of the isoleucine amino acids have been labeled. One isoleucine is easily distinguished from the others on the helical wheel and fixes the orientation of helix about $\mathbf{h_Z}$. The second important finding is that the data from a single amino acid specific labeled sample can also be used to make all of the resonance assignments in a uniformly ^{15}N labeled helix. This is a critically important result, because assigning individual signals in the spectrum to individual atomic sites in the protein is a requirement for high resolution structural characterization.

Membrane proteins represent one of the great frontiers of structural biology today. These proteins are responsible for communication between the outside world and the chemical and biological factories that are housed inside the cell membranes. Ninety percent of today's neuroscience drug targets are membrane proteins. These proteins are responsible for transmitting neuronal signals, for

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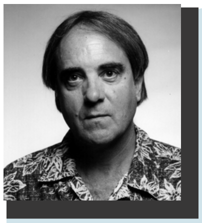
GEOCHEMISTRY continued from page 18

to determine the composition and structure of the principal nutrients within dissolved organic matter (DOM, dissolved organic nitrogen, and dissolved organic phosphorus); high resolution inductively coupled plasma mass spectrometry (ICP-MS) analysis to quantify the amount of radionuclides and metal ions associated with the individual groups of DOM; and electron paramagnetic resonance (EPR) techniques to determine the functional groups responsible for metal binding in DOM. This is exactly the type of interdisciplinary research that is only possible in a place like the NHMFL.

Knowledge of speciation is important because there is mounting evidence that an ecosystem's response to chemical stresses such as excess nutrients or heavy metals is first manifested at the lowest levels in the food web, i.e. in the bacteria, phytoplankton, and other micro-organisms. The response of these primary consumers is related to the chemical form, or speciation, of pollutants, and their stress is ultimately reflected farther up the food web in the macro-organisms. By knowing the chemical speciation of environmental stressors at the molecular level, we will be able to understand their bioavailability and ultimate effect on overall ecosystem health before dramatic changes occur. Our planned research is the first step in obtaining this speciation information.

This article was contributed by Dr. Vincent Salters (850-644-1934, fax 850-644-0827, salters@magnet.fsu.edu), who may be contacted for further information and user assistance.

People in the News



James S. Brooks, professor of physics at FSU and member of NHMFL Condensed Matter/Theory Group, was elected to APS Fellowship in November, 1999, for his work in condensed matter physics and contributions to service and teaching. Only one half of one percent of the total APS membership is selected as Fellows each year.

Andy Gavrilin, assistant scientist/scholar in Magnet Science and Technology, joined the NHMFL in December, 1999, after working at the European Organization for Nuclear Research (CERN, Switzerland/France), National Institute for Fusion Science (Japan), and Kurchatov Institute and P. N. Lebedev Physics Institute (Moscow, Russia). Dr. Gavrilin received his Ph.D. in Thermal Physics from Moscow Engineering Physics Institute; his Master thesis was devoted to Soviet Tokamak T-15. As a magnet analyst, Dr. Gavrilin has taken part in several well-known large projects, such as the Large Helical Device (Japan) and the ATLAS magnet (Europe). While affiliated with the Kurchatov and Lebedev Institutes, he worked in cooperation with research centers of China, India, United States, and Europe, in applied superconductivity and large magnet technology. Dr. Gavrilin will enhance MS&T's capabilities in computer analysis for R&D of diverse magnet systems and his international experience should help the laboratory continue to expand its collaborative activities with other research centers.

Kristina Hakansson, who will begin postdoctoral research in the ICR Facility in Tallahassee in July, has been awarded a competitive $26,720 postdoctoral fellowship from The Swedish Foundation for International Cooperation in Research and Higher Education (STINT). Her research will involve coupling of the new electron capture dissociation technique with the NHMFL electrospray FT-ICR mass spectrometers.

Grzegorz Karczewski, has been visiting the NHMFL from the Institute of Physics of the Polish Academy of Sciences on a Fulbright fellowship. He has been here since last

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regulating a potential across membranes, for transmitting hormonal signals into the cell and for transporting nutrients into the cell and products out of the cells. Modulating the efficiency of these proteins can be critical for the control of the cell and tissue performance and for the control of disease states.

Standard methods of structure determination have not been very successful in elucidating these structures. Now, solid state NMR is providing a new tool for attacking this exiting scientific arena. The discovery of PISA wheels came through a collaboration between two of the NHMFL's staff scientists, Drs. Riqiang Fu and Zhehong Gan, Professor Jack Quine, who is on sabbatical from the Department of Mathematics at FSU in the NHMFL, and Professor Timothy Cross, Director of the laboratory's NMR Spectroscopy and Imaging program. Of course, the individuals who did all of the work were the students, in particular, Junfeng Wang, Sanguk Kim, and Jeffrey Denny.

Calculation of PISA Wheels

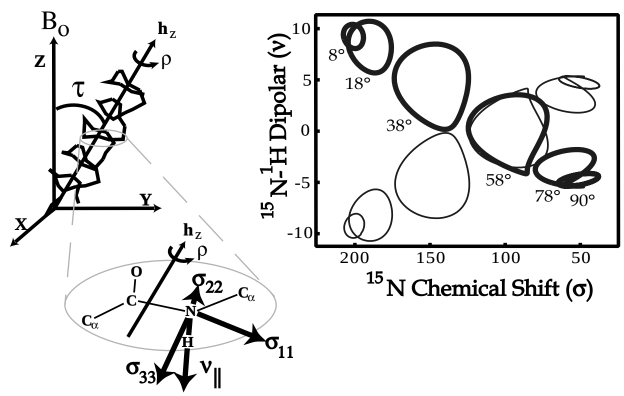
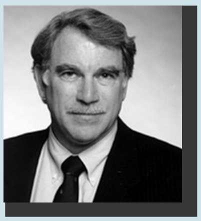


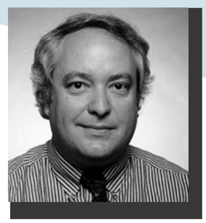
Figure 1. The PISEMA spectrum correlates the anisotropic dipolar and chemical shift interactions. The dipolar interaction gives rise to a symmetry related pair of signals and therefore in Figure 2 only one of the symmetry related patterns is presented. The pattern of resonances is simulated here by calculating the chemical shift and dipolar interactions as the helix and corresponding spin interactions for a single site are rotated about the helical axis.

September studying quantum wells in collaboration with Yongjie Wang and Xing Wei of the User Support Group. He will return to Poland in early June but will be visiting Tallahassee again to continue his research.

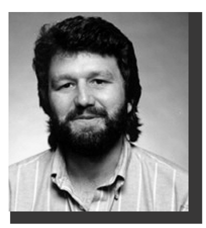


Alan G. Marshall, director of the NHMFL National High-Field Fourier Transform Ion Cyclotron Resonance Mass Spectrometry Facility, has been selected to receive one of the three Thomson Medals this year "for achievement in and service to international mass spectrometry" from the International Mass Spectrometry Society. Dr. Marshall will receive the medal at the 15th International Mass Spectrometry Conference in Barcelona, Spain, August 27 to September 1, 2000. The Thomson Medal is named for Sir J. J. Thomson, who discovered the electron in 1897. He was responsible for the first mass spectrograph, a parabolic trajectory instrument that combined magnetic and electric deflection and which foreshadowed their application in modern mass spectrometers. The Thomson Medal was first presented in 1985 and is awarded no more frequently than every third year. It has been awarded to the following other scientists: John Beynon, Klaus Biemann, Michael T. Bowers, Curt Brunnee, R. Graham Cooks, Carl Djerassi, D. E. Games, Keith R. Jennings, H. Matsuda, Fred McLafferty, Nico M. M. Nibbering, A. O. C. Nier, Helmut Schwarz, and John F. J. Todd.

Amy Mellow, the office assistant for the Magnet Science & Technology Group, won the FSU Exemplary Service Award in the Office Clerical Category. Competition for this honor is very keen, as only eight awards are given university-wide, in eight different categories. Amy provides outstanding day-to-day support for the 80 scientists, engineers, technicians, students, and visitors with the MS&T group.



Timothy Moerland, professor of biological sciences at FSU, has been awarded an FSU Program Enhancement Grant. Dr. Moerland will work with NHMFL colleagues and chemical engineers Stephen Gibbs and Bruce Locke to focus on the development of probes, which are fundamental to research on drug delivery, metabolism, separation science, biotechnology, and several specialized manufacturing processes.



John Pucci, who works in NHMFL Magnet Operations Services, received the FSU Gabor Superior Accomplishment Award, representing the Office of Research. Only five Gabor Awards are given university-wide and selection is based on an employee's superior accomplishment that resulted in or contributed to FSU's efficiency and/or effectiveness. John recieved the award for his extraordinary efforts in advancing the efficiency and reliability of the NHMFL helium supply and recovery system and supporting user activity at the laboratory. He also spent many nights and weekends making the Hybrid cryogenic system work.

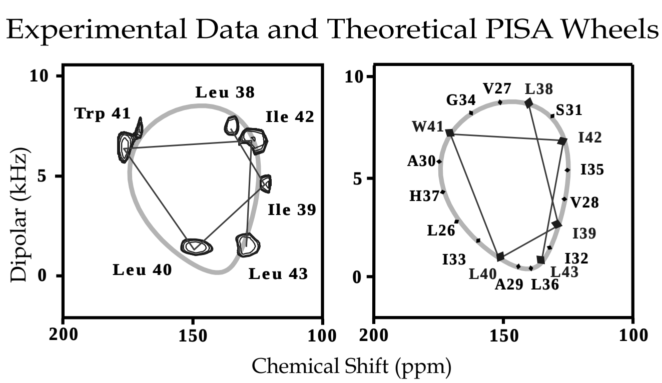


Figure 2. Experimental data from a sequence of amino acids in the transmembrane helix from the M2 protein of Influenza A virus is shown. M2 protein forms a proton channel in the viral coat essential for flu infection. A close correspondence exists between the theoretical PISA wheel and the observed data. Such resonance patterns reflecting a description of the laboratory frame of reference directly in the NMR spectrum has never been recognized before.

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Vincent Salters, scientist with the NHMFL Geochemistry Group, FSU chemist William Cooper, and FSU Oceanographer William Landing have been awarded a university Program Enhancement Grant that will launch a demonstration project to characterize the composition and reactivity of dissolved organic matter in nature surface and ground waters. The team expects their research to lead to improved design and construction of retention ponds and treatment of wetlands important to filtering systems for urban storm water and agricultural run-off and ecosystem restoration projects, such as those proposed for the Florida Everglades. This effort will also collaborate with the NHMFL ICR and EPR groups (see page 18).

David Tanner, condensed matter experimentalist and NHMFL faculty member, was recently promoted to Distinguished Professor of Physics at UF. Dr. Tanner has a second new title as well: Associate Director of UF's new Institute for High Energy Physics and Astrophysics that will be directed by Professor Guenakh Mitselmakher (Physics).

The institute is a type-II center with the funding coming from federal grants (currently at the level of about $3 million a year) and returned overhead. Based in Physics, the institute has an initial membership of more than 20 faculty in five departments (Physics, Mathematics, Chemistry, Materials Science, and Mechanical Engineering). A primary goal for the institute is to facilitate collaborations of UF researchers in large-scale projects in these interdisciplinary areas. Many of the institute's participants are already working in national and international experiments, including experiments at Fermilab, the Cornell Electron Storage Ring, the Laser Interferometer Gravitational-wave Observatory (LIGO), the CMS experiment at CERN, and the axion search at Livermore. Small groups of researchers from the University of Florida have taken active, and in several occasions leadership roles in major national and international experimental efforts. Their activities include designing and constructing new apparatus, collaboration with outside groups, developing major software components, carrying out data analysis and simulation, and providing large-scale computing support for data reduction and simulation.

Yan Xin is a new assistant in research in the Magnet Science and Technology Group. Dr. Xin is originally from Beijing, China. She received her Ph.D. ("Characterization of Novel Superconductors and Semiconductor Heterostructures by Transmission Electron Microscopy") from the University of Cambridge, U.K., and completed postdoctoral work at the University of Illinois at Chicago and Oak Ridge National Laboratory. Dr. Xin will be in charge of the NHMFL high resolution electron microscope, will collaborate extensively with users, and will continue and initiate new studies on semiconductors.

Guillaume van der Rest, a postdoctoral fellow in the ICR Program, has been chosen to receive this year's SFSM (Societe Francaise de Spectrometrie de Masse) award that is designed to recognize a young scientist, less then 35 years old, having worked at least three years in a French industry or university laboratory and whose research, either fundamental or applied, has led to new developments in mass spectrometry. Dr. van der Rest will present his work and receive the award at the SFSM annual meeting in Villeneuve d'Ascq, July 5-7, 2000.

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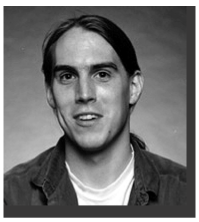
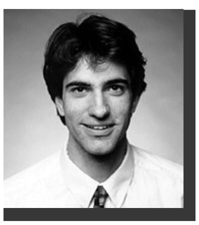
Congratulations New Ph.D.s

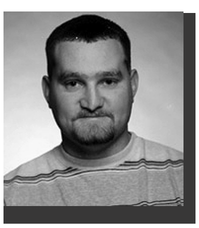
So Young Han, FSU Physics (December 1999), "Theoretical and Experimental Aspects of Tight Binding Parameters in Low Dimensional Organic Conductors: High Magnetic Fields and Uniaxial Pressure." Dr. Han plans to continue her research in North Carolina.



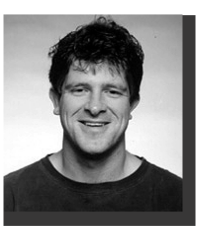
Scott McCall, FSU Physics (April 2000), "Magnetic, Transport, and Thermodynamic Studies of Single Crystal $Ca_3Ru_2O_7$." Dr. McCall has a dual postdoctoral position with Jack Crow, NHMFL director, and Bob Guertin, Tufts University.



Jeremy Qualls, FSU Physics (December 1999), "Fabrication, Characterization, and Electronic Structure of Anisotropic Organic Metals." Dr. Qualls recently accepted a faculty position at Wake Forest University.



Ryan Rodgers, FSU Chemistry (December 1999), "Complex Mixture Analysis by Fourier Transform Ion Cyclotron Resonance Mass Spectrometry: Petrochemical, Environmental, and Forensic Applications." Dr. Rodgers recently assumed a postdoctoral position at Oak Ridge National Laboratory.



Tom F. Stalcup, FSU Physics (April 2000), "Transport and Magnetic Properties of the Organic Superconductor κ-$ET_2Cu[NCCN_2]Br$." Tom is presently going through the postdoctoral interview process.

Student Updates

Jason Detwiler was a summer intern at the NHMFL-Los Alamos in 1997 and 1998 working with Alex Lacerda and Neil Harrison. Jason won a Goldwater Scholarship in 1998, was a finalist for a Rhodes Scholarship and the APS Apker Award for undergraduate research in 1999, and won an NCAA graduate fellowship in 1999. Jason co-authored a paper in the proceedings of Physical Phenomena at High Magnetic Fields III, and wrote another paper that recently appeared in Phys. Rev. B entitled "Magnetization of UBe_{13} to 60 T" (Phys. Rev. B **61**, 402 (2000)). Jason continues his graduate studies at Stanford University.

Says Jason: "I believe that my summers at Los Alamos opened door after door for me. The experience I gained and the connections I made there not only gave me a good understanding of what it means to do cutting-edge physics research, but also fueled my motivation for learning and exploring physics. I owe a great deal of thanks for my successes to Alex Lacerda and the LANL NHMFL staff."

Thanks to NHMFL user **George M. Schmiedeshoff**, Occidental College, who provided this information on his former research student.

Sharmini Pitter (left) and **Saira Anderson** arrange their display at the International Science and Engineering Fair 2000, May 7-12, in Detroit, Michigan. The project entitled "Strontium Isotope Dating of Mineral Samples from the Blue Ridge Mountains" utilized an NHMFL mass spectrometer to date the mountain range. Sharmini began studying with NHMFL geochemist **Roy Odom** in 1998 on the topic of El Nino as part of the NHMFL's mentorship program with middle school students. Saira Anderson joined the team in spring 1999 and the topic changed. The NHMFL strongly encourages ongoing mentorship experiences at the laboratory and was pleased to support the students' travel to Michigan.

HTS Lead Development for the Series-Connected Hybrid

The superconducting outsert for the Series-Connected Hybrid (SCH), which is proposed for construction at the NHMFL, has been conceived to meet the needs of a broad range of high field researchers. It will provide the same field performance as a class of resistive magnets requiring consumption of up to 30 MW of DC power and commitment of as many as three of the laboratory's four power supply modules. Instead, the SCH will require a single power supply module and consume 10 MW or less. The design philosophy of connecting the resistive and superconducting coils in series leads naturally to an extra measure of temporal stability in the field. Simultaneously, it allows mitigation of a number of fault scenarios and system complications associated with independently powered magnets.

Figure 1. EURUS' Richard Hodges and NHMFL's Don Richardson and George Miller prepare the 13 kA leads for preliminary testing at NHMFL.

Series-connection, however, requires the superconducting magnet to be designed for high-current operation (20 kA). Should traditional vapor-cooled current leads be used, this choice would impose a heavy load on the cryogenic system. On the other hand, gas-cooled current leads with high temperature superconductor (HTS) elements at the low-temperature end can significantly reduce this load. If properly adapted to the refrigeration system for cooling the magnet, such leads can provide a reduction of approximately 70 percent versus the 4-K-equivalent refrigeration for traditional vapor-cooled leads (the exact value is dependent upon design details, the refrigeration cycle, and HTS performance). In conjunction with an industrial partner (EURUS Technologies, Inc.), we are developing 20 kA, gas cooled, HTS current leads for our Series-Connected Hybrid application.

The dominant component of the total refrigeration requirement is the amount needed for cooling the resistive section, making its design and fabrication critical to overall lead performance. We fabricate the resistive-section heat exchanger as a "jelly roll" of "stabbed" copper sheet that provides enhanced heat transfer surface for efficient cooling as well as extra heat capacity for stability against thermal runaway. This approach has advantages for economical, high volume production.

The HTS element is constructed by attaching Ag-Au matrix, Bi-2223 tapes to concentrically mounted shunt tubes of stainless steel. The stainless steel shunt is an essential feature that protects the HTS element for the time necessary to discharge the magnet in case of a quench due to loss of coolant or other accident.

The NHMFL/EURUS technology for HTS current leads has been successfully applied to a pair of 13 kA leads delivered to the Large Hadron Collider (LHC) program at CERN. The NHMFL provided development support for this project including preliminary testing of the finished leads (Figure 1). The CERN group tested these leads March 29-31, 2000, against the full LHC specifications and found them to meet all requirements with significant margins.

This article was contributed by Dr. John Miller of the NHMFL Magnet Science and Technology Group, who may be contacted for further information (850-644-0929, miller@magnet.fsu.edu).

Education Opportunities At—*and Extending Beyond*—the Laboratory

The National High Magnetic Field Laboratory, through its Center for Integrating Research and Learning, will host twenty-one undergraduate students from fifteen universities nationwide. The eighth annual **Research Experiences for Undergraduates** (REU) program, through a highly competitive process, selects students to work with faculty mentors at one of the three NHMFL sites—Tallahassee, Los Alamos, and Gainesville. The program provides eight-week mentorships for science majors, who conduct research in areas as diverse as high strength materials, biophysics, condensed matter physics, and assembling and commissioning of a 2.4 MJ, 24 kV capacitor bank. Summer research interns are fully integrated into the science and engineering activities of the laboratory through their mentors. Interns from previous summers have presented at national conferences and have designed research projects and developed skills that bring them back to the NHMFL as part of the user community.

Building on the success of the REU program, the Center is conducting its second annual **Research Experiences for Teachers** (RET) program, bringing teachers, scientists, researchers, and educators together to enhance classroom science. Ten experienced teachers and six pre-service or beginning teachers will conduct research with a mentor from the Tallahassee site of the NHMFL. Center staff will work with scientists and teachers to create classroom materials that translate the excitement and rigor of working at a science research facility for students. The nationally-advertised program has attracted teachers from as far away as the Midwest to Tallahassee.

The NHMFL's Center for Integrating Research and Learning supported Earth Day through its **Earth Day 2000 Inventions and Innovations for a Brighter Tomorrow**—a competition for elementary, middle, and high school students and teachers. Projects were submitted by over fifty students, representing schools from as far away as Tampa, Florida. In keeping with the Earth Day 2000 Clean Energy Agenda, inventions and innovations focused on common-sense ways to use alternative energy resources. Entries addressed areas of transportation, communication, and recreation. Prizes were awarded at a reception held at the NHMFL on April 24, 2000.

The Center for Integrating Research and Learning continues to expand its **teacher outreach program**, conducting workshops across the State of Florida. Center educators will conduct a **Summer Institute** for 30 teachers in Broward County focusing on magnets and magnetism, light and optics, and integrating technology in the classroom. In addition to ongoing teacher trainings and the Summer Institute, the Center will conduct three mini-workshops at Beyond the Blackboard, a mini-conference for teachers from a 10-county area. Curriculum products will be disseminated and concomitant teacher workshops and trainings conducted outside the State of Florida beginning in Fall 2000.

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Tallahassee, Florida 32310