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EFFECTS OF X-RAY RADIATION ON THE MAGNETIZATION OF HIGH T_c SUPERCONDUCTORS

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Abstract

Experimental results are presented on the effects of X-ray radiation on superconducting samples of polycrystalline YBaCuO and BiSrCaCuO. The radiation effects are detected by changes of the magnetization of the sample using a SQUID magnetometer. In the presence of radiation, the changes in magnetization correspond to release of trapped flux, fluxon destruction, and to low frequency noise due to flux flow.

I. INTRODUCTION

The interaction of high frequency electromagnetic radiation with a superconductor leads to interesting phenomena which deal with fundamental aspects of superconductivity. Such interaction can also be used for the detection of electromagnetic waves. This work presents preliminary results on the interaction of X-rays with high T_c superconductors.

The response of thin superconducting films to optical photons is mainly governed by the excitation of "phase slips." This is usually detected by current-biasing the film and measuring the voltage across it. Thin films are used so as to achieve fast response, high sensitivity, and to lead to more than just heating effects by scattering photons off Cooper pairs and creating quasiparticles. Josephson junctions can also be used for detecting optical and higher energy photons by measuring the change in the energy gap when energy is absorbed or by being switched. Since bulk high T_c superconductors are granular with all sorts of defects which act as Josephson junctions and which decouple thermally the grains, we have combined the above features to study the magnetic response of bulk granular samples. They are biased in a magnetic field and the response to X-ray radiation is monitored magnetically by a rf SQUID magnetometer.

In a regular type II superconductor flux starts to penetrate a sample at a field H_{c1} by creating fluxons. As the field is increased the number of fluxons also increases and this causes the diamagnetic magnetization of the sample to decrease. For a high T_c superconductor, the presence of grain boundaries, twins and other defects, leads to the formation of a random array of Josephson junctions and weak link bridges which allow the external magnetic field to penetrate at field values much less than the conventional H_{c1}. The magnetization of such samples was studied here in the presence of X-ray radiation.

II. EXPERIMENTAL DETAILS

We studied polycrystalline samples of $YBa_2Cu_3O_7$ and $Bi_2Sr_2Ca_2Cu_3O_x$. They were approximately 0.25" × 0.25" × 0.20" in shape. Magnetization measurements were taken in a rf SQUID magnetometer where the flux of the sample was coupled to a 6 turn coil with 1 cm id. This coil was part of a gradiometer with a baseline of 1.625". Shielding of the gradiometer was provided by a lead tube, 0.001" thick; this tube was also used to trap the magnetic field H in which the sample magnetization was established. The samples were cooled in magnetic fields ranging from the earth's field to 75 Gauss and magnetization measurements were made in each field at 4.2 K. Fig. 1 shows the experimental set-up. With the sample at 4.2 K, the magnetization was monitored as a beam of X-rays was sent on it. The X-ray dosage was increased by raising the accelerating voltage up to 250 kV. AT 200 kV the fluence was 2.7×10^6 photons/sec/cm^2. The source of X-rays was a model .

III. RESULTS

In the preliminary results reported here we have studied the low frequency response of the magnetization of high T_c sample to X-ray radiation. The magnetization as detected by the SQUID magnetometer was monitored at a given X-ray dosage. The X-ray dosage was varied by adjusting the accelerating voltage; measurements were made up to a maximum voltage of 250 kvolts. Computed photon energy spectra at the position of the sample show that the maximum number of photons was peaked at an energy of 50 keV. This is shown in Fig. 2 for different accelerating voltages.

The X-ray beam was sent through the Dewar onto the sample. To minimize absorption by the apparatus the lead shield around the sample was only 0.001" thick, and most of the Dewar was fabricated out of aluminum. After cooling the sample through T_c in a magnetic field, a magnetic field was trapped in the lead shield for establishing the sample magnetization.

Three main features were observed. First, the X-ray radiation produced sharp magnetization pulses. The number of pulses varied with the dosage. This is shown in Fig. 3 for accelerating voltages of 70 kvolts, 80 kvolts, and 90 kvolts; these changes were observed in a magnetizing field of 12 gauss for a BiSrCaCuO sample in the superconducting state at 4.2 K. The chart speed for Fig. 3 was 4 cm/minute and the SQUID magnetometer was operated with a low pass filter whose cut-off frequency was 100 Hz. After irradiation, a few pulses would appear but at a greatly reduced rate and they would persist for long times. An $YBa_2Cu_3O_7$ sample showed similar effects but of smaller magnitude. A magnetic field of 72 gauss had to be used to produce the same magnitude effects as in the bismuth compound in 12 gauss. This could be due to the large difference in the X-ray cross-section between bismuth and yttrium.

The second effect produced by the X-rays was a change in the dc magnetization of the sample which depended on the radiation dose. This is shown in Fig. 4 for an $YBa_2Cu_3O_7$ sample cooled in 48 gauss and whose magnetization was measured in 72 gauss. The figure also shows the third effect, which is a high frequency noise mixed with the pulses during radiation. Such noise has a large broad spectrum in the range of mHz to 100 Hz, which is the cut-off frequency of the magnetometer.

IV. DISCUSSION

Polycrystalline samples of high T_c superconductors have non uniform structures which consist of grains attached together by weak links which form Josephson junctions. In a magnetic field, the sample is in a mixed state as it is permeated by Abrikosov fluxons, trapped flux, and Josephson fluxons. Such a state of the sample is reflected in its magnetization. When high energy photons interact with the sample, Cooper pairs are destroyed creating quasiparticles; the excited quasiparticles recombine very quickly on a time scale much faster than the response of our magnetometer. The X-ray photons also produce heat locally and this destroys the superconducting currents associated with Abrikosov fluxons, Josephson fluxons, and trapped flux. Each type of current loop will have different spatial extent, ranging from the London penetration depth λ_L to the Josephson penetration depth λ_J and to that of the trapped flux. The latter, being associated with the longest time constant, is expected to be a dominant source of the pulses observed in our experiments; the Josephson junctions being also an important contribution since. The field of the trapped flux is in the same direction as the external magnetic field, it has a paramagnetic type of contribution; when it is destroyed the sample subsequently cools to the superconducting state expelling the flux and thus showing diamagnetic behavior. Such a mechanism can possibly explain the observed sharp pulses in the magnetization. The other current loops are also affected by the X-rays but because of their much faster decays, the magnetometer cannot respond. Since the sample in a magnetic field is in a glassy state, it is not surprising that the pulses continue to occur at a reduced rate after the X-rays perturbation has been switched off. The induced changes in magnetization can be attributed to local heating and rapid random flux motion and irreversibilities. This is supported by analysis of the noise spectral density in the magnetization during X-ray radiation.

Our results show that X-rays can be used to probe the flux state of bulk high T_c superconductors. Also, for a very limited bandwidth, we have shown that generated magnetization pulses due to flux expulsion from a granular high T_c superconductor are proportional to the X-ray dosage. With a much wider bandwidth and better time resolution, the various types of fluxons stored in a high T_c superconductor can be used as sensitive detectors of X-ray radiation.

V. ACKNOWLEDGEMENT.

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VI. REFERENCES

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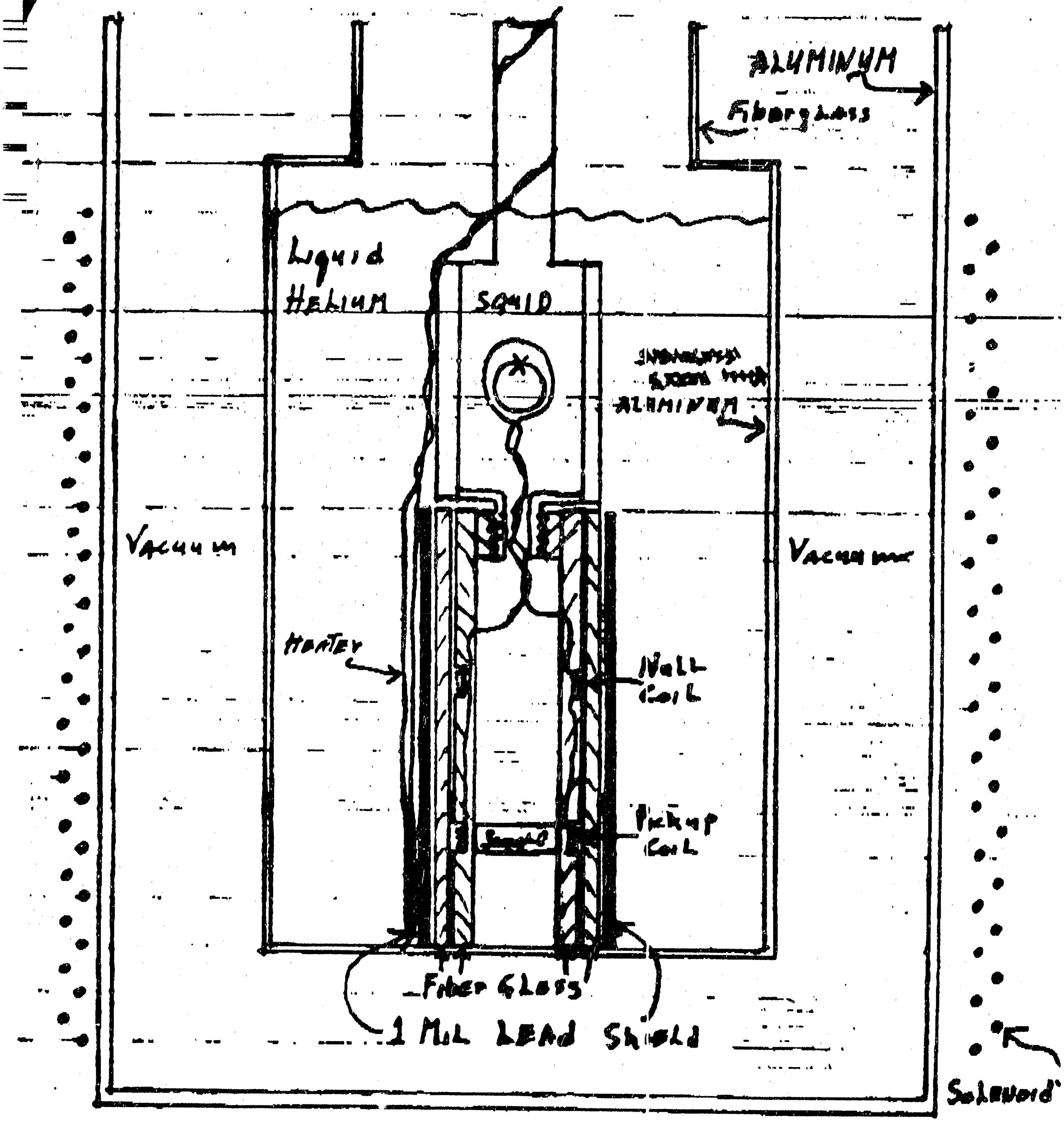
ALUMINUM
Fiberglass
Liquid
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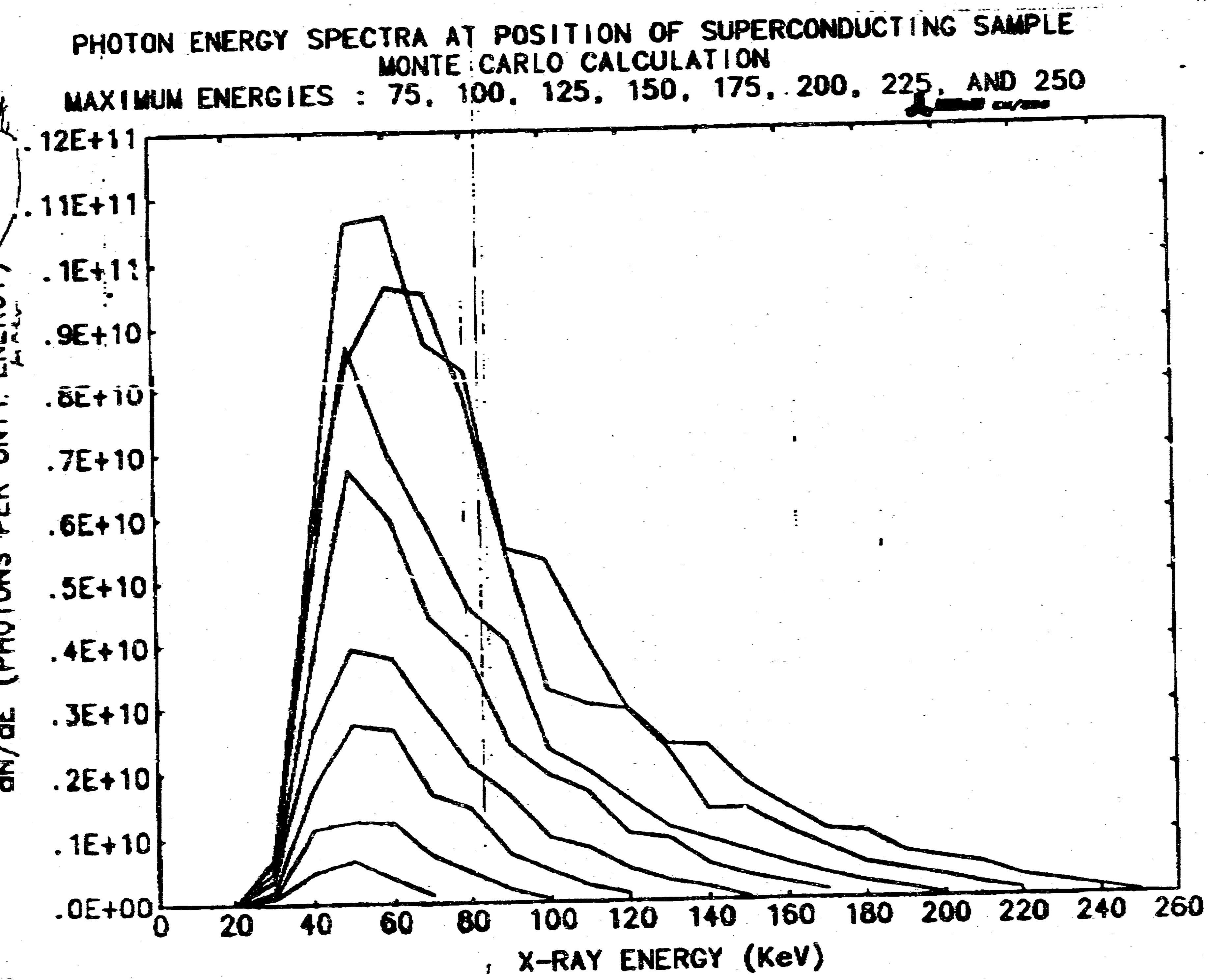
PHOTON ENERGY SPECTRA AT POSITION OF SUPERCONDUCTING SAMPLE
MONTE CARLO CALCULATION
MAXIMUM ENERGIES : 75, 100, 125, 150, 175, 200, 225, AND 250
dN/dE (PHOTONS PER UNIT ENERGY)
.12E+11
.11E+11
.1E+11
.9E+10
.8E+10
.7E+10
.6E+10
.5E+10
.4E+10
.3E+10
.2E+10
.1E+10
.0E+00
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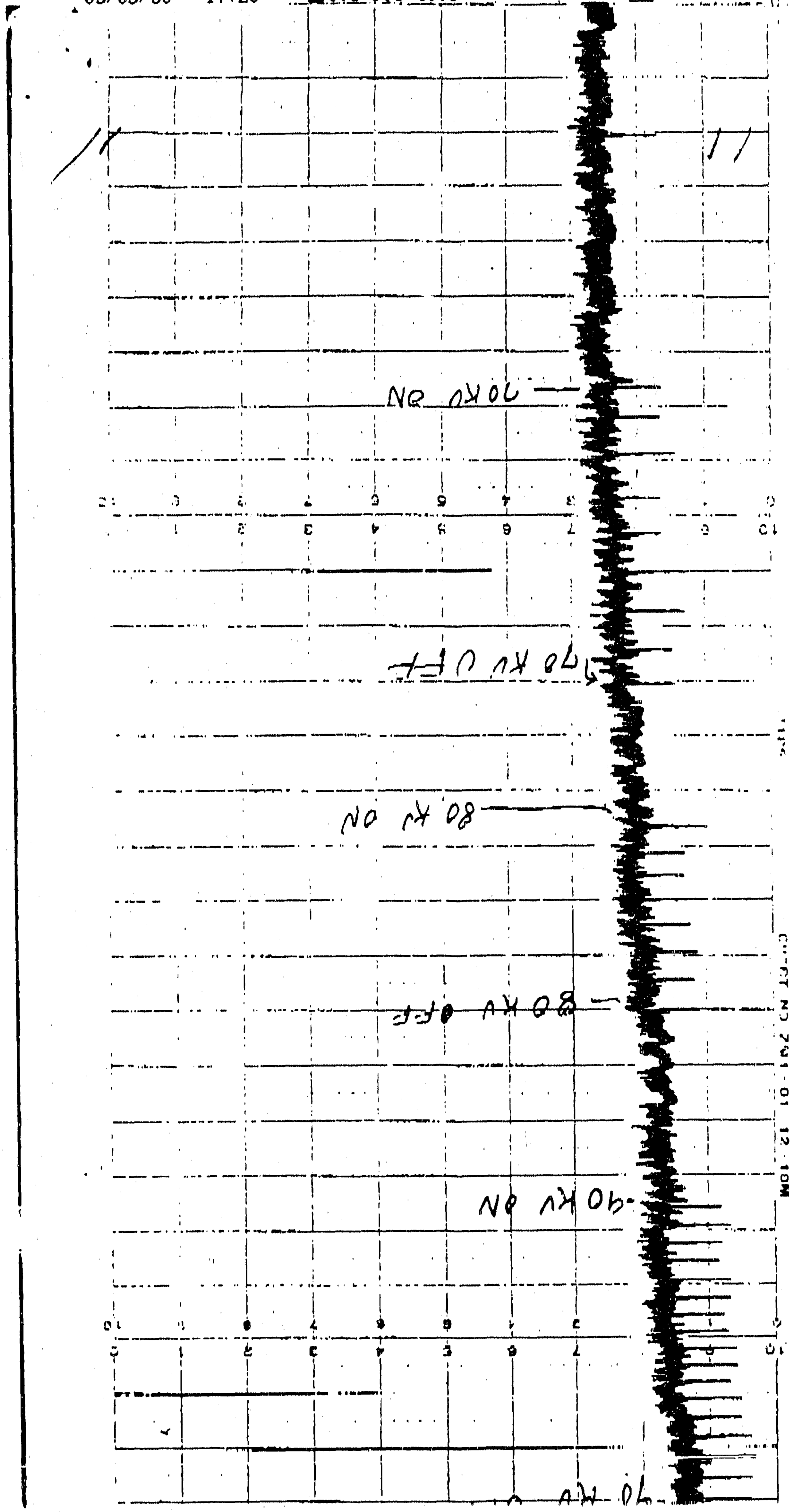
X-RAY ENERGY (KeV)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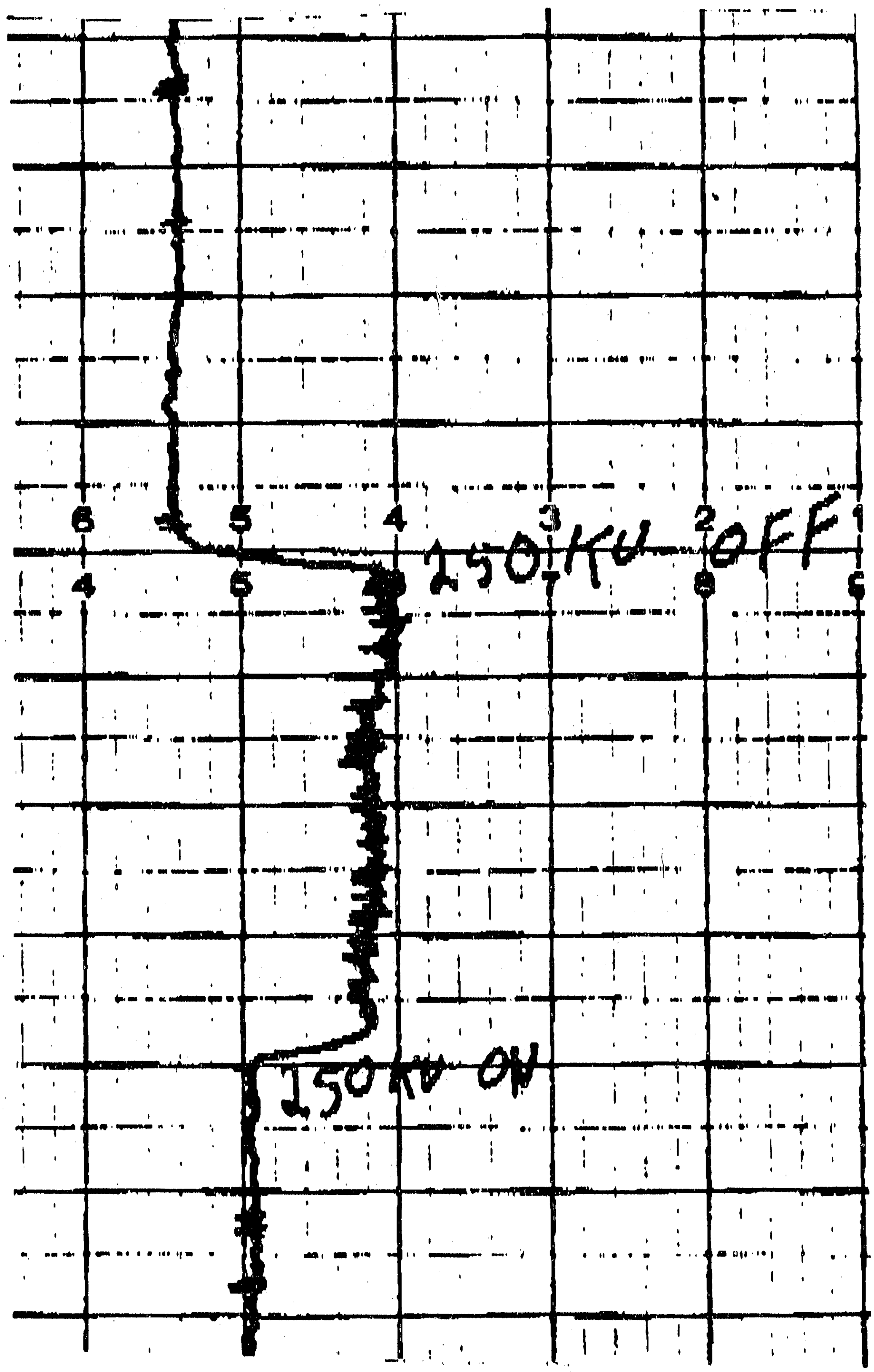
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250 KV OFF
150 KV ON

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