

DEVELOPMENTS IN SNOW MEASUREMENTS WITH
GAMMA RADIATION

Gaston Paulin

Service de la Météorologie, Min. des Richesses naturelles
Gouvernement du Québec, Québec, P.Q.

ABSTRACT

A nuclear snow profiling gauge using a horizontal gamma ray beam is being described. It was originally developed by scientists from "Electricité de France" and modified later in cooperation with the personnel of the Quebec Meteorological Service. Some further modifications are proposed in order to be able to connect the snow gauge to a G.O.E.S. telecommunication platform. A description of a plan relative to developments in operational snow measurements is also being given.

The purpose of this short notice is to describe a snow gauge originally developed by Guillot and Vuillot of "Electricité de France" in Grenoble and modified later by Pierre Gosselin (1969, 1971) from the Quebec Meteorological Service and a private Quebec firm: Simtec Ltée.

The original development work was performed by Guillot and Vuillot from 1962 to 1965. The first prototype consisted of a vertical gamma-ray absorption apparatus. It was found to be inadequate in the French Alps as it required gamma-ray sources of fairly strong radioactivity to traverse the snow depths usually encountered. Between 1964 and 1967, the two French scientists developed a snow gauge characterized by the use of a horizontal rather than a vertical gamma-ray beam. This snow gauge was further developed by Pierre Gosselin in cooperation with Guillot between 1969 and 1974. The Quebec Meteorological Service has tested various versions of the snow gauge. Unfortunately the latest version has not been produced as the local firm responsible for its production ceased to exist in the mid-seventies. A version, produced by Neyrpic, a French company from Grenoble, and used in the French Alps by the "Electricité de France", has been acquired by the Quebec Meteorological Service and erected at a testing site in the Forestry school of Duchesnay, near Quebec City.

The basic principles utilized in determining the snow pack density and water equivalent vertical profiles are the following:

- i) the density and water equivalent of a slab of snow are inferred from the attenuation of a horizontal gamma-ray beam issued from a radioactive Cesium 137 source;
- ii) the apparatus consists in a mechanical arrangement carrying upward and downward in a vertical plane the radioactive source and a radiation detector held at a constant horizontal distance;

- iii) the vertical speed of the source-detector system is regulated by the impulsion count reaching the detector; a greater counting rate at the detector is transmitted electronically to an electric motor which accentuates the upward speed of the tandem system. It follows that the time taken for the source-detector arrangement to traverse vertically a snow slab of fixed thickness is proportional to the mass of the snow in this slab, hence to its density and water equivalent;
- iv) a record of the times taken to traverse the individual slabs of a given snow pack provides a way to obtain the vertical profile of the densities or water equivalent of this snow pack.

The theoretical basis and formulation of the relationship between the independent variable, time "t" with "ρ" or "E", the density or the water equivalent, respectively, may now be developed.

If I is the radioactive intensity of the horizontal beam reaching the detector after having been depleted by the attenuating snow mass, I_0 , the radioactive intensity of the beam at the detector in a free air path, ℓ , the liquid water equivalent path length of the snow between the source and the detector, and μ , the linear attenuation coefficient for gamma-rays in water, the physical law of the exponential decay for the radioactive intensity of the beam may be written as:

$$I = I_0 e^{-\mu\ell} \quad (1)$$

If further, N is a chosen fixed number of impulsions to be read while the source-detector system moves upward across the fixed distance "h" in snow or air, then "t", the time needed for the detector to read these "N" impulsions, may be expressed as:

$$t = \frac{N}{I} = \frac{N}{I_0 e^{-\mu\ell}} = \frac{N e^{\mu\ell}}{I_0} = t_0 e^{\mu\ell} \quad (2)$$

where "t₀" is the time necessary to the detector to count the "N" impulsions when the path between the source and the detector is free air. The water equivalent path length "ℓ" may then be given by equation (2):

$$\ell = \frac{1}{\mu} \ln \left(\frac{t}{t_0} \right) \quad (3)$$

If "L" is the distance separating the source from the detector, the mean horizontal density "ρ" is then:

$$\rho = \frac{\ell}{L} = \frac{1}{\mu L} \ln \left(\frac{t}{t_0} \right) \quad (4)$$

Further, the mean vertical water equivalent "E" of a slab of snow having a vertical thickness "h" becomes:

$$E = \rho h = \frac{h}{\mu L} \ln \left(\frac{t}{t_0} \right) \quad (5)$$

For example, using the actual constant values of the snow gauge in Duchesnay:

L = 60 cm
h = 10 cm
t₀ = 5 seconds
μ = 0.062 cm⁻¹

when for a heavy snow slab, t = 20 seconds, the resulting density ρ is found to be 0.373 and the water equivalent E to be 3.73 cm.

The source of errors associated with the snow gauge may be separated in three parts:

- i) statistical fluctuations of gamma-ray emission and spurious background radiations of terrestrial or cosmic origin:
 - a) the first error is reduced by increasing "N" (error $\propto 1/\sqrt{N}$) i.e. taking longer time interval for counting purpose;
 - b) the second error is eliminated in large part in discriminating on the energy spectrum of the acceptable radiation;
- ii) the influence of the scattered radiative flux: the law holds for the direct flux only and special precautions must be taken in order to eliminate the scattered flux: the use of a ray collimator giving a very narrow beam and a well aligned source-detector apparatus works in the right direction;
- iii) depressions at the snow surface near the two supporting posts due to the wind action initially and later to solar radiation: the error is small until late in season and is inherent to the measuring method.

The profiling snow gauge used at the Quebec Meteorological Service will now be described. It consists in the assembly of two hollow cylindrical tubes inserted vertically in the ground containing the source and the detector. The posts are made out of polyester and epoxy, a material whose heat conduction is poor. The version in Duchesnay is 4 meters high and spans 60 cm across the source and the detector (see fig. 1). The tubes have a circular section with diameters of 15 cm. A bi-directional electric motor with variable speed raises or lowers the source and collector simultaneously at a rate proportional to the collector (Geiger Müller counter) counting rate. The radioactive beam issued from a 10-millicurie Cesium 137 source is collimated in a very narrow and flat cross-section. An electric pulse is sent through the electronic circuit every time the coupled source and collector are displaced vertically by 10 cm (fixed "h"). The needed electrical power is provided by 4 potassium batteries whose individual output is 2000 ampere-hours. They are connected in series in order to give 4.8 volts. The snow gauge requires 12 amperes while in operation and 6 amperes while it returns to its initial position. A nickel-cadmium battery is used to provide such a current during the measuring cycle and is recharged by the 4 potassium batteries in-between measuring operations. The batteries can be operated at temperatures as low as -40°C and present no special problems if they are kept under the snow surface.

The profile of the snow pack can be found once the individual time differentials for the assembly to traverse each 10-cm slab of snow are known. In the Alps, the signals are sent in real time by radio transmission and the densities or water equivalent can then be found using a calibration curve such as the one given in fig. 2 or in applying equations (4) or (5).

NEYRPIC SNOW PROFILING GAUGE # 74

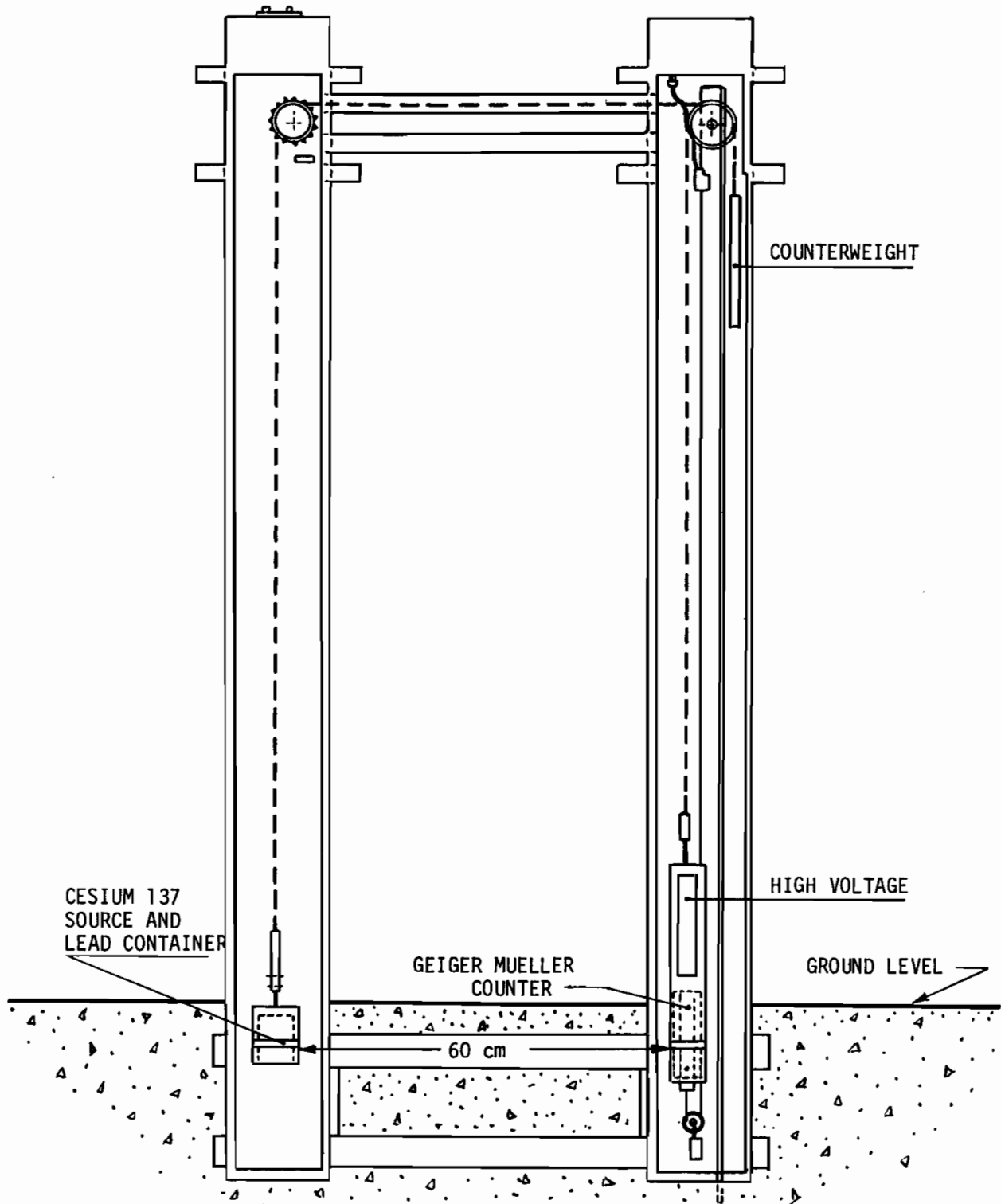


FIGURE 1- SNOW PROFILING GAMMA-RAY ABSORPTION GAUGE (NEYRPIC)

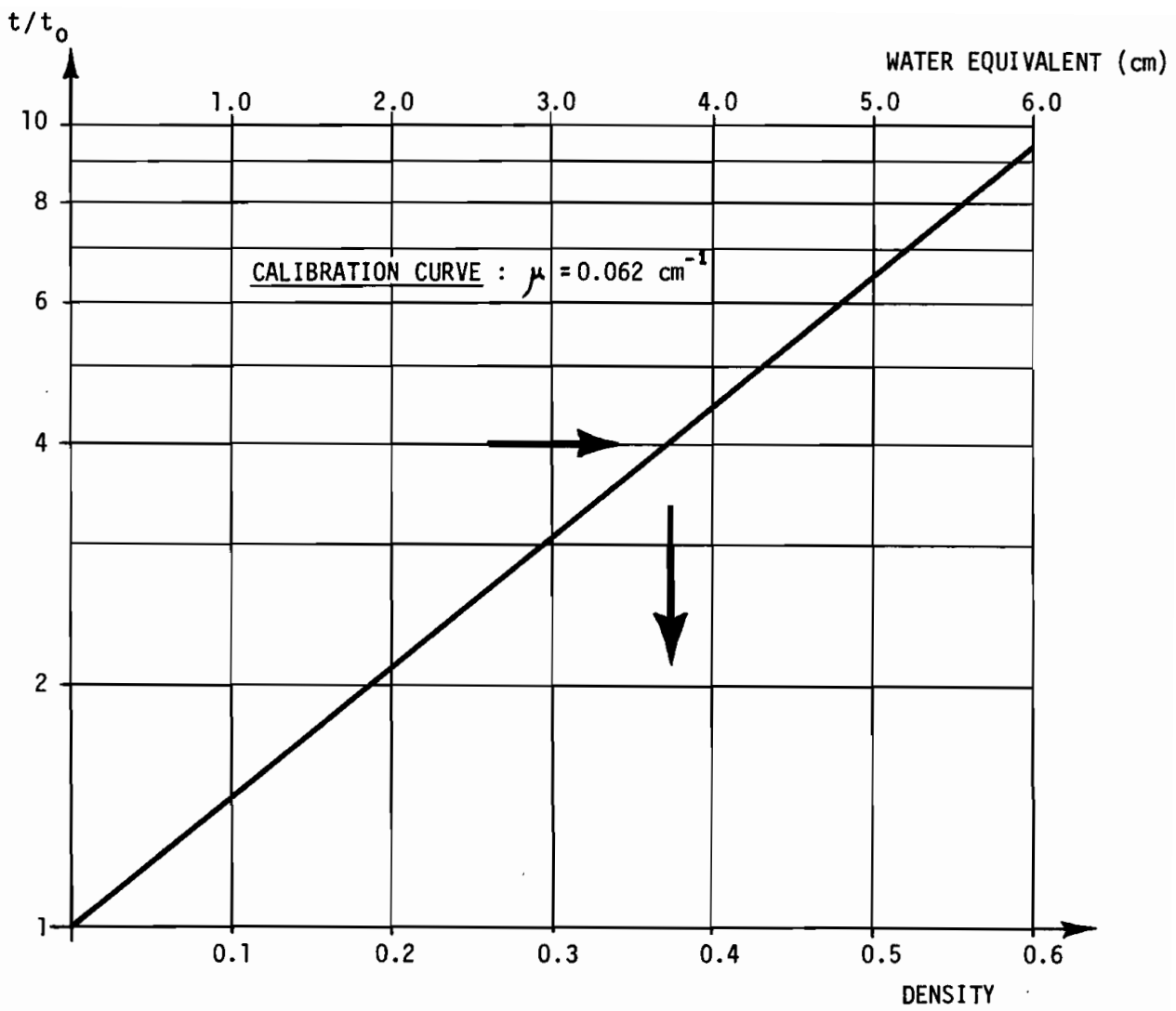


FIGURE 2- CALIBRATION CURVE

Since no radio transmission for this specific purpose is available in Duchesnay, and since the Quebec Meteorological Service has started using the G.O.E.S. system of telecommunication, special temporary arrangements have been developed. Since the profiling gauge has no memory bank to store the time differential while the apparatus is in operation, and that the whole information must be ready on call from the G.O.E.S. transmitting platform, it has been decided, at least temporarily to measure the mean water equivalent and depth of the snow pack. In order to accomplish just that, equation (5) has been modified accordingly and the water equivalent "E_p" of the snow pack becomes:

$$E_p = \frac{nh}{\mu L} \ln \left(\frac{T}{n t_o} \right) \quad (6)$$

where "n" is the number of snow slabs whose constant thickness is "h", "n t_o" is the time that would take the apparatus to traverse "nh" centimeters of free air and "T" is the total time for the instrument to traverse the snow pack. A resettable counter keeps "n" while time T is kept on the clock counter. These two numbers are given to the emitting platform on call.

Some error is associated using equation (6) rather than equation (5). Figure 3 is a computed example of the error amplitudes for a linear vertical density profile in three specific density spectra. This error is nil for n = 1, increases to a maximum as n = 2 and decreases rapidly afterward. It can be seen also that irrespective of "n" the error tends to be proportional to the difference between the lowest and largest densities in the snow pack, at least in the case of a linear profile.

Work is now progressing relative to the tests of various meteorological and hydrometeorological instruments in Duchesnay. A G.O.E.S. telecommunication platform will be installed shortly when the proper interfacing circuits are ready. Platinum resistance thermographs with analog voltage output will be used. A snow pillow with a pressure transducer giving also an analog voltage output is ready to be utilised. A Fischer and Porter rain and snow gauge giving the precipitation intensity by 15-minute increments with parallel BCD digital output will also be connected to the G.O.E.S. platform. A remote snow gauge LSG-1 (Idaho Industrial Instrument Inc.) has been received. It is a gauge using a vertical natural gamma-ray beam to determine the water equivalent of the snow pack. It delivers a parallel BCD digital output. Work towards interfacing this gauge with the G.O.E.S. platform will be started imminently. A regular snow course (10 posts) is also situated adjacent to the testing site.

It is hoped that the bulk of redundant data that will be collected will serve as a guide as well as an estimation of the representativeness of water equivalent information in snow pack measurements by remote means.

REFERENCES

- Gosselin, Pierre, 1969: "Le télénivomètre horizontal de l'E.D.F." Feuillet météorologique, Vol. VIII, No. 11, p. 414-428.
- Gosselin, Pierre, 1971: "Un appareil de mesure automatique de la neige", l'Ingénieur, Vol. 57, No. 270, Sept. 1971, p. 11 - 15.

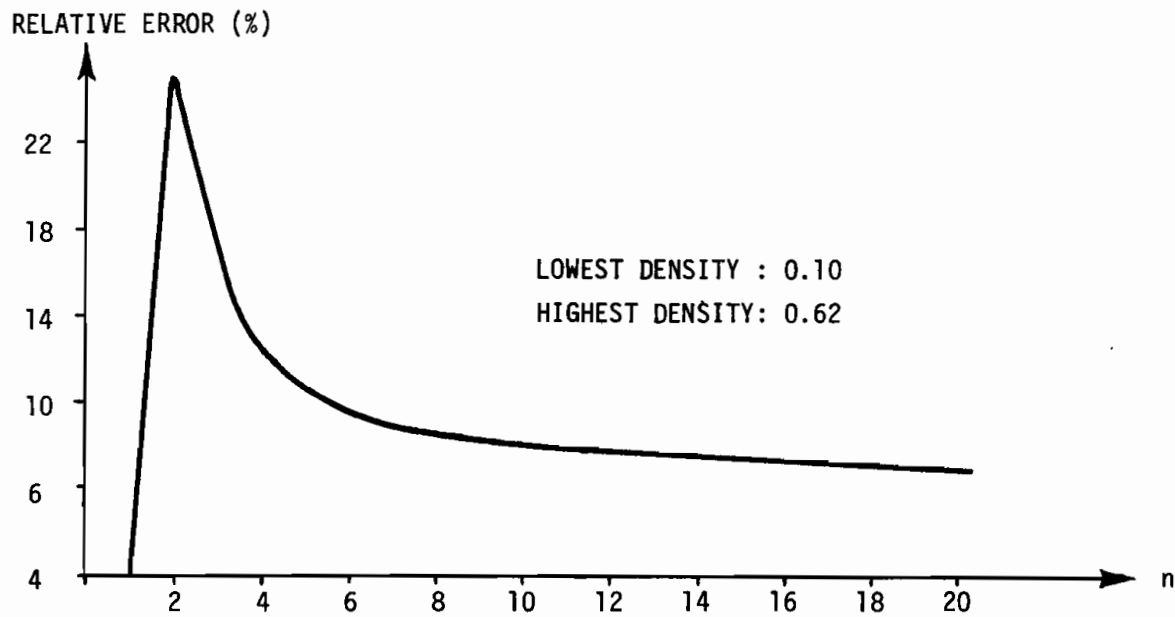
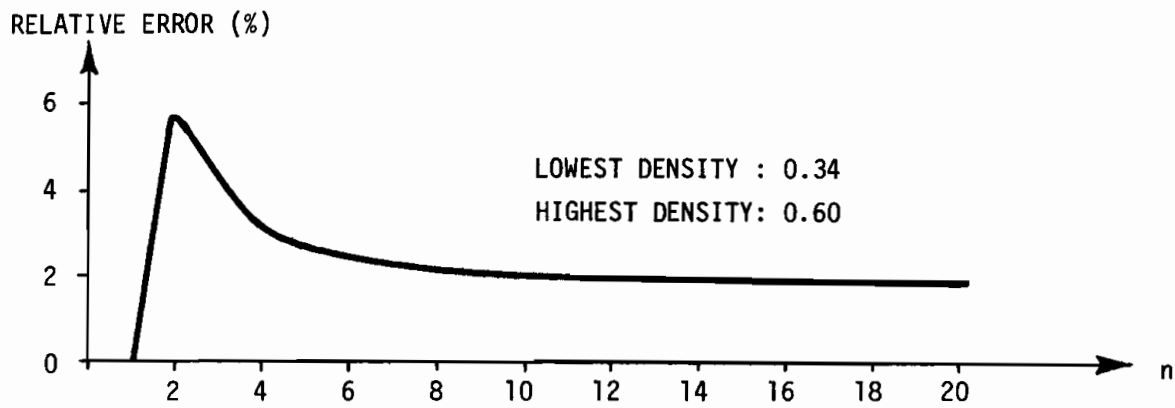
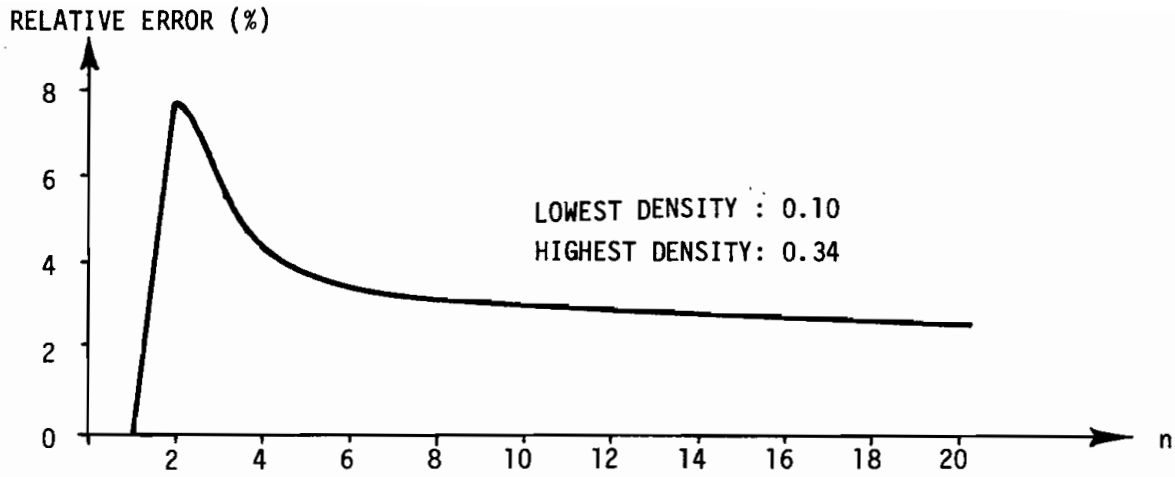


FIGURE 3- RELATIVE ERROR IN TOTAL SNOW PACK WATER EQUIVALENT WHEN EQN. 6 IS USED AS A FUNCTION OF THE NUMBER (n) OF SNOW SLABS OF FIXED THICKNESS SHOWING A LINEAR VERTICAL PROFILE.