Installation Planning

Whole-Body NMR Imaging Systems

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Introduction

This guide assists the customer in selecting and preparing a site to install a Varian whole-body NMR imaging spectrometer system. Using the information presented in this guide should bring about a smooth transition from delivery to installation.

This guide contains the following chapters:

- **Chapter 1, “Site Selection and System Delivery,”** covers site selection, system delivery, receiving preparations, and moving the system.
- **Chapter 2, “General Site Requirements,”** lists the factors to consider when selecting the installation site.
- **Chapter 3, “Equipment Room and Components,”** lists the specific requirements of the computer room and the components contained within the computer room.
- **Chapter 4, “Magnet Room and Components,”** lists the specific requirements of the magnet room and the components contained within the magnet room.
- **Chapter 5, “Control Room and Components,”** lists the specific requirements of the control room and the components contained within the control room.
- **Chapter 6, “Cables, Water, and Room Layouts,”** provides cable length information, water tubing lengths, and some illustrations of typical layouts of whole-body NMR imaging suites.
- **Chapter 7, “Conversion Tables for Standard Units,”** provides definitions and conversions of units used in this guide.

Varian Whole-Body NMR Imaging System Overview

The following is an overview of the components that comprise a Varian whole-body NMR imaging system. The following components are most important:

- Magnet
- Patient table
- Gradient system
- RF system
- Head coil
- Host computer and software
- Documentation devices

**Magnet**

The high-homogeneity superconducting magnet generates a homogeneous magnetic field with a field strength of 3 to 4 tesla (T). The main field is oriented in the horizontal direction along the cylindrical axis of the magnet. The magnet is connected to a power supply integrated into the electronics cabinet for the purpose of ramping for service activities. This magnet uses only helium to maintain the superconducting state of the magnet coils. Helium boil off is reduced through the use of a cold head, which removes heat from the magnet
cryogen vessels. Heat is transferred to a cooling unit in the computer room. The cooling unit is connected to the on-site water cooling system.

Patient Table

The patient table supports the patient and enables proper patient position before the measurement. The power-assisted table is moved into the magnet bore where the anatomy under examination is positioned in the magnet isocenter. The table motion can be locked and released.

Maximum patient weight is 160 kg (353 lbs). With this load, all functions are ensured.

Gradient System

The desired slice position is accurately defined with the gradient system, which comprises the X, Y, and Z magnet field gradient coils. A gradient amplifier is incorporated into the electronics cabinet.

RF System

The rf system consists of a transmit and receive section. The hardware for rf pulse generation (small signal part and power amplifier) is integrated into the electronics cabinet as well as the hardware for processing the received and preamplified NMR signal.

Host Computer and Software

An integrated Sun host computer controls peripheral devices, image selection, and image storage.

The host computer controls and monitors the main functions of the Varian whole-body NMR imaging system and the VNMR software, magnetic resonance (MR) measurement, image reconstruction, image display and evaluation, as well as archiving and documentation.

The host computer can be networked for image transfer and remote operation and diagnostics.

VNMR is the application software package that contains the programs necessary for controlling the processor functions. The software is based on the UNIX operating system and contains the following functions required by the user and technical service:

• Execute and interpret dialogue-driven interactions in multiuser and multitasking functions.
• Organize and control the NMR imaging system.
• Acquire NMR imaging data, preprocess, and reconstruct images.
• Display raw data, as well as image data and results, at the host computer.
• Post-process images for statistical and geometric image evaluation.
• Document and archive images and post-process results.

Documentation Devices

Documentation devices consist of the following:

• Optical disk (optional) for electronic storage.
• Laser printer (optional, PostScript-compatible) for printing images, text data, spectra, and other data.
• Video printer (optional) for hardcopy images.

Safety Precautions

This guide contains important warnings and cautions that you should read and follow carefully. These safety precautions have the following format and meaning:

**WARNING:** Warnings are used when failure to observe instructions or precautions could result in injury or death to humans or animals, or cause significant property damage.

**CAUTION:** Cautions are used when failure to observe instructions could result in permanent damage to equipment or data.

Contacting Varian

We at Varian will make every effort to ensure that the ownership of your NMR imaging system is a lasting and pleasurable experience.

For product sales and service information, contact one of the Varian sales offices:

• Argentina, Buenos Aires, (114) 783-5306
• Australia, Mulgrave, Victoria, (3) 9566-1138
• Austria, Vösendorf, (1) 699 96 69
• Belgium, Brussels, (2) 721 48 50
• Brazil, Sao Paulo, (11) 829-5444
• Canada, Ottawa, Ontario, (613) 260-0331
• China, Beijing, (10) 6846-3640
• Denmark, Herlev, (42) 84 6166
• France, Orsay, (1) 69 86 38 38
• Germany, Darmstadt, (6151) 70 30
• Italy, Milan, (2) 921351
• Japan, Tokyo, (3) 5232 1211
• Korea, Seoul, (2) 3452-2452
• Mexico, Mexico City, (5) 523-9465
• Netherlands, Houten, (30) 635 0909
• Norway, Oslo, (9) 86 74 70
• Russian Federation, Moscow, (95) 241-7014
• Spain, Madrid, (91) 472-7612
• Sweden, Solna, (8) 445 1601
• Switzerland, Zug, (41) 749 88 44
• Taiwan, Taipei, (2) 2698-9555
• United Kingdom, Walton-on-Thames, England (1932) 898 000
• United States, Palo Alto, California, Varian, Inc., NMR Systems
  Customer Sales Support, (650) 424-5145
Service Support, Palo Alto, California, **1 (800) 356-4437**
E-mail: customer.support@nmr.varian.com
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6440 Dobbin Rd, Ste D, Columbia, MD 21045
(410) 964-3065

- Venezuela, Valencia (41) 257608
Chapter 1. Site Selection and System Delivery

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- 1.1 “Site Selection” this page
- 1.2 “Delivery Requirements” page 16
- 1.3 “Transport Routes” page 17
- 1.4 “System Delivery Preparations” page 18
- 1.5 “Magnet Delivery” page 20
- 1.6 “Moving the System” page 20
- 1.7 “Managing the Installation Planning Project” page 20
- 1.8 “System Startup Prerequisites” page 23

Certain supplies not provided by Varian, such as helium and nitrogen supplies, must be obtained by the customer before the Varian installation engineer can begin the installation.

1.1 Site Selection

Site selection is the process of finding a location for the magnet providing the least interference with the building it occupies. The selection of an optimum site is determined almost entirely by the high magnetic fringe field of the system. The process of selection can be complex because of the interaction of the magnetic field with the surrounding environment.

The customer should allow a minimum of eight months for the selection, qualification, design, and construction of a magnetic resonance imaging facility.

Varian provides technical support and advice during the preparation of the site. Typically, a Varian representative visits the site initially and after the site is finished. The role of Varian in the preparation period is to help the process run as smoothly as possible and to be available for consultation on any situation that may arise.

The selection process typically proceeds as follows:

1. The customer locates several potential sites using this guide as a reference.
2. A site planning specialist visits the facility to further refine the selection process if necessary.
3. A facility planner or architect is engaged to assist with preliminary details of the proposed site.
4. Detailed building plans with the magnet location are forwarded to Varian site planning department.
5. Varian reviews all proposed sites.
6. A final location is selected by the customer and site planning department from Varian.
7. An architect or facility planner draws up plans for the proposed facility.
8. Varian reviews and advise on the final site drawings.
9. Site construction begins.

1.2 Delivery Requirements

This section describes what is required and what you can expect before, during, and after delivery.

Before Delivery

In general, the site should be as complete as possible before system delivery (except for magnet access requirements). All services required for the correct operation of the whole-body NMR imaging system, including chilled water and air conditioning, must be installed and operational, with the exception of any final balancing that requires the full system load.

The following must be completed before the system arrives:

- Walls finished and painted.
- Floors in the computer and control room installed and finished.
- Ceilings in place.
- Room lighting installed and ready to use.
- All electrical installation completed.
- All sanding and drilling completed.
- Heating and air conditioning system installed (as far as possible) and ready for use.
- Chilled water connection for ACCU and AMT amplifiers.
  Magnets are delivered 100% full of cryogens. Boil-off is minimized after the chilled water connections are made and the cold head is operational. Failure to provide the required water supply immediately following magnet delivery might result in a claim for costs of lost cryogens.
- RF room (shielding) installed and as complete as possible (opening for magnet provided).
- Interior of rf room as complete as possible.
- Cable ducts installed or presumable.
- Quench tube installed (up to 1 m from the magnet).
  The quench pipe must also be fitted as soon as possible after the magnet arrives to minimize the risk of escaping helium within the magnet room.
- Construction complete so that no construction workers are still working in any of the rooms.
- Rooms swept clean of debris.
  At the time of delivery, the magnet room, equipment room, and control room must be complete and dust free, with the exception of any work necessary for the bringing in of the magnet and magnet shielding through the roof opening.
- A lockable room available for temporary storage of components.
- Dedicated line for a modem or telephone installed.
Varian recommends installing a regular voice telephone line near the host workstation (Sun computer). This telephone would enable the system operator to discuss system operation as it occurs.

Varian also strongly recommends that Internet access be provided during and after system installation. By providing external access to the MR system, technical problems can be quickly analyzed by engineering and scientific personnel in Palo Alto. After the system is installed, applications-related questions can be answered in real time.

If direct access to the Internet is not technically feasible, a high-quality analog telephone line can be used. Varian provides a high-speed modem during system installation. If internal security policies preclude ready modem or Internet access to the system, contact the Varian NMR Installation department for a list of options that might satisfy concerns.

**During Delivery**

Although considerable care is taken during the installation of the MR system, the large size and weights involved can possibly result in some minor damage to the decorations of the installation site. Therefore, final touch-up of paint should be applied after the system is installed, and all floors and special wall coverings should be protected.

**After Delivery**

Following delivery, temporary storage outside of the magnet, control, and equipment rooms is required. This quantity of equipment now on site restricts access to adjacent areas for other trades. Free use of a trash container or other arrangements for disposal of packaging (customers property) should be provided.

Directly following the magnet placement, the magnet room must be made water tight.

Directly after delivery and assembly of magnet, Varian will begin connecting system cables. During this time, connections to the chilled water supplies, quench pipe, and on-site power supply will be made with the support from the appropriate site contractor. The cold head compressor will be switched on and left working 24 hours-per-day.

The initial installation stage takes about one week, after which, Varian personnel might leave the site to allow for any remaining work outside the magnet room to be completed by specialists.

After this remaining work is finished, Varian personnel will return to the site and finish the system installation. From this period on, the MR system rooms should be under Varian control. During the second week after the return to the site, the magnetic field will be energized and no further access by contractors to the magnet room will be allowed.

During filling of the magnet, no special facility is necessary except for one L-size bottle of helium gas close to the magnet room. Temporary storage of cryogen dewars might be required until they are collected.

**1.3 Transport Routes**

All transport activities, including delivery of the system components into the installation site, must be performed by a licensed carrier. Before hiring a licensed carrier, the project manager and the architect/structural engineer must determine the floor loading of the transport routes and the temporary storage areas. The architect/structural engineer must certify in writing that the transport routes and storage areas can withstand the floor loading...
of the system components. The chosen carrier is responsible for obtaining information concerning the various transport routes before the actual transport.

The largest item for delivery is the magnet:

- 14,000 kg (without shielding or gradient frame)
- 2694 × 2300 × 2600 mm (L × W × H)

Minimum door sizes for delivery of the whole-body imaging components and permanent access for liquid helium dewars is 1100 × 2100 mm. The magnet is lowered through a temporary opening in the ceiling.

A covered area within the vicinity of the installation site, with a clear height of 3500 mm, is required for insertion of the helium siphon before bringing the siphon into the magnet room.

Overall clearance of the transport routes to the equipment room must be at least 2.0 m to allow for the MR electronics cabinets.

Ordering Transport

The order for transporting the system must be issued in writing to the selected licensed carrier and must contain the following data and documentation (as well as other general information, including a list of components to be transported):

- Copies of the transport routes and storage areas.
- Copy of the certification of the weight capacity of the floor.
- Final destination of transport (this gives the carrier enough time to obtain information about methods of transport and routes).
- Weight and dimensions of the components to be transported.

The carrier is responsible for selecting the type of transportation and auxiliary tools.

Shipping Documentation

The following documents are provided to help you identify the system components:

- General packing slip – In addition to the carrier’s shipping papers, the general packing slip lists the contents.
- Detailed packing slip – A detailed list of contents
- Technical documentation – The technical documentation is shipped in a separate crate, identified by a blue label.

1.4 System Delivery Preparations

The customer is responsible for providing a rigging crew to move the magnet and other equipment from the delivery truck to the final location of the system. Unpacking of the system is the responsibility of the Varian installation specialist. The system is not to be unpacked without proper authorization from Varian. A Varian installation specialist then assumes responsibility for the installation until it is completely installed and accepted.
CAUTION: Do not open any crate except with direct instructions from an authorized Varian service representative. In particular, the crate containing the magnet has components that could be irreparably damaged if opened incorrectly.

Receiving Preparations

The method of shipping and the current conditions at the destination determine the extent of the receiving preparations. The Varian Order Acknowledgment form indicates the shipping method for the order. The following service is usually provided:

- **Air Freight** – System is delivered to unloading dock or other easily accessible outside unloading point. Factory to destination transit time is about two days (not including time to clear customs).
- **Motor or Moving Van** – System is delivered to an easily accessible interior location or any interior location to which freight can be easily transported by movable dolly. Excluded is transport in elevators that cannot support the weight of the shipment or up stairways. Factory to destination within the United States is about eight days.

Contact the shipping company locally about the service usually rendered. You should also obtain help from the plant facilities department. Be sure to confirm that the local shipping company uses a vehicle that will support the system weight and allow the magnet to be transported in an upright position for all the transport methods that will be used. Sea freight or motor freight without air cushion suspension is not recommended for long distance delivery of systems.

Postdelivery Instructions

When the system is delivered, follow the instructions in the next section to inspect for shipping damage before moving the crates. Do not open any crate.

Inspecting for Shipping Damage

When the shipment arrives, make an immediate visual inspection of the outside of each crate for damage. Take the following steps if any damage is found:

1. Note the nature of the damage on the carrier’s waybill.
2. Request an inspection and written damage report by a representative of the carrier.
3. Forward a copy of the damage report to the local Varian representative.

In case of damage, the FOB block on the Varian Order Acknowledgment form determines owner responsibility:

- **FOB PALO ALTO** – Transfer of ownership occurs when the shipment leaves the factory. The customer is responsible for claims for shipping damage. Upon request, Varian will provide assistance in filing claims.
- **FOB DESTINATION** – Transfer of ownership occurs at customer’s point of receipt. Varian is responsible for claims for shipping damage.

Damage discovered fifteen or more days after delivery generally cannot be recovered. Such damage will be at the expense of the customer.
1.5 Magnet Delivery

Magnets are usually shipped cold to the customer, with a fill level of about 70%. The fill level must be measured immediately after the magnet is moved into the magnet room. In the unlikely event that the electronics cabinet is not operational, the service level meter can be used for measuring the fill level.

A schedule for refilling the magnet must be established on the basis of the fill level table and the fill level protocol shipped with the magnet.

The cold head must be put into operation immediately after it is moved into the building.

1.6 Moving the System

CAUTION: Move the crates in an upright position. Do not drop or mishandle. The crates are packed with G-force and “tip-and-tell” indicators that record mishandling. Be especially careful about moving the magnet crate. If one or more crates cannot be moved into the installation site because of doorway clearance, leave the affected crates in a clean, safe, dry location. Do not open any crate except with direct instructions from an authorized Varian service representative.

Move the crates in an upright position, with a forklift or hydraulic pallet mover, directly to the installation site. Should it appear necessary to uncrate one or more units because of doorway or passage clearance, contact your Varian service representative for further instructions.

To avoid unnecessary expense, be sure moving personnel and equipment are ready for the shipment on the delivery day.

1.7 Managing the Installation Planning Project

Good management of the installation planning project can help reduce installation duration and expense.

In planning the system installation, good communications on a frequent basis are essential between the customer, the facility planner or architect, and Varian. Any questions or problems should be addressed immediately to avoid delays and additional costs.

We recommend that one person from the customer’s institution be appointed as project manager to coordinate site planning and preparation. This person should represent all users of the system in dealing with Varian and the facility planner or architect.

Project Manager

The project manager is the customer’s focal point for the entire project. The project manager must have the authority to execute project tasks and is responsible for the following:

• Communication between customer, suppliers, and Varian.
• All aspects of the installation planning and installation project.
• Coordination between the technical and administrative facets of the project.
• Ensuring that schedules are followed.
• Communicating installation progress.

Table 1 lists the major installation tasks with associated responsibilities.

The project manager takes ownership of the entire process of from quote to turnover.

Table 1. Project Management Tasks and Responsibilities

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<th>Responsibility</th>
<th>Comments</th>
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<tr>
<td>Quotation</td>
<td>sales representative, project manager</td>
<td>project manager provides technical clarifications</td>
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<td>Preliminary room layout</td>
<td>sales representative, project manager, planner</td>
<td></td>
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<tr>
<td>Establish customer file</td>
<td>Varian, project manager</td>
<td></td>
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<tr>
<td>Final room layout</td>
<td>planner, project manager</td>
<td>typically a presentation and explanation followed by customer sign-off.</td>
</tr>
<tr>
<td>Planning of required personnel</td>
<td>Varian</td>
<td></td>
</tr>
<tr>
<td>Schedule installation start date</td>
<td>Varian</td>
<td></td>
</tr>
<tr>
<td>Site and room preparation</td>
<td>project manager</td>
<td></td>
</tr>
<tr>
<td>Preparation for installation</td>
<td>project manager</td>
<td></td>
</tr>
<tr>
<td>Check cable lengths</td>
<td>project manager</td>
<td></td>
</tr>
<tr>
<td>System delivery</td>
<td>Varian, project manager</td>
<td></td>
</tr>
<tr>
<td>System installation</td>
<td>installation team, project manager</td>
<td></td>
</tr>
<tr>
<td>System startup</td>
<td>installation team</td>
<td></td>
</tr>
<tr>
<td>QA test and acceptance tests</td>
<td>installation team, project manager</td>
<td></td>
</tr>
<tr>
<td>Applications training</td>
<td>applications specialist</td>
<td></td>
</tr>
<tr>
<td>Customer acceptance</td>
<td>installation team, sales representative, project manager</td>
<td></td>
</tr>
</tbody>
</table>

Quotation Phase

During the quotation phase, the project manager assists sales in organizing logistics, including delivery dates and special requests.

Order Entry

The project manager helps the order entry process by assuring complete technical clarification.

At this point, cable lengths for the rooms should be confirmed so that the correct cable sets can be ordered.
Order Monitoring

The project manager closely monitors the order process and takes responsibility for the following:

- Coordinating order modifications
- Supervising time tables and project costs
- Tracking site preparation construction work
- Communicating between the customer and Varian
- Coordinating details with the installation supervisor, customer’s architect, installation team, and logistics
- Responding to deadlines

Delivery and Installation

The project manager coordinates and monitors shipping, customs clearance, and system delivery to the site. Before the delivery, the project manager must resolve issues with the carrier before system delivery, including the following:

- Establish the transport route of the truck and crane
- Establish the transport route within the building
- Make sure the equipment for moving the magnet is on site

When the system is delivered, the project manager must be on site to oversee the following:

- Resolve issues with the carrier before the system is delivered
- Support the carrier and eliminate problems
- Clarify the final location of the individual components
- Coordinate the installation of the quench tube

The project manager then controls and audits installation progress.

Turnover to Customer

The project manager assures professional completion of the project and completion of all acceptance documentation.

Project Planning Phase

The following information is required for successful site planning:

- Architectural drawings of the installation site.
- The use of the rooms and surfaces within 40 m of the magnet center (items within the magnetic fringe field that are affected by the magnetic field or items that can affect the magnet homogeneity).
- Location of mass iron girders located in the vicinity of the magnet.

If the homogeneity of the magnetic field might be affected, the interference levels should be measured. Varian will compute the room shielding required for the magnetic fringe fields upon request.

In the case of reasonable doubt, the mechanical vibrations of the installation site should be measured. Suspect locations include upper floors of buildings and areas near railroad tracks or truck routes.
1.8 System Startup Prerequisites

Before the system is started up, the following must be performed:

- System components are positioned in their final locations.
- All cables have been routed.
- All construction work related to the site is complete and the rooms are clean.
- The heating and air conditioning system is operational.
- All tools required for starting up the system are available at the installation site.
Chapter 1. Site Selection and System Delivery
Chapter 2. General Site Requirements

Sections in this chapter:

- 2.1 “Minimum Room Sizes,” this page
- 2.2 “Overview of Components,” page 27
- 2.3 “Floor Loading,” page 27
- 2.4 “Floor Coverings,” page 28
- 2.5 “External Interference Sources,” page 28
- 2.6 “Magnetic Environment,” page 29
- 2.7 “Electrical Requirements,” page 33
- 2.8 “Mechanical Requirements,” page 38
- 2.9 “Other General Requirements,” page 41
- 2.10 “Safety Guidelines,” page 42

2.1 Minimum Room Sizes

The MR suite that houses the whole-body NMR imaging system typically consists of three rooms: equipment room, magnet room, and control room. Figure 1 shows an example. Minimum internal dimensions of the rooms, after the installation of the rf and magnetic shielding, are listed in Table 2. An optional evaluation area has a minimum size $3000 \times 3000$ mm ($9.8 \times 9.8$ ft).

<table>
<thead>
<tr>
<th>Specification</th>
<th>Equipment Room</th>
<th>Magnet Room</th>
<th>Control Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room size, minimum (inside dimensions)</td>
<td>$5000 \times 6000$ mm ($16.4 \times 19.7$ ft)</td>
<td>$9000 \times 6000$ mm ($29.5 \times 19.7$ ft)</td>
<td>$3000 \times 6000$ mm ($10 \times 19.7$ ft)</td>
</tr>
<tr>
<td>Minimum ceiling height</td>
<td>$2200$ mm ($7.2$ ft)</td>
<td>$3300$ mm ($2500$ mm drop) ($11$ ft ($8.2$ ft drop))</td>
<td>no requirement</td>
</tr>
<tr>
<td>Floor requirements</td>
<td>antistatic</td>
<td>antistatic, level</td>
<td>antistatic</td>
</tr>
<tr>
<td>RF shielding</td>
<td>not required</td>
<td>$90$ dB attenuation over $20$ to $200$ MHz</td>
<td>not required</td>
</tr>
<tr>
<td>Magnetic field shielding</td>
<td>not required</td>
<td>depends on site</td>
<td>not required</td>
</tr>
<tr>
<td>Power outlets</td>
<td>See “Mains Supply”</td>
<td>$2-3$ $110/220$ Vac</td>
<td>at least $6$ $120/220$ Vac</td>
</tr>
<tr>
<td>Air conditioning</td>
<td>$15$ kW</td>
<td>$2$ kW</td>
<td>$2$ kW</td>
</tr>
</tbody>
</table>
Figure 1. 3T/4T Whole-Body NMR Imaging Components
2.2 Overview of Components

The whole-body NMR imaging system consists of the components shown in Figure 2. The dimensions and weights of the various components are listed in Table 3 and Table 4. These components are typically arranged in the equipment, magnet, and component rooms of the MR suite, as shown in Figure 1.

![Figure 2. Components of a Whole-Body NMR Imaging System.](image)

2.3 Floor Loading

The heaviest component of the whole-body NMR imaging system is the magnet. Magnets weigh between 14000 and 38000 kg (including shielding or gradient frames). Floor loading is about 102.5 kN (4 plates 820 × 250 mm).

For calculating floor loading, Table 3 and Table 4 list the dimensions and weights of the various components.
Chapter 2. General Site Requirements

2.4 Floor Coverings

Floor coverings within the MR suite must be antistatic and meet these requirements:

- Less than 1.3 kV electrostatic potential
- 3-second half life
- $10^5 - 10^{10}$ ohm impedance
- Carpet meets IBM–CL standards
- Floor covering does not ground the rf shielding

Note that after the magnet is energized, flooring installers and other construction people must not enter the magnet room. Also, the rf shielding must be undamaged in any way and must remain electrically isolated from the building earth ground. Internal finishes to the rf shielding must be fitted according to the manufacturers instructions.

2.5 External Interference Sources

In critical cases, the suitability of the installation site is tested by Varian or by third parties authorized by Varian. The tests focus on the acquisition of electromagnetic and mechanical sources of interference.

Varian is not responsible for inspecting structural prerequisites, such as the weight capacity of floors or the heating and air conditioning system. Varian is also not responsible for executing and monitoring preliminary on-site installation steps. Additionally, Varian is not liable for the customer’s failure to maintain specific operating conditions.

Table 3. Component Dimensions and Weight

<table>
<thead>
<tr>
<th>Components</th>
<th>Size (HWD)</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNITY INOVA NMR console</td>
<td>1182×1106×779.3 mm</td>
<td>272 kg</td>
</tr>
<tr>
<td></td>
<td>(48.54×43.54×30.68 in.)</td>
<td>(600 lb)</td>
</tr>
<tr>
<td>Imaging rf power cabinet</td>
<td>1182×553×779.3 mm</td>
<td>120 kg</td>
</tr>
<tr>
<td></td>
<td>(56.02×21.77×30.68 in.)</td>
<td>(265 lb)</td>
</tr>
<tr>
<td>AMT 4T40 rf amplifier cabinet</td>
<td>1189×635×902 mm</td>
<td>388 kg</td>
</tr>
<tr>
<td></td>
<td>(48.54×25×35.5 in.)</td>
<td>(855 lb)</td>
</tr>
<tr>
<td>AMT 4T70 rf amplifier cabinet</td>
<td>1676×635×902 mm</td>
<td>553 kg</td>
</tr>
<tr>
<td></td>
<td>(66×25×35.5 in.)</td>
<td>(1220 lb)</td>
</tr>
<tr>
<td>ACCU – Water cooling unit cabinet</td>
<td>1800×660×860 mm</td>
<td>325 kg</td>
</tr>
<tr>
<td></td>
<td>(71×26×33.6 in.)</td>
<td>(717 lb)</td>
</tr>
<tr>
<td>EPI – Gradient booster cabinet</td>
<td>1800×660×860 mm</td>
<td>300 kg</td>
</tr>
<tr>
<td></td>
<td>(71×26×33.6 in.)</td>
<td>(661 lb)</td>
</tr>
<tr>
<td>GPS – Gradient power supply</td>
<td>1800×660×860 mm</td>
<td>500 kg</td>
</tr>
<tr>
<td></td>
<td>(71×26×33.6 in.)</td>
<td>(1102 lb)</td>
</tr>
<tr>
<td>PCA – Power distribution unit</td>
<td>1800×660×860 mm</td>
<td>680 kg</td>
</tr>
<tr>
<td></td>
<td>(71×26×33.6 in.)</td>
<td>(1500 lb)</td>
</tr>
<tr>
<td>Patient table</td>
<td>1050 (max)×680×2820 mm</td>
<td>600 kg</td>
</tr>
<tr>
<td></td>
<td>(41×27×111 in.)</td>
<td>(1102 lb)</td>
</tr>
<tr>
<td>Magnet Covers</td>
<td>2230 (max)×2610×3225 mm</td>
<td>not available</td>
</tr>
</tbody>
</table>
2.6 Magnetic Environment

Completely surrounding the magnet is a magnetic field called the fringe field. The first consideration in site planning is the interaction of the fringe field with objects that come within its range. Table 5 lists some sensitive devices and the acceptable stray magnetic field density (in gauss) within which the devices can effectively operate. If you are unsure how the magnetic field will affect a device, contact the device manufacturer. See Table 6 for examples of objects that affect or are affected by the magnetic field.

The fringe field contour around the magnet is typically an ovate-spheroid shape. Figure 3 illustrates the typical shape of the fringe field and provides other useful measurements for calculating the stray field. Refer to “Stray Magnetic Fields” on page 71 for the distances shown in Figure 3.

<table>
<thead>
<tr>
<th>Component</th>
<th>Crated Size (HWD)</th>
<th>Shipping Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessories box</td>
<td>840 × 1800 × 1000 mm (33 × 71 × 39.3 in.)</td>
<td>400 kg (882 lb)</td>
</tr>
<tr>
<td>ACCU (water cooling cabinet)</td>
<td>2170 × 920 × 660 mm (85.4 × 36 × 26 in.)</td>
<td>730 kg (1609 lb)</td>
</tr>
<tr>
<td>AMT 4T40 rf amplifier cabinet</td>
<td>1372 × 864 × 1118 mm (54 × 34 × 44 in.)</td>
<td>406 kg (895 lb)</td>
</tr>
<tr>
<td>AMT 4T70 rf amplifier cabinet</td>
<td>1880 × 864 × 1118 mm (74 × 34 × 44 in.)</td>
<td>572 kg (1260 lb)</td>
</tr>
<tr>
<td>UNITY/NOVA NMR cabinets</td>
<td>1486 × 1350 × 1020 mm (58.8 × 26.5 × 40 in.)</td>
<td>285 kg (630 lb)</td>
</tr>
<tr>
<td>Imaging rf power cabinet</td>
<td>1486 × 675 × 1020 mm (58.8 × 26.5 × 40 in.)</td>
<td>143 kg (315 lb)</td>
</tr>
<tr>
<td>Gradient coil</td>
<td>1400 × 1060 × 2600 mm (55 × 42 × 102 in.)</td>
<td>1738 kg (3832 lb)</td>
</tr>
<tr>
<td>Patient table</td>
<td>1050 × 860 × 3070 mm (41 × 34 × 121 in.)</td>
<td>685 kg (1510 lb)</td>
</tr>
<tr>
<td>MR electronics cabinet (PCA, GPS, EPI)</td>
<td>2250 × 1150 × 2100 mm (88.6 × 45.3 × 82.7 in.)</td>
<td>1812 kg (3995 lb)</td>
</tr>
<tr>
<td>Remaining system components</td>
<td>1160 × 1220 × 2340 mm (45.7 × 48 × 92 in.)</td>
<td></td>
</tr>
<tr>
<td>RF filter plate</td>
<td>920 × 1060 × 1400 mm (36 × 42 × 55 in.)</td>
<td>170 kg (375 lb)</td>
</tr>
<tr>
<td>Set of cables</td>
<td>650 × 1130 × 1110 mm (25.6 × 44.5 × 43.7 in.)</td>
<td>253 kg (558 lb)</td>
</tr>
<tr>
<td>System cover I (front and back cover)</td>
<td>2400 × 1560 × 3000 mm (94.5 × 61.4 × 118 in.)</td>
<td>960 kg (2116 lb)</td>
</tr>
<tr>
<td>System casing II (wooden parts for sides)</td>
<td>840 × 740 × 2320 mm (33 × 29 × 93.3 in.)</td>
<td>287 kg (634 lb)</td>
</tr>
<tr>
<td>Table guide</td>
<td>600 × 800 × 3100 m (23.6 × 31.5 × 122 in.)</td>
<td>124 kg (273 lb)</td>
</tr>
</tbody>
</table>
Chapter 2. General Site Requirements

Table 5. Acceptable Magnetic Field in Which Some Sensitive Devices Can Operate

<table>
<thead>
<tr>
<th>Device</th>
<th>Magnetic Field in Gauss (1 gauss = 0.1 militesla)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scintillation camera</td>
<td>1</td>
</tr>
<tr>
<td>Rotating ECAT</td>
<td>0.6</td>
</tr>
<tr>
<td>CT scanner (using PMTs)</td>
<td>1</td>
</tr>
<tr>
<td>CT scanner (non PMT)</td>
<td>5</td>
</tr>
<tr>
<td>Shielded PMTs</td>
<td>10</td>
</tr>
<tr>
<td>Cyclotron</td>
<td>1</td>
</tr>
<tr>
<td>Image intensifier</td>
<td>1</td>
</tr>
<tr>
<td>Electron microscope</td>
<td>1</td>
</tr>
<tr>
<td>LINAC</td>
<td>1</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>3</td>
</tr>
<tr>
<td>Analytical balance</td>
<td>2</td>
</tr>
<tr>
<td>Color TV</td>
<td>1.5</td>
</tr>
<tr>
<td>EEG (more sensitive to fluctuating field)</td>
<td>1</td>
</tr>
<tr>
<td>Mass spectrometer</td>
<td>1</td>
</tr>
<tr>
<td>Video camera (unshielded)</td>
<td>3</td>
</tr>
<tr>
<td>Video camera (steel case)</td>
<td>10</td>
</tr>
<tr>
<td>B&amp;W monitor (non-critical)</td>
<td>15</td>
</tr>
<tr>
<td>Cardiac pacemaker (5–15 (check with manufacturer))</td>
<td>5–15</td>
</tr>
<tr>
<td>ECG (More sensitive to fluctuating field)</td>
<td>5</td>
</tr>
<tr>
<td>Neuro stimulator</td>
<td>5</td>
</tr>
<tr>
<td>Mechanical watches</td>
<td>10</td>
</tr>
<tr>
<td>High-density magnetic storage media</td>
<td>5</td>
</tr>
<tr>
<td>Credit cards</td>
<td>10</td>
</tr>
<tr>
<td>Disk and tape drives</td>
<td>10</td>
</tr>
<tr>
<td>Computers</td>
<td>10</td>
</tr>
<tr>
<td>X-ray tubes</td>
<td>10</td>
</tr>
<tr>
<td>Operator console</td>
<td>15</td>
</tr>
<tr>
<td>Hearing aids</td>
<td>10</td>
</tr>
<tr>
<td>Electric motors</td>
<td>20</td>
</tr>
<tr>
<td>Photographic equipment</td>
<td>30</td>
</tr>
</tbody>
</table>

**WARNING:** Cardiac pacemaker wearers must remain outside the 5-gauss perimeter in all directions from the magnet until safety is clearly established. An NMR superconducting magnet generates strong magnetic and electromagnetic fields that can inhibit operation of some cardiac pacemakers, resulting in death or serious injury to the user. Consult the pacemaker user’s manual, contact the manufacturer, or confer with a physician to determine the effect on a specific pacemaker. Varian provides signs with each system to warn pacemaker wearers of this hazard.
2.6 Magnetic Environment

Safety Hazards of Strong Magnetic Fields

The potential safety hazards of strong magnetic fields to devices such as certain pacemakers must be understood and planned for.

Cardiac pacemaker wearers should refrain from entering a zone that would subject a cardiac pacemaker to a magnetic intensity that could cause adverse effects. For assistance in determining the effect of a system on pacemaker, consult the pacemaker user’s manual, contact the manufacturer, or confer with a physician to determine the effect on a specific pacemaker. Actual levels vary and should be checked after the magnet has been installed.

Because the magnetic field exists both horizontally and vertically, the effect of the field on persons, electronic equipment, computers, and other objects located above and below the magnet must also be considered. Pacemaker hazard and other signs warning that a magnetic field is present might be needed in the space on the next floor above the magnet and on the floor below the magnet.

NMR workers are exposed to high levels of static magnetic fields. At this time, no conclusive evidence exists indicating adverse health effects at current exposure levels. Although some studies suggest a link between magnetic field exposure and adverse reproductive effects, the body of medical data available is not clear enough to draw any firm conclusions regarding risks to pregnancy. In other words, static magnetic field associated

Table 6. Interaction Between Common Objects and a Magnetic Field

<table>
<thead>
<tr>
<th>Objects That Affect the Magnetic Field</th>
<th>Objects Affected by the Magnetic Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-gauss line or closer</td>
<td>Cardiac pacemakers, ferromagnetic implants, and unrestrained ferromagnetic objects: tools, keys, electronic equipment, analog watches, magnetic data storage media, credit cards, etc.</td>
</tr>
<tr>
<td>5 to 15 gauss</td>
<td>Cardiac pacemakers and electronic equipment: shielded CRTs, computers, shielded image intensifiers, shielded photomultiplier tubes, etc.</td>
</tr>
<tr>
<td>2 to 5 gauss</td>
<td>Very sensitive electronic equipment: unshielded image intensifiers, photomultiplier tubes, etc.</td>
</tr>
<tr>
<td>1 to 2 gauss</td>
<td>Extremely sensitive electronic equipment: linear accelerators, electron microscopes, CRTs, etc.</td>
</tr>
</tbody>
</table>
with the NMR spectrometer magnets are not considered by the scientific community at this
time to comprise a risk to pregnancy or a reproductive hazard.

An American Conference of Governmental Industrial Hygienists (ACGIH) article entitled
Threshold Limit Values and Biological Exposure Indices, 5th ed., states the following:

“TLVs [Threshold Limit Values] refer to static magnetic flux densities to which it is
believed that nearly all workers may be repeatedly exposed day after day without
adverse health effects. These values should be used as guides in the control of exposure
to static magnetic fields and should not be regarded as a fine line between safe and
dangerous levels.

“Routine occupational exposures should not exceed 60 milliteslas (mT)—equivalent to
600 gauss—whole body or 600 mT (6000 gauss) to the extremities on a daily [8 hour],
time-weighted average basis. A flux density of 2 teslas (20,000 gauss) is recommended
as a ceiling value.”

**Magnetic Field Homogeneity**

Building steelworks and reinforcements within 6 meters of the magnet center can affect the
magnetic field homogeneity within the measuring area of the magnet. Details should be
provided to Varian of beams and columns in excess of 100 kg/m around the magnet room
and reinforced concrete or steel beams up to 40 kg/m² below the magnet. This information allows Varian to ensure that the magnet will reach the required specifications.

Performance of the magnet and the quality of the results depend on maintaining the internal quality of the magnetic field. Once the magnet has been placed, it is shimmed for small variations in the field. The presence of the magnet places restrictions on use of areas within the fringe field.

The site must have a minimum of environmental magnetic fields. Common sources of magnetic interference are fluctuating loads on adjacent power lines, radio or television transmissions, heavy-duty transformers, elevator motors, and similar electromagnetic devices. Consult Varian for concerns about the proximity of electromagnets, elevators, loading docks, parking areas, etc.

Similar separation distances must also be maintained between the magnet and anything that can cause a detrimental effect on the field homogeneity or the structural integrity of the magnet. Conditions that could interfere with the magnet include (but by no means limited to) a wall with metal sheathing or steel studding, a concrete support column with steel reinforcing bars, and a storage area containing steel dewars for cryogenic storage. Each site must be carefully analyzed to ensure optimum performance of the system.

2.7 Electrical Requirements

This section describes the electrical requirements of the whole-body NMR imaging system.

Mains Supply

The whole-body NMR imaging system must have a dedicated mains supply. Do not connect mechanical services (e.g., air conditioning) or other domestic circuits to the same supply. The mains supply must meet the following requirements:

- Voltage and Frequency: 380, 400, 420 Vac 3-phase +6%, −10% (50 Hz ± 1%)  
  440, 480 Vac 3-phase +6%, −10% (60 Hz ± 1%)
- Line-to-line unbalance: 2% max.
- Connected load: 40 kVA (50 kVA with options)
- On-site fuse rating: 100 A
- Maximum line impedance: 0.24 ohm at 380 V, 0.32 ohm at 480 V; rising linearly

A line voltage stabilizer is required when line voltage specifications cannot be maintained.

Main Fuse and System Fuse

The main fuse or circuit breaker should comply with local requirements. Use only slow-blow fuses. The system fuse is a fast 100 A fuse installed in the PCA (see Figure 4).

Shielded Power Cable

The power cabinet (PCA) in the equipment room should be connected to the line power distribution panel with a shielded line voltage cable. Figure 4 shows the location of the shielded power cable in relation to the power distribution panel. The shielded power cable must have the following:

- Shielding grounded on both sides.
- Line voltage cable connected to the correct phase balance.
Chapter 2. General Site Requirements

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Figure 4. Power Distribution Panel

This panel must also provide the following:

- 220Vac, 20A, 1-phase for UNITY/NOVA cabinet.
- 208Vac, 20A, 3-phase for AMT cabinet.
2.7 Electrical Requirements

Mains Connection Terminals

Cables with a maximum cross section of 50 mm\(^2\) can be connected to the mains connection terminal of the PCA.

The power supply available at the mains connection terminals should meet the following specifications:

- **Voltage and Frequency**: 380, 400, 420 Vac 3-phase +6%, −10% (50 Hz ± 1%)
- 440, 480 Vac 3-phase +6%, −10% (60 Hz ± 1%)
- **Line-to-line unbalance**: 2% max.
- **Connected load**: 40 kVA (50 kVA with options)
- **Internal line impedance**: 0.2 ohm at 380 V, 0.32 ohm at 480 V; rising linearly
- **Power failure**: 8 ms max.

Temperature Monitoring

The temperature monitoring device for the control room is part of the delivery kit. Exceeded temperature limits greater than 27°C are visually and acoustically indicated on the alarm box and the MRC monitor.

Power Consumption

The average power dissipation is between 12 and 36 kVA, depending on system operation and sequence used.

Distribution Panel

A simple mains distribution panel, shown in Figure 4, is required for the MR system. This panel is provided by the customer and must contain, at a minimum, the following:

- 1 ea. 100 A isolator
- 3 ea. 100 A HRC fuses
- 1 ea. 80 A 4-pole contactor with 2 A protection fuse. The contactor is operated with a panel door mounted on/off switch using an indicator light and several emergency “mushroom type” push buttons situated throughout the suite.
- 1 ea. earth bar

The distribution panel must have an on/off button for switching the on-site power supply on or off.

The whole-body NMR imaging system is switched on or off with the button on the alarm box supplied with the system.

Install emergency shutdown buttons in the MR suite in accordance with the project plans. Figure 5 shows the emergency shutdown circuit.

Only the whole-body NMR imaging system should be shutdown with the shutdown circuitry (i.e., on/off button or emergency shutdown button). If the refrigerator is shut down, system specifications are no longer met.

Make sure that the system cannot be switched on accidently after the emergency shutdown button is unlocked.

For uninterruptible power supplies (UPS), an unused contact on K4 should be used for emergency shutdown.
Chapter 2. General Site Requirements

**Figure 5. Emergency Shutdown Circuit**

For connections a, b, c, d, and PE, see Figure 4.

Note: this panel is provided by customer.

Required for safety class 1 components
2.7 Electrical Requirements

Line Conditioning
To protect the system from unexpected high voltages (transients, surges, and spikes) that can occur in the power lines, we recommend transient surge protector (e.g., Transector Systems ACP2900-277W or similar). The transient surge protector must meet the following requirements:

- Service frequency: 50/60 Hz
- Response time: 5 nanoseconds
- Power dissipations: 300,000 W/phase at Vmax (1 × 1000 µs)
- Standby power: 10 W/phase max
- Minimum clamping voltage: 470 V peak
- Maximum clamping voltage: 700 V peak

Line Voltage Stabilizer
A line voltage stabilizer is required when the line voltage specifications cannot be maintained.

Service Line
The permissible magnetic flux density \( B \) (magnetic induction) for the ac, three-phase power meter is \( B \leq 2mT \)

Magnetic shielding must be provided at higher magnetic flux densities to ensure the proper operation of the ac and three-phase power meter.

Cable Distribution
Cable runs in the ceiling provide the main cable distribution route between the system components.

The electrical contractor will supply and run the 5-core 16 mm\(^2\) type CY screened cable between the mains distribution panel and the mains cabinet, in accordance with the Varian installation plan. Varian will make the connections in the Varian and Siemens cabinets. The electrical contractor will make all other connections.

A 3-meter tail is required for connection of the mains supply cable within the Siemens cabinet. The tail is measured from the center of the power distribution cabinet.

All other system mains and signal cables are supplied by Varian and Siemens and installed directly following delivery of the MR systems to the site. Connections from the system contractor to the emergency off buttons are not considered as part of the equipment installation and, therefore, are the responsibility of the electrical contractor along with lighting and small power (discussed below).

All cable connection to the magnet room must pass through an rf filter, including all lighting and small power. Siemens provides rf filters for the single power circuit (lighting) with a maximum rating of 25 A and for connection of the emergency stops. All circuits within the magnet room are to be completed and tested through a loop of cable temporarily passing through the rf filter plate aperture. Final connection to the filters can be made following deliver and require 4-mm lugs on either side of the filter.

All electrical trunking and conduit in the magnet room is to be nonferrous. Routes are required from the rf filter plates to the magnet, emergency stops, magnet emergency stop,
lighting, and rf door interlock. Cable trunking/tray of various sizes (e.g., \(500 \times 700\) mm, \(100 \times 50\) mm minimum) are required between system components. Cable trays (or trunking) are to be run above the false ceiling, dropping down at the appropriate position within the internal wall makeup. Holes in the ceiling tiles are required at the appropriate locations.

All emergency stops must be mounted at 1800 mm (71 in.) above floor level, except in the magnet room where emergency stops must be mounted 1600 mm (63 in.) above the floor. Magnet stop buttons (supplied by Varian) must be mounted directly above the emergency stops, at 1800 mm above the floor; a conduit is required for this purpose. The cable route must be within the wall finish for the Varian cable, complete with connector.

**Lighting**

No fluorescent lights or dimmer switches are permitted within the magnet room. Tungsten lamps with nonferrous fittings (minimal ferrous content might be acceptable) are required, with different levels of illumination achieved through selective switching within the room. DC voltage is recommended to increase lamp life and prevent any rf from being generated by a faulty bulb. A transformer and rectifier outside the magnet room with output ripple of less than 5% is required.

A minimum of 300 lux is required for service, with a separately-switched fitting mounted directly above the magnet.

**Small Power**

Twin power outlets for servicing are required adjacent to the equipment room. Equipment in the equipment room requires a single outlet.

Twin power outlets for servicing are required for the control and evaluation desks and for cabinets in the equipment room. A single outlet is required adjacent the magnet.

To discourage accidental use of ferrous equipment (e.g., vacuum cleaners), do not install a user-accessible power outlet within the magnet room. Such power outlets could present a safety hazard.

Should a power outlet (or outlets) be required for use with any equipment that will come in contact with the patient (e.g., patient monitoring or anesthesia), the use of an isolation transformer is required. Additional rf filters might also be required.

**Earthing**

To prevent the introduction of earth loops, all earthing must be carried out to the Varian and Siemens requirements.

### 2.8 Mechanical Requirements

This section describes the general mechanical requirements of the whole-body NMR imaging system.
2.8 Mechanical Requirements

Air Conditioning

Air conditioning for the MR suite must meet the following requirements:

- Temperature: 21° ±3°C, limits 17°C and 27°C
- Temperature gradient: 3°C/hour max.
- Relative humidity: 40 to 70%, without condensation
- Filtration: classification EU 4, >80% Ashrae
- Ventilation: local standards and codes

Relative humidity of the MR suite should not be below the dew point. The following relative humidity values are recommended:

- Equipment room: 45 to 70%
- Magnet room: 50% +10%, –5%
  If these values are exceeded and 3W/kg is applied (maximum permitted power in whole-body mode), body temperature can increase by more than 1°C (established tolerance value).
- Control room: 40 to 70%

Table 7 lists the typical heat dissipation-to-air values for each room in the MR suite.

Table 7. Typical Heat Dissipation-To-Air Values in the MR Suite

<table>
<thead>
<tr>
<th>Room</th>
<th>Typical Heat Dissipation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnet room</td>
<td>1200 W</td>
</tr>
<tr>
<td>Equipment room</td>
<td>13500 W</td>
</tr>
<tr>
<td>Control room</td>
<td>1000 W</td>
</tr>
<tr>
<td>Evaluation room (optional)</td>
<td>1500 W</td>
</tr>
</tbody>
</table>

A remote alarm system is supplied to indicate the equipment room temperature is reaching the maximum limit. This unit is sited within the control room (the cable route is required to be adjacent the rf window). A second stage to shut down the system once the limit is reached is also included, which operates if the problem is not corrected.

A chart recorder, or monitoring by a central building management system, for temperature and humidity is recommended to record any problems and give an early warning of any change in the equipment room environment.

Ductwork

All air conditioning ductwork within the magnet room has to be nonferrous and connected to an rf filter (provided by the rf shielding supplier). Ductwork connections to these filters must be electrically isolated by means of a rubber or similar material joint.

For safety reasons during the helium top up of the magnet, the air extract from the magnet room must be directed to waste. A manual switchover is sufficient for this purpose.

Quench Pipe

An emergency means of exhaust must be provided for the helium of the magnet to vent to the outside of the building if the magnet quenches (rapid transformation of helium from liquid to gaseous state). This vent is provided by providing a thermal-insulated duct.
(quench pipe) made from nonferrous material (inside the magnet room) with a 150-mm (6 in.) minimum diameter.

Refer to the section “Quench Pipe Specifications and Construction” on page 64 for detailed specifications and calculations for the quench pipe.

Cooling Water

Two dedicated chilled water supplies are required—one for ACCU and gradient coils and one for the AMT rf amplifier.

Chilled Water for ACCU

To minimize helium loss, the cold head refrigerator on the ACCU requires a chilled water unit to run 24 hours per day, every day of the year. Also, the high-powered gradient coils are water cooled with an intermittent load dependent on system use. The recommended setup is a dual-circuit packaged water chiller with a separate back-up system provided by a second chiller, a connection to an existing hospital system, or mains water to waste. Table 8 lists the chilled water requirements for the cold head refrigerator, gradient power supply, and gradient coils.

Table 8. Chilled Water Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow rate</td>
<td>40 LPM (without antifreeze), 33 LPM (with 34% antifreeze)</td>
</tr>
<tr>
<td>Temperature</td>
<td>6° to 12°C</td>
</tr>
<tr>
<td>Water pressure</td>
<td>2 to 6 bar (6 bar max.)</td>
</tr>
<tr>
<td>Differential water pressure</td>
<td>2 bar</td>
</tr>
<tr>
<td>pH</td>
<td>6 to 8 (1° dH = 17.8 ppm CaCO₃)</td>
</tr>
<tr>
<td>Hardness</td>
<td>106.8 to 142.4 ppm calcium carbonate (CaCO₃)</td>
</tr>
<tr>
<td>Heat dissipation to water</td>
<td>7 to 20 kW (system in measurement mode, 9 kW avg.)</td>
</tr>
<tr>
<td></td>
<td>20 kW (He compressor with gradient cooling)</td>
</tr>
<tr>
<td></td>
<td>7 kW (He compressor without gradient cooling)</td>
</tr>
</tbody>
</table>

Chiller pipe work must terminate above the ACCU, with the final connection a suitable flexible hose (flange fitting for use with 22-mm hose provided). Indication of the flow rate and supply temperature is to be available within the equipment room. A packaged water unit with remote Midas microprocessor control (e.g., Flowcool Systems) is recommended.

Chilled Water for AMT RF Amplifier

The AMT rf amplifiers are water cooled with an intermittent load dependent on system use. A packaged water chiller with an optional backup system is recommended. Table 9 lists the chilled water requirements for the AMT amplifier.

Table 9. Chilled Water Requirements for AMT RF Amplifiers

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow rate</td>
<td>20 LPM (without antifreeze)</td>
</tr>
<tr>
<td>Temperature</td>
<td>18° to 20°C</td>
</tr>
<tr>
<td>Connection pressure</td>
<td>2 to 3 bar</td>
</tr>
</tbody>
</table>
2.9 Other General Requirements

This section describes some other general site requirements to consider.

**Oxygen Monitor**

The publication *Guidelines for Magnetic Resonance Diagnostic Equipment in Clinical Use*, published by the MDA, specifies that an oxygen monitor be provided within the magnet room to monitor the oxygen level in case a leakage of helium gas occurs. An audible or visual display of its status should be located within the control room.

**Metal Detectors**

We recommend hand-held “wand” type metal detectors or a questionnaire to prescreen patients before entering the magnet room. Walkthrough metal detectors have been found to be ineffective.

**Storage Space**

Sufficient storage space is required for all test phantoms, surface coils, and technical documentation. Minimum requirements are a double-door, tall cabinet, within the equipment room, and a 600 × 1500 mm (23.6 × 59 in.) free-standing cupboard unit, with 3 or 4 shelves, within the magnet room.

**Antiglare Lighting**

Use antiglare lighting with dimmer switches, within the control room area.

**Remote-Controlled Door Lock**

A remote-controlled lock should be fitted to the entrance doors of the suite, with entry under control of the receptionist or radiographer.

**Lockers**

Lockers should be provided for storage of items sensitive to strong magnetic fields (e.g., watches, credit cards).

**Fire Extinguishers**

The customer must provide nonferrous fire extinguishers. Notify local fire officials of the presence of an MRI suite and establish local rules and codes associated with MRI systems.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH value</td>
<td>6 to 8</td>
</tr>
<tr>
<td>Hardness</td>
<td>106.8 to 142.4 ppm calcium carbonate</td>
</tr>
<tr>
<td>Heat dissipation to water</td>
<td>3.2 kW</td>
</tr>
</tbody>
</table>
Chapter 2. General Site Requirements

Noise Attenuation

The MR rooms should be noise attenuated. The noise levels in each room are listed below:

- Equipment room: < 73 dB(A)
- Magnet room: < 83 dB(A)
- Control room: < 63 dB(A)

Limit Switches at the Doors of the RF Room

To maintain rf integrity, all doors of the rf room must be equipped with a limit switch.

Storage and Transport Conditions

The relative humidity for storage and transport is 90% noncondensing. The recommended storage temperature range is –20°C to +85°C.

RF Shielding

The rf shielding requirements for 15 to 100 MHz is 90 dB.

2.10 Safety Guidelines

This section contains some safety guidelines to follow when planning a whole-body NMR imaging site.

Fire Prevention

Constructional fire prevention methods should be in accord with local regulations and guidelines. The user is responsible for informing the local fire department of the equipment installed and to comply with the safety requirements specified.

Fire Extinguishers

Fire-fighting equipment must comply with the specifications of the local fire department and consist of nonferromagnetic material.

Smoke Detectors

The type and the location of smoke detectors should be chosen with considerations to the magnetic field. The electrical cable to the smoke detectors installed in the magnet room must be routed through the filter plate.

Keep in mind that during magnet servicing (e.g., removal of boil-off lines, helium refilling), vapor is released from the magnet that can trigger smoke detectors near the magnet.

Before Energizing the Magnet

Before the magnet is energized, the following must be true:

- The exclusion zone (0.5 mT) has been identified.
- The project manager has authorized the energization of the magnet.
• The project manager has informed employees working in the vicinity of the magnet about the pending magnet energization.
• All ferromagnetic material has been removed from the magnet room.
• The necessary nonferromagnetic tools are available on site.
• The magnet stop button has been tested and functions properly.
• Access to the magnet room is restricted. Access can be restricted with a plastic chain attached to two poles. A flashing light is attached to each pole, and a warning sign hangs from the chain that displays the message, “Strong magnetic field warning! Hazardous conditions Do not enter!” in the appropriate language.

Before System Startup
Before the whole-body NMR imaging system is started up, the following must be true:
• On-site operating instructions are available.
• Magnet stop buttons are easily accessible.
• Warning signs are complete and posted:
  • Next to doors leading to the magnet and equipment rooms.
  • Next to areas leading to zones where the magnetic flux density exceeds 0.5 mT.
• Nonferromagnetic fire extinguishers are available.
• Emergency shut-down buttons are functioning.
• Magnetic fringe fields have been measured throughout the magnet room as well as in the floors above and below the magnet room.
• Components have been visually inspected for:
  • Ground connections at the doors.
  • Secured line voltage cables.
• System logbook has been reviewed.

Guidelines for Handling Heavy Loads
When handling heavy loads, always do the following:
• Wear protective clothing, including safety gloves (leather or equivalent) and non-ferromagnetic safety shoes.
• Inspect tools for visual damage before using them. The tools and auxiliary tools must be in satisfactory working conditions and meet with manufacturer’s specifications (adhere to legal regulations).
• Inform the supervisor about incidents of damage.
• Inform temporary personnel about the hazards and the safety measures required when handling heavy loads.
• Use only the transport and lifting devices specified.
• Secure the transport device and load before moving the load.

When handling heavy loads, never do the following:
• Never use defective or damaged tools.
• Never block emergency exits
• Never stretch ropes by twisting them.
• Never knot ropes or chains.
• Never stand under heavy loads.
• Never exceed the load capacity of devices.
• Never route or stretch ropes, chains, or bands over sharp edges.
• Never allow personnel to stay in areas where heavy loads are being moved.

Handling Liquid Cryogens

Follow the guidelines in this section when handling liquid cryogens.

WARNING: Avoid helium or nitrogen contact with any part of the body. Helium and nitrogen can cause an injury similar to a burn. Never place your head over the helium and nitrogen exit tubes. If helium or nitrogen contacts the body, seek immediate medical attention, especially if the skin is blistered or the eyes are affected.

WARNING: Do not remove the relief valves on the vent tubes. The relief valves prevent air from entering the helium vent tube. Air that enters the magnet contains moisture that can freeze, causing blockage of the vent tubes and possibly extensive damage to the magnet. It could also cause a sudden dangerous release of helium gas from the dewar. Except when transferring nitrogen or helium, be certain that the relief valves are secured on the vent tubes.

• Note the manufacturer’s safety instructions affixed to the dewars.
• Inform the manufacturer immediately if the dewars are damaged or covered with ice. Do not attempt to repair or deice the dewar.
• Observe the safety instructions for handling cryogenic gases. The instructions are included in the technical and safety-related documentation.
• Wear the protective clothing prescribed for handling liquid gases, including ZETEX gloves (or leather equivalent), face shield, lab coat, and non-ferromagnetic safety shoes.
• Use a non-ferromagnetic ladder.

2.11 System Maintenance and Operating Costs

This information in this section should give you an idea of some potential costs of operating a whole-body NMR imaging system.

Cold Head and Compressor Service

Cold head and compressor service is required every 8000 to 9000 hours, which costs about $10000 to $12000, including magnet rampdown and rampup. Add to this the cost of cryogens, which varies according to magnet size. The magnet should be topped off typically during this service visit.

Approximate Helium Consumption for a Magnet

Table 10 lists the typical refill intervals and volumes for helium. Locating a reliable source of liquid helium is particularly important. Use the values in Table 10 when making...
arrangements for an on-going supply of liquid helium. Note that refill volumes vary from 20 to 40% depending on the refill efficiency and conditions.

Table 10. Helium Refill Intervals and Volumes

<table>
<thead>
<tr>
<th>Magnet</th>
<th>Refill Interval</th>
<th>Refill Volume (L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3T905 active shielded</td>
<td>8 months</td>
<td>800 (approx.)</td>
</tr>
<tr>
<td>3T905 yoke shielded</td>
<td>10 months</td>
<td>600 (approx.)</td>
</tr>
<tr>
<td>4T905</td>
<td>9 to 10 months</td>
<td>1000 (approx.)</td>
</tr>
</tbody>
</table>

**Average Power Consumption**

The average power consumption for a whole-body NMR imaging system is 12 to 36 kVA, depending on system configuration and pulse sequence used.

**Water Consumption**

The water supply needed for the ACCU cabinet is 35 L at 6–10°C.

The gradient power supply and coils cooled by the ACCU unit require 50 L/min at 20°C. The thermal load is 7 to 20 kW (9 kW average) in measurement mode.

If you are not using a recirculating system, you must have a separate water chiller unit for the following:

- AMT 4-kW rf amplifier requires 20 L/min at 20°C for a thermal load of 3.5 kW.
- AMT 7-kW rf amplifier requires 20 L/min at 20°C for a thermal load of 7.5 kW

**Air Conditioning**

To figure air conditioning costs, you can expect the following heat dissipation to air for a standard system:

- Equipment room – 14 kW
- Magnet room – 2 kW
- Operator area - 2 kW (depending on equipment and number of people)
Chapter 3. Equipment Room and Components

Sections in this chapter:
- 3.1 “Equipment Room Requirements” this page
- 3.2 “Equipment Room Components” page 48

This chapter contains information about the equipment room and the whole-body NMR imaging components it contains.

3.1 Equipment Room Requirements

The equipment room contains the whole-body NMR imaging electronics cabinets and accessories. Table 11 lists the requirements to consider when planning the equipment room.

The equipment room door should be a minimum size of 900 × 2100 mm (35.4 × 82.7 in.), or large enough to accommodate the delivery of the system components. If the room has a drop ceiling, appropriate cutouts should be made for system cables.

Table 11. Equipment Room Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum size</td>
<td>5000 × 6000 mm (164 × 197 in.). The electronics cabinets can be arranged to fit into a smaller room, but a smaller room provides less space to move around the equipment.</td>
</tr>
<tr>
<td>Minimum ceiling height</td>
<td>2200 mm (86.6 in.) minimum. An optional drop ceiling can be placed above or below the ceiling cable trays.</td>
</tr>
<tr>
<td>Minimum door size</td>
<td>900 × 2100 m (35.4 × 82.7 in.)</td>
</tr>
<tr>
<td>Floor requirements</td>
<td>Antistatic</td>
</tr>
<tr>
<td>Insulation, shielding</td>
<td>No requirement</td>
</tr>
<tr>
<td>Power outlets</td>
<td>Typically, a mains distribution cabinet is installed as close to the equipment room as possible for supplying system power. A shielded cable must be used for connecting the power distribution unit (PCA) to the power supply.</td>
</tr>
<tr>
<td>Air conditioning</td>
<td>System that can handle the 15 kW of heat produced by the components.</td>
</tr>
<tr>
<td>Cable runs</td>
<td>Ideally, the room contains three 500 × 70 mm (19.7 × 2.8 in.) wooden or plastic cable trays: one for rf/signal cables and one for high-power gradient cables. The cable trays can be installed above or below the drop ceiling. The two cable runs should be at least 610 mm (24 in.) apart if possible. Cables from the various components are bundled appropriately and run through flexible conduit or aluminum ladder up to the ceiling. The ceiling cable trays hold the cables that go to the filter plates.</td>
</tr>
</tbody>
</table>
Chapter 3. Equipment Room and Components

3.2 Equipment Room Components

The components in the equipment room are described in the following subsections. Table 12 lists the essential specifications of the components.

- “NMR Cabinets” on page 49
- “Imaging RF Power Cabinet” on page 50
- “AMT 4T40 and 4T70 RF Amplifier Cabinets” on page 51
- “Water Cooling Unit Cabinet (ACCU)” on page 52
- “Power Distribution Unit Cabinet (PCA)” on page 56
- “Gradient Power Supply Cabinet (GPS)” on page 57
- “Gradient Booster Cabinet (EPI)” on page 58

Table 12. Equipment Room Components at a Glance

<table>
<thead>
<tr>
<th>Component</th>
<th>Coolant Thermal Loading</th>
<th>Line Voltage</th>
<th>AC Power Requirements</th>
<th>Size (HWD)</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNITY / NOVA NMR console</td>
<td>1.70 kW</td>
<td>220 Vac ±7%, 1 Ø, 50/60 Hz</td>
<td>20 A at 220 V</td>
<td>1182 × 1106 × 779.3 mm (48.54 × 43.54 × 30.68 in.)</td>
<td>272 kg (600 lb)</td>
</tr>
<tr>
<td>Imaging rf power cabinet</td>
<td>1.70 kW</td>
<td>208/220/240 Vac, 1 Ø</td>
<td>30 A</td>
<td>1182 × 553 × 779.3 mm (48.54 × 21.77 × 30.68 in.)</td>
<td>120 kg (264 lb)</td>
</tr>
<tr>
<td>AMT 4T40 rf amplifier cabinet</td>
<td>3.20 kW</td>
<td>208/230 Vac, ±10%, 3 Ø, 50–60 Hz</td>
<td>10A/phase at 208 V, typically at 4 kW rf output</td>
<td>1189 × 635 × 902 mm (46.75 × 25 × 35.5 in.)</td>
<td>388 kg (855 lb)</td>
</tr>
<tr>
<td>AMT 4T70 rf amplifier cabinet</td>
<td>3.20 kW</td>
<td>208/230 Vac, ±10%, 3 Ø, 50–60 Hz</td>
<td>22A/phase at 208 V, typically at 7 kW rf output</td>
<td>1676 × 635 × 902 mm (66 × 25 × 35.5 in.)</td>
<td>553 kg (1220 lb)</td>
</tr>
<tr>
<td>Water cooling unit cabinet (ACCU)</td>
<td>1.00 kW</td>
<td>230 Vac, 1 Ø</td>
<td>10 A</td>
<td>1800 × 660 × 860 mm (71 × 26 × 33.6 in.)</td>
<td>325 kg (717 lb)</td>
</tr>
<tr>
<td>Gradient booster cabinet (EPI)</td>
<td>0.30 kW</td>
<td>230 Vac, 1 Ø</td>
<td>10 A</td>
<td>1800 × 660 × 860 mm (71 × 26 × 33.6 in.)</td>
<td>300 kg (661 lb)</td>
</tr>
<tr>
<td>Gradient power supply (GPS)</td>
<td>3.30 kW</td>
<td>230 Vac, 1 Ø</td>
<td>10 A</td>
<td>1800 × 660 × 860 mm (71 × 26 × 33.6 in.)</td>
<td>500 kg (1102 lb)</td>
</tr>
<tr>
<td>Power distribution unit (PCA)</td>
<td>3.30 kW</td>
<td>Refer to 2.7 “Electrical Requirements” page 33.</td>
<td></td>
<td>1800 × 660 × 860 mm (71 × 26 × 33.6 in.)</td>
<td>680 kg (1500 lb)</td>
</tr>
</tbody>
</table>
NMR Cabinets

Table 13 lists the requirements of the Unity INOVA NMR cabinets, which provide the NMR acquisition computer and rf control system. Figure 6 shows the dimensions of the NMR cabinets.

The rf system consists of a transmit and a receive section. The hardware for rf pulse generation is integrated into the electronics cabinet as well as the hardware for processing the received and preamplified MR signals.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Unity INOVA NMR Console</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling</td>
<td>Air cooled with internal fans</td>
</tr>
<tr>
<td>Coolant thermal loading</td>
<td>1.7 kW</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>21° ±3°C, limits 17°C and 27°C</td>
</tr>
<tr>
<td>Line voltage</td>
<td>220 V ac ±7%, single phase, 50/60 Hz</td>
</tr>
<tr>
<td>AC power requirements</td>
<td>20 A at 220 V</td>
</tr>
<tr>
<td>Dimensions (HWD)</td>
<td>1182 × 1106 × 779.3 mm (48.54 × 43.54 × 30.68 in.)</td>
</tr>
<tr>
<td>Unit weight</td>
<td>272 kg (600 lb)</td>
</tr>
<tr>
<td>Shipping weight</td>
<td>285 kg (630 lb)</td>
</tr>
</tbody>
</table>

Figure 6. Unity INOVA NMR Cabinets
Imaging RF Power Cabinet

Table 14 lists the requirements of the imaging rf power cabinet, which is a single cabinet that provides up to 1 kW of rf power. Figure 7 shows the dimensions of the cabinet.

The cabinet includes an AMT 3200 solid-state linear rf power amplifier capable of 6 to 220 MHz, 1 kW pulse, 100 W continuous wave.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Imaging RF Power Cabinet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling</td>
<td>Air cooled with internal fans</td>
</tr>
<tr>
<td>Coolant thermal loading</td>
<td>1.7 kW</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>21° ±3°C, limits 17°C and 27°C</td>
</tr>
<tr>
<td>Line voltage</td>
<td>208/220/240, single phase</td>
</tr>
<tr>
<td>AC power requirements</td>
<td>30 A</td>
</tr>
<tr>
<td>Dimensions (HWD)</td>
<td>1182 × 553 × 779.3 mm</td>
</tr>
<tr>
<td></td>
<td>(48.54 × 21.77 × 30.68 in.)</td>
</tr>
<tr>
<td>Unit weight</td>
<td>120 kg (264 lb)</td>
</tr>
<tr>
<td>Shipping weight</td>
<td>143 kg (315 lb)</td>
</tr>
</tbody>
</table>

Figure 7. Imaging RF Power Cabinet
3.2 Equipment Room Components

AMT 4T40 and 4T70 RF Amplifier Cabinets

The AMT 4T40 (4 kW) and 4T70 (7 kW) rf amplifiers provide the linear power necessary for whole-body imaging operations. A system can have one or both of these amplifiers.

Table 15 lists the requirements for the AMT amplifier cabinets, and Figure 8 shows the dimensions of both cabinets. The AMT amplifiers require a separate water cooling system than provides about 15–18 lpm (4–5 gpm) at 20°C to 30°C ±1°C.

Table 15. AMT 4T40 and 4T70 RF Amplifiers Details

<table>
<thead>
<tr>
<th>Requirement</th>
<th>4T40 (4 kW)</th>
<th>4T70 (7 kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling</td>
<td>Water</td>
<td>Water</td>
</tr>
<tr>
<td>Coolant thermal loading</td>
<td>3.2 kW at full rated power and duty cycle</td>
<td>7.5 kW at full rated power and duty cycle</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>21°C ±3°C</td>
<td>21°C ±3°C</td>
</tr>
<tr>
<td>Line voltage</td>
<td>208/230 Vac ±10%, 3 Ø, 50–60 Hz</td>
<td>208/230 Vac ±10%, 3 Ø, 50–60 Hz</td>
</tr>
<tr>
<td>AC power requirements</td>
<td>10A/phase at 208 V, typically at 4 kW rf output</td>
<td>22A/phase at 208 V, typically at 7 kW rf output</td>
</tr>
<tr>
<td>Dimensions (HWD)</td>
<td>1189 × 635 × 902 mm (46.75 × 25 × 35.5 in.)</td>
<td>1676 × 635 × 902 mm (66 × 25 × 35.5 in.)</td>
</tr>
<tr>
<td>Unit weight</td>
<td>388 kg (855 lb)</td>
<td>553 kg (1220 lb)</td>
</tr>
<tr>
<td>Shipping weight</td>
<td>406 kg (895 lb)</td>
<td>572 kg (1260 lb)</td>
</tr>
</tbody>
</table>

Figure 8. AMT 4 kW and 7 kW Amplifiers
Water Cooling Unit Cabinet (ACCU)

Table 16 lists the critical requirements for the ACCU. The ACCU, shown in Figure 9, provides water cooling for the gradient coils and gradient power supply. The ACCU must remain outside the 3 mT magnetic field. For service, the ACCU requires a minimum space of 800 mm (31.5 in.) in the rear and 1000 mm (39.4 in.) in front, as shown in Figure 9. The connections to a chilled-water system are shown in Figure 10.

Table 16. Water Cooling Unit Cabinet (ACCU) at a Glance

<table>
<thead>
<tr>
<th>Requirements</th>
<th>ACCU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling</td>
<td>Water</td>
</tr>
<tr>
<td>Coolant thermal loading</td>
<td>1.0 kW</td>
</tr>
<tr>
<td>Limit value for flux density to</td>
<td>max. 3 mT He compressor</td>
</tr>
<tr>
<td>ensure system safety</td>
<td>max. 4 mT chiller</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>21° ±3°C, limits 17°C and 27°C</td>
</tr>
<tr>
<td>Line voltage</td>
<td>230 Vac, 1 Ø</td>
</tr>
<tr>
<td>AC power requirements</td>
<td>10 A (from PCA)</td>
</tr>
<tr>
<td>Dimensions (HWD)</td>
<td>1800 × 660 × 860 mm</td>
</tr>
<tr>
<td>Unit weight</td>
<td>325 kg (717 lb)</td>
</tr>
<tr>
<td>Shipping weight</td>
<td>331 kg (730 lb)</td>
</tr>
</tbody>
</table>

Figure 9. Water Cooling Unit (ACCU)
Figure 10. ACCU Cabinet Connected to Chilled-Water System
He-Pressurized Hoses

He-pressurized hoses, shown in Figure 11, connect the cold head to the ACCU. These pressurized hoses can be extended to 22.5 m (74 ft). Extension and coupling are optional and ordered separately. The minimum bending radius for the 1/2-inch pressurized copper tubing is 150 mm (5.9 in.).

**CAUTION:** Avoid bending the copper tubing to the correct the radius, etc. Repeated bending weakens the copper tubing and causes leaks.

**WARNING:** All pressurized hoses must be galvanically separated from ground.

![Diagram of He-Pressurized Hoses and Extensions](image)

Pressurized hose extension adaptors and couplings

<table>
<thead>
<tr>
<th>Description</th>
<th>Siemens Item No.</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressurized hose, 4.5 m</td>
<td>15 62 474 KE 030</td>
<td>1</td>
</tr>
<tr>
<td>Pressurized hose, 9 m</td>
<td>15 62 482 KE 030</td>
<td>1</td>
</tr>
<tr>
<td>Coupling/adaptor</td>
<td>77 09 868 B 0928</td>
<td>1</td>
</tr>
</tbody>
</table>

**Figure 11.** He-Pressurized Hoses and Extensions
3.2 Equipment Room Components

MR Electronics Cabinet

The MR electronics cabinet is actually three cabinets that are fastened together during installation. The three cabinets are the following:

- Power distribution unit cabinet (PCA)
- Gradient power supply cabinet (GPS)
- Gradient booster cabinet (EPI), optional

Each cabinet is described in a separate section below. Table 17 lists some technical data for the three cabinets together. Figure 12 shows the minimum space requirements of the MR electronics cabinets. This space allows fast and easy access for service.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>MR Electronics Cabinet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>1600 kg (3527 lb)</td>
</tr>
<tr>
<td>Shipping weight</td>
<td>1812 kg (3995 lb)</td>
</tr>
<tr>
<td>HWD</td>
<td>2250 × 1150 × 2100 mm</td>
</tr>
<tr>
<td></td>
<td>(88.6 × 45.3 × 82.7 in.)</td>
</tr>
<tr>
<td>Coolant thermal loading</td>
<td>6 kW</td>
</tr>
<tr>
<td>Maximum magnetic flux density</td>
<td>3 mT</td>
</tr>
</tbody>
</table>

![Figure 12. MR Cabinet Service Space Requirements](image)
Power Distribution Unit Cabinet (PCA)

Table 18 lists the requirements of the PCA, which provides power for the gradients and shims. Figure 13 shows the dimensions of the cabinet. For service, the PCA requires a minimum space of 900 mm (35.4 in.) in the rear and 700 mm (28 in.) in front. The PCA must remain outside the 3 mT magnetic field.

Table 18. Power Distribution Unit Cabinet (PCA) at a Glance

<table>
<thead>
<tr>
<th>Requirement</th>
<th>EPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling</td>
<td>Water</td>
</tr>
<tr>
<td>Coolant thermal loading</td>
<td>3.30 kW</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>21° ±3°C, limits 17°C and 27°C</td>
</tr>
<tr>
<td>Line voltage</td>
<td>From mains. Refer to “Electrical Requirements” on page 33</td>
</tr>
<tr>
<td>Line voltage</td>
<td>100 A fused input</td>
</tr>
<tr>
<td>Dimensions (HWD)</td>
<td>1800 × 660 × 860 mm</td>
</tr>
<tr>
<td></td>
<td>(71 × 26 × 33.6 in.)</td>
</tr>
<tr>
<td>Unit weight</td>
<td>680 kg (1500 lb)</td>
</tr>
<tr>
<td>Maximum magnetic flux density</td>
<td>3 mT (maximum)</td>
</tr>
</tbody>
</table>

Figure 13. Power Distribution Unit Cabinet (PCA)
3.2 Equipment Room Components

Gradient Power Supply Cabinet (GPS)

Table 19 lists the requirements for the GPS, which provides power for the gradients. Figure 14 shows the dimensions of the cabinet. For service, the GPS requires a minimum space of 900 mm (35.4 in.) in the rear and 700 mm (28 in.) in front. The GPS must remain outside the 3 mT magnetic field.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>GPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling</td>
<td>Water</td>
</tr>
<tr>
<td>Coolant thermal loading</td>
<td>3.30 kW</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>21° ±3°C, limits 17°C and 27°C</td>
</tr>
<tr>
<td>Line voltage</td>
<td>230 Vac, 1 Ø (from PCA)</td>
</tr>
<tr>
<td>Dimensions (HWD)</td>
<td>1800 × 660 × 860 mm</td>
</tr>
<tr>
<td></td>
<td>(71 × 26 × 33.6 in.)</td>
</tr>
<tr>
<td>Unit weight</td>
<td>500 kg (1102 lb)</td>
</tr>
<tr>
<td>Maximum magnetic flux</td>
<td>3 mT</td>
</tr>
</tbody>
</table>

Figure 14. Gradient Power Supply Cabinet (GPS)
Gradient Booster Cabinet (EPI)

Table 20 lists the dimensions of the EPI, which provides high power for the gradients. Figure 15 shows the dimensions of the cabinet. For service, the EPI requires a minimum space of 900 mm (35.4 in.) in the rear and 700 mm (28 in.) in front. The EPI must remain outside the 3 mT magnetic field.

Table 20. Gradient Booster Cabinet (EPI) at a Glance

<table>
<thead>
<tr>
<th>Requirement</th>
<th>EPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling</td>
<td>Water</td>
</tr>
<tr>
<td>Coolant thermal loading</td>
<td>0.30 kW</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>21° ±3°C, limits 17°C and 27°C</td>
</tr>
<tr>
<td>Line voltage</td>
<td>230 Vac, 1 Ø (from PCA)</td>
</tr>
<tr>
<td>Dimensions (HWD)</td>
<td>1800 × 660 × 860 mm</td>
</tr>
<tr>
<td></td>
<td>(71 × 26 × 33.6 in.)</td>
</tr>
<tr>
<td>Unit weight</td>
<td>300 kg (661 lb)</td>
</tr>
<tr>
<td>Maximum magnetic flux density</td>
<td>3 mT (maximum)</td>
</tr>
</tbody>
</table>

Figure 15. Gradient Booster Cabinet (EPI)
Chapter 4. **Magnet Room and Components**

Sections in this chapter:
- 4.1 “Magnet Room Requirements” this page
- 4.2 “Magnet Room Components” page 70

This chapter contains information about the magnet room and the whole-body NMR imaging components it contain

### 4.1 Magnet Room Requirements

The magnet room receives most of the attention when planning a whole-body NMR imaging laboratory. Table 21 lists the essential specifications of the magnet room.

The following items must be considered when designing the magnet room:
- “Area Requirements and Floor Loading,” this page
- “Building Vibrations,” this page
- “Magnetic Shielding,” page 60
- “RF Shielding,” page 63
- “Quench Pipe Specifications and Construction,” page 64
- “Gradient and System Filter Plates,” page 67

### Area Requirements and Floor Loading

The following loads do not contain safety or fatigue factors.
- Floor levelness – The floor must be level in the area of the magnet. Acceptable tolerance is ± 2 mm. The four leveling feet of the patient table compensate for unevenness in the floor.
- Floor loading – 22.75 kN vertical load. All areas must be constructed for an actual load of 3.0 kN/m².

### Building Vibrations

External vibrations affecting the magnet can degrade image quality. Gravitational acceleration (\(g_{\text{max}}\)) transferred through building vibrations to the magnet must not be exceeded in the three room directions in the frequency range from 0 Hz to 50 Hz.

The mathematical expression for \(g_{\text{max}}\) is

\[
g_{\text{max}} = \frac{g}{100} \quad \text{with} \quad g = 9.81 \text{m/s}^2
\]
Chapter 4. Magnet Room and Components

Table 21. Magnet Room Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum room size</td>
<td>6000 x 10000 mm (236.2 x 393.7 in.)</td>
</tr>
<tr>
<td>Ceiling height</td>
<td>Typical height is 3300 mm (130 in.) with a drop ceiling at 2500 mm (98.4 in.)</td>
</tr>
<tr>
<td>Floor requirements</td>
<td>Floor must be level (± 2 mm) in the magnet area. Floor coverings should be</td>
</tr>
<tr>
<td></td>
<td>antistatic. Vertical floor loading is 22.75 kN at contact points. All areas</td>
</tr>
<tr>
<td></td>
<td>must be constructed for an actual load of 3.0 kN/m².</td>
</tr>
<tr>
<td>Insulation, shielding</td>
<td>Room requires an rf shield efficiency of at least 90 dB, from 20 to 200 MHz.</td>
</tr>
<tr>
<td></td>
<td>At a minimum, the room has an aluminum sheeting surrounding the magnet</td>
</tr>
<tr>
<td></td>
<td>for rf shielding. More extensive shielding is provided by surrounding the</td>
</tr>
<tr>
<td></td>
<td>entire room with iron walls, 1 to 7 in. thick. The iron shielding contains both</td>
</tr>
<tr>
<td></td>
<td>rf and magnetic fields from the magnet, so the 5-gauss line will be closer in.</td>
</tr>
<tr>
<td></td>
<td>The rf shielding should never be connected with a ground wire, iron reinforcement, lightning rod, or similar object.</td>
</tr>
<tr>
<td>Power outlets</td>
<td>2 or 3 110 or 220 Vac outlets. The outlets should be rf tight and nonmagnetic.</td>
</tr>
<tr>
<td>Air conditioning</td>
<td>System that can handle the 2 kW of heat produced by the components. Supply</td>
</tr>
<tr>
<td></td>
<td>and exhaust air should vent through rf honeycombs.</td>
</tr>
<tr>
<td>Cable runs</td>
<td>1 or 2, 50 x 7 cm wooden or plastic cable trays in the ceiling. The trays can</td>
</tr>
<tr>
<td></td>
<td>be installed above or below the drop ceiling.</td>
</tr>
</tbody>
</table>

Magnetic Shielding

Magnetic shielding, shown in Figure 16, helps to contain the stray magnetic field and helps isolate the magnet from the effects of ferrous objects.

When planning a site, the environment must be considered for the following:

- Influence of the stray magnetic field.
- Effect of any ferrous objects, both static (e.g., reinforcement, beams, columns) and dynamic (e.g., elevators, cars, trucks), on the quality of the measuring field of the magnet.

The extent of the stray magnetic field depends on the field strength of the magnet. The magnetic field should be kept out of other work areas. Consider the following stray magnetic field effects:

- 0.5 mT – Pacemaker, insulin pump, and metal prosthesis limit. A controlled area must be established to ensure all persons fitted with a cardiac pacemaker, insulin pump, or metal prosthesis are prevented from entering.
- 0.05 mT – Limit for x-ray image intensifiers, gamma cameras, and linear accelerators.

Large fixed or moving ferrous objects can affect the quality (homogeneity) of the magnetic field used for imaging. In order to ensure that the magnetic field within the measuring area can be shimmed to within the required homogeneity, you should be aware of all steelworks and reinforcement within 6 m (19.7 ft) of the magnet center. Absolute limits are beams or columns in excess of 100 kg/m around the magnet room periphery and reinforced concrete or steel beams up to 40 kg/m² below the magnet.

Using additional magnetic shielding (iron plates on walls, ceiling, and floor) can help overcome most site conditions. This shielding can be constructed from soft iron plates (e.g., Armco Pure Iron), laminated low-silicon steel (e.g., Losil 500), or any other ferrous material for which the BH curve is known (hystereses curve). The required thickness and extent of the required shielding depends on the characteristics of the site and the properties of the material, and must be calculated by an appropriate specialist.
4.1 Magnet Room Requirements

Magnetic Shielding Example

The type and extent of the magnetic shielding depends on numerous variables, including extent of stray magnetic fields, location of the MR lab, cost, and amount of shielding required. Figure 16 shows a typical magnetic shield box.

The magnetic shield designed for a 4T 905-mm bore magnet is usually 5000 mm high by 9500 mm long (16.4 x 31.17 ft). The magnet is offset axially by 750 mm (2.5 ft) such that the back plate of the magnet is 4000 mm (13 ft) from the back wall of the room.

Wall thickness varies. The side walls of the box are 17.8 mm (7 in.) thick at the center, grading to 127 mm (5 in.) and 76.2 mm (3 in.). End walls are 76.2 mm (3 in.) and 127 mm (5 in.) thick. Ceiling and floor are each 76.2 mm (3 in.) thick. The total weight of the box is about 206 tons.

Combined Magnetic and RF Shielding Example

This section provides details about a typical magnetic/rf shielding structure, including technical data and construction illustrations. Figure 17 shows the floor system detail of the magnetic/rf shield combination, and Figure 18 shows a typical magnet room floor plan with the magnetic/rf shield installed.
Figure 17. Magnet/RF Shield Floor System Detail

Figure 18. Magnetic/RF Shield Typical Floor Plan
Each plate used in the magnetic/rf shield box is typically about $1200 \times 2400 \times 76.3$ mm ($47 \times 94.5 \times 3$ in.) and weighs no more than 1814 kg (4000 lbs). The weight is limited by the size of the equipment used to move or lift the plates.

Shield plates are typically welded to the support structure.

The floor will have rf shielding, and the area below the finished floor will be magnetically shielded. The below-grade magnetic shield plates could be as much as 1200 to 1800 mm (47 to 71 in.) below the finished floor. This would depend on the size of the magnet.

The magnetic shield employs an independent rigid frame structure. None of the magnetic shield is supported by any of the building structure; all of the shield mass is bearing on the structural foundation.

All of the building structure external to the shield could employ standard building materials. The interior engineered-in fill and structural slab should employ only nonmagnetic materials (e.g., fiberglass reinforcing, fiber-fill concrete, 304 stainless steel).

Fully annealed 1006 low-carbon steel should be used; however, 1003 steel can also be used. No stainless steel should be used within the shield.

All above-grade shield mass will bear on the vertical columns of the rigid frame. A shield with 100 mm (4 in.) thick shield plates would impose about 21 kips to the base of each column. Actual column loads would be dependent on the final shield design. All below-grade plates would be loaded to the subfoundation. The engineered-in fill, structural slab, and magnet would comprise the principal load on the subfoundation.

The floor slab must be dry and level before the rf floor is installed.

**RF Shielding**

The magnet room requires an rf shield (Faraday cage) to protect the environment against rf interference and as well as to ensure that the imaging system is protected against external rf sources.

The required attenuation of the rf shield is 90 dB over a frequency range of 20 to 200 MHz. These values must be certified before the system is installed.

RF shielding components, including doors, windows, mechanical waveguides, and electrical filters, are supplied by specialists (e.g., Premise Engineering, Lindgren Rayproof, and Wardray Products). The design of the rf shield must allow for the components.

The rf and gradient filter plates must be incorporated within the rf shield and require an enclosure that allows access to both sides with ventilation grills on the magnet room side.

Interior finishes (i.e., walls, antistatic flooring, and drop ceiling with nonmagnetic grid) must be fixed using the rf shielding supplier’s recommended method after the rf shield is complete.

Consider the following when designing the rf shield for the magnet room:

- **Filter plate cupboard** – Paint grade doors (plain or louvered) are required to enclose the rf filter plates with appropriate ventilation grills. The enclosure should be the full floor-to-ceiling height and be prepared for decoration.

- **Interior wall lining** – An appropriate interior lining (plasterboard or similar) is required for the interior walls of the rf shielding. This lining should be ready for decoration (paint or wallpaper). The method of construction is to be such that following delivery of the magnet, the remaining section can be reinstated with minimum disruption. Reinstatement of this panel is to be carried out by the rf shielding supplier after the magnet is delivered.
Chapter 4. Magnet Room and Components

- False ceiling – A nonferrous 600 x 600 mm (23.6 x 23.6 in.) modular drop-in ceiling is required throughout the room. Nominal height should be 2500 mm (98.4 in.) with a shadow band around the room boundaries. Tiles should be costed such as to allow for either regulated or smooth finish to be selected by the customer. The grid is to be as complete as possible before the magnet is delivered. The remaining section of the ceiling will be finished after the magnet and cabling is installed.

- Floor covering – The floor covering must be antistatic vinyl.

- Specifications – Non-ferrous. Attenuation 90 dB over 15–100 MHz.

- Dimensions – Determined by the magnet room size. The interior of a typical magnet room is 10000 x 6000 mm (393.7 x 236.2 in.)—the rf shield would have to fit around that.

- Door – Standard 1200 x 2100 mm (47.2 x 82.7 in.), single lead with contact switch.

- Window – 2400 x 800 mm (94.5 x 31.5 in.), either a single unit or two separate windows with a central joint.

- Quench pipe – 150, 180, or 200 mm (6, 7, or 8 in.) diameter. Refer to the “Quench Pipe Specifications and Construction,” this page.

- Electrical filters – RF and gradient filter plates are provided. Five spare filters are provided for lighting and emergency stop buttons. Additional filters may be required for other equipment.

- Mechanical waveguides – Two 400 x 400 mm (15.75 x 15.75 in.) for air conditioning. Three 5 cm diameter open waveguides between the magnet room and the control room.

- Medical gases – Additional waveguides may be required for oxygen, nitrous oxide, vacuum, medical air, and gas scavenging.

Quench Pipe Specifications and Construction

The quench pipe allows gasses from cryogenic boil-off to be exhausted to the outside, without significantly increasing the pressure in the cryostat. The parameters to consider when installing the quench pipe are the following:

- Internal pipe diameter (D) – 150, 180, or 200 mm (6, 7, or 8 in.)

- Mean length (L') – the distance from the quench pipe flange on the magnet to the quench pipe exhaust duct

- Number and type of bends – 45° or 90° seamless or segment bends.

- Equivalent length of bends (lb) – gasses flowing through elbows travel the equivalent pipe length, which is longer than the real length of the elbow (Tx).

The quench pipe should have the following characteristics:

- The first 6 m of the quench pipe must be made of non-magnetizable (nonferromagnetic) material, including aluminum, copper, a non-magnetizable steel.

- Pipes must have smooth inside walls.

- The exposed section of the quench pipe should be insulated (e.g., 75-mm Armaflex).

- The loss in pressure (Δp) between the magnet flange and the quench pipe should not exceed 0.07 bar (1 psi).

Calculating Quench Pipe Diameter and Length

The dimensions of the quench pipe depend on the length of the pipe required and the number of bends throughout its length. When configuring the quench pipe, the basic goal
is to have the minimum pipe diameter appropriate for the total length of the pipe. Refer to Figure 19 during this procedure.

![Figure 19. Quench Tube Dimensions](image)

1. Determine the distance from the quench pipe flange on the magnet to the area on the wall or ceiling where the exhaust duct will be located. This is the mean length ($L'$).

2. Refer to Table 22 and determine the minimum pipe diameter you can use for the distance $L'$ you determined in step 1. For example, if $L'$ is 15 m, use an 180-mm pipe as a starting point for the calculation.

3. Determine the number of elbows you need. Then, refer to Table 23 to calculate the equivalent elbow length ($lb$). For example, an 180 mm, 90° seamless elbow is equivalent to 1.7 m of straight pipe.

4. Use the $L_{max}$ value from Table 22 to compute the remaining length ($l$) for straight sections of piping from the following equation:

   \[ l = L_{max} - (lb_1 + lb_2 + lb_n) \]

   where $L_{max}$ is the maximum straight pipe length (in meters) for a given diameter (Table 22) and $lb_1$, $lb_2$, $lb_n$ are the equivalent length (all in meters) of the elbows.

<table>
<thead>
<tr>
<th>Pipe Inside Diameter (mm)</th>
<th>Maximum Straight Pipe Length ($L_{max}$) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>11000</td>
</tr>
<tr>
<td>180</td>
<td>21000</td>
</tr>
<tr>
<td>200</td>
<td>30000</td>
</tr>
</tbody>
</table>
Table 23. Equivalent Pipe Lengths for Elbows

<table>
<thead>
<tr>
<th>Number of Elbows</th>
<th>Pipe Inside Diameter (cm)</th>
<th>Equivalent Length for Seamless Elbows (m)</th>
<th>Equivalent Length for 4-Segment Elbows (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>45°</td>
<td>90°</td>
</tr>
<tr>
<td>1</td>
<td>15</td>
<td>1</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>1.2</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>1.3</td>
<td>1.9</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>2.2</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>2.6</td>
<td>3.8</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>3</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>3.6</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>3.9</td>
<td>5.7</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>4.8</td>
<td>6.8</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>5.3</td>
<td>7.6</td>
</tr>
</tbody>
</table>

For example, for an 180-mm diameter pipe, Table 22 lists a $L_{\text{max}}$ of 210 mm. If this wrench pipe has two 90° seamless elbows, the equation would look like the following:

$$l = 21.0 - (1.7 + 1.7) = 17.6 \text{ m}$$

5. Distribute the value determined in step 4 as needed among the straight sections of pipe.

Exhaust Duct

The exit of the quench pipe (exhaust duct to the outside) must be protected against rain or snow, animals, and objects blown in by the wind. Also, the end of the pipe should be kept free of obstructions to ensure sufficient flow rate and evaporation. Figure 20 shows an example of a vertical and horizontal exhaust duct.

The installation selected for the exhaust duct must prohibit access within 3 m of the gas flow.

The free cross section of the mesh wire at the exhaust duct must be larger or twice as large as the cross section of the quench pipe.

Quench Pipe Flange

The quench pipe flange, which is the interface between the magnet and the quench pipe, must be 5–6 mm thick and have the dimensions shown in Figure 21.
4.1 Magnet Room Requirements

The quench pipe should be removable from the quench pipe flange so that the bursting disk can be checked in case of a magnet quench.

**Cold Head Lifting Point and Deicing Outlet**

The ceiling above the magnet should have a nonmagnetic lifting hook or eye, which is used for servicing the cold head refrigerator. A nonmagnetic 220-V ac outlet is also needed in the ceiling above the magnet for deicing. Figure 22 shows the positions of the lifting point and deicing outlet relative to the magnet.

**Gradient and System Filter Plates**

Table 24 lists the requirements for the gradient and system filter plates. These plates allow signal-carrying cables to pass between the magnet room and the equipment room without compromising the rf shielding of the magnet room.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Filter Plates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling</td>
<td>Air</td>
</tr>
<tr>
<td>Maximum flux density</td>
<td>15 mT (max.)</td>
</tr>
<tr>
<td>Dimensions (HWD)</td>
<td>1500 × 875 mm (71 × 34.5 in.) each filter plate</td>
</tr>
</tbody>
</table>

Figure 21. Quench Pipe Flange
The filter plates are made of stainless steel and allow the rf shielding to remain intact where the cables penetrate the magnet room walls. Thus, the magnet room can be totally enclosed by a continuous conductive surface that contains the electric and magnetic fields created by rf pulse and other events in and around the magnet. The filter plates might only slightly contain the magnetic field.

The filter plates filter the low-voltage and low-frequency signals (with capacitors to ground) and allow the high-frequency rf to go straight through the plates (using bulkhead mounted connectors with no filtering).

We recommend that the customer provide paneling for the rf and gradient filter plates in the magnet room. The paneling, shown in Figure 23, should be about 2000 mm wide by 600 mm deep (78.7 × 23.6 in.) and should provide adequate ventilation and cable access. The intake and exhaust vents should be at least 450 × 100 mm (17.7 × 4 in.).

Figure 22. Cold Head Lifting Point and Deicing Outlet
4.1 Magnet Room Requirements

Figure 23. Gradient and System Filter Plates
4.2 Magnet Room Components

The components in the magnet room are described in the following subsections:

- “Magnet,” this page
- “Patient Table,” page 76
- “Magnet Stop Button,” page 77

Magnet

The superconducting magnet generates a homogeneous magnetic field with field strengths of 3 or 4 T. The main field is oriented in the horizontal direction along the cylindrical axis of the magnet. The magnet is connected to a power supply integrated into the electronics cabinet for the purpose of ramping for service activities. The magnet (with covers) and patient table are shown in Figure 24. The dimensions of a typical 3T magnet are shown in Figure 25.

The magnet uses helium only to maintain the superconducting state of the magnet coils. Helium boiloff is reduced through the use of a cold head, which removes heat from the magnet cryogen vessels. This heat is then transferred to a cooling unit in the equipment room. The cooling unit is connected to the water cooling system.

Varian currently offers four magnets: 4T, 3T, 3T yoke-shielded, and 3T actively-shielded.
4.2 Magnet Room Components

Stray Magnetic Fields

The stray magnetic field (or fringe field) can affect the functions of devices operated in the vicinity of the magnet. Contact the manufacturer of devices that might be affected by magnetic fields. Table 25 lists some stray magnetic field distances for the whole-body NMR imaging magnets.

Table 25. Stray Magnetic Field Distances from Magnet Center

<table>
<thead>
<tr>
<th>Magnet</th>
<th>5 gauss axial (m)</th>
<th>5 gauss radial (m)</th>
<th>10 gauss axial (m)</th>
<th>10 gauss radial (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4T</td>
<td>15.5</td>
<td>12.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3T</td>
<td>14.0</td>
<td>11.5</td>
<td>11.5</td>
<td>8.0</td>
</tr>
<tr>
<td>3T yoke shield</td>
<td>8.8</td>
<td>7.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3T active shield</td>
<td>6.0</td>
<td>4.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Magnet Cover

The magnet is enclosed in a cover similar to that shown in Figure 24 and Figure 26. For more information on the patient table, refer to “Patient Table,” page 76.
Figure 26. Magnet and Patient Table Dimensions, Top View
Area Requirements and Floor Loading

This section describes the area requirements and floor loading of the following magnets:

- Figure 27 and Figure 28 show front views of the 3T and 4T magnets with gradient frame and the 3T magnets with yoke shielding.
- Figure 29 and Figure 30 show footprint views of 3T and 4T magnets with gradient frame and the 3T magnet with yoke shielding.

Remember that the magnet covers, shown in the section “Magnet Cover,” page 71, enclose the magnets and extend beyond the dimensions shown in this section.

Figure 27. 3T and 4T Magnets Front with Gradient Frame and Aluminum Plates

Figure 28. 3T Yoke Shield, Front View
Figure 29. 3T and 4T Magnets with Patient Table Dimensions and Floor Loading
4.2 Magnet Room Components

Figure 30. 3T Magnet with Yoke Shielding and Patient Table Footprint


Chapter 4. Magnet Room and Components

Patient Table

The patient table supports the patient and enables proper patient positioning within the magnet and gradient system.

The power-assisted table is moved into the magnet bore, placing the anatomy to be examined in the isocenter. Table motion can be locked and released.

- Maximum patient weight is 160 kg (353 lb)
- Safety factors according to DIS IEC 601-1 are maintained

Table 26 summarizes patient table specifications, and Table 31 shows patient table dimensions.

Table 26. Patient Table at a Glance

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Patient Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling</td>
<td>Air</td>
</tr>
<tr>
<td>Coolant thermal loading</td>
<td>25 W</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>Ambient (–10°C to +40°C)</td>
</tr>
<tr>
<td>Dimensions (HWD)</td>
<td>See Figure 31</td>
</tr>
<tr>
<td>Unit weight</td>
<td>600 kg (1102 lb)</td>
</tr>
<tr>
<td>Shipping weight</td>
<td>700 kg (1543 lb)</td>
</tr>
</tbody>
</table>

Figure 31. Patient Table
Magnet Stop Button

The magnet stop button is installed in the magnet room. This unit weighs about 0.3 kg (0.7 lb) and is installed about 1800 mm (71 in.) from the floor, as shown in Figure 32.

Figure 32. Magnet Stop Dimensions
Chapter 5. **Control Room and Components**

Sections in this chapter:
- 5.1 “Control Room Requirements,” this page
- 5.2 “Control Room Components,” this page

This chapter contains information about the control room and the whole-body NMR imaging components in the room.

5.1 Control Room Requirements

Table 27 lists the essential specifications for the control room. When planning the control room, be sure to consider your requirements for desk and counter space, lighting, and network connections.

**Table 27. Control Room Requirements**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum size</td>
<td>3000 × 6000 mm (118 × 236.2 in.).</td>
</tr>
<tr>
<td>Ceiling height</td>
<td>A typical ceiling height is 3300 mm (130 in.) with a drop ceiling at 2500 mm (98.4 in.).</td>
</tr>
<tr>
<td>Floor requirements</td>
<td>Floors should be antistatic.</td>
</tr>
<tr>
<td>Insulation, shielding</td>
<td>No special shielding requirements.</td>
</tr>
<tr>
<td>Power outlets</td>
<td>Outlets to accommodate the anticipated needs of the lab. The Sun workstation and peripherals typically require 6 120/220 Vac outlets. To minimize ground loop interference, electrical outlets should all be on the same 20-A service. Surge protection is strongly recommended.</td>
</tr>
<tr>
<td>Air conditioning</td>
<td>System that can handle about 2 kW of heat produced by the components. The Sun workstation and peripherals produce about 0.9 kW.</td>
</tr>
<tr>
<td>Cable runs</td>
<td>1 or 2, 50 × 7 cm, wooden or plastic cable trays in the ceiling. The cable trays can be installed above or below the drop ceiling.</td>
</tr>
</tbody>
</table>

5.2 Control Room Components

The control room contains the host computer and accessories, including printer, plotter, laser camera, and video printer.

- “Host Computer,” page 80
- “Printer, Plotter, and Video Printer Accessories,” page 80
- “Alarm Box/Magnet Stop,” page 80
Host Computer

The host computer is a Sun workstation running VNMR software. The host computer allows the operator to control the various parts of the system as well as obtain, process, and store data.

The host computer can be networked for image transfer to or from other systems and computers.

Printer, Plotter, and Video Printer Accessories

Accessories can include the following:
- Optical disk drive.
- Laser printer (PostScript compatible) for printing images, text data, spectra, etc.
- Video printer for hardcopy images on paper.

Alarm Box/Magnet Stop

The alarm box/magnet box assembly, shown in Figure 33, is installed in the control room. The alarm box/magnet weighs 1.3 kg (2.9 lb). The flux density limit is 4 mT (max.).

![Alarm Box/Magnet Stop Dimensions](image)

Figure 33. Alarm Box/Magnet Stop Dimensions
Chapter 6. Cables, Water, and Room Layouts

Sections in this chapter:

- 6.1 “Cable Lengths,” this page
- 6.2 “Water Tubing and He-Pressurized Hose Lengths,” page 82
- 6.3 “Typical Layouts for a Whole-Body NMR Imaging Suite,” page 83

This chapter provides cable length information, water tubing lengths, and some illustrations of typical room layouts for the whole-body NMR imaging suite.

6.1 Cable Lengths

The total cable length is the length between the components in addition to the length required inside the components.

Figure 34 shows the free cable lengths between the exit points. When planning the final location of the system components, do not exceed the free cable lengths. Cables can be routed in parallel in cable trays or cable ducts.

![Figure 34. Standard Free Cable Lengths](image)

The size of openings (e.g., in walls or ceilings) as well as the cable ducts, should allow for the various shapes of cable connectors used (the largest connector is 100 x 50 mm).
Chapter 6. Cables, Water, and Room Layouts

When installing cables, be aware of the minimum bending radius ($R_B$) for the following cables:

- Gradient cable: $R_B \geq 135$ mm
- Transmitter cable:
  - $R_B \geq 120$ mm when bent once
  - $R_B \geq 360$ mm when bent several times
- Fiber optic cable: $R_B \geq 150$ mm

6.2 Water Tubing and He-Pressurized Hose Lengths

The illustrations in this section show the free length of water tubing and He-pressurized hoses. Figure 36 shows the free length of water tubing between the GPS, ACCU, and the shut-off valves.

Figure 35 shows the free length of He-pressurized hoses between the ACCU and the cold head. The delivery volume includes 60 m of pressurized tubing for the water installation.

Figure 35. He-Pressurized Hose Length
6.3 Typical Layouts for a Whole-Body NMR Imaging Suite

This section shows some different MR suite layouts. See the following illustrations:

- Figure 37, “MR Suite Layout 1,” on page 84
- Figure 38, “MR Suite Layout 2,” on page 85
- Figure 39, “MR Suite Layout 3,” on page 86

Figure 36. Water Tubing Length
Figure 37. MR Suite Layout 1
Figure 38. MR Suite Layout 2
Figure 39. MR Suite Layout 3
Chapter 7. **Conversion Tables for Standard Units**

Sections in this chapter:
- 7.1 “Standard Units,” this page
- 7.2 “Conversion Tables,” page 88
- 7.3 “Converting AWG Numbers,” page 89
- 7.4 “Converting dBm to Volts to Watts,” page 90

This chapter contains conversion tables for some standard units.

### 7.1 Standard Units

Table 28 lists the standard units referenced in this chapter.

**Table 28. Definition of Standard Units**

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>temperature</td>
<td>°C</td>
<td>degree celsius (1.8°C + 32 = F)</td>
</tr>
<tr>
<td>temperature</td>
<td>°F</td>
<td>degree fahrenheit (0.56(F – 32) = C)</td>
</tr>
<tr>
<td>temperature</td>
<td>K</td>
<td>kelvin</td>
</tr>
<tr>
<td>force</td>
<td>N</td>
<td>newton</td>
</tr>
<tr>
<td>force</td>
<td>ft-lb</td>
<td>foot-pound</td>
</tr>
<tr>
<td>power</td>
<td>kcal</td>
<td>kilocalorie</td>
</tr>
<tr>
<td>mass</td>
<td>g</td>
<td>gram</td>
</tr>
<tr>
<td>mass</td>
<td>kg</td>
<td>kilogram</td>
</tr>
<tr>
<td>length</td>
<td>m</td>
<td>meter</td>
</tr>
<tr>
<td>length</td>
<td>mm</td>
<td>millimeter</td>
</tr>
<tr>
<td>length</td>
<td>in.</td>
<td>inch</td>
</tr>
<tr>
<td>length</td>
<td>ft</td>
<td>foot</td>
</tr>
<tr>
<td>area</td>
<td>m²</td>
<td>square meter</td>
</tr>
<tr>
<td>area</td>
<td>cm²</td>
<td>square centimeter</td>
</tr>
<tr>
<td>area</td>
<td>sq. in.</td>
<td>square inch</td>
</tr>
<tr>
<td>area</td>
<td>sq. ft.</td>
<td>square foot</td>
</tr>
<tr>
<td>volume</td>
<td>m³</td>
<td>cubic meter</td>
</tr>
<tr>
<td>volume</td>
<td>cm³</td>
<td>cubic centimeter</td>
</tr>
<tr>
<td>volume</td>
<td>cu. in.</td>
<td>cubic inch</td>
</tr>
<tr>
<td>volume</td>
<td>cu. ft.</td>
<td>cubic foot</td>
</tr>
<tr>
<td>time</td>
<td>h</td>
<td>hour</td>
</tr>
<tr>
<td>magnetic field strength</td>
<td>A/m</td>
<td>ampere per meter</td>
</tr>
</tbody>
</table>
Chapter 7. Conversion Tables for Standard Units

7.2 Conversion Tables

This section contains conversion tables for the following units:

- **Length** – Table 29
- **Volume** – Table 30
- **Power** – Table 31
- **Energy** – Table 32
- **Pressure/force** – Table 33

### Table 29. Units of Length Conversions

<table>
<thead>
<tr>
<th>Unit</th>
<th>mm</th>
<th>m</th>
<th>in.</th>
<th>ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mm</td>
<td>1</td>
<td>0.001</td>
<td>0.0393701</td>
<td>0.0032808</td>
</tr>
<tr>
<td>1 m</td>
<td>1000</td>
<td>1</td>
<td>39.37</td>
<td>3.281</td>
</tr>
<tr>
<td>1 in.</td>
<td>25.4</td>
<td>0.0254</td>
<td>1</td>
<td>0.08333</td>
</tr>
<tr>
<td>1 ft</td>
<td>304.8</td>
<td>0.3048</td>
<td>12</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 30. Units of Volume Conversions

<table>
<thead>
<tr>
<th>Unit</th>
<th>cm³</th>
<th>m³</th>
<th>cu in.</th>
<th>cu ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 cm³</td>
<td>1</td>
<td>0.000001</td>
<td>0.06702</td>
<td>0.03531</td>
</tr>
<tr>
<td>1 m³</td>
<td>1000000</td>
<td>1</td>
<td>61023</td>
<td>35.31</td>
</tr>
<tr>
<td>1 cu in. =</td>
<td>16.39</td>
<td>0.0006452</td>
<td>1</td>
<td>0.000579</td>
</tr>
<tr>
<td>1 cu ft =</td>
<td>28316</td>
<td>0.028316</td>
<td>1728</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 31. Units of Power Conversions

<table>
<thead>
<tr>
<th>Unit</th>
<th>kcal/h</th>
<th>kJ/h</th>
<th>kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 kcal/h =</td>
<td>1</td>
<td>4.1868</td>
<td>0.00163</td>
</tr>
<tr>
<td>1 kJ/h =</td>
<td>0.2388</td>
<td>1</td>
<td>0.0002777</td>
</tr>
<tr>
<td>1 kW =</td>
<td>860</td>
<td>3600</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 32. Units of Energy Conversions

<table>
<thead>
<tr>
<th>Unit</th>
<th>kcal</th>
<th>kJ</th>
<th>kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 kJ =</td>
<td>0.2388</td>
<td>1</td>
<td>0.0002777</td>
</tr>
<tr>
<td>1 kWh =</td>
<td>860</td>
<td>3600</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 33. Units of Pressure/Force Conversions

<table>
<thead>
<tr>
<th>Unit</th>
<th>N/m² (Pa)</th>
<th>N/cm²</th>
<th>kp/m²</th>
<th>kp/cm²</th>
<th>lb/sq. ft</th>
<th>lb/sq. in. (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 N/m² =</td>
<td>1</td>
<td>0.0001</td>
<td>0.1019</td>
<td>0.1019×10⁻⁴</td>
<td>2.088×10⁻²</td>
<td>1.45×10⁻⁵</td>
</tr>
<tr>
<td>1 N/cm² =</td>
<td>10000</td>
<td>1</td>
<td>1019</td>
<td>0.1019</td>
<td>208.8</td>
<td>1.45</td>
</tr>
<tr>
<td>1 kp/m² =</td>
<td>9.80665</td>
<td>9.8066×10⁻⁴</td>
<td>1</td>
<td>0.001</td>
<td>0.2084</td>
<td>1.422×10⁻³</td>
</tr>
<tr>
<td>1 kp/cm² =</td>
<td>98066.5</td>
<td>9.8066</td>
<td>10000</td>
<td>1</td>
<td>2048</td>
<td>14.22</td>
</tr>
<tr>
<td>1 lb./sq. ft.</td>
<td>= 47.87</td>
<td>4.787×10⁻³</td>
<td>4.882</td>
<td>4.882×10⁻⁴</td>
<td>1</td>
<td>6.943×10⁻³</td>
</tr>
<tr>
<td>1 lb./sq. in. ==(psi)</td>
<td>6896</td>
<td>0.6896</td>
<td>703</td>
<td>7.032×10⁻²</td>
<td>144</td>
<td>1</td>
</tr>
</tbody>
</table>

7.3 Converting AWG Numbers

Table 34 lists conversions of AWG numbers to wire diameter and cross-sections.

1 circ mil = 5.07×10⁻¹⁰ m² = 0.000057 mm²

Table 34. AWG Conversions

<table>
<thead>
<tr>
<th>AWG No.</th>
<th>Wire diameter (mm)</th>
<th>Cross-section of conductor (mm²)</th>
<th>circ mils</th>
<th>AWG No.</th>
<th>Wire diameter (mm)</th>
<th>Cross-section of conductor (mm²)</th>
<th>circ mils</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>0.079</td>
<td>0.0048</td>
<td>10</td>
<td>17</td>
<td>1.151</td>
<td>1.04</td>
<td>2052</td>
</tr>
<tr>
<td>39</td>
<td>0.089</td>
<td>0.0062</td>
<td>12</td>
<td>16</td>
<td>1.290</td>
<td>1.31</td>
<td>2581</td>
</tr>
<tr>
<td>38</td>
<td>0.102</td>
<td>0.0081</td>
<td>16</td>
<td>15</td>
<td>1.450</td>
<td>1.65</td>
<td>3260</td>
</tr>
<tr>
<td>37</td>
<td>0.114</td>
<td>0.0103</td>
<td>20</td>
<td>14</td>
<td>1.628</td>
<td>2.08</td>
<td>4109</td>
</tr>
<tr>
<td>36</td>
<td>0.127</td>
<td>0.0126</td>
<td>25</td>
<td>13</td>
<td>1.829</td>
<td>2.63</td>
<td>5184</td>
</tr>
<tr>
<td>35</td>
<td>0.142</td>
<td>0.0159</td>
<td>31</td>
<td>12</td>
<td>2.052</td>
<td>3.31</td>
<td>6529</td>
</tr>
<tr>
<td>34</td>
<td>0.160</td>
<td>0.0201</td>
<td>40</td>
<td>11</td>
<td>2.304</td>
<td>4.17</td>
<td>8226</td>
</tr>
<tr>
<td>33</td>
<td>0.180</td>
<td>0.0255</td>
<td>50</td>
<td>10</td>
<td>2.588</td>
<td>5.26</td>
<td>10384</td>
</tr>
<tr>
<td>32</td>
<td>0.203</td>
<td>0.0325</td>
<td>64</td>
<td>9</td>
<td>2.906</td>
<td>6.63</td>
<td>13087</td>
</tr>
<tr>
<td>31</td>
<td>0.226</td>
<td>0.0412</td>
<td>79</td>
<td>8</td>
<td>3.268</td>
<td>8.37</td>
<td>16512</td>
</tr>
<tr>
<td>30</td>
<td>0.254</td>
<td>0.051</td>
<td>100</td>
<td>7</td>
<td>3.665</td>
<td>10.55</td>
<td>20822</td>
</tr>
<tr>
<td>29</td>
<td>0.287</td>
<td>0.065</td>
<td>128</td>
<td>6</td>
<td>4.115</td>
<td>13.30</td>
<td>26244</td>
</tr>
<tr>
<td>28</td>
<td>0.320</td>
<td>0.081</td>
<td>159</td>
<td>5</td>
<td>4.620</td>
<td>16.77</td>
<td>33088</td>
</tr>
<tr>
<td>27</td>
<td>0.363</td>
<td>0.102</td>
<td>202</td>
<td>4</td>
<td>5.189</td>
<td>21.15</td>
<td>41738</td>
</tr>
<tr>
<td>26</td>
<td>0.404</td>
<td>0.128</td>
<td>253</td>
<td>3</td>
<td>5.827</td>
<td>26.66</td>
<td>52624</td>
</tr>
<tr>
<td>25</td>
<td>0.455</td>
<td>0.163</td>
<td>320</td>
<td>2</td>
<td>6.543</td>
<td>33.62</td>
<td>66358</td>
</tr>
<tr>
<td>24</td>
<td>0.511</td>
<td>0.205</td>
<td>404</td>
<td>1</td>
<td>7.348</td>
<td>42.41</td>
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### 7.4 Converting dBm to Volts to Watts

Table 35 lists values in dBm with equivalent values in effective voltage ($V_{rms}$), peak-to-peak voltage ($V_{p-p}$), and watts (W).

#### Table 35. dBm to Volts to Watts Conversions, 50-Ohm Termination

<table>
<thead>
<tr>
<th>dBm</th>
<th>$V_{rms}$ ($\mu V$)</th>
<th>$V_{p-p}$ ($\mu V$)</th>
<th>W (pW)</th>
<th>dBm</th>
<th>$V_{rms}$ ($\mu V$)</th>
<th>$V_{p-p}$ ($\mu V$)</th>
<th>W (pW)</th>
</tr>
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### Table 35. dBm to Volts to Watts Conversions, 50-Ohm Termination (continued)

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<th>V&lt;sub&gt;p-p&lt;/sub&gt;</th>
<th>W</th>
<th>dBm</th>
<th>V&lt;sub&gt; rms&lt;/sub&gt;</th>
<th>V&lt;sub&gt;p-p&lt;/sub&gt;</th>
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<td>56.36 V</td>
<td>7.943 W</td>
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<td>7.943 nW</td>
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<td>15.95 W</td>
</tr>
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<td>19.95 W</td>
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<td>2.825 kV</td>
<td>19.95 kW</td>
</tr>
<tr>
<td>-17</td>
<td>31.59 mV</td>
<td>89.32 mV</td>
<td>19.95 µW</td>
<td>74</td>
<td>1.121 kV</td>
<td>3.169 kV</td>
<td>25.12 kW</td>
</tr>
<tr>
<td>-16</td>
<td>35.44 mV</td>
<td>100.2 mV</td>
<td>25.12 µW</td>
<td>75</td>
<td>1.257 kV</td>
<td>3.556 kV</td>
<td>31.62 kW</td>
</tr>
<tr>
<td>-15</td>
<td>39.76 mV</td>
<td>112.5 mV</td>
<td>31.62 µW</td>
<td>76</td>
<td>1.411 kV</td>
<td>3.990 kV</td>
<td>39.81 kW</td>
</tr>
<tr>
<td>-14</td>
<td>44.62 mV</td>
<td>126.2 mV</td>
<td>39.81 µW</td>
<td>77</td>
<td>1.583 kV</td>
<td>4.477 kV</td>
<td>50.12 kW</td>
</tr>
<tr>
<td>-13</td>
<td>50.06 mV</td>
<td>141.6 mV</td>
<td>50.12 µW</td>
<td>78</td>
<td>1.776 kV</td>
<td>5.023 kV</td>
<td>63.10 kW</td>
</tr>
<tr>
<td>-12</td>
<td>56.17 mV</td>
<td>158.8 mV</td>
<td>63.10 µW</td>
<td>79</td>
<td>1.993 kV</td>
<td>5.636 kV</td>
<td>79.43 kW</td>
</tr>
<tr>
<td>-11</td>
<td>63.02 mV</td>
<td>178.2 mV</td>
<td>79.43 µW</td>
<td>80</td>
<td>2.236 kV</td>
<td>6.324 kV</td>
<td>100.0 kW</td>
</tr>
<tr>
<td>-10</td>
<td>70.71 mV</td>
<td>199.9 mV</td>
<td>100.0 µW</td>
<td>81</td>
<td>2.509 kV</td>
<td>7.095 kV</td>
<td>125.9 kW</td>
</tr>
</tbody>
</table>
### Table 35. dBm to Volts to Watts Conversions, 50-Ohm Termination (continued)

<table>
<thead>
<tr>
<th>dBm</th>
<th>$V_{rms}$</th>
<th>$V_{p-p}$</th>
<th>W</th>
<th>dBm</th>
<th>$V_{rms}$</th>
<th>$V_{p-p}$</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>–9</td>
<td>79.34 mV</td>
<td>224.4 mV</td>
<td>125.9 µW</td>
<td>82</td>
<td>2.815 kV</td>
<td>7.961 kV</td>
<td>158.5 kW</td>
</tr>
<tr>
<td>–8</td>
<td>89.02 mV</td>
<td>251.7 mV</td>
<td>158.5 µW</td>
<td>83</td>
<td>3.159 kV</td>
<td>8.932 kV</td>
<td>199.5 kW</td>
</tr>
<tr>
<td>–7</td>
<td>99.88 mV</td>
<td>282.5 mV</td>
<td>199.5 µW</td>
<td>84</td>
<td>3.544 kV</td>
<td>10.02 kV</td>
<td>251.2 kW</td>
</tr>
<tr>
<td>–6</td>
<td>112.1 mV</td>
<td>316.9 mV</td>
<td>251.2 µW</td>
<td>85</td>
<td>3.976 kV</td>
<td>11.25 kV</td>
<td>316.2 kW</td>
</tr>
<tr>
<td>–5</td>
<td>125.7 mV</td>
<td>355.6 mV</td>
<td>316.2 µW</td>
<td>86</td>
<td>4.462 kV</td>
<td>12.62 kV</td>
<td>398.1 kW</td>
</tr>
<tr>
<td>–4</td>
<td>141.1 mV</td>
<td>398.9 mV</td>
<td>398.1 µW</td>
<td>87</td>
<td>5.006 kV</td>
<td>14.16 kV</td>
<td>501.2 kW</td>
</tr>
<tr>
<td>–3</td>
<td>158.3 mV</td>
<td>447.7 mV</td>
<td>501.2 µW</td>
<td>88</td>
<td>5.617 kV</td>
<td>15.88 kV</td>
<td>631.0 kW</td>
</tr>
<tr>
<td>–2</td>
<td>177.6 mV</td>
<td>502.3 mV</td>
<td>630.9 µW</td>
<td>89</td>
<td>6.302 kV</td>
<td>17.88 kV</td>
<td>794.3 kW</td>
</tr>
<tr>
<td>–1</td>
<td>199.3 mV</td>
<td>563.6 mV</td>
<td>794.3 µW</td>
<td>90</td>
<td>7.071 kV</td>
<td>20.00 kV</td>
<td>1.000 MW</td>
</tr>
<tr>
<td>0</td>
<td>223.6 mV</td>
<td>632.3 mV</td>
<td>1.000 mW</td>
<td>91</td>
<td>7.934 kV</td>
<td>22.44 kV</td>
<td>1.259 MW</td>
</tr>
</tbody>
</table>
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