TO MODIFY AND IMPROVE NUCLEAR SNOW SURVEY METHODS BECAUSE OF CESIUM DEPOSIT

Servo Kasi

Kajavankatu 6 B 45, FIN-04230 Kerava, Finland, e-mail: servo.kasi@~~helsinki~~aalto.fi, homepage: http://www.~~helsinki~~.fi/~~people/servo.kasi~~

ABSTRACT

Cesium-137 isotope gamma photons have smaller energy, 662 keV, than natural isotopes, but high intensity above soils in Europe. Still 300 H_2Omm snow layers can be most accurately and most fast surveyed with cesium radiation. Compton scatterings of higher energy photons disturb less when the detector is Ge-semiconducter, but scintillators are more effective. TOTAL COUNT is not influenced by cesium radiation when the lower boundary of the window is set at about 750 keV. Th-radiation, 2615 keV, measures most accurately into so high as 600 H_2Omm thick snow layers, but measurement demands a long measuring time.

INTRODUCTION

Airborne measurements have been used for earth radioactivity determinations. Interests have been the rapid observation of areal contamination with artificial radiation and to reveal radioactive point sources (RESUME 1997), geological survey of radioactive rocks, and snow survey for hydrological forecast. Airplanes and helicopters have been used. Radioactive snow equivalent determinations can also be done by point measurements or from driving vehicles just above snow (Kasi, 1998). The gamma-activity snow survey measurements do not depend on temperature and any chemical bindings (Kasi, 2000).

In the snow survey by using natural radiation the photons of the thorium (Th) series isotope ^{208}Tl (2614 keV), uranium (U) series isotope ^{214}Bi (1765 keV) and potassium isotope ^{40}K (1461 keV) cause the scintillation spectrum as in Fig. 1.

Radiation detectors

In (RESUME, 1997) in the addition of scintillators also Ge-semiconductors were applicable. The big advantage of the latters is that their photopeaks are narrow (Knoll, 2000); the half height width of peak is below 0.2 %, when that for scintillator is about 7…10 %, see Figs. 1...3. However, the scintillators are much larger and more effective. IAEA (1991) recommendates so large a scintillator as be well carried, maximum 33 liter for helicopter, 50 l for aeroplane (or other fixed wing works). Unmanned aerial vehicles will be applied too in Finland (Kurvinen, et al., 2002).

The effectivity of detector depends on direction of arriving radiation photon. For cylinderical detectors with equal diameter and height the first approximation is that the detection probability η is constant for the photon arriving it and that the shape of the detector is a sphere. Let A be its detecting area. $D = \eta A$ can be called the detector function. In the airplanes or helicopters 4" thick large scintillators have much been used. For a 25.2 l such detector Kasi (1992) in calculation used the detector function $D = D_0 \cos\theta$, where θ is the angle of ray to vertical direction. For this detector in airplane at the 60 m height above snowless soils in the Kemijoki basin Kuittinen et al. (1985) measured in the Th-window the total counting rates 6...78 c/s (in Figs. 1...3 the c/s are per energy channel).

Count number accuracy

An concept, necessary to be considered, is the mean error ΔN of the number N of counted pulses: i.e.

$$\Delta N = \sqrt{N}.$$

If the number of the pulses is about 100, then the error is 10 %. The counting numbers are easily small when the photons are more energetic (thorium especially).

Mathematical modelling of measurements

Models should be in any relations so physically correct as possible.

For the natural radiation isotopes Vironmäki (1985) and Kasi (1992) have supposed that they are uniformly distributed in homogeneous soil and rock medium, i.e. they form semi-infinite space sources of radiations. Then on the soil surface the radiance of their γ-photons obey the Lambert's law $I = I_i \cos\theta$, where $I_i = q_i/(4\pi\mu\rho)$, μ is the mass attenuation coefficient, ρ density, q_i number of photon emitters per m^3, and i = K, U or Th for the emitted radiation. For the deposit of radioactive cesium it can be supposed a plane at the depth d below soil surface. Then $I_{Cs} = q_{Cs}/4\pi$, i.e. the radiance of their 661.6 keV photons at the plane is direction independent. Above the plane is the soil layer attenuating them. In the measurement the counting rate is

$$R = \int_a^{\infty} \frac{D(\theta) I(\theta)}{r^2} \exp(-\mu\rho r) 2\pi r dr, \qquad (1)$$

where $a = h$ is the detector height above soil surface for the natural radiation, and $a = h + d$ for the cesium measurement. a includes the influence of snow water equivalent s (mm). The formula

$$R = R_0 \exp(-a s^{1-b}), \qquad (2)$$

(Tollan, 1985) also will be considered below.

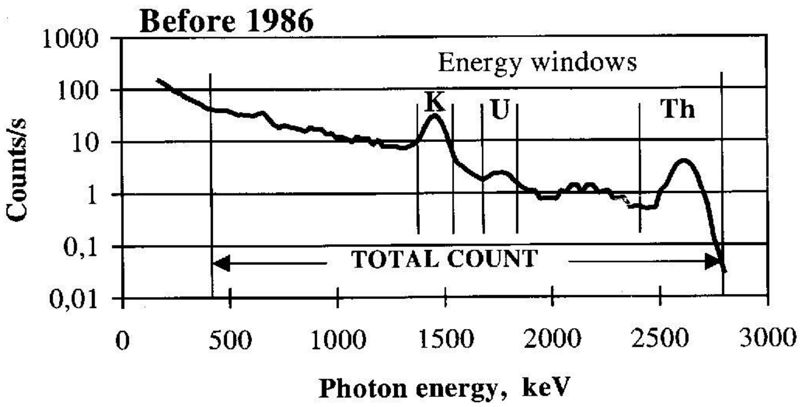

Fig. 1. Airborne gamma ray spectrum (25.2 liter scintillator, counts/s per 24 keV broad channel) of natural radioactive elements before Chernobyl. The TOTAL COUNT as here was used in the surveys before the Chernobyl.

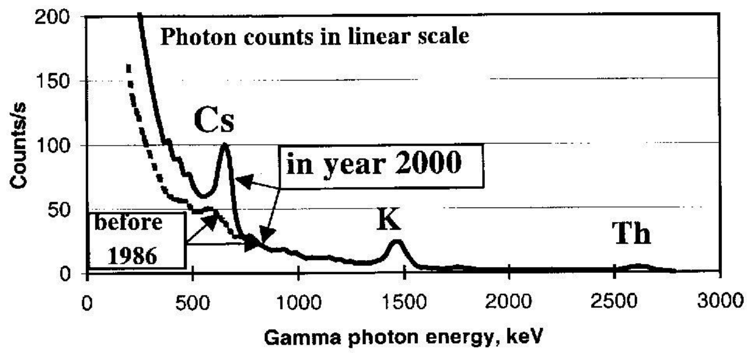

Fig. 2. A year 2000 energy spectrum in linear count number scale.

CESIUM DEPOSIT AND USE

Radioactive ^{137}Cs deposit was about 2 kBq/m^2 in the northern hemisphere until the Chernobyl accident 26.4.1986 occured.

After the accident, a couple of years later, from its fall-out only the cesium isotopes ^{137}Cs and ^{134}Cs were easily detectable and few years later the peaks of ^{134}Cs (half life 2.062 a) were vanishing. Today the latter is not to be seen in the usual spectrum. But the peak of ^{137}Cs (662 keV, half life 30.07 a) is very clear, Figs. 2 and 3. Its deposit today is 15 kBq/m^2 in the southern half of Finland.

The background in the window is caused by those photons, which have originally had higher energies and have scattered. This background is to be subtracted before water equivalent calculation.

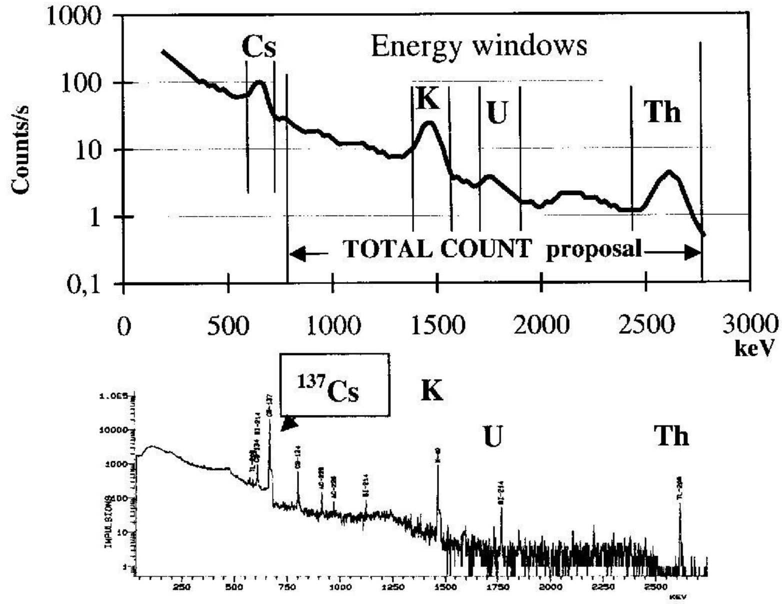

Fig. 3. Photon energy spectrum (25.2 l scintillator, 24 keV channel) in year 2000, cf. Fig. 2, and pure germanium semiconductor GPS spectrum, measured in Finland 15.8.1995 (RESUME 1997, France and Germany).

In Fig. 3 I propose that the lower boundary of TOTAL COUNT window could be about 750 keV, then cesium does not disturb the traditional snow survey procedures. A photon number in any channel below about 720 keV has considerable cesium contribution. Cesium photopeak window (Fig. 3) is now an additional data in measurement. In Fig. 2 and 3 you see that its pulse number is high. I see that the cesium window should be just in the photopeak and its width (in scintillation spectrum of Fig. 3 in four energy channels) should not be much larger than the photopeak half-height-width. This is because the number of Compton-scattered K-, U- and Th-photons in the Cs-window depends on snow and soil moisture. The K-, U- and Th-photons contribution can be determined by using the numbers of pulses in the energy channels just above Cs-photopeak energies. When the Ge-detector is in use, this background subtraction procedure is easier (and the Compton-background also smaller).

In Table 1 there are given the mass attenuation coefficients, μ, of photons in water, dry soil and air. A lot of photons, that reach the detector, penetrate the snow layer in small angles and from long distances. The photon that is detected in its photopeak-window (Thorium-, Uranium, Potassium or Cesium-window) has not lost its energy. For the 16.8 l scintillator package (4" thick) Allyson and Sanderson (1998) have determined detector functions $D(\theta)$ for which can approximately be written $D = D_0 \cos\theta + D_1$ (where $D_1/D_0 =$ 0.44 for cesium, 0.59 for potassium and 0.72 for thorium may be are good enough). For the 25.2 l scintillator and larger ones the D_1/D_0 probably is smaller.

Table 1. Photon mass attenuation coefficients in water, μ_w, dry soil, μ_{ds}, and air, μ_a, determined from the tabulations, Hubbell et al. (1980), Hubbell and Seltzer (1995). The dry soil has the mean content of the earth crust, with H content 0.14 % by weight. For air the water mole fraction 0.0126 is used.

Window	Photon emitter	Energy keV	μ_w 10^{-3} m²/kg	μ_{ds} 10^{-3} m²/kg	μ_a 10^{-3} m²/kg
Thorium	^{208}Tl	2614.5	4.27	3.87	3.85
Uranium	^{214}Bi	1764.5	5.28	4.74	4.76
Potassium	^{40}K	1460.8	5.83	5.22	5.25
Cesium	^{137}Cs	661.7	8.57	7.67	7.71

Let us compare the use of different photon windows. We use the approximations: semi-infinite, homegeneous Th, U and K space sources, and Cs plane source d = 4 cm below dry 1500 kg/m^3 soil surface. Then the solutions of Eq. (1) are $R_i = 2\pi D_i I_i E_j(x)$, where i = Th, U, K or Cs and in the exponential integral $E_j(x)$ the order value j = 1, 2 or 3, $x = \mu_a \rho_a h + (\mu_w \rho_w - \mu_a \rho_a)s$ for Th, U and K, and $x = \mu_s \rho_s d + \mu_a \rho_a h + (\mu_w \rho_w - \mu_a \rho_a)s$ for Cs. Kasi (1992) has shown, how two terms of $D = D_0 \cos\theta + D_1$ determine the order j of $E_j(x)$. In Fig. 4 you see that the influences of these terms of $D(\theta)$ are similar.

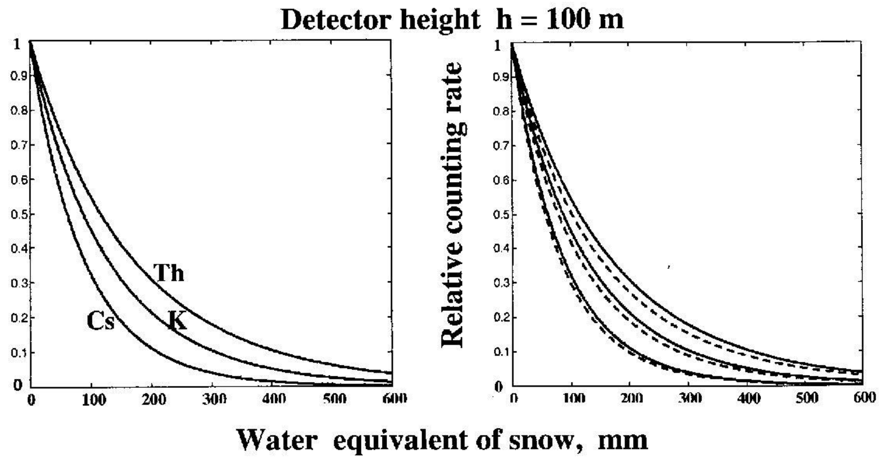

Fig. 4. Relative counting rates of thorium, potassium and cesium, left when $D = D_0 \cos\theta$, and right the same and the result when $D(\theta)$ is constant.

Fig. 4 tells that the Cs snow measurement is accurate when water equivalent is not much more than 300 mm. In Fig. 2 and 3 from southern Finland you see that in one second Cs-window count number is more accurate than 10 %. With Th-window you can measure over 500 H_2Omm snow covers, but in long times. For Th a = 5.6 and b = 0.1 in Eq. (2) are so good that the corresponding curves coincide. — The more relevant radiation sources and density profiles in soil than above are not very difficult to be applied. Have a and b physical explanations?

In RESUME (1997) the chair of its planning (J. Hovgaard) used the scintillation spectrum to determine the depth of cesium. Kasi (1998) points out, that except snow water equivalent, also moisture in surface soil may today be determined.

REFERENCES

Allyson, J. D. and Sanderson, D. C. W. 1998. Monte Carlo simulation of environmental airborne gamma-spectrometry, J. Environ. Radioactivity 38, 259-282.

Hubbell, J. H., Gimm, H. A. and Øverbø, I. 1980. Pair, triplet and total atomic cross sections (and mass attenuation coefficients) for 1 MeV-100 GeV photons in elements Z = 1 to 100, J. Phys. Chem. Ref. Data 9, 1023-1147.

Hubbell, J. H. and Seltzer, S. M. 1995. Tables of X-ray mass attenuation coefficients and mass energy-absorption coefficients 1 keV to 20 MeV for elements Z = 1 to 92 and 48 additional substances of dosimetry interest, U.S. Department of Commerce. NISTR 5632.

IAEA (International Atomic Energy Agency). 1991. Airborne gamma ray spectrometer surveying, Technical Reports Series No. 323, International Atomic Energy Agency, Vienna.

Kasi, S. 1992. Hydrological use of radiocesium fallen down. Nordisk Hydrologisk Konferanse, Alta 4.-6.8.1992, ed. G. Østrem, NHP Report No. 30, 574-583.

Kasi, S. 1998. Determination of water content in soil below the ground surface using radioactive cesium and potassium. XX Nordic Hydrological Conference, ed. J. Kajander, NHP Report No. 44, Vol. II, 413-422.

Kasi, S. 2000. Soil water content more accurately by nuclear methods. XXI Nordic Hydrological Conference, ed. T. Nilsson, NHP Report No. 46, Vol. 2, 549-554.

Knoll, G. F. 2000. Radiation detection and measurement. John Wiley and Sons. Ch. 10.

Kuittinen, R., Autti, M., Perälä, J. and Vironmäki, J. 1985. Lumen vesiarvon määrittäminen luonnon gammasäteilyn ja satelliittikuvien avulla (Determination of snow water equivalent with natural gamma radiation and satelllite pictures, in Finnish) , VTT, Tchnical Research Centre of Finland, Research Reports 370.

Kurvinen, K., Pöllänen, R., Smolander, P., Kettunen, M. and Lyytinen, J. 2002. Radiation surveillance equipment for unmanned aerial vehicle. 36. Physics Days, Joensuu 14-16.3.2002. Abstract.

RESUME (Rapid Environmental Surveying Using Mobile Equipment). 1997. Airborne gamma ray spectrometer surveying, Nordic Nuclear Safety Research, nks, Copenhagen.

Tollan, O. 1985. Snøtaksering med gammametoden når snøen ligger ujevnt. Forsøk i Norge med bruk av geometriske middelverdier. Snötaxering med gammastrålningsteknik, ed. Y. Sucksdorff, NHP-rapport Nr 8, 57-74.

Vironmäki, J. 1985. Tolkningsmodell och dess egenskaper för snötäckets vattenvärde-mätningar med gammastrålningsteknik, Snötaxering med gammastrålningsteknik, ed. Y. Sucksdorff, NHP-rapport Nr 8, 32-39.