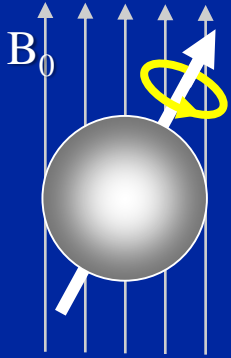


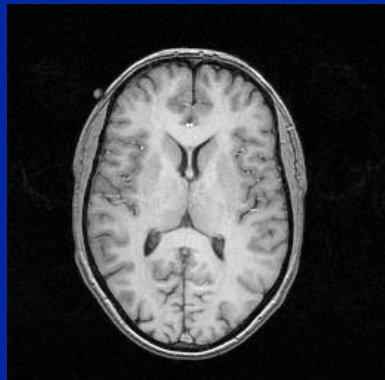
Hi, Dr. Elizabeth?
Yeah, uh... I accidentally took
the Fourier transform of my cat...



Recap of MRI Physics



- Body composed of many nuclear spins (^1H or protons) that have magnetic moment
- B_0 creates a net magnetization
- B_1 (RF) excites the magnetization (spins, protons) making them observable
- Contrast is developed (T1, T2, diffusion, etc.)
- Gradients (G_x , G_y , G_z) are used to localize the spins
- Signals are received and converted to digital images



Typical fMRI Protocol

- Calibrations
 - Estimate power deposition, receive coil patterns
- Scout Acquisition
 - Where am I?
- T1-weighted images
 - To align structure to fMRI maps, rule out pathology
- T2-weighted images
 - To rule out pathology (particularly for patient studies)
- fMRI – T2*-weighted, dynamic
 - Task-based, resting state
 - EPI or spiral, multiband EPI
- Diffusion tensor imaging
 - White matter anatomy, micro architecture
- High-resolution 3D T1-weighted images
 - For segmentation of anatomy
- Quantitative parameter mapping

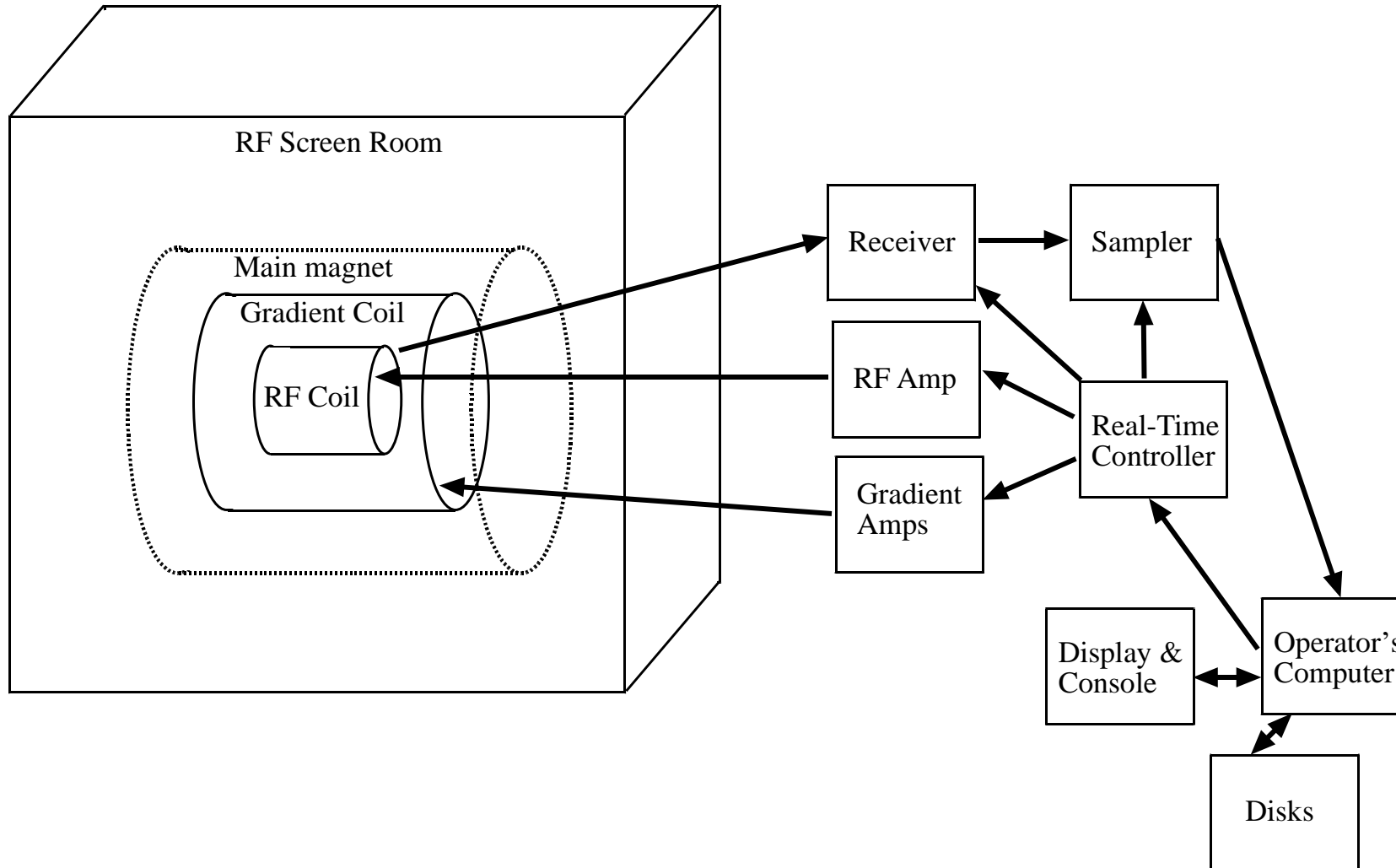
MRI Hardware and Safety

Douglas C. Noll
Biomedical Engineering
University of Michigan

MRI Hardware

- Recall the three magnetic fields
 - B_0
 - B_1
 - G_x, G_y, G_z
- Also, we need pulse control and data acquisition systems

Major MRI Components



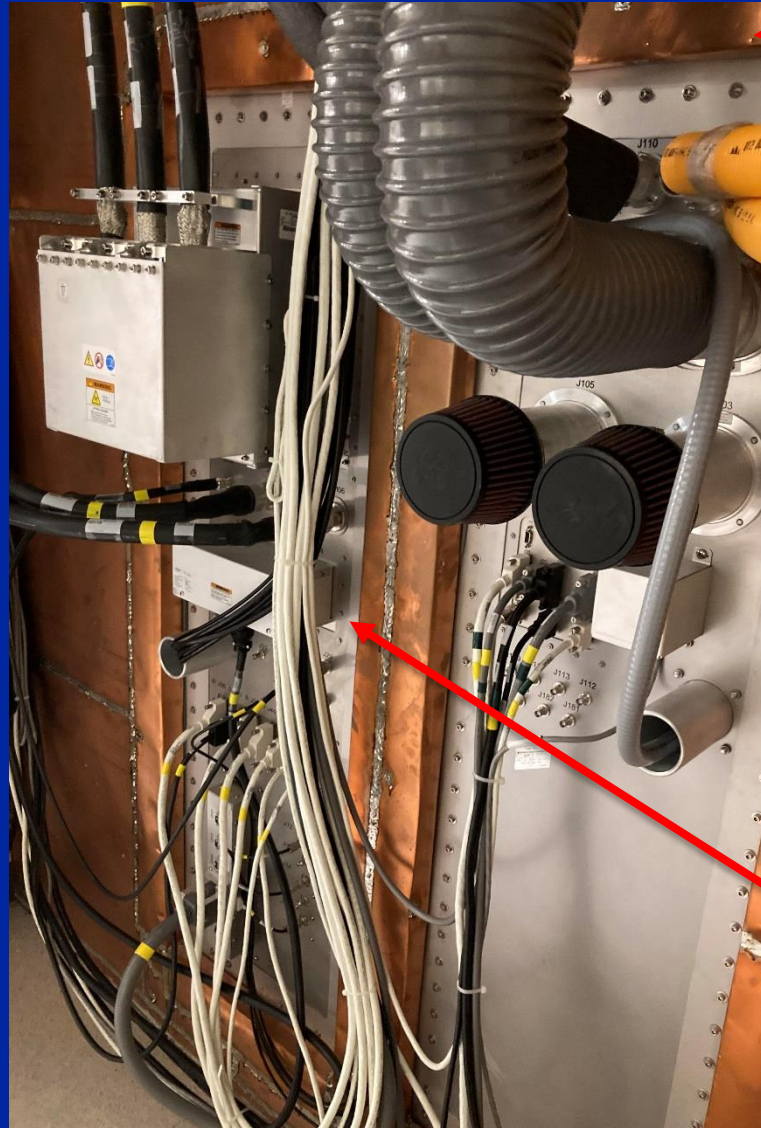
RF Screen Room

- Encloses the MRI device
- Shields MRI scanner from electromagnetic noise from computers, radio stations, etc.
 - MRI signals are weak compared to noise sources
 - Any wires going in/out must be filtered and grounded so they don't introduce noise
- These rooms can also incorporate magnetic shielding to contain the magnetic field.

RF Screen Room



Metal seals
around doors



Copper walls



Filtered panels for experimental
and MRI equipment

The Main Field

- B_0 range: 0.2 T to 7 T are common
- Higher fields:
 - Higher SNR
 - Slightly longer T_1 's,
 - Poorer RF homogeneity
 - Higher power deposition
 - Higher cost
- Typically superconducting
 - Filled with liquid helium

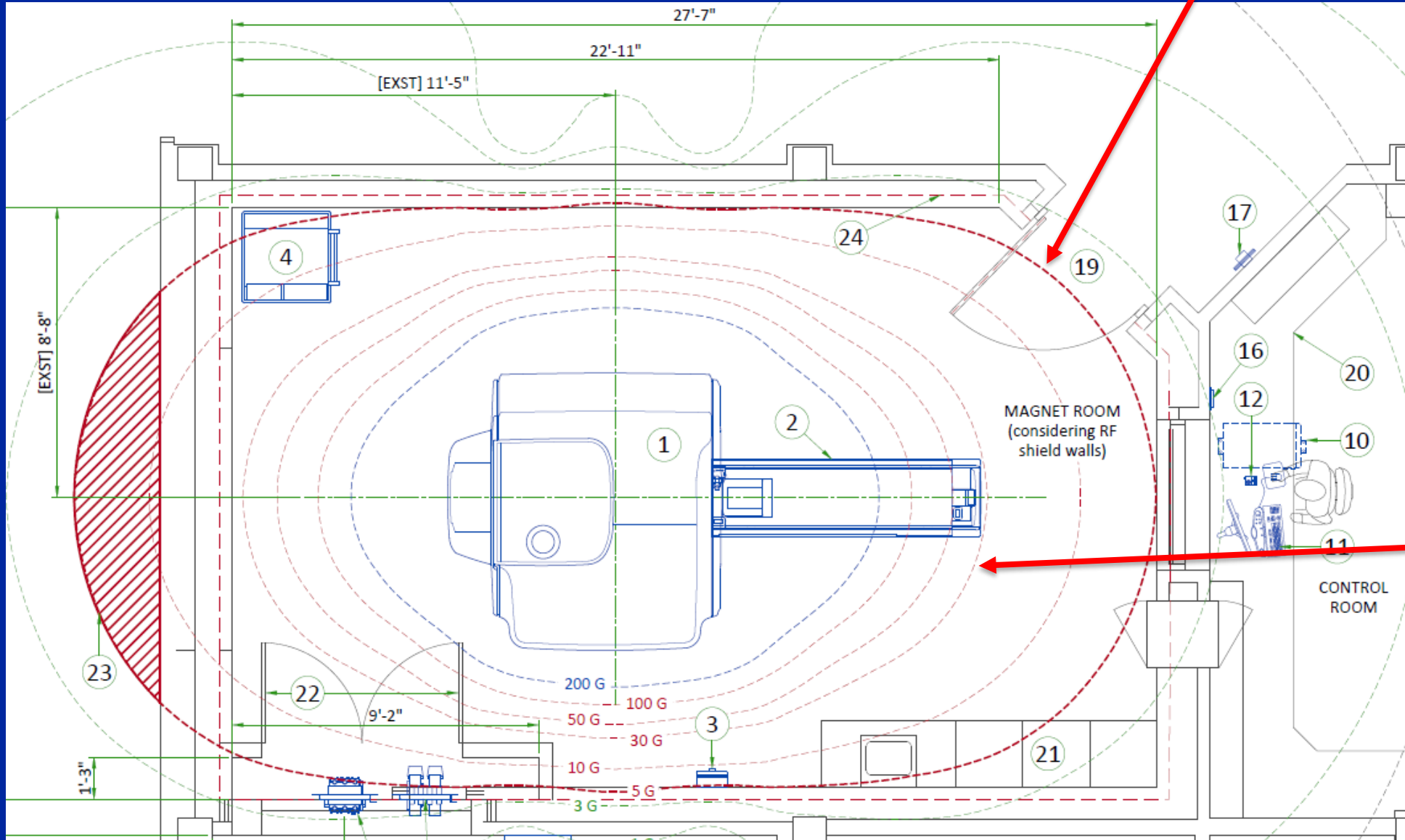


Main Field Safety

- **MAIN MAGNET IS ALWAYS ON!**
- B_0 is the biggest safety concern in MRI
- Mainly attraction of ferrous objects
- Some reports of dizziness, light flashes, unusual tastes, etc. at very high magnetic fields
- Quenching of magnet can result in venting of cryogenic gases
- The FDA has classified 8 T and under as a “non-significant risk”

Main Magnetic Field

5 G line

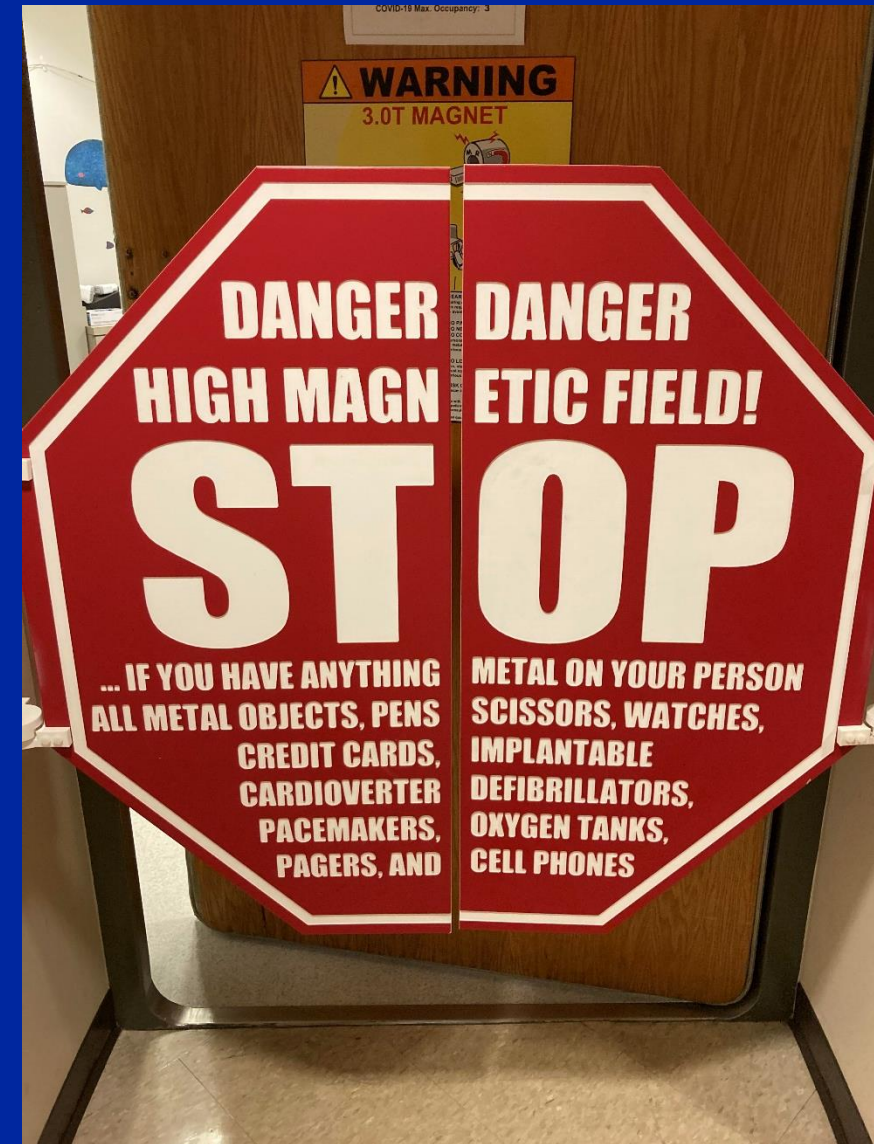


30 G line



The Main Field

- Safety issues:
 - Attraction of metallic implants (e.g. cochlear implants, neurostimulators, pacemakers, and poorly designed/manufactured stents, screws, pins, aneurysm clips, etc.)
 - Attraction of foreign metal objects (metal in eyes, shrapnel, ingested ferrous objects).
 - Affects magnetic switches in pacemakers
 - Ferrous objects brought into the MRI scan room



MRI Screening

http://fmri.research.umich.edu/documents/safety_screening.pdf

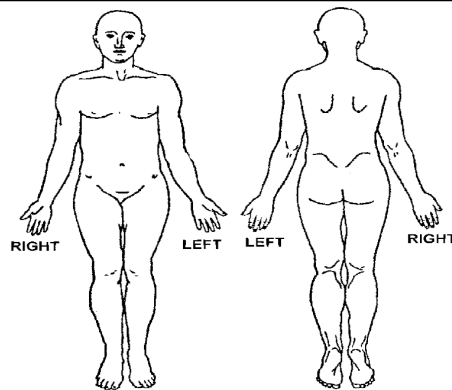


WARNING: Certain implants, devices, or objects may be hazardous to you and/or may interfere with the MR procedure (i.e., MRI, MR angiography, functional MRI, MR spectroscopy). Do not enter the MR system room or MR environment if you have any question or concern regarding an implant, device, or object. Consult the MRI Technologist or Director BEFORE entering the MR system room. The MR system magnet is ALWAYS on.

Please indicate if you have any of the following:

- | | | |
|-----|----|--|
| Yes | No | Aneurysm clip(s) |
| Yes | No | Cardiac pacemaker |
| Yes | No | Implanted cardioverter defibrillator (ICD) |
| Yes | No | Electronic implant or device |
| Yes | No | Magnetically-activated implant or device |
| Yes | No | Neurostimulation system |
| Yes | No | Spinal cord stimulator |
| Yes | No | Internal electrodes or wires |
| Yes | No | Bone growth/bone fusion stimulator |
| Yes | No | Cochlear, otologic, or other ear implant |
| Yes | No | Insulin or other infusion pump |
| Yes | No | Implanted drug infusion device |
| Yes | No | Any type of prosthesis (eye, penile, etc.) |
| Yes | No | Heart valve prosthesis |
| Yes | No | Eyelid spring or wire |
| Yes | No | Artificial or prosthetic limb |
| Yes | No | Metallic stent, filter, or coil |
| Yes | No | Shunt (spinal or intraventricular) |
| Yes | No | Vascular access port and/or catheter |
| Yes | No | Small bowel endoscopy capsule |
| Yes | No | Swan-Ganz or thermodilution catheter |
| Yes | No | Medication patch |
| Yes | No | Any metallic fragment or foreign body |
| Yes | No | Wire mesh implant |
| Yes | No | Tissue expander (e.g., breast) |
| Yes | No | Surgical staples, clips, or metallic sutures |
| Yes | No | Joint replacement (hip, knee, etc.) |
| Yes | No | Bone/joint pin, screw, nail, wire, plate, etc. |
| Yes | No | IUD, diaphragm, or pessary (circle which) |
| Yes | No | Dental braces |
| Yes | No | Tattoo or permanent makeup |
| Yes | No | Body piercing jewelry |
| Yes | No | Hearing aid
(Remove before entering MR system room) |
| Yes | No | Other implant _____ |
| Yes | No | Breathing problem or motion disorder |
| Yes | No | Claustrophobia |

Please mark on the figure(s) below the location of any implant or metal inside of or on your body.



IMPORTANT INSTRUCTIONS

Before entering the MR environment or MR system room, you must remove all metallic objects including hearing aids, dentures, partial plates, keys, beeper, cell phone, eyeglasses, hair pins, barrettes, jewelry, body piercing jewelry, watch, safety pins, paperclips, money clip, credit cards, bank cards, magnetic strip cards, coins, pens, pocket knife, nail clipper, tools, clothing with metal fasteners, & clothing with metallic threads.

Please consult the MRI Technologist or Director if you have any question or concern BEFORE you enter the MR system room.

NOTE: You will be required to wear earplugs or other hearing protection during the MR procedure to prevent possible problems or hazards related to acoustic noise.

- Aneurysm clip(s)
- Cardiac pacemaker
- Implanted cardioverter defibrillator (ICD)
- Electronic implant or device
- Magnetically-activated implant or device
- Neurostimulation system
- Spinal cord stimulator
- Internal electrodes or wires
- Bone growth/bone fusion stimulator
- Cochlear, otologic, or other ear implant
- Insulin or other infusion pump
- Implanted drug infusion device
- Any type of prosthesis (eye, penile, etc.)
- Heart valve prosthesis
- Eyelid spring or wire
- Artificial or prosthetic limb
- Metallic stent, filter, or coil
- Shunt (spinal or intraventricular)
- Vascular access port and/or catheter
- Small bowel endoscopy capsule
- Swan-Ganz or thermodilution catheter
- Medication patch
- Any metallic fragment or foreign body

MRI Screening

What about stuff you might, but shouldn't bring into the scan room:

- Pens, paper clips, clipboards, scissors
- Stuff in pockets, keys
- Clothing belts, buttons, etc.
- Phones, computers
- Wallets (not a safety issue, but magnetic strips get wiped)

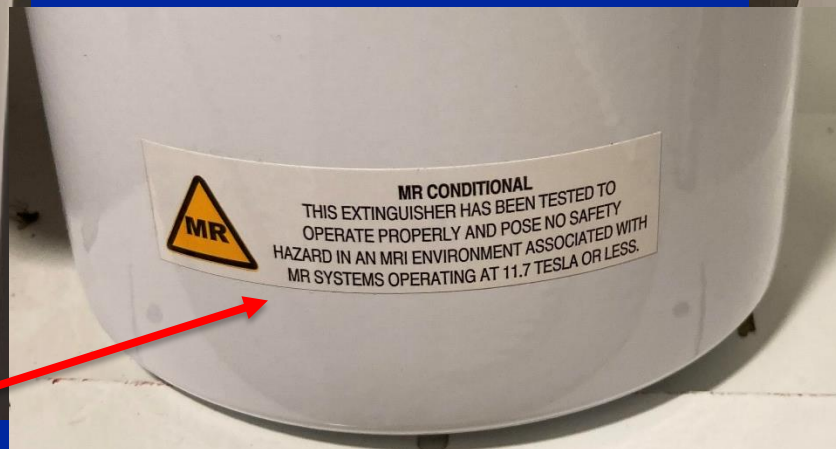
- NOTHING goes into the MRI room without first being cleared by the technologists
- We often use a handheld metal detector to make sure there is no metal on the subjects



Main Field Safety



Quench vent



MRI Oops!



RF Coils

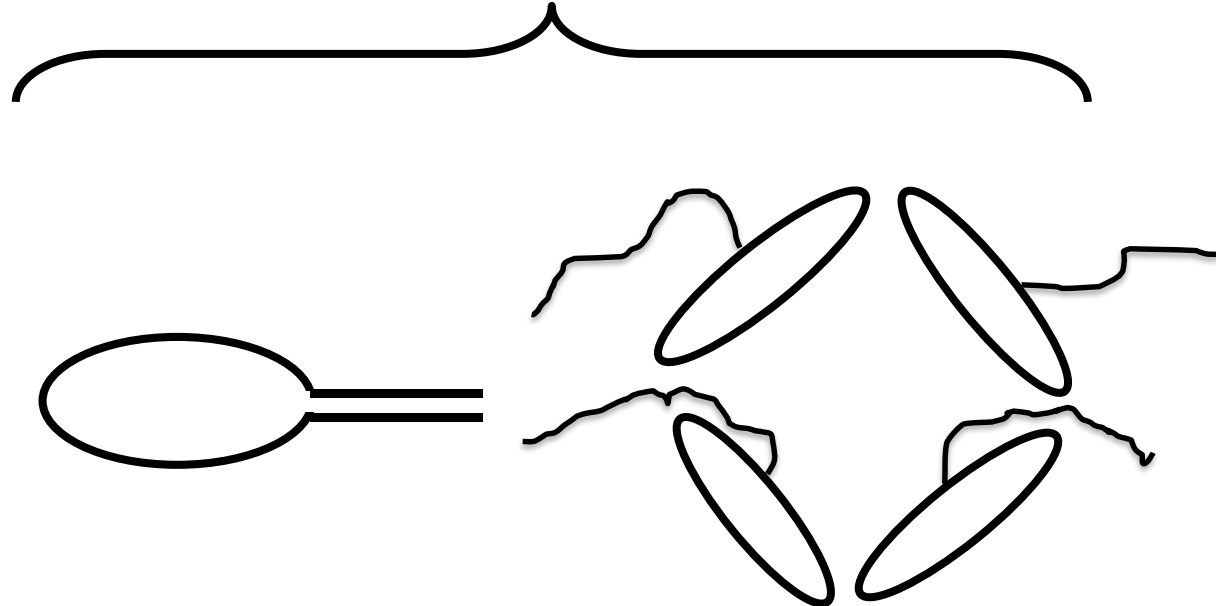
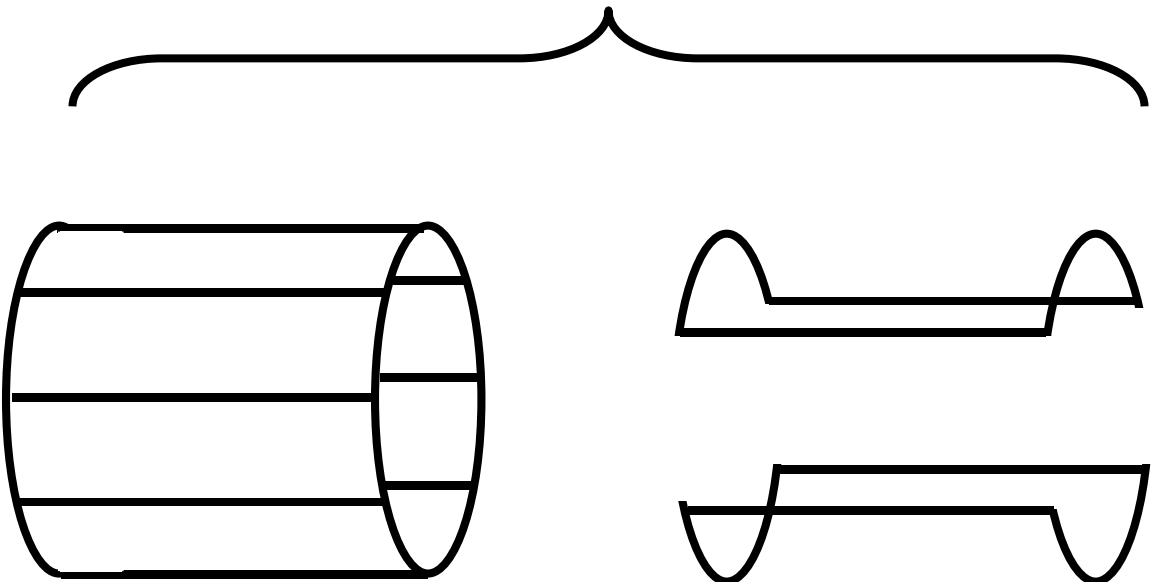
Two purposes:

- Excitation/transmission – tipping magnetization into transverse plane. Requirements:
 - Uniformity of tip angle, covers volume of interest
- Reception – converting precessing spins into voltages. Requirements:
 - Good SNR, sensitive to volume of interest, uniformity not so important

RF Coils

Volume Coils -- Transmit and Receive

Surface and Array Coils -- Receive Only



Birdcage
Coil

Saddle Coils

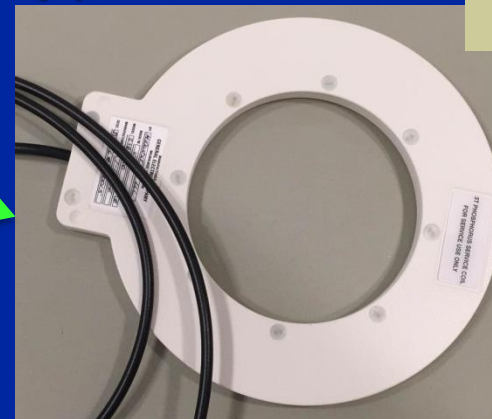
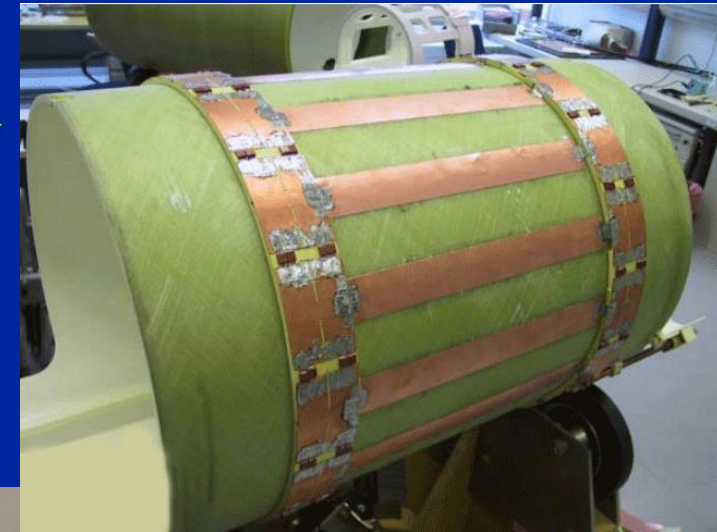
Surface Coil

Array Coil

RF Coils

Typical coils:

- Head Coil (volume birdcage coil)
- Body Coil (volume)
 - Built into system (always there)
 - Can be used for receive (but rarely)
 - Used transmit only for most receive arrays
- Surface Coils (typically receive only)
 - Improved SNR vs. volume coils



RF Coils

- Receive arrays (array of surface coils, receive only)
 - The idea here is that one can receive the SNR benefits of surface coils, but over a larger volume.
 - Also allows use of parallel MRI technology because each coil captures a slightly different part of the image volume



Head Arrays



Flex Arrays

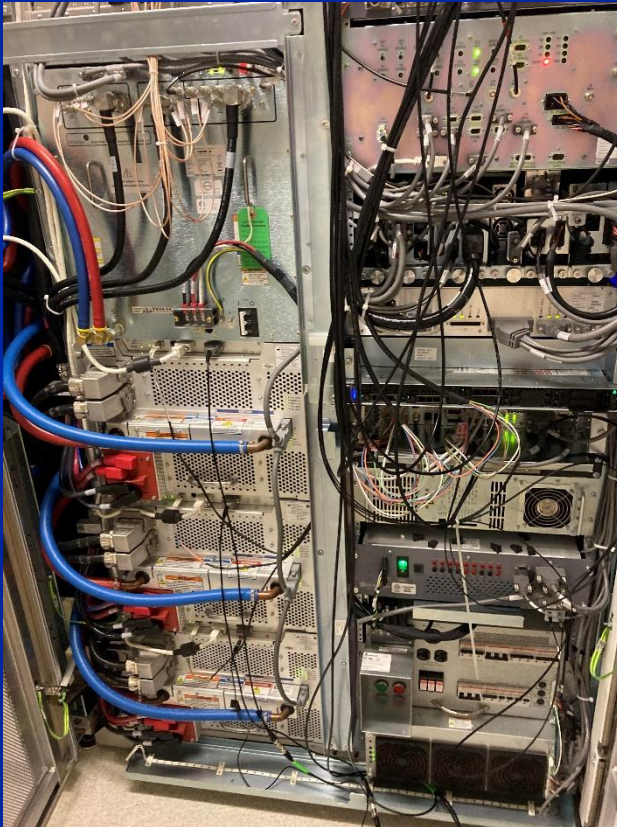


RF Safety

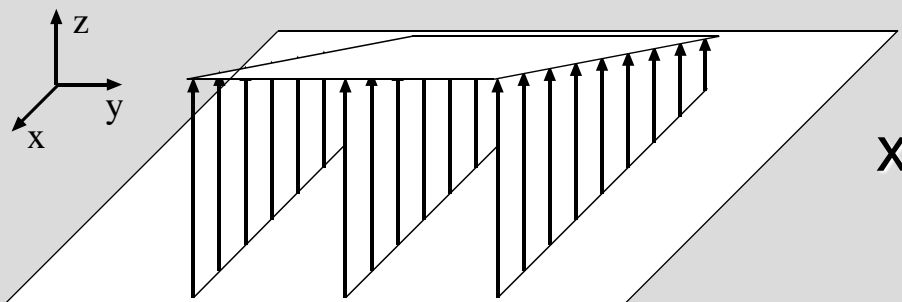
- Diffuse RF heating of the body
 - FDA limits our power deposition (W/kg)
 - Hardware measures this and will shut it down if it gets too high
 - This is why we need to enter patient weight into the scanner
- Focal RF heating around metals and devices
 - Glasses, jewelry & piercings, some tattoos → can lead to burns
 - Implants: cochlear implants, neurostimulators, pacemakers.
 - Usually not a problem (for RF): dental work, stents, screws, pins, aneurysm clips, etc. though could be an issue for B_0

Gradient Fields

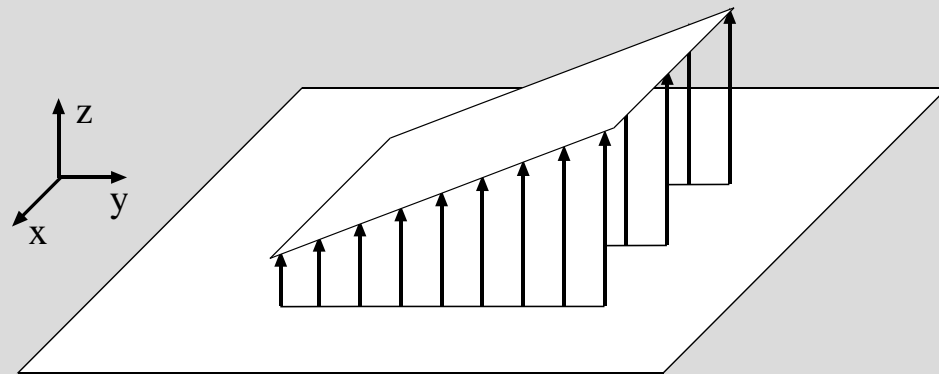
- High power amplifiers generate magnetic fields in the same direction as B_0 , but with variations along x, y and z.
- Provide localization of spins in MRI



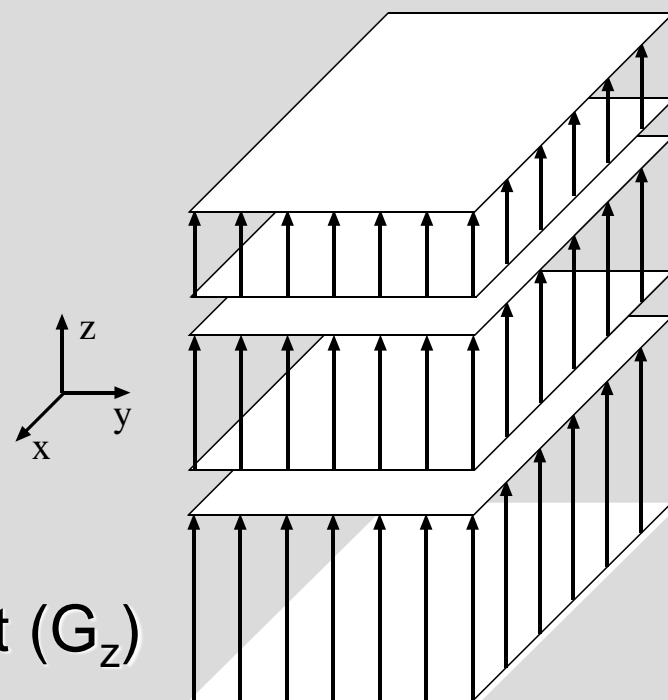
<http://mriquestions.com>



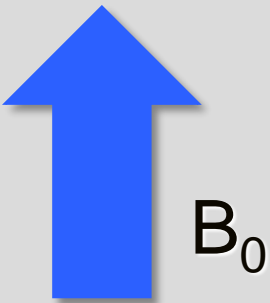
x-gradient (G_x)



y-gradient (G_y)

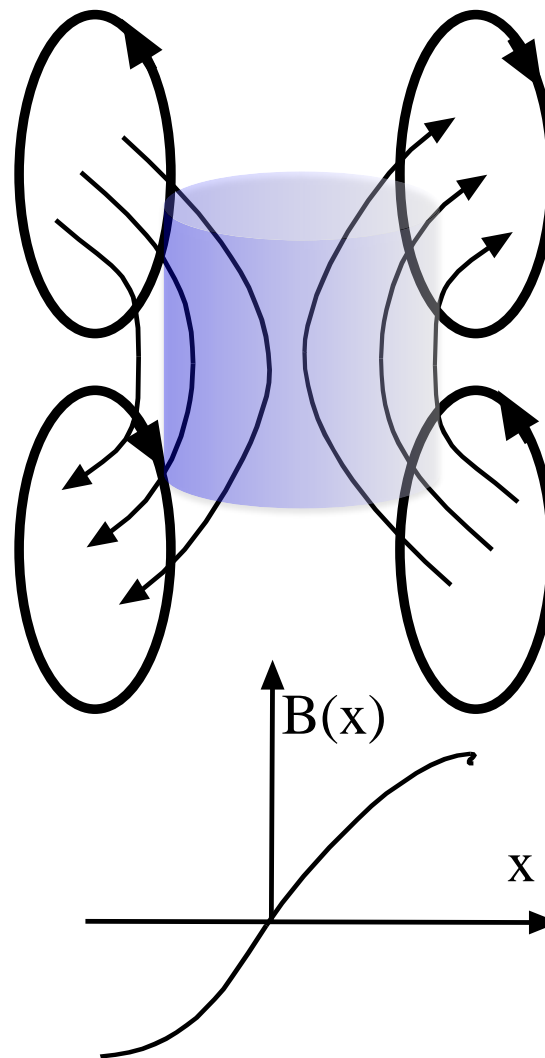
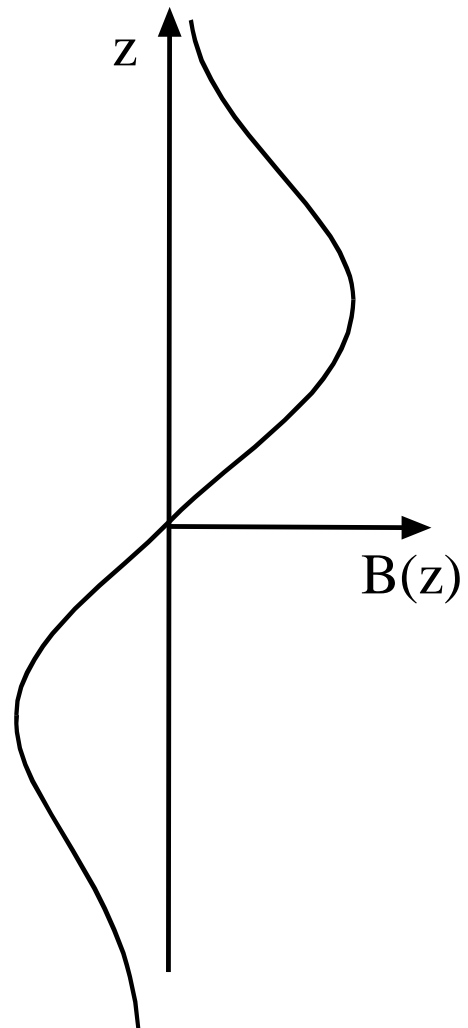
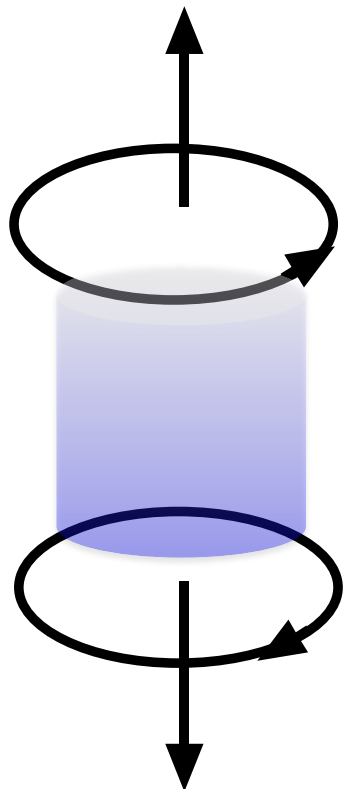
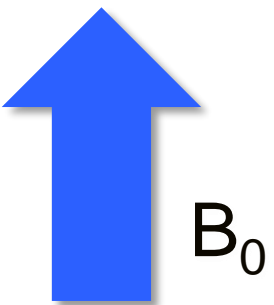


z-gradient (G_z)



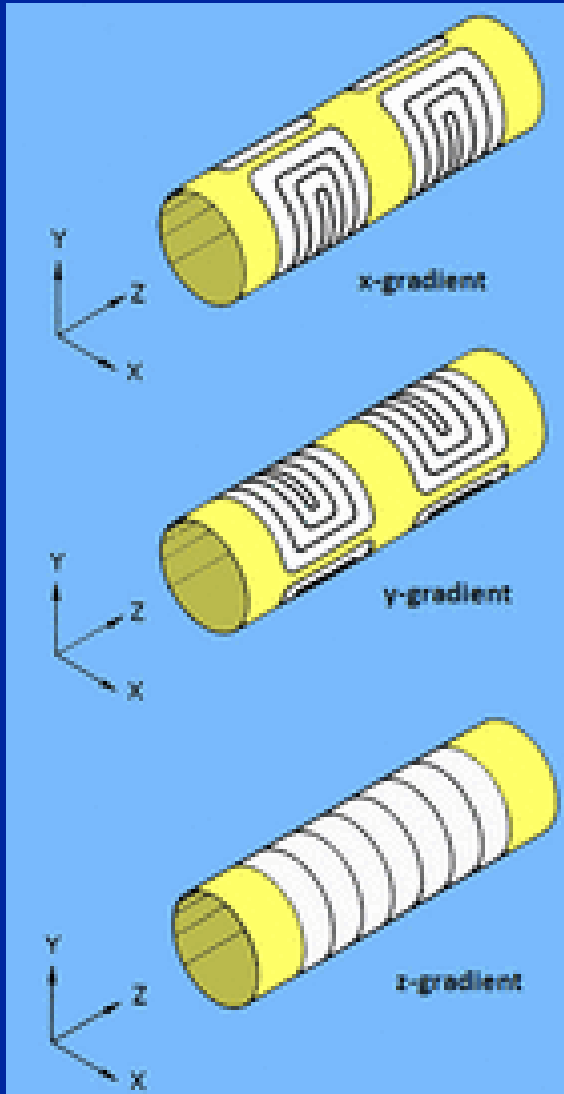
B_0

Gradient Coil Designs



X,Y Gradients

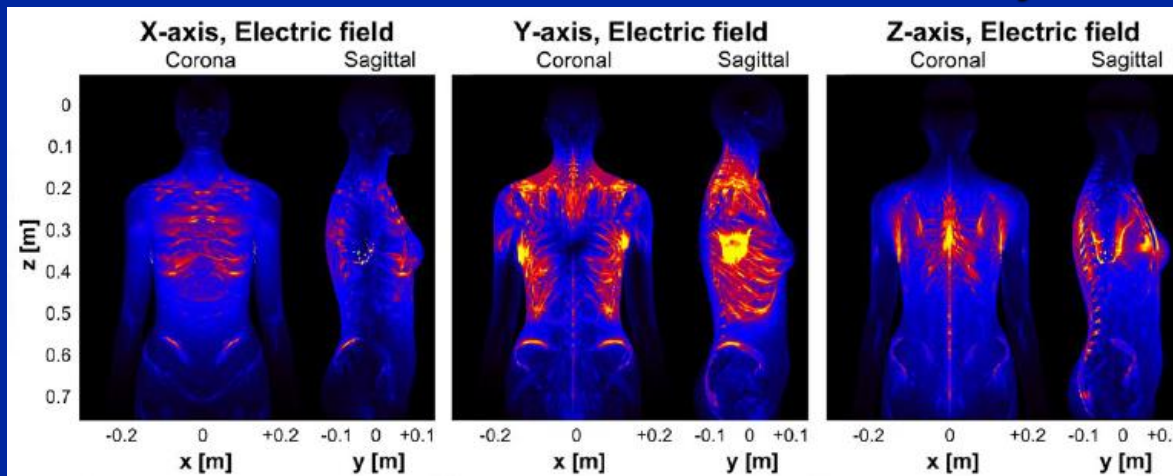
Gradient Coils



<http://mriquestions.com>

Safety of Gradient Fields

- Main source of power consumption in MRI systems
- Rapid changes of fields can lead to peripheral nerve stimulation (PNS) which can feel like twitching in the back or shoulders
 - FDA guidelines state that stimulation cannot be “painful”
 - Lots of individual variability in sensitivity to PNS



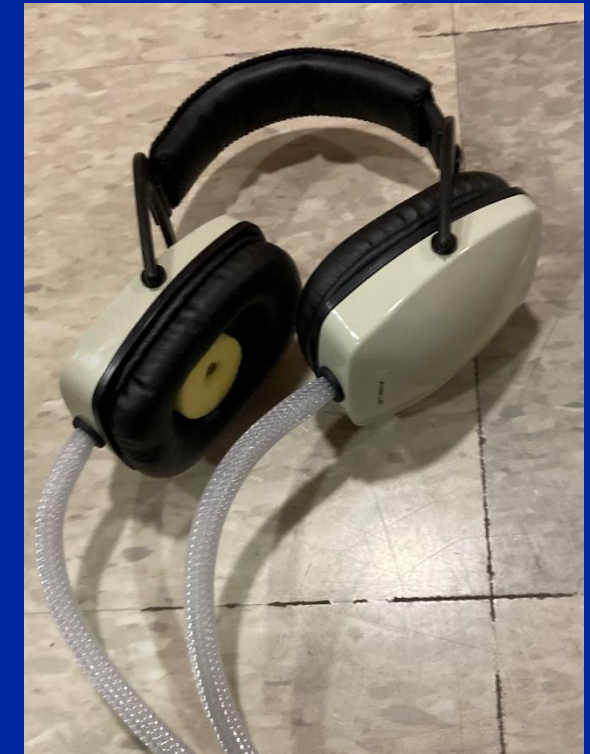
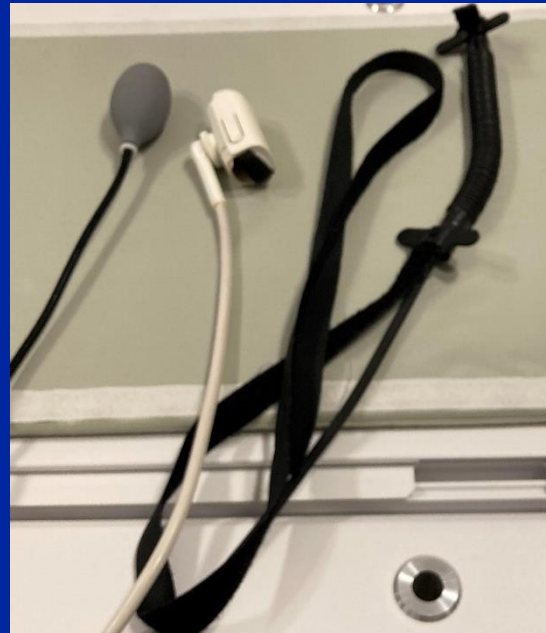
Dauids et al,
MRM, 2018

- The gradients are also responsible for the acoustic noise.
 - FDA says it can't exceed 99 dBA with hearing protection in place.



MR Compatible Devices

- Whole industry on MRI compatible devices
- Physiological signals, response collection, stimulus presentation, auditory stimulation, vision corr.



Other Risks/Safety Matters

- Attraction of ferrous objects
- Focal RF heating
- Loud
- Peripheral nerve stimulation (PNS)
- Dizziness

But also...

- Claustrophobia, anxiety
- Incidental findings (unexpected findings of tumors, etc.)
- Pregnancy is a contraindication for most research studies

MRI Safety Labeling

<https://www.fda.gov/media/101221/download>



MR Unsafe items should not enter the MRI scanner room. Patients with MR Unsafe devices should not be scanned.

MR Conditional items may safely enter the MRI scanner room only under the very specific conditions provided in the labeling. Patients should not be scanned unless the device can be positively identified as MR Conditional AND the conditions for safe use are met.

The conditions for safe use will be different based on the intended use of the device.

For **items intended to enter the bore of the MRI system**, the MRI Safety labeling should be matched with the MRI system for:

- Static field strength
- Maximum spatial field gradient
- dB/dt limitations (usually only applicable to active implants)
- SAR limits
- Any other conditions needed for safe use of the device, for example restrictions on the types of coils that may be used

When present, information about expected temperature rise and artifact extent may inform the risk/benefit decision of whether or not a patient should undergo an MRI examination. Expected temperature rise and artifact extent information are not conditions that must be met.

Items NOT intended to enter the bore of the MRI system usually have gauss line positioning restrictions or requirements to tether or affix the device to an unmovable part of the room.

MR Safe items pose no safety hazards in the MR environment. They may be placed anywhere in the MR environment. Patients with MR Safe devices have no scanning restrictions.

FDA Non-Significance Risk Guidance

See <https://www.fda.gov/media/75459/download>

- Main field (B_0) ≤ 8 Tesla for subjects > 1 month age
- Power deposition (SAR) ≤ 3.2 W/kg for heads, averaged over 10 min
- Peripheral nerve stimulation (dB/dt) not cause severe discomfort or pain
- Sound:
 - Peak unweighted sound pressure level ≤ 140 dB.
 - A-weighted RMS SPL ≤ 99 dBA with hearing protection

