Particle Albedo from Hadrons of 100 to 1000 GeV Interacting in a Calorimeter†

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Abstract

Characteristics of particles emitted backwards from high energy hadrons interacting in a calorimeter are described. It is shown that there exist a substantial flux of backward particles from hadrons when their first interaction point in the calorimeter is confined to the first interaction length in the calorimeter. The average yield of this albedo appears to increase logarithmically with energy of the hadrons going from 100 to 1000 GeV.

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The study of albedo from calorimeters reported in this short note was carried out using single cosmic ray hadrons with energies between 100 and 2000 GeV interacting in the University of Maryland's calorimeter operated at 2900 meters near Sunspot, New Mexico.

The experimental arrangement is shown in Figure 1. The calorimeter[1] has a cross sectional area of $4m^2$ and a depth of about 1000 gms/cm^2 of iron. The nuclear-electromagnetic cascade generated by the hadrons is sampled by liquid scintillators[2], S1 thru S14 thickness of 7 cm of liquid at seven different depths (1λ, 2λ, 3λ, 4λ, 5λ, 6λ, and 8λ). Three wide gap spark chambers SC1, SC2 and SC3 are embedded in the calorimeter at depths of 1λ, 3λ and 6λ for visual identification and reconstruction of hadron jets. In addition, there is a double gap spark chamber, called SCB, to identify the incoming track. A 1/2" thick plastic scintillator T1 is placed below SCB and above the first iron layer of the calorimeter. All scintillators are calibrated in terms of pulse height corresponding to single muons.

The calorimeter is triggered by requiring that the sum signal from S1 thru S14 is greater than a preset threshold and there is a coincidence of CAL signed with T1. All pulse heights from S1 thru S14 and T1 are dignitized and recorded on tape. The spark chamber (photographed in 15° stereo) pictures are examined to select single charged hadrons (SHC) which have a configuration such that there is a single jet in the calorimeter and the jet reconstructs to line up with a beam track in SCB. We accept non-parallel full or half tracks in SCB in this definition.

In figure 2 we show cascade curves for hadrons with average energy of 150 GeV, 600 GeV and 1100 GeV. The point of first interaction is restricted in these events to be in first layer or iron. The energy calibration is done using a Monte-Carlo calculation done for us by W. V. Jones[3]. In figure 3 we compare experimental cascade curve determined in our calorimeter at 290 GeV with that measured by Barish, et al,[4] at Fermilab at 200 GeV and the calculation by W. V. Jones. The agreement is very satisfactory. Our energy resolution is $\sim$ 18% from 300 to 1000 GeV and slowly decreasing.

To study albedo coming upwards we examine the pulse height of the plastic counter T1 as a function of

(a) depth of the point of first interaction in the calorimeter,

(b) energy of the hadron.

In Figure 4 are shown T1 pulse height distributions for hadrons interacting iron layer 1 and iron layer 2; for low and high energy hadrons: - $\langle E \rangle$ = 160 GeV and $\langle E \rangle$ = 1400 GeV. Two observations can be made: (i)The existence of a high pulse height tail for Fe1 events as compared to Fe2 events at both low and high energy, and (ii) The average pulse height increases with energy. Both these effects are more clearly displayed in Figures 5 and 6. Figure 5 shows that once the point of first interaction is below second layer of iron the albedo is negligible at all energies. Figure 6 shows that the average T1 pulse height for Fe1 events is consistent with a log E increase between 100 and 1000 GeV. In using a calorimeter to detect hadrons at hundreds of GeV one should be aware of the existence of this albedo.

A more difficult question is to determine the nature of these backward particles. Some of these must be charged fragments or evaporation particles from target fragmentation. This is visually established by noting how many of the hadrons have associated inclined tracks or half tracks in SCB. This number is shown in figure 7 as a function of energy. It is seen that about 40 to 50% of all Fe1 events have some indication of calorimeter associated particles in SCB. These particles should be prompt. Is there a sizable "slow"neutron flux which makes signals in T1? We are investigating this by time digitizing the T1 pulse with respect to the hadron. T1 consists of two section, each $2m^2$ in area. By knowing in which section the hadron went, and examining the time delay of the other section of T1, we may get a handle on how many neutrons there may be.

In conclusion, we have observed a albedo from hadron interactions in a calorimeter which is energy dependent. Experiments which use counters to identify point of first interaction in using survival method to determine λ must take care to avoid systematics due to this albedo.

We would like to thank Drs. M. LaPointe, J. R. Wayland and P. MacKeown, who participated in t he design and construction of the calorimeter.

References

1. F. Siohan, et al, 13th International Conference on Cosmic Rays, Denver (1973), Conference Papers vol. 3, page 2121 (HE-236).

2. These counters are uniform to better than ±5% and are described in M. . LaPointe, et al, Nuclear Inst. and Methods 72, 173 (1969).

3. W. V. Jones kindly simulated the performance of our calorimeter, private communication.

4. B. Barish, et al, Calif. Institute of Technology Report No. 68-410 September 1973.

Figures

CALORIMETER

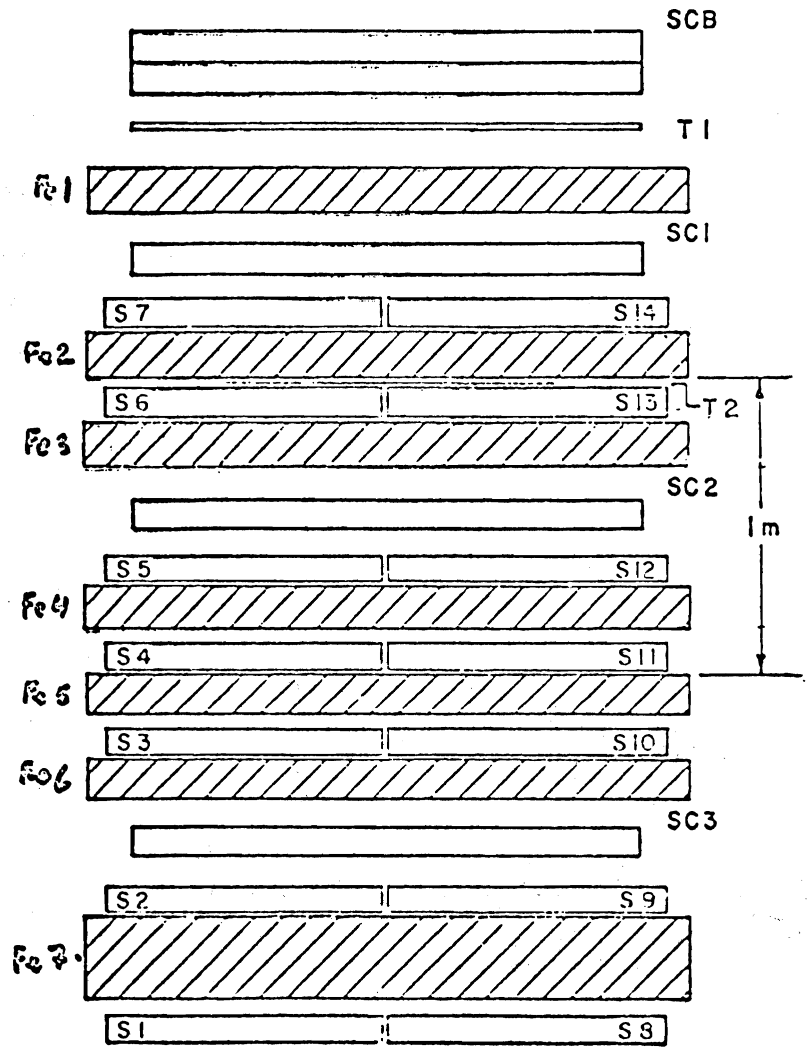


Fig. 1

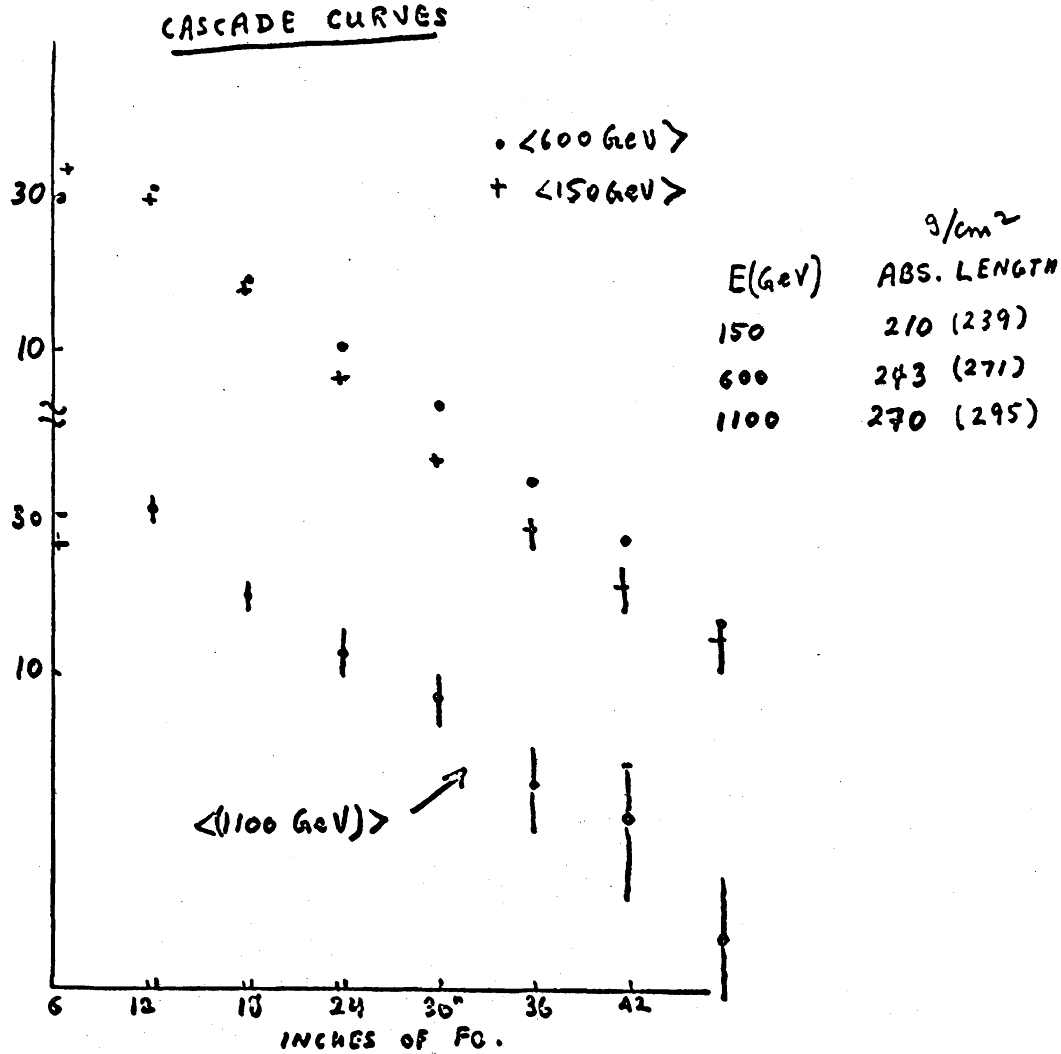

CASCADE CURVES
• <600 GeV>
+ <150 GeV>
g/cm²
E(GeV) ABS. LENGTH
150 210 (239)
600 243 (271)
1100 270 (295)
<(1100 GeV)>
30
10
30
10
6 12 18 24 30" 36 42
INCHES OF FC.

Fig. 2

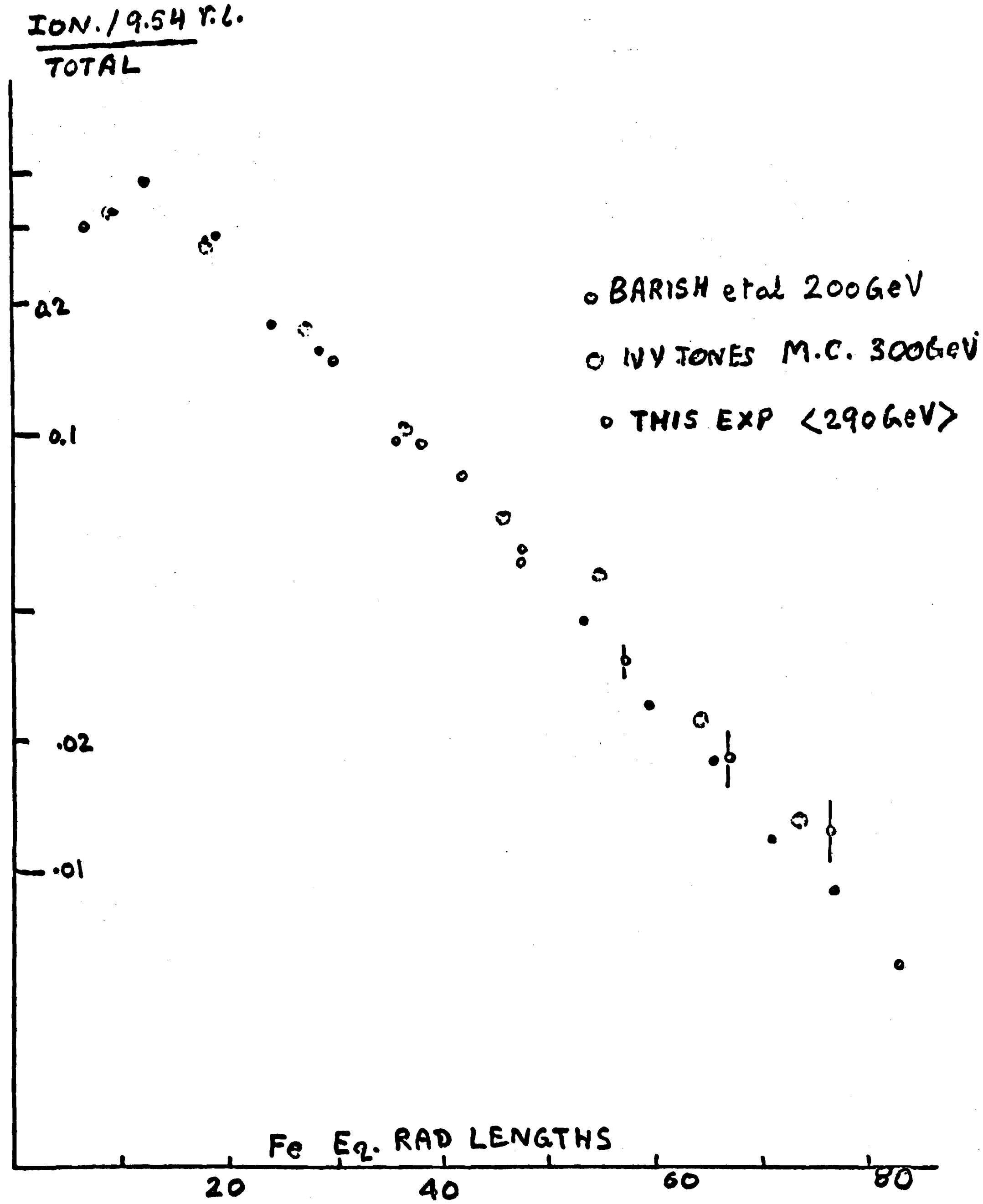
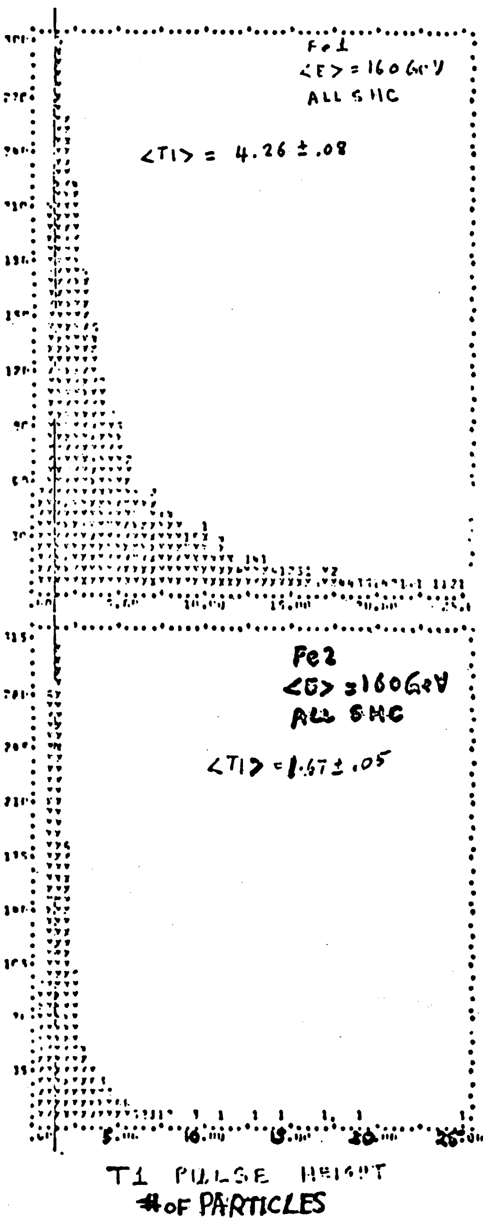

ION./9.54 r.l.
TOTAL
0.2
0.1
.02
.01
BARISH et al 200GeV
NV JONES M.C. 300GeV
THIS EXP <290GeV>
Fe Eq. RAD LENGTHS
20
40
60
80

Fig. 3


Fe1
<E> = 160 GeV
ALL SHC
<T1> = 4.26 ± .08
Fe2
<E> = 160 GeV
ALL SHC
<T1> = 1.67 ± .05
T1 PULSE HEIGHT
OF PARTICLES

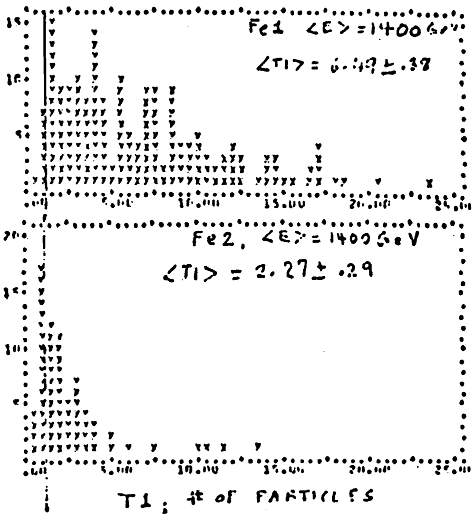
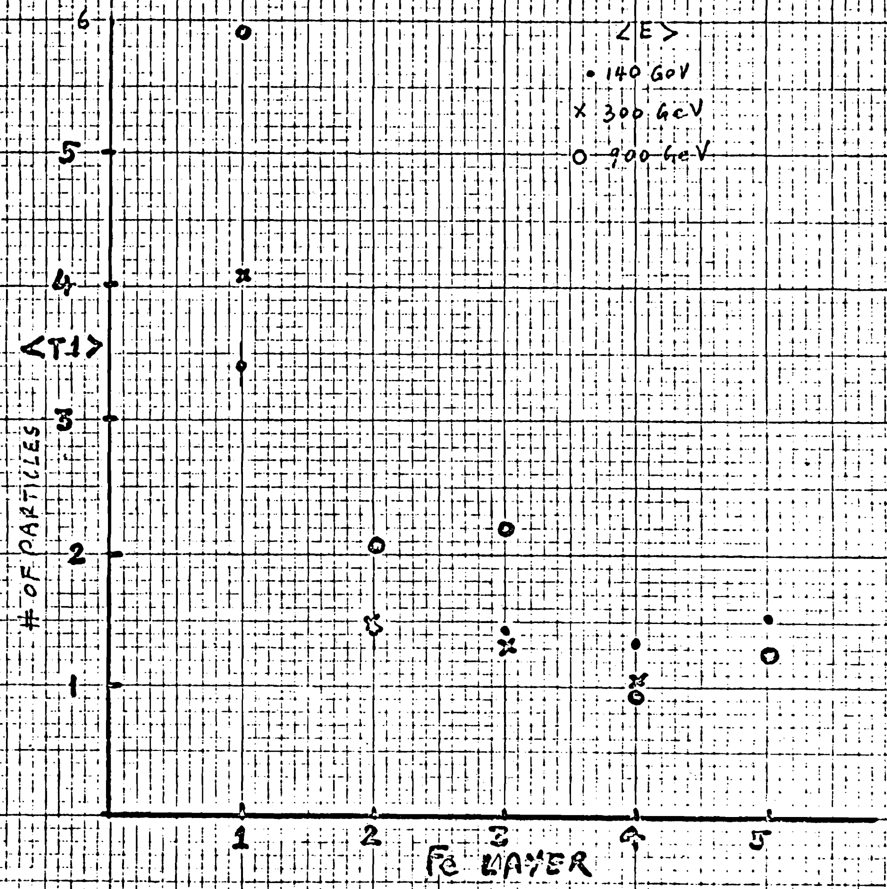

Fe1 <E> = 1400 GeV
<T1> = 6.49 ± .38
Fe2, <E> = 1400 GeV
<T1> = 2.27 ± .29
T1 ; # OF PARTICLES

Fig. 4



<E>
• 140 GeV
× 300 GeV
o 900 GeV
<T1>
OF PARTICLES
1
2
3
4
5
6
1
2
3
4
5
Fe LAYER

Fig 5

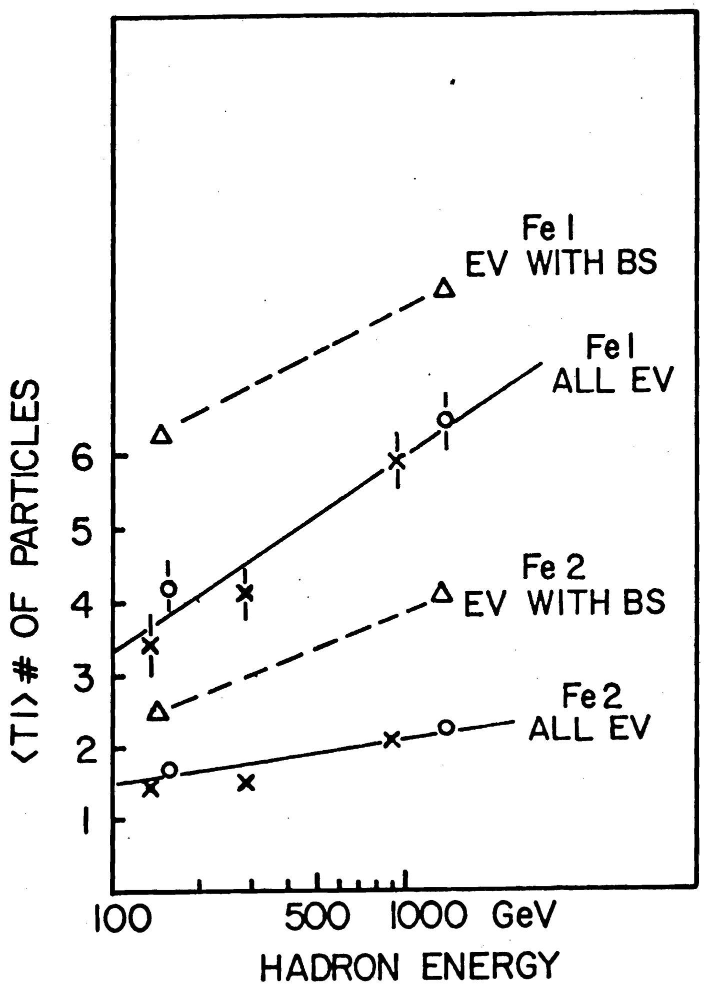

Fe I
EV WITH BS
Fe I
ALL EV
Fe 2
EV WITH BS
Fe 2
ALL EV
⟨TI⟩ # OF PARTICLES
1
2
3
4
5
6
100
500
1000 GeV
HADRON ENERGY

FIG. 6

EV WITH VIS. INDICATION OF
B.S. IN ScB.

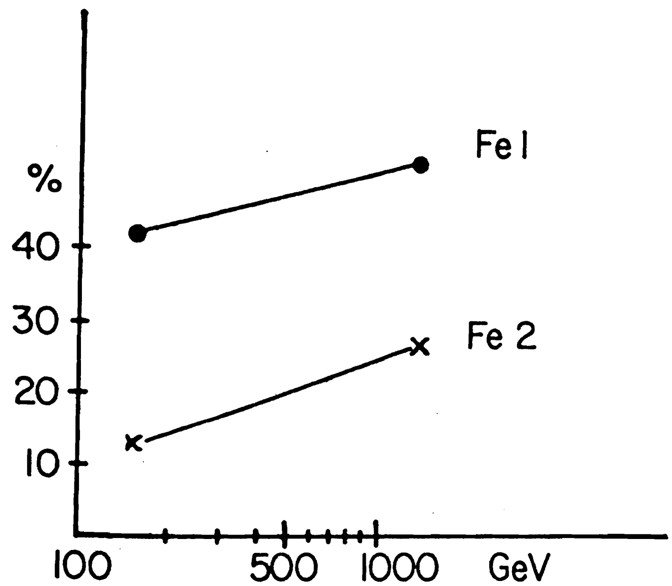


FIG. 7