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Determination of Mobile Layer Thickness of Bed Load Transport in Radioisotope Tracer Study by Scattering to Peak Ratio in Gamma Spectra Acquired on the Field

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SUMMARY. This paper presents a new approach to the determination of the mobile layer thickness in bed-load transport study based on the change of the ratio of scattering per peak counts in gamma spectra acquired in the field with the mixing depth of native and radioactive sand. It is shown both from theoretical considerations and experiments that there is a rather clear relation between the ratio and the mixing depth. The practical capability of the method and the ability of application for common tracer isotopes such as Ir-192, Sc-46 are also estimated. There was a good agreement between the values of the thickness obtained by applying this and core sampling method in the fill-up navigation channel studies at Haiphong Harbour.

1. INTRODUCTION

In bed load transport study using radioisotope tracer technique, the determination of the mobile layer thickness is traditionally based on the attenuation of uncollided photon reaching the detector (1,2). So, the activity of injected tracer material must be known and the counts must be collected on the whole area covered by the radioactive cloud. During the implementation of tracking, some difficulties could occur due to severe working condition on the field, that will be able to affect the results of determination of the thickness.

However, while going from the sand layer to the detector, because of scattering and absorption processes, the relative components of uncollided and collided photons change with the thickness of the media. By calibration procedure, it is possible to determine the mobile layer thickness basing on the ratio of scattering per peak counts in gamma spectrum obtained in the field

2. THEORETICAL BASIS

Let us consider the mixing between radioactive and native sand particles as homogeneous and of thickness E. Let the activity be a_0 per unit area. The volume concentration of activity will be a_0/E.

A detector placed on the surface of the area will record the count dn_1 due to uncollided photon (peak count) emitted from an elemental thickness dz at depth z (see Figure 1):

$$dn_1 = K(z)\,\frac{a_o}{E}\,dz \qquad (1)$$

where

K(z) is a function taking into account all of the appropriate geometry-cum-detector's response and broad beam attenuation effect. It is assumed to be of the following form:

$$K(z) = K_0 e^{-\alpha z}$$

Here, α is defined as combination of the factors of photon flux attenuation with geometrical response of detector; K_0 is response of detector at z=0, i.e. at the surface of the source area.

Then, the count dn_1 may be expressed as follows:

$$dn_1 = K_0 \frac{a_0}{E} e^{-\alpha z} dz \qquad (2)$$

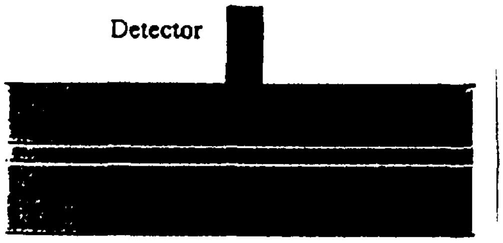

Figure 1. The configuration for theoretical consideration.

The count under the peak in spectrum (peak count) due to uncollided photon reaching the detector from the whole mixing depth is:

$$n_1 = \int dn_1$$

$$= \frac{K_0 a_0}{E} \int_0^E e^{-\alpha z} dz$$

Then

$$n_1 = \frac{K_0 a_0}{\alpha E}(1-e^{-\alpha E}) \qquad (3)$$

The equation (3) is known as the formula for determination of the mixing depth, derived by Courtois and Sauzay since 1960's in the method of "count rate balance"(1).

The scattered photon (collided photon) reaching the detector may be calculated:

$$I_s = (B-1)I_p$$

where

I_s, I_p are scattered and uncollided photon fluxes at the detector, respectively.

The build up factor B defined as $\frac{I_s + I_p}{I_p}$ is a function of atom number of the environment and the primary photon energy. B factor can be expressed in exponential form (3):

$$B = A_1 e^{-\alpha_1 \mu z} + (1 - A_1)e^{-\alpha_2 \mu z}$$

where

A_1, α_1, α_2 are constants depending on the primary photon energy E_0, atomic number Z.

μ is linear attenuation coefficient (cm^{-1}).

The scattered photons from the element dz cause the counts dn_2 as follows:

$$dn_2 = K'(z)\frac{a_0}{E}(B-1)dz$$

$$= K'(z)\frac{a_0}{E}[A_1 e^{-\alpha_1 \mu z} + (1-A_1)e^{-\alpha_2 \mu z} - 1]dz \qquad (4)$$

K'(z) defined as detector response function for scattered photon, is assumed to have the form: $K'(z) = K'_0 e^{-\alpha z}$, where K'_0 is response of the detector at z=0, i.e. at the surface of the source area. Then the equation (4) can be written as follows:

$$dn_2 = K'_0 \frac{a_0}{E}[A_1 e^{-(\alpha_1 \mu + \alpha)z} + (1-A_1)e^{-(\alpha_2 \mu + \alpha)z} - e^{-\alpha z}]dz \qquad (5)$$

Let $\varepsilon_1 = \alpha_1 \mu + \alpha$, $\varepsilon_2 = \alpha_2 \mu + \alpha$, then the integrated count over the whole mixing thickness E will be:

$$n_2 = K'_0 \frac{a_0}{E}[\frac{A_1}{\varepsilon_1}(1-e^{-\varepsilon_1 E}) + \frac{(1-A_1)}{\varepsilon_2}(1-e^{-\varepsilon_2 E}) - \frac{(1-e^{-\alpha z})}{\alpha}] \qquad (6)$$

The ratio $R = \frac{n_2}{n_1}$ is:

$$R = C_0 \alpha \frac{[\frac{A_1}{\varepsilon_1}(1-e^{-\varepsilon_1 E}) + \frac{(1-A_1)}{\varepsilon_2}(1-e^{-\varepsilon_2 E}) - \frac{1}{\alpha}(1-e^{-\alpha E})]}{(1-e^{-\alpha E})} \qquad (7)$$

where $C_0 = K'_0/K_0$.

It is obvious from equation (7) that, for given native-tracer sand mixture and source-detector geometry, the scattering to peak ratio in gamma spectrum would depend only on the thickness E, i.e. R=R(E). On the other hand, the ratio in (7) is not affected by the amount of activity used, as well as by the form of vertical distribution of radioactive sand particle.

Figure 2a illustrates the values of R calculated from equation (7). The values for various parameters were taken as:

for Ir-192

C_0=0.04; α=0.219 (calibration values)
μ=0.221cm^{-1}; A_1=12.5; α_1=-0.111; α_2=0.006 (values taken from (2))

for Sc-46

C_0=0.022; α=0.146 (calibration values)

μ=0.133cm^{-1}; A_1=12.5; α_1=-0.088; α_2=0.29 (values taken from (3)).

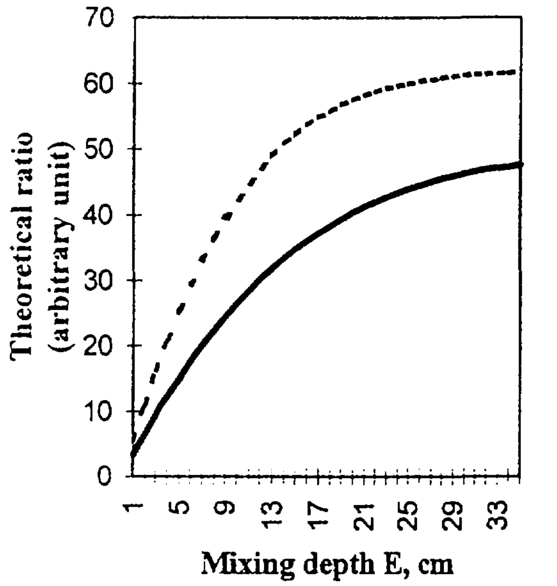

Figure 2a. The theoretical curves of R(E) from equation (7) for Ir-192 and Sc-46.
- - - Ir-192 ——— Sc-46

It is shown that, for Ir-192 the ratio increases rather linearly in the range of upto 17cm in depth, and beyond 20cm, the curve becomes saturated, i.e. the ratio changes not much with depth. The Sc-46' ratio although increases slower than that of Ir-192, but it gets saturation at depth of 35cm because its gamma energy is higher than for Ir-192.

3. CALIBRATION

The calibration curve for determination of the mobile layer thickness E based on the ratio R(E) was built by reproducing the geometrical conditions existing in the field with the plane source. Here, the case of study of calibration using Sc-46 is presented.

An 1mx1m plane source of 100 µCi of Sc-46, consisting of 49 point sources, SILENA NaI 2"x2" detector connected to SILENA MCA were used. The gamma spectra are collected with each 5cm sand layer added covering the source. The spectral region ranged from 100KeV to 850KeV and the region covering the peaks of 890KeV and 1120KeV were selected for scattering count $c_2(z)$ and peak count $c_1(z)$, respectively.

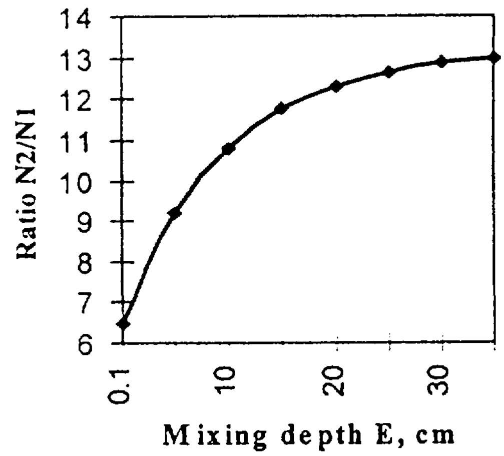

Figure 2b. Calibration curve R(E) for Sc-46.

Table. The mobile layer thickness around the navigation channel.

Experimental site	Mobile layer thickness E (cm)	
	Core sampling	Ratio method
South of the Channel (region A)	10	9 (R=9.8)
Buoy $N_0$10 (region B)	8	10 (R=10.1)
North of the Channel (region C)	4	5.5 (R=8.7)

The ratio R(E) for the mixing depth is obtained by integrating the counts $c_1(z)$ and $c_2(z)$ over the thickness of sand covering the source, as follows:

$$R(E)=\frac{N_2}{N_1}=\frac{\int_0^E c_2(z)dz}{\int_0^E c_1(z)dz} \qquad (8)$$

The calibration curve R(E) for Sc-46 is presented in Figure 2b.

The tracer experiments using Sc-46 as a tracer material were carried out to study bed load transport at the navigation channel of Haiphong Harbour.

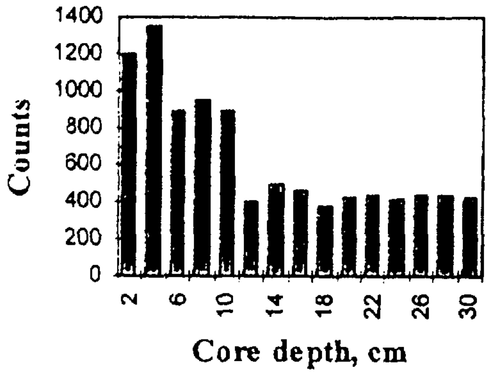

Figure 3a. Vertical contribution of activity along the core sample collected at A region.

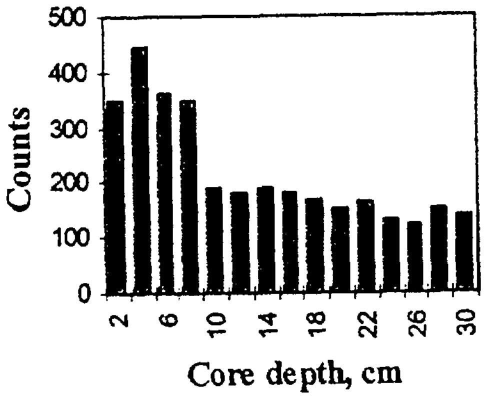

Figure 3b. Vertical contribution of activity along the core sample collected at B region.

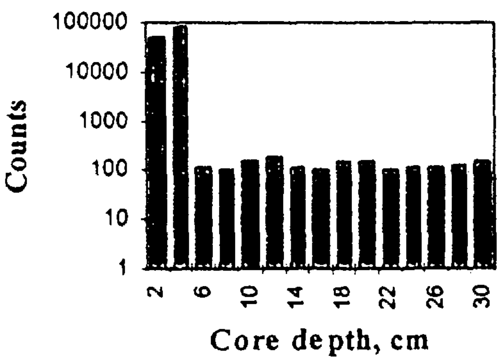

Figure 3c. Vertical contribution of activity along the core sample collected at C region.

The injected sites were at South of the Channel (1992)-A region, round the Buoy $N_0$10 (1993)-B region and at North of the Channel (1995)-C region.

Both methods of core sampling and scattering to peak ratio were used to determine the mobile layer thickness. The results obtained in the experiments are given in the Table. Figures 3a, 3b, 3c show the vertical distribution of activity along the core sample.

4. DISCUSSION AND CONCLUSIONS

It is possible to estimate the variation of the detectable thickness basing on the calibration curve. Consider the case when N_1 and N_2 are counted upto 10^4 and 10^5 total counts respectively, i.e. the statistical deviation in the measurement $\sigma(R)=0.1$, then, in the case of Sc-46 the variations of the thickness at 5, 10, 20 and 35cm are 0.5, 0.6, 1.0 and 2.1cm respectively, i.e. about 5 to 10 percents of the thickness. These would be acceptable in view of the tracer study in sediment transport.

It is obvious that, in order to develop this method for studying the mobile layer thickness, the radioactive isotopes having the gamma peaks located apart from the scattering region in the spectrum are required.

Sc-46 appears to be the most suitable isotope for this purpose because of simple spectrum with two peaks standing separately from the scattering region and with enough high gamma energy to the good results for thickness determination upto 30 cm (see Figure 4a).

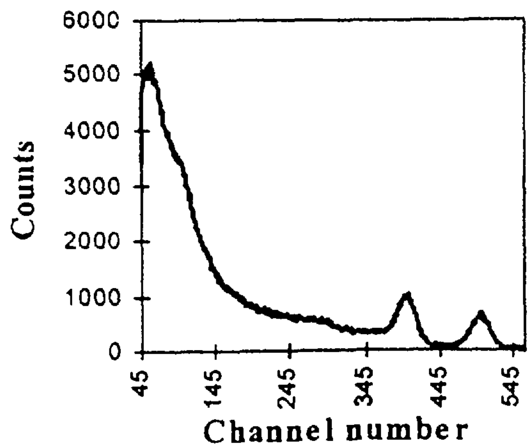

Figure 4a. Gamma Spectrum of Sc-46

Although having a little complex spectra and gamma energies lower than of Sc-46, Ir-192 has the peaks still separated from the scattering region (see Figure 4b). So it can be used for this purpose. However, Ir-192 should be applied for thickness of upto 20cm (see Figure 2a), corresponding to the weak transport of sediment in the area of slight hydraulic condition.

Because the ratio of counts is calculated in the same spectrum, the method allows to determine the thickness without knowing the injected activity. Furthermore, as it is no need to make comparison of the injected activity with the total counts, detailed tracking on the whole area is not necessary.

Owing to that, the determination of the mobile layer thickness can be made successful, even when the working condition on the area is too severe to map adequately the activity distribution. In this method, the error due to measurement of injected activity and tracking total count is negligible.

Nevertheless, because the immersed detector can "see" the area of only about 1m in diameter, so the determined thickness is typical just for this area, but not for the whole studied area. The mean value of mobile layer thickness over the whole area can be derived by moving the detector around the "hot" area and collecting the spectrum.

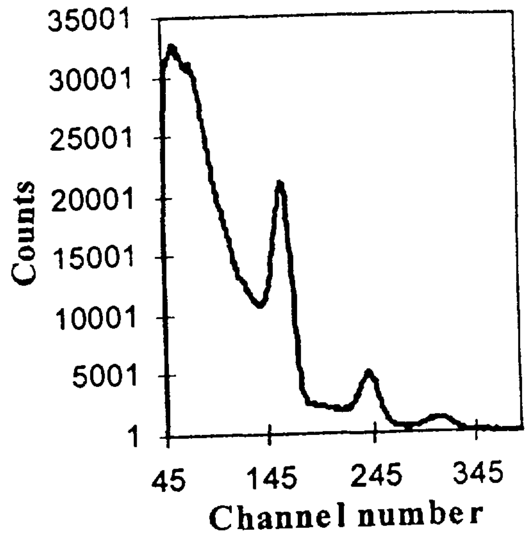

Figure 4b. Gamma Spectrum of Ir-192

Finally, combination of this method with others could improve the accuracy of the thickness determination and the feasibility of the tracer work in the field.

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