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BUDAPEST

ON THE THEORY AND PRACTICE OF DENSITY CORRECTION CONCERNING NEUTRON MOISTURE MEASUREMENT

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Theory of density correction

The systematic error as an accessory effect to the random error induced in the reading of neutron moisture gauges by the variation in the dry bulk density of the medium was investigated theoretically in a previous work of the authors [1] . It was pointed out that two independent measurements have to be performed to obtain the correction for dry bulk density effect of the calculated moisture calibration curve as markedly apparent in Fig. 1. It was found that the actual, density corrected deviation of the moisture content $\Delta\rho_M$ can be expressed as

$$\Delta\rho_M = A\ \Delta n + B\ D\ \Delta n_\gamma \qquad /1/$$

where n and n_γ are the measured independent counts proportional to humidity and density, respectively. A and B are characteristic coefficients of measuring equipments. A is the reciprocal sensitivity of the moisture calibration and D that of the density calibration curve.

$$A = \left(\frac{\partial\rho_M}{\partial n}\right)_{\rho_d} \qquad [g\ H_2O/cm^3/cpm]$$

$$/2/$$

$$D = \left(\frac{\partial\rho_d}{\partial n_\gamma}\right)_{\rho_M} \qquad [g/cm^3/cpm]$$

They are useful and known general parameters, however, we have a new one in the form of the coefficient B. This is also a sensitivity but of the dry bulk density calibration

$$B = \left(\frac{\partial\rho_M}{\partial\rho_d}\right)_n \qquad [g\ H_2O/cm^3/0,1\ g/cm^3] \qquad /3/$$

Expression /3/ shows the measure of the systematic error if the effect of dry bulk density variation is not taken into account.

In Fig. 2 the meaning of equation /1/ is illustrated. Consider two media with different dry bulk densities $\rho_d(1)$ and $\rho_d(2)$ but with identical moisture content. Making a measurement in medium $\rho_d 1$ we get n_1 counts corresponding to the value of $\rho_M 1$ on the calibration curve. Changing from medium $\rho_d 1$ to $\rho_d 2$ the n_2 counts correspond to a moisture content ρ_M^* which is apparently different from the volume assumed above. Therefore, it is easy to see from Fig. 2. that the total value of Δn should be cancelled by density correction.

In Fig. 3. a general case is shown. Here, Δn is seen to have two contributions. One corresponds to an apparent and the other to a real moisture content. The counts originating from dry material can be considered as a background. The density of dry material may vary in practice and therefore produces a varying background. To obtain true information above this background level, we have to check the background counts for every moisture measurement. If the density varies i.e. $\Delta n_\gamma \neq 0$ we subtract from n_2 the counts proportional to Δn_γ. These counts can be evaluated if the value of B is numerically known either from calculations or from measurements. Let us briefly discuss our results in both cases.

During the calculation the investigated medium was considered infinite. In the majority of practical cases /geological, soil mechanical investigations/ this assumption is true. However, the calibration process is carried out generally in such circumstances where the medium is definitely smaller than infinite. Under such conditions neutrons will excape at the boundary of the sample, and thermal neutron counts will decrease as compared with an infinite system. The smaller the moisture content, the larger is the decrease. Therefore, a special care has to be taken to choose a proper sample volume for both calibration and measurement.

The experimental results in comparison with the calculation can be seen in Fig. 4. In connection with this figure the question arises, whether the calculated values of B agree with the values observed in experience or not. The effect of sample volume on B was investigated experimentally. The sample volume was given by the diameter and cubic volume of the containers /in cm and litre/ and the dry density was given in g/cm^3. It is clear from Fig. 4. that on the low end of the calibration curve "B measured" is smaller than "B calculated". Consequently, we usually have smaller B for a sample volume with loss of counts. At the same time, on the upper end the agreement is satisfactory, the measured values have already reached the predicted ones above ρ_M = 20 Vol.%.

Density correction in practice

Two forms of nuclear emission, fast neutrons and gamma radiation, are simulteneously employed in moisture measuring application. The correction for dry bulk density requires two independent measurements in any gauge. In our case, a combined system, developed for the simultaneous determination of moisture and density, consisting of a double scintillator and a pulse-shape descriminator within a single probe serves for the double purpose [2] . In Fig. 5. the experimental arrangement is shown. In this arrangement the pulses of the scintillators are detected by a common multiplier. The probe internal pulse-shape discriminator connected to the multiplier produces two independent output signals, one proportional to humidity and the other to density. In this manner we can get rid of such undersirable signals as the noise of both scintillators, and the useful n and n_γ signals can be processed in conventional manner.

According to expression /1/ the density correction must be performed in such a way that the n and n_γ counts have to be summed after weighting the values with A and $B\ D$ respectively. If we take constant coefficients, which is a good approximation in the case of a reasonably large sample volume, the task can be achieved by simple means. For weighting, both counts can be set by counting rate dividers. The output pulses n and n_γ from pulse-shape discriminator 2 - shown in Fig. 5 - are taken to gates 3 and 4 controlling the input pulses to the predividers 5 and 6 , respectively. The divided output signals from 5 and 6 are added by the summing unit 7 and the sum of the signals n and n_γ is displayed by units 8 and 9. Simutaneously, the direct density counts $/n_\gamma/$ can be displayed by units 10 and 11. The common time base is taken from the timer 12 and the time is measured by clock 13 and recorded by line printer 14. This process ensures that the counting rate caused by the slowing down in the dry material, which appears as a background, is automatically subtracted even if this background varies.

It is well known from soil mechanical investigations that the density varies from place to place. But there are several other practical examples of the density effect which is not negligible , especially on the low end of the calibration curve. The measurement and control of foundry moulding sand with usually 5 to 10 weight per cent of moisture content can be cited as a good example [3]. In this case, because of the large clay content, the relative error may be even 50% or more due to density variation.

To have an automated moisture control system for industrial application further data processing is needed. The scaler 17 - in Fig. 5. - measures the moisture content in weight per cent. It is fed directly from the adding unit 7 through the logic units 15 and 16. The slope of the calibration curve is determined by the counting rate divider 16. The intersection of the curve at null weight per cent of moisture content is set by the treshold logic 15. On termination of the measurement, valve control 19 measures, whether the content of the scaler 17 is smaller than a given preset count or not. The programmed count preset corrresponds to the expected moisture content. If the scaler content is smaller, 19 will open a water valve for as long as the pulses from water quantometer 18 fill the scaler up to the programmed preset. Otherwise, the valve is closed and 21 gives an alarm signal.

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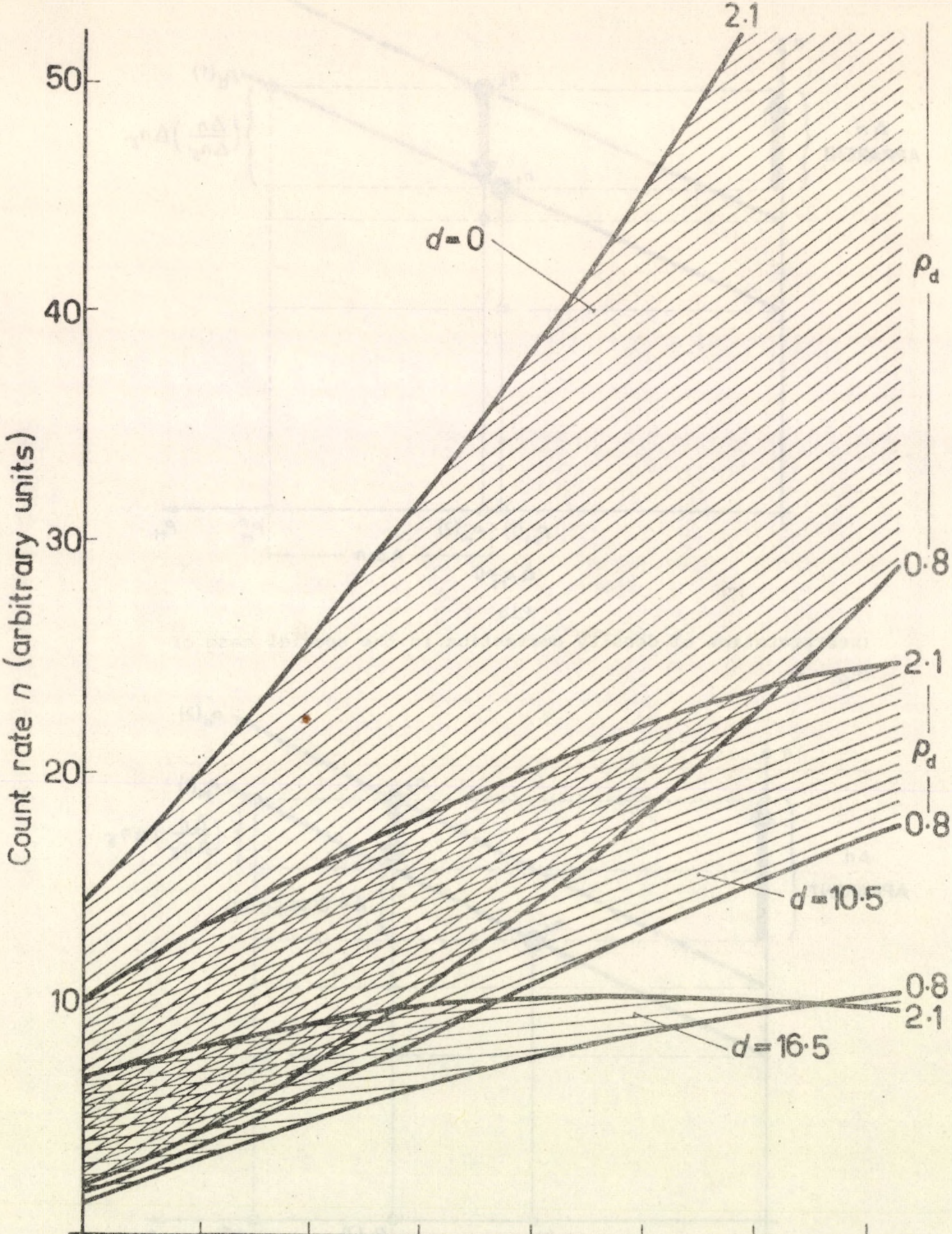

Fig. 1

Influence of dry bulk density /ρ_d varies from 0,8 to 2,1 g/cm^3/ on the calibration curve for source detector spacing d = 0; 10,5 and 16,5 cm.

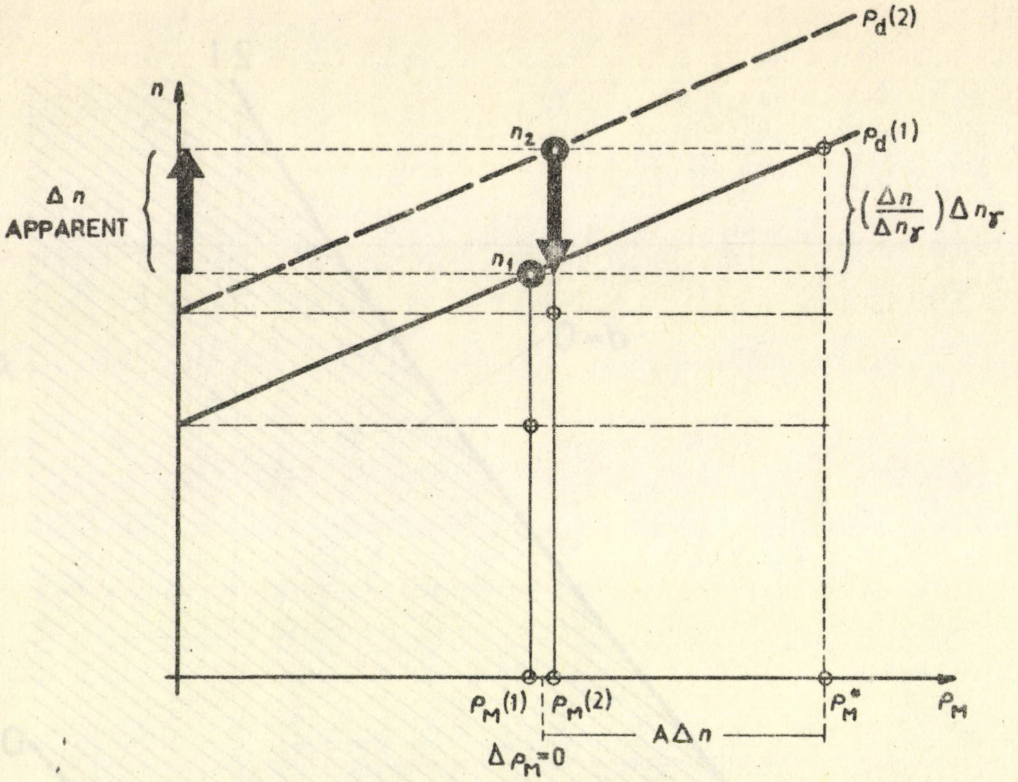

Fig. 2

Interpretation of density correction in the special case of $\Delta\rho_M = 0$.

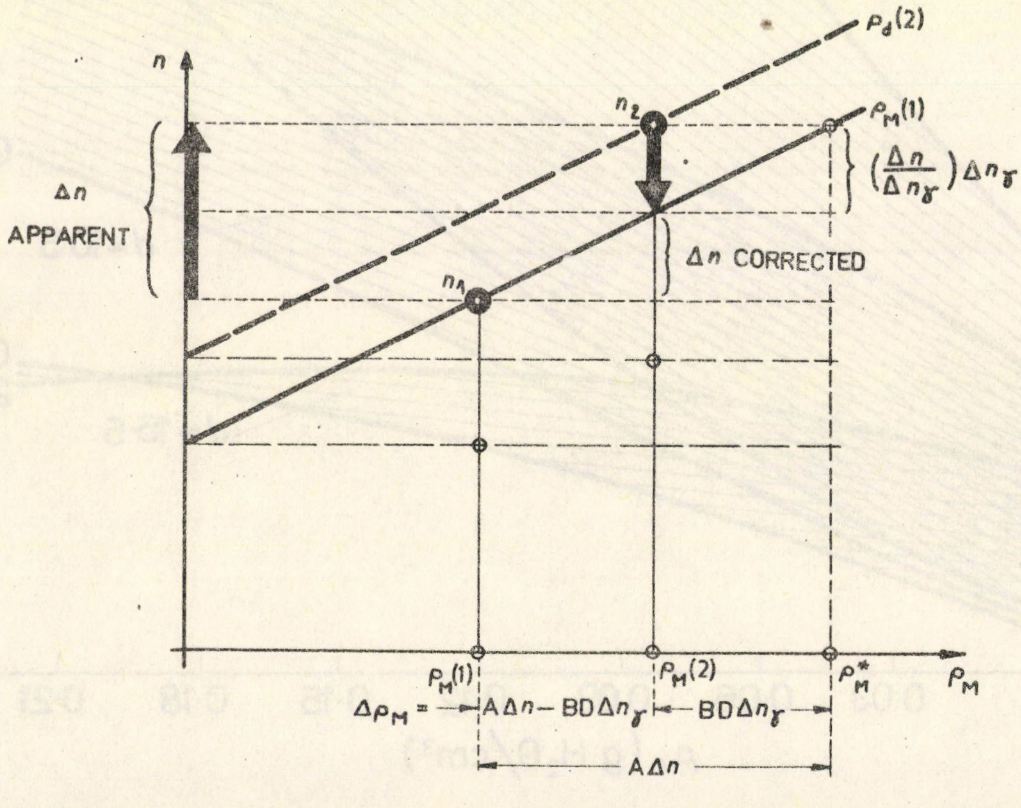

Fig. 3

Interpretation of density correction in the general case, $\Delta\rho_M \neq 0$.

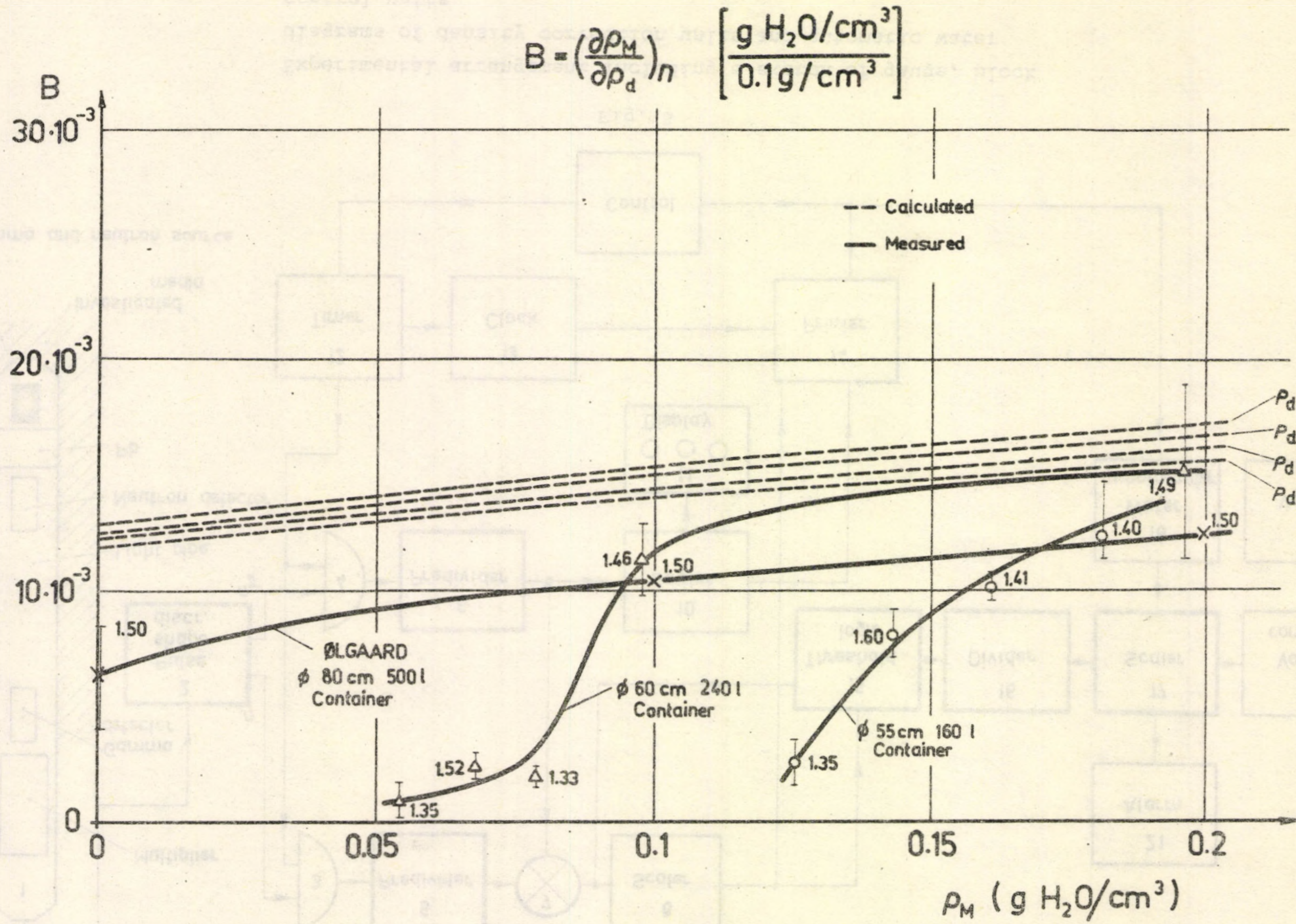

Fig. 4

Comparison between computed and measured values of B. The computation was carried out for infinite homogeneous mixture of investigated medium.

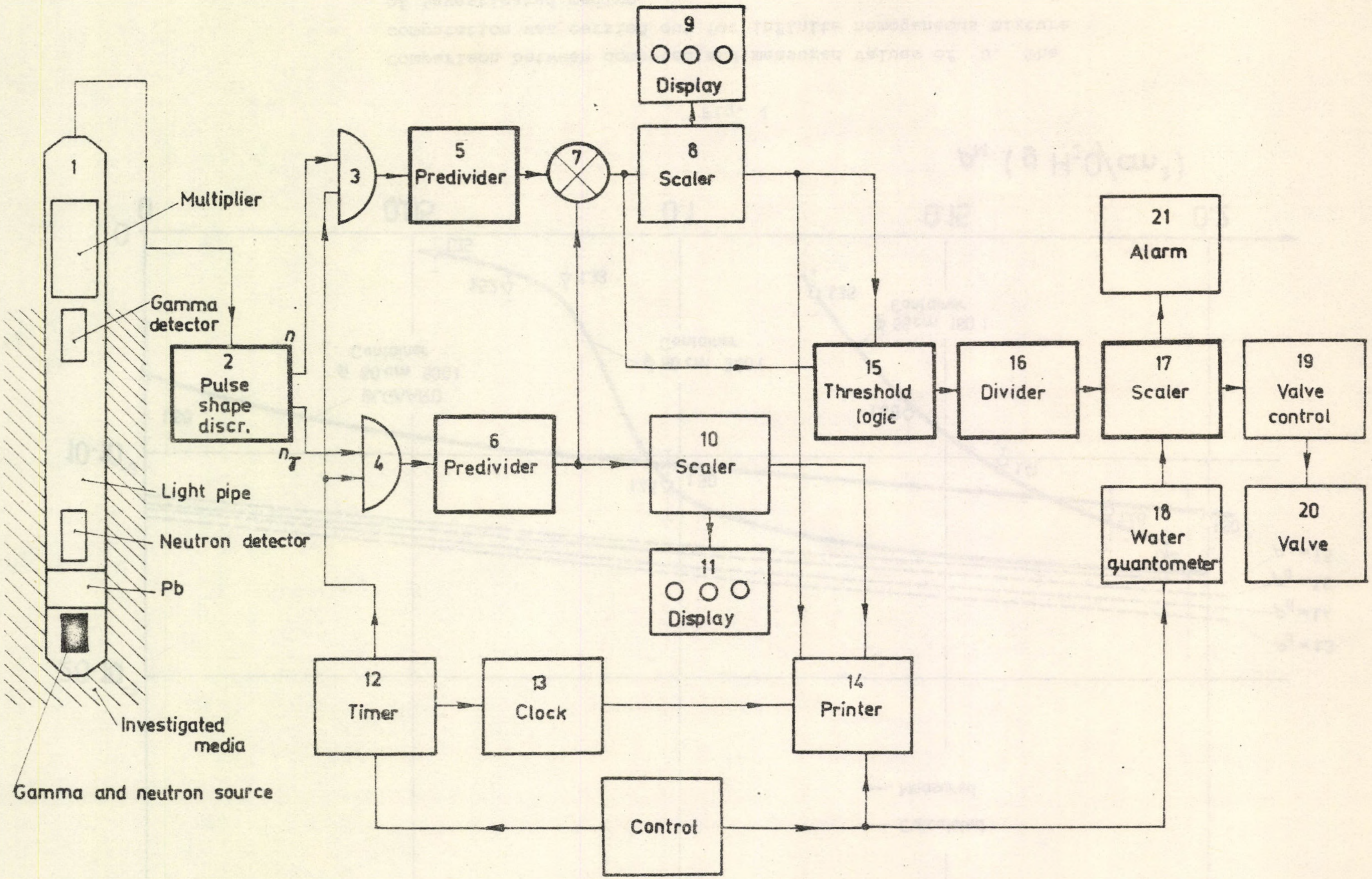

Fig. 5

Experimental arrangement including a sketch of gauge, block diagrams of density correction units and automatic water control units.

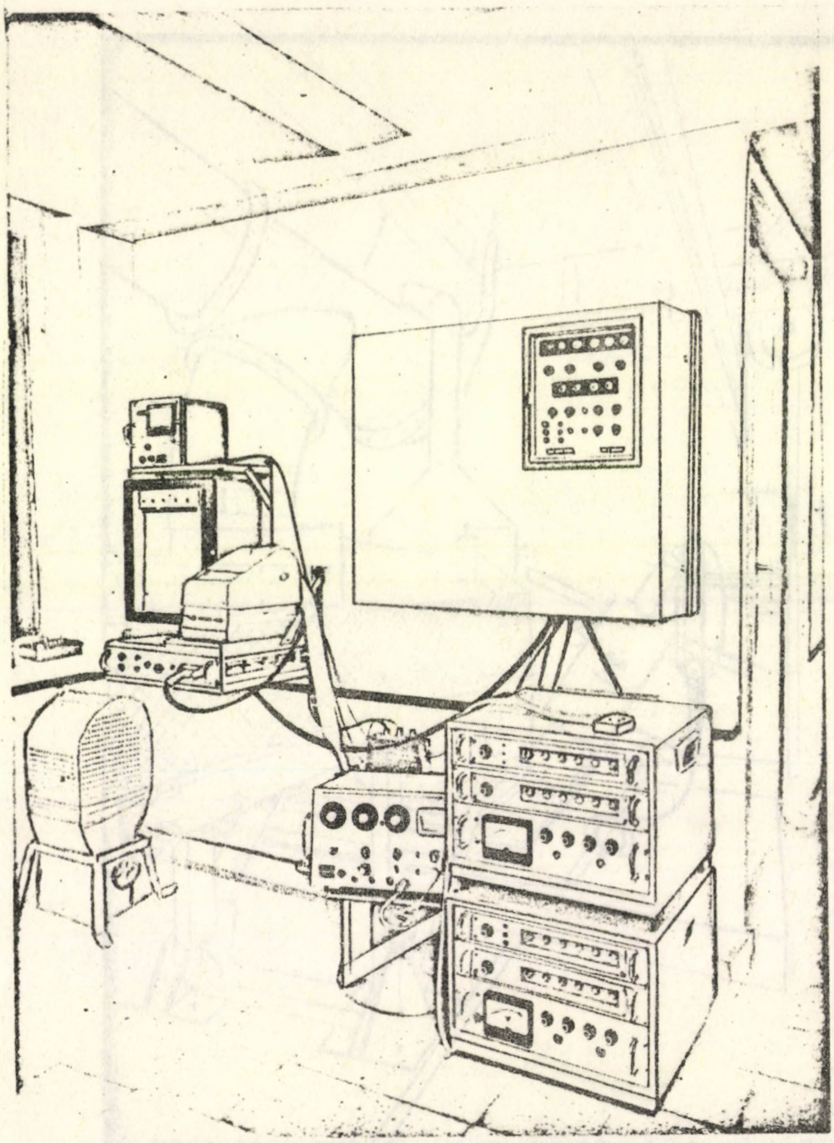

Fig. 6

Probe assembly for foundry sand moisture control.

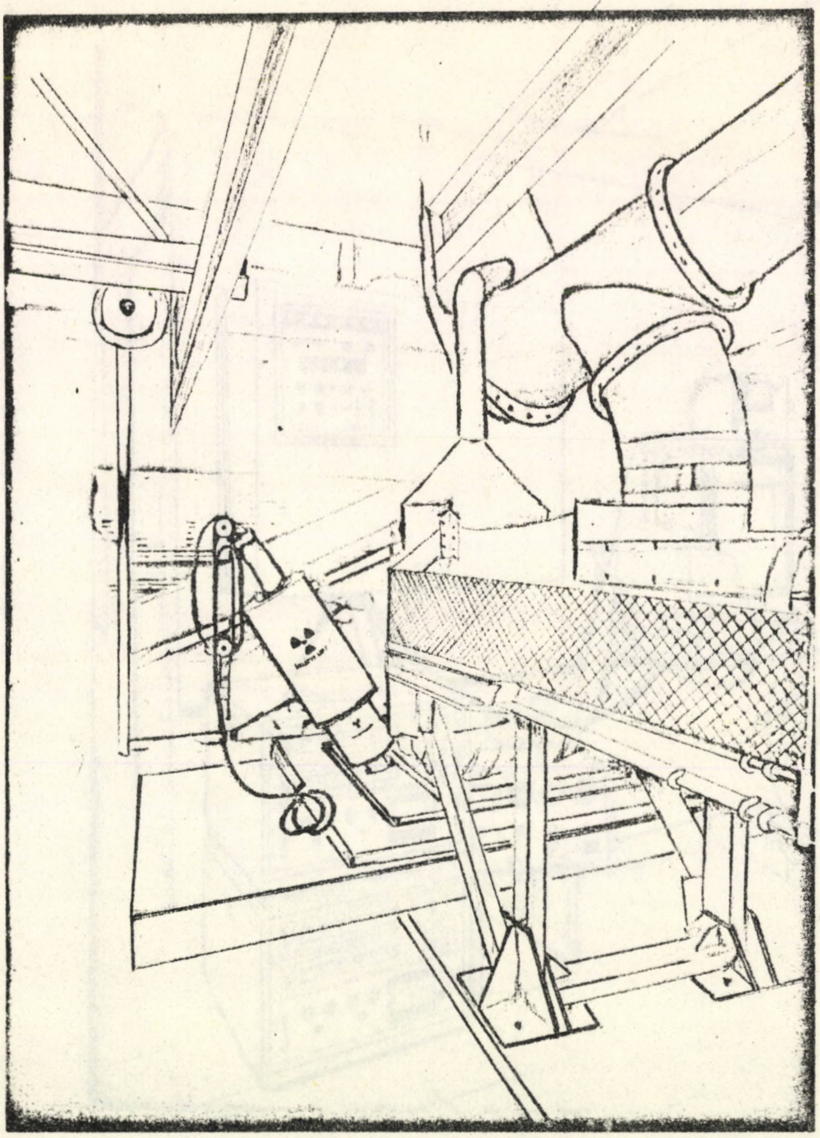

Fig. 7
Electronic control units.

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