MRI Safety Essentials

MRI Safety Framework

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Safety Framework

MR safety policy – Local rules for each scanner	MR safety procedures	Named MR responsible people
MR safety processes/file for implants, safety documentation	Access to MR safety information – books/website	Incident/near miss reporting pathway
MR safety education for MR clinical and medical staff, hospital workers and visitors	Risk assessments – Acceptance testing	MR safety guidelines for referencing

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MRI Safety Policy

Include:

- written safety procedures
- work instructions
- emergency procedures
- operating instructions
- Staff, referrer training

Written by:

MR Superintendent and Physicist

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MRI Safety and Patient Management

HAZARDS

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EMF exposures in MRI

- The fringe field of the magnet
- Static magnetic field in magnet B_0
- Gradients - time-varying fields $G_{x,y,z}$
- RF time-varying magnetic field B_1

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Fringe Field

- The fringe field of the magnet

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Magnetic field Hazards

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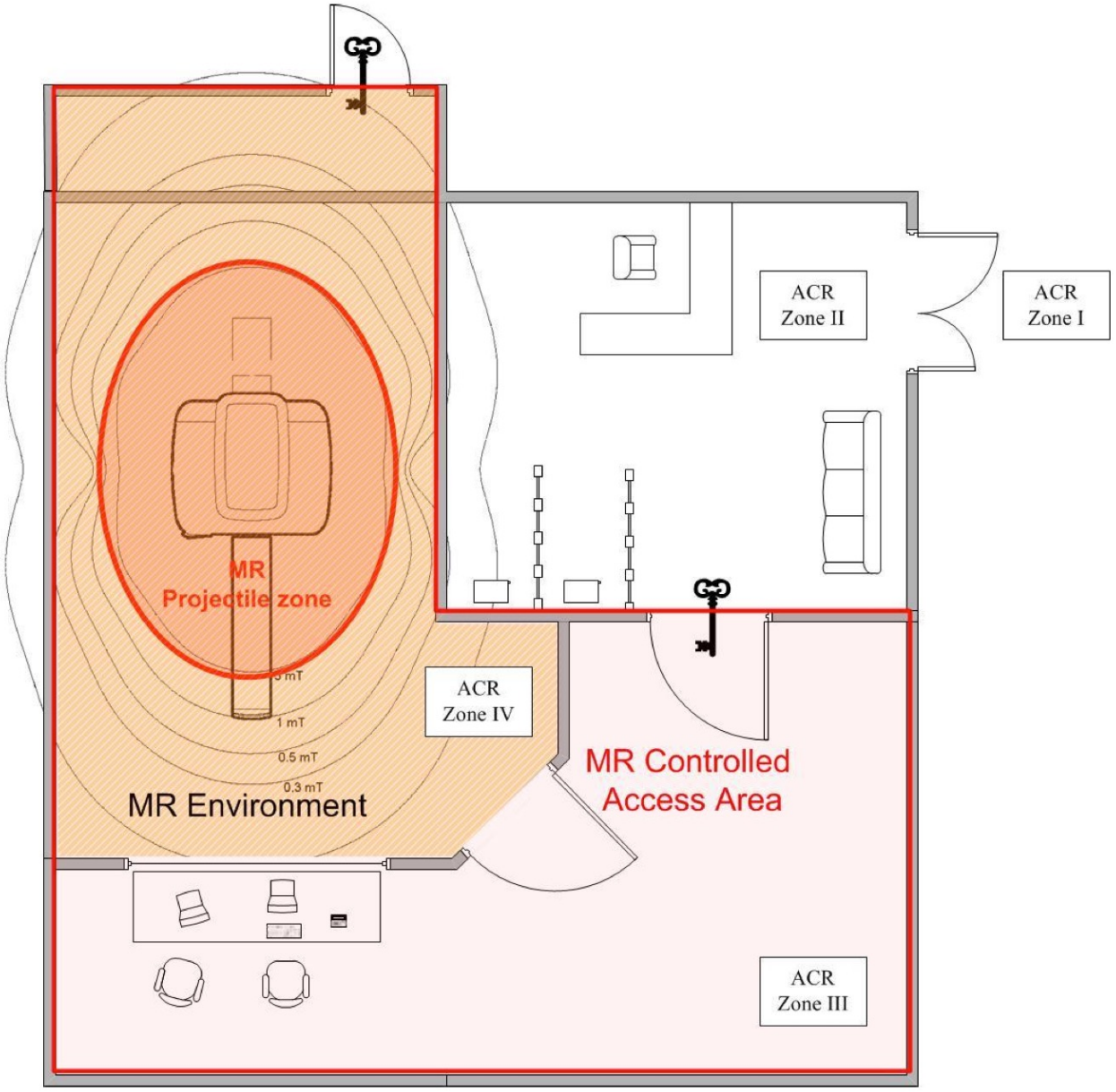
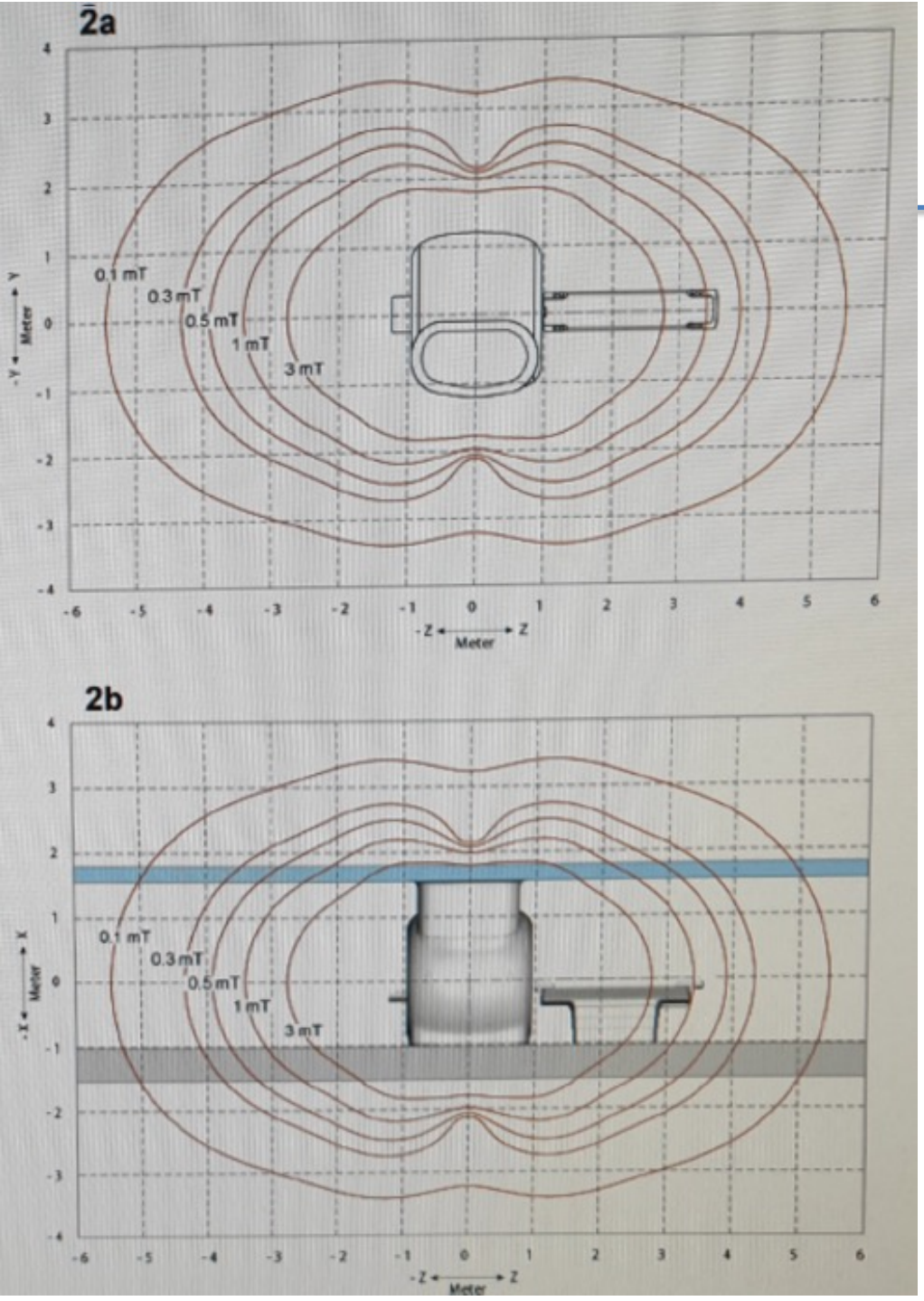


MHRA 2021

Figure 1 Example layout of an MRI unit

Fringe field plots showing at least the 0.5 and 3 mT contours should be on display in MRI departments. These should be shown to staff and explained clearly.

Philips Ingenia 1.5T



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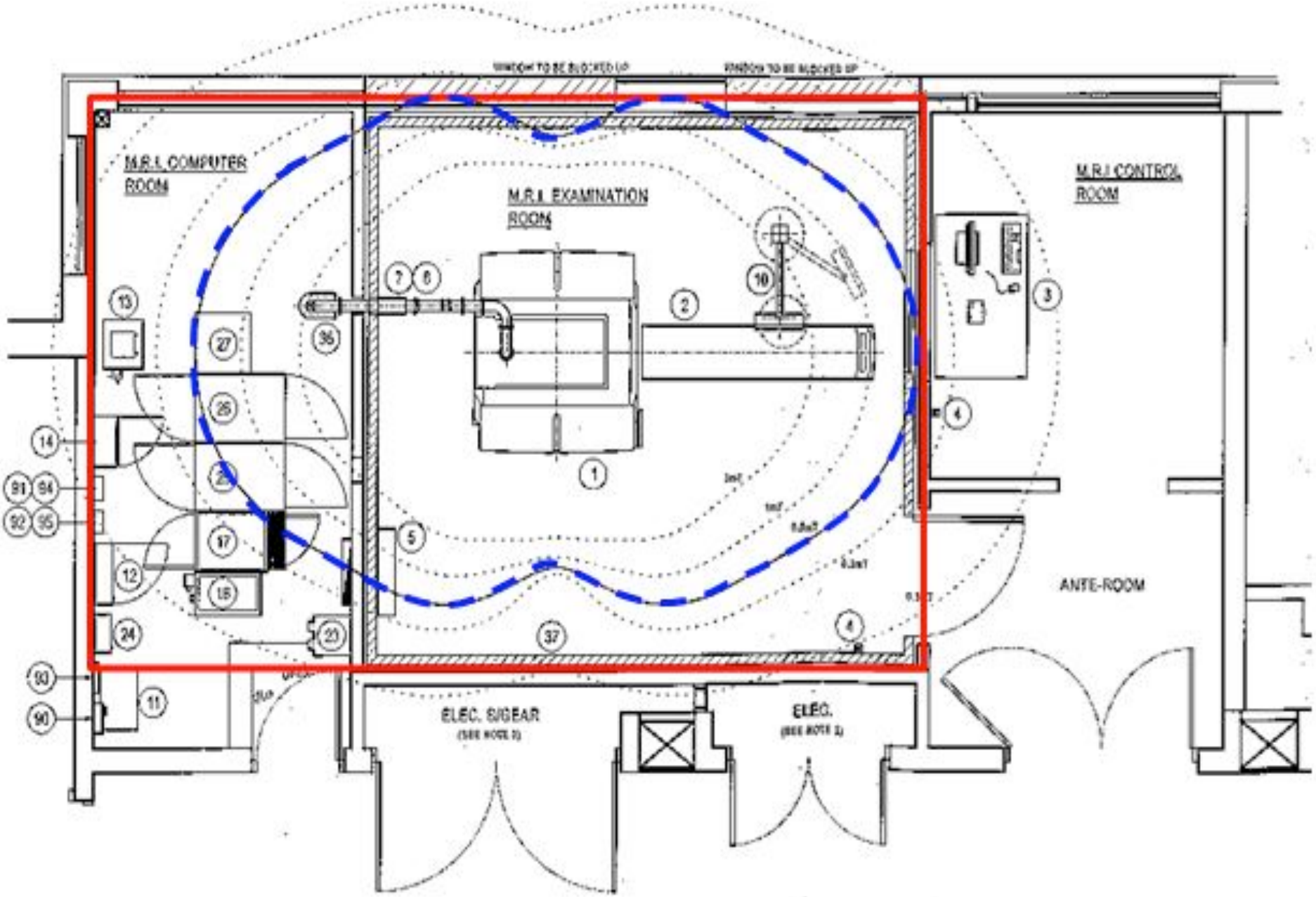
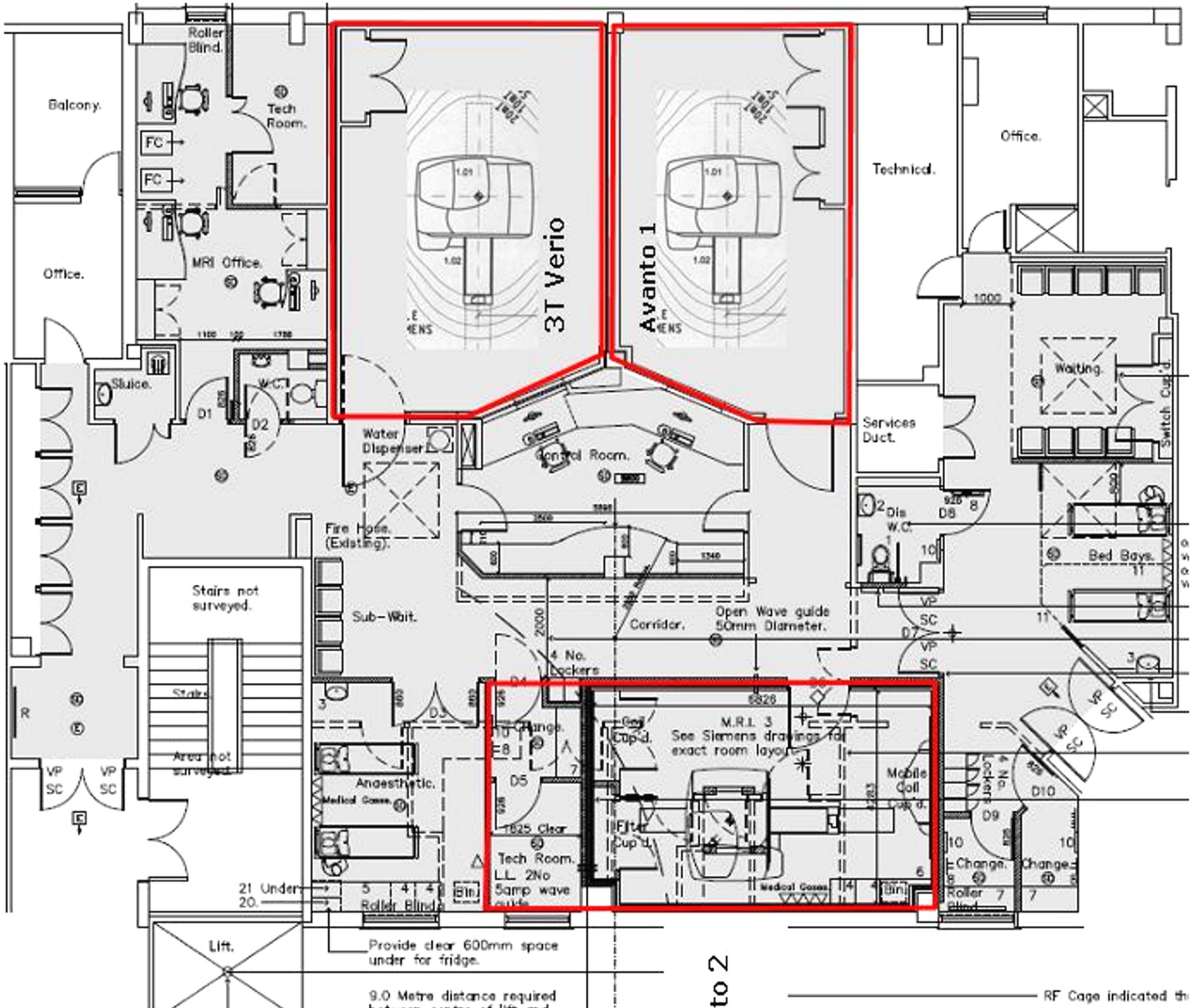

M.R.I. COMPUTER ROOM
M.R.I. EXAMINATION ROOM
M.R.I. CONTROL ROOM
ANTE-ROOM
ELEC. S/GEAR
ELEC.



Balcony.
Roller Blind.
Tech Room.
FC
FC
MRI Office.
Office.
Sluice.
W.C.
D1
D2
3T Verio
Avanto 1
Technical.
Office.
Waiting.
Switch Cup'd.
Services Duct.
Water Dispenser.
Control Room.
Fire Hose. (Existing).
Dis W.C.
D8
Bed Bays.
Stairs not surveyed.
Sub-Wait.
Corridor.
Open Wave guide 50mm Diameter.
4 No. Lockers
VP
SC
D7
Stairs
Area not surveyed.
R
VP
SC
VP
SC
Change.
D3
D4
D5
Coil Cup'd.
M.R.I. 3
See Siemens drawings for exact room layout.
Mobile Coil Cup'd.
Anaesthetic.
Medical Gases.
1625 Clear
Tech Room.
L.L. 2No 5amp wave guide
Filter Cup'd.
Medical Gases.
4 No. Lockers
D9
D10
Change.
Change.
Roller Blind.
21 Under
20.
Roller Blind.
Bin
Lift.
Provide clear 600mm space under for fridge.
9.0 Metre distance required
to 2
RF Cage indicated th

MR safety definitions

MR Safe means the device poses no risk to the patient in the MR environment. Image quality *may* be adversely affected

MR Conditional means that the devices poses no additional risk to the patient when introduced to the MR environment *under specified conditions*.

MR Unsafe means the device may not be introduced into the MR environment as it poses a significant risk to the patient and/or staff.

www.mhra.gov.uk/home/groups/dts-iac/documents/publication/con084717.pdf

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MRI Magnet Room Environment

Apart from consumables, everything needs to be labelled

Non-ferrous IV Poles, wheelchairs, oxygen cylinders, cardiac arrest trolleys, trolleys

Patient monitoring equipment

Infusion equipment

Because it is safe at 1.5T doesn't mean it is safe at 3T

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Patient Screening

- Pacemakers and Pacing Wires
- Aneurysm Clips
- Intra-ocular Ferrous Foreign Bodies
- Metallic Foreign Bodies
- Biomedical Implants and Devices
- Catheters (Thermo Swan-Ganz)
- Coils, Filters and Stents
- Heart Valves
- Personal belongings
- Pregnancy

NHS
Hampshire Hospitals
NHS Foundation Trust

MRI safety questionnaire/consent form

- Please **read both sides** of this questionnaire thoroughly and **complete all boxes** before attending your appointment.
- **Please telephone us on 01962 824011 as soon as possible if you answer Yes to any of the questions below. We will also need an accurate measurement of your height and weight.**
- In some cases, when we are not completely sure about your medical history, we will need to rebook your appointment, until we find out the full details.

Please remove any body piercings before attending for your scan. You will not be able to take any electronic devices such as mobile phones, wallets, credit cards, watches, hair clips, coins, or books into the scan room with you. We will provide a secure place for everything you bring with you.

Patient details	
Surname:	Title:
Forenames:	Date of birth:
Address:	Height:
Post code:	Weight:

Safety check

1. Do you have any implanted devices? If **Yes**, are they listed **overleaf**?	Yes ❑	No ❑
2. Have you had any surgery/procedures to your head, heart, or spine?	Yes ❑	No ❑
3. Have you had any surgery/procedures to other parts of your body?	Yes ❑	No ❑
4. Have you had **any** surgery in the last six weeks?	Yes ❑	No ❑
5. Do you have any metal implants or prostheses?	Yes ❑	No ❑
6. Could you possibly have had any metal fragments enter your eyes?	Yes ❑	No ❑
7. Have you ever suffered a shrapnel injury?	Yes ❑	No ❑
8. Do you wear dentures or hearing aids?	Yes ❑	No ❑
9. Do you have any non-removable piercings, tattoos or permanent make-up (eyeliner, lip liner, eyebrow tattoo)?	Yes ❑	No ❑
10. Are you wearing any medicine patches? (such as hormone or nicotine)	Yes ❑	No ❑
11. Do you suffer with claustrophobia and/or anxiety?	Yes ❑	No ❑
12. Do you have impaired thermoregulation (problems regulating your body temperature)?	Yes ❑	No ❑

Female patients only

13. Are you, or could you be, pregnant?	Yes ❑	No ❑

Please see overleaf for important information

Implant checklist

All MRI scanners are different, so if you have had an MRI scan at another hospital with the implant, it may not be compatible with our scanners at Hampshire Hospitals.

Devices and implants not routinely scanned at Hampshire Hospitals

- Neuro-stimulators (including MRI Conditional stimulators)
- Aneurysm clips (including MRI Conditional clips), dermal body piercings
- Non-MRI conditional cardiac pacemakers/defibrillators (including first time MRI scans on conditional devices)
- Programmable hydrocephalus shunts.

Please indicate if you have any of the following:

• Stents, extracranial clips, aneurysm coils, embolization coils, filters, staples, and metallic markers/sutures	Yes ❑	No ❑
• Heart valves	Yes ❑	No ❑
• Cochlear implant or other ear implants	Yes ❑	No ❑
• MRI conditional pacemakers	Yes ❑	No ❑
• ICD (implantable cardioverter-defibrillator)	Yes ❑	No ❑
• Gastric band	Yes ❑	No ❑
• Reveal device	Yes ❑	No ❑
• Eye implants with magnets	Yes ❑	No ❑
• Gastric sleeve	Yes ❑	No ❑
• Pill camera – endoscopy	Yes ❑	No ❑
• Bowel clips	Yes ❑	No ❑
• Breast ports/expanders	Yes ❑	No ❑
• Abdominal aortic aneurysm (AAA) repair	Yes ❑	No ❑
• Shunts	Yes ❑	No ❑
• Metal-based ink tattoos, metallic hair extension clips	Yes ❑	No ❑
• Magnetically activated implant/device	Yes ❑	No ❑
• Internal electrodes or wires	Yes ❑	No ❑
• Implanted drug infusion device	Yes ❑	No ❑
• Any type of prosthesis/implant (eye, penile, etc.)	Yes ❑	No ❑
• Radiation seeds or implants	Yes ❑	No ❑
• Vascular access port and/or catheter	Yes ❑	No ❑
• Wire mesh implant	Yes ❑	No ❑
• Other implants/devices not mentioned above	Yes ❑	No ❑

If your device is **not** in the list above OR you have relevant information (make and model) regarding your implant, please let us know as soon as possible on 01962 824011. If you do not have any information about your implants, we may need to contact the hospital where the procedure took place. This may take some time and can delay your scan until we receive the relevant information.

Please note that if we are unable to find any information about your implants, we will not be able to scan you. This is for your own safety.

By signing below, you confirm that you have read and understood the questions on this form. You acknowledge that a radiographer has explained the procedure to you.

Patient signature..... **Date:**.....

Radiographer/RDA signature..... **Date:**.....

MRI Dept; May 2021; Review May 2023; FCS/ 284/ 2018/ VER5; © Hampshire Hospitals NHS Foundation Trust

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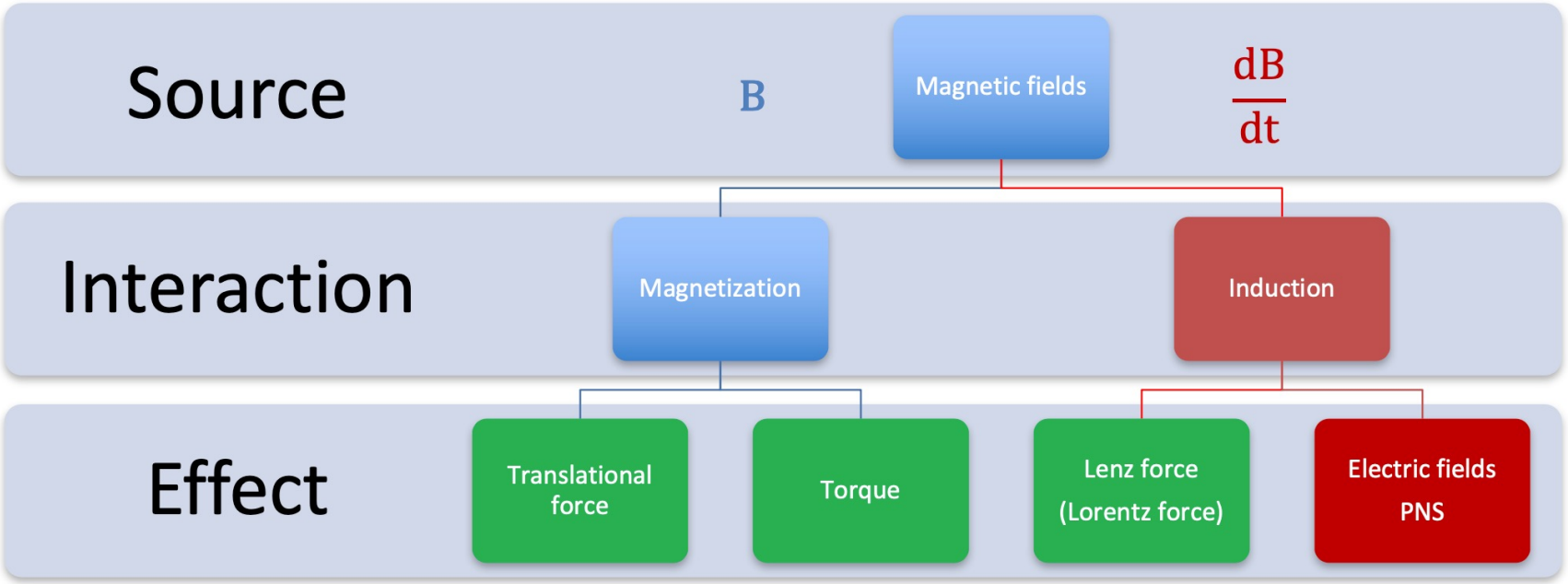
Electromagnetic Interactions

A means to understand and classify mechanisms of effect (and risk)



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Static field - bio effects

High Field Effects - 3T and above

- Nausea
- Headaches
- Taste sensations
- Vertigo
- Associated with head movement
- Uncommon at 1.5T

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Possible biological effects of the static field

- **Magneto-hydrodynamic (Lorentz force)**
  - Movement of electrolytes?
  - Induced field in flowing charge
  - Nerve conduction velocities
  - Unlikely to have any effect <8T
- **Induced electric fields**
  - Nausea, metallic taste, vertigo?
- **Magneto-mechanical**
  - Translation & orientation of molecules?

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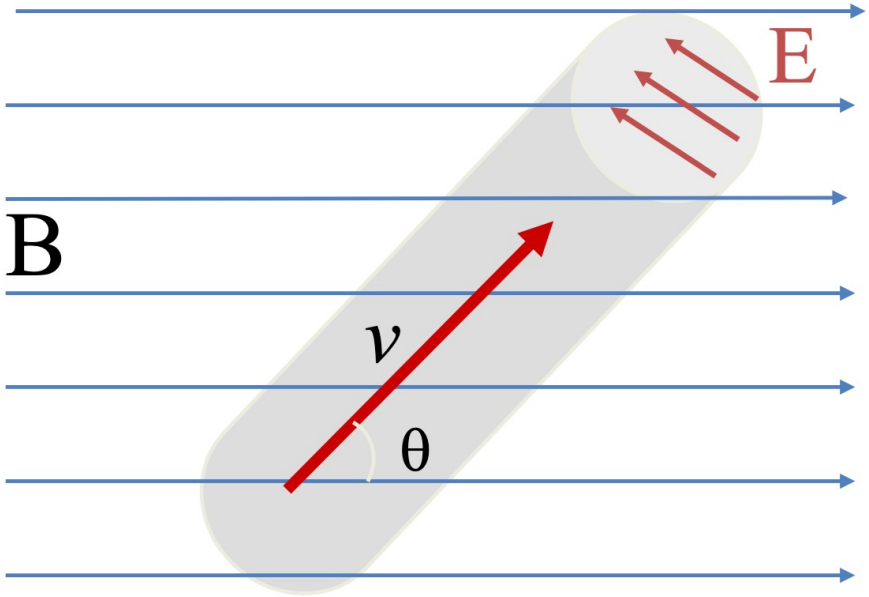
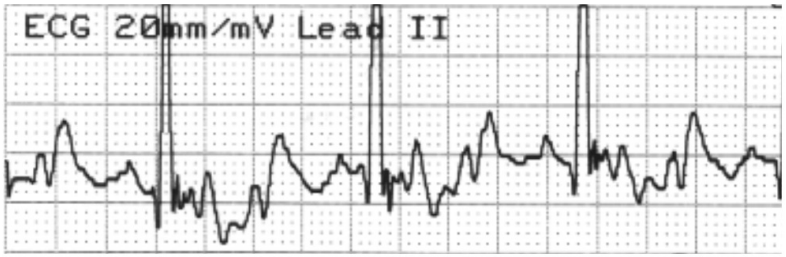
Magneto-hydrodynamic effect





$$V = \mathrm{d}vB\sin\theta$$

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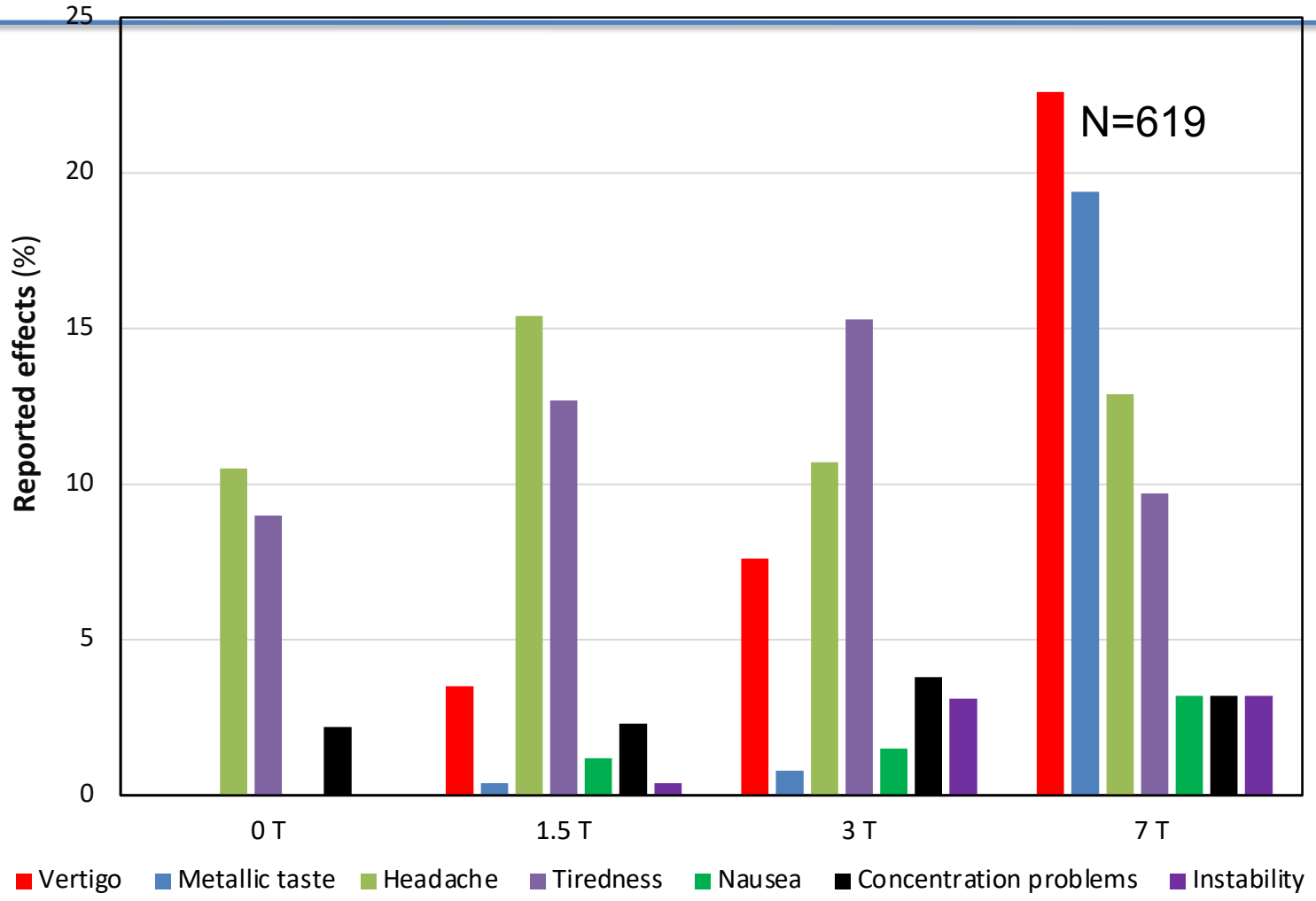
Reported symptoms – Netherlands study



Schaap K et al Occup Environ Med; 2014 Jun;71(6):423-9.

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EMF exposures in MRI

- The fringe field of the magnet
- Static magnetic field in magnet B_0
- Gradients - time-varying fields $G_{x,y,z}$
- RF time-varying magnetic field B_1

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Gradient Safety Concerns – Bio effects

- **Acoustic Noise**
  - Increases with gradient strength
  - Louder with faster imaging sequences
  - Earplugs probably not necessary at 0.2 and 0.35

- **Current Induction**
  - Peripheral nerve stimulation
  - Care should be taken when imaging patients with implanted leads

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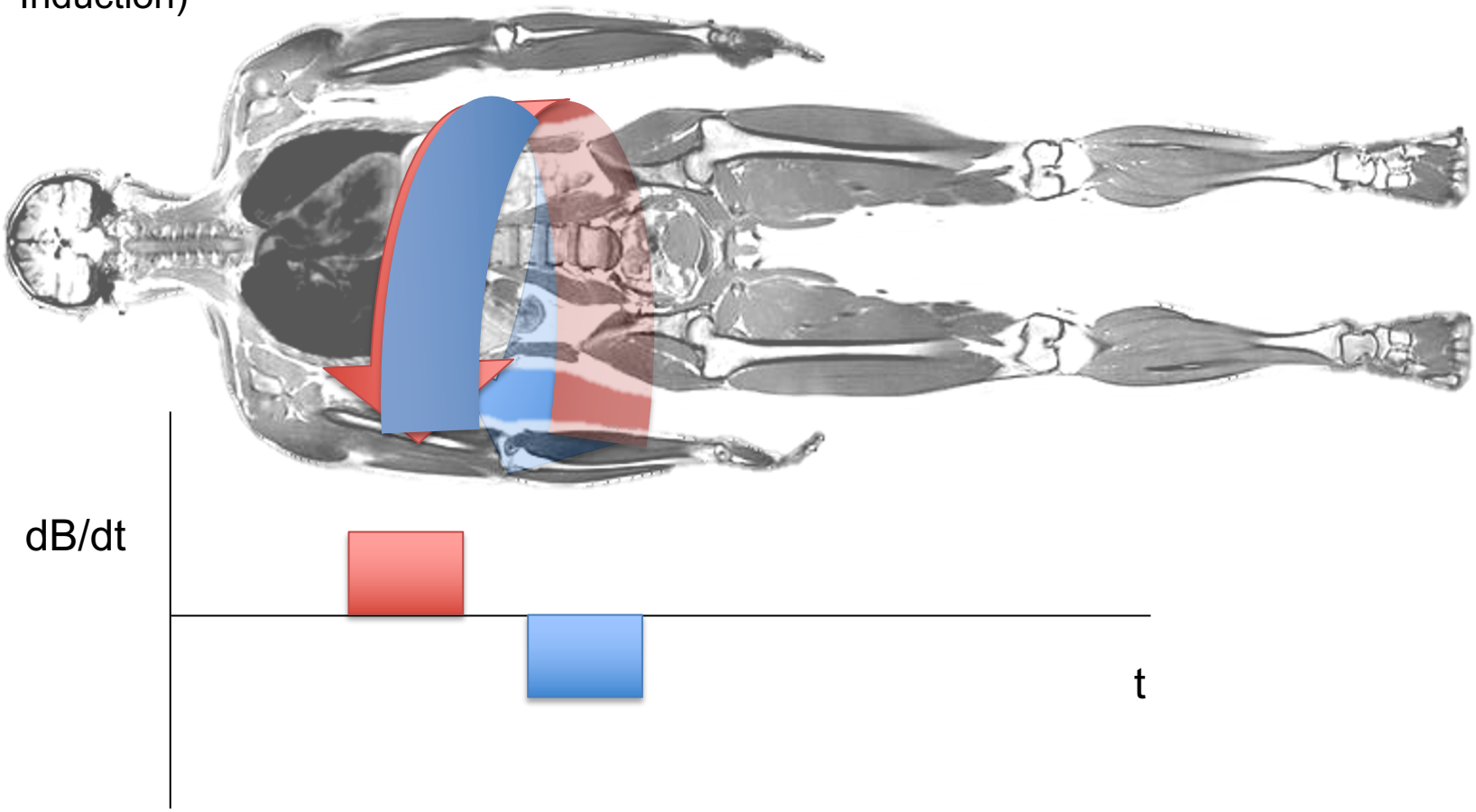
Induced E field

Rapid switching of the gradient field can induce current in conductor (Faraday's Law of Induction)



Nerves, blood vessels and muscles.

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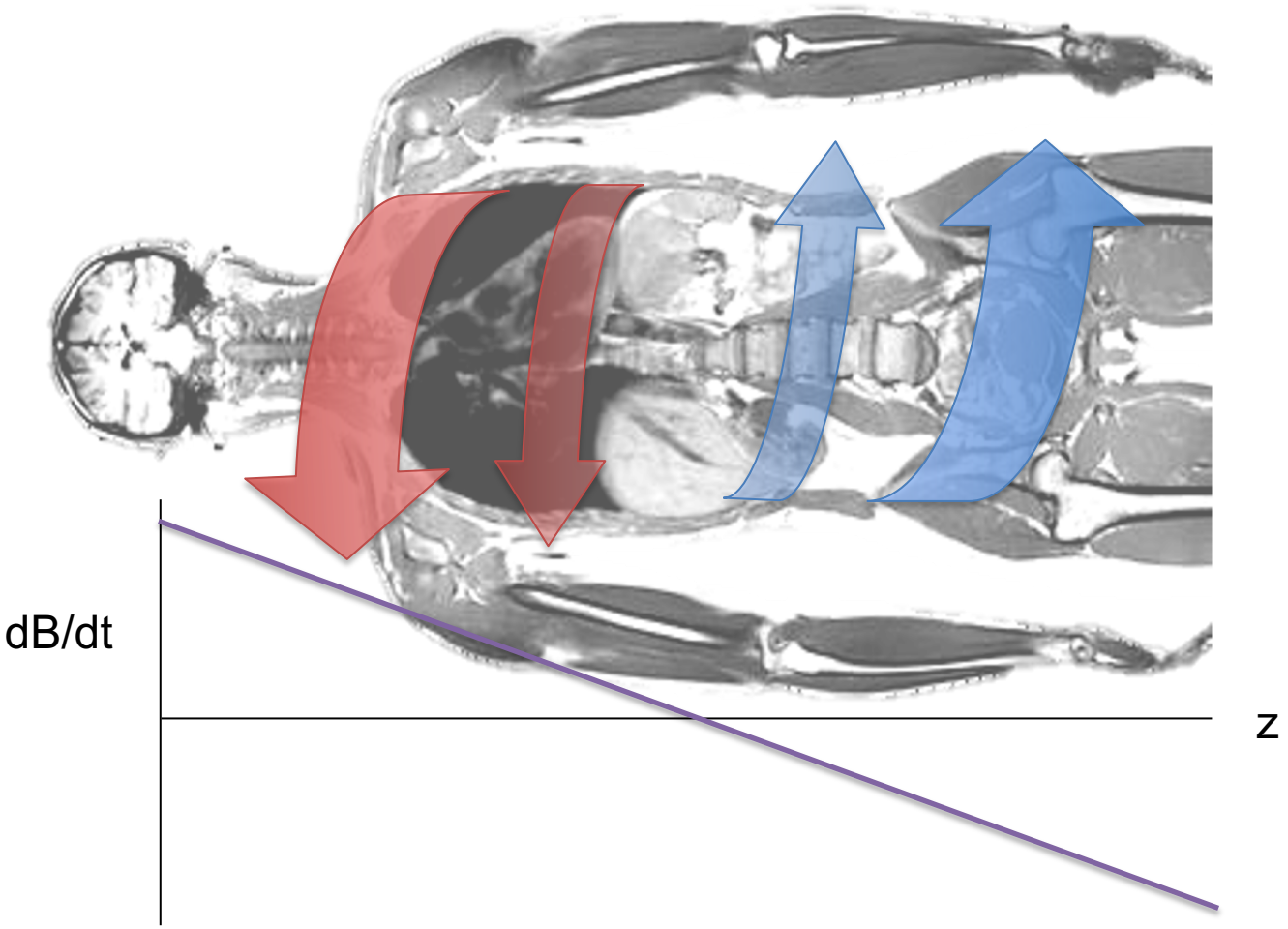
It's a *gradient*



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Peripheral Nerve Stimulation

- Rapidly changing magnetic fields can, under certain conditions, cause nerves close to the skin to become stimulated.

- Peripheral Nerve Stimulation can be thought of as a light "touching" sensation on the surface of the skin.

- The potential for patients experiencing PNS is very low--but still possible.

What To Do?

If a patient complains of PNS, stop the scan if possible and change to another pulse sequence.

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When can PNS occur?

Mostly EPI based pulse sequences.

EPI applications include, but are not limited to:

- Rapid brain imaging
- BOLD: Task activation
- Diffusion Imaging
- Perfusion Imaging
- Abdominal and cardiac imaging

SSFP (TruFISP, b-FFE, FIESTA)

PNS is possible with <u>any</u> sequence, not just EPI.

Remember, PNS is <u>not</u> harmful.

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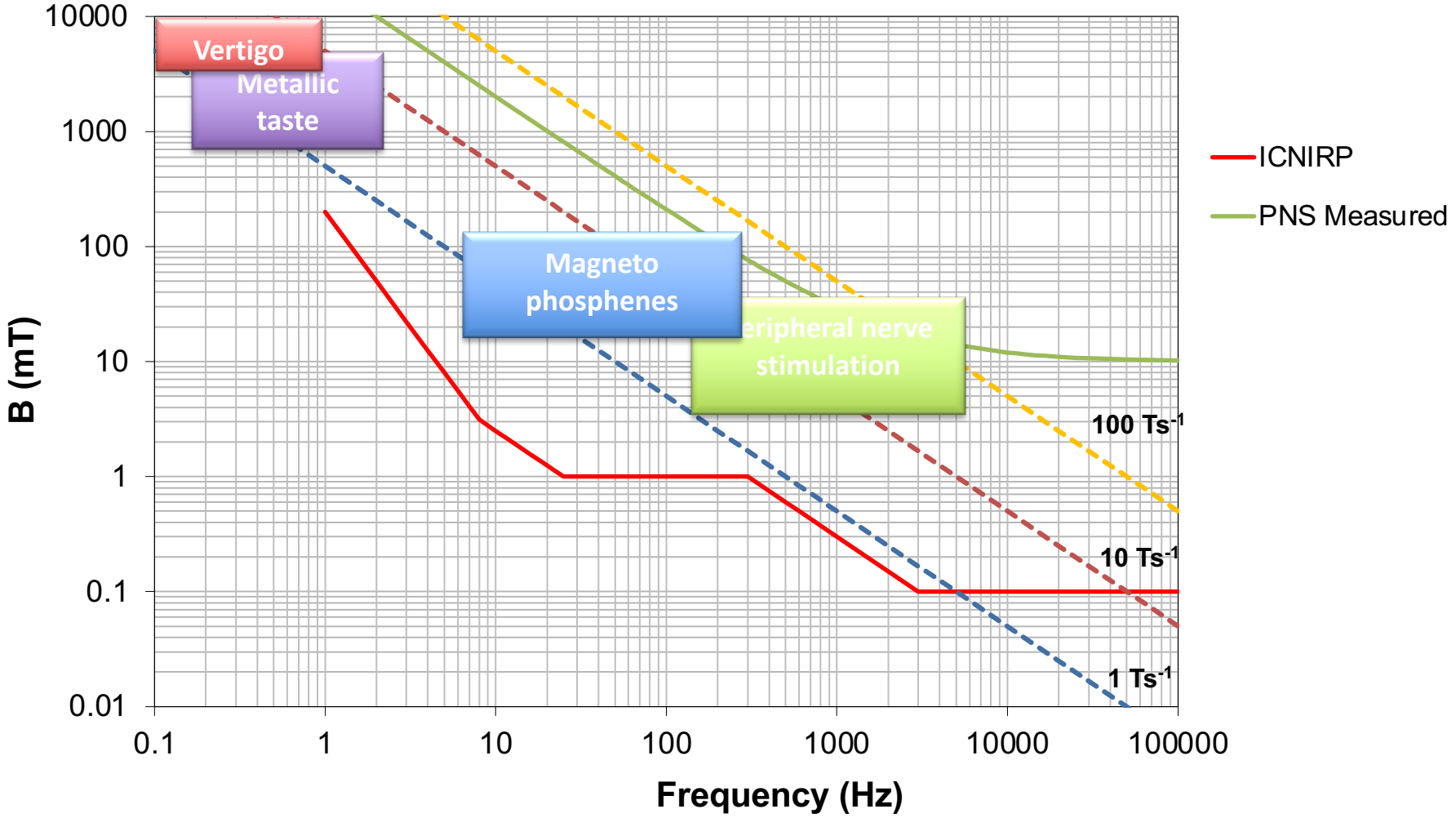
Magneto-stimulation spectrum



Adapted from **Paul Glover**, University of Nottingham

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Conclusions

- No convincing evidence of long term effects
- Physiological function - unaffected
- Acute sensory effects
  - Vertigo
  - Metallic taste
  - Mainly 3T and above
  - ΔB appears to be significant rather than dB/dt

Magnetic Forces the greatest source of hazard

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Acoustic noise

- Typical noise levels for 1.5 T- 80 dB(A) - 110 dB(A)
- MHRA (2014) recommends hearing protection for all patients at levels above 80 dB(A).
- Including the unconscious
- Staff working in the MR room during scanning also require hearing protection.

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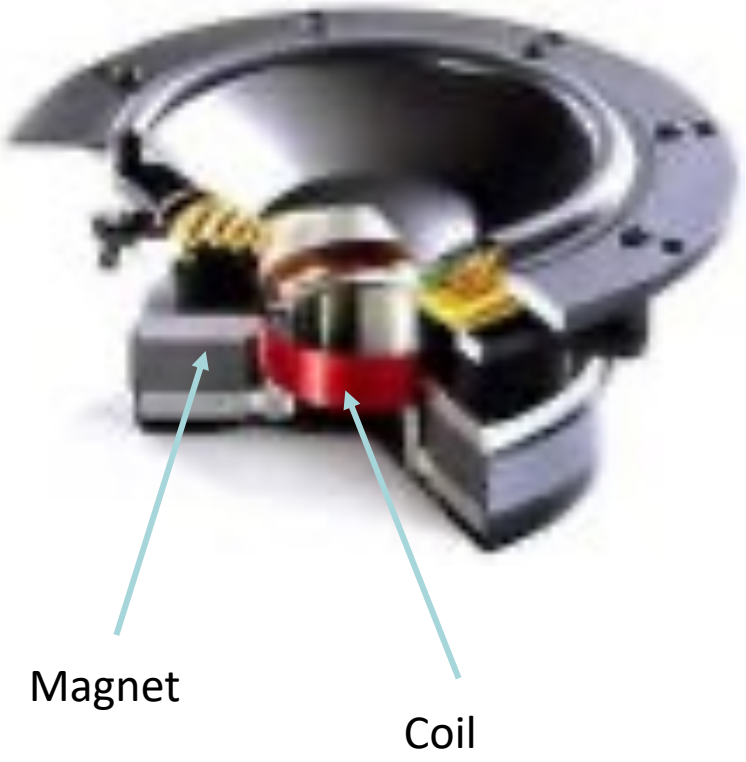
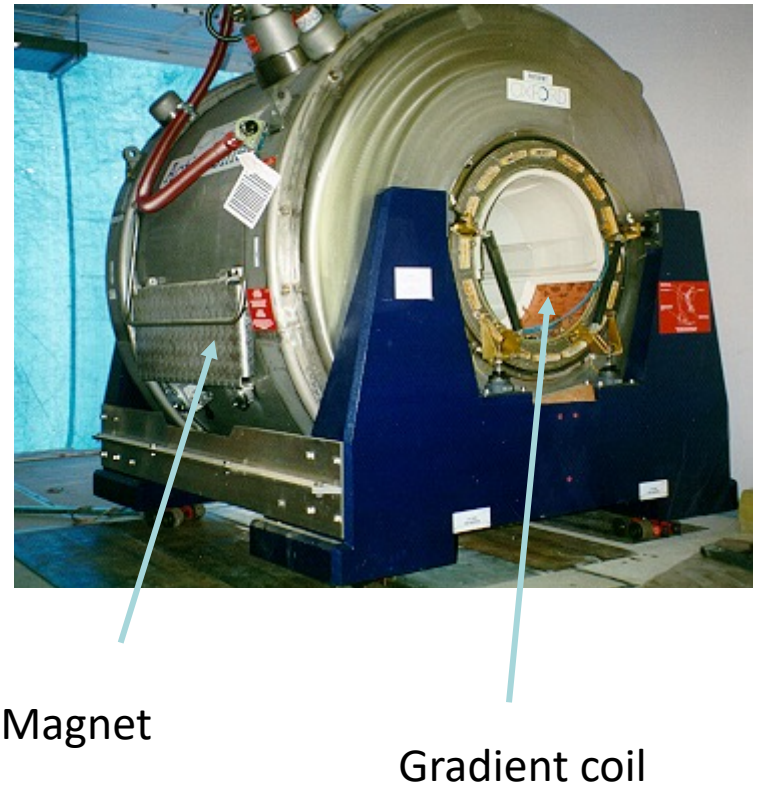
What makes the noise?





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Temporary and Permanent Threshold Shift

- One-off or occasional exposure to noise (<140 dB) can lead to a temporary threshold shift (TTS)
- Extreme impulse noise >140 dB can lead to instantaneous acoustic trauma and permanent threshold shift (PTS)
  - MR systems compliant with the IEC MR Safety Standard cannot produce peak sound pressures >140 dB

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Who's at risk?

- Patients should not be at a significant risk of a PTS because of limited exposure duration
- MR staff performing interventional procedures or comforting patients might be at risk of a PTS in common with workers in other noisy occupations

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Hearing protection

MHRA guidance for patients and volunteers

- Patients should be clearly warned about the noise
- Above 80db ear protection is to be given
- Unconscious patients are to be given ear protection

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Hearing Protection

- Ear plugs
  - Max. attenuation of about 35 dB(A) at the frequencies encountered in MRI
  - Must be fitted correctly in ear canal to provide protection

- Ear defenders/phones
  - Can give better protection depending on type. More reliable fitting although hair can interfere with seal around muff cup. Unfortunately can't always be used with certain RF coils.

  - Must be kept in good order (MHRA)

MHRA: Staff must be trained in correct fitting

Radio Frequency and MRI

- Rf effects are the greatest concern
- Energy deposition
- May cause tissue heating
- Primary concerns elevation of core body temp
- Heat sensitive organs
- Prevention of burns from local RF coils
- Metallic implants may result in greater heating
- Potential skin burns

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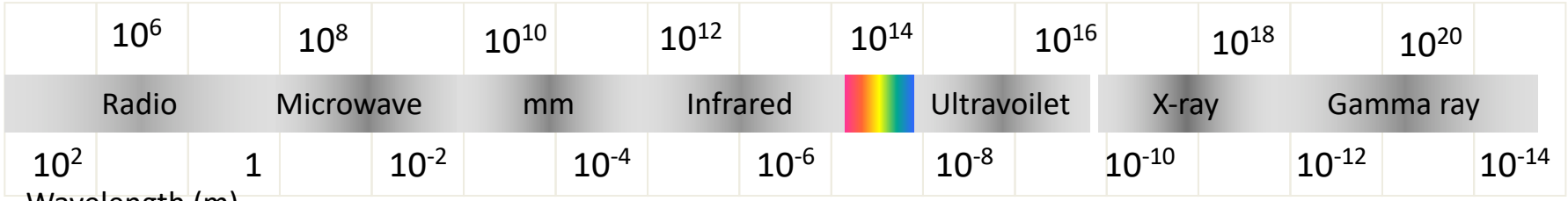
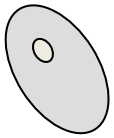
Bio-effects of RF fields

Field	Range	Frequency	Duration
RF	0 - 50 μT	8–300 MHz	Amplitude modulated pulses of few milli-seconds duration. Low duty cycle.

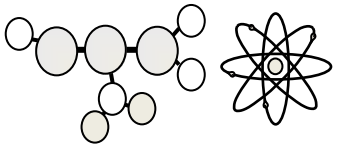
Frequency (Hz) / Energy



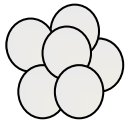
Wavelength (m)



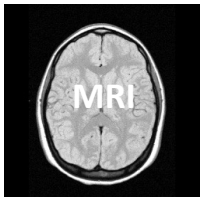
Cell

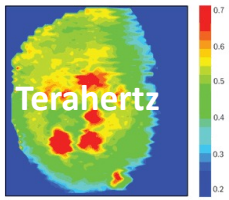


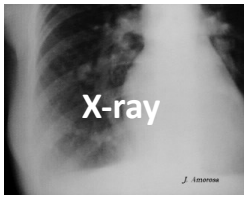
Molecule Atom

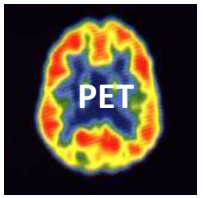


Nucleus









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RF Field: who's at greatest risk?

- Pregnant patients
- Patients with cardiac conditions
- Unconcious patients or heavily sedated
- Patients susceptible to seizures, claustrophobic
- Patients where no reliable communication can be maintained
- Patients with fever, reduced thermal regulatory capabilities or increased sensitivity to raised body temperature.
- Patients who are thermally insulated. (e.g. in a gypsum cast).

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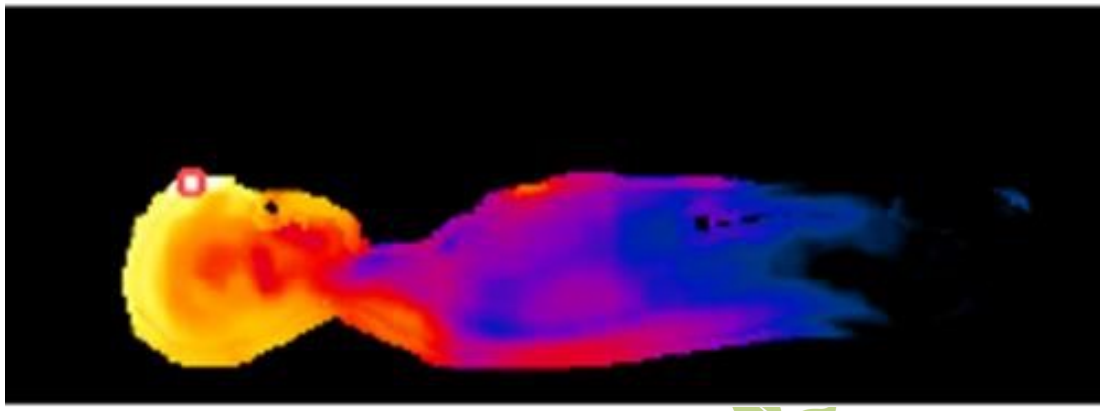
RF Exposure - tissue heating

- Specific Absorption Rate

  SAR = Average Power / Weight (W /kg)

- Depends on
  - Type of sequence (worst = HASTE/TSE)
  - number of slices, echoes
  - TR, flip angle
  - Patient size
  - Conductivity
  - B_0^2



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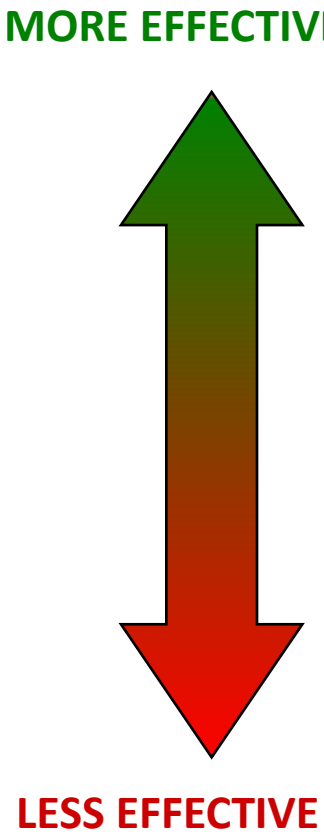
To reduce SAR

- Use gradient echo rather than spin echo if possible
- Use “Hyperechoes”
- Reduce flip angle
  - (e.g. 180° -150 °)
- Reduce number of echoes
- Reduce number of slices
- Increase TR



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IEC- SAR Limits

SAR (W kg^{-1})	**Whole body**	Head	Localized region		
Operating mode		Any	Head	Trunk	Extremity
Normal	**2**	**3.2**	**10**	**10**	**20**
First-level controlled	**4**	**3.2**	**10**	**10**	**20**
Second-level controlled	**4**	**>3.2**	**10**	**10**	**20**
Short-term SAR	The SAR limits over any 10-s period should not exceed three times the stated SAR average				

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Radiofrequency Magnetic Fields – Induced Current Burns

- Induced current burns occur when loops are made with patient's limbs
- Careful positioning of ECG cables
- Avoid conductive loops
- Careful positioning of patient is essential

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RF Magnetic Fields – Contact Burns

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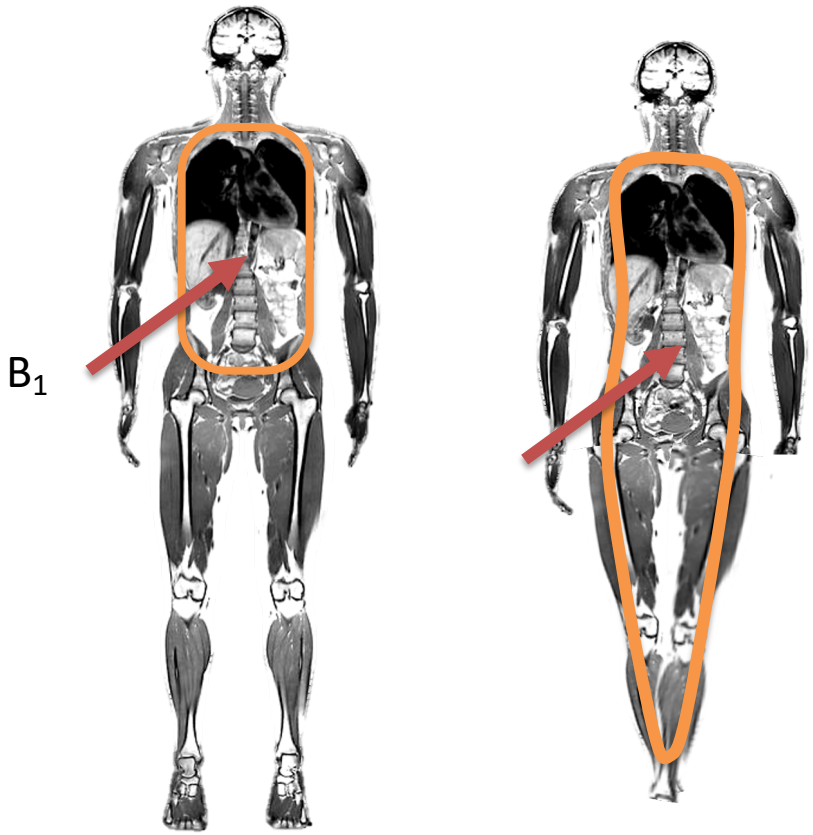
Induction in tissue



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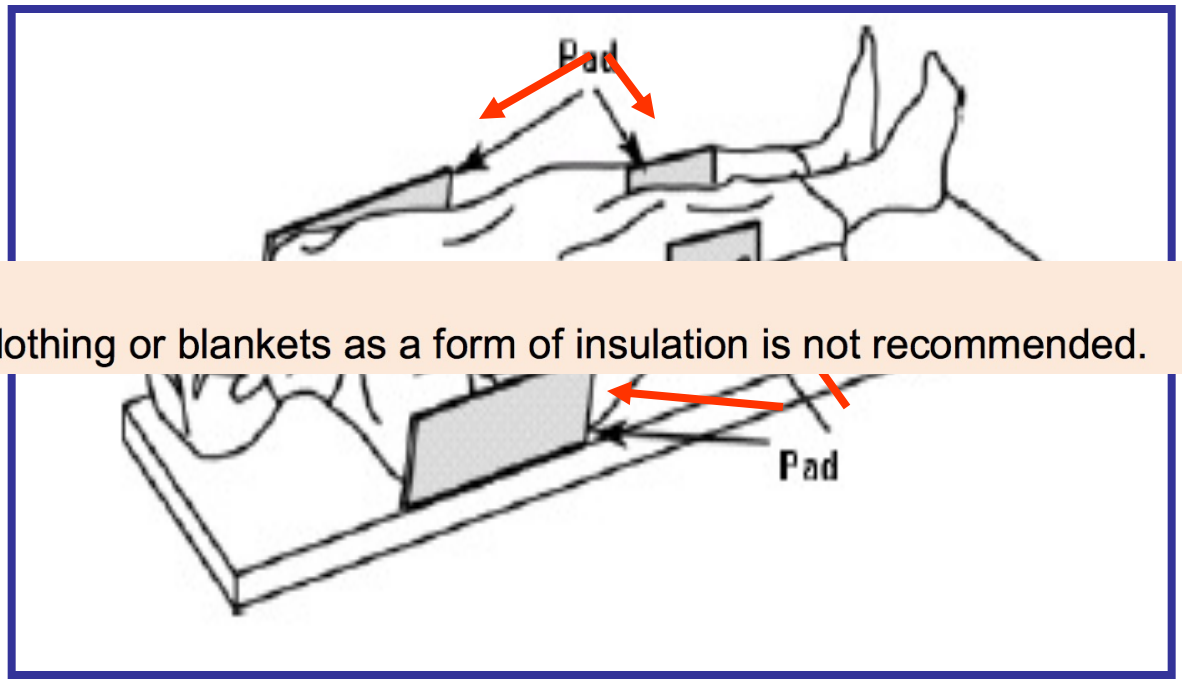
Patient Padding



The use of clothing or blankets as a form of insulation is not recommended.

Patients should never be allowed to come in direct contact with the magnet bore or with any surface coil

The MHRA recommends that users use foam pads, 1–2 cm thick, to insulate the patient from cables, transmitting RF elements, the bore and between limbs.

MRI Safety Guidance

Magnetic resonance imaging equipment in clinical use: safety guidelines

Relevant safety information for users of magnetic resonance imaging (MRI) equipment in clinical use.

From: Medicines and Healthcare products Regulatory Agency
Published: 7 November 2014
Last updated: 4 February 2021, see all updates

Documents

Safety guidelines for magnetic resonance imaging equipment in clinical use

PDF, 1.55MB, 86 pages

This file may not be suitable for users of assistive technology.

▶ Request an accessible format.

https://www.gov.uk/government/publications/safety-guidelines-for-magnetic-resonance-imaging-equipment-in-clinical-use

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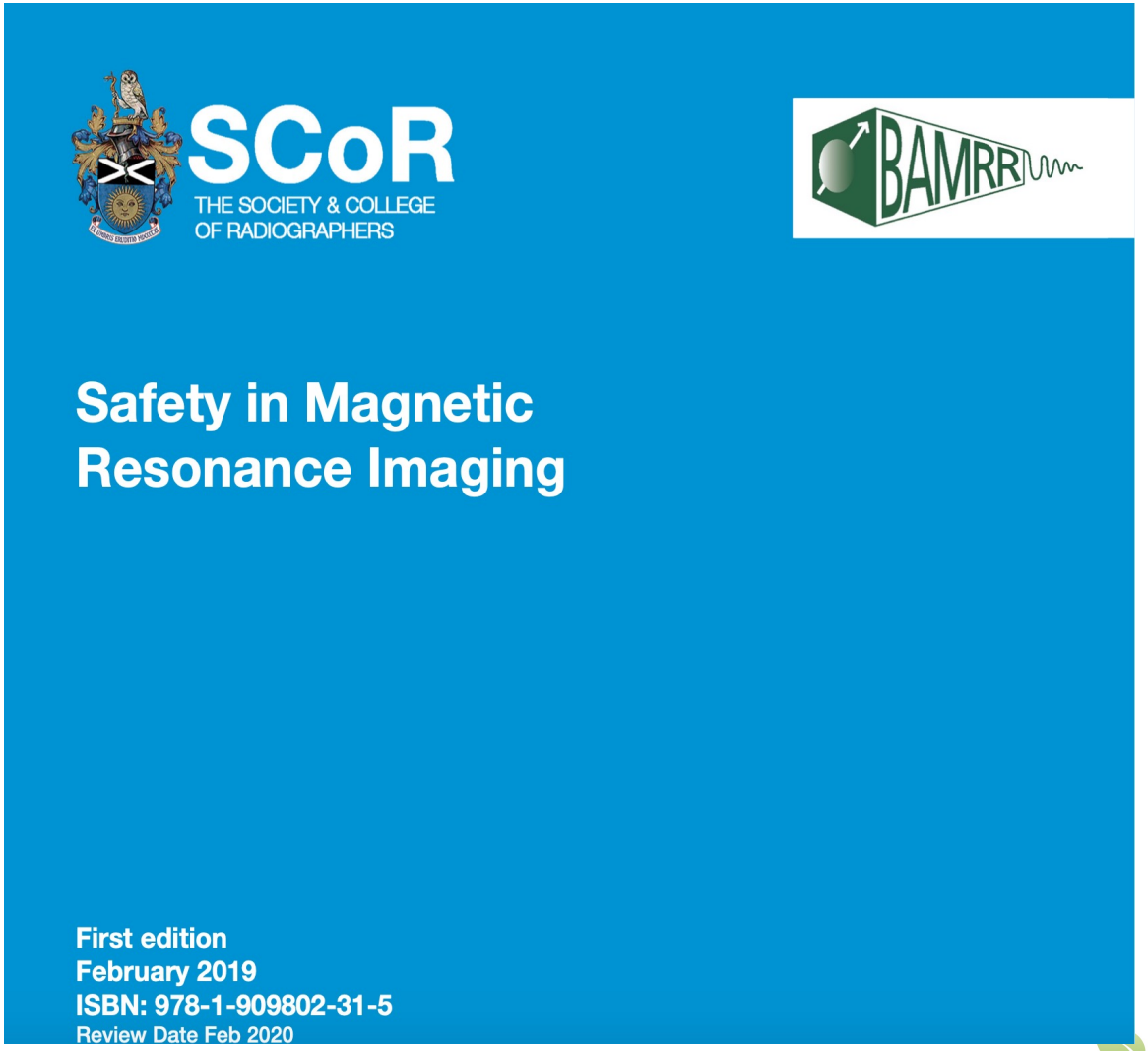
SoR MRI Safety Guidance



https://www.sor.org/getmedia/b7d1db7a-5b04-492e-ad4d-6b188f0d9cb0/safety_in_magnetic_resonance_imaging_3.pdf_2

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MR Safety Top Tips

MHRA

- Use your MR safety adviser as a source of expertise in assessing and managing risks.
- All equipment used in the MR controlled area must be assessed in terms of its MR safety.
- No equipment should be taken into the scanner room unless it is clearly marked MR Safe or MR Conditional, using the ASTM international symbols.
- Anything marked MR Unsafe should not be taken into the scanner room.
- Check the conditions for safe use for MR Conditional devices before allowing them into the scanner room.
- A strong, hand-held magnet should be available to test items to be taken into the scanner room.

Scan preparation

- Screening for entry should include verbal questioning, a written questionnaire and provision of information about the hazards.
- Screening must be undertaken by appropriately qualified personnel.
- Weigh the patient in the MR unit before scanning.
- Patients should change into appropriate clothing provided by the MR unit.
- Patients on trolleys should not be covered whilst they are in the scanner room since MR Unsafe items may be hidden under the sheets/blankets.

Acoustic noise

- The use of earplugs, ear defenders, or other means of hearing protection is highly recommended.
- Staff must be trained in the use and selection of ear protection.
- Ensure that ear defenders are maintained as recommended by the manufacturer.

Implants and metal fragments

- Refer to the implanting clinician's patient notes and the implant manufacturer for information on the MR safety of all implants.
- When in doubt about an implant, the user should assume that it is MR Unsafe.
- A penetrating eye injury may indicate the presence of metal fragments in the eye – obtain an ocular X-ray to check.

Burns and heating

- Use foam pads, 1-2 cm thick, to insulate the patient from cables and the magnet bore. Use also between the legs and between the arm and the torso.
- Regularly inspect all monitor sensor sites if the patient is anaesthetised or

Cryogens

- All MR units should identify who is responsible for the safe upkeep, maintenance and inspection of the magnet's quench pipe system.
- All vent piping should be inspected by appropriately qualified personnel annually to ensure that helium can vent correctly in the event of a quench.

Gadolinium-containing contrast agents

Read the MHRA's current advice on how to minimise the risk of nephrogenic systemic fibrosis (NSF).

Reporting incidents

Report adverse incidents and adverse drug reactions to the MHRA (via www.mhra.gov.uk).

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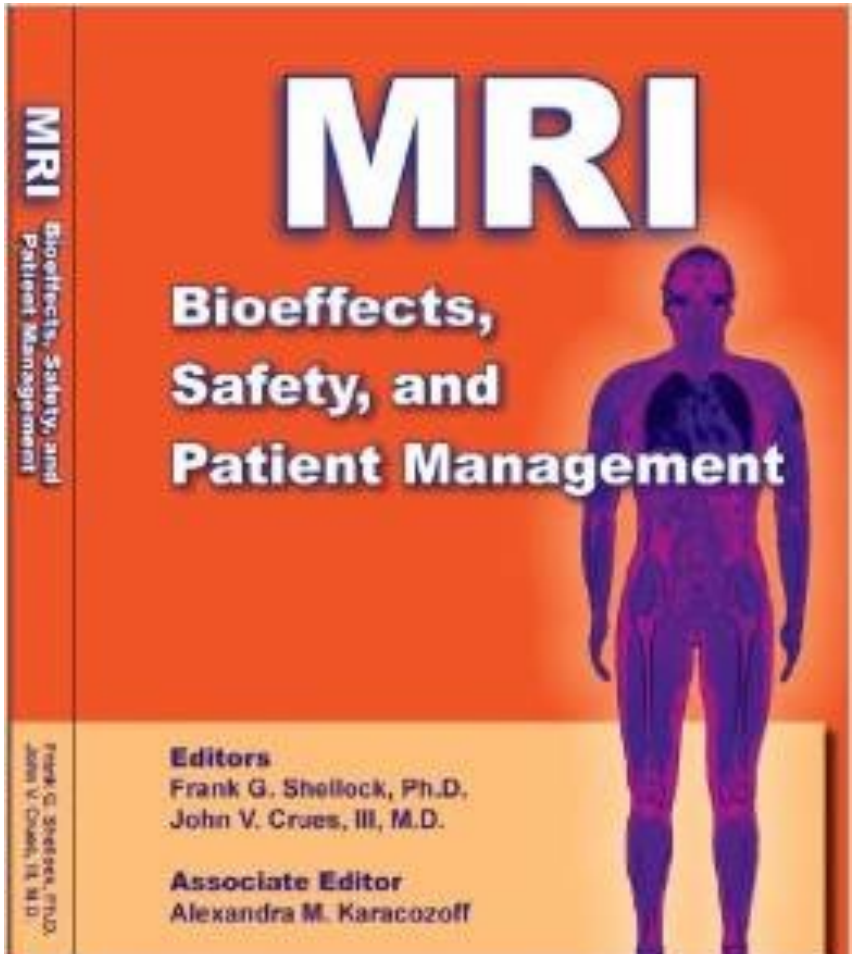
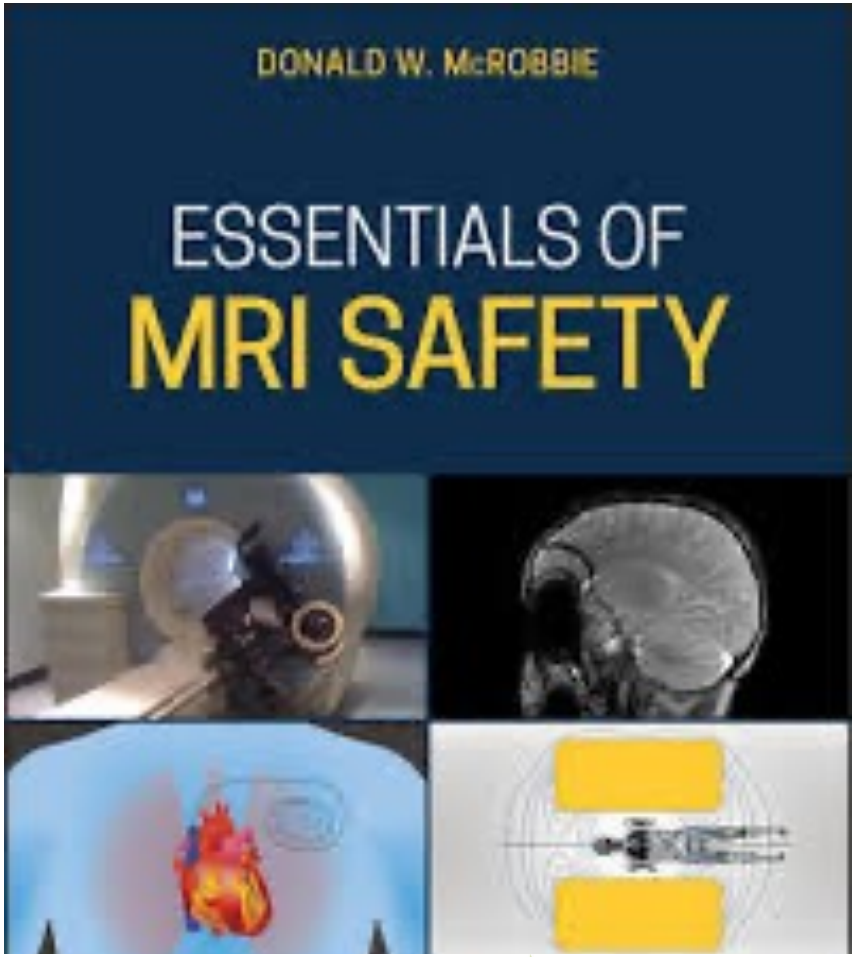
Reference books





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