From counting rate profile to Cs-137 profile

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Highlights

- Nondestructive determination of vertical distribution (profile)
- **Demands inversion calculation**
- Results after Chernobyl accident presented

Abstract

After Chernobyl accident the vertical distribution of ^{137}Cs has been determined in Finland. The tubes, where the nondestructive measurements were performed, were in soil before the accident. Scintillator in different depths in the tube determined the counting rate profile of 662 keV photons. In peat soils was measured without tubes. The paper tells the inversion calculation for to achieve the profile of ^{137}Cs density.

Keywords: Cesium profile; counting-rate; inversion calculation

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1. Introduction

This paper is a simple case of well logging measurement of soil radioactivity after Chernobyl accident. The natural radioactivity can be measured with Geiger tubes and scintillators in bore holes.

The calculations in Fig. 1 show that the instrument detects gamma also before and after the radioactive zone. This figure I drew according to the presentation of Larionov (1963). The density of radioactive elements in zones *q* was constant. The selected zones have the widths: $h_1 = x_o$, $h_6 = 6x_o$ and infinite. $2x_o$ was the hole width. In the calculation he assumed homogenous medium with the "linear" attenuation coefficient $\lambda = \mu\rho = 0.1$ cm^{-1}; ρ is the density and μ is the mass attenuation coefficient of gamma photons in matter.

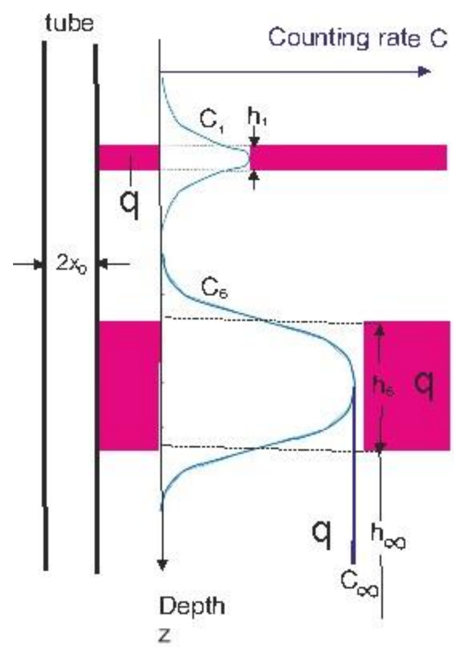


Fig. 1. Calculated countingrate Ci variations in 3 tubes by Larionov (1963).

Keys (2005) has presented all kind of borehole investigations. Among them are the Nuclear logging methods. However, Keys does not include there the presentation of the inversion calculation from gamma logging data (counting rates) to the radiating nuclide profile, which Killeen (1982) describes.

2. Measurement

In the year 1986 after Chernobyl accident I presented, that the vertical distribution, i.e. profile, of radioactive cesium can be determined with scintillator as **b** in Fig. 2. The mesurements were started in December 1986 (Fig. 4) and continued in June 1987 (when I also used measurement **a** for STUK, Radiation and Nuclear Safety Authority in Finland, to determine surface activities on swimming shores, the results in map of Fig 5). Fig. 3 presents spectra in BASC. The radioactive ^{137}Cs atom emits 662 keV gamma photon. In a measurement I first subtracted the influence of the counts of ^{134}Cs and background, and then added the undetermined counts. The scintillation crystal was 1"xϕ1".

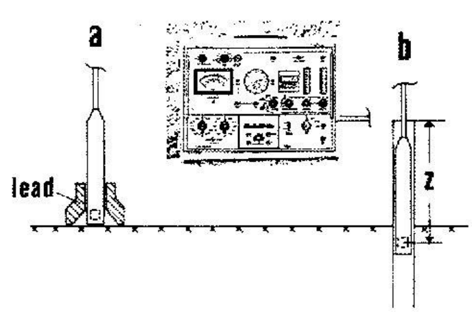


Fig. 2. Scintillator measurements of **a** surface activity and **b** profile of ^{137}Cs. BASC one-channel scaler of Nucletronics

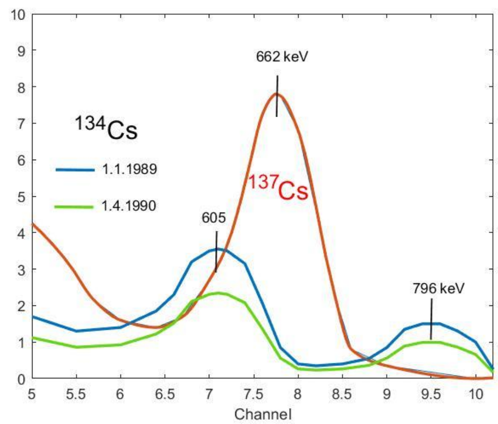


Fig. 3. Cesium spectra (relatives) with BASC scaler after Chernobyl accident. Channel window was 1.0.

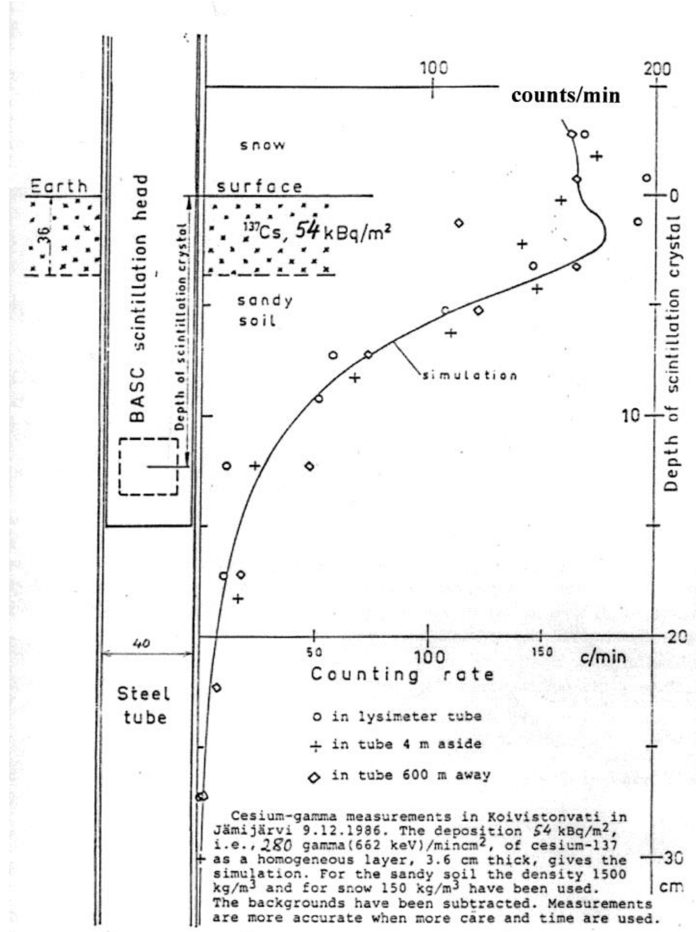


Fig. 4. Cs-137 layer depth and constant activity determination with inversion calculation from counting rates in 3 tubes in Koivistonvati in Finland in 1086-12-09.

The first ^{137}Cs countingrate profile measurement was made in 9th December 1986 in Koivistonvati in Jämijärvi in the soil moisture tubes of the Hydrological Office (today of SYKE), Fig. 4.

This kind of nondestructive radioactive element profile determination is better than the method where samples are taken. Here you can follow the mobility of radioactive elements. From the countingrate profile the cesium density profile is determined with an inversion calculation.

The most tubes where I measured had the inner diameter $2x_0$ = 40 mm. They were in soil before 1986. In bogs I measured without tubes.

In 1987 I reported the investigations (Fig. 5) to STUK. This first nondestructive radiocesium profile measuring method I presented in the Wetland conference in Joensuu, Finland [1]. There I also shew the ^{137}Cs profile measurement (Fig. 9) in Kairessuo bog in Orimattila to south from Lahti, Fig. 5.

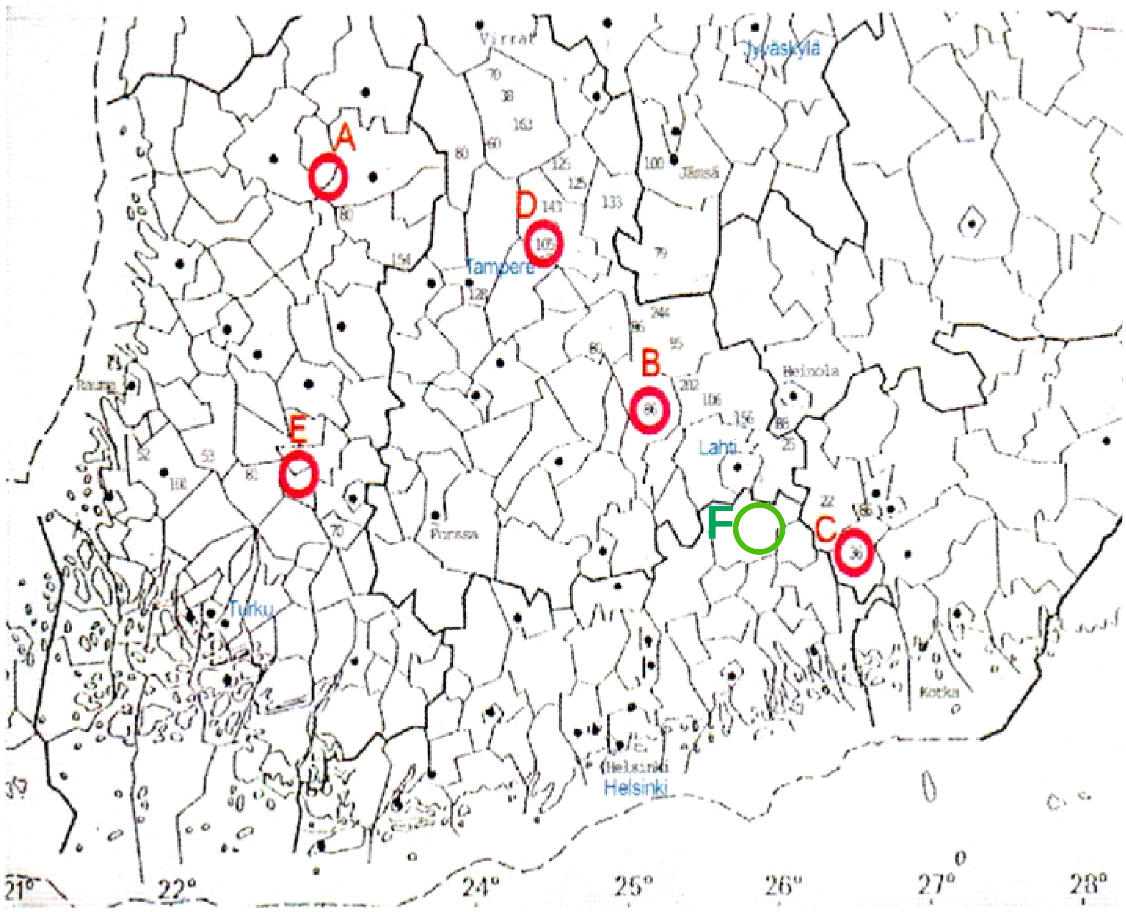


Fig. 5. Finnish Cs gamma profile measurements: A Koivistonvati, B Tullinkangas, F Kairessuo

3. Inversion calculation

In the point P in the volume element dV there is radioactivity *qdV*, where *q* is the radioactive atom density. This qdV in the detector causes the counts/time

$$dC(z_0) = D(r)\, exp\left[-\int_{\frac{x_0}{sin\,\varphi}}^{r} \mu\rho\,(z')dr'\right] q(z)dV/4\pi r^2$$

where $2x_0$ is the inner diameter of tube. $D = \eta A$ is the detector function. η is the efficiency and A is the area of detection. When integrating over x and z we find

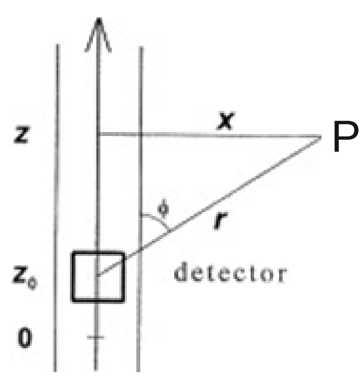


Fig. 6. Geometry of calculation.

$$C(z_0) = \int_{-\infty}^{\infty} q(z) \int_{x_0}^{\infty} D(r)\, exp\left[-\int_{x_0/sin\,\varphi}^{r} \mu\rho\,(z')dr'\right] x\, d\, x/2\, r^2\, dz$$

(Larionov, 1963, Kasi, 2001). In the equation above *C* is the measured counting rate profile and the *q(z)* is the unknown function. The ^{137}Cs activity profile *q(z)* is determined with an inversion calculation.

In the inversion calculation first a form for $q(z)$ is selected. Then $C(z_0)$ is calculated. Then a possibly better $q(z)$ was selected, etc. Let $C'(z_0)$ to be the result of a calculation. We proceed to minimize the difference $||C(z_0) - C'(z_o)||$ between the measured $C(z_0)$ and calculated $C'(z_0)$. This is an iteration for to find the best form of $q(z)$.

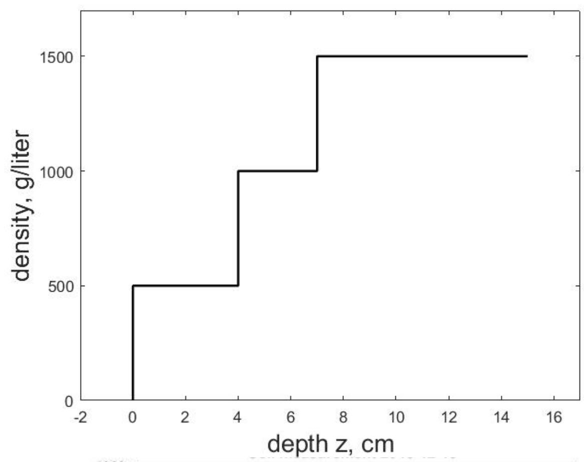
The element composition of matter influences, especially the content of hydrogen.

For the peat measurements Kasi (1988) mentions the Laguerre polynomials, but their use I did not find.

4. Results

In (Kasi 2001 Fig. 2) is the series of countingrate profiles in the Tullinkangas tube. In Fig. 4 above the density ρ was constant. In the 1987-06-26 measurement in Tullinkangas (Kasi 2001, Fig. 4) I set an assumed density profile, Fig. 7.

Fig. 7. Assumed density distribution for Tullinkangas measurement 26.6.1987.



The mass density distribution assumption, Fig. 7, did not have measurements. In Fig. 8, you see the measurement I made 28 years later and 1 meter from the measurement tube. I took the same area soil samples and determined their thickness and weight. (The samples I still have). Also this density distribution can differ from that in 1987.

In Hydrological Office (today in SYKE) I made the calculations of (Kasi 2001 Fig, 4) using SAS-programs.

After 2015 I have tried to make $q(z)$ calculations (MATLAB) using the density distribution in Fig. 8, but I am not ready.

Somebody may be interested to make inversion calculations from the countingrates (Kasi 2001 Fig. 2) using the density distributions here.

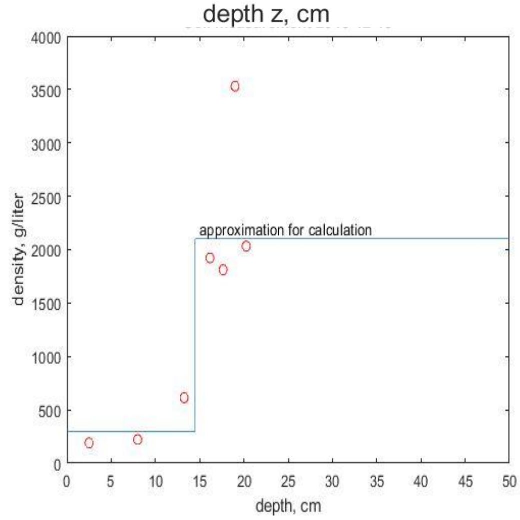


Fig 8. Determination of the mass density profile in Tullinkangas in 2015 and the density profile estimation.

4.1 Peat measurement

In Kairessuo in latter part of summer 1987 I set the gamma detector device in two sites: marshy fen and hummock. In the fen

Depth, cm	Density, kg/m³
0-20	250
20-30	750
30-	1000

the density profile I assumed. The H content in peat was assumed 5 % and in water it is 11.2 %.

For the inversion calculation as good as possible knowledge of the medium is to find. For that the only measurement I made was to determine the depth of water surface in the measuring hole.

In the measuring sites the wooden poles were set into bog.

In marshy hummock the measurement was repeated in 1988/11 and 1997/08, Fig. 10. During the 1988 measurement the groundwater level was in 8.0 cm.

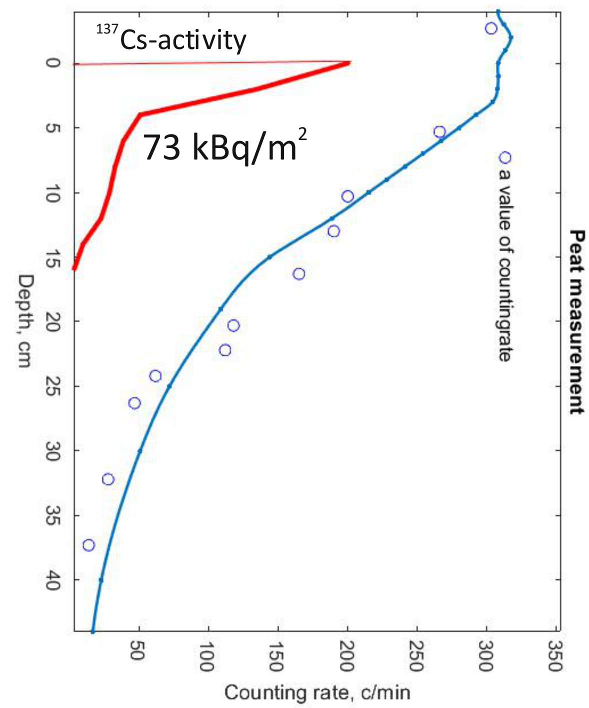


Fig. 9. Inversion calculation from the ^{137}Cs countingrate profile to its activity profile in marshy fen of Kairessuo (Fig. 5) in latter part of summer 1987. Blue line was the best fitting to the countingrate values.

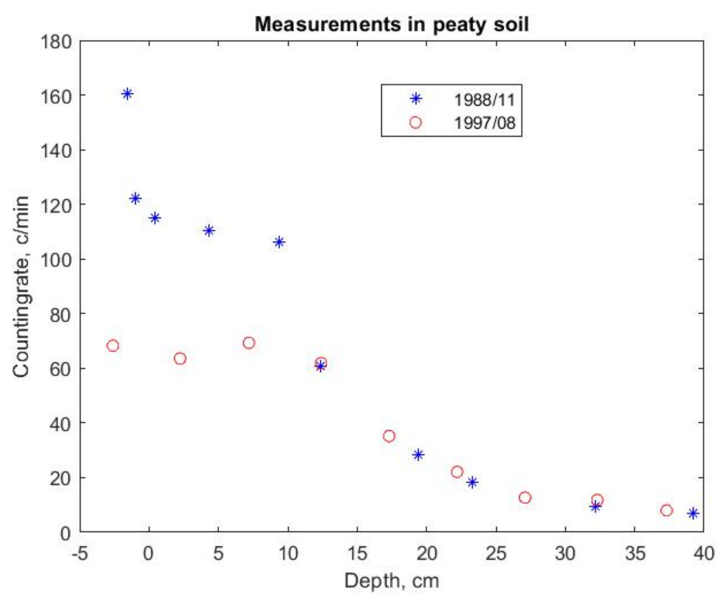


Fig. 10. Two repeated measurements in Kairessuo hummock.

Acknowledgements

In Finland Radiation and Nuclear Safety Authority (STUK) arranged the travels for the first measurements in 1986-87, where in 1987 I had to determine Cs-depositions on swimming shores. The scintillation head of the company Oy Indmeas Ab and BASC battery scaler (Nucletronics ApS) of Hydrological Office I used. The calculations I made in Hydrological Office.

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