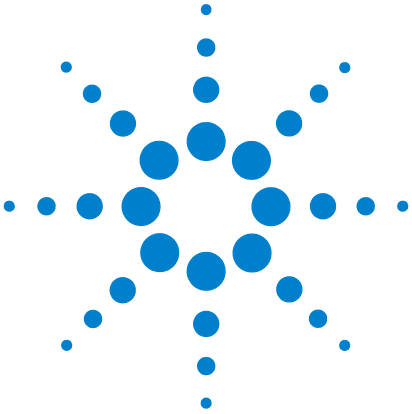


Agilent MRI Systems

Site Planning Guide



Agilent Technologies

Notices

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1 Introduction

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The Imaging Site Planning Guide provides information needed to select a site, prepare a site and workstation for an Agilent MR Imaging system. Using the pre-delivery and post-delivery checklists and following the information presented in this guide will help provide a smooth transition from delivery to installation.

Recommendation

Clear and frequent communication between the customer, facility planner, and Agilent will allow issues to be immediately addressed, avoiding delays and additional costs.

It is recommended that one customer-side person be appointed to coordinate site planning and preparation. This person should represent all users of the system in dealing with Agilent and the facility planner or architect.

Contact Agilent Technologies, Inc.

For product sales and service information, consult www.agilent.com to locate your nearest Agilent office.

2 Safety

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This user guide helps you establish operating conditions that permit safe and efficient use of your equipment. Special considerations and precautions are shown in the form of NOTES, CAUTIONS, and WARNINGS. You must operate your equipment in accordance with this user guide and any additional information provided by Agilent Technologies. Contact Agilent if you have any questions regarding the safe and proper use of your equipment.

Warning and Caution Symbols



This symbol might be used on warning labels attached to the equipment. When you see this symbol, refer to the relevant manual for the information referred to by the warning label

NOTE Notes give additional and important information.

Warning Notices

Observe the following precautions during installation, operation, maintenance, and repair of the instrument. Failure to comply with these warnings or with specific warnings elsewhere in Agilent documentation violates safety standards of design, manufacture, and intended use of the instrument. Agilent assumes no liability for customer failure to comply with these precautions.

Caution Notices

Observe the following precautions during installation, operation, maintenance, and repair of the instrument. Failure to comply with these warnings, or with specific warnings elsewhere in Agilent manuals, violates safety standards of design, manufacture, and intended use of the instrument. Agilent assumes no liability for customer failure to comply with these precautions.

The purpose of this section is to indicate the need to plan from the beginning for a safe site and the safe operation of a site.

Three areas of the spectrometer must be considered and understood for the establishment of a safe operation: the magnetic field, the cryogens, and access to the site. Trained personnel, good work habits, and proper tools are essential to the operation of a safe system.

Magnetic Field

The potential safety hazards of strong magnetic fields to devices such as certain pacemakers must be planned for and understood. Unrestrained ferromagnetic objects (iron, steel, cobalt, and nickel) can be drawn toward the magnet when they are within the 5 gauss line of the magnet, become airborne, and cause injury or damage to the equipment. The larger the ferromagnetic object, the stronger the attraction to the magnet. Chapter 8, “Stray Field Plots”, includes a set of plots indicating the magnitude of the stray fields for each type of magnet. These plots show typical levels of stray field. Actual levels may vary and should be checked after a particular magnet has been installed.

People working around the magnet should be aware of the potential danger. Access to the high magnetic field zones should be restricted.

WARNING **Magnetic dewars are extremely dangerous because they can be drawn to the magnet. Use only non-magnetic dewars. These containers are brought close to the magnet during the transfer of cryogens.**

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. Agilent provides signs with each system to warn pacemaker wearers of this hazard. Chapter 11, “Posting Requirements for Magnetic Field Warning Signs” gives guidelines.**

Cardiac pacemaker wearers should refrain from entering a zone that would subject a cardiac pacemaker to a magnetic intensity that could cause adverse effects. Refer to 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 a particular magnet has been installed.

Agilent provides signs warning of magnetic field hazards. Refer to Chapter 11, “Posting Requirements for Magnetic Field Warning Signs” for an explanation of the types of signs and the sign posting requirements. Additional signs are available from Agilent at no charge.

The stray magnetic field extends in all directions. The effect of the magnetic 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 may 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, there is no conclusive evidence 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, the static magnetic field associated 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:

> "Threshold Limit Values (TLVs) 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) (600 gauss) whole body or 600 mT (6000 gauss) to the extremities on a daily (8 h), time-weighted average basis. A flux density of two teslas (20,000 gauss) is recommended as a ceiling value".

Cryogens

Magnetic resonance spectrometers use liquid helium in the magnet. Liquid nitrogen is always used during the initial cool down of a magnet, and for the operation of some magnets.

The room ventilation system must be capable of exchanging two times the volume of the room air per hour to meet the minimum safety standards for working with cryogens. Sensors for monitoring air flow into the room and oxygen level monitoring are recommended. Since cold helium gas rises and cold nitrogen gas falls there should ideally be two oxygen level sensors in the magnet room, one high and one low.

A quench occurs when the magnet loses its superconductivity and warms the liquid helium, rapidly generating a large volume of gas. If it is vented into the magnet room this gas can create a danger of asphyxiation by displacing the air within the room, as well as hazards from the room potentially becoming pressurized. A quench pipe should always be utilized to vent the gas outside the building.

The handling of cryogens can be hazardous because the liquids are extremely cold. Contact with the liquids or cold gases can cause damage to the skin. Only trained personnel should transfer cryogens.

The configuration of the room should be such that the movement of dewars and the transfer of cryogens can be done quickly and easily. It is strongly recommended that the cryogens be unloaded from the delivery truck, moved to the magnet, and transferred on the same level. Avoid level changes and ramps wherever possible.

Access - General

The magnetic resonance facility should be designed to provide proper access for routine laboratory research, visitors, cryogen transfer, and emergency exits. Emergency exits should not require personnel to pass near the magnet to exit the facility. An event such as a medical emergency should allow outside medical personnel to stay clear of the magnet when they enter and exit the facility.

Magnet restricted zones

The 5 gauss zone of the magnet is a restricted zone. The size of the 5 gauss zone varies with the bore size and the internal field strength of the magnet, see Chapter 8, “Stray Field Plots”. Usually the 5 gauss zone is contained within the magnet room. For that reason, the magnet room should be a restricted area. Entrances to the magnet room should be outside the 5 gauss line. Magnetic field warning signs must be posted around the 5 gauss line.

Visitors should be told of the magnetic field and should be warned about ferromagnetic objects such as keys. Visitors should be warned about pacemakers and surgical implants. Some pacemakers contain magnetic reed relays, which can malfunction in high magnetic fields. Some surgical implants are ferromagnetic and could be dislodged in a strong magnetic field. Visitors should also be warned about probable damage to their watches, credit cards, and magnetic storage media such as floppy disks.

Sites that might have frequent visitors should consider installing a simple metal detector at entrances to the magnet room.

Magnet prohibited zones

The 30 gauss zone should be marked, and access should be restricted to trained site personnel only. If possible, close off the zone with a plastic or wooden barrier. Do not allow visitors in the prohibited zone.

Access - emergency, security, and facilities personnel

The following guidelines should be followed in addition to the warnings and cautions stated above.

Training

Provide training to each of the following groups of personnel. On-site training of medical, fire department, and facilities personnel by the customer is recommended.

Emergency medical personnel

Emergency medical personnel must observe the general guidelines for persons with pacemakers and surgical implants and remain outside the 5 gauss line.

Do not enter the room with any respiratory equipment if the magnet has not been fully discharged. The magnetic field is not dependent upon the building electrical supply.

Do not enter the room with any ferrous metal (for example, steel) equipment or instruments if the magnet has not been fully discharged.

Emergency medical extraction with the magnet at field

Person or persons pinned against the magnet: De-energize (quench) the magnet before attempting to extract the person, using the emergency discharge unit. Be aware of the danger of asphyxiation if any gas is released into the room during the quench. Verify that the oxygen level is at a safe (normal) value before entering the magnet room after a quench.

Person or persons on the ground or otherwise immobilized: Determine if the person can be moved. If the person can be moved, use a non magnetic stretcher and transport the person out of the room. If the person can only be moved using ferrous equipment the magnet must first be de-energized (quenched).

Emergency medical extraction with the magnet not at field

Verify the oxygen levels are at safe (normal) levels before entering.

Do not contact metal surfaces that are frosted.

Fire department personnel

Fire department personnel must observe the general guidelines for persons with pacemakers and surgical implants and remain outside the 5 gauss line.

Do not enter the room with any respiratory equipment if the magnet has not been fully discharged. The magnetic field is

not dependent upon the building electrical supply.

Do not enter the room with any ferrous metal (steel for example) equipment or instruments if the magnet has not been fully discharged.

Do not use any fire extinguishers with steel casings.

Use only CO_2 fire extinguishers in non-magnetic containers.

Security personnel

Security personnel must observe the general guidelines for persons with pacemakers and surgical implants and remain outside the 5 gauss line.

Do not enter the room with any ferrous metal (for example, steel) equipment or instruments if the magnet has not been fully discharged.

Do not enter the room with any respiratory equipment if the magnet has not been fully discharged.

Facilities personnel

Do not enter the room without supervision.

Facilities personnel must observe the general guidelines for persons with pacemakers and surgical implants and remain outside the 5 gauss line.

Do not enter the room with any ferrous metal (for example, steel) equipment or instruments if the magnet has not been fully discharged.

Do not enter the room with any metal tool, devices, or cleaning equipment (mops and buckets made with metal parts).

Medical Gases

The use of medical gases in conjunction with this equipment requires compliance to local and institutional review board (IRB) ventilation codes for the maximum work area concentrations and for evacuation equipment. Evacuation equipment and personnel must meet the guidelines given in "Access - emergency, security, and facilities personnel" on page 15. Anesthetic gas concentrations around respiratory equipment must be at or below the local or IRB (whichever is lower) levels. A scavenger exhaust for anesthetic gases may be needed near the front of the magnet.

Nonmagnetic Tools

Do not use steel tools to perform maintenance on the magnet or to perform maintenance on objects in or near the magnet. Tools made of ferrous materials can be pulled into the magnet bore and they are very difficult to extract. Purchase a minimal set of nonferrous tools for maintenance work in and around the magnet. The tools are generally made of a beryllium copper alloy or titanium and can be expensive.

Emergency Power and Lighting

It is not recommended that the spectrometer be wired into building emergency power. More problems are usually created by the periodic tests of the power than are solved by having the power available.

Emergency lighting with battery powered lamps is recommended. If electromagnetic relays are used as sensors for power loss, place them outside the 15 gauss line.

3
Site Selection and System Delivery

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This chapter covers preparations for receiving and moving the system. Agilent's delivery responsibility ends at Agilent's factory shipping dock or at the customer's receiving dock, depending upon the type of insurance obtained by the customer. In either case, when the system arrives the customer must provide a moving crew to move the shipping crates holding the system from the delivery truck (or storage location) to the installation site.

Site Installation Prerequisites

All costs incurred to meet the general requirements provided in this guide must be in place or met prior to the start of the system installation and are paid for by the customer unless otherwise specifically stated:

- All government, local, and institutional permits, inspections, and approvals related to the site and the delivery and receipt of the system.
- All utilities, as specified in this document and any additional documentation, must be in place prior to the start of the system installation.
- Certain supplies not provided by Agilent such as helium and nitrogen supplies, must be obtained by the customer before the installation engineer starts the installation. Chapter 5, “Site Preparation” describes these supplies in detail.

Agilent reserves the right to charge the customer for all expenses related to incomplete site preparation including but not limited to time and travel expenses of the installation engineer(s) and costs of corrective measures.

Customer must notify Agilent within 60 days of order acceptance by Agilent of all government, local, and institutional permits, inspections, and approvals related to the site and the delivery, receipt, and installation of the system.

Site Selection

Site selection is the process of finding a location for the magnet providing the least interference within 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 six months for the selection, qualification, design, and construction of a magnetic resonance imaging facility. Site Requirements describes in detail all the factors to consider when selecting a site.

Site selection process

The site selection process typically proceeds as follows:

- The customer locates several potential sites using this guide as a reference.
- A site planning specialist visits the facility to further refine the selection process if necessary.
- A facility planner or architect is engaged to assist with preliminary details of the proposed site.
- Detailed building plans with the magnet location are forwarded to the Agilent site planning department.
- Agilent reviews all proposed sites.
- A final location is selected by the customer and Agilent's site planning department.
- An architect or facility planner draws up plans for the proposed facility.
- Agilent reviews and advises on the final site drawings.

After the previous steps are completed, site construction begins.

Agilent provides technical support and advice during the preparation of the site. Typically, an Agilent representative visits the site initially and after the site is finished. The role of Agilent 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.

Site selection considerations

Begin by looking for a site with a series of general requirements in mind. The placement of the magnet is the primary consideration:

- How will the field from the magnet affect its neighbors?
- What will the building and its contents do to the quality of the magnet field?
- Is RF shielding required?

The second requirement is access:

- Will the site limit public access in surrounding areas?
- Can magnetic storage media be taken to the area safely?
- Can cryogen transfers be made quickly and safely?

Finally, look at the area as a whole with the following considerations:

- Look for an area large enough to contain the magnet and as much of the 5 gauss line as possible. The area should have the minimum ceiling height described in Table 3.
- Keep in mind that the spectrometer control electronics must be kept outside the 10 gauss line. Figure 11, “Typical room layouts for a 7T 310 mm ASR system,” on page 88 illustrates tight but acceptable positioning for a 7T 310 mm magnet. Note that the 30 gauss line extends outside the room and thus limits use of those areas. Some components are more tolerant than others in magnetic fields. If the electronics must be positioned inside the 10 gauss line, contact Agilent for advice and authorization.
- When an acceptable space has been found, look for steel and iron in the immediate area. Consider the structural steel of the building, iron pipes, and machinery.
- Look in the near area for elevators, vehicular traffic, large transformers, and other large amounts of steel and iron.
- Consider the ability to control the movement of ferromagnetic objects, such as elevators, automobiles, or carts, within the magnetic field.
- Consider adequate access for the delivery of dewars containing liquid helium and nitrogen.
- Consider public access that might pass through the 5 gauss zone.

- Consider escape routes in case of emergency. Refer to Chapter 2, “Safety” for safety considerations.
- Consider the location of sensitive electronic equipment that might be affected by the magnetic field. Refer to Chapter 2, “Safety” for safety considerations.
- For an exact definition of gauss line boundaries, refer to Chapter 8, “Stray Field Plots” for more information.
- Make sure you have enough ventilation in case of a quench. Refer to “Magnet room ventilation” on page 53.

If the area under consideration is still viable, it will need to be evaluated by an Agilent representative. An initial evaluation can be done from drawings and sketches if they are well documented. Marginal sites can be analyzed through a computer analysis of all pertinent iron in the area and its interaction with the magnet. A computer analysis is complex, but in some cases may be necessary. Agilent provides the computer analysis at no additional charge in cases where an Agilent MRI system has been ordered.

Looking for a building

Wooden buildings work well because they usually lack structural steel. Newer buildings have better support on upper floors and less vibration but have steel support structures that can make location of the magnet difficult. Occasionally, it is more convenient to construct a new facility than to risk installation at a marginal site in an existing building.

Locating a site within the building

A grade-level location is usually preferred. Half of the fringe field then goes harmlessly into the earth, the magnet does not have to be lifted or lowered to the site, and floor loading is usually not a problem.

A corner site is also preferred. A large part of the fringe field can then project into garden areas with a grade-level location or into the air with an upper-floor location. Basements can work well, but the steel support structures, ferrous piping, and heavy equipment usually found in basements must be considered.

In extreme cases, where space is not to be found, magnetic shielding can be considered.

Although site selection can be a difficult process with many iterations, it is unlikely that a site can not be found in a facility. Some are just more difficult to find than others. Contact Agilent Technologies whenever there is a question about the qualification of a site.

Preparing the Site for System Installation

Obtain detailed plans of the proposed site. These should include not only the floor upon which the magnet will be located, but also the floor above and below the site. Structural plans for this location are also necessary. An architect or facility planner can help with this step.

Obtain and mark appropriately the following building drawings:

- General floor plans marked with the 5, 10, and 50 gauss perimeters. See Chapter 8, “Stray Field Plots” for gauss-line boundary details. Looking at your site plan, draw in the location of all objects that might affect or be affected by the field.
- General floor plans showing details of walls, corridors, entrance ways, restrooms, and waiting areas.
- Sectional plans showing major columns and load bearing walls adjacent to the site. These are needed to show the vertical structure of the building.
- Construction plans showing the location of major structural elements such as I-beams.
- Construction plans showing the location of sewers, piping, electrical conduits, and other ferrous construction material.

Use the building construction plans to locate and verify the major steel support beams. Visually inspect for other materials such as conduits, circuit boxes, and pipes. Make certain that this is done for the floor above and the floor below, as well as the floor of the site.

Be sure to examine the piping plan. Iron sewer pipes and drains can cause problems if not detected in advance.

List all public areas inside the 5 gauss perimeter using the information in Chapter 8, “Stray Field Plots” and the floor plan of the chosen site. (Public access to an area means that under normal conditions, any person has access to and can use the area. The front entrance of a hospital is a good example, as are lobby areas and corridors of most buildings.) Show areas such as restrooms, cafeterias, and hallways.

WARNING **Hazardous magnetic fields can extend through walls, floors, and ceilings. If the five gauss line falls within public areas, warning signs must be posted.**

Testing the Site for Equipment Access

Make a plan for moving the magnet from the loading dock to its site within the building. Refer to Site Requirements for the dimensions of the magnet and console crates. Of special concern are the height of corridors and the size of doorways. The minimum doorway height for moving the console is 2.0 m (79 in). The magnet may need a higher doorway. Plan this route by actually walking along the route with the facility planner. Make a list of all items that must be moved from the hallways.

Some freight elevators might be large enough for the magnet, most passenger elevators will not be suitable.

Check the structural strength and rigidity of the floor in the magnet room and along the access route. Remember the weight of the magnet and rigging equipment. Your architect or facility planner can be of great help in determining whether these conditions are met.

Plan an access route to the magnet site for supplies of cryogens needed to service the cryostat on a routine basis, refer to Site Requirements. The dewars needed to transport the cryogens vary in size. The larger sizes are more convenient and may eliminate the need to change dewars during a filling operation.

System Delivery Preparations

The customer is responsible for providing a rigging crew to move the imaging equipment from the delivery truck to the final location of the system. Unpacking of the system is the responsibility of the Agilent installation specialist and the system is not to be unpacked without proper authorization from Agilent Technologies. An Agilent 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 Agilent service representative. In particular, the crate containing the magnet has components that could be irreparably damaged if opened incorrectly

Post delivery activities

When the shipment arrives, make an immediate visual inspection of the outside of each crate for damage. Do not open any crate. Take the following steps if any damage is found:

- Note the nature of the damage on the carrier's waybill.
- Request an inspection and written damage report by a representative of the carrier.
- Forward a copy of the damage report to the local Agilent representative.

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

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

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 unless given direct instructions from an authorized Agilent service representative

If possible, move the crates in an upright position only, with a forklift or hydraulic pallet mover, directly to the installation site. Larger magnets cannot be moved with a forklift when crated. A crane is required to lift the magnet off the pallet. It is then usually placed on skates in order to move it inside the building. Should it appear necessary to uncrate one or more units because of doorway or passage clearance, contact your Agilent service representative for further instructions.

To avoid unnecessary expense, be sure that the rigging crew and equipment are ready for the shipment on the delivery day.

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Delivery and Installation Access

Access during the installation of an MR Imaging system requires movement of the magnet from the loading dock to its final position. Since the magnet weight is significant, pathways, floor loading, elevator capacity and dimensional limits must be considered. Obtain the opinion of a qualified person (architect or engineer) concerning the load limits and rigidity of the floor of the site and of the access route.

Table 1 on page 32 and Table 2 on page 33 list the dimensions and weights needed for calculating vertical, horizontal, and turning clearances, and evaluating the structural strength of passageways. Moving the larger crates of the system requires a forklift, hydraulic pallet mover, or skates, which must be considered when calculating accessibility. The minimum doorway height for moving the console is 2.0 m (79 in). The magnet may need a higher doorway.

If it is not possible to gain access to the installation site unless the system is uncrated, contact an Agilent service representative for further instructions. Do not uncrate the system except with direct instructions from an authorized Agilent representative.

Table 1 Magnets dimensions and weights

Magnets, crated with pallets for shipping[1]

Magnet/Bore (tesla/mm) R = refrigerated	Length cm (in.)	Width cm (in.)	Height cm (in.)	Weight kg (lb)	Notes
4.7T / 210 / ASR	214 (84)	123 (48)	213 (84)	1,690 (3,730)	Forklift
4.7T / 310 / ASR	150 (59)	146 (57)	225 (89)	3,540 (7,800)	Forklift
4.7T / 400 / ASR	170 (67)	185 (73)	233 (92)	4,550 (10,000)	Forklift
7.0T / 160 / ASR	140 (55)	140 (55)	218 (86)	1,800 (3,970)	Forklift
7.0T / 210 / ASR	150 (59)	135 (53)	205 (81)	2,650 (5,840)	Forklift
7.0T / 310 / ASR	226 (89)	192 (76)	259 (102)	5,400 (11,900)	Forklift
7.0T / 400 / ASR	220 (87)	240 (94)	307 (121)	8,600 (19,000)	Forklift
9.4T / 160 / AS	174 (69)	142 (56)	240 (94)	3,250 (7,170)	Forklift
9.4T / 210 / ASR	182 (72)	165 (65)	247 (97)	5,400 (11,900)	Forklift
9.4T / 310 / ASR	198 (78)	194 (76)	233 (92)	8,600 (19,000)	Forklift
9.4T / 400 / ASR	300 (118)	315 (124)	330 (130)	20,000 (44,100)	Crane
11.7T / 160 / ASR	200 (79)	175 (69)	255 (100)	5,000 (11,000)	Forklift
11.7T / 210 / ASR	223 (88)	194 (76)	260 (102)	7,600 (16,800)	Crane/forklift
11.7T / 260	250 (98)	228 (90)	321 (126)	11,700 (25,800)	Crane/forklift
14.1T / 260	350 (138)	210 (83)	300 (118)	14,200 (31,300)	Crane
16.4T / 260/R	367 (144)	230 (91)	323 (127)	20,000 (44,100)	Crane

Note:
1 - Dimensions and weights are typical and can vary ± 5 cm (± 2 in) or ± 5% (weight)

Magnets unpacked, with crate and pallet removed [3]

Magnet/Bore (tesla/mm) R = refrigerated	Height cm (in)	Width cm (in)	Length [1] cm (in)	Weight [2] kg (lb)
4.7T / 210 / ASR	172.5 (67.9)	173.4 (68.3)	101.2 (39.8)	1,350 (2,980)
4.7T / 310 / ASR	185.0 (72.8)	136.0 (53.5)	128.0 (50.4)	3,200 (7,060)
4.7T / 400 / ASR	212.4 (83.6)	169.0 (66.5)	150.0 (59.1)	4,200 (9,260)
7.0T / 160 / ASR	180.5 (71.1)	120.0 (47.2)	116.6 (45.9)	1,550 (3,420)
7.0T / 210 / ASR	160.0 (63.0)	120.0 (47.2)	128.1 (50.4)	2,300 (5,070)
7.0T / 310 / ASR	206.5 (81.3)	169.0 (66.5)	163.6 (64.4)	5,000 (11,000)

Magnets unpacked, with crate and pallet removed [3]				
Magnet/Bore (tesla/mm) R = refrigerated	**Height cm (in)**	**Width cm (in)**	**Length [1] cm (in)**	**Weight [2] kg (lb)**
7.0T / 400 / ASR	267.1 (105.2)	217.1 (85.5)	199.8 (78.9)	8,000 (17,600)
9.4T / 160 / AS	202.0 (79.5)	150.0 (59.1)	126.1 (49.6)	2,800 (6,170)
9.4T / 210 / ASR	206.5 (81.3)	169.0 (66.5)	142.0 (55.9)	5,000 (11,000)
9.4T / 310 / ASR	203.6 (80.2)	174.0 (68.5)	176.9 (69.6)	8,000 (17,600)
9.4T / 400 / ASR	299.5 (117.9)	290.0 (114.2)	234.1 (92.2)	19,000 (41,900)
11.7T / 160 / ASR	215.3 (84.8)	155.0 (61.0)	177.8 (70.0)	4,350 (9,590)
11.7T / 210 / ASR	220.0 (86.6)	169.0 (66.5)	203.0 (79.9)	7,000 (15,400)
11.7T / 260	289.2 (113.9)	210.0 (82.7)	224.2 (88.3)	9,000 (19,800)
14.1T / 260	245.2 (96.5)	182.0 (71.7)	283.0 (111.4)	13,000 (28,700)
16.4T / 260/R	249.5 (98.2)	214.0 (84.3)	332.0 (130.7)	18,800 (41,500)

Notes:
1 - Along the bore
2 - Weight excludes cryogens and gradient coil except where noted
3 - All dimensions are for the shipping configuration

Table 2 Cabinets and components dimensions and weights

Item	Height cm (in.)	Width cm (in.)	Length cm (in.)	Weight kg (lb)
Crated with pallets for shipping				
MRI console	210 (83)	66 (26)	89 (35)	350 (772)
RF power cabinet	150 (59)	69 (27)	102 (40)	143 (315)
Gradient power supply	234 (92)	97 (38)	114 (45)	750 (1,654)
Gradient chiller (Haskris WW1, water cooled)	137 (54)	84 (33)	94 (37)	102 (225)
Gradient chiller (Haskris R175, air cooled)	137 (54)	84 (33)	94 (37)	193 (425)
Compressor chiller (Haskris WW2, water cooled)	137 (54)	84 (33)	94 (37)	125 (275)
Compressor chiller (Haskris R300, air cooled)	152 (60)	102 (40)	109 (43)	340 (750)

Table 2 Cabinets and components dimensions and weights

Item	Height cm (in.)	Width cm (in.)	Length cm (in.)	Weight kg (lb)
RF front end (PIC)	86 (34)	76 (30)	76 (30)	30 (66)
Cryocooler system	122 (48)	102 (40)	150 (59)	350 (770)
Optional 10 A RT shim supply	185 (73)	69 (27)	97 (38)	327 (720)
Unpacked with crate and pallet removed (including casters and eye-bolts, where fitted)				
MRI console	198.5 (78.1)	60.5 (23.8)	78.3 (30.8)	335 (739)
RF power cabinet	116.3 (45.8)	62 (24.4)	88.9 (35)	136 (300)
Gradient power supply	205.8 (81)	60.0 (23.6)	90.5 (35.6)	700 (1,544)
Gradient chiller (Haskris WW1, water cooled)	64 (25)	48 (19)	66 (26)	91 (200)
Gradient chiller (Haskris R175, air cooled)	94 (37)	70 (28)	67 (26)	181 (400)
Compressor chiller (Haskris WW2, water cooled)	86 (34)	76 (30)	64 (25)	113 (250)
Compressor chiller (Haskris R300, air cooled)	122 (48)	89 (35)	79 (31)	317 (700)
RF front end (PIC)	74.9 (29.5)	20.5 (8.1)	66.7 (26.3)	30 (66)
Cryocooler compressor (CP289C)	61.5 (24.2)	49.4 (19.4)	68.6 (27)	119 (263)
Optional 10 A RT shim supply	152 (60)	61 (24)	76 (30)	300 (670)

Component Dimensions and Weights

Dimensions and weights of equipment room components are provided below. Values are based on unpacked components including casters and eye bolts, where fitted (not drawn to scale).

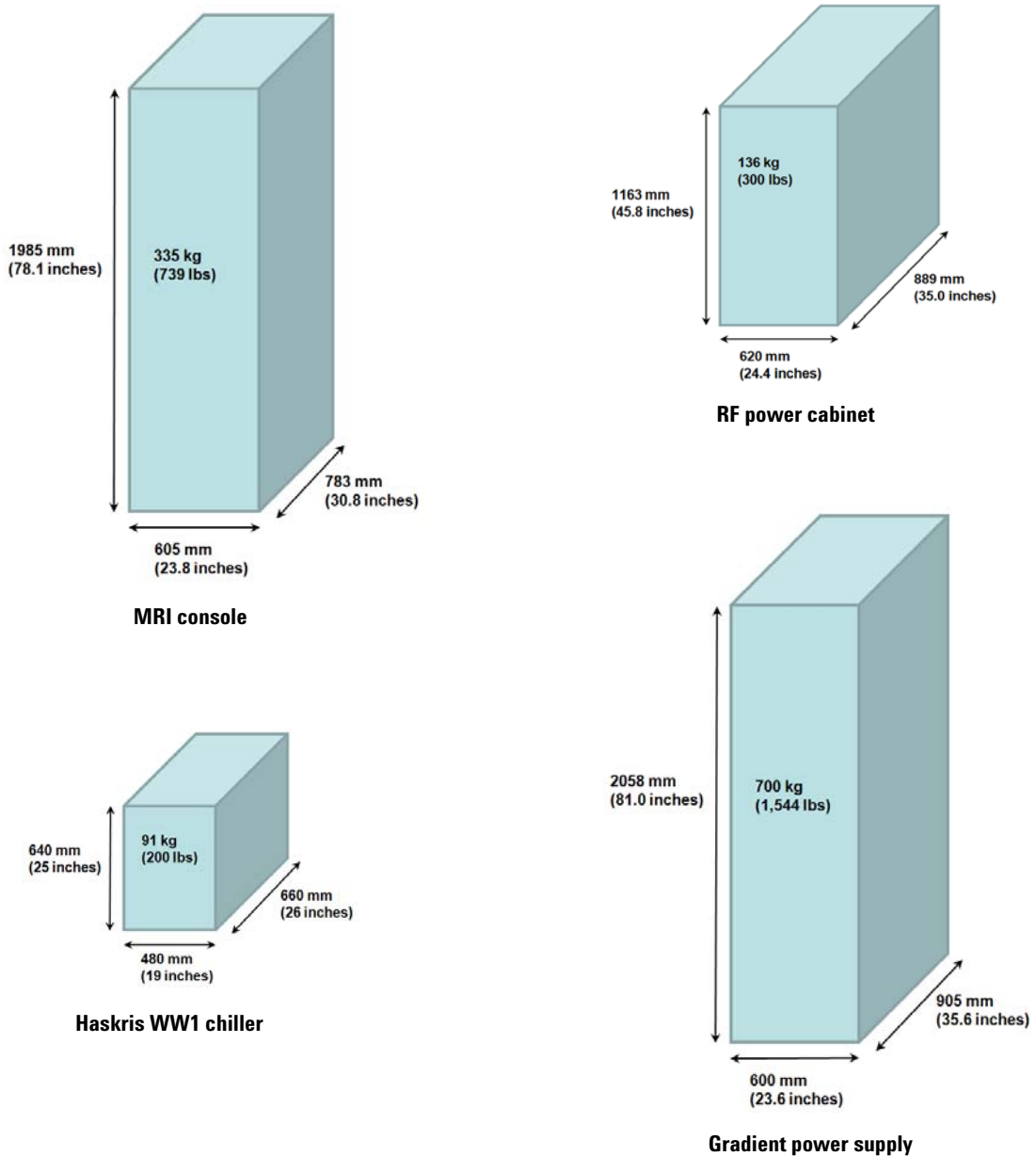


Figure 1 Component dimensions and weights

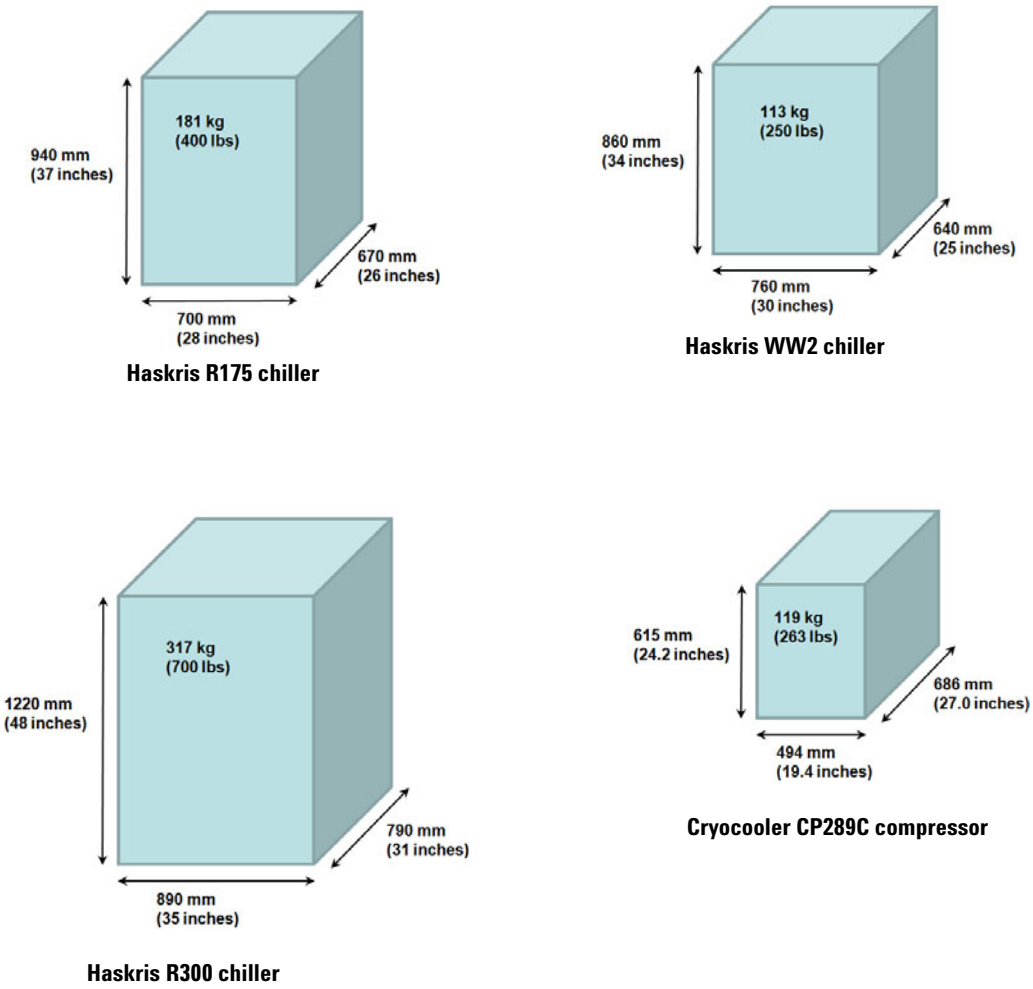


Figure 2 Chiller and compressor dimensions and weights

Maintenance and Service Access After Installation

An access path for routine delivery and transfer of nitrogen and helium is required. The dewars are large and heavy, and proper access will pay off in the ease of filling and safety of those moving the dewars.

When the magnet is brought up to field an appropriate path for the movement of personnel, animals, equipment, and magnetic media, such as computer disks, around the system and through the magnetic field is required, refer to Chapter 2, “Safety,” starting on page 9 and “Magnetic environment” on page 39.

Site size

The site must be large enough to allow free access to all sides of the system and magnet for operation, maintenance, and cryogenic service. Table 1 on page 32, Table 2 on page 33, and Table 3 on page 38 list the dimensions of the system components; Room Plans contains floor plans for the MRI laboratory areas or rooms. These plans are suggestions not specifications.

All cabinets have casters for easy movement, which allows the system to be placed in a relatively small location as long as sufficient space exists for the cabinets to be moved to provide for access on all sides. For comfort and convenience, however, and to provide space for other options, a larger site is highly recommended. The minimum dimensions do not include compensation for external magnetic and RF interference that may be present. Each individual site must be analyzed to ensure optimum system performance.

Ceiling height requirements

The ceiling must provide sufficient headroom to insert the helium tube both into the magnet and the storage dewar. The height of the ceiling (or that part of the ceiling located directly above the magnet) without obstructions, such as lighting and heating ducts, must be equal to or greater than the minimum heights in Table 4 on page 40.

These ceiling minimums allow use of the standard power stick for running up the magnet field. If one of the larger capacity helium dewars is used with the magnet, however, additional ceiling clearance may be necessary. In general, the ceiling height must be at least twice the height of the dewar.

Table 3 Magnet minimum ceiling heights

Magnet/bore (tesla/mm) R = refrigerated	Minimum ceiling height, cm (in.)[1]
4.7T / 210 / ASR	304.2 (119.8)
4.7T / 310 / ASR	312.5 (123.0)
4.7T / 400 / ASR	270.0 (106.3)
7.0T / 160 / ASR	273.5 (107.7)
7.0T / 210 / ASR	277.0 (109.1)
7.0T / 310 / ASR	303.0 (119.3)
7.0T / 400 / ASR	349.1 (137.4)
9.4T / 160 / AS	330.0 (129.9)
9.4T / 210 / ASR	303.0 (119.3)
9.4T / 310 / ASR	299.0 (117.7)
9.4T / 400 / ASR	380.2 (149.7)
11.7T / 160 / ASR	295.0 (116.1)
11.7T / 210 / ASR	303.0 (119.3)
11.7T / 260	426.0 (167.7)[2]

1 - Without AV pads
2 - With iron screen

Structural strength of floor

Contact a structural engineer to confirm that the floor is strong enought to support the magnet weight. The site floor must have sufficient structural strength to support the total system weight plus the weight of the moving equipment used during the installation. Concrete reinforcement should ideally be non-magnetic, although magnetic rebar is often acceptable. Refer to the following:

- Magnet and system shipping weights. Refer to Figure 1 on page 32 and Figure 2 on page 33.
- Magnet and stand footprints. Refer to Chapter 7, “Transporting Magnets” .
- Cryocooler and associated equipment. See “Cryomech CP289C compressor” on page 63.

Floor vibration specifications

Without pneumatic anti-vibration feet, the floor must be sufficiently rigid to reduce the vibration from adjacent dynamic loads to a negligible level, defined as no single peak vibration greater than 20 µg acceleration from 5 to 100 Hz.

Ground floor or basement sites are generally preferred for systems because the natural resonant frequencies of most building structures are typically at low frequencies and horizontal in direction. Also cement slabs on grade are preferred to suspended floors because they are stiffer by nature and generally have fewer low frequency vibrations. Magnets are supplied with anti-vibration pads. For low vibration sites their use is optional, but recommended.

From 15 to 100 Hz there should be no single peak vibration greater than 200 µg.

The maximum allowable vibrations *with* pneumatic anti-vibration feet fitted are:

Greater than 15 Hz	no single peak greater than 200 µg
10 to 15 Hz	no single peak greater than 100 µg
5 to 10 Hz	no single peak greater than 50 µg
Less than 5 Hz	no single peak greater than 5 µg

Vibration measurement services are available from Agilent Technologies.

Floor level and flatness

The floor must level, no more than 0.2% inclination, and flat, no more than 2 mm per sq meter (0.007 in per sq ft) surface height variation.

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 4 on page 40 lists some sensitive devices and the acceptable stray magnetic field density (in gauss) within which they can effectively operate.

Structural steel in the building will affect both the central magnetic field and the fringe field. The effects of ferrous

material on the central field are dependent on the mass, distance from the magnet center and the symmetrical (preferred) or asymmetrical distribution of the material relative to the center of the magnet. Site the magnet in the room such that the highest density of ferrous materials is below the magnet and orient the magnet such that the material is either perpendicular or parallel to the axis of the magnet bore. Downward vertical forces caused by ferrous materials on the magnet are better tolerated than horizontal forces. It's recommended that non-magnetic concrete reinforcement such as glass fiber is used where possible.

Conditions that could interfere with the magnet include (but are 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. See Table 5 on page 41 for examples of objects that affect or are affected by the magnetic field. Computers and peripherals are also affected by the magnetic field.

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 minimal 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 Agilent Technologies for concerns about the proximity of electromagnets, elevators, loading docks, parking areas, and so forth.

Table 4 Acceptable magnetic field in which some sensitive devices can operate

Device	Magnetic Field in Gauss (1 gauss = 0.1 mT)
Scintillation camera	1
Rotating ECAT	0.6
CT scanner	1 (using PMTs) 5 (non PMT)
Shielded PMTs	10
Cyclotron	1

Table 4 Acceptable magnetic field in which some sensitive devices can operate (continued)

Device	Magnetic Field in Gauss (1 gauss = 0.1 mT)
Image intensifier	1
LINAC	1
Ultrasound	3
Electron microscope	1
Analytical balance	2
Color TV	1.5
EEG	1 (more sensitive to fluctuating field)
Mass spectrometer	1
Video camera	3 (unshielded) 10 (steel case)
B&W monitor (non-critical)	15
Cardiac pacemaker	5–15 (check with manufacturer)
ECG	More sensitive to fluctuating field
Neuro stimulator	5
Mechanical watches	10
High-density magnetic storage media	5
Credit cards	10–20
Disk and tape drives	10
Computers	10
X-ray tubes	10
Operator console	15
Hearing aids	10
Electric motors	20
Photographic equipment	30

Table 5 Interaction between common objects and a magnetic field

Objects that affect the magnetic field	
15 gauss line or closer	All ferromagnetic construction materials except small amounts of steel reinforcing bar.
5 to 15 gauss	Presence or movement of ferromagnetic objects over 45 kg (100 lb): pushcarts, hand trucks, gas cylinders, and so forth.

Table 5 Interaction between common objects and a magnetic field

Objects that affect the magnetic field	
2 to 5 gauss	Presence or movement of ferromagnetic objects over 450 kg (1000 lb): small delivery trucks, automobiles, pallet movers, forklifts, elevators, and so forth.
1 to 2 gauss	Presence or movement of ferromagnetic objects over 34,000 kg (75,000 lb): trains, large trucks, and so forth.
Earth's field (~ 0.5 gauss)	Large moving ferromagnetic objects outside the 1 gauss contour may need to be evaluated as they are magnetized by the earth's field.
Objects affected by the magnetic field	
15 gauss line or closer	Cardiac pacemakers, ferromagnetic implants, and unrestrained ferromagnetic objects: tools, keys, electronic equipment, analog watches, magnetic data storage media, credit cards, and so forth.
5 to 15 gauss	Cardiac pacemakers and electronic equipment: shielded CRTs, computers, shielded image intensifiers, shielded photomultiplier tubes, and so forth.
2 to 5 gauss	Very sensitive electronic equipment: unshielded image intensifiers, photomultiplier tubes, and so forth
1 to 2 gauss	Extremely sensitive electronic equipment: linear accelerators, electron microscopes, CRTs, and so forth.

Magnetic Shielding

Magnetic shielding, shown in Figure 3, helps to contain the stray magnetic field and isolate the magnet from the effects of ferrous objects.

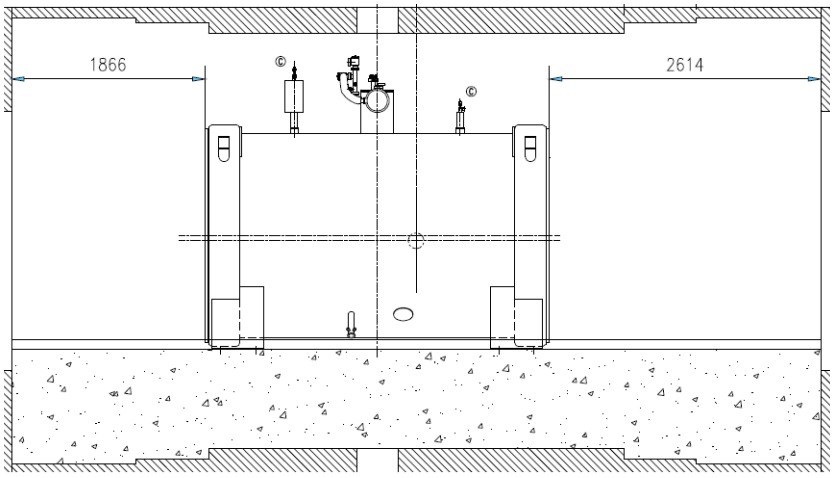


Figure 3 Magnetic shielding example

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 (for example., Armco Pure Iron), laminated low-silicon steel (for example, Losil 500), or any other ferrous material for which the BH curve is known (hysteresis curve). The size and shape of the shielding depends on the characteristics of the site and the properties of the material, and must be calculated by an appropriate specialist. Iron shields must always be approved by Agilent for use with a specific magnet.

Magnetic shielding example

Figure 3 on page 43 shows a typical room shield.

The magnetic shield designed for a 16.4T 260 mm bore magnet is usually 4.5 m high by 8.0 m long (14.8 x 26.2 ft). The center of this magnet is not at the center of the bore, so the cryostat is offset axially by 374 mm (1.2 ft) in order to keep the center of the magnet at the center of the shield.

Wall thickness varies. The side walls of the box are 250 mm (10 in) thick at the center, grading to 150 mm (6 in) and 100 mm (4 in). End walls are 100 mm (4 in) thick. The total weight of the box is about 243 tons.

Each plate used in the magnetic shield is typically about 1200 × 2400 × 76.3 mm (47 × 94.5 × 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 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.

The magnetic shield employs an independent rigid frame structure. None of the magnetic shield is supported by the building structure. The shield's mass is supported by the structural foundation.

All of the building structure outside the shield can employ standard building materials. The interior engineered infill and structural slab should employ only non-magnetic materials (for example, fiberglass reinforcing, fiber-fill concrete, and 304 stainless steel).

The preferred structural steel for the shield is annealed 1006 low-carbon steel. However, 1003 steel can also be used.

Radio-frequency interference

The site should be checked for radio-frequency interference (RFI) at or near the operating frequencies of the spectrometer and most common nuclei. The level of any interference should be attenuated to an electric field strength of less than 150 μV/m at the position of the RF coil (inside the magnet bore). Interference is not uncommon when two spectrometers are located in the same room, referenced to the same power system, or operating at the same frequency. Most RFI comes from transmissions for radio, television, paging systems, and cellular telephones. Some emission comes from electrical and electronic equipment in the immediate area. MR Imaging systems have shielded magnet bores and are not sensitive to average RFI levels. If the room level exceeds 10 mV/m, additional shielding may be required.

Table 6 Operating frequencies for common nuclei

Nuclei	4.70T	7.05T	9.39T	11.74T	14.1T
^{1}H	200.06	299.95	399.94	499.95	599.95
^{19}F	188.22	282.20	376.29	470.39	564.45
^{31}P	80.98	121.42	161.90	202.39	242.85
^{13}C	50.31	75.43	100.58	125.73	150.87
^{29}Si	39.75	59.59	79.46	99.33	119.20
^{2}H	30.71	46.04	61.40	76.75	92.09
^{15}N	20.28	30.41	40.54	50.68	60.80
^{39}K	–	14.00	18.66	23.33	28.00

Installation of a faraday cage (RF shielding) around the magnet room that shields the magnet from frequencies near the operating frequency of the system significantly reduces external RF noise. The faraday cage must be installed by the customer prior to the installation of the imaging system. Agilent does not provide or install the faraday cage as part of the standard installation process. RF shielded bore covers can be supplied as an alternative to an RF room.

Radio-frequency emissions from Agilent Technologies NMR equipment

RF emission from Agilent NMR equipment has been measured and compared with the IEEE/ANSI C95.1-1991 *Standard for Safety Levels with Respect to Human Exposure to RF Radiatio*n. The RF tests included general measurements of systems with particular interest directed toward amplifiers, transmitter boards, and probes. With maximum power applied, measurements were taken both one foot away and as close as possible to the RF source while the source was installed in the console or magnet. The results of the tests found that RF emissions from Agilent NMR equipment were either not detectable or at levels far below the IEEE/ANSI C95.1-1991 standards, (Table 7).

Table 7 IEEE/ANSI C95.1-1991 Standard for RF Radiation Levels

Frequency (MHz)	E-Field (mW/cm2)	H-Field (mW/cm2)
50	1.0	4.0
75	1.0	1.8

Table 7 IEEE/ANSI C95.1-1991 Standard for RF Radiation Levels

Frequency (MHz)	E-Field (mW/cm2)	H-Field (mW/cm2)
125	1.0	1.0
150	1.0	1.0
200	1.0	1.0
300	1.0	1.0

RF shielding

The magnet room may require an RF shield (Faraday cage) to protect the environment against RF interference as well as protecting the imaging system against external RF sources.

The required attenuation of the RF shield is 90 dB over a frequency range of 20 MHz to the system's proton frequency plus 30 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 (for example, ETS-Lindgren, Imedco, Hamaco, PDC and Gaven). The design of the RF shield must allow for the components.

The RF filter plate for the MRI components is supplied by Agilent, (Figure 4 on page 49). The plate size is 936 mm (36.85 in) tall × 676 mm (26.6 in) wide. The opening to mount the plate in the frame must be 848 mm (33.4 in) tall × 587 mm (23.1 in) wide.

Interior finishes (for example, 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.

- **False ceiling** - A nonferrous 600 × 600 mm (23.6 × 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. The grid should 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 or carpet.
- **Specifications** - Non-ferrous. Attenuation 90 dB over 20 MHz to the system's proton frequency plus 30 MHz.
- **Dimensions** - Determined by the magnet room size. The interior of a typical magnet room is 10000 × 6000 mm (393.7 × 236.2 in). The RF shield would have to fit around that.
- **Door** - Standard single door 1200 × 2100 mm (47.2 × 82.7 in).
- **Window** - 2400 × 800 mm (94.5 × 31.5 in), either a single unit or two separate windows with a central joint.
- **Quench pipe** - usually 200 mm (8 in) diameter.
- **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 × 400 mm (15.75 × 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.
- **Passive vent** - For additional safety in the event of a quench.

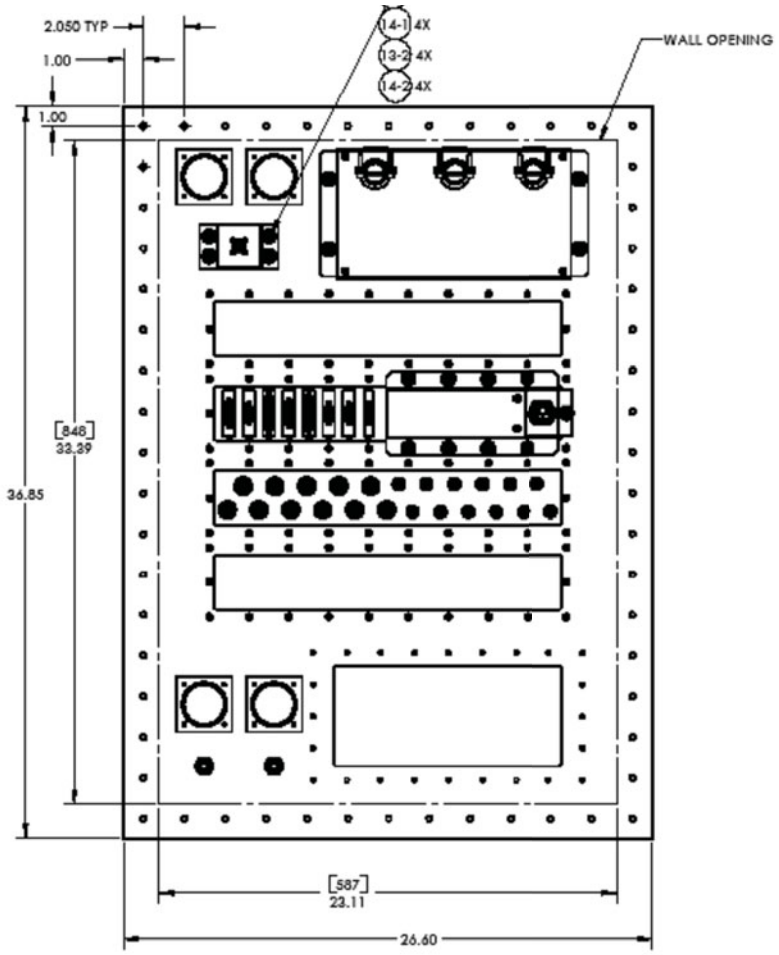


Figure 4 RF filter plate (viewed from inside RF room)

RF shielding example

This section provides details about a typical RF shield. Figure 5 on page 50 shows a typical wall section for an RF shield and Figure 6 on page 51 shows a typical magnet room floor plan with the RF shield installed.

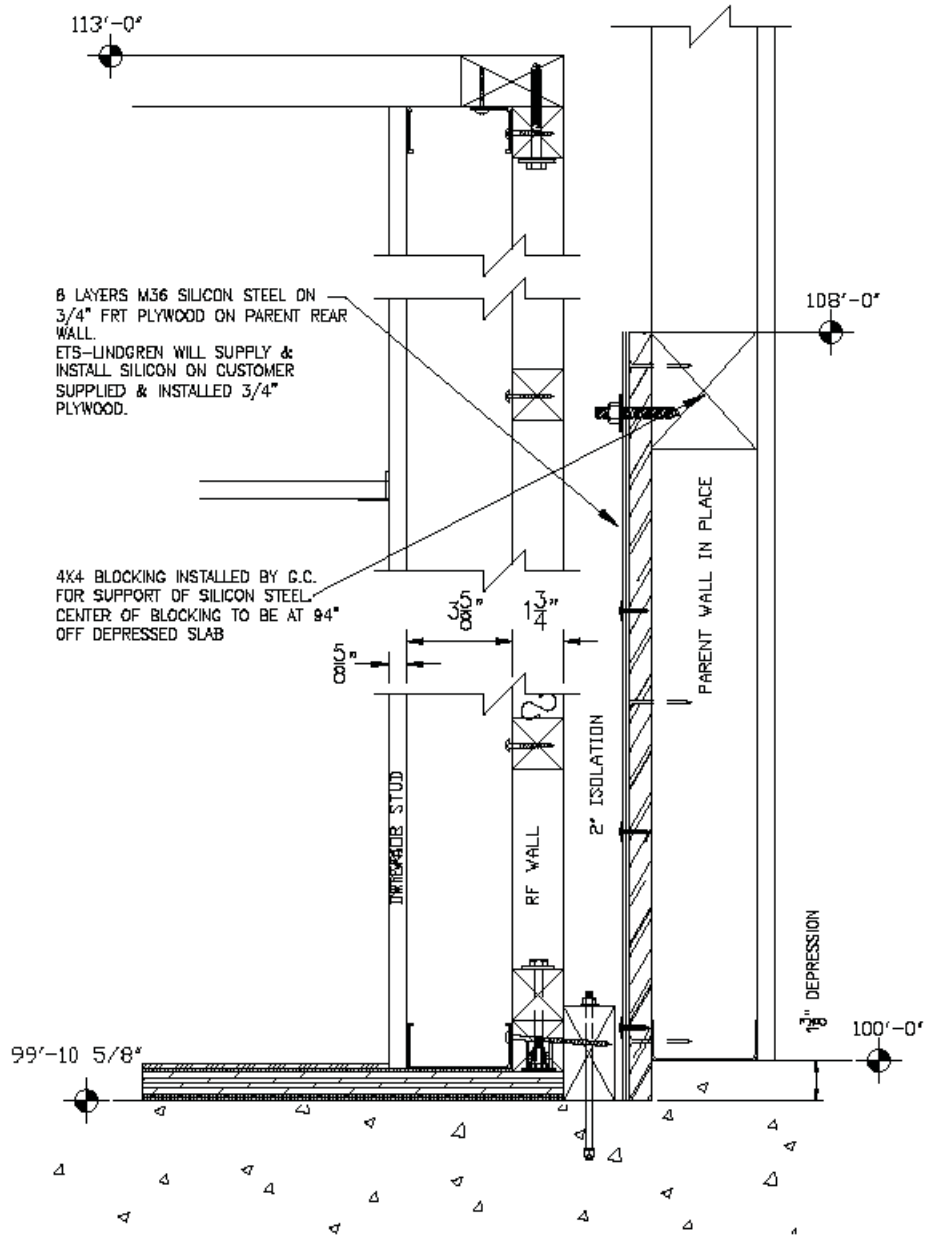


Figure 5 RF shield, typical wall section

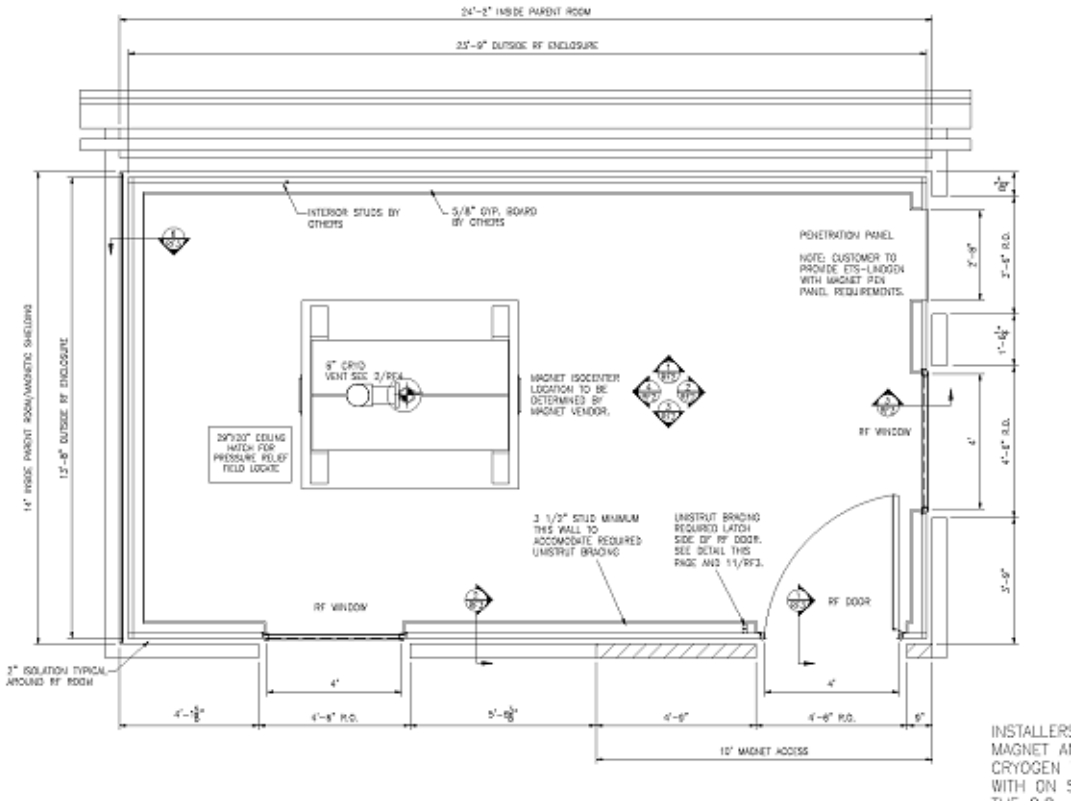


Figure 6 RF shield, typical floor plan

All of the building structure external to the RF shield can usually employ standard building materials. The interior of the RF shield should employ only non-magnetic materials.

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

Air conditioning

Use Table 7 on page 45 to help determine maximum air conditioning requirements.

A filter on the air conditioning intake unit and special air filtration is required in installations exposed to corrosive gases, salt air, or unusual dirt or dust conditions. The air conditioning system requires a power line separate from the spectrometer system. The console and amplifier must not be exposed to direct air flow from the air conditioner.

Table 8 Typical maximum air conditioning requirement for the equipment room

Component	Heat Load per unit[1] (kW)	Cooling (BTU/hr[2])
MRI console[3]	1.7	5,800
RF power cabinet	2.3	7,850
Gradient power supply (IECO 400 A / 700 V)[4]	8.0	27,300
Cold head compressor (sometimes two)	1.0	3,410
Water cooled chiller for compressor	0.5[5]	1,710
Water cooled chiller for gradient	0.5[5]	1,710
TOTAL:	14.0	47,780

1 Steady state.

2 Conversion of the unit of heat energy between BTU and the amount of system power is calculated:
1 kilowatt = 3413 BTU / hour

3 Measurements are only for the standard acquisition and RF console, which does not share an ac power branch with the host computer.

4 An optional water cooled gradient power supply is available.

5 Check manufacturer specifications. If the chillers are air cooled, the additional heat load will be about 18.5 kW (63,000 BTU/hr).

Other typical maximum air conditioning requirements are 3 kW for the magnet room and 2 kW for the operator room. The optional 10 A RT shim supply adds a heat load of 1.5 kW (5,100 BTU/hr).

Ambient temperature and humidity

Table 10 on page 54 lists the required ambient temperature ranges, temperature stability, and humidity levels for the site. For optimal performance, the ambient temperature around the magnet should not vary. Magnet homogeneity is optimized if the ambient temperature stability is maintained for the duration of an experiment and between shimming. Sunlight should never shine on the magnet or the area surrounding the magnet.

Table 9 Typical maximum air conditioning requirement for the equipment room

Area	Operational temperature range °C (°F)	Temperature stability °C (°F)	Relative humidity non-condensing (%)
Equipment room	15–32 (59–90)	± 1.0 (± 1.8)	30 to 75
Magnet room	15–21 (59–70)	± 1.0 (± 1.8)	30 to 60
Operator's room	15–32 (59–90)	± 1.0 (± 1.8)	30 to 75

The recommended temperature is 20 °C (68 °F) in all three rooms. If necessary, install an air conditioning system to maintain the required conditions. Keep the air conditioning system operating continuously to stabilize the temperature and humidity surrounding the spectrometer system. The air flow from the room heating and cooling system must not blow on the magnet. Do not allow moisture to collect on, in, or around the system. At high altitude (above 5000 ft), the cooling efficiency for the electronics is lower. This can be compensated for by lowering the room temperature by one or two degrees from the room temperature specification.

Magnet room ventilation

The magnet room ventilation system must be capable of exchanging 2 times the volume of the room air per hour to meet the minimum safety standards for working with cryogens. Sensors for monitoring air flow into the room and oxygen level monitoring are recommended. Since cold helium gas rises and cold nitrogen gas falls there should ideally be two oxygen level sensors in the magnet room, one high and one low. Liquid nitrogen is used to cool all magnets during the initial installation.

A quench occurs when the magnet loses its superconductivity and warms the liquid helium, rapidly generating a large volume of gas. If it is vented into the magnet room this gas can create a danger of asphyxiation by displacing the air within the room, as well as hazards from the room potentially becoming pressurized. A quench pipe should always be used to vent the gas outside the building. An emergency/passive vent should also be installed in case of an extreme failure such as a blocked quench pipe.

Liquid He (at 4.2 K) has a volume expansion ratio of liquid to gas at room temperature (20 °C) of approximately 750:1. For pumped magnets operating at 2.2 K the liquid He is

denser, giving a larger expansion ratio of about 876:1. The volume of He gas released upon quenching of a 7.0 T / 310 mm actively shielded refrigerated magnet is 1,185 m^3 and results in the displacement of all the oxygen in a room 3.0 m (9.8 ft) × 20.0 m (65.6 ft) × 19.5 m (64.0 ft) with room temperature He gas. See Table 10 for liquid helium volumes and the equivalent quench gas volumes.

Table 10 Liquid helium displacement for room ventilation considerations

Magnet/bore tesla/mm	LHe maximum volume liters	Quench gas maximum volume m^3 (CF)
4.7T / 210 / ASR	400	300 (10,600)
4.7T / 310 / ASR	480	360 (12,700)
4.7T / 400 / ASR	1,200	900 (31,800)
7.0T / 160 / ASR	400	300 (10,600)
7.0T / 210 / ASR	415	311 (11,000)
7.0T / 310 / ASR	1,580	1,185 (41,800)
7.0T / 400 / ASR	2,100	1,580 (55,600)
9.4T / 160 / AS	700	525 (18,500)
9.4T / 210 / ASR	1,170	878 (31,000)
9.4T / 310 / ASR	1,200	900 (31,800)
9.4T / 400 / ASR	5,000	3,750 (132,000)
11.7T / 160 / ASR	1,500	1,130 (39,700)
11.7T / 210 / ASR	1,600	1,200 (42,400)
11.7T / 260	2,100 (at 2.2 K)	1,840 (65,000)
14.1T / 260	1,900 (at 2.2 K)	1,660 (58,800)
16.4T / 260 / R	2,800 (at 2.2 K)	2,450 (86,600)

Quench pipe

The customer must incorporate a quench pipe at the site. Agilent provides a quench pipe adaptor with the magnet but does not include the installation of a quench pipe as part of the standard installation.

The pipe should be as short and straight as possible and be able to cope with an internal overpressure of 10 psi. It also needs to be capable of withstanding temperatures as low as –200 °C (–328 °F) for short periods of time. It is

recommended that it is made from stainless steel since this is non-magnetic. Joints can be welded or utilize bolted flanges. For installations in RF rooms a dielectric break is required at the connection outside the room. Most imaging magnets are supplied with an 8 in adaptor for attaching the quench pipe to the magnet. A typical 8 in quench pipe is shown on page 56. The pipe is normally flexible at the magnet end and attached using an overlap joint secured with a stainless steel clamp. It must be possible to detach the quench pipe from the adaptor in order to allow the adaptor to be removed from the magnet for service access.

It is important that the length and route of the pipe is provided to Agilent before the pipe is installed, as Agilent uses this information to specify the minimum internal diameter required to keep the back-pressure at an acceptable level. If a larger pipe is required the diameter can normally be increased outside the magnet room.

The exit opening should be protected from the ingress of rain, snow, wildlife or any debris which could block the system. It is recommended that the quench pipe exit is inspected periodically to ensure that gas flow has not become restricted by the presence of any debris. If the pipe exits the building horizontally the outlet should be angled downwards by at least one pipe diameter to prevent rain ingress. Alternatively, the horizontal section at the exit can be made with a slight downward slope. Where the exit is vertical a rain cover must be fitted that's twice the pipe diameter at a distance of twice the diameter above the end of the pipe.

Although quenches are short-lived and infrequent phenomena, the temperature of the quench pipe can become low enough to cause cold burns on unprotected skin. This low temperature might also damage electrical wiring or other services routed close enough to touch the quench pipe. (Water pipes should not be routed near quench pipes.) It is therefore recommended that quench pipes are protected with suitable proprietary thermal insulation such as fiberglass cladding or similar.

Such thermal insulation should be:

- Fire resistant (due to the possibility of condensation of liquid oxygen.)
- At least 50 mm (2 in) thick.

- Resistant to deterioration upon contact with water. (Frost formed on the pipe within the insulation will eventually thaw.)

There should be no public access to the exit of the quench pipe or within 3 m (10 feet) of the gas flow. It will usually be acceptable for the exit to be above an external area of public access as long as it is high enough to prevent direct access. Helium gas venting from the pipe will rapidly rise. Care must be taken to ensure that any gas which vents from the quench pipe cannot be drawn in to any air-conditioning or ventilation system intakes. The location of pipe's exit should be carefully sited to prevent this from happening.



Figure 7 Example of a typical eight inch quench pipe

Acoustic noise

Magnet Room Noise

Noise levels in the magnet room during a scan average 90 dB (A) with a nominal range from 70 to 100 dB (A). The noise level may be higher with some imaging sequences. Installing anti-vibration pads under the magnet feet reduces the amount of noise transmitted into the floor.

Electronic Console Noise

Noise generated by the electronics console (gradient amplifier, RF amplifier, NMR electronics console) is typically lower (~ 78 dB (A)) than the peak noise generated by the gradient coil during imaging operations.

Maximum altitude

The MRI system should not be installed at an altitude above 2440 m (8000 ft).

5
Site Preparation

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System Layouts for Utilities and Raceways 72
Construction Considerations 76
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Computer Preparation 83

This chapter will assist in preparing the site for installation of the MR Imaging system. Verify the configuration with an Agilent Technologies representative before designing the room layout. Site preparation must conform with federal, state, and local codes, which take precedence over recommendations in this guide. Approval by a building inspector may be necessary.

Communication during the construction phase of a site is essential. Good communication must be maintained between the architect or facility planner, the institution, and Agilent installation specialists. Any questions, changes, or problems should be addressed immediately to avoid delays and additional costs.

Electric Utility Installation Requirements

The customer is required to provide three-phase power to a wall-mounted circuit breaker and to provide wiring from the wall breaker to the gradient power supply. Each cryocooler compressor also requires a three-phase wall mounted circuit breaker.

Grounding

A dedicated ground wire is required for the spectrometer system. The wire size should be no smaller than #6 AWG copper.

The spectrometer ground is to be connected directly to the grounding terminal at the service entrance, or in the case of a separately derived system (for example, a transformer), at the grounding terminal of that system.

For the purpose of limiting noise on the ground conductors, make no other connections to this equipment grounding conductor other than the spectrometer system. Similarly, this equipment grounding conductor must be connected to the grounding structure only at the point specified in this chapter without making any intermediate connections. Should this grounding conductor pass through a panel board, it must do so without making connection to the equipment grounding bus in that panel.

RF and magnetic room shields should have only one ground connection.

Electrical requirements and outlets

Table 11 Electrical outlet requirements of system components

Component	Outlets/Circuits Required	Electrical Requirements
Host workstation and peripherals	6	120/220 VAC 15 A
MRI console	1	205-235 VAC, 20 A
RF power cabinet	1	205-235 VAC, 30 A
Probe interface console (PIC)	0	Connects to console
Gradient power supply	1	400-480 VAC, 50 A, 3 Ø, 50 or 60 Hz
Gradient chiller (Haskris WW1, water cooled)	1	208-230 VAC, 15 A
Gradient chiller (Haskris R175, air cooled)	1	208-230 VAC, 25 A

Table 11 Electrical outlet requirements of system components (continued)

Component	Outlets/Circuits Required	Electrical Requirements
Compressor chiller (Haskris WW2, water cooled)	1	208-230 VAC, 15 A
Compressor chiller (Haskris R300, air cooled)	1	208-230 VAC, 35 A
Optional 10 A RT shim supply	1	187-229 VAC, 20 A, 3 Ø, 5 wire, 50 or 60 Hz
Magnet monitor + EDU	2	120/220 VAC
Pumping station (only for magnets operating at 2.2 K)	1	198-218 VAC, 8 A, 3 Ø, 60 Hz, 5 wire
Accessories and test equipment	6	120 VAC, 20 A or 230 VAC, 10 A
Cryocooler Compressor	See "Cryocooler Compressor Specifications and Requirements"	

The following paragraphs detail the requirements of each component.

Test equipment - Requires at least two separate electrical outlet circuits with two plugs each, near the computer. Each outlet should provide a minimum of 2.3 kW at the local single-phase line voltage (115 Vac at 20 A in the U.S.). Install additional outlets around the room for later housekeeping and maintenance.

Host computer and peripherals - Requires a minimum of six 120/220 VAC, single-phase power outlets. If your location has ac voltages over 132 VAC, check with your local Agilent service center for power outlet requirements. Locations with voltages over 125 VAC might need at least one step-down transformer. To minimize ground loop interference, these outlets should all be on the same 20 A service. It is strongly recommended that surge protection be provided.

MRI console - Requires a dedicated single-phase, continuous-duty 220 VAC (7%), 50/60 Hz power line with 20 A minimum service. Terminate this line within 2 m (7 ft) of the standard cabinet with a fused, quick-disconnect switch box or circuit breaker. Run a separate, insulated, low-resistance earth ground to the main electrical service entrance ground.

RF power cabinet - Requires a dedicated single-phase, continuous-duty 220 VAC (7%), 50/60 Hz power line with 30 A minimum service. Terminate this line within 3 m (10 ft) of the left side (looking from the rear) of the standard cabinet with a fused, quick-disconnect switch box or circuit breaker. Run a separate, insulated, low-resistance earth ground to the main electrical service entrance ground. The

source of the power should be the original source for the building, and should not be shared with other power needs along the way.

Gradient power supply cabinet - Requires a dedicated three-phase, continuous-duty 400-480 VAC, 50 A, 50/60 Hz power line minimum service. Terminate this line within 2 m (7 ft) of the standard cabinet with a fused, quick-disconnect switch box. Run a separate, insulated, low-resistance earth ground to the main electrical service entrance ground.

Pumping station - 208 VAC ± 5%, 3 phase and earth, 8 A at 60 Hz. 5 m of cable supplied (cable type SY, PVC sheath with wire braid armor, overall diameter 12.6 mm rated to 16 A).
A 5 pin NEMA connector may be used (not supplied).

Pumping station	NEMA
A phase 1	X
B phase 2	Y
C phase 3	Z
D neutral	W
E ground	GN

Other accessories and test equipment - Requires at least six outlets within 1.8 m (6 ft) of the host computer, standard cabinet, and magnet. The outlets must have ground connections and should provide a minimum of 2.30 kW at the local single-phase line voltage (120 VAC at 20 A, or 230 VAC at 10 A).

Line voltage variation

After the three-phase power has been installed the quality of the incoming power should be monitored for one week using a Dranetz Series 606 power line disturbance analyzer or equivalent instrument. Measure and record the ac line voltage for 48 hours using a suitable power line analyzer, such as the BMI Model 4800 or equivalent. Provide a copy for the Agilent installation engineer. Requirements are the following:

- Long-term voltage variations (slow average) do not exceed 7% of nominal line tap voltages.

- Short-term voltage variations (sag or surge), with a duration between several milliseconds and several seconds, do not exceed 10% of nominal line tap voltage.
- Line transients (impulse) with a duration between 1 µs and 800 µs, not to exceed 50 V peak above or below nominal line tap voltage. These transients must be measured at the power plug with a load connected that draws the same power as the spectrometer.
- AC line frequency does not vary by more than + 0.5 to –1.0 Hz.

The purchase of a line conditioner and regulator is strongly recommended. By providing protection against transients and improving line regulation, total system up-time will improve and the electronic components within the system will last longer. In many locations, a good power conditioning system pays for itself within a few years. Contact a local power consultant for suitable equipment in your area. Conditioners and regulators are available from many commercial sources as off-the-shelf items. Agilent will recommend suitable equipment and manufacturers on request.

Uninterrupted power supply

If your site experiences frequent and short (less than 10 min) power outages, you should consider an uninterrupted power supply (UPS). UPS systems supply power when house power is out for a limited time. Consider the placement of a UPS when planning your lab. If you want to use one UPS, it must have output for 208 Vac and 120 Vac and it must be placed such that both the NMR console and the host computer can use it.

Cryomech CP289C compressor

Note that the number and type of cryocooler compressors varies from magnet to magnet. Always check with Agilent for the correct site requirement.

Weights and dimensions

Dimension	Measure
Width	494 mm (19.4 in)
Length	686 mm (27.0 in)
Height	622 mm (24.5 in)

Dimension	Measure
Weight	119 kg (263 lbs)

Utility requirements

Utility	Specification
Electrical*	
Line power - 50 Hz	380/420 VAC 3 phase (3W+PE)
Line power - 60 Hz	460 VAC 3 phase (3W+PE)
Maximum current - 50 Hz	16 A
Maximum current - 60 Hz	13 A
Dedicated circuit breaker	25 A
Operating voltage range - 50 Hz	342–462 VAC
Operating voltage range - 60 Hz	414– 506 VAC
Power consumption	Max. 9.0 kW / Steady state 7.2 kW
Cooling water	See "Other specifications and requirements" , this section.
Air conditioning load	Table 8 on page 52

* Grounded commercial power source source
Do not use inverter for the main power source

Other specifications and requirements

Description	Specification
Ambient temperature range	7–38 °C (45–00 °F)
Maximum relative humidity	80 % for T < 31 °C (88 °F). Decreasing linearly to 50% at 40 °C (104 ° F).
Maximum altitude	2,000 m (6,560 ft)
Pressure relief valve setting	2.86–2.93 MPa (415–425 psig)
Maximum sound level	70 dBA at 1 meter

Chiller requirements and coolant specifications

Parameter	Value
Cooling water: minimum flow at maximum temperature	8.8 lpm (2.3 gpm) at 27 °C (80 °F)
Optimum temperature	15 °C (59 °F) at a flow rate of at least 7.6 lpm (2.0 gpm)
Maximum pressure drop	2.7 bar (39 psig)
Maximum inlet pressure	7.6 bar (110 psig)
Minimum inlet temperature	13 °C (55 ° F)
Chiller cooling capacity	10 kW
pH	5.8 to 8.0
Calcium carbonate (ppm)	80 max
Alternate coolant	Ethylene glycol / water (50 % / 50 %)
Alternate coolant minimum flow rate at maximum temperature	9.7 lpm (2.5 gpm) at 27 °C (80 °F)

Cryomech CP1010 compressor

Weights and dimensions

Dimension	Measure
Width	584 mm (23.0 in)
Length	610 mm (24.0 in)
Height	914 mm (36.0 in)
Weight	213 kg (470 lbs)

Utility Requirements

Utility	Specification
Electrical*	
Line power - 50 Hz	380/420 VAC 3 phase (3W+PE)
Line power - 60 Hz	460 VAC 3 phase (3W+PE)
Maximum current - 50 Hz	22.5 A
Maximum current - 60 Hz	19.5 A
Dedicated circuit breaker	40 A
Operating voltage range - 50 Hz	342–462 VAC
Operating voltage range - 60 Hz	414– 506 VAC
Power consumption	Max. 12.5 kW / Steady state 11 kW
Cooling water	See "Other specifications and requirements" , this section.
Air conditioning load	Table 9 on page 53

* Grounded commercial power source
Do not use inverter for the main power source

Other specifications and requirements

Description	Specification
Ambient temperature range	7–38 °C (45–100 °F)
Maximum relative humidity	80 % for T < 31 °C (88 °F). Decreasing linearly to 50 % at 40 °C (104 °F)
Maximum altitude	2,000 m (6,560 ft)
Pressure relief valve setting	2.89–2.96 MPa (420–430 psig)
Maximum sound level	76 dBA at 1 meter

Chiller requirements and coolant specifications

Parameter	Value
Cooling water: minimum flow at maximum temperature	11.5 lpm (3.0 gpm) at 27 °C (80 °F)
Optimum temperature	15 °C (59 °F) at a flow rate of at least 6.0 lpm (1.6 gpm)
Maximum pressure drop	1.5 bar (22 psig)
Maximum inlet pressure	7.6 bar (110 psig)
Minimum inlet temperature	13 °C (55 °F)
Chiller cooling capacity	15 kW
pH	5.8 to 8.0
Calcium carbonate (ppm)	80 max

Sumitomo F50 compressor

Weights and dimensions

Dimension	Measure
Width	450 mm (17.7 in)
Length	485 mm (19.1 in)
Height	591 mm (23.3 in)
Weight	120 kg (264 lbs)

Utility requirements

Utility	Specification
Electrical*	
Line power - 50 Hz	380 / 400 / 415 VAC 3 phase (3W+PE)
Line power - 60 Hz	460 / 480 VAC 3 phase (3W+PE)
Maximum current	13 A
Dedicated circuit breaker	30 A
Operating voltage range - 50 Hz	342– 457 VAC
Operating voltage range - 60 Hz	414– 528 VAC
Power consumption at 50 Hz	Max. 7.2 kW / Steady state 6.5 kW
Power consumption at 60 Hz	Max. 8.3 kW / Steady state 7.5 kW
Cooling water	See "Other specifications and requirements" ,this section.
Air conditioning load	Table 9 on page 53

* Grounded commercial power source
Do not use inverter for the main power source

Other specifications and requirements

Description	Specification
Ambient temperature range	5– 28 °C (41–82 °F)
Maximum relative humidity	85%
Pressure relief valve setting	2.61–2.75 MPa (378–398 psig)

Chiller requirements and coolant specifications

Parameter	Value
Cooling water: minimum flow at maximum temperature	7.0 lpm (1.9 gpm) at 28 °C (82 °F)
Optimum temperature	15 °C (59 °F) at a flow rate of at least 7.0 lpm (1.9 gpm)
Maximum pressure drop	0.85 bar (12 psig)
Maximum inlet pressure	6.9 bar (100 psig)
Minimum inlet temperature	4 °C (39 °F)
Chiller cooling capacity	10 kW

Parameter	Value
pH	6.5 to 8.2 (at 25 °C)
Electrical conductivity	< 0.08 S / m
Alkalinity	< 100 ppm
Total hardness	< 200 ppm
Chloride	< 200 ppm
Sulfide	< 200 ppm
Iron	< 1.0 ppm
Sulfur	None
Ammonium	< 1.0 ppm
Silica	< 50 ppm
Aggressive carbon dioxide	None
Suspended matter	< 10 mg/liter
Particle size	< 100 µm

Helium level monitor

Table 12

Description	Specification, for model E5083
Dimensions	
Width	483 mm (19 in)
Length	292 mm (11.5 in)
Height	133 mm (5.25 in)
Electrical	
Line power (50/60 Hz)	100 – 230 V single phase
Operating current	170 mA @ 110 V 80 mA @ 220 V
Magnetic field flux density	
	50 gauss, max

Emergency discharge unit

The emergency discharge unit initiates a fast ramp down of the magnetic field in the event of an emergency.

Description	Specification, for model E7007
Dimensions	
Width	214 mm (3U) (8.43 in)
Length	220 mm (8.67 in)
Height	128 mm (5.1 in)
Weight	3 kg (6.7 lbs) approximate
Electrical	
Line power (50/60 Hz)	115/230 V selectable single phase
Operating current	250 mA @ 110 V 125 mA @ 220 V
Magnetic field flux density	
	10 gauss, max

System Layouts for Utilities and Raceways

Suggested room layouts are shown in Figure 8 and Figure 9 on page 73.

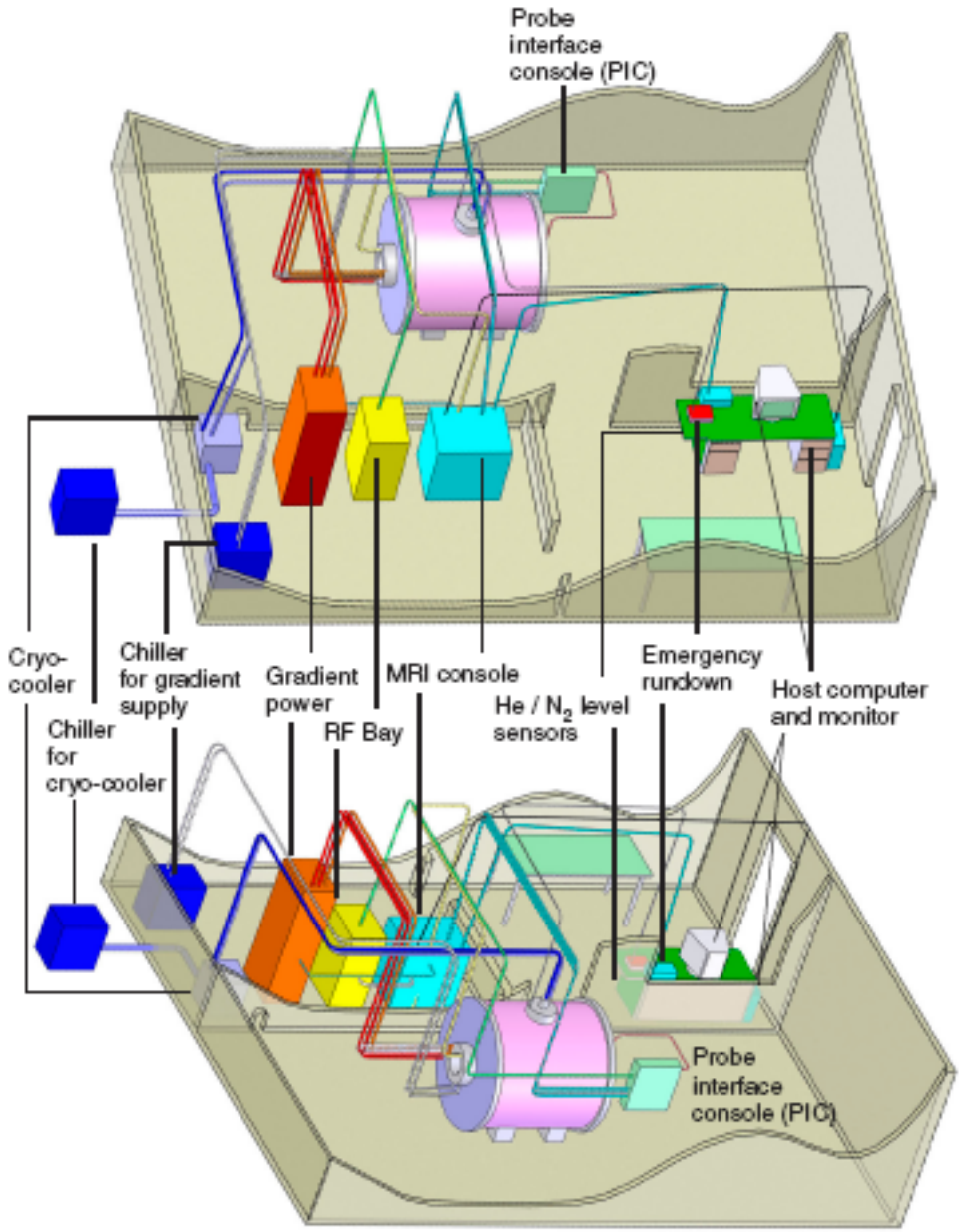


Figure 8 Suggested components, water, and raceway for overhead configurations

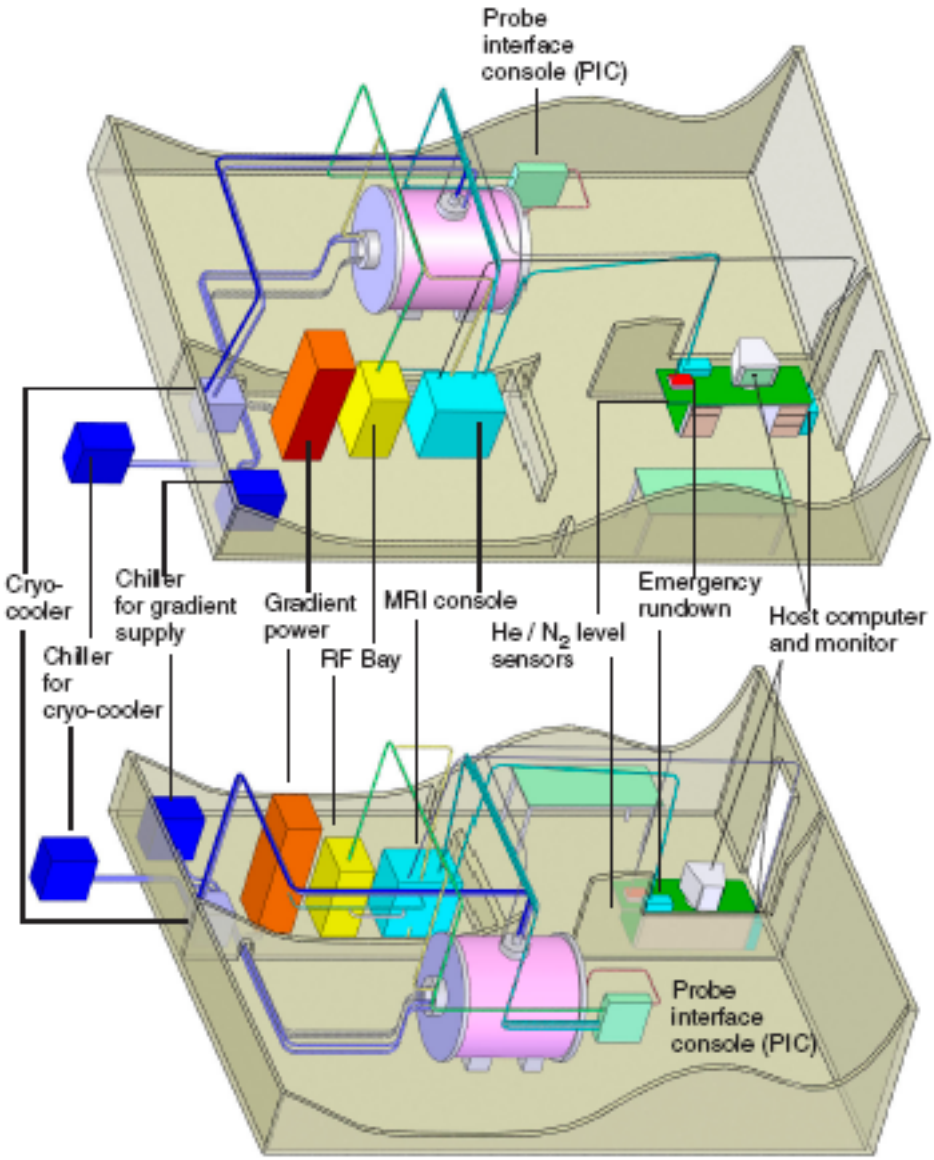


Figure 9 Suggested components, water, and raceway for raised floor configurations

Water cooling

Figure 8 on page 72 and Figure 9 show suggested water system layout.

The gradient coils and cryocooler compressor are water cooled. Cooling can be provided by a single source of water capable of removing 18 kW of heat. The water should be filtered with a CUNO cartridge-type filter (Model #1 ml) or equivalent to remove particles.

For the compressor, it is strongly suggested that a closed-loop water supply be used, with water-to-water heat exchange to a refrigerator type heat exchanger. This type of system can be purchased from local vendors (for example, Neslab or Haskris in the U.S.). Agilent normally supplies an air cooled chiller for the gradient coils, but not the chiller for the compressor. Water-cooled Haskris chillers use ½ inch female standard pipe thread.

Raceways, conduit, and components

Inter-module power cabling installed in raceways is recommended for convenience and safety, and is often required by local building codes. A minimum of a 5 cm by 20 cm channel (2 in by 8 in) is required. The raceways should allow connections between all components including the magnet. To reduce cable lengths, the raceway is most efficient if it is placed in the floor. If the floor raceway is not practical, raceways and conduits in the wall or ceiling may be considered. See Figure 8 on page 72 and Figure 9 on page 73 for a raceway installation plan and a suggested component layout.

The following points should be considered in the location of system components:

- The RF power cabinet must be kept within 12 m (45 ft) of the magnet.
- The gradient supply should be kept as close to the magnet as possible, but should be kept outside the 10 gauss line.

Cable trays

Agilent does not supply or install cable trays for the system wiring. These must be provided and installed by the customer and conform to local codes. All bends and curves must have a minimum radius of 15 cm and not bind or pinch the cables. The type of cable tray is at the customer's discretion, but should be non-magnetic inside the magnet room.

Cable channels

Cable channels from the magnet to the electronics consoles for the system wiring should be as direct as possible. The minimum bend radius is 15 cm to accommodate cables that are rigid. Lay cables in the channels side by side. Cable must be supported every 41 cm (16 in) to 122 cm (48 in)

along both horizontal and vertical cable ways.

Cable lengths

Table 13 Standard cable lengths

From	To	Length meters (feet)
Magnet front	Probe interface console	2 (6)
Magnet back, gradient temperature sensor	Gradient power supply cabinet	4.9 (15)
Magnet, back, shims and gradient coil	Gradient power supply cabinet	4.0 (12)
Magnet, top, N2 level sensor	N_2 level meter	8.5 (28)
Magnet, top, emergency run down and helium level sensor	EDU	17 (56) (two 8.5 m cables)
Magnet, top, temperature sensors	Helium level monitor	17 (56) (two 8.5 m cables)
Magnet, top, pressure heaters	Helium level monitor	17 (56) (two 8.5 m cables)
Magnet, top, cryocooler motor	Compressor	17 (56) (two 8.5 m cables)
EDU	Helium level monitor	0.3 (1)
EDU	Remote quench button	8.5 (28)
Probe interface console (RFFE)	RF cabinet (transmitter)	14 (45) (no RF room)
Electronics console	Probe interface console (RFFE)	14 (45) (no RF room)
Probe interface console (RFFE)	RF cabinet (transmitter)	16 (52) (two 8 m cables) (with RF room)
Electronics console	Probe interface console (RFFE)	16 (52) (two 8 m cables) (with RF room)
Electronics console	RF cabinet	2.5 (7)
Electronics console	Gradient power supply cabinet	3.0 (9)
Electronics console	Host computer	8.0 (24)

Construction Considerations

Consider the following when preparing for room construction.

- Check the room dimensions. The ideal room will contain as much of the 5 gauss field as possible but still keep the electronics on or outside the 10 gauss line.
- Power requirements are 208 V single phase and 380–480 V three phase.
- Some spectrometers require water cooling; check specific product specifications.
- In most cases, RF shielding is not needed.
- Where possible, put electrical raceways in the floor.
- Use non-ferromagnetic construction materials when possible.
- Check with the architect or facilities engineer to be sure that all construction is in compliance with local building codes. Inform Agilent immediately if there is a problem with building codes.

Telephone and internet access

Agilent recommends locating two regular voice telephone lines near the host workstation. These will enable the spectrometer operator to discuss the spectrometer system as it operates. Agilent also strongly recommends that two data lines for internet access be provided during and after system installation. By providing external access to the spectrometer, technical problems can be quickly analyzed by the engineering and scientific staff.

One telephone line and one data line should also be installed in the equipment room, near the console. If the magnet is supplied with a magnet monitoring unit this will require two additional modem quality telephone lines.

Lighting the magnet area

Incandescent lighting is preferred in the magnet area. Ballasts from fluorescent lights, as well as dimmer switches, can increase radio frequency interference levels.

Water supply

Gradient coils, cryocooler compressors and some gradient power supplies require water cooling. For specific information on models that require water cooling, see “Water cooling” on page 73.

Compressed air supply for optional AV legs

An air supply, filtered to 5 µm, preferably from a pressure main, should be available as near as possible to the installation. The feed pipe from the main should carry a connector capable of airtight attachment to the (6 mm or 10 mm od) tube protruding from the side of the control cabinet.

The main line pressure during working hours should be maintained at a level slightly above that demanded by the system, but should not exceed 6.9 bar (100 psi).

Fire protection

- Portable nonferrous units suitable for electrical fires are recommended. The entire portable unit must be nonferrous.
- Water sprinkler systems are not recommended for fire prevention. Water leaking into units can be extremely dangerous. Water leaks could severely damage the electronics.
- An automatic halon fire extinguishing system can be used if local codes require an automatic system.
- Use infrared or photoelectronic detectors. Do not use ionizing fire detectors because they can malfunction in a strong magnetic field.
- Avoid putting smoke detectors near the magnet as some types can be triggered by water vapor condensed by cold helium gas. A good location for a smoke detector is in the HVAC outlet duct outside the magnet room.

Floor covering and electrostatic discharges

Linoleum or vinyl is recommended for the area directly around the magnet, because of ice and water accumulation from the cryogens. Sound deadening material such as low-static carpet is recommended for the rest of the room.

Electrostatic discharges under 15 kV generally do not result

in any perceivable errors or problems. Discharges over 15 kV, however, can result in loss of data and/or errors that are perceivable to the operator. Discharges over 25 kV can cause damage to the equipment.

Install the system over vinyl flooring and ground the system properly to prevent electrostatic discharge damage. Any carpeting should contain only a small percentage of nylon and be installed over antistatic pad. Regular use of a good quality antistatic spray will help in alleviating electrostatic discharge problems.

CAUTION Printed circuit boards are easily damaged by static discharges. Persons removing and handling a circuit board must wear grounded wrist straps.

CAUTION Many components in the system contain highly sensitive electronic devices that must be protected from electrostatic discharges by proper floor coverings and grounding practices. A person walking across a nylon carpet or wearing synthetic fabrics can generate an electrostatic charge that can discharge to the next object that is touched. If this happens to be the system, the system components can be damaged. An overly dry atmosphere also tends to create an electrostatic charge. As with any system based on integrated circuits, the system is susceptible to static spikes, both those generated on the power line and those generated in the lab area, that must be suppressed.

Installation Supplies and Equipment

The installation engineer needs the following non-Agilent supplies and equipment during installation:

- Liquid helium supply
- Liquid nitrogen supply
- Helium gas supply
- Non-ferromagnetic ladder
- Isopropyl alcohol

The following additional items are recommended:

- Face mask and thermal gloves
- Heat gun
- Cryogenic equipment rack
- Electrical power surge protector

Details about each item are presented in the following sections.

Locating a reliable local source of liquid helium and nitrogen is particularly important. Make arrangements for an initial delivery and an on-going supply of liquid helium and nitrogen as soon as possible after ordering a system.

CAUTION To avoid movement caused by magnetic field attraction, gas cylinders made of magnetic material must be kept outside the 5 gauss limit of the magnet and firmly secured.

Liquid helium and nitrogen supplies

The minimum quantities of cryogens required at the beginning of the installation are listed in Table 14.

Table 14 Initial and refill liquid helium and nitrogen supplies

Magnet/Bore (tesla/mm) R = refrigerated, nominally zero LHe boil-off	Estimated Initial LHe supply (+quench contingency) (liters)	Estimated Initial LN2 supply (liters)	Maximum LHe refill volume* (liters)	Minimum LHe refill interval (months)
4.7T / 210 / ASR	1,000	800	300	12
4.7T / 310 / ASR	1,800	1,800	100	12
4.7T / 400 / ASR	3,500	4,000	300	12
7.0T / 160 / ASR	1,000 (500)	750	300	12
7.0T / 210 / ASR	1,250 (750)	1,200	120	12
7.0T / 310 / ASR	3,500 (2,500)	3,000	300	12
7.0T / 400 / ASR	5,000	4,500	300	12
9.4T / 160 / AS	2,400 (1,000)	2,400	200	3.3
9.4T / 210 / ASR	3,000 (2,200)	3,000	300	12
9.4T / 310 / ASR	4,500 (1,500)	6,000	300	12
9.4T / 400 / ASR	12,000	10,000	300	12
11.7T / 160 / ASR	5,000	2,500	100	12
11.7T / 210 / ASR	8,000	5,000	100	12
11.7T / 260	10,000	8,000	350	1.6
14.1T / 260	6,500	5,000	400	1.6
16.4T / 260 / R (not zero boil-off)	13,000	15,000	350	1.4

* Excluding transfer and cooling losses, based on system being operated correctly per the manual

Liquid helium supply

CAUTION Specify that supply dewars be made of nonmagnetic materials. A magnetic supply dewar can be pulled into the magnet, possibly damaging the magnet or causing the magnet to quench.

Request delivery of helium just prior to the scheduled visit of the Agilent installation engineer to prevent unnecessary loss of the supply.

An additional supply of helium for delivery on short notice is also advisable should the initial amount be insufficient.

Liquid nitrogen supply

Table 20 on page 133 lists the recommended quantities of liquid nitrogen. Liquid nitrogen storage containers suffer a loss of contents from boil-off, so request delivery of the supply just prior to the scheduled visit of the installation engineer.

Helium gas supply

The helium gas for helium transfers must be no less than 99.995% or U.S. Bureau of Mines Grade A. If the magnet has a cryocooler, a bottle of ALT UHP or 99.999% helium gas will also be required. Magnetic gas bottles may be used provided that they remain outside the 5 gauss limit of the magnet and are firmly secured.

Non-ferromagnetic ladder

Acquire a 120 to 153 cm (4 to 5 ft) non-ferromagnetic ladder or platform for reaching the top of the dewar while inserting and removing the helium transfer tube. The ladder should be sturdy and self-supporting with rubber feet. A somewhat taller 120 to 180 cm (4 to 6 ft) ladder is recommended for bigger magnets.

Isopropyl alcohol

Obtain 1 pint (500 cm3) of isopropyl alcohol. This is needed to clean O-rings before assembly.

Face mask and thermal gloves

A serious injury (similar to a burn) can occur if cryogenic helium or nitrogen contact living tissue. Order appropriate safety coverings for use during dewar cryofills, including a mask that protects the face completely and loose-fitting thermal gloves.

WARNING **Avoid helium or liquid nitrogen contact with any part of the body. If liquid helium or nitrogen contact living tissue, a serious injury (similar to a burn) can occur. Never place your head over the helium and nitrogen exit tubes on top of the magnet. If helium or nitrogen contacts the body, seek medical attention, especially if the skin is blistered or the eyes are affected**

Heat gun

Order a heat gun of about 2400 W for thawing ice accumulation and drying out moisture on dewar servicing equipment.

Cryogenic equipment rack

Various items are used around the magnet for routine maintenance and handling. These include helium transfer tube, flutter tube, Tygon tubing, stingers, and so forth. To protect the cryogenic equipment from damage and to keep it conveniently available, a rack to hold the items is recommended. A 1.2 m × 2.4 m (4 ft × 8 ft) peg board hung on a laboratory wall, with wood or plastic pegs, works very well.

Electrical power surge protector

To protect the delicate electrical components of the computer system (monitor, disk drive unit, CPU base, and so forth), a good quality surge protector is recommended in the power circuit serving the components. A single surge protector with six outlets can suffice if the components are located relatively close to one another. Contact an electronic professional for advice on quality surge protection in your area.

Computer Preparation

Agilent Technologies spectrometers are operated using either a computer purchased from Agilent or acquired separately. Refer to “Electric Utility Installation Requirements” on page 60.

The spectrometer host computer system and storage media must be located at a sufficient distance from the magnet that the magnetic field cannot damage the data. This value is typically less than 5 gauss. The distances at which this gauss level is present are different for each kind of magnet and must be taken into account when planning the room size. See Chapter 8, “Stray Field Plots”.

6 Room Plans

Disclaimer 85
Requirements for the Equipment Room 86
Examples of Room Layouts 86
System Interconnect Diagrams 89

Disclaimer

Every effort has been made by Agilent Technologies to ensure the information contained in this document is correct and accurate. Agilent accepts no liability for consequential problems, losses, or damages arising from the use of any of the information provided.

Documents and drawings provided by Agilent related to site planning are intended only as guidelines to provide sufficient information for initial evaluation of the installation suite by the customer and the customer's assigned architects and builders.

Site planning recommendations are based on previous installation sites and do not guarantee successful site construction or system operation.

For the construction and commissioning of the site it is the customer's responsibility to comply with national, state, local, and institutional codes and to ensure the accuracy of all information related to them.

Requirements for the Equipment Room

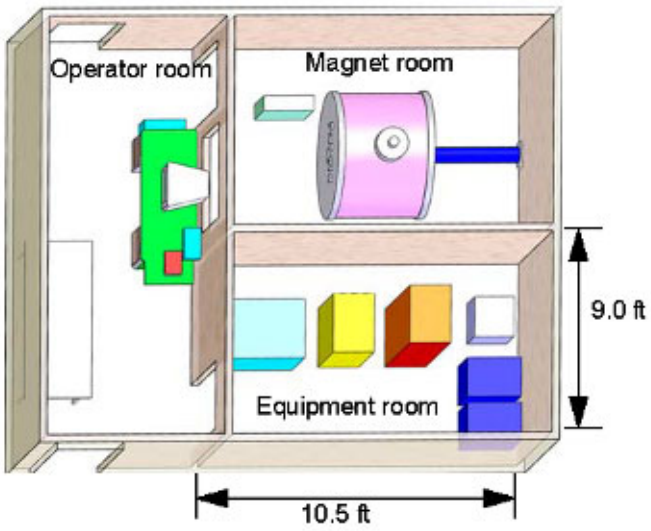
A distance of 1 m (3 ft) should be maintained around the cabinets. The service space should be at least 132 cm (52 in). Service requirements are described in Chapter 2, “Safety” .

Examples of Room Layouts

Illustrations of room layouts- do not scale to these illustrations.

- Figure 10 on page 87 illustrates room layouts for a 9.4T 310 ASR system and a 7T 310 mm ASR System.
- Figure 11 on page 88 illustrates typical room layouts for a 7T 310 mm ASR system and shows the fringe field of the magnet.

Compact room layout with a 7T AS 310mm magnet



Nominal room layout with a 9.4T AS 310 magnet

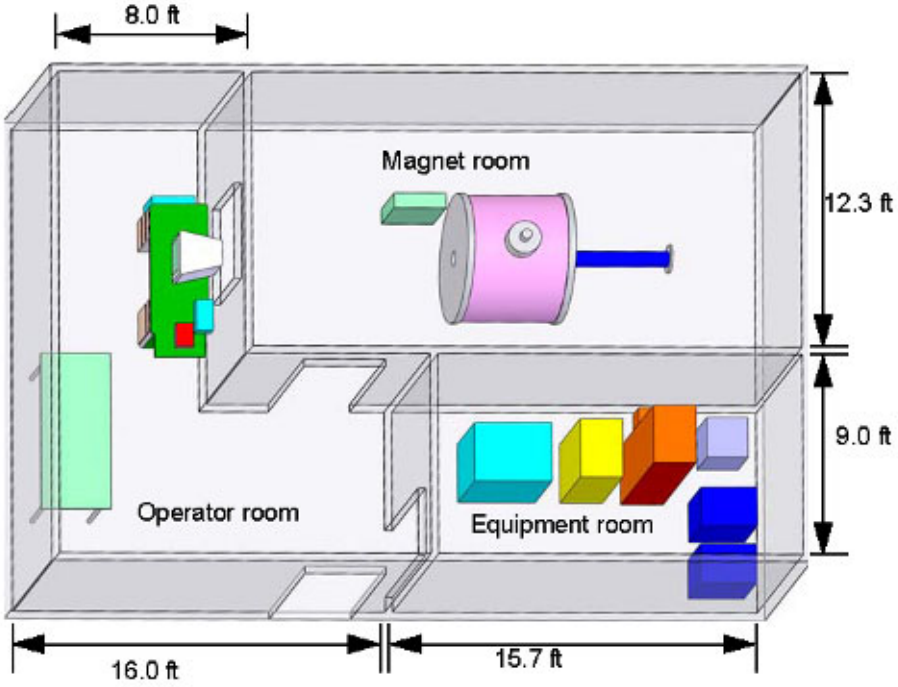


Figure 10 Room layout for a 9.4T 310 mm ASR system and a 7T 310 mm ASR system

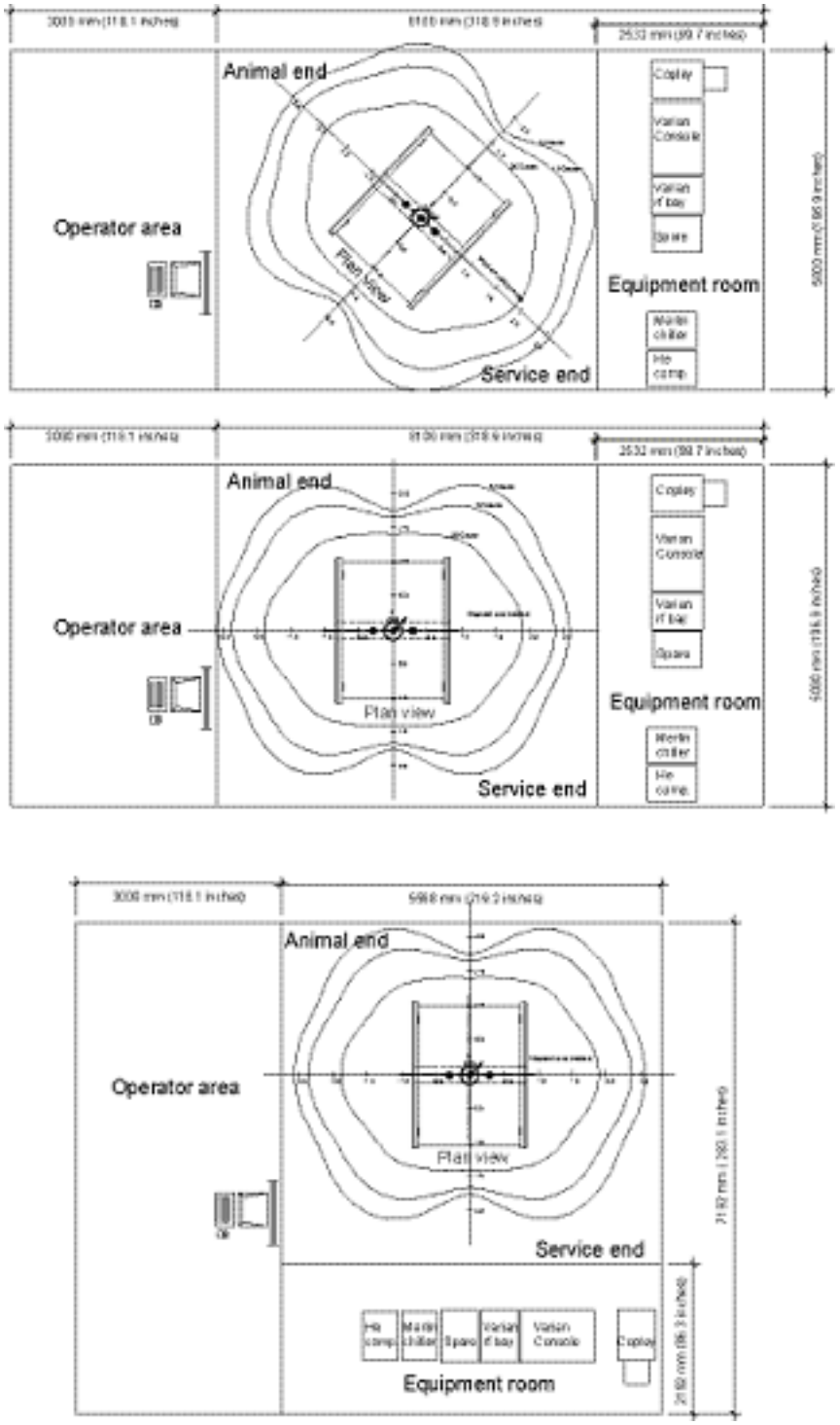
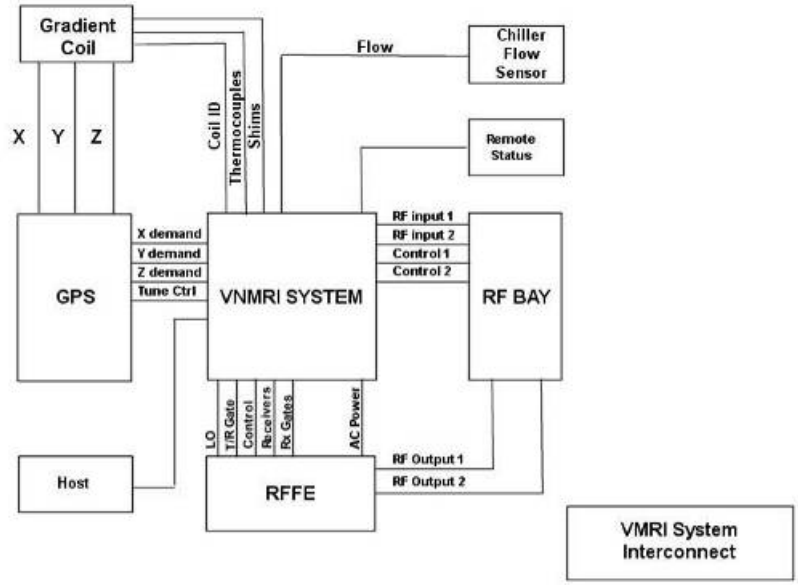
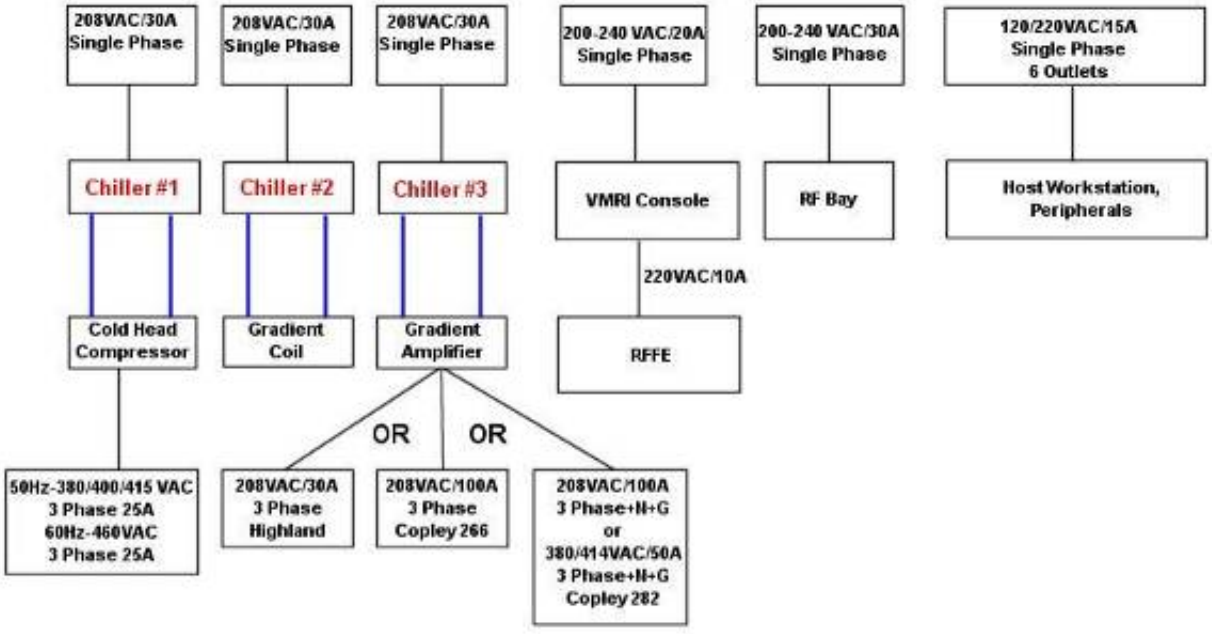


Figure 11 Typical room layouts for a 7T 310 mm ASR system

System Interconnect Diagrams





AC and Water Connection for VMRI System

7
Transporting Magnets

General Transportation 92
Moving the Magnet 93
Magnet Dimensions and Lifting Points 94

General Transportation

Agilent Technologies imaging magnets are shipped warm.

During all phases of transportation the shipper and on site riggers must adhere to the following requirements:

- Maximum random acceleration: 2.0 g
- Maximum vertical acceleration: 2.0 g
- Maximum inclination of the magnet in any direction: 30 degrees
- Do not slide (skid) the magnet along the floor
- Do not drop the magnet
- Use only air-ride trucks for land transport
- Do not transport via railroad

Moving the Magnet

Follow all requirements listed above and the following:

- Magnets that can be moved without the use of a crane must be supported by skates placed directly beneath each magnet foot - refer to Figure 1 on page 32.
- Inclines are limited to 30 degrees of magnet inclination.
- Maximum surface deflection of 0.1 inch (0.25 cm).

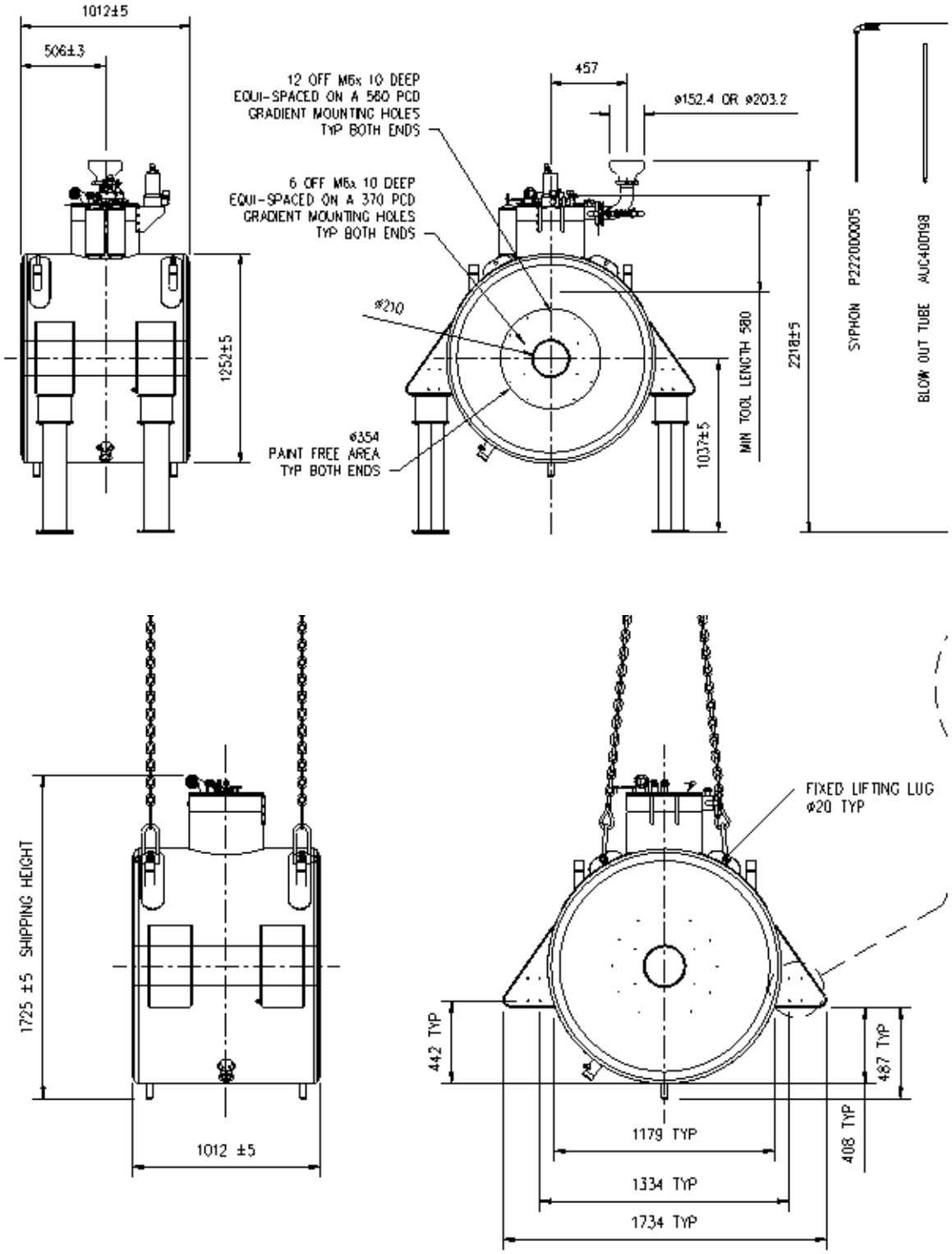
Magnet Dimensions and Lifting Points

Follow all requirements listed above and the following:

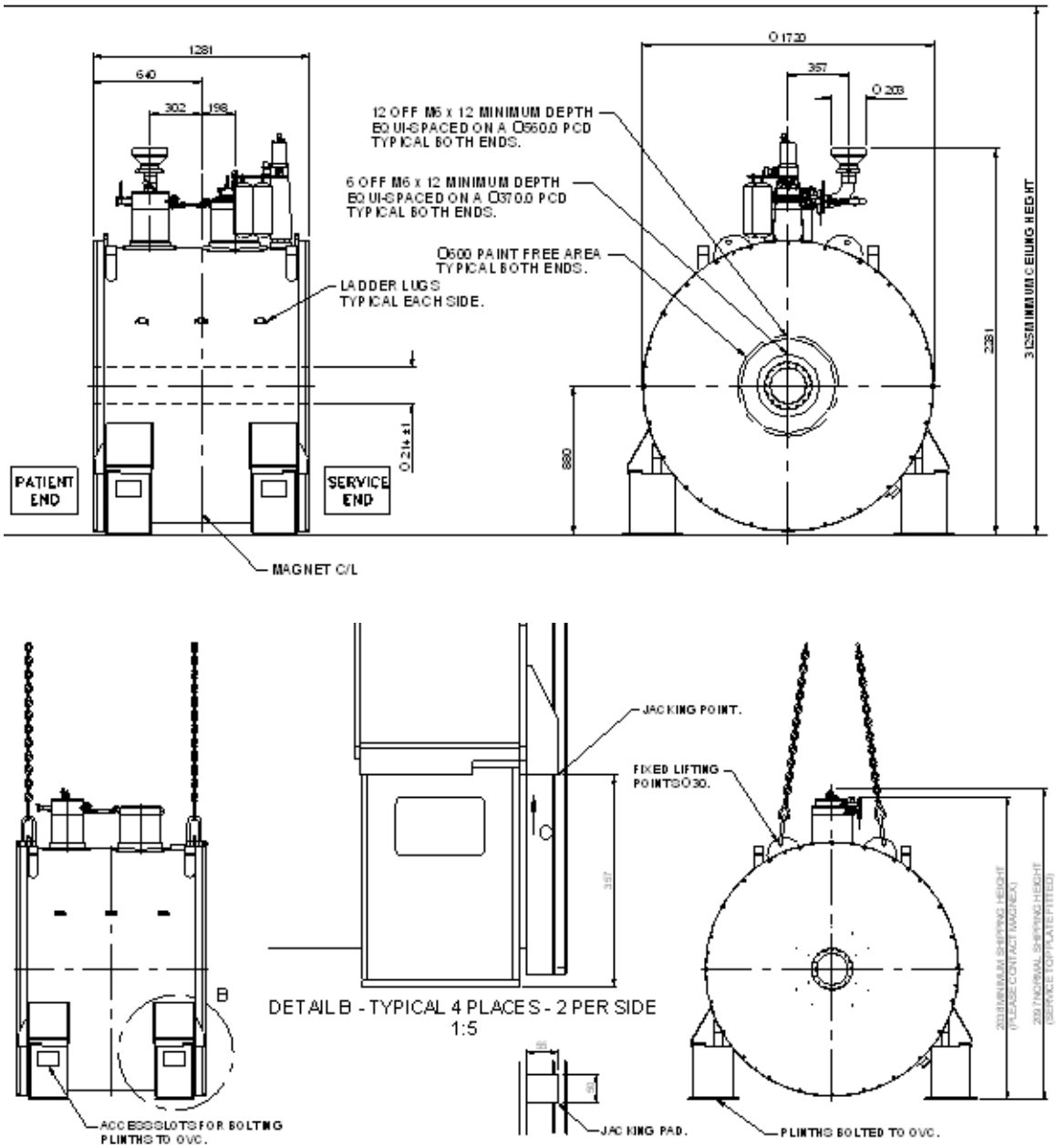
- All magnets are supplied with either lifting plates and jacking brackets or integral eyes and jacking points for lifting and locating the magnet. Do not attempt to lift or move the magnet by attachment or placement of lifting devices in any other location. The lifting points for most magnets are shown in the illustrations.
- Do not drop the magnet or strike any objects while lifting or lowering the magnet.
- Lifting using a crane or hoist, attach lift chains to lift holes.
- Weight of magnet, refer to Table 1.

All dimensions are in millimeters unless otherwise specified.

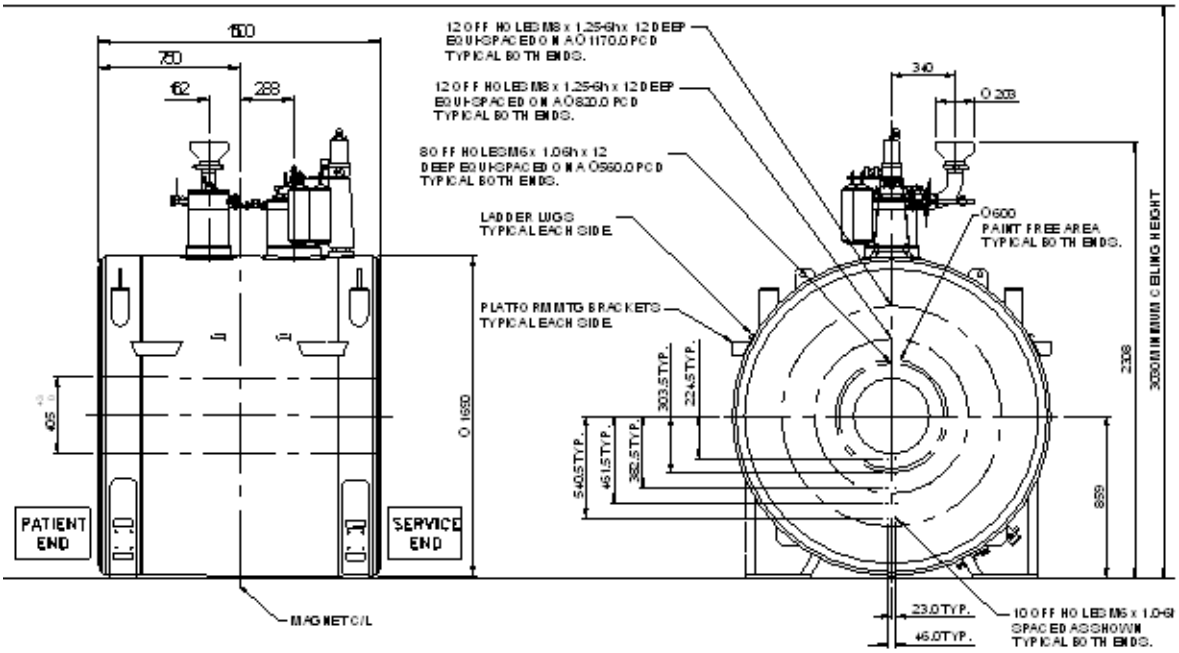
4.7T 210 mm ASR

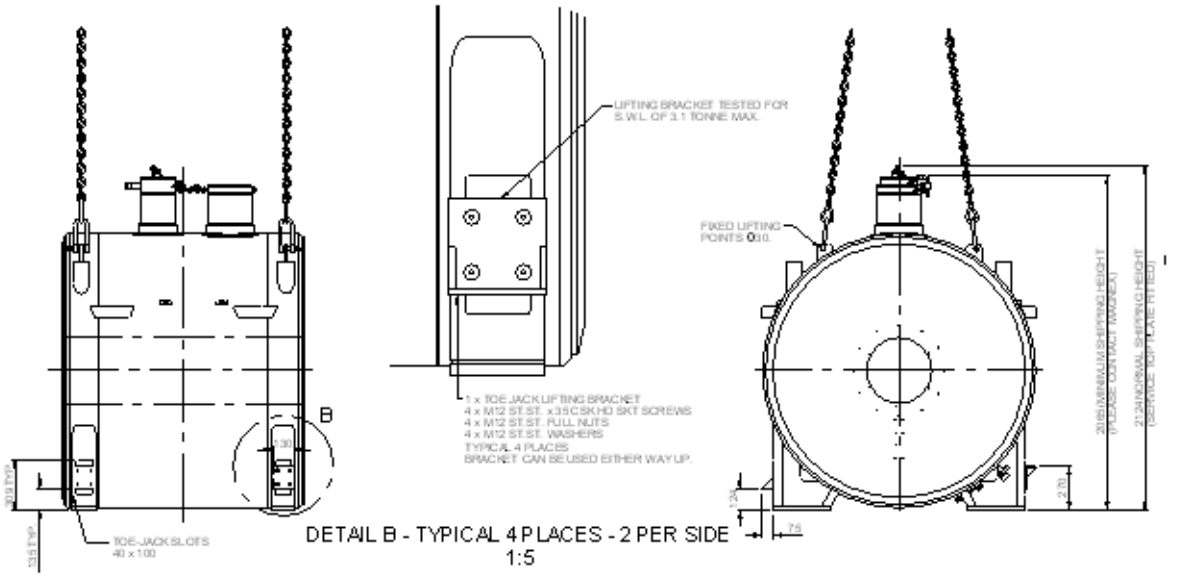


4.7T 310 mm ASR

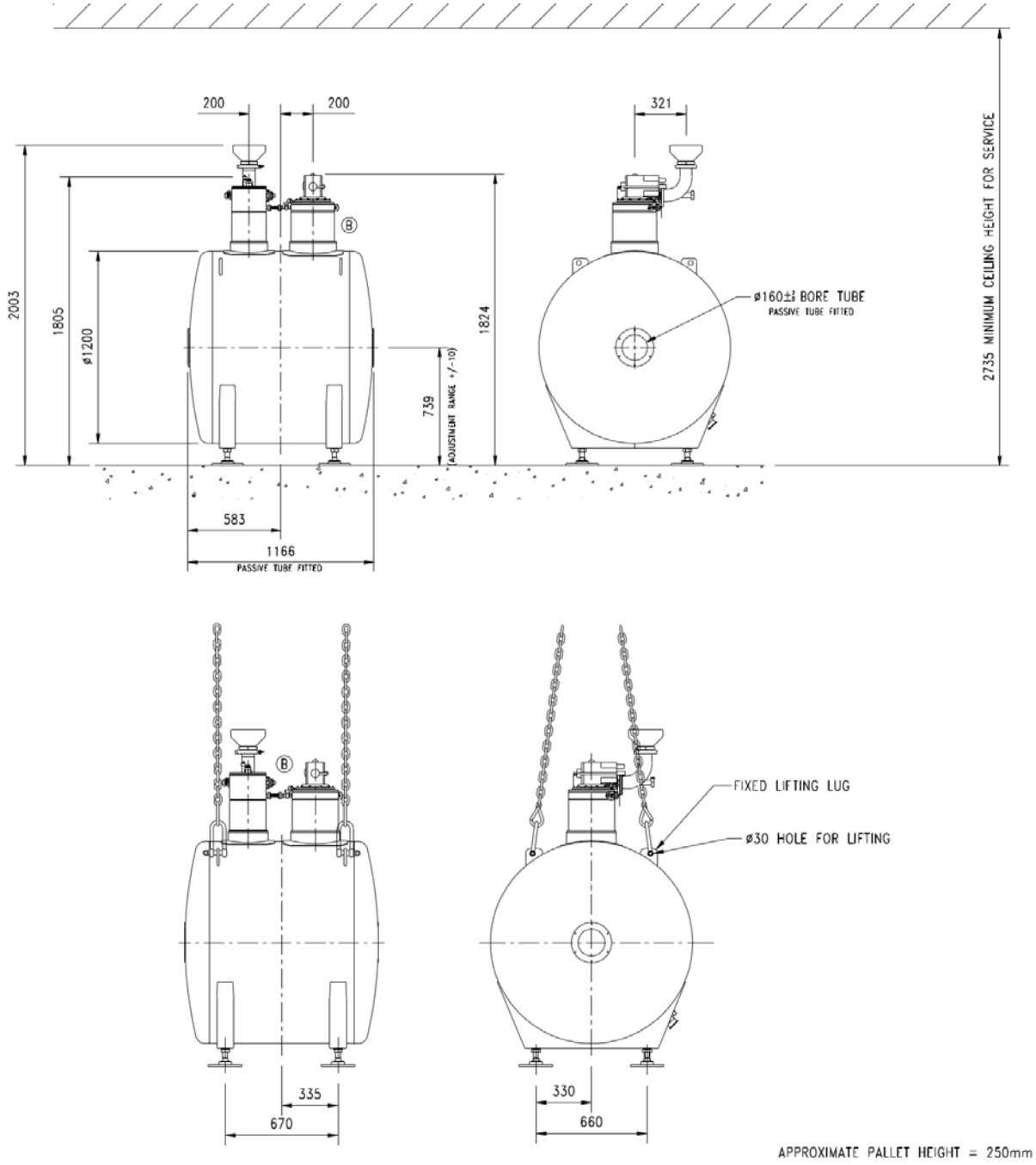


4.7T 400 mm ASR

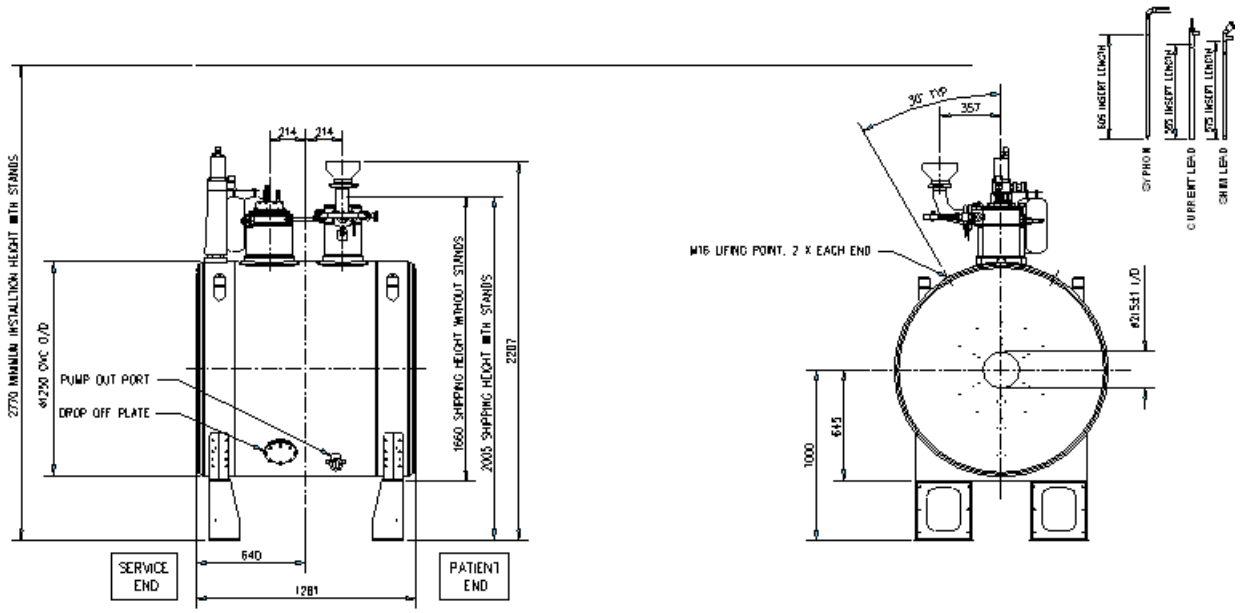




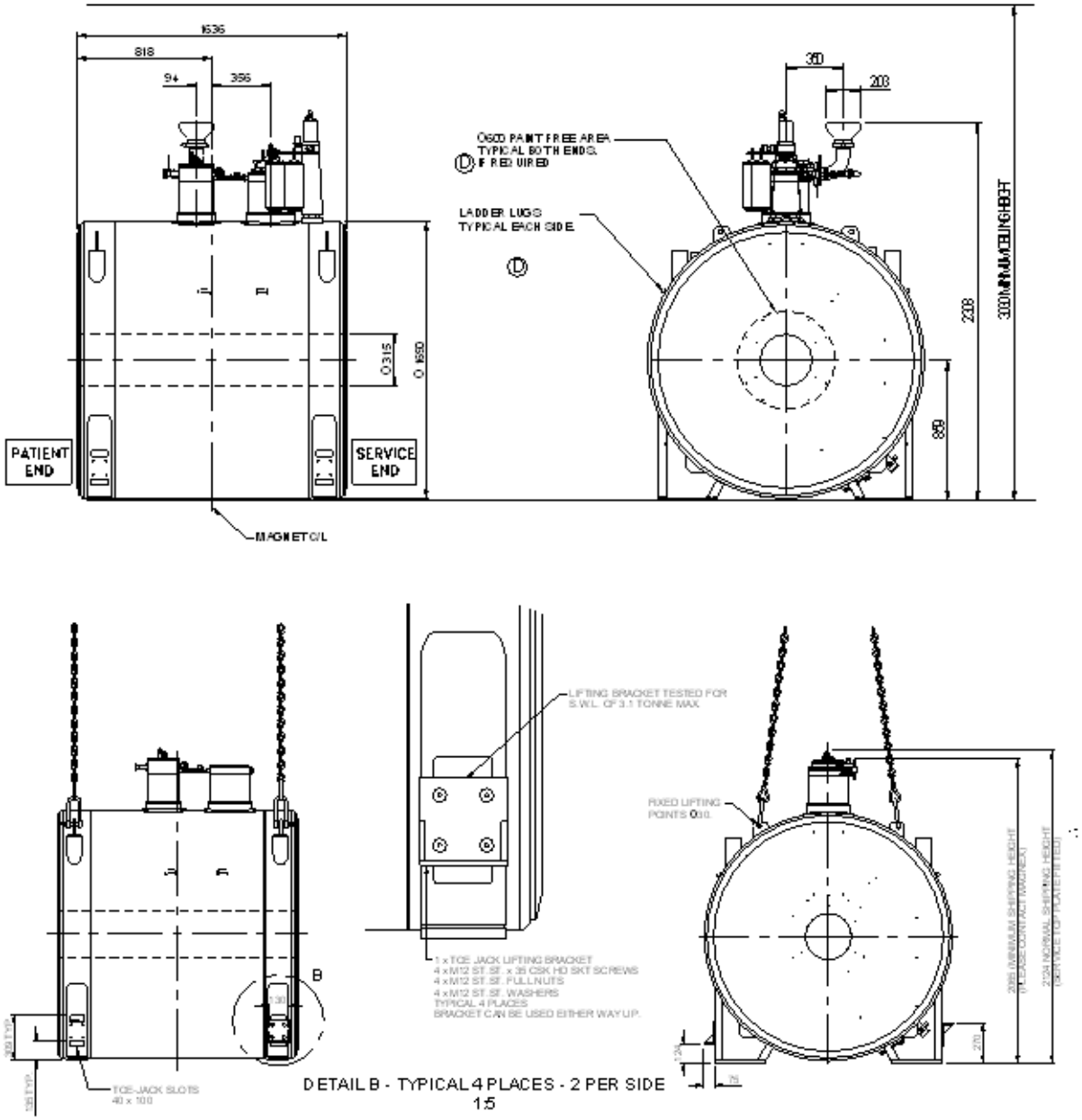
7.0T 160 mm ASR



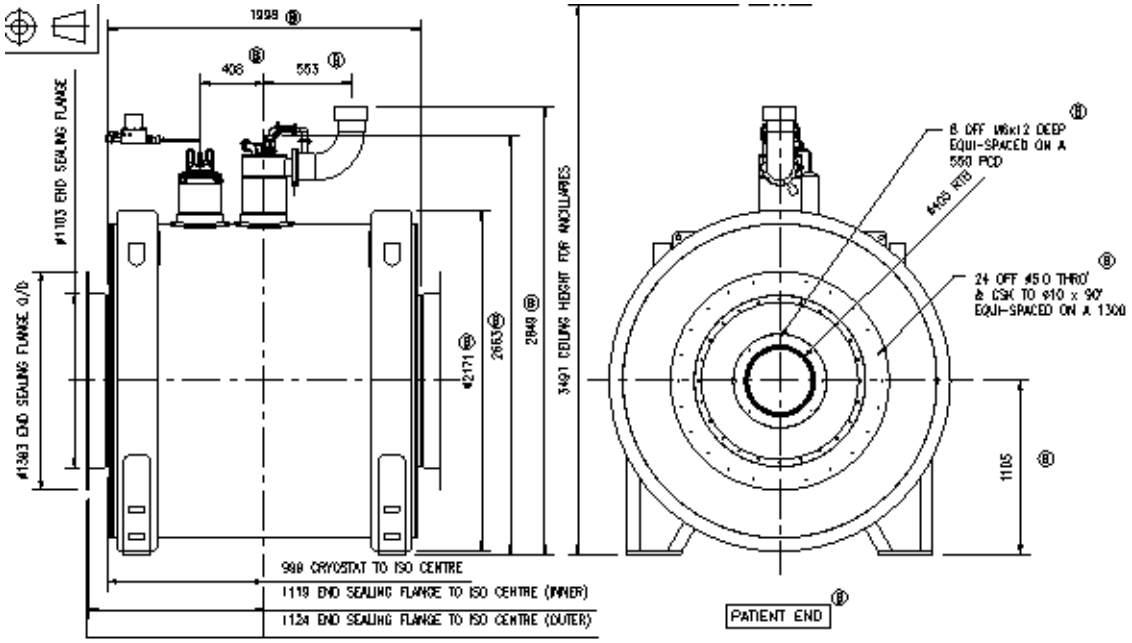
7.0T 210 mm ASR

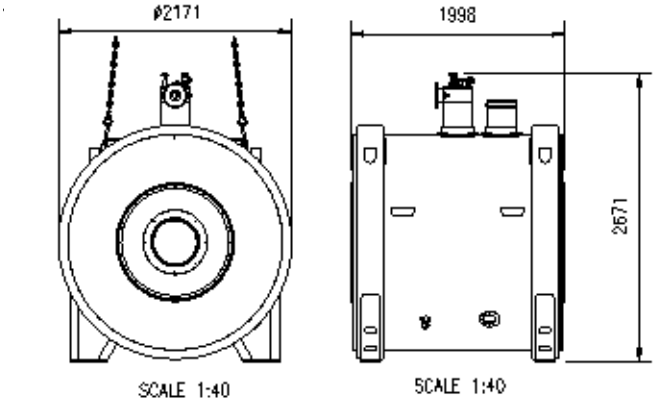


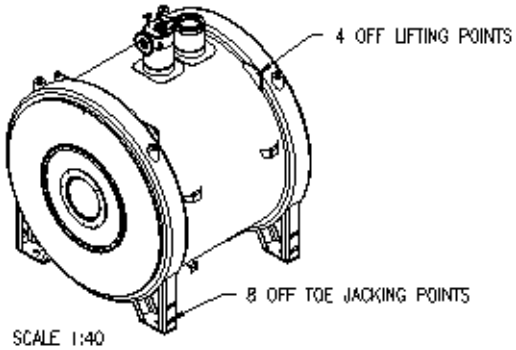
7.0T 310 mm ASR



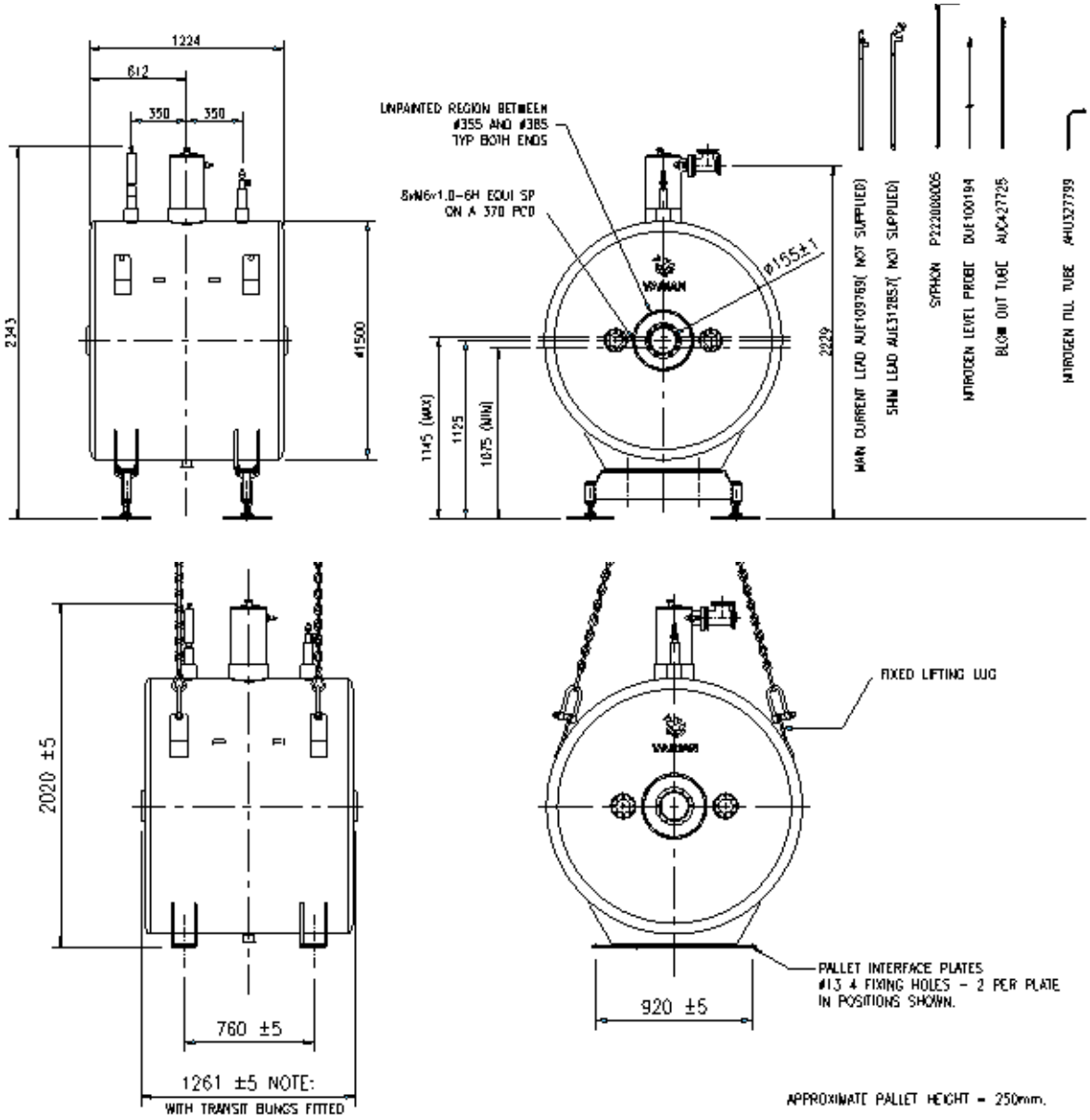
7.0T 400 mm ASR



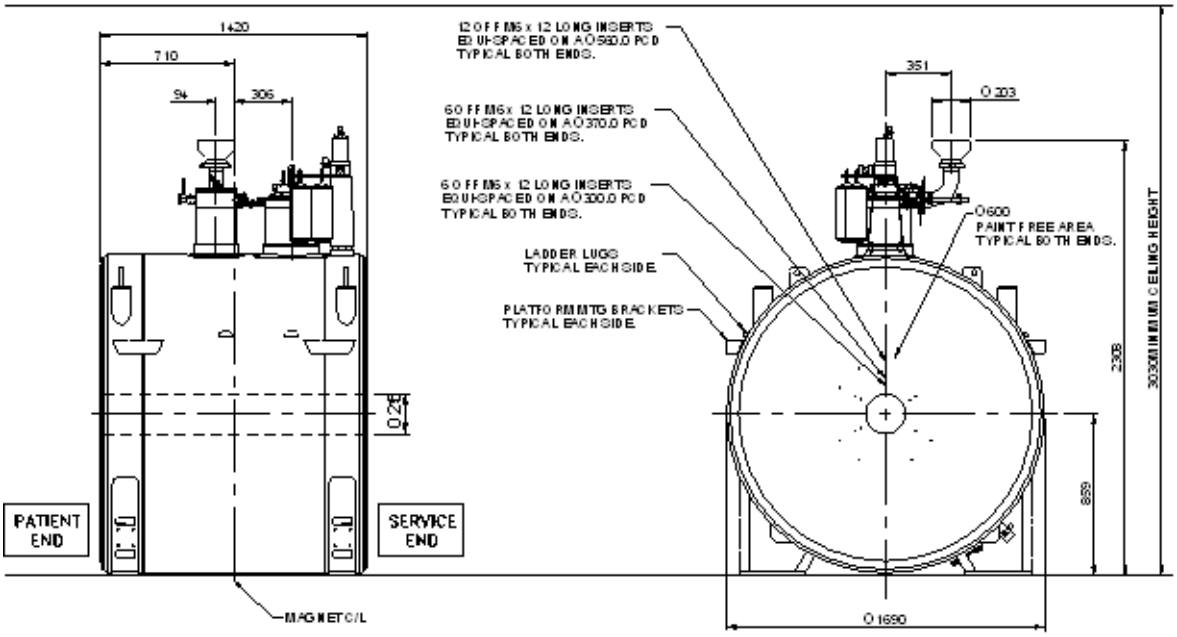


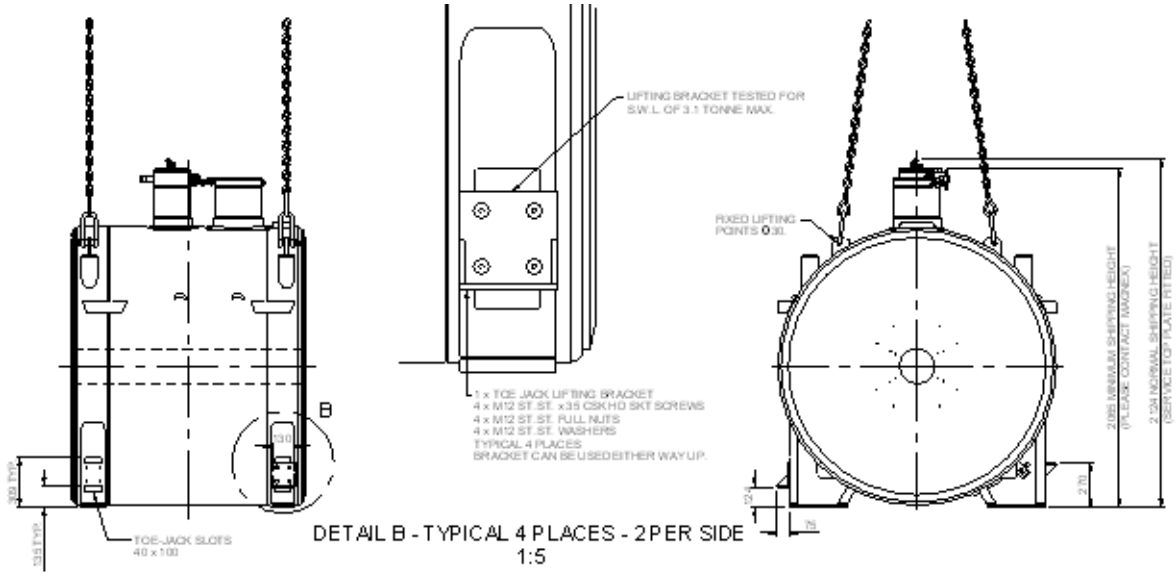


9.4T 160 mm AS


1224
612
350
350
2343
Ø1500
UNPAINTED REGION BETWEEN
Ø355 AND Ø385
TYP BOTH ENDS
8xM6x1.0-6H EQUI SP
ON A 370 PCD
Ø165±1
1145 (MAX)
1125
1075 (MIN)
2229
MAIN CURRENT LEAD AUE1093769(NOT SUPPLIED)
SHIM LEAD AUE3128577(NOT SUPPLIED)
SYPHON P2220080005
NITROGEN LEVEL PROBE DUE100194
BLOW OUT TUBE AUC427725
NITROGEN FILL TUBE AHU527799
2020 ±5
760 ±5
1261 ±5 NOTE:
WITH TRANSIT BUNGS FITTED
FIXED LIFTING LUG
920 ±5
PALLET INTERFACE PLATES
Ø13.4 FIXING HOLES - 2 PER PLATE
IN POSITIONS SHOWN.
APPROXIMATE PALLET HEIGHT = 250mm.

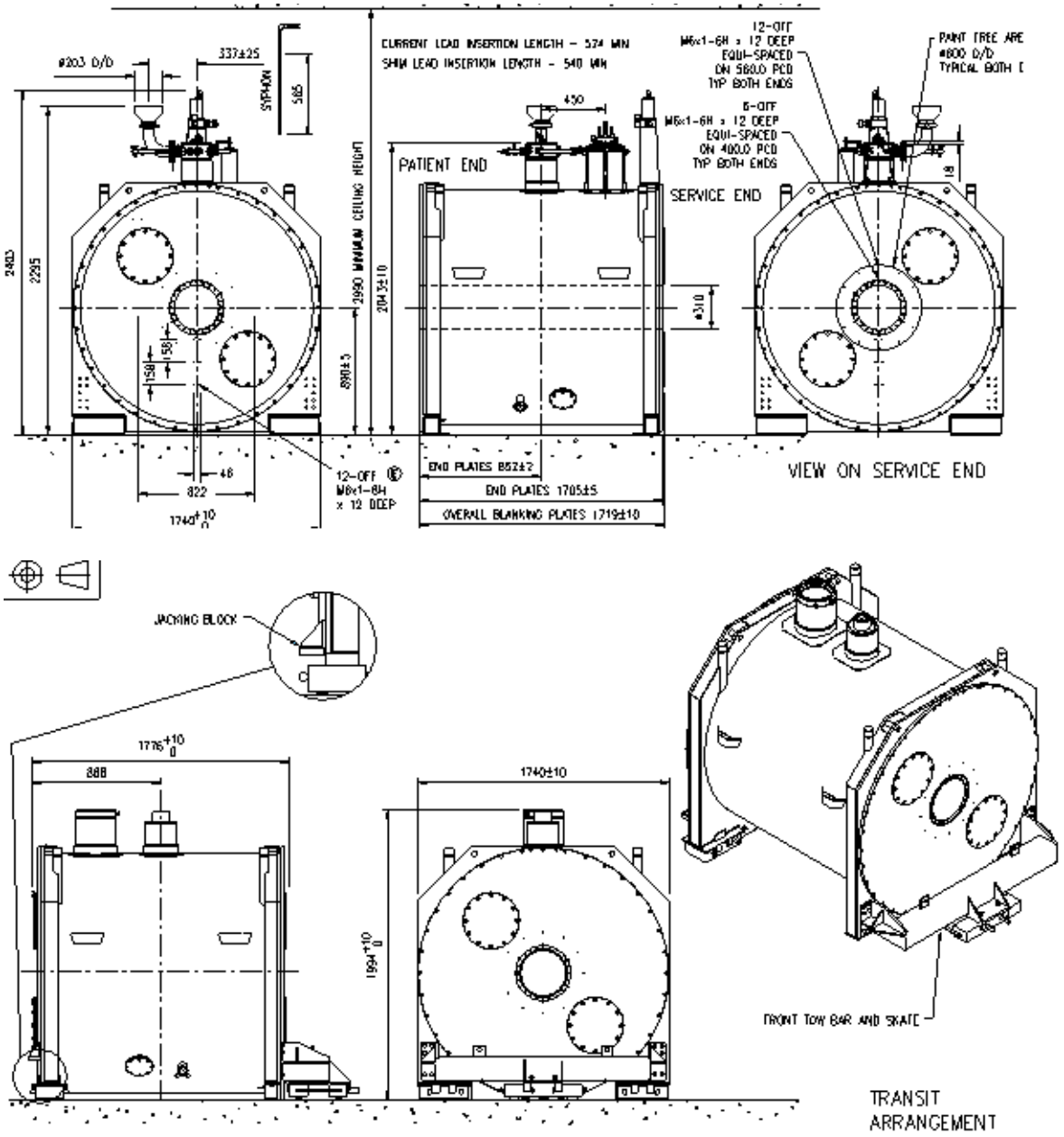
9.4T 210 mm AS



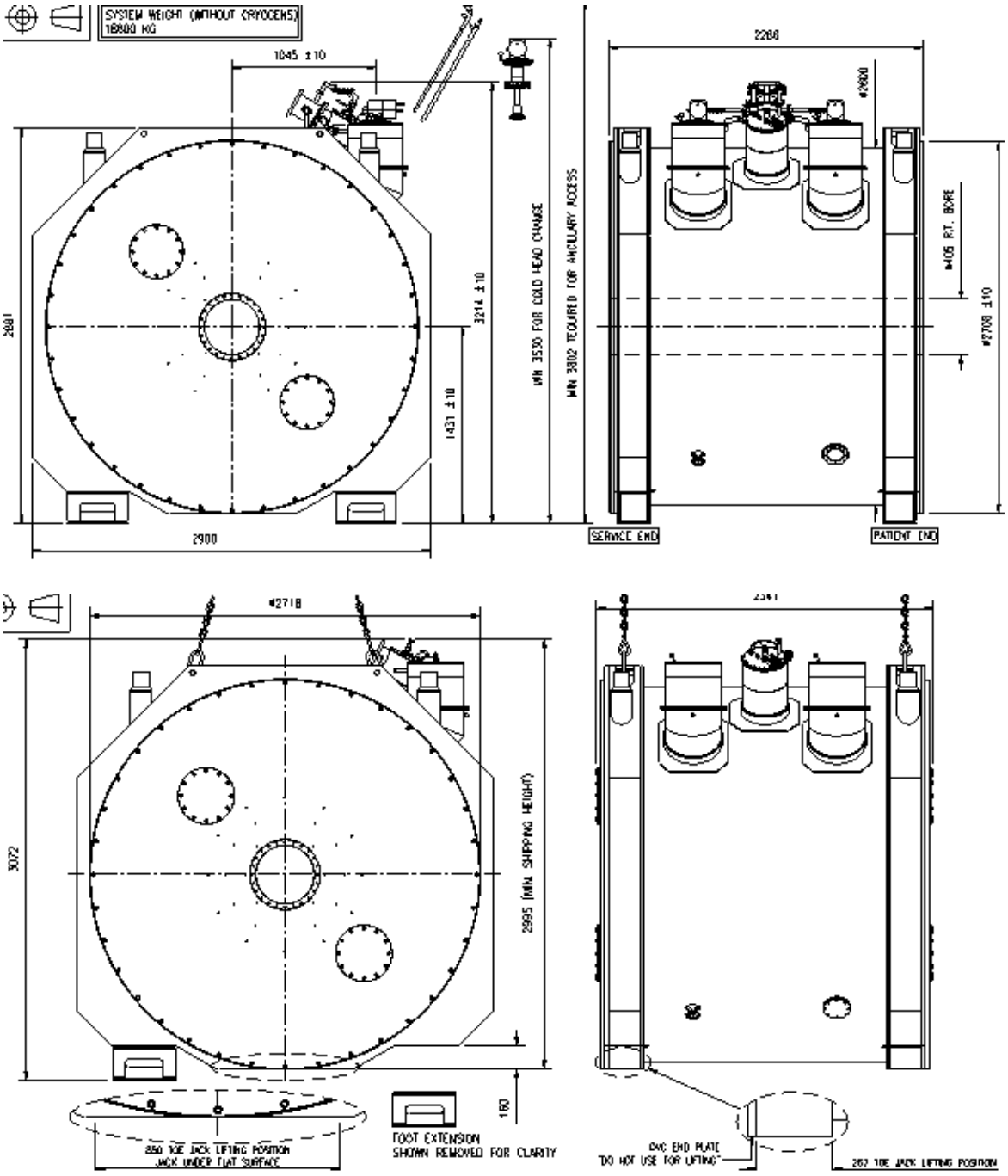


DETAIL B - TYPICAL 4 PLACES - 2 PER SIDE
1:5

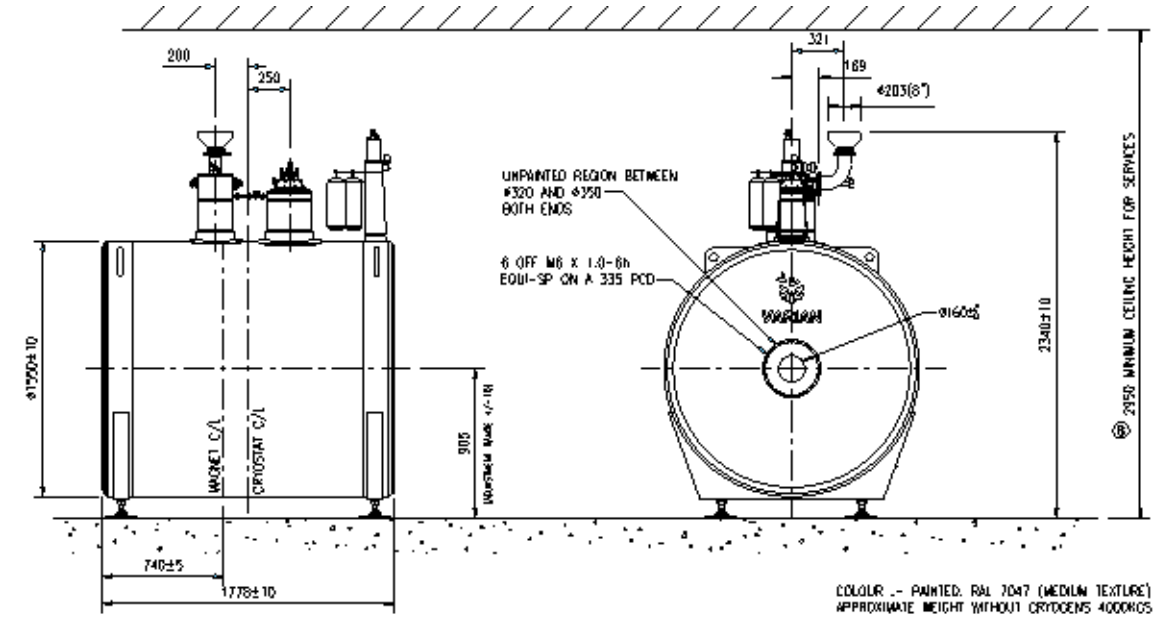
9.4T 310 mm ASR

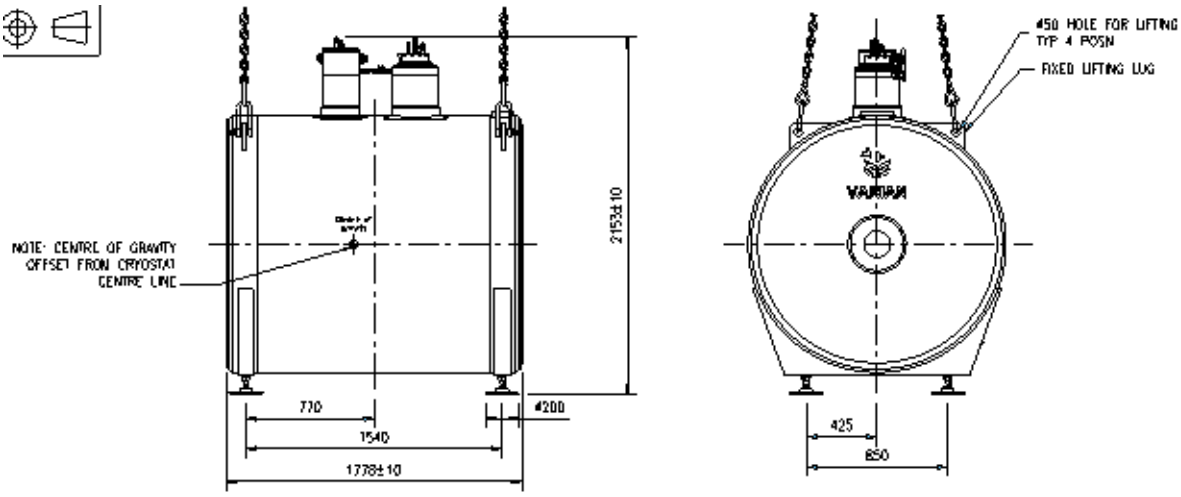


9.4T 400 mm ASR

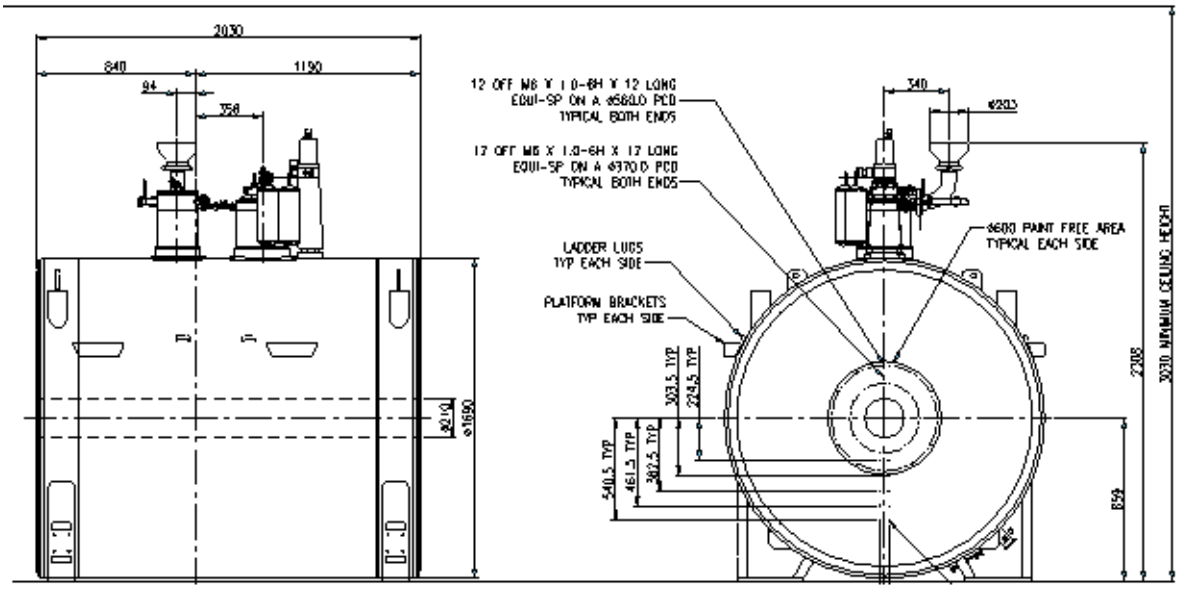


11.7T 160 mm ASR

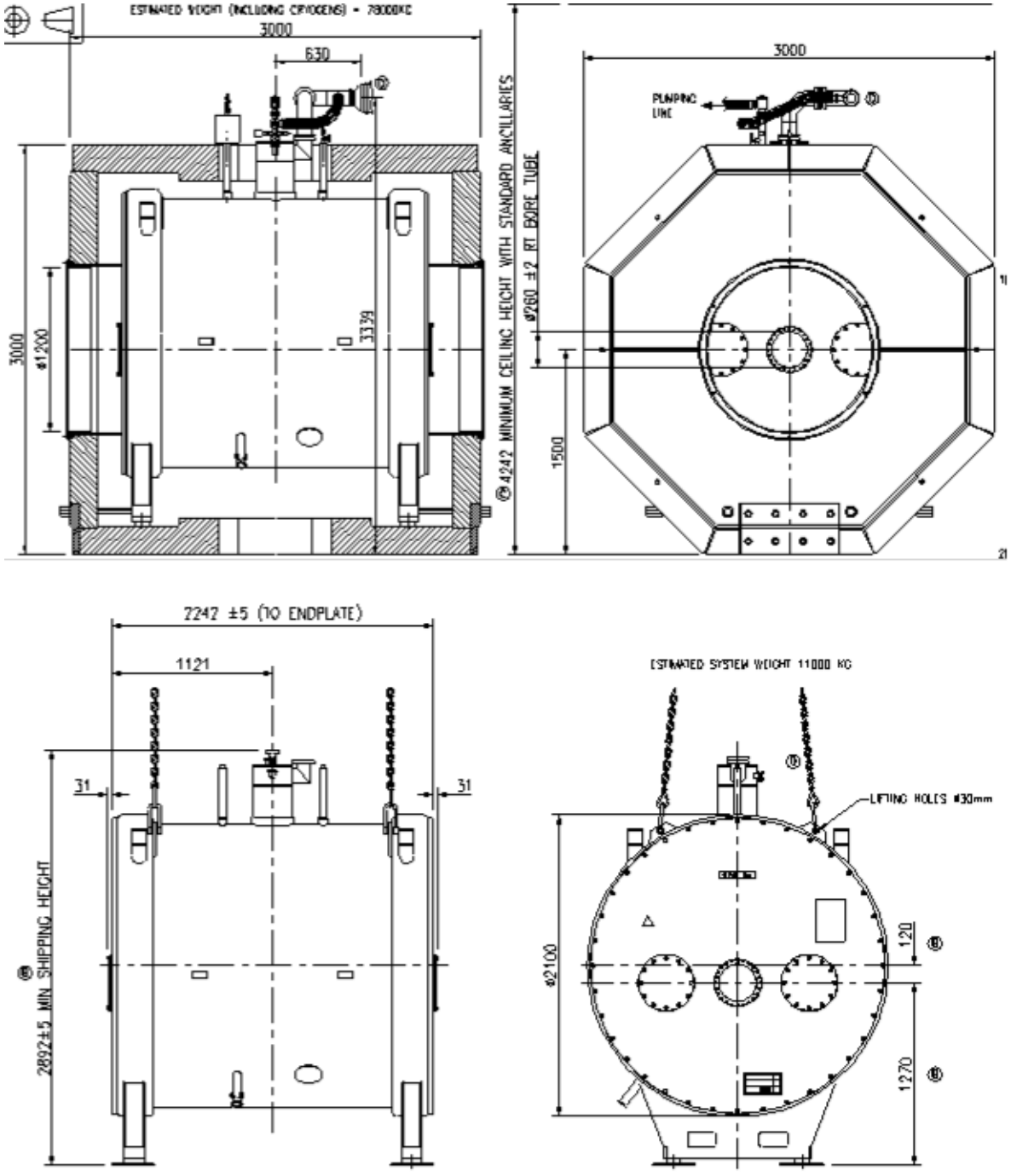




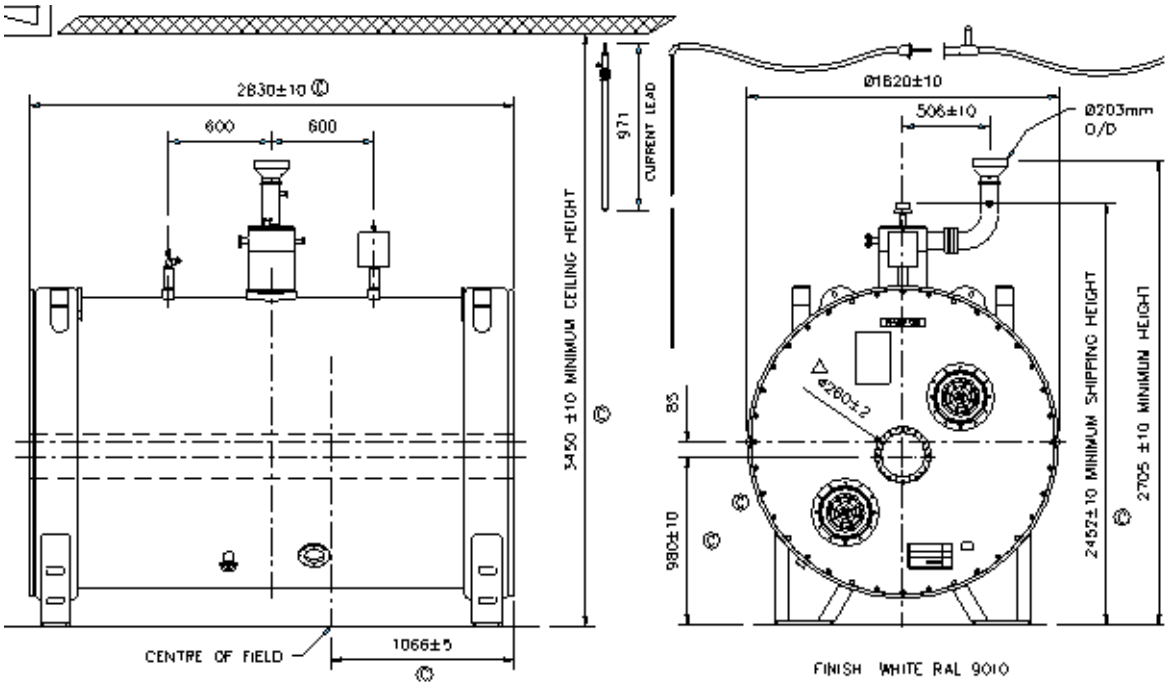
11.7T 210 mm ASR



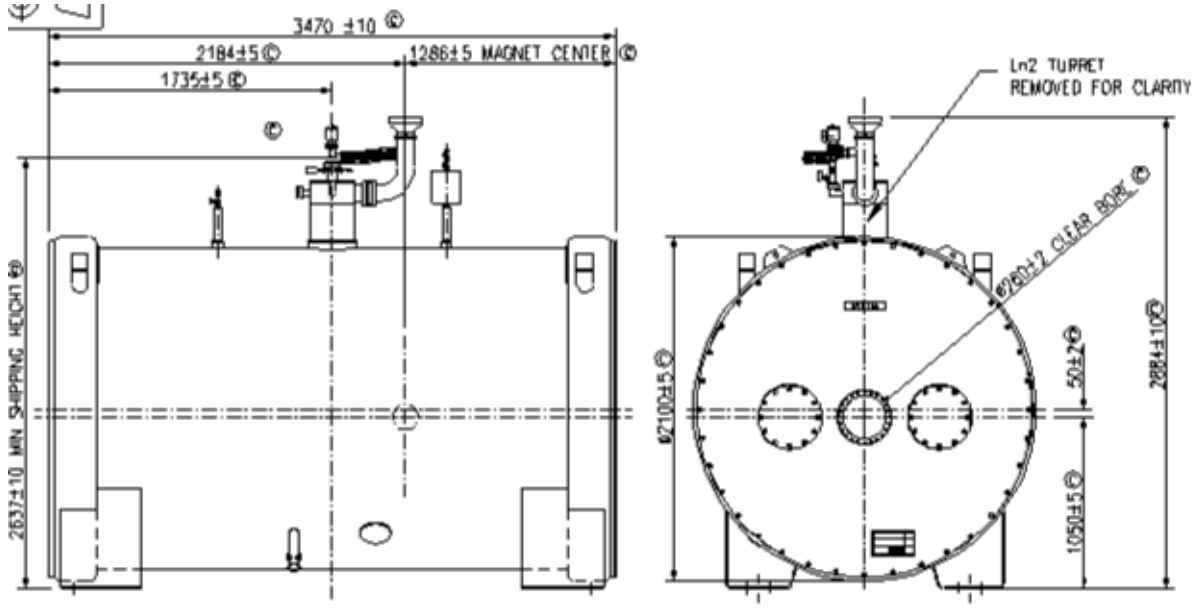
11.7T 260 mm with close coupled iron shield



14.1T 260 mm



16.4T 260 mm



7 Transporting Magnets

8
Stray Field Plots

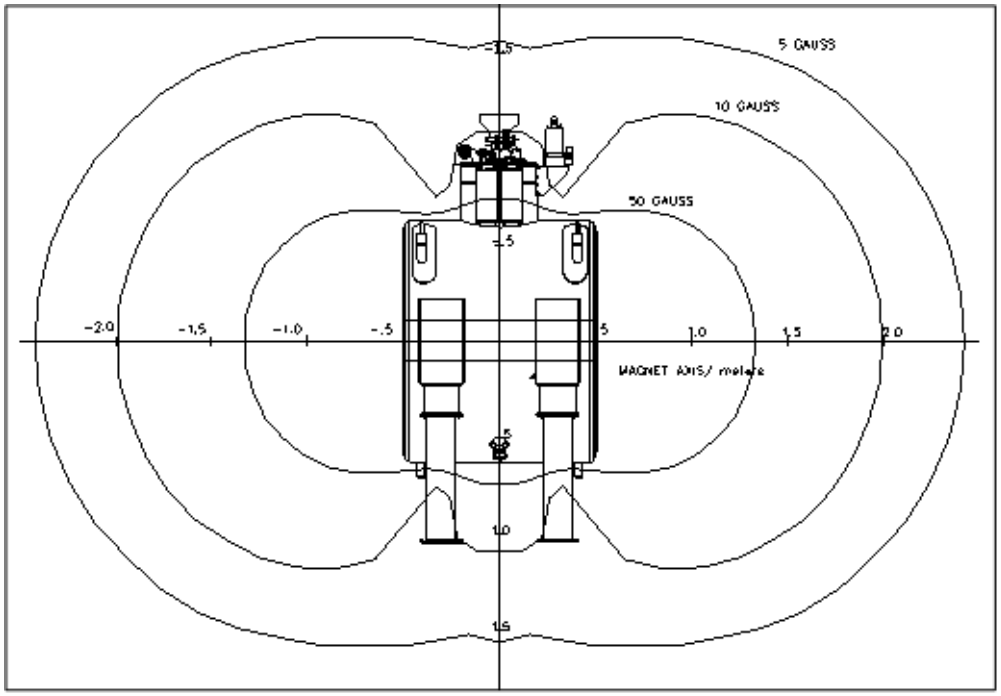
Actively Shielded Magnets 112
Magnets with Close Coupled Iron Shields 119

The illustrations in this chapter show stray field plots for each magnet system. The axial and radial distances shown are measured in meters or centimeters from the center of the magnetic field. For most imaging magnets the magnetic field center coincides with the center of the bore. Structural steel, reinforcing bar, and other ferromagnetic material will alter the stray field contours from the data provided. The stray field plots provided in this guide do not account for the affect of ferrous materials near the magnet. Magnetic field levels should be checked after a particular magnet has been installed.

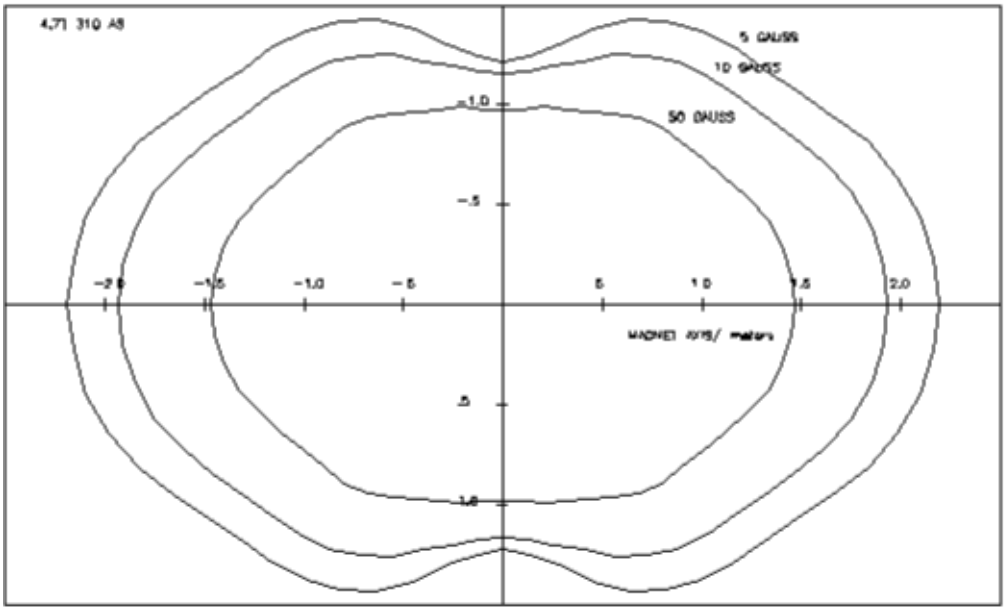
The unshielded fringe fields for larger magnets such as the 14.1T 260 mm are not shown, as the fringe field on site will depend on the type of room shield used.

Actively Shielded Magnets

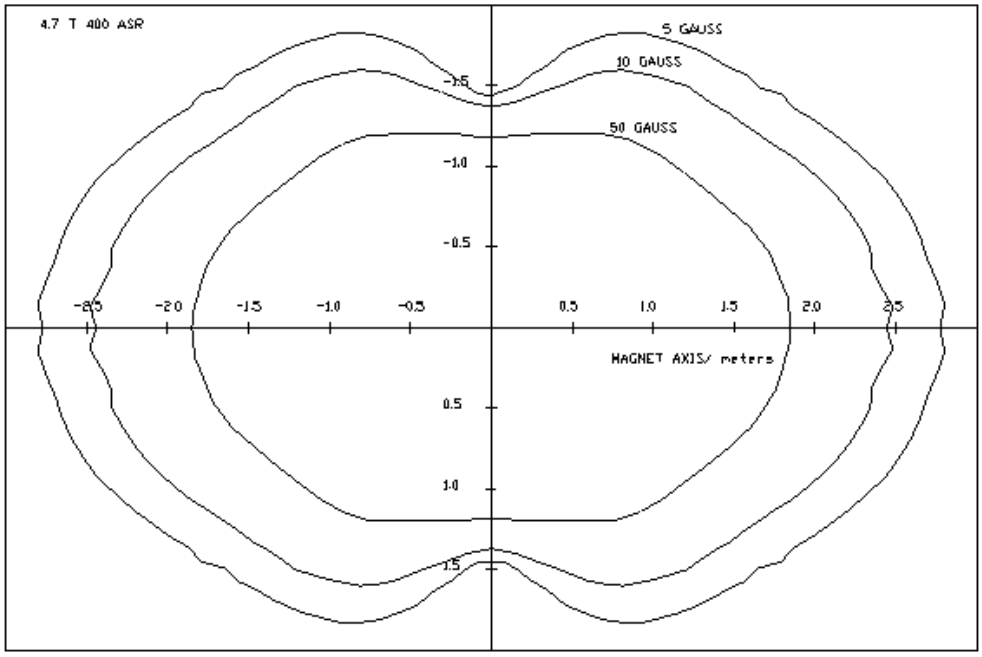
4.7T 210 mm ASR



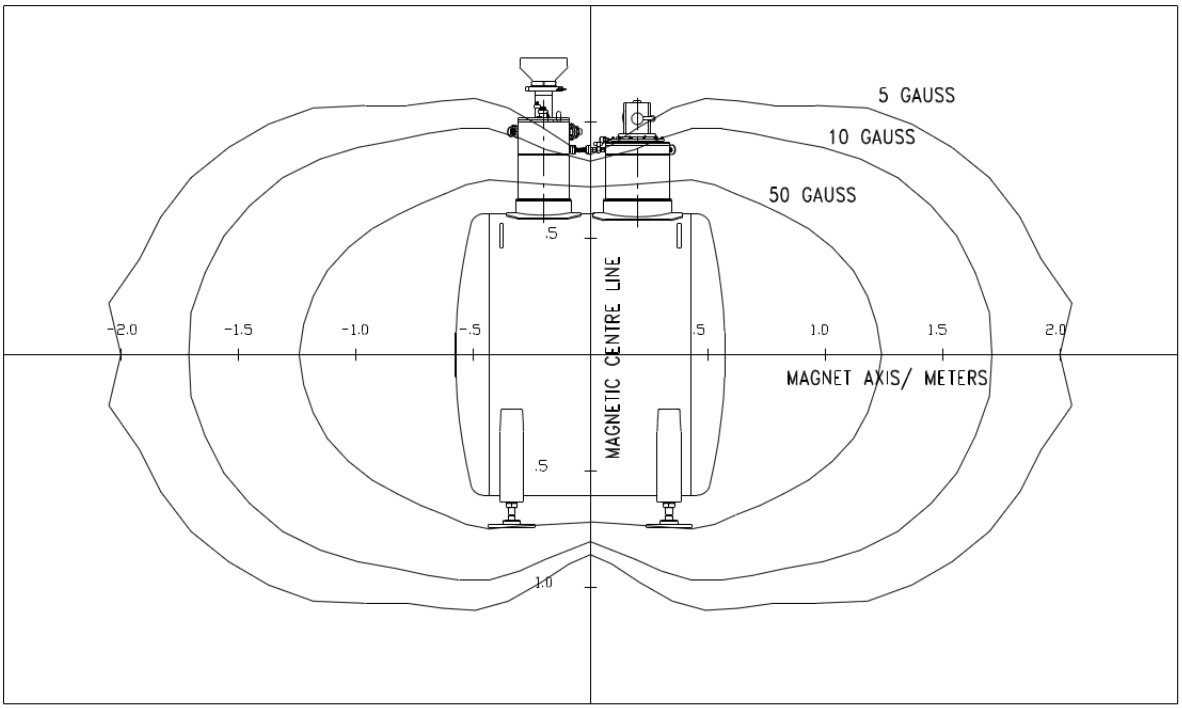
4.7T 310 mm ASR



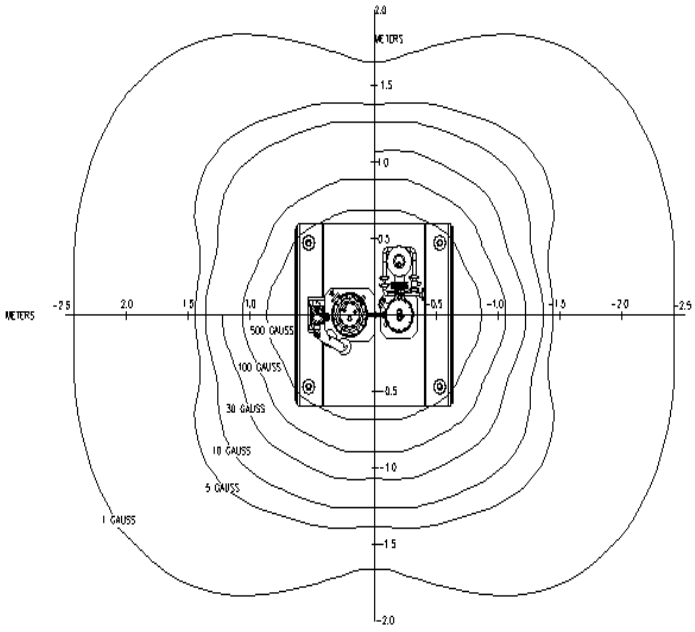
4.7T 400 mm ASR



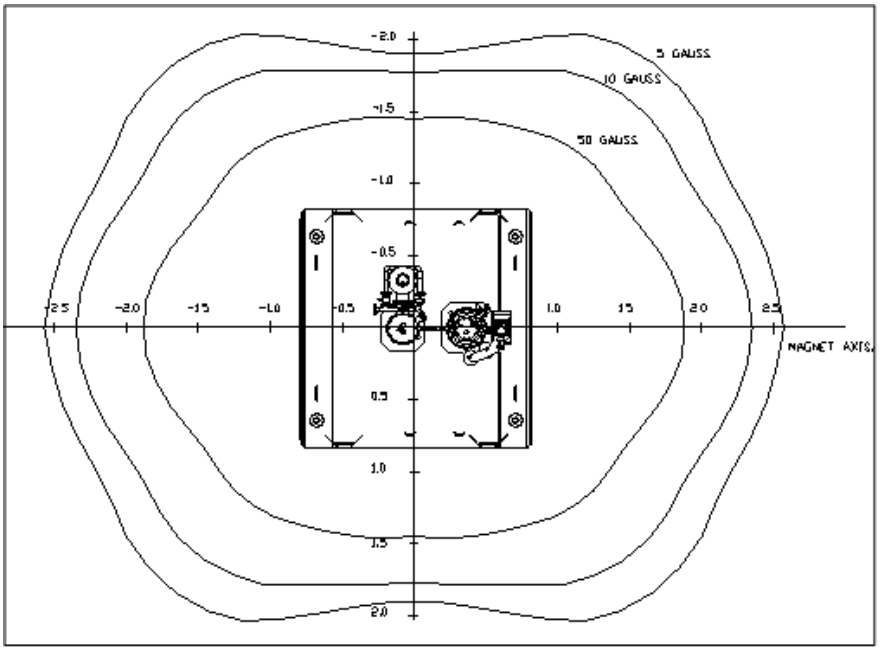
7.0T 160 mm ASR



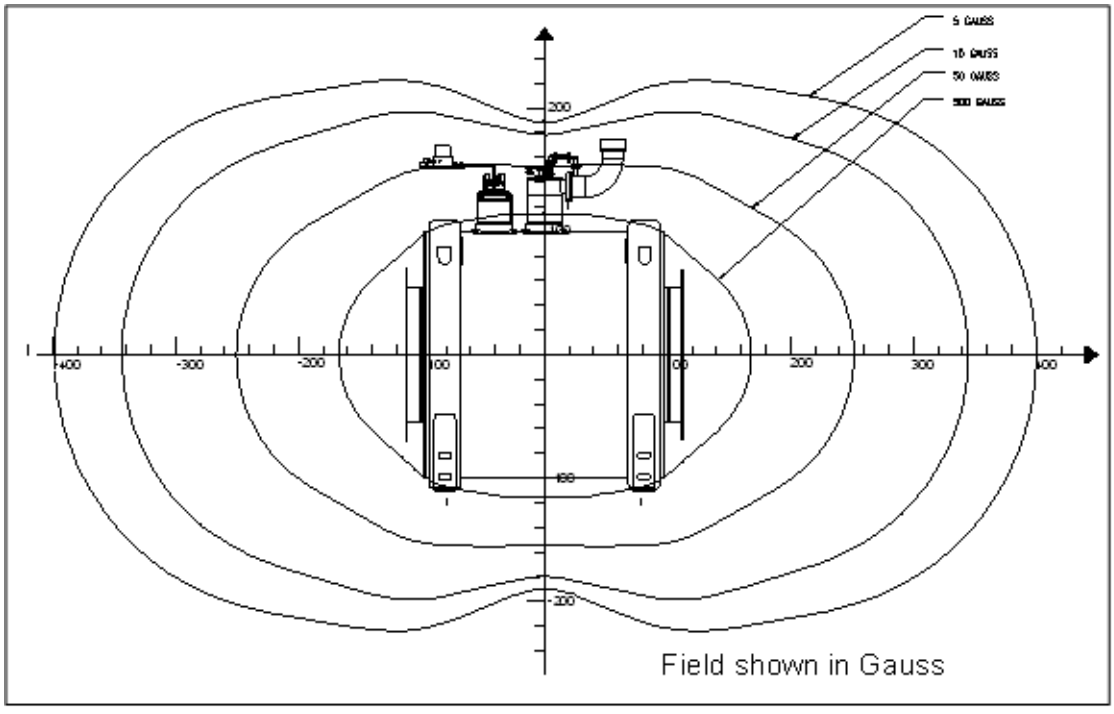
7.0T 210 mm ASR



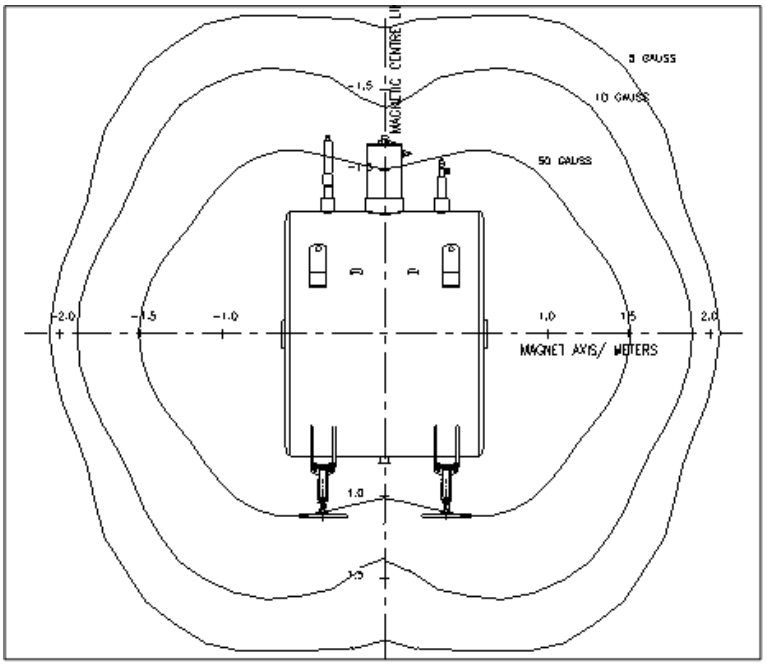
7.0T 310 mm ASR



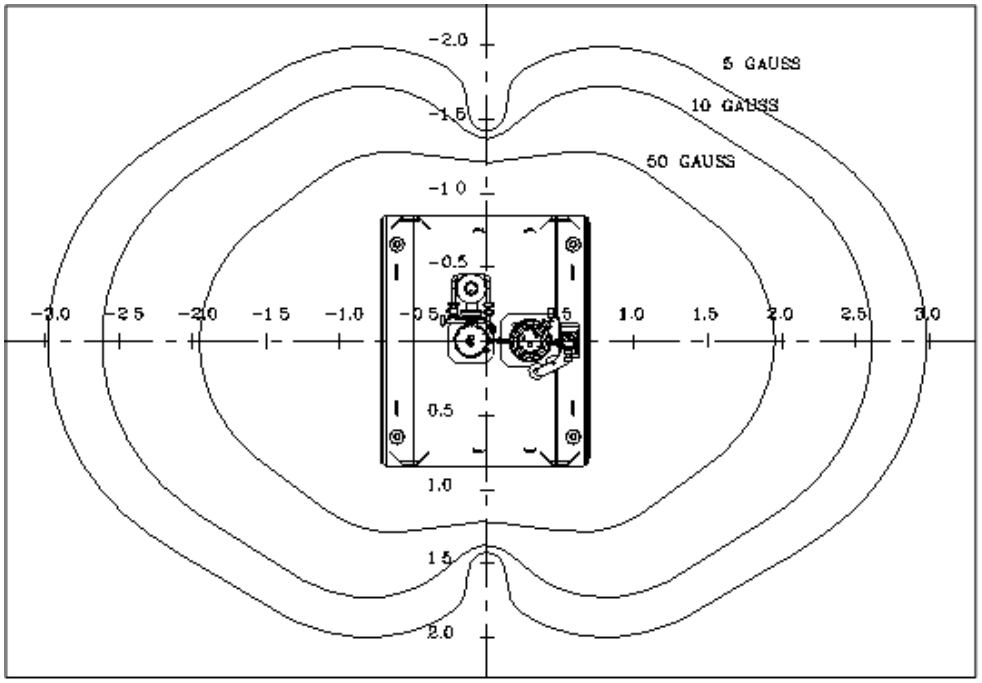
7.0T 400 mm ASR



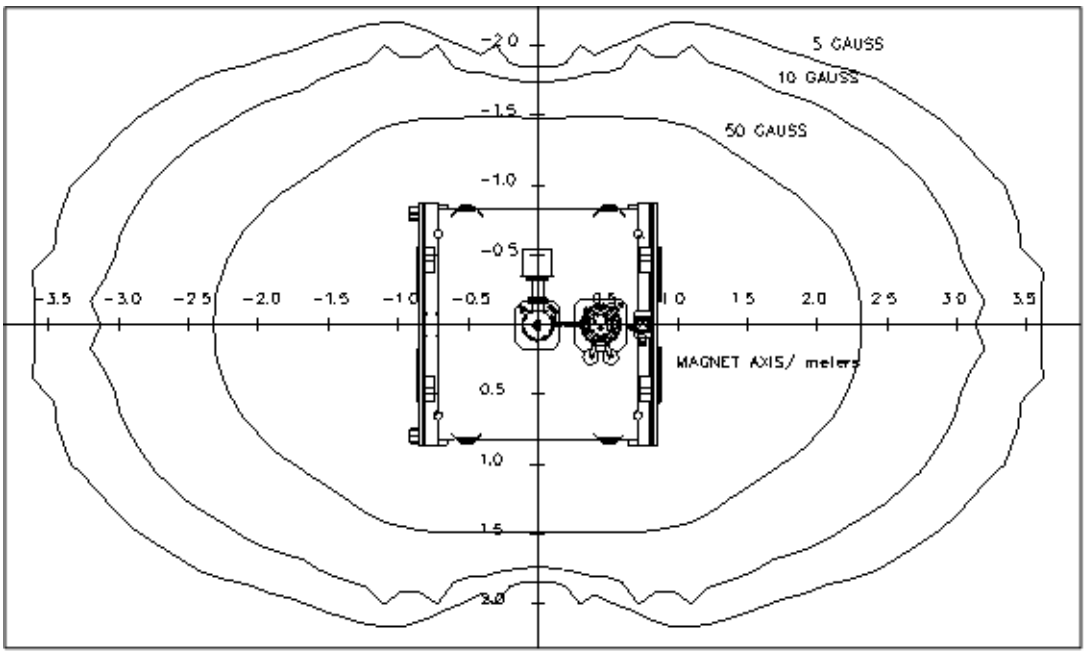
9.4T 160 mm AS



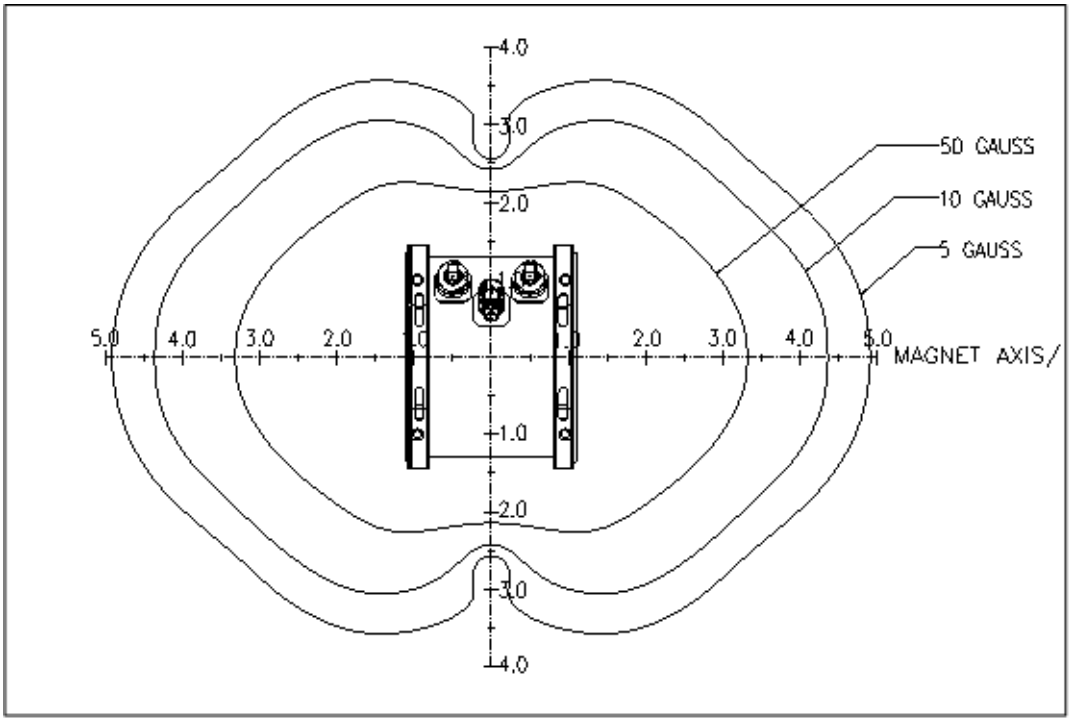
9.4T 210 mm ASR



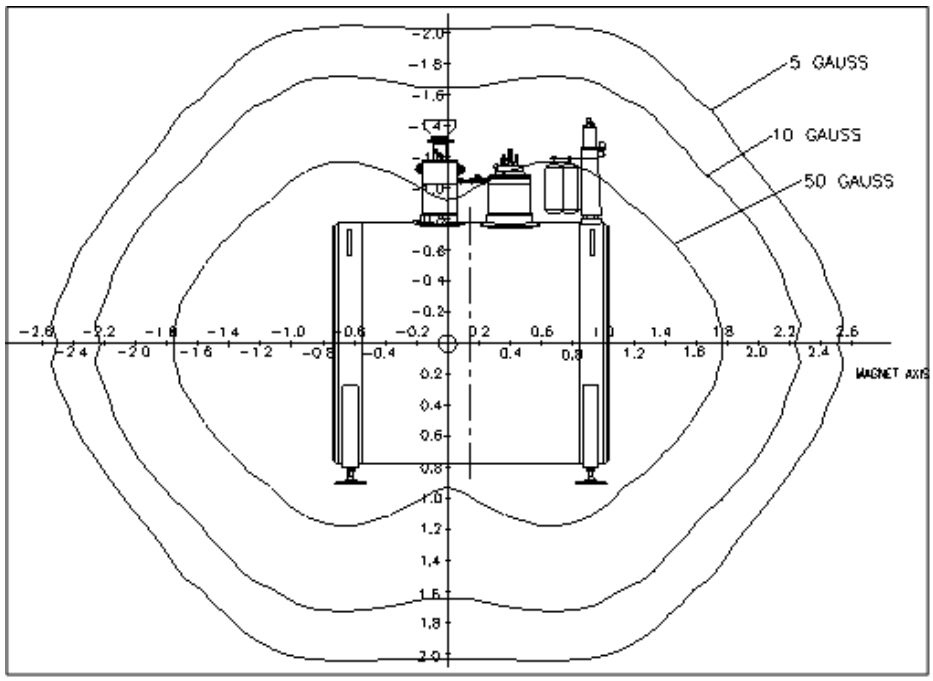
9.4T 310 mm ASR



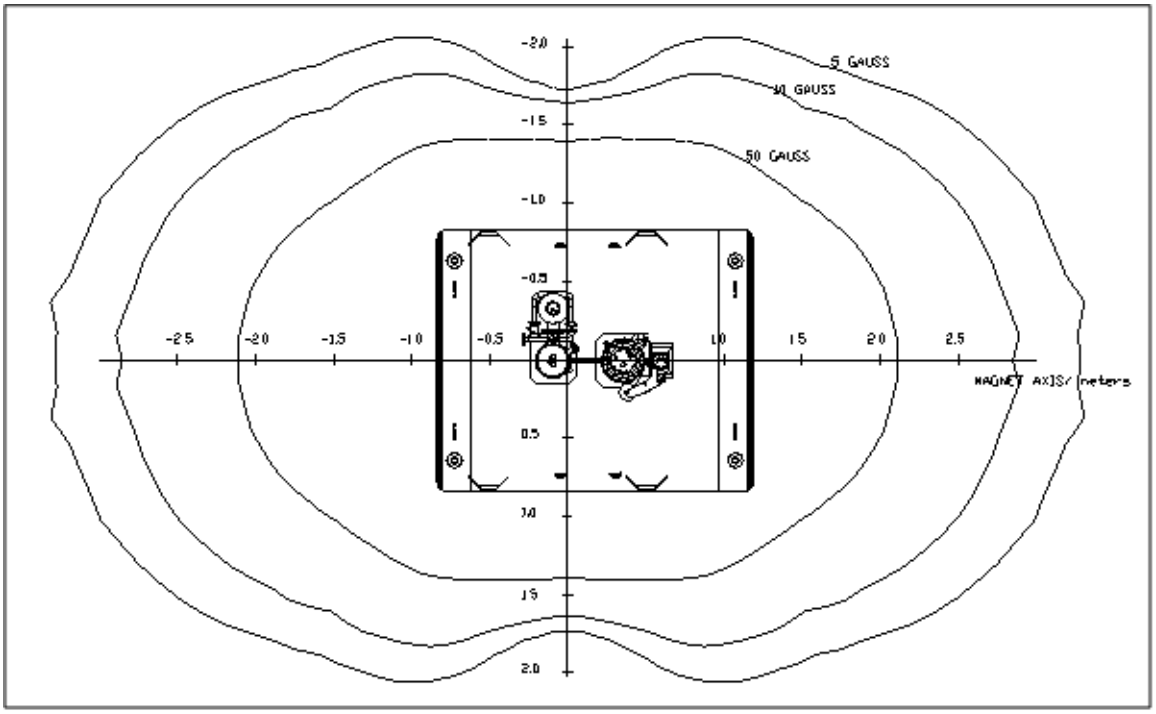
9.4T 400 mm ASR



11.7T 160 mm ASR

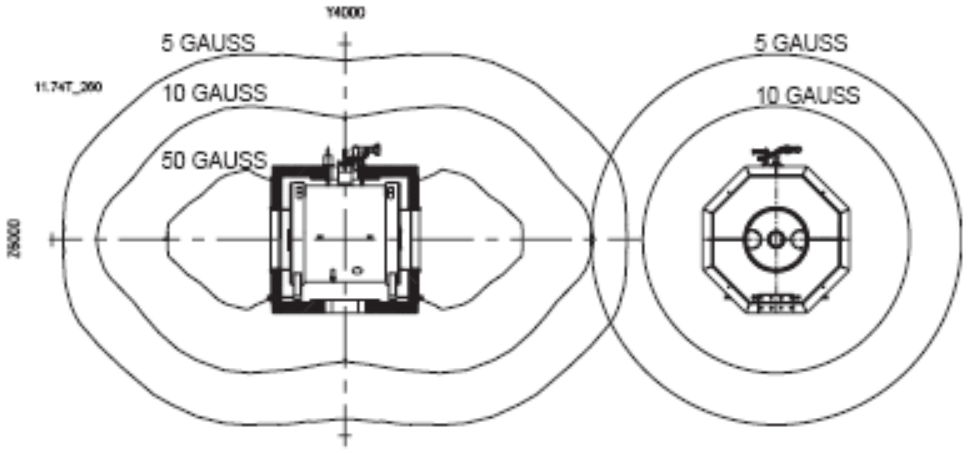


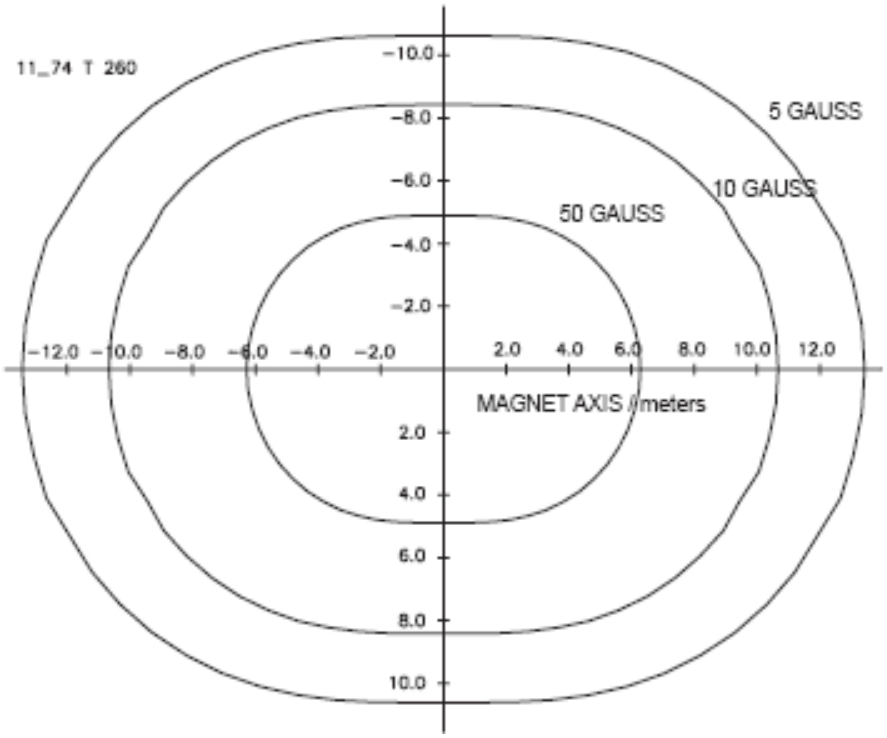
11.7T 210 mm ASR



Magnets with Close Coupled Iron Shields

11.7T 260 mm with 65,000 kg shield





9 Pre-Installation Checklist

"Pre-Installation Checklist" on page 121

Pre-Installation Checklist

Table 15 This checklist if for a typical system with one cryomech compressor

Customer:_____ **Date**_____

		Remarks
Access to site, door heights and widths	yes / no	
Space at customer's site sufficient	yes / no	
Floor loading at site sufficient	yes / no	
Storage space at site for intermediate use	yes / no	
Transport and rigging company selected	yes / no	
Precautions for seismic zone	yes/no	
Modeling of steel cabin finished	yes / no	
Stray field of magnet contained	yes / no	
Floor loading sufficient	yes / no	
Room height sufficient	yes / no	
Cabin manufacturer chosen	yes / no	
Vibration analysis performed, 5–100 Hz < 20 µg, 15–100 Hz < 200 µg (single peak)	yes / no	
Anti-vibration legs required	yes / no	
Extra penetration panel included for future use	yes / no	
Agilent panel included (p/n 0191673800)	yes / no	
675 × 936 mm, 18 holes in vertical direction	yes / no	

Table 15 This checklist if for a typical system with one cryomech compressor (continued)

Customer:_____			**Date**_____
Drawings from cabin manufacturer received		yes / no	_____
Drawings in agreement with customer wishes		yes / no	_____
Doors 1.2m wide (for cryogens)		yes / no	_____
Window in door		yes / no	_____
Windows at correct heights and sizes		yes / no	_____
Quench duct correctly sized and routed		yes / no	_____
Passive vent present, safety considered		yes / no	_____
Vertical movement possible (if anti-vibration legs)		yes / no	_____
Sound insulation sufficient (40 dB attenuation)		yes / no	_____
Coloring scheme selected		yes / no	_____
Non-magnetic scaffold on site		yes/no	_____
			_____
			_____
Water chiller for compressor correctly sized, 10 kW, flow 7 l/min, 15 °C, delta P 2 bar	3-ph	yes / no	_____
Cooling water for He-compressor: 10 kW, 7l/min, 15 °C		yes / no	_____
Flow meter, mains water by-pass, pressure gauges		yes / no	_____
			_____
			_____
Electricity supply high or low voltage		200V/400V	_____
- He-compressor 9 kW (27 A or 16 A per phase)	3-ph		_____
- gradient amplifier (3ph/400 V, 50 A per phase)	3-ph		_____
- gradient chiller (15A, 240V, single)	s-ph	yes / no	_____
- RF bay (32A, 240 V, single)	s-ph	yes / no	_____
- RF console (20 A, 240 V, single)	s-ph	yes / no	_____
- 4 × 13 A, single phase, in cabin	s-ph	yes / no	_____
- 6 × 13 A, single phase, outside cabin, computers	s-ph	yes / no	_____
Total number of sockets in Tech room		yes / no	_____
3 × 3 phase, 5 x single phase (check rating)		yes / no	_____
Location of distribution board fixed		yes / no	_____

Table 15 This checklist if for a typical system with one cryomech compressor (continued)

Customer:_____		**Date**_____
Cabling location	floor/ceiling	_____
		_____
		_____
Air conditioning in Equipment room (20 kW)	yes / no	_____
Air conditioning in cabin (2 - 3 kW approx)	yes / no	_____
		_____
		_____
Timing outline		_____
Start cabin installation	from / to	_____
Deliver magnet	from / to	_____
Finish cabin	from / to	_____
Energize magnet	from / to	_____
Commission NMR	from / to	_____

9 Pre-Installation Checklist

10 Installation Checklists

Predelivery Checklist 125
Postdelivery Checklist 126

Use these predelivery and postdelivery checklists to prepare for system installation.

Predelivery Checklist

Use the following checklist to prepare for delivery of the system. Refer to other parts of this manual for further instructions and safety precautions. Consult knowledgeable persons, such as plant facilities personnel, for help in implementing these instructions.

- ✓ Check the SHIP BY date on the Agilent Order Acknowledgment form. Use this date as a target for completing installation preparations.
- ✓ Select the site for installing and operating the system.

NOTE A site survey is standard with many Agilent spectrometer systems.

- ✓ Prepare the installation site, including electrical outlets, compressed air supply, and air conditioning. Make any computer preparations required.
- ✓ Order supplies and equipment for installation and startup operation.

- ✓ Make arrangements for workers and equipment to move the system upon delivery to the installation site.
- ✓ Read carefully, sign, and mail to Agilent Technologies using the "Object Code License Form." (Note that acceptance of the products on the Order Acknowledgment form constitutes acceptance of the terms stated in the Object Code License Form, whether the form is signed or not.).

Postdelivery Checklist

Use the following checklist to plan for handling the instrument after delivery. Refer to other parts of this manual for further instructions and safety precautions.

- ✓ Upon delivery, check for shipping damage but do not open any shipping crates except with direct instructions from an authorized Agilent representative. Examine crates for shipping damage. Note any apparent damage on the carrier's waybill and contact the insurance company.
- ✓ As soon as possible, move the shipment to a clean, dry location (preferably the installation site). 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. If one or more crates cannot be moved into the installation site because of the doorway clearance, leave the affected crate in a clean, safe, dry location. Again, do not open any crate except with direct instructions from an authorized service representative. In particular, the crate containing the magnet has components that could be irreparably damaged if opened incorrectly.
- ✓ Contact Agilent to schedule the visit of an installation engineer after the shipment is moved to the installation site, the utilities are installed, and non-Agilent installation parts and supplies (listed in the "Installation Supplies and Equipment" section) are received. For installations in the United States, telephone the Installation Department at 1-925-974-7476. For installations in other locations, contact the nearest Agilent sales or service office, listed in the introduction to this guide.

11 Posting Requirements for Magnetic Field Warning Signs

Warning Signs 128

The strong magnetic fields that surround a superconducting magnet are capable of causing death or serious injury to individuals with implanted or attached medical devices such as pacemakers or prosthetic parts. Such fields can also suddenly pull nearby magnetic tools, equipment, and dewars into the magnet body with considerable force, which could cause personal injury or serious damage. Moreover, strong magnetic fields can erase magnetic media such as tapes and floppy disks, disable the information stored on the magnetic strip of automated teller machine (ATM) and credit cards, and damage some watches.

To warn of the presence and hazard of strong magnetic fields, the customer is responsible for posting clearly visible signs warning of magnetic field hazards. This responsibility includes measuring stray fields with a gaussmeter.

Radio-frequency emissions may also pose a danger to some individuals. The RF emission levels from Agilent NMR equipment have been measured and compared to the IEEE/ANSI C95.1-1991 standard. For further information, refer to the
RF Environment section of the Installation Planning Guide.

Warning Signs

Agilent provides signs to help customers meet this posting responsibility. These signs must be posted according to the following requirements before the magnet is energized:

5-gauss warning signs (Figure 12 on page 129) - Post along the 5 gauss perimeter of the magnet so that a sign can be easily seen by any person about to enter the 5 gauss field from any direction. Refer to the manuals supplied with the magnet for the size of a typical 5 gauss stray field. Check this gauss level after the magnet is installed. Note that the stray field may extend vertically to adjacent floors, and additional signs may be needed there.

10 gauss warning signs (Figure 13 on page 129) - Post along the 10 gauss perimeter of the magnet so that a sign can be easily seen by any person about to enter the 10 gauss field from any direction. Refer to the manuals supplied with the magnet for the size of a typical 10 gauss stray field. Check this gauss level after the magnet is installed.

NOTE

The stray field may extend vertically to adjacent floors, and additional signs may be needed there. A sign is not required if the 10 gauss field extends less than 30 cm (12 in) beyond a permanent wall or less than 61 cm (24 in) beyond the floor above the magnet.

Magnet area danger signs (Figure 14 on page 130) - Post at each entrance to the magnet area. Be sure each sign is outside the 5 gauss perimeter.



Figure 12 5 Gauss warning sign



Figure 13 10 Gauss warning sign

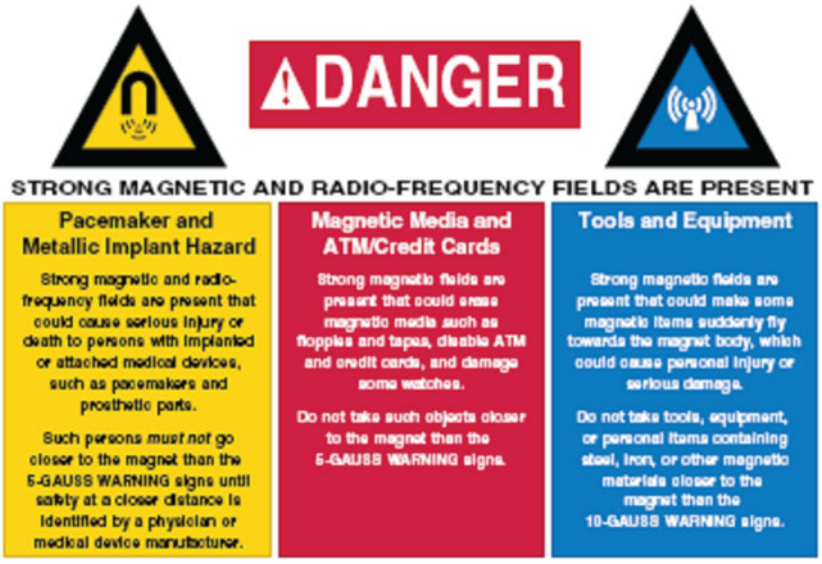


Figure 14 Magnet area danger sign

Stray magnetic fields can reach beyond the published distances when two or more magnetic fields intersect or when the field extends over large ferromagnetic masses or structures (steel doors, steel construction beams, and so forth). In this case, the customer must measure the stray field using a gaussmeter to determine how the 5 and 10 gauss fields are altered (contact a scientific instrumentation supplier for information on acquiring a gaussmeter).

You can request additional signs from Agilent by calling 1-800-227-9770 in the United States or by contacting your local Agilent office in other countries.

12 Standard Units and Conversion Tables

Standard Units 131
Conversion Tables 133
Converting AWG Numbers 135
Converting dBm to Volts to Watts 136

Standard Units

Table 16 Definition of standard units

Quantity	Symbol	Name
Temperature	°C	degree celsius (1.8C + 32 = F)
Temperature	°F	degree fahrenheit (0.56(F - 32) = C)
Temperature	K	kelvin
Force	N	newton
Force	ft-lb	foot-pound
Power	kcal	kilocalorie
Mass	g	gram
Mass	kg	kilogram
Length	m	meter
Length	mm	millimeter
Length	in	inch
Length	ft	foot
Area	m^2	square meter
Area	cm^2	square centimeter
Area	sq in	square inch
Area	sq ft	square foot
Volume	m^3	cubic meter
Volume	cm^3	cubic centimeter
Volume	cu in	cubic inch

Table 16 Definition of standard units

Quantity	Symbol	Name
Volume	cu ft	cubic foot
Time	h	hour
Magnetic field strength	A/m	ampere per meter
Magnetic flux density (induction)	T	tesla (1 T = 10^4 gauss, 1 T = 1 Wb/m^2)
Magnetic flux	Wb	weber

Conversion Tables

Table 17 Units of length conversions

Unit	mm	m	in	ft
1 mm =	1	0.001	0.0393701	0.0032808
1 m =	1000	1	39.37	3.281
1 in =	25.4	0.0254	1	0.08333
1 ft =	304.8	0.3048	12	1

Table 18 Units of volume conversions

Unit	cm^3	m^3	cu in	cu ft
1 cm^3 =	1	0.000001	0.06702	0.03531
1 m^3 =	1000000	1	61023	35.31
1 cu in =	16.39	0.0006452	1	0.000579
1 cu ft =	28316	0.028316	1728	1

Table 19 Units of power conversions

Unit	kcal/h	kJ/h	kW
1 kcal/h =	1	4.1868	0.00163
1 kJ/h =	0.2388	1	0.0002777
1 kW =	860	3600	1

Table 20 Units of energy conversions

Unit	kcal	kJ	kWh
1 kJ =	0.2388	1	0.0002777
1 kWh =	860	3600	1

Table 21 Units of pressure/force conversions

Unit	N/m^2 (Pa)	N/cm^2	kp/m^2	kp/cm^2	lb/sq ft	lb/sq in (psi)
1 N/m^2 =	1	0.0001	0.1019	0.1019×10^{-4}	2.088×10^{-2}	1.45×0^{-5}
1 N/cm^2 =	10000	1	1019	0.1019	208.8	1.45
1 kp/m^2 =	9.80665	9.8066×10^{-4}	1	0.001	0.2084	1.422×10^{-3}
1 kp/cm^2 =	98066.5	9.80665	10000	1	2048	14.22
1 lb./sq ft =	47.87	4.787×10^{-3}	4.882	4.882×10^{-4}	1	6.943×0^{-3}
1 lb/sq in = (psi)	6896	0.6896	703	7.032×10^{-2}	144	1

Converting AWG Numbers

Table 21lists conversions of AWG numbers to wire diameter and cross-sections.

1 circ mil = $5.07x10^{-10}$ m^2 = 0.000507 mm^2

Table 22 AWG Conversions

AWG No.	Wire diameter (mm)	Cross-section of conductor (mm2)	circ mils	AWG No.	Wire diameter (mm)	Cross-section of conductor (mm2)	circ mils
40	0.079	0.0048	10	17	1.151	1.04	2052
39	0.089	0.0062	12	16	1.290	1.31	2581
38	0.102	0.0081	16	15	1.450	1.65	3260
37	0.114	0.0103	20	14	1.628	2.08	4109
36	0.127	0.0126	25	13	1.829	2.63	5184
35	0.142	0.0159	31	12	2.052	3.31	6529
34	0.160	0.0201	40	11	2.304	4.17	8226
33	0.180	0.0255	50	10	2.588	5.26	10384
32	0.203	0.0325	64	9	2.906	6.63	13087
31	0.226	0.0412	79	8	3.268	8.37	16512
30	0.254	0.051	100	7	3.665	10.55	20822
29	0.287	0.065	128	6	4.115	13.30	26244
28	0.320	0.081	159	5	4.620	16.77	33088
27	0.363	0.102	202	4	5.189	21.15	41738
26	0.404	0.128	253	3	5.827	26.66	52624
25	0.455	0.163	320	2	6.543	33.62	66358
24	0.511	0.205	404	1	7.348	42.41	83625
23	0.574	0.259	511	1/0	8.252	53.52	105625
22	0.643	0.33	640	2/0	9.266	67.43	133079
21	0.724	0.41	812	3/0	10.404	85.01	167772
20	0.813	0.52	1024	4/0	11.684	107.21	211600
19	0.912	0.65	1289	5/0	–	135.35	266773
18	1.024	0.82	1624	6/0	–	170.50	336400

Converting dBm to Volts to Watts

Table 23 lists values in dBm with equivalent values in effective voltage (V_{rms}), peak-to-peak voltage (V_{p-p}), and watts (W).

Table 23 dBm to volts to watts conversions, 50-Ohm termination

dBm	V_{rms}	V_{p-p}	W	dBm	V_{rms}	V_{p-p}	W
–90	7.069 µV	19.99 µV	1.000 pW	1	250.9 mV	709.5 mV	1.259 mW
–89	7.934 µV	22.44 µV	1.259 pW	2	281.5 mV	796.1 mV	1.585 mW
–88	8.900 µV	25.17 µV	1.585 pW	3	315.9 mV	893.2 mV	1.995 mW
–87	9.989 µV	28.25 µV	1.995 pW	4	354.4 mV	1.000 V	2.512 mW
–86	11.21 µV	31.69 µV	2.512 pW	5	397.6 mV	1.125 V	3.162 mW
–85	12.57 µV	35.56 µV	3.162 pW	6	446.2 mV	1.262 V	3.981 mW
–84	14.11 µV	39.89 µV	3.981 pW	7	500.6 mV	1.416 V	5.012 mW
–83	15.83 µV	44.77 µV	5.012 pW	8	561.7 mV	1.588 V	6.309 mW
–82	17.76 µV	50.23 µV	6.309 pW	9	630.2 mV	1.782 V	7.943 mW
–81	19.93 µV	56.36 µV	7.943 pW	10	707.1 mV	1.999 V	10.00 mW
–80	22.36 µV	63.23 µV	10.00 pW	11	793.4 mV	2.245 V	12.59 mW
–79	25.09 µV	70.95 µV	12.59 pW	12	890.2 mV	2.517 V	15.85 mW
–78	28.15 µV	79.61 µV	15.85 pW	13	998.9 mV	2.825 V	19.95 mW
–77	31.58 µV	89.32 µV	19.95 pW	14	1.121 V	3.169 V	25.12 mW
–76	35.43 µV	100.2 µV	25.12 pW	15	1.267 V	3.556 V	31.62 mW
–75	39.78 µV	112.5 µV	31.62 pW	16	1.411 V	3.990 V	39.81 mW
–74	44.63 µV	126.2 µV	39.81 pW	17	1.583 V	4.477 V	50.12 mW
–73	50.07 µV	141.6 µV	50.12 pW	18	1.776 V	5.023 V	63.09 mW
–72	56.15 µV	158.8 µV	63.09 pW	19	1.993 V	5.636 V	79.43 mW
–71	63.01 µV	178.2 µV	79.43 pW	20	2.236 V	6.324 V	100.0 mW
–70	70.69 µV	199.9 µV	100.0 pW	21	2.509 V	7.095 V	125.9 mW
–69	79.34 µV	224.5 µV	125.9 pW	22	2.815 V	7.961 V	158.5 mW
–68	89.02 µV	251.7 µV	158.5 pW	23	3.158 V	8.932 V	199.5 mW
–67	99.88 µV	282.5 µV	199.5 pW	24	3.543 V	10.02 V	251.2 mW
–66	112.07 µV	316.9 µV	251.2 pW	25	3.978 V	11.25 V	316.2 mW
–65	125.74 µV	355.6 µV	316.2 pW	26	4.463 V	12.62 V	398.1 mW

Table 23 dBm to volts to watts conversions, 50-Ohm termination (continued)

dBm	V_{rms}	V_{p-p}	W	dBm	V_{rms}	V_{p-p}	W
–64	141.09 µV	399.0 µV	398.1 pW	27	5.007 V	14.16 V	501.2 mW
–63	158.30 µV	447.7 µV	501.2 pW	28	5.615 V	15.88 V	631.0 mW
–62	177.62 µV	502.3 µV	630.9 pW	29	6.301 V	17.82 V	794.3 mW
–61	199.29 µV	563.6 µV	794.3 pW	30	7.069 V	19.99 V	1.000 W
–60	223.61 µV	632.4 µV	1.000 nW	31	7.935 V	22.44 V	1.259 W
–59	250.89 µV	709.5 µV	1.259 nW	32	8.900 V	25.17 V	1.585 W
–58	281.50 µV	796.1 µV	1.585 nW	33	9.989 V	28.25 V	1.995 W
–57	315.85 µV	893.2 µV	1.995 nW	34	11.21 V	31.69 V	2.512 W
–56	354.39 µV	1.002 mV	2.512 nW	35	12.57 V	35.56 V	3.162 W
–55	397.64 µV	1.125 mV	3.162 nW	36	14.11 V	39.89 V	3.981 W
–54	446.15 µV	1.262 mV	3.981 nW	37	15.83 V	44.77 V	5.012 W
–53	500.59 µV	1.416 mV	5.012 nW	38	17.76 V	50.23 V	6.309 W
–52	561.67 µV	1.588 mV	6.310 nW	39	19.93 V	56.36 V	7.943 W
–51	630.2 µV	1.782 mV	7.943 nW	40	22.36 V	63.23 V	10.00 W
–50	701.1 µV	1.999 mV	10.00 nW	41	25.09 V	70.95 V	12.59 W
–49	793.4 µV	2.244 mV	12.59 nW	42	28.15 V	79.61 V	15.95 W
–48	890.2 µV	2.517 mV	15.85 nW	43	31.59 V	89.32 V	19.95 W
–47	998.9 µV	2.825 mV	19.95 nW	44	35.44 V	100.2 V	25.12 W
–46	1.121 mV	3.169 mV	25.12 nW	45	39.76 V	112.5 V	31.62 W
–45	1.257 mV	3.556 mV	31.62 nW	46	44.62 V	126.2 V	39.81 W
–44	1.411 mV	3.989 mV	39.81 nW	47	50.06 V	141.6 V	50.12 W
–43	1.583 mV	4.477 mV	50.12 nW	48	56.17 V	158.8 V	63.09 W
–42	1.776 mV	5.023 mV	63.09 nW	49	63.02 V	178.2 V	79.43 W
–41	1.993 mV	5.636 mV	79.43 nW	50	70.71 V	199.9 V	100.0 W
–40	2.236 mV	6.323 mV	100.0 nW	51	79.34 V	224.5 V	125.9 W
–39	2.509 mV	7.095 mV	125.9 nW	52	89.02 V	251.7 V	158.5 W
–38	2.815 mV	7.961 mV	158.5 nW	53	99.88 V	282.5 V	199.5 W
–37	3.158 mV	8.932 mV	199.5 nW	54	112.1 V	316.9 V	251.2 W
–36	3.543 mV	10.02 mV	251.2 nW	55	125.7 V	355.6 V	316.2 W
–35	3.978 mV	11.25 mV	316.2 nW	56	141.1 V	398.9 V	398.1 W
–34	4.463 mV	12.62 mV	398.1 nW	57	158.3 V	447.7 V	501.2 W

Table 23 dBm to volts to watts conversions, 50-Ohm termination (continued)

dBm	V_{rms}	V_{p-p}	W	dBm	V_{rms}	V_{p-p}	W
–33	5.007 mV	14.16 mV	501.2 nW	58	177.6 V	502.3 V	630.9 W
–32	5.615 mV	15.88 mV	630.9 nW	59	199.3 V	563.6 V	794.3 W
–31	6.301 mV	17.82 mV	794.3 nW	60	223.6 V	632.4 V	1.000 kW
–30	7.069 mV	19.99 mV	1.000 µW	61	250.9 V	709.5 V	1.260 kW
–29	7.938 mV	22.45 mV	1.259 µW	62	281.5 V	796.1 V	1.585 kW
–28	8.900 mV	25.17 mV	1.585 µW	63	315.9 V	893.2 V	1.995 kW
–27	9.989 mV	28.25 mV	1.995 µW	64	354.4 V	1.002 kV	2.512 kW
–26	11.21 mV	31.69 mV	2.512 µW	65	397.6 V	1.125 kV	3.162 kW
–25	12.57 mV	35.56 mV	3.162 µW	66	446.2 V	1.262 kV	3.981 kW
–24	14.11 mV	39.90 mV	3.981 µW	67	500.6 V	1.416 kV	5.012 kW
–23	15.83 mV	44.77 mV	5.012 µW	68	561.7 V	1.588 kV	6.310 kW
–22	17.76 mV	50.23 mV	6.309 µW	69	630.2 V	1.782 kV	7.943 kW
–21	19.93 mV	56.36 mV	7.943 µW	70	707.1 V	2.000 kV	10.00 kW
–20	22.36 mV	63.24 mV	10.00 µW	71	793.4 V	2.244 kV	12.59 kW
–19	25.09 mV	70.95 mV	12.59 µW	72	890.2 V	2.517 kV	15.85 kW
–18	28.15 mV	79.61 mV	15.85 µW	73	998.8 V	2.825 kV	19.95 kW
–17	31.59 mV	89.32 mV	19.95 µW	74	1.121 kV	3.169 kV	25.12 kW
–16	35.44 mV	100.2 mV	25.12 µW	75	1.257 kV	3.556 kV	31.62 kW
–15	39.76 mV	112.5 mV	31.62 µW	76	1.411 kV	3.990 kV	39.81 kW
–14	44.62 mV	126.2 mV	39.81 µW	77	1.583 kV	4.477 kV	50.12 kW
–13	50.06 mV	141.6 mV	50.12 µW	78	1.776 kV	5.023 kV	63.10 kW
–12	56.17 mV	158.8 mV	63.10 µW	79	1.993 kV	5.636 kV	79.43 kW
–11	63.02 mV	178.2 mV	79.43 µW	80	2.236 kV	6.324 kV	100.0 kW
–10	70.71 mV	199.9 mV	100.0 µW	81	2.509 kV	7.095 kV	125.9 kW
–9	79.34 mV	224.4 mV	125.9 µW	82	2.815 kV	7.961 kV	158.5 kW
–8	89.02 mV	251.7 mV	158.5 µW	83	3.159 kV	8.932 kV	199.5 kW
–7	99.88 mV	282.5 mV	199.5 µW	84	3.544 kV	10.02 kV	251.2 kW
–6	112.1 mV	316.9 mV	251.2 µW	85	3.976 kV	11.25 kV	316.2 kW
–5	125.7 mV	355.6 mV	316.2 µW	86	4.462 kV	12.62 kV	398.1 kW
–4	141.1 mV	398.9 mV	398.1 µW	87	5.006 kV	14.16 kV	501.2 kW
–3	158.3 mV	447.7 mV	501.2 µW	88	5.617 kV	15.88 kV	631.0 kW

Table 23 dBm to volts to watts conversions, 50-Ohm termination (continued)

dBm	V_{rms}	V_{p-p}	W	dBm	V_{rms}	V_{p-p}	W
–2	177.6 mV	502.3 mV	630.9 µW	89	6.302 kV	17.88 kV	794.3 kW
–1	199.3 mV	563.6 mV	794.3 µW	90	7.071 kV	20.00 kV	1.000 MW
0	223.6 mV	632.3 mV	1.000 mW	91	7.934 kV	22.44 kV	1.259 MW



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