THE TWIN-PROBE SNOW DENSITY GAGE

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INTRODUCTION

Many techniques have been used to measure snow depth, density and water equivalent. Volumetric samplers include the Federal, Rosen, Bowman, and Adirondack types. Errors inherent in these types of sampler are described by Freeman (1). Photogrammetry has proved useful in measuring snow depth, but not water equivalent (2, 3, 4). Pressure pillows (5, 6, 7) have been used to measure the water content of snow pack.

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Several techniques using radioactive materials have been developed. One method, used for measuring the total water equivalence of a snow pack, employs a fixed source located at the ground surface and a detector mounted 10 to 15 feet above the ground (8, 9, 10, 11). This method gives an error of less than 5% for water equivalent between 2 and 50 inches.

Use of neutron soil moisture probes was not successful because of the large degree of scatter around the mean line (9, 12).

A third technique, (13), a twin-probe snow density gage, involves a radioactive source and a scintillation detector located in separate access tubes. The source and detector are moved through the snow pack and the energy attenuation of gamma photons from the source is recorded. Smith (14) describes two types of profiling snow gages. The first is a portable gage consisting of (1) a positioning "jig"; (2) two access tubes; (3) a battery-driven lift mechanism; and (4) the electronic components, which are commercially available. Signal read-out on a strip recorder is a log function of snow density.

The second unit is a permanently placed snow gage. In this unit the source and detector are raised and lowered by a cable suspended from a radiation tower. The probes are driven by a gear motor. The electronic equipment is the same as that used in the portable gage.

This paper will describe the twin-probe snow density gage(15), the improvements made in the drive mechanism, and the signal read-out equipment designed and developed at the Sleepers River Research Watershed.

THEORY AND INSTRUMENTATION

The twin-probe system uses 5 mc of Cs^{137} as a source, and a sodium iodide (NaI) thallium-activated crystal for a detector.

The source emits, by radioactive decay, gamma photons of 0.661 million electron volts energy and lower, the lower energy photons being produced by compton scattering in the source container. Photons emitted by the source travel in a straight line to the point of collision with an orbital electron of an atom. Upon collision they may be either absorbed or scattered, at a diminished energy, into another path. Thus the attenuation of the energy is a function of the density of the medium and can be measured.

Because the rays are emitted at a uniform intensity in all directions, the radioactive source may be considered a point source. The detector receives the radiation at an intensity proportional to the source activity and to the solid angle at the detector, and inversely proportional to the number of electrons in the snow between the source and the detector. Photons emitted in a direction outside this solid angle, or deflected from the beam by colliding with an electron in the snow pack arrive at the detector with an energy of less than 0.661 MEV, since deflection reduces photon energy.

The detector produces a pulse with the voltage amplitude proportional to the energy of the incident gamma photon. By electronically discriminating against all pulses of less energy than 0.661 MEV, the pulse production rate becomes an inverse logarithmic function of the number of electrons in the snow between the source and detector.

Determination of density between two points using energy discrimination is an extremely accurate method of measurement, see table 1. Photons colliding with orbital electrons may be scattered through a very small angle, thereby losing only a small portion of their energy. These deflected photons will register on the detector but are not sufficient to decrease the system's accuracy. Accuracy of the method is more dependent upon statistical error caused by random emission of photons than by any other factor.

Drive System

A watertight sheet-metal box buried in the ground (see Fig 1) houses the motors, racks, cable takeup reel, and the limiting switches. Aluminum tubes mounted on top of the box house the source and detector, and are the only components above the ground surface. Mounted on the bottom of the box are the takeup tubes for the drive racks.

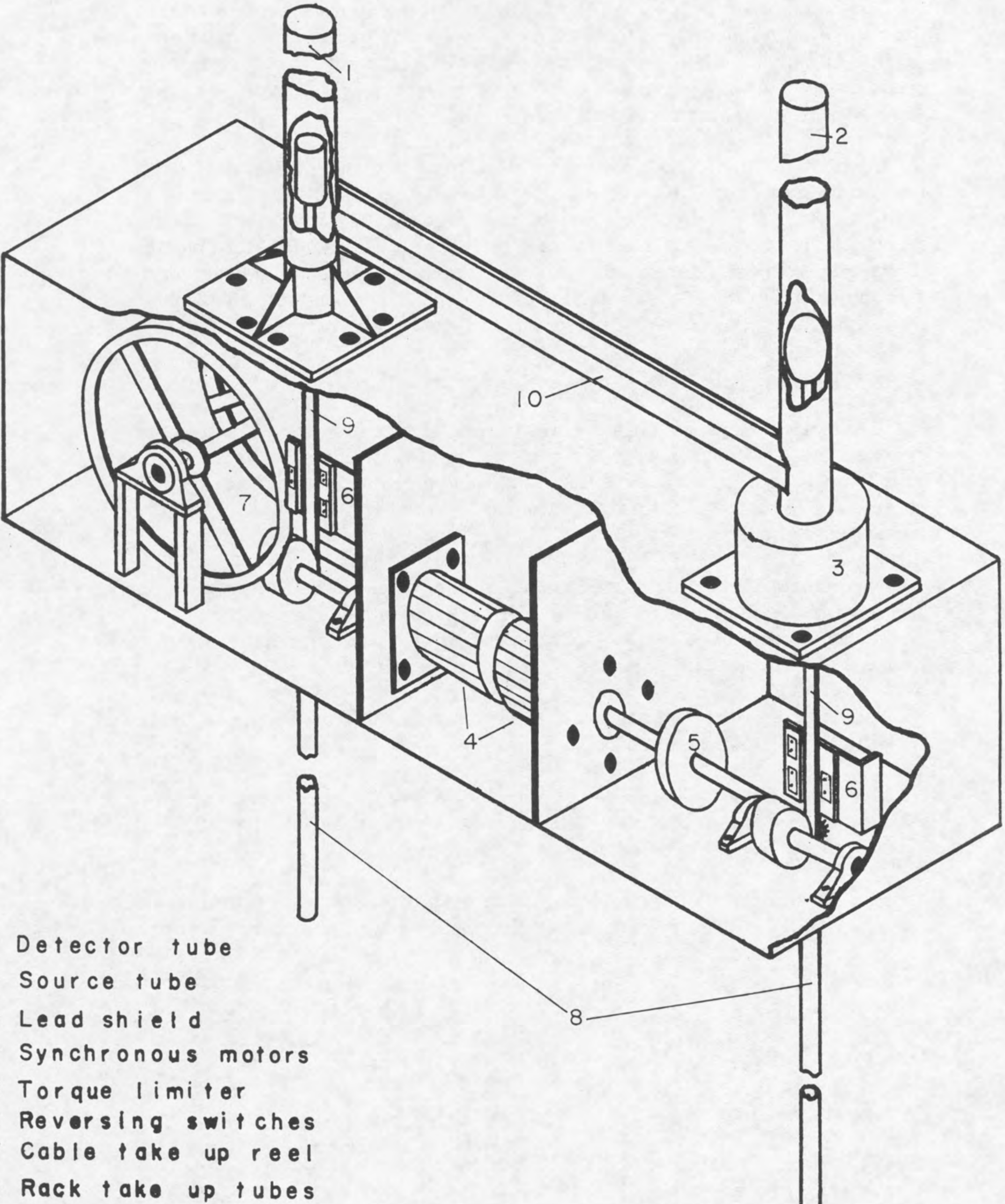
The detector and source are mounted on top of geared racks that move up and down inside the aluminum tubes. The racks are driven by synchronous motors at the rate of 12 inches per minute. Both motors are equipped with torque limiters to prevent damage to the system in case of binding in the tubes.

Notches cut in the racks activate miscroswitches to reverse their direction at the top and bottom points of travel.

The signal cable from the detector is coiled on a spring-loaded reel which allows the upward movement of the detector to unreel the cable and takes up the slack in the cable as the detector moves downward.

Table 1. Comparison of twin probe gamma density gage, three snow pillows, CRREL kit, Adirondack sampler, and Federal sampler, on February 23, 1968.

	Depth (inches)	Density (gm/cc)	Water Content (inches)
Twin probe gamma	23.2	0.25	5.80
Snow pillow #1	19.0	0.24	4.54
Snow pillow #2	24.0	0.22	5.21
Snow pillow #3	21.0	0.21	4.44
CRREL kit	26.5	0.24	6.45
Adirondack sampler	26.2	0.26	6.95
Federal sampler	26.2	0.27	7.10



1 Detector tube
2 Source tube
3 Lead shield
4 Synchronous motors
5 Torque limiter
6 Reversing switches
7 Cable take up reel
8 Rack take up tubes
9 Geared racks
10 Standard reference bar

Fig. 1

Control Panel

The drive system is operated by a control panel located 200 feet from the instrument. It permits the operator to place the system in independent or synchronous mode. Independent mode is used for controlling the motion of the detector and source independently of each other, and is used for lowering the source into the 7-inch lead shield mounted on top of the metal box, or for raising the detector to its top limit for taking a background count. Synchronous mode maintains the detector and source directly opposite each other when making a snow pack profile. When making a calibration check, the calibration switch on the control panel is activated and the detector and source automatically stop opposite the standard reference bar shown in Fig. 1. This activates the lights on the control panel, indicating that the system is ready for the calibration check.

Signal

Photons emitted by the source (see Fig 2) arrive at the detector, producing amplified electronic pulses. These pulses are sent by cable to the pulse height analyser (PHA), located near the control panel, which accepts only photon pulses in the Cs^{137} photo peak range. All other pulses are rejected. The accepted pulses pass from the PHA to a scaler unit which counts these pulses over 1-minute intervals. From the scaler unit the signal, which is an exponential function of density, goes to a logarithmic module designed and built by the junior author, that transforms the counts per minute into snow density. An electronic integrator computes the average density of the total snow pack and displays the result on the scaler decade tubes. Snow density in grams per cubic centimeter versus depth is plotted on a rectilinear chart recorder (Fig. 3).

Calibration Curve

A calibration curve (Fig 4) was determined by placing the standard reference bar and several hand-packed layers of snow and ice of known density between the parallel tubes. Five 1-minute counts were made at each layer after checking the gamma photopeak with the standard reference bar to correct for temperature equilibrium.

The transmission system for measuring density follows the general equation for attenuation of gamma rays (14):

$$I = I. \text{ EXP } (-usx)$$

in which (I) is the final intensity of the transmitted gamma intensity, (u) the mass absorption coefficient, (s) sample density, and (x) the sample material thickness, or the distance separating the source from the detector. Because I_o, u, and x are constant, the final intensity of the attenuated gamma photons is only a function of sample density.

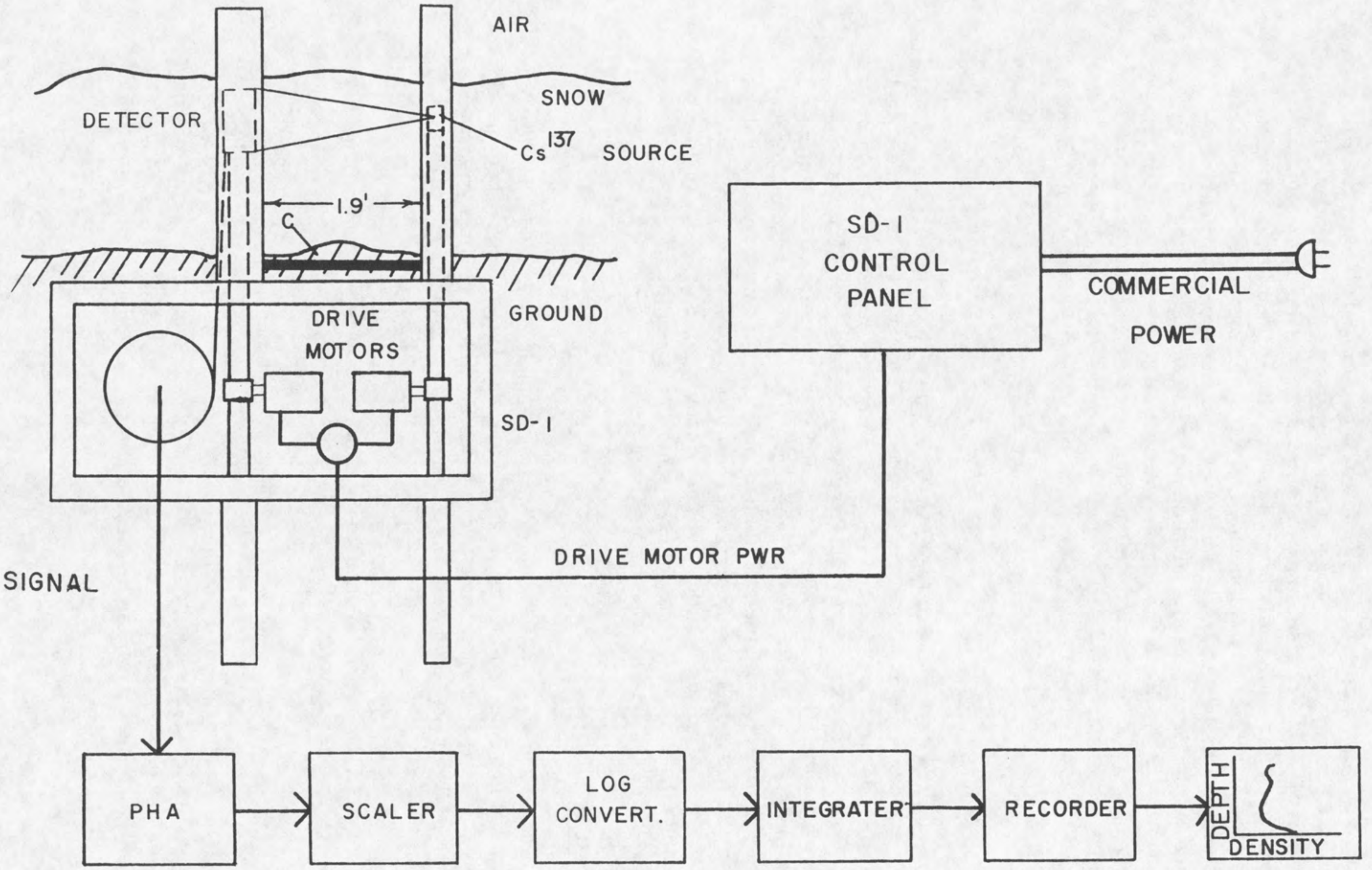


Fig 2

Twin probe snow density gage

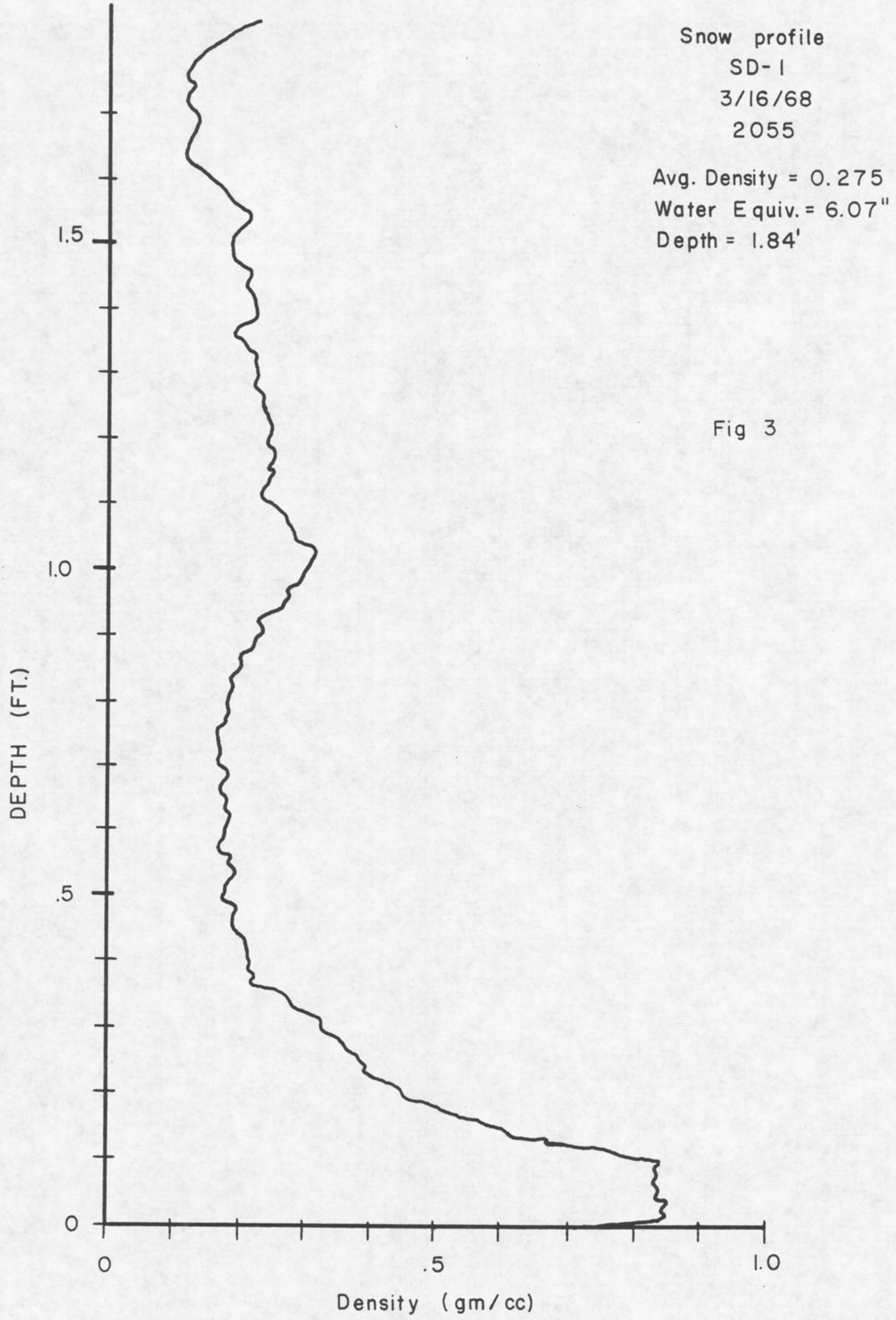

Snow profile
SD-1
3/16/68
2055
Avg. Density = 0.275
Water Equiv. = 6.07"
Depth = 1.84'
DEPTH (FT.)
1.5
1.0
.5
0
0
.5
1.0
Density (gm/cc)

Fig 3

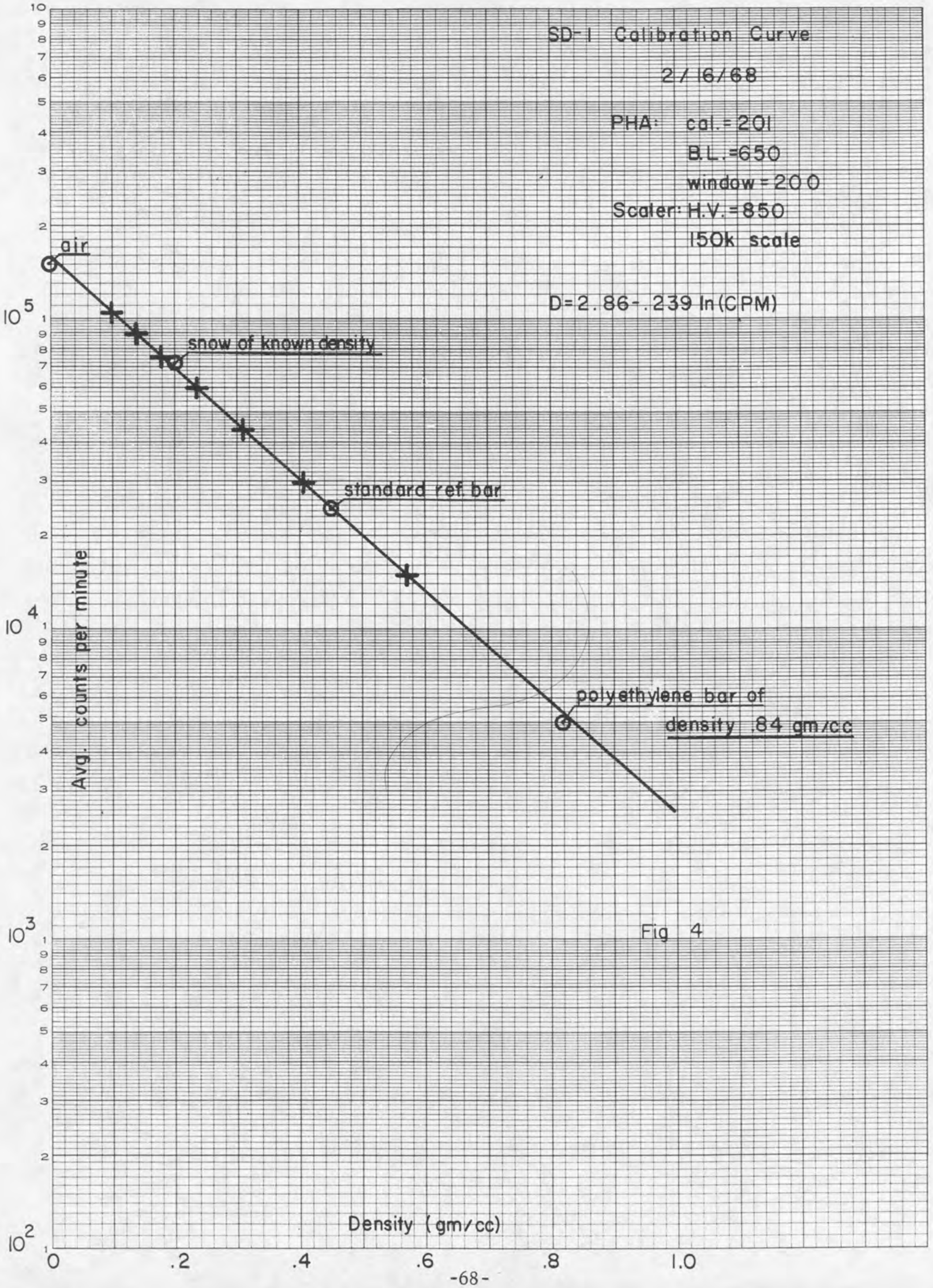

SD-1 Calibration Curve
2/16/68
PHA: cal.=201
B.L.=650
window=200
Scaler: H.V.=850
150k scale
D=2.86-.239 ln(CPM)
air
snow of known density
standard ref. bar
polyethylene bar of density .84 gm/cc
Avg. counts per minute
Density (gm/cc)
10^5
10^4
10^3
10^2
0
.2
.4
.6
.8
1.0

Fig 4

Calibration of the gamma transmission system thus follows a simple linear natural logarithmic regression relationship in the form:

$$D_S = f\ (\ln c)$$

in which estimation of gravimetric snow density (D_S) is a function (f) of log (natural) counts per minute (c). This produces the relationship:

$$\text{snow density} = 0.3972 - 0.1536\ (\ln c),$$ which is

the calibration equation used.

Calibration Test

A calibration test must be made before each profile to correct for drift in the PHA and detector photomultipler tube caused by temperature variations.

The density of the standard reference bar and the standard count through the bar are known. Thus when the detector and source are opposite the standard reference bar, a series of 1-minute counts are made and the count is adjusted to the standard.

Operation

The system is placed in operation by switching the unit to synchronous mode and activating the start button. This sends the source and detector in search of the standard calibration bar. Both stop automatically when opposite the bar, with the source exactly opposite the detector. A count is taken through the calibration bar and the instrument is adjusted if necessary. Another switch is activated and the source and detector move synchronously up the tubes at a rate of 12 inches per minute as the chart recorder plots snow density versus depth. The probes automatically reverse at the top and bottom of the tubes and continue to operate until the unit is switched off.

Temperature Effects

When the air temperature differed from the snow temperature, identical snow profiles could not be produced if the probe rested above the snow-air interface. This was due to the temperature sensitivity of the detector. To avoid this problem the probe was left in the snow pack for 15 minutes to reach the ambient temperature of the pack each time a profile was to be made. This procedure produced identical profiles as shown in Fig. 5.

To reduce this error, the aluminum tubes of the source and detector have been replaced by polyvinylchloride tubing which has a low heat conduction coefficient. This change also helped to prevent sun cupping around the tubes. The detector has also been encased in styrofoam for further insulation. With these renovations this

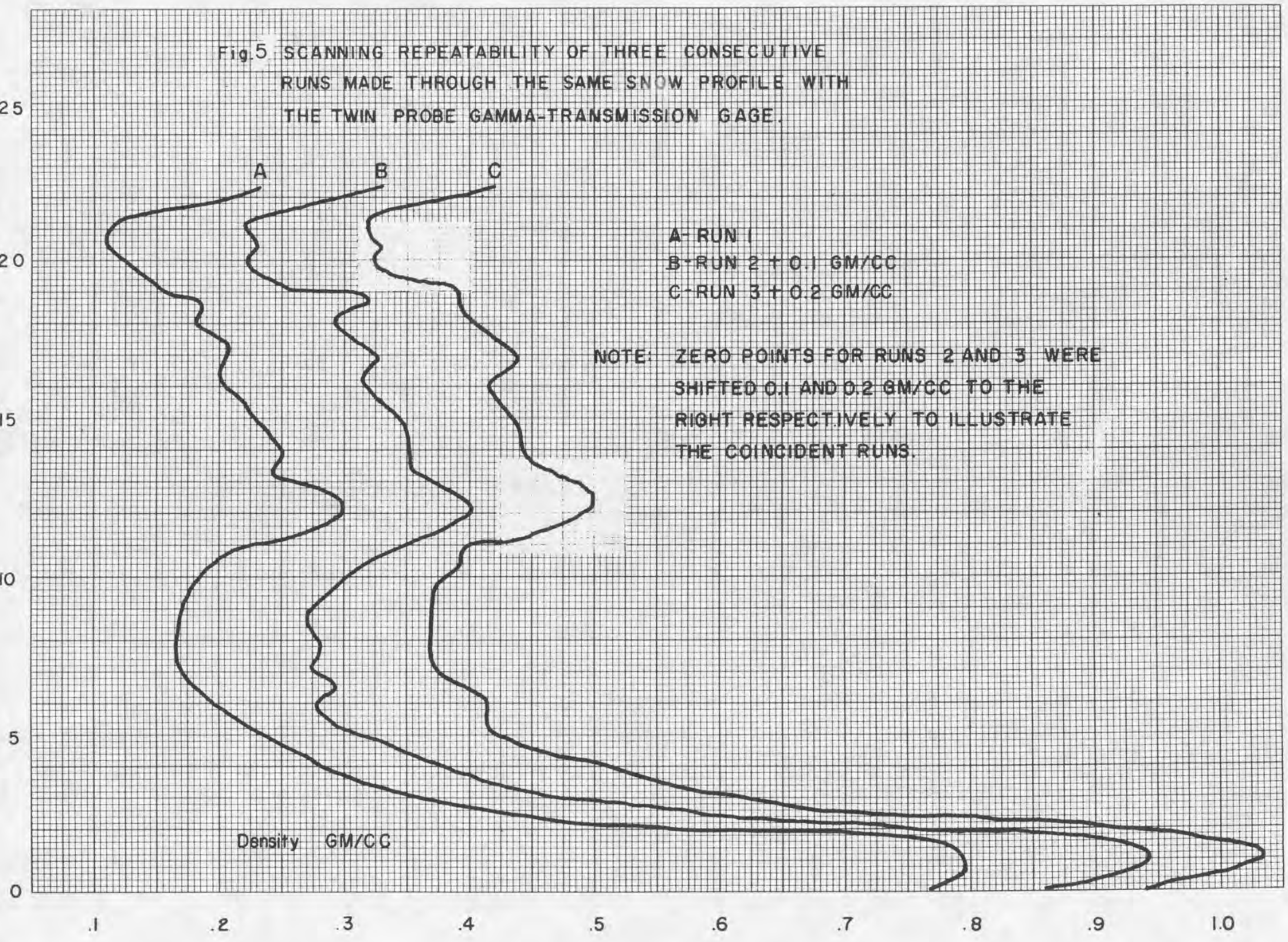


Fig. 5 SCANNING REPEATABILITY OF THREE CONSECUTIVE RUNS MADE THROUGH THE SAME SNOW PROFILE WITH THE TWIN PROBE GAMMA-TRANSMISSION GAGE.

system was tested in a cold room over a temperature range of -22°F to +35°F and results showed that errors due to temperature changes were 1.5 counts per minute per F° per minute.

SUMMARY

The twin-prove scintillcation detector system has probed to be an accurate system for profiling the density of a complete snow pack from below the ground-snow interface to above the snow-air interface. The photons from the source are transmitted through the snow to the detector, which produces electronic pulses that are sent to the pulse height analyser. Photon pulses in the Cs^{137} peak region are sent from the PHA to the scaler to be counted and then to the logarithmic module. Snow density versus depth is plotted on a strip chart recorder. Temperature effects have been a problem with the temperature-sensitive detector, but this has been overcome by the use of styrofoam and polyvinlchloride tubing.

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