



Section 2: Narrative

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General Considerations

Overview

What Is MRI?

Magnetic Resonance Imaging (MRI) uses strong magnetic fields to induce resonance at the nuclear (atomic) level. As the orientation of the magnetic field is manipulated and atoms are knocked off-axis, they emit faint radio frequency energy as they return to their polar orientation. These emissions are measured and allow a computer image to be created by the analysis of the frequencies emitted by resonating atoms comprising cell structures. The image is electronically enhanced, recorded on video, stored on tape or optical disk and reproduced as a laser image.

MR reflects tissue density and body chemistry and is particularly useful in providing images of soft tissues. It offers the advantage of altering the parameters of the exam to specifically respond to the medical question being asked. By changing the exam parameters, tissues in the body may take on different appearances, which is extremely helpful in determining if something seen is normal or abnormal. MRI is also used to image blood flow which is useful for vascular diagnostics.

Unlike conventional X-ray and X-ray-based imaging technologies, such as Computed Tomography (CT), MRI acquires images without the use of ionizing radiation. The magnetic fields generated by contemporary clinical MRI equipment are tens of thousands of times greater than the Earth's own magnetic field as we experience it.

To generate such powerful magnetic fields, MRIs are sometimes high-strength permanent magnets in which the magnetic field can not be dissipated. More commonly used for clinical imaging, however, are electromagnets which generate the magnetic field from electricity passing through a magnetic coil. Most electromagnetic clinical MRIs use coils which are bathed in cryogenic liquid (typically liquid helium) to make them superconducting.

The unique properties of Magnetic Resonance Imaging result in a number of distinct planning, siting and operational challenges. Three types of MR formats are currently in use. The most prevalent is the "bore format". A magnetic field generated by a bore format MRI resembles a lozenge shape for which the magnetic field is primarily horizontal. The second most prevalent format is "open style" which often consists of magnetic fields generated from above and below the patient scanning area. Magnetic fields for open format magnets are more vertical in orientation and may present particular challenges with respect to occupancies and equipment located above and below the MRI scanning room. "Stand up" format magnets are essentially open magnets, turned on their side. The gross shape of the magnetic field generated by a stand up format magnet will be more similar to that of a bore format magnet, with a greater horizontal component. It is important to note that the magnetic field for all MRI scanners, irrespective of strength or format, is a three-dimensional volume and requires appropriate site design considerations.

Current Trends

Clinical Magnetic Resonance Imaging (MRI) is a specialized diagnostic imaging tool capable of anatomic imaging, tissue chemical analysis as well as functional imaging of certain meta-

bolic processes. The breadth of the modality's application, coupled with ongoing advancements in MR technology, continuously leads to new clinical applications. Operational, clinical and technical factors can be expected to change in response to these dynamic conditions.

Throughout MRI's clinical history, the modality has been used to produce anatomical images for diagnosis of disease. Currently, this role is undergoing a significant expansion as MR is serving as an enabler for a variety of interventional applications. MR guided Focused Ultra Sound (MRgFUS) is being used to treat uterine fibroids, MR imaging is being used to guide soft tissue biopsies, and clinical research is underway to capitalize on the incidental heating that occurs during MR examinations and use it to improve the outcomes of radiation and chemo therapies. MRI is also being used intraoperatively to provide diagnostic feedback during a surgical procedure.

Future Trends

As technology evolves, MRI will not only provide anatomic imaging but will also be able to image a greater range of physiological, metabolic and molecular functions in the body. MRI will not only see anatomy, but also image how molecules are behaving. This will promote new ways of using MRI for patient treatment. For example, MRI used during radiation therapy or chemotherapy will allow the physician to determine if a tumor is being treated successfully. MRI will be used in conjunction with other imaging modalities to aid in improved methods of treatment.

It can be expected that the future will see increases in the breadth of both diagnostic and interventional imaging applications for MRI. Developments over the last 30 years of MRI also suggest that the strength of the magnets used for these devices will continue to increase. Anatomy-specific MR devices will also grow in utilization and may result in MR equipment being sited in a variety of practice areas.

At the time of the publication of this Design Guide, 3.0 Tesla MRI scanners comprise the fastest growing segment of the MRI equipment market. Sites installing 1.5 Tesla MRI scanners should, at a minimum, anticipate a future replacement / upgrade to a magnet with site requirements similar to those of contemporary 3.0 Tesla MRI scanners.

Functional Considerations

Operations

Magnetic Resonance Imaging is a program that is part of the Radiology Service. MRI should be coordinated with associated and complimentary diagnostic services to provide an efficient and patient focused model of care.

Imaging Process

MRI is performed on inpatients and outpatients on a regular and scheduled basis. Services are also performed on an unscheduled basis for emergency patients. The VA has adopted an MR Exam duration averaging 45 minutes (including room set-up and break-down). Prior to the exam, however, patients must undergo a thorough screening process to assure their safety and that of the staff.

Patient Care Concept

MRI is frequently a centralized function due to the high cost of the technology, the highly specialized space criteria dictated by permanently installed equipment, and the specialized staffing requirements. MRI will most often be hospital based although the opportunity for satellite imaging facilities is possible if warranted by projected patient usage.

Patient Base

VA MRI Imaging facilities are focused upon serving the Veteran and may include sharing agreements and joint ventures. The aging veteran patient population with co-morbidities and increased severity of illness necessitate design features that emphasize safety and prevention of risks. These co-morbidities coupled with the increasing interventional and emergent uses of MR technology are principal factors in the revisions presented in this Design Guide. All veterans should be provided with a designed environment that promotes accessibility, independence, and dignity.

Medical Records

Diagnostic evaluations generated within the department become part of the veteran's consolidated Health Record with electronic data stored locally within the MRI Service or within a central location. Evaluations are communicated to the ordering physician in electronic form as required. Image manipulation, interpretation, archiving, retrieval, and distribution procedures may occur within the MRI Service or may be consolidated with the Radiology Service.

Patient Protocol

Referring physicians order outpatient and inpatient procedures that occur during regular business hours. Unscheduled and off-hour procedures will depend on the level of care authorized.

Special Requirements

Teaching facilities will require more technical support space, including spaces for small observation groups, interpretation areas, and image manipulation areas. Coordination with related departments, facilities, and program missions is required to verify space needs. These may include patient prep, anesthesia induction and recovery, procedure recovery, exam, and stretcher holding spaces. Related departments may include:

- Hospital – Nursing Care
- Long Term Care Facilities
- Ambulatory Care
- Emergency Service
- Surgical Service
- Satellite Facilities

Space Planning Issues

Human Factors

The VA is committed to providing a healthcare facility that includes components that create a healing environment. It is important that the design of MRI reinforces this concept. Patient's vulnerability to stress from noise, lack of privacy, poor lighting, and other causes, and the harmful effects it can have on the healing process is well known and documented. Large-sized unfamiliar equipment is an additional cause of patient stress. Patient dignity and self-determination should be accommodated while considering operational efficiencies. De-emphasizing the institutional image of traditional health care facilities and surrounding the patient and family members with architectural finishes and furnishings that are familiar and non-threatening should be a prime objective. It is important to remember, however, that this is a healthcare environment and ease of maintenance, durability, and sanitation should be primary considerations when selecting materials and finishes. Planning, design, and detail consideration should address security issues. The application of UFAS and ADA design standards for space and fixed equipment locations satisfy accessibility requirements. An inherent opportunity exists in the design of MRI facilities to address these issues and put forth creative solutions that enhance patient comfort and contribute to positive outcomes.

Efficiency

Economies of shared facilities, functions and staff may be possible with the installation of MRI systems in proximity to other modalities. It is important to note, however, that patient preparation and screening for MR exams is significantly different from that performed for other modalities. In the interest of patient and staff safety it is advised that facilities be planned and constructed to segregate successfully screened MR patients from other patients and restrict access to the MRI scanning room in accordance with the American College of Radiology Guidance Document for Safe MR Practices: 2007.

Contemporary actively-shielded magnets allow MRI technology to be located nearer to equipment and operations which are sensitive to magnetic fields and nearer fixed and moving metallic objects such as building structure, elevators, and vehicular traffic than prior generations of unshielded magnet systems. However, there remain many potential siting conflicts in which building systems and equipment may interfere with MRI operation and where the magnetic fields generated by MR equipment may negatively interact with nearby equipment or devices. Space-planning efficiency goals should not supersede prudent siting practices, which will vary by magnet system and vendor siting parameters.

Technical and Environmental

MRI equipment is sensitive to several environmental factors, and imposes potential hazards that should be factored into site preparations. Site selection and preparation should prospectively account for each of the following factors:

Radio Frequency (RF) Shielding

All current clinical MRI equipment requires Radio Frequency (RF) shielding. This shielding prevents incidental RF energies from entering the scan room and disrupting the MR acquisition process. RF shields may be constructed of thin sheets of copper foil, galvanized steel or aluminum. RF shield assemblies must be contiguous on all sides, floor and ceiling. All provided doors and windows in the MRI scanning room must be RF shielded. Similarly, all

penetrations into the RF shielded enclosure (including power, HVAC, exhaust, piping, and plumbing) must pass through special RF filters or wave guides.

RF shielding typically provides no attenuation of the magnetic fields which will penetrate standard forms of construction. In this regard, RF shielding provided for MR equipment functions opposite of shielding provided for X-ray equipment. Whereas shielding provided for X-ray equipment is installed to contain the potential hazard, RF shielding for MR equipment is intended to keep disruptive signals out of the MRI scanning room and does nothing to contain the magnetic field of the MRI.

Passive Magnetic Shielding

Passive magnetic shielding, typically provided in the form of sheets of solid or laminated steel alloy plates, can be provided in addition to RF shielding for the purposes of attenuating the reach of the magnetic field beyond the MRI scanning room. Effective siting which provides appropriate separation between the MRI and magnetically sensitive equipment or accessible hazard areas should mitigate the need for passive magnetic shielding. However, there are conditions in which passive magnetic shielding is the preferred design solution. Passive magnetic shielding requirements will vary with magnetic field strength, spatial gradient, magnetic field orientation, and the proximity of magnetically sensitive equipment. It is worth considering that the weight of the steel shielding may necessitate structural modifications to support it.

Unlike RF shielding, passive magnetic shielding does not need to be contiguous on all surfaces and can be applied one or more surfaces, either interior or exterior to the RF shield, to provide magnetic field attenuation in the desired direction. Passive magnetic shielding does, however, need to be engineered to minimize the distortion of the magnetic field in the center of the MRI scanner. This may necessitate the placement of compensating or balancing steel opposite the surface receiving the passive magnetic shielding for attenuation purposes.

Passive magnetic shielding is different from active shielding, with which most contemporary MRIs are provided. Active shielding is a series of electromagnets internal to the MRI scanner which act as a magnetic 'girdle', restricting the normal expanse of the magnetic field. Some actively-shielded MRI systems have a failure mode in which the active shielding fails and the magnetic field 'blooms' significantly larger than normal. Design of a MRI suite and passive magnetic shielding should take into account adjacent equipment and populations and their risk factors for magnetic field exposure, under normal and failure conditions.

Ferromagnetic Shim Tolerances

MR imaging depends upon a volume of space within the center of the MRI scanner where the magnetic field is uniform in strength. Ferromagnetic materials used in the construction of the MRI suite, particularly in the floor of the MRI scanner room, can shift and distort this imaging volume. Small amounts of ferromagnetic disturbance can often be corrected by the scanner through a process called 'shimming.' Larger quantities of ferromagnetic disturbance can reduce the effective field of view possible for imaging and can degrade the clinical quality of diagnostic images. Shim disturbances can impact image quality to a point where the MRI may not pass stringent accreditation requirements. Each MR system has vendor-provided shim tolerances for the mass of ferromagnetic material that can be placed in proximity to the MRI. As a general rule, non-ferromagnetic materials are recommended for construction in the immediate vicinity of the MRI scanner. Significant changes to masses of ferromagnetic material outside of the MRI scanner room can necessitate re-shimming to correct for the new distortions.

Moving Metal Sensitivity



While MRI scanners may be shimmed to correct for static or unmoving magnetic materials, moving metal objects in proximity to the MRI scanner can have similarly disruptive effects which can not be corrected through shimming. Sources of moving metal interference can include elevators, cars and trucks, trains, helicopters, even rolling carts. The mass of the moving ferromagnetic object and its distance from the MRI are factors in the amount of disruption that the object can cause. It is best to site MRI scanner rooms away from sources of moving metal. The effective distances required are proscribed by MRI equipment manufacturers. Moving metal interferences can be corrected retroactively, in many cases, through the use of magnetic active cancellation systems.

Electromagnetic Interference

MRI electronics are sensitive to distortions in the electromagnetic field. The proximity to high-amperage power lines, electrical switchgear and transformers, are crucial siting considerations. The effective distances required between MRI equipment and potential sources of electromagnetic interferences are proscribed by MRI equipment manufacturers.

Vibration

As MRI measures radiofrequency responses at the atomic level, vibration can be profoundly disruptive to MR processes. Disruptive vibration can be telegraphed through a building's structure from either external (vehicle traffic, construction or trains, for example) or internal sources (pumps, motors or fans, for example) to the MRI equipment. When possible, it may be advisable to structurally isolate the MRI scanner room from the rest of the building. In elevated floors, however, this may not be possible. Structural systems should be designed with the expressed intention of minimizing vibration in the frequency and amplitude ranges defined by the MRI vendor that are known to be disruptive. For retrofits of MRI equipment in existing structures, it is advisable to obtain site vibration testing early in the preliminary design phase. Many MRI vendors offer vibration mitigating solutions, but these often have significant design implications.

Sound

Many contemporary MRI scanners are capable of producing sound pressure levels well in excess of 110 decibels (dB), the human pain threshold, during certain scan procedures and there are many reports of hearing damage. Without proper design considerations, sound from MRI equipment can be extremely disruptive to other occupants in the building. Just as vibration can travel through a building's structure to an MRI, so, too, can acoustic frequency vibration be telegraphed through building components to surrounding spaces. Construction details and material selections should be carefully considered to maximize absorption and dissipation of acoustic noise from MRI equipment.

Temperature / Humidity

MRI scanner and computer equipment often have stringent parameters for maximum and minimum temperature and relative humidity levels, as well as maximum hourly changes. These thresholds are likely more restrictive than requirements for surrounding areas. Supplemental cooling, humidification or de-humidification may be necessary for these areas. Consult with the MRI vendor's environmental criteria for equipment siting and operation.

Work Flow

Beyond the technical siting considerations for the MRI equipment, of principle importance in the planning and design is the effective and efficient flow of patients, staff and supplies to support maximum safe throughput.

Patients

Arrange reception, clinical and physical screening procedures sequentially.

Identify and 'quarantine' all ferromagnetic materials. Provide transport, portable oxygen, and other supports tested and labeled 'MR Conditional' or 'MR Safe' under current ASTM / FDA criteria for patient use inside secured areas of MRI suite (Zones III and IV).

Provide a single secured point of access for successfully screened inpatients and outpatients.

Provide spaces as operationally / clinically indicated for post-screened patient holding, MRI exam preparation and sedation / anesthesia induction and recovery.

Staff and Administrative Functions

Staff and Administrative areas are to be located outside of patient traffic areas.

Staff functions may be located within the department or in a convenient location shared with another department (frequently with Radiology Service) though patient access should remain segregated.

Clean and Soiled Materials

Locate Clean and Soiled Utility functions close to the patient areas that they support and also away from patient traffic. Consider incidental staff access and safety issues when locating support facilities.

Organizational Concepts

Functional Plan

Reception is strategically located to control access to the patient areas and to secure the MRI from unauthorized access.

The MRI Control Room and the System Component Room need to be adjacent to the MRI Scanning Room.

The MRI Control Room should be located such that the technologist, when seated at the operation console, has a view of the approach to the MRI Scanner Room Door.

The MRI Control Room and MRI Scanner Room should be configured to provide the technologist, when seated at the operation console, a view through the RF shielded window to the patient inside the MRI scanner.

Safety Layout

The 4-Zone suite organization as identified in the American College of Radiology (ACR) *Guidance Document for Safe MR Practices: 2007* and its appendix 2, *MR Facility Safety Design Guidelines*, are recommended for the planning of MRI facilities.

Additional information on MRI suite safety is available in the Safety Considerations section of this document.

Building System Integration

Coordinate locations of depressed slabs, under-floor conduit, recessed floor trenches and structure for equipment, electrical access, and radio frequency and / or magnetic shielding.

Evaluate the need for computer access flooring on a project basis. Coordinate with MRI equipment vendor.

Consider the size and weight of the magnet when establishing locations of facilities. This could require that this service be located on the lowest floor of the facility.

Electromagnetic interferences must be considered in relation to the location of other services located near the MRI Service.

MRI systems, whether provided with passive magnetic shielding or not, require consideration of magnetic fields when establishing room and equipment layouts.

Non-ferromagnetic structural systems are recommended to support MRI equipment.

When steel supported structures are used, ferromagnetic materials must be arranged in a fashion symmetrical to the magnetic field and within allowable shim tolerances, or they may impose special requirements for shielding and compensating steel.

Installation within multiple story facilities may impose planning and operational restrictions on spaces above and below the MRI as a result of the vertical components of the MRI's magnetic fields.

Patient Access / Way Finding

MRI facilities should be located to provide patients with convenient access to parking, ambulatory care, and inpatient access. The location with other diagnostic facilities assists in way finding and coordination of patient services.

Functional Adjacencies

MRI Service should be located as follows:

Close and on the same floor

- Radiology Service
- Ambulatory Care

Close to or on the same floor/ different floor acceptable

- Emergency Department
- Cardiovascular Laboratories
- Digestive Diseases Service
- Intensive Care Nursing Units
- Medical Research and Development
- MS&N Nursing Units
- Nuclear Medicine Service
- Pulmonary Medicine
- Radiation Therapy Service
- Physical Medicine and Rehabilitation Service
- Spinal Cord Injury Center (SCI)
- Surgical Service

Separation Desirable:

- Audiology and Speech Pathology Service
- Canteen Service / Dining Facilities
- Sleep Labs

Despite recommended adjacencies, MRI equipment siting must consider equipment and device sensitivities to magnetic fields emanating from the MRI scanner. This may necessitate minimum separation distances between MRI and Nuclear Medicine, CT, PET, PACS servers and other equipment. These separation distances may apply both horizontally (equipment on the same floor) as well as vertically (equipment located above or below the MRI scanner).

Services Access

MRI installation and replacement requires crane access and a direct route for magnet passage. Superconducting MRI scanners also require periodic cryogen service. Cryogen replenishment is accomplished via cryogen dewars typically brought to the site by third-party contractors. Access is required around and above the magnet for cryogen service.

Magnetic Field

A 1.5 Tesla magnet will generate a magnetic field strength of 15,000 gauss at the magnets' isocenter. This is approximately 30,000 times the strength of the Earth's own magnetic field. The magnetic field diminishes rapidly as the distance from the isocenter increases. The FDA requires that all areas around MRI scanners where the magnetic field is equal to or greater than 5 gauss must be restricted to only those individuals who have successfully completed screening for potential contra-indications. Though many MRI Scanner Rooms for 1.5 Tesla magnets can be designed to contain the 5-gauss line in plan, the magnetic field will project vertically as well and may present hazards to occupancies above and below. The magnetic fields surrounding 3.0 Tesla systems are incrementally larger than those of 1.5 Tesla systems. "Open" MRI systems typically have magnetic fields that have larger vertical dimensions and may present greater hazards to occupancies and equipment above and below. Even unoccupied or nominally occupied areas that fall partially or wholly within the 5-gauss volume, including rooftops, mechanical areas or storage rooms, should be provided with warning signage and access restrictions.

Flexibility

Certain technical space requirements impose special constraints on the location and design of MRI facilities including:

- The size and weight of the magnet
- Venting / exhaust requirements
- Sensitivity to radio frequency interference
- Cryogen service
- Interference from the magnetic field generated by MRI magnet
- Sound isolation
- Vibration isolation
- Future equipment upgrade / replacement

Although specific requirements for an individual system may be identified, the facility should be designed to accommodate a wide range of MRI technology to maximize the potential for future equipment selection options. These design considerations should include the weight, vibration and shim tolerances of more advanced magnet systems. Specifically, contemporary 1.5 Tesla magnet suite designs should anticipate a future replacement / upgrade with a 3.0 Tesla MRI. It would be a mistake to assume that a suite built to a single piece of equipment's minimum standards will be able to readily accept a different MRI without significant alteration to the MRI suite construction.

Technical Considerations

General

Seismic

Where required, install all components and equipment with seismic provisions as outlined in the various discipline specific VA Design manuals for healthcare projects. Refer to VA Construction Standard Handbook PG-18-03 (CD-54), "Natural Disaster Resistant Design Non-structural" for additional information. Consult with MRI equipment vendor for specifications for anchoring MRI scanner and electronics cabinets in seismic zones.

Mycobacterium Tuberculosis

Current Center for Disease Control (CDC) requirements for design of public areas within the building to accommodate Mycobacterium Tuberculosis patients must be addressed by architectural and mechanical disciplines. Check current requirements with the VA task force on transmission of Mycobacterium Tuberculosis, TB criteria in HVAC Design Manual for Hospital Projects, and the CDC Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Healthcare Settings, 2005.

MRI Space Allocation

MRI Service space requirements are outlined in the VA Space Planning Criteria: Chapter 275 Magnetic Resonance Imaging. Space allocation may need to be modified per MRI manufacturer's recommended room dimensions and based on clinical applications for interventional care, emergent exams or projected future equipment requirements.

Sustainability

In 2006, the Department of Veterans Affairs joined other Federal agencies who are participating in principles outlined in the Memorandum of Understanding for the Federal Leadership in High Performance and Sustainable Buildings. The purpose of these guidelines is to encourage the use of life cycle concepts, consensus-based standards, and performance measurement and verification methods that utilize good science and lead to sustainable buildings. The goals of the members of this initiative are to establish and follow a common set of sustainable Guiding Principles for integrated design, energy performance, water conservation, indoor environmental quality, and materials aimed at helping Federal agencies and organizations:

- Reduce the total ownership cost of facilities.
- Improve energy efficiency and water conservation
- Provide safe, healthy, and productive built environments
- Promote sustainable environmental stewardship

These principles should be addressed in the design of all VA facilities. The specific recommendations presented in this MRI Design Guide are intended to be beneficial to life-cycle costs associated with MRI services by reducing maintenance and interruptions to operation,

as well as enhancing staff efficiency and minimizing costs and downtime associated with equipment service and upgrades.

Architectural

Interior Materials and Finishes

Partitions

Partitions around the MRI Scanner Room are typically three distinct assemblies. The 'parent wall' is typically framed and sheathed to the underside of the deck above. The interior (MRI Scanner Room side) of the parent wall assembly is often prepared to a level 2 finish (tape and joint compound, unsanded). The RF shield wall typically stands independent from the 'parent wall,' often with a 2-inch ground isolation cavity. The interior 'finish wall' of the MRI scanner room can be independently framed or furred off of the RF shield wall. Consult with MRI system vendor and RF shield vendor on furring / framing material requirements or restrictions. Light gauge metal studs may be permissible, though fire-treated lumber may be preferable (code authority permitting). Acoustic insulation should be incorporated in the parent wall assembly and finish materials with high STC values should be used throughout the MRI Scanner Room construction. If required, passive magnetic shielding would be typically be installed between the parent wall and the finish wall along with the RF shield.

Windows and doors to the MRI Scanning Room must provide radio frequency (RF) shielding. RF Shielding requirements should be coordinated with the equipment manufacturer and reviewed by a registered health physicist.

The remaining interior partitions elsewhere in the suite should be primarily painted gypsum wallboard on metal studs. Partitions enclosing physician offices, exam rooms, and treatment rooms should be provided with sound attenuation batts between the studs in accordance with H-18-03, VA Construction Standard CD 34-1, Noise Transmission Control.

Floors

Similar to the multi-layered assembly that comprises the MRI Scanner Room walls, floors in MRI Scanning Rooms require a structural subfloor, RF shielding, a protective layer and finish materials. The thickness of the overall RF shield and finish assembly requires that the MRI Scanner Room structural subfloor typically be recessed 1 to 2 inches to avoid ramped thresholds at the MRI Scanner Room entry. The depth of the recess is dependent upon the shield vendor's requirements and must be coordinated. The RF shield is laid on the structural subfloor. The shield material may be prefabricated into a panelized assembly with an integral protective layer, or the RF shield material may be applied directly to the subfloor and protected with either panels or a monolithic grout cover. The floor finish is then applied to the protective layer. Finish flooring in the MRI Scanner Room should be seamless sheet material with a flash-cove base. Many MRI vendors are requiring either astatic or static dissipating flooring materials in the MRI Scanner Room.

Some MRI scanners require a recessed floor trench between the MRI and the MRI System Component room. Subfloor, RF shield, protective cover and finish flooring designs must be modified accordingly, when required.

Some MR Conditional devices, such as anesthesia machines and ventilators, are safe for use up to a manufacturer-specified field strength. Without environmental cues, it may not be

possible for persons operating the equipment inside the MRI Scanner Room to identify the area for safe operation. It is worth considering transposing the location(s) of gauss lines, such as the 5-gauss line or limits for the safe use of clinical devices such as ventilators or anesthesia machines, on floor finishes within the MRI Scanner room.

A computer access floor system may be required in the MRI System Component room and / or to cover the recessed floor trench in the MRI Scanner Room. Computer floor tiles used in the MRI Scanner Room must be non-ferromagnetic.

Floor materials in offices, conference rooms and waiting areas should be carpet with a four inch high resilient base. Floors in toilet rooms should be ceramic tile with a ceramic tile base. Use metal toilet partitions only in remotely located toilet rooms. Floors in most other spaces should be vinyl composition tile with a four inch high resilient base.

Ceilings

As with wall and floor assemblies for the MRI Scanner Room, ceilings in this room are made up of multiple components. The RF shield ceiling is typically suspended from the structural deck overhead. While every effort should be made to keep power, piping, cabling and ductwork from transiting above the MRI Scanner Room any services that must cross above the MRI Scanner Room should do so in the plenum above the RF shield ceiling. It should be noted that this area may be wholly inaccessible without shutting down the MRI, so serviceable equipment (VAV boxes, valves, etc...) should be relocated out from over the MRI Scanner Room.

The architectural ceiling is typically suspended from the RF shield ceiling. Sprinkler lines, lighting, HVAC ductwork, cryogen vent, MRI cabling and piping are run in this plenum between the architectural ceiling and the RF shield ceiling. All materials, fasteners, hangers and appurtenances used inside the RF shield should be non-ferromagnetic, whenever possible.

Any ceiling mounted specialties for the MRI Scanner Room (monitors, illuminated panels, injector arms, procedure lights, medical gasses, etc...) must be carefully coordinated for their attachment to the RF shield. Under no circumstances should anyone other than the RF shield vendor make any modifications to the RF shield system.

Ceilings should be primarily lay-in acoustic ceiling material. The ceiling suspension system in the MRI Scanning Room should be fabricated from non-ferromagnetic material. Coordinate the ceiling height requirements with the equipment manufacturer.

RF Shield Penetrations

Any penetration through the RF shield assembly must be carefully coordinated between the MRI equipment vendor and the RF shield vendor. Penetrations will require special fittings and materials to maintain shield integrity and to prevent ground loops through the RF shield.

Interior Doors and Hardware

There should be only a single point of entrance into the MRI Scanner Room. The door, frame and hardware for the entrance into the MRI Scanner Room is typically provided by the RF shield vendor. It is recommended that this door be a nominal 48 inch wide door. The RF shielded MRI Scanner Room door should swing out from the MRI Scanner Room in such a way that, in the open position, it does not block the view of the technologist seated at the operating console from clearly visualizing persons entering or exiting the MRI Scanner Room.

When permitted by code, roller-latches should be used on out-swinging RF shielded doors. Keyed deadbolts or magnetic locks can be provided to secure the MRI Scanner Room when not in use.

All metal used for the construction of the MRI Scanning Room shall be non-ferromagnetic, whenever possible.

Outside and immediately above the RF shielded MRI Scanner Room door should be an illuminated sign which indicates "magnet is on". This sign should be on emergency power or provided with a battery back-up to remain illuminated in the event of a power outage.

The remainder of the interior doors should be 1 ¾ inch thick solid core flush panel wood doors or hollow metal doors in hollow metal frames. Doorjambes should have hospital type sanitary stops that stop 8 inches from the floor to facilitate mopping. Hollow metal doors should be used where high impact is a concern and where fire rated doors are required. Kick / mop plates should generally be applied to both sides of the doors. Handicapped accessible hardware should be used throughout.

Refer to VA Handbook PG-18-14, Room Finishes, Door and Hardware Schedule, for additional information.

Structural

General

The size and weight of MR magnets is very significant. Structural framing should be configured to support the tremendous weight of the magnet and comply with the allowable shim tolerances established by the manufacturer. Non-ferromagnetic structural systems should be considered when possible. Consideration should also be given to the path that the magnet will travel during installation. Most MRI equipment is too large to pass through interior doorways and is often rigged into magnet rooms through specially designed knock-out wall panels or through roof hatches.

Floor Trenching

Some MRI equipment requires floor trenching. Identify areas where floor trenching is required to receive equipment infrastructure and coordinate among MRI equipment and RF shield vendors.

Maintaining Magnetic Field Homogeneity

The presence of ferromagnetic objects such as steel reinforcement and framing can distort the magnetic field and impact image quality. Mass, shape and distance of ferromagnetic materials relative to magnet isocenter should fall within manufacturer's limitations. Consider the use of non-ferromagnetic materials in the MRI Scanner Room construction.

Maintaining Magnetic Field Stability

Both steady state and transient floor vibrations can affect image quality. Steady state sources include electric motors and air handling equipment. These sources can often be isolated once identified. Transient sources include pedestrian and vehicular traffic. These

sources are very difficult to eliminate. Configure the structure to meet the vibration limits established by the equipment manufacturer.

Shielding

Radio frequency shielding is required for all clinical MRI installations and does not typically contribute significantly to structural loading. Magnetic shielding, by contrast, may be necessary to limit the effect the magnetic field has on adjacent occupancies and preserve image quality. Give proper consideration to the weight and support requirements of these materials. Floor depressions are necessary to accommodate shielding without significant elevation changes at thresholds.

Magnetic Contamination

Another concern about the use of ferromagnetic materials in the construction of the MRI Scanner Room is that these materials will become permanently magnetized as a result of exposure to the magnetic fields of a high-field MRI. While this magnetization will not negatively impact the MRI, if the space is ever converted to another use, the residual magnetic contamination may impair or incapacitate other electronic equipment or imaging modalities sited in the room and may even exceed safe levels of exposure for unscreened individuals. Magnetic contamination is difficult and expensive to reverse and may significantly restrict future uses of existing space until the magnetized materials are removed and disposed of.

Equipment

Casework

Casework may be millwork or modular. Casework systems should be chosen that provide flexibility for planning and utilization purposes. Casework systems should incorporate components dimensioned for ease of multiple re-use installation applications.

Within the MRI Scanner Room, all casework should be constructed of non-ferromagnetic materials. It is also recommended, both for ease of restocking and safe servicing, that facilities consider MR Conditional rolling casework and exchange carts for use in the MRI Scanner Room.

Information Management Systems

Information Management Systems shall include elements of image retrieval, processing, storage, treatment planning, electronic patient records including patient registration, patient charges, physician order entry, and patient / staff movement. When these systems are located in proximity to MRI equipment, additional shielding may be required. Some actively-shielded MRI systems have a failure mode in which the active shielding fails and the magnetic field 'blooms' significantly larger than normal. If this failure mode is possible for the MRI system, coordinate location and shielding for sensitive computer systems accordingly. These systems elements will require access to the main facility information system as well as the departmental local area network. All components should be planned for compatibility.

Picture Archiving and Communications Systems

It is the goal of the VA to implement Picture Archiving and Communications Systems (PACS) in all VA healthcare facilities. As this conversion to PACS is implemented, some existing facilities are currently utilizing conventional film processing. It is anticipated that any significant renovation will include conversion to PACS as a basis for design.

HVAC

Operation

Air conditioning systems should be provided to heat, cool and ventilate the individual spaces, as required to satisfy the VA design criteria.

Provide a dedicated computer-type AC unit to cool the MRI System Component Room. Verify the AC requirements with equipment supplier.

Humidification / dehumidification may be required for the MRI Scanner Room and / or the MRI System Component Room to keep the MR equipment and electronics within MR vendor tolerances.

Return air duct serving the MRI Scanner Room should be equipped with an electronically actuated damper, located outside of the MRI Scanner Room, to close whenever the MRI Scanner Room emergency exhaust fan is activated.

As directed by MRI equipment vendor's siting requirements, provide tie-in for magnet patient ventilation system

All ductwork , fasteners, hangers and appurtenances within the radio frequency (RF) shield shall be non-ferrous. Ductwork penetrations must utilize RF wave guides at the shielding feed-through points.

Capacities

The number of people and the air conditioning load noted on the room design standard sheet is for the purpose of establishing the basis of design guide and its use in planning. Verify the actual number of people and the air conditioning load to agree with the project requirements.

Verify equipment AC loads based on the actual equipment furnished on the project.

Provide a minimum of two air changes / hour of outside ventilation air to all spaces.

Air Quality and Distribution

All rooms shall have positive air pressure unless specified differently with respect to the adjoining areas. This is to help maintain a reduced dust environment for the electronic equipment.

The transferred air should be no more than 150 cfm (71.0 liters/sec) per undercut door.

Design of air distribution system shall be in accordance with criteria given in the HVAC Design Manual. Provide linear diffusers for the spaces qualified to receive linear diffusers.

Cryogen (Quench) Vent Pipe

Provide a dedicated cryogen vent pipe (quench pipe) run as directly as possible to the outdoors. The vent pipe must meet the pressure and diameter requirements of the MRI system manufacturer and is to be fully insulated to the point of discharge. At the discharge, the vent pipe must provide a weather-head to prevent the introduction of horizontally driven precipitation. Discharge direction should be downward. Cryogenic gas vent discharge should be located 25 feet from any air intake or operable window. The 25 foot radius exclusion zone should be clearly marked and staff and contractor personnel should be restricted from working in the area until they have been educated to the risks of cryogenic gasses escaping the vent pipe.

Emergency Exhaust System

Provide a dedicated emergency exhaust system to exhaust the MRI Scanning Room in the event of a cryogen discharge into the room. The system shall be activated either automatically by the MRI alarm panel (or oxygen sensor for MRI systems without a quench alarm relay) or a manual wall switch, one located inside the MRI Scanning Room and another located at the operator's console in the MRI Control Room. Locate the grille for the exhaust system in the ceiling to the rear of the MRI Scanner Room, opposite the location of the MRI Scanner Room door.

Overpressure Relief

All vendors of superconducting MRI now require a form of overpressure relief in the event of a cryogen breach into the MRI Scanner Room. Consult the MRI equipment vendor and RF shield vendor for recommended details. It is strongly recommended that overpressure relief systems not communicate with occupied areas and discharge to the exterior, whenever possible.

Micro bacterium Tuberculosis – refer to General Comments.

MRI waiting rooms to be minimum 12 air changes / hour. Supply air with all air exhausted to the outdoors.

Seismic – refer to General Comments

Noise Level

Select HVAC equipment, ductwork and air distribution devices to achieve noise levels listed in the VA HVAC Design Manual.

Provide hospital grade acoustic duct silencers in all ductwork that communicates between the MRI Scanner Room and any other occupied space.

Plumbing

Water and Waste Systems

If provided in the MRI Scanner Room, domestic water and drain lines must pass through RF wave guides and be provided with dielectric breaks for piping materials. Coordinate plumbing penetrations with both MRI equipment vendor and RF shield vendor. Because of mag-

netic hazards with most conventional tools, all MRI Scanner Room plumbing fixtures should be designed and specified to require minimum maintenance.

The remainder of the plumbing systems should be provided to satisfy the departmental plumbing needs.

The department's domestic cold water should be piped to all plumbing fixtures and equipment requiring this utility. A hot water return system should be provided to ensure the design temperature at the farthest outlet.

The department's plumbing fixtures and drains should be drained by gravity through soil, waste and vent stacks. In addition, the department's special waste should be drained through corrosion-resistant, flame retardant piping into either a local or centralized acid dilution tank.

When an emergency secondary water supply is required to serve as a backup for the equipment chilled water system, proper drainage and backflow prevention assemblies shall be provided.

Plumbing fixtures and equipment shall comply with the Uniform Federal Accessibility Standards (UFAS).

Medical Gas Systems

The department's medical gas outlets are shown to establish a base for the design guide and its use in planning. The engineers / designers shall verify the medical gas location and quantities for individual projects. Individual sites may require additional gasses beyond those indicated on the attached guide plates.

Fire Protection

The recommended fire protection for the MRI Scanner and MRI System Component Rooms is a wet pipe sprinkler system in accordance with the VA Fire Protection Design Manual and NFPA 75 - Standard for the Protection of Information Technology Equipment.

Sprinkler piping and heads within the shielded enclosure shall be of non-ferrous materials.

Electrical

Illumination

Within the MRI Scanner Room fluorescent luminaries are not permitted. Lighting within the MRI Scanner Room must be provided by incandescent fixtures or LED light sources. Fixtures must be dimmable and specifically designed for use in the MRI environment. Lighting levels must be adequate for visualizing fine detail such as reading medication vials or starting IV's. Lighting may be provided through a combination of direct, indirect and portable task fixtures. Lighting is typically controlled by wall mounted switches located at the entrance to the room. Dimmer switches are utilized for variable lighting levels. MRI Scanner Rooms often utilize separate switches for lighting control of individual zones or areas.

For the rest of the suite, illumination is typically provided utilizing recessed fluorescent luminaries with acrylic prismatic lenses. Lighting levels within the MRI Control Room must be adjustable by dimmer switches. The fixtures typically use F32T8 lamps in compliance with the National Energy Policy Act of 1992, with subsequent revisions in 1998 and 2005. Lamps

have a minimum color rendering index (CRI) of 85 and a color temperature of 4100 Kelvin (K), which is close to the “cool white” color temperature of 4150 K. Lighting intensities conform to the VA design criteria, the IES Lighting Handbook, and ANSI/IESNA RP-29-06, the recommended practice: Lighting For Hospitals and Healthcare Facilities.

Power load densities for lighting are listed by use for the mechanical HVAC load calculation purposes. Load densities should be verified for the actual design, as they may vary depending on the room configuration, fixture types, lamps and ballasts used.

Power

MRI power requirements have to be specifically coordinated with the equipment manufacturer. Separate power feeds may be required for MRI computer equipment, power conditioners, and air conditioning systems. General purpose duplex receptacles are typically provided on each wall of a room or space. Workstations with personal computers (PC's) are typically provided with quadruplex receptacles for the PC, monitor, printer, or PACS workstations.

Each hospital determines which specific MRI equipment needs to function during a power outage and be connected to an emergency power system. Duplex receptacles on the critical branch of the emergency power system are provided for selected pieces of equipment (such as refrigerators and PC's) to allow for limited operation during a power outage. If MRI is used for interventional or emergent imaging, provide emergency power receptacles as required to support critical equipment and patient care.

Junction boxes are provided for equipment requiring a hardwire connection. Provide non-magnetic boxes in the scanning room. Certain modular casework units are provided with a utility access module with surface mounted electrical pre-manufactured raceways, which provides a chase for wiring. Conduits and junctions boxes are provided to connect to the utility access module for power wiring.

Power conditioning and uninterruptible power supplies equipment may be required for MRI computer and PACS workstations equipment.

Even if power is interrupted to the MRI, the magnetic field will not dissipate. Superconducting magnets will remain 'at field,' typically for 48 hours or longer. After a protracted period without power to the refrigeration systems, the MRI is at risk of quenching. Consult the MRI equipment vendor for equipment-specific information. If power is restored to the refrigeration systems prior to a quench and cryogen levels are restored to operational parameters, there should be no equipment damage as a result.

Life Safety

Purpose

The life safety program should be developed to provide a reliable system to protect the building occupants, firefighting personnel, building contents, building structure, and building function. This can be accomplished by limiting the development and spread of a fire emergency to the area of origin and thereby reduce the need for total occupant evacuation.

The design aspects of the facility which relate to the fire and life safety include:

- Interdiction of ferromagnetic materials within the MRI suite;

- Fire detection, alarm and suppression;
- Firefighter access and facilities and the unique dangers that MRI equipment presents;
- Structural fire resistance;
- Building compartmentalization;
- Smoke control and exhaust;
- Cryogen venting and room pressurization;
- Emergency power

Because magnetism is not sensible, emergency response in the MRI suite poses significant risks to patients, staff and emergency responders. The hazards and operational protocols for emergency response must be carefully coordinated between the MRI staff and code teams, police, fire and incidental staff who may enter the suite.

New hospital construction and renovated areas of existing facilities are required to be fully protected by an automatic fire suppression system.

The minimum width of corridors and passageways in MRI areas is 5'-0" in areas used by staff. The minimum width of corridors in areas used by inpatients is 8'-0".

Provide handrails on both sides of the corridors in patient areas.

Nurse control areas are permitted to be open to the corridors.

Waiting areas are also permitted to be open to the corridors.

Refer to the latest editions of NFPA 101 "Life Safety Code", International Building Code and additional standards published by the National Fire Protection Association (NFPA).

Refer to ACR Guidance Document for Safe MR Practices: 2007 for MRI specific life safety design considerations.

Energy Conservation

The HVAC, Plumbing, Power and Lighting Systems should be designed for overall energy efficiency and lowest life-cycle cost. This should include the use of high efficiency equipment and fixtures and a programmable control system. The minimum energy standard shall be the latest edition of AS-HRAE/IESNA Standard 90.1.

Communications

Telephone

Telephone outlets are typically provided at each workstation or in each room. Desk outlets are 18" AFF and wall phone outlets are 48" AFF. Certain modular casework units are provided with a utility access module that houses communication outlets and provides a chase for cabling. Conduits and junction boxes are provided to connect to the utility access module for telephone service. New technologies such as "voice over internet protocol", or VoIP, require coordination with the ADP/LAN telecommunications infrastructure.

Automatic Data Processing (ADP)

ADP, or computer outlets, are typically provided at each workstation with a personal computer (PC) and/or printer. ADP includes local area networks (LAN's), PACS applications, and wireless LAN's (WLAN). Desk outlets are 18" AFF. Multi-port telecommunications outlets are provided in accordance with BICSI and ANSI-EIA/TIA standards for telecommunications. Certain modular casework units are provided with a utility access module that houses communication outlets and provides a chase for cabling. Conduits and junction boxes are provided to connect the utility access module for ADP service.

Public Address

The MRI department will not have an independent public address (PA) system. The department will be included as part of the hospital-wide PA system. Speakers are typically located in corridors and public spaces. The actual system configuration will depend on the overall design layout and the functional requirements.

Miscellaneous Systems

A local sound system may be provided for the scanning room to provide background music during the procedure. Nurse call and/or intercom systems may be provided for communications between the control room and the scanning room. A closed circuit TV system may be provided for direct observation of the patient during the examination, though configuring the layout to facilitate direct line-of-sight observation is preferable. Other systems, such as MATV, CATV, or local digital video monitoring may be provided.

Waste Management

Medical Waste

Medical waste is generated in exam and treatment spaces where it is bagged, collected and transported to the soiled utility rooms. Then it is held in separate containers pending transport to the medical waste handling facility.

General Waste

General waste is generated in all spaces and is held in containers for collection and sorting into carts or bagged and placed in a waste chute and transported to the waste handling facility.

Recycling

Methods for sorting, collecting, transporting and disposing of recyclable products must be specifically analyzed for each facility and location.

The optional use of disposable and reusable products should be considered.

Soiled Linen

Soiled reusable linens are generated in exam rooms, treatment spaces, and patient and staff gowning areas. They are collected in carts or hampers in the soiled utility room; or bagged and transported to (a) central collection area(s) via soiled linen chutes or carts.

Disposable linens are included with either general recyclable waste or medical waste as appropriate.

Utensils

Reusable bedpans, emesis basins, etc. are no longer utilized. All such items are disposable and for one time use only. Such items are disposed of in the contaminated trash. Scissors or surgical stainless steel instruments are wrapped, labeled and sent to sterile supply. Any and all utensils and equipment intended for use in the controlled access areas of the MRI suite (Zones III and IV) should be tested and plainly labeled under the current ASTM / FDA guidelines for 'MR Safe' or "MR Conditional". Unlabeled utensils should be presumed to be 'MR Unsafe' unless and until appropriately tested and labeled.

Space Requirements

Space requirements will vary with the selection of waste collection and recycling methods / systems. Space requirements need to be analyzed for each optional method or system considered for new and existing facilities.

Transportation

Patient

Gowning areas with lockers for inpatient and outpatient and control of ferrous materials should be provided. Mobility impaired patients or those requiring ongoing monitoring, intravenous medications, supplemental oxygen or other clinical observation or support must be provided with substitute equipment or devices that are tested and plainly labeled under the current ASTM / FDA guidelines for 'MR Safe' or "MR Conditional". Storage for these devices must be provided near a defined 'transfer' point prior to entering the Zone III area.

Outpatient

Convenient access from patient parking and primary care entrance should be considered.

Passenger elevator access to MRI facilities should be located off main entrance levels.

Techniques like clear access routes, public spaces, landmarks and signage facilitate way-finding.

Inpatient

Stretcher and wheelchair patients should be separated where possible.

Inpatient access from hospital service elevators is required.

Inpatients arrive at a control point common with outpatients.

Inpatients access patient holding through a dedicated route, which is separated from outpatient waiting.

Staff

Staff access should be separated from patient waiting and holding areas.

Staff lounge and locker areas should be located away from inpatient and outpatient traffic and gantry rooms.

Records

MRI utilizes digital imaging and retrieval techniques.

Viewing, interpretation and video image manipulation areas should have data communication access.

MRI film records, accessible by cart traffic, are usually combined with radiology records.

Specimens

Specimens have not historically been drawn in this department, though increasing use of MRI as an image-guided platform to conduct soft-tissue biopsies is changing this. Facilities should prospectively review the current and future potential for image-guided biopsies in the MRI suite and provide for specimen collection and transport, as well as associated infection control issues.

Pharmaceuticals

Pharmaceuticals, including narcotics, are transported by pharmacy personnel in locked carts or by a robotic system to the department.

Narcotics are delivered to a narcotics locker which is located in a clean supply or patient prep area and is remotely alarmed to the nearest nursing control station.

Materials

Clean supplies are transported by exchange carts which are stored in the Clean Supply Room

Supplies are transported by Service Elevator and through hospital corridors separated from patient traffic where possible

Deliveries are scheduled during hours when patient visits are not scheduled. However, ancillary / support staff should not be granted independent, unsupervised access to Zones III and IV of the MRI suite.

Linen

Disposable linens are delivered as part of clean supplies.

Sterile Supplies

The use of sterile supplies is minimal as is accommodated by prepackaged or disposable items delivered with clean supplies.

Food

Meal and nourishment deliveries to MRI are not required.

Waste

Waste is collected by housekeeping staff and transported to the Soiled Utility Room, from where it is disposed.

Safety Considerations

General

While a number of the unique hazards associated with the MRI suite can only be managed by care givers, there are many hazards that can be mitigated by effective suite design and construction.

Physical Hazards and Liabilities

MRI scanners present a number of significant hazards and liabilities, both in certain failure modes as well as during normal operation. Many safety and operational issues hinge on carefully planned design and construction that responds directly to the specifications of the magnet to be sited. The VA National Center for Patient Safety lists 5 types of MR hazards:

Projectile effect: Magnetic material pulled toward the magnet's center can accelerate at speeds of 40 mph. The force of magnetic attraction is a product of the MRI's maximum field strength and spatial gradient. Attractive forces are greatest outside the the MRI.

Twisting: Magnetic objects aligning parallel with the field – torque. Torque effects are greatest at the center of the magnetic field in the middle of the MRI and are directly proportional to magnetic field strength.

Burns: Generally caused by the use of electrically conductive material inside the bore. Electrically conductive material internal to the patient, such as implanted electrical leads for medical devices, have resulted in burns internal to the patient.

Image artifacts: Subtle changes to MRI Image due to various factors, including vibration, shim disturbances, moving metal, and electromagnetic interferences.

Device Malfunction: Electronics or mechanics affected as a result of negative interaction between the device and the magnetic fields surrounding the MRI.

Refer to MR Hazard Summary updated August 2001. vawww.ncps.med.va.gov, www.patientsafety.gov

The above risks not only affect the patient, but also affect the accompanying family members, attending health care professionals, and others who find themselves only occasionally or rarely in the magnetic fields of MR scanners such as security, housekeeping personnel, firefighters, police, etc. MR hazards are complex and not obvious. As a result, major incidents as well as close calls have occurred within MRs that warrant constant diligence to insure safety within MR environment.

In February of 2008, the Joint Commission released Sentinel Event #38 on MRI accidents and injuries. MRI suite designers should review the hazards identified therein, and take ap-

appropriate steps in MRI suite planning and design to mitigate risks to patients, visitors, staff and equipment.

Zoning and Screening

Site Access Restriction is an important component of MRI safety. Per the ACR Guidance Document for Safe MR Practices: 2007, conceptual layout of the suite is divided into four zones:

- Zone I: This includes all areas that are freely accessible to the general public. This area is typically outside of the MR environment itself, and is the area through which patients, health care personnel, and other employees of the MR site access the MR environment.
- Zone II: This area is the interface between the publicly accessible uncontrolled Zone I and the strictly controlled Zones III and IV. Typically the patients are greeted in Zone II and are not free to move throughout Zone II at will, but are rather under the supervision of MR Personnel. It is in Zone II that the answers to MR screening questions, patient histories, physical screening / gowning, medical insurance questions, etc. are typically obtained. Once successfully screened, patients should be moved directly to Zone III.
- Zone III: This zone is defined as areas which present physical hazards as a result of the MRI's magnetic field or areas that offer direct access to the MRI scanner room. This area is the zone in which free access by unscreened non-MR Personnel and / or ferromagnetic objects and equipment are not permitted as they can result in serious injury or death as a result of interactions between the individuals / equipment and the MR scanner's particular environment. These interactions include but are not limited to those with the MR scanner's static and time varying magnetic fields. All access to at least Zone III is to be strictly restricted with access to regions within it, including Zone IV, controlled by and entirely under the supervision of MR Personnel.
- Zone IV: This area is synonymous with the MR scanner magnet room itself. Zone IV by definition, will always be located within Zone III as it is the MR magnet and its associated magnetic field which generates the existence of Zone III itself.

The Design Plates provided as a part of this Design Guide are based on this organizational model for MRI suites. Refer to American College of Radiology *Guidance Document for Safe MR Practices: 2007* for additional information.

Magnetic Field

Missile / Projectile Effect

Magnetic material pulled toward the magnet's center can accelerate at speeds of 40 mph for 1.5 Tesla MRI scanners. The force of magnetic attraction is a product of the MRI's maximum field strength and spatial gradient. Attractive forces increase exponentially as you approach the MRI and are greatest some distance away from the MRI. Small changes in distance can have profound impacts on attractive forces. For this reason it is critically important to identify and quarantine ferromagnetic materials before they enter the MRI Scanner Room.

It is recommended that MRI facilities install ferromagnetic detection systems for use in screening persons and equipment entering Zones III and IV to interdict potential threat objects. While it is possible to install ferromagnetic detection systems at the RF door into the MRI Scanner Room, the preferred location is at the secured access point between Zones II and III. See MRI Functional Diagram.

Rotational / Torque Effect

Torque effects result from the magnetic field's tendency to align the long-axis of ferromagnetic materials with the polar orientation of the magnetic field. Long and slender ferromagnetic objects will experience greater rotational forces than a ferromagnetic sphere of equal mass. The torque effects are greatest at the center of the magnetic field in the middle of the MRI and are directly proportional to magnetic field strength. Torque effects have resulted in injuries, even fatalities, when ferromagnetic objects were rotated within patients' bodies when immersed in high-strength magnetic fields.

Ferromagnetic detection systems are also recommended for identifying ferromagnetic materials that would be subject to rotational / torque effects. Though, at the time of this document's publication, no ferromagnetic detection device has been FDA approved for detection of ferromagnetic materials within a person's body.

Biostimulation Device Interference

While magnetic energies are presumed to have little, if any, harmful effects on biological systems, magnetic fields have demonstrated the capacity to impair and incapacitate crucial biostimulation devices such as pacemakers and other cardiac devices, cochlear implants, implanted insulin pumps, nerve stimulators and other implanted electromechanical devices. To mitigate against these hazards, it is vitally important for patients to have a private environment to disclose all implants and devices. For this reason private interview / clinical screening areas are recommended.

Cryogenics

Super-cold liquefied gases are used to enable superconducting properties of a majority of clinical MRI scanners. The cryogenic liquids are contained within a super-insulated vessel (cryostat) inside the MRI scanner, though under a certain failure mode, these liquids can boil off in an event known as a quench. When this occurs, the liquid cryogen changes state to a gas and undergoes a dramatic, near-explosive, expansion.

Though the cryogenic liquids typically used are chemically inert, their physical properties carry with them significant risks.

Thermal Expansion

Doughnut shaped (bore format) MRI devices can typically hold between 1,000 and 1,800 liters of liquid cryogen. In order to remain in a liquid state, helium must be -454 Degrees Fahrenheit or colder. At temperatures above -454 Degrees Fahrenheit, liquid helium begins to boil into a gaseous state where it undergoes a 760:1 expansion. Should 1,000 liters of liquid helium boil at once, it would yield a gas cloud which, at atmospheric pressures, would occupy a volume of 760,000 liters. This is 3 to 5 times the conventional volume of a typical MRI Scanner Room. Should even a small proportion of this expanding helium gas be vented into the MRI Scanner Room, it would result in a significant pressure increase within the room.

If the RF shielded door into the MRI Scanner Room swings into the room, a modest pressure increase of 0.5 psi would introduce approximately 2,000 pounds of force on the door, pinning it against the frame and making it nearly impossible to open. Should a person be trapped inside the MRI Scanner Room, they would be unable to exit until the pressure was equalized on both sides of the RF shielded door and, in the interim, would be subject to the hazards of exposure to cryogenic gases.

It is for this reason that MRI Scanner Rooms are to be equipped with active exhaust systems, outswing RF doors, as well as overpressure relief systems as identified in the HVAC section of the Technical Considerations in this document.

Oxygen Displacement / Asphyxiation

Due to the enormous potential volume of cryogenic gas, it can easily dilute or displace oxygenated air in the habitable area of the MRI Scanner Room. This introduces the risks of asphyxiation for any person within the MRI Scanner Room in the event of a cryogen breach.

It is for this reason that MRI Scanner Rooms are to be equipped with active exhaust systems as identified in the HVAC section of the Technical Considerations in this document.

Oxygen Liquefaction / Fire

The temperature of the escaping gaseous helium may be well below the temperature at which oxygen condenses to a liquid. Until puddles of liquefied oxygen evaporate, there is substantial risk of fire. At no time should open flame be used to warm or de-ice any part of MRI equipment.

Cold Burns / Hypothermia

One of the most direct risks of exposure to cryogenic gases is that of cold burns / hypothermia. At hundreds of degrees below zero, direct exposure to boiled helium gas can cause substantial tissue damage. Persons should be kept clear of cryogenic liquids and gasses at all times. It is for this reason that warning signage and exclusion zones should be established at the point of cryogen vent discharge.

Regular Vent / Exhaust Inspection

All sites with superconducting MRI equipment should perform inspections on the cryogen vent (quench pipe), active exhaust and pressure equalization systems annually, if not more frequently. Inspections should focus on the soundness of the assembly, functionality of all operable and electronically controlled components, conformance with MRI equipment vendor's current design standards, weather protections for cryogen vent discharge and the presence of warning signage and exclusion zone markings.

Equipment



Furniture, fixtures and equipment used in the MRI suite are at risk of negative interactions with the magnetic fields generated by the MRI. All portable items used within Zones III and IV should be tested and clearly labeled as either 'MR Safe' or 'MR Conditional' per the current ASTM / FDA criteria. These designations indicate that an object is safe under all magnetic and RF excitation conditions (MR Safe) or safe when used within specifically defined parameters for magnetic field strength or spatial gradient (MR Conditional). Materials and objects that are known to be ferromagnetic and potential missile threat objects, should not be kept within Zones III or IV of the MRI suite. Ferromagnetic objects that may be periodically brought to the suite (gurneys, floor polishers, tools, etc...) should be clearly identified with the MR Unsafe designation before being brought into Zone III.

Infection Control

Infection control is a concern in all patient care areas, but the growing use of MRI as an interventional platform is changing the needs for infection control within the MRI suite. When used to perform biopsies, the MRI Scanner Room becomes, in effect, a special procedure room and may require additional considerations for HVAC and Electrical designs. From room finishes to cleaning regimens and handwashing, infection control provisions should be closely coordinated among designers and clinical staff, infection control officer and the technical siting requirements of RF shield and MRI equipment.

Emergency Response

All equipment that may be used inside the MRI Scanner Room in an emergency situation should be tested and identified as MR Safe or MR Conditional. This must include a portable fire extinguisher and may also include portable oxygen, patient monitoring equipment, transport devices, among others. Each facility must assess their individual emergency response needs and furnish the MRI suite appropriately.