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Magnetic Field Sources and Their Threat to Magnetic Media

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Introduction

General

Magnetic storage media (tapes, disks, cards, etc.) may be damaged by external magnetic fields. The potential for such damage has been researched, but no objective standard exists for the protection of such media. This paper summarizes a magnetic storage facility standard, Publication 933, [1] that ensures magnetic protection of data storage media.

Background

Magnetic field sources can occur naturally (lightning) or unintentionally (ac line shorts, ground faults). In addition, the espionage threat exists that some unauthorized person or group could use high-energy magnets to destroy data from some distance away.

The existing standards on this subject [2][3] do not detail the magnitude of the magnetic fields which can be generated, nor the susceptibility threshold of the magnetic media. Instead, the fields are estimated and experimentally tested using magnets which are orders of magnitude less than those possible (and commercially available) today.

What are the threats to magnetic media? This paper summarizes research performed by the author to:

- Quantify the largest magnetic field that could be generated (now and in the near future);
- Characterize the magnetic susceptibility of a variety of magnetic media currently in use;
- Analyze the propagation of a magnetic field in conjunction with the susceptibility of the magnetic media;

and finally,

- Determine the spacing between hypothetical worst-case magnets and magnetic media to ensure that tape or disk erasure will never occur.

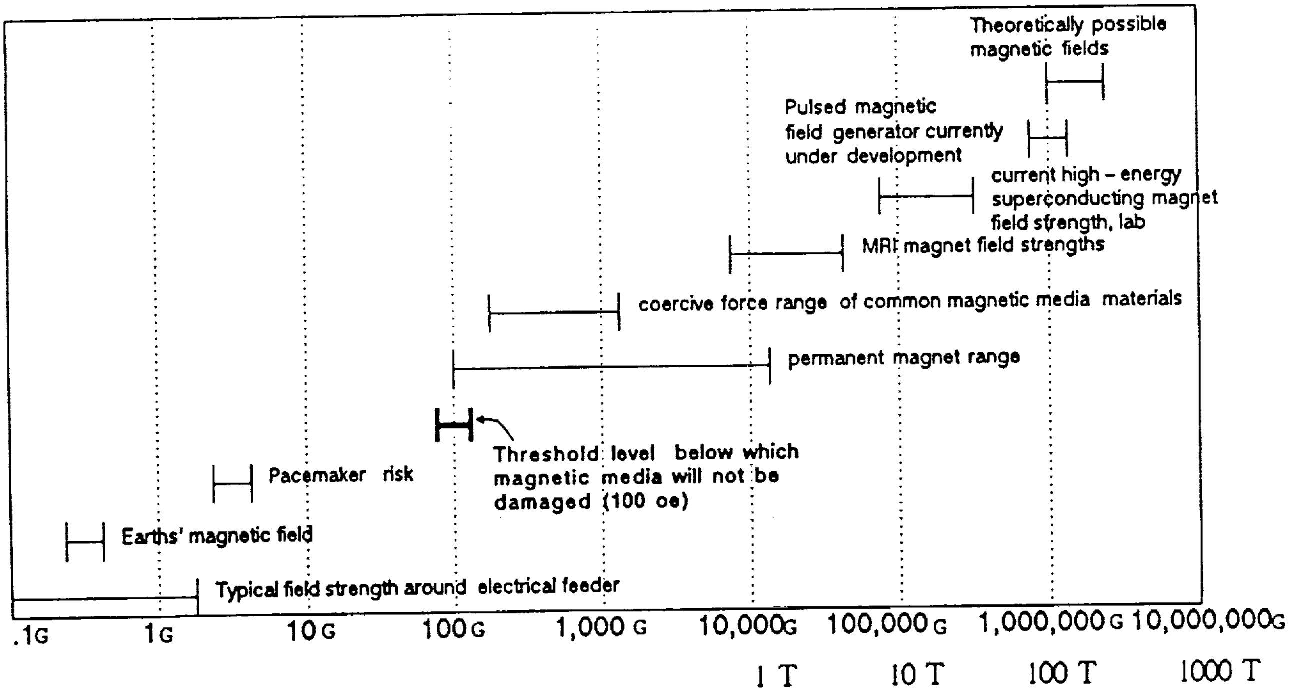
Publication 933 is a new standard that presents minimum spacing requirements between magnetic media and potential magnetic field sources. The procedure ensures both vendors and users of magnetic storage media that their data is safe from magnetic corruption.

Magnetic Basics

Before we begin the discussion, let's review some common magnetic terms and units. Magnetic fields are created whenever a current flows. The amplitude of the magnetic field is proportional to the amount of current flow. The units of the magnetic flux (or magnetic field), **B**, are tesla (1 tesla = 1 weber/meter^2), or, for smaller magnetic fields, gauss (G), where:

1 T = 10,000 G

For reference purposes, the stationary magnetic field of the earth is about .5 gauss. The field of a small permanent magnet can range from 100 G to 13,000 G, and today's superconducting electromagnets can produce steady-state field strengths as high as 500,000 G (or 50 T) [4][5]. Some common magnetic devices and their corresponding fields are shown in figure 1.



MAGNETIC FIELDS AND MAGNETIC SOURCES
(G = value in Gauss, T = value in Tesla)

Figure 1. Magnetic Fields and Field Strengths

The magnetic field vector, **B**, is also known as the magnetic induction, or the magnetic flux density. It should be distinguished from the magnetic field intensity, **H**, which is different, but is also referred to as the magnetic field. The magnetic field intensity is expressed in Oersteds, which are equivalent to gauss in free space. For purposes of simplicity, the value for B and H shall be assumed equivalent for purposes of this paper.

Magnetic Threat

This section discusses magnetic field sources that could destroy magnetic media. The magnetic fields could be generated by natural occurrences (lightning), accidental events (shorting of ac conductors), or other means. However, this chapter will focus on high-energy fields intentionally generated to destroy magnetic media at a distance.

As figure 1 shows, magnetic fields generators up to 50 T have been built, and fields as high as 380 T [6] are theoretically possible. Magnetic field generators of this size use superconductors to carry the enormous currents required.

High-energy, superconducting electromagnets require careful design to keep the coils at cryogenic superconducting temperatures. In addition, the internal magnetic stresses applied to the superconductors can tear the conductors apart, or cause the conductors to revert to a non-superconducting state.

Future advances in room temperature superconductors and the energy transfer capability of batteries and capacitors will significantly improve the ease with which high-energy magnets can be constructed. Indeed, the current state-of-the-art will improve as manufacturing processes are discovered for known high temperature superconductors. The net result will be an increased capability for generating high level magnetic fields that are portable. What then is the maximum field strength that could be developed by a hostile force with sufficient means and motives?

The data available today would limit the value to some field strength below about 50 T, even in a pulsed, destructive mode. However, it is naive to presume that energy storage technology will not also improve with time. In keeping with the intent of providing an absolute worst-case scenario, the highest possible instantaneous applied magnetic field strength is estimated to be 500 T.

The 500 T upper bound was selected because it is unlikely that superconducting magnet technology will yield a magnet exceeding this value in the near future. A more important reason is a fundamental premise of the 933 series of documents. The premise, stated more succinctly, is:

> **This standard (Publication 933-1) defines a process for determining the level of magnetic protection of a facility. The absolute level selected (500 T or 50 T), is not as important as the *process*. If a facility manager chooses to partition the facility space into zones that provide 500 tesla protection, or 5,000 tesla protection, he may do so, as long as the requirements of Publication 933-1 are met at the level specified.**

The purpose of determining the maximum magnetic field, then, is not to define the real threat today. The purpose of the process is to set a limit that magnetic storage media users and providers can agree upon is a worst-case magnetic field.

The upper bound provides a standard that represents the maximum protection required, as opposed to the maximum possible (which is currently much lower). The field applied is assumed to be a constant field (worst-case), to eliminate ambiguities about pulse characteristics or eddy current shielding.

The 500 T limit also may be zoned into lower levels of protection (such as 5 tesla and 50 tesla protection zones) in areas where the 500 T limit cannot be applied. It is then the customer's choice to purchase the magnetic storage protection that is required.

The 500 T limit depends on the magnetic susceptibility of the magnetic media. While 500 T (or 5,000,000 oersteds) is the maximum threat, the next section discusses the threshold for the minimum field that can cause magnetic damage.

Magnetic Media Characteristics

Data can be stored on many types of magnetic media. Disks, floppy disks, tapes, and tape cartridges are the most commonly used magnetic media storage devices. Each of these devices consists of a substrate of poly (ethylene terephthalate) (PET) that is coated with a thin film of magnetic coating (nominally 2 to 5 um thick) [7]. The coating is comprised of a polymeric binder, lubricants, curing agent, solvents, and magnetic particles. The particles selected for a medium are dependent upon a variety of factors including cost, required storage density, and magnetizing force.

The coercive force of the magnetic media is the amount of applied field required to reverse the magnetic field in the material. As figure 1 shows, commercial magnetic media have a coercive force between about 200 and 2000 oersteds (or gauss, in free space). The traditional research [2][3] held that the coercive force is the minimum threshold to induce magnetic destruction. Discussions with industry leaders on this subject [8][9], however, indicated that "levels significantly below this value may induce data errors" [10].

The results of a detailed research effort indicated that the minimum field likely to cause magnetic damage to a tape with a coercivity of 200 oersteds or greater is approximately 100 oersteds. The failures of disks and tapes that have been subjected to field strengths below this figure shall be considered non-destructive in most instances.

Magnetic Field Generators and Models

Magnetic fields can be generated by many means, but electromagnets are the most common source of high energy magnets. Whenever current flows, a magnetic field is generated. The threat to nearby magnetic media is dependent upon:

- The amount of current being carried in the conductor(s) of the electromagnet
- The size of the electromagnet
- The number of windings or parallel current paths for a multi-conductor electromagnet

The most common magnetic field generator configurations are created by long, thin wires, and circular loops (with multiple windings). When fields are generated in this fashion, simple equations can be used to characterize their magnetic field patterns. Publication 933 discusses the derivation of fields in this manner.

In order to provide a consistent basis for the specification, a standard model was needed to model a variety of real-life magnetic field generators. The models and some simple formulas are presented below.

Magnetic Fields from a Current Carrying Wire

The magnetic field produced by a thin wire of infinite length [11] is

$$\mathbf{B} = \frac{\mu_0 \, i}{2 \pi R} \quad \text{tesla} \qquad (1)$$

where:

R = perpendicular distance from the wire to the point in question (in meters)

$\mu_0 = 4\pi \times 10^{-7}$ H/m (the permeability of free space)

and,

i = the current in the conductor in amps

This equation is valid for most single conductors when the point in question is close to a long wire. This equation is used to model the threat from lightning protection systems, ac short circuits, nearby power sources, and other high current line conductors.

Magnetic Fields from a Wire Loop

The next case we review is that for magnetic fields generated from a wire loop. This type is the most commonly used to generate the high-energy fields of superconducting magnets. For ease of presentation, we will forego a discussion on the related subjects of heat dissipation and stress forces associated with high-energy superconducting magnets.

The field of a thin wire bent into a circular loop is easily modeled for the magnetic component on the axis of the loop (the worst case magnetic field). If we consider a magnetic loop with a radius a, the magnetic field at a point (on the axis of the loop) at a distance z from the loop is:

$$\mathbf{B} = \mathbf{B}_z = \frac{\mu_0 I a^2}{2\left(a^2+z^2\right)^{\frac{3}{2}}} \quad \text{tesla} \tag{2}$$

where both a and z are expressed in meters

If we examine this equation, we see that in the far field condition ($z >> a$), the equation reduces to:

$$\mathbf{B} = \frac{\mu_0 I a^2}{2 z^3} \tag{3}$$

Also derived from equation (2) is the field in the center of the loop, given by:

$$\mathbf{B} = \frac{\mu_0 I}{2 a} \tag{4}$$

Modeling Discussion

The magnetic field equations presented are a simple means of determining how fields propagate. In order to create a standard for media protection, however, we also needed to define some fixed parameters and definitions. For example, the following primary assumptions were made:

- The magnetic field from an external, uncontrolled source (an intentionally generated source), shall be assumed to be generated from an infinitely thin loop of infinitely thin wire, with a radius of .1 meters. While a practical magnet must deviate from this value, the assumption allows us to use the equations presented above, and the radius provided is a realistic value.

- The realistic threat must be addressed. If a hostile entity wished to destroy magnetic media, it would be far easier to directly access the space with a small magnet (or other means) than use an expensive, cumbersome superconducting electromagnet. The protection against a magnetic threat should match the physical security already in place at the facility.

  In highly secure storage facilities, the magnetic threat can be divided into two distinct types of threat, defined as follows:

  Type I Magnet - The Type I magnet is small enough to fit into a briefcase, and can be carried into common areas and unprotected areas of the storage facility itself. The Type I magnet has a maximum applied field of 5 Tesla

  Type II Magnet - The Type II magnet is capable of generating field strengths of up to 500 Tesla. Since this type of magnet would require much more preparation time and energy storage components, Type II magnets can only be placed in locations which are not continuously patrolled or inspected (i.e. adjacent office spaces, exterior walls/roof, tenants above and below the magnetic storage area (MSA).

- Damage to magnetic media can come from a variety of sources, including natural and man-made sources. The threat from a lightning strike is at least as likely (and as potentially damaging), as the threat from hostile forces. Electrical power sources, and structural steel members can also produce high level magnetic fields which could damage magnetic media.

- The key notion for magnetic protection is the magnetic protection zone level. This level is the minimum magnetic field which could damage magnetic media in the MSA. The area is partitioned into magnetic protection zones, each of which are rated based on their magnetic protection characteristics. For example, a tape storage rack next to an external wall may have a magnetic protection zone level of 1 tesla, while the center of a huge vault would have (no greater than) a 500 T level.

The computational model and associated variables for each of the magnetic field threats described in Publication 933 are presented in Table I.

Table 1. Summary of Magnetic Field Sources and Modeling Parameters

Magnetic Field Generator/Source	Computational Model Model (Equation #'s)	Minimum Spacing[1]	Comments
Type I Electromagnet	Infinitely thin wire loop, with .1 meter radius, equiv. field in center. Use (4) to calculate I, and (2) to determine field propagation range.	2m	Field equivalent to magnetic protection zone required. No fields > 5 T, or < 1 T.
Type II Electromagnet	Same as above	4m	Same as above, but no fields > 500 T, or < 1 T.
Lightning rod grounded conductor	Infinitely thin wire of length equivalent to conductor. Use 200,000 A current or less.	4m	Reduce current if parallel grounded conductors are present.
AC shorts and related conductors	Infinitely thin wire of length equivalent to conductor. Use short circuit current rating of distribution panel or 10,000 Amps, whichever is greater	1m [2]	Use this value for ac outlets, lights, phone lines, power feeders, thermostat and control lines. greater
Metallic beam or member	Infinitely thin wire loop with radius equiv. to 1/2 the longest diagonal of beam or member	1m [3]	Use for any beams that are not bonded, use B = 2 Tesla.
Water pipes	See ac shorts	1m	

1 Ignore conductors or magnetic sources that are further than this distance from the MSA.

2 Use .5 meters for conductors completely contained within controlled space.

3 For beams with diagonal < .3 meters. Use .1 meters for rebar with diagonal < 2 cm

Publication 933 provides additional guidance on selecting potential threats, modeling their field propagation, and specific guidance on using the equations.

Magnetic Shielding

Some Magnetic Storage Area (MSA) vendors may choose to shield certain portions of their space to improve their magnetic media protection. Other vendors may have existing steel rooms that can be characterized according to the calculations presented herein. A full treatise on magnetic shielding is far beyond the scope of this paper, but characteristics of magnetic field shields are presented in Publication 933.

Summary of Magnetic Shielding Properties

The following statements summarize the characteristics of magnetic shields, and lend insight into their design.

1) If a Magnetic Field shield is exposed to a high level magnetic field, and is insufficiently thick, the material will saturate (become permanently magnetized), and provide little or no magnetic shielding.

2) Constant or low frequency magnetic fields can only be shielded with steel or ferrous metal. The magnetic properties (B/H curve, saturation induction) of the material, as well as its thickness must be used to ensure that the steel will not saturate before it performs its desired shielding goal.

3) Magnetic fields fall off as 1/distance, 1/distance^2, or 1/distance^3. Therefore, the threat magnet must be accurately modeled to determine that field to which the shield will be exposed.

4) Shielding against high-energy magnetic fields is impractical at close range because of the requirement for thick magnetic material.

To illustrate the field strength reduction from magnetic shielding, we now review figure 2. Figure 2 shows several curves which illustrate the free space falloff distance for electromagnets of various field strengths. For example, a .01 Tesla (100 gauss) may destroy data at a separation distance of 0 meters, while a 10 Tesla field can destroy data at distances up to 1 meter (about 39 inches). These distances are based on a .1 meter radius electromagnet as described above.

When shielding steel is correctly installed to the walls of the magnetic storage area, the protection level of the space may increase. Figure 2 shows the minimum separation distances between various thicknesses of steel (cold-rolled, low-carbon strip steel [12]) and the magnetic shielding separations and field strengths [13]. For example, if a shield is required to increase an MSA up to 50 Tesla protection, and if the separation distance (distance between the exterior threat and the shield) is about .5 meters, a minimum of 2 inches of steel will be required for the shield.

As the example shows, shielding can be an expensive proposition, especially when the shield must be close to the external threat or the field to be shielded is excessive. The shield must also be constructed to provide good magnetic flux transfer, which usually involves welding and additional attachment mechanisms. Structural loading can also be a problem.

For this and other reasons, the best magnetic shielding mechanism is physical separation between the magnetic storage area (MSA) and the magnetic threat. While it may be difficult to obtain such separation in some existing facilities, careful design and site selection may reduce or eliminate the cost of protecting against magnetic threats. The next section discusses the magnetic protection certification, a means of verifying that magnetic media stored in a facility could not be adversely affected by magnetic sources of any type.

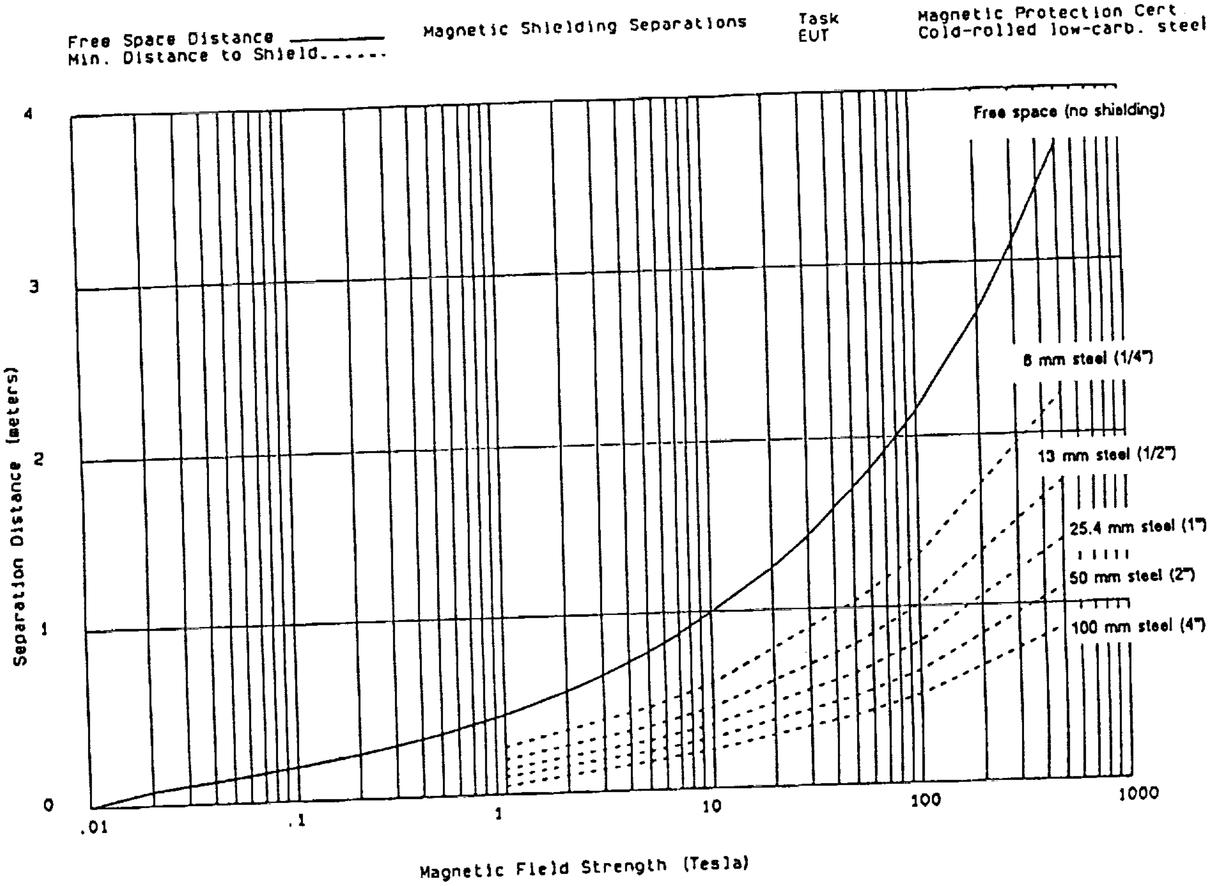


Figure 2. Magnetic Shielding Separation Distances

Magnetic Protection Certification

The purpose of Publication 933 is to provide an objective standard for the magnetic protection of magnetic media storage facilities. The previous sections of this paper discussed the nature of magnetic fields and how magnetic media could be destroyed. We now review a sample magnetic protection certification, which shows how a facility is certified.

Facility Layout and Magnetic Protection Zone Map

In this example facility certification, company X owns an MSA in a facility as shown in figure 3. The L-shaped MSA is shielded on two walls, and has good physical separation on the remaining walls. The roof of the facility is over 4 meters above the MSA. The company X controlled space is the area which the company owns and has alarmed on a 24 hour basis. The MSA has sufficient physical security to preclude unauthorized access, but desires a 50 Tesla magnetic protection level.

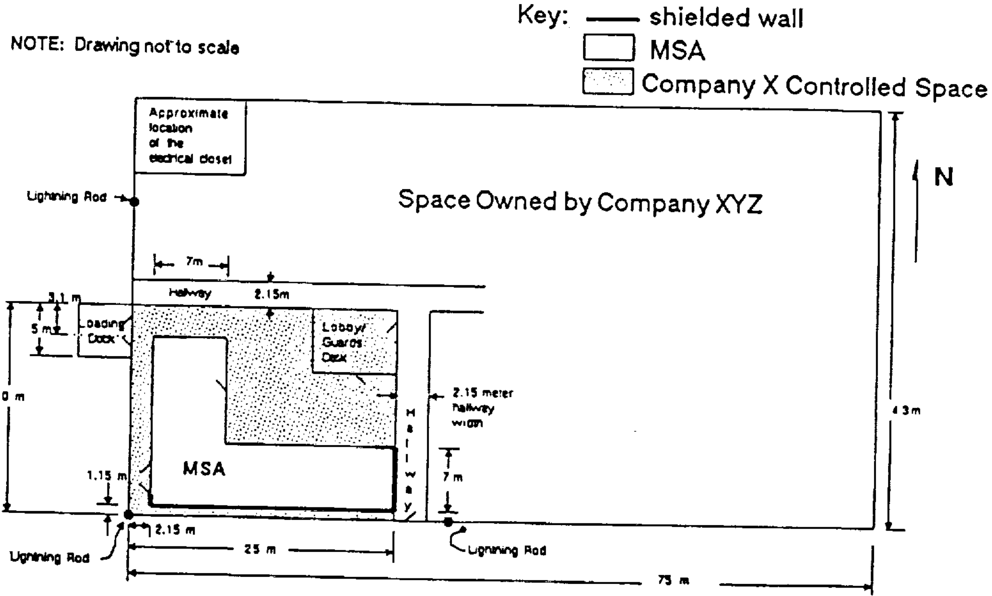


Figure 3. Facility Layout

After a site inspection and authorization to proceed, a magnetic protection zone map is created (in conjunction with a magnetic protection certification report). An example of a magnetic protection zone map is shown in figure 4. The magnetic separation zone map shows the areas within the MSA and their corresponding magnetic protection zones.

As figure 4 shows, some area on the east wall of the space is unsuitable for magnetic storage, even though it is shielded. On the south wall, the 6 mm (1/4") steel shield is performing its intended function of increasing the interior space within the MSA that is rated for 50 T protection. A vast majority of the northern part of the MSA is rated for 500 T protection.

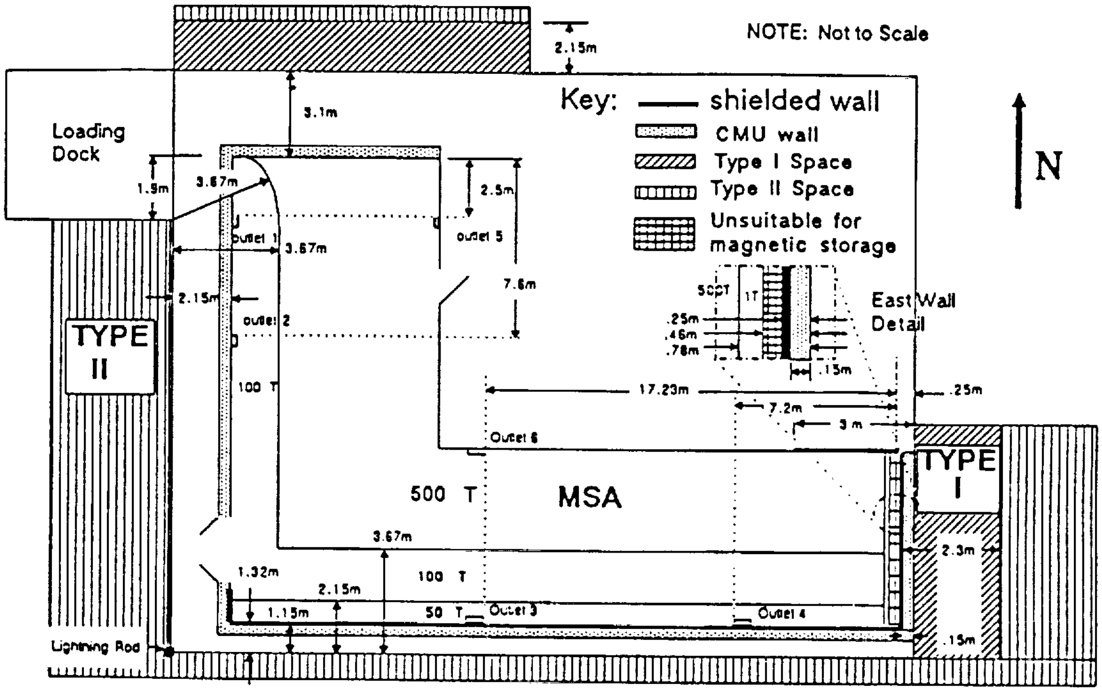


Figure 4. Magnetic Protection Zone Map

Details for the floor and ceiling, and outlets are presented in figure 5. Figure 5 shows the areas which are unsuitable for magnetic storage. The areas which are unsuitable for magnetic storage are based on the following guidelines:

> The floor - the floor of the MSA is poured concrete with rebar reinforcement. If an externally applied magnetic field coupled to the rebar, the ends of the rebar (which are assumed to be randomly oriented in the slab) could be subjected to field strengths of up to 2 Tesla. The separation distance shown (.05 meters, 2 inches) is valid for rebar with diameters up to 13 mm (1/2").
>
> The ceiling - the ceiling of the MSA is lighted with fluorescent lights which are interconnected with flexible conduit. If a light shorted instantaneously to structural steel, the current in the conductor could reach 10,000 amps (limited by the short circuit current of the lighting breaker). The separation distance shown is based on this current, and is present at any point on the ceiling since the cabling runs are flexible.
>
> The outlets - the outlets in the MSA are fed from two breakers, each of which used a separation distance derived in a manner similar to that in the ceiling. The flexible conduit to the outlet can be oriented between the 18" on center studs in any random fashion, therefore, the field radiation is as shown. The separation distance is common for outlets fed from breakers with a similar short circuit rating.

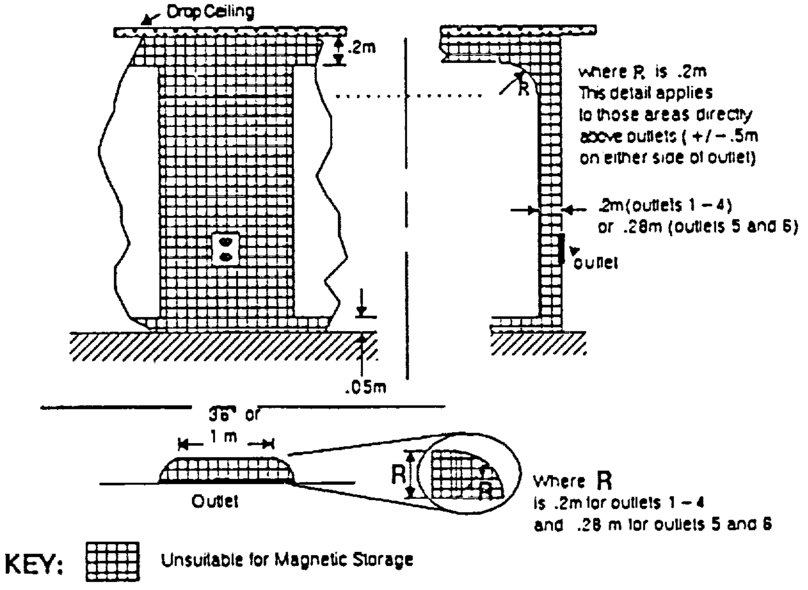


Figure 5. Magnetic Protection Certification Details

The magnetic protection certification report provides a means for MSA vendors and users to ensure magnetic protection. The design and solicitation documentation can now reference Publication 933 and a certain threat level (50 Tesla, for example), instead of subjective terms such as "magnetic protection" and "ferromagnetic shielding". The certification can be performed by a "qualified assessor", or be "self-certified" by a representative of the MSA.

While there may be questions about a specific facility, or the derivation of specific processes, Publication 933 presents a standard which is comprehensive, and can be tailored to a customers' specific application.

Summary

The intent of this paper is to introduce a method for determining the magnetic threat to magnetic storage media. An additional intent has been to introduce Publication 933, an objective standard for magnetic protection of magnetic storage media. In this paper we have learned the following:

> Magnets may destroy magnetic media via natural, unintentional or intentional means.
>
> The highest magnetic fields which can currently be generated have a field strength of about 50 Tesla, and fields as high as 380 Tesla may be theoretically possible.
>
> Magnetic media can be damaged at field strengths as low as 100 gauss (.01 tesla). The coercive force of the magnetic media determines how high the field must be to damage the media.
>
> Simple formulas can be used to estimate the propagation of magnetic fields from simple wire and loop magnets.
>
> Magnetic media can be damaged at distances up to 4 meters (about 13 feet).
>
> Magnetic shielding can be used to reduce the magnetic field and subsequent separation distance between magnetic sources and magnetic media.
>
> Publication 933 is a new standard that presents minimum spacing requirements between magnetic media and potential magnetic field sources. The procedure ensures both vendors and users of magnetic storage media that their data is safe from magnetic corruption.

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