HEALTH AND SAFETY RISKS IN MAGNETIC SHIELDING DESIGN AND CONSTRUCTION FOR MAGNETIC RESONANCE IMAGING (MRI) SUITES

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A thesis submitted to Edinburgh Napier University in fulfilment of the requirements for the Degree of Doctor of Philosophy.

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ABSTRACT

Once energised, and even when the equipment is not imaging, magnets used in magnetic resonance imaging will produce a static magnetic field that extends in three dimensions around the magnet. This static magnetic field is invisible; it is impossible to know that it is present or to be aware of it unless told. It is important to know the position and magnetic flux density of the static magnetic field because those persons having ferromagnetic material embedded within their bodies or their eyes (the result of a welding process for example), or fitted with electronic body implants, could suffer harm from the effects of the static magnetic field at relatively low levels. Those individuals fitted with some heart pacemakers could be affected at 0.5 mT.

The published literature relating to magnetic resonance imaging is, by its nature, restricted to the medico-technical-academic press and does not systematically appear in publications destined for construction professionals. There is no published literature relating to the design of magnetic shielding for MRI suites as it relates to health and safety risks to those exposed to the static magnetic field during the construction, maintenance and demolition phases of a magnetic resonance imaging project.

This thesis is progressive in its structure and fills gaps in knowledge by commencing with a study to determine if the requirements placed on duty holders as defined by The Construction (Design and Management) Regulations 2007 (CDM) and its antecedent regulations are understood by all those parties involved with the conception, design, construction and maintenance of an MRI suite. Several misconceptions are highlighted. A second study gave an evaluation of the availability of as-built drawings showing the position of the 0.5 mT footprint of the static magnetic field of the magnet and gives disappointing results. The third study was to assess the effectiveness of a retrofit installation of passive magnetic shielding and highlights some failings, with the fourth study to investigate if magnetic shielding had been installed to an operational MRI suite. The fifth study was to review if the client had considered the magnetic shielding design requirements of a magnet before it was installed.
Finally, the sixth case study was to evaluate if there was a clear understanding by designers of the function and attributes of RF shielding and of passive magnetic shielding to a Faraday cage. Examples, by the inclusion of annotated drawings, are given.

There was not a clear understanding by CDM duty-holders of responsibilities placed upon them under the CDM Regulations. The introduction of magnetic shielding into a magnetic resonance suite design can distort the symmetry of the 0.5 mT footprint of the static magnetic field, create areas of increased magnetic flux density and push parts of the 0.5 mT footprint to the outside of any designated controlled area. This will consequentially increase the risk of unscreened persons (both inside and outside the control of the employer) being exposed to the effects of the static magnetic field unless the magnitude and position of the 0.5 mT footprint is documented and disseminated to all those persons likely to come into contact with it. The incorporation of magnetic shielding as retrofit can result in leakages of magnetic flux at its joint with the finished floor and through any shielding fixing bolts.

This thesis could be useful to designers in developing risk management plans for MRI suite construction, maintenance and demolition. By making a synthesis that has not been made before, this thesis makes a contribution to knowledge by addressing these issues for the first time.
DECLARATION

This thesis is submitted to Edinburgh Napier University for the Degree of Doctor of Philosophy.

The work described in this thesis was carried out under the supervision of Dr Sam Wamuziri and Professor Naren Gupta. The work was undertaken as a research student with The School of Engineering and the Built Environment, Edinburgh Napier University, Edinburgh, Scotland.

In accordance with the Regulations of Edinburgh Napier University governing the requirements for the Degree of Doctor of Philosophy, the candidate submits that the work presented in this thesis is original unless otherwise referenced within the text.

The following papers were derived from the work in this thesis. Those papers published by the time this thesis was prepared are included in the Appendices.

Published Academic Papers:


Current as yet unpublished Research Paper:

Price, T. MRI suites, the static magnetic field and emergency fire-fighter interventions

Signature of author………………………………………

Date……………....
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Finally, I would like to thank all those persons from whom over the course of my doctoral research I was fortunate enough to receive support and encouragement.

Terence Raymond PRICE, February 2012
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CHAPTER 1 INTRODUCTION

1.1 RESEARCH BACKGROUND

The research in this thesis is concerned with design issues of MRI suite construction as they may affect the health and safety of those working in or around, visiting or carrying out future work to an MRI suite. The subject of this research is important because there are health and safety implications of human exposure to the static magnetic field of an MRI magnet. This research will help the designer to understand the implications of his chosen design solution and demonstrate how he can keep the resultant changes in both the magnitude of the magnetic flux density and of the footprint of the static magnetic field produced by the magnet to a minimum. Having this knowledge will assist clients, CDM co-ordinators, principal contractors, contractors, operational users, visitors and demolition contractors in managing the health and safety of their charges whilst they are in proximity to the MRI magnet.

The magnet safety issues that are highlighted in this thesis are those that deal with site design and planning and demonstrate how, by the client’s timely appointment of CDM co-ordinators competent in MRI suite construction, the health and safety of workers involved in the whole life-cycle of a project might be enhanced. By addressing the issue of MRI site planning from a health and safety viewpoint instead of a technical-medical one, and by correctly applying the CDM Regulations, this may have a positive influence not only on the safety of workers on new sites, but also on the operational use of the building and on its maintenance and eventual demolition.
1.2 THE AUTHOR’S BACKGROUND AND EXPERIENCE

The author’s trade background is as a bricklayer, being first introduced to construction work relating to the installation of ionising (x-ray) and non-ionising (MRI) radiation about 25 years ago, but in the period immediately prior to experiences in this field being employed as an estimator for a general construction company. A fellow employee left the company and became managing director of a construction company specialising in the construction of x-ray rooms and MRI suites in hospitals and clinics as a sub-contractor to x-ray machine manufacturers and MRI magnet suppliers. This work methodology allowed the engineers of the imaging equipment manufacturers/suppliers to install equipment into a previously finished area and to provide a turnkey solution to the client.

The author had left the employment of the company where employed as an estimator, and then one day had a telephone call from the ex-colleague offering a position in his construction company on a three-month contract as an estimator. This was the author’s first experience of x-ray (ionising radiation) and MRI (non-ionising radiation). As a personal anecdote, on the first day of employment the managing director was asked to explain the difference between ionising and non-ionising radiation, and an adequate answer was not forthcoming. This generated a realisation that there was something about this subject that needed investigation – there was perhaps an issue with knowledge transfer.

The estimating contract came to an end and the author then worked in France for various companies. Whilst employed as technical sales manager for a plaster partition block manufacturer, and drawing on his previous experiences
whilst working on x-ray room construction projects in Great Britain, the author decided to develop an x-ray shielding block using barium-loaded gypsum.

This was in the days before lead-backed plasterboard was fully developed as a design solution for x-ray (ionising radiation) shielding. At that time common practice was for a plasterer to apply a 25mm thick coat of barium plaster to a wall in order to achieve the standard x-ray shielding lead equivalent of 2mm. There were two perceived issues with this, one health and safety and the other quality control. From a health and safety viewpoint, barium plaster, being an extremely dense material, made the task for the plasterer extremely arduous. This meant that the plasterer was not able to hold much material on his hawk, nor apply the plaster to the wall without the risk of developing tennis elbow. From a quality point of view it was difficult to ensure that a uniform 25mm thickness of barium plaster was applied.

The author’s ultimate employment whilst living in France was as chargé d’affaires for a Faraday cage manufacturer. The link between this thesis and previous experience is that MRI magnets are housed in a Faraday cage.

On returning to England in the summer of 2000 the author was employed as a construction site manager for a Private Finance Initiative (PFI) hospital project for the installation of 24 x ray rooms, two CTs, a radiotherapy unit and an MRI suite. At site level there was quite a good understanding of the hazards of exposure to x-rays (ionising radiation) but an apparent lack of knowledge regarding the hazards connected with exposure of construction workers to non-ionising radiation in the form of the static magnetic field of the MRI magnet. Later, clients and designers were included within this group. The author failed to understand why an operational MRI suite had controlled access and insisted on
a questionnaire relating to the presence of electronic body implants and/or foreign bodies, including eyes, being completed by the visitor when the same hazards exist towards the end of the construction phase, yet there is no screening of construction workers. The experience of the author was that construction workers or site visitors were only told not to go near the magnet with credit cards, otherwise they would be ‘wiped’ clean and the data contained on them would be lost forever. This advice disregarded the main safety issues regarding the static magnetic field, including the potential for biological effects, the potential for attraction of ferromagnetic objects, and the potential for the quench of cryogens (Behrens, 2005). The author’s experiences both on and off site were that there was never any information or discussion about the actual position of the static magnetic field when the magnet had become energised during the construction phase, nor of the possible effect it could have on humans or on ferromagnetic materials brought within its influence. Case 1 of this thesis was initiated so as to assess if this was because the various CDM duty holders were unaware of current statutory duties under CDM.

The author’s previous life experiences had shown that the footprint of the static magnetic field could not, because of the effect of any surrounding ferromagnetic materials within the structure, be the same as the generic one produced by magnet vendors and copied verbatim by architects and designers of MRI suites onto as-built drawings. Several as-built drawings had been received showing this generic position, even when passive magnetic shielding - introduced to retain the static field of the magnet to within the magnet room – had been introduced into the design process. It was felt that it was necessary to look deeper into the subject by carrying out research into the existence, or otherwise, of as-built drawings showing the true position of this static magnetic
field on completion of a given project. The results of this research are included in Case 2.

The author also wanted to know if the use of retrofitted passive magnetic shielding changed the generic footprint of the static magnetic field and, as there could be perceived health and safety implications if it increased the magnetic flux density within the newly restricted footprint. During research into the availability of as-built drawings it was discovered that there was a case of a hospital in London requiring a retrofit of passive magnetic shielding to an operational MRI suite. The reason for this retrofitting being required was because the 0.5 mT footprint of the static magnetic field was passing into a public corridor. The significance of this is explained later. The opportunity was given to measure magnetic flux densities both internally and externally to the magnet room, both pre and post magnetic shielding introduction. The results of this research are the subject of Case 3.

Whether the client had sufficient knowledge of the shielding that had been installed on his completed project was the subject of the research in Case 4. What the author wanted to investigate was whether the client was in possession of the necessary evidence to substantiate the claim that magnetic shielding had been installed.

An example of how a research magnet installation proceeded without any consideration of passive magnetic shielding design requirements until after the magnet was installed is shown in Case 5.

Finally Case 6 shows a selection of annotated design drawings demonstrating the confusion of designers between RF and magnetic shielding.
This research has led the author to make a contribution to knowledge by:

Carrying out empirical work that hasn’t been done before

Making a synthesis that hasn’t been made before

Using already known material but with a new interpretation

Bringing new evidence to bear on an old issue

Being cross-disciplinary and using different methodologies

Looking at areas that people have not looked at before, and

adding to knowledge in a way that hasn't been done before

Adapted from Phillips (1993)

But most of all, this dissertation tells a story of personal discovery.
1.3 THESIS RESEARCH AIM AND OBJECTIVES

1.3.1 RESEARCH AIM
Careful thought was required on the final objectives to be achieved so as to be able to develop a systematic approach to the aims of the research. The aim of this research was to examine the roles of the CDM duty holders, the availability of as-built information and also the efficiency and implications of a retrofit of magnetic shielding to an MRI magnet room where passive magnetic shielding was not part of the original design.

1.3.2 RESEARCH OBJECTIVES
The objectives of this research were to be realised by carrying out six case studies so as:

- To review duty-holders’ performance under CDM 2007 so that future clients and the Health and Safety Executive (HSE) might use this information in order to revise CDM 2007 so as to clarify the role of duty holders and assist compliance with those Regulations.

- To review if information relevant to the health and safety file for magnetic resonance imaging (MRI) installations having had passive magnetic shielding installed was available from NHS Trusts in Wales, Scotland and England. This information would be useful in developing risk management plans to control exposure of patients, staff and visitors to the static magnetic field of the magnet, which at 0.5 mT or above could affect persons fitted with heart pacemakers by re-setting the apparatus to its factory default position, thus with the potential to cause physical harm to the user. It was also to assess if there is evidence that clients ensure that CDM co-ordinators provide as-built information on the magnitude
and position of the static magnetic field, and include it in the project health and safety file. This is because the information obtained will help to assist clients and other duty-holders appointed under CDM 2007 in managing health and safety during the construction phase and through the whole-life cycle of an MRI project.

- To evaluate the hazards associated with passive magnetic shielding to designers so as to allow them to eliminate or reduce any unnecessary increase in magnetic flux density within the magnet room resulting from the introduction of passive magnetic shielding into the design. This is so as to show to clients that early involvement of a CDM co-ordinator and management of the entire design process from conception of the project through to handover is the efficient method of working. In addition, it is for this information to be able to be used in developing risk management plans to control exposure of patients, staff and visitors to the static magnetic field of the magnet and for contractors when further construction work is carried out at a given project location.

- To assess the need for the early involvement of designers at initial design stage of a project.

- To assess the need for designers to be competent in knowledge of the differences between RF and magnetic shielding.
1.4 LIMITATIONS TO THE RESEARCH

This research did not include:

- NHS Trusts in Northern Ireland. This is because they were undergoing organisational change at the time of the research and there was a risk that information could either be duplicated or omitted during the administrative changeover process.

- Private sector hospitals and clinics. This is because they are not obliged to supply information to researchers or members of the public under the Freedom of Information Act 2000 (HMG, 2000a).

1.5 OUTLINE METHODOLOGY

1.5.1 CASE 1 CDM 2007 DUTY HOLDER RESPONSIBILITIES

The first case was to identify if the Construction (Design and Management) Regulations (CDM) duty holders for a project understood the statutory duties imposed upon them and were aware of the potential safety issues of the exposure of construction workers to the static magnetic field of the magnet. This is because since 1994, the Construction (Design and Management) Regulations (CDM) and its postcedents have imposed a duty on the client of a structure where a notifiable project has been carried out to provide information (the Health and Safety File) which may be needed during future construction work. Under CDM, construction work includes cleaning, maintenance, alterations, refurbishment and demolition. In 2007, the CDM Regulations were amended (CDM 2007) and imposed a further duty on clients to provide information to those who work in the premises (the use of the building). Research questionnaires were sent to clients’ architects, principal contractors, magnet
vendors and RF cage suppliers throughout Scotland, England and Wales so as to establish the current situation.

1.5.2 CASE 2 TO ESTABLISH THE AVAILABILITY OF AS-BUILT DRAWINGS

Case 2 was to determine how many MRI installations in Great Britain were fitted with passive magnetic shielding to the magnet room. Further, it was to assess how many of these installations actually had as-built drawings showing the final and as-built position of the static magnetic field footprint of the magnet included within the project health and safety file. This information would be required to be included by virtue of Paragraph 263 of the Construction (Design and Management) Regulations 2007 (HMG, 2007). Questionnaires were sent to 295 hospitals in England, Scotland and Wales to establish if they possessed magnetic resonance imaging suites.

1.5.3 CASE 3 TO ESTABLISH IF THE MAGNETIC FLUX DENSITY INCREASED

Once the availability and accuracy of as-built drawings was established, then by the research in Case 3, the aim was to assess if the introduction of passive magnetic shielding into the design increased the magnetic flux density within the magnet room, and if so, to what extent, why and how it could be avoided.

1.5.4 CASE 4 WAS PASSIVE MAGNETIC SHIELDING INSTALLED?

To assess the accuracy of evidence made available to the client on completion of his project. The health and safety file did not hold conclusive evidence that magnetic shielding had been installed.
1.5.5 CASE 5 THE DESIGNER SHOULD BE ENGAGED AT PROJECT CONCEPTION

To assess if passive magnetic shielding of the currently installed and operational magnet had been considered at initial design stage.

1.5.6 CASE 6 DESIGNERS’ CONFUSION BETWEEN RF AND MAGNETIC SHIELDING

This research was carried out to study the annotations on sample of drawings so as to assess if designers understood the difference between RF and magnetic shielding.

1.6 THESIS STRUCTURE

The following summarises how this thesis is structured to meet the previously stated objectives:

- Chapter 2 presents the Literature Review by giving an introduction to the magnetic resonance imaging process. It then continues with an explanation of the radiofrequency (RF) field and static magnetic fields and different shielding requirements. It continues with a short discussion on costs of magnetic shielding, then legislative requirements, both statutory and non-statutory. It concludes with a discourse on the physical effects of the introduction of passive magnetic shielding to a magnet room.

- Chapter 3 outlines the research design and methodology for the six case studies comprising this thesis.

- Chapter 4 presents Case Study 1 by reviewing CDM duty holders’ statutory duties in relation to an MRI installation and by use of a
questionnaire analyses the various duty holders’ perception of responsibilities in relation to the design and construction of an MRI suite. Additionally, through the questionnaire, the study enquires as to the level of CDM duty holders’ specialist knowledge of the static magnetic field generated by the magnet.

- Chapter 5 presents Case Study 2 to assess the number of MRI magnets currently installed in England, Scotland and Wales. Once this information became available, the study continued by requesting copies of as-built drawings showing the position of the 0.5 mT footprint of the static magnetic field in installations fitted with passive magnetic shielding and enquired if they were included in the (CDM) Health and Safety File.

- Chapter 6 presents Case Study 3 that relates to a retrofit of passive magnetic shielding to an operational MRI suite. Field surveys were carried out to evaluate magnetic flux densities inside and outside the magnet room both prior to and following the retrofit of magnetic shielding.

- Chapter 7 presents Case Study 4 to assess if a hospital had passive magnetic shielding installed to the magnet room, and if they had, if it had been installed during the original installation or at a later date when further construction works were carried out.

- Chapter 8 presents Case Study 5 which evaluates the problems caused by the client failing to consider the magnetic shielding requirements of a magnet before it was installed. The magnet was installed at a location where the 0.5 mT footprint of the static field of the magnet, without the use of passive magnetic shielding, would naturally encroach into public areas on four sides of the magnet room.
• Chapter 9 presents Case Study 6 to evaluate if there was a clear understanding by designers of the function and attributes of RF shielding and of passive magnetic shielding to a Faraday cage. Examples, by the inclusion of annotated drawings, are given.

• Chapter 10 contains the Conclusions of the research on a case-by-case basis, culminating with a summary of the conclusions reached.

• Chapter 11 contains recommendations based upon the conclusions of the research.

• Chapter 12 contains suggestions for further research work, followed by

• The Appendices containing supporting elements for the material contained within this thesis.
CHAPTER 2  LITERATURE REVIEW

2.1  THE ADVENT OF THE MAGNETIC RESONANCE IMAGING PROCESS

Magnetic resonance imaging (MRI) has become a very important imaging modality since 1977 when one of the first images using a superconductor magnet was produced (Schenk, 2000). The image referred to was obtained using a magnet with field strength of 0.05 – 0.10T at the State University of New York, Brooklyn.

Nevertheless, it was not until 1982 that Magnetic Resonance Imaging (MRI) had its mainstream debut in the medical field. By 1984 more than 150 units were installed worldwide and by 1986 more than 840 units were in operation (Seelye, 1987).

Magnetic resonance imaging as a modality has seen a rapid expansion in the rate of installations since the middle 1990’s when the full benefits of superconducting magnet technology became available. MR imaging data from 2002 indicates that there are almost 15000 whole-body imaging units installed worldwide (Riederer, 2004).

2.2  THE AGE OF CURRENTLY INSTALLED MAGNETS IN BRITAIN

Some of these earlier magnets are still installed in the original locations, but generally and as technology has evolved further, they have been replaced on a regular basis. In a study of MRI installations in NHS hospitals in Scotland, Wales and England, it was determined that the oldest magnet still in use was installed in 1992 (Price, 2010).
2.3 METHODS OF MANAGING THE CONSTRUCTION OF MRI SUITES

Prior to the middle 1990s, NHS hospitals regularly used in-house project management teams to manage both ionising and non-ionising radiation producing equipment installations, with this system working well. For political and economic reasons, and coupled with a rapid rise in installations for both MRI and x-ray, specialist pre-installation companies evolved as a result of this outsourcing. These companies, having specialist knowledge of the particular construction requirements of each modality, of each magnet vendor, and often even of each equipment model were usually appointed as sub-contractors by magnet vendors in order to carry out the necessary construction work to enable installation of the required imaging equipment to take place. The industrial experience of the author is that when a hospital decides that it wishes to install a new magnetic resonance imaging suite or to upgrade an existing installation with a more modern magnet, then the hospital procurement department will ask the magnet vendor for a quotation for the not just the magnet, but for the whole of the works, including construction. Magnet vendors are not construction companies, so they will obtain a quotation for the construction works from a building contractor specialising in all the works necessary for the magnet vendor to be able to install his magnet. The magnet vendor will add a profit margin to the quotation received from the building contractor and submit a turnkey quotation to the hospital. Continual development of new technology dictates that MRI installations not only consist of new projects, but also those of refurbishment of existing installations. The construction of imaging equipment facilities is a specialist process, and as a result, the matching of sub-contractors with the right job by the magnet vendor is made relatively simple by giving the
sub-contractor the projects able to be undertaken effectively and efficiently without default (Okoroh et al., 1999).

The scope of The Construction (Design and Management) Regulations (CDM, 2007) dictates that the magnet vendor will usually be a designer. This is because the magnet vendor will usually decide the (minimum) size of the magnet room, the location of the magnet within it and the specification and position of ancillary equipment for the control and equipment rooms. When the magnet vendor has a design and build contract with a given hospital then the specialist sub contractor is also likely to become a designer by providing the design for the construction work, either directly or through a designer appointed for that purpose. When the magnet vendor does not have design and build contract with the hospital the magnet vendor should liaise with the client’s lead designer as early in the design process as is possible. The CDM co-ordinator should ensure that there is co-operation and co-ordination between designers. The difficulty for the CDM co-ordinator is that some MRI installations go into initial design before the magnet vendor has been appointed, with a risk of the CDM co-ordinator not recognising the magnet vendor as a ‘late designer’ and as a consequence exclude him from the co-ordinated design risk management process required by The Construction (Design and Management) Regulations (CDM, 2007).

2.3.1 F RAGMENTATION OF THE DESIGN AND CONSTRUCTION PROCESSES

However, one disadvantage of outsourcing the management of the design and construction of magnetic resonance imaging suites appears to have been a fragmentation of the design and construction processes, resulting in a possible misunderstanding of CDM duty-holders’ statutory responsibilities. This is most
evident in relation to the design function, where the Approved Code of Practice to CDM 2007 (HSE, 2007) makes it clear in Paragraph 125 those measures that should be taken in order to avoid foreseeable risks of any design. One of the control measures outlined in CDM 2007 is the requirement that risk management proposals/methods that the designers have assumed or decided will be appropriate (APS, 2007b) are made available for development of the construction phase plan by the principal contractor. These are measures that should also be identified, if they are not eliminated during the construction phase, for adoption by those using, de-commissioning or demolishing any structure(s) on completion of the project and to be included in the health and safety file at the end of the project. Having said this, it is quite feasible that the principal contractor would have the opportunity, by utilising his technical and managerial expertise, to eliminate many residual design hazards during the construction phase - but this requires the designer to give him knowledge of them.

Once the superconducting magnet has been energised, which usually takes place whilst still within but towards the end of the construction phase of the project, a static magnetic field is produced. An example of such a scenario is discussed later.

The static magnetic field, including the addition of magnetic shielding to retain it to within any controlled area, is the subject of this thesis because during the construction phase (and throughout the life of the installation) there may be potential hazards and risks to construction employees, third parties, operational staff and contractors because of a gap in information transfer between all those disciplines involved with an MRI suite construction project.
Access control measures are required because 0.5 mT is the threshold for exposure to the static magnetic field of the magnet of all individuals that have not been successfully screened for contra-indications to its possible adverse physical effects. UK government advice is that a person fitted with a heart pacemaker must not enter the MR controlled area (MDA, 2007). One must appreciate however that this hazard is not a direct biological one to the individual, but a risk of magnetic field electro-mechanical interference with the medical device. One description of the effect of the static magnetic field on pacemakers (Young, 2000) is that the magnetic reed switch that varies the heart rate can be inadvertently switched by the static field and revert to its default factory setting. This could lead to irregular heart rhythm of the bearer of the pacemaker and eventually to serious handicap or death.

2.4 BACKGROUND TO THE MAGNETIC RESONANCE IMAGING PROCESS

2.4.1 THE TYPES OF MAGNET USED FOR MAGNETIC RESONANCE IMAGING

The types of magnet used for magnetic resonance imaging are:

**Permanent magnet**

This type of magnet has a high magnetic ramanence because of its high iron content and is not able to produce field strengths in excess of 0.5 Tesla. These magnets have a predominantly vertical static field orientation. This type of magnet is not included in this study and no evidence of common usage has been found.

**Resistive magnet**

A resistive magnet consists of coils that are continuously supplied with an electrical current and is not able to produce field strengths in excess of 0.4
Tesla. Depending on how the magnet has been designed, this type of magnet may have vertical or horizontal orientation. This type of magnet is not included in this study and no evidence of common usage has been found.

**Superconducting magnet**

It is superconducting magnets that are the subject of this research. These magnets operate by the connection of an electrical supply to superconducting coils stored at low temperature in liquid helium (-273°C) and is used to energise and ramp up the magnet to its operating level. At this temperature the electrical resistance of the coils is maintained at zero, and in theory the electrical supply can be removed once the magnet has been ramped up. These magnets are typically used for 1.5 Tesla and 3.0 Tesla magnets, although much stronger magnets are in use for research purposes. These magnets generally have a horizontal static field orientation and any stray magnetic fields will extend for large distances from the magnet unless passive magnetic shielding is used.

Modern MRI scanners usually consist of a superconducting magnet combined with the use of radiofrequency (RF) signals to produce images of the biological matter being examined (usually the human body). A very simple explanation of the imaging process is that within the scanner there is a strong magnet used to create the ambient static magnetic field. In addition, there is gradient system of three coils that are used to produce linear field distortions in the (x, y and z) axis and the amplifiers. These coils are made using niobium-titanium and kept in temperatures near absolute zero, usually by the use of liquid helium (LHe is kept at about 4K). The superconducting properties of the magnet are as a result of the extremely low temperature in which they are stored and as a result they should have no resistance to an electrical current. In theory this allows the
external electrical supply to be disconnected once the magnet has been fully energised.

When a patient enters the bore of the magnet the static magnetic field will align the hydrogen protons present in the patient with the direction of the magnetic field. The imaging process then consists of a radiofrequency (RF) signal of the same sound wave frequency of the target protons being switched on, with the receiving protons absorbing some of the energy and ‘wobbling’ free from the magnetic field. When the RF signal is switched off, the protons release this energy and re-align themselves with the magnetic field in the bore of the magnet, emitting a radio frequency signal as they do so. It is this RF signal that is used to build an image of the tissue being examined. In a personal communication (Cole, 2006), it was explained that the hydrogen nucleus (i.e. the proton) is more commonly used for clinical imaging because as well as being the most plentiful, it has the largest magnetic moment of any stable nucleus present in the human body, manifesting itself mainly as water and fat.

2.5 Magnet Strengths

The majority of magnetic resonance imaging scanners installed for clinical use in the United Kingdom are fitted with magnets having strength of 1.5 Tesla. Some 3.0 Tesla magnets do exist, but are mainly used for research purposes. In the UK magnetic field strength is measured in units of Gauss (G) and Tesla (T). One Tesla is equal to 10,000 Gauss. The main magnetic field of a 1.5 T magnet is about 30,000 times, and of a 3T system 60,000 times the strength of the earth's magnetic field. To put this into perspective the strength of electromagnets used to pick up cars in junk (scrap) yards is about the field strength of MRI systems with field strengths from 1.5-2.0T (ISPUB, 2011). The
unit of milliTesla (mT) is used throughout this thesis. As will be explained later, we are particularly interested in the 0.5 mT footprint of the static magnetic field.

2.6 Radiofrequency (RF) Shielding

MRI magnets are installed within a Faraday (RF) cage (the scanner room). Faraday cages are constructed of conductive material, usually of copper or aluminium, and are essential in ensuring that external static electrical fields are prevented from distorting the RF signal being utilised to create the image. Faraday cages do not protect the magnet from the influence of magnetic fields external to the MRI magnet, or in reverse, protect persons or objects outside the Faraday cage from the reach of the magnetic field produced by the MRI magnet.

2.7 The Static Magnetic Field Produced by an MRI Magnet

Magnetic fields are invisible and it is impossible to know if they are on or off, or to be aware of them unless told. Large magnetic fields extend in three dimensions around the magnet, and a static magnetic field is a component of the MRI environment, which is always present (Dempsey et al., 2002) even when the scanner is not imaging. This strong magnetic field drops off rapidly with distance away from the magnet, producing a large spatial gradient. As a result of this large gradient, objects prone to be magnetised when introduced into the field are accelerated and can quickly become dangerous projectiles. It has been recognised that the force of attraction between a magnet and a ferromagnetic object is determined by the magnetic field strength, the magnetic susceptibility of the object, its mass, distance from the magnet and its orientation to the field (Behrens, 2001). In general, the magnetic field around a solenoid (superconductor or otherwise) is ‘dipolar’ in nature. Stray fields vary as the inverse of the cube of the distance from the magnet. For example, if the
distance to the magnet is halved, then the stray field increases 8-fold. This is a dramatic variation. Also, the heavier the ferrous object is, the stronger the attraction (Behrens, 2001) but this will vary with the object’s magnetic saturation (Cole, 2006).

2.7.1 THE GENERIC STATIC MAGNETIC FIELD FOOTPRINT OF AN MRI MAGNET

There are referenced documents (ACR, 2007) discussing patient and staff exposure to electro-magnetic fields (EMFs) and maximum exposure limits (ICNIRP, 2009). It is important that the principal contractor puts access and exposure controls in place during the construction phase up until the time that the MRI suite reaches the operational stage and is handed over to the client. This is because once the magnet has been energised, which will normally take place during the latter part of the construction phase, the static magnetic field will be surrounding the magnet and be permanently ‘on’.

Magnet Vendors’ generic static magnetic field plots

In the case of MRI suite design as shown in Figures 2.1 and 2.2 below, some magnet vendors’ site-specific planning guides show the magnet room as being positioned on an outside wall with the 0.5 mT footprints passing to areas outside the RF cage.
Figure 2.1: A generic static magnetic field plot – Philips Medical Systems

(Image courtesy of Philips Medical Systems)
Figure 2.2: A generic static magnetic field plot – General Electric Medical Systems

(Image courtesy of General Electric Medical Systems)
Consideration of the position of the y axis is equally important
The static magnetic field consists of three axes, these being x, y and z. A diagram describing these axes is shown in Figure 2.3 below.

![Figure 2.3: Typical x, y and z axes of the static magnetic field](image)

Although it is recommended that the 0.5 mT footprint of the static magnetic field should be restricted to the magnet (examination) room and the technical room (HMG, 1994), the same advice only shows an illustration of a generic footprint of the x (lateral) and z (horizontal) axis of the static magnetic field to a magnet whilst ignoring that of the y (vertical) axis. This is shown in Figure 2.4 below.
Figure 2.4: NHS advice shows the static magnetic field in the x and z axis only
(Image courtesy of NHS Estates)

2.7.2 THE STATIC MAGNETIC FIELD EXTENDS IN ALL AROUND A MAGNET

As the static magnetic field extends in all directions around a magnet, any principal contractor or Employer should also have information on the equally important, but often ignored position, of the 0.5 mT footprint in they axis so as to enable him to fully manage health and safety on site. By ignoring the y axis in this advice (HMG, 1994), this could lead any principal contractor to believe that it was not important.

Figures 2.5 and 2.6 below show the generic location of the 0.5 mT footprint of the x, y and z axis of a bore / tunnel format magnet where the magnetic field is predominantly horizontal and in the z axis. However, there is still a significant vertical component. For ‘open’ format ‘hamburger bun’ type magnets the larger component of the static magnetic field is vertical, resulting in slightly diminished hazards on the same level as the magnet (as compared to bore format
magnets) but greater hazards above and below (Price, 2010). Magnetic fields three-dimensional in nature and without the introduction of magnetic shielding the static magnetic field will typically protrude through the floor assembly and into any ceiling void below the magnet.

Figure 2.5: An end elevation of a generic 0.1 mT and 0.5 mT footprint in the x and y axes

Figure 2.6: A section of a generic 0.1 mT and 0.5 mT footprint in the z axis
2.8 THE SYMMETRY OF THE STATIC MAGNETIC FIELD NEEDS TO BE MAINTAINED

It is crucial to the imaging process that the symmetry of the static magnetic field generated by the magnet remains within limits set by the magnet vendor so as to ensure that a viable image is produced by the magnetic resonance imaging process. In order to achieve this, the introduction of magnetic shielding to protect this symmetry of the static magnetic field of the magnet from outside influence may be required. Although most contemporary MRI systems make use of active shielding as an integral part of the magnet design/manufacture, this may not be sufficient. Passive magnetic shielding, by shimming the magnet or introduced as part of the structure of the MRI suite, may also be required.

2.8.1 ACTIVE MAGNETIC SHIELDING

Modern superconducting magnets are fitted with active magnetic shielding. This is achieved by the introduction of an additional magnet above the main magnet and which produces an opposite, or compensating, magnetic field that constricts the reach of the magnetic field of the main magnet. This reduces the risk of device interference or of conflicts existing outside the MRI exam room.

2.8.2 PASSIVE MAGNET SHIELDING BY SHIMMING THE MAGNET

Additional shimming of the magnet to compensate for the presence of ferromagnetic objects is often required. Special MRI shim sets used to be provided to the magnet vendor’s MRI installation and commissioning engineers for this purpose. However, many contemporary superconducting systems have built-in electromagnetic shim systems, reducing – and often eliminating – the need for the ferromagnetic namesakes of the shim process.
2.8.3 LIMITS OF ACTIVE SHIELDING AND OF PASSIVE SHIMMING OF THE MAGNET.

Active shielding can only help to reduce interference from the presence of stationary ferromagnetic objects. There are also limits to the quantity of (static) ferromagnetic elements within any structure and which passive ‘shimming’ of the magnet can compensate. Due to site-specific magnet location constraints or by user requirements such as a preferred orientation of the magnet, these limits could be exceeded. There may also be a requirement to protect the external environment of the MRI suite from the effects of the magnet, including protection of any adjacent electronic imaging equipment such as a CT, or even another magnet.

2.8.4 PASSIVE MAGNETIC SHIELDING TO THE MAGNET ROOM

Passive shielding to the magnet room is not often required to compensate for the presence of ferromagnetic objects (shim correction). It is, however, very frequently used to reduce risks of magnetic field interactions outside the MRI examination room. This could be because of a potential negative interaction with medical devices / implants, or interference with other equipment / systems that are sensitive to magnetic fields. It should be noted that unlike x-rays, brick, concrete or lead do not attenuate magnetic fields, so these materials cannot be used to provide magnetic shielding to the MRI magnet. Materials used for magnetic shielding often consist of non-grain-orientated or low carbon steel.

2.8.5 MAGNETIC SHIELDING TO THE MAGNET ROOM AS A DESIGN SOLUTION

Passive magnetic shielding as part of the structure of the MRI suite may be a design option, not only to manage the effect on the magnet of static ferromagnetic objects but, because neither active shielding nor passive shimming of the magnet will compensate for the presence of moving ferromagnetic objects such as lorries, cars, ambulances or tube trains falling
within the footprint of the static magnetic field. These elements could have an adverse effect on the symmetry of the static magnetic field of the magnet and the consequential inability of the RF signal to produce accurate information to be translated into a viable image.

There may also be limits to the amount of magnetic shielding which can be incorporated into the MRI suite, either because of magnet location or of structural constraints. These limits may even restrict the use of magnetic shielding – even to the possible extent of having to re-site the magnet. It is feasible that cases could occur (Price T et al., 2010) where the requirement for magnetic shielding could equate to several tonnes of extra loading to the structure, making it important that this possibility is discussed early in the design stage. Each MRI suite design is different, but passive magnetic shielding may not be required if the symmetry of the 0.5 mT footprint of the static magnetic field is not likely to be affected either by proximate static or moving ferromagnetic objects - but the Lead Designer has to be sure of this.

2.8.6 DESIGN FOR REMOVAL OF MAGNETIC SHIELDING AND SUPPORT STRUCTURE

The design of any magnetic shielding should ideally include a provision for it to be easily removed should a change in the use of the room be required at any point in the future. Inclusion of any additional ferromagnetic material used to create the supporting structure required to facilitate easy removal of the magnetic shielding may itself have an effect on the symmetry of the static magnetic field. Information regarding any building elements that could have been permanently magnetised should be included in the CDM2007 (HMG, 2007) health and safety file. Having this information will also be important at demolition stage so as to enable the client to transmit valuable information to the demolition contractor to enable him, not only to deconstruct any structure
safely, but at the same time to maximise on materials recycling and thus avoid the use of landfill (HMG, 2008). By flagging up this information early in the design stage, this ensures that if permanently magnetised elements of the structure are required for recycling following demolition of the structure, they may either be utilised in structures where its magnetisation will have no effect on the future use of the building, i.e. warehouses, or alternatively undergo a process of de-magnetisation. However, the latter may not be a cost effective solution. Nevertheless, although not required by the current CDM 2007 Regulations (HMG, 2007) this will rely on the Site Waste Management Plan being included in the Health and Safety File (Price et al., 2009).

2.9 TYPICAL PASSIVE MAGNETIC SHIELDING COSTS

Typical square metre market rates for the installation of passive magnetic shielding to the structure of a building have been obtained from a large UK based shielding contractor. This shielding contractor has advised that retrofitting magnetic field shielding would be enormously expensive with most additional costs being in preparing the area to receive any magnetic shielding. In a personal communication (King, 2010) it was revealed that the approximate cost of including magnetic shielding as part of the design of a typical new installation would be £600 per square metre, but as a retrofit £1,200 per square metre.

2.9.1 PASSIVE MAGNETIC SHIELDING COSTS WHEN PART OF THE ORIGINAL DESIGN

Assuming one wall of a new installation to be on the borderline of requiring shielding, and then taking a typical wall area requiring shielding of 4600mm x 3000mm in the z axis, this could currently equate to an extra cost to the client of just over £8,000. Should magnetic shielding be specified by one of the tendering design and build contractors in his bid, but not by others, then it may
be prudent for the client to ask why, and ask to see the Designer’s Risk Management Plan. This would ensure that all tendering contractors had considered the possible need for the introduction of magnetic shielding and in theory eliminate the need for retrofit magnetic shielding at a later date – either during the construction phase or following handover to the MRI suite for operational use. Where at detailed design stage a view might be taken that the risk of a requirement for shielding is low and the Designer had decided that it should be eliminated from the original design specification, then by using the wall area cited above, any subsequent future requirement for retrofit shielding would result in an extra cost to the client of over £16,000. This cost would be largely dependent upon the quantity of services installed in the ceiling void below the magnet, as these would have to be temporarily removed whilst any magnetic shielding was being fitted and could involve substantial further costs.

2.9.2 Passive Magnetic Shielding Costs When Carried Out as a Retrofit

It is quite feasible that a case could arise where magnetic shielding may need to be retrofitted because the original design did not fully enclose the 0.5 mT footprint, or even lesser values, that may present interference potential with other modalities or equipment in proximity to the MRI magnet. It is therefore crucial that the lead designer and CDM co-ordinator ensure recognition, cooperation and co-ordination of all designers, including the magnet vendor and his sub-designers, as early as possible in the MRI suite design. This will enable account to be taken of the likely presence of all ferromagnetic material that could fall within the influence of the static field of the magnet – thus allowing the lead designer to be able to make an informed decision on the magnet’s location and/or orientation. Each MRI suite design is different, and by understanding the magnetic resonance imaging process from an early stage in the design, and by
careful siting of the magnet, the designer can often eliminate the need for magnetic shielding.

However, it is feasible that even during detailed design stage the client may not yet have chosen the magnet supplier. When this is the case, the magnet supplier becomes a late designer under CDM 2007 and adds to the difficulties of the CDM co-ordinator in not being able to ensure that all designers are co-ordinating designs with the lead designer and incorporating them into his Design Risk Management Plan. The RF cage supplier would normally be the party designing any necessary magnetic shielding on behalf of a given magnet vendor. Therefore, any late decision on the choice of magnet vendor, even though the client may have instructed the architect to take the worst-case scenario (Price et al., 2009) could still result in a less than perfect design solution when considering the effects of the static magnetic field in deciding on any given MRI suite location.

There is also the question of how these services will be re-fixed to the underside of the floor slab once any retrofitted magnetic shielding has been installed. If the services fixings were ferromagnetic and connected to the bolts used to connect any magnetic shielding to the floor slab, then they may themselves become magnetised by the passage of the static field through them and, if the services themselves were ferromagnetic, to those as well. Having this knowledge is important because any magnetised elements will themselves have an effect on any electronic equipment or storage media falling within the influence of this (extended) static magnetic field. Such electronic equipment may not function correctly due to “wiping” out of information stored on electronic media.
Where retrofit magnetic shielding is found to be required there would also be the additional costs of supplementary design fees, disruption to the MRI facility and a possible loss of patient throughput and of reputation for the hospital/clinic; the real cost of which may not justify magnetic shielding being eliminated from the original design if all the implications of decisions were taken into consideration at detailed design stage. The difficulty arises for the client if designers do not communicate the possibility of magnetic shielding being required for the installation.

The cost of magnetic shielding is such that during any design and construct tender bid for a new MRI suite, introduction of passive magnetic shielding into the design may be considered as an over-specification if the risks of allowing the 0.5 mT footprint of the static magnetic field passing to designated controlled areas outside the magnet room are considered by the Designer to be small.

2.10 THE EFFECT OF MAGNETIC SHIELDING ON THE STATIC MAGNETIC FIELD

When passive magnetic shielding is used to contain the 0.5 mT footprint of the static magnetic field it will have the effect of altering its symmetry. This has been described as trying to stuff a balloon into a box. Pushing on one end of the box invariably causes the balloon (fringe field) to expand out the other (Pavlicek et al., 1984). An illustration of this effect is given in Figures 2.7 and 2.8 below. In practical terms, this means that where magnetic shielding is installed to restrain one or more axis of the static magnetic field, then this will have the effect of pushing the remaining axis out of their generic positions into areas which may not have been included in the Designer’s original risk management proposal.
2.11 **MAGNETISATION OF MATERIAL USED IN MRI SUITE CONSTRUCTION.**

As previously explained, any ferromagnetic elements used in the construction of an MRI suite will become permanently magnetised. These elements could take the form of air-conditioning ducting, steel electrical conduit, use of a steel-frame in the parent structure or in stud partitions to the magnet room, to name a few. An example of use of these materials is shown below in Figures 2.9 and 2.10 below. In its foreground, Figure 2.9 shows metal stud being used for partitions adjacent to the magnet room, and in the background Figure 2.10 shows a structural steel frame being used to support cladding panels to the external wall.
Figure 2.9: Ferromagnetic material being used in the construction of the MRI suite

Figure 2.10: The structural steel frame could be magnetised

Even when the MRI magnet is removed, these ferromagnetic materials will still possess a magnetic remanence relative to the material used, making future use of the room(s) to hold any computers or electronic storage media or to convert the room to accommodate a CT or other electronic equipment questionable. This is because the permanently magnetised construction material will affect the equipment into which it comes into contact. The advice is that:
“You want to keep any significant quantity of steel outside that 5 Gauss threshold…as the watershed in MRI design and construction. You want to keep any significant amount of steel outside that 5 Gauss bubble. A 5 Gauss magnetic exposure seems relatively low, but remember that if you run an MRI for 10 years in the same place, that gentle, constant magnetization (sic) is going to build and build the passive magnetic field in any nearby ferrous material. A suitable analogy might conjure the drip, drip, dripping of mineral rich-water from a cave ceiling, which eventually gives birth to imposing stalactites” (Robb, 2004).

If this permanently magnetised material passes to areas other than those within the direct influence of the magnet’s static magnetic field footprint, then this permanent residual magnetisation will continue into those areas, thus extending the hazard. Thus, where residual magnetisation is suspected “it would be beneficial for hospitals to do residual magnetic-field measurement and to place electronic medical equipment away from strongly magnetised points when strong magnetic fields are found (Hanada et al., 2001)

Magnetisation of any supporting structure could also depend upon the design of fixings and the accuracy of any designed allowance (if any) for the attached magnetic shielding to oversail. This could reduce magnetic contamination of the supporting structure as it has been recognised that edge effects along the periphery of the shielding may result in field strengths in excess of those without shielding (AAPM, 1987). An example of removable magnetic shielding and its supporting structure is shown in Figure 2.11 below.
2.12 STRUCTURE DESIGN AND LOADING CONSIDERATIONS

The orientation of beams and columns in relation to any or all three of the axes of the magnet could also influence the symmetry of the static magnetic field. As a result of any additional loadings that could be imposed on the parent structure by the addition of any passive magnetic shielding to the magnet room, augmentation of the specification for the steel reinforcement to any slab, beam or column may be required and which will also have an effect on the symmetry of the magnet’s static magnetic field. Dependent upon each individual situation, magnetic shielding could be required in the y axis below the magnet, either to retain the 0.5 mT footprint within the magnet room and/or simply to protect the magnet from being influenced by either static or moving ferromagnetic objects proximate to it. An example of passive magnetic shielding fitted to the underside of a floor slab to an MRI magnet room is shown painted yellow and black in Figure 2.12 below. This magnetic shielding was required in order to protect the magnet from the influence of moving ferromagnetic objects (cars, vans, lorries et cetera) moving around in the car park below.

Figure 2.11: Any magnetic shielding should be designed for easy removal
Figure 2.12: Magnetic shielding fitted in a car park below a magnet room

Magnetic shielding may also be required in the x (horizontal) or z (lateral) axes of the magnet as shown in Figure 2.13 below, either to protect the magnet from the environment or the environment from the magnet.

Figure 2.13: Magnetic shielding could be required in any or all three axes of the magnet

2.13 LEGISLATION GOVERNING HUMAN EXPOSURE TO STATIC MAGNETIC FIELDS

The requirements imposed upon the various duty holders both to a magnetic imaging suite construction project and its subsequent operational use are embedded within The Health and Safety at Work, etc. Act 1974 (HMG, 1974),
Although there are no specific regulations relating to exposure to static magnetic fields present in a magnetic resonance imaging suite, subsidiary regulations to The Health and Safety at Work, etc. Act 1974 (HMG, 1974) such as The Management of Health and Safety at Work Regulations 1999 (HMG, 1999) and The Construction (Design and Management) Regulations 2007 (HMG, 2007) impose sufficient requirements on employers for them to protect employees and visitors, including members of the general public, during the construction or following bringing into operational use of an MRI suite. The Health and Safety Executive (HSE) are more likely to use The Health and Safety at Work, etc. Act 1974 (HMG, 1974) in any prosecution as this legislation, being the primary legislation, carries heavier penalties for non-compliance.

2.13.1 THE HEALTH AND SAFETY AT WORK, ETC ACT 1974

The Health and Safety at Work Act, etc. 1974 (HMG, 1974), lays down specific requirements for managing health and safety. All of these requirements are applicable to the construction of MRI suites, including specific duties on employers, employees and visitors. Section 2 (employers’ duties to employees) includes a requirement on employers to ‘provide such information, instruction, training and supervision as necessary’. This Act also includes in Section 3 a duty to ‘those affected by the undertaking’ and in Section 7 a duty ‘to have regard for personal safety and that of other workers in particular’.

Section 2(1) of the HASW Act (HMG, 1974), states that it is the duty of every employer to ensure the health, safety and welfare of all his employees at work ‘as far as is reasonably practicable’. This is the origin of the use of ALARP (As Low As Reasonably Practicable) in risk assessments, the disadvantage of
which, from the viewpoint of the person making that judgement, is that the quality of the assessment can only be decided by a judge after an incident.

2.13.2 THE MANAGEMENT OF HEALTH AND SAFETY AT WORK REGULATIONS 1999
Section 3 of the Management of Health and Safety at Work Regulations 1999 (HMG, 1999) imposes a statutory duty on employers to make a suitable and sufficient assessment of the risks to the health and safety of his employees to which they are exposed whilst they are at work; and the risks to the health and safety of persons not in his employment arising out of or in connection with the conduct by him of his undertaking. The employer (Section 8) shall also establish and where necessary give effect to appropriate procedures to be followed in the event of serious and imminent danger to persons at work in his undertaking and follows later with the requirement ‘to ensure that none of his employees has access to any area occupied by him to which it is necessary to restrict access’.

2.13.3 THE CONSTRUCTION (DESIGN AND MANAGEMENT) REGULATIONS 2007
The Construction (Design and Management) Regulations 1994 (HMG, 1994a) the amendments of 2000 (HMG, 2000) and currently the CDM 2007 Regulations 2007 (HMG, 2007) detail the measures that should be taken in order to reduce health and safety risks of any design. One of the measures outlined in the CDM Regulations, in all the forms that it has been legislated upon, is the requirement for the identification by the designer or designers of any control measures that should be put in place in order to manage any residual risks to the design that were not able to be eliminated at the design stage. These are measures which should identified for adoption by those either constructing, using or de-commissioning and demolishing any structure, as well as those being necessary to protect third parties for the whole of the life of the structure.
Where specialist suppliers also contribute to the design process there is a need for them to be brought into the decision making process as early as possible at initial design stage because each designer needs to discuss the type and format of supporting information with the CDM co-ordinator who has to identify and provide information to those who need it (APS, 2007a).

**The definition of construction work under CDM 2007**

Part 1 (Interpretation) of the Construction, (Design and Management) Regulations 2007 (HMG, 2007) defines construction work as “…. the carrying out of any building, civil engineering or engineering construction work and includes – (a) the construction, alteration, conversion, fitting out, commissioning, renovation, repair, upkeep, redecoration or other maintenance….of a structure” and continues in (e) that this also comprises “the installation, commissioning, maintenance, repair or removal of mechanical, electrical, gas, compressed air, hydraulic, telecommunications, computer or similar services which are normally fixed within or to a structure”.

**Notifiable and non-notifiable projects under CDM 2007**

A project is ‘notifiable’ under CDM 2007 (HMG, 2007) if it is not for a domestic client, will last more than 30 working days or involve more than 500 person days. For example, 50 people working for over 10 days. If a project falls within these criteria then it should be notified to the Health and Safety Executive on Form F10 (HMG, 2007). The CDM co-ordinator (CDM-C) should notify the Health and Safety Executive as soon as possible after their appointment by the client (HSE, 2007). The F10 gives information on the name of the client and the CDM co-ordinator. If already appointed, the designer and any contractor should also be included. It is more likely that the construction of an MRI suite will last
more than the threshold for notification unless it is a minor upgrade, but even for non-notifiable projects. (i.e. those not meeting the domestic client/30 working day/500 person day criteria), designer’s duties under CDM still apply.

As a supplementary observation, with regard to the domestic exemption within CDM 2007 (HMG, 2007) this could change with the Martha Nussbaumer case (EUR-LEX, 2010) which confirmed that amongst other things, adherence to European Directive 92/57/EEC (EC, 1992) on which CDM 2007 (HMG, 2007) is based requires the appointment of a CDM co-ordinator and a health and safety plan to be drawn up for any construction site on which more than one contractor is present. That is not the current situation within the United Kingdom and it may well be that legislation will need to be changed to accommodate this ruling from the European Commission.

Statutory CDM Duty Holder positions

There are five duty holders who have statutory duties under CDM2007 (HMG, 2007). These are the client, the CDM co-ordinator (CDM-C) the principal contractor, designers, and contractors and the self-employed (who have additional duties on notifiable projects)

The role and responsibility of the Client

Clients have a duty under Regulation 9 of the CDM2007 Regulations (HMG, 2007) that those designers, contractors and other team members that they engage are competent, adequately resourced and appointed early enough for the work they have to do. The client should allow sufficient time for the project and not force tight programmes that can only be achieved by compromising health and safety. This not only applies to the construction phase, but also to design as well. Clients should co-ordinate their own work with others involved with the project in order to ensure the safety of those carrying out the
construction work and others who may be affected by it. They should ensure there are suitable management arrangements in place throughout the project to ensure that the construction work can be carried out safely and without risk to health. They should ensure that their contractors have made arrangements for suitable welfare facilities to be provided throughout the life of the project, comply with the requirements of the Workplace (Health, Safety and Welfare) Regulations 1992 (HMG, 1992) and that relevant information likely to be needed by designers, Contractors or others to plan and manage their work is passed to them.

The client should be able to confirm that their designs (and any design changes) have taken account of the requirements of Regulation 11 of CDM2007 (HMG, 2007) which relate to designer’s duties) and that the different design elements will work together in a way which does not create risks to the health and safety of those constructing, using or maintaining the structure.

Strangely, CDM2007 (HMG, 2007) mentions ionising radiation as a significant site risk during the Construction Phase of a project in Appendix 3 (3) (b) of the ACoP to CDM2007 (HSE, 2007), but does not include non-ionising radiation. This could be because of the continuing controversy over EMF exposure action values or by mistakenly disregarding the effects of a static magnetic field on heart pacemakers when construction workers are not exposed to the MRI procedure itself as a patient or MRI technologist, or simply because it has been missed out of the legislation.

**The role of the CDM Co-ordinator (CDM-C)**

The role of the CDM co-ordinator (CDM-C) is to provide the client with a key project advisor in respect of construction health and safety risk management matters (HSE, 2007). As it could be said that any safety issue which results
during the life cycle of a structure is the ultimate responsibility of the person who conceived and/or financed the project (the client), then it is important that he should obtain competent advisors to assist him in creating a safe place to construct, use, maintain and demolish/decommission. In effect, this means that the CDM-C is the client’s ‘friend’ inasmuch that a client, although he may have the financial resources available to him to initiate and complete a project, may not have the technical and health and safety knowledge required to ensure effective management of health and safety for the life of the structure, including the use of the building. The CDM-C will be able ‘to assist and advise the client on the appointment of competent contractors and the adequacy of management arrangements to ensure proper co-ordination of the health and safety aspects of the design process; facilitate good communication and co-operation between project team members and prepare the health and safety file’ (HSE, 2007). The CDM-C is a key player in the effective management of health and safety, not just because of his design co-ordination duties under CDM, but also because he is also charged with ‘managing the flow of health and safety information between clients, designers and contractors’ (HSE, 2007). This can include holding design reviews as a method of satisfying his duties under CDM2007 (HMG, 2007) Regulation 11 so as to ensure that health and safety issues are addressed alongside practicality and cost in a wider review of the design’s buildability, maintainability and usability’ under Paragraph 98 of the CDM2007 ACoP (HSE, 2007).

Under CDM2007 (HMG, 2007) Regulation 11, the CDM co-ordinator has a key duty to ensure that design considerations have given adequate regard to the avoidance of foreseeable risks, combating risks at source and prioritisation of measures to protect all persons at work. The CDM co-ordinator also has to
ensure that the design has included adequate information about the project, structure and materials. This is done by the designers maintaining a risk log which provides documentary evidence that a hazard elimination strategy has been initiated, and ‘provides information on the RESIDUAL RISKS (of the design) that have to be transferred into the pre-tender plan’ (Summerhayes, 2008), now given the appellation ‘Information Pack’ under CDM2007 (HMG, 2007). This information constitutes the measures and methods that the designer has deemed necessary for the successful tendering contractor to put into place to manage those residual risks in the (his) design. This allows the tendering contractors to be aware of any residual design risks and methods, together with any costs which they may entail, and be required in order to manage the design risks should the tender be successful. The contractor will use this information when preparing the initial construction phase plan to submit with the tender, which then enables the contractor to incorporate health and safety management issues into his contract award decision-making process, thus satisfying the issue of competency of the prospective principal contractor organisation as outlined in Paragraph 202-212 of CDM2007 (HSE, 2007).

The role and responsibility of Designers and sub-Designers
Architects and equipment planners are grappling with a lot of unknowns in designing suites for magnetic imaging equipment (Kuntz, 1982). Thirty years later, we still seem to be discussing MRI Suite design issues and not be able to fully understand the need for MRI suites to be designed and installed at locations where static magnetic fields will not be able create hazards both inside and outside of any controlled area.

Any decision by designers to allow the 0.5 mT footprint to pass outside the confines of the magnet room should use the principles of ERIC (Eliminate,
Reduce, Inform and Control) as well as ALARP (as low as reasonably practicable) and which includes five key principles, one of which is to ensure that their chosen design or design concept reduces risk as low as reasonably practicable. Any attempt to use cost/benefit analysis to justify the 0.5 mT footprint not being retained within the RF cage, but more particularly being allowed to pass to external areas of the MRI suite, would be difficult to justify, particularly as it goes against the published advice of the Medical Devices Agency (MDA, 2007) and in the NHS Health Building Note shown in Figure 2.4. A good phrase for designers to remember when designing MRI suites (Einstein et al., 1985) is that the general rule for MRI installations can be summed up one simple phrase - protect the magnet from the environment and the environment from the magnet.

The design of an MRI Suite could involve many designers – some of whom may not consider themselves as such. In situations where end-users are consulted for their preferred layout of the suite and its relationship with other areas, then they become designers. Even a seemingly innocent request by a radiology manager to have a CT installation adjacent to an MRI would make them a designer under CDM2007 (HMG, 2007) and could possibly result in passive magnetic shielding being required to be installed to the parent structure of the magnet in order to retain the 0.1 mT footprint at sufficient distance so as not to affect the adjacent CT equipment. In such a case, should the finance department decide that it would not sanction the extra cost involved for the specification and installation of passive magnetic shielding, then they too would become designers, as would the client, a leaseholder, facilities manager, estates manager, project manager, principal contractor or contractor if their decision could have an effect on the final design. Equally, if the decision has
been made to allow the 0.5 mT footprint to pass to the outside of the magnet room and a fence or other physical barrier has been chosen as the alternative to passive magnetic shielding then the person who decides the specification and position for this physical barrier also becomes a designer under CDM2007 (HMG, 2007). These designers have the same CDM duties, responsibilities and accountability as the more formally recognised Designers to the project, including the requirement for the provision of relevant risk management information to the CDM co-ordinator. The CDM co-ordinator will then be able to arrange diffusion of this information to other designers and to the principal contractor for inclusion in the Project Risk Log, to update his construction phase plan and eventually include it in his submission for the health and safety file if relevant. This information should mention any control measures required to be put in place should there be any residual risks to the design which will still require to be managed on completion of the project and/or during the period of use and eventual demolition of the structure.

The difficulty for the CDM co-ordinator is to be able to recognise these, almost hidden, designers so as to understand the important role they play in the design process and to identify the point in time when the design input needs to be co-ordinated. The CDM co-ordinator needs to be on the lookout for designer switch and designer supply, or design-construct changes negotiated by the client/project manager/design team leader without involvement of the CDM co-ordinator (APS, 2007). This is made more difficult when the client procures the structure under a design and build contract but excludes the fit-out of the MRI suite and supply of the magnet, perhaps later to be incorporated into a turnkey contract directly with a magnet supplier. In this case, the client may not know which magnet vendor will be chosen under his procurement process and
therefore will not be able to fully participate in the design co-ordination process required by CDM2007 (HMG, 2007) at an early enough stage (APS, 2007). In addition, when designing any structure as a workplace, the provisions of the Workplace (Health, Safety and Welfare) Regulations 1992 (HMG, 1992) that relate to the design of, and materials used in, the structure (APS, 2007) should be considered. It makes it all the more difficult for the lead designer if not all the necessary elements are available in order to design the MRI suite. Not having knowledge of the magnet characteristics at the commencement of the initial design stage can have dramatic consequences for the project.

Additionally, the magnet vendor may himself employ a sub-Designer for the RF cage and for any passive magnetic shielding requirement. As mentioned above, the magnet vendor may not be identified at an early stage; therefore the 0.5 mT footprint of the MRI suite and permissible floor loadings may have already been determined by the client, thus making the late specification/introduction of any required passive magnetic shielding difficult.

Identifying designers, especially late ones, will always be an issue in any project. So as to minimise the risk of missing one, it is preferable for the CDM co-ordinator to establish a project register of designers (APS, 2007) which could be circulated at regular design co-ordination meetings, preferably chaired by the CDM co-ordinator, so as to keep it up-to-date.

As part of design reviews CDM co-ordinators need to ensure that the designers have identified a safe method for the construction of unusual or complex designs, and that the designs include the information needed by other designers and contractors to allow them to work safely and without risk to health. This information needs to be clear and concise (HSE, 2007). The most effective way in managing this process is for the client to appoint a lead
designer to carry out effective co-ordination of design work, systematic, collaborative and compatible approaches to design hazard identification, consistent Design Risk Management (APS, 2007) priorities and methods to ensure the free flow of information between designers. Designers have a duty under CDM2007 (HMG, 2007) to avoid foreseeable risks to those involved in the construction and future use of the structure, and in doing so, eliminate hazards (so far as is reasonably practicable, taking account of other design considerations) and reduce risk associated with those hazards which remain (HSE, 2007). Adequate information about any significant risks associated with the design that are not likely to be obvious to a competent contractor or other designers should also be provided. Information about significant hazards and related significant risks that remain in a design, together with any assumptions made by the designer about working methods or precautions, must be provided to the right people at the right times and in an appropriate form (APS, 2007). On a notifiable project, each designer has to pass information on significant residual risks to the CDM co-ordinator who then ensures that health and safety information is made available to those who need it, and places appropriate information in the Project Information Resource and, where appropriate, in the project health and safety file (APS, 2007). But not forgetting that CDM2007 (HMG, 2007) accepts that it is not always reasonably practicable to eliminate all hazards, where this is the case, consideration should be given to incorporating design solutions which reduce the overall risk to an acceptable level.

The role of the principal contractor

Although a separate sub-contractor employed by the client or magnet vendor may be used for the fit-out of an MRI suite, in most cases the principal contractor who had been responsible for the management of health and safety
for the main construction works would remain in this duty holder position until completion of any magnet installation, including commissioning, until the moment of handover to the client. It has been known that delays do occur between completion of the MRI suite and delivery and commissioning of the MRI scanner. It could be the case that when the principal contractor had completed his pure construction works (and possibly wishes to leave site) transferring this CDM principal contractor duty-holder position to the magnet vendor for him to manage health and safety on site until such time as his scanner was installed, commissioned and handed over to the client for operational use. It is at this point that the construction phase would come to an end and the health and safety file compiled by the CDM co-ordinator, using information supplied by the principal contractor and the project designers, would be handed to the client for him to consult when using the building, or carrying out renovations, alterations or demolition.

The role of the principal contractor then in planning, managing and monitoring the construction work (HSE, 2007) is largely dependent upon him having produced a suitable construction phase plan (CPP) before appointed to carry out or manage the work. This CPP is developed from the Information Pack compiled by the CDM co-ordinator on behalf of the client. Information supplied in the Information Pack is crucial to the ability of the tendering principal contractors to prepare the construction phase plan so as to demonstrate how health and safety on site should be managed on winning the contract. Having been awarded the contract, the principal contractor is required to update the construction phase plan during the course of the works (HSE, 2007). This would include information on the magnetic flux densities of the static magnetic field within the 0.5 m footprint and of the position of the footprint itself.
The role and responsibility of Contractors and the self-employed

The principal contractor will be required to have put in place procedures that will allow effective co-operation and consultation between themselves, contractors and workers. This means that everyone should be consulted about how to solve problems together. The principal contractor has to co-ordinate worker engagement and record the details in the construction phase plan. Contractors (including any engineers employed by the magnet vendor) and the self-employed will need to contribute risk assessments and method statements into this plan because of specialist knowledge. The principal contractor has a duty to plan ahead and everyone on site should co-operate with the principal contractor’s systems and procedures, but if the designer has not communicated all the information relating to residual risks of his design to the principal contractor, then there is a possibility that the risk will go unrecognised (Construction Skills, 2007).

CDM Duty Holders - Competency and Resources
The issue of competency is covered within Sections 8 and 9 of the CDM Regulations (HMG, 2007). The basic tenet is that the competency of the duty holders under CDM should be assured and that the persons or organisations appointed also have adequate resources of time, money, technical knowledge, training and experience. As far as the principal contractor, and to an equal extent the designer(s), are concerned this includes the ability to effectively manage the health and safety aspects of any project. Clients automatically approach designers for a project to be developed to design stage. There is a risk of the appointment of a CDM co-ordinator not being made until after the appointment of the designer. This is despite the CDM 2007 Regulations stipulating in Paragraph 119 (HSE, 2007) that designers must ensure that
clients are aware of their duties under CDM before proceeding past feasibility stage with design work. That is to say that as soon as a designer is approached to commence any design it is essential to ensure that the client is aware of his duties under CDM, i.e. the need to instruct a CDM co-ordinator to enable him to advise the client on his competency (HSE, 2007) and adequacy of resources. The client must determine the competency requirements of the appointed CDM co-ordinator who must also confirm that competency before agreeing to take the appointment. One of the things to do is to provide checkable evidence that his ability to deal with key health and accident hazards in the current application were clearly illustrated (Carpenter, 2006).

Once it has been confirmed that a client is aware of his duties under the (CDM) regulations (and the implications of these) and that a CDM-C has been appointed, the designer can start design work (APS, 2007).

The Health and Safety File (for notifiable projects only)

Clients, designers, contractors, other contractors and CDM co-ordinators have legal duties in respect of the health and safety file. CDM co-ordinators must prepare, review, amend, or add to the (health and safety) file as the work progresses, and give it to the client at the end of the project. Clients, designers, principal contractors and other contractors must supply the information necessary for compiling or updating the (health and safety) file. Clients must keep the file to assist with future construction work and everyone providing information should make sure that it is accurate and provided promptly (HSE, 2007). The health and safety file is a source of information that will help to reduce the risks and costs involved in future construction work, including cleaning, maintenance, alteration, refurbishment and demolition. Clients therefore need to ensure that the file is prepared and kept available for
inspection in the event of such work. It is a key part of the information, which the client, or the client’s successor, must pass on to anyone preparing or carrying out work to which CDM 2007 applies (HSE, 2007).

This is reiterated in CDM2007 Regulation 12 (6) (HSG, 2007) inasmuch that ‘the designer shall take all reasonable steps to provide the design with sufficient information about aspects of the design of the structure or its construction or maintenance as will adequately assist…(a) clients, (b) other designers, and (c) contractors’.

Depending on the moment when the client appoints the relevant designer, this residual design risk information will be held either in the ‘Information Pack’ or incorporated into the principal contractor’s construction phase plan (HSE, 2007). Should this residual risk continue to exist at completion of the construction phase, the CDM co-ordinator should ensure that this residual risk information is included in the health and safety file and handed to the client. The health and safety file is for reference by the user of the structure and by any person who may need it to comply with the relevant statutory provisions (HMG, 2007).

The health and safety file is also important because it should be used as a reference document to indicate to the person or organisation using or altering the structure the hazards and risks which continue to exist from the design, and allow them to decide how to work safely. The client will also arrange for the health and safety file to be updated as further work is carried out to the structure.

**The legal provisions of the Health and Safety File**

The CDM Regulations 2007 (HMG, 2007) describe the health and safety file as being a source of information that will help to reduce the risks and costs
involved in future construction work, including cleaning, maintenance, alteration, refurbishment and demolition. Clients therefore need to ensure that the file is prepared and kept available for inspection in the event of such work. It is a key part of the information, which the client, or the client’s successor, must pass on to anyone preparing or carrying out work to which the CDM Regulations 2007 applies (HSE, 2007).

This is as a result of the requirement in CDM2007 Regulation 12 (6) (HMG, 2007) that the designer shall take all reasonable steps to provide with his design sufficient information about aspects of the design of the structure or its construction or maintenance as will adequately assist…. (a) clients, (b) other designers and (c) contractors.

As far as MRI suites are concerned, the furnishing of this information to those who need it [The right information for the right people at the right time (HSE, 2007) will enable the client to comply with the minimum health and safety requirements regarding the exposure of workers to the risks from electromagnetic fields, and in particular the requirement for risk assessments and health surveillance, in that ‘taking account of technical progress and of the availability of measures to control the risk at source, the risks from exposure to electromagnetic fields shall be eliminated or reduced to a minimum (Pavlicek et al., 1984).

The contents of the Health and Safety File

The content requirement of a health and safety file is outlined in Paragraph 263 of the CDM 2007 Approved Code of Practice (HSE, 2007) to the Construction (Design and Management) Regulations 2007 (HMG, 2007). Paragraph 263 (b) (HSE, 2007) specifies the requirement for information on any residual hazards which remain and how they have been dealt with and information and as-built
drawings of the structure, its plant and equipment (Paragraph 263 (g) to be included. Therefore, information regarding the installation of an MRI scanner would fall within these criteria. Additionally, it cannot be argued that where a scanner is installed at a date following completion of construction of a given MRI suite that CDM would not apply, because the purpose of constructing an MRI suite would be to house the scanner. Normally, the construction phase would not end until the scanner had been installed.

In Appendix 3 of the said Approved Code of Practice to the CDM Regulations 2007 (HSE, 2007) advice is given that information on the presence of ionising radiation i.e. x rays, should be included in the health and safety file. However, the requirement for information on the presence of non-ionising radiation i.e. MRI, is not referenced. Inclusion of information in the health and safety file on the presence and location of the static magnetic field around an MRI suite might therefore assist these studies by also including individuals who may otherwise be excluded because of not actually working within the operational MRI suite itself.

The relevant static magnetic field flux density where control measures should be introduced is set at 0.5mT. The reasons for this are discussed later in this thesis, but if the CDM Regulations 2007 (HMG, 2007) were followed correctly, inclusion of this information, not on the theoretical but on the actual position of the 0.5 mT footprint of the static magnetic field, would give value to any health and safety file.

2.13.4 OTHER STATUTORY AND NON-STATUTORY OBLIGATIONS

89/391/EEC and the 18th Individual Directive

The general provisions of the 18th Individual Directive within the meaning of Article 16(1) of EC Directive 89/391/EEC (EC, 2004) lay down minimum
requirements for the protection of workers from risks to their health and safety arising or likely to arise from exposure to electromagnetic fields (0 Hz – 300 GHz) during their work. The Directive refers to the risk to the health and safety of workers due to known short-term adverse effects in the human body caused by the circulation of induced currents and by energy absorption, as well as by contact currents.

Directive 89/391/EEC (EC, 1989) discusses the need for assessment, measurement and calculations of worker exposure to electromagnetic fields and goes on to say that the employer shall assess and, if necessary measure and/or calculate the levels of electromagnetic fields to which workers are exposed, and that the employer shall give particular attention to the level, frequency, spectrum, duration and level of exposure and to any effects concerning the health and safety of workers at particular risk.

The Directive forms part of a package of four directives on the exposure of workers to the risks arising from physical agents: noise, vibration, electromagnetic fields and optical radiation. It provides for measures to protect workers from the risks related to electric, magnetic and electromagnetic fields.

The EMF Physical Agents Directive EC/40/2004

Directive 2004/40/EC (EC, 2004) of the European Parliament dated 29th April 2004 arose from Directive 89/391/EEC (EC, 1989) and was due to be incorporated into UK legislation during 2008. Numerous representations from the medical community were made to the EU using the argument that ‘interventional MRI procedures could cease as healthcare workers would be exposed to electromagnetic fields (EMF’s) greatly exceeding the limits in the Directive’…and ‘that the limits in the directive were inappropriate for application in MRI as they are based on prevention of effects on the Central Nervous
System’, continuing that ‘static electromagnetic fields do not currently have exposure limits under the Directive’ and ‘concerns were raised that unless some convincing evidence is produced’….’ the Directive”…."may well be modified to introduce a limit for static fields (Galston Sciences, 2006).

As a result of representations made, the European Commission reviewed Directive 2004/40/EC and on 23rd January 2008, agreed to postpone entry into force of that Directive until 30th April 2012 to allow for a revision of the exposure limits.

**ICNIRP guidelines on limits of exposure to static magnetic fields**

Nevertheless, the International Commission on Non-ionising Radiation Protection (ICNIRP) has set exposure limits to the static magnetic field (ICNIRP, 2009) and these limits are shown in Table 1 below. Although the limits were produced to protect those exposed to environments containing static magnetic fields, they do not implicitly include construction worker exposure to the static magnetic field during the construction phase of an MRI suite. Where construction workers are exposed to the energised magnet, then the continuous exposure limit set for the general public may be a more prudent figure to adopt. This is because whilst working around a magnet (ceiling installation, et cetera) they will probably not have the opportunity to leave the area at the same frequency, thus not be able to restrict their exposure as a worker in an operational MRI suite might be able to do.
Table 2.1: ICNIRP guidelines on static magnetic field human exposure limits (ICNIRP, 2009)

Occasional access of members of the public to special facilities where magnetic flux densities exceed 40 mT can be allowed under appropriately controlled conditions provided that the appropriate occupational exposure limit is not exceeded (ICNIRP, 2009). These exposure limits are currently under review, but can only be of use to a principal contractor if static magnetic field flux densities and their positions are documented following energisation of the magnet during the construction phase. Even following energisation of the magnet it is possible that the quantity of ferromagnetic material coming within the influence of the magnet’s static magnetic field could increase as the construction works progress, thus affecting the symmetry of both the 0.5 mT and 0.1 mT footprint. In this case the Construction Phase Plan will need to be updated by the principal contractor.

ICNIRP guidelines on time-varying magnetic fields

The ICNIRP has published guidelines on limits of human exposure to time-varying magnetic fields (ICNIRP, 1998) and consideration has to be given by the principal contractor to the possibility of this phenomenon occurring. This is because where persons may be exposed to a static magnetic field, physical...

<table>
<thead>
<tr>
<th>Exposure characteristics</th>
<th>Magnetic flux density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupational</td>
<td></td>
</tr>
<tr>
<td>Whole working day (time-weighted average)</td>
<td>200 mT</td>
</tr>
<tr>
<td>Ceiling value</td>
<td>2 T</td>
</tr>
<tr>
<td>Limbs</td>
<td>5 T</td>
</tr>
<tr>
<td>General Public</td>
<td></td>
</tr>
<tr>
<td>Continuous exposure</td>
<td>40 mT</td>
</tr>
</tbody>
</table>
reactions take place within the body. One of these reactions includes magnetic excitation of sensory receptors leading to sensations such as nausea, vertigo and magnetospheres (Schenk, 2000). This occurs because when a person moves within a static magnetic field, a time-varying field is automatically created. The degree of severity of the reaction to exposure will also depend largely not just on the magnetic flux density, but also on the velocity of the person exposed. In other words, how fast the individual moves in carrying out his assigned tasks. This is explained further (Reilly, 1992) in that with MRI exposure for example, the B field is not uniform in all axes and may undergo a phase change within the exposure area. Ensuring knowledge of the 0.5 m footprint position and magnetic flux densities within the footprint itself is crucial to design risk management of the MRI suite so as to comply with Regulation 11 of CDM2007 (HMG, 2007). That is to say, by the media of the Designer giving information on the residual risks of his design, by him co-operating with other Designers and with the CDM co-ordinator, and finally setting out control measures that should be put in place by the principal contractor at construction phase and by the client during the operational use and demolition of the structure to manage the residual risks of the design. A formula that could be used in laboratory conditions as a basis to calculate the risk is as follows:

\[ J = \delta (E + v B) \]

Equation 1: A formula to calculate site risk of the creation of time-varying fields

In this formula J equals the electric current density produced by an electrical field E within material with an electrical conductivity \( \delta \), moving with a velocity v and where a magnetic field of B is present. (Schenck, 2000).

The practicalities, of course, of attempting to control the head movement of a person within an environment such as a live construction site, or by the user at
operational stage or maintenance would be impossible. What this formula does do however is to bring attention to the risks of any movement of the head whilst working within a high static magnetic field. It is for this reason that Designers should identify where those areas exist, together with their magnitude following magnet energisation, so the principal contractor, user or maintainer is made aware of the potential hazard in creating a time-varying field. Having this knowledge would be able to highlight the dangers of rapid head movement within these identified areas and suggest to the principal contractor to include this information in the site programme of toolbox talks as well as to introduce control measures. These control measures could be as simple as not allowing working at height other than on a scaffold tower or lone working not being permitted. The process of risk assessment is outlined in Directive 89/391/EEC 47 (EC, 1989) as referenced above.

2.14 SCREENING OF INDIVIDUALS EXPOSED TO THE STATIC MAGNETIC FIELD

The dangers of working within a magnetic field are not easily apparent, but Designers should focus on issues that are known to have the potential to cause significant harm and where there are known, solutions that reduce the risks to everyone exposed (HSE, 2007). Employers should be able to recognise that for example, a maintenance worker working above the ceiling over the magnet isocentre in the y axis, or a person re-filling cryogenic gases could easily come into contact with a high magnetic flux density, suffer vertigo because of moving quickly. Obviously only a rough risk assessment can be made, as in addition to the rate of head movement in a given field strength, each person’s body mass and other physical attributes will vary. However, in any risk assessment it should be envisaged that these effects could include dizziness and nausea, with the consequential ability of operatives to carry out ‘safe working’ whilst working
within the stronger magnetic fields of the magnet. Where the worker is made aware of this residual hazard, mitigation of this risk to personal safety is possible by limiting the rate of motion within the field (Schenck, 2004)

2.14.1 Sensory indications of exposure to strong magnetic fields

Therefore, all persons including construction workers, MRI staff and visitors screened as being able to work within the 0.5 mT footprint of the static magnetic field should be made aware of the possible static magnetic field effects in the production of flow and motion-induced currents in human tissue. Tissue motion, such as bulk physical movements (e.g. rapid movement in or out of the magnet, or rapid head-turning) or internal movements (e.g. blood flow), in strong static fields can produce additional physical effects beyond those directly associated with permanent magnetism and magnet susceptibility (Schenck, 2000). The World Health Organisation (WHO, 2004), reports that there are individuals that report a wide range of symptoms that they attribute to electromagnetic fields or being close to electromagnetic equipment. However, they admit that to date experimental and epidemiological studies have failed to provide clear support for a causal relationship between electromagnetic fields and complaints. Nevertheless, the reality of these effects has not been discounted, with the term Idiopathic Environmental Tolerance (Electromagnetic field attributed symptoms), or IEI-EMF being adopted. If a causal relationship can be attributed to EMF or any other explanation is forthcoming then the name of this condition may be changed. (WHO, 2004)

2.14.2 The mapping of magnetic flux density surrounding the magnet

Even when the scanner is not in imaging mode (by definition this would include the construction phase once the magnet has been energised), it is the ever-present static magnetic field (and the mapping of its magnetic flux density
encircling the magnet) that is of interest to those involved with construction and operational risk management. This information enables them to identify and set-up a controlled area around the magnet installation. Having this knowledge also enables the employer (including the principal contractor during the construction phase following energisation of the magnet) to screen and possibly exclude, any individuals who may be fitted with electronic implants or devices, such as heart pacemakers, from the controlled area of the MRI suite. Assessments of magnetic field interactions for 109 different biomedical implants and devices for magnetic field interactions at 3 Tesla have been made and it was concluded that the presence of a metallic implant in a patient or individual in the magnetic resonance (MR) environment may create a hazardous situation primarily due to excessive magnetic field interactions (Shellock, 2002). The test results are listed and it concluded that 4% of heart pacemakers were found to possess magnetic qualities that may cause them to be unsafe and showed that there are important safety issues related to the use of these powerful MR systems, especially with regard to the management of patients and individuals fitted with metallic implants.

2.15  THE CONTROLLED AREA TO AN MRI SUITE

In an operational MRI suite within the UK there would normally consist of a hierarchy of two controlled areas as a minimum, with the Outer Controlled Area being a volume totally enclosed, and of such a size to contain the 0.5 mT magnetic field contour. Access should be restricted and suitable signs should be displayed at all entrances, and an Inner Controlled Area, being a volume totally enclosed and of such a size to contain the 3 mT (30 Gauss) magnetic field contour (MDA, 2007) should be included.

2.15.1  THE OUTER CONTROLLED AREA
Demarcation of the Outer (0.5 mT) Controlled Area is necessary because 0.5 mT is the threshold for exposure to the static magnetic field of all individuals that have not been successfully screened for contra-indications. UK government advice is that a person fitted with a heart pacemaker must not enter the MR Controlled Area (MDA, 2007). However it should be appreciated that this hazard is not a direct biological one to the individual, but a risk of magnetic field electromechanical interference with the medical device. One description of the effect of the static magnetic field on pacemakers is that ‘the magnetic reed switch that varies the heart rate can be inadvertently switched by the static field and revert to its default setting (Young, 2000) which could lead to irregular heart rhythm of the bearer of the pacemaker, and eventually serious handicap or death.

2.15.2 THE INNER CONTROLLED AREA

The ICNIRP (ICNIRP, 1998) have recommended that an inner controlled area (where there is a field strength of 30 Gauss (3 mT) be set up around the magnet to avoid the hazard of the ‘projectile effect’ on ferromagnetic elements being brought within the influence of the magnet’s static magnetic field.

2.16 SITE ACCESS CONTROLS AND ZONING DURING THE CONSTRUCTION PHASE

The American College of Radiology’s (ACR) White Paper on MR Safety (ACR, 2007) recommends a controlled area and does not restrict this area to the 0.5 mT footprint, but to the MRI suite itself and includes four zones of control. This is shown in Figure 2.14 below.
Figure 2.14: ACR advice regarding the setting up of controlled areas for MRI suites

This layout, whereas it may be worthy of consideration for an operational suite, shows the unsuitability of access control zoning of MRI suites during the construction phase, particularly where the exact position of the 0.5 mT footprint is unknown and where unscreened construction site operatives may have unrestricted access to areas contiguous to the RF cage. Even if the position of the 0.5 mT footprint was identified, it would still be difficult for the principal contractor to police access. Therefore, the entire MRI suite should be designated a single controlled area.

There is a view (Lipton, 2004) that this controlled area should be reduced to two zones, with Zone 1 being areas with direct access to the doors of the MRI scanner room and Zone 2 being the scanner room (RF cage) itself. This is all very well, but both these sets of advice relate to operational MRI Suites. The difficulty with MRI suites when they are under construction is that it is not just the RF cage that is being worked upon. It is the greater area, where construction workers may require unrestricted access to other areas within the MRI suite in order to carry out their tasks, and particularly where the 0.5mT line
may extend to areas outside the scanner room (RF cage). This is also a possibility at operational stage so the client will need to be absolutely sure that the 0.5 mT footprint does not pass to uncontrolled areas outside the MRI suite. Further pressure to increase the size of the MRI suite, causing enlargement of the working area during the construction phase comes from anaesthetists who ask for consideration to be given for the requirement to provide adequate space for an anaesthesia service during the design of the MRI Suite. (AAGBI, 2002), thus increasing the size of the construction area with a consequential rise in the number and frequency of visits of individuals who may be working within any controlled area. The American College of Radiology’s (ACR) White Paper on MR Safety (ACR, 2007) is only concerned with safety of operational use of the MRI Suite and four zones of control may be an adequate safeguard to exposure to the static magnetic field in an operational situation, but is not relevant to post energisation of the magnet whilst still at the (construction) pre-handover stage. Division of any controlled area during the construction phase could create the additional risk of access control procedures being compromised to areas where the 0.5mT footprint is present, either inside or outside the RF cage as the case may be during the construction period. Four zones are overly complex and the more complex a system, the more it is disregarded and/or circumvented by workers, or the more confusion it generates.

2.17 THE PHYSICAL HAZARDS OF EXPOSURE TO THE STATIC MAGNETIC FIELD

It has already been indicated that exposure of persons to areas within the 0.5 mT footprint of the static magnetic field can create a hazard to those persons fitted with heart pacemakers or other implants. Individuals fitted with electronic medical devices have an extremely restrictive recommended exposure limit for static magnetic fields. The International Commission on Non-Ionising Radiation
Protection (ICNIRP, 1998) has endorsed the upper limit of exposure to those persons fitted with such devices as being 0.5 mT. A reason for the safety limits decided upon in the original National Radiological Protection Board (NRPB) thinking was largely because there was no data that might cause any concern and because they appeared to those involved to be set so generously that no one would even be interested in approaching them (Young, 2000).

The effect of the static magnetic field on pacemakers is that the magnetic reed switch that varies the heart rate can be inadvertently switched by the static field and revert to its default setting (Einstein et al., 1985). This could lead to irregular heart rhythm of the bearer of the pacemaker and eventually to serious handicap or death. Additionally, persons having ferromagnetic metal fragments embedded into bodies can also be at risk if exposed to a high magnetic flux density. This could include those persons having metal fragments embedded in eyes through, for example, having an occupation as a welder because any embedded metal particles could be drawn across the eye by the static magnetic field, inducing blindness.

Further research into the molecular effects of the static magnetic field is recommended as ‘there are still poorly understood effects, especially discreet effects which may be reversible or only appear after a long latency, which remain difficult to evaluate’ (de Certaines et al., 2001). Results obtained with simplified models, such as cell cultures, cannot be extrapolated to humans. This shows how little we know about these effects on humans and this is reinforced by the case that over the last few years the lack of positive results – reportable health risks – has discouraged publication of scientifically valid results. The lack of damage evidence led researchers to conclude or assume that health risks are too low or non-existent to deserve further study and that scientists who
continually disprove their hypotheses soon lose funding, and their scientific careers are threatened so researchers have either ceased studying the area of safety or failed to publish their results (Ordidge, 1999).

Where persons may be exposed to a static magnetic field, physical reactions take place within the body. One of these processes includes 'magnetic excitation of sensory receptors leading to sensations such as nausea, vertigo and magnetospheres (Schenck, 2004). This occurs because when a person moves within a static magnetic field a time-varying field is automatically created. The degree of severity of the reaction to exposure will also depend largely not just on the magnetic flux density, but also on the velocity of the person exposed. This is explained further by (Patrick Reilly, 1992) in that with MRI exposure for example, the B field is not uniform in all axes and may undergo a phase change within the exposure area. Therefore, making knowledge of its position and field strength is crucial to design risk management of the MRI suite so as to comply with Regulation 11 of CDM2007. That is to say by the medium of the Designer giving information on the residual risks of his design, by him co-operating with other Designers and with the CDM co-ordinator, and finally setting out control measures that should be put in place by the principal and/or pre-installation contractor at construction phase and during the operational use and demolition of the structure so as to manage the residual risks of the design.

2.17.1 Torque and Translational Attraction of Ferromagnetic Objects

In addition to electro-mechanical interference, there are also two other physical forces, being (a) torque and (b) translational attraction, which can be exerted by magnetic fields upon ferromagnetic objects.
The effect on humans

When subjected to magnetic fields, a heart pacemaker or other medical device or implant could twist (torque) within the individual so as to align itself with the magnetic field to which it is exposed, or be pulled towards the magnet by translational attraction whilst embedded in the individual’s body. Both these events can be particularly dangerous where the implant or device is close to major organs. Contra-indications to exposure of individuals to the static magnetic field also include those persons who have embedded metal fragments within their bodies. One issue which should be considered by the principal contractor under CDM2007 (HMG, 2007) is that many construction workers, by the nature of their occupation, may have been exposed to operations or tasks which could have resulted in metallic fragments being, unknowingly, embedded into eyes. One of the most vulnerable parts of the body is the eye. The adequate screening of patients or others with suspected intra-ocular ferromagnetic metallic objects is most important before being allowed to enter the MRI suite (MDA, 2007).

The effect on tools and plant

There is a risk of ferromagnetic gas cylinders becoming projectiles in an MR environment and advises that that appropriate policies and discipline are essential to avoid such deadly and expensive gas cylinder accidents (Colletti, 2004). Therefore it is extremely important that ferromagnetic objects, including plant and tools, are excluded from the influence of the static magnetic field of the magnet as these ferromagnetic objects brought within near proximity to the static magnetic field can become projectiles that could cause harm to someone standing between the object and the magnet. It has been identified that a firefighter was trapped and nearly suffocated as he was drawn into the bore of the
magnet when the breathing apparatus he was wearing became magnetised in an MRI room (Bucsko, 2005). Where magnet rooms are not completed as far as is possible before delivery and energisation of the magnet, then the risk of construction workers introducing ‘normal’ ferromagnetic tools into the area of influence of the static magnetic field increases. This is a real risk, because any construction works yet to be carried out to a magnet room will necessarily require the operative not just to be confined to the area outside the 0.5 mT footprint, but also to come within it whilst carrying or using plant and tools which could be of varying mass and physical composition. This makes knowledge of the ‘true’ position of the various magnetic flux densities of the static magnetic field footprint crucial to the safety of the individual and of protection of the magnet from damage because any object striking the magnet could cause the magnet to quench i.e. become resistive (UC Davis, 2002).

Where the 0.5 mT footprint has been allowed (unknowingly or not) to pass to the exterior of the RF cage, then the risk of the ‘Projectile Effect’ is largely absent, not because any ferromagnetic objects being pulled by the magnetic field could be halted by the RF cage parent wall, but because the projectile effect is only likely to occur at 30mT or more (Cole, 2006) - a level unlikely to be found outside the RF cage except when blooming occurs as a result of a quench. The highest risk exists within the RF cage itself, where there would be an uninterrupted route to the bore of the magnet and an operative could be positioned between the projectile and the magnet itself.
2.18 MAGNET VENDOR GUIDANCE ON THE SAFETY OF STATIC MAGNETIC FIELDS

Magnet vendors’ site planning guides are by their very nature, generic documents and all carry caveats. For example they variously advise;

Siemens

- the customer should protect the controlled access area (0.5 mT) with the delivered warning signs
- that all doors leading to the 0.5 mT area must be protected with a warning sign
- the Project Manager provides the customer with the position of (the) 0.5 mT line as a table from the planning guide which is showing the distances, or the customer site drawings which are indicating the 0.5 mT gauss line based on e.g., a table from the planning guide that shows the distances, or the customer site drawings that indicate the 0.5 mT line.
- the warning sign “cardiac pacemaker” is for identifying the entrance doors into the examination room or the 0.5 mT line”
- the warning sign “strong magnetic field” is, e.g. for identifying the entrance doors into the examination room or the 0.5mT line, and that;
- additional iron shielding is required e.g. if the 0.5 mT line has to be within the examination room walls, dynamic interferences are present, and public areas have to be protected against the 0.5 mT fringe field.

Philips Medical Systems

‘It is the responsibility of the hospital that the following safety requirements are satisfied’.

- During the site planning of the Philips (Achieva) system, a controlled zone must be defined where the field strength is more than 0.5 mT (5
Gauss). Warning signs “CAUTION - magnetic field permanently switched on” shall be used to indicate this area.

- ‘persons having a pacemaker, neurostimulator, insulin pump, or other bio-stimulation device, implants consisting of ferromagnetic material such as surgical clips, artificial cardiac valves and prostheses or metal splinters, must not be brought into a strong magnetic field. Such persons must stay outside the “Controlled Zone”‘.

- Security procedures at the entrances of the examination room shall prevent ferromagnetic objects being brought into the examination room. Metal detection equipment can be used.

But again, the position of the 0.5 mT footprint of the static magnetic field needs to be known by the principal contractor.

2.19 Magnet Room Preparation Before Delivery of the Magnet

Magnets are fitted with a quench pipe in order to allow, in case of a quench, the rapid evacuation of helium gas from the magnet to the outside atmosphere. The usual process of room preparation would be for any required magnetic shielding to be installed to the parent structure, for the RF cage to be constructed and tested. The room would receive the necessary finishes, including erection of the suspended ceiling, walls plasterboarded and emulsioned, electrics completed and tested and the laying of anti-static covering to the magnet room floor completed. During this period the wall of the parent structure will be a temporary structure. When the magnet is delivered, following a successful RF test, one wall of the RF cage would be temporarily removed to allow access for the magnet. Once the magnet had been delivered and the RF cage wall put back, wall and ceiling finishes can be completed and the remaining floor covering at that position, including its (usually) integrated skirting finished off. A case where
completion of the magnet room was not achieved before delivery of the magnet can be seen in Figure 2.15 below. The floor covering was laid so as to permit the magnet to be installed, thus allowing the magnet to be delivered, bolted down onto its anti-vibration pads and the quench pipe connected in case a magnet quench event were to occur during the continuing construction phase. The helium gas replenishment was then completed and the electricity supply connected. However, as can be seen from Figure 14 below, despite magnet vendors’ advice that magnet rooms should be completed before delivery of the magnet, there is a substantial amount of finishing works remaining to be carried out to the magnet room. It makes it difficult for the principal contractor to set up a controlled area so as to exclude unscreened personnel or visitors to the as yet unknown position of the static magnetic field of the magnet. Additionally, there will be, because of the continuing construction works when the magnet is energised, a hazard of tools possibly being subjected to the ‘projectile effect’.

Figure 2.15: An energised magnet in a partially completed magnet room

2.20 A QUENCH OF THE MAGNET

A quench of the magnet occurs when the cryogenic gas used to cool the coils, employed to enable them to retain their superconducting properties, ‘boils off’. Therefore attention needs to be paid to ensuring that levels remain sufficiently high so as to prevent any part of the wire used to construct the coil becoming
overheated, thus provoking a chain reaction causing the coil and its stored energy to be converted into heat, causing the liquid helium surrounding the coils to boil off and ‘quench. But in the unlikely event of the magnet quenching (the rapid release of gaseous cryogens from the cryostat into the room) or of a cryogenic container failure, up to 100 m$^3$ of helium gas may evolve over a period of several minutes with the helium expanding at a rate of 760:1 (UC Davis, 2002) and there could be a risk of asphyxiation in a confined space.

2.20.1 HELIUM GAS REPLENISHMENT

Liquid helium is normally delivered to an MRI suite location by tanker, and then transferred to Dewars to be taken into a given MRI suite. The magnet’s helium is then replenished from these Dewars. An example is shown in Figure 2.16 below, and as can be seen, helium gas escapes during this process.

![Figure 2.16: a Dewar being filled with helium before being taken to the MRI suite](image)

2.20.2 A CONTROLLED QUENCH OF THE MAGNET

MRI systems are built with a quench button inside the magnet room. The primary use for the button is to render the unit non-magnetic in case of an emergency, i.e. an object projected into the magnet, but is also utilised to quench when the magnet (MRI) is being taken out of service. The quench
button activates a release valve that allows the liquid helium to escape.

The quench button brings current to a heater element in the cryostat which makes the liquid helium turn to gas and the magnet pressure goes up. High pressure causes the burst disk in the vent to rupture, allowing the helium gas to evacuate. The quench button is normally used only in an emergency because it wastes liquid helium and potentially the magnet could be damaged. Usually the magnetic field is removed by connecting the power supply to the magnet, matching the current of the magnet, then reducing the current.

The example in Figure 2.17 below shows a controlled quench of a magnet.

![Figure 2.17: Showing a controlled quench of a magnet](Image courtesy of Siemens, 2012 (Magnetom Impact in Vasteras 1995-2007))

2.20.3 QUENCH PIPE SITING CONSIDERATIONS

In a quench of the magnet the helium gas is so cold that it is below the condensation and freezing points for nitrogen and oxygen. Exposure to super-cold helium gas will distill the gasses out of atmospheric air and freeze them. It is this frozen atmospheric air that forms a ‘snowball’ and therefore extremely
important to ensure that in the case of a quench, siting of the quench pipe and of its termination cannot pose any risks to other users of the building or to visitors. An example of bad siting of a quench pipe can be seen below in Figure 2.18. This example shows how the siting of the quench outlet is too close to the edge of the roof thus allowing, in the case of a quench, the possibility for any 'snowball' to hit the edge of the roof and shatter and diffuse debris to the area below.

Figure 2.18: The quench pipe outlet points at the roof edge

2.21 LITERATURE REVIEW SUMMARY

Literature of hazards relating to the exposure of individuals to the static magnetic field was found to be orientated towards the medical profession, whilst ignoring the pivotal role played by the magnetic shielding Designer and the building contractor. There is a lack of literature relating to the practical aspects of MRI suite design and construction and associated hazards. This situation creates an information gap between construction professionals on the one hand
and academics and magnet engineers on the other. This thesis hopes to contribute to redressing that imbalance.
CHAPTER 3 RESEARCH DESIGN AND METHODOLOGY

3.1 INTRODUCTION

This thesis contains six case studies that progressively demonstrate the current situation within industry as it concerns the application of the Construction (Design and Management) Regulations 2007 (HMG, 2007) to the design and construction of Magnetic resonance imaging (MRI) suites. It was necessary to combine knowledge and experience from the paramedical administration and from the academic and operational medical and construction disciplines.

Various sources of information were drawn upon during the research process. These included textbooks, construction and medical journals, scientific papers, conference proceedings and through the Freedom of Information Act, 2000.

Living and working in London was a great advantage as it allowed literature searches to be carried out in the reading rooms of the British Library.

Various PhD and MSc theses were consulted, not just by using Index to Theses, but also by talking to academics involved in the subject.

MagNet at Imperial College, London was able to allow participation in two magnet safety training courses which gave further background knowledge to previous training and experiences on site.

Questionnaires were sent out to CDM duty-holders (clients, designers, principal contractors) to assess their understanding of their statutory duties under the Construction (Design and Management) Regulations 2007 (HMG, 2007).

Once this information was collated it was necessary to quantify the number of MRI magnets currently installed in England, Scotland and Wales. This
information was then filtered so as to determine how many installations included passive magnetic shielding within the design. This is the subject of Case 1.

Health and safety files were then asked from those installations that included passive magnetic shielding to the magnet room. This was so as to discover if the CDM co-ordinator, (or planning supervisor under the antecedent 1994 CDM Regulations), had included as-built drawings showing the extent of any passive magnetic shielding and more importantly, the actual position of the 0.5 mT footprint of the static magnetic field at the end of the construction phase. This is the subject of Case 2.

During the period of collection of health and safety files four opportunities arose which were crucial to this research.

The first opportunity, and which is the main focus of this research, was when it was discovered that a particular hospital required magnetic shielding to be retrospectively installed on the rear wall of an operational magnet room. The reason given for magnetic shielding to be required to this already operational site was that the 0.5 mT footprint was encroaching on the public corridor at the rear of the magnet. The opportunity was given to measure the magnetic flux leakage through the bolts fixing the shielding to the corridor wall and to highlight design issues. This allowed development of a simple formula for Designers to use when calculating the area of magnetic shielding required in order to retain the 0.5 mT footprint of the static magnetic field within the required controlled area of the MRI suite. It also highlighted the failings of introducing retrofit magnetic shielding to a pre-existing installation. This is outlined in Case 3.

The second opportunity was when during the research it was discovered that a client was not sure whether magnetic shielding was fitted to a magnet
installation. Dialogue was initiated with the hospital concerned and the opportunity was given to be able to visit the site to carry out site-based discussions and take field survey measurements of the static magnetic field to validate the situation. This is the subject of Case 4.

The third opportunity was to be able to make a site visit to find a solution to introducing magnetic shielding to a newly installed 15 Tesla research magnet. This demonstrated that there had been no thought given, even though it was a construction project defined by CDM 2007 Regulation 2, to the design of passive magnetic shielding, nor of its buildability. This is outlined in Case 5.

During the course of the research examples of confusion between RF and magnetic shielding became apparent. Some of those examples are shown in Case 6 so as to compliment the arguments of this thesis.

3.1 CASE 1

The research commenced by establishing if those individuals concerned with the procurement, design and construction of an MRI suite were aware of the requirements of The Construction (Design and Management) Regulations 2007 (HMG, 2007) and of the responsibilities of the various duty-holders under that legislation. Informal discussions took place with construction site managers, magnet vendors’ engineers, Faraday cage manufacturers and installers, magnetic shielding installers and suppliers, hospital radiology managers, designers and construction operatives. So as to form a valid conclusion and submit recommendations, questionnaires were sent to client’s architects, pre-installation contractors, RF cage and magnet suppliers. These questionnaires are included in Appendix D.1. Once this information was obtained it was collated into an Excel spread sheet in order to be able to summarise the data
collected and to assess understanding of statutory duties under CDM 2007 (HMG, 2007). This spreadsheet is included in Appendix D.2.

3.2 **CASE 2**

So as to quantify the incidence of passive magnetic shielding to the installed base of MRI suites, initial requests for information by the use of two questionnaires were sent to NHS Trusts. These requests were made under the Freedom of Information Act 2000 (HMG, 2000a). The first questionnaire enquired as to the location of MRI suites that were part of each individual NHS Trust. Once this information was obtained further enquiries were made of the Trusts by using the second questionnaire so as to obtain as-built drawings from those fitted with magnetic shielding to establish if they existed, and if so, if they showed the as-built position of the 0.5 mT footprint of the static magnetic field of the magnet. These two questionnaires are shown in Appendix D.3. Northern Ireland was excluded from this research because the re-organisation of the Northern Ireland Health Board at the time of the survey made it difficult to guarantee that all MRI installations could be identified.

Information on the age of currently installed magnets, the rate of installation of magnets since the first identified site installation in 1992, the number of currently installed magnets and whether they contained magnetic shielding or otherwise was collected at the same time from the Health Protection Agency. Drawings received as a result of the second questionnaire were examined for their relevance to the request for as-built drawings showing the as-built position of the 0.5 mT footprint of the static magnetic field of the magnet.
3.3 CASE 3
Following discussions with hospitals, magnetic shielding installers and designers and Faraday cage manufacturers led to the discovery that a hospital site required magnetic shielding to be installed to an existing operational magnet. Permission was obtained from the hospital concerned that a survey of the 0.5 mT footprint of the magnet both inside and outside the magnet room and before and after shielding was installed by the contractor. The contractor also gave permission for photographs of the installation to be taken. The purpose of the surveys was to establish if the actual position of the 0.5 mT footprint of the static magnetic field was distorted by the introduction of the retrofitted shielding and if the magnetic flux density inside and outside the magnet room increased as a result of its introduction.

3.4 CASE 4
A site visit was made following receipt of a supposed as-built drawing showing the need for magnetic shielding to the magnet room. The radiology manager was not sure if magnetic shielding had actually been installed and the records held in the project health and safety file were incomplete.

3.5 CASE 5
Case 5 demonstrates the quandary in which the client had been placed by installing an MRI magnet without considering the design or buildability of the shielding required and resulting in a shielding solution not being found which could meet the user’s requirements.

3.6 CASE 6
During the period of research various other design issues were discovered and these have been included in the chapter ‘Further Work’. These include quench
pipe siting, quench pipe maintenance and the creation of confined spaces over the magnet room.
CHAPTER 4  CASE 1

4.0 CDM DUTY HOLDERS AND MRI SUITE DESIGN AND CONSTRUCTION

4.1 CASE SUMMARY

This case was to identify if the Construction (Design and Management) Regulations (CDM) duty holders for a project understood the statutory duties imposed upon CDM duty holders and were aware of the potential safety issues of the exposure of construction workers to the static magnetic field of the magnet. This is because since 1994, The Construction (Design and Management) Regulations (HMG, 2007) and its postcedents have imposed a duty on the client of a structure where a notifiable project has been carried out to provide information (the Health and Safety File) which may be needed during future construction work. Under CDM, construction work includes cleaning, maintenance, alterations, refurbishment and demolition. In 2007, the CDM Regulations were amended (CDM 2007) and imposed a further duty on clients to provide information to those who work in the premises (the use of the building). Research questionnaires were sent to clients’ architects, contractors, magnet vendors and RF cage suppliers throughout Scotland, England and Wales so as to establish the current situation. The results showed that there was no agreement on many aspects of duty holders’ responsibilities under CDM 2007, nor on hazards of the static magnetic field, operative screening, or who should police any controlled area. Recommendations to ameliorate this situation are given.
4.2 CASE INTRODUCTION

The author’s experiences both on and off site were that there was rarely any information or discussion with construction personnel about the actual position of the static magnetic field when the magnet had become energised during the construction phase, nor of the possible effect it could have on humans or on ferromagnetic materials brought within its influence. Case 1 of this thesis was initiated so as to assess if this was because the various CDM duty holders were unaware of current statutory duties under CDM.

4.3 RESEARCH AIMS AND OBJECTIVES

The aim of this work was to identify if the various CDM duty holders understood the potential safety issues of the exposure of construction workers to the static magnetic field of the magnet.

The objective was that the information obtained would help assist clients and their duty holders appointed under CDM 2007 in managing health and safety during the construction phase of an MRI suite project.

4.4 RESEARCH METHODOLOGY

The research commenced by establishing if those individuals concerned with the procurement, design and construction of an MRI suite were aware of the requirements of The Construction (Design and Management) Regulations 2007 (HMG, 2007) and of the responsibilities of the various duty-holders under that legislation.

It was necessary to discover the relationship between the client, the architect/designer, the magnet supplier, the RF cage supplier and the pre-installation or principal contractor so as to determine if there was sufficient acceptance of health and safety responsibilities of each of the parties, as well
as to establish the hierarchy of health and safety management from site start-up until completion and handover of the MRI suite to the client. Safety management hierarchy is of particular interest to HSE safety inspectors, and legal notices can be issued if the hierarchy is not clearly documented. It was necessary to determine how, during the construction process, access to the immediate area of the magnet was controlled, and by whom. It was also necessary to establish if operatives working on the construction of the MRI suite were made aware of any residual risks notified by designers and of the control measures put in place on site by the principal contractor in order to manage those risks. It was necessary to enquire if information on these hazards and contained in magnet suppliers’ site planning guides was being made available to operatives in the form of site specific risk assessments and method statements, and how this was being managed.

The author also wanted to find the opinions and perceptions of the people and companies with hands-on experience of what was actually happening on site, rather than what was supposed to be happening. Magnet vendor project managers, pre-installation company contracts managers and RF cage owner/managers were interviewed, being the persons who had actually experienced conditions on site whilst an MRI suite was being constructed. Architects involved with current MRI projects were also interviewed, as were two PFI contractor design managers.

Informal discussions took place with construction site managers, magnet vendors’ engineers, Faraday cage manufacturers and installers, magnetic shielding installers and suppliers, hospital radiology managers, designers and construction operatives. This was so as to bring existing competence
(knowledge, training and experience) up-to-date so as to be able to validate the problems perceived in order to formulate viable research questionnaires.

Internet searches were made to obtain contact details of magnet suppliers, Faraday cage manufacturers and of architects known to have worked on MRI projects and were used to supplement the author’s existing knowledge.

So as to form a valid conclusion and submit recommendations, questionnaires were sent to client’s architects, pre-installation contractors, RF cage and magnet suppliers. Once this information was obtained it was collated into an Excel spread sheet in order to be able to summarise the data collected. The questionnaire replies are included in Appendix D.1 and the spread sheet showing the replies in Appendix D.2.

Additional material supplied by architects from a parallel questionnaire was included in the research. The study was limited because only one magnet vendor was forthcoming in allowing his project managers to answer the questionnaire, but the results obtained highlight the need for clear lines of responsibility in any construction project to be clearly determined and understood.

4.4.1 THE QUESTIONNAIRES

A questionnaire for each of the parties involved in the study was compiled. An example can be found in Appendix D.1. That is to say: architect, RF cage supplier, magnet vendor and pre-installation contractor. Each questionnaire had the same questions, but was orientated from each CDM duty holder position in the supply chain so as to identify differences in each duty holders’ perception of what should be happening on site. Some persons to whom the questionnaire
was sent felt that some of the information was commercially sensitive and refused to reply.

4.4.2 TO WHO WERE THE QUESTIONNAIRES SENT?

**Pre-installation Contractors**

In cases where the contract is turnkey to the magnet vendor, the pre-installation contractor will normally carry out the role of principal contractor. Where the contract is a PFI, the principal contractor will normally sub-contract the works, but not always to specialist sub-contractors.

In the following, read principal contractor (under CDM 2007) for pre-installation contractor (PIC) and vice versa, but not as him being the Site Waste Management Plans Regulations 2008 (SWMP 2008) principal contractor, although there may be cases where this could be the same duty holder position under both sets of Regulations, but with each having different responsibilities. (Price *et al.*, 2009). The author's previous experience in this discipline gave knowledge of the major pre-installation contractors within Great Britain. As a result of this pre-existing knowledge eight pre-installation contractors were identified and questionnaires were sent to all. Of the eight sent questionnaires five replied, giving a return rate of 62.5%.

**RF Cage Suppliers**

Questionnaires were sent to five cage suppliers, with two not responding, thus giving a return rate of 60%.

**Architects**

Questionnaires were sent to three architects and two PFI contractor design managers whose specialty was hospital design. Replies were received from all five, giving a return rate of 100%.
Magnet Vendor

Following telephone conversations to ascertain agreement to participating in the study by completing the questionnaires and by having a one hour meeting with their health and safety manager, the questionnaires were sent by e-mail to the national project manager of a magnet vendor, where four of his eight project managers supplied separate responses to the questionnaire, a return rate of 50%.

4.5 QUESTIONNAIRE RESULTS AND INTERPRETATION

Questionnaire results

(a) Graphs showing the number of questionnaires sent out and replies received

![Number of questionnaires sent out](image)

Figure 4.1: The number of questionnaires sent out
Figure 4.2: The number of questionnaires returned

(b) Graphs showing the geographical source of the returned data

Figure 4.3: The number of Scottish questionnaires returned
Figure 4.4: The number of English questionnaires returned

Figure 4.5: The number of Welsh questionnaires returned
Results

The survey questionnaires were scored on the Likert (1932) scale from 1, strongly disagrees, through to 5, strongly agree. The results are shown in Appendix D.2 and are summarised here:
What became apparent is that the responses to the questionnaires by the pre-installation contractors and the magnet vendors were sufficiently conflicting to justify concentration of the research on these groups, but with peripheral input of architects

**Who has input into the RF cage design?**

The study commenced with questions relating to design input by the parties and was a prelude to determining the relationship between the lead designer (architect) and sub-designers, who in a simple case are the cage supplier and the magnet vendor, but can also include the PIC (pre-installation contractor).

For Questions I – III, the magnet vendors and PIC replies broadly corresponded with one another inasmuch that in a turn-key project, the RF cage supplier submitted the quotation to the pre-installation contractor for incorporation into the quotation to the magnet supplier, who in turn would quote the client. The PIC felt largely responsible for specifying the RF cage supplier, which was confirmed by the RF cage suppliers’ replies. This was the case for all countries consulted. However, from magnet vendors’ replies it was not so definitive.

In PFI contracts, it was the PIC who to some extent believed the PIC specified which RF cage supplier to use. However, it was not so clear with the magnet vendors and cage suppliers. This could be because PIC’s can be directly consulted by PFI bidders or directly by the client.

Question IV elicited that the magnet vendor was the party who believed the most that involvement in the design process was early enough to be able to make a contribution to the siting of the MRI suite. The PIC felt otherwise. Architects broadly thought to be involved early enough, with the respondent in Wales giving the highest score. In Question V the RF cage supplier in all
countries consulted felt that magnet vendors fitted magnets into cages supplied by others even when they had not been involved in the cage procurement process. As the cage supplier would be the party designing any necessary magnetic shielding, it casts doubt on who is actually specifying the design of the RF cage and any magnetic shielding, as architects would not normally have such specific knowledge.

Question VI confirmed that the magnet vendor was not faced with a *fait accompli* regarding the overall suitability of siting of the magnet, a fact also borne out to some extent by architects’ replies, indicating that in cases where the magnet vendor was not specified at the early design stage, architects had nevertheless taken magnet vendors general siting requirements into consideration. However, Scottish architects did not hold this view. From discussions with architects, this was found to be the client instructing the architect to ‘take the worst case’ when considering the effects of the static magnetic field when deciding an MRI Suite location.

This subject is further developed in later questions.

**Pressure to reduce magnetic shielding**

Continuing the theme of design, Question VII attempted to discover who was involved in discussions regarding magnetic shielding requirements of the cage design. The magnet vendor was the most positive, followed by architects and the cage supplier, with the exception of the Welsh cage supplier who held the opposite view. The PIC seemed not to be involved to the same extent. Question VIII attempted to discover if magnetic shielding was discussed with the parties before the magnet supplier had been chosen, with the cage supplier from the PIC from 'not at all' through to ‘a small extent’ and the magnet vendor
from ‘not at all’ through to ‘to some extent’, indicating that there was no clear process.

**Safety and Magnetic Shielding**

The purpose of Questions IX, X and XI was to determine the parties involved in any magnetic shielding requirements, so as to establish if they were able to influence the management of health and safety on site. Responses showed that the PIC, magnet and cage suppliers as well as architects were involved in magnetic shielding discussions if it affected the safety of site operatives, but where it did not affect the operation of the magnet the PIC was consulted less, which appears logical. Where magnetic shielding (or the lack of it) was discussed then all parties were consulted, including the PIC ‘to some extent’, except that where the operation of the magnet was not affected, the PIC was not consulted. This leads to the impression that the design emphasis is solely on the effect of the environment on the magnet rather than to include the effect of the magnet on the environment, which by implication includes the health and safety of the construction operatives (and eventually users of the completed magnet installation).

Question XII was to determine if the parties felt they were part of the design process. The two Scottish architects held opposing views. The magnet vendor was the most positive party, with the PIC ‘to some extent’ and the Welsh cage supplier again gave the lowest score. Question XIII went further in determining that even when supply of the cage was not in the magnet vendor’s package, the magnet vendor still felt to be part of the design process, whereas the PIC did consider himself to be, but not to the same extent. Clearly there is no proof of design co-ordination.
The principal contractor under the CDM Regulations

Questions XIV and XV were intended to determine which of the players usually held the CDM duty holder position of principal contractor and were therefore responsible for the management of health and safety on site. As expected, the PIC showed greater acceptance of the role of principal contractor. In two cases, the magnet vendor had replied ‘to a small extent’ or ‘to some extent’ and accepted this CDM duty holder position. Strangely, the national project manager for the magnet vendor had stated that the position was ‘not at all’ accepted. The magnet vendor replies showed them to be unanimous in that they produced risk assessments and method statements before energisation of the magnet, as was broadly the case with the cage supplier. The score of the PIC was very low and may be because of reliance on the magnet vendor to manage the whole magnet energisation process and in isolation from the other site controls. It would make sense for the PIC to be appointed principal contractor during the first part of the process and until the construction works had finished. At this stage the magnet vendor could become the principal contractor and manage site health and safety. It would be unrealistic to expect any PIC who had become principal contractor at the commencement of the works to continue in this role once construction work had finished. If continuing as principal contractor, the management health and safety in this period up until final handover of the MRI suite to the client would become impossible, particularly as this could include instruction and training of hospital staff in the use of the product.
The Principal Contractor and Static Magnetic Field Safety Management

Questions XVI – XIX were set so as to determine if there was site specific information on the position of the 0.5 mT footprint and measures advised by the magnet vendor that should be used to control residual risks as a result of magnet energisation. The study was trying to establish if the site-specific physical position of the 0.5 mT footprint had been identified to the principal contractor. In particular, the study wanted to determine if the magnet vendor (as a designer) had made new plots of the 0.5 mT footprint to take into consideration (a) the effect of any magnetic shielding where symmetry of the static fields may have been distorted and the 0.5 mT footprint was being allowed to pass around any magnetic shielding to areas which had previously been deemed ‘safe’ and (b) if allowance for fringe field distortion by the ferrous content of the building structure had been allowed for in the magnet vendors’ site specific documentation.

The magnet vendor believed that site-specific information regarding the position of the 0.5 mT footprint was supplied to the PIC, but the PIC did not agree. On the issue of a site specific site planning guide, the magnet vendor scored 50% ‘to a considerable extent’ and 50% ‘to a large extent’ whereas the PIC scored 40% ‘to a large extent or ‘to a considerable extent’ and 60% ‘not at all’, thus contradicting the magnet vendor. Results from the RF cage supplier were in line with the responses of the PIC. But in Question XVIII it was the PIC who did not attach so much importance to annotated site specific drawings and in Question XIX the magnet vendor scored highest, then the PIC, with the cage supplier scoring lowest in believing that site specific information was included so as to control the magnet’s residual risk to site operatives once the magnet had been
energised. One English architect did not agree. There was absence of signs of a clear process.

**Should the 0.5 mT footprint be kept within the RF cage?**

Question XX was to determine if the parties were aware of the published advice that the 0.5 mT footprint should be retained within the RF cage. Of the two Scottish architects, only one replied and he gave the lowest score.

It was the magnet vendor who scored highest. 60% of the PIC’s replied ‘from a considerable extent’ to ‘to a large extent’, with 66% of the RF cage suppliers replying ‘to a large extent’, again with the results indicating a general awareness, but no process.

**Who sets up a controlled area around the magnet?**

Question XXI asked who set up the controlled area around the magnet and in Question XXII who set it up for the areas contiguous to the RF cage.

In Question XXI the magnet vendor advocated setting up a controlled area around the magnet, with 40% of the PIC’s replying ‘to some extent’ and 40% ‘not at all’. In Question XXII this response was mirrored in that the magnet vendor was the party most likely to set up a controlled area where the 0.5 mT footprint was not retained within the cage. The PIC is supposed to be in control of the site, but 20% of the PIC’s replied ‘not at all’ or ‘to a small extent’ on the desirability of setting up a controlled area. The cage supplier is the CDM duty holder most likely to be involved with the design, but despite the required knowledge of the hazards of the static magnetic field the Welsh respondent gave the lowest score.
Who polices access to the controlled area?

Questions XXIV wanted to determine who was felt to be responsible for policing access to the controlled area and in Question XXIII to other areas to where the 0.5 mT footprint may extend. With both questions, responses from the magnet vendor scored the highest, with the PIC scoring the lowest. Again and under CDM, the PIC is supposed to be in control of the site, as well as being responsible and accountable for the good management of health and safety on the site. The PIC appeared (wrongly) to relinquish this task to the magnet vendor when engineers arrived on site to prepare the magnet for energisation – as subsequent questions elucidate. It was the Welsh architect and Scottish cage supplier who gave opposite views to the rest of the sample.

Risk Assessment of the areas where the 0.5 mT footprint may be a hazard

Question XXV asked if a risk assessment was carried out to determine the areas where the static magnetic field may be a hazard to operatives.

The cage suppliers from all countries questioned gave the lowest scores, but again the magnet vendor scored highest, with responses from the PIC’s varying from ‘to some extent’ as the highest down to ‘not at all’ as the lowest (20%). Without having site-specific knowledge of the actual position of the 0.5 mT footprint the theoretical position presented by the magnet vendor in the magnet’s site planning guide may be all the PIC has. Personal experience is that the magnet vendor accepts this without question, as there is no one prepared to pay to have a site-specific survey of the fringe field carried out.
Screening of operatives

Questions XXVI - XXVIII asked about screening to operatives generally, and XXIX –XXXI specifically for implants, with XXXII and XXXIII for screening of tools and any colour coding utilised.

The magnet vendor again scored the highest with Question XXVI – XXXVIII whereas it was not confirmed by the PIC. The magnet vendor may just be referring to the work within the RF cage. This is contradicted by the magnet vendor in Question XXIX where it was the PIC who gave a more positive response in feeling that operative and contractor screening for implants or metal objects in bodies should be carried out. Again in Question XXX it was the magnet vendor who scored the highest for the controls on tools and plant to the controlled area, with both PIC and magnet vendor scoring high in that these controls were just to the RF cage. Continuing this vein, the magnet vendor again scored highest in believing that screening for use of non-ferromagnetic tools and plant was desirable. Question XXXIII regarding colour coding of the tools and plant did not seem to be a priority for the magnet vendor, but for the PIC, 20% felt that it should be. This may be because of confusion about whose tools and plant is introduced into the MRI suite. The magnet vendor will be equipped with titanium or other non-ferromagnetic tools, but the PIC’s contractors and employees will have steel ones. The magnet vendor may be replying from the position of not being concerned with controls outside the RF cage because the machine will be ‘safe’ from the ‘projectile effect’ and also believe that there is sufficient knowledge amongst the ‘regular’ site operatives employed by the PIC of the dangers of the introduction of ferromagnetic tools into the RF cage as to be a barrier to this occurring.
Responsibility of highlighting any RF cage design failings that may cause workers to come into contact with the 0.5 mT footprint of the static magnetic field.

The purpose of Question XXXIV was to establish if the principal or pre-installation contractor understood that there was a responsibility to give feedback to the designers if felt that the operation was allowing operatives to come into contact with the 0.5 mT footprint. With the exception of low scores given by one of the Scottish architects and the Welsh cage supplier the replies were as expected in that all parties felt they had a responsibility, with the magnet vendor scoring highest. However, the actual site position of the 0.5 mT footprint needs to be identified in order for this to become effective.

Desirability of health monitoring of operatives’ exposure to the static magnetic field

Question XXXV was to establish if the parties believed that health monitoring of operatives’ exposure to the static magnetic field was desirable. Interestingly, 75% of the ‘experts’, the magnet vendor, replied ‘not at all’. The exception was the Scottish magnet vendor. Conversely, all the PIC’s thought health monitoring to be desirable, indicating a lack of co-ordination between the magnet vendor and the PIC in the management of health and safety on site.

Control by contractors of operatives’ exposure to the hazards of magnet installation

Question XXXVI enquired if contractors should do more to control operatives’ exposure to the hazards of magnet installation. With the exception of the Welsh architect, all responders felt that contractors should do more.
Contribution to control measures to manage the residual risks of the magnet installation

Question XXXVII was designed to determine if the duty holders felt that a fair opportunity was given to the magnet vendor by the contractor so that the residual risks of the magnet installation could be managed effectively. All except the cage supplier (generally) felt they were given the opportunity.

Pressure from the client to eliminate magnetic shielding and allow the 0.5 mT footprint to pass into areas not generally accessible

Question XXXVIII was to establish if the client ever put pressure on the parties to eliminate magnetic shielding where it passed to areas which were not within normal hospital circulation areas and where lack of shielding did not pose a threat to the quality of the image.

The magnet vendor and the PIC felt ‘not at all’ or ‘to a small extent’, but 66% of cage suppliers replied ‘to a considerable extent’. This may be because the magnet vendor would realistically be the CDM duty holder who would wish, for cost reasons, to avoid the use of magnetic shielding so as to ensure his winning the contract.

Permits to Work

Question XXXIX was an attempt to discover if the parties felt that a Permit to Work system during MRI suite construction would be beneficial to health and safety. 85% of the PIC’s and all magnet vendors felt it would. The exception was a Scottish PIC and a Welsh architect.

Who should administer any Permit to Work system?

Questions XL and XLI were to find out by whom the parties felt any Permit to Work system should be administered. In Question XL in asking if it should be
the magnet vendor, only the English magnet vendor (20%) felt that it should ‘to a large extent’ and one ‘to some extent’. Likewise (20%) of PIC’s thought ‘to a considerable extent’, with three (60%) ‘not at all’, whereas in Question XLI it was the PIC who felt it should be, with the magnet vendor disagreeing. This highlights some of the conflict that may be present between the magnet vendor and PIC regarding site health and safety responsibilities and accountability.

Confusion with RF and static magnetic fields.
Question XLII elucidated from both magnet vendor and PIC, albeit in varying degrees, that there was confusion between operatives of the effects of these electro-magnetic fields (EMF’s), with both respondents thinking considering adequate control within the RF cage. As our study shows, this is not always the case as far as the static magnetic field is concerned. The PIC responses as the CDM duty holder responsible for the management of health and safety on site varied between ‘to a small extent’ through to ‘to a large extent’.

The dominance of one CDM duty holder over the other
Questions XLIII and XLIV were to establish if health and safety management was undermined by the dominance of the magnet vendor, RF cage supplier or PIC. In Question XLIII, 40% of the PIC’s felt management was undermined, with 50% of the magnet vendors also agreeing. In Question XLIV it was the RF cage supplier who, in 33% of cases, thought management was undermined.

Is there a gap in health and safety information transfer between the magnet vendor and contractors?
In Question XLV all parties, albeit in varying degrees, felt that there was a gap in health and safety information transfer, excepting for Wales, with the PIC
feeling more strongly than the magnet vendor. Again, this highlights the problem of lack of health and safety communication on site.

**Do survey participants believe there could be dangers to health from exposure to static magnetic fields?**

Surprisingly in Question XLVI 80% of the PIC’s felt there was a danger from static magnetic fields, but only 50% of the magnet vendors agreed, with the other 50% replying ‘not at all’. Both architects from Scotland, the architect from Wales and a PIC from England gave the highest scores. This signals that there could be inadequate information coming from the magnet vendor that may be used to carry out a risk assessment used to develop a method statement to take account of the risks to construction operatives from the static magnetic field.

**Should improvements in health and safety with regard to exposure of operatives to the static magnetic field come from designers, the magnet vendor or the pre-installation contractor?**

In Question XLVII, 100% of the magnet vendors and 60% of the PIC’s agreed improvements should come from the magnet vendor, with 20% of the PIC’s replying ‘not at all’. This may signify that the minority of PIC’s do not recognise the magnet vendor as a designer, as in Question XLVIII it was 100% of the PIC’s who felt that information should come from the magnet vendors, thus contradicting themselves. The magnet vendor did in all cases believe, although to a lesser degree than the PIC’s, that the improvements should come from the magnet vendor. Conversely, in Question XLIX it was the magnet vendor who felt it should come from the PIC, with only 40% of the PIC’s agreeing and with 60% replying ‘not at all’. This is strange as the PIC should be in charge of health and safety management on site. Again confusing the issue, in Question L it
was the magnet vendor who thought improvements should come from the
designer, reinforcing the hypothesis in Question XII that the magnet vendor did,
at last, consider himself to be a designer.

4.6 CONCLUSIONS

The aim of this work was to identify if the various CDM duty holders understood
the potential safety issues of the exposure of construction workers to the static
magnetic field of the magnet. The research found that the management of
health and safety on site appears not to have any formal process, with
confusion between the magnet vendor and the PIC as to who was actually
managing health and safety on site once the magnet was energised. As a result
it could be established that the various CDM duty holders did not understand
the potential safety issues of the exposure of construction workers to the static
magnetic field of the magnet.

The objective was that the information obtained would help assist clients and
their duty holders appointed under CDM 2007 (HMG, 2007) in managing health
and safety during the construction phase of an MRI suite project. This has been
achieved inasmuch that the conclusions of this research could be used by CDM
duty holders to ensure that they carried out the statutory duties as required by
The CDM Regulations (HMG, 2007).

The survey questionnaire highlighted the fact that there was no agreement on:

- whether exposure to the 0.5 mT footprint was hazardous to health
- identification of the actual site specific position of the 0.5 mT footprint of
  the static magnetic field, whether it should be confined to the RF cage, or
  that the static magnetic field (SMF) is different from radiofrequency fields
  (RF).
- whether site specific planning guides containing site specific information on methods of controlling residual risks of the energised magnet are issued by the magnet vendor
- who should carry out operative screening and be responsible for its documentation, or even whether screening should be documented at all
- who should police access to the controlled area - or even if there should be a controlled area either inside or to areas outside the RF cage where the 0.5 mT footprint may be present

When reviewing the questionnaires it was clear that the pre-installation contractor, even when in the duty holder position of principal contractor, was not fully managing health and safety on site, on occasions giving dominance to the magnet vendor as being the party who were the experts and who ‘knew’ the hazards of magnet installation after the energisation stage. However it was noted that there was general agreement that the present scheme of health and safety management on site was inadequate and was in need of more robust procedures to control access to the 0.5 mT footprint and to the controlled area of the MRI suite generally.

Evidence gleaned from the questionnaire on operative screening for implants was worrying. There was no agreement that the 0.5 mT footprint should be retained within the RF cage. There appears to be such a contrast between operational MRI suite procedures and those at construction stage that it is almost as if the medical academics have totally neglected to consider the risks to construction staff, resulting in a dangerous gap in information transfer covering the period between magnet energisation on site and handover to the client for operational use.
Despite the fact that all the published NHS documentation (MDA, 2007) advises that the 0.5 mT footprint be retained either within the magnet room itself, or is allowed to encroach into the technical room; the majority of magnet vendors’ site planning guides appear not to mention this advice.

4.7 RECOMMENDATIONS

- The CDM Regulations make it clear that a CDM co-ordinator should be appointed by the client before he appoints designers, thus allowing the CDM co-ordinator to establish, on behalf of the client, the competency and resources of designers and to co-ordinate the design process where several designers are involved. This also avoids the problem of the late appointment of designers where the inability to effectively co-ordinate any residual risks is compromised. Unfortunately, this is not always the case. MRI Suites are often ‘designed’ using the ‘worst case’ magnet vendor generic site planning information, with the magnet vendor chosen at the final stage of the design (a late appointment under the CDM Regulations). In the case of an MRI suite, as a minimum the designers would be the RF cage supplier, the magnet vendor and the client’s architects, design and build or PFI contractor, but could also be the pre-installation contractor.

- The CDM Regulations (HMG, 2007) make it clear that the CDM co-ordinator’s main responsibility is to ensure that all those carrying out design work on a project collaborate and pay proper attention to the need to reduce risk wherever possible. This includes identifying hazards in the early stages of design work to enable elimination, thus leaving the remaining risks to be reduced through good design.
• Clients should not expect their architects to allocate space requirements for MRI suites based on generic site planning guides from magnet vendors which themselves often systematically portray the 0.5 mT footprint on their generic site drawings as extending to areas outside the RF cage. Where any decision for magnetic shielding is made, it should not be primarily based on the need to protect magnet image quality but, as a priority, also include the hazard of the energised magnet and risk to ALL personnel. Specifying realistically dimensioned magnet rooms which fully contain the 0.5 mT footprint of the static magnetic field would seem a more practical and safer solution from a health and safety management point of view both at construction and operational stages, particularly where installations are on the ground floor. The portrayal by one magnet vendors’ generic planning guides of the magnet room being situated so as to incorporate two external walls (see Figure 2.1) can only add to the possibility of the 0.5 mT footprint becoming a risk to members of the public and others not connected with the MRI Suite. In 2005 MagNet noted incidents where the stray field strength in public areas is above acceptable limits and give as examples one case where 0.5 mT was measured in a picnic area outside an MRI Unit and in another case where 1.6 mT was measured in a public corridor outside an MRI Unit. Understandably, there will be pressure on space when a new magnet installation is planned, but any attempt to install the MRI suite at any level other than the ground floor (where the 0.5 mT footprint of the static magnetic field can be absorbed into the ground) will cause trouble. Where the magnet is installed on floors other than the ground floor, because of the low position of the magnet iso-centre the magnet will
probably require magnetic shielding to be installed at least on areas below the magnet (a fact which could distort the static magnetic field and push it in another direction, thus transferring the hazard to another position inside or outside the suite and perhaps a resultant increased risk of exposure). An unsuspecting (and unscreened) maintenance plumber or electrician may be asked to work in a ceiling area below the magnet iso-centre and become exposed to the 0.5 mT footprint. Where it is unavoidable that CT’s or other equipment susceptible to the static field requires to be positioned adjacent to a magnet, then allowance should be made in the magnet room size and format to take account of any distortion of the static magnetic field by any required magnetic shielding to restrain the 0.1 mT footprint, so as to ensure the continued retention of the potentially distorted 0.5 mT footprint within the RF cage. It is important to have cognisance of the tendency for the increased magnetic flux density at this position to attempt to ‘creep’ around any magnetic shielding if it is not of an adequate dimension.

- The pre-installation contractor, in the role of principal contractor under the CDM Regulations, should take full control of management of health and safety on site and be aware of the control measures deemed necessary by the magnet vendor and cage supplier to manage the residual risk of the energised magnet and specifically, the actual position of the 0.5 mT footprint. So as to be able to do this, the actual position of the 0.5 mT footprint of the static magnetic field needs to be identified by the perpetrator designer, the magnet vendor. It is essential that information about residual risks be conveyed to the principal contractor to allow the management of these risks and ‘it is not acceptable for a
designer just to carry out his design and then expect the contractor to control all the risks resulting from the design, once on site. (Construction Industry Council 2005).

- Once the principal contractor has been appointed, works have commenced on site and the magnet has been energised, an independent survey of the actual site position of the 0.5 mT footprint should be carried out and delineated on site in a manner which can be easily recognised, with a controlled area being established for the entire MRI suite and not just the magnet room, by the use of barriers and danger signs. This includes areas above and below the magnet, which should also be included in any controlled area. The principal contractor should update his construction phase plan with the current information on the position of the 0.5 mT footprint, with the CDM co-ordinator ensuring this information is eventually transferred to the health and safety file with details of the control measures to be put into place to prevent visitors and employees, whether present or future, becoming exposed to the 0.5 mT footprint of the static magnetic field. As an additional security measure, screening should be a condition of access to the entire MRI suite, with those operatives and visitors being fitted with pacemakers or other metal implants not being permitted to access any area of the MRI suite. A permit to work system should be introduced. The Medical Devices Agency ‘Guidelines for Magnetic Resonance Equipment in Clinical Use’ correctly state in Section 3.1.2 that ‘The employing authority is ultimately responsible for the implementation and maintenance of procedures to ensure the health and safety of all persons’. This duty exists under Section 3 of the Health and Safety at Work Act 1974. However, the
magnet vendor, in complying with his CDM duties as designer, has the responsibility of informing the client of the residual risks to his installation. It is therefore for the magnet vendor to ensure a site-specific survey of the static magnetic field pertaining to the installation is supplied to the client. The client will then transmit this information to the principal contractor via the CDM co-ordinator, who will then update his construction phase plan. As the principal contractor is, under CDM, responsible for the management of health and safety on site, validated surveys of the site-specific position of the static magnetic field should be received in documented form. So as to satisfy the requirements of the Health and Safety at Work Act 1974, the PIC should not allow site operatives access to the magnet once energised unless this information, which should include a full DRA (Design Risk Assessment) has been received from the magnet vendor.

- Operatives working within the suite should receive training in the hazards of magnet installation and be supplied with personal dosimeters, presence within the 0.5 mT footprint monitored and documented, with these records retained for future health surveillance to be carried out so as to help establish, the so far undocumented and valuable information on the possible effects of static magnetic fields on human health. The current ICNIRP reference levels should be used at the initial stage of assessing compliance with basic restrictions on exposure, but further investigations on compliance that are indicated by exceeding these reference levels should use the most up-to-date dosimetry methods. (NRPB 2004)
• Regarding the magnet room itself, Colletti PM (2004) discusses the risks of ferromagnetic gas cylinders becoming projectiles in an MR environment and that ‘appropriate policies and discipline are essential to avoid such deadly and expensive gas cylinder accidents’. A similar situation could equally apply to the introduction of construction workers’ tools, plant and equipment into the RF cage. Although magnet vendors insist on magnet rooms being completed by the pre-installation contractor before energisation of the magnet, this cannot be guaranteed in every case. This is due to various reasons such as the need to snag finishes, the commissioning of medical gases, ceiling repairs following replenishment of cryogenic gases to the magnet, late client requirements for coil and other cupboards, et cetera.

• Any attempt at zoning any controlled area is not advised as this could only be effective within an operational MRI suite where primary access controls are in place at the suite entrance. In the construction phase the entire MRI suite should be designated a controlled area by the principal contractor.

• Once the magnet has been energised and so as to protect the magnet bore from damage from ferromagnetic tools, a strict policy of controlling the introduction of tools, plant and equipment into the RF cage should be adopted. A system of clearly marking tools e.g. with insulating tape – RED: not MRI safe, BLUE: MRI safe should be adopted by the principal contractor as part of a permit to work system.

• Where only ferromagnetic tools are available, such as saws, knives, screwdrivers these should be kept to a minimum ferrous content, with use within the RF cage being restricted. Where operatives are working
within the confines of the RF cage, the bore of the magnet should be protected. If the machine were damaged, this could lead to workplace stress for the operative and/or site manager, as well as for the pre-installation company stakeholders because of the potential affect of such an occurrence on the reputation of the business in what is an extremely small market.

- The CDM Regulations (HMG, 2007) do not require clients to monitor the performance of appointees. However, clients have a duty under Section 2 of the Health and Safety at Work Act if the work of contractors could put their own employees at risk. Section 3 imposes a statutory duty on employers to make a suitable and sufficient assessment of the risks to the health and safety of employees to which they are exposed whilst at work; and the risks to the health and safety of persons not in an employment arising out of or in connection with his undertaking. The client has a duty to ensure that the effective management of health and safety on site is being carried out.

- Any decision by designers for allowing the 0.5 mT footprint to pass outside the confines of the magnet room should use the principles of ERIC (Eliminate, Reduce, Inform and Control) as well as ALARP (as low as reasonably practicable) and would have to meet the Health and Safety Executive’s criteria laid out in its policy document ‘Policy and Guidance on reducing risks as low as reasonably practicable in design’ (HSE 2006) which includes five key principles, one of which is that ‘It is for duty holders under the CDM Regulations (HMG, 2007) to ensure that the chosen design or design concept reduces risk as low as reasonably practicable’. Any attempt to use cost/benefit analysis to justify the 0.5 mT
footprint not being retained within the RF cage, but more particularly being allowed to pass to external areas of the MRI suite, would be difficult to justify, particularly as it goes against the advice of the MDA (MDA, 2007) and the NHS Health Building Note detail shown in Figure 4. Einstein et al., (1985) state that the general rule for NMR installations can be summed up one simple phrase: ‘protect the magnet from the environment and the environment from the magnet’.

- Where there are sub-contractors to magnet vendors, the difficulty of pre-installation contractors in insisting on being supplied with site-specific plots of the 0.5 mT footprint of the energised magnet from the client is recognised. A CDM co-ordinator experienced in MRI installations and completely independent of the parties can alleviate this problem specific to the PIC by co-ordinating the design – even those designs produced by ‘late designers’ - as can be the case of the magnet vendor for example, but

- Any appointment by the client of a CDM co-ordinator carrying out another, but separate function on behalf of the magnet vendor such as quantity surveyor, cost consultant, designer for example, should be discouraged so as to avoid a conflict of interest when decisions are made on any siting or shielding requirements for the magnet. The client should recognise this fact when negotiating contracts.
CHAPTER 5 CASE 2

5.0 THE AVAILABILITY AND ACCURACY OF AS-BUILT DRAWINGS

5.1 CASE SUMMARY

The aim of this research was to quantify the number and locations of MRI magnets and to identify those fitted with passive magnetic shielding. This was achieved by sending out two questionnaires to NHS Trusts. The first questionnaire was sent out so as to establish which hospitals had MRI suites installed. Once these were known a second questionnaire was sent out so as to assess how many of the MRI suites had passive magnetic shielding fitted to them, and to obtain drawings for those suites which showed the as-built position of the 0.5 mT footprint of the static magnetic field of the magnet. Examples of these questionnaires are included in Appendix D.1.

5.2 CASE INTRODUCTION

Paragraph 263 of The Construction (Design and Management) Regulations 2007 (HMG, 2007) require that as-built drawings should be provided in the health and safety file which is compiled by the client’s CDM co-ordinator and delivered to the client at the end of a project. In some circumstances such as when a project comes into operational use, but construction work is still continuing, this could be as early as practical completion. The accuracy of these as-built drawings is important because they should contain information that would be relevant to any designer or contractor carrying out future work at that location and to any user of the facility. The as-built position of the 0.5 mT footprint of the static magnetic field of any given installed magnet has health and safety implications to anyone working in or around an MRI suite, or to any
visitors. This information would, along with any installed passive magnetic shielding, be expected to be shown on any as-built drawing.

5.3 **Research Aims and Objectives**

The research aim was to quantify the number and locations of MRI magnets and to identify those fitted with passive magnetic shielding.

The research objective was to obtain as-built drawings showing the as-built position of the 0.5 mT footprint of the static magnetic field of the magnet.

5.4 **Research Methodology**

In order to quantify the incidence of passive magnetic shielding to the installed base of MRI suites, initial requests for information by use of a questionnaire were made to NHS Trusts under the Freedom of Information Act 2000 (HMG, 2000a) so as to determine which of the hospitals under their control had Magnetic Resonance Imaging (MRI) suites installed. Northern Ireland was excluded from this research because the re-organisation of the Northern Ireland Health Board at the time of the survey made it difficult to guarantee that all MRI installations could be identified.

Once the location of these MRI suites was obtained, then by using a second questionnaire, further enquiries were made of the NHS Trusts to determine which MRI suites had passive magnetic shielding incorporated into the magnetic resonance imaging suite design so as to manage the static magnetic field of the magnet. As previously described, the reason for this line of enquiry was because the introduction of passive magnetic shielding can affect the symmetry, and therefore the 0.5 mT footprint of the static magnetic field, possibly forcing it to extend to areas outside the RF cage or to areas where the (unscreened) general public has access and where it could become a hazard (the ‘balloon in a box’ effect (Pavliceck et al., 1984) described above.)
MRI suites fitted with passive magnetic shielding being identified, information from the health and safety file regarding the site-specific designed and the actual post-installation position of the static magnetic field of the magnet within and around the examination room, together with copies of as-built drawings, was requested.

5.5 RESULTS AND INTERPRETATION

5.5.1 QUESTIONNAIRE 1

How many clinical MRI suites are there and what is their location?
The Health Protection Agency (HPA) were consulted and found to hold a live list of hospitals having MRI suites installed both for clinical and research use and covering the entire United Kingdom. As mentioned above, because of the reorganisation of the Northern Ireland Health Board at the time of the survey, it made it difficult to guarantee that all MRI installations could be identified when validating the information supplied by the Health Protection Agency with the various NHS Trusts. Information was requested of the Trusts under the Freedom of Information Act 2000 (HMG 2000a), and each Trust has a designated Freedom of Information Officer who is responsible for ensuring that, amongst other things, Freedom of Information requests made which related to hospitals under the Trust’s control were dealt with.

An initial questionnaire was sent to NHS Trusts that were situated in England, Scotland and Wales to establish which of the hospitals under their management had clinical MRI magnets installed. The questionnaire can be found in Appendix D.
The growth rate of clinical MRI magnet installations

A survey of MRI installations concluded that, as shown in Figure 5.1 below, the rate of MRI suite installation in 2006 in the clinical sector alone was 44 per annum. However, there was a large reduction in magnet installations between 2006 and 2010. Because of a lack of funding the long-term trend for continued growth in installations may now be ended.

Figure 5.1: The number of installations by year – all magnets

The growth rate in the use of passive magnetic shielding installation

The initial questionnaire also enquired if any of the installations had passive magnetic shielding installed to manage the static magnetic field of the magnet. The survey was carried out in 2007 and from a total of 295 installed magnet installations 82 were identified by the Trusts as having passive magnetic shielding fitted, giving an average of >27% over what was then 15 years of installation history.
Within 15 of these installations, passive magnetic shielding had been installed to the suite. That is to say that 34% of all clinical MRI installations had passive magnetic shielding installed.

**The installed age of all clinical magnets**

The oldest currently installed magnet found in the survey dated from 1992. The age of existing of magnet installations since that date is shown below in Figure 5-3 below.
Figure 5.3: The age of currently installed magnets

From the graph below in Figure 5-4 it can be seen that growth in the inclusion of passive magnet shielding to clinical MRI suites started to increase from 1996 (Year 15 in the graph). For information, this was one year after the introduction of CDM 1994 (HMG 1994).

Figure 5.4: The Installation age in years – by magnet vendor
Market share, by vendor, of currently installed magnets

From the data collected, the market share of the magnet vendors as it relates to installations with and without magnetic shielding was collated.

All MRI installations, 1992-2010

Figure 5.5 below shows the annual rate of the installation of clinical MRI installations by magnet vendor for all installations, along with their year of installation.

![Market share by all Magnet Vendors](image)

Figure 5.5: Market share by all market vendors – 1992 - 2010

Passive magnetically shielded MRI installations 1992-2010

Figure 5.6 below shows the annual rate of the installation of clinical MRI installations by magnet vendor where passive magnetic shielding was installed, including their year of installation.
5.5.2 Questionnaire II

Was the 0.5mT line of the static field retained in the magnet room?

NHS Trust responses to the second questionnaire were consulted. It was established that of the 54 locations where magnetic shielding was claimed to be installed, evidence that the passive magnetic shielding had been effective in retaining the 0.5mT static magnetic field of the magnet within the MR suite examination room had been given in only two cases, and even this information was dubious.

Of the 54 installations identified by the NHS Trusts as having passive magnetic shielding installed to the magnet, two were found to be retro fitted installations. One was in 2003 and the other in 2006.

Of these two cases neither gave a plot of the 0.5mT footprint of the static magnetic field as it related to the y axis and, although asked for in the questionnaire, information was not given on the use of the building above and/or below the magnet. Therefore, from the information supplied from the
health and safety files, it was not possible to determine if the passive magnetic shielding installed to any of the 54 installations had been effective in retaining they axis of the static magnetic field.

**Were readings of the 0.5mT footprint taken OUTSIDE the magnet room?**

Again some information was supplied, inasmuch that 9 of the 54 installations showed random areas of increased magnetic flux density outside the room, but not on the actual position of the 0.5mT footprint. In two installations, random magnetic flux density readings of 1.2 mT and 0.62 mT were shown but there was no indication if these readings were recorded from a public or from a controlled area. One hospital, where the Freedom of Information Officer directed the initial request to an MRI physicist, showed that random magnetic flux density readings taken outside the magnet room were within anticipated limits, except for those taken inside the adjacent equipment room where readings of 0.75 and 0.53 were recorded. These can be seen in the layout shown in Figure 5.7 below.

![Plan of Cardiac MRI Unit](image)

*Figure 5.7: Random magnetic flux densities around an operational magnet Image courtesy of Southampton NHS Trust*
As a result of receiving this layout, the hospital was asked further questions, two of which were based on the photograph taken during the construction phase in Figures 5.8, 5.9 and the plan of the MRI suite in Figure 5.10 below. This is because the generic 0.5 mT footprint was shown on the drawing, but we know that magnetic shielding should have changed its format.

Figure 5.8: Magnetic shielding below the magnet and with a pipe passing through

Figure 5.9: The column housing the magnet shown from a different angle
Figure 5.10: The magnetic shielding panels fitted below the magnet room
*Image courtesy of Southampton NHS Trust*

As there would be a strong anticipation of changes being made to the 0.5 mT footprint both by the ferromagnetic pipe and its proximity to the edge of the magnetic shielding, further enquiries were made of the hospital concerned and this took the form of two further questions as follows;

**Q1** There is what appears to be a cast iron dry riser adjacent to a column at the edge of the 0.5mT footprint on Level E. Nevertheless;

- The symmetry of the 0.5 mT footprint appears not to have been affected by this feature and it looks exactly the same as a generic 0.5 mT footprint.
- Can we assume that this is the same dry riser which passes through Level D at the periphery of the magnetic shielding installed to the underside of the floor slab to Level E.

**A1.** The column you refer to houses a waste outlet. The exact extent of the magnetic shielding is not shown on the plan but the assumption you make would seem reasonable.

**Q2** If this is the case then I wonder if you can confirm that the 0.5 mT footprint is in the position as you have previously stated?
A2 The information shown on the plan previously supplied displays the measurements taken at the time at those specific points indicated on the plan on level E. The position of the 0.5 mT footprint is an approximation based on those measurements and not plotted itself by measurement.

The answers to the questions above confirmed that the ‘true’ as-built position of the 0.5 mT footprint was not formally identified. This information therefore would not be able to be used in any viable risk management process.

**Partial post-energisation plots of the 0.5 mT footprint?**

This information was supplied within the health and safety file in only one case out of the 54 files received.

**Were there full post-energisation plots of the 0.5 mT footprint?**

Four Trusts had supplied lead architects’ as-built drawings of the plots in the x and z axis but these, despite the known and proven effects on the symmetry of the static magnetic field caused by the introduction of magnetic shielding to the magnet room, corresponded exactly to the magnet vendors’ generic 0.5 mT static magnetic field footprints and were therefore not able to be regarded as credible. No information was given on the position of they axis and field-verified static magnetic field plots were not recorded.

**The designed position 0.5 mT footprint at the end of the project**

This information as to whether the 0.5 mT footprint was in its designed position at the end of the construction phase was not available from the health and safety files. In 8 cases out of the 54 where health and safety files were supplied, although the plots were site specific, they were proposed and not as-built drawings. The 0.5 mT footprint was shown passing to the outside of the RF cage with the qualification that either magnetic shielding should be fitted or a fence erected. In these eight cases, the NHS Trusts confirmed that
magnetic shielding had been fitted to the structure, which in turn would distort the position of the 0.5 mT footprint.

**The documentation of Designers’ residual risk control measures**

From the 54 health and safety files received, there were no cases which mentioned the control measures that the designer had envisaged should be adopted by the constructor, user, maintainer or decommission / demolition company to manage the residual risks of the design as far as it related to the static magnetic field of the magnet.

**Analysis and discussion of findings**

From the 54 health and safety files received out of a possible total of 82 installations, there were only two main contractor as-built drawings supplied and these did not show nor alert any future user to the position of the 0.5mT footprint of the static magnetic field, nor even to the existence of the static magnetic field itself.

Although some of the information contained within magnet vendors’ site specific proposal drawings was supplied in lieu of as-built drawings for 10 cases of the 54 health and safety files received, the information was not sufficiently specific as to mention whether magnetic shielding had been installed or not, but only to intimate that it may have to be, with no further details given.

Of the 13 magnetic shielding proposal drawings supplied, none were later confirmed in the health and safety files as being as-built. No evidence was given that the suites were constructed as per these drawings.

There were two as-built magnetic shielding drawings supplied with the health and safety files. Of these two drawings one was incorrect and the other showed the magnetic shielding, but there was no confirmation that magnetic shielding
had been installed, although the static magnetic field survey carried out by the author suggests that it probably had.

There were no Design Briefs or Conceptual Design Statements included in any of the health and safety files. Of the 54 drawings supplied, there were four vector plots showing the effect of any magnetic shielding to be introduced to the cage, but this was not confirmed by the existence of as-built drawings.

In only one case were there any design calculations supplied for the passive magnetic shielding and in 9 cases there was a specification supplied, but this was not confirmed by the as-built drawings.

Control measures which the designer had envisaged should be put into place by the principal contractor or the user, maintainer or decommissioning company to control the residual risks of the static magnetic field of the magnet were absent in every one of the 54 cases where the health and safety file had been supplied.

In 4 cases the NHS Trusts refused to divulge the information contained within their health and safety files. The balance of 24 magnetically shielded installations for which health and safety files have not yet been received exists because the NHS Trusts have either not been able to obtain the information requested (the health and safety files) or they have ceased to respond to the author’s Freedom of Information requests, despite being continually asked to do so.

In 4 cases involving 3 NHS Trusts who had previously indicated that magnetic shielding had been fitted to the installations for which they supplied health and safety files under the Freedom of Information Act, the author was referred back to the magnet vendor as being the body who held this information about their installations, because they themselves did not have it.
5.6 CONCLUSIONS

The availability of information from clients in the form of the statutory requirement for health and safety files is sparse, incomplete and is sometimes irrelevant as it relates to the residual risk and as-built position of the 0.5 mT footprint of the static magnetic field. Reliance on the generic 0.5 mT position of the static magnetic field in lieu of the magnet’s post-energisation position when developing risk management procedures could create a hazard. The requirements of the Construction (Design and Management) Regulations do not appear to be well understood.

5.7 RECOMMENDATIONS

It is recommended that The Construction (Design and Management) Regulations 2007 (HMG, 2007) are amended so that non-ionising radiation is included alongside ionising radiation in Appendix 3 – Arrangements for controlling significant site risks - of the Approved Code of Practice (ACoP) to The Construction (Design and Management) Regulations 2007 (HSE, 2007).

Additionally, an explanation should be given of the qualities of these two types of radiation and of the differences of the effect on the human body.

Adoption of these recommendations should bring the hazards of exposure to the 0.5 mT footprint of the static magnetic field of the magnet to the notice of clients, CDM co-ordinators, designers, contractors and sub-contractors and to take measures to manage exposure to it.
CHAPTER 6  CASE 3

6.0 TO ASSESS IF RETROFITTED PASSIVE MAGNET SHIELDING RETAINED THE 0.5 mT FOOTPRINT WITHIN THE CONTROLLED AREA OF THE MRI SUITE.

6.1 SUMMARY

During the research process carried out in Case study 2, one hospital replied to the author’s request for as-built drawings showing the 0.5 mT footprint of any installed magnets by stating that no MRI magnets at that hospital were fitted with passive magnetic shielding, but that one magnet would require retrofitted magnetic shielding in the near future. The reason given was because of concerns that the 0.5 mT footprint of a magnet’s static magnetic field was being allowed to pass into a public corridor at a ‘live’ hospital.

Measurements of the magnetic flux density both inside and outside the magnet room were taken prior to the retrofit magnetic shielding being installed. Once the shielding had been completed the measurements were repeated using the same grid as used for the first set of measurements.

An as-built drawing was supplied prior to the magnetic shielding retrofit being started. The installation did not correspond with this drawing. The static magnetic field of the magnet was shown to leak at joints in the shielding and through the screws used to fix the shielding panels to its supporting structure. High levels of magnetic flux were found at the edges of the shielding (‘the edge effect’) and at the joint of the retrofit shielding with the finished floor.

This Case Study shows that the introduction of retrofitted passive magnetic shielding was not effective in retaining the 0.5 mT footprint within the controlled area of the MRI suite and identifies information that might be useful in aiding
designers of magnetic shielding to identify hazards associated with this practice. This information could help them to consider how, along with the advice of the CDM co-ordinator, the initial design could be amended to eliminate or reduce these hazards.

6.2 CASE INTRODUCTION

The 0.5 mT footprint of a magnet’s static magnetic field was being allowed to pass from the magnet room into an adjacent public corridor. This situation necessitated a retrofit of passive magnetic shielding in order to protect visitors, patients and staff using the public corridor from the influence of the static magnetic field. If retrofit magnetic shielding was not fitted, then either the public corridor would have to be drastically reduced in width by constructing a permanent physical barrier to prevent exposure to the 0.5 mT footprint of the static magnetic field, or the MRI installation would have to be shut down. As a result of means of escape requirements, it would not be possible to reduce the width of the public corridor, nor because of operational requirements, to be able to close the MRI installation. The introduction of magnetic shielding was the only viable solution available to remedy the original design error.

On questioning the hospital concerned it was found that a contract had been placed to install retrofit passive magnetic shielding, the purpose of which was to retain the 0.5 mT footprint within the magnet room. An opportunity was given to witness the installation of a magnetic shielding retrofit and to take physical measurements of the static magnetic field from both within and outside the MRI examination room, pre and post-shielding installation. The static magnetic field was present around the magnet at all times.
From the perspective of the current research aims, this seemed an ideal site on which to measure the magnetic flux density at the rear of the MRI examination room both before introduction of magnetic shielding and again after its installation to determine if the designed magnetic flux density corresponded with the actual. Further survey measurements were also taken at salient heights within the room, both before and after the introduction of magnetic shielding so as to establish if there had been any increase in magnetic flux density within the room as a result of the introduction of magnetic shielding. Survey plots were taken at different heights above FFL inside the magnet room along the wall adjacent to the public corridor.

From a management of health and safety viewpoint, and given the requirements of current statutory and non-statutory legislation, having all the information relating to the as-built position and magnetic flux density plots of the static magnetic field footprint is important to the client, his CDM co-ordinator, the lead designer and any principal contractor and contractor. Having this information would enable them to ensure that any and all areas of increased magnetic flux density are included in both the Outer and Inner Controlled Area of any MRI suite; but these areas require to be known and their magnetic flux density plots identified and made available to everyone working on or visiting the location before this can take place.

6.3 RESEARCH AIMS AND OBJECTIVE

The aim of this research was to identify if there was any residual design risk in relation to the static magnetic field associated with the use of retrofitted magnetic shielding to MRI suites, and if the remedy of introducing retrofitted passive magnetic shielding was effective in retaining the 0.5 mT footprint within the controlled area of the MRI suite.
The research objective was to identify information that might be useful in aiding designers of magnetic shielding to identify hazards associated with this practice so as to help them consider how, along with the advice of the CDM co-ordinator, the initial design could be amended to eliminate or reduce them.

6.4 **Survey methodology**

Measurements of magnetic flux density were taken inside the magnet room both before and after installation of magnetic shielding and also taken to the corridor side of the rear wall to the magnet. This was so as to establish the efficiency of the newly introduced magnet shielding. Photographs and measurements of the magnetic shielding, including details of fixing methods used were taken.

Static magnetic field readings at the shielding fixing points were taken to establish if the introduction of the mechanical fixings which were able to pass through the magnetic shielding to a backing board used to support the shielding were as efficient as the shielding itself.

A previous attempt at setting out a 500mm grid had been made on a live construction site to establish the practicability of the method chosen. The method attempted was by using a measuring tape, a timber baton and blackboard chalk to mark out a 500mm grid on the examination room floor slab, see Figure 6.1 below. It was found that this method was far too time-consuming and would not be possible to replicate in the time available during a survey to a live MRI suite.
Figure 6.1: Marking out a 500mm grid for a test run for a survey

By using the internet a search of the market to find a semi-rigid yet light sheet material on which to set out a 500mm grid using a permanent marker pen prior to arrival at the survey site was carried out. The area to be surveyed was in a high risk area and within a live hospital environment. This fact necessitated that the sheet material chosen needed to be flame resistant.

The company Cordek Ltd produce a temporary floor covering (Correx) with a flame resistant surface that can be used in environments where heavy construction traffic over finished floor surfaces, such as vinyl, is likely.

This product was then utilised by laying it on the floor of the examination room and by using the 500mm grid intersections previously marked upon the sheeting as the reference points for the survey measurements.

Figure 6.2: The magnet room that was the subject of the research
Static magnetic flux density measurements were taken both within the magnet room and on the corridor side of the rear wall.

The generic drawing of the 0.5 mT static magnetic field footprint for the installed scanner showed a maximum reach of 3.900m for the z axis and 2.300m for the x axis from the magnet’s isocentre, necessitating a minimum room size of 7.800m x 4.600m. This minimum room size assumes that the magnet isocentre is situated at the centre-point of the magnet room and that proximate ferromagnetic objects will not have an effect on the symmetry of the static magnetic field.

In this case study, the z axis of the 0.5 mT footprint of the static magnetic field was being retained in the examination room at the entrance door end, but encroaching on a public corridor at the opposite end of the room. The magnet room was dimensioned at 6.976m in the z axis x 4.400m in the x axis. Not only had the magnet been installed off-centre to the room, but also the room dimensions were insufficient to retain the static magnetic field within the magnet room even if the magnet had been installed with its isocentre at the centre-point of the room. In the z axis the magnet isocentre was protruding into the public corridor by 2.030m and in the x axis into the adjacent Technical Room by 0.490m.
Figure 6.3: The 0.5 mT footprint of the magnet extended into the adjacent public corridor

The construction drawing was also the as-built drawing

To complicate the issue, the installers were in possession of an as-built drawing issued before the installation had been carried out. This drawing is shown in Figure 6.4 below.

Figure 6.4: The installation (as built) drawing of the magnetic shielding panels

*Image courtesy of Lindgren Rayproof Limited*
6.4.1 **CHOICE OF TESLAMETER REQUIRED FOR THE SURVEY**

The site to be surveyed was an operational MRI suite and there was a short time scale that would be allowed in which to carry out a field survey. It was decided to attempt to reduce the need for on-site calculations by obtaining an instrument which would be capable of the simultaneous measurement of the three axes of x, y and z set at a 90° angle, thus allowing a direct measurement of the magnetic flux density.

**Bartington Mag-01 and Mag-01H**

This instrument was found to be too cumbersome to set up and to move to the next grid survey position. Although the instrument’s tripod was extremely useful for orientation and fixing the survey height of the sensor, it was not possible for it to be extended to the required survey height.

The need for a connection to a battery pack and to a laptop was also deemed a requirement that would hamper the survey process. The equipment was not readily available for loan, purchase or hire. Therefore, this instrument was not chosen for the survey.

![Figure 6.5: The Bartington MAG-1 Teslameter being used on a dummy run](image)
**Holiday HI-3627**

This equipment was not readily available for hire or for purchase within the time scale in which it was required. The planned survey date for which the equipment was required had already been fixed by others. This date was when the magnet was being serviced by the magnet vendor’s engineers. Therefore, this instrument was not chosen on for this reason and not because of any anticipated technical failings.

**Metrolab Instruments ETM-1**

The decision was made to purchase a hand-held Metrolab Instruments ETM-1 because it met the criteria specified, was light, easy to understand the instruction manual, easy to set up and to load and change the battery. The sensor lead was of a convenient length so as to be able to be utilised for field measurements at the maximum height that was anticipated to be required (2.0m). The instrument was available for immediate delivery. The Serial Number of the instrument was AC-0054 and the Calibration Certificate valid from 23rd February 2007 until 23rd February 2009. This certificate can be found in Appendix E and was valid whilst the static magnetic field surveys were carried out.

A decision to use a Metrolab Instruments ETM-1 Teslameter was made based on the following criteria;

- Size and weight
- Simple and quick to take readings
- mT range
- Battery
- Zero-field chamber
• Sensor cable length
• Immediate availability from the supplier

Figure 6.6: The ETM-1 Teslameter which was used for the research

6.4.2 ETHICAL ISSUES

The scanner was undergoing a maintenance check and the hospital had closed the MRI examination room for patient examinations during this period. Therefore there were no consequences to patients as a result of the physical measurements of the static magnetic field being taken.

6.4.3 SURVEY METHOD

A generic static magnetic field footprint has a relatively smooth contour. The need to carry out a substantial number of readings and checks in order to obtain an accurate representation of the magnitude and (perceived but as yet
unproven) distortion of values following introduction of passive magnetic shielding to the corridor wall led to the decision to base the survey on a 500mm grid. The isocentre of the machine at its z-axis and the rear wall of the examination room being the reference points for the grid orientation.

**Survey heights from FFL**

Using the ETM-1 Teslameter, plots were measured at 500mm centres along the corridor wall, both before and after introduction of the retrofitted passive magnetic shielding. N.B All magnetic flux density units are in mT.

It was decided to take magnetic flux density readings at the following heights above FFL

- (FFL)
- 500mm
- 1000mm
- 1500mm
- 2000mm
- 2500mm

The reasons for these heights above FFL to be taken were based on the following;

- **0 (FFL)** as being imperative, in learning of the effect of the shielding at its edge at Finished Floor Level (FFL) within the magnet room.

- **500mm above FFL** because this was deemed to be the average height above FFL of the head of a person working from their knees. (A person
perhaps cleaning the floor manually, as ferromagnetic cleaning equipment would not be allowed into the magnet room).

- **1000mm above FFL** as being that of a small child’s head height.

- **1500mm above FFL** as being an arbitrary height that an adult’s head may be.

- **2000mm above FFL** as being where the heart of someone working at suspended ceiling height may be.

- **2500mm above FFL** as being where a worker’s head may be when working at high level. For example, to replenish cryogenic gases, prepare to enter the ceiling void, et cetera.

Surveys were carried out to measure the magnetic flux density on the corridor side and internally to the MRI examination room both before introduction of magnetic shielding and again after its installation so as to determine if the designed magnetic flux density footprint corresponded with the actual footprint. Photographs and measurements of the magnetic shielding, including details of fixing methods used, were taken. Static magnetic field readings at the fixing points were also taken to establish if the introduction of the mechanical fixings, which were able to pass through the magnetic shielding to a backing board used to support the shielding, were as efficient as the shielding itself.

6.5 **RESULTS AND INTERPRETATION**

The first two survey results show readings of magnetic flux density taken from both inside and outside the magnet room before passive magnetic shielding was installed to the wall between the magnet room and the public corridor.
The second two survey results show readings taken at the same positions, but after passive magnetic shielding was installed.

6.5.1 **WITHIN THE MRI EXAMINATION ROOM**

**Before magnetic shielding was installed**

Table 2 below shows the results of field measurements of magnetic flux density taken at each survey position on the MRI side against the plasterboard and studwork wall dividing the MRI examination room and the adjacent public corridor partition wall.

| Plot positions on the MRI room side of the public corridor wall 0 - 3.2 metres before shielding |
|---|---|---|---|---|---|---|---|---|---|
| 3.70 | 3.20 | 2.70 | 2.20 | 1.70 | 1.20 | 0.70 | 0.20 | 0.00 |
| **0.00** | 0.82 | 1.88 | 2.55 | 5.96 | 8.54 | 6.31 | 2.97 | 1.66 | 0.67 |
| **0.50** | 1.22 | 2.34 | 3.02 | 10.78 | 17.47 | 11.21 | 3.13 | 2.58 | 1.06 |
| **1.00** | 1.32 | 2.66 | 5.66 | 20.14 | 26.50 | 18.28 | 4.95 | 4.22 | 1.36 |
| **1.50** | 2.11 | 2.90 | 3.70 | 11.34 | 16.03 | 9.83 | 5.65 | 3.32 | 2.32 |
| **2.00** | 0.84 | 2.76 | 4.02 | 9.34 | 14.09 | 9.60 | 2.38 | 2.22 | 1.11 |
| **2.50** | 0.63 | 1.45 | 1.74 | 3.78 | 5.88 | 4.32 | 1.31 | 0.89 | 0.99 |

Table 6.2: Magnetic flux density within the magnet room BEFORE shielding

**After magnetic shielding was installed**

Table 3 below shows the results of field measurements of magnetic flux density taken on the MRI side at each survey position against the plasterboard and studwork wall dividing the MRI examination room and the adjacent public corridor partition wall.
Plot positions on the MRI room side of the public corridor wall 0 - 3.2 metres after shielding

<table>
<thead>
<tr>
<th>Height above FFL (metres)</th>
<th>3.70</th>
<th>3.20</th>
<th>2.70</th>
<th>2.20</th>
<th>1.70</th>
<th>1.20</th>
<th>0.70</th>
<th>0.20</th>
<th>0.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>1.79</td>
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<td>6.87</td>
<td>3.13</td>
<td>1.85</td>
<td>1.55</td>
</tr>
<tr>
<td>0.50</td>
<td>1.73</td>
<td>2.98</td>
<td>3.81</td>
<td>11.26</td>
<td>21.23</td>
<td>12.94</td>
<td>3.52</td>
<td>2.74</td>
<td>1.67</td>
</tr>
<tr>
<td>1.00</td>
<td>1.92</td>
<td>5.42</td>
<td>7.20</td>
<td>19.13</td>
<td>31.80</td>
<td>20.17</td>
<td>6.42</td>
<td>5.11</td>
<td>1.85</td>
</tr>
<tr>
<td>1.50</td>
<td>1.33</td>
<td>3.70</td>
<td>5.29</td>
<td>12.47</td>
<td>18.04</td>
<td>11.88</td>
<td>6.74</td>
<td>4.21</td>
<td>1.58</td>
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<td>1.57</td>
<td>3.47</td>
<td>4.34</td>
<td>10.03</td>
<td>15.64</td>
<td>9.97</td>
<td>2.98</td>
<td>2.45</td>
<td>1.32</td>
</tr>
<tr>
<td>2.50</td>
<td>1.23</td>
<td>1.59</td>
<td>1.97</td>
<td>4.23</td>
<td>6.35</td>
<td>4.16</td>
<td>1.57</td>
<td>1.19</td>
<td>1.06</td>
</tr>
</tbody>
</table>

Table 6.2: Magnetic flux density within the magnet room AFTER shielding

Comparison of the survey results

The introduction of magnetic shielding to the MRI examination room resulted in increased magnetic flux densities within the room. The contour graphs in Figures 6.7 and 6.8 below and demonstrate the effect of the shielding on increasing the ambient magnetic flux density against the MRI side of the MRI/corridor dividing wall. The threshold for exposure of unscreened personnel to the static magnetic field has been set as 0.5 mT. As the minimum magnetic flux density measured within the room was above this level, the following contour plots use 0.5 mT as the baseline figure.
6.5.2 THE PUBLIC CORRIDOR SIDE OF THE MRI/CORRIDOR PARTITION WALL

Before magnetic shielding was installed

The reason for the introduction of retrofit passive magnetic shielding was to restrict the 0.5 mT footprint to prevent it passing from the examination room to the adjacent public corridor where unscreened members of the public may be exposed to magnetic flux densities in excess of 0.5 mT. Table 4 below shows the results of field measurements of magnetic flux density taken at each measurement position against the plasterboard and studwork wall dividing the

**Figure 6.7:** The magnetic flux density inside the magnet room before shielding

**Figure 6.8:** The magnetic flux density inside the magnet room after shielding
MRI examination room and the adjacent public corridor on the public corridor side of the partition wall BEFORE magnetic shielding was installed.

Table 6.3: Magnetic flux density on the corridor side BEFORE shielding

<table>
<thead>
<tr>
<th>Height above FFL (metres)</th>
<th>0.00</th>
<th>0.15</th>
<th>0.19</th>
<th>0.21</th>
<th>0.26</th>
<th>0.34</th>
<th>0.34</th>
<th>0.28</th>
<th>0.26</th>
<th>0.27</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>0.19</td>
<td>0.21</td>
<td>0.36</td>
<td>0.35</td>
<td>0.55</td>
<td>0.53</td>
<td>0.43</td>
<td>0.43</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>0.22</td>
<td>0.25</td>
<td>0.37</td>
<td>0.42</td>
<td>0.72</td>
<td>0.63</td>
<td>0.61</td>
<td>0.50</td>
<td>0.58</td>
<td></td>
</tr>
<tr>
<td>1.50</td>
<td>0.16</td>
<td>0.18</td>
<td>0.25</td>
<td>0.52</td>
<td>0.69</td>
<td>0.64</td>
<td>0.63</td>
<td>0.45</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>2.00</td>
<td>0.14</td>
<td>0.16</td>
<td>0.21</td>
<td>0.74</td>
<td>0.72</td>
<td>0.63</td>
<td>0.59</td>
<td>0.30</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>2.50</td>
<td>0.13</td>
<td>0.16</td>
<td>0.17</td>
<td>0.19</td>
<td>0.26</td>
<td>0.20</td>
<td>0.12</td>
<td>0.11</td>
<td>0.22</td>
<td></td>
</tr>
</tbody>
</table>

These readings have been transposed into a contour graph shown below in Figure 6.9.

Figure 6.9: The magnetic flux density on the corridor side before shielding
After magnetic shielding was installed

Table 5 below shows the results of field measurements of magnetic flux density taken at each measurement position against the plasterboard and studwork wall dividing the MRI examination room and the adjacent public corridor, but on the public corridor side of the partition wall AFTER magnetic shielding was installed.

<table>
<thead>
<tr>
<th>Plot positions along the public corridor wall 0 - 3.2 metres</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.70 3.20 2.70 2.20 1.70 1.20 0.70 0.20 0.00</td>
</tr>
<tr>
<td>0.00</td>
</tr>
<tr>
<td>0.50</td>
</tr>
<tr>
<td>1.00</td>
</tr>
<tr>
<td>1.50</td>
</tr>
<tr>
<td>2.00</td>
</tr>
<tr>
<td>2.50</td>
</tr>
</tbody>
</table>

Table 6.4: Magnetic flux density within the magnet room AFTER shielding

It has been shown that the incorporation of magnetic shielding into the design of a magnet room will change the symmetry of the static magnetic field. The introduction of magnetic shielding to the MRI examination room resulted in reduced magnetic flux densities on the corridor side of the MRI/corridor partition wall.

The magnetic flux density readings within the MRI examination room have been transposed into the contour graph in Figure 6.10 below. The threshold for exposure of unscreened personnel to the static magnetic field has been set as 0.5 mT. As the apparent minimum magnetic flux density measured in the public corridor was below this level, the following contour plots use 0.00 mT as the baseline figure.
Figure 6.10: The magnetic flux density on the corridor side after shielding

6.6 ANALYSIS AND DISCUSSION OF FINDINGS

These contour charts demonstrate the effect of the introduced passive magnetic shielding on reducing the magnetic flux density against the public corridor side of the MRI/corridor dividing wall, but it can be seen that this was at the expense of the magnetic flux density increasing within the MRI examination room.

6.6.1 SPOT MAGNETIC FLUX DENSITY MEASUREMENTS TAKEN FOLLOWING RETROFIT

The method of construction used to fix the magnetic shielding (steel screws and spot welds), led to the decision that it would be appropriate to take readings of the corridor wall (public side) at these grouped positions (see Table 6.5 below) to determine if any local variations could be detected. These positions were logged prior to the wall finishings being applied. This was achieved by placing a clear Cordec™ sheet previously marked up with the 500mm grid used to carry out the main magnetic flux density survey on to the wall surface. By being able to view the screw and weld positions through the Cordec™ sheet and to mark
them up using a permanent black marker. The following results were achieved.

These results confirm the hypothesis (White, 1980) that in any practical, real life situation, leakage effects may be identified, amongst other criteria, as being due to screws inserted into the shielding.

Table 6 below shows a selection of readings taken at an offset of 20mm in the z axis of the grid of the magnetic shielding to the public corridor wall. This position was chosen because there was a grouping of fixing screws where some, but not all, included spot-welds at these positions over the surface of the magnetic shielding.

<table>
<thead>
<tr>
<th>Height above FFL (metres)</th>
<th>0.00</th>
<th>0.50</th>
<th>1.00</th>
<th>1.50</th>
<th>2.00</th>
<th>2.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.58</td>
<td>0.47</td>
<td>1.21</td>
<td>0.66</td>
<td>0.63</td>
<td>0.57</td>
</tr>
<tr>
<td>0.50</td>
<td>1.20</td>
<td>0.70</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
<td>0.50</td>
</tr>
<tr>
<td>1.00</td>
<td>1.20</td>
<td>1.40</td>
<td>0.50</td>
<td>0.60</td>
<td>0.60</td>
<td>0.70</td>
</tr>
<tr>
<td>1.50</td>
<td>1.31</td>
<td>0.60</td>
<td>0.50</td>
<td>0.50</td>
<td>0.40</td>
<td>0.60</td>
</tr>
<tr>
<td>2.00</td>
<td>1.10</td>
<td>0.60</td>
<td>0.50</td>
<td>0.50</td>
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<td>0.60</td>
</tr>
<tr>
<td>2.50</td>
<td>1.20</td>
<td>0.60</td>
<td>0.50</td>
<td>0.40</td>
<td>0.30</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Table 3.5: Magnetic flux density at screw clusters on the corridor side AFTER shielding

The contour graph in Figure 6.11 below is developed from Table 6.5 and shows results of these readings. The screws were used to fix the magnetic shielding to a 15mm ply backing panel on 50 x 100mm timber studs.

Comparison with the contour plot of readings taken at screw fixing positions shows major differences.
6.6.2 CONTROLLED ACCESS FOR MAINTENANCE TO AREAS BELOW THE MAGNET

Allowances for the alterations to the symmetry of the static magnetic field as a result of introduction of retrofit shielding to the magnet room could result in a repositioning of the existing 0.5 mT footprint. Where retrofit magnetic shielding is utilised as a design solution, then cognisance of the likely result of an enlarged footprint reaching deeper into the services void above the suspended ceiling to the floor below, or of the use of the room above, is essential. This is because there will be a tendency for increased magnetic flux density to occur at the base of the shielding (at Finished Floor Level) because of the edge effect and distortion of the static magnetic field by the ‘balloon in a box’ effect as described above. In these situations, particular recognition of increased risks to personnel working in any ceiling void below any retrofitted magnetic shielding needs to be made.
Without knowledge of the as-built position of the 0.5 mT footprint of the static magnetic field, unscreened construction and/or maintenance workers may have unrestricted access to those areas where the 0.5 mT footprint of the static magnetic field may be present. In Figure 6.12 below, a construction worker is working in the void between the top of the (aluminium) RF cage and the underside of the floor slab above. This area is within the influence of the y axis of the 0.5mT footprint. Situations similar to this could occur because in the absence of detailed information of the actual and as-built position of the 0.5 mT footprint these areas may be deemed (either by the principal contractor during the construction phase or by the employer following handover for operational use) to be outside any controlled area, including the area in the suspended ceiling above the magnet, because this area was presumed ‘safe’.

Figure 6.12: A construction worker exposed to the y axis of the static magnetic field

There are also other issues related to the RF cage. These include joints being designed into the air-conditioning ducting above the RF cage, thus necessitating access for maintenance, a lack of walkway and insufficient room to work safely and the unnecessary creation of a confined space. The imposed
load of the operative on the thin (usually 2mm thick) aluminium sheet or on the box sections forming the structure of the RF cage and the reliance on the 10mm threaded bolts in being able to support his load is also a potentially significant hazard.

6.6.3 CORRESPONDENCE WITH THE AS-BUILT DRAWING OF THE WORK CARRIED OUT

The installation (as-built) drawing showed the first panel as the ‘cut’. This is logical as the panels are one metre x one metre which would mean that the first horizontal joint would not correspond with the isocentre of the magnet and which, depending on which magnet was installed, would be at approximately one metre above FFL in line with the isocentre of the magnet and where the strongest magnetic field would be situated. However, from the photographs taken at installation stage, Figure 6.13 below shows that the first panel was in fact not cut, but was installed at the top of the shield, making the first joint (at one metre) fall in the magnet isocentre position and thus increasing the risk of leakage.

Figure 6.13: The cut panel is at the top and not as shown in the as built drawing
Additionally, there was need for a cut on the left-hand end of the shielding, thus again not corresponding to the as-built drawing and therefore introducing another joint into the shielding. This is shown in Figure 6.14 below.

![Figure 6.14: Square edge panels were used, necessitating the use of cover strips](image)

Use of multiple panels with square edges has necessitated the introduction of cover strips to hide the panel joints. This can be seen in Figures 6.15 and 6.16 below.

![Figure 6.15: a view of the square edge panels and their fixing screws](image)
6.6.4 **Edge Leakage of the Shielding (the Edge Effect)**

The sketch in Figure 6.0.17 below showing the 0.5 mT footprint leakage in the z axis at FFL was developed from Table 6.5. Field measurements of the static magnetic field taken on the z axis at the base of the applied retro-fitted magnetic shielding showed that the 0.5 mT footprint was not being retained by the shielding. A field strength of 1.31 mT was measured at this point and did not reduce to 0.5mT until it achieved 148mm distance from the shielding on the corridor and public side of the magnet room wall, or when measured against the shielding, not until a height of 25mm from FFL. See Figure 6.17 below. Although a request was made to study the position of the 0.5 mT footprint below the floor slab at this point so as to determine the total distortion of the static magnetic field, access to the ceiling void below the shielded wall was denied. Readings of the static magnetic field at this point were therefore, not possible.
Figure 6.17: A sketch showing the 0.5 mT footprint leakage in the z axis at FFL
6.7 CONCLUSIONS

This Case Study has shown that the introduction of passive magnetic shielding can cause an increase in the magnetic flux density at the edges (‘the edge effect’) and that the introduction of retrofitted passive magnetic shielding was not effective in retaining the 0.5 mT footprint within the controlled area of the MRI suite.

The research objective was to identify information that might be useful in aiding designers of magnetic shielding to identify hazards associated with this practice so as to help consider how, along with the advice of the CDM co-ordinator, the initial design could be amended to eliminate or reduce them. This Case Study has achieved that objective by highlighting design errors in a retrofit of magnetic shielding to an existing MRI suite.

In this installation the method of screw-fixing the shielding panels has created hot spots where the magnetic flux density can increase to a level higher than the surrounding shielding. This is aggravated by the use of square edge (instead of staggered edge) laminated magnetic shielding panels, which necessitates the use of additional fixing screws to fix cover strips to ‘hide’ the square edge joints. It was also evident that additional problems were created by the installation of the cover strips to the square edge joints. This necessitated the use of more screws and therefore more penetrations of the magnetic shielding. Variations in magnetic flux density at screw heads in Figure 6.16 appear to be for two reasons.

The main shielding panels were fixed to the ply backing board with 32mm steel screws and which passed through the shielding.
The cover strips were fixed with 15mm steel screws, but because the cover strips were not all tight fitting and the fixing screws did not pass through all six shielding panels (three panel thickness plus three thicknesses to the cover strips), then varying magnetic flux density would naturally be recorded and hence the variation in readings taken at the joint positions on the corridor side of the wall.

It is also apparent that as far as retrofitted magnetic shielding is concerned, the physical restraints preventing the shielding from passing below Finished Floor Level (FFL) could create an additional hazard to areas below the shielded wall, where this increased magnetic flux density may be in excess of 0.5mT and affect those persons working in ceiling voids.

The passive magnetic shielding panels used in this case study consisted of three 1mm layers of non-grain-orientated steel produced in a 1.00m x 1.00m format. The layers to each panel were not staggered so as to hide the panel joints, making the introduction of cover strips essential in order to eliminate leakage through them at these positions.

The designer had not made provision for the area to be retrofitted to match the magnetic shielding panel sizes, or for the panel sizes to match the dimensions of the area to be shielded. This introduced the requirement for a cut panel and therefore introduction of another joint requiring a cover strip.

The shielding panel joints were not staggered and the panels not fabricated to site dimensions. As a result, the entire shielding consisted of a criss-cross of penetrations, welds and cover strips.

A close up of the cover strips can be seen in Figure 6.0.16 above. Note that the joint to the horizontal cover strip shown in the photograph is not hiding the
straight joint in the shielding behind, thus allowing leakage of the static magnetic field at this point. It can also be seen that there are areas of spot welding on the cover strips. This is despite previous research work having been carried out showing that the residual magnetisation of welds in a hospital environment should not be overlooked (Hanada et al., 2001) as areas of strong residual magnetic flux density, which may cause electro-magnetic interference (EMI) with electronic medical equipment, has been found near the electric welds of steel frames and deck plates.

The surface of the retrofitted magnetic shielding was set back sufficiently from the finished face of the plasterboard partition so as to allow two layers of 19mm plasterboard plank to be fitted in front of the shielding, as shown in Figure 6.18 below.

![Figure 6.18: The shielding on the corridor side is covered with plasterboard](image)

As-built drawings of the retrofitted passive magnetic shielding as the subject were not available.
6.8 RECOMMENDATIONS

6.8.1 PASSIVE MAGNETIC SHielding SHOULD BE A SIX-SIDED BOX

Previous work has recognised (White, 1980) that passive magnetic shielding should ideally be formed as a six-sided box and have no penetrations, and that no real-life and useful shielded compartment is homogeneous. However, this information has hitherto been restricted to industrial applications – perhaps because of its perceived unique importance to the military. Examples of the application of this knowledge are; the shielding of equipment from broadband electromagnetic pulses (EMP’s) resulting from ground-level nuclear detonations, from the effects of broadcasting stations, or from nearby electric generators. Passive magnetic shielding materials supply and installation costs and the additional structural requirements in order for the parent structure to take the increased loading generated by the shielding, would not make a six-sided box a viable solution if incorporated into the design of an MRI suite.

Therefore, the use of retrofitted passive magnetic shielding may be undesirable, with preference given to correct siting of the magnet and consideration giving to increasing magnet room sizes where the introduction of passive magnetic shielding would not be required.

6.9 CONTRIBUTION TO KNOWLEDGE

This case study has advanced knowledge beyond that which has been previously published in finding that:

- The ‘edge effect’ phenomenon (AAPM, 1987) found in this case study ceased to exist where the angle from the magnet isocentre to the edge of the installed passive magnetic shielding exceeded 30° on the z axis. This
information could be useful to designers when designing magnetic shielding, either as an initial design solution or as a retrofit.

- Any magnetic shielding finishing at Finished Floor Level (FFL), whether as a retrofit or as part of the original design, may not be effective in shielding areas below the shielding; the evidence gathered shows that the magnetic flux density at the joint between the magnetic shielding and the floor slab is increased.

- The introduction of magnetic shielding to the MRI suite as the subject of this case study has caused magnetic flux densities within the magnet examination room to be of a greater magnitude than they were without shielding. This makes reliance on magnet vendors’ generic static magnetic field plots questionable by employers attempting compliance with the minimum requirements for the protection of workers from risks to their health and safety (EC 1989) arising or likely to arise from exposure to electromagnetic fields during their work. As mentioned above, the Directive requires that the employer should assess and if necessary measure and/or calculate the levels of electromagnetic fields to which workers are exposed and give particular attention to the level, frequency, spectrum, duration and level of exposure and to any effects concerning the health and safety of workers at particular risk. Should the Employer neglect this duty and an accident occur, it is quite possible that a personally prosecution could be made (HMG 2007b). Additionally, the designer is required (HMG 2007a) to take all reasonable steps to provide sufficient information with his design about aspects of the design of the structure or its construction or maintenance, as will adequately assist clients, other designers, and contractors.
The design and use of square edge shielding panels, and their installation using screws and spot welds, can create hot spots in the magnetic shielding where the magnetic flux density can increase to a level higher than the surrounding shielding. Variations in magnetic flux density at screw heads shown in Figure 6.0.11 are for three reasons:

- The main shielding panels were fixed to the ply backing board, with 32mm steel screws that were allowed to pass through the shielding.
- The shielding panels were square edge and butt-jointed. This necessitated the use of cover strips over the joints, thus requiring the use of further screw fixings and therefore additional shielding penetrations.
- The cover strips were not all tight fitting and, like the main shielding, were butt-jointed with the individual leaves spot welded together to form one shielding panel. There was buckling to the cover strips and as a result they were not tight to the shielding panels in all screw fixing positions. This meant that the 15mm fixing screws did not pass through all six shielding panels (three layers of main shielding and three layers to the cover strips) because there were instances where they were not long enough to be able to compensate for the variations in the buckling of the cover strips and the resultant increase in distance across both sets of shielding i.e. the shielding panels themselves and the cover strips. This was demonstrated by there being a variation in magnetic flux density readings taken at the (panel) joint positions on the corridor side of the wall.
Therefore, leakage of the static magnetic field occurs at the junction between the finished floor level (FFL), the introduced passive magnetic shielding at its joints and through the bolts used to fix the shielding to its supporting structure.

This case study has shown that the introduction of passive magnetic shielding can cause an increase in the magnetic flux density within the MRI examination room and at the edges of the shielding (‘the edge effect’) to a level in excess of that present before its introduction. This ‘edge effect’ could be explained (White, 1980) because the metal sheet planar dimension was not designed so it would be much greater than the distance between an emission source and the shield. The exception is the top horizontal (x axis) edge of the shielding where the ‘edge effect’ was not present. It is argued that because of its (sufficiently great) distance from the magnet isocentre, and although not shown on the graphs, the shielding in this study extended to an overall height of 3.20m from FFL. In this case study, by disregarding the hidden effects of the shielding fixings, the ‘edge effect’ disappeared where the angle from the magnet’s isocentre to the edge of the shielding was in excess of 30° in the z-axis.

The use of fixings which penetrate the shielding, and the practice of shielding panels being spot welded together led to reduction in the homogeneity of the shielding panel material and caused leakage of the static magnetic field at these locations.
CHAPTER 7 CASE 4

7.0 TO ESTABLISH IF A MAGNET WAS FITTED WITH MAGNETIC SHIELDING

7.1 SUMMARY

During the research carried out in Case 2 to obtain as-built drawings, a drawing marked ‘Approved for Construction’ was received from a hospital. This showed magnetic shielding as being required on a wall in the x axis of the static magnetic field of the magnet. The original request for information asked for a copy of the as-built drawing. The client had conflicting information in the project health and safety file and was not sure if magnetic shielding had been installed either as part of the original installation or a later retrofit when the MRI suite was refurbished. This case study shows the results of a survey that was carried out to establish if magnetic shielding had been installed. The results were not conclusive and show the need for clients to ensure that as-built information is compiled and included in the location health and safety file at the completion of a project so that any design for future work can be based on reliable and accurate information and thus eliminate the need for a survey.

7.2 CASE INTRODUCTION

Case 2 was concerned with obtaining as-built drawings for those MRI installations that were deemed by the designers to have a requirement for magnetic shielding. During the course of the research for that case study a drawing was received from a hospital that was marked ‘Approved for Construction’. This drawing showed magnetic shielding as being required on a wall in the x-axis of the static magnetic field of the magnet. The original request for information asked for a copy of the as-built drawing. Further dialogue with the hospital took place in order to elicit more information from the health and
safety file. During these discussions it was determined that there was doubt about whether passive magnetic shielding had been installed at site because the health and safety file held an Approved for Construction (AFC) drawing for the passive magnetic shielding, and not an as-built one. A copy of that drawing is shown in Figure 7.1 below.

![Figure 7.1: A proposed shielding drawing. No as built drawing was available](image courtesy of Nottingham NHS Trust)

After further enquiries were made, the MRI manager (on 18 February 2008) informed the author that the shielding was not carried out during the original installation but was added afterwards and built to the same specification as the Approved for Construction drawing. The specification was not available, however. As a result of the author’s enquiries the MRI manager asked the hospital’s Estates Department for as-built information but was told that passive magnetic shielding had not been installed.
7.3  **RESEARCH AIMS AND OBJECTIVE**

The research aim was to establish if magnetic shielding had been installed as shown on the Approved for Construction (AFC) drawings held by the hospital in the project health and safety file. The research objective was to inform the hospital if passive magnetic shielding had been fitted to the magnet room.

7.4  **SURVEY METHODOLOGY**

As in Case 3, a Metrolab Instruments ETM-1 hand-held Teslameter was used to carry out the survey. Again a 500mm grid was used both horizontally and vertically. Plot positions were situated along the outside wall of the magnet room (+ 1500m and – 1500mm from the x axis).

The grid extended from FFL to 1.00 metre above FFL so as to give a quick indication as to the presence of magnetic shielding in the position shown in the Approved for Construction (AFC) drawing embodied in the location health and safety file.

7.5  **RESULTS AND INTERPRETATION**

From the figures in Table 7 below it can be seen that there are some inconsistencies in the readings obtained, but which should not have existed if magnetic shielding had been installed when the MRI suite was originally constructed. High readings at positions 2.5m of 0.51 mT, at 3.0m of 0.53 mT and at 3.5m of 0.63 mT (the isocentre of the magnet) along the corridor wall indicate that there is leakage of magnetic flux at the joint of the magnetic shielding with the floor. The fact that expected levels of magnetic flux density were obtained either side of these high readings either side of the magnet’s isocentre, and that they were not uniformly distributed is not a clear indication of retrofitted shielding being installed, but nor of an installation having taken place.
during the original construction of the MRI suite. One reason for having high readings at only a few points could indicate that there was a quality issue during any original installation. If magnet shielding had been retrofitted then it would be expected that there would be increased (high) magnetic flux density readings taken all along the bottom of any shielding at its joint with the floor.
Distance in metres along the corridor side of the magnet room wall (taken from each side of the magnet’s isocentre)

<table>
<thead>
<tr>
<th>Height above FFL (in metres)</th>
<th>1.50m</th>
<th>1.00m</th>
<th>0.50m</th>
<th>Magnet isocentre</th>
<th>0.50m</th>
<th>1.00m</th>
<th>1.50m</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00m</td>
<td>0.18</td>
<td>0.18</td>
<td>0.42</td>
<td>0.63</td>
<td>0.53</td>
<td>0.51</td>
<td>0.2</td>
</tr>
<tr>
<td>0.50m</td>
<td>0.11</td>
<td>0.13</td>
<td>0.15</td>
<td>0.17</td>
<td>0.2</td>
<td>0.36</td>
<td>0.32</td>
</tr>
<tr>
<td>1.00m</td>
<td>0.09</td>
<td>0.1</td>
<td>0.12</td>
<td>0.13</td>
<td>0.15</td>
<td>0.27</td>
<td>0.31</td>
</tr>
</tbody>
</table>

Table 4: Magnetic flux density readings taken along the corridor side of the magnet room. Units are mT.
Nevertheless, field surveys carried out to the outside of the magnet room, see Figure 7.2 below, indicate passive magnetic shielding has most likely been installed to this site (because of edge effects being detected at FFL).

![Field plots taken 1.50m each side of the magnet’s isocentre and at 500mm graduations](image)

**Figure 7.2: A contour plot of the survey area**

### 7.6 CONCLUSIONS

The unusually high magnetic flux density at FFL at the magnet isocentre would give suspicion to a strong possibility that magnetic shielding had been installed, but retrospectively. The reason for this hypothesis is that the hot spot of 0.63 at FFL 0.00 shown in the sketch below in Figure 7.3 would indicate a leakage of magnetic flux below the magnetic shielding at its junction with FFL and confirm the phenomenon found also found in Case Study 3. The fact that readings of between 0.51 mT and 0.42 mT have been found at Finished Floor Level between points 0.5m one way and 0.50m the other from the magnet isocentre, but which rapidly diminish at a height of 0.50m from Finished Floor Level would indicate that magnetic shielding has been retrofitted and there was leakage at its joint with the floor.
As these readings were taken outside the magnet room and on the outside of the magnetic shielding, the discrepancies in the reasons cannot be fully explained by possible eddying of the static field within the magnet room. Also, The lack of as–built information coupled with the fact that it was not possible to conduct an intrusive survey, it is impossible to confirm that the hot spots are due to the presence of screw heads in the shielding, but because of the low readings taken above Finished Floor Level it remains a possibility, but there is no evidence of this.

Figure 7.3: Magnetic flux leakages under the shielding in the z axis at FFL
7.7 Recommendations

Although not so pronounced as in the previous experiment, the results show that consideration needs to be made as to the siting of magnets so as to avoid retrofitting of magnetic shielding and thus eliminate the risks of leakage at FFL.

In complying with the provisions of Paragraph 263 of the ACoP to the CDM Regulations (HSE, 2007) the client should ensure that the CDM co-ordinator obtains all information regarding the design and construction of the project, that it is accurate, and it is included in the location health and safety file. This would avoid the uncertainty found in this case study and avoid the need for a survey should future work to the building be envisaged.
CHAPTER 8  CASE 5

8.0 THE IMPORTANCE OF ENGAGING DESIGNERS AT CONCEPTION OF A PROJECT

8.1 CASE SUMMARY

The author was given the opportunity to visit a site with a Faraday cage manufacturer who also carried out passive magnetic shielding design and construction. The reason for the visit was because the client had asked for a quotation for the installation of passive magnetic shielding around a previously installed and operational magnet. On arrival on site it was immediately apparent that, because of the magnet strength (15 mT), the magnet location and the lack of a robust controlled area, site measurements of magnetic flux densities produced by the magnet were necessary in order to be able to assess any shielding requirements.

The Faraday cage manufacturer decided that the location of the magnet meant that it would not be possible to provide a viable design solution for passive magnetic shielding to be installed around the magnet. As a result a quotation was not given and the client was advised of his alternative.

The magnet’s current location does not allow it to be shielded effectively, and as a permanent solution, it was recommended that the magnet be moved to another location where it can be installed in a room large enough so as not to require passive magnetic shielding to be required in order for the 0.5 mT footprint of the static magnetic field to be retained within it.

8.2 CASE INTRODUCTION

The development of this thesis required on-going discussions with those connected with the conception, design, construction and maintenance of magnetic resonance imaging (MRI) suites. Consequently a situation arose
where a University Physics Department had asked a Faraday cage manufacturer to advise and quote for passive magnet shielding to an operational magnet, and which was based on operational requirements.

![The 15 Tesla magnet](image)

Figure 8.1: The 15 Tesla magnet

8.3 **Research Aims and Objective**

The aim of this case study was to assess if the 0.5 mT footprint was contained within the magnet room and, if it passed to areas outside the room, to measure magnetic flux density values which were not retained.

The research objective was to be able to use this information to decide if a passive magnetic shielding design solution could be introduced so as to retain the 0.5 mT footprint of the magnet.

8.4 **Research Methodology**

The laboratory technician explained that the normal practice was to ramp the 15 Tesla magnet up to 13.5 Tesla. When this took place, exhibition-type temporary screens were used to block off the public corridor so as to prevent unscreened personnel and visitors from exposure to the static magnetic field of the magnet.

Figure 8.2 below shows an example of the screen at the end of the corridor and
which was put in position before the magnet was ramped up and the survey commenced.

Figure 8.2: A temporary screen to prevent access can be seen at the end of the corridor.

As in Case 3, a Metrolab Instruments ETM-1 hand-held Teslameter was used to carry out the survey. A 500mm grid was used horizontally along the corridor adjacent to the magnet room for a distance of 7.00m one direction from the magnet’s isocentre and 5.50m in the other. In order to efficiently identify the magnetic flux density changes in the vertical plane, magnetic flux density readings were taken along the wall at random heights so as to establish the size of the vertical grid required. It was found that high readings of magnetic flux density were being recorded against the magnet room wall. As a result it was decided to use a 1.00m grid to a height of 2.00m. It was also decided to extend the survey to measure the magnetic flux density across the public corridor, but at 500mm horizontal graduations, so as to determine the extent of the magnet’s 0.5 mT footprint. These 500mm graduations were marked up using a chalk, measuring tape and timber baton marked up with 500mmm graduations. The measuring tape was used to mark up the survey positions on the vinyl floor along the corridor side of the magnet room wall and across the corridor. Figure 8.3 below shows readings of the magnetic flux density being taken along the
corridor at three separate axes, with the survey grid superimposed on the image. These axes were designated as ‘A’, ‘B’ and ‘C’. The magnet room wall is the wall in the left of the picture and the jamb of the entrance door to the magnet room can just be seen in the foreground.

![Image of corridor with survey grid superimposed](image)

Figure 8.3: The survey grid superimposed on a photograph of the corridor

The opposite side of the magnet room contained a window that was facing a car park, with pedestrian and vehicular traffic passing in front of the window. The magnet isocentre was 1.50m from the window. A location plan of the magnet room showing the magnet room and location of the magnet, the public corridor, adjacent rooms and car park is shown in Figure 8.4 below.
The magnet was not always in use, but whilst on site for the survey it was noted that even when the machine was ramped up to 13.5 Tesla there were no physical barriers or warning signs erected in the car park.

The adjacent Rooms 70 and 74 were not under the control of the client and therefore other than the exhibition-type screens positioned at the end of the corridor, no access controls were in place.

Figure 8.5 below shows a view of the access door from the adjacent Room 70 to the magnet room and during the survey it was left open so as to be able to ensure that although the entrance door from the corridor was locked, no persons entered the room whilst the magnet was energised.
Figure 8.5: The connecting door to Room 70 is on the right of the picture
8.5 Results and Interpretation

8.5.1 Survey Results

Survey Position ‘A’ on the grid. Units are mT

| Height above FFL (m) | 7.00 | 6.50 | 6.00 | 5.50 | 5.00 | 4.50 | 4.00 | 3.50 | 3.00 | 2.50 | 2.00 | 1.50 | 1.00 | 0.50 | 0.00 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 |
|---------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 0.00                | 0.14 | 0.17 | 0.19 | 0.25 | 0.28 | 0.31 | 0.39 | 0.53 | 0.62 | 0.93 | 1.15 | 1.45 | 1.59 | 1.74 | 1.76 | 1.69 | 1.56 | 1.29 | 1.03 | 0.69 | 0.56 | 0.47 | 0.37 | 0.34 | 0.27 | 0.21 |
| 1.00                | 0.17 | 0.19 | 0.22 | 0.26 | 0.28 | 0.40 | 0.48 | 0.54 | 0.81 | 0.95 | 1.15 | 1.32 | 1.39 | 1.40 | 1.34 | 1.33 | 1.17 | 1.06 | 0.85 | 0.67 | 0.49 | 0.40 | 0.29 | 0.25 | 0.21 | 0.15 |
| 2.00                | 0.13 | 0.16 | 0.18 | 0.20 | 0.19 | 0.22 | 0.25 | 0.29 | 0.39 | 0.51 | 0.57 | 0.70 | 0.73 | 0.81 | 0.81 | 0.82 | 0.75 | 0.68 | 0.50 | 0.37 | 0.29 | 0.19 | 0.14 | 0.11 | 0.09 | 0.06 |

Table 5.1: Magnetic flux density readings at Position ‘A’ on the survey grid in Figure 8.3. Units are mT
Figure 8.6: Position ‘A’ plots at 00.0m, 1.00m and 2.00m heights in the public corridor.
Survey Position ‘B’ on the grid. Units are mT

| Height above FFL (m) | ROOM 70 | 7.00 | 6.50 | 6.00 | 5.50 | 5.00 | 4.50 | 4.00 | 3.50 | 3.00 | 2.50 | 2.00 | 1.50 | 1.00 | 0.50 | 0.00 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 3.00 | 3.50 | 4.00 | 4.50 | 5.00 | 5.50 |
|---------------------|---------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 0.00                |         | 0.16 | 0.19 | 0.21 | 0.23 | 0.25 | 0.30 | 0.33 | 0.33 | 0.43 | 0.51 | 0.65 | 0.77 | 1.07 | 1.15 | 1.15 | 1.16 | 1.16 | 1.02 | 0.89 | 0.70 | 0.54 | 0.47 | 0.44 | 0.42 | 0.42 | 0.28 | 0.24 |
| 1.00                |         | 0.16 | 0.19 | 0.20 | 0.23 | 0.28 | 0.33 | 0.40 | 0.45 | 0.50 | 0.66 | 0.76 | 0.89 | 0.98 | 1.04 | 1.01 | 0.99 | 0.90 | 0.76 | 0.62 | 0.50 | 0.42 | 0.33 | 0.26 | 0.20 | 0.15 | 0.15 |
| 2.00                |         | 0.15 | 0.15 | 0.17 | 0.18 | 0.19 | 0.22 | 0.23 | 0.28 | 0.35 | 0.38 | 0.47 | 0.49 | 0.61 | 0.64 | 0.65 | 0.66 | 0.59 | 0.47 | 0.38 | 0.29 | 0.21 | 0.17 | 0.11 | 0.09 | 0.07 | 0.07 |

Table 8.2: Magnetic flux density readings at Position ‘B’ on the survey grid in Figure 8.3. Units are mT
Figure 8.7: Position ‘B’ plots at 00.0m, 1.00m and 2.00m heights in the public corridor
Survey Position ‘C’ on the grid. Units are mT.

<table>
<thead>
<tr>
<th>Height above FFL (m)</th>
<th>ROOM 70</th>
<th>Limit of magnet room</th>
<th>ROOM 74</th>
<th>Magnet isocentre</th>
<th>Limit of magnet room</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.00</td>
<td>0.10</td>
<td>0.09</td>
<td>0.15</td>
<td>0.14</td>
<td>0.15</td>
</tr>
<tr>
<td>6.50</td>
<td>0.13</td>
<td>0.14</td>
<td>0.14</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
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<td>0.16</td>
<td>0.16</td>
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<td>0.24</td>
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</tr>
<tr>
<td>4.00</td>
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<td>0.29</td>
<td>0.29</td>
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</tr>
<tr>
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<td>0.85</td>
<td>0.46</td>
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</tr>
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<td>0.41</td>
</tr>
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<td>0.64</td>
<td>0.31</td>
<td>0.31</td>
<td>0.31</td>
</tr>
</tbody>
</table>

Table 8.3: Magnetic flux density readings at Position ‘C’ on the survey grid in Figure 8.3. Units are mT.
Figure 8.8: Position ‘C’ plots at 00.0m, 1.00m and 2.00m heights in the public corridor
8.5.2 Survey Discussion

Magnetic flux surveys carried out in the ‘A’ and ‘B’ positions are grouped in Figure 8.9 below so as to be able to visualise and compare the readings taken. The top chart is Position ‘A’ that was against the corridor/magnet room wall, and the lower chart is Position ‘B’ that was 500mm into the corridor. The readings were taken at Finished Floor Level (Point 0.00m), at 1.00m and at 2.00m.

Given that 0.5 mT is the threshold for exposure of unscreened persons to static magnetic fields, extremely high readings were recorded. These readings were
not only high at the magnet’s isocentre, but also for a distance of 3.50m one way and 4.00m the other, both extending to 1.00m high before they started to drop off. Nevertheless, because of the strength of the magnet, it was not surprising that these levels were recorded.

Figure 8.10 below shows a graph of the readings taken at the ‘C’ Position and again, at FFL, 1.00m and 2.00m high.

![Figure 8.10: The Position ‘C’ plot shows high magnetic flux density 1.00m into the corridor](image-url)

Once again high readings were recorded 1.00m into the corridor at Position C on the survey grid and at all three survey heights. Even at 1.00m into the corridor magnetic flux density levels were sufficiently high as to pass the threshold of 0.5 mT for exposure of unscreened persons to static magnetic fields.
8.5.3 **Shielding Design Proposal**

The client required that a shielded wall be constructed between the magnet and the corridor wall so as to protect students and staff using the adjacent corridor from the effects of the static magnetic field of the magnet. Access through this shielding was required because unless this was provided the entrance door to the magnet would be outside the proposed position of the shielding. This access would need to be wide enough so as to be able to allow containers containing cryogenic gases to be wheeled up to the magnet when the gas to the magnet needed to be replenished.

Shielding was also required to the window in the wall on the opposite side of the magnet and to the walls to Rooms 70 and 74 on either side of the magnet. No mention was made of shielding being required to the ceiling of the magnet room.

Figure 8.11: The proposed magnetic shielding is shown in red
8.6 CONCLUSIONS

The aim of this case study was to assess if the 0.5 mT footprint was contained within the magnet room and, if it passed to areas outside the room, to measure magnetic flux density values which were not retained.

High magnetic flux densities in excess of the threshold of 0.5 mT for exposure of unscreened persons to static magnetic fields to a height of 2.00m were recorded for a distance of 1.00m across the public corridor. Although magnetic flux densities across the remainder of the width of the public corridor were not measured, but because of the high readings still being achieved at a distance of 1.00m into the corridor there was sufficient evidence to be able to declare the whole corridor as requiring being part of the magnet's controlled area.

The magnet was not energised all the time and students and staff used the public corridor adjacent to the magnet room as a short cut through the department. There would be unnecessary disturbance to the movement of students and staff if a permanent controlled area was set up. However, the use of temporary exhibition screens to prevent unscreened persons being exposed to values in excess of 0.5 mT was not seen to be a solution.

The research objective was to be able to use this information to decide if the passive magnetic shielding design solution suggested by the client could be introduced so as to retain the 0.5 mT footprint.

The client had requested a quotation for passive magnetic shielding to be installed around the magnet. This was not a viable solution because the design proposal showed shielding in front of the window facing the car park and with two doors installed in the proposed shielded wall in front of the magnet. As these elements would necessarily include openings and contain penetrations
made by fixing screws, we know that from the work in Case Study 3 that the integrity of the shielding would be compromised. In addition, the shielding solution suggested made no allowance for shielding to the ceiling of the magnet room. We know from previous work in Case Study 3 that the introduction of passive magnetic shielding will result in the static magnetic field being distorted – the ‘balloon in a box’ and it is feasible that with the absence of shielding to the ceiling, the static magnetic field could be pushed upwards to encroach into areas above the magnet room.

The client had not involved a CDM co-ordinator when the installation of the magnet entered the design stage and so the full implications on the client’s proposals could not be taken into consideration. Although the magnet installation _per se_ did not exceed the 30-day criterion for the project to be notifiable under the CDM Regulations (HMG, 2007) the fact that passive magnetic shielding would be required as part of the project would probably have meant that the project would have exceeded this 30 day time-scale and been notifiable, requiring the client to appoint a CDM co-ordinator. Even if the installation were not expected to last more than 30 days the project would nevertheless become non-notifiable and The CDM Regulations (HMG, 2007) would still apply. This is because the project would include construction work as defined by Regulation 2 and designer’s duties, which include the requirement to reduce health and safety risks of any design, still apply.

Although the client does not need to appoint a CDM co-ordinator for non-notifiable work under The CDM Regulations (CDM, 2007) he is not prevented from doing so. Where the client does not appoint a CDM co-ordinator for non-notifiable work he is still bound by Regulation 7 of The Management of Health
and Safety at Work Regulations 1999 (HMG, 1999) to ‘appoint one or more competent persons to assist him in undertaking the measures needed to take to comply with the requirements and prohibitions imposed under the relevant statutory provisions’. This includes satisfying the requirements of The CDM Regulations (CDM, 2007).

8.7 RECOMMENDATIONS

As a temporary measure it was recommended that during periods when the magnet is energised there should be a member of staff positioned at each end of the corridor in order to control access and who has been screened so as to be safe to be exposed to values in excess of 0.5 mT.

Alternatively, a permanent wall with a doorset and keypad could be installed at each end of the corridor; with a bell for visitors should they require access. This system could operate much in the same way as an operational MRI suite in a hospital. However, this may not be a practical solution for users of the rooms leading off from the corridor to the magnet room and could present administrative problems in planning the use of the rooms leading off the corridor containing the magnet room.

It is recommended that a survey of the static magnetic field be carried out to the room(s) above the magnet and across the remainder of the corridor and the area beyond so as to ensure that the threshold of 0.5 mT for exposure of unscreened persons to static magnetic fields is not being exceeded.

The magnet's current location did not allow it to be shielded effectively, and as a permanent solution it was recommended that the magnet be moved to another location where it can be installed in a room large enough so as not to require passive magnetic shielding to be required in order for the 0.5 mT footprint of the
static magnetic field to be retained within it. The client was advised to appoint a CDM co-ordinator to assist him in this process.
CHAPTER 9   CASE 6

9.0   DESIGNERS’ CONFUSION WITH RF SHIELDING

9.1  CASE SUMMARY

9.2  CASE INTRODUCTION

During the course of the research for this thesis it was found that several designers appeared not to be aware of the difference between RF and magnetic shielding. This information, being complimentary contribution to this thesis, has been included as a short case study. A selection of examples is included.

9.3  RESEARCH AIMS AND OBJECTIVE

The aim of this case study was to assess if any of the drawings received during the course of the research for this thesis contained any drawings that may have shown if designers understood the purpose and differences between RF and magnetic shielding.

The objective was to bring any examples to designers so as to confirm understanding of RF and magnetic shielding so as to help identify such instances of confusion should a position of lead Designer be assumed for any future project.

9.4  RESEARCH METHODOLOGY

This was achieved by examining the drawings received from hospitals, in discussions with shielding companies and with architects.

9.5  RESULTS AND INTERPRETATION

The examples below show some current RF cage design proposals, including requirements for magnetic shielding.
Figure 9.1 below shows a designer's plot of the y axis of the 0.5 mT footprint of a magnet's static magnetic field.

Figure 9.1: Showing a designer's confusion between RF and magnetic shielding

*Image courtesy of Radiation Protection Limited*

The designer was obviously aware that the static magnetic field should be prevented from passing to the area below the magnet and that additional shielding would be required. The notes on the drawing state “0.5 mT Line. This line will be contained by the RF shielding. Dims of shielding to be provided by Contractor” and the purple line showing this shielding making it obvious, by its position and overhang past the magnet room above, that the designer believed that RF shielding could contain static magnetic fields. Further, the contractor
has been left to decide the dimensions of the ‘shielding’ without the designer knowing if the contractor was competent in magnetic shielding design.

As can be seen in Figure 9.2 below, this is not an isolated incident. The previous example showed the additional shielding as a purple line on the CAD layer. In this case the RF cage manufacturer is left to decide the dimensions that is an acceptable solution as he could be a competent designer, but this designer has designed the shielding to be housed within the floor slab below the magnet in the recess that would normally be provided to accept the floor to the RF cage. This recess in the floor slab is provided so that the thickness of the RF cage floor is taken up so that the Finished Floor Level (FFL) to the completed RF cage will be at the same level as the corridor and adjacent rooms to the magnet room without having to form a ramp. As the designer appears to have believed that, in comparison with magnetic shielding, relatively light RF shielding will retain the static magnetic field of the magnet he has not considered the extra loading and possible requirement to increase the depth of the reinforced concrete floor slab. Additionally, a competent designer would know, not only the difference between RF and magnetic shielding, but that because of the attraction of the magnet, it would be impractical to place the magnetic shielding above the concrete floor slab.
Figure 9.2: Another example of designer’s confusion between RF and magnetic shielding

*Image courtesy of Radiation Protection Limited*

The proposal drawing shown in Figure 9.3 below shows the generic plot of the 0.5 mT footprint of the static magnetic field in the x and z axes conveniently fitting inside the magnet room and embedded within an external wall to the parent structure and is perfectly symmetrical.

Figure 9.3: The 0.5 mT footprint sits conveniently within the RF cage

*Image courtesy of Radiation Protection Limited*
The drawing in Figure 9.4 below shows a magnet room design with a generic 0.5 mT footprint, indicating that the designer has not taken the possible effects of ferromagnetic materials upon the position of incorporated into the structure into consideration.

Figure 9.4: The proposed magnetic shielding (in red) will distort the 0.5 mT footprint

*Image courtesy of Radiation Protection Limited*
Figure 9.5 below shows how the designer had envisaged allowing the 0.5 mT footprint of the static magnetic field to pass into the adjacent stairwell.

An example of a situation where two magnets are to be installed adjacent one another and where the static magnetic fields converge are shown in Figure 9.6 below.

It is likely that the static magnetic fields will affect each other, particularly as they are both lined up to the z axis (the axis with the furthest reach) of their respective magnets.
Figure 9.6: Despite the overlap of the 0.1 mT footprints magnetic shielding was not specified

*Image courtesy of EEP Limited*
9.6 CONCLUSIONS

This Case Study, although restricted, demonstrates the difficulty of clients when using the usual architect who may be well experienced in general hospital construction but have no understanding of magnetic resonance issues. Designers should bear in mind that where two magnets are in close proximity to one another then static magnetic field of each of them could have an effect on the other.

9.7 RECOMMENDATIONS

Clients should adhere to the CDM 2007 Regulations (CDM, 2007) by appointing a CDM co-ordinator before making a designer appointment, thus allowing the CDM co-ordinator to ensure that an architect competent in magnetic resonance imaging suite design is appointed by the client.
CHAPTER 10  CONCLUSIONS

10.0  SUMMARY

This thesis is important because it has brought together both existing knowledge and new research. Medical/technical/academics on the one hand and construction professionals on the other held the existing knowledge. This thesis has joined this knowledge together and also introduced new research that will enhance the understanding of the health and safety aspects of magnetic resonance suite construction amongst the various players.

This thesis commences by examining the performance of CDM (2007) (HMG, 2007) duty holders in relation to management of the static magnetic field during the construction phase of a project. Questionnaires were sent to the various CDM duty holders and the responses showed that despite it being clear in CDM 2007 (HMG, 2007) there was no agreement of their various roles in the management of health and safety. Recommendations are made to rectify this situation so that they might fully comply with CDM 2007 (HMG, 2007) and that these Regulations are amended to include a reference to non-ionising radiation.

The introduction of magnetic shielding can distort the symmetry of the 0.5 mT footprint of the static magnetic field and consequentially increase the risk of unscreened people, both inside and outside the control of the employer, being exposed to the effects of the static magnetic field unless the magnitude and position of the 0.5 mT footprint is documented and disseminated to all those persons likely to come into contact with it.
Retrofitting of magnetic shielding will result in areas of increased magnetic flux density where the shielding meets the finished floor (FFL). This area could fall into any outer controlled area and because it is at floor level, at first sight may not appear to be a significant risk. Nevertheless, it may be possible for this leakage of magnetic flux to be a risk to cleaners or decorators working at low level and those persons working below the magnet should they be fitted with heart pacemakers or other electronic body implants.

Designers should consider the effects on the 0.5 mT footprint of any ferromagnetic material that is utilised in the structure. This material could include steel reinforcement, steel air-conditioning ducting, etc. The co-ordination of all designers is important because any ferromagnetic material coming within the influence of the 0.5 mT footprint of the static magnetic field will have an effect on its symmetry and cause it to vary from the generic field plots supplied by the magnet vendor. This will therefore, when magnetic shielding is chosen as a design solution, have an effect on the size of the magnet room required in order to retain the 0.5 mT footprint and should be taken into consideration by the designer in any calculations made in determining the optimum size of the magnet room. Additionally, where any magnetic shielding is designed to be fitted to the underside of the reinforced concrete slab on which the magnet is placed, then there is a risk that any leakage of the static magnetic field through the shielding fixing bolts could be transferred to any ferromagnetic material fixed to it.

The statutory duty of duty holders under the Construction (Design and Management) Regulations 2007 (HSE, 2007) do not appear to be understood by the parties involved with the design and construction of an MRI suite.
CASE 1 in this thesis is important because there has been no previously published work in this field as far as it relates to the performance of CDM duty holders in relation to management of the static magnetic field during the construction phase of a project.

Questionnaires were sent to the various CDM duty holders and the responses showed that, despite it being made clear in CDM 2007 (HMG, 2007), there was no agreement of their various roles in the management of health and safety. In addition there was no common agreement on:

- whether exposure to the 0.5 mT footprint was hazardous to health
- identification of the actual site specific position of the 0.5 mT footprint of the static magnetic field, whether it should be confined to the RF cage, or that SMF is different to RF.
- whether site specific planning guides containing site specific information on methods of controlling residual risks of the energised magnet are issued by the magnet vendor
- who should carry out operative screening and be responsible for its documentation, or even whether screening should be documented at all
- who should police access to the controlled area - or even if there should be a controlled area either inside or to areas outside the RF cage where the 0.5 mT footprint may be present
Mapping with the original objectives of the research

The objective of establishing duty-holders’ performance under CDM 2007 so that future Clients and the Health and Safety Executive (HSE) might use this information in order to revise CDM 2007 so as to clarify the role of duty holders in its compliance as it relates to MRI suites has been achieved.

Recommendations

- Clients should appoint a competent CDM co-ordinator before entering design stage so as to ensure the magnet room size is adequate to contain the 0.5 mT footprint of the static magnetic field of the magnet.

- Clients should appoint the magnet supplier early enough in the design stage (but after the appointment of the CDM co-ordinator) so that any requirements for magnetic shielding can be taken into consideration by other sub-designers so as to ensure co-operation and collaboration as required by CDM 2007 (HMG, 2007)

- Designers should avoid the use of generic static magnetic field footprints because use of any ferromagnetic material in the structure, whether primary or secondary elements, could affect the position of the 0.5 mT footprint in all its axes by distorting it to other areas in the MRI suite where it could become a hazard. This hazard could be to humans or to other electronic equipment.

- The principal contractor should ensure the control of health and safety even after the magnet is delivered and energised up until handover for operational use to the client. This includes knowing the true position of the 0.5 mT footprint of the static magnetic field of the magnet, including
this information in his Construction Phase Plan and, by using site briefings, ensuring construction staff and visitors are made aware of it.

- Construction workers and site visitors should, as is the case for visitors to an operational MRI suite, be screened for heart pacemakers and body implants before being allowed to work in or around an MRI suite.

- Construction workers should be prevented from entering the 0.3 mT footprint with ferromagnetic tools. A procedure for the use of MRI safe tools could be adopted by the principal contractor as part of a permit to work system.

- Any appointment by the client of a CDM co-ordinator carrying out another, but separate function on behalf of the magnet vendor such as quantity surveyor, cost consultant for example, should be discouraged so as to avoid a conflict of interest when decisions are made on any siting or shielding requirements for the magnet. The client should recognise this fact when negotiating contracts.

- The CDM Regulations 2007 (HMG, 2007) should be amended so as to include non-ionising radiation alongside ionising radiation as a being significant hazard.

10.1.2 CASE 2

Case 2 is similar in that a lack of compliance with CDM was found regarding the population of health and safety files with as-built drawings showing the position of the 0.5 mT footprint of the static magnetic field of those MRI suites fitted with passive magnetic shielding, nor of the availability of health and safety files to “any person who may need it to comply with the relevant statutory provisions” [CDM2007 Regulation 17 (3) (a)].
The Health Protection Agency was consulted so as to obtain their list of installed MRI magnets to NHS Trust hospitals in Great Britain.

It was found that the oldest magnet still in use was installed in 1992. From 1996 installations started to increase from 4 magnets that year up to 44 being installed in 1996. From that year there was rapid decline to an average of 6 per year up until 2010. Information received from the Health Protection Agency is that this is because funding from the NHS has been reduced. Figures are not yet available for 2011, but from the figures which we do have the use of magnetic shielding has broadly followed the graph of installations without magnetic shielding. Over the period 1992-2006 magnetic shielding was installed in 34% of cases.

Questionnaires were sent to NHS Trusts in Scotland, England and Wales to determine the quantity and location of MRI suites having had magnetic shielding installed, either as a retrofit or as part of the main construction.

During the time that this part of the research was carried out (2007) it was identified that from a total of 295 MRI installations, 82 were identified as having magnetic shielding installed. A second questionnaire asked for as-built drawings showing this shielding and the position of the 0.5 mT footprint of the static magnetic field. Only 54 replies were received as a result of this request. Of these 54 installations where as-built drawings of MRI suites identified by the NHS Trusts as having passive magnetic shielding installed to the magnet, two were found to be retro fitted installations.

Of these two cases neither gave a plot of the 0.5mT footprint of the static magnetic field as it related to the y axis and, although asked for in the questionnaire, information was not given on the use of the building above and/or below the magnet. Therefore, from the information supplied from the health and
safety files, it was not possible to determine if the passive magnetic shielding installed to any of the 54 installations for which as-built drawings had been requested had been effective in retaining the y axis of the static magnetic field.

The availability of information from clients in the form of the statutory requirement for health and safety files is sparse, incomplete and is sometimes irrelevant as it relates to the residual risk and as-built position of the 0.5 mT footprint of the static magnetic field. Reliance on the generic 0.5 mT position of the static magnetic field in lieu of the magnet’s post-energisation position when developing risk management procedures could create a hazard. The requirements of the Construction (Design and Management) Regulations do not appear to be well understood.

**Mapping with the original objectives of the research**

From the information supplied from the health and safety files none of the 54 as-built drawings received from the 82 installations identified as having magnetic shielding installed to the MRI suite showed the as-built position of the 0.5 mT footprint of the static magnetic field of the magnet.

*The research objective to obtain as-built drawings showing the as-built position of the 0.5 mT footprint of the static magnetic field of the magnet has been achieved inasmuch that the research showed that they were unavailable.***

**Recommendations**

It is recommended that The Construction (Design and Management)

Regulations 2007 (HMG, 2007) are amended so that non-ionising radiation is included alongside ionising radiation in Appendix 3 – *Arrangements for controlling significant site risks* - of the Approved Code of Practice (ACoP) to The Construction (Design and Management) Regulations 2007 (HSE, 2007).
This would ensure inclusion of as-built drawings showing the position of the 0.5 mT footprint of the static magnetic field of the magnet was included in the health and safety file. Additionally, an explanation should be given of the qualities of these two types of radiation and of the differences of their effect on the human body.

10.1.3 Case 3

During the research process carried out in Case study 2, one hospital replied to the author’s request for as-built drawings showing the 0.5 mT footprint of any installed magnets by stating that no MRI magnets at that hospital were fitted with passive magnetic shielding, but that one magnet would require retrofitted magnetic shielding in the near future.

Measurements of magnetic flux density were taken inside the magnet room by using a Metrolab Instruments ETM-1 Teslameter both before and after installation of magnetic shielding, and also taken to the corridor side of the rear wall to the magnet. This was so as to establish the efficiency of the newly introduced magnet shielding. Photographs and measurements of the magnetic shielding, including details of fixing methods used were taken.

It was found that the panels used were square edged and not lapped. It was necessary to fit cover strips to these joints. The panels and cover strips were fixed by using steel screws. There was magnetic flux leakage through the joint of the cover strips with the shielding panels and through all steel fixing screws, both to the panels and to the cover strips. These leakages were seen to be highest at the periphery of the shielding and at Finished Floor Level (FFL). At FFL they ranged from 0.26 mT at Position 2.20m before shielding to 1.30 mT after shielding. The edges of the shielding also increased following shielding so
that in every case the magnetic flux density was increased from being below the threshold for exposure of unscreened personnel to the static magnetic field (0.5 mT) to values of up to 1.10 mT.

In this case study, by disregarding the hidden effects of the shielding fixings, the ‘edge effect’ disappeared where the angle from the magnet’s isocentre to the edge of the shielding was in excess of 30° in the z-axis.

The research in Case 3 has shown that the practice of retro-fitting passive magnetic shielding to Magnetic Resonance Imaging (MRI) suites may not be effective in fully retaining the 0.5 mT footprint of the static magnetic field to within its designed position. It may increase the magnetic flux density within the MRI magnet room and allow it to encroach into contiguous areas of the MRI suite. The methods of fixing magnetic shielding panels used in this case study allow the static magnetic field to pass to areas outside the shielding. The locations of these fixing positions are difficult to pinpoint on a finished wall, and unless they were known beforehand, could easily be overlooked by any person carrying out a cursory survey of magnetic flux densities at a given location outside any controlled area. Depending on the magnitude and ‘reach’ of these leakage points in the passive magnetic shielding, close contact between an individual wearing certain heart pacemakers or other electronic implants with these leaking joints could have safety implications for the individual concerned.

**Mapping with the original objectives of the research**

This Case Study has shown that the use of retrofitted magnetic shielding may not be effective in retaining the 0.5 mT footprint of the static magnetic field within the magnet room. There is evidence that there may be magnetic flux leakages at Finished Floor Level (FFL) and which, because of the ‘edge effect’
may be higher than before shielding. Magnetic shielding panels should not be square edge and fixings should ideally be designed so that so as not to penetrate the shielding so as to avoid puncturing the shielding and thus allowing the static magnetic field to leak through these positions. The ‘edge effect’ disappeared where the angle from the magnet’s isocentre to the edge of the shielding in the z-axis was in excess of 30°. As any magnetic shielding could distort the 0.5 mT footprint of the static magnetic field there may be an increased magnetic flux density below the magnet room (in the y axis). This research did not cover that situation, as access to areas below the magnet room was not given.

The research objective was to identify information that might be useful in aiding designers of magnetic shielding to identify hazards associated with the use of retrofitted magnetic shielding to MRI suites, and if the remedy of introducing retrofitted passive magnetic shielding was effective in retaining the 0.5 mT footprint within the controlled area of the MRI suite so as to help them consider how, along with the advice of the CDM co-ordinator, the initial design could be amended to eliminate or reduce these hazards. That research objective has been achieved.

**Recommendations**

- Any magnetic shielding finishing at Finished Floor Level (FFL), whether as a retrofit or as part of the original design, will not be effective in shielding areas below the shielding; the evidence gathered shows that the magnetic flux density at the joint between the magnetic shielding and the floor slab is increased.
The introduction of magnetic shielding to the MRI suite as the subject of this case study has caused magnetic flux densities within the magnet examination room to be of a greater magnitude than they were without shielding. This makes reliance on magnet vendors’ generic static magnetic field plots questionable by employers attempting compliance with the minimum requirements for the protection of workers from risks to their health and safety (EC 1989) arising or likely to arise from exposure to electromagnetic fields during their work. As mentioned above, the Directive requires that the employer should assess and if necessary measure and/or calculate the levels of electromagnetic fields to which workers are exposed and give particular attention to the level, frequency, spectrum, duration and level of exposure and to any effects concerning the health and safety of workers at particular risk. Should the Employer neglect this duty and an accident occur, it is quite possible that he could be personally prosecuted (HMG 2007b). Additionally, the designer is required (HMG 2007a) to take all reasonable steps to provide sufficient information with his design about aspects of the design of the structure or its construction or maintenance, as will adequately assist clients, other designers, and contractors.

The design and use of square edge shielding panels, and their installation using screws and spot welds, can create hot spots in the magnetic shielding where the magnetic flux density can increase to a level higher than the surrounding shielding. Variations in magnetic flux density at screw heads shown in Figure 6.11 are for three reasons:

The main shielding panels were fixed to the ply backing board, with 32mm steel screws that were allowed to pass through the shielding.
• The shielding panels were square edge and butt-jointed. This necessitated the use of cover strips over the joints, thus requiring the use of further screw fixings and therefore additional shielding penetrations.

• The cover strips were not all tight fitting and, like the main shielding, were butt-jointed with the individual leaves spot welded together to form one shielding panel. The 15mm fixing screws did not pass through all six shielding panels (three layers of main shielding and three layers to the cover strips). This was demonstrated by there being a variation in magnetic flux density readings taken at the (panel) joint positions on the corridor side of the wall.

Therefore, leakage of the static magnetic field occurs at the junction between the finished floor level (FFL), the introduced passive magnetic shielding at its joints and through the bolts used to fix the shielding to its supporting structure.

This case study has shown that the introduction of passive magnetic shielding can cause an increase in the magnetic flux density within the MRI examination room and at the edges of the shielding (‘the edge effect’) to a level in excess of that present before its introduction. This ‘edge effect’ could be explained (White, 1980) because the metal sheet planar dimension was not designed so it would be much greater than the distance between an emission source and the shield. The exception is the top horizontal (x axis) edge of the shielding where the ‘edge effect’ was not present. It is argued that because of its (sufficiently great) distance from the magnet isocentre, and although not shown on the graphs, the shielding in this study extended to an overall height of 3.20m from FFL. In this case study, by disregarding the hidden effects of the shielding fixings, the ‘edge
effect’ disappeared where the angle from the magnet’s isocentre to the edge of the shielding was in excess of 30° in the z-axis.

The use of fixings which penetrate the shielding, and the practice of shielding panels being spot welded together led to a reduction in the homogeneity of the shielding panel material and caused leakage of the static magnetic field at these locations.

10.1.4  **CASE 4**

The research in Case 4 revolved around the fact that it was not clear if magnetic shielding had been introduced to the RF cage. The Estates Department, who held the CDM health and safety file for the project and which only contained an Approved for Construction (AFC) drawing said that it had not been installed. The radiology manager however said that it had.

A Metrolab Instruments ETM-1 hand-held Teslameter was used to carry out the survey. A 500mm grid was used both horizontally and vertically. Plot positions were situated along the outside wall of the magnet room at distances of +1500mm and –1500mm from the x axis of the magnet. The grid extended from FFL to 1.00 metre above FFL so as to give a quick indication as to the presence of magnetic shielding in the position shown in the Approved for Construction (AFC) drawing held in the location health and safety file.

The grid extended from FFL to 1.00 metre above FFL so as to give a quick indication as to the presence of magnetic shielding in the position shown in the Approved for Construction (AFC) drawing embodied in the location health and safety file.
The fact that magnetic flux density readings of between 0.51 mT and 0.42 mT have been found at Finished Floor Level between points 0.50m one way and 1.00m the other from the magnet isocentre, but which rapidly diminish at a height of 0.50m from Finished Floor Level. There are some inconsistencies in the readings obtained, but which should not exist if magnetic shielding had been installed when the MRI suite was originally constructed. There was leakage of magnetic flux at an unexpected high level at the joint of the magnetic shielding with the floor, indicating that magnetic shielding has probably been retrofitted – but there is no conclusive evidence.

**Mapping with the original objectives of the research**

*The research objective was to inform the hospital if passive magnetic shielding had been fitted to the magnet room has been partially achieved. This is because the evidence was not conclusive and a further intrusive survey will be required.*

**Recommendations**

Early involvement of a CDM co-ordinator, his management of the design process and population of the health and safety file with relevant as-built information would ensure that the client held accurate information regarding his MRI suite. This would allow the development of a risk management strategy for those working in or around the MRI suite and for those designers working on any future design proposals.

10.1.5 Case 5

Case 5 showed an example of a 15 Tesla magnet installation (the most commonly installed magnets in the UK are 1.5 Tesla, ten times less powerful). This example demonstrated how the issue of containment of the static magnetic field of the magnet, although being surrounded on all four sides by public areas,
had not been considered until after magnet installation and commissioning. This is because the client did not appoint a CDM co-ordinator for the project and, as a result, the magnet was installed without any involvement of shielding designers. High magnetic flux densities in excess of the threshold of 0.5 mT for exposure of unscreened persons to static magnetic fields to a height of 2.00m were recorded for a distance of 1.00m across the public corridor. For example, against the magnet room wall at Position 0.00m (the magnet’s isocentre) readings of 1.76 mT at FFL, 1.34 at 1.00 high and 0.81 at 2.00m high were recorded. Further readings at these heights above FFL continued into the corridor at 500mm from the magnet room wall. These readings were 1.16 mT, at FFL, 1.01 mT at 1.00 m high and 0.61 mT at 2.00m high and yet were still in excess of the threshold for the exposure of unscreened humans to the 0.5 mT footprint of the static magnetic field produced by the magnet. Further readings at 1.00m into the corridor were recorded and these still exceeded the 0.5 mT threshold at FFL and at 1.00m high, but just peaked below the threshold (0.46 mT) at 2.00m high. Although magnetic flux densities across the remainder of the width of the public corridor were not measured, the high readings still being achieved at a distance of 1.00m into the corridor was sufficient evidence to be able to declare the whole corridor as requiring being part of the magnet’s controlled area.

The magnet’s current location did not allow it to be shielded effectively, and as a permanent solution it was recommended that the magnet be moved to another location where it can be installed in a room large enough so as not to require passive magnetic shielding to be required in order for the 0.5 mT footprint of the static magnetic field to be retained within it. The client was advised to appoint a
CDM co-ordinator to assist him in this process in order that any future design could be co-ordinated.

**Mapping with the original objectives of the research**

*The objective to demonstrate the need for the early involvement of designers at initial design stage of a project has been achieved.*

**Recommendations**

As a temporary measure it was recommended that during periods when the magnet is energised there should be a member of staff positioned at each end of the corridor in order to control access and who has been screened so as to be safe to be exposed to values in excess of 0.5 mT.

Alternatively, a permanent wall with a doorset and keypad could be installed at each end of the corridor; with a bell for visitors should access be required. This system could operate much in the same way as an operational MRI suite in a hospital. However, this may not be a practical solution for users of the rooms leading off from the corridor to the magnet room and could present administrative problems in planning the use of the rooms leading off the corridor containing the magnet room.

It is recommended that a survey of the static magnetic field be carried out to the room(s) above the magnet and across the remainder of the corridor and the area beyond so as to ensure that the threshold of 0.5 mT for exposure of unscreened persons to static magnetic fields is not being exceeded.

The magnet’s current location did not allow it to be shielded effectively, and as a permanent solution it was recommended that the magnet be moved to another location where it can be installed in a room large enough so as not to require passive magnetic shielding to be required in order for the 0.5 mT footprint of the...
static magnetic field to be retained within it. The client was advised to appoint a CDM co-ordinator to assist him in this process.

10.1.6 CASE 6

Case 6 showed that there was confusion of designers as to the differences between RF and magnetic shielding.

During the research for this thesis various drawings were collected from discussions took place with hospitals, principal contractors, contractors, shielding companies and architects. Examples of some drawings that were presented are shown in the Case Study. They show confusion of designers between the purpose of RF and magnetic shielding. This is evidenced by comments such as “This line will be contained by the RF shielding when it is clearly referring to magnetic shielding shown below the floor slab and independently to the RF shielding for the Faraday cage. Another shows magnetic shielding fitted to a floor slab, but still shows the generic 0.5 mT footprint of the static magnetic field. e know from the research in this thesis that the introduction of magnetic shielding will distort the 0.5 mT footprint.

Mapping with the original objectives of the research

*The objective to show that designers need to be competent in their knowledge of the differences between RF and magnetic shielding has been achieved.*

Recommendations

Clients need to ensure the appoint only designers who are competent in the knowledge of the differences in the qualities and purpose of both RF and magnetic shielding. A CDM co-ordinator competent in MRI suite construction should be able to assist the client in his choice of designer.
10.2 OVERALL SUMMARY OF CONCLUSIONS

This research has shown that there is no clear understanding of duty holders’ responsibility under the Construction (Design and management) Regulations 2007 (HMG, 2007) nor of the hazards of human exposure to static magnetic fields for unscreened personnel.

The research found no evidence that health and safety files compiled for MRI suite projects contained as-built drawings showing the 0.5 mT footprint of the energised magnet. When exposed to the 0.5 mT footprint of a magnet’s static magnetic field, lack of this knowledge could create a possible hazard to visitors and maintenance contractors for the remaining life-cycle of the MRI suite.

The practice of retrofitting passive magnetic shielding to Magnetic Resonance Imaging (MRI) suites may not be effective in fully retaining the 0.5 mT footprint of the static magnetic field to within its designed position. It may increase the magnetic flux density within the MRI magnet room and allow it to encroach into contiguous areas of the MRI suite. The methods used to fix magnetic shielding panels should be designed so as not to penetrate the shielding as this will prevent the static magnetic field from using this route to pass to areas outside the shielding.

Clients should ensure that their appointed CDM co-ordinators have sufficient competency in the design and construction of MRI suites so as to be able to ensure that all information on significant risks and accurate as-built drawings are included in the location health and safety file once practical completion has taken place.
The issue of containment of the static magnetic field of the magnet needs to be considered at initial design of the project and not left until after magnet installation and commissioning.

Designers need to be competent and have the knowledge of the differences in the qualities and purpose of both RF and magnetic shielding.
CHAPTER 11  RECOMMENDATIONS

11.0  RECOMMENDATIONS TO PRACTICAL PROCESSES AND TO LEGISLATION

11.1  RECOMMENDED CHANGES TO PRACTICAL PROCESSES

11.1.1  ADEQUATE MAGNET ROOM SIZES

By designing the size of the magnet room to enable it to accommodate the 0.5 mT footprint of the magnet, and by the siting of the magnet away from both static and mobile ferromagnetic objects which may influence or be influenced by it, the need for passive magnetic shielding, retrofitted or otherwise could be eliminated. Where this is not possible, up until now designers have had no simple guidelines as to where any retrofitted magnetic shielding might need to extend in order to retain the static magnetic field within the magnet room. In cases where the designed magnetic shielding is undersized, then the ‘edge effect’ could be created to the shielding and thus unnecessarily increase the magnetic flux density at these points. Where the magnetic shielding is oversized, then this imposes additional and unnecessary costs on the client.

Clients should not expect their architects to allocate space requirements for MRI Suites based on generic site planning guides from magnet vendors which themselves often systematically portray the 0.5 mT footprint on their generic site drawings as extending to areas outside the RF cage.

Where any decision for magnetic shielding is made it should not be primarily based on the need to protect magnet image quality but, as a priority, also include the hazard of the energised magnet and risk to ALL personnel. Specifying realistically dimensioned magnet rooms which fully contain the 0.5 mT footprint of the static magnetic field would seem a more practical and safer
solution from a health and safety management point of view both at construction and operational stages.

Clients should ensure that they appoint a CDM co-ordinator before initial design of a project commences so as to ensure that all designers, both formal and informal, have been identified and included in the design co-ordination process.

11.1.2 THE LOCATION OF THE MAGNET WITHIN THE HOSPITAL/CLINIC STRUCTURE

The portrayal by two magnet vendors’ generic planning guides locating the exam room so as to incorporate two external walls can only add to the possibility of the static magnetic field becoming a risk to members of the public and others not connected with the MRI Suite. In 2005 MagNet noted that they have found incidents where the stray field strength in public areas is above acceptable limits and give as examples one case where 0.5mT was measured in a picnic area outside an MRI Unit and in another case where 1.6 mT was measured in a public corridor outside an MRI Unit. Understandably, there will be pressure on space when a new magnet installation is planned, but any attempt to install the MRI suite at any level other than the ground floor (where the 0.5 mT footprint of the static magnetic field can be absorbed into the ground) could cause trouble. Where the magnet is installed on floors other than the ground floor, because of the low position of the magnet iso-centre the magnet will probably require magnetic shielding to be installed at least on areas below the y axis of the magnet.
11.1.3 THE STATIC MAGNETIC FIELD FOOTPRINT COULD BECOME DISTORTED

Should magnet rooms, as in Case 3, have been designed to the magnet vendor’s generic room dimensions the requirement for retrofit magnetic shielding may have been avoided. Nevertheless, even in cases where the room is designed so as to have adequate dimensions to accommodate the 0.5 mT footprint of the static magnetic field, the introduction of ferromagnetic elements into the design could still cause the generic 0.5 mT footprint to be distorted. For this reason designers should use magnet vendors’ plots of generic static magnetic field footprints as being indicative only, and only to be used as a basis for development of a robust process of design risk management. Where magnetic shielding distorts the static magnetic field and pushes it in another direction, it will be transferring the hazard to another position inside or outside the controlled area to the MRI suite and perhaps with a resultant increased risk of exposure by unscreened individuals. An unsuspecting (and unscreened) maintenance plumber or electrician may be asked to work in a ceiling area below the magnet isocentre and become exposed to the 0.5 mT footprint. Where it is unavoidable that CT’s or other equipment susceptible to the static field requires to be positioned adjacent to a magnet, then allowance should be made in the magnet room size and format to take account of any distortion of the static magnetic field by any required magnetic shielding to restrain the 1 mT footprint so as to ensure the continued retention of the potentially distorted 0.5 mT footprint within the RF cage. It is important to have cognisance of the tendency for the increased magnetic flux density at this position to attempt to ‘creep’ around any magnetic shielding if it is not of an adequate dimension.
11.1.4 USE OF SHIELDING FIXING BOLTS TO SUSPEND SECONDARY ELEMENTS

Where ferromagnetic non-structural elements are fixed to any magnetic shielding installed to the underside of any reinforced concrete slab to an MRI suite, then the same considerations as above will apply. An example where the designer has ignored the possibility of the “edge effect” contamination to non-structural construction elements fixed to the magnetic shielding is shown in Figure 10.1 below.

Cognisance should be made of the need to take account of all ferromagnetic elements falling within the influence of the footprint of the static magnetic field. This includes steel reinforcement in floor slabs, beams and columns, the orientation of the magnet to the longitudinal direction of the steel, as well as its proximity to them. Any additional ferromagnetic elements which may be introduced by mechanical services contractors, such as air-conditioning ducting, should also be taken into consideration as this could also have an effect on the symmetry of the static magnetic field footprint. It is feasible that retrofit magnetic shielding may be installed on the underside of a concrete floor slab so as to protect areas below which would otherwise be affected by the y axis of the magnet. In this case it is conceivable, based on the evidence from Case 3 above that any ferromagnetic mechanical or electrical services suspended from the ceiling by making use of the bolts used to fix any magnetic shielding to the slab could become permanently magnetised by the ‘leakage’ of the static magnetic field through them, and should be avoided.

Figure 11.1 below shows a typical case where a designer has taken advantage of this opportunity, thus demonstrating that there is a real risk of designers inadvertently using this method when not having full knowledge of the hazards relating to their choice of fixing solution. In this particular case, the steel bolts
fixing the passive magnetic shielding to the underside of the concrete floor slab, as in the case study of this paper, could allow the static magnetic field to pass through them.

![Image](image1.png)

Figure 11.1: Ferromagnetic elements fixed to the shielding fixing bolts

11.1.5 RETROFITTED MAGNETIC SHIELDING MAY NOT BE THE SOLUTION

From Case 3 it is apparent that as far as retrofitted magnetic shielding is concerned, the physical restraints preventing the shielding from passing below Finished Floor Level (FFL) of any MRI suite could create an additional hazard to areas above or below the shielded wall. This is an important point because the magnetic flux density at this position may already be in excess of 0.5 mT. The introduction of retrofitted passive magnetic shielding cannot be claimed to be an effective design solution unless a full design review process is in place from initial design stage through the entire design process. This would ensure that any hazards are recognised at an early stage in the design and give the opportunity for them to be eliminated.
11.1.6  **CO-OPERATION AND CO-ORDINATION OF DESIGNERS**

It is therefore crucial that the lead designer and CDM co-ordinator ensure recognition, co-operation and co-ordination of all designers, including the magnet vendor and his sub-designers, as early as possible in the design of an MRI suite so as to be able to take account of the likely presence of all ferromagnetic material within the influence of the static field of the magnet and to be able to make an informed decision on the magnet’s location and/or orientation. Co-operation and co-ordination of all designers should ensure the actual as-built positions of all three axes (x, y and z) of the static magnetic field are as close as possible to the designed position. This will eliminate unplanned distortion of the magnetic field where it may unwittingly be directed to areas (including those areas above and below the magnet) where operatives may be exposed to magnetic flux densities of 0.5 mT or above and of which they have not been informed.

11.1.7  **THE IDENTIFICATION OF THE ACTUAL AS-BUILT 0.5 MT FOOTPRINT**

Knowledge, by identification of the true position and magnetic flux density of the static magnetic field, is important to ensure a valid controlled area has been set up around the MRI suite so as to protect unscreened individuals from the effects of the static magnetic field. This is important because magnetic fields, like electricity, are invisible. Even when the magnet room is not in use the magnet, and consequently the static magnetic field, is still ‘on’. Unless told they exist, an individual would be oblivious to its presence.
11.1.8 THE SCREENING OF INDIVIDUALS

Even when the scanner is not in imaging mode (by definition this would include the construction phase once the magnet has been energised), it is the ever-present static magnetic field (and the mapping of its magnetic flux density encircling the magnet) that is of interest to those involved with construction risk management. This information enables identification and set-up of a controlled area around the magnet installation. Having this knowledge also enables the employer (including the principal contractor during the construction phase, following energisation of the magnet) to screen and possibly exclude, any construction workers or visitors who may be fitted with electronic implants or devices, such as heart pacemakers from the controlled area of the MRI suite.

11.1.9 THE DESIGNATION OF CONTROLLED AREAS

Generic static magnetic field plots supplied by magnet vendors should not be relied upon when setting up a controlled area around an MRI suite. As these generic plots sometimes only cite the position of the static magnetic field in the x and z axes, areas above and below of the magnet (in the y axis) should also be included in any given controlled area. This is because of the risk of unscreened persons being asked to work within areas where magnetic flux densities in excess of 0.5 mT are present. Any person carrying out a risk assessment for the proposed work to that location may have not perceived these sometimes infrequently visited areas as having any relationship with the MRI suite.

11.1.10 THE CLIENT SHOULD APPOINT A COMPETENT CDM-C

The inclusion of a CDM co-ordinator experienced in MRI suite design and construction within the Project Team at the initial design stage is of paramount importance. The use of a competent CDM-co-ordinator should assure the
process of the identification of all designers, of co-operation and co-ordination during the design process, and assist in the elimination and/or reduction of hazards resulting from the presence of static magnetic fields around the magnet during the whole-life cycle of an MRI suite project. Field verification of the location of critical magnetic field lines (0.5 mT is cited) may have value beyond the immediate issue of exposure of individuals who have not been successfully cleared of any contraindications.

11.1.11  THE TIMING OF THE APPOINTMENT OF A CDM CO-ORDINATOR

The CDM Regulations make it clear that a CDM co-ordinator should be appointed by the client before appointing designers, thus allowing the CDM co-ordinator to establish, on behalf of the client, the competency and resources of his designers and to co-ordinate the design process where several designers are involved. This also avoids the problem of the late appointment of designers where the inability to effectively co-ordinate any residual risks is compromised. Unfortunately, this is not always the case. MRI Suites are often ‘designed’ using the ‘worst case’ magnet vendor generic site planning information, with the magnet vendor chosen at the final stage of the design (a late appointment under the CDM Regulations). In the case of an MRI suite, as a minimum the designers would be the RF cage supplier, the magnet vendor and the client’s architects, design and build or PFI contractor, but could also be the pre-installation contractor.
11.1.12 THE PRINCIPAL CONTRACTOR MUST MANAGE HEALTH AND SAFETY

The pre-installation contractor in his role of principal contractor under the CDM Regulations, should take full control of management of health and safety on site and be aware of the control measures deemed necessary by the magnet vendor and cage supplier to manage the residual risk of the energised magnet and specifically, the actual position of the 0.5 m footprint. So as to be able to do this, the actual position of this 0.5 m footprint of the static magnetic field needs to be identified by the perpetrator, the magnet vendor. It is essential that information about residual risks be conveyed to the principal contractor to allow him to manage these risks and ‘it is not acceptable for the designer just to carry out his design and then expect the contractor to control all the risks resulting from the design, once on site. (Construction Industry Council, 2005).

11.1.13 THE LOCATION OF THE 0.5 mT FOOTPRINT OF THE MAGNET

Once the principal contractor has been appointed, works have commenced on site and the magnet has been energised, an independent survey of the actual site position and magnetic flux density of areas within the 0.5 mT footprint should be carried out and delineated on site in a manner which can be easily recognised, such as by the use of barriers and danger signs. A controlled area should be established for the entire MRI suite and not just the magnet room. This should include areas above and below the magnet and areas outside the magnet room if relevant. The principal contractor should update his construction phase plan with the current information on the position and density of the 0.5 mT footprint, with the CDM co-ordinator ensuring this information is eventually transferred to the Health and Safety File. From a principal contractor perspective, when the programme for the magnet is to be energised is produced, the construction phase plan should include details of the control
measures to be put into place to prevent visitors and employees, whether present or future, becoming exposed to the 0.5 mT footprint of the static magnetic field. As an additional security measure screening should be a condition of access to the entire MRI suite, and include areas even outside the building where the 0.5 mT footprint may be present. Of particular risk is that to window cleaners, roofing contractors whilst carrying out normal, perhaps unassociated, work activities. So as to protect operatives and visitors fitted with pacemakers or other metal implants they should not be permitted to access any area of the MRI suite. A Permit to Work system should be introduced. The employing authority is ultimately responsible for the implementation and maintenance of procedures to ensure the health and safety of all persons (MDA, 2007). This duty also exists under Section 3 of the Health and Safety at Work, etc. Act 1974 (HMG, 1974). However, the magnet vendor, in complying with his CDM (HMG, 2007) duties as designer, has the responsibility of informing the client of the residual risks to his installation. It is therefore for the magnet vendor to ensure a site-specific survey of the static magnetic field pertaining to his installation is supplied to the client. The client will then transmit this information to the principal contractor via the CDM co-ordinator, who will then update his construction phase plan. As the contractor is, under CDM (HMG, 2007), responsible for the management of health and safety on site, it is his responsibility to ensure that validated surveys of the site-specific position of the static magnetic field are given him in documented form. So as to satisfy his duty under the Health and Safety at Work, etc Act 1974 (HMG, 1974), once energised not allow site operatives access to the magnet unless this information is included in the construction phase plan, which should include a full DRA (Design Risk Assessment) from the magnet vendor’s designer.
Following any magnetic shielding installation, comprehensive magnetic flux density surveys should be made of the shielding to ensure that hot spots in excess of 0.5 mT (as demonstrated by Case 3) have not occurred at magnetic shielding panel fixing positions, or at any other point on or around the magnetic shielding. If they are found to be present, then these areas should be included within the 0.5 mT Controlled Area of the MRI suite before being handed back to the Client for operational use.

11.1.14 **TRAINING AND HEALTH SURVEILLANCE**

Operatives working within the suite should receive training in the hazards of magnet installation and be supplied with personal dosimeters, their presence within the 0.5 mT footprint monitored and documented. These records retained for future health surveillance to be carried out so as to help establish, the so far sparsely documented and valuable information on the possible effects of static magnetic fields on human health. The current reference levels (ICNIRP, 2009) should be used at the initial stage of assessing compliance with basic restrictions on exposure, but further investigations on compliance that are indicated by exceeding these reference levels, should use the most up-to-date dosimetry methods. (NRPB, 2004).

11.1.15 **FERROMAGNETIC TOOLS**

It is imperative that the principal contractor ensures that there is no introduction of construction workers’ tools, plant and equipment into the RF cage. Magnet vendors’ engineers will only use non-ferromagnetic tools but somehow this information does not appear to be systematically, in the shape of a method statement and risk assessment, pass to the principal contractor for him to adopt for his sub-contractors’ use. This is an important point because although
magnet vendors insist on magnet rooms being completed by the pre-installation contractor before energisation of the magnet. This cannot be guaranteed in every case because of various reasons such as the need to snag finishes, the commissioning of medical gases, ceiling repairs following replenishment of cryogenic gases to the magnet, late requirements for coil and other cupboards, etc.

A case is demonstrated in the PFI contractor’s memorandum in Appendix G where the client wishes to install the floor only of the RF cage, with the remainder being constructed around the magnet. As the magnet would inevitably be energised at this stage, one can only question the thinking behind this proposal in being able to ensure a safe system of work.

Once the magnet has been energised, and so as to protect the magnet bore from damage from ferromagnetic tools, a strict policy of controlling the introduction of tools, plant and equipment into the RF cage should be adopted. A system of clearly marking tools e.g. with insulating tape – RED: not MRI safe, BLUE: MRI safe should be adopted by the principal contractor as part of a permit to work system.

Where only ferromagnetic tools are available, such as saws, knives, screwdrivers these should be kept to a minimum ferrous content, with use within the RF cage being restricted. Where operatives are working within the confines of the RF cage, the bore of the magnet should be protected. If the machine were damaged, this could lead to workplace stress for the operative and/or site manager, as well as for the pre-installation company stakeholders because of the potential effect of such an occurrence on the reputation of the business in what is an extremely small market. A damaged magnet could result in a quench. An additional safety measure might be to install a sheet of 25mm ply
over the entrance to the bore of the magnet – but by ensuring padded protection is put between the ply and the scanner so as not to damage it. This could prevent flying ferromagnetic objects from entering the bore of the magnet.

11.1.16 **THE CLIENT ALSO HAS HEALTH AND SAFETY MANAGEMENT DUTIES**

The CDM Regulations (HMG, 2007) do not require clients to monitor the performance of appointees. However, clients have a duty under Section 2 of the Health and Safety at Work, etc. Act (HMG, 1974) to ensure that the work of contractors does not put employees at risk. Section 3 imposes a statutory duty on employers to make a suitable and sufficient assessment of the risks to the health and safety of his employees whilst at work; and the risks to the health and safety of persons not in his employment arising out of or in connection with the conduct by him of his undertaking. The client has a duty to ensure that the effective management of health and safety on site is being carried out.

Any decision by designers for allowing the 0.5 mT footprint to pass outside the confines of the magnet room should use the principles of ERIC (Eliminate, Reduce, Inform and Control) as well as ALARP (as low as reasonably practicable) and would have to meet the Health and Safety Executive's criteria laid out in its policy document ‘Policy and Guidance on reducing risks as low as reasonably practicable in design’ (HSE 2006). This document contains five key principles, one of which is that it is for duty holders (under the CDM Regulations) to ensure that the chosen design or design concept reduces risk as low as reasonably practicable. Any attempt to use cost/benefit analysis to justify the 0.5 mT footprint of the static magnetic field not being retained within the RF cage, but more particularly being allowed to pass to external areas of the MRI Suite, would be difficult to justify, particularly as it goes against the advice of the Medical Devices Agency (MDA 2007) and NHS Health Building Note.
The general rule for NMR installations can be summed up one simple phrase: protect the magnet from the environment and the environment from the magnet (Einstein et al., 1985). It this mantra that needs to be instilled into the minds of MRI suite designers in order to reduce hazards created by the design.

11.1.17 **THE CDM CO-ORDINATOR SHOULD BE INDEPENDENT**

Where they are sub-contractors to magnet vendors, the difficulty of pre-installation contractors in insisting on being supplied with site-specific plots of the 0.5 mT footprint of the energised magnet from the client is recognised. A CDM co-ordinator experienced in MRI installations and completely independent of the parties can alleviate this problem specific to the pre-installation contractors by co-ordinating the design – even those designs produced by ‘late designers’ - as can be the case of the magnet vendor for example. But any appointment by the client of a CDM co-ordinator carrying out another, but separate function on behalf of the magnet vendor (quantity surveyor, cost consultant, designer, et cetera), should be discouraged so as to avoid a conflict of interest when decisions are made on any siting or shielding requirements for the magnet. The client should recognise this fact when negotiating contracts.

11.1.18 **USE OF MATERIALS WHICH COULD BE PERMANENTLY MAGNETISED**

Information regarding any building elements that could have the prospect of becoming permanently magnetised should be included in the CDM2007 (HMG 2007a) health and safety file. Having this information will be important at demolition or refurbishment stages of any MRI suite, not only to ensure that any structure is deconstructed safely, but at the same time to maximise on materials recycling (HMG 2008) and thus avoid the use of landfill. By flagging up this
information early in the design stage, its recognition ensures that if permanently magnetised elements of the structure are required for recycling following demolition of the structure, they may be utilised in structures where its magnetisation will have no effect on the future use of the building (storage units, et cetera). Alternatively the magnetised material will have to undergo an expensive, and probably not cost-effective, process of de-magnetisation. Although not required by the current CDM 2007 Regulations (HMG, 2007) or its Approved Code of Practice (HSE 2007) knowledge of these magnetised components will rely on the Site Waste Management Plan (HMG, 2008) being included in the health and safety file (Price et al., 2009a). If this does not occur then this important information may be unavailable for the remaining life of the structure. This is because the principal contractor is only required to keep any completed Site Waste Management Plan for two years and is not obliged to pass it to the client at the end of the project.

11.2 RECOMMENDED CHANGES TO LEGISLATION

11.2.1 THE CDM 2007 APPROVED CODE OF PRACTICE

Guidance to The CDM Regulations 2007 (HSE, 2007) through the publication of a subject-specific Approved Code of Practice (ACoP) is in place to guide clients, CDM co-ordinators, designers, principal contractors and contractors, but it is not explicit in mentioning non-ionising radiation or the hazards of human exposure to the static magnetic field. For example, Appendix 3 of CDM 2007 (HMG 2007a) advises headings that should be considered for the construction phase plan and mentions health risks from ionising radiation, but fails to mention those hazards arising from non-ionising radiation (as generated by a magnet installed within an MRI suite).
CDM 2007 (HMG 2007) is directed at clients, designers, CDM co-ordinators, principal contractors and contractors and is the suggested most appropriate current medium for the hazards from the use of non-ionising radiation to be made explicit. In the absence of an Approved Code of Practice relating to MRI installations, the proposed amendment of CDM 2007 (HMG 2007) could be utilised so as to highlight the hazards of non-ionising radiation to those concerned with the conception, design, construction and refurbishment, maintenance or demolition of an MRI suite. Other UK legislation relating to the safety of workers and visitors to MRI suites is, because of its broad application base, implicit in not mentioning the effects of the static magnetic field surrounding an MRI magnet and therefore does not create awareness of the hazards involved with the static magnetic field present in MRI suites.

11.3 Key findings of the study and contribution to knowledge

Cases 1 and 2 give an insight as to how CDM 2007 (HMG, 2007) is applied to the design and construction of magnetic resonance imaging (MRI) suites and provide the background to the rest of the research detailed in the thesis, and in particular to the work carried out in Case 3.

Case 3 builds on previously published work (White, 1980), by providing a synthesis that hasn’t been made before between existing knowledge of magnetic shielding as applied to military uses and current design of passive static magnetic field shielding for MRI suites. As a result of structural and/or financial constraints, magnetic shielding forming a six-sided box as promulgated by White (1980) is not a practical solution for MRI suite designers. The alternative design solution in current use for MRI suites is to shield only the wall(s) where that part of the static magnetic field footprint needs to be retained within the controlled area of any given MRI suite. Until now there has been no
design principle to enable MRI suite designers to calculate the optimum extent of the shielding required for a 1.5 Tesla magnet, and thus avoid the creation of the additional, and unnecessary, hazard of the ‘edge effect’ (increase in magnetic flux density at the edges of the magnetic shielding). Case 3 gives a design solution to designers in that by ensuring that the angle from the magnet’s isocentre to the edge of the designed passive magnetic shielding is in excess of 30° will eliminate the phenomenon of the ‘edge effect’. Additionally, this design solution will prevent over-specification of magnetic shielding requirements in any given situation and potentially provide cost savings to the Client.

There is no previously published literature examining the possible presence of hotspots due to fixing methods used in magnetic shielding construction. This thesis carries out empirical work that has not been done before.

There has been no holistic study to determine the consequences and effectiveness of the introduction of such shielding, whether as part of the original design or as a retrofit solution. By being cross-disciplinary and using different methodologies, this thesis bridges the gap between the medical profession’s knowledge of the hazards of the static magnetic field and the need for that knowledge by the MRI suite designer.

This thesis also brings new evidence to bear on the old issue of magnetic shielding to MRI suites whilst at the same time looking at areas that people in the discipline have not looked at, and adding to knowledge that hasn’t been done before.

In summary, this thesis sets down a major piece of information in writing for the first time.
With the objective of producing guidelines for magnetic shielding designers, further case studies are required. These studies could examine various non-penetrational shielding fixing methods, distances of shielding edges and of the shielding proper (in the axis / axes to be restrained) from the magnet isocentre, and by utilising a range of magnetic flux densities and magnet strengths. Additionally, a study on the rate at which permanent magnetisation of passive magnetic shielding and of any supporting structure would be useful. Such studies could help in determining if, over time, permanent magnetisation of passive magnetic shielding can affect the value of the magnetic flux density both within and external to the magnet room or any designated controlled area. If this does occur, then it could indicate that regular monitoring of the static magnetic field position and flux densities to existing installations may be required.
CHAPTER 12  FURTHER WORK

12.1  THE REPLENISHMENT OF CRYOGENIC GASES DURING THE CONSTRUCTION PHASE

A useful project would be to develop a risk management handbook for clients and contractors to demonstrate the signals that could indicate to individuals being within a strong magnetic field and the precautions that should be taken in order to reduce the risk.

12.2  FRINGE FIELD BLOOMING AT CONSTRUCTION AND OPERATIONAL PHASES

The introduction of ferromagnetic tools and plant into MRI suites during the construction phase once the magnet has been energised is likely to be a prevailing problem to principal contractors and contractors. In the event of a ferromagnetic object being drawn into the magnet and a quench being provoked then the fringe field will bloom. It would be useful for construction and operational personnel to both know the consequences of their actions and to have an indication of the extent of any fringe field blooming so as to be able to set up a risk management plan should there be such an eventuality.

12.3  IDENTIFICATION OF THE 0.5 mT FOOTPRINT IN COMPLETED AND MRI UNITS

During the course of the research for this thesis it became clear that hospitals and clinics are relying on generic 0.5 mT footprints to determine the extent of the 0.5 mT footprint of a given magnet. It would be useful to those hospitals and clinics not having had the benefit of an accurate survey of the 0.5 mT footprint to do so.
12.4 **OPERATIONAL ADVICE TO FIRE BRIGADES**

During the course of this thesis it became evident that on arrival at an emergency incident in an MRI suite some Fire Authorities rely on the accuracy of as-built drawings to inform themselves of the position of the 0.5 mT footprint of the static magnetic field. From the research carried out by this thesis we know that these as-built drawings are unlikely to be correct. Some Fire Authorities also indicated that when their officers were within an RF cage they would communicate by radios which were integrated into breathing equipment. We have shown in this thesis that officers wearing breathing equipment could be drawn into the magnet and we know that radio signals will not penetrate an RF cage. It might be useful for this information to be set out in a Paper in order to inform Fire Brigade risk managers of the potential hazards of emergency fire-fighter intervention at MRI suites.

12.5 **BEST PRACTICE FOR THE SITING AND MAINTENANCE OF QUENCH PIPES**

An issue which was noted during the research and which is not directly connected with magnetic shielding of MRI suites is worthy of mention nevertheless.

The research showed designers’ lack of consideration of the need to site quench pipes in a location where there will not be a danger to employees, the public or other third parties. An example of how a quench pipe was sited over a doorway reached by accessing a balcony at roof level is shown in Figure 11.0.1 below.
Figure 12.1: A quench pipe with its outlet pointing at an external door and a walkway

The same quench pipe is shown at roof level in Figure 11.0.2 below and demonstrates the precarious position when any maintainer might need to access the quench pipe to carry out any programmed maintenance procedure.

Figure 12.2: The siting of the quench pipe necessitate use of a lanyard for maintenance

An example of a quench pipe designed to be maintenance user-friendly is shown in Figure 12.3 below. Clearly there is some way to go in educating
designers in good design risk management as it relates to quench pipe siting and Design but it does demonstrate how simple it could be to eliminate the risk of falling from height of the maintenance operative by the designer incorporating a proper access platform to the quench pipe support steelwork.

Figure 12.3: This design could easily have incorporated a working platform for maintenance.

The development of a best practice design guide for the siting and maintenance of quench pipes may be useful in reducing the hazard of falls from height and of the necessity to work in confined spaces in order to carry out a maintenance task. Examples of these hazards are shown in Figures 12.4, 12.5 and 12.6 below.
Figure 12.4: The designer could have avoided this joint in the quench pipe

Figure 12.5: A bad location for a joint in the quench pipe

Figure 12.6: A confined space has been created for the maintainer to work in
12.6 GUIDANCE NOTES FOR USE BY CDM CO-ORDINATORS

The design and construction of MRI suites is not such a common event as for a block of offices, a factory or the like. For that reason it would be impracticable for CDM co-ordinators to specialise in this subject alone. However, it is a specialist subject worthy of a CDM co-ordinator competent in MRI suite construction. The compilation of a CDM co-ordinators’ Guide to MRI suite construction could be a valuable aid in reducing the risks inherent in MRI suite construction. The research in this thesis might be a starting point for such a tome.

12.7 PERMANENT MAGNETISATION OF PASSIVE MAGNETIC SHIELDING

A study on the rate at which permanent magnetisation of passive magnetic shielding and of any supporting structure would be useful. Such studies could help in determining if, over time, permanent magnetisation of passive magnetic shielding can affect the value of the magnetic flux density both within and external to the magnet room or any designated controlled area.
REFERENCES


Cole, P.R., (2006) personal interview


EUR-LEX, 2010 (EUR-LEX) European Lexicon


Gosbee, J. VANCPS National Center for Patient Safety; MR Hazard Summary
http://patientsafety.gov/mrihazardsummary2.html accessed on 19th March 2011

Hanada, E., Takano, K., Mishima, H., Kodama, K., Antoku, Y., Watanabe, Y. and Nose, Y., Possibility of electromagnetic interference with electronic medical equipment by residual magnetization in a building with a steel structure. IEEE EMC Newsletter 189, 15–19


HMG, 1994 Accommodation for magnetic resonance imaging. Health Building Note 6 - Supplement 1. Fig 4: NHS Estates. Her Majesty’s Stationery Office, London


King, I., (2010) personal communication


APPENDIX A  PUBLISHED RESEARCH PAPERS

A.1  PRICE, T. (2010) SAFETY SCIENCE
A case study on the influence of a magnetic shielding retrofit on the static magnetic field present in a Magnetic Resonance Imaging (MRI) suite

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ABSTRACT

Purpose: The purpose of this research is to assess whether the practice of retro-fitting passive magnetic shielding to Magnetic Resonance Imaging (MRI) suites is effective in retaining the 0.5 mT footprint of the static magnetic field to within its designed position.

Methodology: The research methodology involved identification of an MRI installation where passive magnetic shielding was to be fitted to an installation already in operational use. Site based physical measurement of the magnetic flux density of the static field were then taken both ante and post installation of the shielding, so as to be able to determine its effectiveness.

Findings: The results identified areas in the retrofitted magnetic shielding where, as a result of its design, hot spots in excess of 0.5 mT occurred.

Practical implications: The research highlights design, construction and safety issues that the designer could, if he had this prior knowledge, have eliminated at source.

Value: As the planning stage of a new MRI suite, designers could use the information contained in this research as part of their design risk management process. This research serves to demonstrate the importance of eliminating any possible future need to install retrofitted passive magnetic shielding to an original MRI suite design. It also shows the need for designers to identify the location of any hot spots in the shielding installation where the magnetic flux density may exceed 0.5 mT and becomes a potential hazard to those individuals fitted with heart pacemakers or other electronic body implants.

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1. Introduction

1.1. Background to the magnetic resonance imaging process

Modern MRI scanners usually consist of a superconducting magnet combined with the use of radiofrequency (RF) signals to produce images of the biological matter being examined (usually the human body). A very simple explanation of the imaging process is that within the scanner there is a strong magnet used to create the ambient static magnetic field. In addition, there is gradient system of three coils that are used to produce linear field distortions in the z, y and x axes and the amplifiers. These coils are made using niobium-titanium and kept in temperatures near absolute zero, usually by the use of liquid helium (it is kept at about 4 K). Their superconducting properties are as a result of the extremely low temperature in which they are stored and as a result they should have no resistance to an electrical current. In theory this allows the external electrical supply to be disconnected once the magnet has been fully energized.

When a patient enters the bore of the magnet the static magnetic field will align the hydrogen protons present in the patient with the direction of the magnetic field. The imaging process then consists of a radiofrequency (RF) signal of the same sound wave frequency of the target protons being switched on, with the receiving protons absorbing some of the energy and "wobbling" free from the magnetic field. When the RF signal is switched off, the protons release the energy and re-align themselves with the magnetic field in the bore of the magnet, emitting a radio frequency signal as they do so. It is this RF signal that is used to build an image of the tissue being examined. The hydrogen nucleus (i.e., the proton) is more commonly used for clinical imaging because as well as being the most plentiful, it has the largest magnetic moment of any stable nucleus present in the human body and manifests itself mainly as water and fat.

The rate of installation of magnetic resonance imaging scanners has seen steady growth over the last ten years, but has since tailed off dramatically. Fig. 1 below demonstrates this. The reasons given for this reduction in installations for 2007/2008 (personal communication, 2009) are because the central funding programmes were coming to an end, National Health Service Trusts are not yet ready to replace those scanners installed earlier in the programmes, and
they are not yet committing to purchasing additional scanners to supplement those in place.

1.2. Electro-magnetic fields

MRI magnets are installed within a Faraday (RF) cage (the scanner room). Faraday cages are constructed of conductive material, usually of copper or aluminium, and are essential in ensuring that external static electrical fields are prevented from distorting the RF signal being utilised to create the image. Faraday cages do not protect the magnet from the influence of magnetic fields external to the MRI magnet, or in reverse, protect persons or objects outside the Faraday cage from the reach of the magnetic fields produced by the magnet.

1.3. Magnetic shielding options

It is crucial to the imaging process that the symmetry of the static magnetic field generated by the magnet remains within limits set by the magnet vendor. This will ensure that the magnetic resonance imaging process produces a viable image. In order to achieve this, the introduction of magnetic shielding to protect this symmetry of the static magnetic field of the magnet from outside influence may be required. Depending upon location and local environmental parameters magnetic shielding can be active (incorporated into the magnet design), passive (by shimming the magnet), or as part of the structure of the MRI suite.

However, MRI suite design has its issues and it has been recognised (Kurtz, 1982) that architects and planners are grappling with many unknowns in designing suites for magnetic resonance imaging equipment.

1.4. The use of ferromagnetic materials in the general construction of an MRI suite

Any ferromagnetic elements used in the general construction of an MRI suite and coming into contact with the magnet’s fringe field could become permanently magnetised. This could be by use of ferromagnetic air-conditioning ducting, steel electrical conduits, use of a steel frame in the parent structure or in stud partitions to the magnet room, to name a few.

Even when the MRI magnet is removed, these ferromagnetic elements will still possess a magnetic remanence relative to the material used, making future use of the room(s) to hold any computers or electronic storage media, or the ability to convert the room to accommodate electronic equipment, questionable. This is because the permanently magnetised construction material will affect any electronic equipment into which it comes into contact. The advice is that even though a 0.5 mT magnetic exposure seems a relatively low figure, any significant amount of steel needs to be kept outside its footprint because if an MRI were in place for a number of years, it would cause a static magnetic field to build up in any nearby ferrous materials. A suitable analogy (Kob, 2004) might be the effect of the dripping of mineral rich-water from a cave ceiling and which eventually gives birth to imposing stalactites.

1.5. Information on materials susceptible to permanent magnetisation

Information regarding any building elements that could have the prospect of becoming permanently magnetised should be included in the CDM 2007 (HMG, 2007a) health and safety file. Having this information will be important at demolition or refurbishment stages of any MRI suite, not only to ensure that any structure is deconstructed safely, but at the same time to maximise on materials recycling (HMG, 2008) and thus avoid the use of landfill. By flagging up this information early in the design stage, its recognition ensures that if permanently magnetised elements of the structure are required for recycling following demolition of the structure, they may be utilised in structures where its magnetisation will have no affect on the future use of the building (storage units, etc.). Alternatively the magnetised material will have to undergo an expensive, and probably not cost-effective, process of demagnetisation. Although not required by the current CDM 2007 Regulations (HMG, 2007a) nor Approved Code of Practice (HSE, 2007) knowledge of these magnetised components will rely on the Site Waste Management Plan (HMG, 2008) being included in the health and safety file (Price et al., 2009a). If this does not occur then this important information may be unavailable for the remaining life of the structure. This is because the principal contractor is only required to keep any completed Site Waste Management Plan (HMG, 2008) for a period of two years following completion of the project.

1.6. Passive magnetic shielding as part of the structure

Passive magnetic shielding as part of the structure of the MRI suite may be a design option, not only to manage the effect on the magnet of ferromagnetic objects but, because neither active shielding nor passive shielding of the magnet will compensate for the presence of moving ferromagnetic objects such as lorries, cars, ambulances or tube trains falling within the footprint of the static magnetic field. These elements could have an adverse effect on the symmetry of the static magnetic field of the magnet and the consequential inability of the RF signal to produce accurate information to be translated into a viable image.

There may also be limits to the amount of magnetic shielding which can be incorporated into the MRI suite, either because of magnet location or of structural constraints. These limits may even restrict the use of magnetic shielding – even to the possible extent of having to re-site the magnet. It is feasible that cases could occur (Price et al., 2010) where the requirement for magnetic shielding could equate to several tonnes of extra loading to the structure, making it important that this possibility is discussed early in the design stage.

A case could arise where magnetic shielding may need to be retrofitted because the original design did not fully enclose the 5 Gauss footprint, or even lesser values, that may present interference potential with other modalities or equipment within the controlled area of the MRI suite. It is therefore crucial that the Lead Designer and CDM co-ordinator ensure recognition, co-operation and
and co-ordination of all designers (including the magnet vendor) including their sub-designers, as early as possible in the MRI suite design. This will enable account to be taken of the likely presence of all ferromagnetic material which could fall within the influence of the static field of the magnet - thus allowing the Lead Designer to be able to make an informed decision on the magnet's location and/or orientation. Each MRI suite design is different, and by understanding the magnetic resonance imaging process from an early stage in the design, and by careful siting of the magnets, the designer can often eliminate the need for magnetic shielding. However, it is feasible that even during detailed design stage the client may not yet have decided on his magnet supplier. When this is the case, the magnet supplier becomes a late designer under CDM 2007 and adds to the difficulties of the CDM co-ordinator in him ensuring that all designers are co-ordinating their designs with the Lead Designer and incorporated into his Design Risk Management Plan. The RF (radiofrequency) cage (in which the magnet is installed) supplier would normally be the party designing any necessary magnetic shielding on behalf of a particular magnet vendor. Therefore any late decision on the choice of magnet vendor, even though the client may have instructed the architect to take the worst-case scenario (Price et al., 2009b) could still result in a less than perfect design solution when considering the effects of the static magnetic field in deciding on any given MRI suite location.

1.7. Typical passive magnetic shielding costs

Typical square metre market rates for the installation of passive magnetic shielding to the structure of a building have been obtained from a large UK based shielding contractor. This shielding contractor has advised that retrofitting magnetic field shielding would be enormously expensive with most additional costs being in preparing the area to receive any magnetic shielding. In a personal communication (King, 2009) it was revealed that the approximate cost of including magnetic shielding as part of the design of a typical new installation would be £600 per square metre, but as a retrofit £1200 per square metre.

1.8. Passive magnetic shielding as part of the original design

Assuming one wall of a new installation to be on the borderline of requiring shielding, then taking a typical wall area of 4000 mm x 3000 mm in the z axis, this could currently equate to an extra cost to the Client of just over £8000. Should magnetic shielding be specified by one of the tendering design and build contractors in his bid, but not by others, then it may be prudent for the client to ask why, and ask to see the Lead Designer's Risk Management Plan. This would ensure that all tendering contractors had considered the possible need for the introduction of magnetic shielding and in theory eliminate the need for retrofit magnetic shielding at a later date - either during the construction phase or following handover to the MRI suite for operational use. Where at detailed design stage a view might be taken that the risk of a requirement for shielding is low and the designer had decided that it should be disallowed from the original design specification, then using the wall area cited above any subsequent future requirement for retrofit shielding would result in an extra cost to the Client of over £16,000. This cost would be largely dependant upon the quantity of services installed in the ceiling void below the magnet as these would have to be temporarily removed whilst any magnetic shielding was being fitted and could involve substantial costs. There is also the question of how these services will be re-fixed to the underside of the floor slab once any retrofit magnetic shielding has been installed. If the services fixings were ferromagnetic and connected to the bolts used to connect any magnetic shielding to the floor slab, then they may themselves become magnetised by the passage of the static field through them and, if the services themselves were ferromagnetic, to those as well. The reader may ask why this happens. This is because any magnetised elements will themselves have an effect on any electronic equipment or storage media falling within the influence of this (extended) static magnetic field. Such electronic equipment may not function correctly due to “wiping” out of information stored on electronic media.

1.9. Passive magnetic shielding as a retrofit

Where retrofit magnetic shielding is found to be required there would also be the additional costs of supplementary design fees, disruption to the MRI facility and a possible loss in patient throughput and reputation for the hospital/clinics - the real cost of which may not justify magnetic shielding being eliminated from the original design if all the implications of their decision were taken into consideration at detailed design stage. The difficulty arises if the client is not informed of the possibility of magnetic shielding being required for his installation.

The cost of magnetic shielding is such that during any design and construct tender bid for a new MRI suite, introduction of passive magnetic shielding into the design may be considered as an overspecification if the risks of allowing the 0.5 mT footprint of the static magnetic field passing to designated controlled areas outside the magnet room are considered by the designer to be small.

1.10. Controlled areas of the static magnetic field of an MRI suite

In the United Kingdom an operational MRI suite would normally consist of a minimum of two controlled areas:

- an Outer Controlled Area, where the 0.5 mT is the reference value (MDA, 2007) and being totally enclosed and of such size so as to contain the 0.5 mT (5 Gauss) magnetic field contour.

Having knowledge of the exact as-built position of the 0.5 mT footprint of the static magnetic field in all its axes is important because of its effect on certain heart pacemakers or other electronic implants within the human body. This is because 0.5 mT is the threshold for exposure to the static magnetic field of all individuals that have not been successfully screened for contra-indications and therefore (MDA, 2007) a person fitted with a heart pacemaker must not enter the MR Controlled Area. However, it should be understood that this effect is not a direct biological one to the individual, but is a risk of a magnetic field electro-mechanical interference with the medical device by causing the magnetic reed switch that varies the heart rate to be inadvertently switched (Young, 2000) by the static magnetic field and revert to its default setting. This could lead to irregular heart rhythm of the wearer of the pacemaker and eventually to his or her serious handicap or death.

This hazard is not restricted to operational MRI suites. The same hazard will exist during the construction phase where construction workers and site visitors could be at risk, making it important that a controlled area encompassing the 0.5 mT footprint of the static magnetic field be set up on site and workers and visitors screened for access before the magnet is energised. It should be noted that there are also other hazards of human exposure to the static magnetic field and there have been serious injuries and a few fatalities documented (mirasafety.com, 2009) which were associated with the inadvertent introduction or presence of ferromagnetic objects into MRI suites.

- an Inner Controlled Area, being totally enclosed and of such size so as to contain the 3.0 mT (30 Gauss) magnetic field contour (MDA, 2007).
The reason for a requirement for this outer controlled area is because ferromagnetic objects coming within the 3.0 mT footprint could become attracted by the magnet — the 'projectile effect' (also known as translational attraction) that can be exerted by magnetic fields upon ferromagnetic objects and become a safety hazard to those individuals in the object's path as it is drawn towards the bore of the magnet. There is also one other physical force or torque, which needs to be considered. When subjected to magnetic fields, a heart pacemaker or other medical device or implant could, as well as be affected by electro-mechanical interference described above, also become translated (torque within the individual so as to align itself with the magnetic field to which it is exposed. At the same time it could be pulled towards the magnet by translational attraction whilst embedded in the individual's body. Therefore, it is not only individuals who may be fitted with heart pacemakers or other electronic implants who could be at risk from exposure to the magnet's static magnetic field, but could also include those persons who may have been subjected to metal particles being lodged in the eye. This could be as a result of the individual having been involved in welding operations, general metalwork and the like. In the management of MRI suites (MDA, 2007) it is known that one of the most vulnerable parts of the body is the eye. The adequate screening of anyone with suspected intra-ocular ferromagnetic metallic objects is most important before they are allowed to enter the Outer (0.5 mT) Controlled Area of the MRI suite.

1.11. Access to the 0.5 mT controlled area of the static magnetic field

On visiting an MRI suite as a patient controls in the form of a questionnaire will be presented for completion by the person wishing to enter the Outer Controlled Area containing the 0.5 mT footprint of the static magnetic field. This questionnaire will enquire as to whether, amongst a range of possibilities, a ferromagnetic object could be present in that person's body or if the person is fitted with a heart pacemaker or other bodily implant (including prostheses). Those persons having contra-indications for exposure to electro-magnetic fields (EMFs) will be excluded from the suite. However, during the construction phase of an MRI suite and although the magnet will be energised whilst construction works take place, construction workers are not normally subjected to the same screening criteria as for an operational unit (Price et al., 2004).

1.12. Ambiguity in the recommended position of the 0.5 mT footprint

Large magnetic fields extend in three dimensions around the magnet. Magnetic fields are invisible; it is impossible to know if they are on or off, or to be aware of them unless told. Although it is important to know the position of the 0.5 mT (5 Gauss) footprint of the static magnetic field, there is some ambiguity in published NHS advice regarding its recommended position. One publication (NHS Estates, 1997) states that it should ideally be constrained within the confines of the MRI scanner room. However, in another document still being referenced by MRI suite Designers, there is a figure that gives conflicting advice (NHS Estates, 1994) that it should be restricted to the magnet (examination) room and the technical room.

1.13. The static magnetic field is also present in the y axis of the magnet

To complicate matters further the figure referred to above only shows an illustration of a generic footprint of the x (lateral) and z (horizontal) axes of the static magnetic field to a magnet, whilst ignoring that of the y (vertical) axis, thus only telling only part of the story. Because information provided only relates to the position of the x and z axes, it is possible that any principal contractor, contractor or maintainer could mistakenly believe that either there was no potential hazard from the static magnetic field, or at worst, that it did not exist. With the rapid expansion of MRI suite installations in recent years it is conceivable that without it being pointed out to them, not all principal contractors or contractors likely to work within or around an MRI suite, although being competent contractors, can be sure to be adequately informed of the hazards of the static magnetic field.

1.14. The main MRI magnet configurations

There are two main configurations for MRI magnets; being bore/tunnel magnets and 'open' format 'hamburger bun' type magnets. In both cases the y axis of the static magnetic field is present. The magnetic field of a bore/tunnel format magnet is predominantly horizontal and in the z axis but there is still a significant lateral (x axis) and vertical (y axis) component. For 'open' format 'hamburger bun' type magnets the larger component of the static magnetic field is in the y axis, resulting in slightly diminished hazards on the same level as the magnet (as compared to bore format magnets), but greater hazards above and below. Generic x, y and z axes of the 0.5 mT footprint of the static magnetic field are shown in Fig. 2, below.

The difficulty in not highlighting the presence of this vertical (y axis) component of the magnet's static magnetic field to designers is that construction or maintenance personnel may not fully appreciate its relevance to their safety. Recognition of the presence of the static magnetic field is important where access is required to areas, such as ceiling voids, below the magnet. This is because these areas are extremely likely to come within the influence of the y axis of the static magnetic field; whether magnetic shielding (retrofits or as part of the original design) is fitted or not. Magnetic shielding which is employed to retain the x and z axes will have an effect on the position (making it larger) of this y axis, with a consequential change in the magnetic flux density above and below the magnet — knowledge of which is crucial to any risk management process.

1.15. Passive magnetic shielding and its effect on the symmetry of the footprint of the static magnetic field

The introduction of passive magnetic shielding to an MRI suite design, whether as part of the initial design or as a retrofit solution can also, because of its ferromagnetic properties, affect the symmetry of the footprint of the static magnetic field and possibly force it to extend to areas outside the RF cage or to areas where the (unscreened) general public has access and where it could become a hazard.

Where the original design of the MRI suite did not include the provision of passive magnetic shielding to the magnet room, and there has since been a change in the use of adjacent areas of the magnet room where the 0.5 mT footprint of the static magnetic field may previously have been allowed to pass without it becoming a hazard, then the introduction of retrofit magnetic shielding to retain the 0.5 mT footprint within the RF cage could be a design solution. Bearing in mind that passive magnetic shielding should ideally be formed as a six-sided box and have no penetrations, (White, 1980) this is not practically possible in MRI suite design. Consequently, where magnet vendors' generic static magnetic field plots may be seen to extend to areas outside the MRI suite, any magnetic shielding deemed by the designer as being required to retain the 0.5 mT footprint of the static magnetic field within
that footprint will not be a six-sided box and therefore have limitations on its shielding performance.

Using magnetic shielding (Pavlicek et al., 1984) is like trying to stuff a balloon into a box. Pushing on one end of the box will cause the balloon (fringe field) to expand out the other. Because of this effect on the footprint of the static magnetic field it is particularly important to ensure that any designed magnetic shielding which is not symmetrical around the magnet has made allowances for distortion of the fringe field by the magnetic shielding itself. Under the CDM 2007 Regulations (HSE, 2007a) one of the principal targets for designers should be to design out or minimise risks from safety hazards, and not to create them.

1.16. Increased magnetic flux density at the edges of passive magnetic shielding

When magnetic shielding is introduced into an MRI suite design an additional problem can occur as 'edge effects' could be caused by the magnetic shielding. These edge effects along the periphery of the shielding (AAPM, 1986) may result in field strengths within the magnet (examination) room being in excess of a magnet room without shielding. Although magnetic shielding can reduce the stray field, this screening may create areas of flux concentration and therefore some local areas of high flux density and large flux density gradients (Bore and Timms, 1984). This fact makes it important for the Lead Designer, principal contractor and client to have knowledge of these site-specific magnetic flux densities so as to be able to manage safety within (and around) the MRI suite.

1.17. Limits of worker exposure to static magnetic fields

Knowledge of these site-specific magnetic flux densities is crucial so as to enable compliance with the published guidelines (ICNIRP, 2009) on limits of exposure to the static magnetic field for the general public of any part of the body to a magnetic flux density not >400 µT. In using the term 'general public' this is taken to describe those persons not being members of the MRI imaging operational team who are exposed to the static magnetic field of the magnet. Therefore, having information on site-specific magnetic flux densities is relevant to both the construction and maintenance phases of an MRI suite.

1.18. Creation of time-varying magnetic fields by movement within the static magnetic field

Motion in a magnetic field (Scherck, 2004) will cause the flow of electric current even if there is no applied electric field. These magnetic field-induced currents will manifest themselves any time that there is movement within the field. Therefore, any worker moving within a static magnetic field will, by definition, automatically trigger the creation a time-varying field. For some years it has been known (Bolley, 1992) that time-varying magnetic fields produced by alternating-current devices induce electric currents in conductive material, including the human body.

1.19. Limits of worker exposure to time-varying electric and magnetic fields

As a result of this knowledge, as well as there being guidelines on limits of exposure of workers to static magnetic fields, guidelines have also been produced for limiting exposure to time-varying electric and magnetic fields up to 300 GHz. These guidelines (ICNIRP, 1998) contain basic restrictions for exposure to time-varying electric and magnetic fields for various frequencies up to 300 GHz. So as to reinforce worker protection from exposure to these time-varying fields, Directive 2004/40/EC of the European Parliament dated 20th April 2004 (EC, 2004) was due to be incorporated into UK legislation during 2006. Representations made to the European Commission by the medical community using the argument that 'interventional MRI procedures could cause as healthcare workers would be exposed to electro-magnetic fields (EMFs) greatly exceeding the limits in the Directive',...and 'that the limits in the directive were inappropriate for application in MRI as they are based on prevention of effects on the Central Nervous System'.

Concerns were raised (Galston Sciences, 2006) that unless some convincing evidence is produced the directive may well be modified to introduce a limit for worker exposure to static fields. As a result of representations made, the European Commission reviewed Directive 2004/40/EC, and on 23rd January 2008 agreed to postpone entry into force of that directive until 30th April 2012 to allow for a revision of the exposure limits.

This directive refers to the risk to the health and safety of workers due to known short-term adverse effects in the human body.
caused by the circulation of induced currents and by energy absorption and contact currents. This reinforces the arguments given earlier that workers should be given knowledge of the true (post magnet-energisation) position and magnetic flux densities of areas around the magnet in which they are asked to work. Without this knowledge the employer will be unable to satisfy the requirement in the directive. The directive requires that the employer should assess and, if necessary measure and/or calculate the levels of electro-magnetic fields to which workers are exposed and give particular attention to the level, frequency, spectrum, duration and level of exposure and to any effects concerning the health and safety of workers at particular risk.

In the meantime, the guidelines on limits of exposure of workers to time-varying electric, magnetic and electro-magnetic fields up to 300 GHz (ICNIRP, 1998) are those that are current until the exposure limits are revised by Directive 89/330/EEC (EC, 1989).

As result of these ICNIRP guidelines (ICNIRP, 1998) any increased magnetic flux density within the examination room will reduce the length of time that workers can be exposed to its influence and any activity within these areas will need to be monitored and documented. In addition, the position of the areas where the static magnetic field footprint of the magnet is known, increased magnetic flux density could enable sensory thresholds of internally induced electric fields from whole body exposure to a time-varying magnetic field to be reached in a different location within the MR examination room than may have been envisaged by the Lead Designer for the original MRI suite. Not having comprehensive information on the magnetic flux density of the static magnetic field would make any monitoring of workers’ exposure and therefore compliance with the ICNIRP guidelines (ICNIRP, 1998) impossible.

1.20. Exposure of construction and maintenance personnel to static and time-varying electric and magnetic fields

However, as mentioned above is it not only MRI personnel or patients and their visitors who may be exposed to these high levels of magnetic flux density and the resultant likely creation of time-varying electric and magnetic fields following handover by the construction company to the client for operational use. One also has to consider the construction phase of an MRI suite. Construction workers and site visitors would be exposed to the static magnetic field in the period between energisation of the magnet by the magnet vendor’s engineers during the final stages of construction phase until handover to the client for operational use.

Even following handover to the client, regular visits by an ‘external’ operator in order to replenish the cryogenic gases used to cool the magnet’s coil, or by maintenance personnel wishing to carry out a simple task, could risk exposure to this hazard. This is a particularly important point because a worker may, having moved his head quickly whilst in an area of high magnetic flux density within the MRI examination room, experience vertigo whilst working from a pair of steps or a ladder (whilst replenishing the cryogenic gas for example) and fall to the ground. The current regulations governing work at height (HMG, 2005) do not explicitly mention this scenario. However, it’s a real possibility and should figure in the Lead Designer’s Residual Hazard and Risk log and be included in the CDM 2007 health and safety file (HMG, 2007a) handed to the Client at the end of the construction project. This possibility is highlighted as it is relevant to 1.6 The Health and Safety Executive’s latest published figures (KIND1) which show that for the period 2007/2008 there were four fatal events, 536 non-fatal major injuries and 306 injuries where there was an absence from work of three days or more resulting from a fall from height of up to and including 2 m. This is the height range in which an operative working in an MRI suite may perhaps be required to fit cupboards for coo storage, or for storing patient sup- phrases. This could be as the result of a local request or through the Lead Designer.

1.21. Managing the hazards created by the use of magnetic shielding

In designing an MRI suite it would be impossible to eliminate the hazard of the static magnetic field completely, but it can be stated that the most efficient methods of reducing the risks of worker exposure are either to avoid the creation of areas of high magnetic flux density as much as possible (limiting worker exposure to static magnetic fields), or to limit rapid head movement of individuals moving within these areas (exposure to time-varying magnetic fields). Where the worker is made aware of this hazard, he may be able to mitigate the risk to his personal safety by utilising the advice given to MRI suite operational staff. Within the context of an operational MRI suite it was noted that by moving patients slowly whilst they are in regions of very strong fields their effect, and vertigo in particular, (Scherr, 2000) could be reduced. Similar information is available to the scientific community and operational MRI personnel in particular. Providing information on the early physical signs of electric field induction, notably hair vibration (Reilly, 1992). This information could also include those effects (Courtois, 2007) which could give the work experiences of headaches, nausea, paresthesies (light flashes), numbness and tingling, loss of proprioception and balance, or of a metallic taste in the mouth. During the construction phase of an MRI suite, and including the period whilst it is being maintained during the operational phase, there is no reason why the same tell-tale signs used by MRI operational staff cannot be used to inform construction and maintenance workers of their exposure to the static magnetic field.

This would assist them in reducing the risks of their physical exposure to it. There are also other clues that could be used by workers to signal that they had come within the influence of an area of high magnetic flux density. There are individuals (WHO, 2004) that report a wide range of symptoms that they attribute to exposure to electromagnetic fields, or to being close to electromagnetic equipment. However, WHO (WHO, 2004) admit that to date experimental and epidemiological studies have failed to provide clear support for a causal relationship between electro-magnetic fields and complaints. Nevertheless, the reality of these effects has not been discounted, with the term ‘Idiopathic Environmental Tolerance’ (Electromagnetic field attributed symptoms), or IE-EMF, being adopted.

1.22. Relevant UK legislation relating to worker exposure to electromagnetic fields

Currently, there is no specific UK legislation which refers to the effects of non-ionising radiation on humans. However, there are three main pieces of general legislation that could be used to protect workers if it became necessary. The difficulty in using such general legislation is that its use will rely on any prosecutor’s strength of evidence presented to the court. Specific legislation would overcome this hurdle, as any litigation would merely need to prove if the specific legislation, or advice given in any Approved Code of Practice (ACoP), had not been complied with.

Nevertheless, a requirement does exist that employers must protect those affected by their undertaking (HMG, 1974) and to have regard for personal safety and that of other workers in particular. This imposes an implicit duty on any employer to ensure that his employees know the true (post magnet-energisation) position and magnetic flux density of the static magnetic field within or around any MRI suite, are given instruction and training, and are adequately supervised. This requirement is reinforced by other legislation (HMG, 1959) imposing a statutory duty upon employers to...
make a suitable and sufficient assessment of the risks to the health and safety of his employees to which they are exposed whilst at work; and the risks to the health and safety of persons not in his employment arising out of or in connection with the conduct of his undertaking. Under this legislation, the employer must ensure that none of his employees has access to any area occupied by him to which it is necessary to restrict access. This legislation suggests a requirement for a controlled area around the perimeter of the 0.5 mT footprint of the static magnetic field of the magnet to be set up, not just restricted to general field areas supplied by a given magnet vendor, but to include all those areas where the 0.5 mT footprint has an influence. Again, this translates into the need for the employer to have knowledge of the true (post magnet-energy) position and magnetic flux density of the static magnetic field within or around any MRI suite. The employer is also required to establish, and where necessary, give effect to appropriate procedures to be followed in the event of serious and imminent danger to persons at work in his undertaking.

As far as MRI suites are concerned, the furnishing of this safety-related information is critical to those who are working within the 0.5 mT footprint of the static magnetic field of the magnet. CDM 2007 (HMG, 2007a) defines this as a requirement to supply the right information for the right people at the right time. Compliance with this advice will enable the client to comply with the minimum health and safety requirements regarding the exposure of workers to the risks from electro-magnetic fields, and in particular (Pavlicek et al., 1984) the requirement for risk assessments and health surveillance. By taking account of technical progress and of the availability of measures to control the risk at source, the risks from exposure to electro-magnetic fields should be eliminated or reduced to a minimum. Again, this translates into the need for the employer to have knowledge of the true (post magnet-energy) position and magnetic flux density of the static magnetic field within or around any MRI suite. This information should be readily available to the employer because the designer is required (HMG, 2007a) to take all reasonable steps to provide sufficient information with his design about aspects of the design of the structure or its construction or maintenance, as will adequately assist clients, other designers, and contractors. This can be taken as a requirement for the identification, by the designer or designers, of any control measures that should be put in place in order to manage any residual risks to the design that were not able to be eliminated at the design stage. These are measures which should identified for adoption by those either constructing, using or de-commissioning and demolishing any structure, as well as those being necessary to protect third parties for the whole of the life of the structure.

2. Rationale for the case study

2.1. The 0.5 mT footprint of a magnet's static magnetic field was passing into a public corridor in a live hospital

The reason for embarking on this case study was because of concerns that the 0.5 mT footprint of a magnet's static magnetic field was being allowed to pass into a public corridor at a ‘live’ hospital. The case study was to establish if the remedy of introducing retrofitted passive magnetic shielding was effective in retaining the 0.5 mT footprint within the controlled area of the MRI suite.

From a management of health and safety viewpoint, and given the requirements of current statutory and non-statutory legislation, having all the information relating to the sit-built position and magnetic flux density plots of the static magnetic field footprint is important to the Client, his CDM co-ordinator, the Lead Designer and any Principal Contractor and Contractor. Having this information would enable them to ensure that any and all areas of increased magnetic flux density are included in both the Outer and Inner Controlled Area of any MRI suite; but these areas require to be known and their magnetic flux density plots identified and made available to everyone working on or visiting the location before this can take place.

3. Research aim and objective

3.1. Research aim

The aim of this case study was to identify if there was any residual design risk in relation to the static magnetic field associated with the use of retrofitted magnetic shielding to MRI suites.

3.2. Research objective

The research objective was to identify information that might be useful in aiding designers of magnetic shielding to identify hazards associated with them. This study investigated the risk along with the advice of the CDM co-ordinator, the initial design could be amended to eliminate or reduce them.

4. Research methodology

4.1. Choice of site

Initial requests to hospitals for details of any passive magnetic shielding that had been installed to their MRI suites (Price et al., 2010) led to the discovery that a magnet had previously been installed to a hospital with the 0.5 mT footprint of the static magnetic field of a 1.5T magnet being allowed to pass into an adjacent public corridor. On questioning the hospital concerned, it was found that a contract had been placed to install retrofit passive magnetic shielding, the purpose of which was to retain the 0.5 mT footprint within the magnet room. An opportunity was given to witness the installation of a magnetic shielding retrofit and to take physical measurements of the static magnetic field from both within and outside the MRI examination room, pre and post-shielding installation. The static magnetic field was present around the magnet at all times.

4.2. The reason for the need to install retrofitted passive magnetic shielding

The generic 0.5 mT footprint of the static magnetic field for the installed scanner showed a maximum reach of 3.900 m for the z axis and 4.600 m for the x axis from the magnet’s isocentre, necessitating a minimum room size of 7,800 m² x 4,600 m. This minimum room size assumes that the magnet isocentre is situated at the centre-point of the magnet room and that proximate ferromagnetic objects will not have an effect on the symmetry of the static magnetic field.

In this case study, the z axis of the 0.5 mT footprint of the static magnetic field was being retained in the examination room at the entrance door end, but encroaching on a public corridor at the opposite end of the room. The magnet room was dimensioned at 6.976 m in the z axis x 4.400 m in the x axis. Not only had the magnet been installed off-centre to the room, but also the room dimensions were insufficient to retain the static magnetic field within the magnet room even if the magnet had been installed with its isocentre at the centre-point of the room. In the z axis the isocentre was protruding into the public corridor by 2.030 m and in the x axis into the adjacent Technical Room by 0.450 m. This is shown in Fig. 2 below.

Please cite this article in press as: Price, T. A case study on the influence of a magnetic shielding retrofit on the static magnetic field present in a Magnetic Resonance Imaging (MRI) suite. Safety Sci. (2010), doi:10.1016/j.ssci.2010.04.013
This situation necessitated a retrofit of passive magnetic shielding in order to protect visitors, patients, and staff using the public corridor from the influence of the static magnetic field. The adjacent Technical Room had two access doors, one being from the MRI Control Room and the other from the public corridor. As this door was fitted with a suited key, controlling access to the Technical Room from the public corridor would be difficult to manage. If retrofit magnetic shielding was not fitted, then either the public corridor would have to be drastically reduced in width by constructing a permanent physical barrier to prevent exposure to the 0.5 mT footprint of the static magnetic field, or the MRI installation would have to be shut down. Because of means of escape requirements, it would not be possible to reduce the width of the public corridor, nor because of operational requirements, close the MRI installation. The introduction of magnetic shielding was the only viable solution available to remedy the original design error.

4.3. Choice of Testimeter required to carry out the survey

Because the site to be surveyed was an operational MRI suite there was a short time scale that would be allowed in which to carry out a field survey. It was decided to attempt to reduce the need for on-site calculations by obtaining an instrument which would be capable of the simultaneous measurement of the three axes of x, y and z set at a 90° angle, thus allowing a direct measurement of the magnetic field intensity.

A decision to use a Metrolab Instruments ETM-1 Testimeter, shown in Fig. 4 below, was made based on the following criteria:

- Size and weight.
- Simple and quick to take readings.

- mT range.
- Battery.
- Zero-field chamber.
- Sensor cable length.
- Immediate availability from the supplier.

4.4. Ethical issues

The scanner was undergoing a maintenance check and the hospital had closed the MRI examination room for patient examinations during this period. Therefore there were no consequences to patients as a result of the physical measurements of the static magnetic field being taken.

4.5. Survey method

Surveys were carried out to measure the magnetic flux density on the corridor side and internally to the MRI examination room both before introduction of magnetic shielding and again after its installation so as to determine if the designed magnetic flux density footprint corresponded with the actual footprint. Photographs and measurements of the magnetic shielding, including details of fixing methods used, were taken. Static magnetic field readings at the fixing points were taken to establish if the introduction of the mechanical fixings, which were able to pass through the magnetic shielding to a backing board used to support the shielding, were as efficient as the shielding itself.

It was decided to base the survey on a 500 mm grid, with the isocentre of the machine at its z axis and the rear wall of the examination room being the reference points for the grid orientation.

Static magnetic field measurements were taken both within the
magnet room and on the corridor (public) side of the rear wall before and after the retrofit passive magnetic shielding had been installed.

5. Results

5.1. Within the MRI examination room

5.1.1. Before magnetic shielding was installed

Table 1 below shows the results of field measurements of magnetic flux density taken at each survey position on the MRI side against the plasterboard and studwork wall dividing the MRI examination room and the adjacent public corridor partition wall.

5.1.2. After magnetic shielding was installed

Table 2 shows the results of field measurements of magnetic flux density taken on the MRI side at each survey position against the plasterboard and studwork wall dividing the MRI examination room and the adjacent public corridor partition wall.

5.1.3. Comparison of the survey results

The introduction of magnetic shielding to the MRI examination room resulted in increased magnetic flux densities within the room. Tables 1 and 2 above have been transposed into contour graphs in Figs. 5 and 6 below and demonstrate the effect of the shielding on increasing the ambient magnetic flux density against the MRI side of the MRI/ corridor dividing wall. The threshold for exposure of unscreened personnel to the static magnetic field has been set as 0.5 mT. As the minimum magnetic flux density measured within the room was above this level, the following contour plots use 0.5 mT as the baseline figure.

5.2. The public corridor side of the MRI/corridor partition wall

5.2.1. Before magnetic shielding was installed

The reason for the introduction of retrofit passive magnetic shielding was to restrict the 0.5 mT footprint to prevent it passing from the examination room to the adjacent public corridor where unscreened members of the public may be exposed to magnetic flux densities in excess of 0.5 mT. Table 3 shows the results of field measurements of magnetic flux density taken at each measurement position against the plasterboard and studwork wall dividing the MRI examination room and the adjacent public corridor on the public corridor side of the partition wall BEFORE magnetic shielding was installed.

5.2.2. After magnetic shielding was installed

Table 4 shows the results of field measurements of magnetic flux density taken at each measurement position against the plasterboard and studwork wall dividing the MRI examination room and the adjacent public corridor on the public corridor side of the partition wall AFTER magnetic shielding was installed.

5.2.3. Comparison of the survey results

The introduction of magnetic shielding to the MRI examination room resulted in reduced magnetic flux densities on the corridor side of the MRI/corridor partition wall.

The threshold for exposure of unscreened personnel to the static magnetic field has been set as 0.5 mT. As the apparent minimum magnetic flux density measured in the public corridor was below this level, the following contour plots use 0.00 mT as the baseline figure.

Tables 3 and 4 above have been transposed, as has been utilised above for the magnetic flux density readings within the MRI examination room, into contour graphs in Figs. 7 and 8 below.

---

**Table 1**

<table>
<thead>
<tr>
<th>Height above FL (m)</th>
<th>Plot positions on the MRI room side of the public corridor wall 9–3.70 m before shielding</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.70</td>
</tr>
<tr>
<td>0.00</td>
<td>0.82</td>
</tr>
<tr>
<td>0.50</td>
<td>0.82</td>
</tr>
<tr>
<td>1.00</td>
<td>0.82</td>
</tr>
<tr>
<td>1.50</td>
<td>0.82</td>
</tr>
<tr>
<td>2.00</td>
<td>0.82</td>
</tr>
</tbody>
</table>

---

**Table 2**

<table>
<thead>
<tr>
<th>Height above FL (m)</th>
<th>Plot positions on the MRI room side of the public corridor wall 9–3.70 m after shielding</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.70</td>
</tr>
<tr>
<td>0.00</td>
<td>1.99</td>
</tr>
<tr>
<td>0.50</td>
<td>1.99</td>
</tr>
<tr>
<td>1.00</td>
<td>1.99</td>
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<tr>
<td>1.50</td>
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</tr>
<tr>
<td>2.00</td>
<td>1.99</td>
</tr>
<tr>
<td>2.50</td>
<td>1.99</td>
</tr>
</tbody>
</table>

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Fig. 5. From Table 1 above, a contour chart of the magnetic flux density (given in mT) within the MRI examination room BEFORE the introduction of magnetic shielding. Readings were taken against the examination room/public corridor wall (MRI side).

Fig. 6. From Table 2 above, a contour chart of the magnetic flux density (given in mT) within the MRI examination room AFTER the introduction of magnetic shielding.

These contour charts demonstrate the effect of the introduced passive magnetic shielding on reducing the magnetic flux density against the public corridor side of the MRI/corridor dividing wall. But as can be seen in Fig. 6 above, this was at the expense of the magnetic flux density increasing within the MRI examination room.

By using the raw data in Table 4, Fig. 8 above shows a contour graph of the static magnetic field after introduction of the magnetic shielding to the public corridor wall. The graph demonstrates that the magnetic shielding has apparently (see below) been effective in retaining the 0.5 mT footprint of the static magnetic field to within the MRI examination room.

5.3. Spot magnetic flux density measurements taken on the public side of the MRI/corridor partition wall following the retrofit

Because of the method of construction used to fix the magnetic shielding (steel screws and spot welds), it was decided that it might be appropriate to take readings of the corridor wall (public side) at these positions (see Table 5 below) to determine if any local variations could be detected. These positions were logged prior to the wall finishing being applied. This was achieved by placing a clear cordex™ sheet previously marked up with the 500 mm grid used to carry out the main magnetic flux density survey. By being able to view the screw and weld positions through
Table 3
The magnetic flux density (given in mT) on the public corridor side of the MRI examination room - before shielding.

<table>
<thead>
<tr>
<th>Height above FL (m)</th>
<th>Plot positions along the public corridor wall 0–3.70 m before shielding</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.11 0.19 0.21 0.26 0.44 0.54 0.26 0.26 0.27</td>
</tr>
<tr>
<td>0.50</td>
<td>0.19 0.21 0.26 0.35 0.53 0.45 0.43 0.49</td>
</tr>
<tr>
<td>1.00</td>
<td>0.22 0.25 0.37 0.42 0.72 0.63 0.61 0.58</td>
</tr>
<tr>
<td>1.50</td>
<td>0.16 0.18 0.25 0.52 0.69 0.64 0.63 0.45</td>
</tr>
<tr>
<td>2.00</td>
<td>0.14 0.16 0.21 0.74 0.72 0.63 0.59 0.30</td>
</tr>
<tr>
<td>2.50</td>
<td>0.13 0.16 0.17 0.19 0.26 0.20 0.12 0.11</td>
</tr>
</tbody>
</table>

Table 4
The magnetic flux density (given in mT) within the MRI examination room - after shielding.

<table>
<thead>
<tr>
<th>Height above FL (m)</th>
<th>Plot positions along the public corridor wall 0–3.70 m after shielding</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.01 0.02 0.10 0.10 0.10 0.09 0.09 0.10</td>
</tr>
<tr>
<td>0.50</td>
<td>0.02 0.02 0.02 0.02 0.02 0.02 0.02 0.02</td>
</tr>
<tr>
<td>1.00</td>
<td>0.03 0.02 0.02 0.02 0.02 0.02 0.02 0.02</td>
</tr>
<tr>
<td>1.50</td>
<td>0.05 0.02 0.02 0.02 0.02 0.02 0.02 0.02</td>
</tr>
<tr>
<td>2.00</td>
<td>0.03 0.02 0.02 0.02 0.02 0.02 0.02 0.02</td>
</tr>
<tr>
<td>2.50</td>
<td>0.03 0.02 0.02 0.02 0.02 0.02 0.02 0.02</td>
</tr>
</tbody>
</table>

Fig. 7. From Table 3 above, a contour chart of the magnetic flux density (given in mT) on the public corridor side of the MRI examination room BEFORE the introduction of magnetic shielding.

The corotec™ sheet and to mark them up using a permanent black marker, the following results were achieved. These confirm the hypothesis (White, 1980) that in any practical, real-life situation, leakage effects may be identified, amongst other criteria, as being due to screws inserted into the shielding.

Table 5 above shows a selection of readings taken at an offset of 20 mm in the z axis of the grid of the magnetic shielding to the public corridor wall. This position was chosen because there was a grouping of fixing screws where some, but not all, included spot welds at these positions over the surface of the magnetic shielding. The contour graph in Fig. 9 below is developed from Table 5 and shows results of these readings. The screws were used to fix the magnetic shielding to a 15 mm ply backing panel on 50 × 100 mm timber studs. Comparison with the contour plot shown in Fig. 8 above shows major differences.

6. Discussion
6.1. Passive magnetic shielding should ideally be formed as a six-sided box

Previous work has recognized (White, 1980) that passive magnetic shielding should ideally be formed as a six-sided box and have no penetrations, and that no real-life and useful shielded compartment is homogeneous. However, this information has hitherto been restricted to industrial applications - perhaps because of its perceived unique importance to the military. Examples of the application of this knowledge are; the shielding of equipment from broadband electromagnetic pulses (EMP) resulting from ground-level nuclear detonations, from the effects of broadcasting stations, or from nearby electric generators. Because of pas...

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Fig. 8. Taken from Table 4 above, a contour chart of the magnetic flux density (given in mT) on the public corridor side the MRI examination room AFTER the introduction of magnetic shielding.

Table 5
The magnetic flux density (given in mT) within the MRI examination room - after shielding. Readings were taken against the examination room/public corridor wall (public corridor side).

<table>
<thead>
<tr>
<th>Height above PFL (m)</th>
<th>Shielding fixing screw clusters at plot positions along the public corridor wall 0-3.79 m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.68</td>
</tr>
<tr>
<td>0.00</td>
<td>0.96</td>
</tr>
<tr>
<td>0.50</td>
<td>0.47</td>
</tr>
<tr>
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<td>2.00</td>
<td>0.63</td>
</tr>
<tr>
<td>2.50</td>
<td>0.57</td>
</tr>
</tbody>
</table>

Fig. 9. From Table 5 above, a contour chart of the magnetic flux density (given in mT) on the public corridor side the MRI examination room AFTER the introduction of magnetic shielding. Readings were taken against the examination room/public corridor wall (public corridor side) but at a 20 mm offset in the x-axis and at fixing screw clusters.

sive magnetic shielding materials supply and installation costs and the additional structural requirements, in order for the parent structure to take the increased loading generated by the shielding. A six-sided box would not be a viable solution if incorporated into the design of an MRI suite.

6.2. Passive magnetic shielding to affected walls only

Space allocation for MRI suites is becoming more of an issue, and as a result, their location within a hospital or clinic may not always be ideal. This may result in the 0.5 mT footprint of the static magnetic field of the magnet extending to areas outside the magnet (examination) room and possibly to areas where the public have access. To overcome this problem the original design, for the reasons outlined above, may include for passive magnetic shielding to be installed only to the walls where this is likely to occur.

For MRI suite installations where the original design failed to retain the 0.5 mT footprint of the static magnetic field to the magnet (examination) room, then retrofitted passive magnetic shielding may be required. This case study is one of those situations.

6.3. Critique of the retrofitted passive magnetic shielding design used in this case study

The passive magnetic shielding panels used in this case study consisted of three 1 mm layers of non-grain-orientated steel produced in a 1.00 m × 1.00 format. The layers to each panel were not staggered so as to hide the panel joints, making the introduction of cover strips essential in order to eliminate leakage through them at these positions. An example is shown in Fig. 10 below.

The designer had not made provision for the area to be retrofitted to match the magnetic shielding panel sizes, or for the panel sizes to match the dimensions of the area to be shielded. This introduced the requirement for a ‘cut’ as shown in Fig. 11 below, and therefore introduction of another joint requiring a cover strip.

Because shielding panel joints were not staggered and the panels not being fabricated to site dimensions, the entire shielding consisted of a criss-cross of penetrations, welds and cover strips. This can be seen in Fig. 12 below.

A close up of the cover strips can be seen in Fig. 13 below. Note that the joint to the horizontal cover strip in the photograph is itself not hiding the straight joint in the shielding behind, thus allowing leakage of the static magnetic field at this point. It can also be seen that there are areas of spot welding on the cover strips. This is despite previous research work having been carried out showing that the residual magnetisation of welds in a hospital...
6.4. Increased magnetic flux density at FFL

The sketch in Fig. 15 below has been developed from Table 4 above. Field measurements of the static magnetic field were taken on the z axis at the base of the applied retrofit magnet and showed that the shielding was not retaining the 0.5 mT footprint. A magnetic flux density of 1.31 mT was measured at this point and did not reduce down to 0.5 mT until it achieved a perpendicular distance of 148 mm from the shielding on the public corridor side of the magnet room wall, or when measured against the shielding, not until a height of 25 mm from FFL.

6.5. Increased magnetic flux density below the magnet

A request was made to study the position of the 0.5 mT footprint below the floor slab at this point so as to determine the total distortion of the static magnetic field by the introduced magnetic shielding, but access to the ceiling void below the shielded wall was denied.

6.6. How this case study has advanced knowledge beyond what has already been published

This case study has advanced knowledge beyond that which has been previously published in finding that:
The 'edge effect' phenomenon (AAPM, 1987) found in this case study is that the distance from the magnet isocentre to the edge of the installed passive magnetic shielding exceeded 30°. This information could be useful to designers when designing magnetic shielding, either as an initial design solution or as a retrofit.

Any magnetic shielding finishing at Finished Floor Level (FFL), whether as a retrofit or as part of the original design, will not be effective in shielding areas below the shielding; the evidence gathered shows that the magnetic flux density at the joint between the magnetic shielding and the floor slab is increased.

The introduction of magnetic shielding to the MRI suite as the subject of this case study has caused increased magnetic flux densities within the magnetic examination room to be greater than without shielding. This makes reliance on magnet vendors' generic static magnetic field plots questionable by employees attempting compliance with the minimum requirements for the protection of workers from risks to their health and safety (EC, 1989) arising or likely to arise from exposure to electro-magnetic fields during their work. As mentioned above, the Directive requires that the employer should assess and if necessary measure and/or calculate the levels of electro-magnetic fields to which workers are exposed and give particular attention to the level, frequency, spectrum, duration and level of exposure to any effects concerning the health and safety of workers at particular risk. Should the Employer neglect this duty and an accident occur, it is quite possible that he could be personally prosecuted (HMG, 2002a). Additionally, the designer is required (HMG, 2007a) to take all reasonable steps to provide sufficient information with his design about aspects of the design of the structure or its construction or maintenance as well as adequately assert clients, other designers, and contractors.

The design and use of square edge shielding panels, and their installation using screws and spot welds, can create hot spots in the magnetic shielding where the magnetic flux density can increase to a level higher than the surrounding shielding. Variations in magnetic flux density at screw heads shown in Table 5 and Fig. 5 could be for three reasons:

- The main shielding panels were fixed to the ply backing board with 32 mm steel screws that were allowed to pass through the shielding.
- The shielding panels were square edge and butt-jointed. This necessitated the use of cover strips over the joints, thus requiring the use of further screw fixings, and therefore additional shielding penetrations.
- The cover strips were fixed with 15 mm steel screws and spot welds, but because the cover strips were not all tight fitting, were themselves butt-jointed and did not pass through all the shielding panels behind (three panel thicknesses plus three thicknesses of the cover strips). This was demonstrated by there being a variation in magnetic flux density readings taken at the (panel) joint positions on the corridor side of the wall.

Therefore, leakage of the static magnetic field occurs at the junction between the Finished Floor Level (FFL) the introduced passive magnetic shielding at its joints, and through the bolts used to fix the shielding to its supporting structure.

7. Findings

This case study has shown that the introduction of passive magnetic shielding can cause an increase in the magnetic flux density within the MRI examination room and at the edges of the shielding ('the edge effect') to a level in excess of that present before its introduction. This 'edge effect' could be explained (White, 1989) because the metal sheet planar dimension was not designed so it would be much greater than the distance between an emission source and the edge of the shielding where the 'edge effect' was not present. This could be because of its (sufficiently great) distance from the magnet isocentre because, although not shown on the graphs, the shielding in this study extended to an overall height of 3.20 m from FFL. In this case study, by disregarding the hidden effects of the shielding fixings, the 'edge effect' disappeared where the angle from the magnet's isocentre to the edge of the shielding was in excess of 30°.

The use of fixings which penetrate the shielding, and the practice of shielding panels being spot welded together, led to reduction in the homogeneity of the shielding panel material and caused leakage of the static magnetic field at these locations.

Literature relating to the hazards relating to the exposure of individuals to the static magnetic field was found to be oriented towards the medical profession, whilst ignoring the practical role played by the magnetic shielding designer and the building contractors.

Although within the UK legislation and guidance through UK Approved Codes of Practice (ACoPs) is in place to guide designers and building contractors, it is not explicit in mentioning non-ionising radiation or the hazards of human exposure to the static magnetic field. For example, Appendix 3 of CDM 2007 (HMG, 2007a) advises headings that should be considered for the construction phase plan and mentions health risks from ionising radiation, but fails to mention those hazards arising from non-ionising radiation (as generated by a magnet installed within an MRI suite).

CDM 2007 (HMG, 2007a), in giving guidance on the contents of the health and safety file, advises that where they are relevant to the health and safety of any future construction work mention should be made of any residual hazards that remain and where they have been dealt with. However, the guidance omits mention of hazards from the static magnetic field. This information should be made available to the designer by the CDM co-ordinator by use of the CDM information pack and be updated as the design progresses.

8. Recommendations

This case study demonstrates the importance of design co-ordination and the key role to be played by a CDM co-ordinator throughout the design and construction phase of a project. Although relating to the previous CDM Regulations (HMG, 2000) adherence to the guidelines for the selection of designers and contractors (Carpenter, 2005) by the Client is of paramount importance. Failure to do so could initiate a prosecution of the Client's company and of its Directors (HMG, 2007b).

Should the original magnet room have been designed to be the magnet vendor's generic room dimensions the situation as the subject of this case study may have been avoided. Nevertheless, even in cases where the room is designed so as to have adequate dimensions to accommodate the 0.5 mT footprint of the static magnetic field, the introduction of ferromagnetic elements into the design could still cause the generic 0.5 mT footprint to be distorted. For this reason, designers should use magnet vendors' plots of generic static magnetic field footprints as being indicative only, and only to be used as a basis for development of a robust process of design risk management. Cognizance should be made of the need to take account of all ferromagnetic elements falling within the influence of the footprint of the static magnetic field. This includes steel reinforcement in floor slabs, beams and columns, the orientation of the magnetic to the longitudinal direction of the steel, as well as its proximity to them. Any additional ferromagnetic elements which may be introduced.

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by mechanical services contractors, such as air-conditioning ducting, should also be taken into consideration as this could also have an effect on the symmetry of the static magnetic field footprint. It is feasible that retrofit magnetic shielding may be installed on the underside of a concrete floor slab so as to protect areas below which would otherwise be affected by the y axis of the magnet. In this case it is conceivable, based on the evidence from Table 5 and Fig. 9 above, that any ferromagnetic mechanical or electrical services suspended from the ceiling by making use of the bolts used to fix any magnetic shielding to the slab could become permanently magnetised by the 'leakage' of the static magnetic field through them, and should be avoided. Fig. 16 below shows a separate case where a designer has taken advantage of this opportunity, thus demonstrating that there is a real risk of designers inadvertently using this method when not having full knowledge of the hazards relating to their choice of fixing solution. In this particular case, the steel bolts fixing the passive magnetic shielding to the underside of the concrete floor slab, as in the case study of this paper, could allow the static magnetic field to pass through them.

Generic static magnetic field plots supplied by magnet vendors should not be relied upon when setting up a controlled area around an MRI suite. As these generic plots sometimes only cite the position of the static magnetic field in the x and z axes, areas above and below of the magnet (in the y axis) should also be included in any given controlled area. This is because of the risk of unscreened persons being asked to work within areas where magnetic flux densities in excess of 0.5 mT are present. Any person carrying out a risk assessment for the proposed work to that location may not have perceived these sometimes infrequently visited areas as having any relationship with the MRI suite.

It is also apparent that as far as retrofitted magnetic shielding is concerned, the physical restraints preventing the shielding from passing below Finished Floor Level (FFL) of any MRI suite could create an additional hazard to areas above or below the shield wall. This is an important point because the magnetic flux density at this position may already be in excess of 0.5 mT. The introduction of retrofitted passive magnetic shielding cannot be claimed to be an effective design solution unless a full design review process is in place from initial design stage through the entire design process. This would ensure that any hazards are recognised at an early stage in the design and give the opportunity for them to be eliminated.

Following any magnetic shielding installation, comprehensive magnetic flux density surveys should be made of the shielding to ensure that hot spots in excess of 0.5 mT have not occurred at magnetic shielding panel fixing positions, or at any other point or on the around the magnetic shielding. If they are found to be present, then those areas should be included within the 0.5 mT Controlled Area of the MRI suite before being handed back to the client for operational use.

It is extremely important for the Lead Designer to ensure that all designers have provided sufficient information at an early stage in the MRI suite design. This will allow the magnetic shielding designer to include the effects of any additional ferromagnetic material on the static magnetic field footprint before deciding on using retrofitted magnetic shielding as a design option. It may be more cost-effective at initial design stage to completely isolate areas to where the 0.5 mT footprint passes, or is likely to pass. This may be achieved by designing the MRI suite as an independent and stand-alone unit at basement level so that it contains no contiguous areas likely to be contaminated by the static magnetic field. Any fringe field (except the northern y axis) would thus pass into the surrounding sub-soil.

Therefore dialogue between the CDM co-ordinator, the Lead Designer and the magnet vendor in the early stages of any new MRI suite design process is of paramount importance as all the factors affecting the final position of the 0.5 mT footprint are to be taken into consideration.

9. Recommendations for further work

With the objective of producing guidelines for magnetic shielding designers, further case studies are required. These studies could examine various non-penetrating shielding fixing methods, distances of shielding edges and of the shielding proper (in the (x, y, z) axes) on the total magnetic field footprint before deciding on using passive magnetic shielding. Such studies could help in determining if, over time, permanent magnetisation of passive magnetic shielding can affect the value of the magnetic flux density both within and external to the magnet room or any designated controlled area.

10. Conclusions

This research has shown that the practice of retro-fitting passive magnetic shielding to Magnetic Resonance Imaging (MRI) suites may not be effective in fully retaining the 0.5 mT footprint of the static magnetic field within its designated position. It may increase the magnetic flux density within the MRI magnet room and allow it to encroach into contiguous areas of the MRI suite. The methods of fixing magnetic shielding panels used in this case study allow the passage of the static magnetic shielding to pass to areas outside the shielding. The locations of these fixing positions are difficult to pinpoint on a finished wall, and unless they were known beforehand, could easily be overlooked by any person carrying out a cursory survey of magnetic flux densities at a given location. Depending on the magnitude and 'reach' of these leakage points in the passive magnetic shielding, close contact between an individual wearing certain heart pacemakers or other electronic implants with these leaking joints could have safety implications for the individual concerned.

The introduction of magnetic shielding can distort the symmetry of the 0.5 mT footprint of the static magnetic field and consequently increase the risk of unscreened persons, both inside and outside the control of the employer, being exposed to the effects of the static magnetic field. Designers should consider the effects on the 0.5 mT footprint of any ferromagnetic material that is

![Fig. 16. The steel bolts fixing the passive magnetic shielding to the underside of a concrete floor slab could allow the static magnetic field to pass through them.](image-url)
utilised in the structure. This material could include steel reinforcement, steel air-conditioning ducting, etc. The co-ordination of all designers is important because any ferromagnetic material coming within the influence of the 0.5 mT footprint of the static magnetic field will have an effect on its symmetry, causing it to vary from the generic field plots supplied by the magnet vendor.

This will, therefore, have an effect on the size of the magnet room required to retain the 0.5 mT footprint and should be taken into consideration by the designer in any calculations he makes in determining the optimum size of the magnet room. For this reason it is important for the client to employ a CDM co-ordinator competent in MRI suite construction. The CDM co-ordinator will thus be able to manage the input of designers and any sub-designers by advising them on the methods by which hazards created by the static magnetic field of the magnet could be eliminated from the design.

CDM 2007 (HMG, 2007a) is directed at clients, designers, CDM co-ordinators, building contractors and contractors and is the suggested most appropriate current medium for the hazards from the use of non-ionising radiation to be made explicit. In the absence of an Approved Code of Practice relating to MRI installations, the proposed amendment of CDM 2007 (HMG, 2007a) could be utilised so as to highlight the hazards of non-ionising radiation to those concerned with the conception, design, construction and refurbishment, maintenance or demolition of an MRI suite. Other UK legislation relating to the safety of workers and visitors to MRI suites is, because of its broad application base, implicit in not mentioning the effects of the static magnetic field surrounding an MRI magnet and therefore does not create awareness of the hazards involved with the static magnetic field present in MRI suites.

By designing the size of the magnet room to accommodate the 0.5 mT footprint of the magnet, and by the siting of the magnet away from both static and mobile ferromagnetic objects which may influence or be influenced by it, the need for passive magnetic shielding, retrofitted or otherwise, could be eliminated. Where this is not possible, until new designers have had simple guidelines as to where any retrofit magnetic shielding might need to extend in order to retain the static magnetic field within the magnet room. In cases where the designed magnetic shielding is undersized, then the ‘edge effect’ could be created to the shielding and thus unnecessarily increase the magnetic flux density at these points. Where the magnetic shielding is oversized, then this imposes additional and unnecessary costs on the client.

This case study builds on previously published work (White, 1980) to provide a simple solution for designers of passive static magnetic field shielding for MRI suites to enable them to estimate the optimum extent of the shielding required for a 1.5T magnet, and thus avoid the creation of the additional, and unnecessary, hazard of the ‘edge effect’ by ensuring that the angle from the magnet’s isocentre to the edge of the designed passive magnetic shielding is in excess of 30°.

There is no previously published literature examining the possible presence of hotspots due to fixed methods of magnetic shielding construction. There has been no holistic study to determine the consequences and effectiveness of the introduction of such shielding, whether as part of the original design or as a retrofit solution. This case study bridges the gap between the medical profession’s knowledge of the hazards of the static magnetic field and the need for that knowledge by the MRI suite designer.

This paper reports part of an ongoing research programme at Edinburgh Napier University which aims to develop guidelines to improve the nature and quality of information to be included in future health and safety files for MRI installations in hospitals, and in particular the designer’s Residual Hazard and Risk Log, including the identification of appropriate and viable scientifically-based risk control measures.

References


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MRI suites and residual design risk from static magnetic fields

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Since the inception of the UK Construction (Design and Management) Regulations 1994 through to the 2007 Construction (Design and Management) Regulations a duty has been imposed upon the client of premises where a notifiable project has been carried out, to provide a health and safety file which may be needed during future work. This work includes cleaning, maintenance, alterations, extensions, refurbishment and demolition. The Construction (Design and Management) Regulations 2007 also impose further duties on clients to provide information to those who will use their premises as a workplace. This paper reports the results of a study which assessed whether information relevant to the health and safety file for magnetic resonance imaging (MRI) installations in hospitals having had passive magnetic shielding installed was available from National Health Service trusts in Wales, Scotland and England. Information on both the site-specific design and the actual position of the static magnetic field was lacking, as were the existence of as-built drawings showing the magnetic shielding. Information relevant to the risk management of the static magnetic field of MRI suites in the form of a health and safety file is sparse, incomplete and sometimes irrelevant.

1. INTRODUCTION

1.1. Application of the CDM Regulations 2007 to construction of MRI suites

Construction work in the UK is defined as the carrying out of any building, civil engineering or engineering construction work and includes - (a) the construction, alteration, conversion, fitting out, commissioning, renewal, repair, uprating, recreation or other maintenance ... of a structure.

and continues that this also comprises the installation, commissioning, maintenance, repair or removal of mechanical, electrical, gas, compressed air, hydraulic, telecommunication, computer or similar services which are normally fixed within or to a structure (HSE, 2007, p. 3).

In most cases the principal contractor which had been responsible for the management of health and safety for the main construction works would remain in duty-holder position under the UK Construction (Design and Management) (CDM) Regulations (HMG, 2007) until completion of any magnet installation, including commissioning, until the moment of handover to the client. It has been known that delays do occur between completion of the magnetic resonance imaging (MRI) suite and follow-up commissioning of the MRI scanner. It could be the case that when the principal contractor had completed its pure construction works (and possibly wishes to leave site) it would transfer this CDM principal contractor duty-holder position to the magnet vendor for it to manage health and safety on site until such time as the scanner was installed, commissioned and handed over to the client for operational use. It is at this point that the construction phase would come to an end and the health and safety file compiled by the CDM coordinator, using information supplied by the principal contractor and the project designers, would be handed to the client for it to consult when using the building or carrying out any renovations, alterations or demolition.

The contents of a health and safety file are well defined (HSE, 2007). Paragraph 263 specifies the requirement for information on "any residual hazards which remain and how they have been dealt with" (Paragraph 263 (b)) and "information and as-built drawings of the structure, its plant and equipment" (Paragraph 263 (d)).

Therefore, information regarding the installation of an MRI scanner would fall within these criteria. Additionally, it cannot be argued that where a scanner is installed at a date following completion of construction of a given MRI suite that CDM would not apply, because the purpose of constructing an MRI suite would be to house the scanner.

Advice is given (HSE, 2007) that information on the presence of non-ionising radiation (X-rays, etc.) should be included in the health and safety file. However, the requirement for information on the presence of non-ionising radiation (MRI, etc.) is not referenced. Inclusion of information in the health and safety file on the presence and location of the static magnetic field around an MRI suite might be relevant to individuals who may otherwise be excluded from control measures because they do not work within the MRI suite itself.

The relevant static magnetic field flux density where control measures should be introduced is set at 5 gauss (0.5 mT). The...
reasons for this are discussed later in this paper, but if the CDM regulations 2007 were followed correctly, inclusion of this information, not on the theoretical but on the actual position of the 5 g/m² footprint of the static magnetic field, would give value to any health and safety file. Guidance is given on the purpose of any health and safety file, in that

The health and safety file should contain the information needed to allow future construction work, including cleaning, maintenance, alterations, refurbishment and demolition to be carried out safely. Information in the file should alert those carrying out work to risks and should help them to decide how to work safely. The file should be useful to:

(a) clients, who have a duty to provide information about their premises to those who carry out work there;
(b) designers during the development of further designs or alterations;
(c) CDM co-ordinators preparing for future construction work;
(d) principal contractors and contractors preparing to carry out or manage each work. (HSE, 2007, Paragraph 256)

2. DISCUSSION

Modern MRI scanners usually consist of a superconducting magnet combined with the use of radiofrequency (RF) signals to produce images of the biological matter being examined usually the human body. A very simple explanation of the imaging process is that within the scanner there is a strong magnet used to create the ambient static magnetic field. In addition there is a gradient system of three coils, which is used to produce linear field distortions in the (x, y and z) axes, and the amplifiers. These coils are made using aluminium-titanium and kept near absolute zero usually in liquid helium (He is kept at about 4 K). Their superconducting properties are a result of the temperature, and should have no resistance to an electrical current, thus in theory allowing the external electrical supply to be disconnected.

When a patient enters the bore of the magnet, the static magnetic field will align the hydrogen protons present in the patient with the direction of the magnetic field. The imaging process then consists of an RF signal of the same sound wave frequency of the target protons being switched on, with the receiving protons absorbing some of the energy and ‘whipping’ free from the magnetic field. When the RF signal is switched off, the protons release this energy and realign themselves with the magnetic field in the bore of the magnet, emitting an RF signal as they do so, which is used to build an image of the tissue being examined. The hydrogen nucleus (i.e. the proton) is more commonly used for clinical imaging because, in addition to being the most plentiful, it has the largest magnetic moment of any stable nucleus present in the human body, mainly as water and fat (F. R. Coles, personal communication, 2005).

The majority of MRI scanners installed for clinical use in the UK are fitted with magnets that have a strength of 1.5 T.

MRI magnets are installed within a Faraday (RF) cage (the scanner room). Faraday cages are constructed of conductive material, usually of copper or aluminium, and are essential in ensuring that external static electrical fields are prevented from distorting the RF signal being utilised to create the image. Faraday cages do not protect the magnet from the influence of magnetic fields external to the MRI magnet, or in reverse, protect persons or objects outside the Faraday cage from the reach of the magnetic fields supported by the MRI. Therefore, the incorporation of passive magnetic shielding to the magnet room may be required.

The magnetic field extends all around the magnet. Although it is recommended that the 5 g/m² line of the static magnetic field should be restricted to the magnet (examination) room and the technical room (HSE Estates, 1994, Fig 4), this published advice shows an illustration of a generic footprint of their lateral and Z (horizontal) axes of the static magnetic field to a magnet, while ignoring that of the y (vertical) axis.

It is crucial to the imaging process that the symmetry of the static magnetic field generated by the magnet remains within the limits set by the magnet vendor so as to ensure that a viable image is produced by the MRI process. In order to achieve this, the introduction of magnetic shielding to protect this symmetry of the static magnetic field of the magnet from outside influence may be required.

Modern superconducting magnets are fitted with active magnetic shielding, the result of which is to constrict the reach of the magnetic field. This reduces the risk of device interference or conflict outside the MRI examination room, but additional shielding of the magnet to compensate for the presence of ferromagnetic objects is often required and many contemporary superconducting systems have built-in electromagnetic shield systems, reducing – and often eliminating – the need for the ferromagnetic nameplates of the older systems. Active shielding can only help to reduce interference from the presence of stationary ferromagnetic objects. There are also limits to the quantity of (static) ferromagnetic elements within any structure and which passive ‘shimming’ of the magnet can compensate, and passive shielding to the magnet room is not often required to compensate for the presence of ferromagnetic objects (shim correction). It is, however, very frequently used to reduce risks of magnetic field interactions outside the MRI examination room (whether that is potential negative interaction with medical devices/implants, or interference with other equipment/systems that are sensitive to magnetic fields). The introduction of passive magnetic shielding may not always be a perfect design solution because there may be limits to the amount of magnetic shielding which can be incorporated into the MRI suite; either because of magnet location or of structural constraints. These limits may even restrict the use of magnetic shielding – even to the possible extent of having to rehouse the magnet. Each MRI suite design is different and is by understanding the MRI process from an early stage in the design, and by careful location of the magnet, the designer can often alleviate the need for magnetic shielding.

However, it is important to know that when passive magnetic shielding is used to contain the static magnetic field, it will have the effect of altering its symmetry. This has been described as ‘trying to stuff a balloon into a box. Pushing on one end of the box invariably cause the balloon (fringe field) to expand out the other’ (Pawlak et al, 1989). This effect is described in Figures 1 and 2. In practical terms, this means that where magnetic shielding is installed to restrain one or more axes of
the static magnetic field, then this will have the effect of pushing the remaining areas out of their generic positions into areas which may not have been included in the designer’s original risk management proposal.

Additionally, any ferromagnetic elements used in the construction of an MRI suite will become permanently magnetised. These elements could take the form of air-conditioning ducting, steel electrical conduit, use of a steel-frame in the prenatal structure or in stud partitions to the magnet room, to name a few. Even where the MRI magnetic field is removed, these ferromagnetic materials still possess a magnetic remanence relative to the material used, making future use of the room(s) to hold any computers or electronic storage media, or to convert the room to accommodate a CT (computed tomography) or other electronic equipment, questionable. This is because the permanently magnetised construction material will affect any equipment that it comes into contact with. The advice to this is that:

You want to keep any significant quantity of steel outside that 5 Gauss threshold … in the watershed in MRI design and construction. You want to keep any significant amount of steel outside that 5 Gauss bubble. A 5 Gauss magnetic exposure seems relatively low, but remember that if you run an MRI for 10 years in the same place, that gentle, continuous magnetisation is going to build and build and build, and make magnetic field in any nearby ferrous material. A suitable analogy might compare the drip, drip, dripping of mineral-rich water from a cave ceiling, which eventually gives birth to limonite. (Robb, 2006)

Therefore, it is important to ensure that at the demolition stage or at refurbishment of any MRI suite, any ferromagnetic materials that may have been utilised are not reused or recycled for use in structures where their magnetisation may be a hazard if its future use, in formation regarding any building elements that could have been permanently magnetised should be included in the CDM 2007 health and safety file. Nevertheless, although not required by the current CDM Regulations, this will rely on any site waste management plan (SWMP) being included in the health and safety file (Price et al., 2009).

It is feasible that cases could occur where the requirement for magnetic shielding could equate to several times of extra leading to the structure, so it is important that this possibility is discussed early in the design stage. A case could arise where magnetic shielding may need to be retrofitted because the original design did not fully enclose the 5 Gauss footprint, or even lesser values, that may present interference potential with other modalities or equipment within the controlled area of the MRI suite. It is therefore crucial that the lead designer and CDM coordinator ensure recognition, cooperation and coordination of all designers (including the magnet vendor) and sub-designers as early as possible in the design of an MRI suite in order to be able to take account of the presence of all ferromagnetic material within the influence of the static field of the magnet and to be able to make an informed decision on the magnet’s location and/or orientation. Sharing this knowledge also enables the employer (including the principal contractor during the construction phase, following energisation of the magnet) to screen and possibly exclude any individuals who may be fitted with electronic implants or devices, such as heart pacemakers, from the controlled area of the MRI suite.

Ferromagnetic objects brought within near proximity to the static magnetic field can become projectiles that could cause harm to someone standing between the object and the magnet. It is recommended that a controlled area with field strength of 20 Gauss (3 mT) be set up around the magnet to avoid the hazard of the projectile effect on ferromagnetic elements being brought within the influence of the magnet’s static magnetic field. If the distance to the magnet is increased by a factor of 4, the attractive force on the ferromagnetic object is increased by a factor of 54, thus increasing the risk of damage either to individuals, to the magnet or both.

Generic positions of the static magnetic field will necessarily change with each individual project. For ‘open’ format ‘hamburger’ type magnets, the larger component of the static magnetic field is vertical, resulting in slightly diminished hazards on the same level as the magnet (as compared to bore format magnets) but greater hazards above and below.

An operational MRI suite would normally contain a minimum of two controlled areas, an outer and inner one, with the outer controlled area being a volume totally enclosed, and of such a size to contain the 5 Gauss (50 Gauss) magnetic field contour. Access should be restricted and suitable signs should be displayed at all entrances to an inner controlled area, being a volume totally enclosed and of such a size to contain the 3 Gauss (30 Gauss) magnetic field contour (MDA, 2007).

Demarcation of the outer (5 Gauss) controlled area is because 5 Gauss is the threshold for exposure to the static magnetic field

![Figure 1. The balloon in a box before being ‘pushed’ and its symmetry distorted](image1.png)

![Figure 2. The balloon in a box after being ‘pushed’ and its symmetry distorted](image2.png)
of all individuals that have not been successfully screened for cardiac pacemakers, UK government advice is that; 'A person fitted with a heart pacemaker must not enter the MRI controlled area' (MDA, 2007). However, it should be appreciated that this hazard is not a direct biological one to the individual, but a risk of magnetic field electromagnetic interference with the medical device. One description of the effect of the static magnetic field on pacemakers (Young, 2000) is that: “the magnetic field switch that varies the heart rate can be inadvertently switched by the static field and revert to its default setting”. This could lead to irregular heart rhythm of the wearer of the pacemaker and eventually to his/her serious handicap or death.

In addition to this electromagnetic interference, there are also two other physical forces, namely (a) torque and (b) translational attraction, which can be exerted by magnetic fields upon ferromagnetic objects. When subjected to magnetic fields, a heart pacemaker or other medical device or implant could twist (torque) within the individual so as to align itself with the magnetic field to which it is exposed, or be pulled towards the magnet by translational attraction while embedded in the individual’s body. One of the most vulnerable parts of the body is the eyes. The adequate screening of patients or others with suspected intraocular ferromagnetic metallic objects is most important before they are allowed to enter the MR suite’ (MDA, 2007).

A quench of the magnet occurs when the cryogenic gas used to cool the coils, employed to enable them to retain their superconducting properties, “boils off.”

In the unlikely event of the magnet quenching the rapid release of gaseous cryogens from the cryostat into the room of a cryogenic container, up to 15000 l of helium gas may evolve over a period of several minutes with the helium expanding at a rate of 760 l. (UNSWM, 2003)

To mitigate the effect of a quench, magnets are fitted with a quench pipe in order to allow the rapid evacuation of helium gas from the magnet to the outside atmosphere. In a quench of the magnet, the helium gas is so cold that it is below the condensation and freezing points for nitrogen and oxygen. Exposure to super-cooled helium gas will chill the gases out of atmospheric air and freeze them. It is this frozen atmospheric air that could form a ‘snowball’ and therefore makes it extremely important for designers to ensure that in the case of a quench, the location of the quench pipe and its termination cannot pose any risks to other users of the building or visitors.

3. STATUTORY OBLIGATIONS OF CLIENTS AND EMPLOYERS UNDER UK LEGISLATION

3.1. Current UK legislation governing construction worker exposure to static magnetic fields

Currently, there is no UK legislation except the general Health and Safety at Work etc. Act 1974, the Management of Health and Safety at Work Regulations 1999 (HMG, 1999), and the CDM Regulations 2007 (HMG, 2007) which could be used to protect workers from static magnetic fields, but this is itself would be adequate to protect operatives during the construction of an MRI suite. The Health and Safety Executive is more likely to use the Health and Safety at Work etc. Act 1974 in any prosecution, as this legislation carries heavier penalties for non-compliance.

3.2. The Health and Safety at Work etc. Act 1974

The Health and Safety at Work etc. Act 1974 lays down specific requirements for managing health and safety. All of these requirements are applicable to the construction of MRI suites, including specific duties on employers, employees and visitors. Section 2 (employers’ duties to employees) includes a requirement on employers to provide such information, instruction, training and supervision as necessary. This Act also includes in section 3 a duty to “those affected by the undertaking” and section 7 a duty “to have regard for personal safety and that of other workers in particular”.

Section 2(3) of the Health and Safety at Work etc. Act 1974 states that it is the duty of every employer to ensure the health, safety and welfare of all his employees at work “as far as is reasonably practicable”. This is the origin of the use of the ALARP (as low as is reasonably practicable) in risk assessments, the disadvantage of which is that the quality of the assessment can only be decided by a judge after an incident.

3.3. The Management of Health and Safety at Work Regulations 1999

Section 3 imposes a statutory duty on employers to make a suitable and sufficient assessment of the risks to the health and safety of its employees to which they are exposed while they are at work; and the risks to the health and safety of persons not in its employment arising out of or in connection with the conduct by him of his undertaking. The employer (section 8) shall also establish and where necessary give effect to appropriate procedures to be followed in the event of serious and imminent danger to persons at work in his undertaking and follows later with the requirement “to ensure that none of his employees has access to any area occupied by him to which it is necessary to restrict access”.

3.4. The Construction (Design and Management) Regulations 2007

The CDM Regulations 2007 (HMG, 2007) detail the measures that should be taken in order to reduce health and safety risks of any design. One of the measures outlined in the CDM Regulations, in all the forms that it has been legislated upon, is the requirement for the identification, by the designer or designers, of any control measures that should be put in place in order to manage any residual risks to the design that were not able to be eliminated at the design stage. These are measures which should be identified for adoption by those either constructing, using or decommissioning and demolishing any structure, as well as those being necessary to protect third parties, for the whole of the life of the structure.

Depending on the moment when the client appoints the relevant designer, this residual design risk information will be held either in the ‘information pack’ (under CDM, 2007) or incorporated into the principal contractor’s construction phase plan. Should this residual risk continue to exist at completion of the construction phase, then the CDM coordinator should ensure that this residual risk information is included in the health and safety file and handed to the
client. The health and safety file is for reference by the user of the structure and is 'any person who may need it to comply with the relevant statutory provisions' (EHM, 2007, Regulation 1(3)(b)).

The health and safety file is also important because it should be used as a reference document to indicate to the person or organisation using or altering the structure the hazards and risks which continue to exist from the design, and allow them to decide how to work safely. The client will also arrange for the health and safety file to be updated as further work is carried out on the structure.

3.5. Legal provisions in relation to the health and safety file under the CDM Regulations 2007

The CDM Regulations 2007 describe the health and safety file as being a source of information that will help to reduce the risks and costs involved in future construction work, including cleaning, maintenance, alteration, refurbishment and demolition. Clients therefore need to ensure that the file is prepared and kept available for inspection in the event of such work. It is a key part of the information, which the client, or the client’s representative, must pass on to anyone preparing or carrying out work to which the CDM Regulations 2007 apply (EH, 2007, Part 2).

This is reiterated in CDM (2005) Regulation 12 (3) inasmuch that the designer shall take all reasonable steps to provide with his design sufficient information about aspects of the design of the structure or its construction or maintenance as will adequately assist... a client, (the) designer, and (c) contractor. (EHM, 2007)

Regarding the contents of the health and safety file, the ACoP advises that certain information should be included such as an 'any residual hazards which remain and how they have been dealt with' (EH, 2007, Paragraph 263 (b)) and 'information and a visual drawing of the structure, its plant and equipment' (EH, 2007, Paragraph 263 (b)) and concludes that designers should provide any information needed for the ... health and safety file' (EH, 2007, Paragraph 139 (1)).

As far as MRI suites are concerned, the furnishing of this information to those who need it (The right information for the right people at the right time (EH, 2007, Paragraph 5)) will enable the client to comply with the minimum health and safety requirements regarding the exposure of workers to the risk from electromagnetic fields, and in particular the requirement for risk assessments and health surveillance, in that 'taking account of technical progress and of the availability of measures to control the risk at source, the risks from exposure to electromagnetic fields shall be eliminated or reduced to a minimum' (Pavlović et al., 1989).

4. STATUTORY OBLIGATIONS OF CLIENTS AND EMPLOYERS UNDER OTHER LEGISLATION

4.1. 89/391/EEC and the 18th individual directive

The general provisions of the 18th individual directive within the meaning of article 16(1) of EEC directive 89/391/EEC (EC, 1989) lay down minimum requirements for the protection of workers from risks to their health and safety arising or likely to arise from exposure to electromagnetic fields (0-300 GHz) during their work. The directive refers to 'the risk to the health and safety of workers due to known short-term adverse effects in the human body caused by the circulation of induced currents and by energy absorption as well as by contact currents.'

The directive (89/391/EEC) discusses the need for assessment, measurement and calculations of worker exposure to electromagnetic fields and goes on to say that 'the employer shall ensure, and, if necessary measure and/or calculate the levels of electromagnetic fields to which workers are exposed', following with: 'the employer shall give particular attention to the level, frequency, spectrum, duration and level of exposure and to any effects concerning the health and safety of workers at particular risk.'

The directive forms part of a package of directives on the exposure of workers to the risks arising from physical agents: noise, vibration, electromagnetic fields and optical radiation. It provides for measures to protect workers from the risks related to electric, magnetic and electromagnetic fields.

4.2. The EMF physical agents directive EC/40/2004

Directive 2004/40/EC of the European Parliament dated 29 April 2004 [EC, 2004] arose from directive 89/391/EEC and was due to be incorporated into UK legislation during 2008. Numerous representations from the medical community were made to the EU using the argument that 'interventional MRI procedures could cease as healthcare workers would be exposed to electromagnetic fields (EMFs) greatly exceeding the limits in the Directive' and 'that the limits in the Directive were inappropriate for applicators in MRI as they are based on prevention of effects on the Central Nervous System' continuing that 'static electromagnetic fields do not currently have exposure limits under the Directive' and 'concerns were raised that unless some convincing evidence is produced ... the Directive ... may well be modified to introduce a limit for static fields' (Glasston, Sciences, 2006).

As a result of representations made, the European Commission reviewed directive 2004/40/EC and on 23 January 2008 agreed to postpone entry into force of that Directive until 30 April 2012 to allow for a revision of the exposure limits.

5. INTERNATIONAL COMMISSION ON NON-IONISING RADIATION PROTECTION EXPOSURE LIMIT GUIDELINES

5.1. International Commission on Non-Ionising Radiation Protection Guidelines on limits of exposure to static magnetic fields

Nevertheless, the International Commission on Non-ionising Radiation Protection (ICNIRP, 2009) has set exposure limits to the static magnetic field, of which this paper is concerned. These limits are shown in Table 1.

As the ICNIRP suggests in the table reproduced in Table 1, practical policies need to be implemented to prevent inadvertent harmful exposure of persons with electronic devices and implants containing ferromagnetic material coming into contact with the static magnetic field. Any risk management process should also take account of the potential hazard of translational attraction of ferromagnetic materials, tools or plant to the magnet. This may necessitate much lower restrictions, and 0.5 mT (5 gauss) is suggested.
In order to comply with Regulation 11 of CDM 2007, having knowledge of the 5 gauss footprint position is crucial to design risk management of the MRI suite, and the process of risk assessment is outlined in Directive 89/391/EEC (HI, 1989).

6. RESEARCH AIMS AND OBJECTIVES
The aim of this work is to determine whether information relevant to the health and safety file for MRI installations having had magnetic shielding fitted was available from NHS Trusts in Wales, Scotland and England. This information would be useful in developing risk management plans to control exposure of patients, staff and visitors to the static magnetic field of the magnet.

The overall central objective of this paper is important in that it produces a snapshot of the current state of the health and safety file residual risk content as far as it relates to the location of the static magnetic fields within MRI suites. It also clarifies what information regarding the magnitudes, position and residual risks of the design of the passive magnetic shielding used to manage the static magnetic field of the magnet is actually documented following construction and handover of an MRI suite to the client.

7. RESEARCH METHOD
In order to quantify the incidence of passive magnetic shielding in the installed base of MRI suites as the subject of this paper, initial requests for information were made to NHS trusts under the Freedom of Information Act 2000 so as to determine which of the hospitals under their control had MRI suites installed. Northern Ireland was excluded from this research because of the reorganisation of the Northern Ireland Health Board at the time of the survey made it difficult to guarantee that all MRI installations could be identified.

Once the location of these MRI suites was obtained, then further queries were made of the trusts to determine which of the MRI suites had passive magnetic shielding incorporated into their magnetic resonance imaging suite design so as to manage the static magnetic field of the magnet. The reason for this line of enquiry was because the introduction of passive magnetic shielding can affect the symmetry, and therefore the 5 gauss footprint of the static magnetic field, possibly leading to extend to areas outside the RF cage or to areas where the unscreened general public has access and where it could become a hazard. Having identified these MRI suites fitted with passive magnetic shielding, information from the health and safety file regarding the site-specific designed and the actual post-installation position of the static magnetic field of the magnet within and around the examination room, together with copies of as-built drawings, was requested.

8. RESULTS
Figure 3 shows the cumulative annual totals of currently installed magnets since 1992, both with and without the addition of passive magnetic shielding to the patient structure or RF cage.

From Figure 3 it can be seen that there are 285 current magnet installations, of which 82 have passive magnetic shielding fitted to manage the static magnetic field of the magnet. This represents 29% of all installations. Of those 82 magnet installations and despite the use of the Freedom of Information Act to obtain information from the projects' health and safety files, information was received covering only 56 installations. Figure 4 below shows the number of responses to the Freedom of Information requests. It can be seen that there was a majority of responses directly from Freedom of Information officers (61%) with the majority (59%) of responses coming directly from the estates manager of the hospitals consulted, and being 61%. Overall, the replies from professionals did directly concern with the discipline were 61% from the 56, being 86% of the total.

9. QUESTIONNAIRE REPLIES
9.1. Was the 0.5 T line of the static field retained in the magnet room?
It was established that of the 56 locations where magnetic shielding was claimed to be installed, evidence that the passive...
magnetic shielding had been effective in retaining the 0.5 mT static magnetic field of the magnet within the MRI suite examination room had been given in only two cases.

9.2. Did the physical position of the 0.5 mT match its designed position?
Not one single NHS trust had supplied credible as-built static magnetic field plots with the health and safety files. From the limited information given, four scenarios could be extracted from the health and safety files supplied by the NHS trusts.

9.2.1. Random magnetic flux density readings taken inside the magnet room. Information was forthcoming on eight of the 51 installations for which health and safety files were supplied, but all identified only part of the 0.5 mT footprint of the static magnetic field. The information did show random areas of elevated magnetic flux density, but without mentioning the addition of passive magnetic shielding or where it was situated in relation to the survey results. Should the presence of magnetic shielding have been highlighted by the surveys, it could be a pointer to conduct a deeper investigation in order to determine increased magnetic flux density levels as proximity to the shielding decreased. This information could be used to form the basis for a risk management plan for those working in the area surveyed.

9.2.2. Random magnetic flux density readings taken outside the magnet room. Again, some information was supplied, inasmuch as nine of the 51 installations showed random areas of increased magnetic flux density outside the room, but not on the actual position of the 0.5 mT footprint. In two installations, random magnetic flux density readings of 1.2 mT and 0.62 mT were shown but there was no indication if these readings were recorded from a public or from a controlled area.

9.2.3. Were there partial post-conversion plots of the 0.5 mT footprint? This information was supplied within the health and safety file in only one case out of the 51 files received.

9.2.4. Were there full post-conversion plots of the 0.5 mT footprint? Four trusts had supplied lead architects’ as-built drawings of the plots in the 2 and 3 axes but these, despite the known and proven effects on the symmetry of the static magnetic field caused by the introduction of magnetic shielding to the magnet room, corresponded exactly to the magnet vendors’ generic 0.5 mT magnetic field footprints and were therefore at odds to be regarded as credible. No information was given on the position of the x-axes and field verified static magnetic field plots were not recorded.

9.3. Was the actual physical location of the 0.5 mT footprint within the anticipated location derived from the prospective engineered shield design?
This information was not available from the health and safety files. In eight cases out of the 51 where health and safety files were supplied, although the plots were site specific, they were prepared and not as-built drawings. The 0.5 mT footprint was shown as passing to the outside of the cage with the qualification that either magnetic shielding should be fitted or a fence erected. In these eight cases, the NHS Trust confirmed that magnetic shielding had been fitted to the structure, which in turn would disturb the position of the 0.5 mT footprint.

9.4. Were designers’ residual risk control measures in the health and safety files?
From the 51 health and safety files received, there were no cases which mention the central measures that the designer had envisaged should be adopted by the contractor, user, maintainer or decommission/ demolition company to manage the residual risks of the design as far as it related to the static magnetic field of the magnet.

9.5. Other relevant information gleaned from the health and safety files?
From the 51 health and safety files received out of a possible total of 82 installations, there were only two main contractor as-built drawings supplied, and these did not show or alert any future user to the position of the 0.5 mT footprint of the static magnetic field, or even to the existence of the static magnetic field itself.

Although some of the information contained within magnet vendors’ site-specific proposal drawings was supplied in lieu of as-built for 10 cases of the 51 health and safety files received, the information was not sufficiently specific as to mention whether magnetic shielding had been installed or not, but only to intimate that it may have to be, with no further details given.

(a) Of the 15 magnetic shielding proposal drawings supplied, some were later confirmed in the health and safety files as being as-built. No evidence was given that the suites were constructed as per these drawings.
(b) There was no design brief or conceptual design statements included in any of the health and safety files.
(c) Of the 51 drawings supplied, there were four vector plots showing the effect of any magnetic shielding to be introduced to the cage but this was not confirmed by the existence of as-built drawings.
(d) In only one case were these any design calculations supplied for the passive magnetic shielding and in nine cases, there was a specification supplied, but this was not confirmed by the as-built drawings.

(e) Control measures which the designer had envisaged should be put into place by the principal contractor or the user, maintainer or decommissioning company to control the isovallial levels of the static magnetic field of the magnet were absent in every case of the 54 cases where the health and safety file had been supplied.

(f) In four cases involving three NHS trusts who had previously indicated that magnetic shielding had been fitted to the installations for which they supplied health and safety files under the Freedom of Information Act, the author was referred back to the magnet vendor as being the body who held this information about their installations, because they themselves did not have it.

16. FINDINGS

The availability of information from clients in the form of the statutory requirement for health and safety files is sparse, incomplete and is sometimes irrelevant as it relates to the residual risk and not to the health and safety of all the people of the electromagnetic field of the static magnetic field. Reference to the generic position of the static magnetic field in relation to the magnet's post-eruption position when developing risk management procedures could create a hazard. The requirements of the CDM Regulations (HMG, 2007) do not appear to be well understood.

11. CONCLUSION

The inclusion of a CDM coordinator experienced in MRI safety design and construction within the project team at the initial design stage is of paramount importance. The use of a competent CDM coordinator should ensure the process of the identification of all designers, of their cooperation and coordination during the design process, and assist in the elimination and/or reduction of hazards resulting from the presence of static magnetic fields around the magnet during the whole-life cycle of an MRI suite project. Field verification of the location of critical magnetic field lines 0.5 mT/m must have value beyond the immediate issue of exposure of individuals who have not been successfully cleared of any contraindications. Many products designed for use in the MRI room (e.g., stimulators, air-conditioning machines, patient monitors) have maximum allowable static field exposure limits beyond which they may not operate as intended. A direct clinical care benefit to having the 0.5 mT/m mapped on-site would be that these critical field lines can be mapped within the MRI examination room to help ensure the safe use of the clinical support equipment.

This paper is important because there has been no previously published work on this field as far as it relates to the population of health and safety files with information regarding the position of the 0.5 mT/m footprints of the static magnetic field of those MRI suites fitted with passive magnetic shielding, nor of the availability of health and safety files to anyone who may need it to comply with the relevant statutory provisions (HMG, 2007, regulation 17(6)).

17. FURTHER WORK

This paper reports ongoing research at Edinburgh Napier University. This research project aims to develop guidelines to improve the nature and quality of information to be included in future health and safety files for MRI installations in hospitals, and in particular the designer's residual risk log and identification of appropriate risk control measures.

REFERENCES


Pashley W, Mac㎢ary W, Gru R (1983) Special architectural considerations in designing a magnetic resonance (MR) facility. In Technology of Nuclear Magnetic Resonance (Esser P) and Johnson RE (eds). The Society of Nuclear Medicine, Reston, VA, USA, pp 233–252.
MAGNET SAFETY IN MAGNETIC RESONANCE IMAGING SUITE CONSTRUCTION

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This paper examines whether the parties concerned with the design and construction of Magnetic Resonance Imaging (MRI) suites adequately address the risks to construction staff from the presence of the static magnetic field of the magnet during the construction phase, and whether this hinders effective health and safety management on site. Concerns are raised about which party to the works is actually responsible for site access controls once the magnet has been energised and to where these controls should extend. Screening of operatives, the need for its documentation and the desirability of health surveillance for those operatives exposed to the static magnetic field of 0.5 mT and above is discussed. Evidence is presented of conflicting advice from the NHS regarding the designed position of the 0.5 mT footprint of the static magnetic field being retained within the MRI scanner room or allowed to pass to the technical room. There appears to be a contrast between operational MRI suite procedures and those at construction stage. This results in there being a gap in knowledge needed for the efficient management of health and safety on site covering the period within the construction phase between magnet energisation and handover of the MRI suite to the Client for operational use.

Keywords: design management, health and safety, project management.

INTRODUCTION

Although MRI suite projects are specifically the subject of this Paper, the findings themselves could just as equally apply to any construction project where specialist suppliers also contribute to the design process, thus demonstrating the need for them to be brought into the decision making process as early as possible at initial design stage as, “each designer needs to discuss the types and format of supporting information with the CDM-Co-ordinator who has to identify and provide information to those who need it”. (The Association for Project Safety 2007 (a) p. 90)

Magnetic resonance imaging as a modality has seen a gradual rise in the rate of installations since the middle 1990s, when the full benefits of superconducting magnet technology became available. Some of these earlier magnets are still installed in their original locations, but generally and as technology has evolved further, they have been replaced on a regular basis. In a study of MRI installations in NHS hospitals in Scotland, Wales and England, it was determined that the oldest magnet still in use was installed in 1992. (Price, T. et al. (a) in press)

Prior to the middle 1990s, NHS hospitals regularly used their project management teams to manage both ionising and non-ionising radiation producing installations, with this system working well. For political and economic reasons, and coupled with a rapid rise in installations for both MRI and X-ray, specialist pre-installation

companies evolved. These companies, having specialist knowledge of the particular construction requirements of each modality, each magnet vendor and often even of each equipment model were usually appointed as sub-contractors to magnet vendors in order to carry out the necessary construction work to enable installation of the required imaging equipment to take place. However, one disadvantage of this change in methodology appears to have been a fragmentation of the design and construction processes, resulting in a possible misunderstanding by CDM duty holders of their responsibilities to each other and to their charges. This is most evident in relation to the design function, where CDM 2007 makes it clear that measures should be taken in order to ‘avoid foreseeable risks’ of any design. (The Approved Code of Practice (ACoP) to The Construction (Design and Management) Regulations [CDM 2007] Paragraph 125) One of the control measures outlined in CDM 2007 is the requirement that “Risk Management proposals/methods that the Designers have assumed or decided will be appropriate”, (The Association for Project Safety 2007 (b) Para 11.2.5) and made available for development of the Construction Phase Plan by the principal contractor. These are measures that should also be identified, if they are not eliminated during the construction phase, for adoption by those using, decommissioning or demolishing any structure(s) on completion of the project and to be included in the health and safety file at the end of the project. Nevertheless, it is quite feasible that the Principal Contractor would have the opportunity, by utilising his technical and managerial expertise, to eliminate many residual design hazards during the construction phase - but this requires him to have knowledge of them.

MRI magnets are installed within a Faraday (RF) cage (the scanner room). Faraday cages are constructed of conductive material, usually of copper or aluminium, and are essential in ensuring that external static electrical fields are prevented from distorting the RF signal being utilised to create the image. This RF cage will be normally have been designed and constructed by a specialist RF cage supplier either through the Client, the magnet vendor or the pre-installation contractor. Faraday cages do not protect the magnet from the influence of magnetic fields external to the MRI magnet, or in reverse, protect persons or objects outside the Faraday cage from reach of the magnetic fields supported by the MRI.

Once the superconducting magnet has been energised, which usually takes place whilst still within, but towards the end of the construction phase of the project, a static magnetic field is produced. The strength of this static magnetic field is measured in Gauss (G) or millitesla (mT).

An operational MRI suite would normally contain of a minimum of two controlled areas - an outer and an inner one, with the outer controlled area being an area “totally enclosed, and of such a size to contain the 0.5 mT (5 Gauss) magnetic field contour” (Device Bulletin, December 2007 Section 4.5.1)) and an inner controlled area, “within the confines of the MRI Controlled Area containing the 3 mT (30 Gauss) magnetic field contour.” (Device Bulletin, December 2007 Section 4.6.1)

The static magnetic field is the subject of this Paper because during the construction phase (and throughout the life of the installation) there may be potential hazards and risks to construction employees and third parties because of a gap in information transfer between all those disciplines involved with an MRI construction project because;
• Unlike other medical imaging equipment, MRI superconducting magnets to which this Paper is restricted, once energised, are always ‘on’ and producing a static magnetic field.

• Large static magnetic fields extend in three dimensions around the magnet and generic positions of the static magnetic field will necessarily change with each individual project. For ‘open’ format ‘hamburger bun’ type magnets the larger component of the static magnetic field is vertical, resulting in slightly diminished hazards on the same level as the magnet (as compared to bore format magnets) but greater hazards above and below. (Price, T et al. 2009 a)

• Magnetic fields are invisible and it is impossible to know if they are on or off, or to be aware of them unless told. There are referenced documents (The American College of Radiology Guidance Document for Safe MR Practices 2007) discussing patient and staff exposure to electro-magnetic fields (EMF’s) and maximum exposure limits (ICNIRP 2004 pp 267-311). Despite this advice, these controls do not appear to be considered until the MRI suite reaches the operational stage and is handed over to the Client even though, once the magnet has been energised, the same hazards exist during the construction phase.

• 5 gauss is the threshold for exposure to the static magnetic field of all individuals that have not been successfully screened for contra-indications. UK government advice is that “A person fitted with a heart pacemaker must not enter the MR Controlled area”. (Device Bulletin 2007 Section 4.11.1.1) However, it should be appreciated that this hazard is not a direct biological one to the individual, but a risk of magnetic field electro-mechanical interference with the medical device. One description of the effect of the static magnetic field on pacemakers (Young R. 2000) is that “the magnetic reed switch that varies the heart rate can be inadvertently switched by the static field and revert to its default setting.” This could lead to irregular heart rhythm of the bearer of the pacemaker and eventually to his/her serious handicap or death.

• Within the published NHS Estates literature there is ambiguity as to the area(s) within the MRI suite to which the 5 Gauss footprint should be contained.

![Diagram of MRI suite](Image)

Figure 1: NHS Estates advice regarding the retention of the 5 gauss footprint within the magnet (scanner) room and technical (equipment) room, but without mentioning the y axis (Image Courtesy of NHS Estates)

Although it is recommended that the 5 gauss line of the static magnetic field should be restricted to the magnet (examination) room and the technical room, this published advice shows an illustration (reproduced in Figure 1 above) of a generic footprint of
the x (lateral) and z (horizontal) axes of the static magnetic field to a magnet, whilst ignoring that of the y (vertical) axis. (Health Building Note 6 - Supplement 1, p 16 Fig: 4). Conflicting advice is that the 5 gauss line is ideally “constrained within the confines of the MRI scanner room” (NHS Estates. Magnetic Resonance Imaging - Health Guidance Note 1997 p 6).

- In addition to this electro-mechanical interference, there are also two other physical forces, being (a) torque and (b) translational attraction (the projectile effect) which can be exerted by magnetic fields upon ferromagnetic objects. When subjected to magnetic fields, a heart pacemaker or other medical device or implant could twist (torque) within the individual so as to align itself with the magnetic field to which it is exposed, or be pulled towards the magnet by translational attraction whilst embedded in the individual’s body. “One of the most vulnerable parts of the body is the eye. The adequate screening of patients or others with suspected intra-ocular ferromagnetic metallic objects is most important before they are allowed to enter the MR controlled area of the MRI suite.” (Device Bulletin 2007 Section 4.11.5.1)

- Exposure of unscreened plant and tools also risks causing the ‘projectile effect’, thus giving rise to the possibility of workers being injured whilst in the path of the projectile. Additionally, there is the potential of the cost of damage to the magnet bore, or those of a quench of the magnet in order to remove the object.

- Although the ACoP to CDM 2007 is clear, it is difficult to ascertain the hierarchy and perception of accountability of the parties during the pre-handover (construction phase) period of an MRI project.

**RESEARCH AIMS AND OBJECTIVES**

The aim of this work is to identify the potential safety issues of the exposure of construction workers to the static magnetic field of the magnet, with the objective that the information obtained will help to assist clients and their duty-holders appointed under CDM 2007 in managing health and safety during the construction phase of an MRI project.

**RESEARCH METHOD**

It was necessary to discover the relationship between the Client, his architect/designer, the magnet supplier, the RF cage supplier and the pre-installation or Principal Contractor to determine if there was sufficient acceptance of safety responsibilities of each of the parties, as well as to establish the hierarchy of health and safety management from site start-up until completion and handover of the MRI suite to the Client. Safety management hierarchy is of particular interest to HSE Safety Inspectors, and legal notices can be issued if the hierarchy is not clearly documented. It was necessary to determine how, during the construction process, access to the immediate area of the magnet was controlled, and by whom. It was also necessary to establish if operatives working on the construction of the MRI Suite were made aware of any residual risks notified by designers and of the control measures put in place on site by the Principal Contractor in order to manage those risks. It was necessary to enquire if information on these hazards and contained in magnet suppliers’ Site Planning Guides was being made available to operatives in the form of site specific risk assessments and method statements and how this was being managed.
So as to validate the hypotheses and in order to form a valid conclusion and submit recommendations, questionnaires were sent to pre-installation contractors, RF cage and magnet suppliers before assembling the information gathered in order to extract a snap-shot of current practice. Additional material supplied by architects from a parallel questionnaire was included in the research. The study was limited because only one magnet vendor was forthcoming in allowing his project managers to answer the questionnaire, but the results obtained highlight the need for clear lines of responsibility in any construction project to be clearly determined and understood.

**Interview and data collection process**

The most important element of the research was to find the opinions and perceptions of the people and companies with hands-on experience of what was actually happening on site, rather than what was supposed to be happening. Magnet vendor Project Managers, pre-installation company Contracts Managers and RF cage owner/managers were interviewed, as they were the persons who had actually experienced conditions on site whilst an MRI suite was being constructed. Architects involved with current MRI projects were also interviewed, as were two PFI Contractor Design Managers.

**The Questionnaire**

A questionnaire for each of the parties involved in the study was compiled, that is to say; architect, RF cage supplier, magnet vendor and pre-installation contractor. Each questionnaire had the same questions, but was orientated from their own position in the supply chain so as to identify differences in each player’s perception of what they or others should be doing on site. Some persons to whom the questionnaire was sent felt that some of the information was commercially sensitive and refused to reply.

**RESULTS**

**To whom were the questionnaires sent?**

Pre-installation Contractors: In cases where the contract is turnkey to the magnet vendor, the pre-installation contractor will normally carry out the role of Principal Contractor. Where the contract is a PFI, the Principal Contractor will normally subcontract the works, but not always to specialist sub-contractors. In the following, read Principal Contractor (under CDM 2007) for Pre-installation Contractor (PIC) and vice versa, but not as him being the Site Waste Management Plans Regulations 2008 (SWMP 2008) Principal Contractor, although there may be cases where this could be the same duty holder position under both sets of Regulations, but with each having different responsibilities. (Price, T. et al. 2009b pp 12-17)

RF cage Suppliers: Questionnaires were sent to five cage suppliers, with two not responding, thus giving a return rate of 60%.

Architects: Questionnaires were sent to three Architects and two PFI Contractor Design Managers whose speciality was hospital design. Replies were received from all five, giving a return rate of 100%.

Magnet Vendor: Following telephone conversations to ascertain their susceptibility to participating in the study by completing the questionnaires and by having a one hour meeting with their Health and Safety Manager, the questionnaires were sent by e-mail to the National Project Manager of a magnet vendor, where four of his eight Project Managers supplied separate responses to the questionnaire, a return rate of 50%.

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DISCUSSION

What became apparent is that the responses to the questionnaires by the pre-installation contractors and the magnet vendors were sufficiently conflicting to justify concentration of the research on these groups, but with peripheral input of architects and RF cage suppliers.

Siting of the magnet

The siting of the magnet (examination) room within an MRI suite is important because if the static magnetic field produced by the magnet is allowed to pass to areas outside the RF cage, then third parties may be affected if the footprint is not identified and controlled areas set up to manage the risk of persons coming into contact with high magnetic fields.

The magnet vendor was the party who believed the most that he was involved in the design process early enough to be able to make a contribution to the siting of the MRI suite. The PIC felt he himself was not. Architects broadly thought that they were involved early enough, but the RF cage supplier stated that magnet vendors fitted magnets into cages supplied by others even when they had not been involved in the cage procurement process. As the cage supplier would normally be the party designing any necessary magnetic shielding, it casts doubt on who is actually specifying the design of the RF cage and any required magnetic shielding to the magnet room, as architects would not normally have such specific knowledge.

It was confirmed that the magnet vendor was not faced with a fait accompli regarding the overall suitability of siting of the magnet, a fact also borne out to some extent by architects’ replies, indicating that in cases where the magnet vendor was not specified at the early design stage, architects had nevertheless taken magnet vendors general siting requirements into consideration. From discussions with architects, this was found to be manifested by the Client instructing the architect to ‘take the worst case scenario’ when considering the effects of the static magnetic field when deciding on any given MRI suite location.

Which of the players considered themselves to be designers?

Questions were posed to determine if the parties felt they were part of the design process. The magnet vendor was the most positive party, with the PIC ‘to some extent’. It was discovered that even when supply of the cage was not in the magnet vendor’s package, the magnet vendor still felt he was part of the design process, whereas the PIC did consider himself to be, but not to the same extent. Clearly there is no proof of design co-ordination by the Client’s CDM Co-ordinator.

Further questions were developed to determine if the parties were involved in any magnetic shielding requirements, so as to establish if they were able to influence the management of health and safety on site. Responses showed that the PIC, magnet vendors and cage suppliers as well as architects were involved in magnetic shielding discussions if it affected the safety of site operatives, but where it did not affect the operation of the magnet the PIC was consulted less, which appears logical. Where magnetic shielding (or the lack of it) was discussed then all parties were consulted, including the PIC ‘to some extent’, except that where the operation of the magnet was not affected, the PIC was not consulted. This leads to the impression that the design emphasis is solely on the effect of the environment on the magnet rather than to include the effect of the magnet on the environment, which by implication includes the health and safety of the construction operatives (and eventually users of the
completed magnet installation). ‘The general rule for NMR installations can be summed up one simple phrase: protect the magnet from the environment and the environment from the magnet’. (Einstein S.G. and Hilal S.K. 1985 pp 267-311)

The Principal Contractor under the Construction (Design and Management) Regulations 2007 (CDM 2007)

Further questions were intended to determine which of the players usually held the Duty Holder position of Principal Contractor and were therefore responsible for the management of health and safety on site. As expected, the PIC showed greater acceptance of the role of Principal Contractor. In two cases, the magnet vendor had replied that he ‘to a small extent’ or ‘to some extent’ accepted this CDM Duty Holder position. The magnet vendor replies showed them to be unanimous in that they produced risk assessments and method statements before energisation of the magnet, as was broadly the case with the cage supplier. The score of the PIC was very low and may be because he was relying on the magnet vendor to manage the whole magnet energisation process and in isolation from the other site controls. It would make sense for the PIC to be appointed Principal Contractor during the first part of the process and until he had finished construction works and left site. At this stage, the magnet vendor could become the Principal Contractor and manage site health and safety. It would be unrealistic to expect any PIC who had become Principal Contractor at the commencement of the works to continue in this role once he had finished the pre-installation works and left site. If he remained Principal Contractor, he would be unable to manage health and safety in this period up until final handover of the MRI suite to the Client, particularly as this period could include instruction and training of hospital staff in the use of the imaging equipment.

The Principal Contractor and the management of safety relating to the static magnetic field

Questions were set so as to determine if there was site-specific information on the position of the 5 gauss footprint and measures advised by the magnet vendor that should be used to control residual risks as a result of magnet energisation. The study was trying to establish if the site-specific physical position of the 5 gauss footprint had been identified to the Principal Contractor. The magnet vendor believed that he did supply site-specific information regarding the position of the 5 gauss footprint, but the PIC did not agree. In further questions, it was the PIC who did not attach so much importance to annotated site specific drawings with the magnet vendor scoring highest, then the PIC, with the cage supplier scoring lowest in believing that site specific information was included so as to control the magnet’s residual risk to site operatives once the magnet had been energised. There was absence of evidence showing a clear process. This situation is complicated further in that there are no clear guidelines as to where the 5 gauss footprint of the static magnetic field should be allowed to extend, inasmuch that in discussing the fringe (or ‘stray’) field and the implications for safety, the NHS state that ‘The controlled area is normally defined from the boundary of the 5 gauss fringe field contour. Ideally, this is constrained within the confines of the MRI scanner room’, but later goes on to say in paragraph 5.15 that ‘the 0.5 mT contour should be entirely contained within the boundaries of the MRI scanner and technical room’. (NHS Health Guidance Note 1997. Magnetic Resonance Imaging: Para 2.13)
Who sets up a controlled area around the magnet?

A question asked who set up the controlled area around the magnet, with another enquiring who set up any controlled area for areas contiguous to the RF cage. The magnet vendor advocated setting up a controlled area around the magnet, with 40% of the PIC’s replying ‘to some extent’ and 40% ‘not at all’. Later, this response was mirrored in that the magnet vendor was the party most likely to set up a controlled area where the 5 gauss footprint was not retained within the cage. Surprisingly and as they were supposed to be in control of the site, 20% of the PIC’s replied ‘not at all’ or ‘to a small extent’ on the desirability of setting up a controlled area.

Who polices access to the controlled area?

From questions to ascertain who was felt to be responsible for policing access to the controlled area and to other areas to where the 5 gauss footprint may extend, responses from the magnet vendor scored the highest, with the PIC scoring the lowest. Again and under CDM, the PIC is supposed to be in control of the site, as well as being responsible and accountable for the management of health and safety on the site. The PIC appeared (wrongly) to relinquish this task to the magnet vendor.

Screening of operatives

Questions asked about screening to operatives generally and then specifically for the presence of implants, followed by questions relating to the screening of tools and equipment for ferromagnetic properties.

The magnet vendor again scored the highest, whereas it was not confirmed by the PIC. The magnet vendor contradicts this statement in a later question where it was the PIC who gave a more positive response in feeling that operative and contractor screening for implants or metal objects in their bodies should be carried out. Again in another question, it was the magnet vendor who scored the highest for the controls on tools and plant to the controlled area, with both PIC and magnet vendor scoring high in that these controls were just to the RF cage.

Responsibility of highlighting any RF cage design failings that may cause workers to come into contact with the 5 gauss footprint of the static magnetic field

The purpose of another question was to establish if the Principal Contractor or Pre-installation Contractor understood he had a responsibility to give feedback to the designers if he felt the design was allowing his operatives to come into contact with the 5 gauss footprint. The replies were as expected, in that all parties felt they had a responsibility, with the magnet vendor scoring highest. However, the actual site position of the 5 gauss footprint needs to be identified in order for this to become effective.

Desirability of health monitoring of operatives’ exposure to the static magnetic field

A question aimed to establish if the parties believed that health monitoring of operatives’ exposure to the static magnetic field was desirable. Interestingly, 50% of the magnet vendors replied ‘not at all’. Conversely, all the PIC’s thought health monitoring to be desirable, indicating a lack of co-ordination between the magnet vendor and the PIC in the management of health and safety on site.
Control by contractors of operatives’ exposure to the hazards of magnet installation

A question enquired if contractors should do more to control operatives’ exposure to the hazards of magnet installation. All respondents felt that contractors should do more.

Confusion with RF and static magnetic fields

It was elucidated from both magnet vendor and PIC, albeit in varying degrees, that there was confusion between operatives of the effects of these EMF’s, believing them to be adequately controlled within the RF cage. The responses of the PIC’s to this question as the CDM Duty Holder responsible for the management of health and safety on site varied between ‘to a small extent’ through to ‘to a large extent’.

Is there a gap in health and safety information transfer between the magnet vendor and contractors?

All parties, albeit in varying degrees, felt that there was a gap in health and safety information transfer, with the PIC feeling more strongly than the magnet vendor.

Do survey participants believe there could be dangers to health from exposure to static magnetic fields?

80% of the PIC’s felt there was a danger from static magnetic fields, but only 50% of the magnet vendors agreed, with the other 50% replying ‘not at all’. This signals that inadequate information is used to carry out a risk assessment used to develop a method statement to take account of the risks from the static magnetic field.

CONCLUSIONS

The survey questionnaire highlighted the fact that there was no agreement on:

- whether exposure to the 5 gauss footprint of the static magnetic field was hazardous to health
- whether identification of the actual site specific position of the 5 gauss footprint of the static magnetic field was necessary and whether it should be confined to the RF cage
- whether site specific planning guides containing site specific information on methods of controlling residual risks of the energised magnet are issued by the magnet vendor.
- who should carry out operative screening and be responsible for its documentation, or even whether screening should be documented at all.
- who should police access to the controlled area - or even if there should be a controlled area either inside or to areas outside the RF cage where the 5 gauss footprint may be present.

Evidence gleaned from the questionnaire on construction operative screening for implants, etc and its lack of documentation was worrying. Despite the hazard of a static magnetic field being forever present once the magnet had been energised during the construction phase, this is in stark contrast to the documentation requiring to be completed by an individual entering the controlled area of an operational MRI suite, even as a visitor, where he/she would be required to satisfactorily complete a questionnaire before being granted access. There was no agreement that the 5 gauss footprint should be retained within the RF cage or of whether its (installed) 5 gauss footprint should be mapped on site. There appears to be a contrast between operational MRI suite procedures and those at construction stage. The evidence produced shows
that there is a gap in knowledge transfer. This gap needs to be filled so as to ensure the efficient management of health and safety on site covering the period within the construction phase between magnet energisation and the handover of the completed MRI suite to the Client for operational use.

FURTHER WORK

This paper reports ongoing research at Edinburgh Napier University. The aim of this research is to develop guidelines to improve the nature and quality of information to be included in future Information Packs and Health and Safety Files prepared by CDM Co-ordinators, and by Construction Phase Plans prepared by Principal Contractors under CDM 2007.

REFERENCES


The Approved Code of Practice (ACoP) to the Construction (Design and Management) Regulations 2007 (HSGL144) Her Majesty’s Stationery Office, London.


Einstein S.G and Hilal S.K (1985) Site planning design: influences and implementation, Mag Reson Annu.


SITE WASTE MANAGEMENT PLANS, THE DESIGNER AND THE CDM PRINCIPAL CONTRACTOR

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The Site Waste Management Plans Regulations 2008 (SWMP) have as their purpose the requirement for the elimination, recycling or re-use of construction waste so as to reduce the use of landfill. The results of a survey carried out to establish designers’ involvement in waste reduction during the design stage shows a lack of understanding and commitment to this process. A second survey shows that information from the designer on the quantity and type of waste, which the principal contractor is expected to manage once the construction phase commences, is lacking. It is argued that as a result, any waste reduction achieved during the construction phase would be at the initiative of the CDM principal contractor, thus placing an unreasonable responsibility on him to reduce waste resulting from a design over which he has had no control. This could result in increased health and safety risks for the CDM 2007 principal contractor as he would have no prior knowledge of the designer-imposed waste management activity required of him (site storage/working areas required for materials recycling or re-use, etcetera) once the construction phase commences, thus having increased risk of environmental damage and/or pollution resulting from his unplanned site-based waste triage activities.

Keywords: construction planning, design management, environmental impact, health and safety, recycling.

RESEARCH AIMS AND OBJECTIVES

Under the Site Waste Management Plans Regulations 2008 (HMG 2008) clients are responsible for preparing the site waste management plan for a given project. The aim of this work is to identify, through a survey of designers and principal contractors, if any decisions were taken by designers in order to minimise the quantity and type of waste produced on site once the construction phase begins, and if this information was included in the pre-construction information pack for the successful tendering CDM 2007 (HMG 2007a) principal contractor to incorporate into his construction phase plan.

The objective is to highlight the risks to which the client may be exposed if information on the estimated quantity and type of waste, as well as advice regarding viable on-site locations for the waste management process, is not forthcoming from the designer via the pre-construction information pack (CDM2007a) at tender stage of the project.

INTRODUCTION

UK construction sites use around 360 million tons of resources each year and generate some 100 million tons of waste (equivalent to a third of all UK waste).

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Estimates suggest that 10-30 per cent of the materials that end up as waste on-site have never actually been used – a major waste of resources. The true cost of waste (Envirowise 2007) can be up to 15 times more than the cost of waste disposal. Available landfill sites are rapidly being used up. In tandem with the general policies of re-use and recycling and with the aim of reducing our carbon footprint, the government have introduced a landfill tax (HMG 1996) to act as a disincentive to sending waste to landfill. The objective is to increase the re-use or recycling of waste.

The Site Waste Management Plans Regulations 2008

The Site Waste Management Plans Regulations 2008 (HMG 2008) came into force on 6th April 2008. These Regulations are known as SWMP 2008 (HMG 2008) in their short form. Currently these Regulations only apply to construction projects carried out in England.

The purpose of SWMP 2008 (HMG 2008) is to protect the environment by reducing the amount of construction waste being sent to landfill. This is to be achieved by identifying materials that can be re-used or recycled. In order to do this, the SWMP 2008 (HMG 2008) regulations impose a duty on any client who intends to carry out a project on any one construction site, with an estimated cost greater than £300,000 excluding VAT, to prepare a site waste management plan before construction work begins. To facilitate this process, Regulation 6 stipulates that the client must record any decision taken before the site waste management plan was drafted on the nature of the project, its design, construction method or materials employed in order to minimise the quantity of waste produced on site. The client must appoint a (SWMP) principal contractor. Once the construction phase begins, then the SWMP principal contractor should ensure that the site waste management plan (SWMP) is updated as work proceeds. However, SWMP 2008 (HMG 2008) imparts no clear duty of enforcement (Baldwin 2010) with any particular body. Either the Environment Agency, any local government area with a principal authority, any district or county council or, in the City of London the council, may enforce the SWMP Regulations. This lack of clear direction could lead to non-compliance by industry.

In Wales devolved power is given to ministers in the Welsh Assembly Government to require developers and contractors to produce a written site waste management plan for both construction and demolition projects. In the meantime, and in the absence of formal legislation, Local Authority planning departments are also promoting resource efficiency and recycling in the form of guidance.

In Scotland, whilst the Scottish Government supports site waste management plans as a tool to reduce waste generated through construction and demolition work and with a view to halving the amount of waste sent to landfill by 2012, there is no intention (APS 2010b) to legislate to require site waste management plans - although it retains the option to make them compulsory if necessary, through the powers in the Climate Change (Scotland) Act 2009 (SP 2009).

The Construction (Design & Management) Regulations 2007

The CDM 2007 Regulations (HMG 2007a) are intended to focus attention, from design concept onwards, on planning and management throughout construction projects. These Regulations apply to the whole of the United Kingdom.

The aim of CDM 2007 (HMG 2007a) is for health and safety considerations to be treated as an essential, but normal part of a project’s development – not an afterthought or bolt on extra. In order for him to fulfil his duties for notifiable projects
(those construction projects which are expected to last more than 30 days or involve more than 500 person days) under CDM2007 (HMG 2007a), the client will appoint a (CDM) principal contractor. His responsibility is to manage the construction phase of the project, to produce (before commencement on site) a suitable construction phase plan - and then update it during the course of the works.

**DISCUSSION**

Although site waste management has been the subject of numerous studies over the last twenty years or more, industry does not appear to have overcome the challenges that, without clear client/designer buy-in to the process, seem impossible to surmount.

Decisions will need to be made and waste minimisation plans initiated by designers in all senses of the term (Coventry et al 1998) but designers have traditionally been appointed by clients on the basis of the aesthetics of their design, and not on their waste reduction performance. Should clients leave the successful tendering principal contractor to be the party relied upon to manage waste generated on site, the perceived costs to the principal contractor and his contractors will naturally have been reflected in the tender price to the client. Putting the financial benefits to the client of waste reduction during the design stage of his project to one side, there are also health and safety matters that need to be considered. This is because there is a common connection between health and safety implications of the design and of the waste management process, of the contents of the construction phase plan required by CDM 2007, (HMG 2007a) and of the site waste management plan. (HMG 2008) Each designer needs to discuss the type and format of supporting information with the client’s CDM-Co-ordinator who has to identify and provide information to those who need it”. (APS 2007a) At design stage this person would be the Lead Designer.

Unfortunately there appears to be a lack of joined-up thinking in Government about how this should be achieved. These two pieces of legislation, both closely linked and interchangeable with construction waste reduction and health and safety. (Price et al 2009) have been put together at almost the same time [2007 for CDM and 2008 for SWMP] and by two different government departments – the Health and Safety Executive (HSE) for CDM 2007 and the Department for Environment, Food and Rural Affairs (DEFRA) for SWMP 2008. There is no evidence of a common dialogue.

Once the design has been completed and the construction contract awarded, it is the principal contractor who now has to accept any residual risk to the design (including waste management). One of the control measures outlined in CDM 2007 (HMG 2007a) is the requirement that risk management proposals/methods that the designers have assumed or decided will be appropriate (APS 2007b) will made available for development of the construction phase plan by the (CDM) principal contractor. This is based on the advice embodied in Paragraph 125 of The Approved Code of Practice to CDM 2007 (HMG 2007b), which makes it clear that measures should be taken in order to ‘avoid foreseeable risks’ of any design.

Even when if the designer has reduced waste in his design as far as is possible there will still be waste to manage. It cannot be totally eradicated, only reduced. Therefore, it is important to the CDM 2007 (HMG 2007a) principal contractor that before he tenders for the works the client should inform him of the likely quantity and type of materials that he would be expected to re-use, recycle or send to landfill should he be successful in winning the construction contract. Thus, the CDM principal contractor would be able to transmit this information to his sub-contractors in order for them to mimic his waste management process in their price submissions to him. Bearing in
mind that considerable savings can be achieved by adopting site based strategies for handling waste (McDonald and Smithers 1998) and that source separation requires less effort and results in better segregation of inert and non-inert wastes (Poon et al 2001) as compared with waste sorting centrally carried out at a designated area either on or off-site, the CDM principal contractor will need to know, through the pre-construction information pack, where the client has deemed that any on-site waste storage and/or triage activities should be situated, or if the SWMP (HMG 2008) principal contractor has decided that he wishes to send his waste as mixed waste away to an external triage station. The CDM principal contractor will, if the SWMP (HMG 2008) principal contractor wishes to segregate waste at source, perhaps by the strategic siting of bins in live working areas on site, have additional housekeeping issues such as fire safety and manual handling to manage. This is one area, and there are others, where the crossover between SWMP 2008 (HMG 2008) and CDM 2007 (HMG 2007a) occurs.

Although design is only one of the influencing factors in the volume of waste produced on construction sites (Coventry et al 1998) it can play a major part in reducing the volume that goes to disposal. Therefore, by his input to the site waste management plan, the designer could indicate the likely volume and type of waste that the CDM principal contractor may wish, by using a site guide to waste minimisation, (Guthrie et al 1997) to re-use, recycle or send to landfill. As this will be occurring in parallel with development of the construction phase plan, (APS 2008) this information, because of the health and safety issues relating to waste management on site, should be incorporated into the construction phase plan. There may also be useful contents of any site waste management plan that could be added to the health and safety file (APS 2009). In particular, information could be given on materials which the designer has envisaged should be re-cycled or re-used and how, using a deconstruction plan, such a process should be carried out so as to minimise damage to those materials and to include instructions on how the designer has envisaged that their retrieval can be carried out safely (Price et al 2009). Mention could also be made of those materials that, because of any physical properties that they may have acquired during their installation in a given structure, may place restrictions on their use once recycled. For example, steelwork originally used in the construction of a magnetic resonance imaging (MRI) suite may be affected by residual magnetisation (Price et al 2010) and therefore would not be able to be re-used in an area where this newly acquired physical property could affect electronic equipment.

Even if a CDM principal contractor was efficient in his process of re-using waste construction materials during the construction phase, real savings by the use of recycled materials is still not fully accepted by architects who are often reluctant to specify recycled materials in their projects. This is mainly due to: concerns relating to their properties (Sassi 2004); uncertainties that a guaranteed standard can be achieved, and because of lack of knowledge (Coventry et al 2001, Osmani et al 2008).

The Site Waste Management Plans Regulations 2008 (HMG 2008) misnomer (Philip. A. Baker, personal communication – April 2010) could lead the construction industry to believe that it is the site that should bear responsibility for reducing construction waste sent to landfill. This research sets out to test this hypothesis.

**RESEARCH METHOD**

In order to achieve the objective, it was decided to conduct a survey of middle size designers and principal contractors whose portfolio covered a broad range of
disciplines, but with project values the minimum value of which was set at £300,000 and the maximum as £1,000,000, both figures excluding VAT. This research has the limitations that the results may not apply to projects that have a greater or lower value than those studied, and that it did not include any design and build contracts.

Data collection process
By consulting Chambers of Commerce and using telephone calls to obtain their agreement to participating in the survey, an ad hoc selection of ten design practices and ten principal contractors was made from ten counties of England.

The questionnaires
Designers were chosen based on their project speciality and value of the project. This is shown in Table I below. CDM principal contractors were chosen simply because it was they who had won the construction contract.

Survey questionnaires were sent out as hard copies to those designers and principal contractors who had previously agreed to participate in the survey. Although three designers and two principal contractors were required to be reminded of their commitment to the survey, a final return rate of 100% was eventually achieved.

Table 1: Project cost, project description and designer speciality

<table>
<thead>
<tr>
<th>Designer identification reference</th>
<th>Value excluding VAT (GB£)</th>
<th>Project Type</th>
<th>Designer speciality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>965,000</td>
<td>Hospital x-ray department extension</td>
<td>Health</td>
</tr>
<tr>
<td>2</td>
<td>783,000</td>
<td>New offices with two shop units below</td>
<td>Offices</td>
</tr>
<tr>
<td>3</td>
<td>348,000</td>
<td>Library extension</td>
<td>Public Works</td>
</tr>
<tr>
<td>4</td>
<td>321,000</td>
<td>New children's paddling pool and play area</td>
<td>Public Works</td>
</tr>
<tr>
<td>5</td>
<td>315,000</td>
<td>New doctors' surgery</td>
<td>Health</td>
</tr>
<tr>
<td>6</td>
<td>302,000</td>
<td>New electrical sub-station and civils infrastructure</td>
<td>Utilities (Power)</td>
</tr>
<tr>
<td>7</td>
<td>318,000</td>
<td>New engineering factory</td>
<td>Industrial</td>
</tr>
<tr>
<td>8</td>
<td>763,000</td>
<td>Bus station</td>
<td>Public Works</td>
</tr>
<tr>
<td>9</td>
<td>426,000</td>
<td>New retail warehouse</td>
<td>Industrial/retail</td>
</tr>
<tr>
<td>10</td>
<td>512,000</td>
<td>New school classrooms and cafeteria extension</td>
<td>Schools</td>
</tr>
</tbody>
</table>

RESULTS
Replies to the questionnaires sent both to designers (Table II) and to CDM principal contractors (Table III) follow. The questionnaires contain similar questions so as to be able to compare two different CDM duty-holder (designer and principal contractor) biased results. This allowed validation of the replies, with the designer answering the questionnaire from his experiences and the principal contractor from his.

From Table 1 above, it can be seen that a range of project types were chosen so as to maximise the value of the survey.
Table II Designer questionnaire

| (a) As designers are you aware of the design out waste tool for buildings for use with RIBA Stages A-C? | 2 | 8 |
| (b) Are you aware of Regulation 6 of SWMP 2008? (Requirements for a site waste management plan) | 4 | 6 |
| (c) Do your clients normally request you to minimise waste in your design submissions to them? | 2 | 8 |
| (d) If clients do not request waste to be minimised in the design do you normally carry out the process of waste reduction on your own initiative? | 2 | 8 |
| (e) If clients do not request waste to be minimised in the design, do you inform them of their obligations under SWMP 2008? | 1 | 9 |
| (f) Do you always prepare a site waste management plan for the client to give to his SWMP champion? | 2 | 8 |
| (g) Do you discuss waste reduction with the Client’s CDM-co-ordinator during your CDM 2007 Design co-ordination meetings with him? | 2 | 8 |
| (h) Have you ever been asked by the client’s CDM co-ordinator to include your prepared SWMP in the CDM 2007 pre-construction information pack? | 2 | 8 |
| (i) If you have not been asked by your prepared SWMP to be included in the CDM 2007 pre-construction information pack by the Client’s CDM co-ordinator, then do you send it him along with your Designer’s Residual Hazard and Risk Log? | 0 | 10 |
| (j) Do you ever include information for the CDM 2007 information pack on where the principal contractor might set up his waste triage facilities on site? | 0 | 10 |

Table II above shows that designers have little knowledge of their responsibilities under SWMP, (HMG 2008) generally leaving the management of waste minimisation to the principal contractor once he arrives on site. From the replies in Table II, one may agree with the designers’ view that waste is mainly produced during site operations (Osmani *et al* 2007) and rarely generated during design stages; however about one-third of construction waste could essentially arise from design decisions.

SWMP 2008 (HMG 2008) only requires designers to record any (waste reduction) decision made. Where no decision has been made there is no statutory requirement on them to do anything more. The evidence from the survey intimates that designers really have no interest in waste reduction during the design phase of a project, and unless asked by CDM co-ordinator, take no further action in this respect. Table II above also shows that there is a gap in information transfer between the principal contractor (whether CDM or SWMP) and the CDM health and safety file.

Table III below demonstrates that CDM 2007 (HMG 2007a) principal contractors receive little information on their responsibilities from neither SWMP 2008 (HMG 2008), designers nor CDM co-ordinators. The replies show that responsibilities for waste minimisation are left to the CDM principal contractor once he arrives on site. This confirms previous research (Baldwin 2010) in that Clients did not believe that they were responsible for the SWMP (HMG 2008) either at design stage or during the construction process. Late designers need to be avoided or recognised as soon as possible, as substantial amount of waste is directly related to late design changes during site operations, (Coventry *et al* 2001) and could alter the type or quantity of building materials required at later stages of the construction phase. This places additional (and possibly unforeseen) burdens on the CDM principal contractor in managing health and safety on site. The questionnaire to principal contractors in Table III below seeks to confirm the replies received from designers.
Table III CDM 2007 principal contractor questionnaire

<table>
<thead>
<tr>
<th></th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) As principal contractor are you aware of the design out waste tool for buildings for use with RIBA Stages A-C?</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>(b) Are you aware of Regulation 6 of SWMP 2008? (Requirements for a site waste management plan)</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>(c) Do your clients normally give you (either through the CDM-C or the Client’s SWMP 2008 Champion) designers’ waste minimisation information?</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>(d) If clients do not request waste to be minimised in the design, do you normally carry out the process of waste reduction on your own initiative?</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>(e) If clients do not supply you with waste minimisation information, do you inform them of their obligations under SWMP 2008?</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>(f) Do you always receive a Site Waste Management Plan for the client to give to his SWMP Champion?</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>(g) Do you ever discuss waste reduction with the client’s CDM-Co-ordinator?</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>(h) Have you ever been asked by the client’s CDM co-ordinator to include your prepared SWMP in the CDM 2007 pre-construction Information Pack?</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>(i) If you have not been asked for your prepared SWMP to be included in the CDM 2007 pre-construction Information Pack by the client’s CDM co-ordinator, then do you send it him along with your information for the health and safety file?</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>(j) Do you ever receive information within the CDM 2007 information pack on where you as principal contractor should set up your waste triage facilities on site?</td>
<td>2</td>
<td>8</td>
</tr>
</tbody>
</table>

It is also evident from Table III that the CDM 2007 (HMG 2007a) principal contractor is aware that the client’s designers should record any decision taken before the site waste management plan was drafted, but is as the case with designers, he does not discuss methods of waste reduction, re-use or recycling with the clients CDM co-ordinator - nor of its inclusion in the health and safety file.

CONCLUSIONS

Given the lack of specificity of designers’ duties in SWMP 2008 (HMG 2008) and the previous research findings that duty-holders (Baldwin 2010) do not have a good understanding of their duties and responsibilities, or of the considerable potential (WRAP 2009a) that exists for reducing key environmental burdens resulting from construction, the results in Tables II and III above are not particularly surprising.

The survey questionnaires confirm previous research in that it is contractors who bear the brunt of the responsibility (Baldwin 2010) for waste reduction on construction sites. There is a perception (Osmani et al. 2008) that waste is produced as a consequence of contractor’s poor site planning, misinterpretation of architect’s drawings and specification, and on-site logistical and operational activities. Although this may be true to some extent, the need for better client leadership (Briscoe et al. 2004) is confirmed by the evidence from Tables II and III above. This demonstrates the fact that in the surveys undertaken, the principal contractor is unable to rely on receiving adequate information from designers (who are working under the directions of the client) on waste reduction measures and/or the likely quantity, type and location of waste triage activities required by him once the construction phase begins. This leaves the CDM 2007 (HMG 2007a) principal contractor in a position where he will be unable to plan his waste triage activities, including the placement of the necessary facilities on his site, until the construction phase commences. Hence, the client could be accused of not allowing him, the CDM 2007 principal contractor, sufficient time for planning and preparation before work is expected to start on site.

Despite the health, safety and environmental implications and self-imposed extra costs as a result of him not ensuring that the designer designs out waste, and that this
information is transmitted to the CDM principal contractor at tender stage, evidence from the research shows the client to be ignoring this important designer function.

Figure I below shows the financial implication for the client, management of health and safety for the CDM principal contractor and the risk of environmental damage for the community where inadequate waste management information has been supplied.

In such a situation, the question for the CDM Co-ordinator to ask himself is whether he can justifiably advise the client to allow the construction phase to commence whilst the information required on waste triage for re-use or recycling is absent from the principal contractor’s construction phase plan. This point is explicitly supported in Schedule 2(1) of SWMP 2008 (HMG 2008) under ‘additional duties on the client’ where the client must give reasonable directions to any contractor so far as is necessary to enable the principal contractor to comply with these (SWMP 2008) Regulations.

RECOMMENDATIONS

SWMP 2008 (HMG 2008) only requires designers to record any (waste reduction) decision made and where no decision has been made, there are no sanctions against either the Client or the Designer. CDM 2007 (HMG 2007a) is currently under review by the HSE. It is therefore an opportune moment for SWMP 2008 (HMG 2008) to be integrated into CDM 2007 (Price et al 2009) so as to allow the CDM Co-ordinator to co-ordinate designers in both their waste reduction and their health and safety design processes. Designers’ take-up and use of the Designing Out Waste Tool for Buildings (WRAP 2009b) could be used as part of a Key Performance Indicator process for use by clients in choosing designers for their future projects. Additionally, the Institution of Civil Engineers have issued a demolition protocol (ICE 2008) which could be used by designers to provide a framework for the use of buildings, infrastructure, products, etc; whilst at the same time helping to deliver more sustainable processes by establishing quantities and targets for recovering materials and identifying the potential for procuring recovered materials for use in a new build project. It could be cheaper for the client if he could choose a designer who as well as being able to produce a design which, as well as pleasing the client aesthetically, also reduced waste generated by the principal contractor and his contractors once on site.

Relevant SWMP-related information on substantial residual design risks should be given to the CDM co-ordinator for him to insert into the CDM health and safety file. This health and safety file would then contain (Price et al 2009) relevant waste
management information (safe de-construction methods, et cetera) that could be valuable at the end of the life of building. The current requirement (HMG 2008) is for the site waste management plan to be held by the CDM principal contractor either at his principal place of business or at the site of the project for the statutory two years and then perhaps being lost or discarded.

Should a construction phase event occur that could be remotely attributed to the client having given inadequate waste management information to the CDM principal contractor, then this could give rise to a contractual claim. This relevant waste management information could be deemed to include designer’s calculations of quantities, types of waste likely to be produced by the works, or where any on-site waste triage activities were to be situated. At tender stage the CDM principal contractor would be oblivious to this information unless told. Therefore, it may be in the client’s best interest to insist that designers do actually make decisions before the site waste management plan is drafted and that their advice is taken, in conjunction with the CDM co-ordinator, of the location of any site waste storage and/or triage activities and the likely volume and type of waste to be produced during the works.

FURTHER WORK

The apparent reticence of the client to engage their designers in waste reduction measures could be the subject of further work. This could examine reasons why clients seemingly prefer, as the evidence from the survey shows, to subject the principal contractor to a fait accompli to manage a designer-imposed waste management process of which he has had neither input, nor control.

REFERENCES


Baldwin, D (2010) Site waste regulations are failing. “Construction Research and Innovation”, 1(1), 38


Price, T.


**Book review**

How to get a PhD

by Estelle Phillips and Derek Pugh


**Reviewed by Terry Price**

It is extremely easy to use this book as a simple atlas to successful PhD study, and its cover of soft colours reflects the easy-to-read style of the text within.

Now published as a fourth edition, this essential handbook for students and supervisors has been updated, and contains additional information to take account of new doctoral degrees such as EdD, DBA and D.Eng. New material for overseas, part-time and mature students is added, as is a diagnostic questionnaire for use by students to enable them to self-monitor their progress.

*How to get a PhD* is a 220 page lavishly detailed volume which succeeds in covering the whole subject of achieving a successful PhD, including the administrative and emotional issues connected with such a task, both from a research student's and supervisor's viewpoint. As the authors describe in the first chapter, this book is both a handbook and a survival manual for PhD students.

The first four chapters of the book are devoted to background information and advice on helping students decide whether they should be studying for a PhD or not, getting into the university system, the historical aspects of a doctorate, the different agenda of students and supervisors, followed by advice on the do's and don'ts of obtaining a PhD. This first section was adequate in easing the prospective PhD student
into the next two chapters of the book, dealing with types of research and the form and structure of the PhD thesis. Although unable to direct students to a particular model for a thesis (something which many students hope they can find) the book does give some useful pointers which could be common to all theses, provided this is taken as general rather than specific advice. The two chapters on how to do research and on the form of a thesis are extremely useful to those students who may have entered their PhD directly from an undergraduate course where they may not have had the necessary previous research experience. Chapters eight and nine deal with the psychological aspects of researching for a PhD, with chapters ten, eleven and finally twelve dealing with administrative matters, all of which is valuable information for the nascent PhD student. The self-diagnostic questionnaire used to monitor student progress is rather weak and would need to be expanded by the student before it could be of any real use. Likewise, the sections describing the new degrees and part-time students need further work as the book fails to address the issues faced, in particular, by mature students wishing to make the choice between researching for a PhD, DBA or a D.Eng. For example, the dilemma of a self-funded part-time mature student in trying to identify a suitable university without giving away his idea for his doctorate for others already embedded in the university system to use. Otherwise, a valuable aid for research students.
APPENDIX D  RESEARCH QUESTIONNAIRES

D.1  CASE ONE – CDM DUTY HOLDER POSITIONS

D.1.1  QUESTIONNAIRE FOR THE ARCHITECT
Please ask your Project Architects to complete this questionnaire.

Project Architect reference: .................................................................
Date of completion of the questionnaire: .....................................................

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<th></th>
<th>Not at all</th>
<th>To a small extent</th>
<th>To some extent</th>
<th>To considerable extent</th>
<th>To a large extent</th>
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Architect

1

307
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<th>To some extent</th>
<th>To considerable extent</th>
<th>To a large extent</th>
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<td>X Would you ever become involved in the discussions about static magnetic field shielding requirements if it affects the safety of the operatives carrying out the site pre-installation works?</td>
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<td>2</td>
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<tr>
<td>XI Or if it affects the safety of the operatives carrying out the site works not connected with the magnet regulation?</td>
<td>1</td>
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<td>Xll Do you believe that you as designers are fully involved as part of the design process for MRI Suites?</td>
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<td>2</td>
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<tr>
<td>XllI Even when you have not included design of the RF cage in your package?</td>
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<td>XIV Do you ever accept the Duty Holder position of Principal Contractor under the CDM Regulations?</td>
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<td>XV Before energisation of the magnets do you contribute to the health &amp; safety management of the site by producing method statements and risk assessments for the Principal Contractor (or pre-installation contractor)?</td>
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<tr>
<td>XVI Does this include site specific information regarding the position of the 5 Gwatt line of the static magnetic field?</td>
<td>1</td>
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<td>XIX Do any of the above options include information on specific methods to control the residual risks of the magnets to site operatives once energised?</td>
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<td>XX Would you advise that the 5 Gwatt line should be kept within the confines of the RF cage?</td>
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<td>XXI Do you as designer advocate the setting up of a controlled area around the magnet?</td>
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<td>And around contiguous areas where the 5 Gauss line is not contained within the confines of the RF cage</td>
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<td>Do your design risk assessments advocate systematic screening of those site operatives who may come into contact with the 5 Gauss line of the static magnetic field?</td>
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<td>Do you advise this screening to be documented?</td>
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<td>Do you advice on these made and plant being colour-coded?</td>
<td>Not at all</td>
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<td>XL</td>
<td>Should it be administered by the magnet supplier or expert in this field?</td>
<td>1</td>
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<tr>
<td>XL1</td>
<td>Or by the pre-installation or building contractor?</td>
<td>1</td>
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<td>XLI</td>
<td>Do you think that there is confusion amongst site operatives between the RF and the static magnetic field, with site operatives believing that these are one and the same thing and to which they could be exposed but are usually adequately contained within the RF cage?</td>
<td>1</td>
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<td>To considerable extent</td>
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<tr>
<td>Do you believe that management of health and safety by you as the designer is undermined by the dominance of the pre-installation or Principal Contractor?</td>
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<td>2</td>
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<td>4</td>
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<tr>
<td>Or by the RF cage supplier?</td>
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<tr>
<td>Do you believe there is a gap in health and safety information transfer between you as designer and contractors?</td>
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<tr>
<td>Do you believe that there could be dangers to health from exposure to static magnetic fields?</td>
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<tr>
<td>Where do you believe improvements in health and safety with regard to exposure of operatives to the static magnetic field should come from?</td>
<td>1</td>
<td>2</td>
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<tr>
<td>The RF cage supplier?</td>
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<tr>
<td>If, the Magnet Supplier</td>
<td>1</td>
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<td>4</td>
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</tr>
<tr>
<td>The Pre-installation of Principal Contractor?</td>
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<td>5</td>
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<tr>
<td>If, yourself as Architect / Designer</td>
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<td>2</td>
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</tbody>
</table>

D.1.2 QUESTIONNAIRE FOR THE RF CAGE SUPPLIER (A DESIGNER UNDER CDM)
RF Cage Supplier

Please ask your Project Managers to complete this questionnaire.
Project Manager reference: ________________________________
Date of completion of the questionnaire: ____________________

<table>
<thead>
<tr>
<th>Please circle the appropriate number</th>
<th>Not at all</th>
<th>To a small extent</th>
<th>To some extent</th>
<th>To considerable extent</th>
<th>To a large extent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Where the contract is turnkey, do you quote the building /pre-installation company for supply of the RF cage so he can include it in the quotation which he presents to the magnet supplier?</td>
<td>1</td>
<td>2</td>
<td>3</td>
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<tr>
<td>11 Where supply of the RF cage is in the turnkey contract’s quotation, are you specified by the magnet vendor?</td>
<td>1</td>
<td>2</td>
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<tr>
<td>111 Where the contract is a RF, are you specified by the magnet vendor?</td>
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<td>3</td>
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</tr>
<tr>
<td>1V Purely from a health and safety point of view, when you are involved with RFs, do you believe you are involved in the design process early enough to be able to make an effective contribution to the siting of the MRI Suite?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>V Are magnets fitted into RF cages where you as cage supplier have not been involved in the magnet procurement process?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>V1 Where specification of the RF cage is carried out by others are you ever presented with a fact accomplish regarding overall suitability of the siting of your cage?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
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<tr>
<td>V11 In this case, do you become involved in discussions about the necessary static magnetic field shielding required to be fitted to the cage?</td>
<td>1</td>
<td>2</td>
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<td>4</td>
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<tr>
<td>V111 To this before you have been chosen as the preferred cage supplier?</td>
<td>1</td>
<td>2</td>
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<td>4</td>
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<tr>
<td>1X Would you ever become involved in the discussions about any static magnetic field shielding needs if it did not affect the operation of the magnet?</td>
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<td>2</td>
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<tr>
<td>X Would you ever become involved in the discussions about static magnetic field shielding requirements if it affects the safety of the operatives carrying out the site pre-installation works?</td>
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<tr>
<td></td>
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<tr>
<td>X1</td>
<td>Did it affect the safety of the operatives carrying out other site works not connected with the magnet installation?</td>
<td>1</td>
<td>2</td>
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<tr>
<td>X11</td>
<td>Do you believe that you and the cage supplier are part of the design process?</td>
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<td>2</td>
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<tr>
<td>X111</td>
<td>Even when supply of the cage was not in the magnet vendor’s package?</td>
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<td>2</td>
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<td>X1V</td>
<td>Do you ever accept the Duty Holder’s position of Principal Contractor under the CDM Regulations?</td>
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<tr>
<td>X1X</td>
<td>Do any of the above options include information on specific methods to control the residual risks of the magnet?</td>
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<td>XX</td>
<td>Would you advise that the 5 Gauss line should be kept within the confines of the RF cage?</td>
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<td>XX1</td>
<td>Are you at cage supplier involved in setting up a controlled area around the magnets?</td>
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RF cage supplier
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<td>Do you believe that those responsible for access controls should carry out systematic screening of those site operatives who may come into contact with the 5 Gauss line of the static magnetic field?</td>
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<td>XXVII</td>
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<tr>
<td>XXXVI.1.1. Do you believe that you as the RF cage supplier are given a fair opportunity by the contractor or the magnet supplier to contribute to the control measures necessary to manage the residual risks of the magnet installation?</td>
<td>1 2 3 4 5</td>
<td></td>
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<td>XL Should it be administered by the magnet supplier or the MRI operator?</td>
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<td>XLII.1. Do you believe that healthcare and safety by your as the RF cage supplier is undermined by the decision of the magnet supplier?</td>
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<td>XLIV Or by the Pre-Installation or Principal Contractor?</td>
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<td>XLV Do you believe there is a gap in health and safety information transfer between the magnet supplier and constructors?</td>
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<td>XLI Do you believe there could be dangers to health and safety from exposure to static magnetic fields?</td>
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<td>XLVI.1. Where do you believe improvements in health and safety with regard to exposure of operatives to the static magnetic field should come from? The designer?</td>
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<td>Ø, The Maggot Supplier</td>
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<td>XLIX</td>
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<td>Ø, The Pre-installation or Principal Contractor²</td>
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<td></td>
<td>Ø, Yourself as RF cage supplier</td>
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### Questionnaire for the Magnet Vendor

Please ask your Project Managers to complete this questionnaire.

**Project Manager reference: .................................................................
Date of completion of the questionnaire: .............................................

Please circle the appropriate number

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<tbody>
<tr>
<td>I  Where the contract is turned over to your magnet company, which is included in the quotation from the building contractor/magnet installation company which you present to the client?</td>
<td>1</td>
<td>2</td>
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<tr>
<td>II Where supply of the RF cage is in your contractor’s quotation, do you specify which cage supplier to use?</td>
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<td>III Where the contract is for a PFI, do you specify the cage supplier?</td>
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<tr>
<td>IV Where you are involved with PFI’s and purely from a health and safety point of view, do you believe you are involved in the design process early enough to be able to make an effective contribution to the siting of the MRI Suite?</td>
<td>1</td>
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<tr>
<td>V  Do you ever fit magnets into RF cages where you have not been involved in the cage procurement process?</td>
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<tr>
<td>VI Where procurement of the RF cage is carried out by others, are you ever presented with a final assembly regarding overall suitability of the siting of your magnet?</td>
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<tr>
<td>VII In this case, do you become involved in discussions about the necessary static magnetic shielding required to be fitted to the cage?</td>
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<tr>
<td>VII Where the supplier is not involved and has not been involved in discussions about the necessary static magnetic shielding required to be fitted to the cage?</td>
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<td>IX Would you ever become involved in discussions about any magnetic shielding requirements if it did not affect the operation of the magnet?</td>
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<td>X  Would you ever become involved in discussions about static magnetic field shielding needs if it affects the safety of the operator carrying out the site pre-installation works?</td>
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<tr>
<td>X1</td>
<td>Or if it affects the safety of the operatives carrying out the site works not connected with the magnet installation?</td>
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<tr>
<td>X11</td>
<td>Do you believe that you as magnet supplier are part of the design process?</td>
<td>1</td>
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<tr>
<td>X111</td>
<td>Even when you have not included supply of the cage in your package?</td>
<td>1</td>
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<td>X1V</td>
<td>Do you ever accept the Duty Holder position of Principal Contractor under the CDM Regulations?</td>
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<td>XV</td>
<td>Before commencing energisation of the magnet do you contribute to the health and safety management of the site by producing method statements and risk assessments to the Principal Contractor or pre-installation contractor?</td>
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<tr>
<td>X VI</td>
<td>Does this include site specific information regarding the position of the 5 Gauss line of the static magnetic field?</td>
<td>1</td>
<td>2</td>
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<td>4</td>
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<tr>
<td>X VI1</td>
<td>Do you make a site issue of a site specific Site Planning Guide?</td>
<td>1</td>
<td>2</td>
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<td>4</td>
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<tr>
<td>X VI11</td>
<td>Or do you rely on annotated site specific drawings?</td>
<td>1</td>
<td>2</td>
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<tr>
<td>XIX</td>
<td>Do any of the above options include information on specific methods to control the residual risks of your magnet to site operatives once energised?</td>
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<tr>
<td>XX</td>
<td>Would you advise that the 5 Gauss line should be kept within the confines of the RF cage?</td>
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<td>2</td>
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<tr>
<td>X XI</td>
<td>Do you as magnet supplier set up a controlled area around the magnets?</td>
<td>1</td>
<td>2</td>
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<tr>
<td>X XI1</td>
<td>And around contiguous areas where the 5 Gauss line is not contained within the confines of the RF cage</td>
<td>1</td>
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<tr>
<td>X XI11</td>
<td>Where the 5 Gauss line passes into the Technical Room areas to the side, above and below to the cage do you believe it is the responsibility of your installation engineers to police across?</td>
<td>1</td>
<td>2</td>
<td>3</td>
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<tr>
<td>XXIV</td>
<td>Do you consider that you as magnetic supplier are responsible for access controls to the controlled area once the magnet has been energised?</td>
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<tr>
<td>XXV</td>
<td>Do you carry out a risk assessment to determine the areas where the 5 Gauss line of the static magnetic field may be a hazard to operatives?</td>
<td>1</td>
<td>2</td>
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<tr>
<td>XXVI</td>
<td>Where you are responsible for access controls, do you carry out systematic screening of those site operatives who may come into contact with the 5 Gauss line of the static magnetic field?</td>
<td>1</td>
<td>2</td>
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<tr>
<td>XXVII</td>
<td>Is this screening documented?</td>
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<tr>
<td>XXVIII</td>
<td>Is this screening process common to all strength static magnetic fields? i.e., is it the same for a 2T magnet as for 1.5T?</td>
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<tr>
<td>XXIX</td>
<td>Do contractors ever subject your engineers to screening for the presence of biomedical implants or metal objects in their bodies?</td>
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<td>XXX</td>
<td>Do you as magnet supplier control access of tools and plant to the controlled area?</td>
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<tr>
<td>XXXI</td>
<td>Or just to the RF cage?</td>
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<tr>
<td>XXXII</td>
<td>Do you screen to ensure use of only non-magnetic tools and plant?</td>
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<tr>
<td>XXXIII</td>
<td>Do you insist on these tools and plant being colour-coded?</td>
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<tr>
<td>XXXIV</td>
<td>Do you believe you have a responsibility as supplier of the magnet to highlight any failings in design contributions made to the MRI Suite by others and which may cause site operatives to come into contact with the static magnetic field of your magnet?</td>
<td>1</td>
<td>2</td>
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<tr>
<td>XXXV</td>
<td>Do you believe that health monitoring of operatives' exposure to the static magnetic field is desirable?</td>
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<tr>
<td>XXXVI</td>
<td>Do you believe that contractors should do more to control operatives' exposure to the hazards of magnet installation?</td>
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Magnet Vendor 3
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<tr>
<td>XXXVII</td>
<td>Do you believe that you and your magnet supplier are given a fair opportunity by the client to contribute to the control measures necessary to manage the residual risks of your magnet installation?</td>
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<tr>
<td>XXXVIII</td>
<td>Do you ever come under pressure from the client to eliminate magnetic shielding, thus allowing the Gauss line to pass to areas which are not generally accessible to the public or hospital staff and do not pose a threat to the image quality of the magnet?</td>
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<tr>
<td>XXXIX</td>
<td>Do you believe a Permit to Work system for an MRI suite would be beneficial to health and safety?</td>
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<td>XL</td>
<td>Should it be administered by you, the magnet supplier and expert in this field?</td>
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<td>-xl</td>
<td>Or by the pre-installation or building contractor?</td>
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<td>XLII</td>
<td>Do you think there is confusion amongst site operatives between the RF and the static magnetic field, with site operatives believing that these are one and the same thing and to which they could be exposed but are usually adequately contained within the RF cage?</td>
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<td>XLIII</td>
<td>Do you believe that management of health and safety by you, the magnet supplier, is undermined by the dominance of the pre-installation or principal contractor?</td>
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<td>Or by the RF cage supplier?</td>
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<td>XLV</td>
<td>Do you believe there is a gap in health and safety information transfer between you as magnet supplier and contractors?</td>
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<td>XLI</td>
<td>Do you believe that there could be dangers to health from exposure to static fields?</td>
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<td>XLVI1</td>
<td>Where do you believe improvements in health and safety with regard to exposure of operators to the static magnetic field should come from? The Designer?</td>
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<td>Or, the RF gate supplier?</td>
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<td>Or, The Pre-installation or Principal Contractor?</td>
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<td>L</td>
<td>Or, Yourself as Magnet Vendor</td>
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D.1.4
CONTRACTOR

QUESTIONNAIRE FOR THE PRE-INSTALLATION OR PRINCIPAL
Pre-Installation Contractor or Principal Contractor

Please ask your Project Managers to complete this questionnaire.

Project Manager reference: .................................................................
Date of completion of the questionnaire: ............................................

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<td>1 Where the contract is turnkey, is supply of the RF cage for the magnet included your quotation as the building contractor/pre-installation company which you present to the magnet supplier?</td>
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<td>11 Where supply of the RF cage is in your contractor’s quotation, do you specify which cage supplier to use?</td>
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<td>111 Where the contract is a FPL do you specify which cage supplier to use?</td>
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<tr>
<td>1V Where you are involved with RFIs and purely from a health and safety point of view, do you believe you are involved in the design process ever enough to be able to make an effective contribution to the design of the HVE Suite?</td>
<td>1</td>
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<td>V Do magnet suppliers fit magnets into RF cages where you alone have been responsible for the cage procurement process?</td>
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<tr>
<td>V1 Where procurement of the RF cage is carried out by others, are you ever presented with a fait accompli regarding overall suitability of the design of the magnet?</td>
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<tr>
<td>V11 In this case, do you become involved in discussions about the necessary static magnetic field shielding required to be fitted to the cage?</td>
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<tr>
<td>V111 Is this before the preferred magnet supplier has been chosen?</td>
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<td>LX Would you ever become involved in the discussions about any static magnetic field shielding requirements if it did not affect the operation of the magnet?</td>
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<td>X</td>
<td>Would you ever become involved in the discussions about static magnetic field shielding requirements if it affects the safety of the operatives carrying out the site pre-installation works?</td>
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<td>X1</td>
<td>O- if it affects the safety of the operatives carrying out other site works not connected with the magnet installation?</td>
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<td>Do you believe that you as a pre-installation contractor are part of the design process?</td>
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<td>Before energisation of the magnet is commenced, do you contribute to the health and safety management of the site by asking the magnet supplier to provide you with method statements and risk assessments?</td>
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<td>X11</td>
<td>Do you ever receive a site issue of a site specific Site Planning Guide from the magnet supplier?</td>
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<td>X111</td>
<td>Or do you rely on annotated site specific drawings?</td>
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<td>X1X</td>
<td>Do any of the above options include information on specific methods to control the residual risks of the magnet to site operatives once energised?</td>
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<td>Would you advise that the 5 Gauss line should be kept within the confines of the RF cone?</td>
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<td>XX1</td>
<td>Do you as pre-installation contractor or Principal Contractor set up a controlled area around the magnet?</td>
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<td>To considerable extent</td>
<td>To a large extent</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>-----------</td>
<td>------------------</td>
<td>---------------</td>
<td>-----------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>XX11</td>
<td>And around contiguous areas where the 5 Gauss line is not contained within the confines of the RF cage</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>XX11</td>
<td>Where the 5 Gauss line penetrates into the Technical Room, next to the side, above and below to the cage do you believe it is the responsibility of your company to police access?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>XX1V</td>
<td>Do you consider that you as pre-installation contractor or Principal Contractor are responsible for access controls to the controlled area once the magnet has been energized?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>XXIV</td>
<td>Do you carry out a risk assessment to determine the areas where the 5 Gauss line of the static magnetic field may be a hazard to operators?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>XXVI</td>
<td>Where you are responsible for access controls, do you carry out systematic screening of those site operatives who may come into contact with the 5 Gauss line of the static magnetic field?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>XXVII</td>
<td>Is this screening documented?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>XXVI1</td>
<td>Is this screening process common to all strength static magnetic fields? i.e. Is it the same for JT as for 1ST?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>XXIX</td>
<td>Do you expect your operatives, the magnet suppliers’ engineers or other contractors to screening for the presence of biomedical implants of metal objects in their bodies?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>XXX</td>
<td>Do you as pre-installation contractor or Principal Contractor control access of tools and plant to the controlled area?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>XXXI</td>
<td>Or just to the RF cage?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>XXXII</td>
<td>Do you screen to ensure use of only non-ferromagnetic tools and plant?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>XXXIII</td>
<td>Do you insist on these tools and plant being colour-coded?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Pre-installation Contractor or Principal Contractor
<table>
<thead>
<tr>
<th>Question</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you believe you have a responsibility as pre-installation contractor or Principal Contractor to highlight failings in any design contributions made to the MRI Suite by others and which may cause site operatives to come into contact with the static magnetic field of the magnet?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Do you believe that health monitoring of operatives' exposure to the static magnetic field is desirable?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Do you believe that contractors should do more to control operatives' exposure to the hazards of magnet installation?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Do you believe that magnet suppliers are given a fair opportunity by contractors to contribute to the control measures necessary to manage the residual risks of their magnet installation?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Do you ever come under pressure from the Client to eliminate static magnetic field shielding, thus allowing the 5 Gauss line to pass to areas which are not generally accessible to the public or hospital staff and do not pose a threat to the image quality of the magnet?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Do you believe a Permit to Work system for an MRI Suite would be beneficial to health and safety?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>If yes, should it be administered by you as pre-installation contractor or Principal Contractor?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Or by the magnet supplier?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Do you think that there is confusion amongst site operatives between the RF and the static magnetic field, with site operatives believing that these are one and the same thing and to which they could be exposed but are usually adequately contained within the RF cage?</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>abc</td>
<td>bcd</td>
<td>cde</td>
<td>def</td>
<td>efg</td>
<td></td>
</tr>
<tr>
<td>-----</td>
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<td>-----</td>
<td>-----</td>
<td>-----</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

Please circle the appropriate number

<table>
<thead>
<tr>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

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## D.2. 1 QUESTIONS I - XXV

### PARTICIPANT COUNTRY

| Engineer A   | Scotland|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Engineer B   | England|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Project Manager A | England |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Site Manager B | Wales   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Site Manager C | Wales   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Site Manager D | Wales   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |

### KEY

1. Not at all
2. To a small extent
3. To some extent
4. To a considerable extent
5. To a large extent

### CHAPTER 4 - CASE 1 QUESTIONNAIRE QUESTIONS 1 - XXV

- Do you believe that any part of the design process?
- Do you think that the CDM duty-holder was satisfied with the design process?
- Do you feel that the CDM duty-holder felt involved in the design process?
- Do you feel that the CDM duty-holder was informed of the design process?
- Do you feel that the CDM duty-holder understood the design process?
- Do you feel that the CDM duty-holder was consulted during the design process?
- Do you feel that the CDM duty-holder was informed of the design process?
- Do you feel that the CDM duty-holder was consulted during the design process?
- Do you feel that the CDM duty-holder was informed of the design process?
- Do you feel that the CDM duty-holder was consulted during the design process?
<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Where you are responsible for access controls, do you carry out systematic screening of those site operatives who may come into contact with the 5 gauss line of the static magnetic field?</td>
<td>Yes</td>
</tr>
<tr>
<td>Do you think that screening of those operatives who you consider might come into contact with the 5 gauss line should be documented?</td>
<td>Yes</td>
</tr>
<tr>
<td>Should site operating procedures, e.g., should sites operating procedures, e.g., be submitted to screening for the presence of biological implants or metal objects in their bodies?</td>
<td>Yes</td>
</tr>
<tr>
<td>Do you control access of tools and plant to the controlled area?</td>
<td>Yes</td>
</tr>
<tr>
<td>Do you control access of tools and plant just to the RF cage?</td>
<td>Yes</td>
</tr>
<tr>
<td>Should screening be carried out to ensure use of only non-metallic tools and plant?</td>
<td>Yes</td>
</tr>
<tr>
<td>Do you believe in plant and tools being colour-coded?</td>
<td>Yes</td>
</tr>
<tr>
<td>Do you believe you have a responsibility to highlight any failure in design contributions to move the MRI Suite by others and what may cause operatives to come into contact with the static magnetic field?</td>
<td>Yes</td>
</tr>
<tr>
<td>Do you believe that health monitoring of operatives’ exposure to the static magnetic field is described?</td>
<td>Yes</td>
</tr>
<tr>
<td>Do you believe that contractors should now come to control operative’s exposure to the hazards of magnetic radiation?</td>
<td>Yes</td>
</tr>
<tr>
<td>Do you believe that you are given a fair opportunity to contribute to the control measures necessary to manage the residual risk of the magnetic installation?</td>
<td>Yes</td>
</tr>
<tr>
<td>Do you ever come under pressure from the Client to minimise magnetic shielding, thus allowing the 5 gauss line to pass to areas which are not generally accessible to the public or hospital staff and where it does not pose a threat to the image quality of the image?</td>
<td>Yes</td>
</tr>
<tr>
<td>Do you believe that a Permit to Work system for an MRI Suite would be beneficial to health and safety?</td>
<td>Yes</td>
</tr>
<tr>
<td>Do you believe that any Permit to Work system should be administered by the magnet supplier and expert in this field?</td>
<td>Yes</td>
</tr>
<tr>
<td>Do you believe that any Permit to Work system should be administered by the pre-installation contractor?</td>
<td>Yes</td>
</tr>
<tr>
<td>Do you believe that there is insufficient evidence to support the use of the static magnetic field, with site operatives believing that the use of the same is not justified, but are usually adequately contained within the RF cage?</td>
<td>Yes</td>
</tr>
<tr>
<td>Do you believe that management of health and safety by the pre-installation contractor or RF cage supplier is undermined by the dominance of the pre-installation contractor?</td>
<td>Yes</td>
</tr>
<tr>
<td>Do you believe that there is a gap in safety and security information transfer between the magnet supplier and contractor?</td>
<td>Yes</td>
</tr>
<tr>
<td>Do you believe that there could be dangers to health from exposure to static magnetic fields?</td>
<td>Yes</td>
</tr>
<tr>
<td>Do you believe that improvements in health and safety with regard to exposure of operatives to the static magnetic field should come from Designers?</td>
<td>Yes</td>
</tr>
<tr>
<td>Do you believe that improvements in health and safety with regard to exposure of operatives to the static magnetic field should come from the magnet supplier?</td>
<td>Yes</td>
</tr>
<tr>
<td>Do you believe that improvements in health and safety with regard to exposure of operatives to the static magnetic field should come from the pre-installation company or Principal Contractor?</td>
<td>Yes</td>
</tr>
<tr>
<td>Do you believe that improvements in health and safety with regard to exposure of operatives to the static magnetic field should come from your own function in the process?</td>
<td>Yes</td>
</tr>
</tbody>
</table>
D.3 CASE TWO- INFORMATION FROM THE HEALTH AND SAFETY

D.3.1 QUESTIONNAIRE ONE – LOCATION OF MRI SUITES

1st January 2007

Dear Sir or Madam,

I am a PhD research student at Napier University carrying out research on magnetic resonance imaging installations throughout the United Kingdom.

In order for me to be able to target my research, I would be obliged if you would let me have the following information regarding MRI installations within the geographical area of your Trust’s control. This request excludes installations in the private sector:

1. The name(s) and address(es) of the hospital(s) where the MRI(s) are located
2. The number of installations at each address
3. The magnet strength at each installation
4. The vendor of the magnet at each installation (Siemens, Philips, etc)
5. The model of magnet at each installation
6. The year of each installation
7. If, in addition to the RF cage, magnetic shielding has been installed to the magnet room (either in whole or in part) at each of the installations
8. If any of the installations are mobile units
    (a) Whether they are used to provide supplementary capacity to an existing fixed installation, or
    (b) Whether they are used whilst an existing MRI suite is being constructed or upgraded
    (c) The anticipated year when the mobile unit will no longer be required
D.3.2  QUESTIONNAIRE TWO - TO OBTAIN AS-BUILT INFORMATION

Date:

Dear

I am a part-time PhD student at Napier University. You will recall that you were kind enough to reply to my recent request to you for information regarding MRI installations within your Trust's area.

The next stage of my research is concerned with gathering design information on sites where magnetic shielding has been installed to manage the static magnetic field of the magnet. This will allow me to measure the efficiency of the design, with a view to improving the design and design process.

I explained in my original letter to you that I may need further help as I develop my research. As your reply to my original request stated that additional shielding had been installed to the RF cage (either in whole or in part) to your installation(s) and so as to assist me with my research, would you please arrange to send me a copy of the information contained in the Health and Safety File (as defined by the CDM Regulations) as it relates to the following elements of the MRI installation(s) controlled by your Trust. This request relates only to those installations which you have indicated have additional shielding installed to the magnet room(s) to manage the static magnetic field.

1. The Site Specific Site Planning Guide issued by the magnet vendor, including a plot of the designed 5 gauss footprint of the static magnetic field (for each installation).
2. As-Built drawings of the MRI Suite, showing plans and elevations of the MRI Suite (for each installation).
3. The Design Brief, Conceptual Design Statement, Vector Plots, Design Calculations and Specification for the magnetic shielding used to manage the static magnetic field (for each installation).
4. A plan and elevations/sections showing the post-installation/magnet energisation plots of the 5 gauss footprint of the static magnetic field, including notations showing the use of the rooms above, below and to the sides of the magnet (for each installation).
5. Where static magnetic field shielding has been installed as a result of the proximity of either another magnet, a CT, or other equipment likely to be affected by the installations referred to, then please also give information (as in 1-4 above) for this equipment, showing the field strengths being managed (for each installation).

I appreciate the fact that much of this information may be embedded within a larger H&S File, but if it is easier for yourselves, then I would have no objection to receiving the whole file, when I will extrapolate the information I require. This will reduce the cost to yourselves. I would appreciate receiving the information on a CD or DVD, depending on the size of the file, but will accept a hard copy.

If you do not have any post-installation/magnet energisation plots of the 5 gauss footprint of the static magnetic field, then I would appreciate you letting me know. In which case and without prejudice, I would welcome the opportunity to take field measurements in order to facilitate my research and would provide my services free of charge.

I thank you in advance for your understanding and co-operation in this important piece of research. If you require any clarification of my request, then please do not hesitate to contact me by e-mail.

I look forward to your early reply.

Yours faithfully

[Signature]
E.1 CALIBRATION CERTIFICATE FOR THE ETM-1 TESLAMETER

CERTIFICATE OF CALIBRATION

Certification No.: 09986
Meter Type: ETM-1
Serial No.: AC-0054
Customer: Terry Price
Customer Ref.: Email Enq
Link Microtek Ref.: GRD00986

Link Microtek hereby confirms that the referenced instrument has been calibrated by qualified personnel in the Manufacturer's approved test procedures.

The meter meets all published specifications and the calibration has been performed with the use of test instrumentation that, where applicable, is traceable to National Standards.

The calibration measurements are traceable to National Standards and are in accordance with the Jenda Microtemp Calibration Procedures.

Authorized By: [Signature]
Date Calibrated: 23/02/07
Next Due Date: 23/02/09

APPENDIX F  PRE-MRI SCREENING FORM
F.1 PRE-MRI PROCEDURE SCREENING FORM
PRE-MRI PROCEDURE SCREENING FORM

**MR Facility**

<table>
<thead>
<tr>
<th>Date</th>
<th>/</th>
<th>/</th>
<th>MR#</th>
</tr>
</thead>
</table>

**Name**
- Last name
- First name
- M.I.

<table>
<thead>
<tr>
<th>Height</th>
<th>Weight</th>
</tr>
</thead>
</table>

**Birthdate**
- Social Security 
- / 
- /

**Address**

<table>
<thead>
<tr>
<th>State</th>
<th>Zip Code</th>
<th>Phone (H)</th>
<th>Phone (W)</th>
</tr>
</thead>
</table>

**Physician’s name & address**

1. **Have you ever had surgery or any other invasive procedures?**
   - Yes
   - No
   - If yes, please list:
     - Type:
     - Date: / /

2. **Have you had any previous studies?**
   - Yes
   - No
   - If yes, please list below:
     - **Body part**
     - **MRI:**
       - CT/Computed Tomography:
       - X-Ray:
       - Ultrasound:
       - Nuclear Medicine:
     - **Date**: / 

3. **Have you ever**
   - worked as a machinist, metal worker, or in any profession or hobby grinding metal?
   - been injured by a metallic foreign body (e.g., bullet, BB, buckshot, or shrapnel)?
   - Yes
   - No
   - If yes, please describe:

4. **Are you pregnant, experiencing a late menstrual period, or having fertility treatments?**
   - Yes
   - No

5. **Are you breast feeding?**
   - Yes
   - No

6. **Date of last menstrual period:** / /

7. **Are you taking oral contraceptives or receiving hormone treatment?**
   - Yes
   - No

8. **Are you currently taking or have recently taken any medication?**
   - Yes
   - No
   - If yes, please list:

9. **Do you have anemia, diseases affecting your blood, history of kidney disease or seizures?**
   - Yes
   - No
   - If yes, please describe:

10. **Do you have drug allergies?**
    - Yes
    - No
    - If yes, please list:

11. **Have you ever had asthma, an allergic reaction, respiratory disease, or a reaction to a contrast medium used for an MRI or CT exam?**
    - Yes
    - No
    - If yes, please describe:

---

Figure 1. The pre-MRI procedure screening form used for patients and other individuals before allowing them into the MR environment. (This form is available in an electronic format at www.MRisafety.com.)
Some of the following items may be hazardous to your safety and some can interfere with the MRI examination. Please check the correct answer for each of the following.

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac pacemaker</td>
<td></td>
</tr>
<tr>
<td>Implanted cardiac defibrillator</td>
<td></td>
</tr>
<tr>
<td>Aneurysm clip</td>
<td></td>
</tr>
<tr>
<td>Carotid artery vascular clamp</td>
<td></td>
</tr>
<tr>
<td>Neurostimulator</td>
<td></td>
</tr>
<tr>
<td>Insulin or infusion pump</td>
<td></td>
</tr>
<tr>
<td>Implanted drug infusion device</td>
<td></td>
</tr>
<tr>
<td>Spinal fusion stimulator</td>
<td></td>
</tr>
<tr>
<td>Cochlear, otoologic, or ear implant</td>
<td></td>
</tr>
<tr>
<td>Ear tubes</td>
<td></td>
</tr>
<tr>
<td>Prosthesis (eye/orbital, penile, etc)</td>
<td></td>
</tr>
<tr>
<td>Implant held in place by a magnet</td>
<td></td>
</tr>
<tr>
<td>Heart valve prosthesis</td>
<td></td>
</tr>
<tr>
<td>Artificial limb or joint</td>
<td></td>
</tr>
<tr>
<td>Other implants in body or head</td>
<td></td>
</tr>
<tr>
<td>Electrodes (on body, head or brain)</td>
<td></td>
</tr>
<tr>
<td>Intravascular stents, filters, or coils</td>
<td></td>
</tr>
<tr>
<td>Shunt (spinal or intraventricular)</td>
<td></td>
</tr>
<tr>
<td>Vascular access port and/or catheters</td>
<td></td>
</tr>
<tr>
<td>Swan-Ganz catheter</td>
<td></td>
</tr>
<tr>
<td>Transdermal delivery system (Nitro)</td>
<td></td>
</tr>
<tr>
<td>IUD or diaphragm</td>
<td></td>
</tr>
<tr>
<td>Pessary or bladder ring</td>
<td></td>
</tr>
<tr>
<td>Tattooed eyeliner or eyebrows</td>
<td></td>
</tr>
<tr>
<td>Body piercings</td>
<td></td>
</tr>
<tr>
<td>Metal fragments (eye, head, ear, skin)</td>
<td></td>
</tr>
<tr>
<td>Internal pacing wires</td>
<td></td>
</tr>
<tr>
<td>Aortic clips</td>
<td></td>
</tr>
<tr>
<td>Venous umbrella</td>
<td></td>
</tr>
<tr>
<td>Metal or wire mesh implants</td>
<td></td>
</tr>
<tr>
<td>Wire sutures or surgical staples</td>
<td></td>
</tr>
<tr>
<td>Harrington rods (spine)</td>
<td></td>
</tr>
<tr>
<td>Metal rods in bones, joint replacements</td>
<td></td>
</tr>
<tr>
<td>Bone/joint pin, screw, nail, wire, plate</td>
<td></td>
</tr>
<tr>
<td>Hearing aid (Remove before scan)</td>
<td></td>
</tr>
<tr>
<td>Dentures (Remove before scan)</td>
<td></td>
</tr>
<tr>
<td>Breathing or motion disorders</td>
<td></td>
</tr>
<tr>
<td>Claustrophobia</td>
<td></td>
</tr>
<tr>
<td>Other:</td>
<td></td>
</tr>
</tbody>
</table>

Please mark on the figure below, the location(s) of any implants or metal inside or on your body.

![Figure showing locations of implants and metal](https://www.imrser.org/PaperPDFRecord.asp?WebRecID=74&PgName=MR+Safety+Papers&WebRecID=&sb.SummaryTitle=)

You are required to wear earplugs or earphones during the MRI examination.

<table>
<thead>
<tr>
<th>Signature of Person Completing Form</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Form Completed by:</td>
<td></td>
</tr>
<tr>
<td>Patient</td>
<td>Relative:</td>
</tr>
<tr>
<td>Physician or other:</td>
<td></td>
</tr>
</tbody>
</table>

To Be Completed By MRI Department | Medical Record number: | Completed by: |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedure:</td>
<td></td>
<td>Clinical History</td>
</tr>
</tbody>
</table>
APPENDIX G  THE CLIENT BECOMES A DESIGNER UNDER CDM 2007

G.1  THE CLIENT INSTRUCTS THE DESIGNER TO OMIT REQUIRED MAGNETIC SHIELDING
Meeting held at XXXXX Project Office to review proposal from XXXX for Shielding, Faraday cage installation, and X-ray protection measures

Present

XXX and 4mo radiation protection officers

1.00 MRI Installation

1.01 The Client stated their concerns in respect of the extent and costs for the static magnetic shielding put forward by XXX on the two XXX units.

1.02 The Client felt that there was no requirement to provide static magnetic shielding for either facility. He felt that a safe workable solution could be achieved by a realignment of each MRI instrument without shielding or alteration to the layout. It was noted that the indications from XXX’s advisors were that, strictly speaking, all the requirements could not be met. The Client’s specialist stated that they were optimistic that technical advances would solve the relatively minor problems by the time of installation. They had several fallback strategies including reversion to a 1.5T magnet.

XXX comment
XXX disagree with the comments regarding a 3T MRI being adjacent to a CT scanner at XXX. See XXX drawing XXX. We have adjusted the position of the MRI scanner in XXX MRI room XXX. In our opinion the 0.1 mT (1 Gauss) field line will be too close to the CT. As a minimum we suggest XXX (a magnet vendor) are consulted regarding these equipments being adjacent.

1.03 The Client stated that XXX should provide a ‘shell’ space only, in line with the agreed 1:200 layouts which is capable of taking the MRI equipment installation. In doing so it is incumbent upon XXX to provide a space for the ‘worst case scenario’. This would include providing a floor structure compatible with the technical requirements of the equipment, and prime services to a point within the boundary of the shell unit. The services provision should take into account the process demands for cooling, power, air and medical gas supplies, ventilation, and data terminals.
1.04 It was agreed, by The Client that the equipment being used for this exercise to establish building performance, is the XXXX 3T appliance. Technical data for this equipment has been circulated to all relevant parties.

1.05 A review of the situation resulted in the instruction from The Client to XXX to stop working on detailed design for this portion of the works. XXX will carry out the works under a separate contract post Practical Completion. This to include the installation of Faraday cage. MRI equipment, associated control equipment and technical control rooms, finishes to the rooms, electrical and data supplies and associated circuitry. environmental controls and equipment, process plant and associated ducting. All in all a turnkey package to supply the MRI installation complete.

1.06 The Client stated that their clinical operational procedures would be devised to obviate the need for static shielding. This is confirmed as an instruction. It was stated that static shielding would not be required at the XXX facility, despite the proximity of operating theatres where it had previously been stated that the intended use of mobile X-ray equipment would produce a conflict.

1.07 The Client stated that they would accept the 5 gauss line limitation as a consequence of no static shielding in respect of maintenance workers working within the magnetic field. XXX reserved their position on this matter. It was noted that XXX expressed concern that the 5 gauss line intruded into clinical spaces.

1.08 It was stated that XXX are providing a shell unit that satisfies the technical requirement of the user brief, based on the XXX 3T machine, subject to the above assurances from the Client.

2.0 Faraday protection to MRI installation.

2.01 The Client stated that they would instruct the contract to install the Faraday cage for each MRI. This would be included within the order/contract for the MRI machine. No further discussion was required on this matter although XXX’s advisor noted that the Client’s proposal to install the MRI machine before the Faraday cage (except the floor) and all the finishes was unusual and would put the machine itself at some risk.

XXX comment
It is our opinion installation of the RF shield around the MRI scanner is risky for the MRI machine and would take longer than the ‘conventional’ method of completion of the cage, test then installation of the MRI.

TP’s comments. Re 2.01 Regarding the proposed erection of the cage around the magnet, apart from anything else, there are serious health and safety considerations to be made. The cage supplier’s and the fit-out contractor’s operatives will be working within the 0.5 mT footprint. There will also be increased danger of the ‘Projectile effect’. It is strongly advised that the CDM co-ordinator be made aware of this proposal, as he is charged under the CDM Regulations with co-ordinating the (safe) design. Note that the names of the parties to this memorandum have been obliterated in order to preserve anonymity.
PHD Thesis

AN ANALYSIS OF HEALTH AND SAFETY RISKS IN MAGNETIC SHIELDING DESIGN AND CONSTRUCTION FOR MAGNETIC RESONANCE IMAGING (MRI) SUITES

Written by PRICE, T.R. February 2012

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