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THE RATIO OF ELECTRO- TO PHOTO-PRODUCTION IN THE 3 - 16 GeV ENERGY REGION

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Introduction

The interaction of incident electrons, positrons and photons with aluminum produces ^{24}Na by the (e,e$'$^{3}He) or (γ, ^{3}He) processes. At lower energies in the 11 to 360 MeV region the photo-production per equivalent quanta cross section is much larger than the electro-production cross section. The ratio decreases with an increase in energy so a measurement was necessary in the GeV region to establish the relative importance of these production processes. When a series of relatively thin metal sheets in a stack are placed in the beam of electrons, the first plate produces radioactive products almost entirely due to electro-production processes with a buildup of activity due to the additional contribution of the photons produced by the bremsstrahlung process in plates deeper in the stack. With a stack of aluminum sheets it is possible to measure the induced radioactivity quite conveniently by detecting the gamma rays from the 15 h ^{24}Na decay. By extrapolating back to the entrance to the stack, an electron only measurement can be derived.

The Measurement

Two stacks of aluminum have been used for these measurements consisting of sheets each about 12.7 cm square and .000705 radiation lengths (.00635 cm) thick. Table I lists the irradiation that were made including two using stacks smaller in diameter than the aluminum plate series.

Each of the irradiation of group I were made down stream of another experiment with hydrogen targets and associated windows of about .03 radiation lengths in the beam. As the angular distribution of electrons and photons leaving these targets differ, the exact contamination of the electron beam at the aluminum target stack is not known. No corrections have been introduced for the photon component which could only reduce the value of the ratio determined.

The radioactivity measurements were made using a 20 cc Ge(Li) gamma ray spectrometer with a 1600 channel pulse height analyzer. Care was taken to position the samples in a consistent manner and time the measurements with a live timer so that corrections for radioactive decay could be calculated accurately. One set of data has been plotted in Figure 1, typical in principle, the best in practice. Each point represents a 10.0 minute count of the total of all channels above the 511 keV photopeak. Figure 2 shows the decay of activity in two of the sheets. The background is less than 0.3% for these samples so no subtraction was required. The data is seen to fit the ^{24}Na 15.0 hour decay lines very well so that it is quite safe to assume that no activity from other nuclides contribute significantly to the counts measured here.

The data from the 7.91 and 13.3 GeV aluminum stacks was similarly convincing.

The data obtained for the 3.0 GeV aluminum stack was not as complete. In addition the beam size, as measured by the darkening of red plexiglass irradiated behind the aluminum stack, was quite broad in this case. Edge effects have not been evaluated but might effect this lower energy run as well as both irradiations using smaller discs of copper, iron, and nickel along with the aluminum. The beam spot measurements taken with a densitometer are shown in Figure 3.

The 10 GeV data was least complete in the measurements taken and shows an internal inconsistency which it has not been possible to account for.

The results of the six measured F ratios are plotted in Figure 4 along with data derived from the work of Barber[1], Barber and Wielding[2] at lower energies and Fulmer[3] at 3 GeV. To emphasize the poorer quality of three of the points reported here, they have been shown as square points.

The Calculations

Using the notation of Barber[1] the quantity $F = (N_\gamma/tN_e)\ 4\ \ln(183\ Z^{-1/3})/137$ where the counts N_γ and N_e are due to the x-ray and electron induced activity respectively, the thickness t is measured in radiation lengths and Z is the atomic number of the stack material. For aluminum this becomes $F = .1273\ N_\gamma/t\ N_e$, and for the other stack used $F = .1196\ N_\gamma/t\ N_e$.

Discussion

The statistical precision of the radioactivity measurements is far greater than the accuracy. This may be due to 1) positioning of the samples during irradiation and measurement, 2) nonuniformity in the sample thickness, 3) background variation during measurement, 4) measuring system gain or base line changes, 5) edge effects due to broad beams, 6) photon or neutron flux accompanying the incident electrons, or 7) back scattering of high energy photons into the samples.

In addition there may be a more complicated atomic mass dependence than implied by the expression for k used by Barber. This point could be measured in a separate experiment using larger diameter metal samples with intervening materials of several different Z values.

Acknowledgements

This project was pursued at the suggestion of C. B. Fulmer. Ted Jenkins performed some of the irradiations and participated in a number of fruitful discussions. Al Rossell assisted in the data taking. We are grateful.

References

1. W. C. Barber and T. Wiedling, Nuclear Phys. 18, 575 (1960).

2. W. C Barber, Phys. Rev. 111, 1642 (1958).

3. C. B. Fulmer, Private communication.

Captions

1. Counts vs. aluminum sheet number for the 16.0 GeV electron case. Counts accumulated in channels 254 to 1600 have been accumulated for 10 minutes for each case with a calculated decay correction applied.

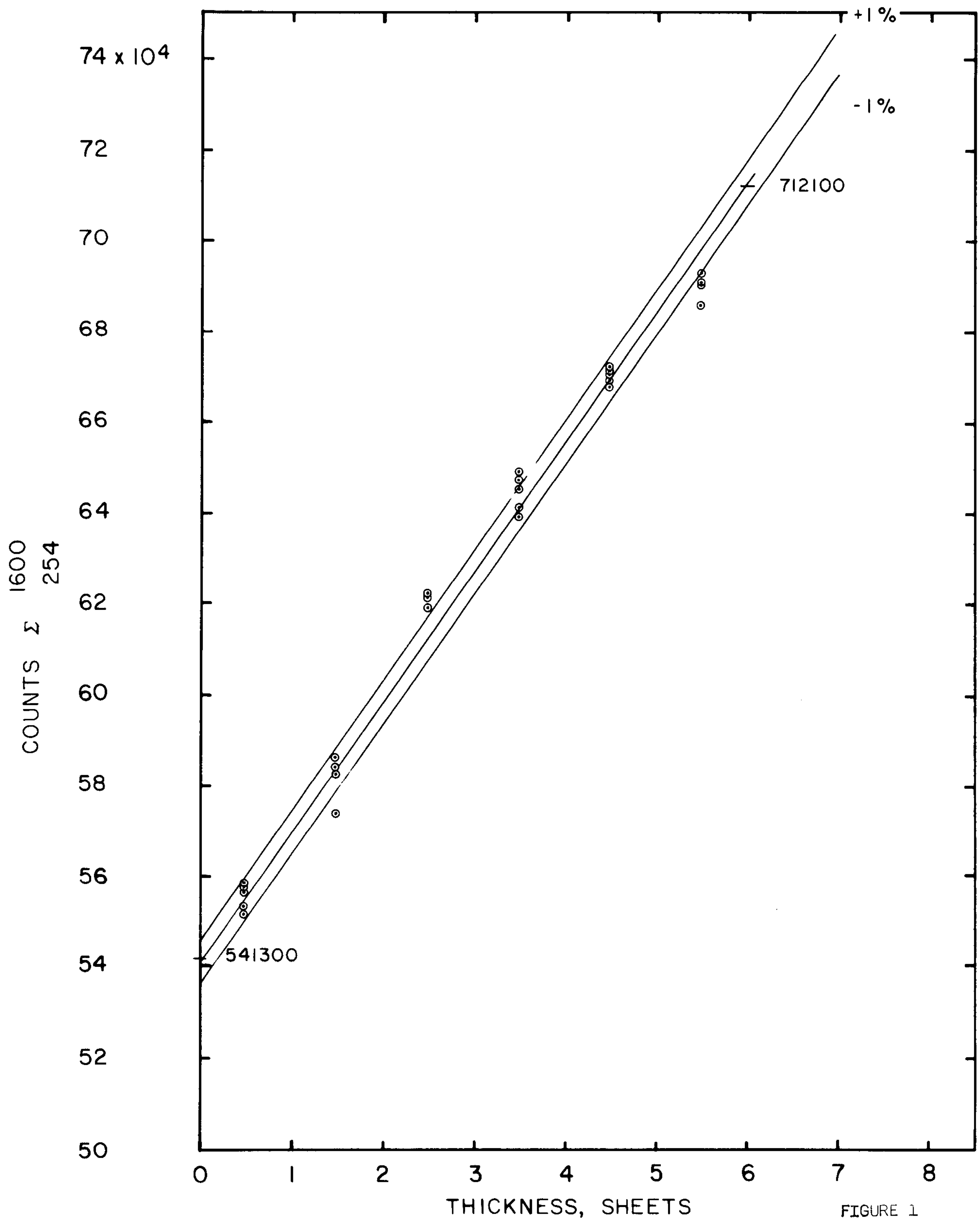
2. The decay of counts taken during a 10-minute period for the front and rear aluminum sheets. The straight lines have slopes corresponding to the 15.0-hour half-life of ^{24}Na.

3. The spatial distribution of electrons incident on the samples of aluminum as measured by a microdensitometer measurement of the darkening of red plexiglass sheets placed behind the samples. The vertical scale is arbitrary and varies from samples to sample.

4. F values as measured by a number of experiments: ✖ $^{12}C(\gamma,n)\ ^{11}C$ and ⊙ $^{19}F(\gamma,2p)\ ^{17}N$ by Barber; ▲ $^{181}Ta(\gamma,n)\ ^{180}Ta$, ⊡ $^{181}Ta(\gamma,3n)\ ^{178}Ta$ 9.3m, ◇ $^{181}Ta\ (\gamma,3n)\ ^{178}Ta$ 2.1h by Barber and Weidling; ⊕ $^{27}Al(\gamma,^{3}He)\ ^{24}Na$ by Fulmer; ■ this report limited accuracy and ● this report. The curved line has been drawn in as an arbitrary fit to the experimental data.

TABLE I: LIST OF IRRADIATIONS

	Energy-GeV	Stack Material	F
Group 1	3.00	Al (201-207)	0.694
	7.91	Al (101-106)	0.912
	13.3	Al (201-207)	0.918
	16.0	Al (101-106)	0.935
Group 2	10.0	Al, Ni, Cu, Fe, Al	0.57
			1.50
	13.3	Al, Cu, Ni, Fe, Cu, Al	0.685



74 x 10^4
72
70
68
66
64
62
60
58
56
54
52
50
COUNTS Σ 254 1600
0
1
2
3
4
5
6
7
8
THICKNESS, SHEETS
+1%
-1%
712100
541300

FIGURE 1

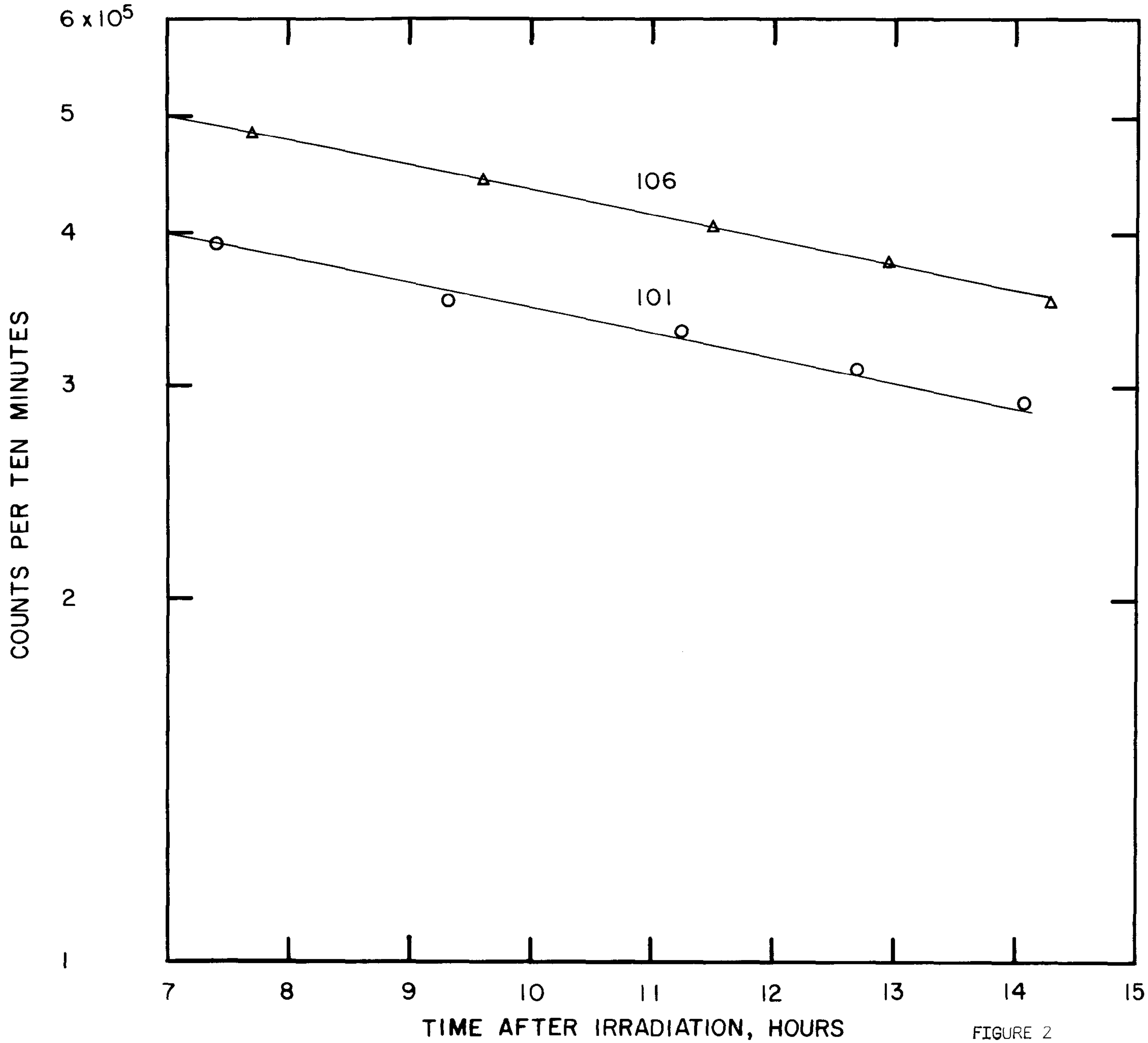

6 x 10^5
5
4
3
2
1
COUNTS PER TEN MINUTES
106
101
7
8
9
10
11
12
13
14
15
TIME AFTER IRRADIATION, HOURS

FIGURE 2

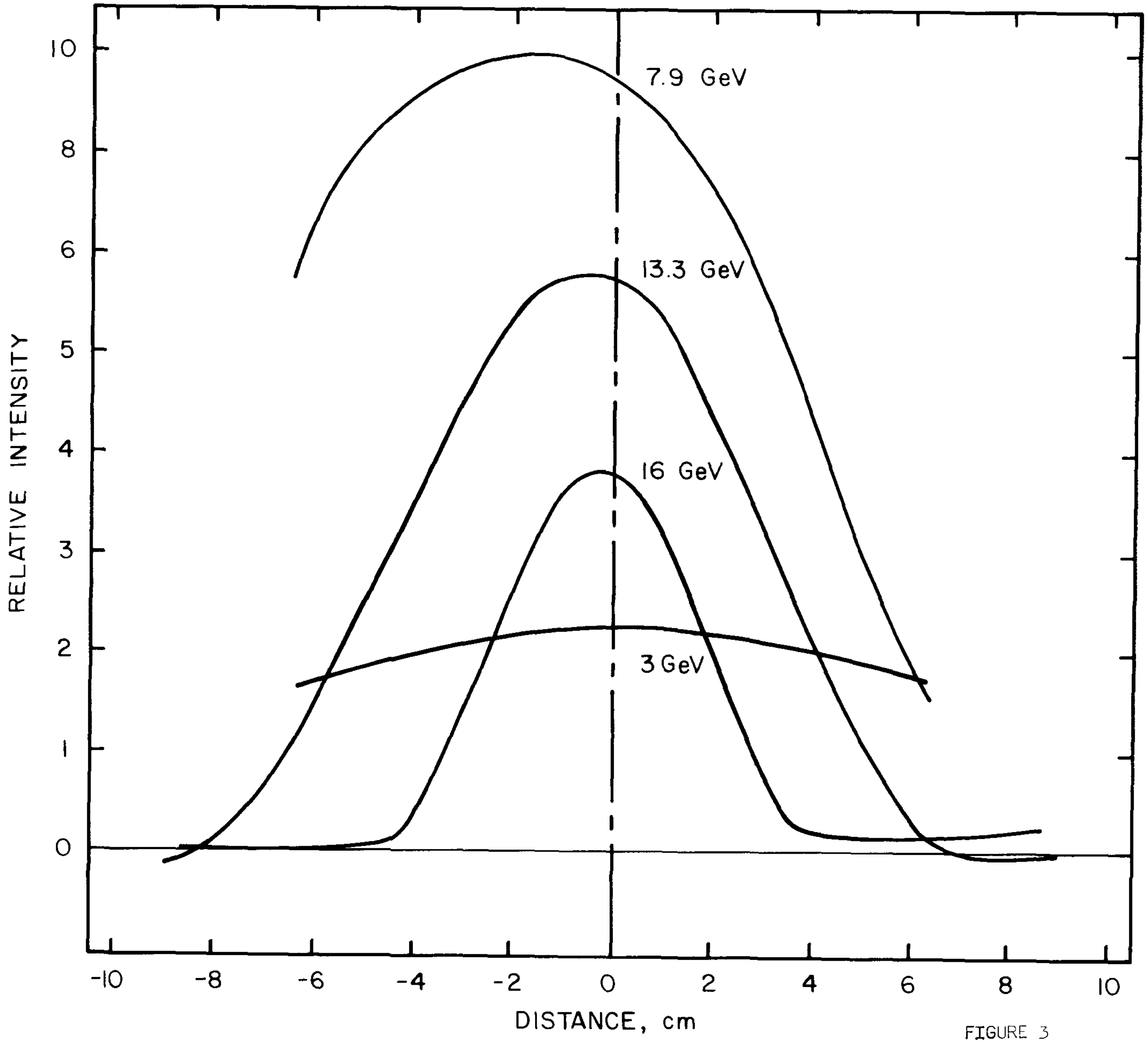

7.9 GeV
13.3 GeV
16 GeV
3 GeV
RELATIVE INTENSITY
DISTANCE, cm
10
8
6
5
4
3
2
1
0
-10
-8
-6
-4
-2
0
2
4
6
8
10

FIGURE 3

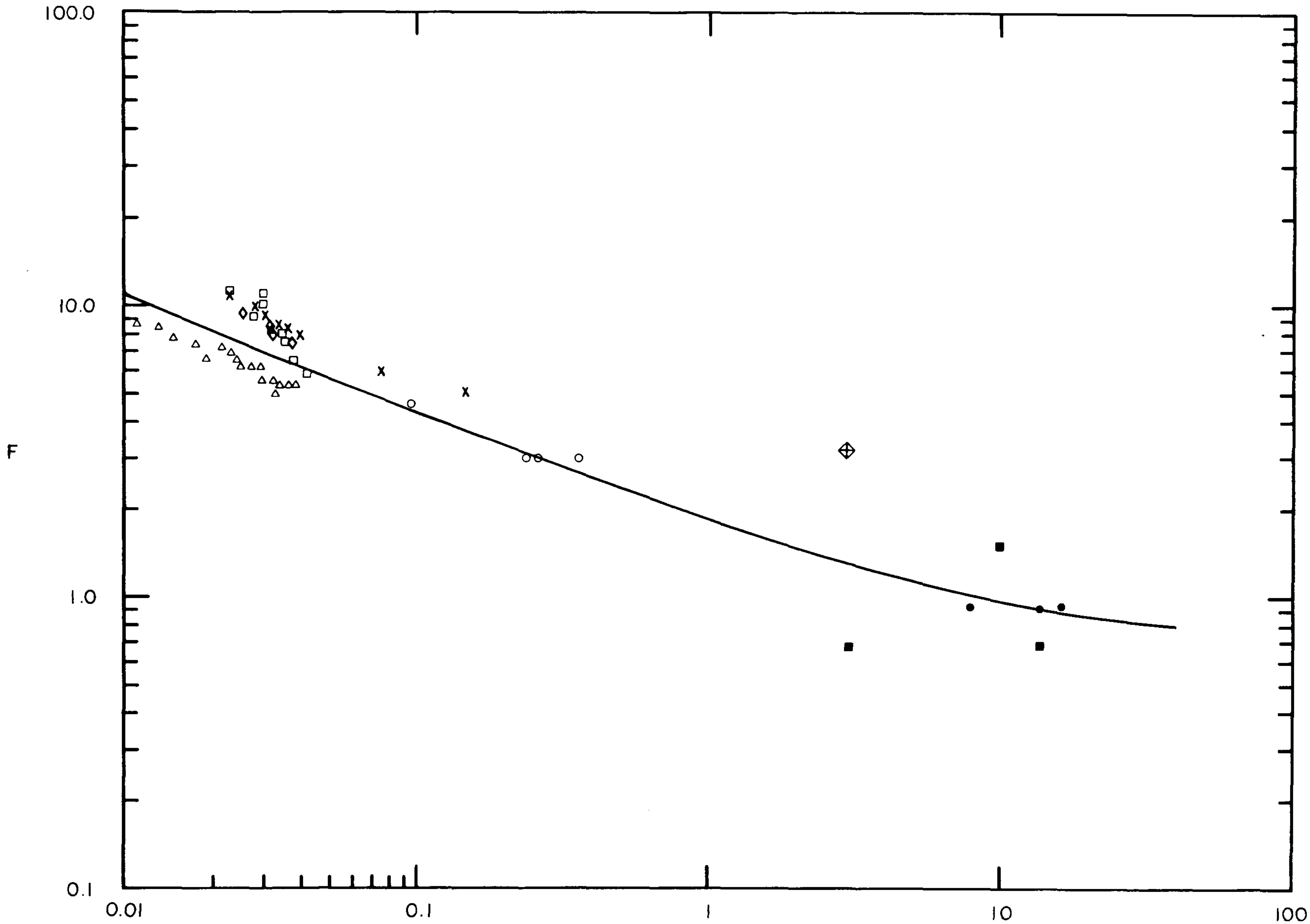


FIGURE 4