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Design and Field Test of a Scintillation Probe for γ-Logging of Small Diameter Boreholes

von

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Vorwort der Schweizerischen Geotechnischen Kommission

Die Schweizerische Geotechnische Kommission dankt den Autoren C. Sprecher, dipl. Geophys., und PD Dr. L. Rybach, dass sie die Arbeit „Design and Field Test of a Scintillation Probe for γ-Logging of Small Diameter Boreholes“ für die „Kleineren Mitteilungen“ zur Verfügung stellten. Die Studie ging aus Untersuchungen für die im Text genannten Organisationen hervor, die sich mit der Prospektion auf radioaktive Elemente in der Schweiz befassen.

Zürich, Februar 1975

Der Präsident der
Schweiz. Geotechnischen Kommission

Dr. A. von Moos

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Design and Field Test of a Scintillation Probe for γ-Logging of Small Diameter Boreholes[1])

By C. Sprecher[2]) and L. Rybach[2])

Summary – A 68-cm long probe of 2.5 cm diameter, containing a NaI (Tl) crystal, photomultiplier, HV stabilization and preamplifier, is described. Special attention is paid to the probe-cable coupling: it is designed to withstand hydrostatic pressures up to 10 atm. For logging of inclined, up to 20-m long holes, aluminium extension pipes assembled by push-button closures are used. The probe, operated together with a portable ratemeter, has a sensitivity of 1200 c.p.s. per mR/h (Ra^{226}). For quantitative log interpretation the conversion factor was determined to be 0.4 p.p.m. U/c.p.s. Radiometrically determined uranium contents agree remarkably well with results of chemical analysis of cores.

1. Introduction

Uranium prospecting in Switzerland has been carried out under the auspices of the Federal Government since 1966 by two organizations: 'Arbeitsausschuss für die Untersuchung schweizerischer Mineralien und Gesteine auf Atombrennstoffe und seltene Elemente' and 'Studiengesellschaft für die Nutzbarmachung schweizerischer Lagerstätten mineralischer Rohstoffe'. Terrain with favourable rock formations (mainly located in the Alps) has been traversed on foot and scanned for radiometric anomalies using portable scintillation counters.

In selected areas with especially promising surface indications, exploratory adits and drill holes have been sited. The objectives of these operations are:

i) to locate mineralized zones,
ii) to determine the extent of such zones,
iii) to evaluate the distribution of uranium contents in them.

These data should be determined *in situ* by γ-ray measurements.

Exploratory holes (rotary drilled to avoid costly diamond core drilling) in rugged terrain, especially those drilled in different directions from adits, can only be made with light portable equipment. For this reason, drill hole diameters must be kept small (about 1 in).

Determination of γ-activity in these exploratory holes called for a *small portable logging device* with a detector of *less than 1 in diameter*. High sensitivity and good depth

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resolution were necessary to permit exact location of the thin mineralized zones which were expected. Further requirements were rugged construction for reliable operation under field conditions, and a watertight design capable of withstanding hydrostatic pressures of up to 10 atm. Since many of the exploratory holes drilled from adits were horizontal or inclined upward it was necessary to construct a device for pushing the probe into the holes, some of which were up to 20 m long.

Almost all portable radiation detectors now used in the field are either Geiger-Müller or scintillation counters. Scintillation instrumentation has a much better efficiency for γ-rays: a detector with 1 in diameter would require an 80 cm long arrangement of Geiger-Müller tubes to match the sensitivity of a 2.5×2.5 cm scintillation crystal. Thus a small-diameter scintillation borehole probe not only provides better depth resolution, and consequently more detailed γ-logs, but also a lower cosmic ray background. Currently available photomultipliers allow one to take advantage of these favourable features of the scintillation detector even for a borehole probe with small diameter. No equipment with the requirements mentioned above is commercially available at present. Most organizations prospecting for uranium (e.g. United Kingdom Atomic Energy Authority, Danish Atomic Energy Commission) are faced with the same problem of developing their own logging tools (Miller and Loosemore [1], Løvborg [2, 3]).

2. *Description of the scintillation probe*

The borehole probe is operated together with the *rate-meter type instrument* EMD 2.1d manufactured by Landis & Gyr Co., Zug, Switzerland (Fig. 1). The EMD 2.1d instrument is a small ($20 \times 10 \times 11$ cm high), light (1.2 kg), portable, single-channel pulse-height analyser; it was used for the present study in the integrating mode, measuring all pulses above a certain, selectable threshold. The unit is powered from five 1.5 V batteries and furnishes adjustable high voltage of from 500 V to 2800 V as well as a supply voltage for a preamplifier. A full-scale reading can be obtained from the front

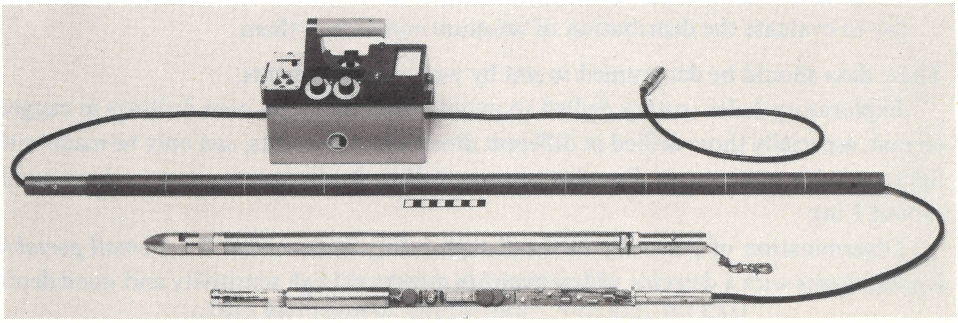

Figure 1
Electronic insert, borehole probe, extension pipe and rate meter unit

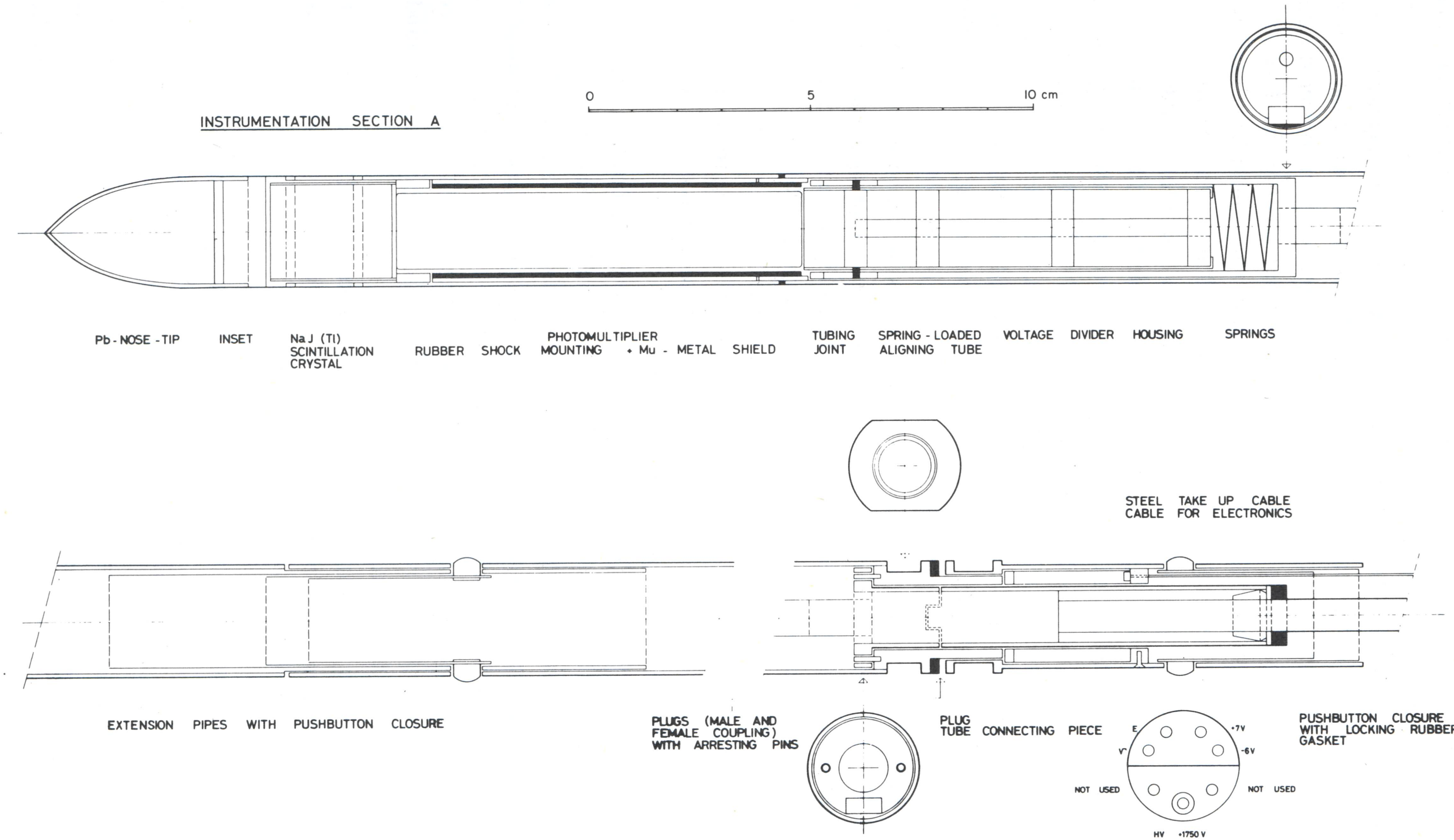

Figure 2
Probe cross-section. Top: probe head; bottom left: extension pipe closure; bottom right: probe-cable coupling and pushbutton adapter for the first extension pipe

panel meter in nine ranges from 3 to $3 \cdot 10^4$ c.p.s. (deadtime losses corrected). The time constant can be selected as 1, 5 or 25 sec.

High voltage is stabilized in the borehole probe at 1300 V by two voltage regulating tubes. The Philips XP 1115A photomultiplier (with ten dynodes) is operated at 1050 V, corresponding to the centre of its plateau region. An emitter follower, powered from the +7 V and –6 V supply voltages of the rate meter, is used as a preamplifier. Its output impedance is matched to the 75 Ω impedance of the cable (maximum length 100 m) connecting the borehole probe to the rate meter. Photomultiplier, voltage divider for the dynodes, HV-stabilizer and preamplifier are placed in a 63-cm long stainless-steel casing with an external diameter of 2.5 cm (Fig. 2). The rounded-off front part of the probe (top left on Fig. 2) is fitted to the casing by a watertight screw connection. It contains a lead nose-tip and a Harshaw Type PA *16 mm × 25 mm NaI (Tl) crystal.* The rear part of the detector head is lined with a rubber sleeve and a mu-metal shield to protect the photomultiplier tube from mechanical shock and the influence of magnetic field. By removing the front part, the electronic insert (bottom in Fig. 1) can be pulled out of the casing. The resistors and stabilizing capacitors of the voltage divider are arranged cylindrically around a plexiglass rod which is fixed to the socket of the PM tube. The whole unit is movable within a thin aluminium tube. A spring at the rear end of the tube presses the voltage divider-photomultiplier assembly against the scintillation crystal. This arrangement (which enables the replacement of the PM tube), together with a thin layer of silicon oil between the front face of the PM tube and the crystal, provides a good optical coupling. The printed-circuit board carrying the components of the preamplifier and the female coupling of the plug are mounted on an aluminium support which is fixed to the voltage divider housing.

Special attention had to be paid to a reliable and *tight coupling* of the plug connection between probe and cable (bottom right in Fig. 2). The male and female couplings of the plug were placed in thin aluminium tubes which were filled completely with Araldite cement. After the plugs are put together the probe is assembled by screwing an adapter piece to the rear end of the casing. A rubber gasket in the interior of the adapter is thereby squeezed and pressed against the plug tube which fixes the plug into its proper position. A leakage test in the laboratory showed that the plug connection can withstand hydrostatic pressures up to 10 atm.

Aluminium *extension pipes* can be slipped on the adapter piece (bottom right on Fig. 2) if inclined holes are to be logged. The 1 m long, lightweight extension pipes are assembled by means of push-button closures (bottom left in Fig. 2).

3. Calibration

3.1. Sensitivity

The sensitivity of a radiation detector is usually expressed as the ratio of count rate (as indicated on a rate meter) versus dose rate (of a given reference source) in terms of c.p.s. per mR/h. The γ-ray intensity I (dose rate) of a point source decreases with the

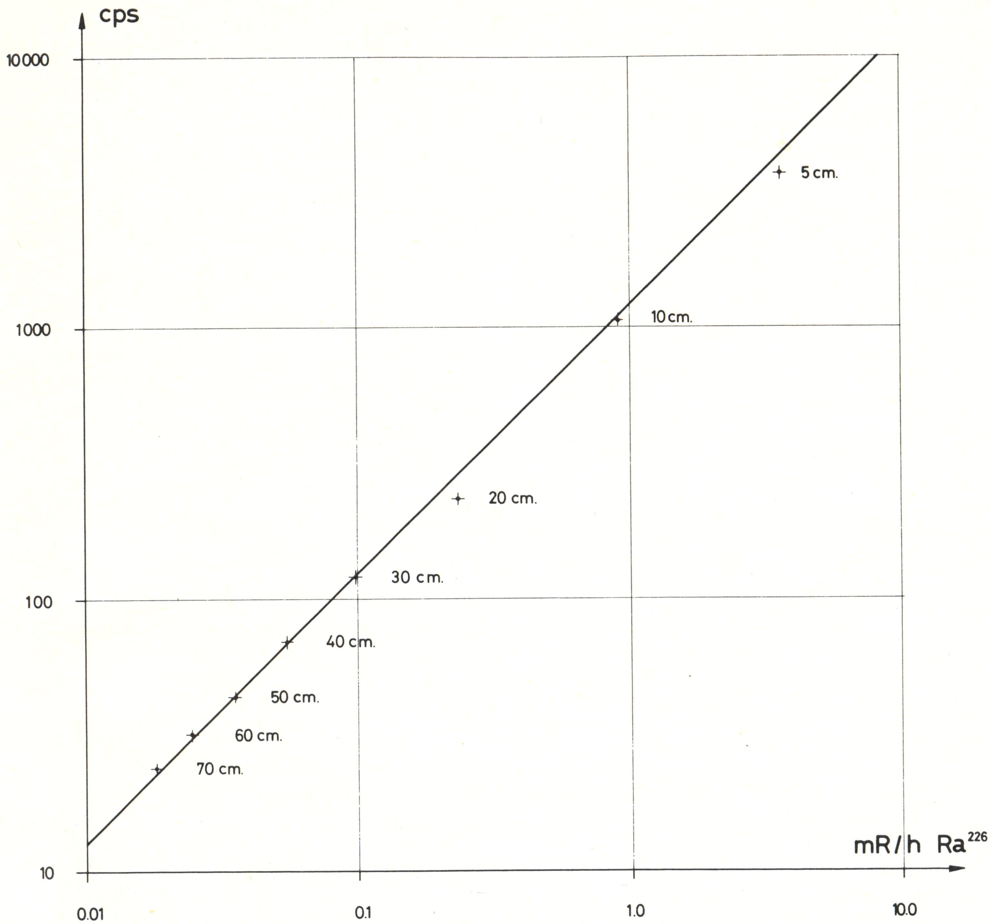

Figure 3
Sensitivity calibration with a Ra^{226} reference source at different distances from the probe head

square of distance d, provided that back-scattering and absorption effects are negligible:

$$I(d) = \frac{q \cdot D}{d^2}, \tag{1}$$

where D is the specific γ-ray constant of the source and q is the source strength. Since D depends on the γ-ray energy, sensitivity calibration was carried out with a Ra^{226} reference source characterized by a γ-radiation similar to that of the spectrum to be measured (decay products of U^{238}).

Measurements have been carried out with a Ra^{226} needle with $D = 0.825$ Rm²/hCi and $q = 10.8$ μCi. In this case

$$I(d) = \frac{89 \cdot 1}{d^2} \text{ mR/h}. \tag{2}$$

$I(d)$ values for different distances have been plotted versus measured net count rates in Fig. 3. The slope of the line gives a sensitivity of 1200 c.p.s. per mR/h. Background in the laboratory was 17 c.p.s.

3.2. Conversion factor for quantitative log interpretation

Determination of uranium contents in layered rocks penetrated by boreholes is based on the relationship (Scott *et al.* [4])

$$\bar{c}_U \cdot h = k \cdot A, \tag{3}$$

where $\bar{c}_U$ (p.p.m.) is the mean uranium content of a mineralized layer with thickness h (cm), A is the area under the corresponding peak in the γ-log (c.p.s.·cm) and k the conversion factor. The thickness of the layer equals the distance between the half amplitude points at each side of the anomaly peak curve.

The conversion factor is usually evaluated by measuring A in full-scale models with known $\bar{c}_U$ and h. An alternative method is to determine k from γ-logs of boreholes from which analysed cores are available. For the probe described above, k was found to be 0.4 p.p.m. U/c.p.s.

4. Field work

Near Truns (Canton Graubünden) a uranium mineralization occurs in gneisses and schists of the 'Tavetscher Zwischenmassiv', the main uranium mineral being pitchblende (for details see Kramers [5]). This mineralization has been traced using an adit of 150 m total length, as part of the exploration programme of the 'Studiengesellschaft'. A number of horizontal, or near-horizontal holes 5 to 20 m long were drilled from the adit, mostly perpendicular to its axis. γ-Logs were obtained by inserting the probe with extension pipes.

Several mineralized zones have been located by peaks in the γ-logs. The thickness h of each zone has been determined from the inflection points of the peaks, the mean uranium content $\bar{c}_U$ from equation (3).

Near Finhaut (Canton Valais) the Vallorcine granite, a 0.5 to 1.5 km wide, 15 km long part of the Aiguilles Rouges Massif, contains several uranium mineralizations (pitchblende) which are mainly confined to fracture zones (for details see Labhart and Rybach [6, 7]). Field investigations of these mineralizations have been carried out by the 'Arbeitsausschuss'. Drilling in a fan-like pattern has been used to delineate the form of a relatively isometric mineralization. The holes were logged without the extension pipes, inside plastic tubing inserted for protective purposes. By connecting points of equal γ-ray intensity on the different logs the distribution of radioactivity, and thus of the uranium content, has been delineated.

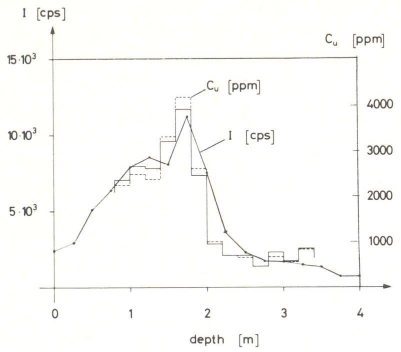

Figure 4
γ-Log of a borehole at the Finhaut site (line with dots). Close correspondence of radiometrically determined uranium contents (solid line) with chemical analyses from cores (dashed line) indicates radioactive equilibrium

In one of the boreholes cores were taken for radiometric and chemical analysis of uranium; close correspondence of chemical[3]) and radiometric results (Fig. 4) indicates the presence of radioactive equilibrium in this mineralization.

Acknowledgements

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