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Latest achievements in the development of nuclear suspended sediment gauges

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ABSTRACT *In situ* measurement of suspended sediment concentrations is especially important at higher concentrations, i.e. during floods or in countries where streams have a very high sediment transport capacity. The new Hungarian nuclear gauge for measuring suspended sediment includes previously developed features like the horizontal arrangement, the capability of taking measurements close to the bed, and an adjustable distance between the radiation source and the detector. In addition it has the following new features: (a) a semiconductor detector instead of a scintillation detector, enabling a lower supply voltage to be used, and having a tolerance of voltage fluctuations; (b) a built-in programmable pocket calculator which directly converts measured radiation intensity into sediment concentration. The range of measurement of the gauge is about 500-12 000 mg l^{-1}, high enough for most semiarid or tropical streamflow conditions. Because it is battery powered and portable the gauge can be rushed to the site of a sudden flood.

Derniers perfectionnements dans la mise au point d'appareils nucléaires pour la mesure des sédiments en suspension

RESUME La mesure *in situ* de la concentration en sédiments suspendus est particulièrement importante dans le cas de concentrations élevées, c'est à dire pendant les crues ou dans les pays où les cours d'eau présentent une capacité très élevée de transport de sédiments. Le nouvel appareil nucléaire hongrois pour la mesure des transports solides en suspension comporte des dispositions déjà au point auparavant telles que l'alignement des éléments sur une ligne horizontale, la possibilité de procéder à des mesures très prés du fond du lit et celle de régler la distance entre la source de radiations et le détecteur. En plus il comporte les nouveautés suivantes: (a) un détecteur semi conducteur au lieu d'un détecteur à scintillations permettant d'utiliser une plus faible tension d'alimentation et admettant une certaine tolérance pour les fluctuations de tension, (b) une machine à calculer de poche programmable incorporée qui convertit directement les intensités de radiations que l'on mesure en concentration en sédiments. L'intervalle de concentrations que l'appareil permet de mesurer est

sensiblement le suivant: 500 à 12 000 mg l^{-1}, ce qui est suffisamment élevé pour la plupart des conditions rencontrées dans la plupart des rivières des pays semi arides ou tropicaux et comme l'electricité est fournie par une batterie qu'il est transportable, il peut être amené rapidement sur le site lors d'une crue brutale.

NOTATION

c concentration of sediment
I measured instantaneous radiation intensity
I_o instantaneous radiation intensity measured in a sediment free medium
x length of absorption, i.e. distance between radiation source and detector
μ' linear absorption coefficient of the absorbing medium
μ mass absorption coefficient
ρ mass density of the medium
Subscripts s and w refer to sediment and water, respectively.

INTRODUCTION

The determination of the quantity and/or concentration of suspended sediment in streams is an important factor in the design and operation of river management structures and water intakes for various purposes. Most rivers carry much more suspended sediment annually than bed load, thus, sediment concentration variations need to be measured in order to calculate the dimensions of settling basins and to prevent sedimentation at particular locations and/or particular times.

There are several types of suspended sediment sampler from the simplest milk bottle to the more complicated pumping systems. However, they have a common drawback: the samples need a lengthy transporting, processing and analysing procedure.

In order to avoid these difficulties, there arose an increasing demand for direct *in situ* determination of sediment concentration. Different electro-optical devices have been developed, using a photocell to measure the changes of light intensity from a special submerged lamp of constant brightness due to the turbidity of the water. These instruments are usually applicable only for lower concentrations (10-300 mg l^{-1}), i.e. during low and medium flows. For the estimation of annual suspended sediment transport, however, the high concentrations occurring during flood waves are of primary interest. The application of electro-optical devices is further limited by the fact that they are not only sensitive to the presence of suspended mineral sediment particles, but also to organic matter and to the colour of water, frequently influenced by dissolved industrial wastes.

Since the mid-1960's, nuclear suspended sediment gauges have been developed in various countries. After submersion, they indicate the instantaneous value of concentration; in addition they are not affected by the colour of the water or by suspended organic matter. Several types of nuclear sediment gauge

developed by the Section of Isotope Hydrology at the International Atomic Energy Agency (Florkowski, 1970; Rákóczi, 1973) were put into operation in various developing countries. This paper describes how these devices have been further developed in Hungary.

NUCLEAR SEDIMENT GAUGES DEVELOPED IN HUNGARY

Nuclear suspended sediment gauges can be divided into two main groups: those measuring the attenuation of radiation intensity (a) back-scattered by the water and sediment particles, (b) directly absorbed by the water-sediment mixture.

Instruments of the first group are usually slightly more sensitive to small changes in sediment concentration, however, their measuring geometry is rather big, preventing their application in streams shallower than about 1.5 m and in the vicinity of the river bed. The latter problem is a big disadvantage since there is generally a steep sediment concentration gradient close to the bed. This near-bed layer usually remains unmeasured by ordinary sampling techniques, due to the dimensions of the sampler and the lead weight.

With respect to the above considerations, instruments measuring the direct attenuation of gamma-rays were developed. One reason for this decision was the need to measure higher concentrations, another was the very small measuring geometry of these instruments. The few millimetres thickness of the applied beam of radiation also made it possible to measure sediment concentrations close to the stream bed.

The measurement of the gamma-ray attentuation due to absorption by the suspended sediment particles is based on the well-known absorption law of Lambert-Beer:

$$I = I_o \exp - \mu' x \tag{1}$$

In order to take into account the mass density of the medium to be measured, the mass absorption coefficient

$$\mu = \mu'/\rho \tag{2}$$

is used instead of the linear absorption coefficient.

Substituting the value of the intensity measured in sediment-free water, I_w, in place of I_o in equation (1), the following expression is obtained:

$$\frac{I}{I_w} = \exp - (\mu_s - \mu_w \frac{\rho_w}{\rho_s}) \text{ cx } \rho_m \tag{3}$$

The accuracy of concentration measurement highly depends on the measuring sensitivity, i.e. the ratio of the relative change in radiation intensity to the corresponding change in concentration:

$$S = \frac{\partial I/I}{\partial c/c} = (\mu_s - \mu_w \frac{\rho_w}{\rho_s}) \text{cx } \frac{\rho_m^2}{\rho_w} \tag{4}$$

It can be seen that the sensitivity depends mainly upon the distance x (detector-radiation source) and on the difference between the mass absorption coefficients of the water and the

sediment.

The distance x cannot be easily increased, partly due to constructional difficulties, partly because this would also involve a significant increase of the applied activity, regarding the inverse relation of radiation intensity to the square of the distance. In the case of a given absorbing medium, the mass absorption coefficient depends only on the energy of radiation. Without discussing the details of this correlation, it can be stated, that in the case of sediment the lower the energy, the higher the mass absorption coefficient. However, the lower the energy, the greater are the difficulties encountered in its detection, i.e. in filtering out the disturbing background "noise".

With this in mind, the Hungarian instrument was equipped with an americium-241 source of 100 mCi activity, emitting gamma radiation of 60 keV energy.

The instrument consists of two main parts: the submersible probe and the scaler. The latter processes the signals given by the detector and displays the counts as concentration values. As shown in Fig. 1 the probe consists of a 100 mm diameter stainless steel tube. Near the sharp nose the lead case of the source can be seen. The detector is installed at the other end of the tube together with the electronic equipment necessary to amplify the impulses. A circular opening at the nose and several elongated holes in the side wall allow water in and out of the probe.

The lead casing of the source can be shifted axially within the tube, changing the source-detector distance between 200 and 300 mm. The collimated source can emit radiation through a 8 mm diameter window facing the detector, made watertight by a thin steel plate. A removable lead cover prevents radiation entering the probe during storage and transportation.

The detector is also lead-shielded in order to decrease the effect of background radiation and is protected by a watertight cover on the collimated window facing the source. The lead shielding provides the necessary mass (above 45 kg) so that the probe can then be submerged to a depth of 6-8 m in a medium-sized stream having flow velocities around 1 m s^{-1}. The probe is suspended on a steel cable and can be lowered or lifted by a winch.

Previous instruments were equipped with a scintillation detector consisting of a NaI/Tl crystal and a photomultiplier. Though having a good detecting efficiency, it was rather sensitive to mechanical impacts and required a stable high voltage power supply (1000-1200 V). A further disadvantage of this type of detector is the inherent high "noise level" of the photomultiplier, requiring a complicated amplifier circuit to filter out the signals from the applied low energy radiation.

To overcome these problems, a semiconductor detector was installed in the probe of the new instrument. Its long-term stability and detecting efficiency are excellent and its own background noise can be neglected compared with the measured counts. The scaler of the former type had built-in high voltage generating and stabilizing circuits and a quartz timer. As an

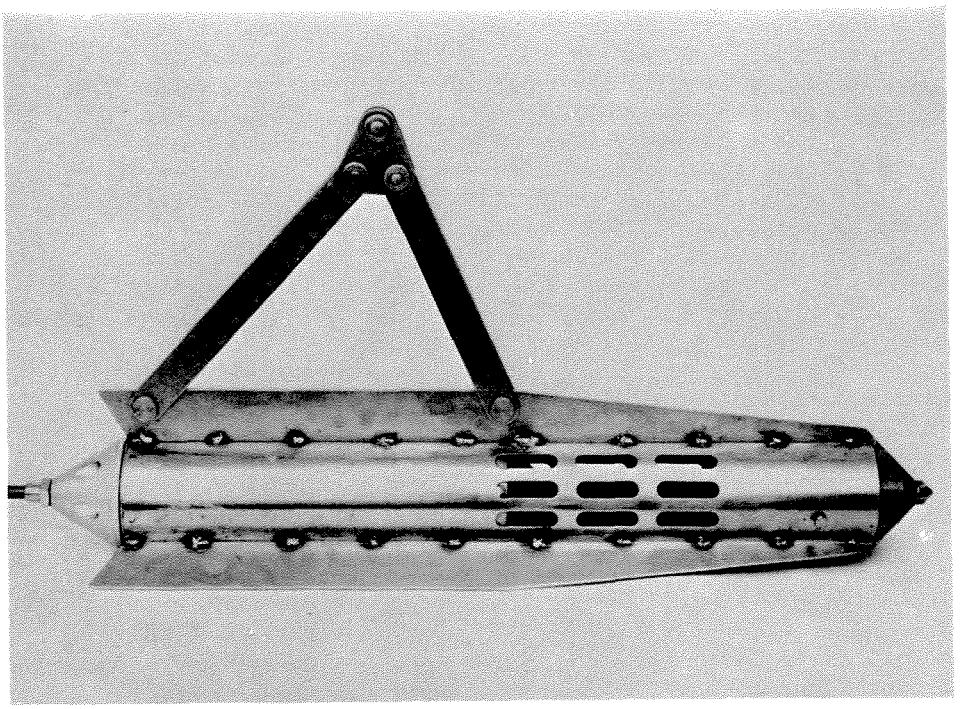

Fig. 1 The probe of the Hungarian suspended sediment gauge.

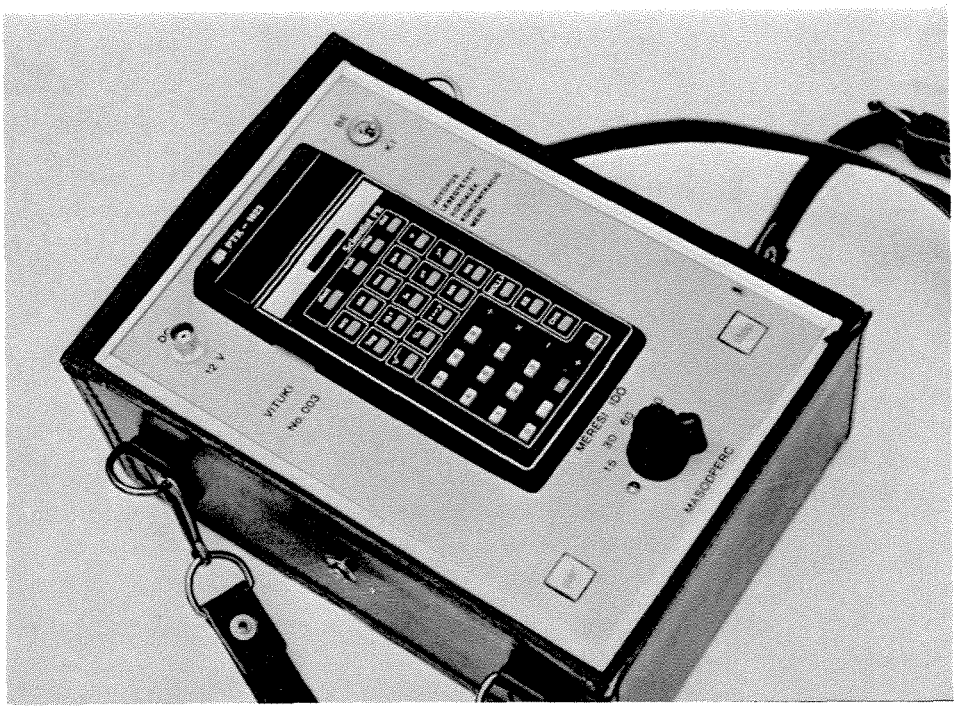

Fig. 2 The scaler with the built-in programmable calculator.

addition, the new scaler has a built-in programmable pocket calculator. The measuring time period can be preset by a switch seen in Fig. 2 beneath the calculator. After the calibration equation has been programmed into the calculator, it can display directly the sediment concentration in the desired units. When the START button is pushed, counting begins and the previous count is cancelled. By pushing PROGRAM START the concentration value is displayed.

In the opinion of the authors, it is feasible to store a nuclear suspended sediment gauge in good working condition at regional hydrographic centres, from which it can be rushed to the site of a sudden flood wave. The equipment is practically harmless to the operating personnel, however, the technician maintaining and repairing the device should have some basic isotope knowledge. By using a sealed isotope, the probe cannot contaminate the aquatic environment in any way.

The calibration of the gauge can take place either in a tank or a closed recirculating pipeline able to keep known amounts of sediment in suspension, or in a natural stream under different flow conditions. For comparison, simultaneous samples have to be repeated 5-10 times in order to decrease measurement errors. The "clear water reading" can be taken in any kind of basin or barrel filled with tap water large enough to submerge the probe. If the river is polluted by dissolved industrial chemicals, the natural but sediment free river water should be used instead of tap water. Usually the range of measurement is between 500 and 12 000 mg l^{-1}. The battery powered instrument is capable of working for about 8 h from rechargeable batteries.

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