Designing for Magnetic Resonance Imaging and Spectroscopy
A Case Study

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Figure 1: Exterior. Center for Magnetic Resonance Research(CMRR) in Minneapolis, RSP Architects Ltd. Photo by Philip Prowse.

Figure 2: Commons Area, CMRR; RSP Architects Ltd.

Since the early 1970s, a wealth of scientific discoveries has greatly advanced the use of magnetic resonance (MR) technology for noninvasive cell and organ analysis. The enhanced image resolution provided by high-field magnets has extended applications of MR technology beyond brain mapping to include the study of medical conditions and diseases ranging from diabetes, obesity, and cystic fibrosis to psychiatric disorders, multiple sclerosis, and, quite recently, breast cancer.

Kamil Ugurbil, director of the Center for Magnetic Resonance Research (CMRR) in Minneapolis, eloquently predicted the future of MRI technology in his 1996 grant application to the National Institute of Health (NIH) when he wrote:

> *"The exquisite anatomical information provided by MRI…has only been a prelude as the boundaries of this imaging have been relentlessly expanded."*

Through centers such as the CMRR, which was originally one of four sites in the world equipped with a 4.0 Tesla instrument for high-field human research, the diagnostic capabilities of magnetic resonance imaging (MRI) and spectroscopy (MRS) will continue to increase. Medical equipment manufacturers will expand their knowledge of magnetic resonance hardware and software. The public will ultimately benefit as the MRI and MRS technology currently used for research purposes becomes a clinical tool.

The extremely restrictive requirements imposed by the high-level magnetic fields present formidable site-election and building-esign challenges. This article examines these unique issues by tracing the planning and design decisions that led to construction of anew 38,000 square-foot CMRR building.

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Introduction

The Center for Magnetic Resonance Research (CMRR) is located in Minneapolis. As part of the University of Minnesota's Academic Health Center, it provides state-of-the-art equipment, expertise, and infrastructure for researchers using high-field magnetic resonance imaging (MRI) and spectroscopy (MRS) methodologies for biomedical applications, neurosciences, functional brain mapping, and the study of metabolic disorders, cardiac pathology, and bioenergetics. The CMRR also supports researchers throughout the world by developing magnetic resonance hardware for high magnetic fields and creating visualization and data analysis software.

The CMRR is the home of one of the world's first 7.0 Tesla whole-body-imaging instruments. By capitalizing on the depth and knowledge of its staff, the CMRR has grown to become a major international resource for new scientific developments.

By 1996, the CMRR had outgrown its space on the Academic Health Center's campus. Of the 14,000 square feet it occupied, 9,000 s.f. were intended to be temporary when the facility was constructed in 1989. The CMRR needed wet labs, improved computer resources, on-site animal research facilities, high-speed computer networking, and more space to house a second human MR instrument and additional staff.

Developments in magnetic resonance spectroscopy and imaging had begun to have a major impact on biomedical and behavioral research. Yet no single group of scientists—neuroscientists, cardiac physiologists, etc.—could successfully carry out all aspects of the studies required to explore these areas of inquiry. It was clear that a new CMRR facility designed to further foster interdisciplinary interaction and provide centralized support would amplify the contributions of each group of scientists by providing shared resources and a place for synergy.

Special Site Considerations

Preliminary programming demonstrated that the CMRR could no longer occupy an area within the hospital complex for a number of reasons.

- The existing facility lacked the infrastructure and the space needed to accommodate the CMRR's growing activities. There was no room to care for patients while they were volunteering for research protocols or to add a much-needed fourth high-field magnet and house the staff who would use it.

- Since the existing facility didn't have a vivarium, animals had to be transported in and out of the CMRR daily by vehicles or carts. Some were hand-carried. This was stressful for the animals and inefficient because it restricted the use of MR instrumentation to weekdays and only to hours when transport was available.

- The proximity of surrounding structures and nearby traffic made it impossible to prevent interference with the high magnetic fields generated by the CMRR's instruments.

Three critical levels of magnetic fields heavily influenced site selection and the preliminary organization of functions within the new CMRR building:

- **1 Gauss Line**: The CMRR staff needed to control access by large moving metal objects—buses, delivery and service vehicles, ambulances, or cars—within this boundary because such masses interfere with the magnetic fields created by the high-field magnets.

- **5 Gauss Line**: Access by humans must be closely controlled within this boundary. Individuals with implantable medical devices are at particular risk and should not enter this zone. All objects that contain iron—even those as small as individual keys or pen caps—can become dangerous when they are attracted by a magnetic field and become airborne.

- **20 Gauss Line**: Magnetic materials, such as steel piping, ductwork, and structural reinforcement, should be eliminated within this boundary.

Figure 3: Site plan illustrating impact of magnet fields on site selection and building configuration. CMRR; RSP Architects, Ltd.

The 1 Gauss Line restriction led the project team to select a site remote from high-density areas of the campus where this boundary could not be infringed upon by large magnetic masses.

At the new CMRR building, vehicular access within the 1 Gauss Line is controlled via an entry gate. The high-field magnets cannot be conducting imaging experiments during the time that vehicles are moving within this boundary.

Designers carefully avoided the use of magnetic materials in the structure, equipment, and building systems within the 5 Gauss Line.

Security and Safety Issues

The separated, remote structure provided new levels of control. Immediately on entering the facility, all visitors, staff, trainees, and patients must register at a central desk and store in nearby lockers any metal materials they are wearing or carrying. The reception staff also advises at-risk individuals not to enter this zone.

On the exterior, aluminum fences restrict circulation outside of the 5 Gauss Line.

Figure 4: Exterior view with security fences CMRR; RSP Architects, Ltd. Photo by Philip Prowse.

Balancing the Forces of Attraction

Beyond tackling the site and essential layout issues associated with the Gauss Line boundaries, the design team had to address how the magnets would affect each other, their impact on building operations, and how to properly shield the magnetic fields from interference.

Achieving the ideal placement of four high-field magnets in a single building was particularly challenging because the CMRR's magnets generated incredibly strong magnetic fields of varying sizes. The minimum distance required between magnets depended upon their respective strengths.

To ensure that the magnets' axes were properly located, the architects and CMRR staff decided to align the magnets in both the x and y directions with equal distances between them.

Placing the magnets at the four corners of a concept diagram directed the form of the building and inspired creation of the central commons area.

Figure 5 – Diagram illustrating influence of the magnetic fields on the building form. CMRR; RSP Architects Ltd.

This arrangement achieves symmetry in the fields, enables the fields to push against each other, and maximizes the separation between the magnets. It also creates neutral or "low field" areas between them that can be occupied by people and where electronic equipment, such as computers or office machines, can function without interference.

The main lobby, commons area, offices, classrooms, wet labs, seminar room, electronic equipment rooms, and support areas are all located in neutral zones. Computers that are very close to the high-field magnets use liquid crystal screens because the magnetic fields distort the image of a typical CRT and can erase digital data.

Maintaining Pure Magnetic Fields

CMRR researchers also stressed the importance of maintaining pure magnetic fields. To accomplish this, the design team minimized the iron shielding around each magnet and took steps to prevent other forms of interference by eliminating ferrous material within the building's envelope and structure.

Controlling Environmental Conditions

Three out of the four magnet rooms at the CMRR have special protection from outside radio waves. In these instances, a copper box constructed around each magnet provides radio frequency shielding on all six sides.

Figure 6 – Copper box enclosure for high-field magnet. CMRR; RSP Architects, Ltd.

Building systems or equipment that penetrate the copper box are routed through wave guides or filters to eliminate possible interference from outside radio waves. Temperature and humidity levels are strictly controlled within the experiment zones to dissipate effectively the high levels of energy generated in these areas.

Since vibrations can distort research results, the magnets are set on four-foot thick, concrete isolation slabs that are completely separate from the rest of the building's floor structure. Half-inch-thick rubber pads line the perimeter of each slab to further minimize vibration.

Science and Synergy

The CMRR not only supports a tremendous range of collaborative research between departments at the University of Minnesota, it also provides centralized resources, critical data, hardware, and software innovations, and high-powered instrumentation for researchers across the U.S. and around the world.

It was clear that the new building should reflect the CMRR's international standing and enhance its interdisciplinary approach to research. Thus a unifying design objective was to create a place for synergy, where researchers could immerse themselves in their work, gather to exchange ideas, and build upon each other's findings. Such a place would also enable the CMRR to continue to attract top faculty, staff, and students.

The design team responded by organizing building functions into four programmatic areas, providing flexibility; creating formal and informal group gathering spaces; and selecting materials, engineering systems, and forms that address the unique challenges of the CMRR. These design elements express the high-tech nature of MR research while conveying the open, collaborative spirit of the building's occupants.

The Organizational Structure

Figure 7: Building plan illustrating organization of major functions. CMRR; RSP Architects Ltd.

Primary building functions of the CMRR are organized into the following areas:

- **Human Research:** Anchored on one end by a 4.0 Tesla/90 cm bore magnetic resonance (MR) spectroscopy and imaging instrument and by a new 7.0 Tesla/90 cm on the other, equipment housed in this area generates some of the highest magnetic fields available for human studies.

  Providing sufficient space and specialized construction for the second magnet for humans and including a "mock magnet room" ranked at the top of the client's planning priorities for this area. Volunteer patients are trained for the exact conditions they will experience during the actual study in the mock magnet room. Such preparation is essential to the accuracy of brainmapping studies.

  Since many of the patient volunteers must be transported to the CMRR from the medical campus, this area also provides ambulance access and a satellite nursing center with all of the infrastructure needed to care for ill patients on a short-term basis.

- **Animal Research**: Whereas the existing CMRR facility had no animal housing areas, the Research Animal Resources (RAR) Core in the new building is a full-service animal care unit with spaces for animal husbandry, facility maintenance, and veterinary care.

  In addition to two magnet bays that house one 4.7 Tesla instrument and one 9.4 Tesla instrument, this area contains: procedural suites, a common RF equipment room, a separate receiving area, a quarantine area, a complete diagnostic laboratory, and provisions for proper disposal of biohazards and other waste.

  Figure 8: The 9.4 Tesla instrument. CMRR; RSP Architects, Ltd.

  Figure 9: The 4.7 Tesla instrument. CMRR; RSP Architects, Ltd.

  This area also features environmental monitoring and control, an independent HVAC unit with a 100-percent fresh-air supply and exhaust, a security system, cage and rack washer, kennels, and disinfectant hose stations.

  Concrete-masonry walls surround the animal rooms. Wall cavities are filled with sand to isolate sound and treated with pest-control chemicals. This entire area is under negative pressure relative to the rest of the CMRR building.

- **Shared Resources:** The computational resources of the existing CMRR had evolved rapidly due to swift developments in functional magnetic resonance imaging. The new facility brings these and other shared resources into a cohesive structure.

  It includes a room for the central server and data storage systems, an image viewing room, and various work stations for staff, faculty, and students who develop the equipment and software needed to generate and present research paradigms, monitor responses, analyze results, and visualize magnetic resonance images.

Providing a centralized resource for rapid, large-capacity data storage made the CMRR the first building on the university's campus to be wired for fiber optic communications.

An electronics workshop, a mechanical workshop, and three wet labs (for blood and tissue analysis) are located along a corridor that connects the animal and human cores so researchers in each area can share these facilities.

The mechanical and electrical building-support areas are located outside of the 5 Gauss Line to minimize the magnetic effect on motors and transformers.

Figure 10: Wet lab. CMRR; RSP Architects, Ltd.

- **Scientific Exchange and Synergy:** A single-story, 38,000 square-foot building with a warm, red brick veneer exterior greets researchers from around the world. A clerestory crowns the commons area that runs more half the length of the CMRR, which bathes the center of the building in natural light that spills into open office areas, conference rooms, and other areas via glass interior walls and windows.

The rhythmic vectors created by the reception desk and the walls of a locker hub, open offices, computer work room, and conference room combine with curved patterns in the carpet to usher visitors from the entry vestibule to the receptionist and on into the heart of the CMRR.

Figure 11: View of the Central Commons Area. CMRR; RSP Architects, Ltd.

The commons area is the genesis of the synergistic core, creating an activity center for researchers. It strengthens the sense of community by providing a place for informal and formal gatherings or chance encounters between faculty, staff, and students. The opportunity to share information and insights is critical to advancing knowledge.

Flexibility

The new CMRR building acknowledges that fluidity and spontaneity are key to achieving breakthrough discoveries in scientific research. The design team addressed this issue by maximizing the flexibility of equipment-intensive and specialized research areas.

For example, the design provides ample space for installing multiple RF-amplifying systems to accommodate rapidly changing technology, minimize downtime, and facilitate experimentation. Raised floors and dual cable tray systems provide easy access to cabling and connections. The cable trays serving permanent building systems, such as fiber optic networking, are concealed. A second, exposed system provides immediate access for experiment-specific cabling. Perforations in the raised-floor surface allow air to circulate and cool equipment.

CMRR researchers now have sufficient space for their equipment and an environment that enables them to reconfigure it quickly and easily.

Systems and Materials

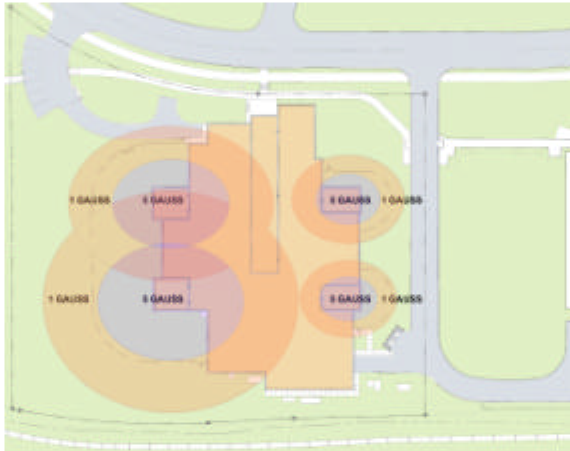
As previously noted, the magnetic fields created by the CMRR's instruments prohibited the use of ferrous objects in specific areas of the building. This criterion extended into the design of the building's structural, mechanical, and electrical systems. It also governed and informed the use of finish and construction materials.

In the general building and magnet areas, the CMRR has a wood-frame structure. The service and animal areas have concrete block walls and a precast plank-roof structure. Non-ferrous structural materials used in close proximity to magnets include wood doors, wood or aluminum door and window frames, fiberglass-reinforced concrete footings, five-inch slab-on-grade floor construction, and concrete masonry foundation walls.

Interior partition walls are constructed of wood studs, gypsum board and nonmagnetic fasteners. The air distribution system serving the magnet areas and the cable trays used for routing voice/data services are aluminum. Lighting in the MRI rooms consists of special, nonmagnetic, DC incandescent fixtures.

Protecting and ensuring the reliability of sophisticated electronic equipment and computers was also critical for CMRR staff. This equipment generates enormous heat, which requires consistent cooling, and even a brief power outage could lead to a loss of irretrievable data, which could substantially delay research projects. Thus the CMRR is equipped with a 100 kW/125 kVA emergency generator that serves an uninterruptible power supply (UPS) system, the main computer, the chilled-water loop, and life-safety systems. The building is fully sprinklered and a FM200, clean-agent fire suppression system protects the raised-floor equipment areas.

The design also creatively employs finishes to convey information about the building. For example, the edge of the carpet signals the perimeter of the neutral zones, with the curves in the carpet pattern communicating the positions and pull of the four magnets.



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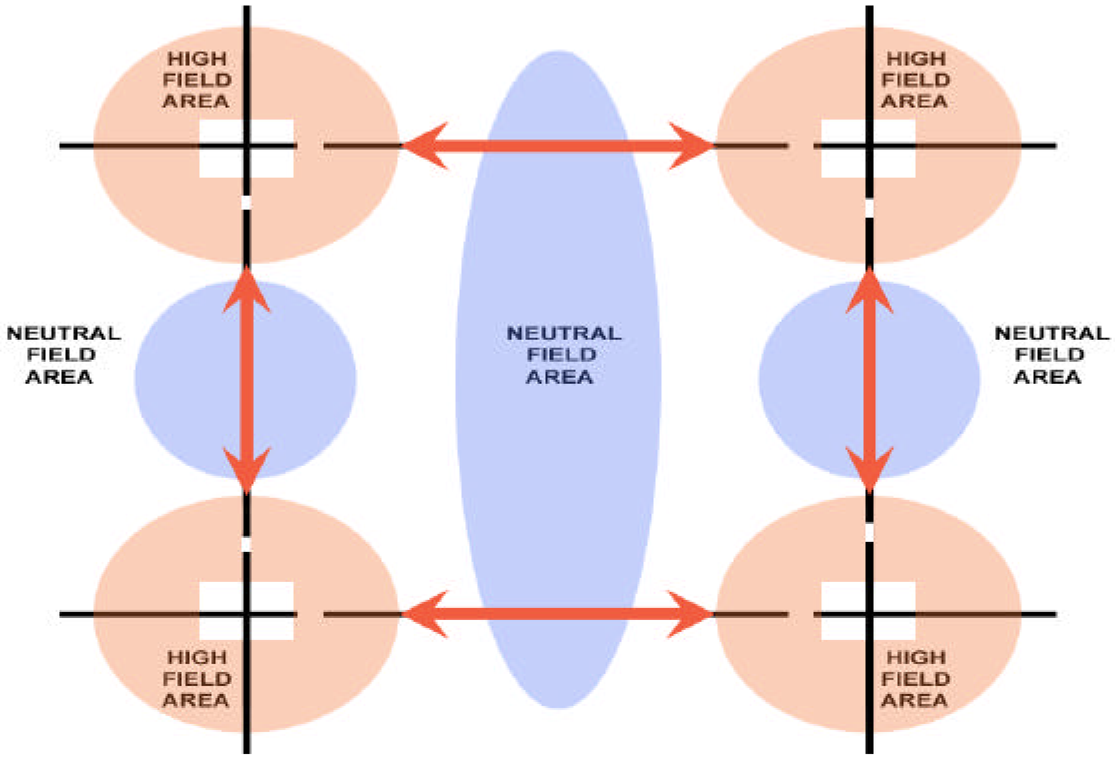

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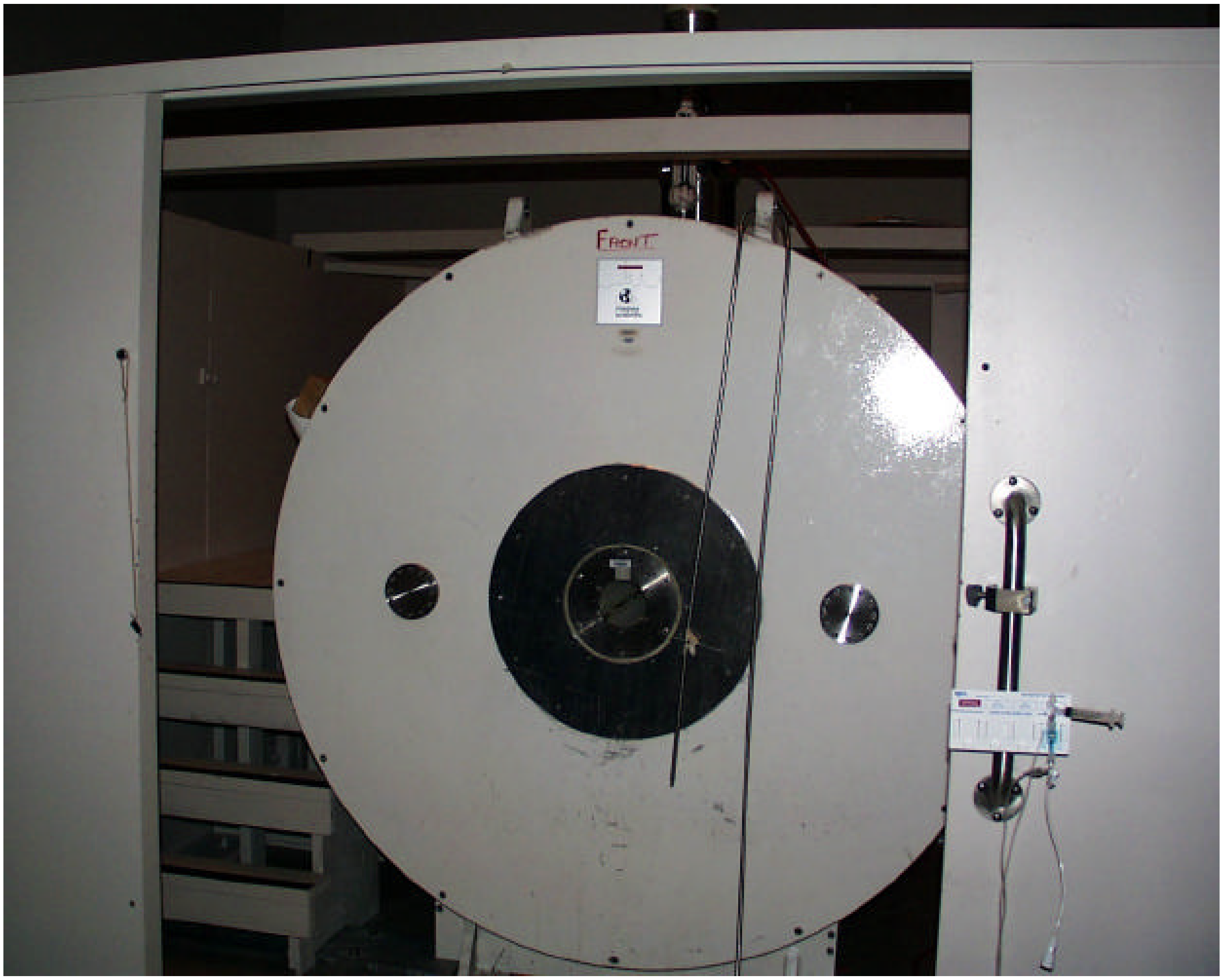

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