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Magnetic Deflector for Mesons Produced in the 184-inch Cyclotron

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MAGNETIC DEFLECTOR FOR MESONS PRODUCED IN THE 184-INCH CYCLOTRON

Wolfgang K. H. Panofsky and Ernest A. Martinelli

October 11, 1948

Berkeley, California

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National Bureau of Standards	49-50
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NEPA	52
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Technical Information Division, ORDO	64-78
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University of Rochester	85-86
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Chicago Directed Operations	88
Declassification Procedure
Declassification Officer	89-92
Publication Officer	93
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Magnetic Deflector for Mesons Produced in the 184-Inch Cyclotron

Wolfgang K. H. Panofsky and Ernest A. Martinelli

The artificial production of mesons by means of high energy α-particles in the 184-inch cyclotron at Berkeley[1] indicated the desirablility of making mesons available outside the cyclotron tank in order to make investigations possible by means other than photographic plates inside the tank. A magnetic deflector to draw mesons out into a re-entrant chamber in the cyclotron wall was therefore constructed.

The circulating α-particle beam strikes a target at a radius of 80 1/2" from the center of the cyclotron. The magnetic field at the target position is close to 14,000 gauss, so that low energy mesons are unable to leave the cyclotron. The magnetic deflector consists simply of a magnetic shield placed in such a manner that it shields the meson beam and permits it to enter a re-entrant chamber in the cyclotron wall. (Fig. 1).

A magnetic shield for this purpose has to meet four requirements: 1. The field in the channel must be sufficiently low to permit exit of the mesons from the field. 2. It must have a sufficiently high geometrical aperture. 3. The shield must not disturb the field at a radius less than target radius. 4. The shield must not interfere with the electrostatically deflected beam[2] in the cyclotron.

The problem of shielding magnetically to a sufficient extent in an external field of 14,000 gauss is made difficult by the saturation of iron. Saturation effects are reduced if the shield is not circular but has its large dimension perpendicular to the field; this will only give a small increase in flux density in the iron relative to

[1] E. Gardner and C. M. G. Lattes, Science, 107, 270, (1948).

[2] W. M. Powell, L. R. Henrich, Q. A. Kerns, D. C. Sewell, and R. L. Thornton, Rev. Sci. Inst., 19, 506, (1948).

the external field. These considerations lead to the choice of a shield approximately

an ellipsoid whose smallest axis is parallel to the field. The ellipsoidal shape is

superior to any rectangular geometry since corners would saturate and thus not contribute

to the shielding while still contributing to the disturbing field.

The ellipsoidal shape can be easily analyzed mathematically for a given mag-

netization curve of the iron used. Fig. 2 shows a theoretical plot of the shielding ratio

attainable with an oblate spheroidal[3] shield with a small cylindrical hole inside the

spheroid. The curve is computed for cold rolled steel in an external field of 14,000 gauss.

Note the rapid improvement of the attainable shielding ratio with increase in axial ratio

of the ellipsoid. An axial ratio of 4:1 was chosen here.

The theoretical disturbance in the field due to the ellipsoid is shown in Fig. 3

for an ellipsoid of 12 in. x 3 in. axis. The shield was placed 3 1/2" from the target

radius, thus disturbing the field by approximately 3 1/2%. This disturbance is compensated

by shims supported on the cyclotron poles, in accordance with the method of Powell, et al[4].

A radial experimental field plot and the field corrected by the shims is shown in Fig. 4.

The position and geometry are also shown in Fig. 4.

Owing to the fact that the shielding action of the iron cannot be computed

accurately it was necessary to estimate the meson trajectory first, construct a deflector,

compute the trajectory and then build a new deflector to conform to the computed trajectory.

The final shape of the shield and the position of the meson trajectory is shown in Fig. 5.

Fig. 6 shows the magnetic field in the channel with and without the shield. Owing to the

curvature of the trajectory and the ellipsoidal cross section of the shield, the shield

is constructed of 12 layers of hot rolled steel plate, flame-cut to proper shape and

bolted together. The hole for the trajectory tapers from an initial hole of 1 1/2 in.

vertical x 1 in. horizontal to 2 1/2 in. x 2 1/2 in. square at the exit end. Fig. 7

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[3] For solution of potential problem, see e.g. Smythe, Static and Dynamic Electricity, McGraw-Hill, 1939, pp. 156 ff.

[4] Powell, et al. loc. cit.

shows the assembled deflector.

The deflector is designed for a central trajector corresponding to $B \times \rho =$ 147,000 gauss-cm, corresponding to an 8.5 Mev μ-meson (taking the mass of the μ-meson as 215 m_e) or a 6.0 Mev π-meson (taking the mass of the π-meson as 286 m_e). The deflector will accept beams of vertical divergences of $\pm 6°$, horizontal divergences of $\pm 7.2°$ (at central value of energy); the range of momenta accepted is $\pm 12\%$ about the central value.

At this date the deflector has been used only in conjunction with the photographic mesons of detection. With a cyclotron bombardment of 3×10^{-7} amp of α-particles for 30 minutes the meson yield is about 30 π mesons in the edge of a 100 micron emulsion; this corresponds to a total flux of about 500 mesons/minute out of the aperture of the deflector.

The problem of deflecting mesons by means of a magnetic shield was suggested by Prof. L. W. Alvarez. We are greatly indebted to the magnetic measurements group of the laboratory, notably D. C. Sewell and A. J. Hulse for making magnetic measurements and to Prof. Wilson Powell for valuable discussion. This work was performed under the auspices of the Atomic Energy Commission.

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Figure Captions

Fig. 1 - Geometrical Distribution of Meson Deflector and Target in the Magnet of the
184-inch Cyclotron. Note the Trajectory of the Alpha-particle Beam and the
Mesons Produced in the Target.

Fig. 2 - Theoretical Shielding Ratio of an Oblate-spheroidal Shield with Cylindrical
Hole as a Function of Axial Ratio of the Spheroid in an External Field of
14,000 Gauss.

Fig. 3 - Per cent Field Disturbance due to Spheroidal Shield of Axial Ratio 1 to 4
on the Magnetic Field in the Cyclotron.

Fig. 4 - Radial Magnetic Field in the Cyclotron under the Following Conditions: (a)
Before Introduction of Meson Deflector. (b) After Introduction of Meson
Deflector, but Uncompensated. (c) Meson Deflector in Place and Compensated
with Shims as Shown.

Fig. 5 - Meson Trajectories from Target Through Meson Deflector, as Plotted from
Field Measurements.

Fig. 6 - Experimental Magnetic Field as a Function of Position Along Meson Trajectory
Through Meson Deflector.

Fig. 7 - Photograph of Meson Deflector in Retracted Position.

MESON TRAJECTORY

380 MEV α PARTICLE BEAM
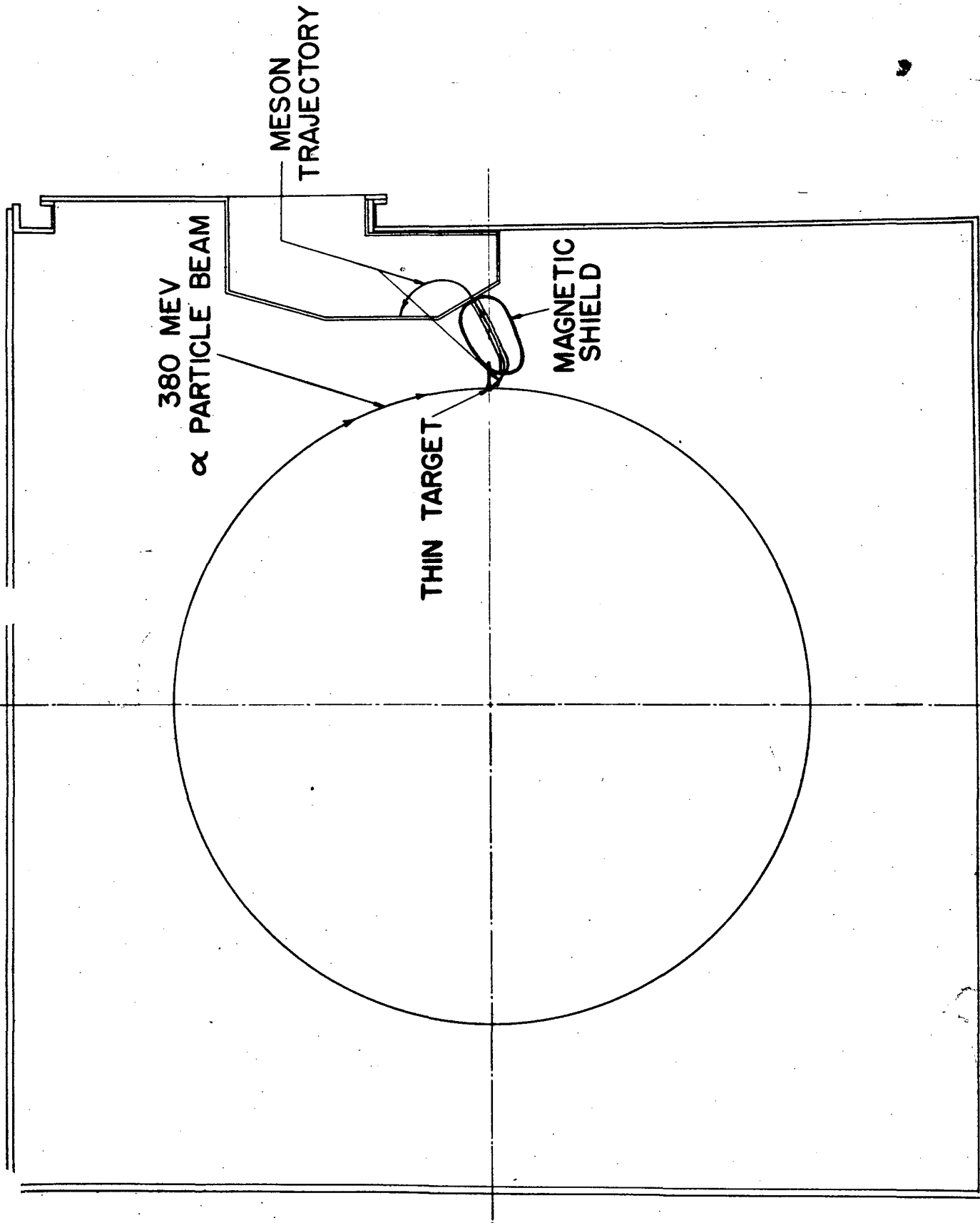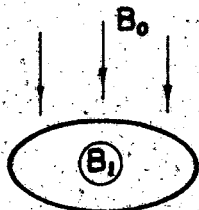
MAGNETIC SHIELD

THIN TARGET

FIG 1

SHIELDING RATIO FOR CYLINDRICAL HOLE IN OBLATE SPHEROIDAL IRON SHIELD IN EXTERNAL FIELD OF 14,000 GAUSS - (COLD ROLLED STEEL)

FIELD PARALLEL TO MINOR AXIS

FIG. 2

COMPUTED FIELD DISTURBANCE DUE TO MESON
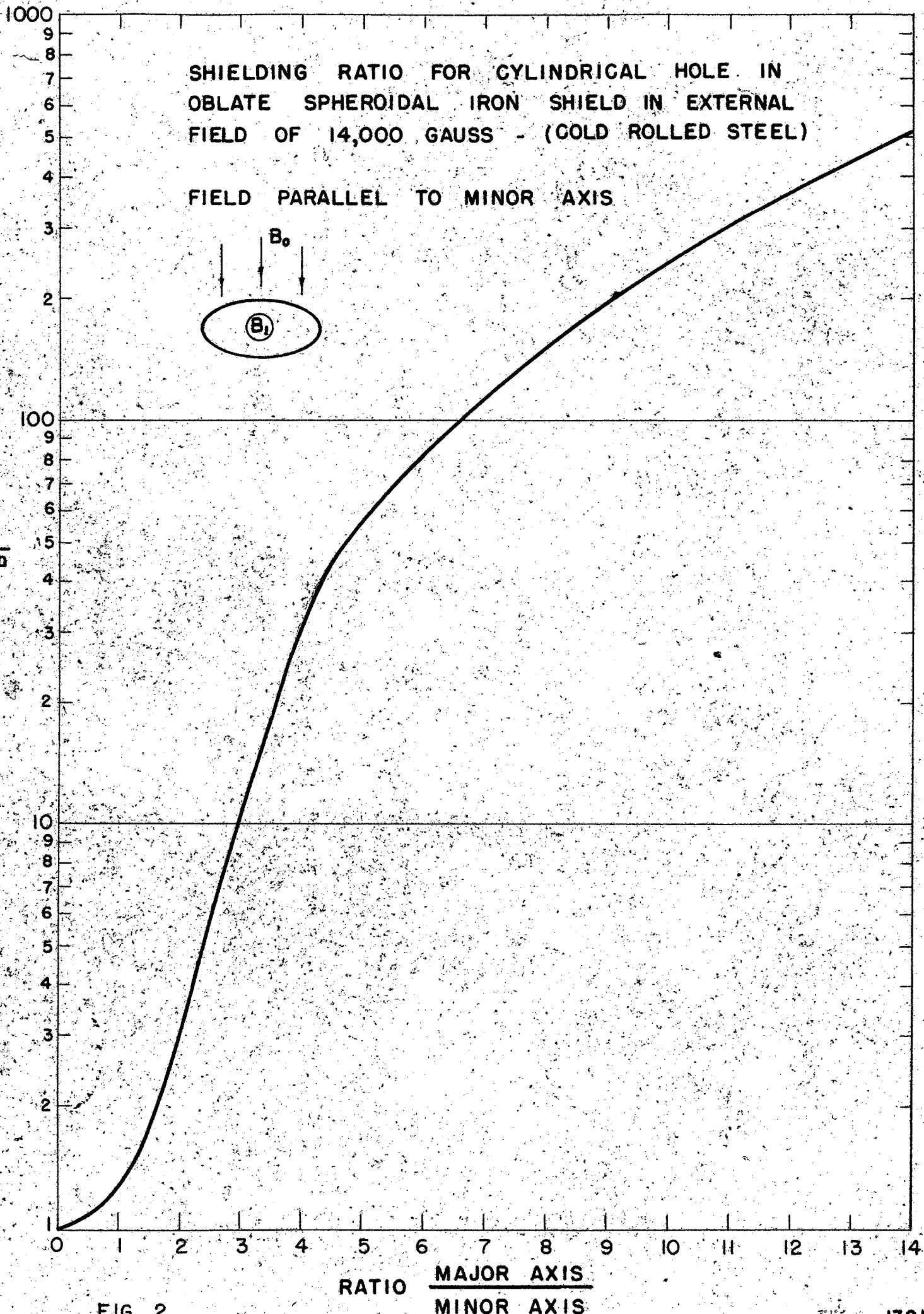DEFLECTING ELLIPSOID OF AXIAL RATIO 4:1

PERCENT FIELD DISTURBANCE
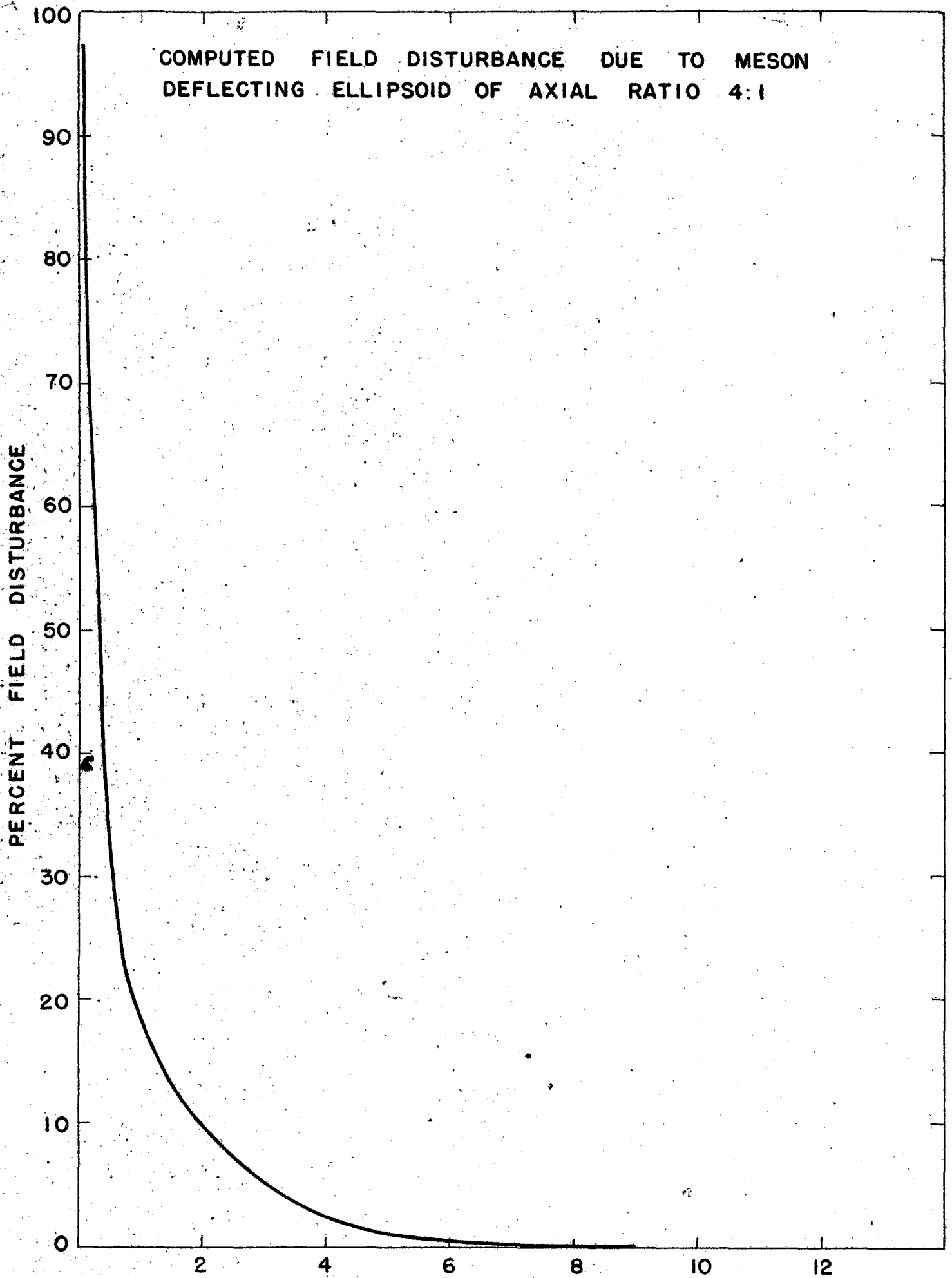
RADIAL DISTANCE FROM EDGE OF DEFLECTOR

FIG. 3

FIG. 4

EFFECT OF MAGNETIC DEFLECTOR AND COMPENSATING SHIMS ON CYCLOTRON FIELD

(a) NORMAL FIELD
(b) MAGNETIC DEFLECTOR ONLY
(c) DEFLECTOR 8 SHIMS

MAGNETIC DEFLECTOR

PERCENT OF FIELD AT CENTER (15,000 GAUSS)

RADIUS (INCHES)

POLE

CYCLOTRON
MAGNET

TARGET

CENTRAL TRAJECTORY

EXTREME TRAJECTORY

A

A
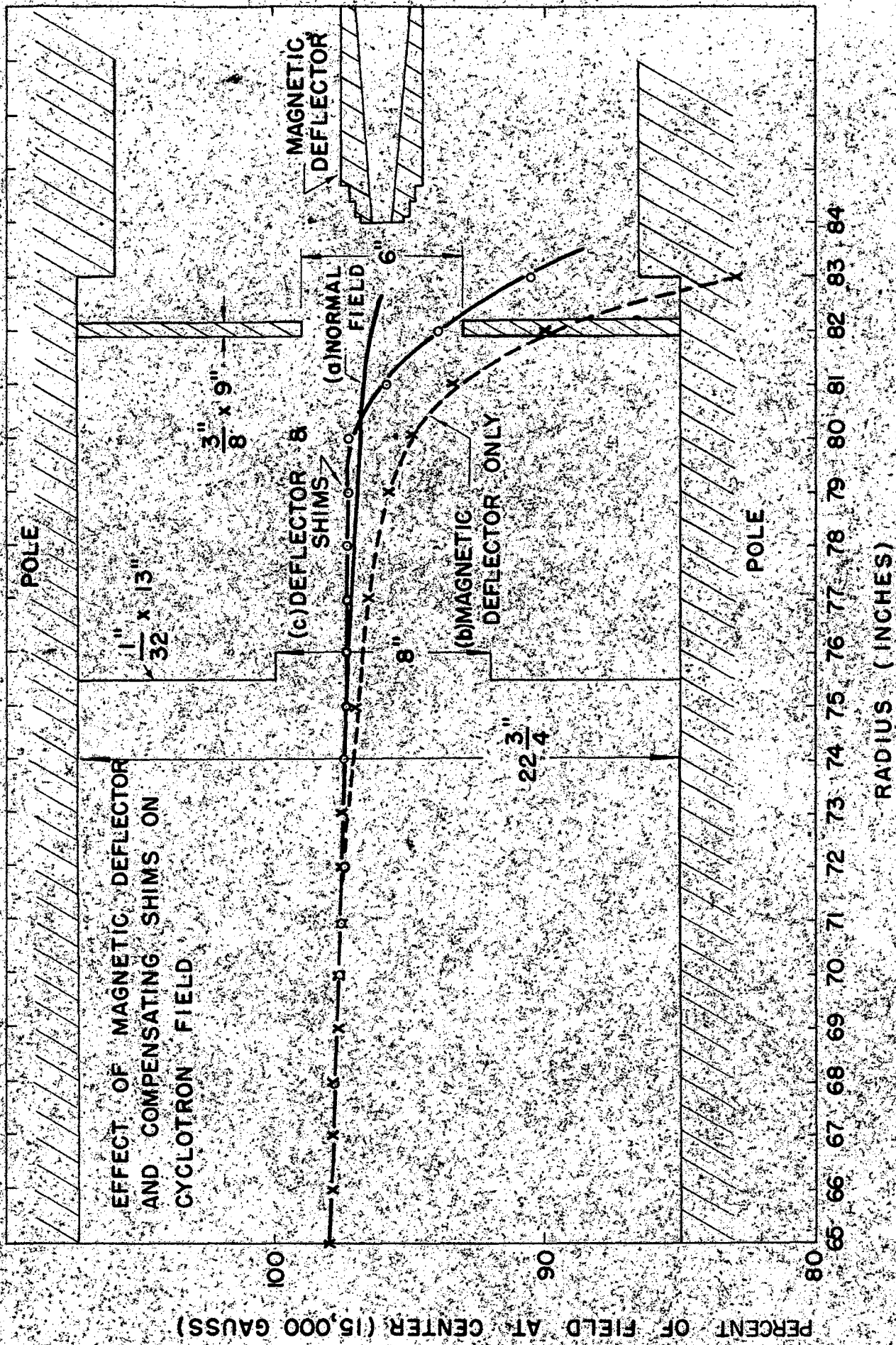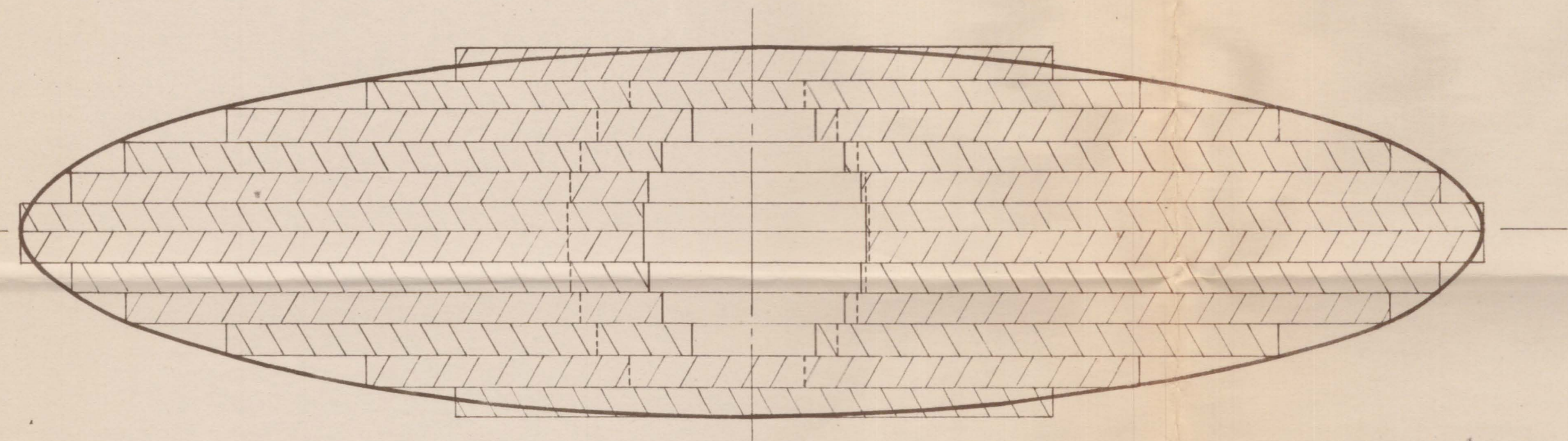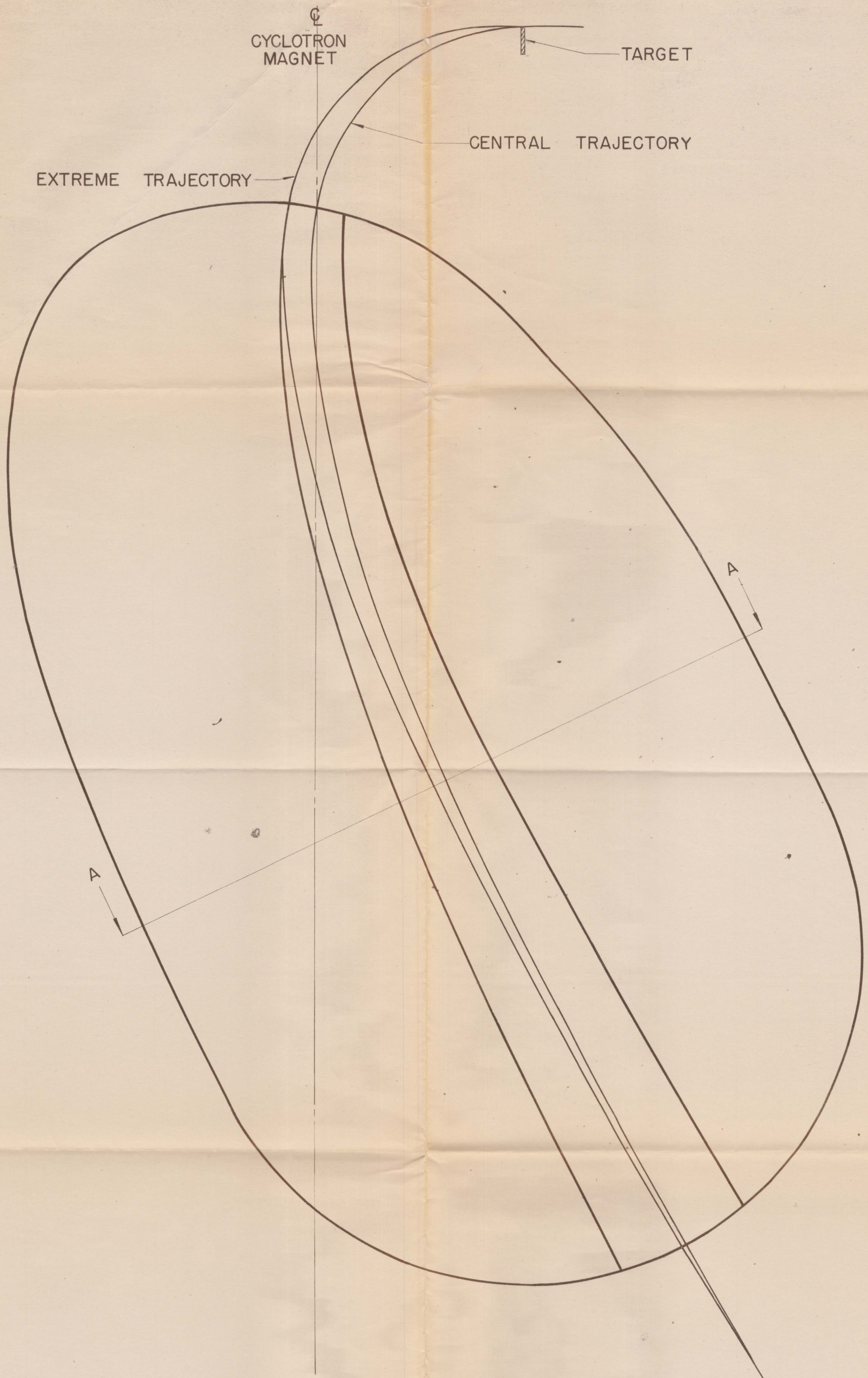
SECTION A-A

SCALE: FULL

FIG. 5

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MAGNETIC FIELD ALONG MESON TRAJECTORY

FIG. 6