SAFETY NOTE #21

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TECHNICAL SUPPLEMENT TO MAGNETIC FIELDS

This technical supplement describes the basis for the safety manual chapter on magnetic fields. In general, static magnetic fields interact only weakly with biological material and harmful effects must be mediated by ferrous objects.

1. Cardiac Pacemaker Interference

Cardiac pacemakers use magnetically activated reed switches to alter their operating mode. Normally pacemakers sense and amplify the heart's natural pacing signal. In the alternate safety backup mode pulses are sent out at a fixed rate. The magnetic switch is provided to allow testing of the backup mode by holding a permanent magnet to the person's chest. In seriously ill individuals, the fixed frequency signal could destructively compete with the heart's natural pacing signal. Some pacemakers can be switched by magnetic fields as low as 1.4×10^{-3} tesla (=14 gauss).[1]

At the time of this writing, there are no employees with cardiac pacemakers and it is unlikely that an individual with such a device would venture near one of the Lab's analyzing magnets. However, since the consequences are grave, it was decided to prohibit pacemaker wearers from exposure to magnetic fields $\geq 10^{-3}$ tesla (=10 gauss).

2. Magnetic Force on Ferrous Objects

Ferrous objects such as tools, carts, gas cylinders and metal components in safety shoes and medical implants/devices experience a force when immersed in a magnetic field gradient. When this force is on the order of one-tenth that due to gravity, mechanical problems arise which significantly increase the risk of accidents or medical emergencies (such as the removal of aneurysm clips).

$$F_{mag} = 0.1\ F_{grav}$$

The magnetic force can be calculated from the gradient of the change in the magnetic field energy density resulting from the presence of the ferrous object in the magnetic field.

$$F_{mag} = \nabla\ [(u-u_o)V]$$

where F_{mag} = the magnetic force on the ferrous object (N)

U = energy density with ferrous object (J/m^3)

U_o = energy density without ferrous object (J/m^3)

V = volume of ferrous object (m^3)

The magnetic field energy density is given by:

$$U = \frac{1}{2}\overline{B} \cdot \overline{H}.$$

The magnetic field in the absence of the ferrous object is

$$\overline{B}_o = \mu_o \overline{H}.$$

If it is assumed that the ferrous object is spherical (other geometries are incredibly complicated), the internal magnetic field is[2]

$$\overline{B} \approx 3\mu_o \overline{H}.$$

Therefore, the magnetic force is approximately

$$F_{mag} = \nabla\left\{\left[\frac{1}{2}(3\mu_o\overline{H} \cdot \overline{H}) - \frac{1}{2}(\mu_o\overline{H} \cdot \overline{H})\right]V\right\}$$

$$= \nabla(\mu_o H^2 V)$$

$$= \nabla\left(\frac{V}{\mu_o} B_o^{2}\right)$$

$$F_{mag} = \frac{2V}{\mu_o} B_o \frac{dB_o}{dr}$$

Calculate the field conditions which result in a magnetic force which is one-tenth that due to gravity. (The object is assumed to be an iron sphere.)

$$F_{mag} = 0.1\ F_{grav}$$

$$\frac{2V}{\mu_o} B_o \frac{dB_o}{dr} = 0.1 pVg$$

$$B_o \frac{dB_o}{dr} = \frac{0.1 \mu_o p g}{2}$$

$$= \frac{(0.1)(4\pi X 10^{-7}\ \mu / m)(7200 kg / m^3)(9.8 m / s^2)}{2}$$

$$B_o \frac{dB_o}{dr} = 4.4 X 10^{-3}\ T^2 / m (= 4.4 X 10^5 G^2 / m)$$

3. Magnetohydrodynamic Effects

When an electrically conductive fluid flows in a magnetic field, an electric current is produced, as is a force opposing the flow. This occurs when blood flows through the vessels of a person exposed to a static magnetic field and the effects are greatest when flow is perpendicular to the field. The potential across such a vessel is

$$E = 0.1\ B_o v\ d,$$

where E = potential across the vessel (mV),
B = magnetic field intensity (T),
v = blood flow velocity (cm/s) and
d = blood vessel diameter (cm).

This potential is negligible in all but the largest arteries, i.e., the aorta and femoral artery, where values on the order of 5 mV/T can occur. On an electrocardiogram, this appears as an enhancement of the T-ware, though the sources of the potentials are unrelated. No harmful effect has been associated with this mechanism.

The force opposing flow appears as an increase in blood pressure:[4]

$$\Delta BP = 3 \times 10^{-3} B_o^2$$

where ΔBP = increase in blood pressure (mmHg)
and B_o = magnetic field intensity (T)

This relation predicts a negligible increase, requiring 18T to obtain 1 mmHg. There appears to be no reason to limit magnetic field exposures based on the consequences of magnetohydrodynamic effects.

4. Other Effects

There are other effects of exposure to static magnetic fields which are either poorly substantiated or are theoretically predicted to have negligible consequences. The former includes small changes in behavior, reproduction or growth which have not been confirmed in well-controlled studies. The latter includes changes in conduction velocity of nervous impulses (10% reduction at 24T), quenching of superconductivity in enzyme reaction kinetics (if it exists) and cell orientation. This last effect has been observed experimentally in turtle retinal rods at 1T and human sickled red blood cells at 0.35T.[3] The alignment of sickled blood cells may cause local circulatory reductions in small vessels at fields substantially greater than this value (several T). However, this level of exposure would generally be controlled by following the restriction for ferrous objects presented earlier. Therefore, persons with sickle cell anemia should be kept out of such areas.

References

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2. Plonus, M.A.: Applied Electromagnetics. McGraw Hill: New York. pp. 388-389 (1978).

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4. Easterly, C.E.: Cardiovascular Risk From Exposure to Static Magnetic Fields. Am. Ind. Hyg. Assoc. J. 43:533-539 (1982).