SLAC-PUB-5670
LBL-31345
June 1992
(M)

THE EFFECT OF THE STATIC MAGNETIC FIELD ON THE RESPONSE OF RADIATION SURVEY INSTRUMENTS*

James C. Liu, Stan Mao, R. C. McCall,‡ and R. Donahue†
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309

ABSTRACT

The effects on the response of eight radiation survey instruments in static magnetic fields up to 0.03 T (300 G) have been investigated. The instruments studied are the Xetex 303B Pacer, the Bicron Micro Rem survey meter, the Victoreen 450p survey meter, the Victoreen 440 survey meter, the SLAC orange meter, the Keithley 36150 survey meter, the Andersson–Braun neutron remmeter, and the Victoreen 488 neutron survey meter. The results show that the effect may depend on several factors; for example: the instrument design, the alignment of the instrument axis with the magnetic flux lines, whether the instrument is stationary or moving relative to the magnetic field, the direction of the movement relative to the magnetic flux lines, and the magnetic field intensity. Results of work to enhance magnetic shielding of some of the instruments are also presented.

Submitted to *Journal of Health Physics.*

---

* Work supported by Department of Energy contracts DE-AC03-76SF00515 (SLAC) and DE-AC03-76SF00098 (LBL).
‡ Present address: McCall Associates, 170 Hobart Heights, Woodside, CA 94062.
† Present address: Lawrence Berkeley Laboratory, 1 Cyclotron Road, MS 90–2148, Berkeley, CA 94702.

INTRODUCTION

Man-made magnetic fields are everywhere. They exist in high energy technology and research facilities, industries, medical facilities, laboratories, offices, and residences. Stuchly (1986) has given a very good review on the possible human exposure to magnetic fields in many areas of human activity. Specific examples for places which may have high magnetic fields (> 1 mT = 10 G) are high energy accelerators, fusion reactors, magnetic resonance imaging and spectroscopy, etc.

When making radiation measurements in an accelerator facility, the pulsed nature of the radiation field and the possible existence of magnetic fields are the two main factors that may affect the response of the instruments. Compared with the pulse effect, the magnetic effect on the response of radiation survey instruments has not received detailed study.

American National Standards Institute (ANSI 1971, 1978) has set the performance specifications and the required tests for portable radiation survey instruments. However, there is no requirement in ANSI about the important magnetic shielding for portable radiation survey instruments.

At the Stanford Linear Accelerator Center (SLAC), radiation areas around klystrons, which are used to provide energy for electron acceleration, can have magnetic fields of a few tenths of a tesla. General areas around the SLAC Large Detector have magnetic fields less than 3 mT, but the maximum field can be as high as about 10 mT. To cope with different radiation measurement conditions (e.g., high radiation intensity measurements in initial beam checkout, low level measurements during normal beam operation, and low level residual radiation survey), several different radiation survey instruments are used at SLAC. The study of the effects of the static magnetic field on the response of these radiation survey instruments at SLAC is presented. Results of work to enhance the magnetic shielding of some instruments are also presented.

INSTRUMENTS AND METHODS

The radiation survey instruments‡ tested are the Xetex 303B Pacer, the Bicron Micro Rem survey meter, the Victoreen 450p survey meter, the Victoreen 440 survey meter, the SLAC orange meter, the Keithley 36150 survey meter, the Andersson–Braun (AB) remmeter, and the Victoreen 488 neutron survey meter.

The static magnetic fields used to test the instruments were generated with a large SLAC-made solenoid, unless otherwise stated. The magnetic field intensity was measured with a Gaussmeter.§ The magnetic field intensity varies less than ± 20% of the peak value in a spatial region over which the sensitive part of an instrument was positioned and tested.

The magnetic effect was evaluated with the long axis of the whole instrument perpendicular or parallel to the static magnetic flux lines, and the whole instrument was stationary or moving in the field. In the case of movement, instrument response moving in both directions [North to South (N to S) and South to North (S to N)] was tested. A photon (or neutron) source was taped to the instrument to create an exposure signal (regarded as the true signal). Then, the measured response of an instrument in the magnetic field up to 30 mT was compared with the true signal. The effect is determined by the ratio of the measured signal to the true signal.

‡ Xetex 303B Pacer, Xetex Inc., 1275 Hammerwood Avenue, Sunnyvale, CA 94089.
Bicron Micro Rem survey meter, Bicron Corporation, 12345 Kinsman Road, Newbury, OH 44065
Victoreen 450p, 440 and 488 meters, Victoreen Inc., 5806 Hough Avenue, Cleveland, OH 44103.
Keithley 36150 survey meter, Keithley Instruments, Inc., 28775 Aurora Road, Cleveland, OH 44132.

§ F. W. Bell Model 4048 Gaussmeter, 6120 Hanging Moss Road, Orlando, FL 32807.

RESULTS

Xetex 303B Pacer

The commercially available Xetex 303B Pacer is very susceptible to magnetic effect, if it is not modified. An unmodified Pacer in a field of 1 mT (meter axis perpendicular to the flux lines of a permanent magnet) would respond low by a factor of 10 (see the "unmodified" curve in Fig. 1). It was suspected that the main sensitive part for magnetic effect is the photodiode used for its small NaI radiation sensor. Because of the low voltage (6–9 V) used for the photodiode,* the magnetic field can sweep away the electrons easily and, therefore, reduce the signal. The effect should occur for both a stationary meter and a moving one.

Figure 1 shows how the sensitive part (photodiode) was shielded for better magnetic shielding. With three layers of shielding foils (Telshield‖ or Conetic¶) wrapped around the photodiode, the Pacer was free from magnetic effect up to 4–6 mT. The Conetic foil is superior to the Telshield foil under these conditions. The best shielding solution tried was that a layer of Conetic foil followed by a piece of paper (to act as an insulator), and then a thin steel conduit tubing (0.16 cm thick and 2.54 cm internal diameter). The Pacer with this magnetic shielding enhancement has an unaffected response up to 10 mT (see the horizontal line labeled "modified" in Fig. 1). All the Xetex 303B Pacers in the Operational Health Physics Department at SLAC and those made by Xetex after this work have been shielded in this manner. The above tests were performed with the Pacer stationary and the meter

* Ken Sinclair, personal communication, Xetex Inc., 1275 Hammerwood Avenue, Sunnyvale, CA 94089; 1991.

‖ Telshield, Telcon Metals Limited, Manor Royal, Crawley, Sussex, UK 28800.

¶ Conetic is a trademark of Perfection Mica Co., 742 North Thomas Drive, Bensenville, IL 60106.

axis perpendicular to the flux lines in the magnetic fields from a small permanent magnet.

The modified Pacer was further tested with the SLAC solenoid and the result is shown in Fig. 2. When the long axis of the Pacer is parallel to the flux lines (in this case the axis of the photodiode is perpendicular to the flux lines), the response is unaffected up to 20 mT (10% lower at 30 mT). In the perpendicular case, the effect is larger (10% lower at 10 mT; 30% lower at 20 mT). The cause of the different effects in the parallel and perpendicular cases is because the steel conduit shields the photodiode only on the side not on the head and tail of the photodiode. As expected, the effect is not dependent on whether the Pacer is stationary or moving relative to the flux lines. There is no difference for a Pacer moving from N to S or from S to N, either.

Bicron Micro Rem Meter

The Bicron Micro Rem meter uses a tissue-equivalent plastic scintillator as the detector. Therefore, it can be expected that the photomultiplier tube (PMT) and/or the high voltage power supply are the sensitive parts to magnetic effect. Schlapper et al., (1984) showed that, due to the PMT, their ^{6}LiI remmeter ceased to measure the neutron dose equivalent rates in a magnetic field of 0.2 mT around a cyclotron. By covering the PMT with Mumetal* (a low magnetic field shielding material), the ^{6}LiI remmeter can still be used only up to 0.5 mT.

The magnetic shielding of the Bicron Micro Rem meters that SLAC purchased has been enhanced by wrapping the PMT on the side with a steel shim stock. The magnetic effect of the modified Bicron Micro Rem meter is shown in Fig. 3. In the perpendicular case (in this case the PMT axis is also perpendicular to the flux lines), the response is unaffected up to 10 mT, 30% lower at 20 mT, and 65% lower at 30 mT (no difference between the cases of stationary and moving). The effect in the parallel case is larger than that in the perpendicular case. A stationary Micro Rem meter is slightly more affected (only 20% response at 10 mT).

The results for both the Pacer and the Micro Rem meter show that a meter with its shielded PMT (or photodiode) axis parallel to the flux lines would be affected more seriously than a meter with its shielded PMT (or photodiode) axis perpendicular to the flux lines.

Victoreen 450p ion chamber survey meter

The digital Victoreen 450p meter uses a high pressure ion chamber as the detector. An ion chamber needs a high voltage for operation, which is generally supplied from a circuit of oscillator, transformer and rectifier, or from batteries. Using a needle magnet to probe the circuit board of the Victoreen 450p meter, it was determined that the sensitive part of the instrument is the step-up transformer of the high voltage supply circuit.

The magnetic effect of the Victoreen 450p meter depends on many factors, and some results are shown in Fig. 4. When the meter axis is parallel to the flux lines and the meter is moving from S to N, the meter overresponds by a factor of three at 5 mT and a factor of 70 at 10 mT. When the meter moves from N to S, the result is reversed (the response is down to 20% at 10 mT). In the perpendicular case, the interference is much less than in the parallel case (10% lower at 10 mT and 40% lower at 20 mT, when the meter moves from N to S or from S to N). Although this effect is pronounced when the meter moves in magnetic field, there is no effect when the meter is stationary. Explanation of this difference follows. The ion chamber itself is a capacitor. When the chamber moves through an inhomogenous magnetic field, the

* Mumetal, Telcon Metals Limited, Manor Royal, Crawley, Sussex, UK 28800.

induced voltage on the capacitor changes, and in doing so produces a signal. Since there is no induced voltage change in a stationary ion chamber meter, there is no effect either.

Victoreen 440 ion chamber survey meter

The analog Victoreen 440 meter uses a vibrating reed electrometer to detect the small current from its ion chamber detector. Similarly to that of the Victoreen 450p meter, the effect is pronounced and is dependent on several factors, but the results are quite different.

The underresponse results of the Victoreen 440 meter are shown in Fig. 5. The effect of a meter moving from S to N and the meter axis parallel to the flux lines is similar to that of a meter moving from N to S and the meter axis perpendicular to the flux lines (about 10% lower at 5 mT and nearly zero response at 20 mT). The meter would overrespond by 10%–20% at 10 mT and a factor of 3 to 6 at 20 mT, when the meter moves parallel to the field from N to S or perpendicular from S to N. In either case (parallel or perpendicular), a stationary meter would respond only 20% lower at 20 mT (almost no effect at 10 mT).

The effect for a stationary 440 meter is probably due to a direct action of the magnetic field on the dynamic capacitor of the vibrating reed of the electrometer. When the magnetic field becomes high enough to change the magnetic coupling of the dynamic capacitor, it starts to decrease the amplification of the signal. A moving meter would have the same direct action effect and an additional magnetic induction effect, due to the flux change from the meter movement in the field.

SLAC orange meter

The SLAC orange photon survey meter, an ion chamber survey meter made at SLAC, has features designed specifically for better magnetic shielding. For example,

the ion chamber voltage of 90 V is from batteries, instead of a high voltage supply circuit. Therefore, the SLAC orange meter is free from any magnetic effect up to 30 mT.

Keithley 36150 ion chamber survey meter

The digital Keithley 36150 meter uses reed relays and, therefore, is very susceptible to magnetic fields. Even in a field of 2 mT, the signal will be zero, because the reed relay closes and shorts out the detector signal.

Andersson–Braun neutron remmeter

The Andersson–Braun remmeter (made by the Lawrence Livermore National Laboratory) is a moderating-type neutron remmeter that has a BF_3 gas proportional counter as the sensor. The D'Arsonval meter is well shielded. The response of the Andersson–Braun remmeter is not affected in a field up to 30 mT, when it is stationary in the field. Due to its large size, the effect of the AB remmeter moving in the field was not studied.

Victoreen 488 neutron survey meter

The Victoreen 488 meter is a moderating-type neutron remmeter that has a boron-lined proportional counter. There is a serious magnetic effect on the response of the Victoreen 488 neutron survey meter, shown in Fig. 6. The effect is the same for both a stationary meter and a moving one. When the meter axis is parallel to the flux lines, it overresponds by 20% at 1 mT and 50% at 2 mT. It would be overscaled at 3 mT. In the perpendicular case, the meter underresponds by 40% at 1 mT and 50% at 2 mT. This large magnetic effect is most probably due to direct influence of the magnetic field on the D'Arsonval meter, because the D'Arsonval meter of the Victoreen 488 meter is not well shielded against the magnetic field.

SUMMARY AND CONCLUSIONS

Magnetic effects of the radiation survey instruments are very complex. In general, it is difficult even to speculate about causes and effects, although it may be easy to identify the cause(s) in some cases. Regulations and standards should be established to set the magnetic shielding level required for instruments that will be used in magnetic fields, so that magnetic shielding and testing will become part of the manufacturing process of the instruments.

The force of the magnetic field of about 7–10 mT can be felt on a hand-held survey meter with ferromagnetic metal parts. A field of 10 mT (100 G) is common in accelerator facilities. Therefore, the authors suggest that the magnetic shielding requirement for an instrument should be such that the response error of the instrument in a magnetic field up to 10 mT is less than 10%, in any case. Of the instruments tested in this study, only the modified Xetex 303B Pacer, the SLAC orange meter and the Andersson–Braun remmeter meet this proposed requirement.

Some observations from this study are:

(1) All instruments tested are unaffected by a magnetic field intensity of 2 mT in any case, except the unmodified Xetex 303B Pacer, the Keithley 36150 meter and the Victoreen 488 neutron meter.

(2) Instruments which use a PMT (or photodiode) show magnetic effects above 2 mT, if the sensitive part is not shielded. The underresponse effect is very similar for both a stationary meter and a moving one, and the effect is the same for a meter moving in either direction. For a PMT (or photodiode) shielded with iron conduit on the side, the effect is worse when the PMT (or photodiode) axis is parallel to the flux lines. For an unshielded PMT (or photodiode),

the situation would be reversed. The magnetic shielding of this type of meter can be enhanced without too much difficulty.

(3) Ion chamber type meters, which use high voltage supply circuits instead of batteries, have serious and less predictable magnetic effects. However, an affected meter would generally give fluctuating, alerting signals. A stationary one would have much smaller effects. A meter moving from N to S has reverse effect to that of a meter moving from S to N. The magnetic shielding of this type of meter can not be enhanced easily.

(4) For those instruments using D'Arsonval meters for current measurement and display, the movement of the D'Arsonval meter will be affected in a high magnetic field. This effect would generally occur in a field of a few hundred gauss. A meter with an external magnet design (the poles of the magnet encompass the coil of the needle) is inherently more resistant to external magnetic fields than one with an internal magnet design.

ACKNOWLEDGMENTS

The authors would like to thank Dave Jensen and Joe Cobb of the Magnetic Measurements Group at SLAC for their help in the use of their solenoid magnet. The authors would also like to thank H. Smith, D. Reagan and S. Carlson for their useful discussions on the possible causes of the magnetic effects.

REFERENCES

American National Standards Institute. American National Standard for the specifications of portable x- or gamma-radiation survey instruments. New York, NY: ANSI, ANSI N134; 1971.

American National Standards Institute. Radiation protection instrumentation test and calibration. New York, NY: ANSI, ANSI N 323; 1978.

Schlapper, G.A.; Kay, D.C.; Neff, R.D.; Sandel, P.S. Dose equivalent measurements in an area of reduced shielding at the Texas A&M Variable Energy Cyclotron. Radiat. Prot. Management. 1:57–64; 1984.

Stuchly, M.A. Human exposure to static and time-varying magnetic fields. Health Phys. 51:215–225; 1986.

FIGURE CAPTIONS

Fig. 1. Response of the Xetex 303B Pacer with different magnetic shieldings wrapped around the photodiode. The instrument is stationary and the meter axis is perpendicular to the flux lines in the field of a permanent magnet.

Fig. 2. Response of the modified Xetex 303B Pacer. The magnetic effect on the response is the same for a stationary Pacer and a moving one. True signal is 1.55 μC kg^{-1} h^{-1} (6 mR h^{-1}).

Fig. 3. Response of the modified Bicron Micro Rem meter. True signal is 0.77 μC kg^{-1} h^{-1} (3 mR h^{-1}).

Fig. 4. Response of the Victoreen 450p ion chamber survey meter. True signal is 0.77 μC kg^{-1} h^{-1} (3 mR h^{-1}).

Fig. 5. Response of the Victoreen 440 ion chamber survey meter. True signal is 1.3 μC kg^{-1} h^{-1} (5 mR h^{-1}).

Fig. 6. Response of the Victoreen 488 neutron survey meter.

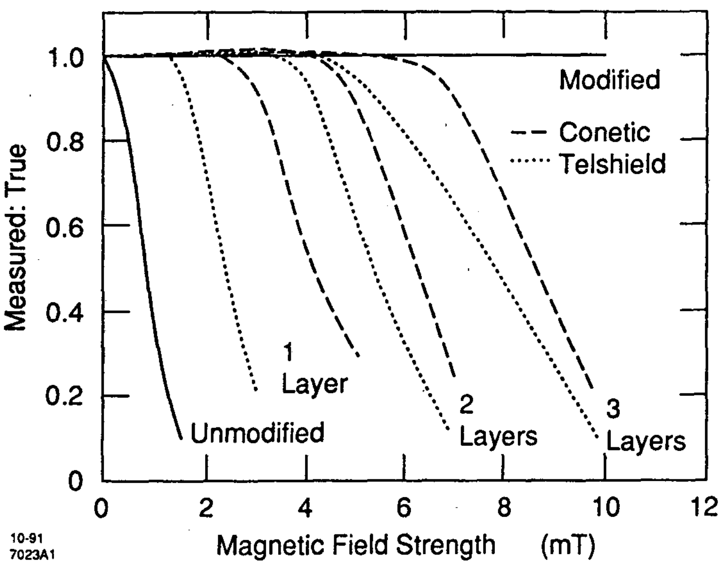

1.0
0.8
0.6
0.4
0.2
0
Measured: True
Modified
Conetic
Telshield
1
Layer
2
Layers
3
Layers
Unmodified
0
2
4
6
8
10
12
Magnetic Field Strength (mT)
10-91
7023A1

Fig. 1

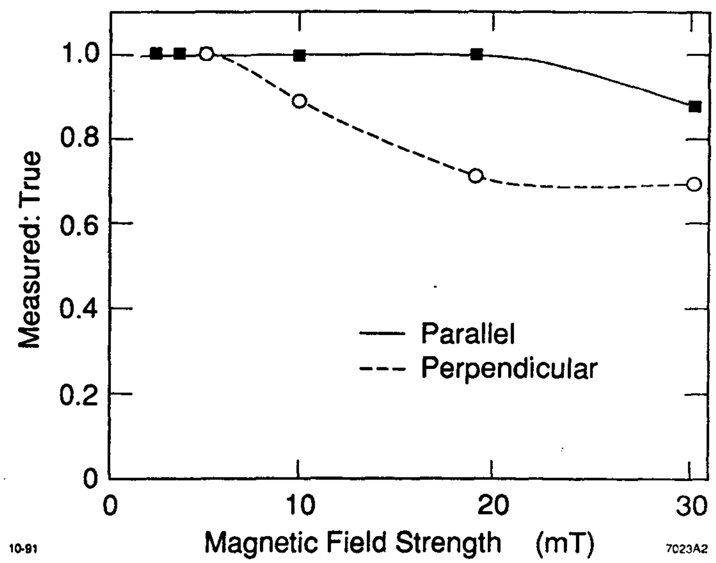

1.0
0.8
0.6
0.4
0.2
0
Measured: True
Parallel
Perpendicular
0
10
20
30
Magnetic Field Strength (mT)
10-91
7023A2

Fig. 2

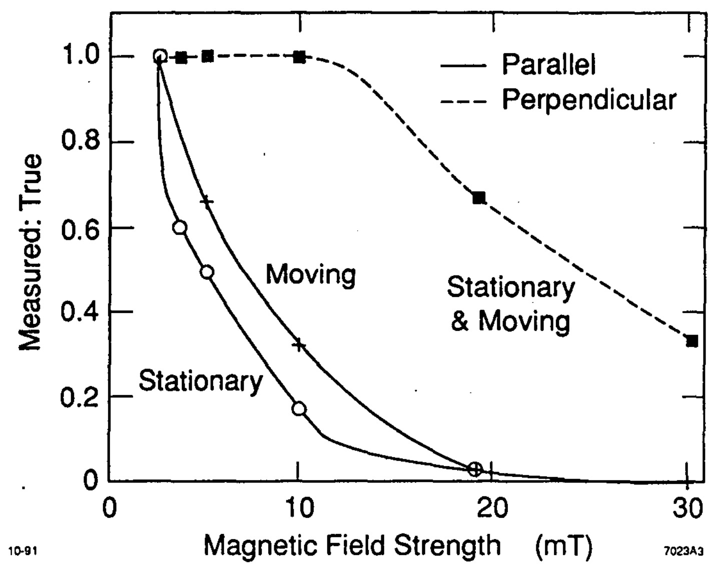

1.0
0.8
0.6
0.4
0.2
0
10
20
30
Measured: True
Magnetic Field Strength (mT)
Parallel
Perpendicular
Moving
Stationary
Stationary
& Moving
10-91
7023A3

Fig. 3

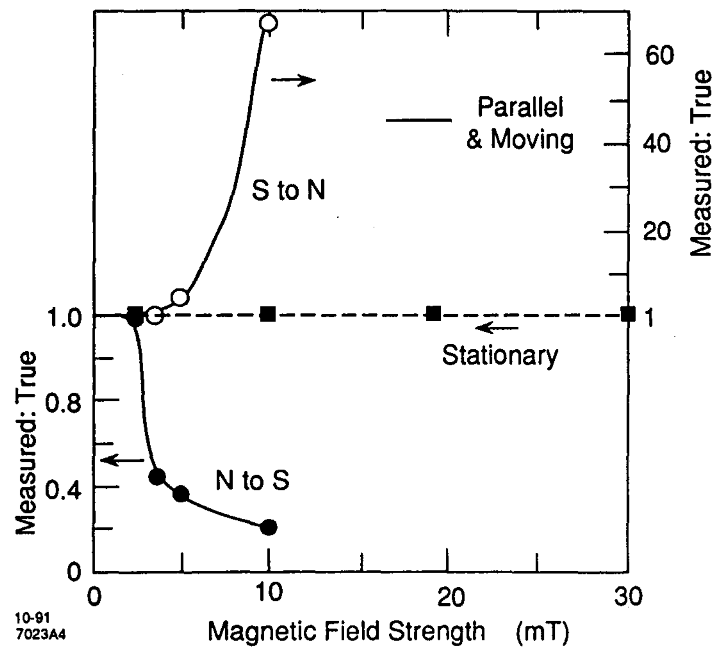
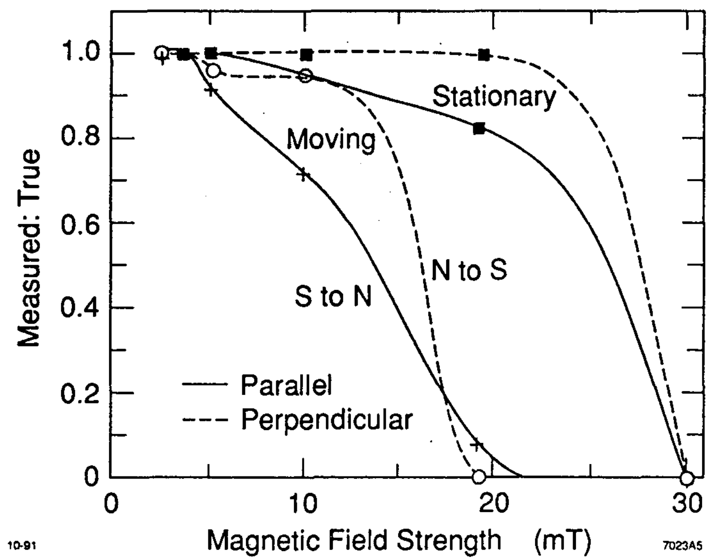
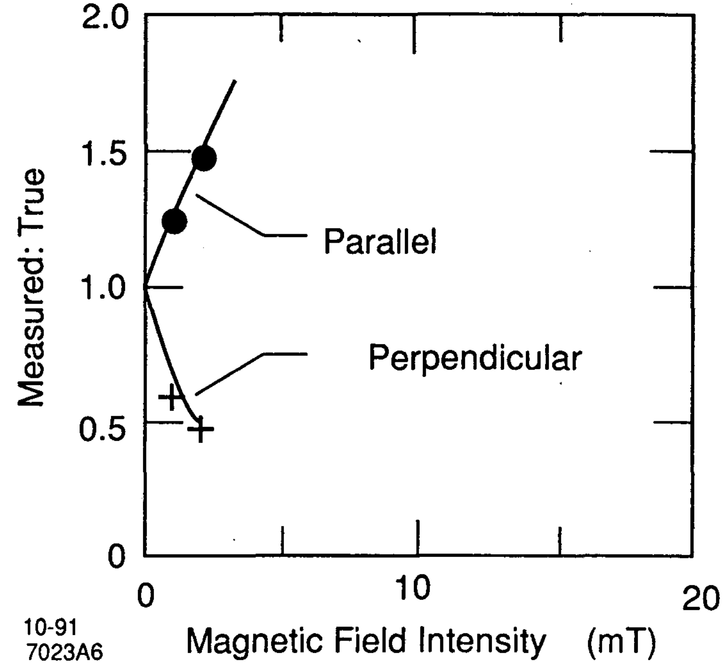

1.0
0.8
0.4
0
10
20
30
60
40
20
1
Measured: True
Measured: True
Magnetic Field Strength (mT)
Parallel
& Moving
S to N
N to S
Stationary
10-91
7023A4

Fig. 4



1.0
0.8
0.6
0.4
0.2
0
Measured: True
Stationary
Moving
N to S
S to N
Parallel
Perpendicular
0
10
20
30
Magnetic Field Strength (mT)
10-91
7023A5

Fig. 5



2.0
1.5
1.0
0.5
0
Measured: True
Parallel
Perpendicular
0
10
20
Magnetic Field Intensity (mT)
10-91
7023A6

Fig. 6