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SPECTRAL MEASUREMENTS OF HOT ELECTRONS FROM LASER-PRODUCED PLASMAS*

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ABSTRACT

Spectral measurements have been made of electrons emanating from CD_2 and LiD plasmas produced in the multiple-beam laser experiments at Sandia Laboratories. Spherical CD_2, LiD and LiDT pellets were irradiated in a tetrahedral geometry with energies up to 50 J/beam in one nsec from a Nd:glass laser system. The electron spectral measurements were done with a magnetic spectrometer in the energy range 50-160 keV. The spectra obtained are a monotonically decreasing function of intensity with increase in kinetic energy.

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INTRODUCTION

Only a relatively small number of papers are found in the open literature dealing with experimental determinations or theoretical calculations of the electron spectral emission from laser-produced plasmas. Yet, there has been a need to establish whether or not hot electrons are an important energy sink. Thus, one of the laser-plasma experiments done at Sandia Laboratories, in which spherical solid targets were irradiated in a tetrahedral geometry, addressed this subject. Spherical CD_2, LiD and LiDT targets were irradiated with the four beams from the Nd:glass laser system. The pellets ranged in diameter from 50 to 200 μm and were irradiated with a pulse of width equal to 0.97 nsec FWHM and of energy up to 50 J/beam. The maximum power density on the pellets was $\sim 10^{14}$ w/cm^2. In general, the pellets were irradiated in a background pressure of 2×10^{-7} Torr. However, data also were obtained using CD_2 targets in a background of deuterium gas ranging in pressure from 0.1 to 10 Torr.

LASER

The Sandia 4-beam laser system has already been described on other occasions and more will be said about it in a later paper. Thus, I will not discuss it here.

EXPERIMENTAL HARDWARE

Insofar as experimental hardware is concerned, the experiment was done by means of a magnetic spectrometer and PIN-diode solid state detectors. Slide I shows an overall view of the experiments chamber and includes the β-spectrometer. The distance from the plasma source at the center of the chamber to the entrance aperture of the spectrometer was about 65 cm. This aperture was 0.5 cm x 1.0 cm. The total distance from plasma source to detectors was approximately 1 meter. Slide 2 shows a close-up view of the unit (describe setup).

Slide 3. This slide shows a cross-sectional view of the β spectrometer. The overall size is 23 cm x 51 cm x 25 cm and contains about 50 lbs of magnets. The magnetic field, 128 gauss, is uniform to ~ 1 gauss over an area 15 cm x 33 cm, and the analyzing region is well within this area. Electrons and ions enter the magnetic field through the 0.5 cm^2 aperture. The ions proceed into a "get-lost" hole or an ion detector placed on a port directly across from the entrance aperture. Electrons, because of their lower magnetic rigidity, follow orbit paths, as given by well-known laws relating to magnetic fields and energetic charged particles, to the appropriate detector placed along a line parallel to and colinear with the entrance aperture. Ten detectors were utilized in the spectral measurements. Halfway along the orbit is placed an orbit-defining aperture 1 cm wide x 11 cm long.

The PIN diode detectors are very sensitive to electromagnetic radiation. Thus, a pinhole-free foil of Al, 0.2 μm thick was placed immediately before all the detectors to preclude light from the expanding plasma from getting to them. The effect of this Al foil was later taken into account in determining the β-intensity in each channel. A background detector of the same type but without a foil was located within the spectrometer.

This detector was exposed to scattered light but was out of reach of scattered electrons (indicate location). By placing, on alternate shots, a 350 G magnetic field perpendicular to a line through two beam-defining apertures prior to the entrance into the spectrometer, the background noise could be accounted for. Normally, signal to noise ratios of two were obtained.

RESULTS

Slide 4. This slide shows the relation found between relative β-signal/energy as a function of beta kinetic energy for a given shot. The target was a CD_2 pellet of diameter 100 μm and the total energy in the four beams going into the chamber was 130 J. The function is monotonic and shows a flattening in the high energy end, and indicates that there may be a substantial number of electrons of energy ≤ 50 keV.

Slide 5. This is a semilog plot similar to the last one. However, this is for an LiD sphere 95 μm in diameter. The energy absorbed was 85 J, as determined from recording the transmitted, scattered and reflected energies. Here is plotted relative intensity/energy versus kinetic energy. That is, the Al foil has been corrected for. The relation is also monotonic and indicates much higher numbers of betas below 50 keV than above.

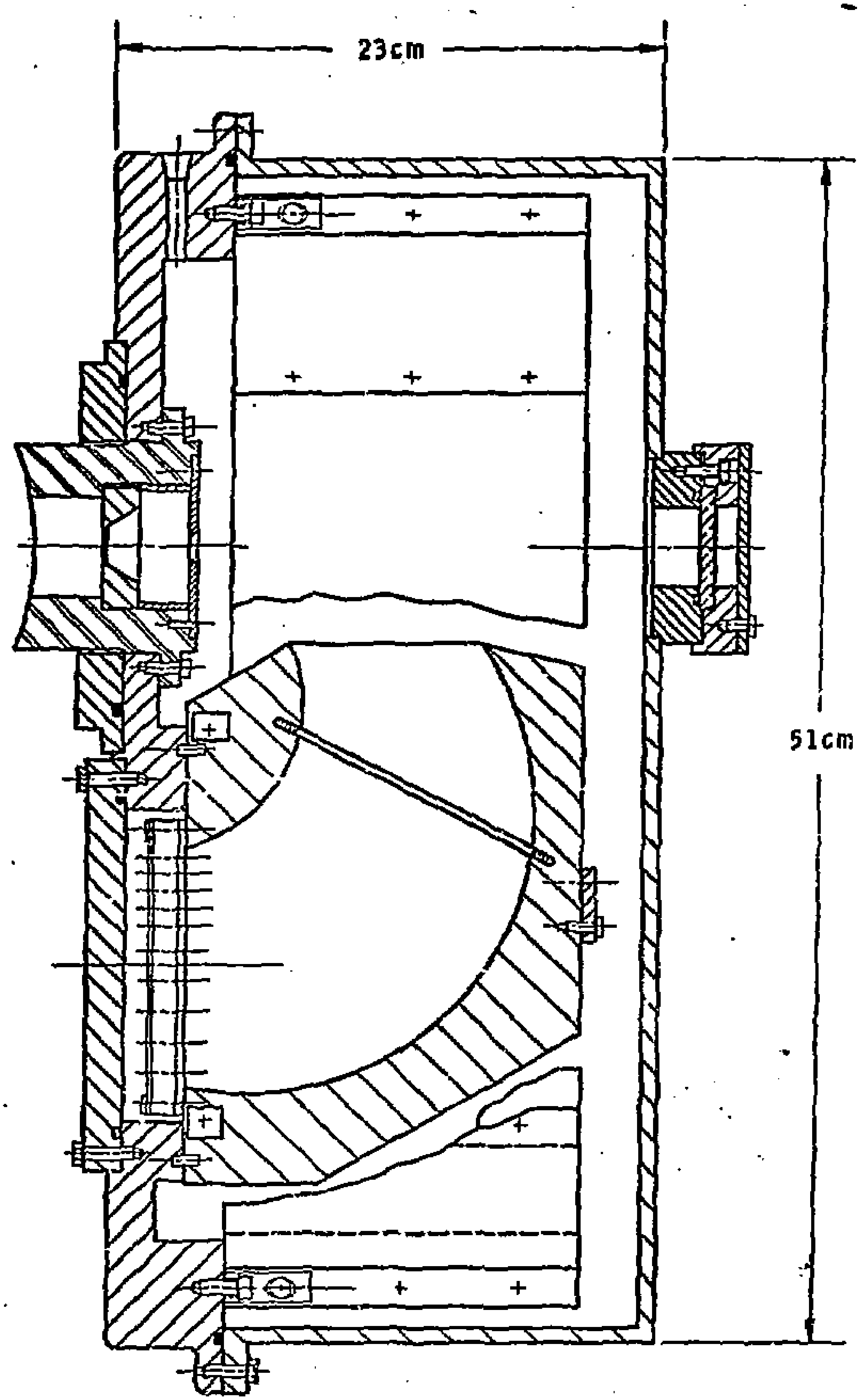
Slide 6. The three curves shown on this slide are for CD_2 targets. The one with the uncertainties indicated is the same one shown two slides back, but now corrected for the Al foil. The dominant effect of this was to raise the low energy end w/r to the high energy side. The other two lines are for CD_2 pellets irradiated in a deuterium background gas of pressure as indicated. The pellets were bigger than on previous shots shown and the energy absorbed was larger. Why the shape of the curves are different with and without a background gas is not known. The range of a 50 keV electron in a deuterium gas at 1.0 Torr is about 15 meters. Thus, in their path to the detectors 1 meter from the plasma source, the electrons lose < 10% of their energy to bremstrahlung and to background thermal electrons by coulomb collisions. Also, the fractional energy change for the lower energy electrons would be more than for the higher energy electrons. Thus, the curves should be similar.

By integrating the β-intensities/energy for a typical shot, it was established that the total number of betas coming from the laser-produced plasma in the energy range 50 to 150 keV, assuming isotropic emission, was of the order of 10^{10}. The total kinetic energy carried by these electrons, again assuming isotropy, was ~ 1 mj of the absorbed energy. It must be mentioned that hot electrons did not occur on every shot. In fact, they appeared in only about 1/2 of the shots for CD_2 and about 1/3 for LiD, and not at all for LiDT.

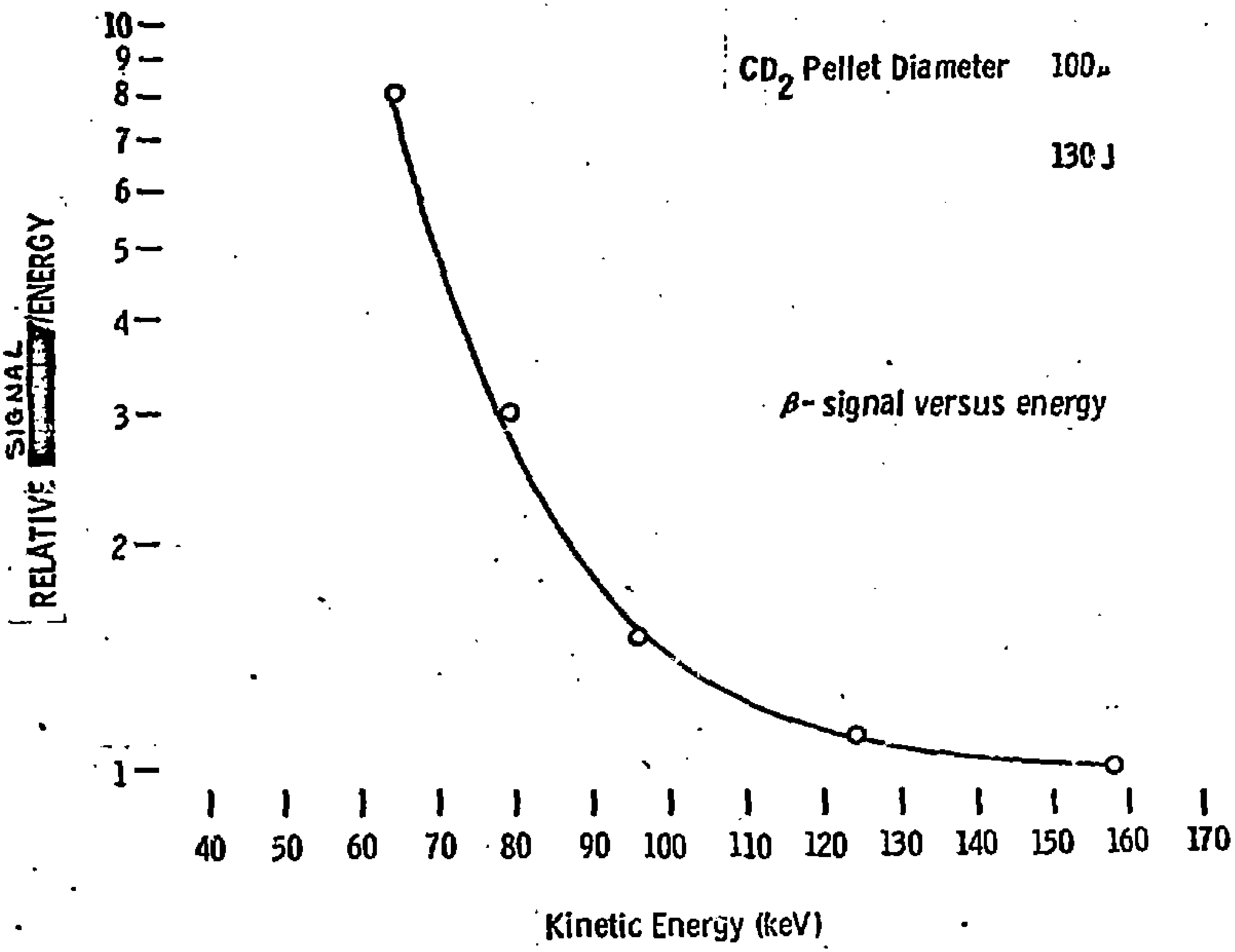
In summary and conclusion, spectral measurements were made of electrons emanating from CD_2 and LiD laser-produced plasmas. No electrons in this energy range were observed coming from LiDT and only in about 1/2 of the shots for CD_2 and 1/3 for LiD. Possible reasons for this are nonuniformities in the four beam intensities, but more probably it was due to oxygen and other impurities, as Ar, in LiD and LiDT as preparation of the pellets for irradiation was done in an Ar atmosphere.

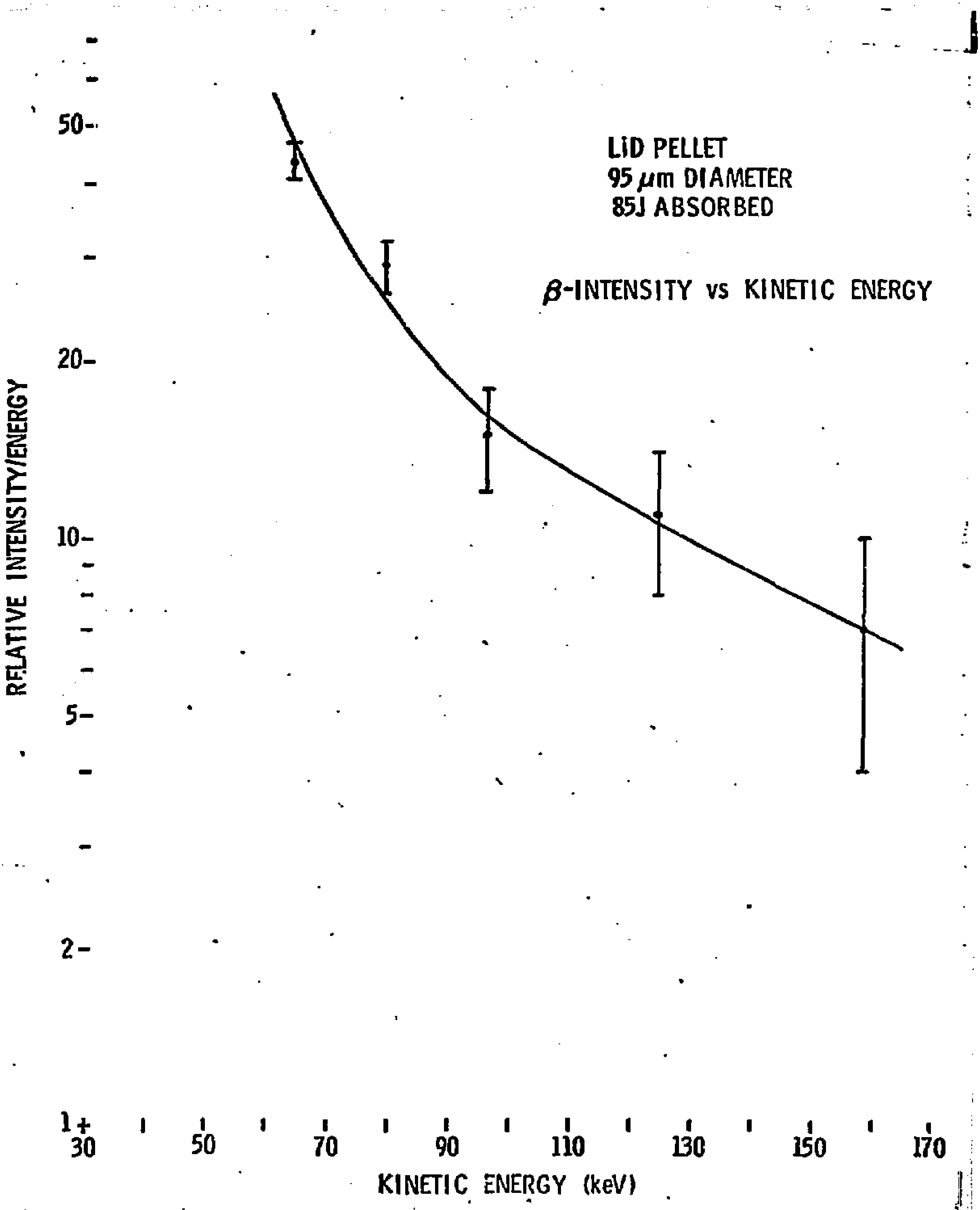
The spectra are a monotonically decreasing function of intensity with increase in kinetic energy. In some cases, the distribution appears much like the high energy tail of a Maxwell distribution. The total number of electrons ejected into 4π in the energy range studied was of order 10^{10} and contained only ~ 1 mJ of the absorbed energy.

Finally, although hot-electron spectral information has been obtained in about 20 shots, it must still be considered preliminary data.

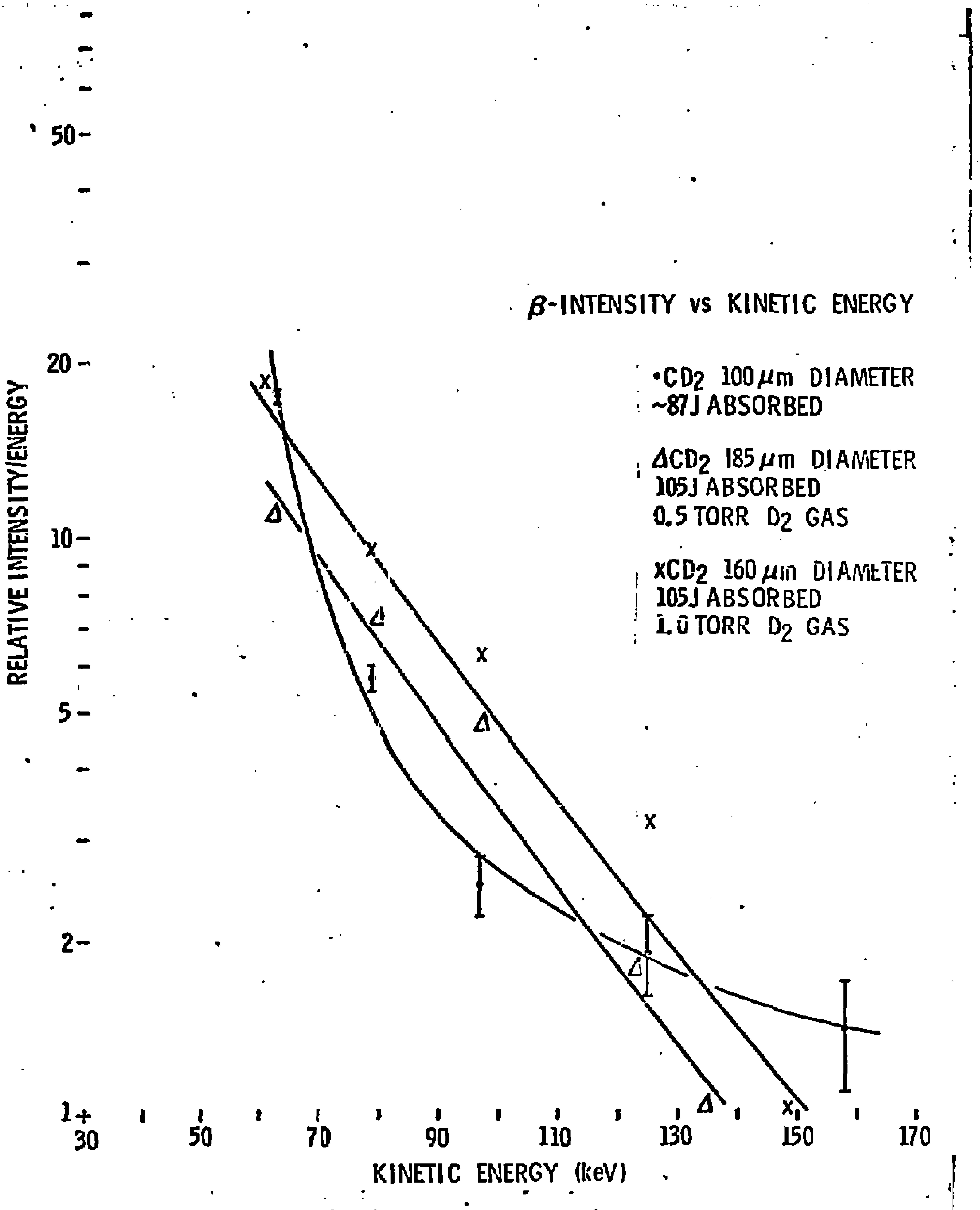


SECTIONAL VIEW OF BETA SPECTROMETER


RELATIVE SIGNAL [redacted] /ENERGY
10
9
8
7
6
5
4
3
2
1
40 50 60 70 80 90 100 110 120 130 140 150 160 170
Kinetic Energy (keV)
CD_2 Pellet Diameter 100μ
130 J
β- signal versus energy



LiD PELLET
95 μm DIAMETER
85J ABSORBED
β-INTENSITY vs KINETIC ENERGY
RELATIVE INTENSITY/ENERGY
50
20
10
5
2
1
30
50
70
90
110
130
150
170
KINETIC ENERGY (keV)


β-INTENSITY vs KINETIC ENERGY
•CD2 100 μm DIAMETER
~87J ABSORBED
ΔCD2 185 μm DIAMETER
105J ABSORBED
0.5 TORR D2 GAS
xCD2 160 μm DIAMETER
105J ABSORBED
1.0 TORR D2 GAS
RELATIVE INTENSITY/ENERGY
50
20
10
5
2
1
30
50
70
90
110
130
150
170
KINETIC ENERGY (keV)