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The development of nuclear sediment concentration gauges for use on the Yellow River

LU ZHI, LIU YUREN, SUN LELING, XU XIANGLIN, YANG YUJING & KONG LINGQI
Institute of Hydraulic Research, Yellow River Conservancy Commission, Zhengzhou, China

ABSTRACT The paper describes the development and field application of three types of nuclear sediment concentration gauge developed successfully for use on the Yellow River. The three gauges differ mainly in the construction of the probe. They have been developed to meet the particular requirements of the sediment regime of the Yellow River; emphasis has been placed on increasing the rate of impulse-counting, reducing statistical errors and improving the sensitivity of the devices while using low energy sources. Preliminary results from the use of these gauges on the Yellow River are encouraging and support the extension of their use on this river.

Mise au point des sondes nucléaires pour la mesure de la concentration en sédiments du Fleuve Jaune
RESUME Le présent article montre comment, en tenant compte des caractéristiques des transports solides du Fleuve Jaune, des limites et des normes de jaugeage imposées pour l'appareil, on a successivement étudié puis mis au point trois types d'appareils nucléaires pour la mesure de la concentration en sédiments, tous trois étant pourvus de sondes différentes. Ceci dans le but d'augmenter le taux du décompte des impulsions, de réduire l'erreur statistique et d'augmenter la sensibilité de la mesure tout en utilisant de faibles sources d'énergie. On a également étudié l'utilisation de ces appareils sur le terrain. Enfin les résultats partiels obtenus sur le Fleuve Jaune présentent de très bonnes perspectives pour l'extension de l'utilisation de ces sondes nucléaires pour la mesure de la concentration en sédiments du Fleuve Jaune.

INTRODUCTION

Since the late fifties research has been carried out in many countries on nuclear techniques applied to sediment gauges, and the results have been very encouraging (Rakoczi, 1973; Florkowski, 1970; Ziegler, 1967). Field use of nuclear sediment gauges has shown that they give results directly, continuously and more rapidly than conventional sampling methods.

Emphasis has been attached to the development of a sediment concentration gauge suitable for measuring quickly, accurately and continuously the widely changeable sediment concentrations typically found in the Yellow River, so that sediment movement in the Yellow River can be properly understood. This research was begun in the sixties, and in the early seventies a nuclear device for measuring hyperconcentrations of sediment using ^{137}Cs as the radiation source was developed and used for measuring sediment concentrations higher than 15 kg m^{-3}. The device was approved for use on the Yellow River after being appraised by the state in 1975. Since then further experiments have been carried out to increase the rate of impulse-counting, to improve the sensitivity of the device, and to widen the application to measure sediment concentrations well below previous lower limits. ^{241}Am has been used successfully as the radiation source in two different probes, namely, that with a scintillation detector and that with a proportional counter. Both may be used to measure sediment concentrations below 1 kg m^{-3} with an accuracy of ±0.05 kg m^{-3}. After carrying out *in situ* tests the observed results were found satisfactory. This paper describes the performance of the devices and gives a brief account of their field use.

NUCLEAR SEDIMENT GAUGE FOR MEASURING HYPERCONCENTRATIONS AND ITS APPLICATION

The nuclear sediment gauge for measuring hyperconcentrations of suspended load was based on the principle of gamma scattering and uses a Geiger-Müller counter with a tungsten cathode as well as a transistorized quench circuit. The radiation source is ^{137}Cs (200 mCi). The probe is shown in Fig. 1. The distance (R) between the source and counter is 45 cm. The addition of a transistorized quench circuit makes it possible to increase the resolving power of the probe (to 3 μs) as well as the rate of counting impulses by the Geiger-Müller counter (6000 pulses per second). The measuring time is 100 s and the error range of sediment concentration measured is ±0.56 kg m^{-3}. In order to reduce the effect of radiation, openings are made on the sonde in the horizontal direction, shielded with lead both above and below, so that the probe has effective ranges of 25 and 35 cm respectively. In doing so, the resolving power is raised. In order to improve the lower limit of detection, ^{241}Am (1000 mCi) was used as the radiation source. The distance between the

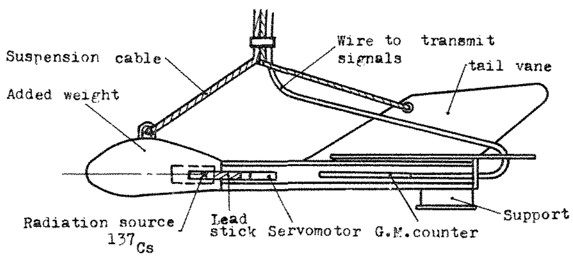

Fig. 1 Schematic diagram of the probe of the nuclear gauge for measuring hyperconcentrations of sediment.

source and the tip of the counter was then changed to 17 cm. Consequently, the sensitivity of the probe was increased appreciably (Fig. 2), the bottom limit of detection lowered and the effect of radiation and the scope of measurements limited.

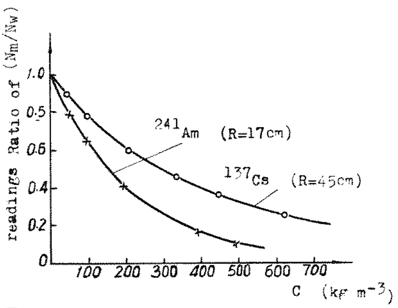

Fig. 2 Calibration curves.

It has been proved experimentally that in measuring hyperconcentrations of sediment the nuclear gauge with ^{137}Cs as source is less affected by the chemical composition of the sediment than by the temperature of water (Section of New Techniques, Research Institute, Yellow River Conservancy Commission, 1973). Comparisons have been made of the use of the nuclear device and the conventional method of sampling in the Yellow River. The correlation is rather constant, which indicates that the effect of the chemical composition of the sediment does not significantly affect the nuclear gauge, therefore this device is considered suitable for use on the Yellow River. When ^{241}Am is used as the source, the effect of the chemical composition of the sediment is also insignificant. To eliminate systematic errors due to the long-term effect of factors such as temperature changes and diminution of the radiation intensity due to decay of the source, the method of correcting the calibration curves by *in situ* sampling at regular intervals is adopted.

The scaler of the recording device is powered from a d.c. source. The probe is also equipped with an automatic lead shield for cutting off or letting through the radiation by means of a d.c. servomotor. When the instrument is not in use or being transported, the radiation source is shielded automatically so as to reduce the effect of radioactivity on the operators.

Since the device was first used on the Yellow River, many measurements have been collected using the gauge suspended from cableways, from boats attached to overhead cableways, or from motor boats.

Although the nuclear sediment gauge as such is used for measuring hyperconcentrations of suspended load only during the flood season every year, it has a number of advantages over the conventional gauges, in that the measurements are carried out swiftly and accurately and the sediment regime is obtained directly. Furthermore, the working conditions of the operating personnel are improved and the task can be carried out more safely, with less time and labour. Large numbers of observation data have shown that the gradual increase of sediment

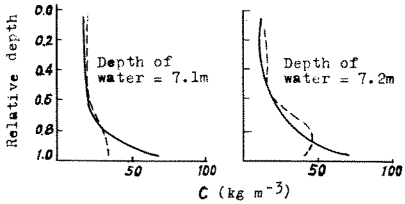

Fig. 3 Variations of sediment concentrations with depth along verticals, Luokou station: —— measured by the nuclear gauge; ---- measured by sampling.

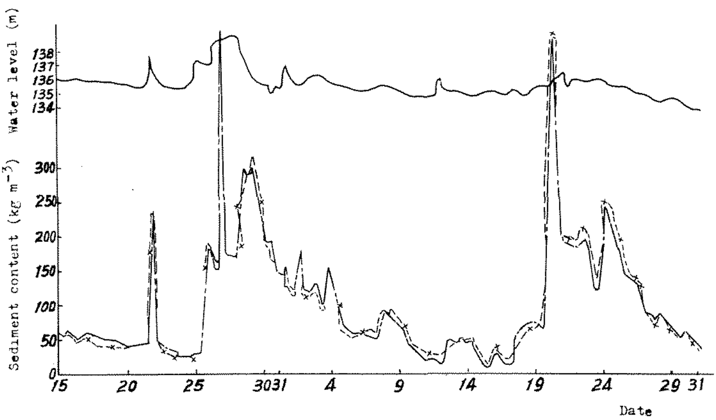

Fig. 4 Sediment concentrations at Xiaolangdi station in July and August 1971: ———–—— by radioisotope method; --x---x-- with horizontal sampler.

concentration with the depth is quite reasonable (Fig. 3).

Figure 4 shows the sediment concentrations measured in July and August 1971 using both the nuclear gauge and the conventional method of sampling. It can be seen that the results agree closely for sediment concentration between 15 and 500 kg m^{-3}. A peak concentration of very short duration which occurred on 27 July was detected accurately by using the nuclear device, but missed by using the conventional sampling method. Therefore, it is very important that the nuclear device performs well in monitoring the sediment regime continuously.

NUCLEAR SEDIMENT CONCENTRATION GAUGES FOR MEASURING LOW SEDIMENT CONCENTRATIONS

One of the principle errors in measurements using the nuclear gauge is that due to statistical fluctuations of the gamma radiation. In order to reduce the error, either the total number of impulses during the measurement should be increased, or the intensity of the source or the efficiency of the probe should be raised. In practice, the former two approaches are not appropriate, so the only acceptable way is to raise the efficiency of the probe and increase the rate of impulse-counting, so that the instrument may operate reliably and in a more stable manner. Increasing the rate of impulse-counting seems to be the ideal method of attaining the lowest possible detection level for sediment concentrations.

Based on this rationale since 1975 two nuclear sediment gauges for measuring low concentrations of sediment have been developed: the scintillation detector type and that with a proportional counter. A ^{241}Am (1000 mCi) source has been used in both devices which are shown in Fig. 5. The distance between the source and the detector is about 32 cm, the time of measurement 100 s and the rate of impulse-counting 10^5 pulses per second or so. The range of detection is approximately 20 cm. The resolving power of the device is very high in reflecting fluctuations in the density of the medium.

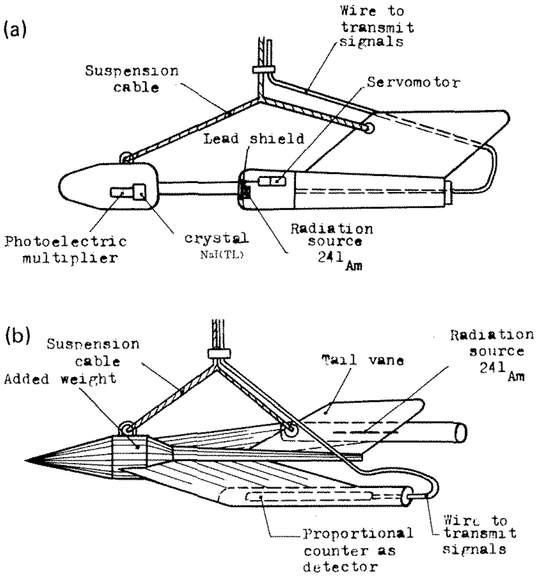

Fig. 5 Construction of the two probes for measuring low sediment concentrations: (a) scintillation type and (b) type with proportional counter as detector.

The mechanism of the acceptance of gamma radiation is different in the two types of detector. A large amplification factor is used in the circuit of the probe with the scintillation detector, also the amplification factor of the photoelectric multiplier used in combination is reduced appropriately, and the performance of the photoelectric multiplier under high rates of impulse-counting (liable to fatigue) is also improved, so that the instrument is very precise. A thin-walled aluminium counter is used in the proportional type detector in combination with a charge-sensitive preamplifier for high efficiency when receiving gamma radiation of low energy. Thus the rate of impulse-counting is increased to as high as 1.4×10^5 pulses per second, and the sensitivity of sediment measurement is 1.2% per kg m^{-3}, which is relatively high.

It has been proved that fluctuations in water temperature and changes in dissolved soluble mineral salts affect both types of gauges. If these factors are disregarded, large systematic errors will be incurred in measurements of very low sediment concentrations. Some work has been done concerning the corrections necessary to account for the effect of water temperature and dissolved soluble mineral salts. Fluctuations in sediment concentration itself due to temperature changes may actually be negligible, their effect being mainly due to changes of the density of water. In the case of low sediment concentrations, changes in the properties of lightly sediment-laden stream water and those of clear water due to temperature fluctuations are practically the same. Based on the principle of correlation and using the method of comparative measurements, the ratio of the reading N_m for calibrating measurements in stream water and N_w for clear water at the same temperature (N_m/N_w) is plotted against sediment concentration C to obtain the calibration curves shown in Fig. 6. The effect of temperature fluctuations can thus be identified.

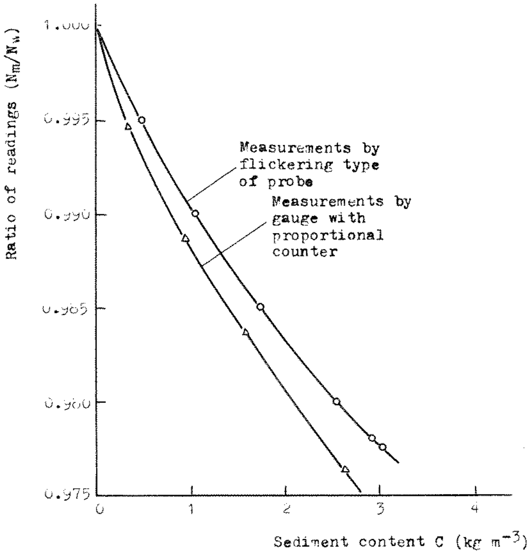

Fig. 6 Calibration curves.

The effect of the chemical composition of the sediment is different for different reaches of the river, so that it is difficult to find a simple way of solving the problem. The calibration of the scintillation detector type of gauge is made at regular intervals using a container of limited volume to compare and correct field calibrations in the form of $N_m/N_w \sim C$ curves. Corrections can thus be made for the effects of fluctuations in water temperature and dissolved soluble mineral salts, and the field work necessary for the calibration curves is much simplified. The value of N_w may be read off at any moment and the readings of the instrument are very accurate. It has been proved by a number of *in situ* experiments that the results obtained by using this method are satisfactory (Fig. 7).

The source-detector distance is adjustable for the probe with the scintillation type of detector for measuring low concentrations of suspended material. When this distance is 37 cm, the upper limit of detection is 250 kg m^{-3}. If the source-detector distance is reduced appropriately, higher contents of sediment

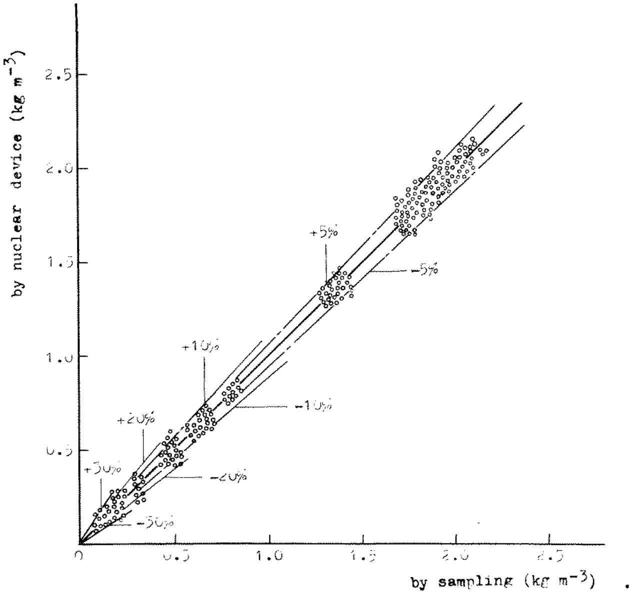

Fig. 7 Relationship between measurements of sediment concentrations at Xiaolangdi using the scintillation detector type of nuclear gauge and by sampling.

can be measured.

CONCLUDING REMARKS

The method of using nuclear techniques for measuring the sediment concentrations in streams is practicable and has marked advantages over the conventional method of sampling in that it gives more accurate results and can be conducted more swiftly and continuously. The development of nuclear gauges for measuring low concentrations of sediment makes it possible to carry out observations using this type of gauge the whole year through. As corrections can be made to offset the effect of fluctuations in water temperature and changes in dissolved soluble mineral salts, it opens up new prospects for further improving the method of measuring low sediment concentrations in the future.

Sediment concentrations measured by a nuclear device are time averaged values of the sediment concentrations within the range of detection that pass the probe in an interval of 100 s. The efficiency and the precision of measurements can be further improved by studying the relationship between time averaged and instantaneous values of sediment concentration along verticals or in the entire section, by reducing the range of detection of the probe appropriately and by using point depth integrated methods.

The problem of simplifying the field calibration needs further study, and the construction of the probes may be further improved so as to suit better the different characteristics of streams and to facilitate the operation.

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