Glaser

DRAFT

DOCUMENTATION on

STATIC MAGNETIC FIELDS

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TLV

These threshold limit values (TLVs) refer to static magnetic field flux densities to which it is believed that numerous workers may be repeatedly exposed day after day without adverse effects. These values should be used as guides in the control of exposure to static magnetic fields, and should not be regarded as a fine line between safe and dangerous levels.

Routine occupational exposures should not exceed 60 mT (600 G) whole body or 600 mT (6000 G) to the extremities on a daily, time-weighted average basis. A flux density of 2 T is recommended as a ceiling value. Safety hazards may exist from the mechanical forces exerted by the magnetic field upon ferromagnetic tools and medical implants. Workers having implanted cardiac pacemakers should not be exposed to field levels exceeding 1 mT (10 G). Adverse effects may also be produced at higher flux densities resulting from forces upon other implanted ferromagnetic devices, e.g. suture staples, aneurism clips, prostheses, etc.

DOCUMENTATION

Strictly speaking, there are no static fields. In other words, virtually all fields can be seen as exhibiting an onset and decline or possibly oscillation as a function of time. Usually the rate of oscillation of a field is used to characterize the frequency of the signal being considered. The onset and decline are generally used to describe the pulse character of the signal.

For the purposes of this document, a static magnetic field is taken to be any field having a frequency of oscillation of less than 1 millihertz (mHz) or an onset and decline separated by more than 1 kilosecond (ks). Such fields are characterized by a fixed polarity which is maintained for times in excess of several hundred seconds. An example of such a field is the constant component of the earth's magnetic field. Thus, fields which alternate at frequencies below 1 mHz, or have onset and decline separated by 1 ks or more, will be arbitrarily called static. This time interval is already used frequently as an exposure-limiting interval in guidelines dealing with other parts of the spectrum. It is also a long interval compared to the periodicities related to the lowest EEG frequencies commonly studied, and a short interval compared to physiological and biochemical biorhythms. Thus, it provides a convenient demarcation point with which to distinguish between static and extremely low-frequency fields.

From a practical point of view, if the frequency of an electromagnetic field is very high (300 GHz and above), questions of exposure to pure electric or pure magnetic fields do not arise because pure fields can only exist in the so-called near field of a source (typically within a few wavelengths of the source). As the frequency decreases, the wavelength becomes longer. Consequently, the near field region extends farther from the source so that pure fields become relevant to discussions of bioeffects for low-frequency signals, especially in the static region as defined above. Various points in the near field region will be dominated by either the electric or magnetic field to varying degrees depending on the characteristics of the source and the medium in which it is embedded. Outside the near field region, an electric or magnetic field is always accompanied by a complementary magnetic or electric field, respectively. The relation between the two components is well defined by Maxwell's equations, and is determined by the local geometry and the electric and magnetic properties of the region in which the fields are being observed.

The SI units recommended for use with magnetic quantities of interest are:

1. The weber, Wb, for magnetic flux.
2. The tesla, T, for magnetic flux per unit area.
3. The ampere per meter, A/m, for magnetic field strength.
4. The henry, H, for inductance.

In terms of more fundamental units they may be expressed as follows:

$$1\ \mathrm{Wb} = 1\ \mathrm{V \cdot s},$$
$$1\ \mathrm{T} = 1\ \mathrm{Wb/m^2},$$
$$1\ \mathrm{H} = 1\ \mathrm{Wb/A}.$$

The cgs units for magnetic quantities commonly used in the past and still widely used today are:

1. The maxwell, Mx, for magnetic flux.
2. The gauss, G, for magnetic flux per unit area.
3. The oersted, Oe, for magnetic field strength.

These may be converted to SI units by using the conversion formulae given below:

$$1\ \mathrm{Mx} = 10^{-8}\ \mathrm{Wb},$$
$$1\ \mathrm{G} = 10^{-4}\ \mathrm{T},$$
$$1\ \mathrm{Oe} = (1000/4\pi)\ \mathrm{A/m} = 79.57747\ \mathrm{A/m}.$$

Static magnetic fields may occur or be applied in theft detection and airport security systems, high voltage direct current (HVDC) power transmission, a wide variety of industrial and commercial processes, scientific research laboratories and, in the future, within the proximity of fusion reactor facilities and magnetic levitation transport systems.

It has been pointed out[1] that in many practical circumstances the effect of a static magnetic field is equivalent to that of a time-varying magnetic field because of repetitive motions of the exposed subject. Situations also occur where the subject may experience a transient exposure to a nonalternating field. It is for such situations that the consideration of possible magnetostatic effects continues to be relevant.

No specific target organ(s) for deleterious magnetic field effects can be identified at the present time.[1-13] Researchers have studied static magnetic field effects on blood composition and the cardiovascular system, and also on both the central and peripheral nervous systems. Attempts have also been made to identify possible genetic effects. Although some effects have been observed in both humans and animals, there have not been any clearly deleterious effects conclusively demonstrated at magnetic field levels up to 2 Tesla.

One biological effect that has been documented in extensive studies with rodents and primates is the induction of electrical potentials in the major arteries of the circulatory system during magnetic field exposure.[14-18] Experiments with monkeys have demonstrated that magnetically-induced potentials of 1 mV or less do not produce significant cardiovascular stress effects.[15] The minimum static magnetic field flux density that would produce a 1 mV potential in the aorta of an adult human is 60 mT, and this value has therefore been chosen as the whole-body occupational limit for continuous exposures. This rationale was previously used as the basis for setting the maximum average whole-body exposure limit at 60 mT for workers at the Lawrence Livermore National Laboratory.[17]

Another effect of static magnetic fields that is of particular concern is their influence on implanted cardiac pacemakers.[18,19] The reed relay switch in a modern pacemaker that operates in a demand mode can be closed in static magnetic fields with flux densities as low as 1.7 mT, thereby causing the pacemaker to revert to an asynchronous pacing mode. Because of the possible adverse cardiac effects of this pacing mode, it is recommended that pacemaker wearers should be excluded from magnetic fields with flux densities that exceed 1.0 mT. The same restriction should apply to persons with implanted medical devices, e.g., aneurysm clips and prostheses, that may experience significant magnetic forces and torques as a result of containing ferromagnetic materials.[20]

An important consideration in the process of establishing guidelines for occupational exposures is the lack of a complete understanding of possible mechanisms of magnetic field interactions with living systems. As indicated above, considerable research has been published on this subject. However, several recent studies have demonstrated the existence of magnetic field interactions that were not previously suspected. Two examples are cited in the following paragraphs.

Recent studies on mechanisms of magnetic field interactions have demonstrated that lipid bilayer membranes are sensitive to magnetic fields at temperatures approaching a phase transition, where the membrane is inherently unstable.[21,22] At temperatures slightly above the normal physiological range, magnetic fields ranging from 10 mT to 7.55 T were observed to increase membrane permeability to solutes. The possible implications of these observations for magnetic field effects on the membranes of animal cells has not been examined to date. Further research is needed on this subject before the findings can be related to potential health effects of magnetic field exposure.

Strong static magnetic fields have also been alleged to change thermoregulatory abilities of animals.[23] The effects on mice and rats exposed to high intensity static magnetic fields were investigated at the Lawrence Berkeley Laboratory.[24] The summary of results obtained in these experiments stated that: "....the earlier reports of thermoregulatory alterations in response to magnetic field exposures could not be reproduced in the present series of experiments involving 16 rodents...."

Experience in one operational magnet laboratory where high-intensity magnetic fields occur more or less routinely[4] appears to indicate that whole body exposures on the order of 20 mT (200 G) do not produce any acute health effects even for exposure durations on the order of hours. Exposure to field strengths about a factor of 10 greater than this level appear to be tolerable for the hands. If exposures are limited to durations on the order of minutes, fields which are a factor of ten greater in magnitude appear to be tolerable. It is not yet clear whether repeated or chronic exposures at these higher levels are tolerable. Further studies in this area would prove useful. It must be emphasized that the values quoted above reflect the highest fields in which work is done more or less routinely. It appears that these values simply represent operational limits rather than maximum permissible levels as presented by some authors.[3,9]

Magnetic field measurements have also been made[25] in industrial facilities using electrolytic cells to produce magnesium and sodium. Mean magnetic field strengths were reported to be 44 to 63 Oe (4.4 to 6.3 mT). No measurements were reported in relation to specific job locations. Slight increases in blood pressure and a decrease in white cell count were observed, but the changes were considered to be within normal ranges. A similar finding of no adverse health effects was reported for employees during the period 1951-1983 in a chloralkali plant in Sweden, where a direct current of 100 kA is used in the production of chlorine by electrolysis.[26] The exposed group consisted of 157 men who worked in static magnetic fields with flux densities ranging from 4 to 29 mT. As compared with the Swedish male population, these workers had no excess cancer incidence, and the mortality rate from all causes was similar to that of the general population.

Another epidemiological study has characterized the prevalence of disease among 792 workers at U.S. National Laboratories who were exposed occupationally to static magnetic fields.[27] The control group consisted of 792 unexposed workers matched for age, race and socioeconomic status. The range of magnetic field exposures was from 0.5 mT for long durations to 2 T for periods of several hours. No significant increase or decrease in the prevalence of 19 categories of disease was observed in the exposed group relative to the controls. Of the 792 exposed subjects, 198 had experienced exposures of 0.3 T or higher for periods of 1 hr or longer. No difference in the prevalence of disease was found between this subgroup and the remainder of the exposed population or the matched controls. No trends were observed in the health data suggestive of a dose-response relationship.

In another series of investigations on personnel exposed to static magnetic fields, aluminum workers were stated to have an increased risk of developing leukemia.[28] No measurements of magnetic fields at work stations were made, but it was stated that exposures were related to the "high ampere" direct current (75 kA) used in the pots in the aluminum reduction process. The smallness of the sample size in this study made any connection between leukemia and magnetic field exposure questionable. However, a subsequent study involving 21,829 workers in 14 aluminum reduction plants also led to the finding of an excess of leukemias.[29] In addition, an excess incidence of pancreatic, genitourinary, and benign tumors was found among the aluminum workers in this second study. In contrast to these initial two studies, a recent survey of the health records of 6455 French aluminum plant workers showed their cancer mortality not to differ significantly from that observed for the general male population of France.[30] The mortality statistics on these workers were analyzed for the period 1950 through 1976. The only finding of significance was an elevated risk of lung cancer among workers who had been employed for 10 years or less. However, this elevated risk of lung cancer was not associated with any particular electrolysis process used in aluminum production.

There is very little information in the published literature on measured levels of static magnetic fields to which workmen have been exposed at their specific work stations. A review of several guidelines for exposure to static magnetic fields has been published by Repacholi.[31] No measurements of exposures of workers to magnetic fields at work stations were included. An international committee of experts was assembled by the WHO to develop health criteria for workers exposed to static magnetic fields.[13] Among their conclusions was the following:

> "4. For human exposure to static magnetic fields, it is not possible to make any definite statement about the safety or hazard associated with short or long term exposure to fields above 2 T. Available knowledge suggests the absence of any measurable effect of static fields on many major developmental, behavioral or physiological parameters in higher organisms....."

The National Radiological Protection Board in England developed a document entitled "Advice on the Protection of Workers or Members of the Public From Possible Hazards of Electric and Magnetic Fields with Frequencies Below 300 GHz."[32] In the document they state:

> "Whole body exposure to static external field strengths should not exceed 40 kV/m or 16 kA/m (20 mT equivalent magnetic flux density) for total periods not exceeding five hours per day. Arms, legs, ankles and feet may be exposed to static magnetic flux densities of up to 200 mT."

No data on worker exposures are discussed in the document.

The paucity of published data on the levels of workers' exposures to static magnetic fields may be the result of difficulties in making the appropriate measurements. The news of improved instrumentation developed at the Lawrence Berkeley Laboratory[33,34] is very welcome. The new instruments are personal dosimeters that continuously record both peak and average magnetic field exposures (1 to 10,000 G) for an 8-hr workday.

The exposure guidelines set in this TLV are based on a relatively extensive biological data base, and contain a sufficient margin of safety to ensure that no adverse health effects should occur in workmen chronically exposed to static magnetic fields. Further research is needed, however, to characterize all of the possible mechanisms of interaction of these fields with living systems. There is also a need to obtain additional data on occupational exposures to magnetic fields using advanced dosimetry techniques. Exposure information of this nature will be important in any future attempts to determine whether a relationship exists between occupational exposure to static magnetic fields and human health effects.

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