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REDUCING COMPUTATION TIMES IN CALCULATION OF DOSE

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INTRODUCTION

PIPLAN, the computer program designed for treatment planning patients undergoing pion therapy at the Los Alamos Meson Physics Facility, Los Alamos, NM, calculates dose in three dimensions. It is not practical to calculate the energy deposited for all 10^{11} particles entering a patient. We therefore model the beam with approximately 10^5 real particles, each particle representing a monoenergetic pencil beam of a large number of particles, about 10^6.

Each pencil beam contains an analytic description of the dose deposited by a small bundle of monoenergetic particles. There is no statistical uncertainty in the dose deposited by a single pencil beam. However, there is statistical uncertainty in the distribution of pencil beams coming from the particle measuring process.

This paper describes a technique to reduce the uncertainty in the calculation of dose using the pencil beam model. Results show that a statistical accuracy of 2.5% in the dose calculation is achieved with a factor of 10 fewer number of pencil beams than would be required with a purely random set of incident particles.

II. CALCULATION MODEL

The pencil beam model is important for pion treatment planning for the following reasons. It allows for correcting for inhomogeneities in the volume, given the complexities of the pion beam. There are important correlations, for example, between the locations of the particles in the

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plane of incidence, the angles with which they traverse the volume and their individual momentum. An additional complication is the appropriate representacion of muons and electrons. The calculational model represents these complex distributions by using the measured trajectories of individual particles as the source of the PIPLAN pencil beams.

In our model, the intensity in the pencil beam is not constant. Intensity falls off radially according to a Gaussian function. The standard deviation, sigma, of the function is 0.5 cm and increases with depth due to multiple scattering. This is shown schematically in Fig. 1. Individual pencil beams used in the calculation are selected from a large number of randomly distributed incident particles, for which location and momentum vectors were measured experimentally. The particles are selected so that the dose measured in air using an ionization chamber is precisely reproduced.

Accumulation of dose at the center of the dose box shown in Fig. 1 is done from a table in which dose contributions at each depth have been calculated for water. Thicknesses of inhomogeneities encountered by the centroid of the pencil beam are translated into equivalent thicknesses of water.

The dose as a function of depth used in the calculation is shown in Fig. 2. It is a Bragg curve calculated for the mean magnitude of the momentum of the beam. The so-called "star" dose, a unique feature of the pion beam, includes the contributions of the heavy particle fragments, neutrons, and protons that are a result of pion star events. Dose contributions due to muons and electrons are added with the same method.

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III. COMPARISON OF CALCULATION AND MEASUREMENTS

A measurement of the dose in air using an ionization chamber in a plane perpendicular to the beam direction yielded a smooth distribution, shown in Fig. 3 (solid line). Superimposed on the graph is the dose calculated with PIPLAN with 50,000 and 200,000 random events. Both statistical and systematic effects are evident. In order to achieve a better agreement between calculations and measurement, we selected from about 400,000 random events a reduced number of particles that gave a satisfactory dose calculation in air. In the absence of systematic errors, we estimate that 250,000 events would give an accuracy of about 2.5%. With the selected subset of particles, our so-called "smoothed" distribution, we achieved this accuracy with 25,000 events, a factor of 10 smaller.

The dose calculated with this "smoothed" distribution is compared with the experimental result in Fig. 4 for the distribution along the x-axis and Fig. 5 for the distribution along the y axis.

The next step was to examine the result of a calculation as the beam penetrates a water phantom. The first calculation with the smoothed fluence distribution did not give good agreement between calculated and measured depth dose curves. We had to adjust slightly for each particle the deviation from the mean momentum value. Then we obtained the results already shown in Fig. 2. The dose distribution in the lateral dimensions at depth in water under a collimator are compared in Fig. 6. The lower curve is in the plateau region of a modulated beam at a depth of 6 cm while the upper curve is near the maximum of a modulated beam at Z = 12 cm. The agreement is not as precise as was achieved for the air dose, but should be adequate for treatment planning purposes.

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IV. CONCLUSIONS

In conclusion, a pencil beam model used in the 3-D calculation of dose achieves a given statistical accuracy with a significantly reduced number of beams by selection from a random distribution of a large number of incident particles.

The particles, which represent the pencil beams, were selected so as to reproduce the dose measured in air with an ionization chamber. Using this subset of pencil beams to calculate the dose at depth in water, a very large gain in contour smoothness at all depths was observed. This was achieved with a reduction in computation time by a factor of 10.

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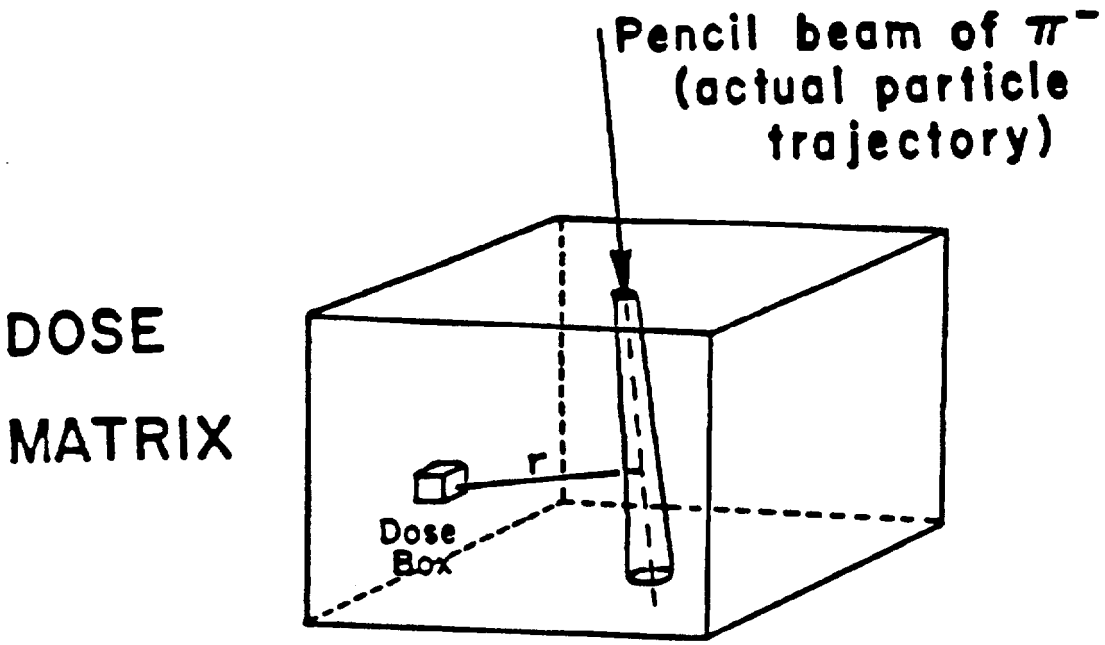

FIG. 1

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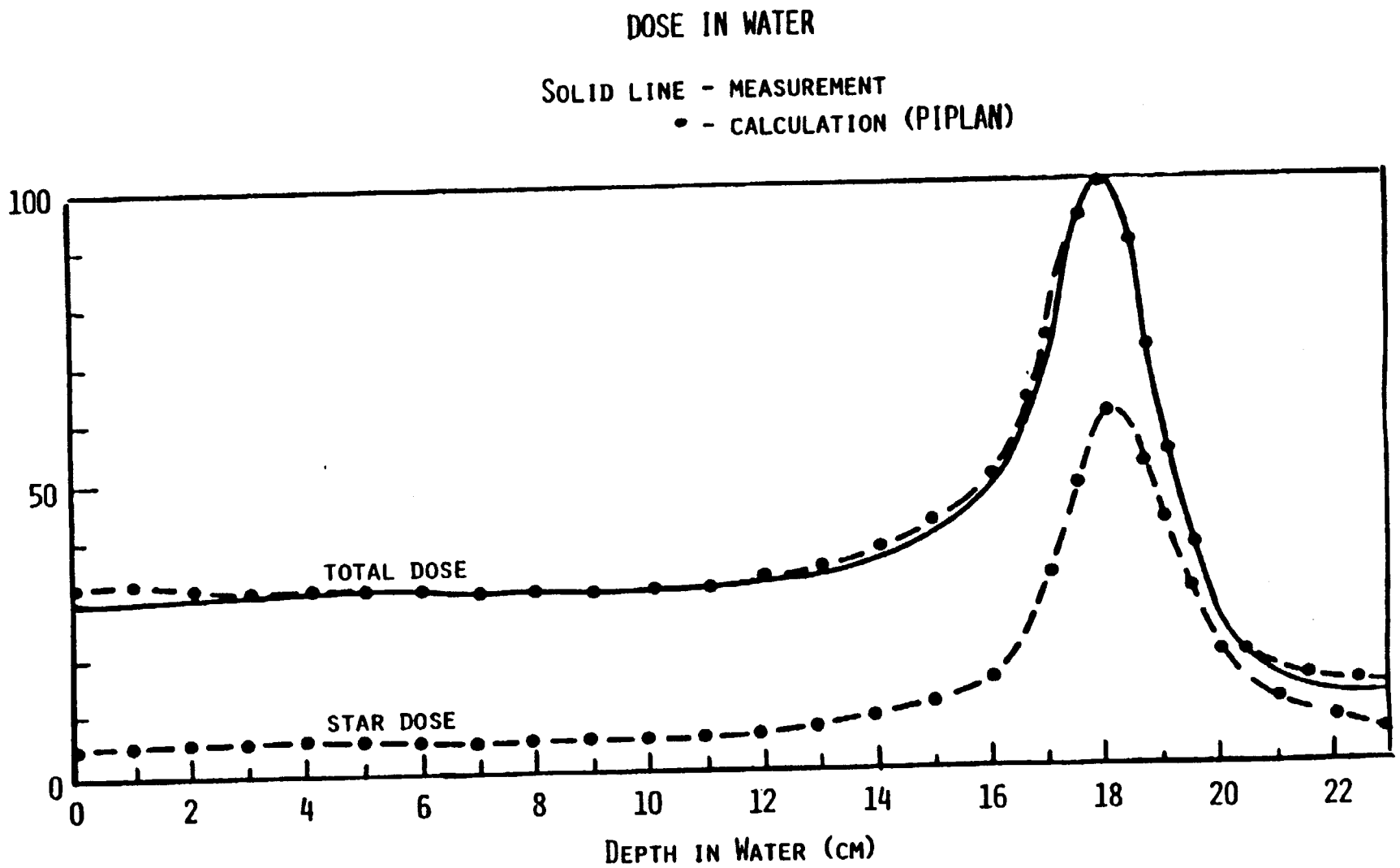

FIG. 2

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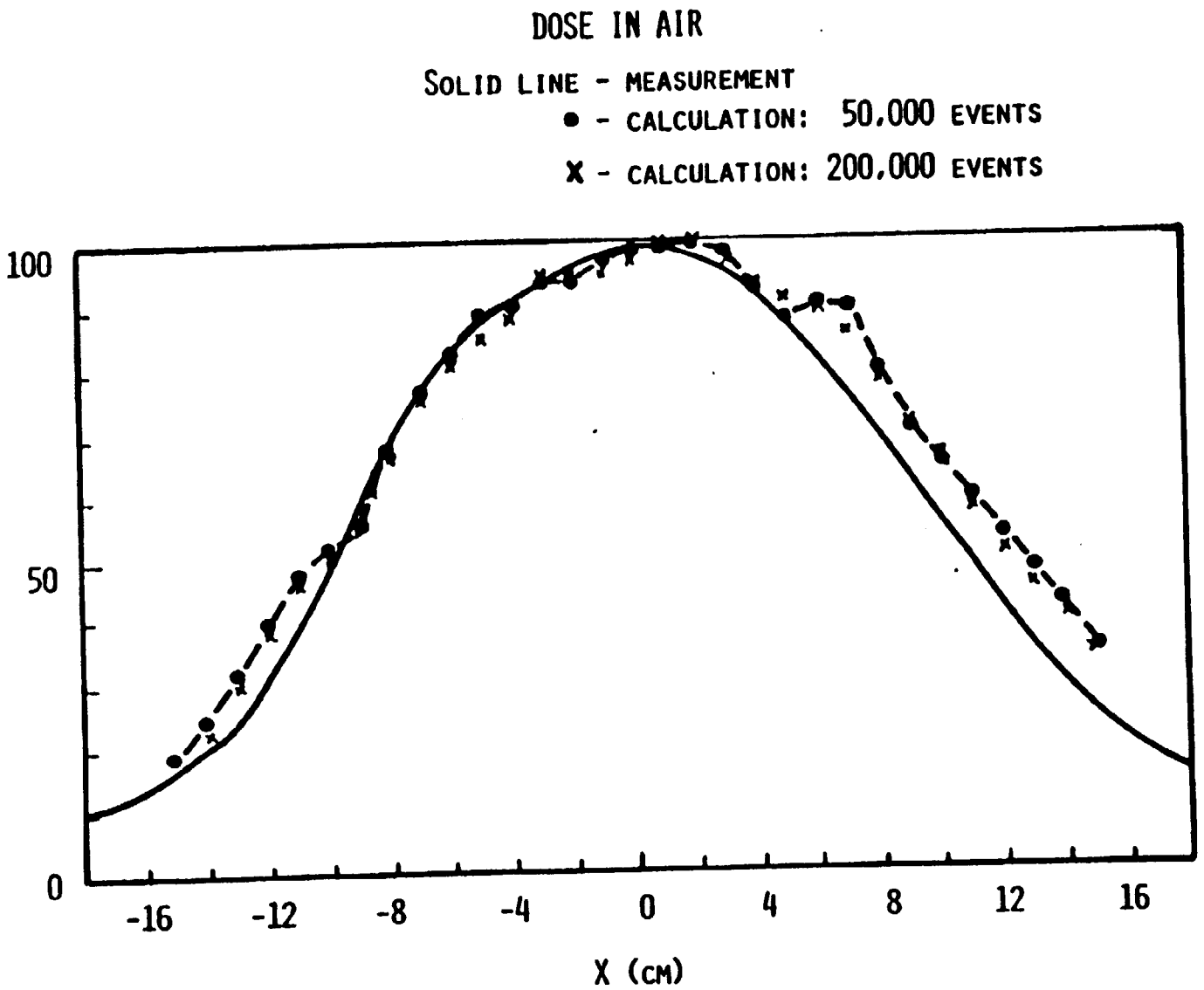

FIG. 3

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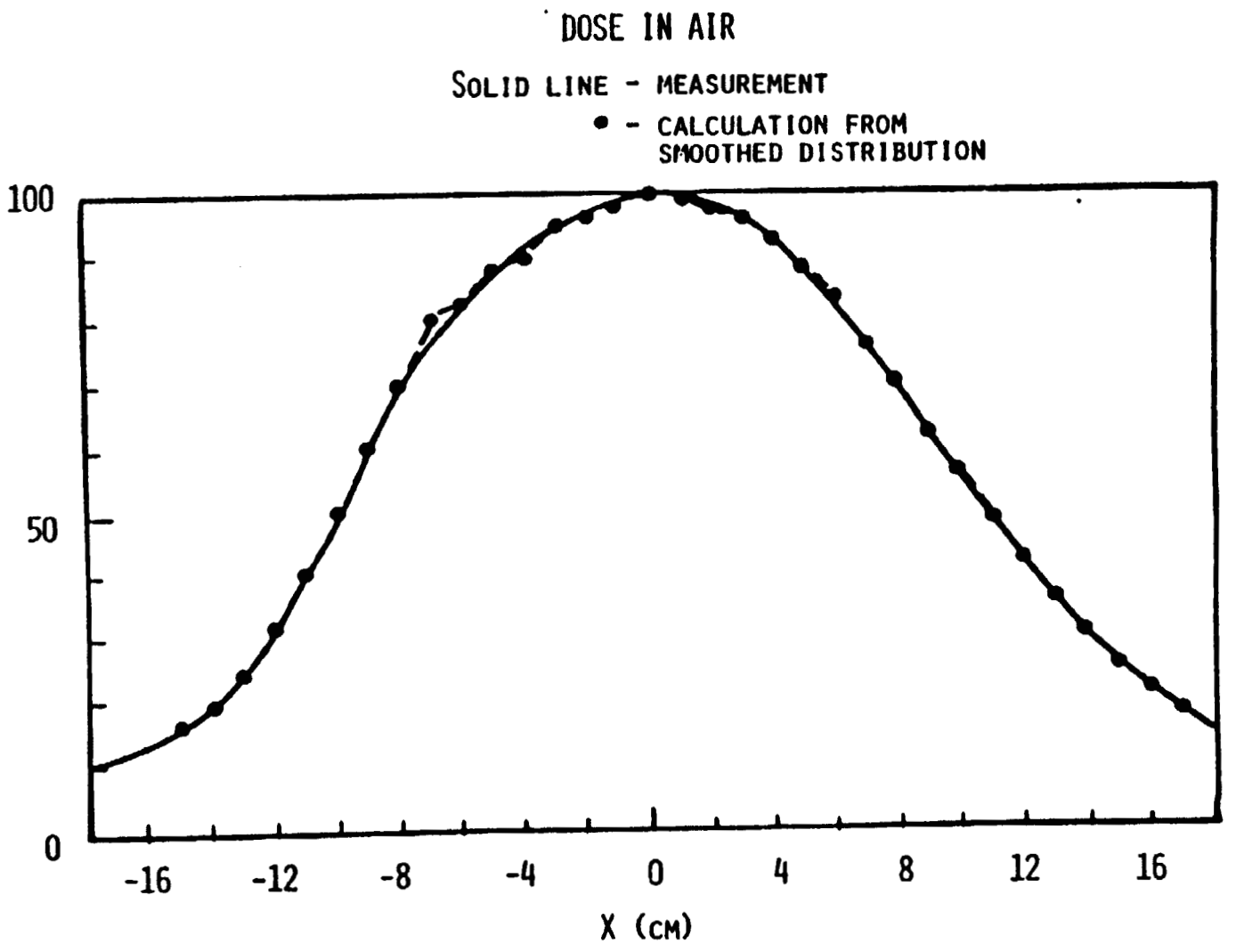

FIG. 4

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DOSE IN AIR

SOLID LINE - MEASUREMENT

• - CALCULATION FROM SMOOTHED DISTRIBUTION (25,000 EVENTS)

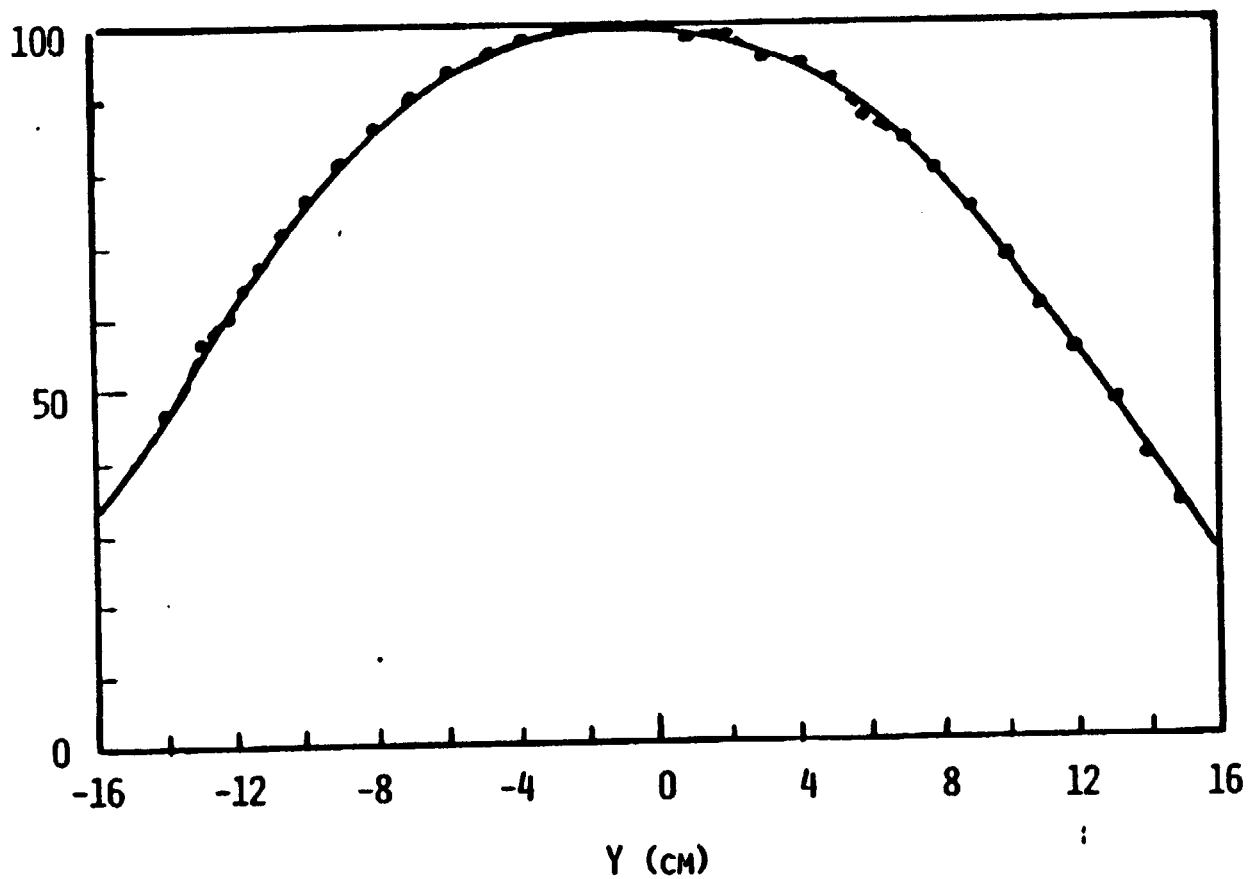

FIG. 5

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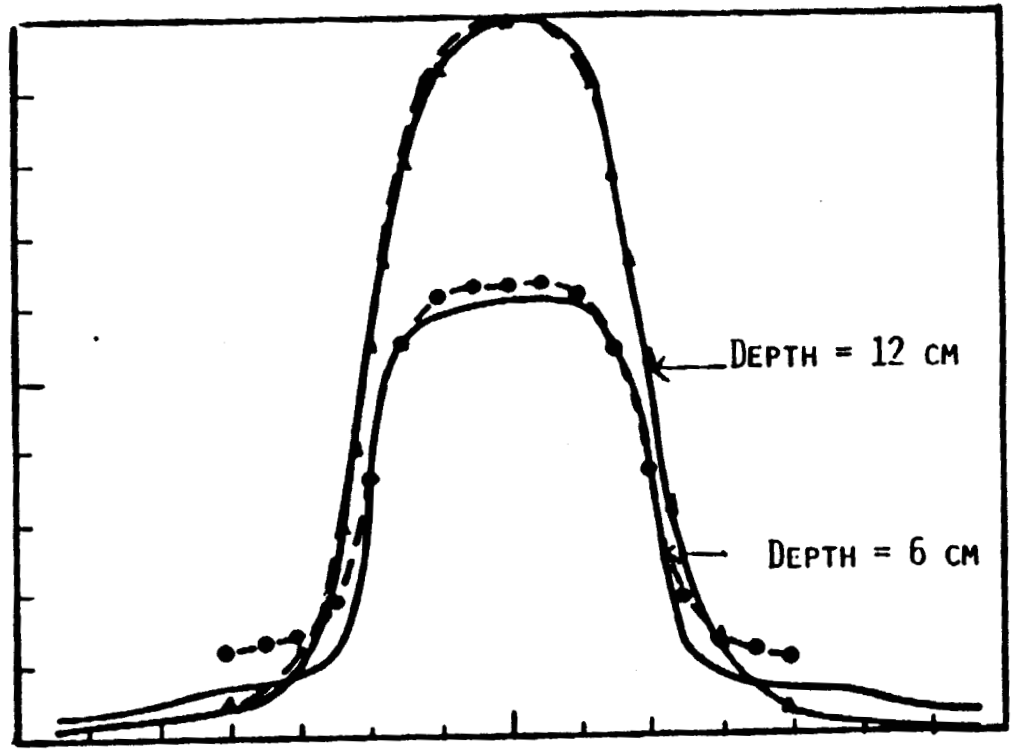

FIG. 6

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