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Cesium deposition in soil and its effects

S.S.H. Kasi*

Helsinki University of Technology, P.O. Box 1000, FIN-02015 HUT, Finland

Abstract

Stabilization of the ^{137}Cs profile after 1986, has been observed in a mineral soil in southern Finland. An inversion calculation is presented to determine the ^{137}Cs profile from the photo-peak (662 keV) counting rate profile. Snow water equivalent (snow mass) can be accurately determined by using snow attenuation of the cesium radiation. When counting, at the same time, the 1461 keV photons of ^{40}K as well, it may then be possible to determine the surface soil moisture. The ^{137}Cs profile information is also important for the determination of its contribution to human dose.

Keywords: ^{137}Cs; Snow; Soil water; Dose

1. Cesium deposition and profiles in soils

In the 20th century, the natural environment has been contaminated by artificial radioactivity. In the northern hemisphere the atom bomb explosions increased the radioactivity, most significantly in the first half of the 1960s. In 1986 after the Chernobyl accident, the deposition of radioactive cesium increased (Fig. 1) considerably in large areas of Europe. In the southern half of Finland there was a 20 kBq/m^2 average deposition of ^{137}Cs.

The profile of ^{137}Cs was measured with a NaI(Tl) ∅1×1″ scintillator in steel tubes which were set vertically in soil (before 1986) or in holes in peat. Because cesium is an alkali metal, its ions easily find adsorption sites at soil grain surfaces. The time for its thorough fixation on surfaces of soil particles is more than one year (Konoplev et al., 1996). After that time the mobility of ^{137}Cs is similar to that of the stable isotope ^{133}Cs (Riise et al., 1990). The radiocesium profile seems to be stabilised in this way in forest soil in Lammi, southern Finland (Fig. 2). In 1986–1989 the first profile determinations in four other sites of mineral soil and in two peat sites in Finland were also made, and one in peat repeated in 1997.

2. Cesium profile determination

The profile concept assumes that the cesium distribution is one-dimensional and vertical. The coordinate of the vertical dimension is z. The geometry of the profile measurement is illustrated in Fig. 3. The response of the scintillator detector is the photo-peak counting rate of cesium 662 keV photons. The effects of small-angle inelastic and elastic scatterings are small. ^{137}Cs activity profile $q(z)$ is to be calculated from the measured counting rate profiles $c(z)$. For the calculation, it must also be assumed that the density $\rho(z)$ is one-dimensional as well.

The counting rate for a detector at z_0 is given by

$$c(z_0) = \int_{-\infty}^{\infty} q(z)K(z_0, z)\,\mathrm{d}z,$$

where the kernel

$$K(z_0, z) = \int_{x_0}^{\infty} D(r)\exp\left[-\int_{x_0/\sin\phi}^{r} \mu\rho(z')\mathrm{d}r\right] x\,\mathrm{d}x/2r^2$$

calculates the effects of geometry, attenuation μ in medium and detection efficiency η. $D(r) = \eta A(r)$ where

*HUT, Otakaari 1, Espoo, Finland. Tel.: +358-9-2428550.
E-mail address: servo.kasi@helsinki.fi (S.S.H. Kasi).

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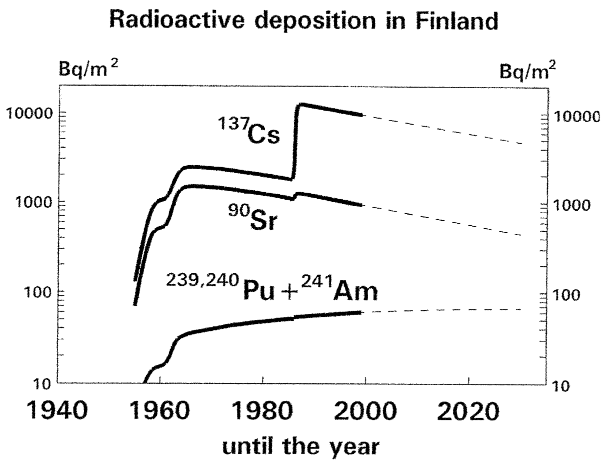

Fig. 1. Deposit of radioactive long-lived elements from atom bombs and accidents.

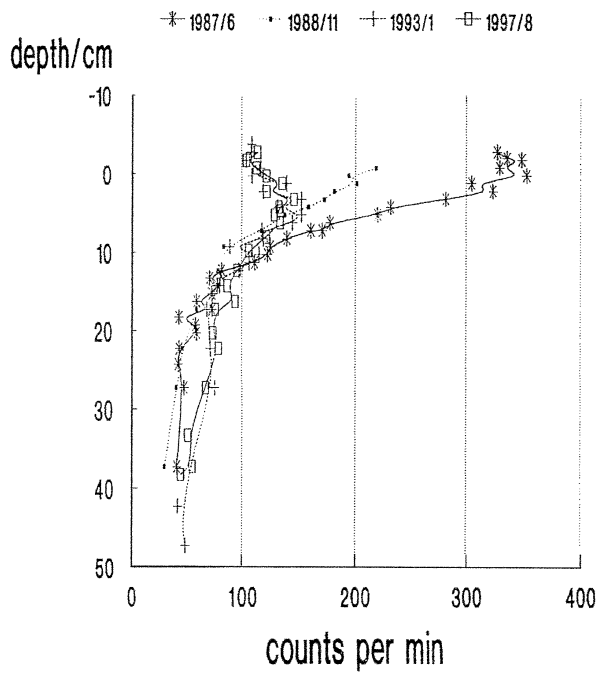

Fig. 2. Evidence of cesium profile stabilization in a mineral soil.

$A(r)$ is the cross section of detector against the direction of photon. Also $\eta = \eta(r)$, and can be determined experimentally. $dr = dz/\cos\phi$ and $2x_0$ is the diameter of hole or tube. In this application the iterative calculation of $q(z)$ from $c(z)$ has been rather fast. The $c(z)$ is the total photo-peak counting rate without the background. The density distribution $\rho(z)$ must be known accurately enough. It also may vary temporally.

Fig. 4 is a cesium profile result. The density profile used in the calculation was a rough three-step presentation. The effect of huge density profile variations was

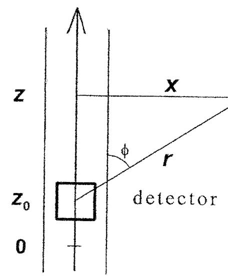

Fig. 3. Geometry for a relatively small photopeak detector in a vertical tube or hole.

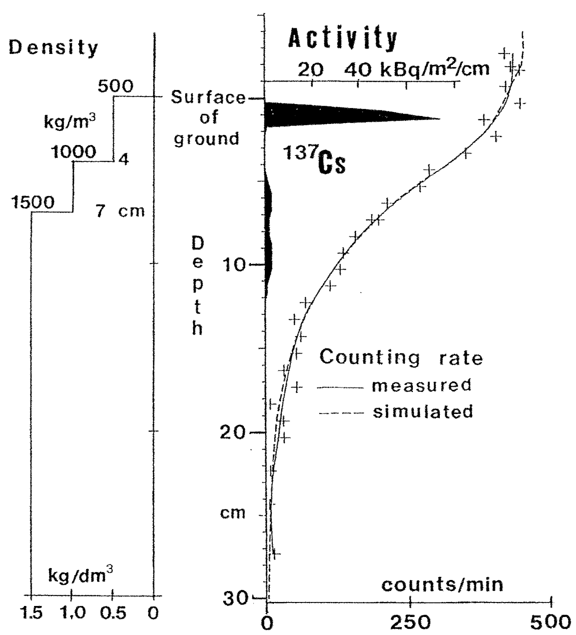

Fig. 4. The ^{137}Cs profile determined from the year 1987 counting rate profile of Fig. 2.

found in practice to be almost insignificant. The purpose is, however, to apply more adequate density profiles.

3. Snow water equivalent by using deposited cesium

Cesium photons are attenuated by soil and also by snow on the ground. This attenuation effect of snow can be used for measuring snow cover thicknesses, i.e. its weight burden (kg/m^2), or its water equivalent (H_2O mm). Soon after the accident some field experiments were performed with the $1 \times 1''$ NaI scintillator 1 m above the soil surface in Finland, in Lammi and Padasjoki. The scintillator (so big as a 16 l package has been used) may be mounted in a vehicle, in an airplane or on a steep-sided hill. Kasi (1988, 1998) has pointed out that the cesium radiation can often determine the water equivalent more accurately than potassium radiation.

4. Use today of two photon sources in nature

In a single scintillator, in addition to the cesium 662 keV photons, potassium 1461 keV photons can be measured (Kasi, 1998). Because the cesium source is near the soil surface, but the ^{40}K source is almost uniform in soil, the water content near the soil surface can be determined, in summer and winter.

5. Personal dose caused by radiocesium

Gale et al. (1964) measured cesium activity in soil using ionisation chambers and then also found profile information. Knowledge of the profile is also needed for the determination of cesium contribution to the dose of a person on the soil surface. When the cesium profile is stabilized, the dose contribution of cesium activity follows the half-life 30.03 a of ^{137}Cs.

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