Laboratory Environment Safety and Health Committee
Cryogenic Safety Subcommittee

MINUTES OF MEETING 03-06
August 25, 2003

FINAL

Committee Members Present	**Committee Members Absent**
M. Gaffney	R. Travis*
J.W. Glenn	M. Iarocci
W. Gunther	S. Kane
R. Karol* (Acting Secretary)	P. Kroon
E. Lessard (Chairperson)	P. Mortazavi
K.C. Wu	M. Rehak
(*non-voting)	

Visitors
W. Rooney
C. Du
B. Colichio
F. Horn
J. Curtiss
R. Selvey
N. Bernholc
C. Harris

Agenda:
Medical Department Animal MRI Facility in B490

Minutes of Meeting: Appended on pages 2 through 7.

ESH COMMITTEE MINUTES APPROVED:
_____ _______ Signature on File ___________

E. Lessard
LESHC Chairperson

DM2120.

Chairperson E. Lessard called meeting 03-06 to order at 1510 on August 25, 2003.

1. W. Gunther led the project's presentation to the committee (copy of slides attached). Supporting personnel were present (Facility Manager: C. Du, MRI Technical Advisor from Chemistry Department: W. Rooney, ESH Coordinator: R. Colichio, Building 490 Manager: C. Harris).
2. Plant Engineering has prepared a suite of rooms in B490 for receipt of the Animal MRI in the next week. These rooms will contain the magnet (~20 cm bore), power supplies, RF system and the imaging system. The MRI manufacturer will install the unit during a 2-week period following delivery. The manufacturer will train BNL staff on operation of the unit. This will be followed by ~4 weeks of acceptance testing and further BNL staff training. The expectation is that the MRI will become a User Facility in FY05.
3. The 9.4 T MRI magnet's 5 Gauss field will be contained completely within the MRI room, which will be posted in accordance with the static magnetic field SBMS subject area requirements. Access into the MRI room will be by manual keypad to prevent unauthorized personnel entry.
4. Preliminary ODH calculations were completed by M. Gaffney (SHSD), showing that with the room exhaust fan operating, the room is classified ODH 0. The exhaust fan has battery backup power.

Comments and questions from the Committee during the meeting resulted in the following actions that need to be completed by the project and submitted to the Committee for further review:

1. ODH calculations need to be documented and submitted related to normal operation, maintenance, filling operations and for rooms used for LHe and LN_2 storage.
2. Written procedures are needed to assure that required ODH controls for normal and emergency conditions are in place.
3. Critical ODH equipment must be tested and maintained in order to assure that the required safety controls are operable.
4. More information is needed regarding the BNL installed portions of the electrical and cryogenic systems of the MRI system. It is suggested that the MRI manufacturer certify this BNL equipment.
5. A review of the vent piping and relief valve needs to be completed by a cryogenic expert from the Cryo-Subcommittee. This includes assurance that it is properly sized, and that it cannot become blocked over time by water, bugs, animals, nests, etc.
6. A selected group of the LESHC will walk down the facility following installation (perhaps during the ORE scheduled for the last half of September).
7. The Cryo-subcommittee needs more information on the design of the quench piping to assure that it meets BNL expectations and needs assurance that it satisfies manufacturer's recommendations.
8. More information is needed on how whole-body and extremity magnetic field exposures will be controlled. Procedures should document these requirements.

9. Noise measurements need to be conducted by SHSD to assure a proper hearing protection program and postings. A review of the RF system (400 MHz, up to 1 Kw) needs to be conducted to assure that RF exposures are within those allowed by BNL SBMS. Procedures need to specify if controls are needed to prevent overexposure to RF.
10. Training of Users who conduct “hands on” experiments needs to be documented. This training needs to define clearly what the User is allowed to do.
11. Assurance is required to show that adequate instrumentation is available to allow monitoring of critical parameters of the MRI facility.
12. Written procedures that incorporate manufacturer’s generic maintenance and operations instructions into BNL-specific procedure steps need to be written.
13. Specific frequencies for maintenance and testing of all sub-systems need to be established.
14. The MRI manufacturer should have all required BNL training, or acceptable equivalent, for the work that will be performed by them at BNL.

E. Lessard noted that the LESHC needs to review the above items before it can recommend approval to perform acceptance testing that requires filling the cryogenic vessels and operating the MRI to the BNL Deputy Director of Operations. W. Gunther agreed to provide this information.

The meeting adjourned at 1650.

Subsequent to the meeting, comments were received on the draft minutes resulting in the following additional issues that need to be addressed by the Animal MRI project staff:

1. Ensure locally designed/manufactured parts meet Bruker's expectations (e.g., vent system materials).

2. The cabling to the power supply and the supply are critical to controlled dumps unless there's some sort of free wheeling diode involved. If there is, its health is critical to prevent 'meltdown'.

3. The design of the 'sample' holder must consider the near 10 Tesla field.

4. Ensure all the precautions that Bruker identifies in its manuals are understood and incorporated in operating procedures.

5. The emergency discharge unit requires periodic testing and maintenance. It may not dump the magnet below 7 Tesla. There is still 3+ mega Joules of energy stored in the magnet that needs a way out; or is it self-protecting at this time?

6. Calibration records need be kept.

7. The He level monitor holds and displays old values. How do you assure decisions are made with reasonably current data?

8. The ODH memo uses 800 L; the 'Operating Data' mentions 1060 L, and the PED Design Report lists 1203 L. Would these higher numbers affect the result? What is the real number?

9. The 'acceptable' leak rate of 133 cu-ft/min would not reduce the oxygen levels below 18%. No estimate of the probability of exceeding this is given. The maximum leak rate from a component failure must be determined. This leak rate can be compared to the 133 cu-ft/min in order to find out if ODH controls are adequate.

Slide 1

Slide 2

MicroMRI at BNL - *Background*

- 9.4T Superconducting Magnet
  - Actively Shielded Gradient System
  - Located in building 490 (suite of rooms near the BLAF)
  - Continued growth of BNL's Imaging Research Program
  - Additional spaces to be renovated to support data acquisition and processing
- Installation September 2003 (9/4/03)
  - ~2 weeks of vendor work including training
  - ~4 weeks of acceptance testing (and more training)
  - Foreseen as a "user facility" by FY05

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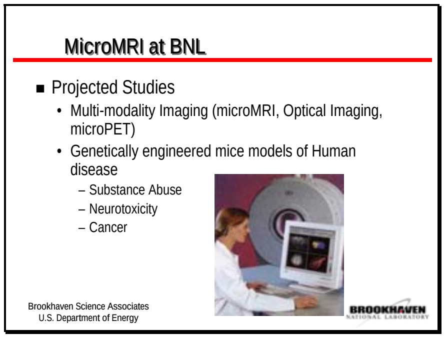
Slide 3

Slide 4



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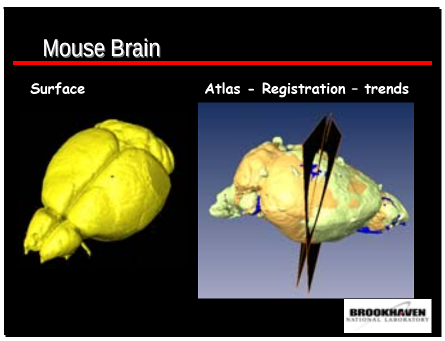

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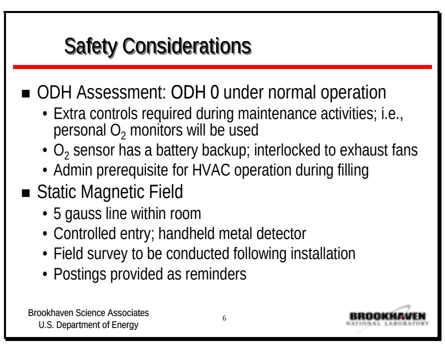

Slide 7

Other Safety Considerations

- Approximately 800 liters of He; 248 L of N_2
- Filling operations every 3 months for He; every 2 weeks for N_2
- Training for staff provided by Bruker; JTAs developed for staff
- Noise survey following startup
- Non-magnetic fire extinguishers and ladder

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Slide 8

Safety Committee Discussion

BNL 9.4 T MRI being prepared for shipment

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INSTALLATION AND SERVICE MANUAL

for

Horizontal Bore Magnet Systems

Prepared : Jan 2003

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CONTENTS

1. IMPORTANT NOTICE

Please inspect goods immediately on arrival for possible transit damage and notify MAGNEX SCIENTIFIC LIMITED within 3 days of receipt of goods.

Failure to do this will invalidate any possible claim.

WARNING

The User must refer to the document "Safety Considerations For The Installation & Operation Of Magnet Systems" enclosed with this system manual.

This device produces a high magnetic field. The stray field surrounding the magnet extends far beyond the confines of the vessel. The existence of this field produces several Hazards. Firstly the field will interfere with sensitive electronic devices and will erase magnetic storage devices such as tapes and credit cards. In particular people with cardiac pacemakers should be kept well clear of the region of field. The F.D.A. guideline for cardiac pacemakers is currently 5 Gauss. Fields higher than this can cause malfunction of the pacemaker.

Secondly ferromagnetic objects in the vicinity of the magnet will become magnetised and will be attracted toward the magnet. The force on such objects is proportional to their mass so that even large objects will move toward the magnet with considerable velocity.

It is possible, under fault conditions, for large amounts of helium and/or nitrogen to be released from the system, e.g. Magnet Quench. Under these conditions the gas is very cold and will cause 'cold burns'. More importantly if the gas is not vented properly asphyxiation is possible due to the displacement of oxygen within the room. It is the responsibility of the user to ensure adequate venting of the gas is provided and adequate ventilation within the final installation site.

It is the responsibility of the user to take all necessary precautions to prevent accident or loss from use of the magnet. Magnex Scientific Limited accepts no responsibility for any loss or damage cause either directly or indirectly from use of the magnet. Whilst every effort is made that the information contained in this manual is correct Magnex Scientific Ltd. accepts no responsibility for any inaccurate statements or omissions.

2. LAYOUT AND SITING

Siting the magnet is very important and should be given careful consideration prior to taking delivery. The factors to consider are as follows :-

a) Fringing Fields : The magnet produces a magnetic field for some distance surrounding itself. This field will interfere with sensitive equipment such as computers, magnetic storage devices (discs, tapes and credit cards), cathode ray oscilloscopes, and many others. In particular cardiac pacemakers may be affected by magnetic fields and the FDA has set guidelines of 5 Gauss as the maximum field allowable in public areas. Thus you must determine where the field will extend beyond your laboratory and ensure you have adequate control of these areas. You should signpost clearly areas where the public may inadvertently enter and you should consider carefully the necessity for other security devices to prevent unauthorised personnel entering, such as security locks and/or metal detectors. The stray field of the magnet is shown in the Operating Data Manual.

b) Local Iron : If the magnet is sited close to ferromagnetic material it will magnetise the material and this in turn will produce it's own magnetic field. Where a large amount of iron is present, such as main structural girders or large drains the field produced can distort the field of the magnet to such an extent that the shims are unable to cope. For beams or drains containing less than 50 kg/metre (33 lb/ft) it is unlikely that gradients will be produced for which the shims are unable to cope. It is usually easier to shim out such gradients if the offending beam is situated along a direction of high symmetry with respect to the magnet (i.e. directly parallel to it's axis or directly perpendicular to it's axis and crossing the centre-line).

Another consideration for local iron is that of equipment in the vicinity of the magnet. Objects containing iron which are not firmly anchored to the building can be attracted to the magnet. If such objects are brought too close they will move toward the magnet with considerable force and represent a danger. Note that any electronic instruments will almost certainly contain a transformer with iron in it.

Transformers can be caused to saturate by a strong magnetic field (20-50 Gauss) and this can cause malfunction of the equipment by reducing the output from the transformer and therefore the voltage to any devices being powered.

Note that large structural girders can act as 'flux-pipes' that is they may be magnetised and cause a magnetic field to appear at the other end of the beam. This field may be higher than it would have been if the beam were not present.

c) Weight and Physical dimensions : The weight and base layout of a particular magnet system is given in the Operating Data Manual.

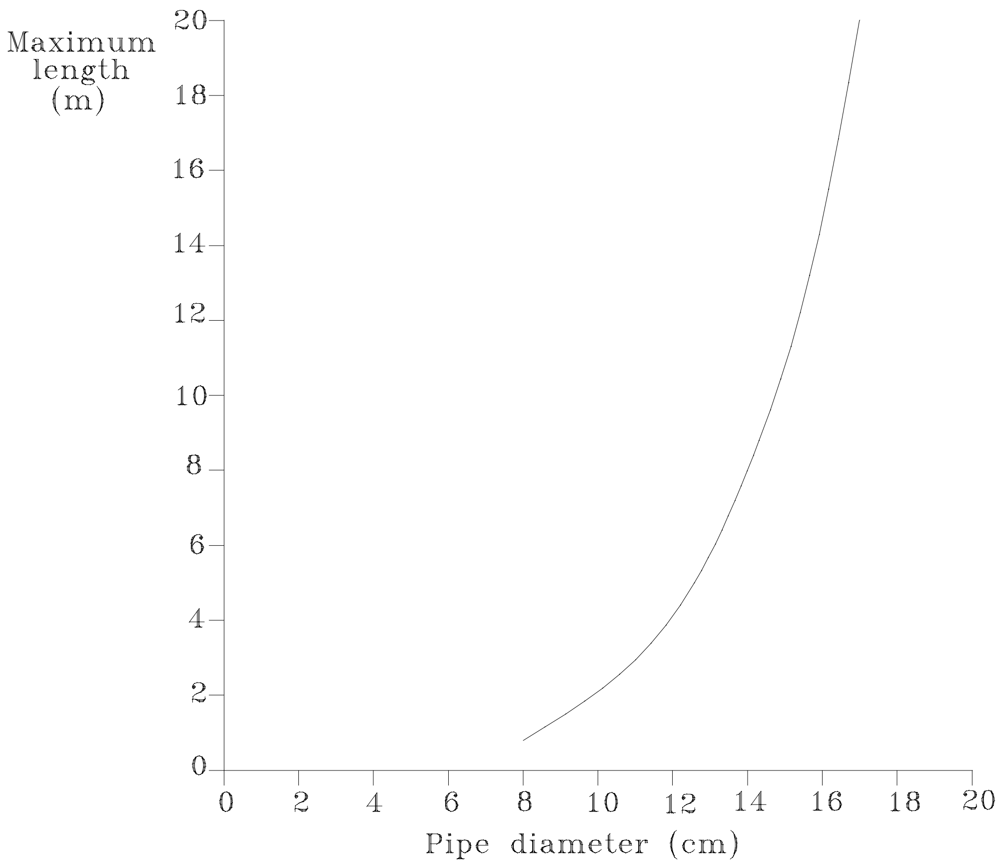
Depending on the maximum permitted floor loading, load spreading plates may be required. These should preferably be of Aluminium or some other non ferrous material.

General Layout : When choosing a position for the magnet in a laboratory consideration should be given to comfortable access for such things as inserting samples, venting exhaust gases, and topping up liquid cryogens. Siting ancillary equipment such as power supplies spectrometer consoles and computing facilities should be considered both for convenience and with the foregoing considerations of fringe field taken into account.

The 'top-stack' of the cryostat contains the normal helium vent, and a larger vent port. This contains a graphite burst disc which will rupture should the pressure in the cryostat exceed the design pressure. Some systems also have a second spring loaded quench valve. It is recommended that these vents are ducted to channel escaping gases to a safe exit. The normal exhaust gas can be returned to a compressor to be stored in gas cylinders or simply allowed to escape to atmosphere, the economics of this will depend on your position and helium supply arrangements. The main quench vents should be ducted with large diameter ducting (aluminium) to the outside world.

Note that the volume of gas evolved during a quench - even one due to low helium level - can be enough to saturate a normal sized laboratory giving rise to a potential asphyxiation hazard.

Figure 2.1 Recommended Diameter of Helium Exhaust Ducting



The main quench vents should be ducted with large diameter ducting (aluminium) to the outside environment. Figure 2.1 shows a graph of the recommended duct diameter versus length to avoid excessive pressure build up due to the flow impedance of the duct. The graph should only be used as an approximate guide, contact Magnex Scientific for a detailed analysis of the proposed quench ducting.

Only service personnel should have access to the exit end of the exhaust duct; in addition the exit opening should be protected from the ingress of rain, snow or any debris which could block the system.
Insulation of accessible exhaust piping should be provided to prevent cold burns during a quench.

3. SYSTEM COMPONENT PARTS

This section lists the component parts which could possibly be supplied with a magnet system. Please refer to the Customer Interface drawing for a plan view of the main turret and liquid nitrogen fill ports. The Customer Interface drawing can be found in the Operating Data section of the manual for the magnet. Figure 3.1 shows the ancillary items typically supplied with a magnet system.

- **Cryostat valve** : the cryostat is evacuated through the valve, when the correct vacuum has been reached the valve can be closed maintaining the vacuum in the cryostat after the pumps have been removed.

- **Drop off plate** : this is supplied with some systems to prevent a dangerous build up of pressure in the vacuum space.

- **Ten pin seals** : a number of ten pin seals will be located on the cryostat close to the cryostat valve, these provide electrical access to the vacuum space. The temperature sensors mounted on the cryostat shields can be accessed through these seals.

- **Nitrogen fill/vent stack** : during normal operation the nitrogen vessel will vent through this stack, a heat sink reduces the build up of ice on this turret. The bung at the top can be removed in order to fill the nitrogen vessel.

- **Nitrogen level monitor stack** : the liquid nitrogen monitor probe inserts into the nitrogen vessel through this stack. During normal operation the port is closed with an over-pressure valve. During liquid nitrogen fills the valve should be removed to allow exhaust gases to exit. After filling it is extremely important that this valve is immediately replaced to prevent ice forming in the stack.

- **Turret (Top Hat)** : this mounts on the top of the main central stack and provides entry / exit for various magnet services.

- **Helium can burst disc** : this prevents the pressure inside the helium vessel exceeding a specified pressure (normally 5 or 10 psi).

- **Quench valve** : A spring loaded valve which will allow gas to escape during a quench.

- **Non return valve (helium exhaust**) : During normal operation the evaporated gas will exit through this valve. The valve prevents air entering the helium vessel and has a typical cracking pressure of 0.05 bar. The non return valve should be removed or by passed during helium refills.

- **Electrical lead through (19 way)** : This provides electrical access to magnet and its level probes. The 19 way service cable will connect the magnet to the helium level monitor and quench unit.

- **Siphon entry seal** : This provides entry for the siphon for refills.

- **Demountable helium level probe** : this probe enters the helium vessel through an entry seal in the top hat.

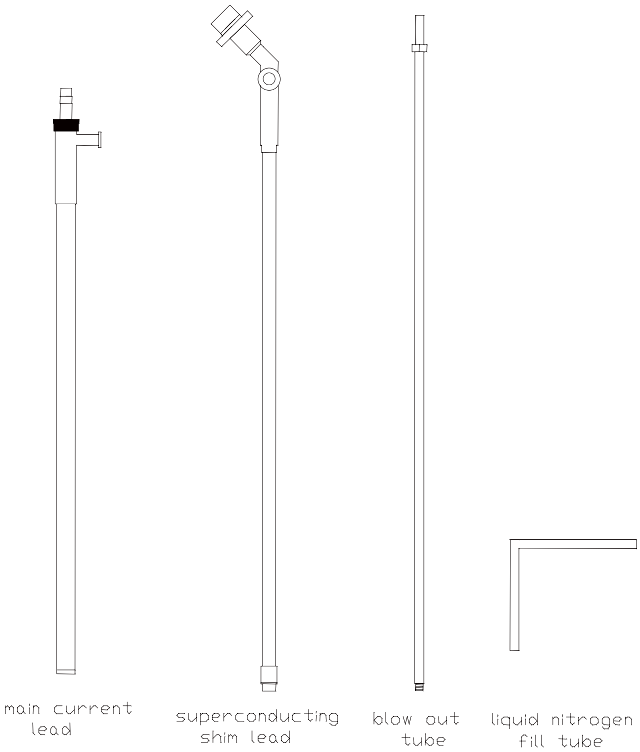
- **Main current lead** : This engages with a connector inside the cryostat. It is used to deliver current to the magnet. It connects at its top to the main current cables via two copper blocks. The current cables in turn connect to the magnet power supply. When the magnet has been persisted at field the lead may be removed from the cryostat. The main current cable has two different size lugs to ensure the cables are connected with the correct polarity.

- **Superconducting shim lead** : This engages with a connector inside the cryostat. It enables the superconducting shims to be energised. It connects to the superconducting shim cable which in turn connects to the magnet power supply. When the current in the superconducting shims has been set the lead may be removed.

- **Blow out tube** : This enters the cryostat through the siphon entry seal and screws into a connector inside the cryostat. The tube is used to remove liquid nitrogen from the helium vessel after the pre-cool.

- **Liquid nitrogen fill tube** : this tube inserts into the liquid nitrogen fill port of the cryostat.

Figure 3.1 <u>Ancillary Items</u>



4. LEVEL MONITORING AND EMERGENCY DISCHARGE UNITS

a) Helium (Model E5010 or E5011)

The helium liquid level is measured and displayed in mm. The volume of helium remaining is a non linear function of the depth because of the annular nature of the helium reservoir. In addition the probe forms the arc of a circle so that length measured is not a vertical depth. A calibration chart is supplied with the instrument.

The principle of operation of the level meter is as follows. A fine superconducting wire with a resistive matrix is placed around the magnet. The liquid level normally sits somewhere along the length of this wire. During the read cycle the instrument passes a pulse of current along the wire and simultaneously heats the top end. The result of this is to cause the wire to go normal at the top end and for the normal zone to propagate down the wire. If the size of the current pulse is chosen correctly then the normal zone propagates only to the liquid surface. Thus the resistance of the wire is proportional to the length of it above the liquid level. This is measured and converted to a reading in mm and displayed on the front panel meter.

The level monitor has an alarm facility which can be used to trigger a warning device for low liquid level.

b) Nitrogen (Model E5030 or E5031)

The nitrogen level probe consists of a capacitance type sensor. A head oscillator is mounted on top of the probe. The level monitor consists of an analogue meter reading from 0 to 100 %.

The level monitor has an alarm facility which can be used to trigger a warning device for low liquid level.

c) Emergency Discharge Unit (Model E7000, E7001 or E7002)

The emergency discharge unit consists of a small power supply with battery back-up. This can be used in an emergency to energise a heater embedded in the magnet windings and initiate a quench.

Note that large amounts of cryogen will be released during a quench and must be ducted away. The event can be noisy but will not damage the magnet or cryostat.

The magnet will discharge in 10 to 20 seconds when operating this device.

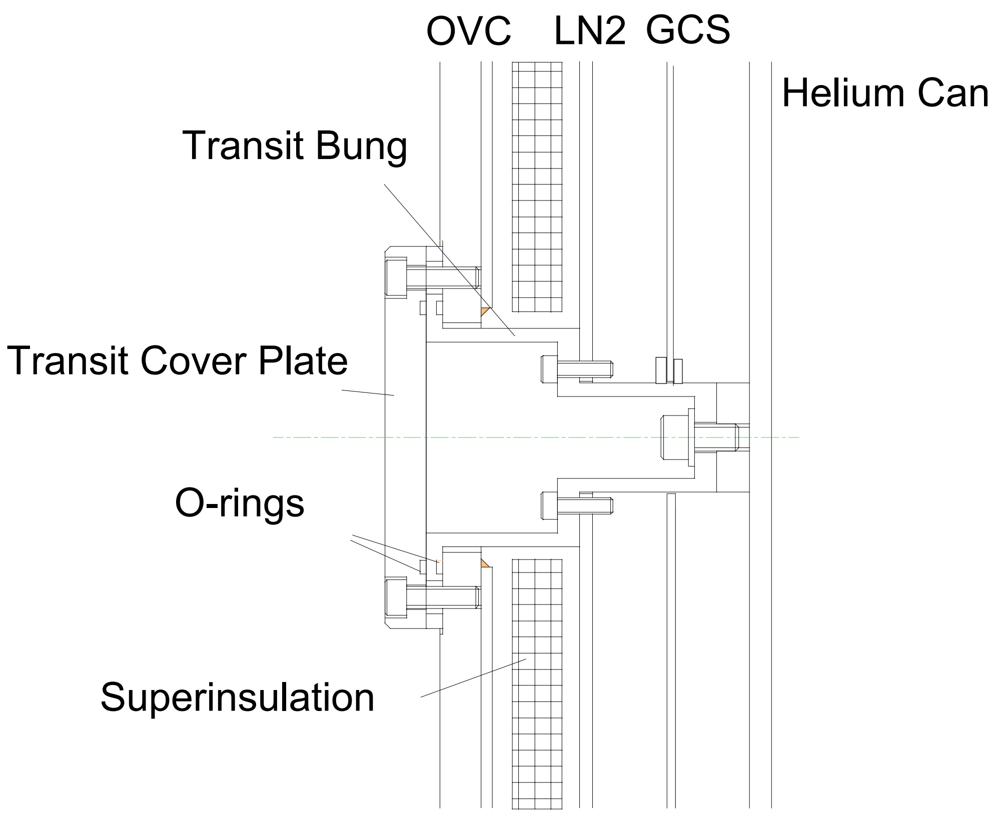
Model E7001 provides the additional facility of an automatic and manual dump of a B0 shield coil (if fitted to the magnet).

5. DE-TRANSITING THE MAGNET

a) General

When the magnet has been warm shipped the internal can of the cryostat will be secured with the aid of bungs inserted into the cryostat via holes in the end flange. These bungs need to be removed and replaced with caps before the system can be cooled down. Figure 5.1 shows how a transit bung typically mounts in a cryostat.

Figure 5.1 Transit Bung Shown in Location



The cryostat will normally be shipped under vacuum, before the bungs can be removed the vacuum space should be purged with nitrogen gas. NOTE : as the vacuum space is purged the end flanges of the cryostat tend to bulge out which will cause damage to any room temperature shim or gradient set which is bolted tightly to the end flanges of the cryostat, therefore before purging the vacuum space any assembly mounted off the end flanges of the cryostat should be loosened.

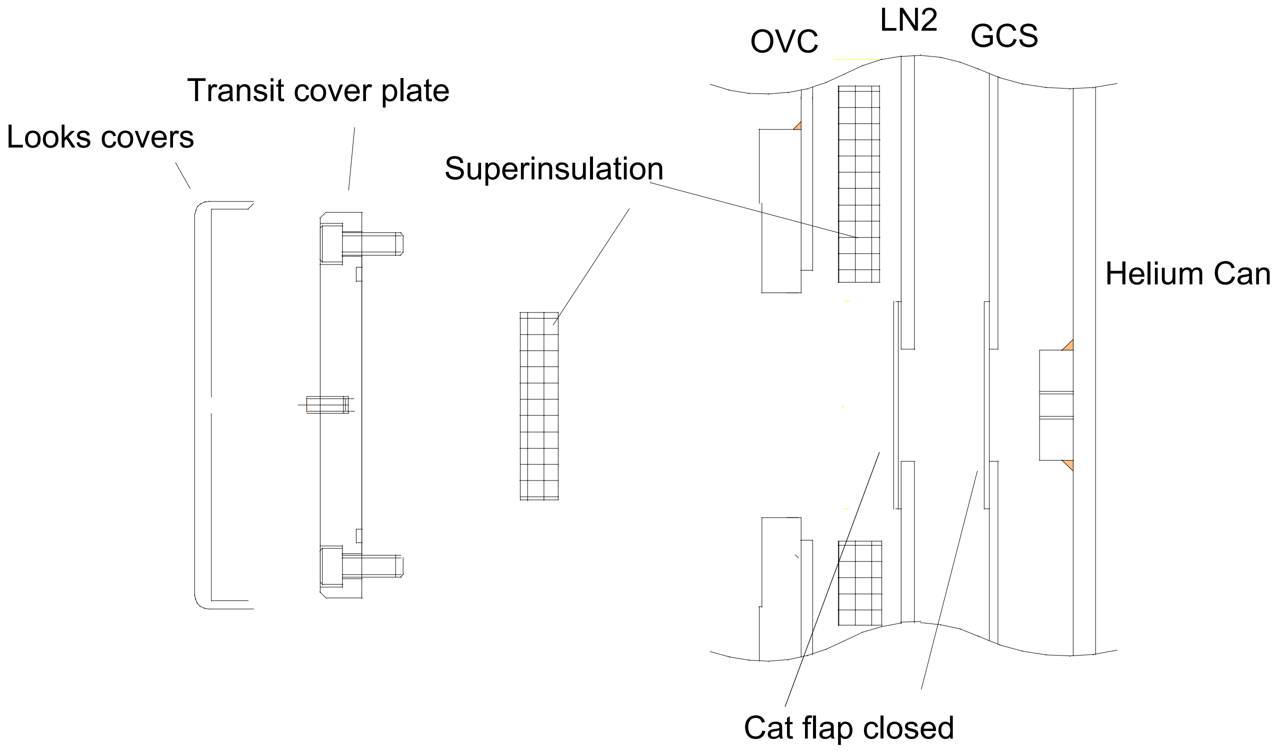
b) Purging the Vacuum Space

The cryostat is usually sealed with a 47mm diameter brass bung. A special tool is reqired to remove the bung and allow connection to vacuum pumps.

The tool is fitted to the cryostat with an NW50 O ring and clamp arrangement. Once the tool is fitted, the nitrogen gas source should be connected to the NW40 port of the pump out tool. The tool has an M8 thread which should be screwed into the tapped hole in the brass bung. The bung can now be pulled out of the cryostat using the handle of the tool, this is likely to be very stiff and will require a great deal of force to achieve.

c) Removal of Transit Bungs

Figure 5.2 Transit Bung Removal



Once the vacuum space has been purged the transit bungs may be removed by unscrewing the eight M8 screws which hold each bung to the cryostat. This allows for the removal of a plate which is to be used to blank the holes once the bung is removed. The removal of the plate exposes four M6 and one M8 cap head bolts. All of these are to be unscrewed allowing for the removal of the complete bung. **Note: On the 9.4T' there is a key on the transit bung to lock into the GCS. This requires the bung to be rotated before it can be removed from the cryostat** When the bungs are removed the two shields of the cryostat can be seen. Flaps are attached to the GCS and Nitrogen can and should be turned to cover over the holes left by the bungs and then taped in place. (Fig 5.2).

These actions are important to prevent radiation from the outside of the cryostat falling onto the surface of the helium vessel.

After the flaps have been secured in position a patch of super-insulation should be placed over the hole left by the bung. The cover plates can now be positioned over the holes left in the cryostat end plate. In order to provide a vacuum tight seal the O-rings which were used to seal against the transit bungs should be cleaned and lightly greased before being inserted between the cover plates and the cryostat end plates.

The cryostat is now ready for evacuation.

NOTE:

Transiting of the magnet for shipment is a very important process and a small error could cause substantial damage to the system. For this reason it should only be under taken by a Magnex engineer or a competent engineer working under the strict guidance of Magnex Scientific

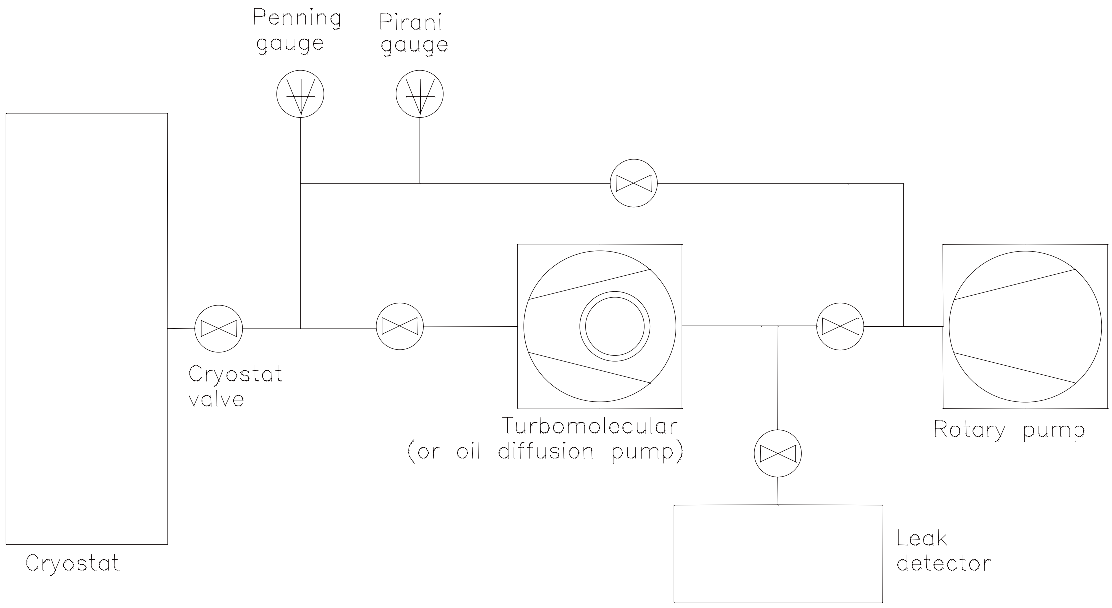
6. EVACUATING THE CRYOSTAT

Equipment Required:-

Rotary vacuum pump minimum capacity 22M^3/hour.
High vacuum pump of ultimate pressure 10^{-6} mbar.
(e.g. turbo-molecular pump or oil diffusion pump, 100 mm)
Helium mass-spectrometer leak detector.
Pirani and Penning Vacuum Gauges.
Fittings and pumping lines, preferably not less than 40 mm diameter.

The recommended pumping circuit is shown in figure 6.1.

Figure 6.1 Recommended Pumping Circuit



It is assumed that the system is fully assembled with all 'O' rings lightly greased and seated properly. If the system is warm then it is recommended that the vacuum space be flushed with dry nitrogen gas at least once in order to remove any traces of helium which may be present. To do this connect the rotary pump to the evacuation valve via a 'T' fitting and valve and evacuate to about 1 mbar. Close off the pump and admit dry nitrogen gas via the 'T' connection. A source of dry nitrogen gas is best derived from the boil off of liquid nitrogen from a storage vessel. This can easily be done by attaching a plastic line from the 'T' connector and dipping this into the neck of a storage vessel. Before admitting gas to the vacuum space purge the line by allowing gas to flow through until all the air is displaced from the tube. It will do no harm if some liquid is sucked up during the procedure as this will vaporise into the vacuum space. Try not to dip the tube to the bottom of the vessel as it may then pick up particles of solid moisture.

Allow the pressure to increase to 1 atmosphere with the dry nitrogen. Close off the 'T' connector to the nitrogen supply and begin pumping again.

Repeat this procedure, especially if it is suspected that helium has entered the vacuum space.

When the vacuum space is fully purged pump on it with the rotary pump to a pressure if .05 mbar. This should take 3 to 4 hours. Switch over to the high vacuum pump which should now be backed with the rotary pump. Continue pumping for about 48 hours but at least until the pressure is less than 1×10^{-3} mbar. During this time the helium mass- spectrometer can be attached at the point indicated in the diagram and leak detecting carried out to check if any leaks exist.

It is recommended that pumping be continued during the nitrogen pre- cool stage. This allows continuous monitoring of the pressure and leak detection when the vessels are cold. Once the liquid helium transfer is started however pumping should be discontinued as the helium vessel will begin to cryopump and can act as a more efficient pump than those being used to evacuate the cryostat. If this occurs the space can become contaminated by flow of gas and oil vapour backwards through the pumping set.

7. LIQUID NITROGEN PRE-COOL

The liquid nitrogen pre-cool is a procedure that is used in order to cool the magnet, liquid helium vessel and liquid nitrogen vessel down to a temperature of 77K. During the pre-cool process liquid nitrogen is transferred in the liquid helium vessel and the liquid nitrogen vessel.

The Liquid Nitrogen Pre-cool of the system is a very important process and a small error could cause substantial damage to the system due for example to a large build up of pressure. For this reason it should only be undertaken by a Magnex Engineer or a competent engineer working under the strict guidance of Magnex Scientific

8. FLUSHING HELIUM RESERVOIR

Equipment required:

Helium gas bottle with pressure reducer
Dial gauge -1 bar to +1 bar
1/2" diameter blow-out tube
Rotary pump of minimum capacity 16 M^3/hour
Mass-spectrometer leak detector
'T' piece connector with valve

Once the helium reservoir is cooled to 77K the liquid must be removed to allow the helium transfer. It is recommended but not essential that the pressure in the helium vessel, above the liquid nitrogen be reduced to approximately 200 mbar. This has the effect of supercooling the liquid and magnet. When the liquid nitrogen is supercooled it is more easily removed from the vessel, also because the magnet will now be at a lower temperature (typically 70K) the helium transfer will be more efficient.

Ensure that the quench valve is in place and its 'O' ring is in good condition. Ensure also that the Graphite bursting disc is in place and that a backing plate is incorporated. The backing plate is essential to prevent the disc from bursting inwards. If there is no backing plate then close off the burst port with a metal disc seated on the 'O' ring to give a vacuum tight seal.

Insert the bungs into the two lead entry ports and siphon entry port connect the dial gauge to the valve on the 'T' piece. Check that all these items are secure and a gas tight seal is made.

Connect the rotary pump to the normal vent port via a 'T' piece to the NW 25 fitting provided. Begin pumping and monitor the pressure on the dial gauge. The pumping time will depend on the size of the pump used and the amount of liquid nitrogen. Do not let the pressure fall below 200 mbar as the liquid nitrogen will begin to solidify below this pressure.

After pumping, allow the pressure to rise by admitting helium gas to the vessel through the 'T' piece.

The liquid can now be removed from the helium vessel by inserting the blow out tube into the siphon cone and pressurising the helium vessel with helium gas. The siphon cone has a 10 mm thread and the blow out tube is threaded to match. Ensure that the tube is properly engaged in the thread so that a good seal is made. The tube should be rotated at least several turns into the thread.

Connect a flexible plastic tube to the top end of the blow out tube to direct the liquid into a suitable container. Pressurise the helium vessel with helium gas to a few psi (5 psi maximum) until liquid is seen to issue from the tube. Maintain the pressure in the vessel until all the liquid has gone as indicated by cold gas issuing from the tube with no trace of liquid. Continue to allow gas to purge through the tube for several minutes to ensure all traces of liquid have been removed.

Once the liquid has gone remove the blow out tube and replace it with the plug. Evacuate the helium vessel this time to a pressure of about 1 mbar. It is recommended that the helium level probe be connected and energised at this point, leave it on the 10 second rate. This will have the effect of ensuring all traces of liquid nitrogen which may be trapped within the probe are vaporised. Small droplets of solid nitrogen remaining in the helium level probe can upset it's operation. Watch the pressure reduce on the dial gauge. A pause or reduction in the rate of decrease of pressure at about 90 to 120 mbar indicates that some residual liquid remains and is solidifying. If this is suspected stop pumping, vent to helium gas and try the blow out procedure again.

Once the helium vessel is evacuated admit helium gas to 1 atmosphere. Repeat this flushing procedure at least once to ensure all residual traces of nitrogen have been removed.

9. <u>HELIUM TRANSFER</u>

Equipment required:

Liquid helium (amount required specified in magnet manual)
1/2" diameter. transfer siphon
Helium gas bottle with pressure reducer
Resistance measuring equipment for monitoring magnet temperature (4 wire, approximately 300 ohm to 4.5K ohm, 100 micro A excitation

With the helium can purged of nitrogen and filled with one atmosphere of helium gas insert the leg of siphon into the siphon entry port. At the same time insert the other leg of the siphon into the storage dewar. Both vessels should be vented.

Lower both the legs slowly into their respective vessels, until the leg in the cryostat enters the siphon cone, and the leg in the storage dewar reaches the bottom.

Ensure that the leg in the cryostat is firmly seated in the siphon cone, lift the leg in the storage dewar about one inch above the bottom. Tighten the retaining nuts to give a gas tight seal.

Close off the vent in the storage dewar so that the pressure begins to rise. Admit helium gas to increase the pressure to 2 or 3 psi. Cold helium gas should be seen to emerge from the vent in the cryostat. A flow rate of 3 to 5 1/min. will give optimum cooling, the plume of cold gas should extend several feet from the vent.

Continue to transfer and monitor the carbon resistance thermometer attached to the magnet (see the wiring diagrams for the connections). When the magnet has reached 4.2K indicated by the carbon resistors (Allen Bradley) approaching 4.0K ohm resistance and a decrease in the plume length from the vent, liquid is being transferred and the pressure in the storage dewar can be increased to 5 psi maximum.

10. ENERGISING THE MAGNET

This procedure assumes the magnet is properly cooled and full with liquid helium. The procedure is based on using a Magnex Scientific magnet power supply E1030 or E1001 however whatever supply is used many of the procedures listed below are extremely important.

1) Identify the following items :

   De-mountable current lead
   De-mountable shim lead
   Main current cables
   Shim current cable
   Electrical service cable
   Siphon shorting pin and inserting tool
   Nut washer and 'O' ring for main current lead
   Nut washer and 'O' ring for shim current lead

2) Position the power supply at a safe distance from the magnet, in a field of less than 50 Gauss. Choose the position such that the power supply can be removed from the room without it going too close to the magnet. The distance from the magnet should not be so far that the cables will not reach.

3) Check that the electrical mains requirement for the power supply is set for the mains voltage available. Make sure the power supply is turned off and the main switch heater is turned off.

4) Check that the terminals on the main current lead are not shorting, either to each other or the outer tube of the lead.

5) Connect the main current cables to the copper lugs, note that the cables have different sized crimped ends to distinguish positive and negative. Ensure that the correct size crimped end goes to the correct copper lug determined by the stud diameter.

6) Connect the copper lugs to the terminals on top of the current lead. Spring apart with a screw-driver if necessary, and ensure that the locking screw is firmly tightened. Check that the lug is firmly gripping the copper and brass terminal on the lead. Check that the studding or cable ends are not touching thereby creating a short.

7) Connect the other end of the cables to the lugs on the rear power supply unit. Observe the correct polarity determined by the stud diameter.

8) Position a NON MAGNETIC ladder or stool near to the cryostat, if necessary, to be able to reach the service entry ports comfortably.

9) Remove the bung from the shim lead for entry port and move the nut washer and 'O' ring from the bung onto the shim lead. Do not leave the port open to atmosphere for more than a few seconds as air will condense in the port and will lead to a blockage. Push the lead in gradually so as to avoid too large a rush of cold gas. When the lead is felt to touch the connector at the bottom then gently rotate the lead until it is felt to engage in the keyways. Do not apply downward pressure while rotating the lead to find the keyways. DO NOT ROTATE THE LEAD ONCE ENGAGED. Push the lead home and tighten the nut to effect a gas tight seal. Check that neither of the copper lugs on the main current lead.

10) Switch on the magnet power supply.

11) Connect the S/C shim cable between the magnet and the power supply.

12) Operate the shim switch heater button. The LED should light up indicating that the shim switch is working.

13) Repeat step 12 for each of the eight shim channels using selector switch. If the LED fails to light up then this could mean that shim lead is not properly engaged. If the lead cannot be made to engage then it should be removed from the cryostat and warmed up before re attempting the procedure. Ensure the connecting pins are completely dry before re-insertion.

14) Remove the bung from the main current entry port and move the nut washers and 'O' ring from the bung to the main current lead . Do not leave the port open to atmosphere for more than a few seconds as air will condense in the port and will lead to blockage.

Push the lead down gradually. Cold helium gas will emerge from the entry port. If the rush of gas becomes too great then hold the lead steady, or retract it a few inches, until the rush of gas decreases. Finally when contact can be felt with the male connector in the cryostat push the lead home. The length of the male pin in the cryostat is 50 mm. Ensure that the lead is pushed fully home so that contact is made over the whole length.

15) Rotate the lead gently so that the cables and exhaust port do not touch the shim lead. Tighten the nut so as to effect a gas tight seal. DO NOT USE FORCE TO ROTATE THE LEAD.

16) Connect the 9 way D type cable between the emergency discharge unit and the magnet power supply unit.

17) Determine if the magnet has a B0 shielding / stabilisation coil, this can be found in the system operating data manual which contains information specific to a particular magnet system. Looking at the Electrical Diagram of the Service Turret Connector, the B0 coil, if fitted will normally be found on pins U and V.

18) Ensure power supply mode is set to 'MAGNET'.

19) Press the 'DC ON' button, the power supply should indicate that the DC supply is on.

20) Switch the shim channel selector to the Z2/Z4 channel and open the shim switch.

21) Open the main switch by turning the key. The LED above the key should now light up.

22) Turn on the B0 switch (if the magnet has one), a current of typically 60 mA is required to do this. The E7001 B0 / Quench unit has a button which allows manual operation of the B0 coil. It is extremely important that if a B0 switch is open during the energisation procedure. If the operator is unsure if the B0 switch is working, energise the magnet for about 5 amps with the B0 switch closed, the effect of opening the B0 switch can be seen by looking at the voltage across the magnet terminals, (a voltage kick will be seen).

23) The rate at which the current is increased and therefore the rate at which the magnet is energised is controlled by the magnet power supply. A Model E1001 power supply has a switch labelled 'RAMP RATE' which controls the rate of increase of current. A Model E1030 power supply controls the rate of energisation by limiting the inductive voltage across the magnet using the 'voltage limit' potentiometer. Select the recommended rate as indicated in the magnet manual.

24) Press the 'SET' button, the current should start to rise at the selected rate. Monitor the output voltage. It should begin to rise reaching a steady positive value after 5 minutes or so. This is the inductive voltage driving the current into the magnet. A typical starting voltage of 1.5 to 2V is normal. At higher fields it is usual to reduce the rate and so the voltage. Note however that as current increases the lead-drop increases also. To see only the magnet voltage look at the 'external' voltage not the 'internal' .

25) As the magnetic field increases monitor the current and magnetic field. Observe the recommended rates for running the magnet as described in the manual. Also monitor the voltage at the terminals (internal and also on the 'TEST' lead).

26) The current will continue to rise until it reaches its limit which is set by the ten turn potentiometer labelled 'SET CURRENT'. When the current reaches the limit the central LED 'at set point' will light. It will be necessary to adjust the 'SET CURRENT' control to obtain the desired magnet current.

27) The recommended procedure for 'over-filling' is as follows:

Run the magnet to between 0.1% and 0.2% higher in current than that given for full field. Leave the switch open for 1 or 2 minutes once the current is reached. Before closing the switch run the current down to the correct value and leave for 5 minutes.

The over-fielding procedure is not essential but omitting this could result in a field drift for about 1 week of about 0.5 ppm/hr. The ultimate drift will not be affected.

28) Once the magnet has been at the correct current for about 5 minutes the switch can be closed by turning off the switch heater at the key-switch. Note the voltage at the magnet (external).

This voltage should have reduced to a few millivolts. The switch will not close if this voltage is more than 30 or 40 mV. As the switch closes and becomes superconducting the residual voltage can be seen to reduce to zero (the sign of the residual voltage can be positive or -negative depending on whether the magnet has been running up to field or down from over field).

29) The current can now be run down in the leads leaving the magnet in 'persistent mode'. Select a sweep rate of between 10 and 20 amps per minute (for example 10%/minute) and press the zero button. Watch the voltage on the magnet (external). This should remain at zero. If this voltage begins to increase in the negative direction then it indicates that the switch is not closed and the magnet is beginning to run down. If this happens then press 'set-point' again so that the current runs back up to the recommended value. Then wait a little longer for the switch to close, and try again to run down the leads.

30) When the current reaches zero connect an electrical short across the terminals of the power supply and press the DC off button. Wait for the DC off light to illuminate and turn off the mains switch. The function of the short is to guard against any voltage spikes appearing at the magnet terminals which might cause the switch to open.

31) Switch off the B0 coil (if there is one).

32) If the system has a shorting pin/plug then it will be provided with a tool to which it screws. The tool allows the pin to be inserted or removed from the cryostat. Remove the bung from the siphon port and insert the

pin using the tool provided. Do not push it home too quickly, allow it to be cooled by the outgoing gas before pushing it fully home. Unscrew the rod and withdraw it. Replace the bung.

33) The main current lead can now be withdrawn. Loosen the black nut (it may be necessary to leave it to warm first if a plug of ice has formed around it).

Pull vertically upward on the lead and withdraw it fully. Quickly replace the nut and baffles so that air does not condense in the entry port. Wear gloves during the operation as it will be necessary to hold the body of the cold lead.

34) If superconducting shimming is to be carried out then the shim lead can remain in place. If shimming is complete or to be carried out at a later date then remove the shim lead as follows :

Disconnect the electrical plug from the top of the lead. Undo the black seal nut. Pull vertically on the lead to disconnect it. DO NOT ATTEMPT TO ROTATE THE LEAD AS THIS WILL DAMAGE THE CONNECTOR INSIDE THE CRYOSTAT. Remove the lead completely and replace the baffles quickly so as to avoid air condensing in the entry port. Tighten the black seal nut to effect a gas tight seal.

Occasionally the lead can be difficult to remove due to the formation of ice around the connector. In this case a moderate amount of leverage can be used to dislodge the lead. The leverage can be effected by a bar of suitable non magnetic material wedged against the top of the main current lead port and underneath the horizontal exhaust port of the shim lead. USE ONLY A VERTICAL FORCE. In severe cases it will be necessary to connect a source of pure helium gas to the exhaust port of the lead. The gas is arranged to flow into the exhaust port of the lead, down the lead body and into the cryostat. The gas will eventually exit from the main exhaust port of the cryostat.

The effect of this gas flow will be to warm up the connector and eventually to disperse the ice around the bottom connector. This will only be effective if the helium level is below the connector.

35) After removal of all the leads a final check should be made that the cryostat is properly fitted with the non-return valve and that all exhaust ports are correctly sealed. Check the following:-

a) Main current baffles are in and sealed properly by tightening the black seal nut.

b) Shim baffles are in and sealed properly by tightening the black seal nut.

c) Siphon baffles are in and sealed properly by tightening the black seal nut.

d) The non-return valve (or helium recovery line) is connected to the main exhaust port.

e) The 'Quench Valve' is seated properly.

f) The burst disc is correctly seated and making a gas tight seal.

11. OPERATING THE SUPERCONDUCTING SHIMS

The superconducting shims are served by two current circuits. The first circuit serves the Z1, Z2, X, Y, ZX, ZY, XY and X^2-Y^2 shims. The second current circuit serves the Z3, Z4, Z^2X, Z^2Y, X3, Y3, ZXY and $Z(X^2$-$Y^2)$ shims. The number of shims and their strengths is given in the magnet operating manual. The shim switches are operated in eight pairs, Z1 & Z3, Z2 & Z4, X & Z^2X, Y & Z^2X, ZX & X^3, ZY & Y^3, XY & ZXY and X^2-Y^2 & $Z(X^2$-$Y^2)$.

Adjusting the superconducting shims

1) Slowly insert superconducting shim lead.

2) Ensure shim switch heater button is NOT depressed.

3) Connect S/C shim cable between magnet and power supply.

4) Ensure power supply mode is set to 'SHIM'.

5) Connect a short across the main (magnet) output terminals of the magnet power supply.

6) Switch on the magnet power supply.

7) Ensure the 10 turn pots controlling BOTH shim current channels are set to zero.

8) Press 'DC ON' button, power supply should now indicate that the DC supply is on.

9) If the system is fitted with a B0 coil then it is recommended that the B0 switch is open when the shims are adjusted (particularly the Z2 / Z4 shims).

10) Select the desired shim channel using the shim heater selector switch.

11) Carefully adjust BOTH shim current control pots to the old settings for the shim channel selected. IMPORTANT if a change of polarity is required ensure that current is at zero before operating the polarity switch.

12) Use the DPM switch to monitor the current flowing in both channels.

13) Turn on the shim switch heater.

14) Slowly adjust the shim current control pots to set the new shim current in both current channels.

15) Wait at least 5 seconds for the shim current to stabilise, the Z2 and Z4 shim channels may require much more time to settle, watch the field to check shim has stabilised.

16) Switch off the shim switch heater.

17) Wait at least 10 seconds for the switch to cool.

18) If another shim requires adjustment go back to step 10.

19) When all the adjustments have been made, use the shim current control pots to set the currents in both channels back to zero.

20) If no more adjustments are to be made then press 'DC OFF'.

21) The SC shim lead can now be removed from the magnet.

12. PLOTTING AND SHIMMING

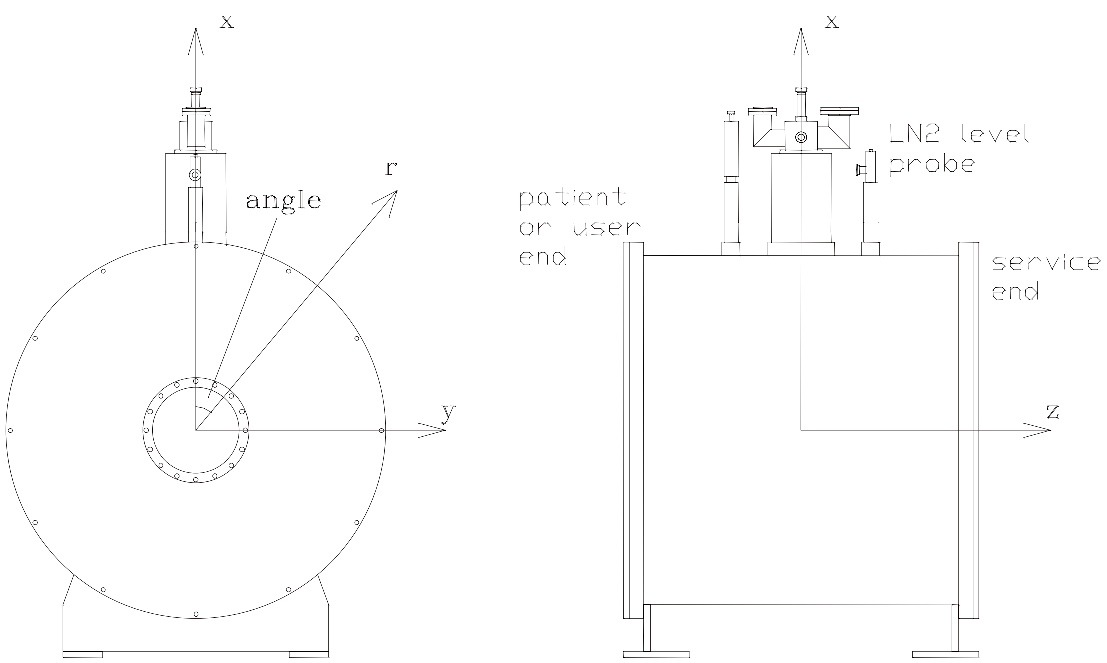
Equipment Required

1. Plotting Rig (used to position the field measuring probe)
2. Field Measuring Equipment (such as a Metrolab)
3. Field Analysis program (such as MULTI)
4. Calibration of shim strengths (usually found in manual)

12.1 Plotting

Plotting consists of measuring the strength of the magnetic field at various points over the central region of the magnet. Plotting is usually based on the cylindrical co-ordinate systems with the z (axial) ordinate coinciding with the magnet axis and the r radial ordinate representing the distance of a point from the magnet axis. Magnex convention has the angular position of a point measured clockwise from the vertical. Figure 12.1 shows this co-ordinate system.

Figure 12.1 Plotting Co-ordinate System



Plotting is normally performed over a series of 'planes' or circles (usually seven or twelve), each plane has a distinct axial and radial co-ordinate. On each plane the field is measured at a series of equally spaced angular positions (normally every 30 degrees). Magnex chooses to measure the field over points on the outside of a spherical volume, the chosen axial and radial positions for each plane of a seven or twelve plane plot are given below as a proportion of the radius of the spherical volume.

Seven plane plotting positions (as a proportion of the spherical radius)

Plane	Axial Position	Radial Position
1	0.949	0.315
2	0.742	0.671
3	0.406	0.914
4	0.0	1.0
5	-0.406	0.914
6	-0.742	0.671
7	-0.949	0.315

Twelve plane plotting positions (as a proportion of the spherical radius)

Plane	Axial Position	Radial Position
1	0.982	0.191
2	0.904	0.428
3	0.770	0.638
4	0.588	0.809
5	0.368	0.930
6	0.125	0.992
7	-0.125	0.992
8	-0.368	0.930
9	-0.588	0.809
10	-0.770	0.638
11	-0.904	0.428
12	-0.982	0.191

Figure 12.2 **7 Plane Plotting sheet**

Project # _______ Magnet Type _______ Date _______ Plotting Radius _______ Base Field _______ Plot # _______ Tested by ______

	Z1	Z2	Z3	Z4	X	Y	ZX	ZY	XY	X2-Y2	Z2X	Z2Y	ZXY	Z(X2-Y2)
Shim setting (amps)														
Pot setting														

PLANE	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Axial position	0.949	0.742	0.406	0	-0.406	-0.742	-0.949
Radial position	0.315	0.671	0.914	1.0	0.914	0.671	0.315

Plane / Angle	**1**	**2**	**3**	**4**	**5**	**6**	**7**
0							
30							
60							
90							
120							
150							
180							
210							
240							
270							
300							
330							
360							

Figure 12.3 **12 Plane Plotting sheet**

Project # _______ Magnet Type _______ Date _______ Plotting Radius ______ Base Field ______ Plot # _______ Tested by ______

	Z1	Z2	Z3	Z4	X	Y	ZX	ZY	XY	X2-Y2	Z2X	Z2Y	ZXY	Z(X2-Y2)
Shim setting (amps)														
Pot setting														

PLANE	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Axial position	0.982	0.904	0.770	0.588	0.368	0.125	-0.125	-0.368	-0.588	-0.770	-0.904	-0.982
Radial position	0.191	0.428	0.638	0.809	0.930	0.992	0.992	0.930	0.809	0.638	0.428	0.191

Plane / Angle	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
0												
30												
60												
90												
120												
150												
180												
210												
240												
270												
300												
330												
360												

Figures 12.2 and 12.3 show the empty plotting sheets used to note down the magnetic field measurements for seven and twelve plane plots respectively.

It is important when doing a plot that the magnet centre is accurately known as all measurements are made relative to this point. The position of the centre should be determined by careful measurement of the distance from one of the magnets end flanges. This point should coincide with the position of null deflection of the Z shim.

12.2 Field Analysis

The computer programme MULTI analyses the plotted data into amounts of particular shim functions which characterise the inhomogeneities in the magnetic field.

The first part of the programme allows data input and correction, it also provides the opportunity to write the measured data to a file. The programme requires the input of the field values in integers. As the analysis only requires relative field values it is not necessary to type in (or write down) the total field value for each point.

The second part of the programme displays the amounts of each particular shim function evaluated at a spherical radius chosen by the operator (as the magnitude of a particular shim function varies with radius it is necessary to give the evaluation radius when expressing the amount of a shim function). The spherical radius for output is normally chosen to be the same as the radius chosen in the calibration of each shim.

The final part of the programme (error analysis) shows the variation of each point from the mean field either with or without a set of shims (chosen by the operator). This part of the programme is useful in showing up any errors in the data and also gives an estimate of the peak to peak homogeneity assuming all the shims were perfectly set. There is little point in continuing to adjust the shims if the actual peak to peak measurement is close to the theoretical ultimate homogeneity predicted by the programme.
A sample run of the program MULTI is shown below.

```
      **********************************************************
      *                                                        *
      *                     MULTI                              *
      *                                                        *
      *         Multi-plane field analysis programme           *
      *                                                        *
      *         Version 2.2                 13-08-93           *
      *                                                        *
      *                MAGNEX SCIENTIFIC LTD                   *
      *                                                        *
      *                11-19 Blacklands Way                    *
      *               Abingdon Business Park                   *
      *         Abingdon    Oxfordshire OX14 1DY    ENGLAND    *
      *     TEL : 0235 534488         FAX : 0235 554917        *
      *                                                        *
      **********************************************************


type 1 to input from file
```

```
type 2 to type in a 7 plane plot
type 3 to type in a 12 plane plot
type 0 for all other cases
2
```

Offers choice of input

```
input centre field in Tesla (or MHz)  0.5026
```

```
input field unit in micro Tesla (or Hz)  1
```

Would be 0.1 if last figure on Metrolab was used

```
input plotting radius  20
```

Spherical radius over which magnet has been plotted

```
   PLANE  1

integer field value for   0 degrees   46
integer field value for  30 degrees   46
integer field value for  60 degrees   46
integer field value for  90 degrees   46
integer field value for 120 degrees   47
integer field value for 150 degrees   48
integer field value for 180 degrees   48
integer field value for 210 degrees   46
integer field value for 240 degrees   44
integer field value for 270 degrees   44
integer field value for 300 degrees   45
integer field value for 330 degrees   46
integer field value for 360 degrees   46

   PLANE  2

integer field value for   0 degrees   46
integer field value for  30 degrees   42
integer field value for  60 degrees   43
integer field value for  90 degrees   48
integer field value for 120 degrees   52
```

etc.

```
                  PLOTTED DATA                    MULTI  Version 2.2
                  ************
 Base field :    .5026          Field units :    1.0

PLANES     1        2        3        4        5        6        7

   Z    18.98    14.83     8.12      .00    -8.12   -14.83   -18.98
   R     6.30    13.42    18.28    20.00    18.28    13.42     6.30

  0        46       46       46       45       46       47       49
 30        46       42       40       41       44       47       49
 60        46       43       41       40       43       46       48
 90        46       48       48       45       44       44       47
120        47       52       53       50       47       45       46
150        48       53       53       51       49       46       46
180        48       46       45       48       48       47       47
210        46       39       38       42       48       46       47
240        44       39       37       41       49       47       48
270        44       43       42       46       49       48       49
300        45       47       49       52       48       45       49
330        46       49       51       49       46       46       49
360        46       46       46       45       46       47       49


Type plane number to edit plane   0 = continue analysis    -1 = write to file
-1
```

Offers chance to edit data

```
input file name
temp.dat
```

Saves plotted data to a file

```
Input radius of sphere for output
```

```
20
```

Evaluation radius
Should be the same as the radius at which the shim strengths are expressed.

```
Evaluation of coeficients at a radius of  20.000      MULTI  Version 2.2
AXIAL GRADIENTS                               Filename : temp.dat
Z 1    =    -1.73 ppm
Z 2    =     1.07 ppm
Z 3    =      .69 ppm
Z 4    =     1.16 ppm
Z 5    =    -1.86 ppm
Z 6    =     1.06 ppm
TRANSVERSE GRADIENTS
X      =    -1.37 ppm          Y      =      .54 ppm
ZX     =      .39 ppm          ZY     =     2.93 ppm
X2Y2   =      .26 ppm          XY     =    -3.41 ppm
Z2X    =      .43 ppm          Z2Y    =      .75 ppm
ZX2Y2  =      .02 ppm          ZXY    =    -1.22 ppm
X3     =     -.01 ppm          Y3     =      .05 ppm
Z3X    =     -.88 ppm          Z3Y    =     -.56 ppm
Z4X    =      .15 ppm          Z4Y    =     -.30 ppm
Z2X2Y2=       .05 ppm          Z2XY   =      .02 ppm    HIT RETURN

        ******************************************************
        *                                                    *
        *      Analysis stored in file ANALYSIS.DAT          *
        *                                                    *
        *   (use PRINT command in DOS for hardcopy output)   *
        *                                                    *
        ******************************************************

                        Hit Return
```

Shows variation of data from average

MEASURED VARIATION (ppm)

PLANES	1	2	3	4	5	6	7
0	-.1	-.1	-.1	-2.1	-.1	1.9	5.9
30	-.1	-8.1	-12.0	-10.0	-4.1	1.9	5.9
60	-.1	-6.1	-10.0	-12.0	-6.1	-.1	3.9
90	-.1	3.9	3.9	-2.1	-4.1	-4.1	1.9
120	1.9	11.8	13.8	7.9	1.9	-2.1	-.1
150	3.9	13.8	13.8	9.9	5.9	-.1	-.1
180	3.9	-.1	-2.1	3.9	3.9	1.9	1.9
210	-.1	-14.0	-16.0	-8.1	3.9	-.1	1.9
240	-4.1	-14.0	-18.0	-10.0	5.9	1.9	3.9
270	-4.1	-6.1	-8.1	-.1	5.9	3.9	5.9
300	-2.1	1.9	5.9	11.8	3.9	-2.1	5.9
330	-.1	5.9	9.9	5.9	-.1	-.1	5.9
360	-.1	-.1	-.1	-2.1	-.1	1.9	5.9

```
     31.83 ppm peak to peak                                          HIT RETURN

 The following shim functions will be subtracted  1=yes 0=no
1   Z1 : 1                 11      X & Y    : 1
2   Z2 : 1                 12     ZX & ZY   : 1
3   Z3 : 1                 13  X2Y2 &  XY   : 1
4   Z4 : 1                 14    Z2X & Z2Y  : 1
5   Z5 : 0                 15  ZX2Y2 & ZXY : 1
6   Z6 : 0                 16     X3 & Y3   : 1
                           17    Z3X & Z3Y  : 0
                           18 Z2X2Y2 & Z2XY: 0
```

Choose which shims will be adjusted when calculating the theoretical homogeneity

```
Input reference number of shim to be used/not used
Type 0 to continue with analysis (-1 to exit error analysis)
0
```

THEORETICAL VARIATION (ppm)

PLANES	1	2	3	4	5	6	7
0	-1.2	.5	1.6	-.6	.6	1.1	3.2
30	-.8	-1.2	.2	-.2	-.4	1.0	3.2
60	-1.9	-.7	1.8	-1.3	-1.0	.1	1.7
90	-4.4	-.1	3.0	.1	-.6	-2.2	.5
120	-4.0	-.8	-.6	-.9	1.3	.1	-1.1
150	-.4	2.9	-1.0	-1.5	2.3	.3	-1.7
180	4.0	1.3	-2.4	1.1	.8	-.4	-.9
210	4.4	.1	-.6	-.8	2.6	-4.6	-2.1
240	1.8	2.4	-.7	-2.1	4.3	-3.2	-.5
270	-.3	1.6	-2.9	-.5	2.3	.0	2.0
300	-1.6	-.7	-1.7	3.8	-.2	-3.9	2.8
330	-1.4	.7	1.3	-1.1	-2.4	-.7	3.2
360	-1.2	.5	1.6	-.6	.6	1.1	3.2

8.99 ppm peak to peak HIT RETURN

Theoretical homogeneity assuming the above shims were correctly set

```
The following shim functions will be subtracted  1=yes 0=no
1   Z1 : 1              11     X & Y    : 1
2   Z2 : 1              12    ZX & ZY   : 1
3   Z3 : 1              13  X2Y2 &  XY  : 1
4   Z4 : 1              14   Z2X & Z2Y  : 1
5   Z5 : 0              15  ZX2Y2 & ZXY : 1
6   Z6 : 0              16    X3 & Y3   : 1
                        17   Z3X & Z3Y  : 0
                        18 Z2X2Y2 & Z2XY: 0

Input reference number of shim to be used/not used
Type 0 to continue with analysis (-1 to exit error analysis)
-1

Type 1 if you wish to edit data (0 to end)
0
Stop - Program terminated.
```

12.3 Shim Adjustment

Using the analysis from the computer and a list of superconducting shim strengths (including polarities) the required adjustment of a shim channel can be calculated.

$$\text{Required change (amps)} = \frac{-\text{ size of gradient (ppm)}}{\text{strength of shim (ppm/amp)}}$$

The size of gradient and the shim calibration MUST be expressed on the same evaluation radius.

The polarity of each shim can be determined by setting the plotting probe to the following positions and noting in which direction the field moves when the current is changed in the direction given in the table (positive for all shims except Z2 and Z4).

If the field moves upwards the polarity of the shim is positive.
If the field moves downwards the polarity of the shim is negative.

Shim	Axial Position	Radial Position	Angle	Change of current
Z1	R	0	0	positive
Z2	0	R	0	**negative**
Z3	R	0	0	positive
Z4	R	R	0	**negative**
X	0	R	0	positive
Y	0	R	90	positive
ZX	R	R	0	positive
ZY	R	R	90	positive
XY	0	R	45	positive
X2-Y2	0	R	0	positive
Z2X	R	R	0	positive
Z2Y	R	R	90	positive
X3	0	R	0	positive
Y3	0	R	30	positive
ZXY	R	R	45	positive
Z(X2-Y2)	R	R	0	positive

The exact value of R is not important, normally R is chosen to be the spherical radius over which the shim strengths are defined.

Setting shims by eye

Adjustment of shims such as X Y and Z are usually best set by 'eye'. This is best done after all the higher order shims have been set. The X Y and Z shims should each be set by looking at two points close to, equidistant and either side of the magnet centre. The shim in question should be adjusted to make the two points have the same field value.

For example for a magnet whose homogeneity is defined over a 20 cm radius could use the following points.

X shim	(x = +4cm y = 0cm z = 0cm)	and	(x = -4cm y = 0cm z = 0cm)
Y shim	(x = 0cm y = +4cm z = 0cm)	and	(x = 0cm y = -4cm z = 0cm)
Z shim	(x = 0cm y = 0cm z = +4cm)	and	(x = 0cm y = 0cm z =-4cm)

13. TOP-UPS AND GENERAL MAINTENANCE PROCEDURES

a) General Maintenance

Daily

Check cryogen levels to see whether refills are required. It is good practice to keep a log of cryogen use, an increase in consumption over a period of time may be the first sign that the vacuum space needs to be re-pumped.

Weekly

The operation of the non-return valve should be periodically checked to see that no leaks exist which would result in air condensing inside the neck. Check also that all the fittings on the top stack are properly sealed and that the 'O' rings and bursting disc are intact. Check the compressor pressure. Check the vent ports for the nitrogen vessel are free of ice.

WARNING Only Magnex Scientific approved replacement parts should be used in order to ensure the integrity of the working system.

b) Liquid Helium Top-Ups

Anybody about to attempt a helium top-up on the system should be aware of the following points:

a) USE ONLY NON-MAGNETIC TRANSPORT VESSELS

b) Absolutely no air must be allowed to get into the helium reservoir during the operation.

WARNING It is quite common for the helium boil-off to fall to zero immediately after a transfer or after magnet energisation. There is then a serious risk of air entering the helium reservoir. However if the procedures detailed below are followed correctly any associated problems can be avoided.

c) The transfer siphon must be pre-cooled with liquid helium before inserting it into the refilling port. This applies to refills only and it is not necessary for the initial filling of the system.

WARNING: There is a significant risk of quenching the magnet if the siphon is not pre-cooled before a top-up.

d)There is no need to connect the siphon into the socket as for initial filling.

Before a top-up the refill volume for the system should be determined, refer to the System operating data manual for information about volumes of cryogen required for installation and refilling and evaporation rates..
Before starting the transfer, remove the seal fittings from the siphon fill port (three components) and quickly replace them with a temporary plug to keep air out of the system. A rubber bung of the right size or a tight wad of tissue paper is convenient for this purpose. Push the compression nut, the brass washer and the o-ring,, onto the leg of the siphon which will go into the cryostat. Push them to the top of the leg (the junction with the right-angled bend).

Pre-cooling the siphon : Insert the other leg of the transfer line, with an extension piece fitted, into the storage dewar; close off the vent of the dewar and slowly push the siphon down into the liquid. The pressure in the dewar will rise as some liquid boils. Keep the pressure down to about 0.1 bar at this stage, venting the storage dewar as necessary. The helium vapour exiting from the cryostat leg will make a regular 'chuffing' sound. After some time (about 1 to 3 minutes) the vapour will become denser, more opaque, and the pulsing sound of the exhaust will slow down and then stop, at which point liquid is emerging from the end of the siphon and immediately vaporising on contact with the air.

The siphon can now be inserted into the entry port of the helium reservoir (remove the temporary plug first!). If a check valve was fitted on the exhaust up to this point then it should be removed now. Carefully push the siphon down as far as it will go in the system, then pull it back upwards by 20 to 50 mm. Push the seal components down the siphon leg and tighten the compression seal. If the system is connected to a helium gas recovery line the line must be capable of taking a substantial flow, otherwise the transfer will be unacceptably slow or even completely stopped. If the line is too restrictive then it must be disconnected and the exhaust allowed to vent to the atmosphere.

During the transfer maintain the storage dewar pressure at about 0.2 bar over atmospheric. Check that the helium level in the system is rising at a reasonable rate, but note that the level gauge may not read correctly during the transfer. An accurate reading can often only be obtained if the transfer is temporarily stopped, by releasing the over pressure in the storage dewar. There is then no need to pre-cool the siphon again when the transfer is restarted provided the over pressure in the storage dewar is restored to 0.2 bar slowly, over one or two minutes.

A transfer rate of 100 litres per hour is reasonable, possible reasons for slow transfer rates are:

- air blockages in the siphon or the system itself;
- the siphon may be soft, or have a hard touch;
- the exhaust from the cryostat may be restricted.

Stop the transfer when the level probe shows the helium vessel is full. Remove the siphon from the cryostat and replace the plug in the siphon entry port. Ensure that the plug seats properly on it's 'O' ring to prevent leakage of air into the cryostat.

c) Liquid Nitrogen Top-ups

The liquid nitrogen reservoir must also be refilled regularly. There is no specific minimum level but some liquid should remain in the reservoir at all times. The level probe is of the capacitance type (depending on the difference in the dielectric constants of nitrogen liquid and gas) and is calibrated at the factory to read 0% when the reservoir is empty, and 100% when full (at the base of the filling ports).

To refill the reservoir a length of suitable transfer line and a non- magnetic storage dewar of suitable capacity will be required, preferably (but not necessarily) of the self-pressurising type. A regulated cylinder of helium or nitrogen gas will be needed if the dewar is not self-pressurising.

USE ONLY NON-MAGNETIC TRANSPORT VESSELS

The top-up procedure is very simple. Remove the non-return safety valve normally fitted on one of the ports of the system nitrogen reservoir: two ports will then be free. The liquid outlet of the storage dewar should then be connected to one of the free ports via the suitable transfer line and liquid nitrogen can then be transferred using a back-pressure in the storage dewar of about 0.2 to 0.3 bar (1.2 to 1.3 bar absolute pressure). The transfer should continue until liquid starts to overflow from the free port of the system nitrogen reservoir; this will take about 30 minutes on most systems.

If a pressurisable storage dewar is not available then it is possible to pour liquid into the reservoir via a non-magnetic funnel from a small nitrogen bucket. This is much less convenient and will take considerably longer but does allow a top-up to be performed in an emergency.

d) Re-evacuation of the Vacuum Space

The magnet must be de-energised to do the following procedure.

To check the vacuum in the cryostat a helium mass-spectrometer leak detector is required. Use only lines which have not been used for helium gas. Connect the mass-spectrometer to the vacuum port but do not open the valve. Evacuate the lines and set the mass-spectrometer registering the background level. Slowly open the valve to the cryostat and monitor the pressure and helium background level. A temporary increase in the level may be expected as the 'O' ring in the valve unseats and outgasses. This should recover in a minute or so.

e) De-icing the Neck

Should the neck become iced up for any reason then it is important to clear it. If the whole of the neck becomes blocked so that there is no passage for the helium gas to escape then a dangerous pressure build-up may occur in the vessel.

To de-ice the neck take a thin walled stainless steel tube (e.g. nitrogen blow-out tube) and connect it to a supply of pure helium gas.

If a helium gas bottle is used then use a long connecting line, approximately 15 metres. ON NO ACCOUNT BRING THE GAS BOTTLE WITHIN THE 10 GAUSS CONTOUR. Set a flow of helium gas through the tube and, when the air is judged to have been displaced insert the tube in turn into the iced-up parts. The helium gas will evaporate solid condensed air.

f) Procedures following a Quench or Bursting Disc Rupture

Following a quench or bursting disc rupture the neck of the cryostat should be checked for ice blockages, if blockages have occurred then the procedure described above should be followed. Once any blockages have been cleared the bursting disc should be replaced with a new disc of the same type. Ensure the O rings are correctly fitted to make the helium exhaust of the cryostat air tight.

g) Cryocooler Cold Head Replacement

Tools and equipment required :

1. Non magnetic metric hexagonal key set
2. Non magnetic spanners for high pressure gas lines
3. Blanking flange : He gas and regulator
4. 0-30 volts 3 amp PSU and connect cables
5. Rotary vacuum pump with 3M pumping line NW16 flanges

It is recommended that a complete tested replacement cold head is available to the service technician to minimise time spent on site and eliminate embarrassing problems. This means the unit with copper flanges, stainless steel flanges, heaters and sensors all fitted and wired to lead throughs.

1. Switch off compressor.
2. Disconnect power cable to cold head motor.

3. Disconnect gas lines.

4. Admit He gas into the vacuum space around the cold head. Remove the NW16 blanking flange to allow He gas to flow through the system. Pressure at the regulator less than 2 psi.

5. Connect the interface heaters (pins K-L) to the power supply. Pass 2 Amps through the heaters.

6. After approx. 30 minutes to remove screws from the main flange and check whether the interfaces have expanded sufficiently to release the cold head from the turret. Remove the unit. Fit blanking flange to turret to minimise water vapour ingress.

7. Remove the steel magnetic shield from the old unit and fit to the replacement.

8. Remove the blanking flange and check the fit of the new heat exchange interfaces. Adjust if necessary, then as quickly as possible fit the cold head in place to minimise the ingress of water vapour. The turret should not be left open to atmosphere for more than 30 seconds.

9. Clamp down the flange and pump out the vacuum space around the cold head to less than 2×10^{-1} mb.

10. Connect gas lines and power cable and switch on compressor. Check gas pressure on gauge on front of the compressor should be 20-22 bar when running, 14-16 bar static.

11. Check water flow through compressor heat exchanger must be greater than 5L/min.

12. Check temperatures of cold head 1st and 2nd stages. Should reduce to less than 80^{o}K and less than 20^{o}K within two hours.

    NB. Great care must be taken throughout this operation due to the high magnetic field in which the cold head is situated.

14. OPERATING THE EMERGENCY DISCHARGE UNIT

To operate the emergency discharge locate the red emergency button on the electronic cabinet. Lift the flap and press the button. Hold it down for 10 seconds or until the magnet is seen to quench.

The power supply in this unit is backed up with lead acid batteries which are on constant trickle-charge whilst mains electricity is connected. It is recommended that the battery level is checked regularly by pressing the green 'test' button. Both battery and 'heater' lights should illuminate indicating that the batteries are charged and the heater is connected.

See the Top-ups and General Maintenance section procedures for required actions following a quench.

15. TROUBLESHOOTING

CRYOGENIC PROBLEMS

Poor vacuum in OVC

High impedance pumping line	Shorten line or use line with larger bore
Defective pump	Rectify or replace
Outgassing from internal surfaces	Pump on gas ballast until clear
Leak into vacuum space	Locate leak with mass spectrometer
1. Leak in OVC	Inspect o-rings. Clean and apply new grease; or replace if necessary
2. Leak into helium can	Pump helium can. Helium signal will diminish
3. Leak into nitrogen can	Pump nitrogen can. Helium signal will diminish

Vacuum case pressure does not decrease on filling with LN2.

Leak into vacuum space	See above

Vacuum case pressure does not decrease on filling with LHe.

Leak into vacuum space	See above
Diffusion pump back streaming	Close main OVC evacuation valve

Difficulty in transferring liquid helium during system cool-down.

Liquid helium does not collect during cool-down.

Siphon not properly located	Ensure siphon is located into siphon entry cone for cool down to 4.2K
Siphon blocked	Remove siphon warm up then clear siphon bore with warm helium gas
Storage vessel empty	Replace

Magnet temperature above 77K	Check magnet temperature. If greater than 100K continue pre-cool
Liquid and/or solid nitrogen left in helium can after pre-cool	Warm to 77K with dry helium gas;remove nitrogen as described in Section 6.5. Continue with helium cool

<u>Siphon faults</u>

Touch (cold spot)	Indicates damage; consult Magnex Scientific Ltd
Exterior of siphon frosted	Siphon vacuum space is soft. Pump siphon to high vacuum with suitable fitting.
Leak	Locate leak and/or consult Magnex Scientific Ltd.

<u>Excessive frosting of cryostat exhaust line during transfer.</u>

Transfer rate too fast	Reduce pressure in storage dewar

<u>High helium evaporation rate; nitrogen evaporation rate normal or reduced below normal.</u>

Touch between GCS and nitrogen can	Confirm cause of problem by looking at the GCS temperature; check pressure and vacuum integrity. Warm up system. Check for loose spacer rods; adjust bore tube clearances; cool system down again.

<u>High nitrogen evaporation rate; helium evaporation rate normal.</u>

Touch between GCS and helium can	Confirm cause of problem from GCS temperature; check vacuum pressure and integrity. Warm up system. Check for loose spacer rods; adjust bore tube clearances; cool system down again.

<u>High helium and nitrogen evaporation rates.</u>

Poor vacuum	See above

MAGNET PROBLEMS

Superconducting switch does not open.

Switch heater current too low	Increase current (up to a maximum of 100 mA)
Heater connection open circuit	Check continuity; locate break in circuit and rectify. If the break is in the helium can then consult Magnex Scientific Ltd.

Superconducting switch will not close.

Residual voltage across coil	Monitor voltage between sense points (see Section 8); adjust voltage to less than 100 mV by controlling current in main current leads then attempt to close switch.
Inadequate time allowed for switch to cool	Wait longer; check for low helium helium level in cryostat.
Helium level too low	Check and refill

Magnet discharges spontaneously.

Helium level too low	Check and refill

Magnet quenches.

Training quench	Refill and energise again; if a second quench occurs consult Magnex Scientific Ltd.
Helium level too low	Refill; Check that magnet can be operated normally when energising again.

Main current cables replaced withincorrect polarity	Refill helium; check that magnet can be operated normally when energising again.
Current too high	Check setting
Ramp rate too high	Check setting
Nitrogen remaining in helium can	Technique for extracting nitrogen after pre-cool was incorrect. Warm to >77K

Lifting lug on 9.4T 210 OVC.

Total weight of magnet: $M := 5000\text{kg}$

Four lugs - distrbution of load using chains can mean any one lug may be required to take half the total weight.

Load on each lifting lug: $P := \frac{M \cdot g}{2}$ $\qquad P = 24516.63\,\text{N}$

Material: - Stainless Steel 304

Ultimate tensile stress: $UTS := 485 \cdot 10^6 \text{Pa}$ $\qquad$ Proof Stress: $R_{0.2} := 170 \cdot 10^6 \text{Pa}$

Allowable design stress
for a safety factor of 4 on UTS: $\sigma_{max} := \frac{UTS}{4}$ $\qquad \sigma_{max} = 121.25 \times 10^6\,\text{Pa}$

Plate geometry:

Plate thickness: $t := 12\text{mm}$

Effective width of tensile loaded plane: $b := 35\text{mm}$

Effective area of tensile loaded plane: $A := 2 \cdot t \cdot b$ $\qquad A = 840\,\text{mm}^2$

Stress in vertical lift: $\sigma_v := \frac{P}{A}$ $\qquad \sigma_v = 29.19 \times 10^6\,\text{Pa}$

This is safely below allowable design stress

Minimum weld area: Allowable shear stress in weld: $AWS := 0.3 \cdot UTS$ $\qquad AWS = 1.455 \times 10^8\,\text{Pa}$

Area of weld required: $A_{weld} := \frac{P}{AWS}$ $\qquad A_{weld} = 168.499\,\text{mm}^2$

Actual weld area:

Leg of base weld:
(To OVC tube) $z_b := 5\text{mm}$

Throat of base weld: $a_b := \frac{\sqrt{2 \cdot z_b^2}}{2}$ $\qquad a_b = 3.54\,\text{mm}$

Length of base weld: $l_b := 73\text{mm}$

Area of base weld: $A_b := a_b \cdot l_b$ $\qquad A_b = 258.09\,\text{mm}^2$

Leg of top welds: $z_t := 4\text{mm}$ $\qquad$ (Ignoring chamfer)

Throat of top welds: $a_t := \frac{\sqrt{2 \cdot z_t^2}}{2}$ $\qquad a_t = 2.83\,\text{mm}$

Total length of
top welds: $l_t := 75\text{mm}$

Area of top welds: $A_t := a_t \cdot l_t$ $\qquad A_t = 212.13\,\text{mm}^2$

Total area of welds: $A_{Total} := A_b + A_t$ $\qquad A_{Total} = 470.226\,\text{mm}^2$

Therefore exceeds minimum area required.

Limits of horizontal loading:

Distance from point of lift to top weld: $l_1 := 91mm$
(Centre of area of top weld)

Distance from top weld to base weld: $l_2 := 38mm$
(Centre of areas of welds)

Maximum horizontal load, limited by top weld:

Maximum reaction at top weld: $F_t := AWS \cdot A_t$ $\quad F_t = 30.865 \times 10^3 N$

Maximum horizontal load, limited by plate bending:

Effective beam width: $b_e := 93mm$

Moment of inertia: $I := b_e \cdot \frac{t^3}{12}$ $\quad I = 1.339 \times 10^{-8} m^4$

Stress limited by allowable stress:

Maximum bending moment: $M_{max} := \frac{\sigma_{max} \cdot 2 \cdot I}{t}$ $\quad M_{max} = 270.63 N \cdot m$

Maximum horizontal load: $P_h := \frac{M_{max}}{l_1}$ $\quad P_h = 2973.956 N$

Maximum angle of chain: $\alpha := asin\left(\frac{P_h}{P}\right)$ $\quad \alpha = 7 deg$

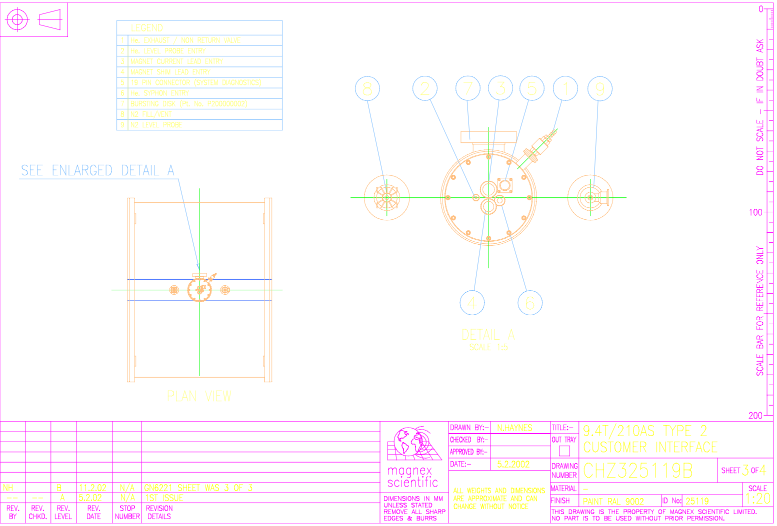
Stress limited by yielding:

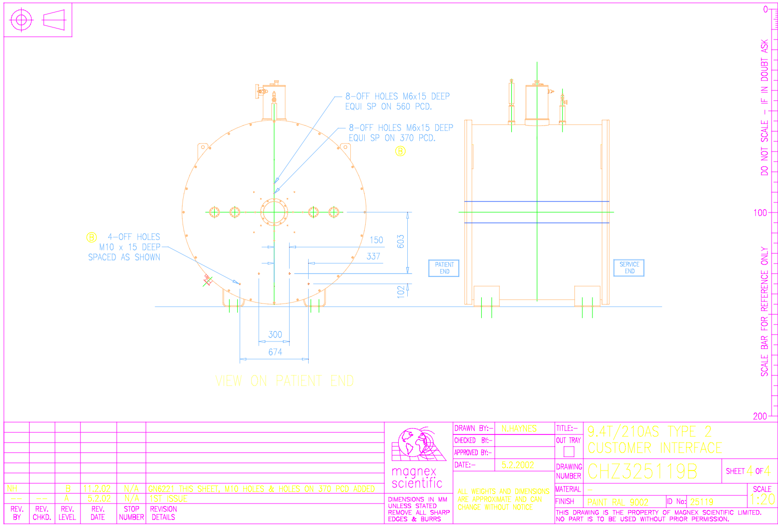
Maximum bending moment: $M_{max} := \frac{R_{0.2} \cdot 2 \cdot I}{t}$ $\quad M_{max} = 379.44 N \cdot m$

Maximum horizontal load: $P_h := \frac{M_{max}}{l_1}$ $\quad P_h = 4169.67 N$

Maximum angle of chain: $\alpha := asin\left(\frac{P_h}{P}\right)$ $\quad \alpha = 9.8 deg$

The lifting chains should be kept vertical when viewed from the side of the system, as they can only safely tolerate an angle of 7^o from vertical.


LEGEND
1 He. EXHAUST / NON RETURN VALVE
2 He. LEVEL PROBE ENTRY
3 MAGNET CURRENT LEAD ENTRY
4 MAGNET SHIM LEAD ENTRY
5 19 PIN CONNECTOR (SYSTEM DIAGNOSTICS)
6 He. SYPHON ENTRY
7 BURSTING DISK (Pt. No. P200000002)
8 N2 FILL/VENT
9 N2 LEVEL PROBE
SEE ENLARGED DETAIL A
PLAN VIEW
DETAIL A
SCALE 1:5
SCALE BAR FOR REFERENCE ONLY
DO NOT SCALE - IF IN DOUBT ASK
NH B 11.2.02 N/A GN6221 SHEET WAS 3 OF 3
--- --- A 5.2.02 N/A 1ST ISSUE
REV. BY REV. CHKD. REV. LEVEL REV. DATE STOP NUMBER REVISION DETAILS
magnex scientific
DIMENSIONS IN MM UNLESS STATED REMOVE ALL SHARP EDGES & BURRS
DRAWN BY:- N.HAYNES
CHECKED BY:-
APPROVED BY:-
DATE:- 5.2.2002
ALL WEIGHTS AND DIMENSIONS ARE APPROXIMATE AND CAN CHANGE WITHOUT NOTICE
TITLE:- 9.4T/210AS TYPE 2 CUSTOMER INTERFACE
OUT TRAY
DRAWING NUMBER CHZ325119B
SHEET 3 OF 4
MATERIAL -
FINISH PAINT RAL 9002
ID No: 25119
SCALE 1:20
THIS DRAWING IS THE PROPERTY OF MAGNEX SCIENTIFIC LIMITED. NO PART IS TO BE USED WITHOUT PRIOR PERMISSION.


8-OFF HOLES M6x15 DEEP EQUI SP ON 560 PCD.
8-OFF HOLES M6x15 DEEP EQUI SP ON 370 PCD.
4-OFF HOLES M10 x 15 DEEP SPACED AS SHOWN
150
337
603
102
300
674
PATIENT END
SERVICE END
VIEW ON PATIENT END
NH B 11.2.02 N/A GN6221 THIS SHEET, M10 HOLES & HOLES ON 370 PCD ADDED
--- --- A 5.2.02 N/A 1ST ISSUE
magnex scientific
DRAWN BY:- N.HAYNES
DATE:- 5.2.2002
TITLE:- 9.4T/210AS TYPE 2 CUSTOMER INTERFACE
DRAWING NUMBER CHZ325119B
SHEET 4 OF 4
FINISH PAINT RAL 9002
ID No: 25119
SCALE 1:20
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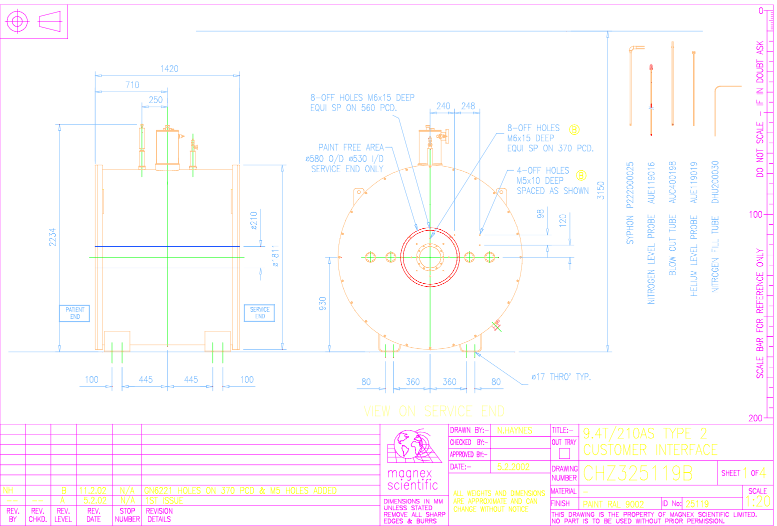
B


1420
710
250
2234
PATIENT END
SERVICE END
100 445 445 100
8-OFF HOLES M6x15 DEEP EQUI SP ON 560 PCD.
PAINT FREE AREA ⌀580 O/D ⌀530 I/D SERVICE END ONLY
240 248
8-OFF HOLES M6x15 DEEP EQUI SP ON 370 PCD.
4-OFF HOLES M5x10 DEEP SPACED AS SHOWN
⌀210
⌀1811
98
120
930
3150
80 360 360 80
⌀17 THRO' TYP.
VIEW ON SERVICE END
SYPHON P222000025
NITROGEN LEVEL PROBE AUE119016
BLOW OUT TUBE AUC400198
HELIUM LEVEL PROBE AUE119019
NITROGEN FILL TUBE DHU200030
NH B 11.2.02 N/A GN6221 HOLES ON 370 PCD & M5 HOLES ADDED
--- --- A 5.2.02 N/A 1ST ISSUE
magnex scientific
DRAWN BY:- N.HAYNES
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TITLE:- 9.4T/210AS TYPE 2 CUSTOMER INTERFACE
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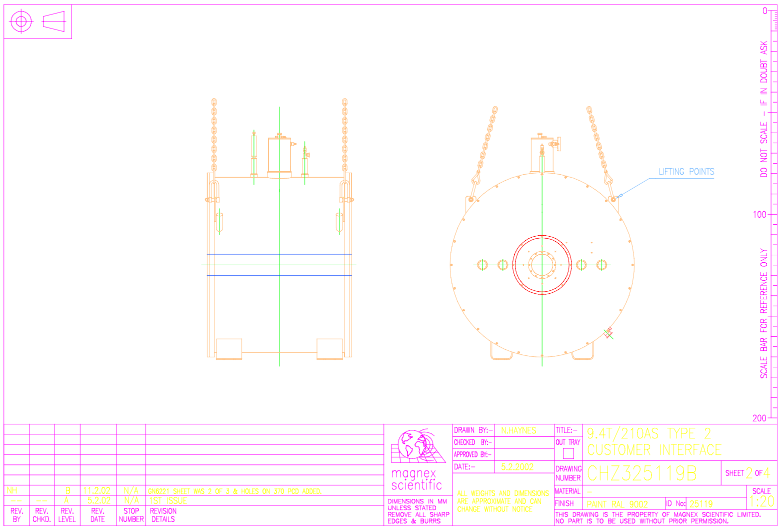
LIFTING POINTS
NH B 11.2.02 N/A GN6221 SHEET WAS 2 OF 3 & HOLES ON 370 PCD ADDED
--- --- A 5.2.02 N/A 1ST ISSUE
magnex scientific
DRAWN BY:- N.HAYNES
DATE:- 5.2.2002
TITLE:- 9.4T/210AS TYPE 2 CUSTOMER INTERFACE
DRAWING NUMBER CHZ325119B
SHEET 2 OF 4
FINISH PAINT RAL 9002
ID No: 25119
SCALE 1:20
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SAFETY CONSIDERATIONS FOR THE INSTALLATION & OPERATION OF MAGNET SYSTEMS

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CONTENTS

1. INTRODUCTION

The site for a superconducting magnet system should be designed to meet the Food and Drug Administration (FDA) safety recommendations. These recommendations primarily concern the magnetic fringe field and liquid cryogens. This document summarises the dangers presented by these and outlines the FDA safety recommendations for the facility.

2. NATURE OF THE MAGNETIC FIELD

The greatest hazard presented by a superconducting magnet is the fringe magnetic field. Once the magnet is energised, the magnetic field is always present, even when all power to the system has been turned off. This magnetic field extends above, below and to the sides of the magnet. It extends through doors, walls ceilings, and floors.

The strength of the magnetic field increases dramatically as the magnet is approached. Objects and people at risk from the magnetic field are considered safe outside the 5 gauss line.

Occasionally, fault conditions may cause magnets to lose their superconducting properties, which in turn will cause their magnetic fields to collapse. In the case of a magnet that is *actively shielded*, before the magnetic field collapses it can momentarily "bloom" slightly beyond its normal dimensions. For further details on this subject for any specific magnet, please consult Magnex Scientific Ltd.

3. HAZARDS PRESENTED BY THE MAGNETIC FIELD

The strong magnetic field creates hazards because it strongly attracts ferromagnetic metal alloys. Ferromagnetic metal alloys contain iron, nickel or cobalt. They are used in most types of tools and equipment and in some surgical implants.

The strong magnetic field can cause the following hazards:

- Projectiles
- Displacement of surgical implants
- Stoppage of electrical and mechanical implants and devices

A loose metal object (such as a wrench or pen) becomes a projectile if it gets too close to the magnet, as the force of the magnetic field pulls the object towards the magnetic centre. This metal projectile can seriously injure anyone standing between it and the magnet.

Ferromagnetic metals are sometimes used in surgical implants and prosthetic devices. The magnetic field can twist metallic implants out of place, causing tissue damage and pain to the person in whom they are implanted, possibly creating a life-threatening situation.

Some cardiac pacemakers, biostimulators and neurostimulators are mechanically activated and may stop in the presence of the magnetic field. This could also create a life-threatening situation.

4. FDA REQUIREMENTS

The FDA requires that the hazards listed above are prevented by establishing two secure and clearly marked zones:

- the exclusion zone
- the security zone

Exclusion Zone

The exclusion zone comprises the area (rooms, hallways and so on) inside the magnets 5-gauss line. *Individuals with cardiac or other mechanically active implants must be prevented from entering this area.*

The magnetic field surrounds the magnet in a three dimensional fashion. Access must be limited and warning given to individuals who are potentially at risk, not only at the same floor as the magnet, but also at the levels above and below the magnet.

The exclusion zone must be enforced with a combination of warning signs and physical barriers. Figure 1 shows the warning sign recommended by Magnex Scientific Ltd

Figure 1 Warning Sign

Security Zone

The security zone is usually confined to the room that houses the magnet. The security zone is established to prevent ferromagnetic objects from becoming projectiles. *Ferromagnetic objects should **not** be allowed inside the security zone.*

5. NATURE OF LIQUID CRYOGENS

A superconducting magnet uses two types of cryogens, liquid helium and liquid nitrogen. Helium is a naturally occurring, inert gas that becomes a liquid at approximately 4K. It is colourless, odourless, non-flammable and non-toxic. In order to remain in a superconducting state the magnet is immersed in a bath of liquid helium.

Nitrogen is a naturally occurring gas that becomes liquid at approximately 77K. It is also colourless, odourless, non-flammable and non-toxic. It is used to cool the shield which surrounds the liquid helium reservoir.

During normal operation, liquid cryogens evaporate and will require replenishment on a regular basis. The cryogens will be delivered to site in dewars; ***it is essential that these dewars, including any carriers, are non-magnetic.***

6. HAZARDS PRESENTED BY CRYOGENS

Helium and nitrogen in both their liquid and gaseous forms, present the following hazards:

- A large quantity of gas released in an area that is not well ventilated can cause asphyxiation
- Liquids or cold gases can cause cryogenic burns.
- The filling procedure produces an oxygen-rich liquid, which is a fire hazard when it drops on a combustible material

The extremely low temperature of the liquids and their cold vapours can cause severe frostbite, or a cryogenic burn. This is mainly a danger during the filling process, when the fill line and other equipment freezes. Touching the fill line or any other piece of equipment during a transfer can freeze the skin or cause it to stick to the surface of the equipment. To prevent cryogenic burns, protective gloves and a face shield should be worn; long-sleeved clothing and long trousers/pants are also recommended.

During the filling process, atmospheric air condenses on the fill line or pipes, leaving an oxygen-rich liquid, or even liquid oxygen. If this should drip onto a combustible material, like oil or grease, a fire could start. (Liquid oxygen can spontaneously ignite upon contact with oils or greases.)

For these reasons it is strongly recommended that:

- All sources of ignition are excluded from magnet rooms.
- All tools and equipment used for transferring cryogenic liquids are kept clean and free from oils and grease.
- All sources of ignition should be excluded from the magnet room, which should also be a No Smoking zone.

Helium or nitrogen gas released in an area that is not well ventilated can displace air and reduce the oxygen content to an unsafe level, leading to asphyxiation. It is also worthy of note that, when cold, gaseous helium remains lighter than air, but gaseous nitrogen becomes heavier than air. The greatest risk of asphyxiation will be during commissioning of the magnet. However, after the magnet is in service, a risk of asphyxiation could still occur during a "quench".

A "quench" occurs when the magnet loses its superconductivity, and warms the liquid helium, causing it to turn to gas. This large amount of gas escapes through the magnet venting. The following section describes the safety recommendations that prevent the possibility of asphyxiation after a magnet quench.

7. SITING REQUIREMENTS

Vents or Quench Ducts

Ideally, the helium exhaust from the magnet should be vented to the outside of the building to reduce the risk of asphyxiation in the event of a quench occurring. The ducting to the outside of the building should be of large enough diameter to avoid excessive pressure build up due to the flow impedance of the duct. (This exhaust ducting is often referred to as a "quench duct".) Only service personnel should have access to the exit end of the quench duct; in addition the exit opening should be protected from the ingress of rain, snow or any debris which could block the system. It is recommended that the quench duct exit is inspected periodically to ensure that gas flow has not become restricted by the presence of any debris.

It is also essential to ensure that any gas which vents from the quench duct cannot be drawn in to any air conditioning or ventilation system intakes. The location of duct's exit should be carefully sited to prevent this from happening in all atmospheric conditions and winds.

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

- Fire resistant (due to the possibility of condensation of liquid oxygen.)
- At least 50 mm thick.
- Resistant to deterioration upon contact with water. (Frost formed on the pipe within the thermal insulation will eventually thaw.)

Adequate Ventilation During Magnet Installation

During the installation and cooling of superconducting magnets, under certain conditions, large volumes of nitrogen or helium gases may be generated. Although these gases are inert, if generated in large enough quantities, they can create dangerous circumstances if they displace the oxygen in the room. The table below illustrates this with examples:

Magnet Type	Quantity of liberated N_2 gas during pre-cool	Time taken to liberate N_2 gas during pre-cool	Quantity of liberated He gas during filling	Time taken to evolve He gas during filling	Quantity of He gas liberated during a "quench"	Time to liberate He gas during a "quench"
800/89	3400 m^3	40 hours	1750 m^3	14 hours	800 m^3	1 min
900/52	13600 m^3	160 hours	7000 m^3	56 hours	315 m^3	1.5 min
4T940	5400 m^3	48 hours	5400 m^3	72 hours	900 m^3	10 min

For this reason, adequate means of transporting evolved gases from the magnet out of the magnet room and also good ventilation of the magnet room is essential.

Oxygen Monitor

An oxygen monitor is strongly recommended for the magnet room. The oxygen monitor sounds an alarm when the oxygen level in the room rises above or falls below a safe level. This would happen if the ventilation system malfunctions, either during a quench or during a normal boil-off, and a large amount of helium gas is released into the room.

Routine Maintenance Involving Transfer of Cryogens

For safety reasons, routine maintenance tasks involving transfer of cryogenic liquids MUST be performed by personnel formally trained to do so

Advice

Should you have any queries concerning your siting requirement, advice can be obtained from the Installation Manager at Magnex Scientific Ltd.

8. ELECTRICAL SAFETY

The following precautions and safe practices **must** be observed:

- WARNING - Isolate or disconnect equipment from mains supply before opening this unit for any reason. LIVE PARTS INSIDE.

- WARNING - For continued protection against risk of fire or electric shock, always replace fuses with the same type, rating and UL listing.

- CAUTION - Magnets power supplies contain internal protection fuses, follow the guidelines in the trouble-shooting section of the magnet manual before replacement of these devices.

- CAUTION – Your magnet power supply has been pre-set to a voltage range suitable for your country's national supply. Should any fuses require replacement they must be of the correct type and rating.

You should consult the relevant chapter of your magnet manual for further specific details.

9. SAFE ACCESS WHEN WORKING AT HEIGHT

Safe access to the top of magnets is important for routine topping up of cryogens; the frequency of doing so will vary from magnet to magnet, but may needed as often as weekly. Safe access to the top of magnets is also essential for installation work. Experience has shown that normal ladders and stepladders are not best suited to this task: They often fail to offer a secure platform when working on top of magnets when both hands are occupied by tasks *other than* holding on**.**

Suitable access equipment should be selected and purchased *before* the arrival of the magnet. Remember that any such equipment must be non-ferrous and immune to magnetic attraction. Choosing the height and size of access equipment in advance of the magnet's arrival will be helped by referring to the magnet's System Interface Drawing sent in advance to all customers of Magnex Scientific.

10. CONSIDERATIONS FOR THE OUTBREAK OF FIRE

Specific precautions regarding fire safety will vary dependant on legislation and regulations in the country where the magnet is installed. The considerations discussed below are intended to help customers review their site(s) fire precautions following the installation of a superconducting magnet. **These considerations are advisory in nature.**

(Very) broadly speaking, there could be two types of fire that could affect a magnet room – small fires and large fires. For the purposes of this document "small fires" are defined as being of a size that a customer's staff might wish to fight with a first aid fire extinguisher. "Large fires" are defined here as major fires that only professional fire fighters should attempt to extinguish.

<u>Small Fires</u>. Most premises should already have fire & emergency procedures in place in accordance with current safety legislation. Within this context, any fire extinguisher provided in a magnet room, or likely to be taken into or through a magnet room in response to a fire, **must be of non-ferromagnetic construction** to avoid it becoming attracted to the magnet, possibly causing personal injury, and becoming useless for fire fighting purposes.

<u>Large Fires</u>. One again, each customer should already have in place fire and evacuation procedures in accordance with current safety legislation. **The most important advice that Magnex Scientific Ltd can offer its customers is to invite the Fire Department (or Fire Brigade) for a liaison visit to see for themselves the customer's building layout and the hazards associated with superconducting magnets.** The Fire Department (or Brigade) needs to understand – before attending a major fire at a magnet lab – the hazards *in addition to* flames and smoke that these installations represent. The hazards that should be discussed with professional fire fighters on such occasions should include the following:

> <u>Magnetic Attraction of Ferrous Equipment</u>. Even assuming the magnetic field warning signs are still intact when fire fighters arrive to fight a fire, most firemen will probably have no conception of the strength of magnetic attraction that superconducting magnets can generate. In the worse case this could attract equipment, compressed air cylinders etc. possibly complete with fireman attached! The following web page illustrates this hazard only too well:
>
> http://abclocal.go.com/wabc/news/WABC_073001_mrideath.html
>
> <u>Quenches</u>. Quench ducts could fail in a large fire or be broken by falling debris. This could liberate quench gases into the magnet room with a risk of asphyxiation for any fire fighters present. Magnet rooms with several vertical magnets, which may not possess dedicated quench ducts, could be faced with more than one magnet quenching simultaneously, venting large quantities of nitrogen or helium gas into the magnet room. Because these gases are inert, with nitrogen comprising 80% of the air we breathe, most people do not realise that as few as three breaths of 100% inert gas can cause asphyxiation. Magnet rooms of very large volumes may represent a lower risk than magnet rooms of small volumes. Never the less, it is suggested that fire fighters should be made fully aware of the asphyxiation hazard, and may choose to wear breathing apparatus when fighting a fire in a magnet room.
>
> <u>Explosions</u>. In a disaster scenario, magnets very close to or enveloped in flames will get (unsurprisingly) very hot; this could cause them to quench and release inert gases extremely rapidly, possibly faster than their pipes and fittings might normally permit. In the worse case, a magnet could become over pressurised and explode violently. It is therefore suggested that if

magnets become physically hot in a fire they should be treated in a similar way to hot compressed gas cylinders: hosed down and kept cool.

Fire Doors and Exits. It is recommended that fire doors and exits from magnet rooms should open outwards. In a disaster scenario, should large quantities of gas be vented into the magnet room, the pressure in the room may temporarily rise, making inward-opening doors difficult to open. This could make access difficult for fire fighters, or potentially fatal for anyone still inside the magnet room under such circumstances.

NOTE: Large fires are usually considered very unlikely; all staff should normally be evacuated before a fire becomes fully established in accordance with customers' standard fire procedures or evacuation plans. The information contained within the section on "Large Fires" above is, therefore, likely to be more applicable to professional fire fighters than customers' employees.

OPERATING DATA

for

9.4 Tesla, 210mm Bore Actively Screened Magnet System

Project No. :

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WARNING

MAGNET IS REVERSE ENERGISED

CONTENTS

CE NOTICE

Marking by the symbol CE indicates compliance of this device to the PED (Pressure Equipment Directive) directive of the European Community. This unit is to be installed and operated as detailed. Any modification or maintenance procedure undertaken which is not approved by Magnex Scientific Ltd could nullify the CE marking of this product and lead to prosecution. A 'Declaration Of Conformity' in accordance with the above directive has been made and is located at Magnex Scientific, Yarnton, Oxfordshire, UK.

1. WARNING

The User must refer to the document "Safety Considerations For The Installation & Operation Of Magnet Systems" enclosed with this system manual.

When the magnet is lifted the lifting chains must be vertical as shown in the side view of the magnet on sheet 2 of the customer interface drawings (see section 8).

This device produces a magnetic field which extends beyond the confines of the vessel. The existence of this field produces several hazards. Firstly the field will interfere with sensitive electronic devices and will erase magnetic storage devices such as tapes and credit cards. In particular people with cardiac pacemakers should be kept well clear of the region of field. The FDA guideline for cardiac pacemakers is currently 5 gauss. Fields higher than this can cause malfunction of the pacemaker.

Secondly ferromagnetic objects in the vicinity of the magnet will become magnetised and will be attracted toward the magnet. The force on such objects is proportional to their mass so that even large objects will move toward the magnet with considerable velocity.

It is possible, under fault conditions, for large amounts of helium and / or nitrogen to be released from the system, e.g. Magnet Quench. Under these conditions the gas is very cold and will cause "cold burns". More importantly if the gas is not vented properly asphyxiation is possible due to the displacement of oxygen within the room. It is the responsibility of the user to ensure adequate venting of the gas is provided and adequate ventilation within the final installation site.

It is the responsibility of the user to take all necessary precautions to prevent accident or loss from use of the magnet. Magnex Scientific Limited accepts no responsibility for any loss or damage caused either directly or indirectly from use of the magnet. Whilst every effort is made that the information contained in this manual is correct, Magnex Scientific Limited accepts no responsibility for any inaccurate statements or omissions.

The magnet power supply should be limited to the operating current of the magnet plus 10% and the magnet should only be energised after completion of cooling.

Note
Magnex Scientific Limited will make available technical information and parts for repair or maintenance where appropriate.

2. EMERGENCY DISCHARGE

In an emergency if the magnet is to be discharged quickly an internal heater incorporated in the windings can be used to initiate a quench that will discharge the magnet in about 20 seconds. To operate this, lift the flap on the emergency discharge button and press it. The magnet will quench.

Note that if the magnet is persistent at a field below 7.0T the heater may not initiate a quench.

3. MAGNET DATA

IMPORTANT NOTE: ENERGISATION

In terms of the Magnex convention Bruker magnets must be reverse energised i.e. the centre conductor of the coaxial magnet current lead must be connected to the negative (-) terminal of the magnet power supply and the outer conductor of the current lead must be connected to the positive (+) terminal of the magnet power supply.

Maximum central field : 9.405 T

Nominal current for maximum field : 222.7 Amps

Recommended maximum energisation rate

0 - 160 Amps	**1.2 amps/min. (5V)**	**2.3 hrs**
160 - 210 Amps	**0.72 amp/min. (3V)**	**1.2 hrs**
210 – 222.7 Amps	**0.36 amps/min. (1.5V)**	**0.6 hrs**
		Total 4.1 hrs

Overfield by 0.005 T

Field stability : Drift less than 0.05 ppm/hour after 72 hours at field

Magnet inductance : 250.7 Henries

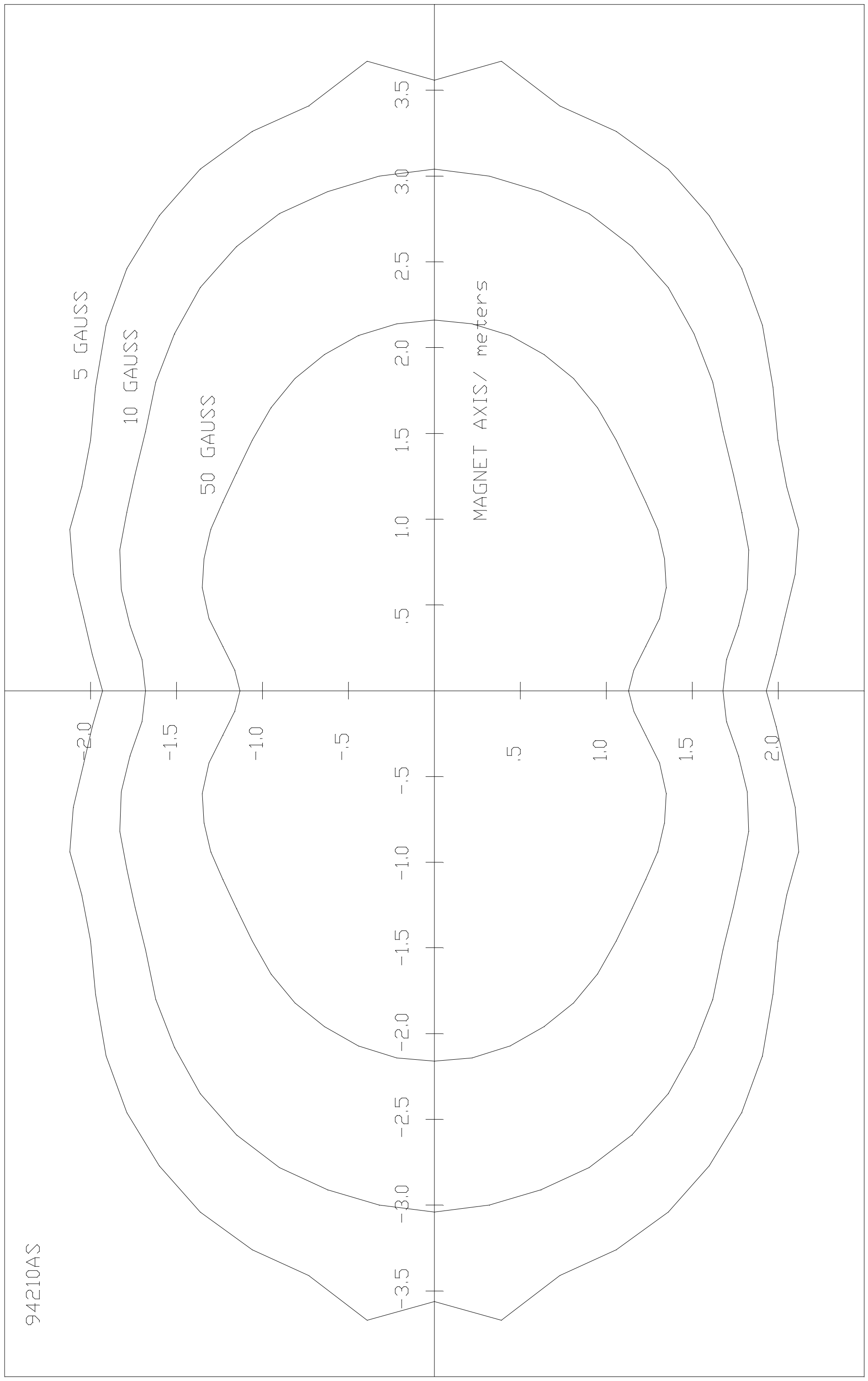
S/C switch normal resistance : 5 Ohms

S/C switch heater resistance : 100 ohms

S/C switch heater energisation current : 40 - 60 mA

Fringe field (see figure 3.1) : 3.80 m. axially by 2.15 m. radially from magnet centre

FIGURE 3.1 Fringe Field



4. SUPERCONDUCTING SHIM DATA

Shims provided : Z1 Z2 Z3 X Y ZX ZY X2-Y2 XY

Maximum recommended current : 20 Amps

Shim switch heater resistance : 100 ohms

Shim switch energisation current : 60 mA

Superconducting Shim Strengths

Shim	Strength at 10.0cm dsv (ppm/amp)	Factory shim settings (amps)	Installation shim settings (amps)
Z1	26.5	-0.37	
Z2	4.1	-3.72	
Z3	0.29	0.0	
X	5.0	-8.78	
Y	5.0	-5.95	
ZX	0.38	-6.43	
ZY	0.38	2.79	
XY	0.23	13.0	
X2-Y2	0.23	0.0	

5. CRYOSTAT DATA

Helium can volume	: 1050 litres
Nitrogen can volume	: 248 litres
Installation requirements	
Liquid helium	: 3000 litres
Liquid nitrogen	: 3000 litres
Minimum liquid helium volume	: 750 litres
Maximum liquid nitrogen refill volume	: 238 litres
Minimum operating liquid helium level See Tables 5.1 and 5.2 for level probe calibration.	: 760 mm.
Recommended minimum energisation liquid level	: 840 mm.
Liquid helium hold time	Greater than 100 days
Liquid nitrogen hold time	: Greater than 14 days

Nominal dimensions (see Section 8)

Clear bore	: 210 mm
Length of cryostat	: 1420 mm
Overall diameter	: 1811 mm
Overall height	: 2234 mm
Minimum ceiling height	: 3150 mm.

TABLE 5.1
Probe 1 Calibration

Resistance of probe wire : 181.54 ohms/m

READING ON LEVEL MONITOR (mm)	VOLUME REMAINING (litres)	
1200	1016	
1180	1008	
1160	1002	
1140	997	
1120	992	
1100	983	
1080	974	
1060	963	
1040	952	
1020	939	
1000	927	
980	913	
960	899	
940	885	
920	870	
900	854	
880	839	
860	823	
840	806	Minimum Energisation Level
820	789	
800	774	
780	760	
760	747	Minimum Operating Level
740	734	
720	722	
700	710	
680	698	
660	686	
640	674	
620	661	
600	649	
580	636	
560	624	
540	611	
520	598	
500	586	
480	573	
460	560	
440	548	
420	535	
400	522	
continued…..	continued…..	

continuation of TABLE 5.1
Probe 1 Calibration

READING ON LEVEL MONITOR (mm)	VOLUME REMAINING (litres)
380	509
360	496
340	484
320	471
300	458
280	446
260	433
240	420
220	408
200	395
180	381
160	368
140	354
120	340
100	325
80	309
60	293
40	275
20	254
0	233

TABLE 5.2
Probe 2 (Demountable) Calibration

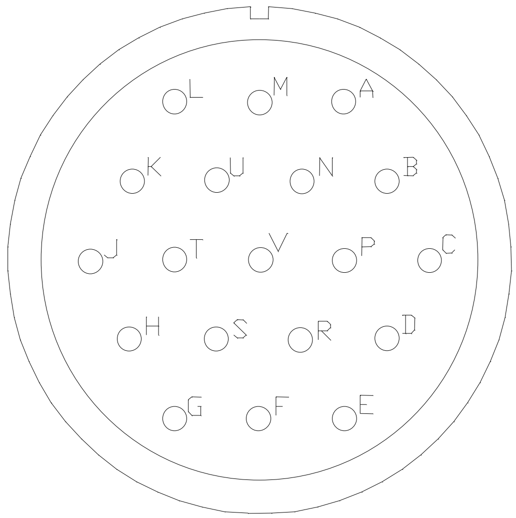
Resistance of probe wire : 181.54 ohms/metre

Please note probe 2 is not a fixed probe and so its calibration is not as exact as probe 1. Probe 2 is supplied to monitor the level during filling and to provide verification of the operation of probe 1.

READING ON LEVEL MONITOR (mm)	VOLUME REMAINING (litres)	READING ON LEVEL MONITOR (mm)	VOLUME REMAINING (litres)
267	1049	97	964
262	1048	92	960
257	1046	87	956
252	1044	82	952
247	1042	77	948
242	1040	72	944
237	1038	67	939
232	1035	62	935
227	1033	57	931
222	1030	52	926
217	1027	47	922
212	1024	42	917
207	1021	37	913
202	1018	32	908
197	1015	27	903
192	1012	22	898
187	1010	17	893
182	1007	12	888
177	1005	7	883
172	1003	2	878
167	1001		
162	999		
157	998		
152	996		
147	994		
142	992		
137	990		
132	987		
127	984		
122	981		
117	978		
112	975		
107	971		
102	967		

6. ELECTRICAL DIAGRAMS

FIGURE 6.1
Service Turret Connector

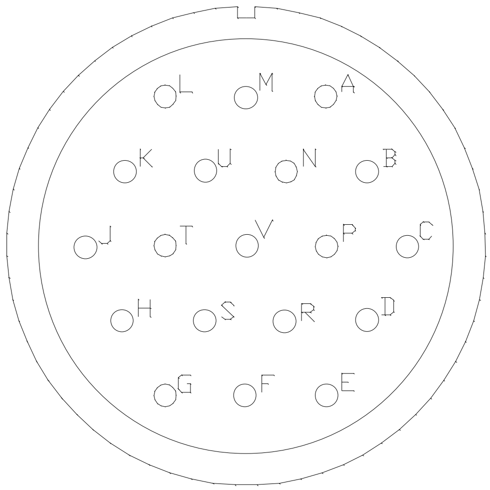


19 WAY CONNECTOR WIRING

PIN	FUNCTION	
A	Level probe 1	V+
B	Level probe 1	I+
C	Level probe common	V−
D	Spare Level probe	V+
E	Spare level probe	I+
F	Level probes common	I−
G	Quench heater	I+
H	Quench heater	I−
J	Magnet voltage sense	V+
K	Magnet voltage sense	V−

PIN	FUNCTION	
L	Main switch heater	I+
M	Main switch heater	I−
N	Spare switch heater	I+
P	Platinum sensor PT100	
R	Temperature sensor common	
S	Allen Bradley sensor lead	
T	Temperature sensor	
U	B0 shield switch heater	I+
V	B0 shield switch heater	I−

FIGURE 6.2
Superconducting Shim lead Connector



19 WAY CONNECTOR WIRING

PIN	FUNCTION
A	Z1-Z3 Switch Heater
B	Z2 switch heater
C	X switch heater
D	Y switch heater
E	ZX switch heater
F	ZY switch heater
G	XY switch heater
H	X2-Y2 switch heater
J	Switch heater common
K	

PIN	FUNCTION
L	
M	Current circuit 2 +ve
N	Current Circuit 2 +ve
P	Current Circuit 2 -ve
R	Current Circuit 2 -ve
S	Current circuit 1 -ve
T	Current circuit 1 -ve
U	Current circuit 1 +ve
V	Current circuit 1 +ve

FIGURE 6.3
System Connecting Leads

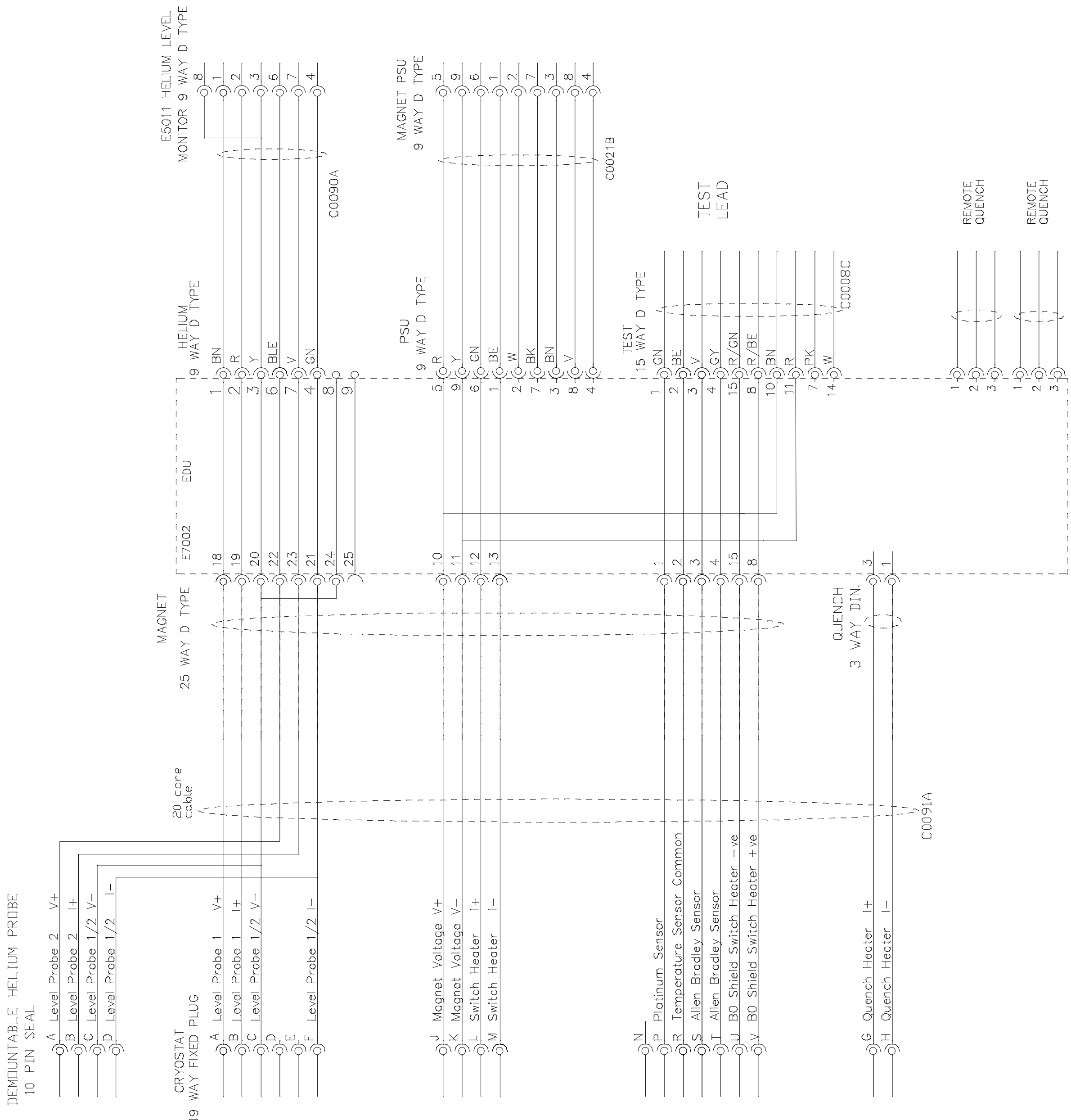
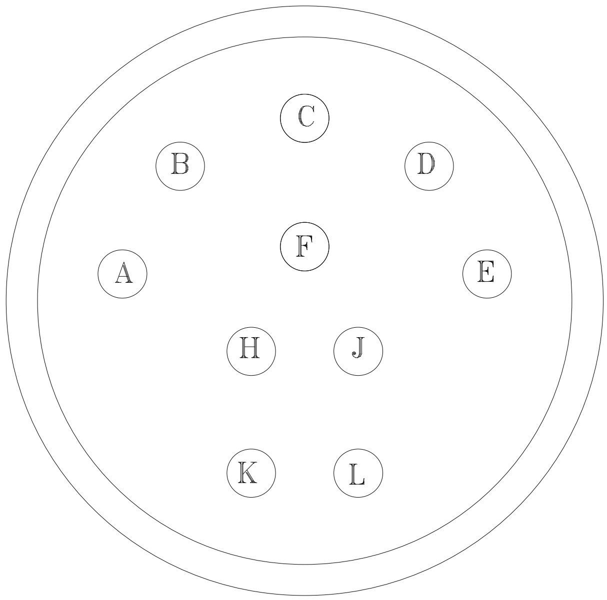


FIGURE 6.4
Shield Temperature Sensor Wiring



SHIELD END PLATES

PIN	FUNCTION	
A	Allen Bradley gas cooled shield	I +
B	Allen Bradley gas cooled shield	V+
C		
D	Allen Bradley gas cooled shield	V-
E	Allen Bradley gas cooled shield	I -
F		
H	Platinum sensor LN2 shield	I +
J	Platinum sensor LN2 shield	V+
K	Platinum sensor LN2 shield	V-
L	Platinum sensor LN2 shield	I -

7. TEMPERATURE SENSOR CALIBRATION

Table 7.1 Allen Bradley Resistor Calibration (gas-cooled shield)

Table 7.2 PT100 Resistor Calibration (LN2 shield)

TABLE 7.1
Allen Bradley Resistor Typical Calibration

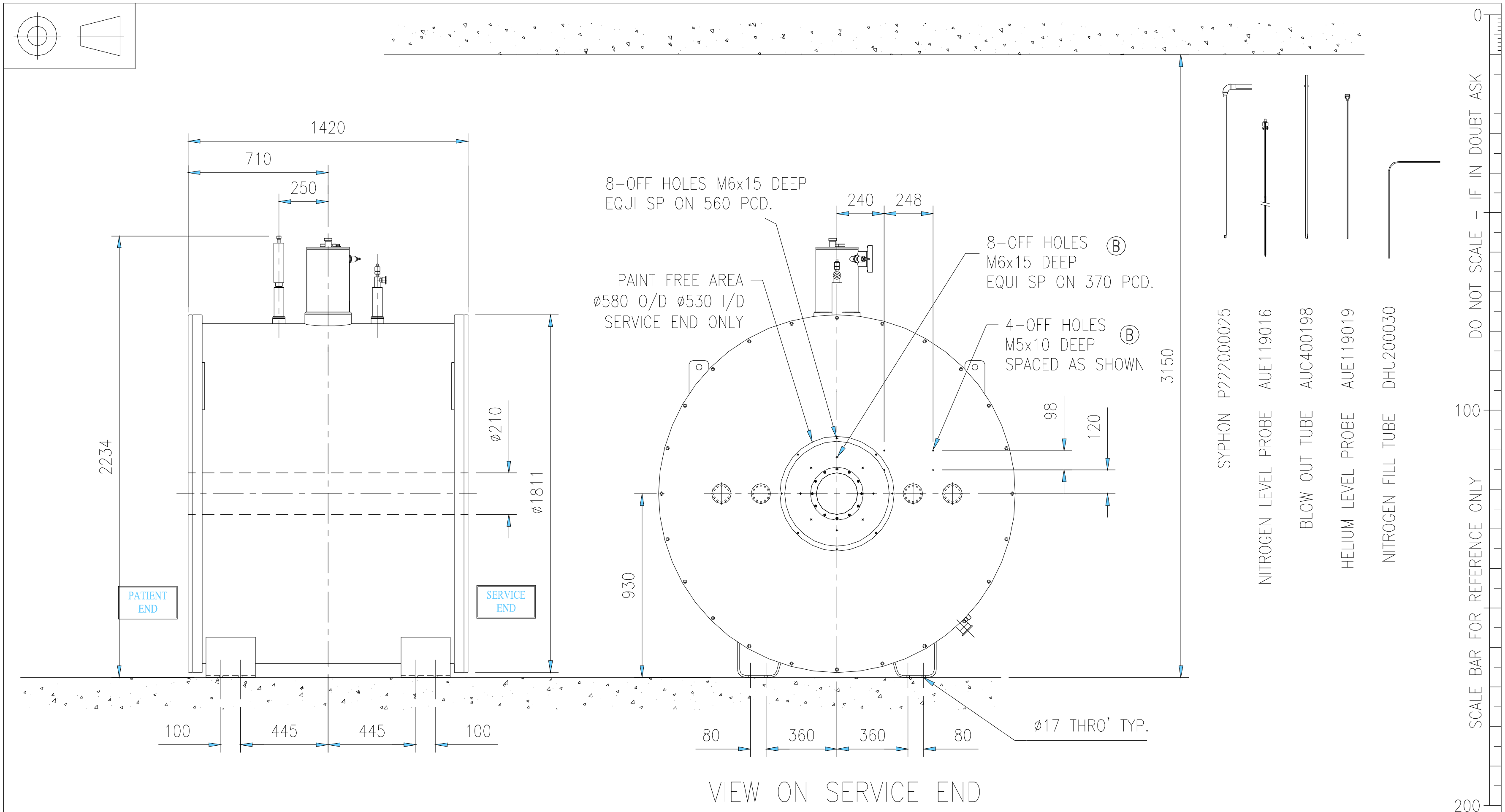
Temperature (K)	Resistance (ohm)	Temperature (K)	Resistance (ohm)
11	689.34	12	655.48
13	627.56	14	604.08
15	584.04	16	566.69
17	551.53	18	538.15
19	526.26	20	515.57
21	505.93	22	497.36
23	489.42	24	482.04
25	475.16	26	468.74
27	462.89	28	457.50
29	452.43	30	447.64
31	443.11	32	438.81
33	434.85	34	431.09
35	427.52	36	424.11
37	420.86	38	417.75
39	414.82	40	412.02
41	409.33	42	406.75
43	404.28	44	401.90
45	399.62	46	397.44
47	395.33	48	393.30
49	391.34	50	389.45
51	387.62	52	385.85
53	384.14	54	382.49
55	380.88	56	379.33
57	377.83	58	376.37
59	374.95	60	373.57
61	372.24	62	370.94
63	369.67	64	368.44
65	367.24	66	366.07
67	364.94	68	363.84
69	362.76	70	361.70
71	360.67	72	359.67
73	358.69	74	357.74
75	356.81	76	355.89
77	355.00	78	354.13
79	353.28	80	352.45
81	351.63	82	350.83
83	350.05	84	349.29
85	348.54	86	347.81
87	347.09	88	346.39
89	345.70	90	345.02
91	344.36	92	343.71
93	343.08	94	342.45
95	341.84	96	341.24
97	340.65	98	339.97
99	339.26	100	338.57

TABLE 7.2
PT100 Resistor Typical Calibration

Temperature (K)	Resistance (ohm)	Temperature (K)	Resistance (ohm)
77	20.00	79	20.82
81	21.63	83	22.45
85	23.26	87	24.08
89	24.90	91	25.71
93	26.53	95	27.34
97	28.16	99	28.98
101	29.79	103	30.61
105	31.42	107	32.24
109	33.06	111	33.87
113	34.69	115	35.50
117	36.32	119	37.14
121	37.95	123	38.77
125	39.58	127	40.40
129	41.22	131	42.03
133	42.85	135	43.66
137	44.48	139	45.30
141	46.11	143	46.93
145	47.74	147	48.56
149	49.38	151	50.19
153	51.01	155	51.82
157	52.64	159	53.46
161	54.27	163	55.09
165	55.90	167	56.72
169	57.54	171	58.35
173	59.17	175	59.98
177	60.80	179	61.62
181	62.43	183	63.25
185	64.06	187	64.88
189	65.70	191	66.51
193	67.33	195	68.14
197	68.96	199	69.78
201	70.59	203	71.41
205	72.22	207	73.04
209	73.86	211	74.67
213	75.49	215	76.30
217	77.12	219	77.94
221	78.75	223	79.57
225	80.38	227	81.20
229	82.02	231	82.83
233	83.65	235	84.46
237	85.28	239	86.10
241	86.91	243	87.73
245	88.54	247	89.36
249	90.18	251	90.99
253	91.81	255	92.62
257	93.44	259	94.26
261	95.07	263	95.89
265	96.70	267	97.52
269	98.34	271	99.15
273	99.97	275	100.78
277	101.60	279	102.42
281	103.23	283	104.05
285	104.86	287	105.68
289	106.50	291	107.31
293	108.13	295	108.94
297	109.76	299	110.58

8. CUSTOMER INTERFACE DRAWINGS

SEE FOLLOWING PAGES



REV. BY	REV. CHKD.	REV. LEVEL	REV. DATE	STOP NUMBER	REVISION DETAILS
NH		B	11.2.02	N/A	GN6221 HOLES ON 370 PCD & M5 HOLES ADDED
--	--	A	5.2.02	N/A	1ST ISSUE

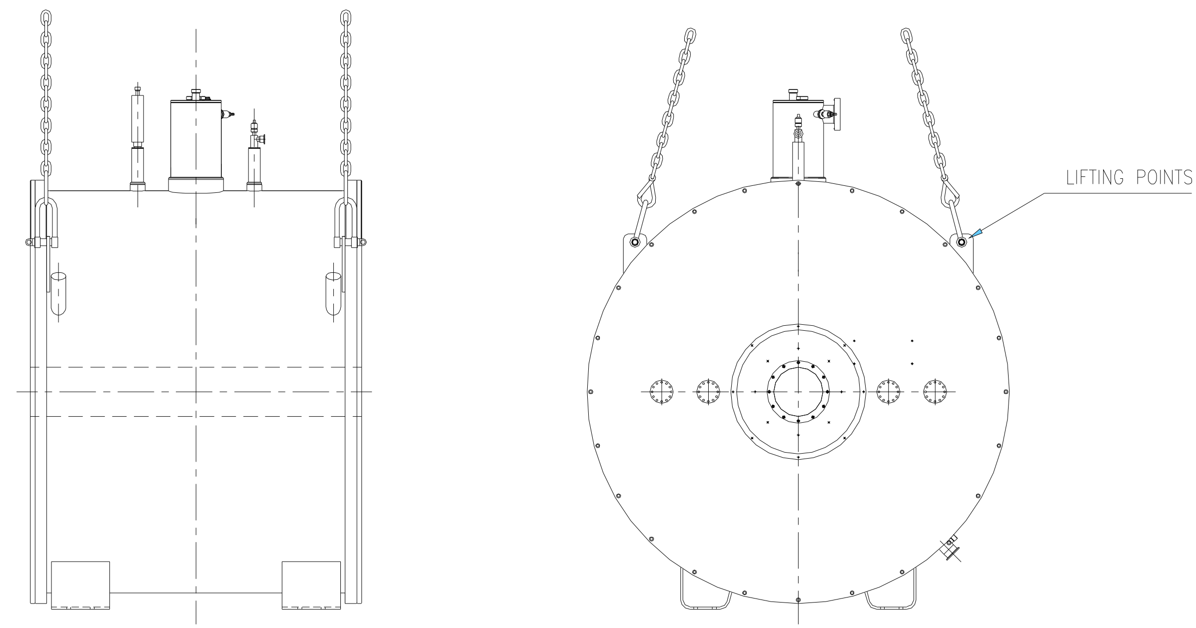
magnex scientific

DIMENSIONS IN MM UNLESS STATED
REMOVE ALL SHARP EDGES & BURRS

DRAWN BY:-	N.HAYNES
CHECKED BY:-	
APPROVED BY:-	
DATE:-	5.2.2002

ALL WEIGHTS AND DIMENSIONS ARE APPROXIMATE AND CAN CHANGE WITHOUT NOTICE

TITLE:-	9.4T/210AS TYPE 2 CUSTOMER INTERFACE
OUT TRAY	
DRAWING NUMBER	CHZ325119B — SHEET 1 OF 4
MATERIAL	–
FINISH	PAINT RAL 9002 — ID No: 25119 — SCALE 1:20



0
100
200
SCALE BAR FOR REFERENCE ONLY - IF IN DOUBT ASK
DO NOT SCALE - IF IN DOUBT ASK

REV. BY	REV. CHKD.	REV. LEVEL	REV. DATE	STOP NUMBER	REVISION DETAILS
NH		B	11.2.02	N/A	GN6221 SHEET WAS 2 OF 3 & HOLES ON 370 PCD ADDED.
--	--	A	5.2.02	N/A	1ST ISSUE

magnex scientific

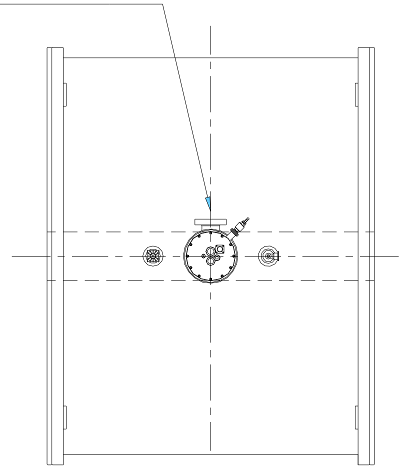
DIMENSIONS IN MM UNLESS STATED
REMOVE ALL SHARP EDGES & BURRS

DRAWN BY:-	N.HAYNES	TITLE:-	9.4T/210AS TYPE 2 CUSTOMER INTERFACE
CHECKED BY:-		OUT TRAY	
APPROVED BY:-			
DATE:-	5.2.2002	DRAWING NUMBER	CHZ325119B — SHEET 2 OF 4
		MATERIAL	-
		FINISH	PAINT RAL 9002 — ID No: 25119 — SCALE 1:20

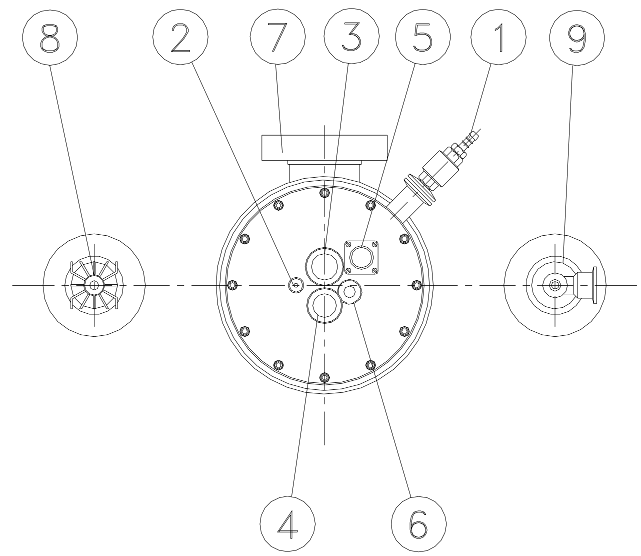
ALL WEIGHTS AND DIMENSIONS ARE APPROXIMATE AND CAN CHANGE WITHOUT NOTICE

	LEGEND
1	He. EXHAUST / NON RETURN VALVE
2	He. LEVEL PROBE ENTRY
3	MAGNET CURRENT LEAD ENTRY
4	MAGNET SHIM LEAD ENTRY
5	19 PIN CONNECTOR (SYSTEM DIAGNOSTICS)
6	He. SYPHON ENTRY
7	BURSTING DISK (Pt. No. P200000002)
8	N2 FILL/VENT
9	N2 LEVEL PROBE

SEE ENLARGED DETAIL A



PLAN VIEW



DETAIL A
SCALE 1:5

0
DO NOT SCALE – IF IN DOUBT ASK
100
SCALE BAR FOR REFERENCE ONLY
200

REV. BY	REV. CHKD.	REV. LEVEL	REV. DATE	STOP NUMBER	REVISION DETAILS
NH		B	11.2.02	N/A	GN6221 SHEET WAS 3 OF 3
--	--	A	5.2.02	N/A	1ST ISSUE

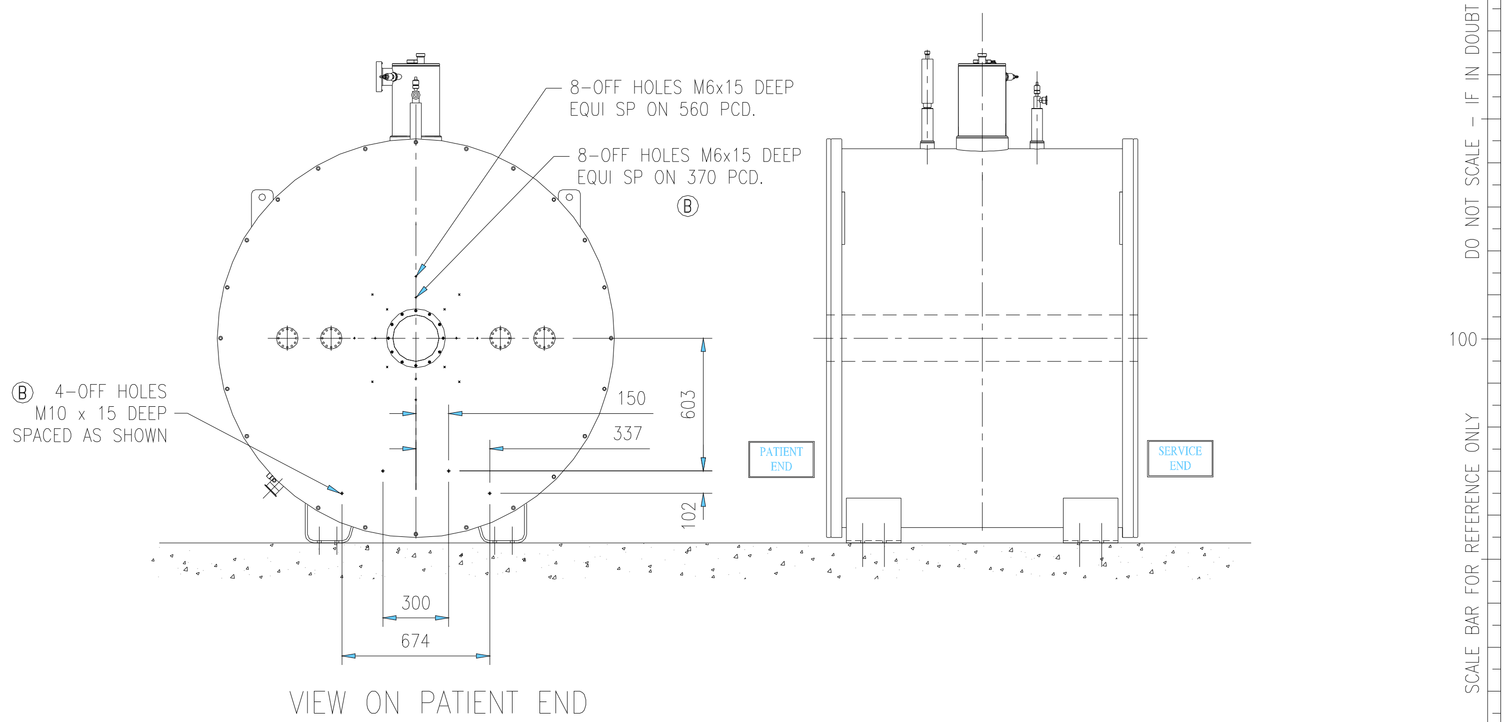
magnex scientific

DIMENSIONS IN MM UNLESS STATED REMOVE ALL SHARP EDGES & BURRS

DRAWN BY:-	N.HAYNES
CHECKED BY:-	
APPROVED BY:-	
DATE:-	5.2.2002

ALL WEIGHTS AND DIMENSIONS ARE APPROXIMATE AND CAN CHANGE WITHOUT NOTICE

TITLE:-	9.4T/210AS TYPE 2 CUSTOMER INTERFACE		
OUT TRAY			
DRAWING NUMBER	CHZ325119B	SHEET 3 OF 4	
MATERIAL	–		SCALE
FINISH	PAINT RAL 9002	ID No: 25119	1:20



REV. BY	REV. CHKD.	REV. LEVEL	REV. DATE	STOP NUMBER	REVISION DETAILS
NH		B	11.2.02	N/A	GN6221 THIS SHEET, M10 HOLES & HOLES ON 370 PCD ADDED
--	--	A	5.2.02	N/A	1ST ISSUE

magnex scientific

DIMENSIONS IN MM UNLESS STATED
REMOVE ALL SHARP EDGES & BURRS

DRAWN BY:- N.HAYNES
CHECKED BY:-
APPROVED BY:-
DATE:- 5.2.2002

ALL WEIGHTS AND DIMENSIONS ARE APPROXIMATE AND CAN CHANGE WITHOUT NOTICE

TITLE:- 9.4T/210AS TYPE 2 CUSTOMER INTERFACE
OUT TRAY
DRAWING NUMBER CHZ325119B
SHEET 4 OF 4
MATERIAL -
FINISH PAINT RAL 9002
ID No: 25119
SCALE 1:20

9. ADDITIONAL INFORMATION

SPECIAL INSTALLATION TOOLS

17mm allen key - required to unscrew the M20 helium can bolts on the transit bungs

OPERATING MANUAL

for

Magnex Model E7001 Emergency Discharge Unit

Prepared : February 2002

Issue : C

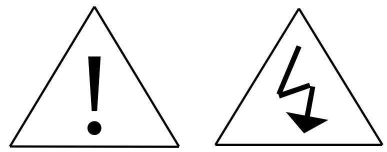
Document : E7001MANrevC

Magnex Scientific Limited
The Magnet Technology Centre
6 Mead Road
Oxford Industrial Park
Yarnton, Oxford OX5 1QU, UK

Telephone No. : +44 (0)1865 853800
Telefax No. : +44 (0)1865 842466
E-mail : sales@magnex.com
www.magnex.com

CONTENTS

1. SAFETY



WARNING **CAUTION**

1. WARNING - Do not remove any protective covers whilst this unit is open. LIVE PARTS INSIDE.

2. WARNING - For continued protection against risk of fire or electric shock, replace fuses with the same type, rating and UL listing.

3. CAUTION - This unit contains internal protection fuses. Follow the guidelines in Trouble-shooting section before replacement of these devices.

4. CAUTION - This unit has been pre-set to a voltage range suitable for the national supply. The unit has a selectable input voltage, 115V~ or 230V~. Fuses F1 and F2 must be rated to suit the input voltage, if selected to 115V~ they must be rated at T250mA 250V. If selected to 230V~ they must be rated at T125mA 250V.

   To select the mains supply voltage or replace mains fuses, prise open the flap on the mains input socket using a suitable tool in the slot provided. This affords access to the voltage select drum and two fuse trays.

   To select the supply voltage, pull out the drum and rotate until the 230V~ or 115V~ lettering is uppermost, ie. in line with the drum slots, and replace. When the socket flap is replaced the correct voltage must be visible through the window.

   To replace the input fuse, pull out the fuse trays and replace with the correct value of fuse. Re-insert the fuse trays, noting the correct orientation of the arrows.

5. WARNING - If replacing the back-up batteries, follow the instructions in the Battery Care section of this manual.

6. WARNING - The batteries and fuses are the only serviceable parts within this unit. No other circuitry should be tampered with as this may effect the operation of the discharge system.

2. IMPORTANT NOTICE

Please inspect goods immediately on arrival for possible transit damage and notify Magnex Scientific Limited within 3 days of receipt of goods.

Failure to do this will invalidate any possible claim.

DISCLAIMER

Every precaution has been taken in the preparation of this publication. Magnex Scientific Limited assumes no responsibility for errors or omissions. Neither is any liability assumed for damages resulting from the use of the information contained herein.

Details of circuitry and user serviceable spare parts are available upon request from :-

Magnex Scientific Limited
The Magnet Technology Centre
6 Mead Road
Oxford Industrial Park
Yarnton
Oxon OX5 1QU

CE NOTICE

Marking by the symbol CE indicates compliance of this device to the EMC (electromagnetic compatibility) and LV (low voltage) directives of the European Community. This unit is to be installed and operated as detailed. Any modification or maintenance procedure undertaken which is not approved by Magnex Scientific Ltd could nullify the CE marking of this product and lead to prosecution. A 'Declaration Of Conformity' in accordance with the above directives has been made and is located at Magnex Scientific, Yarnton, Oxfordshire, UK.

3. SPECIFICATIONS

Suitable quench heater and connecting cable resistance	:	6.8Ω minimum 18.0Ω maximum
Quench voltage	:	18V ⎓ maximum
Quench cycle duration	:	30 seconds (+/- 20%)
Test circuit control input	:	TTL/CMOS Compatible
Test circuit monitor output	:	TTL/CMOS Compatible
B0 switch heater current	:	19 to 100 mA (variable)
Mains voltage	:	115/ 230 V ~ selectable
Mains input current	:	250 mA @ 115V~ 125 mA @ 230V~
Mains input frequency	:	50/60 Hz
Fuse ratings	:	F1, F2 T125 mA for 230V~ supply OR T250 mA for 115V~ supply F3, F4 T1.6A 250V
Dimensions		
Height	:	128mm (3U)
Width	:	214mm (42HP)
Depth	:	220mm

4. DESCRIPTION AND OPERATING PRINCIPLE

Magnex Model E7001 Emergency Discharge Unit

Features

* Magnet quench indication
* Indication that the discharge button has been operated
* Remote emergency discharge button option
* Battery backed
* Heater and battery test facility
* Programmable B0 coil dump clock timer.

Description

The principle function of the E7001 emergency discharge unit (EDU) is to initiate a 'quench' in order to run down a superconducting magnet in case of any emergency. This is achieved by passing current through a heater built into the magnet windings. A mains derived dc voltage drives the current into the heater. The unit is also battery backed to ensure operation during a power failure.

A test facility is provided to check the condition of the battery and the integrity of the heater circuit.

A further facility is a clock controlled output current used to energize the B0 shield switch heater allowing the fluxes within the B0 coil to decay.

Operation

To initiate a magnet quench; lift the emergency discharge button guard and press the red button. Current will flow into the quench heater causing the magnet to quench very quickly. Quench current will flow for approximately 30 seconds. This will be indicated by the illumination of the front panel emergency discharge button.

WARNING - Following a quench, the bursting disc must be replaced and care must be taken to ensure that the cryostat is properly sealed to prevent air entering the helium reservoir.

The condition of the battery and heater circuit is observed by pressing the **TEST** button. The **BATTERY OK** and **HEATER OK** LED's will only illuminate if the battery capacity is okay and the quench heater circuit is intact.

The test circuit can also be initiated by applying a TTL input signal via the 9 ‘D’ **PSU** socket. A TTL output signal is available to indicate heater integrity, making it suitable for inclusion in digital control systems.

The B0 dump clock timer is programmed to pass current through the B0 shield switch heater for 1 minute every 24 hours. (This must be set during installation when the clock is also set to the correct time).

This setting can be manually over-ridden by pressing the **B0 DUMP** button or via an external TTL signal applied to the **PSU** or **TEST** connectors.

The **B0 DUMP ON** LED will illuminate to indicate that the B0 shield switch heater is energised.

CAUTION - When the B0 shield switch heater is quenched by these methods, the winding remains permanently ‘dumped’ until the **B0 DUMP** button is pressed or the TTL signal is removed.

5. INSTALLATION

To install follow the instructions below :

1. Remove lid. Reconnect battery terminal 3.

   CAUTION - Failure to reconnect the battery will mean that the magnet 'quench', B0 dump circuit and the B0 dump clock will not function in the event of a mains power failure.

2. Set the B0 dump clock (refer to setting the B0 dump clock section).

   CAUTION - Failure to set the clock may cause the B0 dump function to remain energised.

3. Press the **RESET** button and ensure that the PCB LED is extinguished. Replace lid.

4. Ensure that the unit has been set to the correct mains input voltage. Connect mains power and ensure the **POWER** LED illuminates.

5. Fit cable ferrite to cable C0091A12.5 20mm from 25 'D' plug end. Secure using cable tie.

6. Connect the cables as shown on the interconnect diagram.

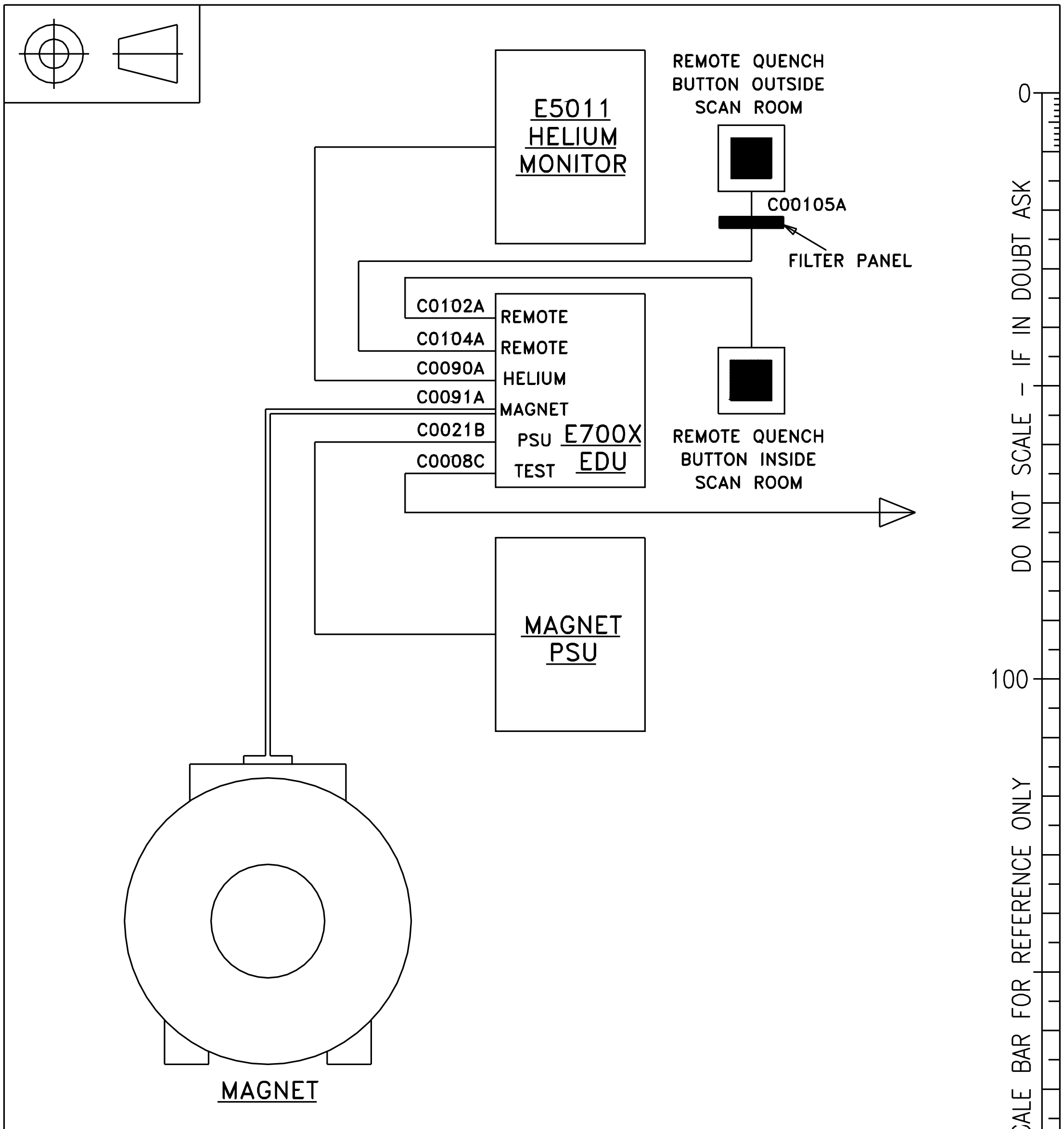
7. Press the **TEST** button and ensure that both the **BATTERY OK** and **HEATER OK** LED's illuminate (The **BATTERY OK** LED may not illuminate if the batteries have not been charged for at least 24 hours).

Note

Once the magnet is operational, cables C0008 and C0021 may be removed.

6. SYSTEM INTERCONNECTING DIAGRAMS

BLANK



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REV. BY	REV. CHKD.	REV. LEVEL	REV. DATE	STOP NUMBER	REVISION DETAILS

magnex scientific

DIMENSIONS IN MM UNLESS STATED
REMOVE ALL SHARP EDGES & BURRS

DRAWN BY:-	JOHN EVINS
CHECKED BY:-	
APPROVED BY:-	
DATE:-	08.10.98

TOLERANCE UNLESS STATED
0 –±0.5mm OR ±0.02 INCHES
0.0 –±0.3mm OR ±0.012 INCHES
0.00–±0.1mm OR ±0.004 INCHES
ANGULAR TOLERANCE TO MAGNEX SPECIFICATION AND SURFACED FINISH N7 UNLESS STATED

TITLE:- E700X EDU INTERCONNECTING DIAGRAM

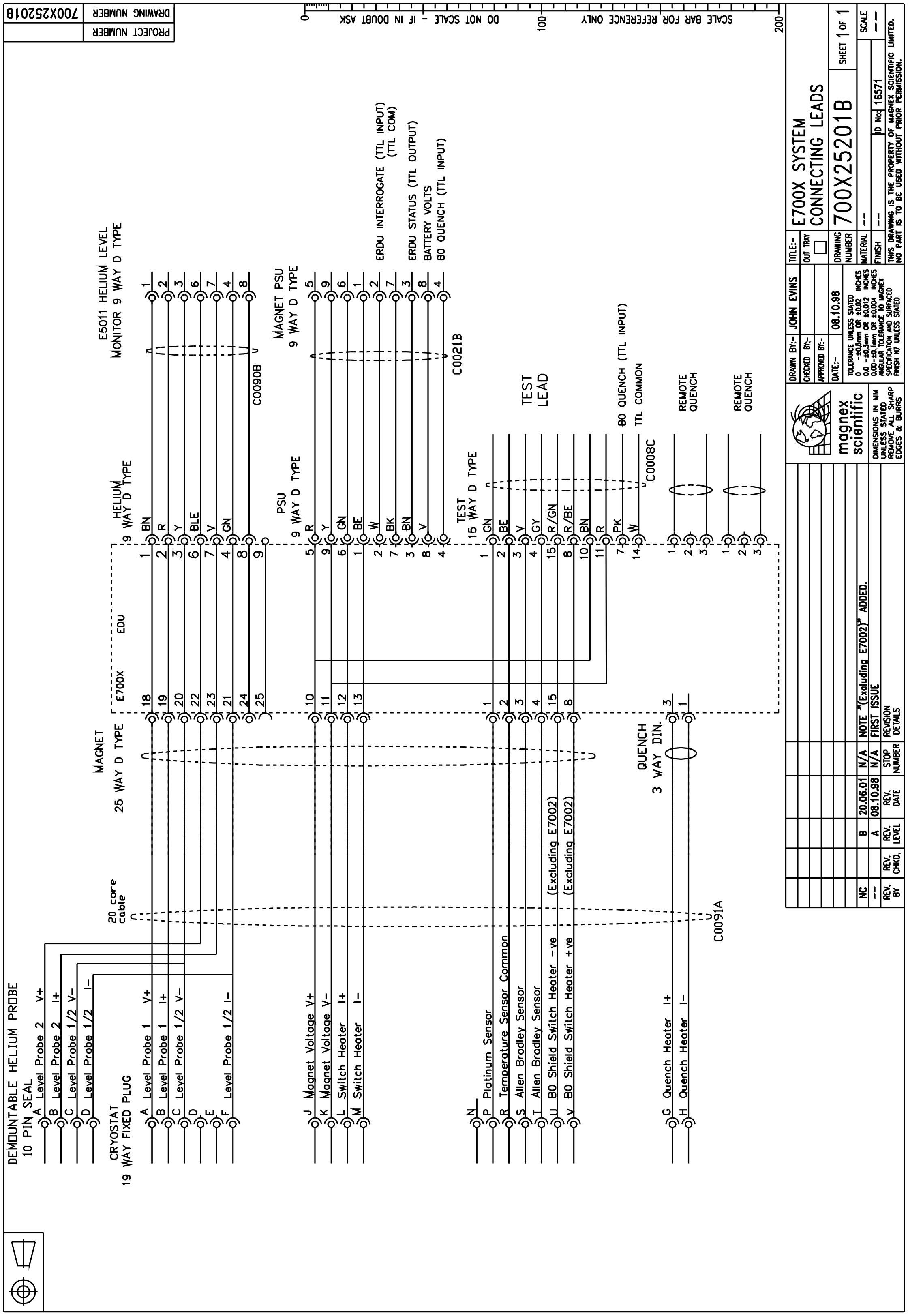
OUT TRAY

DRAWING NUMBER 700X45202A SHEET 1 OF 1

MATERIAL --

FINISH -- ID No: 15080

SCALE --

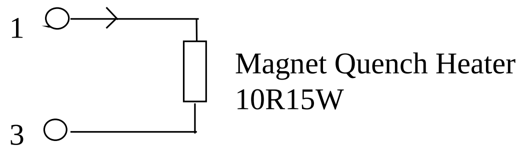

DEMOUNTABLE HELIUM PROBE
10 PIN SEAL
CRYOSTAT
19 WAY FIXED PLUG
MAGNET
25 WAY D TYPE
E700X
EDU
HELIUM
9 WAY D TYPE
PSU
9 WAY D TYPE
TEST
15 WAY D TYPE
QUENCH
3 WAY DIN.
E5011 HELIUM LEVEL
MONITOR 9 WAY D TYPE
MAGNET PSU
9 WAY D TYPE
TEST
LEAD
REMOTE
QUENCH
C0090B
C0021B
C0008C
C0091A
E700X SYSTEM
CONNECTING LEADS
700X25201B
magnex
scientific

7. PERIODIC TESTING

It is recommended that the quench and B0 dump currents are periodically tested to ensure correct operation.

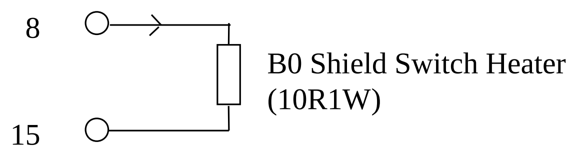
The following test loads must be attached in place of the service cable.

1A (10V)



3 Pin 'Din' Plug

.1A (1V)



25 'D' Plug

Magnet Quench Heater Current

To test the magnet quench heater current, press the emergency discharge button on the front panel. The button will illuminate. A minimum of 10V must be developed across the 'magnet quench heater' load indicating that 1A of current is flowing. This current will flow for approximately 30 seconds then cease.

WARNING : Do not reconnect the service cable during this time as a magnet quench will result.

The remote quench buttons must also be tested, they are tested in the same manner, however the buttons will not illuminate to indicate that current is flowing.

B0 Dump Switch Heater Current

Remove the top panel of the unit to access the clock timer. To test the B0 dump switch heater current, press the **CHANGE** button. The **B0 DUMP ON** LED will illuminate and a minimum of 1V must be developed across the 'B0 shield switch heater' load indicating that 100mA of current is flowing.

The current can be adjusted using VR2 mounted on the PCB. Press the **CHANGE** button to stop the flow of current.

Check the clock timer settings to ensure that the time is correct and the B0 shield switch heater is energised for 1 minute every 24 hours. To review the set programmes press and hold the **PROGRAM** button.

Ensure that the slider switch is in the **TIMED** position.

Check Batteries

Check the dated 'tested' label on the batteries to ensure that they are within their service life (refer to Battery Care section).

Completion

Refit top panel to unit. Reconnect service cable. Press **TEST** button. The **HEATER OK** and **BATTERY OK** LED's must illuminate.

8. TROUBLE SHOOTING

Front panel display conditions can give an indication of the problem.

Display	Possible Fault
No **POWER** LED	Loss of F1, F2 (rear panel mounted) or F3 (PCB mounted). *
HEATER OK LED not illuminated when **TEST** button pressed.	Loss of F4 (PCB mounted) *. Heater and cable resistance > 18Ω. Heater open circuit.
BATTERY OK LED not illuminated when **TEST** button pressed.	Batteries not fully charged or require replacing **(ensure batteries have charged for at least 24 hours prior to testing)
B0 DUMP ON LED not illuminated when B0 dump circuit operated	B0 shield switch heater open circuit.
B0 DUMP ON LED permanently illuminated	B0 dump clock timer incorrectly set (refer to setting B0 dump clock section)
B0 DUMP CLOCK MODULE Display blank on initial power up	Internal battery needs to charge for 30 minutes (refer to setting B0 dump clock section)

For any faults first check that proper connection is made both at the cryostat and at the unit.

If these tests do not highlight the fault then check the continuity and resistances at the cryostat end.

***** To change the PCB mounted fuses follow the instructions given below :-

1. Remove top panel of unit
2. Locate fuse
3. Remove fuse insulation cover, remove 'blown' fuse and replace with fuse of correct ratings.
4. Replace fuse insulation cover, replace top panel

****** Refer to Battery Care Section

9. USER SERVICEABLE PARTS

COMPONENT		DESCRIPTION	PART NUMBER
B1		12V 1.2 A/h Battery	P188160001
B2		6 V 1.2 A/h Battery	P188160002
F1, F2		5 X 20mm T125mA 250V Fuse	P188030005
	OR	5 X 20mm T250mA 250V Fuse	P188030007
F3, F4		5 X 20mm T1.6A 250V Fuse	P188030012

10. SETTING THE B0 DUMP CLOCK

Note: The top panel of the unit must be removed to access the B0 Dump Clock Timer

Clock Timer

The clock timer is used to energise the B0 switch heater allowing the fluxes within the B0 coil to decay.

It is recommended that the B0 switch heater is energised for 1 minute every 24 hours.

CAUTION - Failure to set the clock timer may cause the B0 coil to be permanently energised.

CAUTION - The clock timer is mains operated and battery backed, however it is recommended that the clock settings be checked should the unit be disconnected from the mains supply for periods greater than 72 hours.

Clock Setting

The clock timer operates in 24 hour mode and has the option to set up to 4 individual programmes.

A programme is a pair of ON/OFF settings which will dictate when the appliance will switch ON & OFF.

To prepare the module for programming set the slider switch to the **TIMED** position. Press the **CHANGE** and **PROGRAM** buttons simultaneously until the display goes blank.

The display will reappear to show a clock and flashing hours digits. The module is now ready to enter the correct local time.

Press the **CHANGE** button to advance the hour setting. Press the **PROGRAM** button to select the minute digits, they should start flashing. Use the **CHANGE** button to advance the minute setting. Press the **PROGRAM** button once to store the clock time.

The display should now show --:-- on with a flashing on. Set the first time on time to 00.01 as before. This has set the timer to switch on at 12 o'clock midnight and switch off at 1 minute past midnight. Programmes 2, 3 and 4 can be ignored, by pressing the **CHANGE** until the display shows the normal operating mode (current time).

Instant ON/OFF (over-ride)

To over-ride the programme in operation and to immediately switch ON or OFF press the **CHANGE** button.

Note

Button pauses greater than 1 minute during programming will result in automatic return to the normal operating mode.

On, Off and Timed slider switch

The **TIMED** position allows the module to operate using the programmed settings. The module must be left in this **MODE** to ensure that the B0 coil is dumped at regular intervals. The ON position permanently dumps the B0 coil, regardless of the timer settings. The OFF position disables the timer settings. The clock continues to function as normal.

11. BATTERY CARE

Manufacturers data shows that the batteries have a service life of between 4 ½ and 5 ½ years.

It is recommended that the batteries are replaced after the minimum time has elapsed.

Refer to dated ‘tested’ label on the batteries.

Replacement Batteries

Replacement battery packs can be obtained from Magnex Scientific Limited.

To replace batteries :-

1. Remove top panel of unit.
2. Disconnect battery terminals. Remove battery clamp by removing fixing screws. Lift out old batteries.
3. Fix new batteries to base plate using double sided tape provided.
4. Replace battery clamp firmly.
5. Reconnect terminals (leads and terminals are labelled). OBSERVE CORRECT POLARITY.
6. Refit top panel of unit.
7. Ensure batteries are charged for at least 24 hours prior to testing.

Magnex Ref : QA2
Rev : 0

Dear Customer,

In order to help us maintain our quality records and ensure traceability of our products, could you please complete and return this form if this unit was, or is to be, supplied by you with a system different to the one listed.

Unit Description ....

Unit Serial Number ....

Project Number Supply by Magnex on ....

System Description ....

Please complete the duplicate form overleaf if necessary and return to :-

The Quality Assurance Manager
The Magnet Technology Centre
6 Mead Road
Oxford Industrial Park
Yarnton
Oxford OX5 1QU, UK

Your co-operation is appreciated.

9.4T210AS Brookhaven (Project 15648) – Site Pressure Vessel Questions

There are various questions from Robert Colichio in the e-mail below. I have responded below each question.

<u>E-mail from Robert Colichio</u>

Andy, Graham,

The critical lift evaluation is going slow, but, getting there. I now
have to start accumulating data for the laboratory's Cryogenic Safety Committee evaluation. Unfortunately I have no documents/drawings to present
to them.

Specifically what they are looking for is the following:

* Physical layout

see customer interface drawings in technical specification TS1177

* Piping and Instrumentation Drawings

attached

* Design parameters, including:
* Maximum design/Allowable working pressures
* Pressure vessel, piping and component ratings
* Total quantity of cryogens

See PED Design Report

* Maximum release rate:

Magnet quench 6.43 litres/sec LHe (2894 kg/hr LHe)

* heat flux

11.3 kW

* pressure relief capabilities

Maximum allowable pressure 11 psig, predicted maximum quench pressure 8.69 psi (excluding site pipework).

* Quench protection (if necessary)

Please clarify question

* Stress Analyses (may require Finite Element Analyses)

See PED design report

* Must meet ASME Boiler & Pressure Vessel code and piping code requirements

System is designed and manufactured to the requirements of the European Pressure Equipment Directive (PED) – see PED design report

* Materials used (and their suitability for cryogenic temperatures)

Covered by PED requirements

*   Oxygen deficiency hazard classification calculations

Please clarify question

*   Test plans/results

Please clarify question

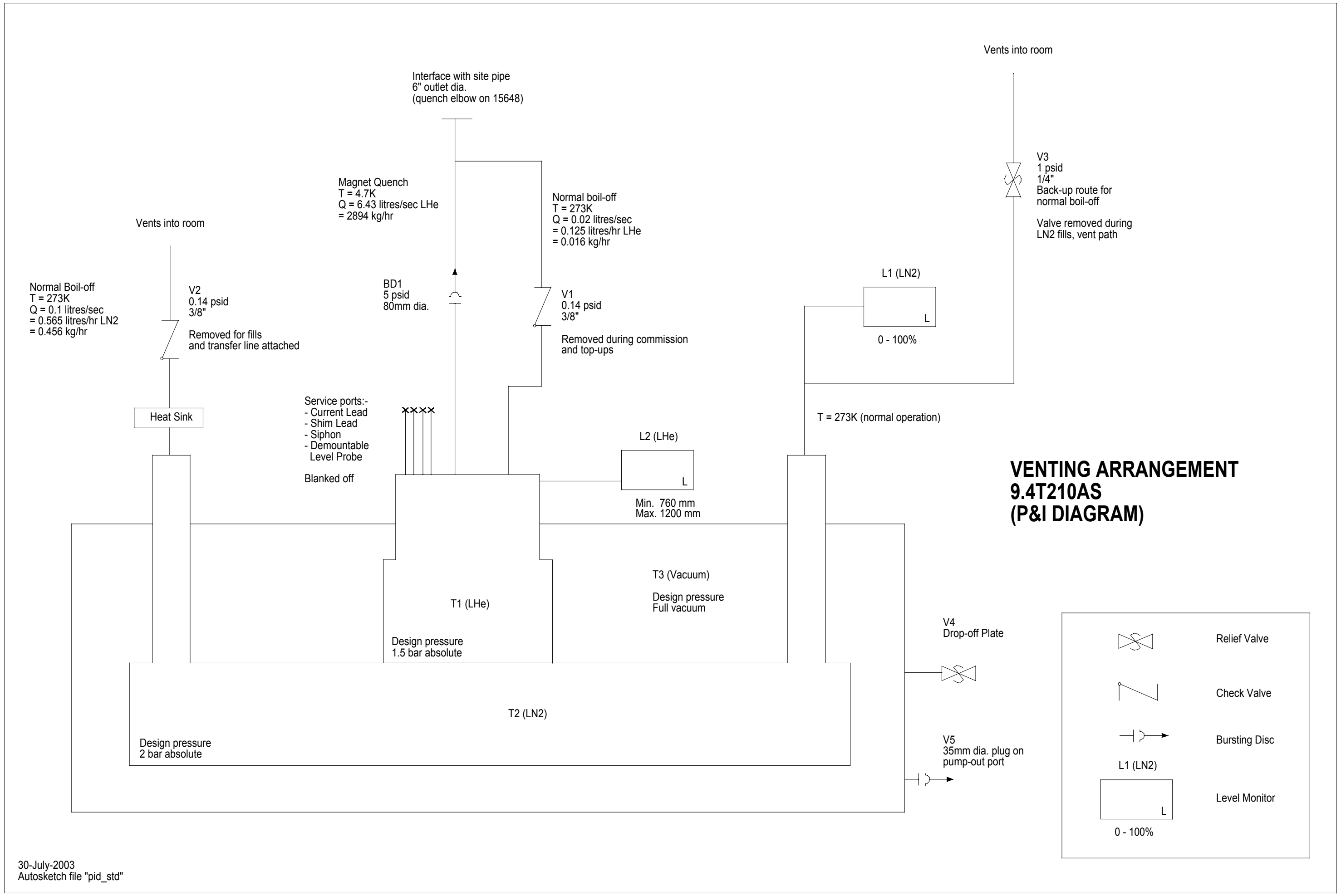
*   Operating procedures/emergency procedures

See System manual

Is this something you can help me out with?

Bob

Robert L. Colichio
Environment, Safety & Health Manager
Life Sciences Directorate
Brookhaven National Laboratory
Upton, NY 11973-5000


Interface with site pipe
6" outlet dia.
(quench elbow on 15648)
Vents into room
Magnet Quench
T = 4.7K
Q = 6.43 litres/sec LHe
= 2894 kg/hr
Normal boil-off
T = 273K
Q = 0.02 litres/sec
= 0.125 litres/hr LHe
= 0.016 kg/hr
V3
1 psid
1/4"
Back-up route for
normal boil-off
Valve removed during
LN2 fills, vent path
Vents into room
Normal Boil-off
T = 273K
Q = 0.1 litres/sec
= 0.565 litres/hr LN2
= 0.456 kg/hr
V2
0.14 psid
3/8"
Removed for fills
and transfer line attached
BD1
5 psid
80mm dia.
V1
0.14 psid
3/8"
Removed during commission
and top-ups
L1 (LN2)
L
0 - 100%
Service ports:-
- Current Lead
- Shim Lead
- Siphon
- Demountable
Level Probe
Blanked off
Heat Sink
T = 273K (normal operation)
L2 (LHe)
L
Min. 760 mm
Max. 1200 mm
VENTING ARRANGEMENT
9.4T210AS
(P&I DIAGRAM)
T3 (Vacuum)
Design pressure
Full vacuum
T1 (LHe)
Design pressure
1.5 bar absolute
V4
Drop-off Plate
Relief Valve
Check Valve
T2 (LN2)
Design pressure
2 bar absolute
V5
35mm dia. plug on
pump-out port
Bursting Disc
L1 (LN2)
L
Level Monitor
0 - 100%
30-July-2003
Autosketch file "pid_std"

OPERATING INSTRUCTIONS AND SPECIFICATIONS

for

Magnex Model E5011
Liquid Helium Level Monitor

Prepared : November 2000

Issue : i

Document : E5011MAN

Magnex Scientific Limited
The Magnet Technology Centre
6 Mead Road
Oxford Industrial Park
Yarnton, Oxford OX5 1QU, UK

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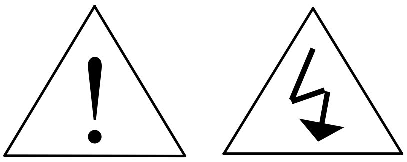
Fax No : +44 (0)1865 842466
E:mail: sales@magnex.com
www.magnex.com

CONTENTS

1. SAFETY



WARNING CAUTION

1. WARNING - Isolate or disconnect equipment from mains supply before opening this unit for any reason. LIVE PARTS INSIDE.

2. WARNING - For continued protection against risk of fire or electric shock, replace fuses with the same type, rating and UL listing.

3. CAUTION - This unit contains internal protection fuses. Follow the guidelines in Trouble- shooting section before replacement of these devices.

4. CAUTION - This unit has been pre-set to a voltage range suitable for the national supply. The unit has a selectable input voltage, 110V~ or 220V~. Fuses F1 and F2 must be rated to suit the input voltage, if selected to 110V~ they must be rated at T250mA 250V. If selected to 220V~ they must be rated at T100mA 250V.

   To select the mains supply voltage or replace mains fuses, prise open the flap on the mains input socket using a suitable tool in the slot provided. This affords access to the voltage select drum and two fuse trays.

   To select the supply voltage pull out the drum and rotate until the 230V~ or 115V~ lettering is uppermost, ie. in line with the drum slots, and replace. When the socket flap is replaced the correct voltage must be visible through the window.

   To replace the input fuse, pull out the fuse trays and replace with the correct value of fuse. Re-insert the fuse trays, noting the correct orientation of the arrows.

2. IMPORTANT NOTICE

Please inspect goods immediately on arrival for possible transit damage and notify Magnex Scientific Limited within 3 days of receipt of goods.

Failure to do this will invalidate any possible claim.

DISCLAIMER

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Details of circuitry and user serviceable spare parts are available upon request from :-

Magnex Scientific Limited
The Magnet Technology Centre
6 Mead Road
Oxford Industrial Park
Yarnton
Oxon OX5 1QU, UK

FCC NOTICE

Federal communications commission statement on Class A.

This unit has been tested and found to comply with the limits for a Class A digital device, pursuant to part is of the FCC rules. These limits are designed to provide reasonable protection against harmful interference when the unit is operated in a commercial, industrial or business environment.

Operating is subject to the following two conditions:

1) The unit may not cause harmful interference.

2) This device must accept any interference received, including interference that may cause undesired operation.

Note that FCC regulations provide that changes or modifications not expressly approved by Magnex Scientific Ltd could void your authority to operate this equipment.

CE NOTICE

Marking by the symbol CE indicates compliance of this device to the EMC (electromagnetic compatibility) and LV (low voltage) directives of the European Community. This unit is to be installed and operated as detailed. Any modification or maintenance procedure undertaken which is not approved by Magnex Scientific Ltd could nullify the CE marking of this product and lead to prosecution. A 'declaration of conformity' in accordance with the above directives has been made and is located at Magnex Scientific, Yarnton, Oxfordshire, UK.

3. DESCRIPTION AND OPERATING PRINCIPLE

Magnex Model E5011 Liquid Helium Level Monitor

Features

- Direct digital display of liquid helium level in mm.
- Variable interval sample and hold facility fill/normal.
- Adjustable low level alarm facility with visual and change-over relay output.
- Modular design.

Description

The model E5011 Monitor has been designed to operate with a superconducting level probe and provides a sampled digital display of liquid helium levels in cryogenic vessels. By the use of an adjustable interval sample and hold facility liquid helium consumption during operation is minimised. The instrument also incorporates an adjustable low level alarm facility with both visual and electrical outputs and can be offered for use with a range of superconducting level probes.

Operating Principle

The helium level probe consists of a length of superconducting wire with a heater wound around the top. A constant current is passed through the heater and probe wires. The heater maintains that part of the probe that is above the liquid level at a temperature above its critical temperature for super- conductivity. The part of the probe above the liquid therefore has resistance, the part immersed has none. A voltage signal is available from the probe which is proportional to the length of the probe not immersed in the liquid. This voltage is subtracted from a reference voltage and applied to a linear measuring circuit which drives a digital panel meter.

Heating the probe causes the liquid to boil, therefore to minimise this effect the helium level is read at intervals and ‘held’ on the display. The sample interval is derived and controlled by a timer and logic circuits, which allows current to flow into the probe heater until the temperature of the probe above the liquid helium level reaches a steady condition. A low level alarm system is driven from the measuring circuits.

4. SPECIFICATIONS

Magnex Model E5011 Liquid Helium Level Monitor

Output display		:	3 ½ digit L.C.D. scale in mm
Instant up-dating facility		:	Via front panel push button
Sample and hold interval	normal	:	7 hours (+/- 20%)
	fill	:	10 seconds (+/- 20%)
Interval selection		:	Via front panel switch
Maximum number of probes		:	2
Probe selection		:	Via front panel switch
Low level alarm indicator		:	Via flashing LED display
Low level alarm output		:	Relay change-over contacts Maximum switched voltage 30V dc Maximum switched current 1 A dc (mains failure will indicate an alarm condition)
Low level alarm adjustment		:	Via front panel multiturn preset. Span 0-95% of total length (factory set to 50%)
Mains input voltage		:	110/220V ~ selectable
Mains input current		:	80mA @ 220V ~ 170mA @ 110V ~
Mains input frequency		:	50/60 Hz
Fuse rating		:	F1, F2 T100mA 250V for 220V supply OR T250mA 250V for 110V supply F3 T800mA 250V F5 T200mA 250V

Dimensions :

Height	:	128mm (3U)
Width	:	106mm (21E)
Depth	:	220mm Plug in unit or stand alone

Probe Input Connector : 9 way 'D' socket
Connector details :

1	Probe 1	V +
2	Probe 1	I +
3	Probe 1	V -
4	Probe 1	I -
5	N/C	
6	Probe 2	V +
7	Probe 2	I +
8	Probe 2	V -
9	Probe 2	I -

<u>Liquid Helium Probe</u>

Probe resistance : 0.2-0.05Ω/mm

The probe wire resistance varies from batch to batch. If the exact probe resistance is required please contact Magnex Scientific Limited with the probe serial number.

Excitation current : 80-245mA dependent upon probe wire resistance

Probe length : 100mm to 2000mm

Probe output connector : 10 way SIL plug

E5011 MONITOR CABLE
C0025AXXX.X

9D Plug	Colour	1- Pin Socket
1	Brown	A
2	Red	B
3	Yellow	C
4	Green	D
5	N/C	N/C
6	Blue	E
7	Violet	F
8	White	H
9	Black	J

9d Plug	Colour	10 Pin Socket
1	Red	A
2	Blue	B
3	Green	D
4	Yellow	E
5	N/C	N/C
6	N/C	N/C
7	N/C	N/C
8	N/C	N/C
9	N/C	N/C

5. CALIBRATION

The instrument is normally supplied pre-calibrated to a particular probe before leaving the factory. If recalibration is required it must be carried out using a test unit to simulate the probe, the circuit of which is (Figure 1) shown on page 9.

Equipment Required

* Multimeter
* Helium monitor calibration unit
* Insulated adjustment tool

Method

Connect the calibration unit to the helium monitor via the 9 'D' PROBE plug at the rear of the helium monitor.

Calculate the resistance for the active length of the helium probe for which calibration is required and set the variable potentiometer on the calibration unit to this resistance.

Set the monitor READ time to NORMAL.

The probe current (as listed in 'Specifications' section or advised by Magnex) is set by adjusting the rear panel potentiometer PROBE CURRENT or on earlier models potentiometer VR1 on the power supply PCB. The probe current is measured as a voltage across the 10Ω HEATER resistor on the calibration unit (hold the READ button in when adjusting probe current).

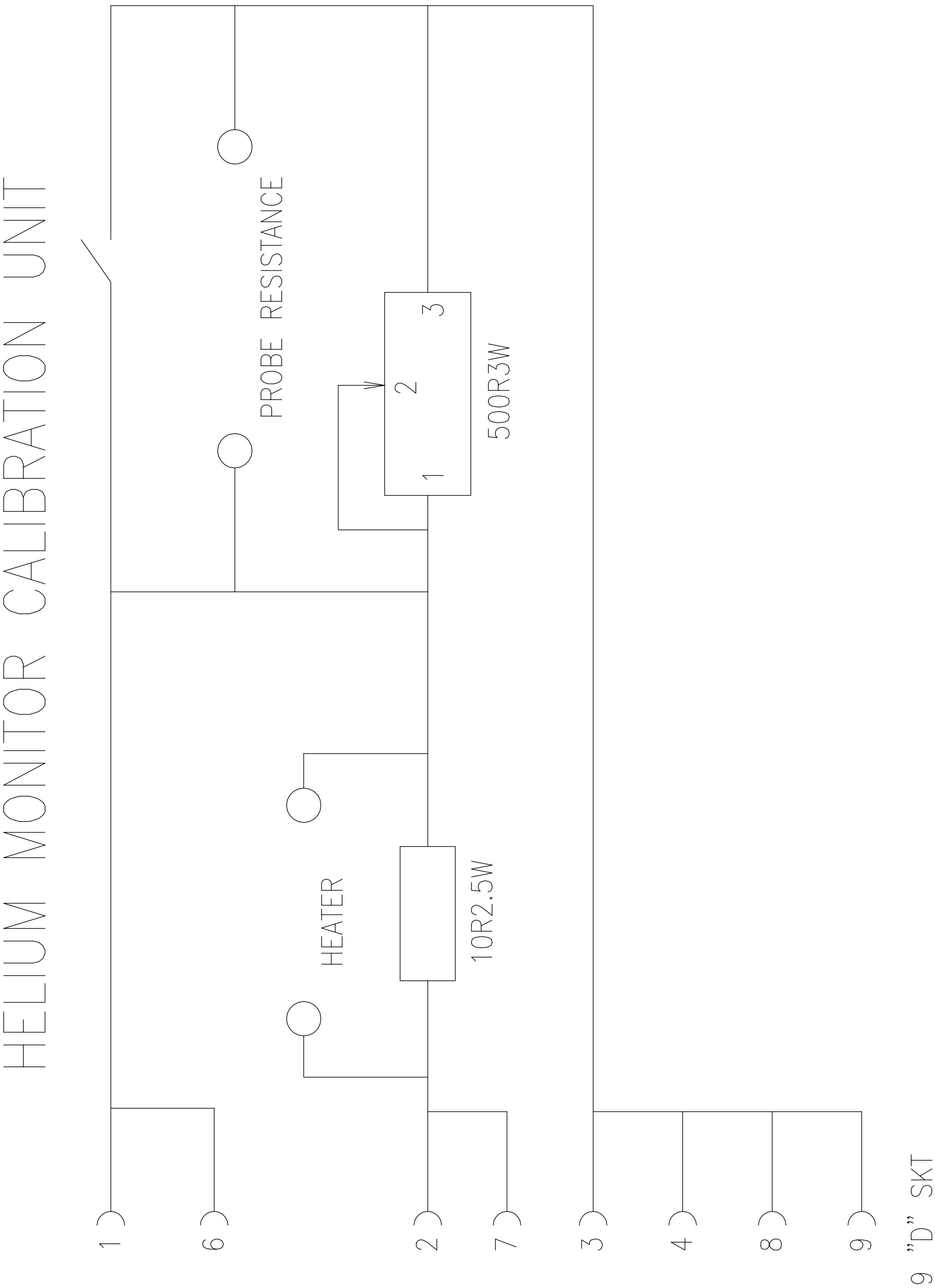
CAUTION : MIS-ADJUSTMENT OF THE PROBE CURRENT CAN UPSET THE OPERATION OF THE INSTRUMENT AND CAUSE SPURIOUS READINGS

To select the required probe operate the front panel switch marked PROBE 1-2.

The helium monitor digital panel meter (DPM) is set to read zero with the calculated resistance set on the calibration unit. Place the calibration unit PROBE switch to the RESISTANCE position. Adjust the appropriate rear panel mounted PROBE ZERO potentiometer until the DPM reads zero (hold the READ button in when adjusting for zero).

Place the calibration unit PROBE switch to the S/C position and adjust the rear panel mounted DPM SPAN potentiometer until the DPM reads the active length of the helium probe (hold the READ button in when adjusting for the active length).

FIGURE 1


HELIUM MONITOR CALIBRATION UNIT
PROBE RESISTANCE
1
2
3
500R3W
HEATER
10R2.5W
1
6
2
7
3
4
8
9
9 ”D” SKT

6. SETTING THE LOW LEVEL ALARM

The helium monitor alarm level can be set by pressing the DISPLAY button and changing the ADJUST potentiometer until the DPM reads the desired level (hold the DISPLAY button in when adjusting for the alarm level). Once the alarm level has been set, press the READ button to display the current probe level.

An alarm state is indicated by the flashing ALARM LED on the front panel and the operation of the rear panel alarm relay contacts, which allow the inclusion of additional external alarm indicators. During normal operation contacts 1 & 2 will be connected and 2 & 3 open circuit.

During alarm conditions contacts 2 & 3 will be connected and 1 & 2 open circuit.

7. TROUBLE-SHOOTING

For loss of continuity in the probe circuit the front panel display can give an indication of the problem.

Display	**Possible Fault**
No LCD display No POWER LED	Loss of F1, F2 (rear panel mounted) or F3 (PCB mounted) *
ALARM LED flashes. Display reads 'Full'. READ LED does not operate	Loss of I+ / I- connection or F5 (PCB mounted)*
The READ LED operates normally and the ALARM LED remains off. The level reads full continuously	Loss of V+ connection
The READ LED comes on continuously. ALARM LED remains at the last reading shown	Loss of V- connection

For any of the above symptoms first check that proper connection is made to the instrument and to the probe or cryostat.

If these tests do not prove to be the cause of the problem then check the continuity and resistances of all combinations at the cryostat connector. Refer to the cryostat manual for the wiring diagrams.

* To change PCB mounted fuses

1. Remove mains supply lead.
2. Remove unit top cover.
3. Locate fuse (refer to pcb layout).
4. Remove fuse installation cover, remove 'blown' fuse and replace with fuse of correct ratings.
5. Replace fuse installation cover and unit top cover.

OPERATING INSTRUCTIONS AND SPECIFICATIONS

for

Magnex Model E5031 Liquid Nitrogen Level Monitor

Prepared	:	November 2000
Issue	:	g
Document	:	E5031MAN

Magnex Scientific Limited
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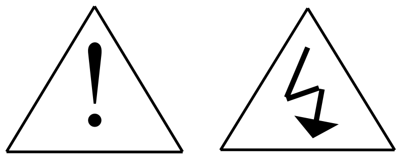
E-mail : sales@magnex.com
www.magnex.com

CONTENTS

1. SAFETY



WARNING CAUTION

1. WARNING - Isolate or disconnect equipment from mains supply before opening this unit for any reason. LIVE PARTS INSIDE.

2. WARNING - For continued protection against risk of fire or electric shock, replace fuses with the same type, rating and UL listing.

3. CAUTION - This unit contains internal protection fuses, follow the guidelines in trouble-shooting section before replacement of these devices.

4. CAUTION - This unit has been pre-set to a voltage range suitable for the national supply. The unit has a selectable input voltage, 110V~ or 220V~. Fuses F1 and F2 must be rated to suit the input voltage, if selected to 110V~ they must be rated at T250 mA 250V. If selected to 220V~ they must be rated at T100 mA 250V.

   To select mains supply voltage or replace mains fuses, prise open the flap on the mains input socket using a suitable tool in the slot provided. This affords access to the voltage select drum and two fuse trays.

   To select the supply voltage pull out the drum and rotate until the 230V~ or 115V~ lettering is uppermost, i.e. in line with the drum slots, and replace. When the socket flap is replaced the correct voltage must be visible through the window.

   To replace the input fuses, pull out the fuse trays and replace with the correct value of fuse. Re-insert the fuse trays, noting the correct orientation of the arrows.

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3. DESCRIPTION AND OPERATING PRINCIPLE

Magnex Model E5031 Liquid Nitrogen Level Monitor

Features :

- Direct display of liquid nitrogen level in %.
- Adjustable low level alarm facility with visual and change-over relay contact output.
- Modular design.

Description

The Model E5031 monitor has been designed to operate with a capacitive level probe and provides a continuous analogue display of liquid nitrogen in cryogenic vessels via a moving coil meter.

The instrument also incorporates an adjustable low level alarm facility with both visual and electrical outputs.

The monitor can be offered for use with a range of capacitive level probes.

Operating Principle

The Nitrogen Level Probe consists of two electrodes which form a capacitance, with the liquid nitrogen as a dielectric. As the level of the liquid nitrogen dielectric varies with the level in the cryostat then the capacitance of the probe varies.

The Head Oscillator Unit monitors the change in probe capacitance and sends this information to the main unit where it is processed and used to drive the analogue panel meter and analogue output voltage.

The low level alarm system is also driven from the measuring circuits.

4. SPECIFICATIONS

E5031 Liquid Nitrogen Level Monitor

Output display	:	Analogue meter, scale 0-100%
	:	Analogue voltage 0 - 500 mV dc
Low level alarm indicator	:	Via flashing led display
Low level alarm output	:	Relay change-over contacts
	:	Maximum switched voltage 30V dc
	:	Maximum switched current 1A dc (mains failure will indicate an alarm condition).
Low level alarm adjustment	:	Via front panel multi-turn preset Span 0-95% of total probe length
Mains input voltage	:	110/220V~ Selectable
Main input current	:	30mA @ 220V~ 60mA @ 110V~
Mains input frequency	:	50/60 Hz
Fuse rating	:	F1,F2 T100mA 250V @ 220V supply or F1,F2 T250mA 250V @ 110 V supply F3 T800 mA 250V F4 T800 mA 250V
Dimensions	:	Height = 128mm (3U) Width = 106mm (21E) Depth = 220mm Plug-in unit or free standing.

Liquid Nitrogen Probe

Input connector	:	TNC Socket
Standard Probe Diameter	:	6.35mm
Probe Length	:	To customer requirement.

E5031 MONITOR CABLE

CCO113AXXX.X

9D Plug	Colour	10 Pin Socket
1	Brown	A
2	Red	C
3	N/C	N/C
4	Green	H
5	N/C	N/C
6	Violet	B
7	White	D
8	Black	E
9	Blue	J

5. CALIBRATION

This monitor has been calibrated for a particular probe length. Should the instrument fail to produce accurate readings or is to be used with a different probe it may be re-calibrated following the instructions below:-

Note

During the initial cool down of the system the capacitance of the probe increases slightly causing the meter to display a false reading. The head oscillator unit ‘zero’ potentiometer must not be adjusted. When the system reaches liquid nitrogen temperature, the probe capacitance will decrease and the meter reading will return to zero. Filling can now commence.

Equipment Required

Capacitance meter
Select On Test (S.O.T.) capacitor (C4)
Insulated adjustment tool
Nitrogen monitor calibration unit.

Method 1

(Operation 1 is not necessary if the probe was supplied with the monitor, because the correct S.O.T. capacitor, C4, will have been fitted).

1. Measure the capacitance of the probe at room temperature. Remove the head oscillator cover and fit a S.O.T. capacitor to C4 equal to the probe value. (Remove any existing capacitor first). Replace the cover.

2. Attach the head oscillator unit to the probe and insert into the cryogenic vessel. Connect the head oscillator unit to the monitor using the inter-connecting cable, adjust the head oscillator unit ‘ZERO’ potentiometer fully anti-clockwise. Adjust the monitor ‘GAIN’ potentiometer fully clockwise.

3. With the vessel cold but empty adjust the head oscillator unit ‘ZERO’ potentio-meter until the panel meter reads 2%.

Vertical Systems Only

If the above is not possible since the vessel is already full of liquid nitrogen, it Is possible to simulate this condition by immersing the probe into the liquid nitrogen until it is cold then withdrawing it into the air. Whilst it is still cold adjust the head oscillator unit ‘ZERO’ potentiometer until the panel meter reads 2%.

THIS SHOULD NOT BE ATTEMPTED FOR HORIZONTAL SYSTEMS. DAMAGE OF FLEXIBLE PROBE MAY RESULT.

4. With the vessel full of liquid nitrogen adjust the monitor ‘GAIN’ potentiometer until the panel meter reads 100%

5. The low level alarm can now be set to the desired level. Alternatively the monitor can be re-calibrated using the nitrogen monitor calibration unit.

Method 2

(Operation 1 is not necessary if the probe was supplied with the monitor, because the correct S.O.T. capacitor, C4, will have been fitted).

1. Measure the capacitance of the probe at room temperature. Remove the head oscillator cover and fit a S.O.T. capacitor to C4 equal to the probe value. (Remove any existing capacitor first). Replace the cover.

2. Insert the probe into the cryogenic vessel. Measure the probe capacitance when the vessel is empty and also when it is completely full of liquid nitrogen.

Vertical Systems Only

If the above is not possible since the vessel is already full of liquid nitrogen, it is possible to simulate this condition by immersing the probe into the liquid nitrogen until it is cold then withdrawing it into the air. Whilst it is still cold, measure the capacitance.

THIS SHOULD NOT BE ATTEMPTED FOR HORIZONTAL SYSTEMS. DAMAGE OF FLEXIBLE PROBE MAY RESULT.

3. Adjust the head oscillator unit 'ZERO' and the monitor unit 'GAIN' potentiometer fully anti-clockwise.

4. Attach the nitrogen monitor calibration unit to the head oscillator unit.

5. Set the calibration unit capacitance to the 'Vessel Empty' value and adjust the head oscillator unit 'ZERO' potentiometer until the panel meter reads 2%.

6. Set the calibration unit capacitance to the 'Vessel Full' value and adjust the monitor 'GAIN' potentiometer until the panel meter reads 100%.

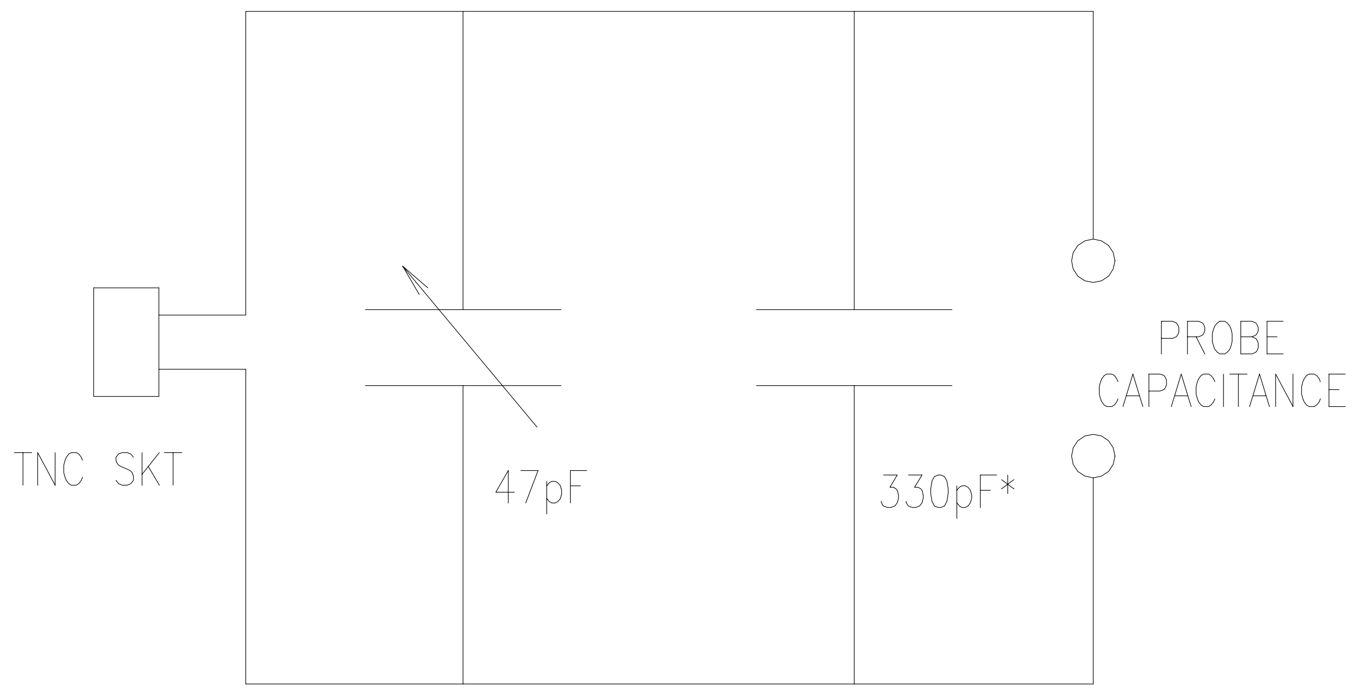
7. The low level alarm can now be set to the desired level.

8. Disconnect the calibration unit and connect the head oscillator to the probe.

Note : Probe Capacitance

The probe capacitance's may be obtained from Magnex Scientific Ltd. Please state probe serial number or system serial number with correspondence.

NITROGEN MONITOR CALIBRATION UNIT



*THIS VALUE MAY BE CHANGED TO SUIT PROBE CAPACTIANCE

6. SETTING THE LOW LEVEL ALARM

The nitrogen monitor alarm level can be set by pressing and holding the DISPLAY button while changing the ADJUST potentiometer until the analogue meter reads the desired level.

An alarm state is indicated by the flashing ALARM LED on the front panel and the operation of the rear panel alarm relay contacts, which allow the inclusion of additional external alarm indicators. During normal operation contacts 1 & 2 will be connected and 2 & 3 open circuit.

During alarm conditions contacts 2 & 3 will be connected and 1 & 2 open circuit.

7. TROUBLE SHOOTING

Display	Possible Fault
No POWER LED Meter reading 0%	Loss of F1,F2 (rear panel mounted)
Meter reading 0% POWER LED on	Loss of F3,F4 (PCB mounted*)
Meter reading 0% ALARM LED flashing POWER LED on	Loss of continuity between probe and monitor. Probe short circuit.
Meter reading erratic	Monitor incorrectly calibrated for particular probe (refer to calibration section of manual).

For any of the above symptoms first check that proper connection is made to the instrument and to the probe or cryostat.

* To Change PCB Mounted Fuses.

1. Remove mains supply leads.

2. Remove unit top cover.

3. Locate fuse.

4. Remove fuse insulation cover, remove ‘blown’ fuse and replace with fuse of correct ratings.

5. Replace fuse cover and unit to cover.

PED Design Report
For The
9.4T/210 AS MRBR

Report No	DR1177
Field	9.4 Tesla
Cryogens	Helium and Nitrogen
Group	2
Category	III
No. of Sheets	18
Created on	11/06/2002

Contents

Originator	I. Hussain	
Checked	A. Courtney	
Approved	J. Bird	

PED design report for the 9.4T/210 AS MRBR

Two vessels, the Helium and Nitrogen cans, fall within the scope of the PED.
The vessels are both designed to contain cryogenic liquids and gases. In both cases the gases may reach a vapour pressure greater than 0.5 bar above atmospheric pressure {i.e. greater than 1.5bar(abs)} and are treated as containing Group 2 gases.

The Helium vessel has a capacity of approx. 1203 litres, a design pressure of 1.69bar(abs) and will operate at 4K.

The Nitrogen vessel has a capacity of approx. 243 litres, a design pressure of 2.0 bar(abs) and will operate at 77K.

Both vessels are contained within a third vessel, the Outer Vacuum Chamber (OVC), such that failure of any one vessel will affect both of the others. Therefore for conformity assessment purposes the pressure*volume function should be combined. This places the vessels within Category III.

This design report covers the requirement to document all the design calculations made.

The third vessel, the Outer Vacuum Chamber, falls outside the PED's requirements for conformity assessment, having a design pressure of only one atmosphere (external).

The vessel has been designed using PD5500 calculations for external pressure loading, but these are not included within this report. The vessel will be manufactured to sound engineering practice.

Summary of design calculations.

The 9.4T/210 AS FTMS is a conventional horizontal magnet (Ref. drawing No. AHC025637).

Helium can . (AHC125434)

The Helium-can contains the superconducting magnet. It consists of an outer tube, a bore tube, two endplates and a neck tube. The vessel is suspended from suspension straps attached to the endplates. The neck tube consists of a pair of bellows and three tube sections, manufactured in one piece and supplied tested and certificated for the design pressure

Calculation 1.

The outer tube of the Helium can (DHC125437) is a Stainless Steel 304 rolled tube with a single seam weld and one opening for the neck tube. The calculations show that the outer tube is thick enough for the pressure loading and provides sufficient reinforcement around the neck opening.

Calculation 2.

The end-plates of the Helium can (DHC125435 & DHC125436) are both annular plates welded around their outside edges to the outer tube and around their central openings to the bore tube. PD5500, Section 3.5.5 (flat plates) cannot be applied to this configuration so Roark & Young formulae have been used to show that the stresses do not exceed the limits defined by PD5500 Annex A.

Calculation 3.

The bore tube of the Helium can (DHM325438) is a Stainless Steel 304 rolled tube with a single seam weld. The calculations show that the bore tube will not collapse under the external pressure exerted on it.

Nitrogen Can. (AHC025453)

The Nitrogen can is an annular vessel that sits around the Helium can. It consists of an outer tube, an inner tube, two annular rings and two neck tubes. The vessel is also suspended from its endplates.

Two cases are considered for the Nitrogen can components. The first is normal operation where the design pressure is 2 bar. The second is for a vacuum leak test where the design pressure is 1 bar applied externally.

The joints between the stainless steel neck tubes and the aluminium outer tube are made using friction welded junctions. These components, as well as being well proven in many of Magnex's magnet systems, are being certificated for use in this application. The joints are welded to stainless steel bellows which are supplied certificated for the design pressure.

Calculation 4.

The outer tube of the Nitrogen can (DHC125454) is an Aluminium 5083 rolled tube with a single seam weld and three openings. The large central opening is for the service tube, which connects the inner and outer tubes providing an opening for the helium can neck tube to pass through. The other two openings are for the Nitrogen neck tubes. The calculations show that the tube thickness is fine for both design cases.

Calculation 5.

The inner tube of the Nitrogen can (DHC025455) is also an Aluminium 5083 rolled tube with a single seam weld. This tube features just the one central opening for the service tube. The pressures act in the opposite directions to those applying to the outer tube. The calculations show that the tube thickness is fine for both design cases.

Calculation 6.

The end rings of the Nitrogen can (DHC425457) are annular rings welded around their outside edges to the outer tube and around the inside edges to the inner tube. PD5500, Section 3.5.5 cannot be applied to this configuration so the Roark & Young formulae have been used to show that the stresses do not exceed the limits defined by PD5500 Annex A. Only one case has been considered, the normal operation case of 2 bar, as the vacuum test case only applies half this load albeit in the opposite direction.

Conclusions:

The calculations show that the vessels are both of sound design and that the majority of components demonstrate high safety margins. There are no areas that stand out as raising concern.

Inam Hussain

B.Eng(Hons) PDM, AMIMechE

Mechanical Engineer

Calculation 1 - 9.4T/210 AS MRBR
Helium Can Outer Tube - DHC125437
Calculations to PD5500 (2000)

Shell material: Stainless Steel 304

Design Strength: $f := 120\text{MPa}$ (to Category 3).

Youngs Modulus: $E_2 := 220000\text{MPa}$ at 4K

Poisson's ratio: $\nu := 0.3$

Cylinder dimensions

Inside diameter: $Di := 1442\text{mm}$

Unsupported Length: $L := 1129.9\text{mm}$

Design Thickness: $t := 4.76\text{mm}$

Outside diameter: $D_o := Di + (2 \cdot t)$ $D_o = 1451.52\,\text{mm}$

Mean diameter: $D := Di + t$ $D = 1446.76\,\text{mm}$ Mean radius: $r := \frac{D}{2}$ $r = 723.38\,\text{mm}$

Pen ring dimensions - DHU322158

Nozzle mean diameter: $d := 119\text{mm}$

Nozzle analysis thickness: $e_{ab} := 5\text{mm}$

Design Cases

Case 1 Normal Operation: Design Pressure: $p_1 := 1.69 \cdot \text{bar}$

Design Temperature: $t_1 := 4\text{K}$

Case 1 Normal Operation:

Section 3.5.1.2 Minimum thickness for pressure loading only: Cylindrical shells.

or (3.5.1-1) $e := \frac{p_1 \cdot Di}{2 \cdot f - p_1}$ $e = 1.016\,\text{mm}$

Openings in cylinder wall - refer to assy drg - AHC125434

Vessel analysis thickness: $e_{as} := t$ $e_{as} = 4.76\,\text{mm}$

Min Vessel thickness: $e_{ps} := e$ from Case 1. above. $e_{ps} = 1.016\,\text{mm}$

<u>Section 3.5.4.3.3</u> Openings fitted with nozzle connections:

h) For a minimum vessel thickness of $e_{rs} := e_{as}$

and nozzle thickness of $e_{rb} := e_{ab}$

$\frac{e_{rb}}{e_{rs}} = 1.05$ $\frac{d}{D} = 0.082$

Nozzle design parameter: $\rho := \frac{d}{D} \cdot \sqrt{\frac{D}{2 \cdot e_{rs}}}$ $\rho = 1.014$

External loads factor: $C := 1.1$

$C \cdot \frac{e_{rs}}{e_{ps}} = 5.153$ > 1.0 minimum value from Figure 3.5-9, therefore the thickness of the parent shell and nozzle exceed the requirements of 3.5.4

Calculation 2 - 9.4T/210 AS MRBR
Helium Can End Plates - DHC125435 and DHC125436
Calculations to PD5500 (2000)

Section 3.5.5.4 cannot sensibly be applied to these flat end plates as both are annular plates. Both plates are fixed at their outer diameters to the outer tube and at their inner diameters to the bore tube. The plates are identical in their major dimensions and differ only in small details that have no influence on how they perform as part of the pressure vessel.

Both plates can be examined using formulae from Roark & Young Table 24 and thereby assessed using Annex A.

Annular Plate analysis:

Plate Dimensions

Outside diameter: $D_o := 1440.5mm$ Outer Radius: $a := \frac{D_o}{2}$ $a = 720.3\,mm$

Inside diameter: $D_i := 283.5mm$ Inner Radius: $b := \frac{D_i}{2}$ $b = 141.8\,mm$

Design Thickness: $t := 16 \cdot mm$

Plate material: Stainless Steel 304

Design Strength: $f := 120MPa$ (to category 3)

Youngs Modulus: $E_2 := 220000MPa$ at 4K

Poisson's ratio: $\nu := 0.3$

Design Cases

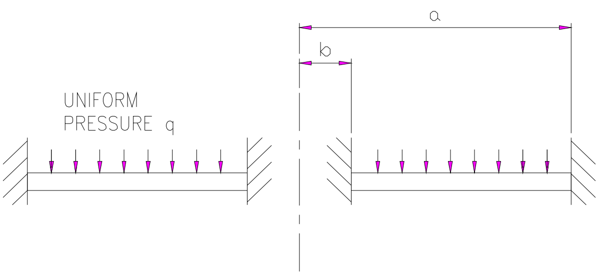
Case 1 Normal Operation: Design Pressure: $p_1 := 1.69 \cdot bar$

Design Temperature: $t_1 := 4K$

Roark & Young, Table 24 Formulas for flat circular plates of constant thickness:

Case 2h. Outer edge fixed, inner edge fixed.

Uniform load over entire plate. $r_o := b$ and $q := p_1$



Constants required for assessing Case 2h:

$$C_2 := \frac{1}{4}\cdot\left[1 - \left(\frac{b}{a}\right)^2\cdot\left(1 + 2\cdot\ln\left(\frac{a}{b}\right)\right)\right] \qquad C_2 = 2.1\times 10^{-1}$$

$$C_3 := \frac{b}{4\cdot a}\cdot\left[\left[\left(\frac{b}{a}\right)^2 + 1\right]\cdot\ln\left(\frac{a}{b}\right) + \left(\frac{b}{a}\right)^2 - 1\right] \qquad C_3 = 3.6\times 10^{-2}$$

$$C_5 := \frac{1}{2}\cdot\left[1 - \left(\frac{b}{a}\right)^2\right] \qquad C_5 = 4.8\times 10^{-1}$$

$$C_6 := \frac{b}{4\cdot a}\cdot\left[\left(\frac{b}{a}\right)^2 - 1 + 2\cdot\ln\left(\frac{a}{b}\right)\right] \qquad C_6 = 1.1\times 10^{-1}$$

$$C_8 := \frac{1}{2}\cdot\left[(1+\nu) + \left[(1-\nu)\left(\frac{b}{a}\right)^2\right]\right] \qquad C_8 = 6.6\times 10^{-1}$$

$$C_9 := \frac{b}{a}\cdot\left[\frac{(1+\nu)}{2}\cdot\ln\left(\frac{a}{b}\right) + \frac{(1-\nu)}{4}\cdot\left[1 - \left(\frac{b}{a}\right)^2\right]\right] \qquad C_9 = 2.4\times 10^{-1}$$

$$L_{11} := \frac{1}{64}\cdot\left[1 + 4\cdot\left(\frac{r_o}{a}\right)^2 - 5\left(\frac{r_o}{a}\right)^4 - 4\left(\frac{r_o}{a}\right)^2\cdot\left[2 + \left(\frac{r_o}{a}\right)^2\right]\cdot\ln\left(\frac{a}{r_o}\right)\right] \qquad L_{11} = 9.9\times 10^{-3}$$

$$L_{14} := \frac{1}{16}\cdot\left[1 - \left(\frac{r_o}{a}\right)^4 - 4\left(\frac{r_o}{a}\right)^2\cdot\ln\left(\frac{a}{r_o}\right)\right] \qquad L_{14} = 4.7\times 10^{-2}$$

$$L_{17} := \frac{1}{4}\cdot\left[1 - \frac{(1-\nu)}{4}\cdot\left[1 - \left(\frac{r_o}{a}\right)^4\right] - \left(\frac{r_o}{a}\right)^2\cdot\left[1 + (1+\nu)\cdot\ln\left(\frac{a}{r_o}\right)\right]\right] \qquad L_{17} = 1.8\times 10^{-1}$$

Moment resisting bending on inner diameter:

$$M_{rb} := -q\cdot a^2\cdot\frac{(C_3\cdot L_{14} - C_6\cdot L_{11})}{(C_2\cdot C_6 - C_3\cdot C_5)} \qquad M_{rb} = -7.7\times 10^3\,N$$ (per unit circumference)

Reaction at inner diameter:

$$Q_b := q\cdot a\cdot\frac{(C_2\cdot L_{14} - C_5\cdot L_{11})}{(C_2\cdot C_6 - C_3\cdot C_5)} \qquad Q_b = 9.6\times 10^4\,\frac{N}{m}$$ (per unit circumference)

Moment resisting bending on outer diameter:

$$M_{ra} := M_{rb}\cdot C_8 + Q_b\cdot a\cdot C_9 - q\cdot a^2\cdot L_{17} \qquad M_{ra} = -3.9\times 10^3\,N$$ (per unit circumference)

Reaction at outer diameter:

$$Q_a := \frac{q}{2\cdot a}\cdot\left(a^2 - r_o^{\,2}\right) - Q_b\cdot\frac{b}{a} \qquad Q_a = 39.6\times 10^3\,\frac{N}{m}$$ (per unit circumference)

As the plates are rigidly fixed at their extremities, the angular displacements will be zero at the inner and outer diameters. Therefore the tangential bending moments will relate directly to the radial bending moments: $M_t = \nu . M_r$

Radial bending stress on inner diameter:

$$\sigma_{rb} := 6 \cdot \frac{M_{rb}}{t^2} \qquad \sigma_{rb} = -179.73 \times 10^6 \, Pa$$

Tangential bending stress on inner diameter:

$$\sigma_{tb} := 6 \cdot \frac{\nu \cdot M_{rb}}{t^2} \qquad \sigma_{tb} = -53.9 \times 10^6 \, Pa$$

Radial bending stress on outer diameter:

$$\sigma_{ra} := 6 \cdot \frac{M_{ra}}{t^2} \qquad \sigma_{ra} = -91.3 \times 10^6 \, Pa$$

Tangential bending stress on outer diameter:

$$\sigma_{ta} := 6 \cdot \frac{\nu \cdot M_{ra}}{t^2} \qquad \sigma_{ta} = -27.4 \times 10^6 \, Pa$$

Shear stress at inner diameter:

$$\tau_{wb} := \frac{Q_b}{t} \qquad \tau_{wb} = 6 \times 10^6 \, Pa$$

Shear stress at outer diameter:

$$\tau_{wa} := \frac{Q_a}{t} \qquad \tau_{wa} = 2.5 \times 10^6 \, Pa$$

The peak stress seen is the radial bending stress ($\sigma_{rb} = -179.729 \times 10^6 \, Pa$)acting on the inner diameter.

Annex A (Figure A.1) gives the safe limit for a primary bending stress as 1.5f, which equates to 180MPa for 304 Stainless steel to category 3 i.e. across a weld. Design strength for 304 Stainless steel (as given in PD5500) is 143MPa therefore stress limit (1.5f) would be 214.5MPa. Therefore, the plate design, though highly stressed around the inner diameter, is within the acceptable stress limits.

Calculation 3 - 9.4T/210 AS MRBR
Helium Can Bore Tube - DHM325438
Calculations to PD5500 (2000)

Design Cases

Case 1 Normal Operation: Design Pressure: $p_1 := 1.69 \cdot bar$ external

Design Temperature: $t_1 := 4K$

Shell material: Stainless Steel 304

Design Strength: $f := 120MPa$ (to Category 3)

Youngs Modulus: $E_1 := 220000MPa$

Poisson's ratio: $\nu := 0.3$

Bore tube - Case 1 Normal Operation:

Dimensions

Inside diameter: $Di := 274.5mm$

Unsupported Length: $L := 1129.9mm$

Thickness: $t := 4mm$

Section 3.6 Vessels under external pressure.
3.6.2 Cylindrical shells.
There are no stiffeners so stiffener parameter $\gamma := 0$
therefore the interstiffener parameter G does not require evaluating.

Yield point factor $s := 1.1$

Mean radius of cylinder: $R := \frac{Di + t}{2}$ $R = 139.25\,mm$

3.6.2.1 a)
Pressure at which the mean circumferential stress reaches yield point:

$$P_y := \frac{s \cdot f \cdot t}{R \cdot (1 - \gamma \cdot G)} \qquad P_y = 3.792 \times 10^6 Pa \qquad (3.6.2\text{-}7)$$

3.6.2.1 b)

node number for minimum buckling pressure: $n := 3$

Strain parameter $Z := \frac{\pi \cdot R}{L}$ $Z = 0.387$ (3.6.2-10)

Mean elastic circumferential strain at collapse:

$$\varepsilon := \frac{1}{n^2 - 1 + \frac{Z^2}{2}} \cdot \left[\frac{1}{\left(1 + \frac{n^2}{Z^2}\right)^2} + \frac{t^2 \cdot \left(n^2 - 1 + Z^2\right)^2}{12 \cdot R^2 \cdot \left(1 - \nu^2\right)} \right] \qquad \varepsilon = 6.548 \times 10^{-4} \quad (3.6.2\text{-}9)$$

Elastic instability pressure for collapse:

$P_m := \frac{E_1 \cdot t \cdot \varepsilon}{R}$ $P_m = 4.138\,\text{MPa}$ (3.6.2-8)

3.6.2.1 c)

$K := \frac{P_m}{P_y}$ $K = 1.091$

From Figure 3.6-4: $\Delta := 0.36$

3.6.2.1 d)

Allowable external pressure: $P := \Delta \cdot P_y$ $P = 1.365 \times 10^6\,\text{Pa}$

Therefore design pressure $p_1 = 1.69 \times 10^5\,\text{Pa}$ is acceptable.

Assessment of stresses due to combined loads acc. to <u>Annex A3</u>. Ref: Figure A.1

Reaction at inner diameter: $Q_b := 9.6 \times 10^4 \frac{N}{m}$ (per unit circumference)
(from Calculation 2)

Longitudinal stress: $f_{mx} := \frac{Q_b}{t}$ $f_{mx} = 24 \times 10^6\,\text{Pa}$ is < $1.5 \cdot f = 180 \times 10^6\,\text{Pa}$

Circumferential stress: $f_{m\phi} := \frac{p_1 \cdot Di}{2 \cdot t}$ $f_{m\phi} = 5.799 \times 10^6\,\text{Pa}$ is < $1.5 \cdot f = 180 \times 10^6\,\text{Pa}$

Calculation 4 - 9.4T/210 AS MRBR
Nitrogen Can Outer Tube - DHC125454
Calculations to PD5500 (2000)

Dimensions

Inside diameter: $Di := 1632mm$

Length: $L := 1115mm$

Thickness: $t := 8mm$

Mean radius: $r := \frac{(Di + t)}{2}$ $r = 820\,mm$

Design Cases

Case 1 Normal Operation: Design Pressure: $p_1 := 2 \cdot bar$

Design Temperature: $t_1 := 77K$

Weight (full of LN2) $w_1 := 270kg$

Case 2 Vacuum Leak test: Design Pressure: $p_2 := 1bar$ external

Design Temperature: $t_2 := 290K$

Weight (empty) $w_2 := 155kg$

Shell material: Aluminium Alloy 5083

Design Strength: $f := 83MPa$ (at both design temperatures).

Youngs Modulus: $E_2 := 69300MPa$ at 290K

Poisson's ratio: $\nu := 0.3$

Case 1 Normal Operation:

Section 3.5.1.2 Minimum thickness for pressure loading only
a) Cylindrical shells.

Minimum thickness: $e := \frac{p_1 \cdot Di}{2 \cdot f - p_1}$ $e = 1.969\,mm$ (3.5.1-1)

Therefore the design thickness is fine for normal operation.

Case 2 Vacuum Leak test:

Section 3.6 Vessels under external pressure.
3.6.2 Cylindrical shells.
There are no stiffeners so stiffener parameter $\gamma := 0$
therefore the interstiffener parameter G does not require evaluating.
Yield point factor $s := 1.1$

Mean radius of cylinder: $R := \frac{Di + t}{2}$ $R = 820\,mm$

3.6.2.1 a)
Pressure at which the mean circumferential stress reaches yield point:

$P_y := \frac{s \cdot f \cdot t}{R \cdot (1 - \gamma \cdot G)}$ $P_y = 8.907 \times 10^5\,Pa$ (3.6.2-7)

3.6.2.1 b)
node number for minimum buckling pressure: $n := 7$

Strain parameter $Z := \frac{\pi \cdot R}{L}$ $Z = 2.31$ (3.6.2-10)

Mean elastic circumferential strain at collapse:

$$\varepsilon := \frac{1}{n^2 - 1 + \frac{Z^2}{2}} \cdot \left[\frac{1}{\left(1 + \frac{n^2}{Z^2}\right)^2} + \frac{t^2 \cdot \left(n^2 - 1 + Z^2\right)^2}{12 \cdot R^2 \cdot \left(1 - \nu^2\right)} \right] \qquad \varepsilon = 6.799 \times 10^{-4} \text{(3.6.2-9)}$$

Elastic instability pressure for collapse:

$$P_m := \frac{E_2 \cdot t \cdot \varepsilon}{R} \qquad P_m = 4.596 \times 10^5 \, Pa \qquad \text{(3.6.2-8)}$$

3.6.2.1 c) $K := \frac{P_m}{P_y}$ $K = 0.516$

From Figure 3.6-4: $\Delta := 0.19$

3.6.2.1 d)
Allowable external pressure: $P := \Delta \cdot P_y$ $P = 1.692 \times 10^5 \, Pa$

Therefore design pressure $p_2 = 1 \times 10^5 \, Pa$ is acceptable.

Openings in cylinder wall - refer to assy drg - AHC025453

Vessel mean diameter: $D := Di + t$ $D = 1.64 \times 10^3 \, mm$

Vessel analysis thickness: $e_{as} := t$ $e_{as} = 8 \, mm$

Min Vessel thickness: $e_{ps} := e$ from Case 1. above. $e_{ps} = 1.969 \, mm$

Large opening for service turret tube. - DHC325456

Nozzle mean diameter: $d := 192.5mm$

Nozzle analysis thickness: $e_{ab} := 19.5mm$

Section 3.5.4.3.3 Openings fitted with nozzle connections: $\frac{d}{D} = 0.117$

h) For a minimum vessel thickness of $e_{rs} := e_{as}$

and nozzle thickness of $e_{rb} := e_{ab}$

$\frac{e_{rb}}{e_{rs}} = 2.438$

Nozzle design parameter: $\rho := \frac{d}{D} \cdot \sqrt{\frac{D}{2 \cdot e_{rs}}}$ $\rho = 1.188$

External loads factor: $C := 1.1$

$C \cdot \frac{e_{rs}}{e_{ps}} = 4.47$ > 2.76 from Figure 3.5-9 therefore the thickness of the parent shell and nozzle exceed the requirements of 3.5.4

<u>Small opening for friction weld tube - DHC400066</u>

Nozzle mean diameter: $d := 30.3mm$

Nozzle analysis thickness: $e_{ab} := 4.5mm$

Section 3.5.4.3.3 Openings fitted with nozzle connections: $\frac{d}{D} = 0.018$

h) For a minimum vessel thickness of $e_{rs} := e_{as}$

and nozzle thickness of $e_{rb} := e_{ab}$

$\frac{e_{rb}}{e_{rs}} = 0.563$

Nozzle design parameter: $\rho := \frac{d}{D} \cdot \sqrt{\frac{D}{2 \cdot e_{rs}}}$ $\rho = 0.187$

External loads factor: $C := 1.1$

$C \cdot \frac{e_{rs}}{e_{ps}} = 4.47$ > 1.0 lower limit of Figure 3.5-11, therefore the thickness of the parent shell and nozzle exceed the requirements of 3.5.4

Calculation 5 - 9.4T/210 AS MRBR
LN2 Can Inner Tube - DHC025455
Calculations to PD5500 (2000)

Dimensions

Inside diameter: $Di := 1521mm$

Length: $L := 1115mm$

Thickness: $t := 10mm$

Design Cases

Case 1 Normal Operation: Design Pressure: $p_1 := 2 \cdot bar$ external

Design Temperature: $t_1 := 77K$

Case 2 Vacuum Leak test: Design Pressure: $p_2 := 1bar$

Design Temperature: $t_2 := 290K$

Shell material: Aluminium Alloy 5083

Design Strength: $f := 83MPa$ (at both design temperatures).

Youngs Modulus: $E_1 := 76600MPa$ at 77K

Poisson's ratio: $\nu := 0.3$

Case 1 Normal Operation:

Section 3.6 Vessels under external pressure.
3.6.2 Cylindrical shells.
There are no stiffeners so stiffener parameter $\gamma := 0$

therefore the interstiffener parameter G does not require evaluating.
Yield point factor $s := 1.1$

Mean radius of cylinder: $R := \frac{Di - t}{2}$ $R = 755.5\,mm$

3.6.2.1 a)
Pressure at which the mean circumferential stress reaches yield point:

$$P_y := \frac{s \cdot f \cdot t}{R \cdot (1 - \gamma \cdot G)} \qquad P_y = 1.208 \times 10^6\,Pa \qquad (3.6.2\text{-}7)$$

3.6.2.1 b)
node number for minimum buckling pressure: $n := 6$

Strain parameter $Z := \frac{\pi \cdot R}{L}$ $Z = 2.129$ (3.6.2-10)

Mean elastic circumferential strain at collapse:

$$\varepsilon := \frac{1}{n^2 - 1 + \frac{Z^2}{2}} \cdot \left[\frac{1}{\left(1 + \frac{n^2}{Z^2}\right)^2} + \frac{t^2 \cdot \left(n^2 - 1 + Z^2\right)^2}{12 \cdot R^2 \cdot \left(1 - \nu^2\right)} \right] \qquad \varepsilon = 1.008 \times 10^{-3} \quad (3.6.2\text{-}9)$$

Elastic instability pressure for collapse:

$P_m := \frac{E_1 \cdot t \cdot \varepsilon}{R}$ $\quad P_m = 1.022 \times 10^6 \, Pa$ $\quad$ (3.6.2-8)

3.6.2.1 c) $\quad K := \frac{P_m}{P_y}$ $\quad K = 0.846$

From Figure 3.6-4: $\quad \Delta := 0.25$

3.6.2.1 d)
Allowable external pressure: $\quad P := \Delta \cdot P_y$ $\quad P = 3.021 \times 10^5 \, Pa$

Therefore design pressure $p_1 = 2 \times 10^5 \, Pa$ is acceptable.

Case 2 Vacuum leak test:

Section 3.5.1.2 Minimum thickness for pressure loading only
a) Cylindrical shells.

Minimum thickness: $\quad e := \frac{p_2 \cdot Di}{2 \cdot f - p_2}$ $\quad e = 0.917 \, mm$ $\quad$ (3.5.1-1)

Therefore the design thickness is fine for both normal operation and the vacuum leak test.

Openings in cylinder wall - refer to assy drg - AHC025453

Vessel mean diameter: $\quad D := Di + t$ $\quad D = 1.531 \times 10^3 \, mm$

Vessel analysis thickness: $\quad e_{as} := t$ $\quad e_{as} = 10 \, mm$

Min Vessel thickness: $\quad e_{ps} := e$ from Case 1. above. $\quad e_{ps} = 0.917 \, mm$

Large opening for service turret tube - DHC325456

Nozzle mean diameter: $\quad d := 192mm$

Nozzle analysis thickness: $\quad e_{ab} := 19.5mm$

Section 3.5.4.3.3 Openings fitted with nozzle connections:

For a minimum vessel thickness of $\quad e_{rs} := e_{as}$ $\quad \frac{d}{D} = 0.125$

h) and nozzle thickness of $\quad e_{rb} := e_{ab}$

$\frac{e_{rb}}{e_{rs}} = 1.95$

Nozzle design parameter: $\quad \rho := \frac{d}{D} \cdot \sqrt{\frac{D}{2 \cdot e_{rs}}}$ $\quad \rho = 1.097$

External loads factor: $\quad C := 1.1$

$C \cdot \frac{e_{rs}}{e_{ps}} = 11.998$ > 1.0 minimum value from Figure 3.5-9 therefore the thickness of the parent shell and nozzle exceed the requirements of 3.5.4

Calculation 6 - 9.4T/210 AS MRBR NitrogenCan End Rings - DHC425457 Calculations to PD5500 (2000)

Section 3.5.5.4 cannot sensibly be applied to these flat end plates as both are annular plates. Both plates are fixed at their outer diameters to the outer tube and at their inner diameters to the bore tube. The plates are identical in their major dimensions and differ only in small details that have no influence on how they perform as part of the pressure vessel.

Both plates can be examined using formulae from Roark & Young Table 24 and thereby assessed using Annex A.

Annular Plate analysis:

Plate Dimensions

Outside diameter: $D_o := 1630\text{mm}$ Outer Radius: $a := \frac{D_o}{2}$ $a = 815\,\text{mm}$

Inside diameter: $D_i := 1542\text{mm}$ Inner Radius: $b := \frac{D_i}{2}$ $b = 771\,\text{mm}$

Design Thickness: $t := 16\text{mm}$

Shell material: Aluminium Alloy 5083

Design Strength: $f := 83\text{MPa}$ (at both design temperatures).

Youngs Modulus: $E_2 := 76600\text{MPa}$ at 77K

Poisson's ratio: $\nu := 0.3$

Design Cases

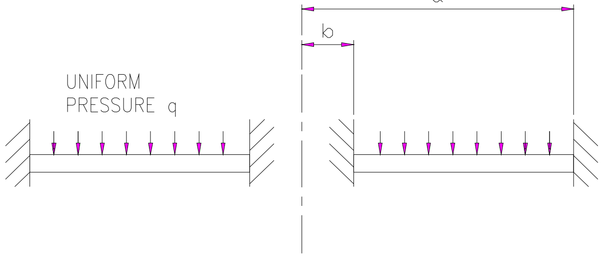
Case 1 Normal Operation: Design Pressure: $p_1 := 2\cdot\text{bar}$

Design Temperature: $t_1 := 77\text{K}$

Roark & Young, Table 24 Formulas for flat circular plates of constant thickness:

Case 2h. Outer edge fixed, inner edge fixed.

Uniform load over entire plate. $r_o := b$ and $q := p_1$



Constants required for assessing Case 2h:

$$C_2 := \frac{1}{4}\cdot\left[1-\left(\frac{b}{a}\right)^2\cdot\left(1+2\cdot\ln\left(\frac{a}{b}\right)\right)\right] \qquad C_2 = 1.431\times 10^{-3}$$

$$C_3 := \frac{b}{4\cdot a}\cdot\left[\left[\left(\frac{b}{a}\right)^2+1\right]\cdot\ln\left(\frac{a}{b}\right)+\left(\frac{b}{a}\right)^2-1\right] \qquad C_3 = 2.551\times 10^{-5}$$

$$C_5 := \frac{1}{2}\cdot\left[1-\left(\frac{b}{a}\right)^2\right] \qquad C_5 = 0.053$$

$$C_6 := \frac{b}{4\cdot a}\cdot\left[\left(\frac{b}{a}\right)^2-1+2\cdot\ln\left(\frac{a}{b}\right)\right] \qquad C_6 = 1.405\times 10^{-3}$$

$$C_8 := \frac{1}{2}\cdot\left[(1+\nu)+\left[(1-\nu)\left(\frac{b}{a}\right)^2\right]\right] \qquad C_8 = 0.963$$

$$C_9 := \frac{b}{a}\cdot\left[\frac{(1+\nu)}{2}\cdot\ln\left(\frac{a}{b}\right)+\frac{(1-\nu)}{4}\cdot\left[1-\left(\frac{b}{a}\right)^2\right]\right] \qquad C_9 = 0.052$$

$$L_{11} := \frac{1}{64}\cdot\left[1+4\cdot\left(\frac{r_o}{a}\right)^2-5\left(\frac{r_o}{a}\right)^4-4\left(\frac{r_o}{a}\right)^2\cdot\left[2+\left(\frac{r_o}{a}\right)^2\right]\cdot\ln\left(\frac{a}{r_o}\right)\right] \qquad L_{11} = 3.462\times 10^{-7}$$

$$L_{14} := \frac{1}{16}\cdot\left[1-\left(\frac{r_o}{a}\right)^4-4\left(\frac{r_o}{a}\right)^2\cdot\ln\left(\frac{a}{r_o}\right)\right] \qquad L_{14} = 2.551\times 10^{-5}$$

$$L_{17} := \frac{1}{4}\cdot\left[1-\frac{(1-\nu)}{4}\cdot\left[1-\left(\frac{r_o}{a}\right)^4\right]-\left(\frac{r_o}{a}\right)^2\cdot\left[1+(1+\nu)\cdot\ln\left(\frac{a}{r_o}\right)\right]\right] \qquad L_{17} = 1.413\times 10^{-3}$$

Moment resisting bending on inner diameter:

$$M_{rb} := -q\cdot a^2\cdot\frac{(C_3\cdot L_{14}-C_6\cdot L_{11})}{(C_2\cdot C_6-C_3\cdot C_5)} \qquad M_{rb} = -32.633\,N$$ (per unit circumference)

Reaction at inner diameter:

$$Q_b := q\cdot a\cdot\frac{(C_2\cdot L_{14}-C_5\cdot L_{11})}{(C_2\cdot C_6-C_3\cdot C_5)} \qquad Q_b = 4.459\times 10^3\,\frac{N}{m}$$ (per unit circumference)

Moment resisting bending on outer diameter:

$$M_{ra} := M_{rb}\cdot C_8 + Q_b\cdot a\cdot C_9 - q\cdot a^2\cdot L_{17} \qquad M_{ra} = -31.917\,N$$ (per unit circumference)

Reaction at outer diameter:

$$Q_a := \frac{q}{2\cdot a}\cdot\left(a^2-r_o^{\,2}\right)-Q_b\cdot\frac{b}{a} \qquad Q_a = 4.345\times 10^3\,\frac{N}{m}$$ (per unit circumference)

As the plates are rigidly fixed at their extremities, the angular displacements will be zero at the inner and outer diameters. Therefore the tangential bending moments will relate directly to the radial bending moments: $M_t = \nu.M_r$

Radial bending stress on inner diameter:

$$\sigma_{rb} := 6 \cdot \frac{M_{rb}}{t^2} \qquad \sigma_{rb} = -764.841 \times 10^3 \text{ Pa}$$

Tangential bending stress on inner diameter:

$$\sigma_{tb} := 6 \cdot \frac{\nu \cdot M_{rb}}{t^2} \qquad \sigma_{tb} = -2.295 \times 10^5 \text{ Pa}$$

Radial bending stress on outer diameter:

$$\sigma_{ra} := 6 \cdot \frac{M_{ra}}{t^2} \qquad \sigma_{ra} = -7.48 \times 10^5 \text{ Pa}$$

Tangential bending stress on outer diameter:

$$\sigma_{ta} := 6 \cdot \frac{\nu \cdot M_{ra}}{t^2} \qquad \sigma_{ta} = -2.244 \times 10^5 \text{ Pa}$$

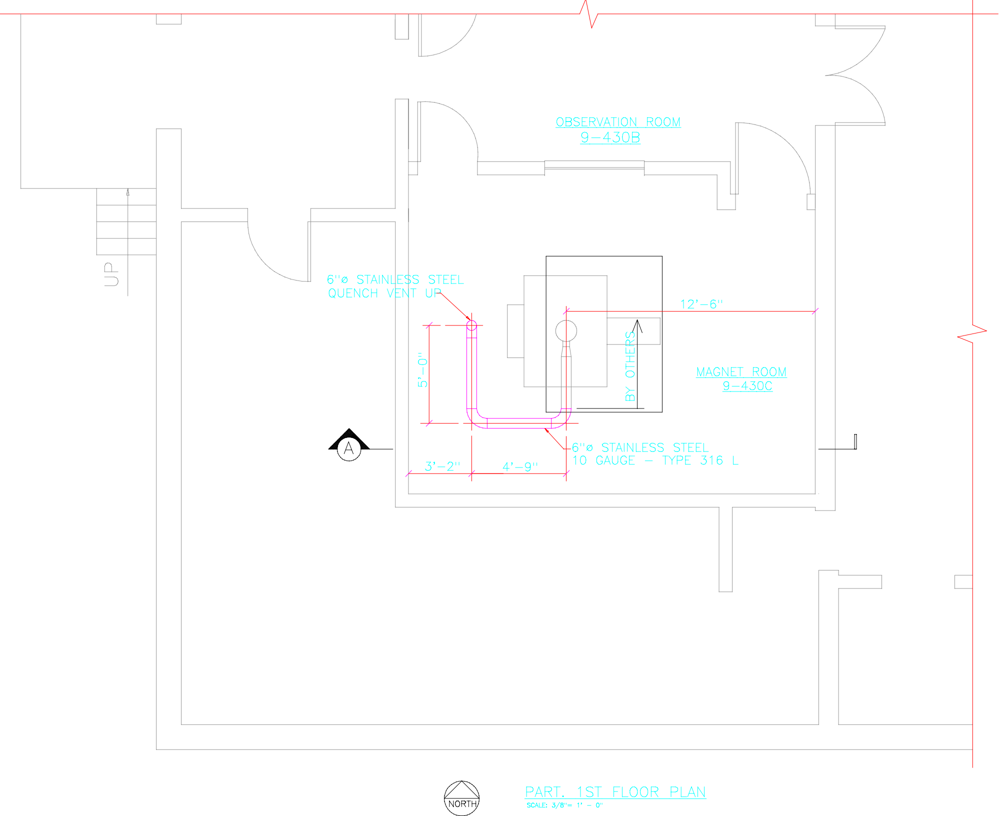
Shear stress at inner diameter:

$$\tau_{wb} := \frac{Q_b}{t} \qquad \tau_{wb} = 2.787 \times 10^5 \text{ Pa}$$

Shear stress at outer diameter:

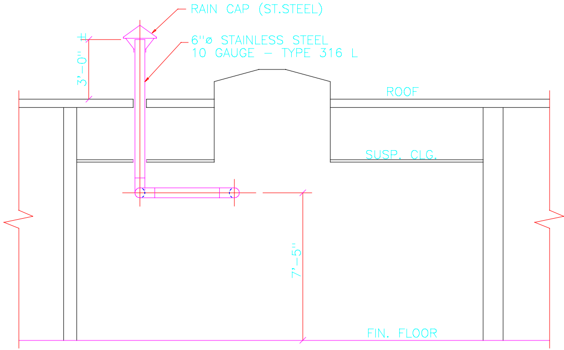
$$\tau_{wa} := \frac{Q_a}{t} \qquad \tau_{wa} = 2.715 \times 10^5 \text{ Pa}$$

The peak stress seen is the radial bending stres (s $\sigma_{rb} = -0.76 \text{ MPa}$) acting on the inner diameter.
Annex A (Figure A.1) gives the safe limit for a primary bending stress as 1.5f, which equates to 124.5 MPa for Aluminium to Category 3.
Therefore, these plates design are within the acceptable stress limits.



PART. 1ST FLOOR PLAN

SCALE: 3/8"= 1" - 0"



SECTION A

SCALE: 3/8"= 1" - 0"

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managed by Brookhaven Science Associates
for the U.S. Department of Energy

Memo

date: *July 1, 2003* *SE88SR03*

to: *R. Colichio*

from: *Michael Gaffney*

subject: ***Initial ODH Assessment of the Animal MRI Facility, Building 490***

reference:
(a) Brookhaven National Lab SBMS Subject Area, "Oxygen Deficiency Hazard Classification and Controls,"
(b) Test, Adjust, and Balance Report for BNL: Animal MRI Facility, dated April 11, 2003, performed by John Mazza (PE) Engineering & Technical Services, Smithtown, NY

The purpose of this memo is to document the initial Oxygen Deficiency Hazard (ODH) concerns in respect to reference (a) for the Animal MRI Facility in Building 490.

A 9.4-Tesla helium cooled superconducting MRI is being installed in Building 490, Room 9-430C. The MRI will have 800-liters (211-gallons) of liquid helium capacity. There is a liquid nitrogen heat shield with a 248-liter (65½ gallons) capacity.

For the purpose of the analysis, the free space volume (V) of the room is 6000 cubic feet. Based of the ventilation testing documented in reference (b), the ventilation flow rate (Q) is 800 cubic feet per minute.

The MRI will be installed with a quench exhaust tube. For the purpose of the evaluation, it is assumed that the quench tube is designed so a loss of insolating vacuum and/or any overpressure in either the helium or nitrogen system will vent through the quench tube to the outside.

Using the following ventilation equation from the exhibit in reference (a):

$$l := \frac{Q + R}{V}$$

$$C(t) := \left[\frac{0.21}{Q + R}\cdot\left[Q + R\cdot e^{-(l\cdot t)}\right]\right]$$

The minimum leak rate (R) that would result in Oxygen concentration dropping less than 18% would be 133 ft^3/min. At that leak rate, the MRI would be empty in 2½ hours. This would be a significant loss of helium (not a case of a slow leak through a fitting) and should be easily detectable by personnel. In addition, using the post leak ventilation equation from reference (a):

$$C(t) := 0.21 - (0.21 - C_{te}) \cdot e^{-(l \cdot t)}$$

(assume the room's oxygen concentration after the end of the release, C_{te}= 10%)

oxygen concentration would be over 18% after 10 minutes.

Conclusion:

Based on the following:

- The ventilation system operates as design,
- The quench tube vent system properly removes cryogens out the room from overpressure and loss of thermal isolation vacuum.

Room 9-430C can be classified as an **ODH 0** area under normal operation due the low probability of an occurrence ($< 10^{-6}$) and capability of the room's ventilation system maintain oxygen concentrations during small volume releases.

Recommendations:

As long as there is positive indication that the ventilation system is operating correctly, then constant oxygen monitoring is not required for normal operation. However, maintenance operations that may affect the cryogenic systems introduce additional risks and extra controls should be used. Due to recent fatalities, it is strongly recommended that during the cooling and filling process, personal oxygen monitors be use. Additional ventilation systems may be used if practical.

The Cryogenic part of the MRI, including quench piping must be reviewed and approved by the Laboratory's Cryogenic Safety Committee.

If you have any questions, I may be reached at extension 8236.

cc:

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