Title

An Assessment of the Effects of Radiation on Permanent Magnet Material in the ALS Insertion Devices

Permalink

https://escholarship.org/uc/item/6hv7h8kd

Authors

Hassenzahl, W.V.
Jenkins, T.M.
Namito, Y.
et al.

Publication Date

1989-08-07

LBL-27808

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

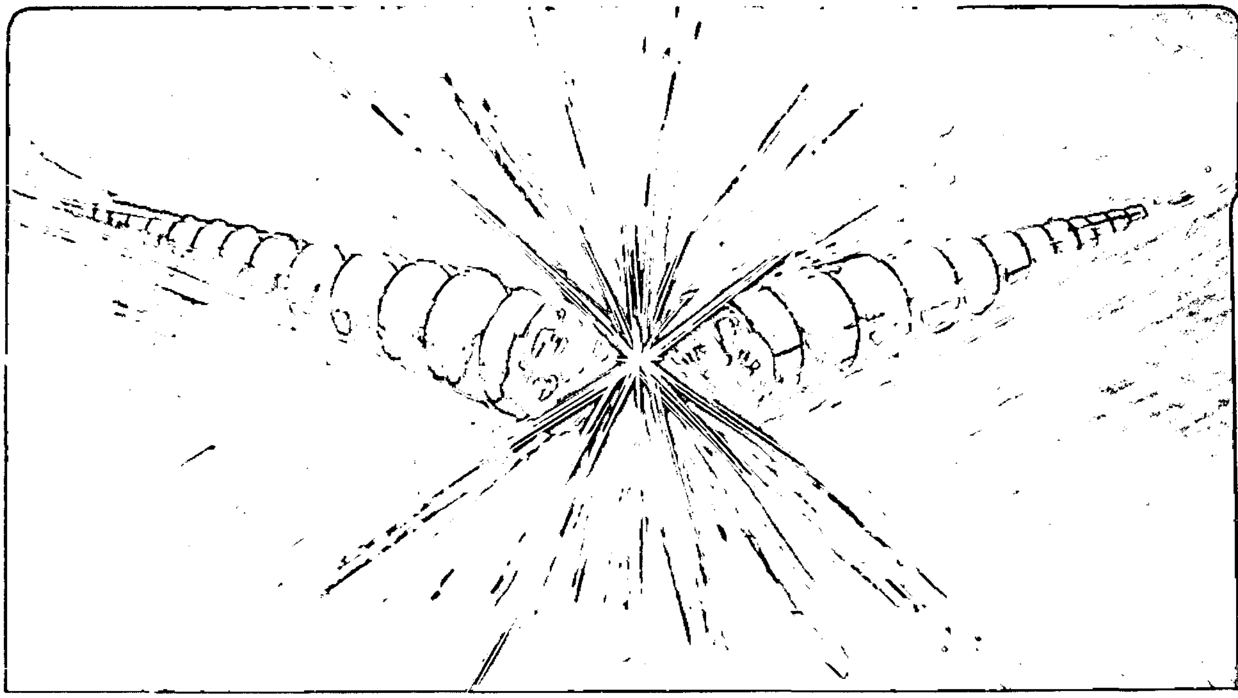
Accelerator & Fusion Research Division

Presented at the Sixth National Conference on Synchrotron
Radiation Instrumentation, Berkeley, CA, August 7–10, 1989

An Assessment of the Effects of Radiation on Permanent Magnet Material in the ALS Insertion Devices

W.V. Hassenzahl, T.M. Jenkins, Y. Namito,
W.R. Nelson, and W.P. Swanson

August 1989



Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

LBL-27808

An Assessment of the Effects of Radiation on Permanent Magnet Material in the ALS Insertion Devices

W.V. Hassenzahl, T.M. Jenkins, Y. Namito,
W.R. Nelson, and W.P. Swanson

Accelerator and Fusion Research Division
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, California 94720

August 1989

An assessment of the effects of radiation on permanent magnet material in the ALS insertion devices.

W. V. Hassenzahl*, T. M. Jenkins**, Y. Namito**,
W. R. Nelson**, and W. P. Swanson*

ABSTRACT

Electrons that are lost from the beam during normal operation of a synchrotron radiation source and during a beam dump at the end of a run produce both ionizing radiation and neutrons. This radiation has the potential for damaging sensitive materials, in particular those that need to be very close to the beam. The wigglers and undulators for the Advanced Light Source (ALS) at LBL will use magnetic materials such as the very high performance neodymium-iron-boron, which will be as close as 1 cm away from the electron beam during operation. This material, which is preferred because of its high remanence, is known to be more sensitive to radiation than some other magnetic materials. Simple energy loss estimates and the EGS4 code were used to estimate the radiation levels in the ALS insertion devices in the regions of the magnetic materials. The radiation levels were estimated for both aluminum and stainless steel vacuum chambers to determine if one would provide significantly better shielding. We conclude that Nd-Fe-B can be used in the ALS insertion devices and that there is little difference in the radiation levels for aluminum and stainless vacuum vessels.

This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Sciences Division, of the U.S. D.O.E., under Contract No. DE-AC03-76SF00098.

*Lawrence Berkeley Laboratory. ** Stanford Linear Accelerator Center

Introduction

The issue of radiation damage in the permanent magnet material was raised when the initial work on the concept of a generic insertion device structure for the ALS began in the fall of 1988, . Two important questions had to be addressed before proceeding with the detailed design. First, it is well known that samarium-cobalt is more radiation resistant than the higher performance neodymium-iron-boron, which was used on the beam line X wiggler at Spear and is proposed for the ALS insertion devices. Thus, if the radiation level is significant, it might be appropriate to use Sm-Co materials, or to substitute them in the parts of the insertion devices near the beam where the radiation level will be highest. Second, the radiation level at the magnetic material may depend to some extent on the choice of the vacuum chamber material. Stainless steel and aluminum are being considered for the chambers. An aluminum chamber would be much less expensive, but, as stainless steel might provide significantly better shielding due to its higher Z, it might be cost effective in the long run. Thus, it is necessary to compare the effects of thin-walled vacuum chambers made of these two materials on the basis of the radiation levels in the nearby magnetic material. This report addresses both issues and sets design criteria for the vacuum chamber and for the permanent magnet materials.

Effects of Radiation on Magnetized Neodymium Iron Boron

There have been a few studies of the effects of radiation on permanent magnet materials such as samarium-cobalt and neodymium-iron-boron (1-3). In general the sensitivity to radiation in these materials is rather low; however, over the projected 20 year life of the ALS the integrated dose may be quite large. Recent studies (1,2) to determine the effects of charged particle radiation and neutrons on Nd-Fe-B are probably the most relevant for estimating the significance of radiation in the ALS. The materials used for the study were high performance Hicorex 94EB (made by Hitachi) and Crumax 282 (made by Crucible Magnetics), which are similar to the Nd-Fe-B materials that are being proposed for the ALS insertion devices. The sensitivity of the Crumax 282 to neutrons (1) is shown in Fig. 1. The abscissa is the total integrated neutron flux, and the ordinate is the fractional reduction in magnetization. A flux of 10^{15} n/cm^2 is required to produce a 6 % decrease in performance.

The effect of charged particle radiation is not so well understood as that of neutrons. The data by Kulak et al. of Livermore (2) as summarized in Fig. 2, shows some effect in the Hicorex material after 2×10^6 Gy (100Rad = 1Gy). This effect is not very large and the variation from sample to sample is great.

These data suggest that integrated neutron fluences of less than 3×10^{14} n/cm^2 and ionizing radiation levels of less than 6×10^4 Gy can be considered as thresholds below which there will be no significant damage to the Nd-Fe-B materials.

Radiation doses expected in ALS Insertion Devices

We first summarize the results of one of the authors, W. Swanson (4). The dose due to ionizing radiation was calculated assuming the electron beam is lost uniformly around the ring and that the mechanism for beam loss is bremsstrahlung. The energy available is that due to the full beam and it is assumed that the machine is charged and dumped or decays so that the annual energy loss is $2x10^6$ J. This corresponds to about 2 fills per day of 400 mA of electrons at an energy of 1.5 GeV. To estimate the dose, it is assumed that all the energy in the electron beam is converted into radiation in the structure around the beam. Though the maximum energy goes in the forward direction, some small amount of radiation even goes off in the backwards direction. The net result is that the radiation level, assuming the beam is lost uniformly around the accelerator, is about $1.5x10^3$ Gy per year, which leads to a total dose of about $3x10^4$ Gy over 20 years. This value is indicated on Fig. 2.

The neutron dose in a relatively low energy electron machine might be expected to be small because there is little interaction of the electrons or gammas produced with the nuclei of atoms in the materials. Thus there is little chance of producing neutrons. The neutron level has been measured at Aladdin (5) and the results were scaled to estimate the neutron fluence in the the materials around the ALS beam. The dose expected in the 20 year life of the ALS is about $7x10^{11}$ n/cm^2. This is quite small relative to the radiation damage threshold (1) of the Nd-Fe-B materials, as can be seen in Fig. 1.

Recent results with EGS4

The analysis described above assumed that most of the electron beam energy went into bremsstrahlung, which resulted in subsequent irradiation of the materials surrounding the beam. In fact, most of the energy in the beam is deposited in material around the accelerator by particles that collide with gas molecules in the accelerator or are Touschek scattered into an unstable orbit and which are eventually lost by hitting a slit that defines the beam size or by colliding with the wall at a very small angle. The most serious source of radiation in the insertion devices will be due to these particles with low incident angles that collide with the walls of the vacuum chamber within the ID itself.

Jenkins et al. (6,7) carried out a study of the radiation that could be expected in the insertion devices when electrons with low incident angles strike the vacuum chamber walls. Both aluminum and stainless steel vacuum chambers were considered. The ID geometry was simulated by 3 mm diameter cylinders (shown in Fig. 3) of either aluminum or iron that were surrounded by and in direct contact with thick cylinders of iron that simulate the Nd-Fe-B and the iron poles. The shower produced by an electron beam incident on the center of the inner cylinder was tracked with the EGS4 code to determine the radiation in the cylinders at various distances downstream from the point of incidence as a function of radial position.

Several direct results of these studies are shown in Figs. 4 to 7. These figures show the loss of a few particles in the cylinders, but have enough statistics to get a good feel for the level and extent of radiation loss. The different curves in the figures refer to the size of the incident beam. The maximum energy deposited is for the stainless steel vacuum chamber rather than for the aluminum, but it is over a shorter distance. The radiation peaks in the SS chamber at a distance of about 3.7 radiation lengths, whereas for the aluminum it is at a shorter distance, about 2.3 radiation lengths. The exact cause for this difference is not clear, but may have to do with the contribution of the insertion device materials to the shower.

The results of the EGS4 data in Ref. 7 can be applied to the losses in the ALS insertion devices. Here we assume that half the beam from 700 fills per year is lost in a set of 5 IDs that are each 5 meters long and then calculate the number of electrons (or equivalently the energy) incident per unit length of vacuum chamber wall. This loss can be converted to dose by using the relation:

$$\mathrm{Dose} = \left(\frac{dE}{E_0\,dV}\right)\left(\frac{E_0}{\rho e^-}\right)\left(0.16\,\frac{\mathrm{Gy}}{\mathrm{MeV}}\right)(\#e^-)$$

The local radiation depends on the material in the vacuum chamber, as shown in Figs. 6 and 7. For stainless steel the dose is locally higher, but extends over a shorter distance than for the aluminum. It is necessary to combine these effects, as in Table I, to estimate the radiation levels in the magnetic materials. The doses associated with aluminum and stainless steel vacuum chambers are nearly identical. Over the 20 year life of the ALS they will be $3\text{x}10^4$ and $2.6\text{x}10^4$ Gy, respectively.

Conclusions

Two major conclusions can be derived from this assessment. First, it would appear that the Nd-Fe-B material will not be damaged by the radiation levels expected in the ALS insertion devices. Second, there is essentially no difference in the radiation levels expected for stainless steel and aluminum vacuum chambers. Thus, it is appropriate to choose the less expensive material, aluminum, for the chambers.

After this study was completed another set of measurements (8) of the effects of radiation on magnetic materials was pointed out to the authors. The observed effects of ionizing radiation are similar to those of Ref. 2, showing a degradation of less than 0.5 % at 10^5 Gy.

Table I

Location, Magnitude, and Linear Extent of Radiation in Magnetic Materials of Insertion Devices for Aluminum and Stainless Steel Vacuum Chambers.

Vacuum Chamber Material	Position of Maximum Radiation	Maximum Radiation	Radiation Extent	Dose
	(cm)	(cm^{-3})	(cm)	(10^4 Gy/yr)
Aluminum	20	0.022	10	0.15
Stainless Steel	7	0.035	5	0.13

References

1. J. R. Cost, R. D. Brown, A. L. Giorgi, and J.T. Stanley, "Effects of Neutron Irradiation on Nd-Fe-B Magnetic Properties", IEEE Trans. on Magnetics, Vol 24 No. 3, pp 2016-2019, May 1988.

2. B. Kulke and J. Palomar, "Permanent Magnet Radiation Hardness Tests at the 100 MeV Linac: Preliminary Results", LLNL Research Note, RM88-16.

3. E. W. Blackmore, "Radiation Effects of protons on samarium-cobalt permanent magnets," IEEE Trans. Nucl. Sci., vol NS-32, pp. 3669-3671, Oct. 1985.

4. W. P. Swanson, "Estimates of bremsstrahlung doses and neutron fluences close to beam losses - effects on permanent magnet installations," LBL internal report, Nov. 1988.

5. W. P. Swanson, P. M. DeLuca Jr., R. A. Otte, and S. W. Schilthelm, "Aladdin Upgrade design Study: Shielding", Aladdin Report, April 1985.

6. T. M. Jenkins, Y. Namito, and W. R. Nelson, "Additional calculations related to Swanson's note of November 9, 1988," SLAC informal report, Jan., 1989.

7. SLAC memo dated March 1, 1989, from Y. Namito, T. M. Jenkins, and W. R. Nelson to W. V. Hassenzahl (LBL) summarizing EGS4 calculations of radiation doses on materials in insertion devices.

8. A. F. Zeller and J. A. Nolen, "Radiation and Temperature Effects of Sm-Co and

Nd-Fe-B Magnets in Low Permeance Configuration," paper WP 3.2 at the 9th International Workshop on Rare-Earth Magnets and Their Applications, Bad Soden, FRG, August 31-September 2, 1987, hosted by: Deutsche Physikalische Gessellschaft e. V., D-5340 Bad Honnet 1, FRG.

Figure 1. Loss of remanence in Nd-Fe-B due to neutron irradiation.

Figure 2. Effects of ionizing radiation on the remanence of Nd-Fe-B magnetic material. Note the estimated dose of about $2x10^4$ Gy for the ALS insertion devices.

Figure 3 Two material geometry used for EGS4 calculation of energy loss.

Figure 4 Cascade shower produced in iron by two 1.5 GeV electrons. Charged particles (e^+ and e^-) are shown as solid lines and photons as dots.

Figure 5 Energy deposition density versus radial shell. The different curves correspond to different beam sizes, from a point or pencil beam (simple solid curve) to a 1000 µ diameter beam (curve indicated with an open square). This legend for different beam size also applies to Figures 6 and 7.

Figure 6 Maximum energy-deposition density versus depth in the Nd-Fe-B for the aluminum vacuum chamber case (with $r > 0.3$ cm).

Figure 7 Maximum energy-deposition density versus depth in the Nd-Fe-B for the stainless steel vacuum chamber case (with $r > 0.3$ cm).

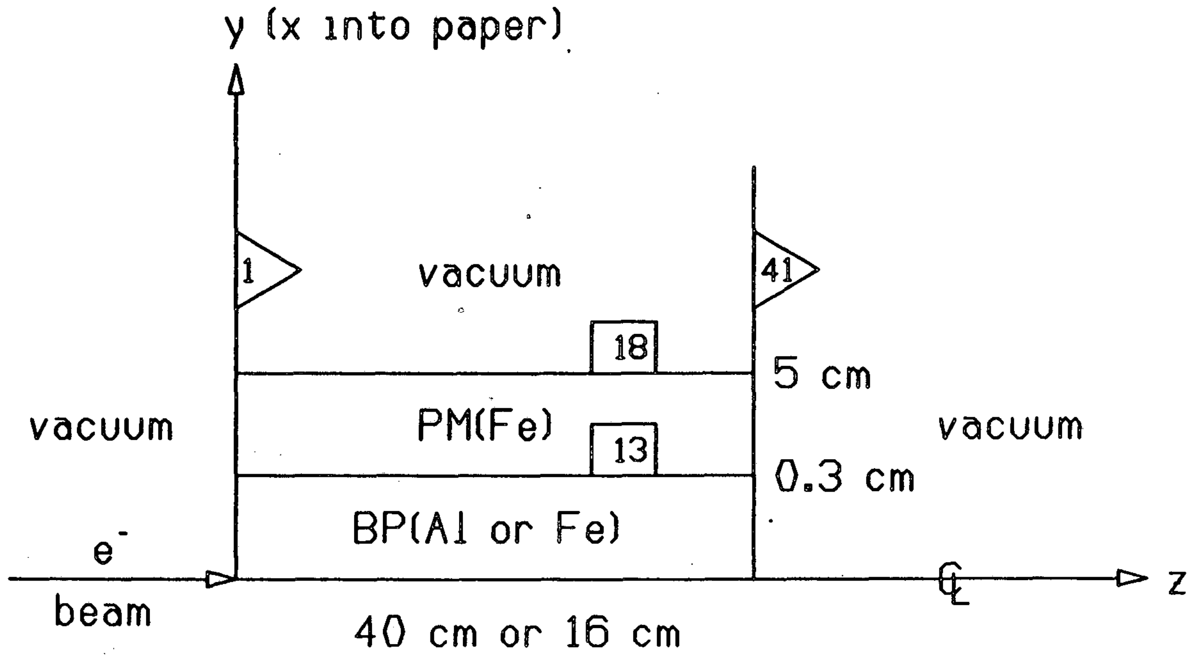

y (x into paper)
1
vacuum
41
18
5 cm
vacuum
PM(Fe)
13
vacuum
0.3 cm
BP(Al or Fe)
e-
beam
℄
z
40 cm or 16 cm

Fig. 1

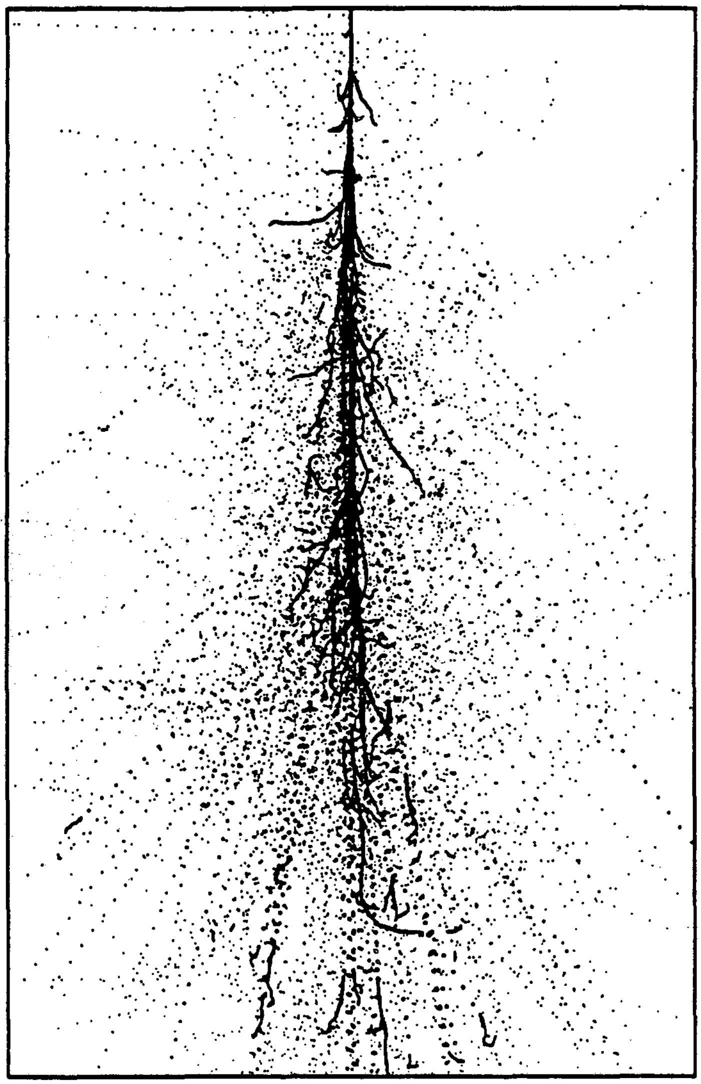


Fig. 2

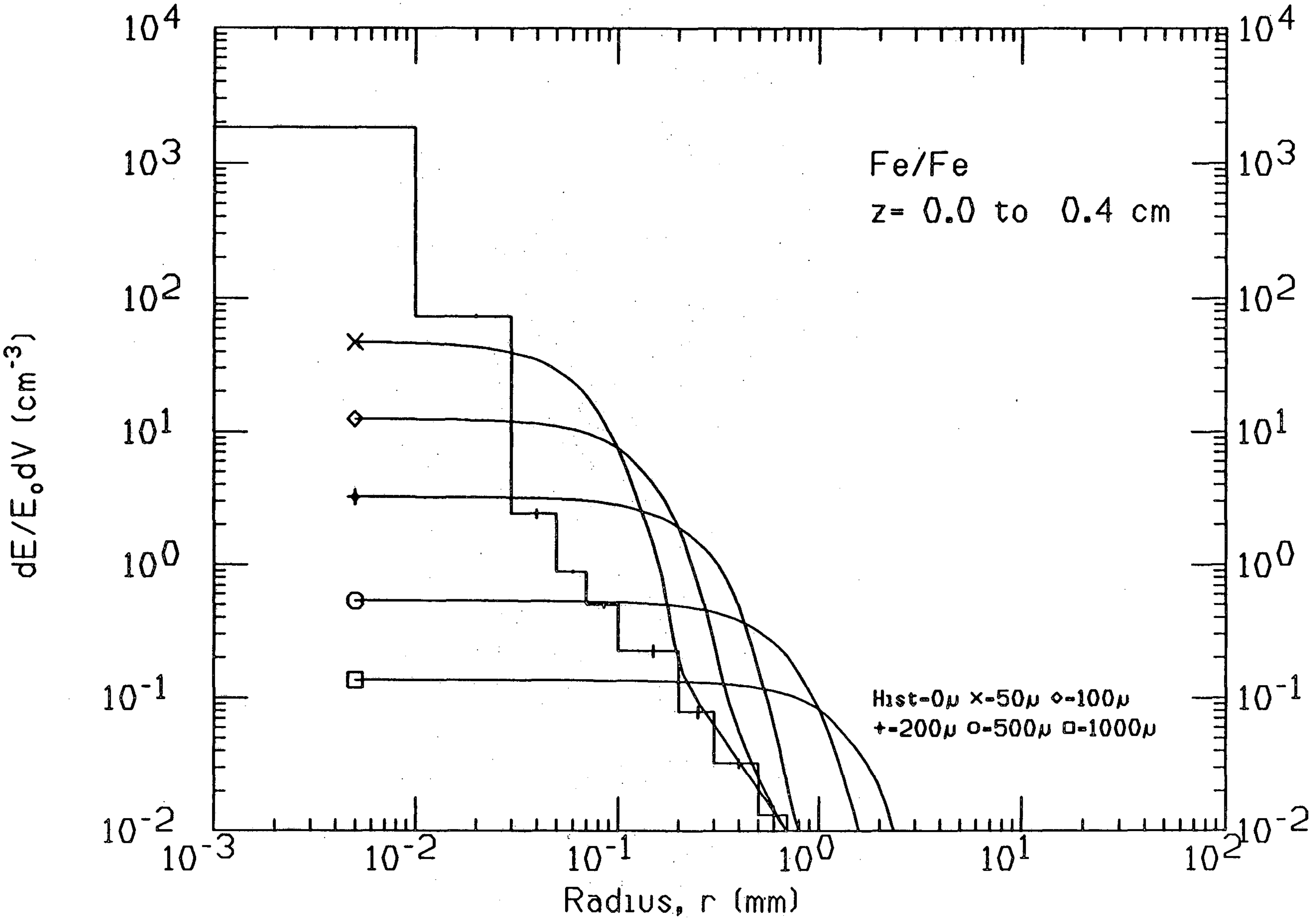

Fe/Fe
z= 0.0 to 0.4 cm
Hist-0μ ×-50μ ◇-100μ
+-200μ ○-500μ □-1000μ
dE/E_0dV (cm^{-3})
Radius, r (mm)
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}

Fig. 3

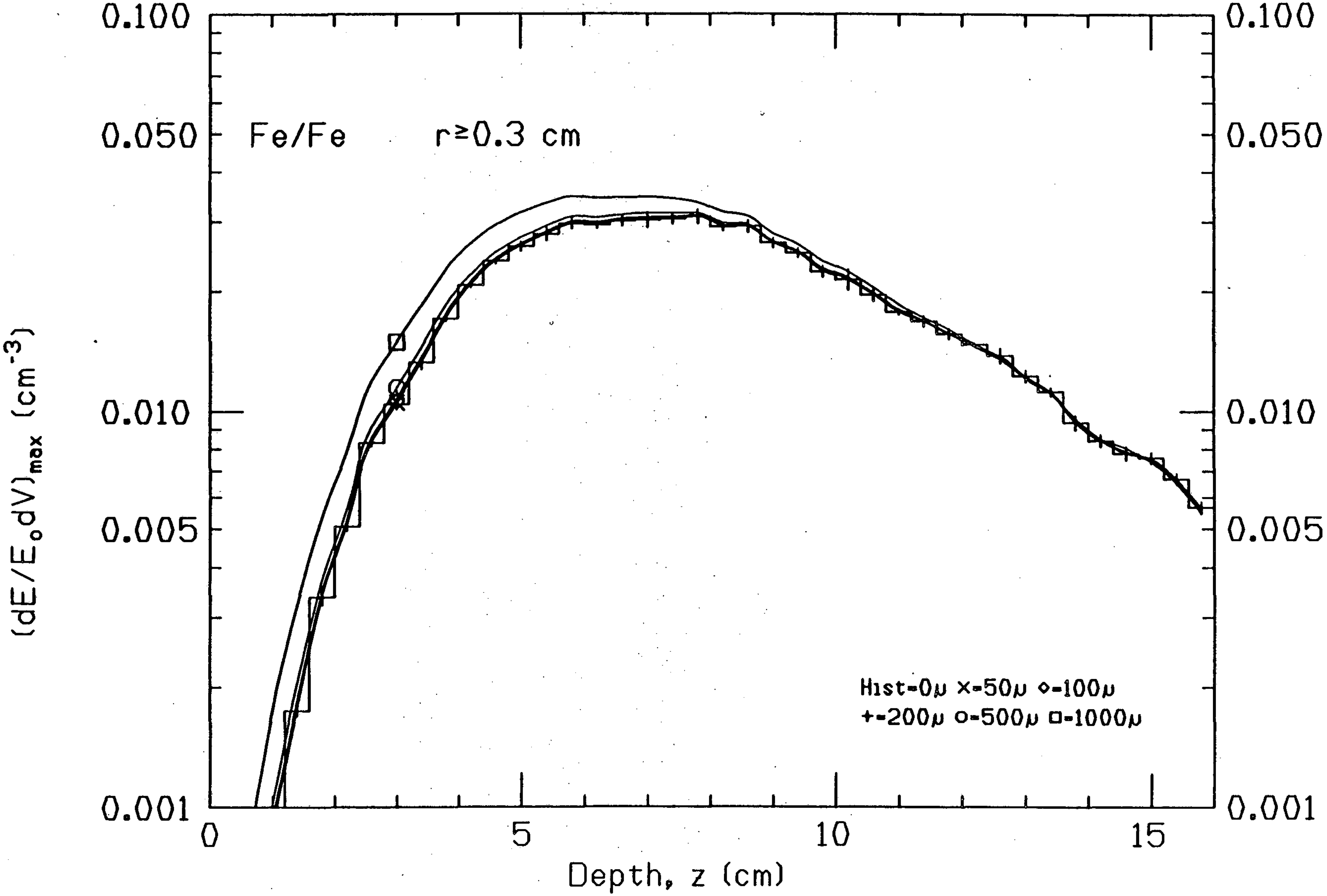

0.100
0.050
0.010
0.005
0.001
Fe/Fe
r≥0.3 cm
(dE/E$_o$dV)$_{max}$ (cm^{-3})
Hist-0μ ×-50μ ◇-100μ
+-200μ ○-500μ □-1000μ
0
5
10
15
Depth, z (cm)

Fig. 4

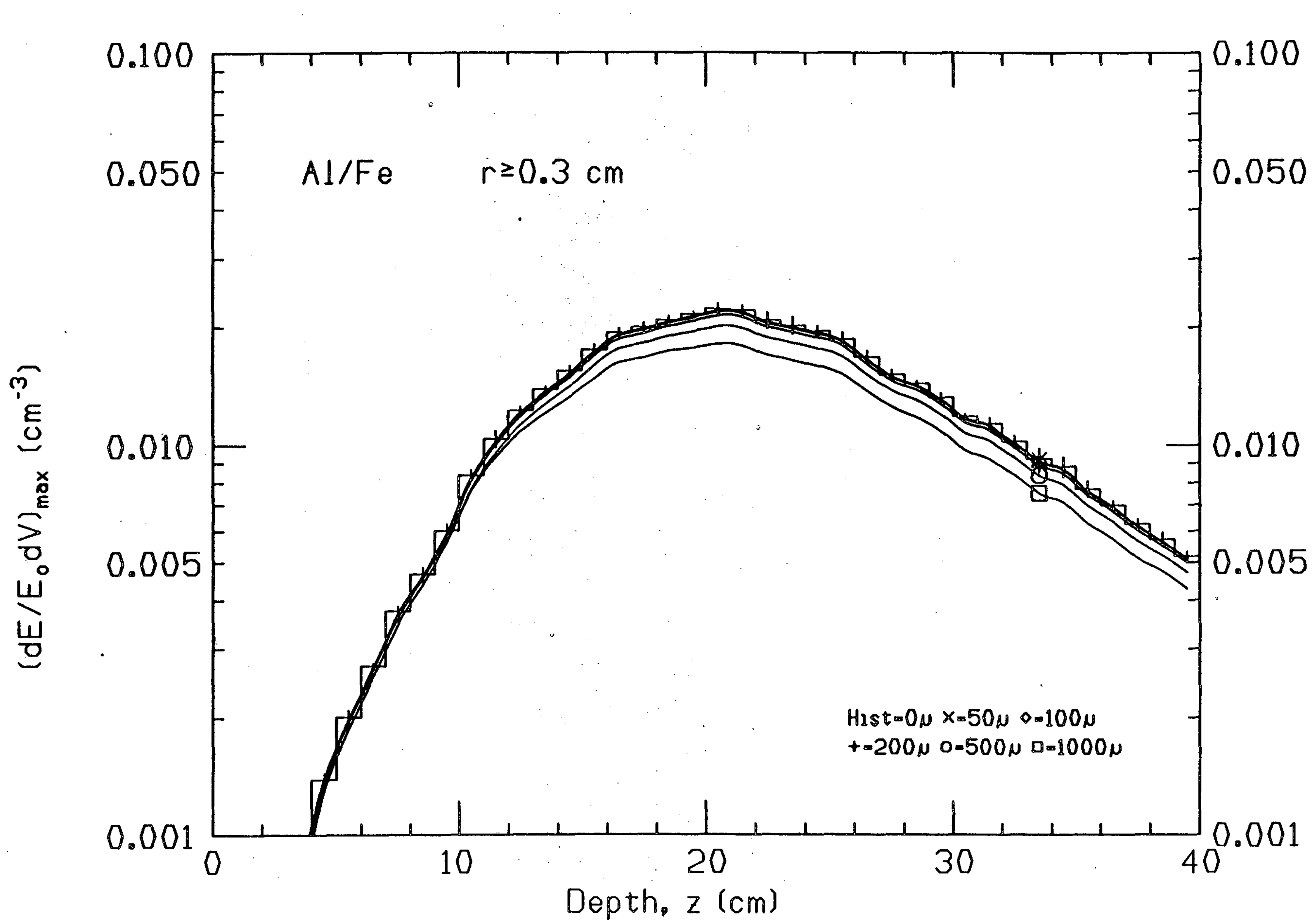

Al/Fe
r≥0.3 cm
$(dE/E_o dV)_{max}$ (cm^{-3})
0.100
0.050
0.010
0.005
0.001
0
10
20
30
40
Depth, z (cm)
Hist=0μ ×=50μ ◇=100μ
+=200μ ○=500μ □=1000μ

Fig. 5

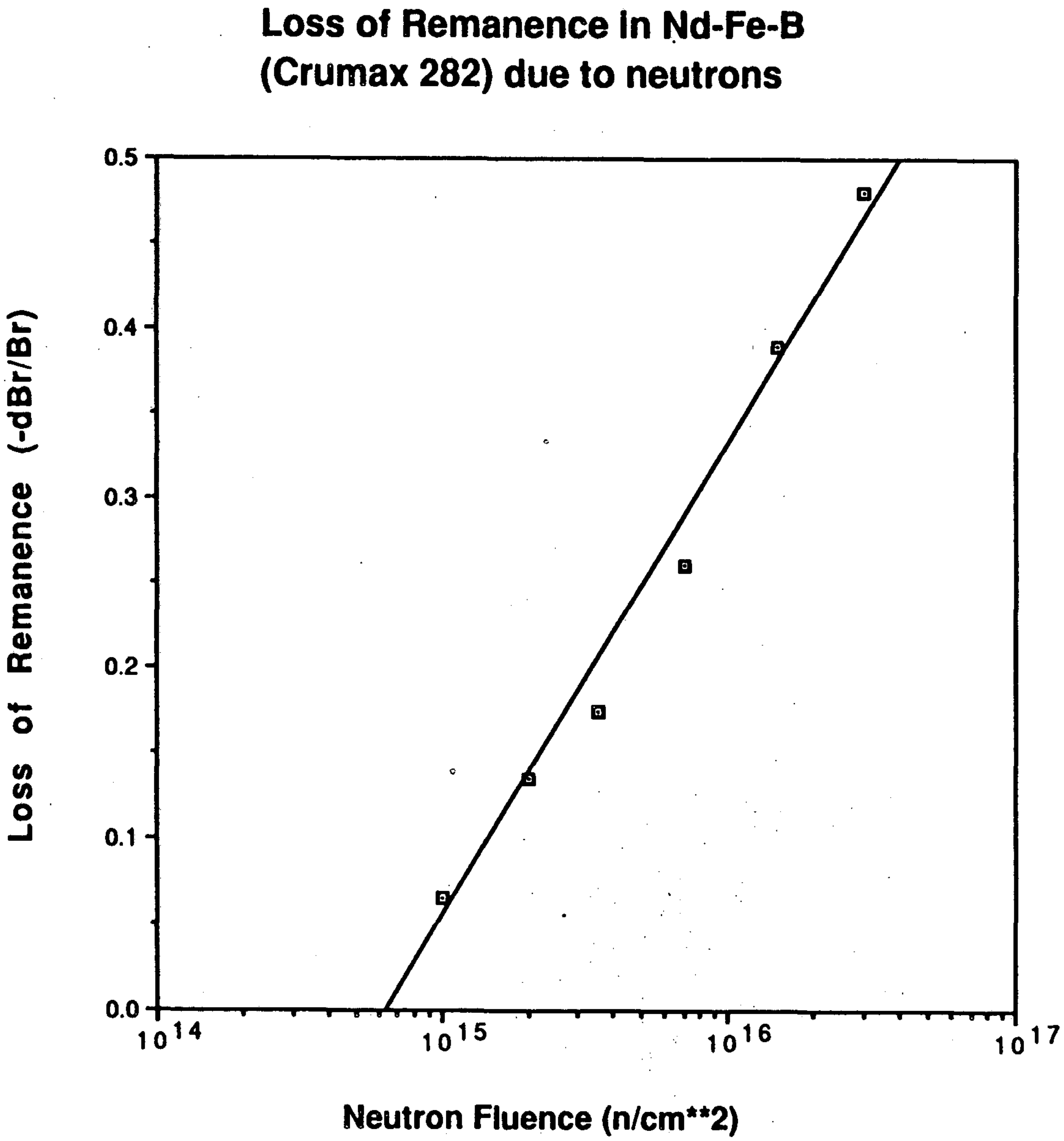

Loss of Remanence in Nd-Fe-B
(Crumax 282) due to neutrons
Loss of Remanence (-dBr/Br)
0.5
0.4
0.3
0.2
0.1
0.0
10^{14}
10^{15}
10^{16}
10^{17}
Neutron Fluence (n/cm**2)

Fig. 6

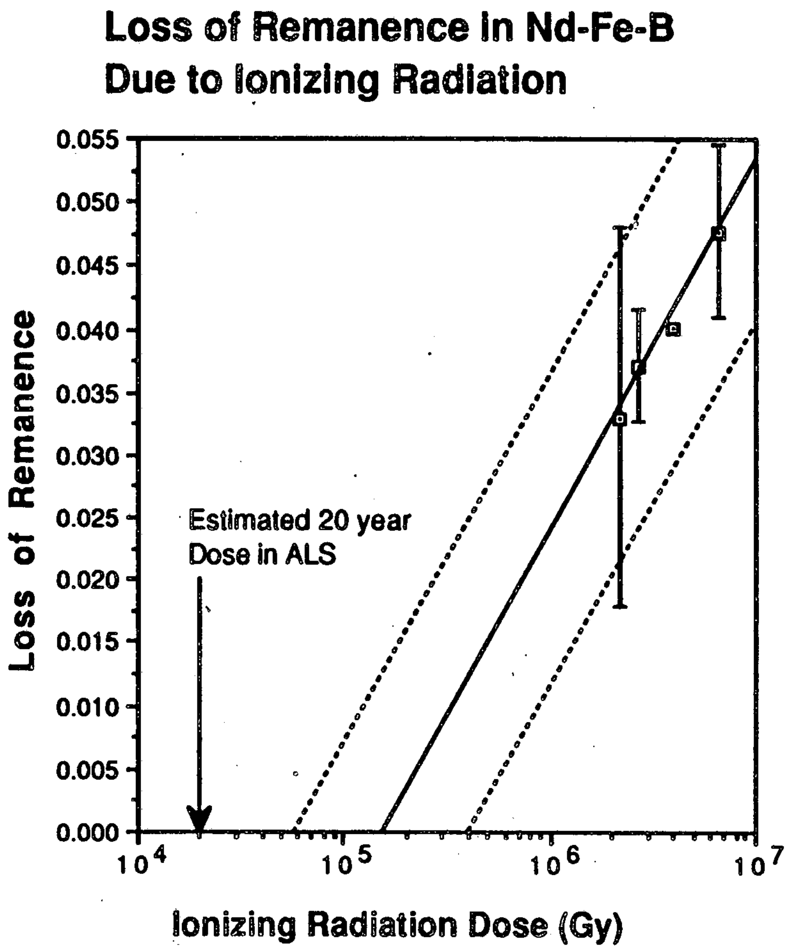

Loss of Remanence in Nd-Fe-B
Due to Ionizing Radiation
Loss of Remanence
0.055
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
Estimated 20 year
Dose in ALS
10^4
10^5
10^6
10^7
Ionizing Radiation Dose (Gy)

Fig. 7

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
1 CYCLOTRON ROAD
BERKELEY, CALIFORNIA 94720