ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR

Quarterly Status Report No. 7

DISPERSION AND PENETRATION OF POLLENS AND INDUSTRIAL CONTAMINANTS

January 1, 1955 to March 31, 1955

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This report, not necessarily in final scientific form, is intended only for the internal management uses of the contractor and the Air Force.

Project 2160

DEPARTMENT OF THE AIR FORCE, GEOPHYSICS RESEARCH DIRECTORATE
AIR FORCE CAMBRIDGE RESEARCH CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
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ABSTRACT

Project activities have for the most part been moved into the new Meteorological Laboratory. Experimentation with artificial dissemination of pollen and with direct observations of plume shape and rate of fall-out in relation to local turbulence has continued. Direct measurements of pollen density are being attempted. An aerodynamic analysis of the changes in time of the space density of particles suspended in the air of a room is presented. Qualitative agreement of the theoretical results with available experimental data is good, but the data are not adequate for quantitative comparison.

OBJECT

The object of the research reported herein is to study both theoretically and experimentally (1) the dispersion of airborne particulates and (2) the penetration of these particulates into structures as a function of atmospheric turbulence and wind velocity and direction.

I. INVESTIGATIONS BEING UNDERTAKEN AND PLANNED

A. INTRODUCTION

The project supplies, equipment, and personnel were moved into the new Meteorological Laboratory, Room 5500, East Engineering Building, during the report period. Materials and files which had accumulated were unpacked and organized in the new laboratory. The parts for the tower have arrived as have also numerous additional items of furniture, equipment, and instrumentation for the laboratory.

B. EXPERIMENTATION DURING THE REPORT PERIOD

1. Preliminary Tests on Artificial Emission of Pollen.—The atomization technique described in the last report was tried in conjunction with the spacial-distribution-measuring array of slides which also was described in the last report. Figure A is a photograph of this array arranged for one of the preliminary tests. In this photograph the frames are spaced 6 ft apart, and the support for the pollen source is set 6 ft upwind from the first frame. One coated microscope slide is borne horizontally (facing upward) and one vertically (facing upwind) at each of 19 stations on a frame. The frames are set so as to give 12- x 12-ft cross sections of the pollen plume at various distances downwind.

A number of difficulties arose in the course of these initial tests, so further study of several aspects of the experiment was undertaken.

A method for atomizing the dry pollen grains directly, without the liquid suspension, was suggested and tested. It was found that this method is efficient for breaking up clumps of pollen. Since the apparatus can be constructed easily in the glass shop, several atomizers of this type (Figure B) were made. Advantages of the design include (1) a better control over the emission of pollens than was available by the other method and (2) light total weight, which makes possible the use of a microbalance for measuring the amount of pollen dispersed.

Problems of interpretation of the data (Appendix) arise because of the relationship of the emission period to that of some of the prominent turbulence elements. This suggests that puff-wise emission over a longer period of time might be preferable to the continuous emission used in these initial

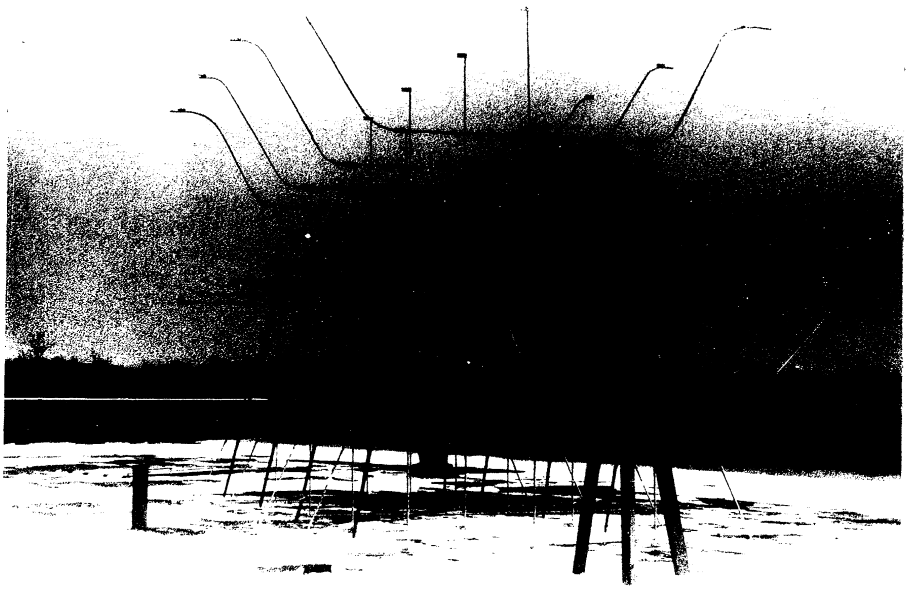

Fig. A. Spacial distribution array in position for test.

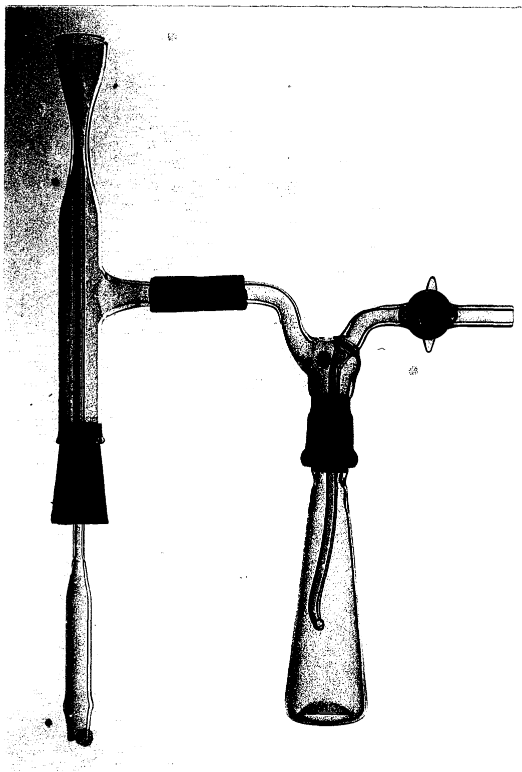

Fig. B. Pollen dust atomizer, half size.

tests, and might give a more complete picture of pollen dispersal under natural conditions.

2. The Direct Measurement of Pollen Density.—A review of the literature on fall rates and specific gravity estimates for ragweed pollen revealed that no one has actually measured the density of pollen. Durham's estimate of the volume of the pollen grains* is extremely crude. Crawford's result** is by far the best available, but it depends on the use of Stokes' Law to compute density from fall rate.

The direct measurement of the density of A. trifida pollen by means of pycnometry has been undertaken. One difficulty is to find a liquid for use in the measurements which will not dissolve fractions of the pollen contents. The results of the measurements will be of broad interest and will therefore be prepared for publication when they are complete.

C. EXPERIMENTS PLANNED

1. Another preliminary test will be made with the dry atomization technique and puff-wise emission. Independent measures of wind speed and and gustiness will also be taken preparatory to complete instrumentation of test 2 (below).

2. The test room will be exposed to an artificial bath of pollen, emitted from the dust atomizer. The plume will be traced by means of the array of slides described above. In addition, the instrumentation that was used during the 1954 pollen season will be activated both inside and outside the test room. Some additional samples will be collected in the test room in order to judge the representativeness of the earlier samples.

3. As a further check on the representativeness of pollen samples in the test room, a sequence of six volumetric samples will be taken during experiment 2 (above). These will serve to show the time variability of the samples taken at the station occupied by the volumetric sampler during the 1954 season and will give an estimate of the decay of the counts due to sedimentation and impaction.

4. Test 3 will be repeated according to requirements for reasonably firm interpretation and the limitations of weather conditions. Following this experimentation, a careful analysis of the 1954 season data will

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*Journal of Allergy, 14(6), 1943, pp. 455-461.
**Pub. Health Reports, 64, 1949, pp. 1195-1200.

be carried out, and the design of the experimental program for the 1955 season will be undertaken.

D. AEORDYNAMIC ANALYSIS OF CHANGE OF PARTICLE DENSITY

A theoretical analysis has been made to explain the change of particle density in the air within an enclosed room. The results of this analysis are briefly described below.

In an enclosure, such as a room, the total number of particles suspended in the air decreases with time. The causes responsible for this phenomenon include: (1) particle impaction on the walls and (2) coagulation of particles.

In the last progress report, the impaction process was analyzed by considering the random motion of particles, which is the main cause of impaction, as the output of a linear system with turbulence of air as the input.

Along the same line of approach, the coagulation process has been investigated. The general procedure is similar to that for the impaction process, namely, to start with the search for the probability density function for the relative velocity between two particles with which the collision rate of particles can be calculated.

Again we postulate that the random variable which represents the relative velocity between two particles has a Gaussian distribution. Thus, only the mean square value of the random variable is needed to calculate its probability-density function. The mean value of the relative particle velocity vanishes because of isotropy and homogeneity of the turbulent field. Again, we restrict our discussion to the one-dimensional problem.

Let

$$V(t) = \dot{\chi}_i(t) - \dot{\chi}_j(t)$$

be the relative velocity between particles i and j. $\dot{\chi}_i$ and $\dot{\chi}_j$ represent the velocities of particles i and j, respectively. By substituting in V(t) the Fourier expansions of $\dot{\chi}_i(t)$ which constitute the output of a linear system together with its input, the turbulence velocity, also represented by a Fourier expansion, we can obtain the mean square value, $\overline{V^2}$, as we did in the last progress report. In the general case, the expression for $\overline{V^2}$ thus obtained will include spectra of turbulence corresponding to correlation functions of turbulence velocity at different points and different times. By introducing an assumption, which is plausible under certain circumstances, that the distance between the two particles, the mean square value of whose relative velocity is of interest, is very small compared to the typical length scale of turbulence so that both particles can be considered as excited by an "identical" turbulence velocity, we obtain

$$\overline{V^2} = \int_0^\infty \frac{36\pi^2\mu^2 r_i r_j (m_i r_j - m_j r_i)}{(36\pi^2\mu^2 r_i^2 + m_i^2 w^2)(36\pi^2\mu^2 r_j^2 + m_j^2 w^2)} p_u(w)dw$$

where μ = viscosity of air;
r_i, r_j = radii of particles i and j, respectively; and
$p_u(w)$ = power spectrum (density) of turbulence (Lagrangian).

The probability-density function of the random variable V is

$$P(V) = \frac{1}{\sqrt{2\pi}\,\sigma_V} e^{-\left(\frac{V^2}{2\sigma_V^2}\right)}$$

Before entering into the analysis of the number of particles of the kind i to be swept and coagulated with particle j, the mutual interference due to induced flow which would reduce the effective relative velocity should be considered. To deal with this effect we introduce Langmuir's collision efficiency factor*, which is defined as the ratio of the actual collision cross section to the cross section of particle j.

$$E(k) = 0 \qquad k \leq 1.214$$

$$E(k) = \left[1 + \frac{(3/4)\ln(2k)}{k - 1.214}\right]^{-2} \qquad k > 1.214,$$

where k is a dimensionless parameter given by

$$k = \frac{2 r_i^2 \rho_i V}{9\mu r_i} \equiv \frac{V}{V_0}$$

where ρ_i = density of particle i.

The volume swept by particle j per unit time

$$= \pi(r_i + r_j)^2 \, 2\int_0^\infty EVP(V)dV$$

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*I. Langmuir, *J. Met.*, 5, 1948, p. 175.

$$= \sqrt{2\pi}(r_i + r_j)^2 V_o \int_o^\infty E(k) \frac{k}{\sigma_k} e^{-\frac{k^2}{2\sigma_k^2}} dk \quad .$$

Let the probability density function for the particle size be f(r) and the total number per unit volume, N . At the beginning of the coagulation process, we can assume that particle sizes and relative velocities between particles are statistically independent. Then the rate of collision can be written as

$$\frac{dN}{dt} = \sqrt{2\pi} \int_o^\infty \int_o^\infty (r_i + r_j)^2 \left(\frac{9\mu r_j}{2r_i^2 \rho_i}\right) \int_o^\infty E(k) \frac{k}{\sigma_k} e^{-\frac{k^2}{2\sigma_k^2}} dk \cdot Nf(r_i)dr_i \cdot Nf(r_j)dr_j$$

$$= \beta N^2 .$$

Integrating the above equation, we obtain

$$\frac{1}{N} - \frac{1}{N_o} = \beta t \; ,$$

where N_o = initial particle number density. This is a very interesting result considering the experimental results obtained by Langstroth and Gillespie* in measuring the coagulation rate of smoke particles in a chamber, the air in which is made turbulent by fans.

The coagulation equation we obtained checks with Langstroth and Gillespie's experimental results in a qualitative manner.

In order to make a quantitative check for our theory and Langstroth and Gillespie's experimental results, the turbulence intensity in the chamber has to be measured; this is not given in their paper.

A paper which covers the complete theoretical analysis of impaction and coagulation processes thus obtained is being prepared.

II. PERSONNEL, ADMINISTRATIVE, AND FISCAL INFORMATION

The following changes in student employment on the project occurred.

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*G. P. Langstroth and T. Gillespie, Canad. J. Res., B25, 1947, p. 455.

Name	Position	Date Employment Terminated
G. C. Sutaria	Assistant in Research	28 January 1955

Name	Position	Date Employment Started
Fang-Cher Chang	Assistant in Research	7 February 1955
David A. Lundy	Assistant in Research	5 March 1955

Actual expenditure up to the end of March, 1955, were approximately \$54,630 plus an encumbrance of \$150, for a total of \$54,780. Balance as of that date is approximately \$20,220.

APPENDIX

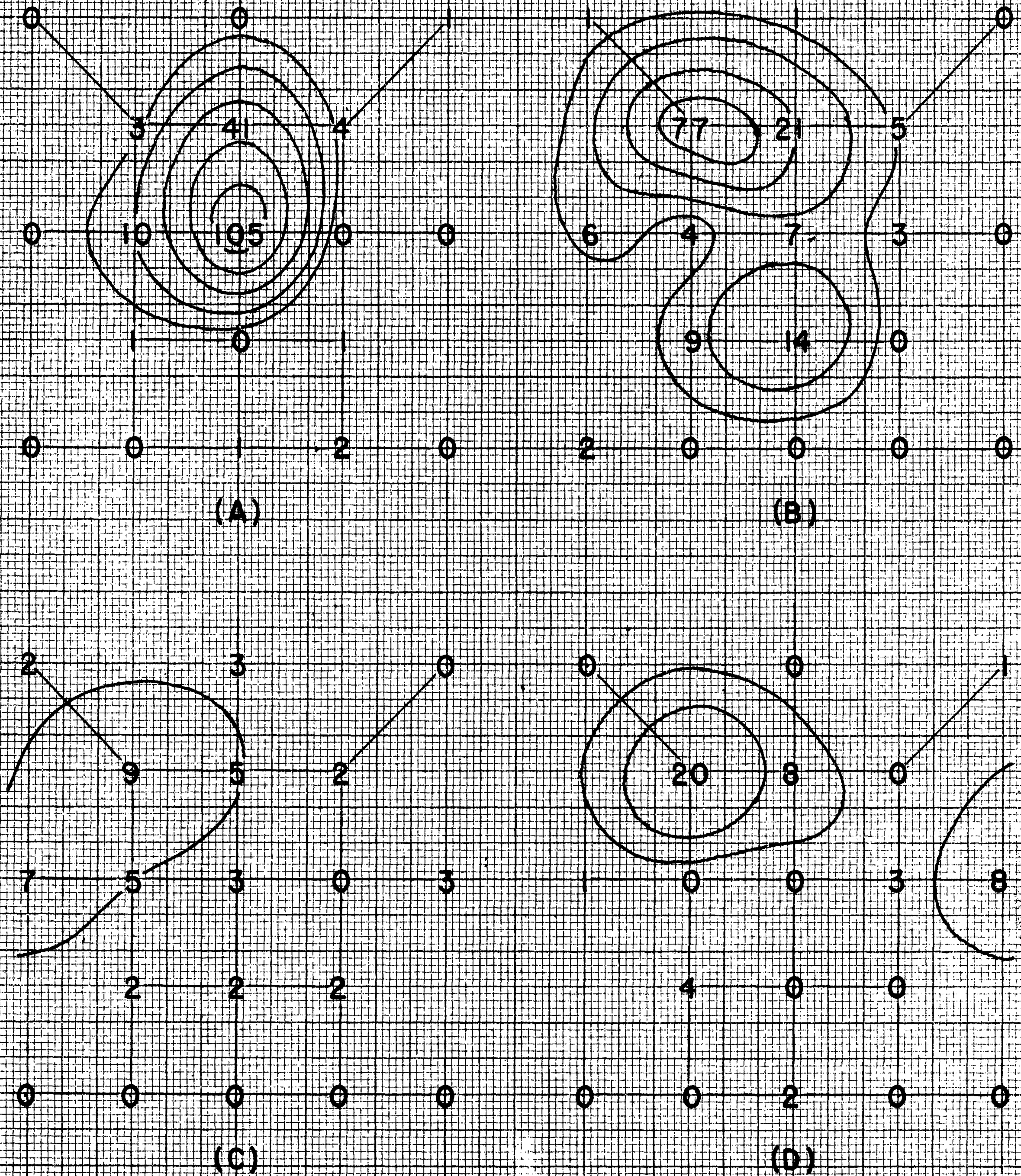

Fig 1
Vertical cross-sections thru plume showing catch on vertical slides

A – 6 ft. from source

Scale: 1 cm = 2 ft.

B – 12 ft. from source

C – 18 ft. from source

D – 24 ft. from source

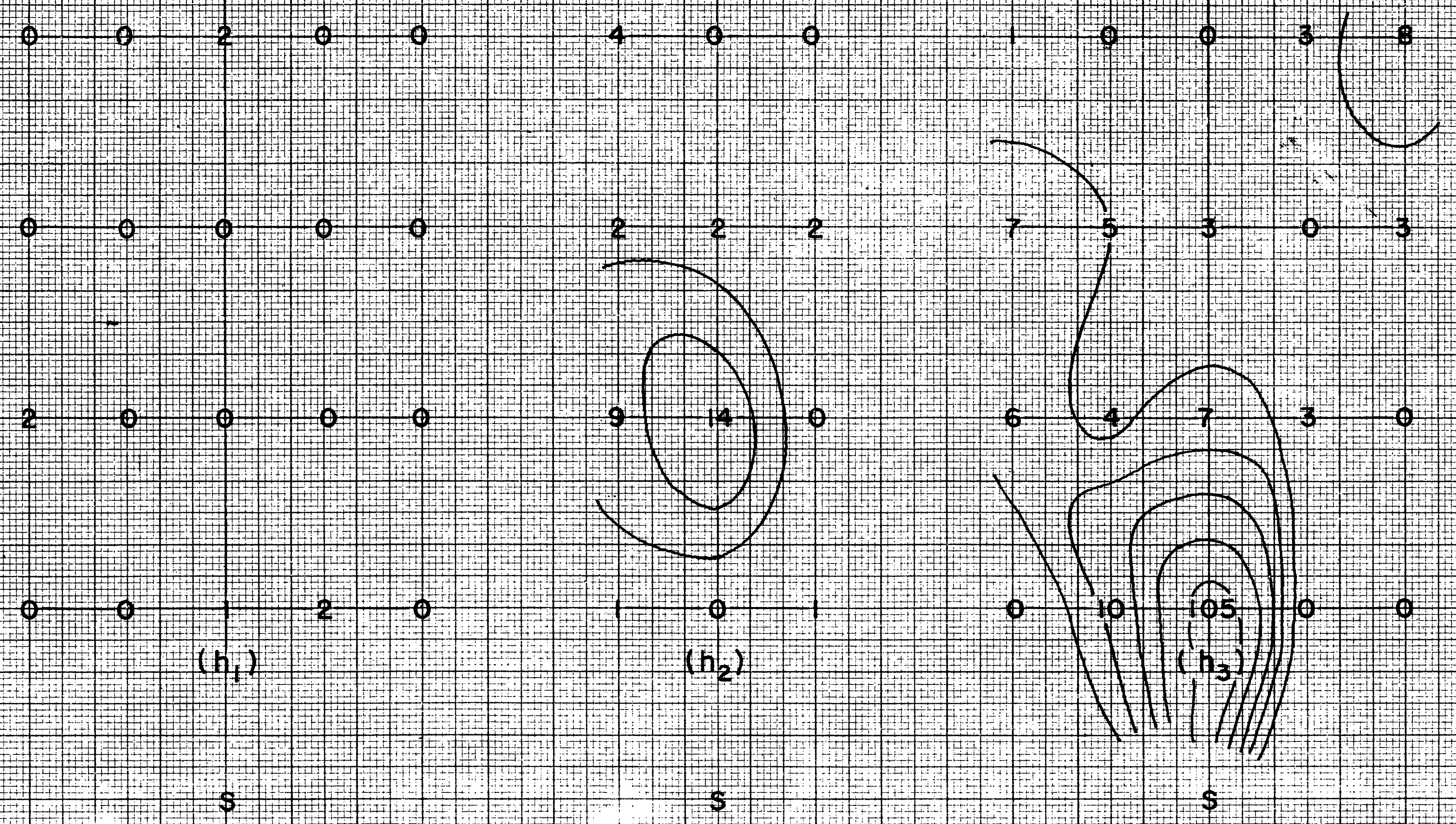

Fig. 2a—Horizontal sections thru plume showing catch on vertical slides

h_1 – 6 ft. below source

Scale : 1 cm.= 2 ft.

h_2 – 3 ft below source

h_3 – at level of source

S – Source

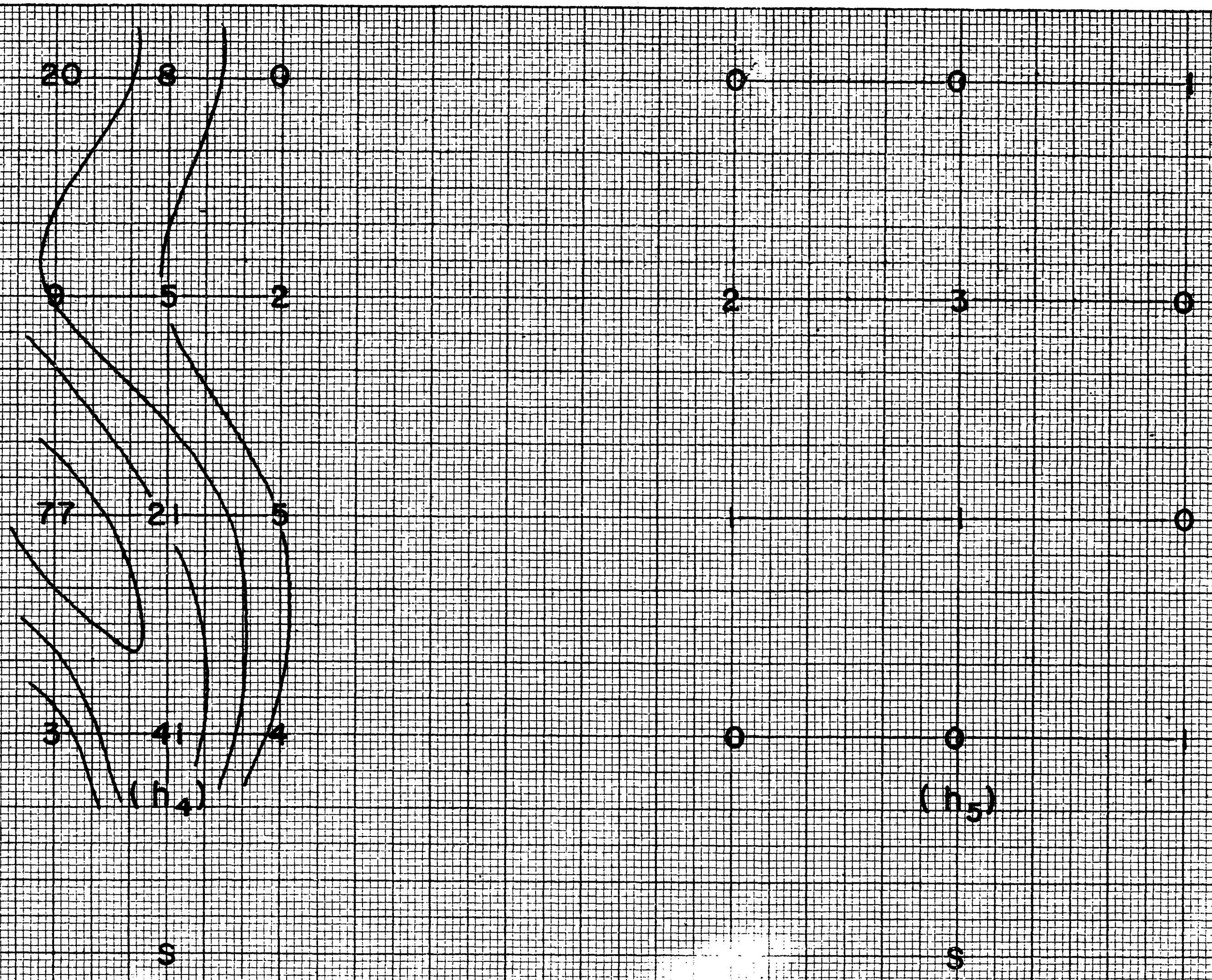

Fig. 2b — Horizontal sections thru plume showing catch on vertical slides

h_4 – 3 ft above source

Scale: 1 cm = 2 ft

h_5 – 6 ft above source

S – Source

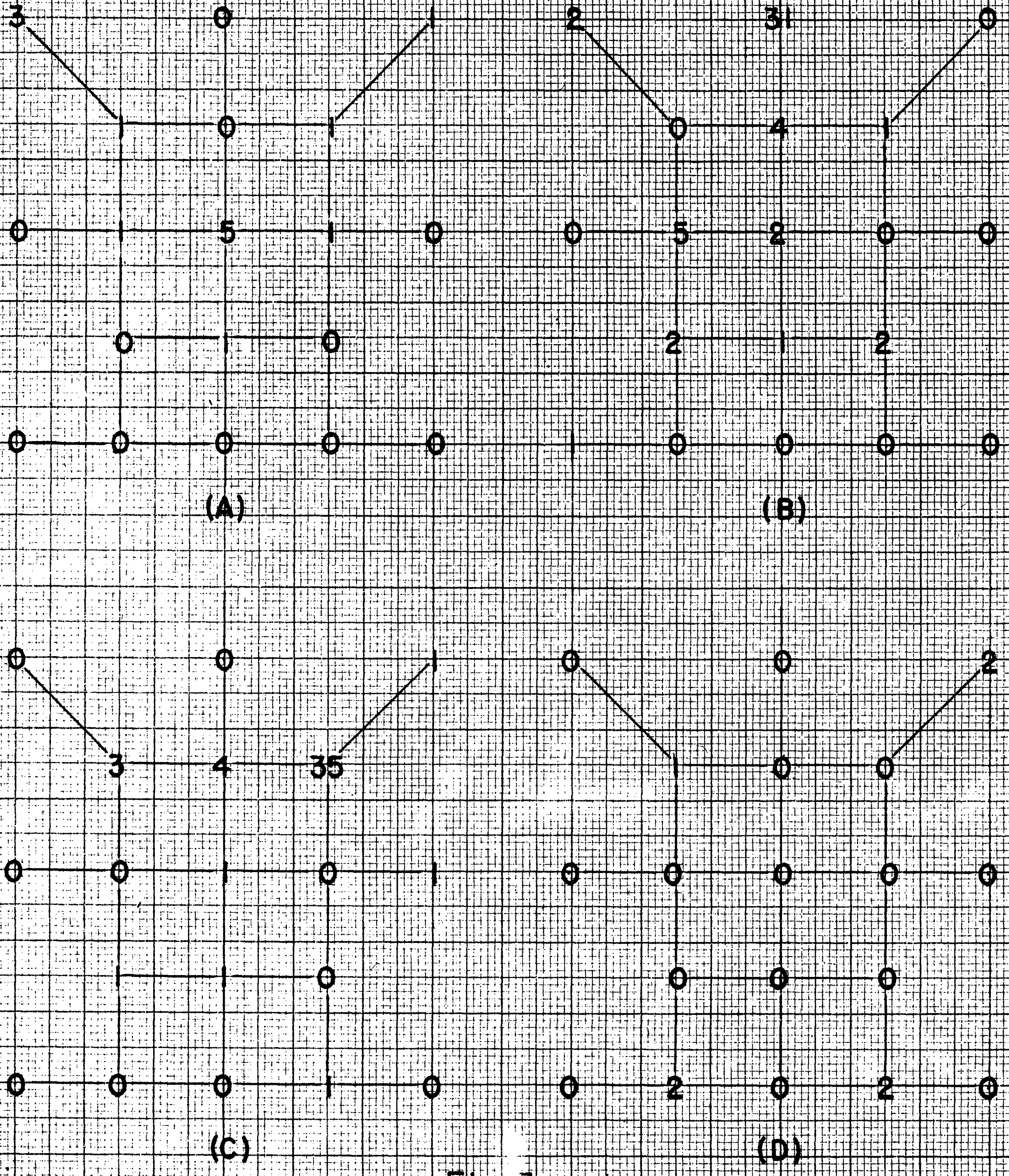

Fig. 3
Vertical cross-sections thru plume showing catch on horizontal slides

A – 6 ft. from source

B – 12 ft. from source

C – 18 ft. from source

D – 24 ft. from source

Scale: 1 cm = 2 ft.

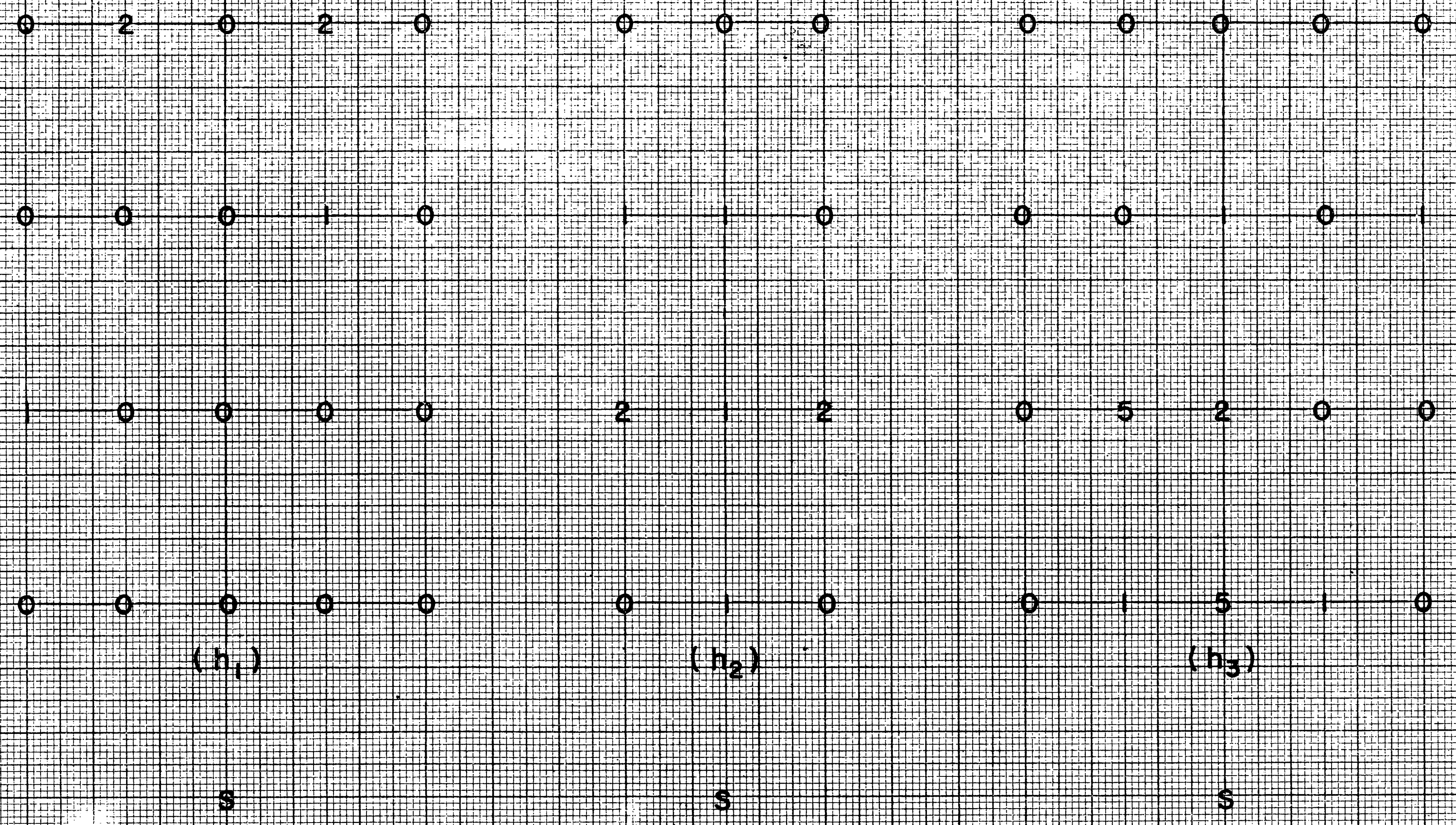

Fig. 4a—Horizontal sections thru plume showing catch on horizontal slides

Scale: 1 cm = 2 ft.

h_1 – 6 ft below source

h_2 – 3 ft below source

h_3 – at level of source

S – Source

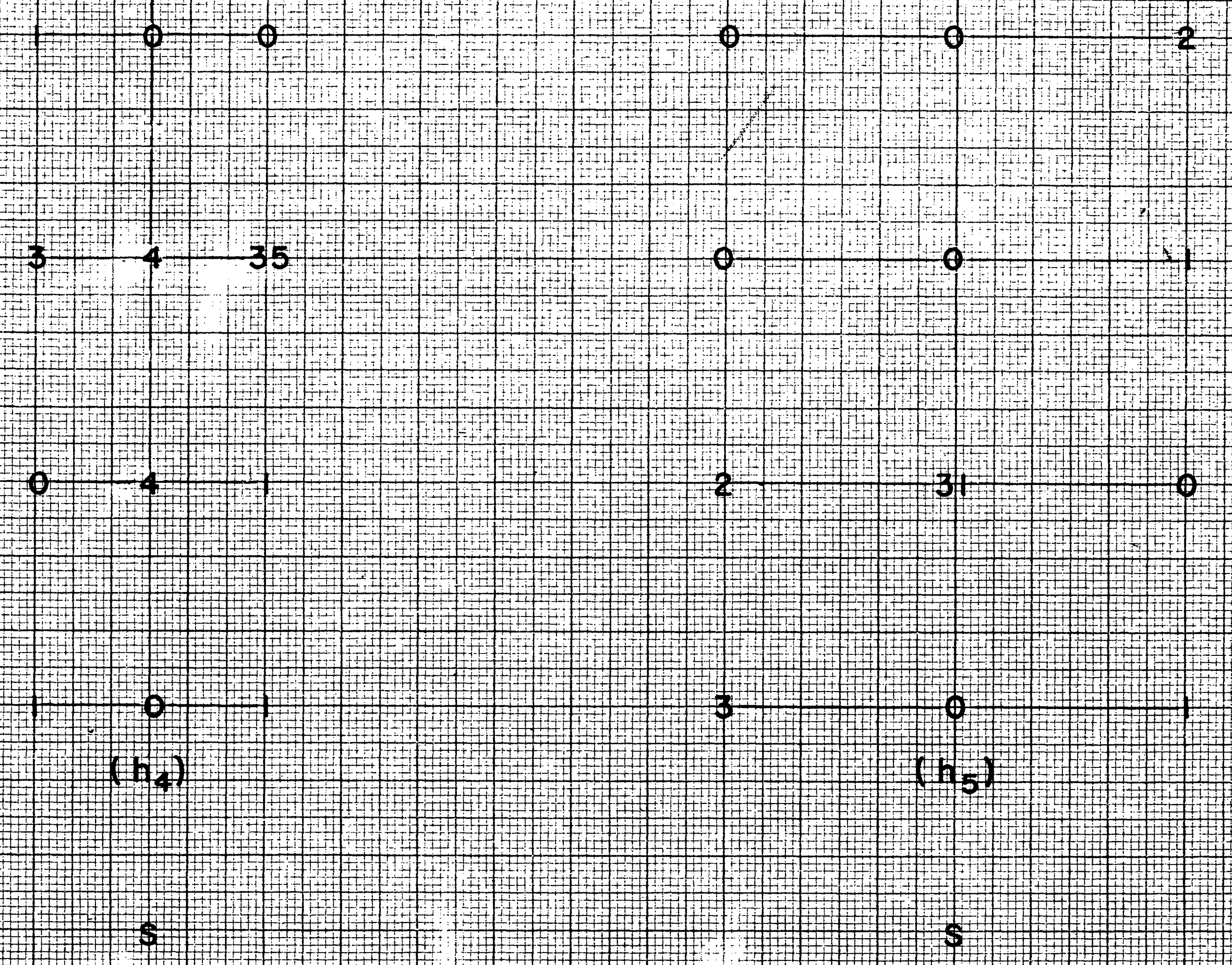

Fig. 4b — Horizontal sections thru plume showing catch on horizontal slides

h_4 — 3 ft above source

Scale: 1 cm = 2 ft

h_5 — 6 ft above source

S — Source