A METHOD FOR THE DETERMINATION OF VERTICAL DISTRIBUTION PROFILES OF RADIOACTIVE CONTAMINATION IN SOILS

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ABSTRACT

A method for precise determinations of vertical profiles of radioactive contamination in soils is described.

A polyethylene tube is driven into the ground and the tube, together with a soil core, withdrawn. The tube and the core are frozen and the whole sectioned with a diamond saw. The technique produces 'precision engineered' parallel-sided circular discs. Discs of less than 1 cm in thickness can be produced if desired, thus permitting a well resolved soil profile. The individual sections are dried, weighed and analysed.

The method was used in the city of Gävle in Sweden and showed that more than eight years after contamination by fallout from Chernobyl, the radiocaesium concentration in undisturbed soil (sandy loam) peaked at a point several centimetres below the ground surface. Trace amounts of radiocaesium were found to have migrated to a depth of at least 15 cm. The data obtained are suitable for testing models designed to represent downward migration of caesium fallout in soils and for calculating dose-rate over undisturbed soils contaminated with radiocaesium.

INTRODUCTION

Computer modelling, as well as direct dose rate measurements, has shown that when a housing environment has become contaminated by airborne radiopollutants (essentially ^{137}Cs) deposited after a nuclear accident, areas of soil in the environment are often the main contributors to the dose rate. This is the case immediately after the deposition, and as time goes by the relative dose rate contribution from soil areas will normally increase. The reason for this is the relatively strong fixation of radiocaesium in the upper soil layers. Many different decontamination or reclamation procedures have been suggested over the years to reduce the external radiation dose to populations by for instance burial deep in the vertical profile of a thin top soil layer containing almost all the radionuclides or by total removal of a thin top layer.

The crucial question is : how deep a layer should be removed ? This question can not be answered by the generally applicable computer models of radionuclide migration, which are not sufficiently case-specific. If too little is removed, the reduction in dose rate may not be worth the effort, whereas if too much is removed, areas with thin fertile layers (typical of e.g. large areas of the former Soviet Union) could be turned into desserts. It is therefore very important to know the vertical contaminant profile before any clean-up operation is initiated. Refined techniques have been developed, by which estimates of 'mean' penetration depths can be made from in situ measurement spectra obtained at the surface, but these assume an exponentially decreasing pollutant depth profile, and this assumption is not valid in reality. Soil profile sampling is therefore the only certain way to investigate soil radionuclide penetration.

METHODS

Cylindrical polyethylene tubes with an inner diameter of 81.0 mm and a wall thickness of 4.5 mm are driven into the ground using a rubber hammer. When the full length of the tube (about 20 cm) has penetrated the ground, it is withdrawn along with a soil core. The withdrawal is performed with special care to prevent loose material in the bottom from falling out. Therefore, the soil surrounding the outer surface of the tube is first excavated. The sample cores (still in plastic tubes) are wrapped in a thin plastic film to prevent them from drying out and falling apart. When the sample cores have been transported to the laboratory, 200 ml of distilled water is added to each tube, which is subsequently transferred to a deep freezer (-20°C), where it is left for two days.

The tubes with the samples are then sliced with a diamond saw. The blade of the saw is 2.57 mm thick. Consequently, by this slicing procedure, a corresponding layer of the soil core is lost by each sectioning. A spacing device on the diamond saw makes it possible to accurately adjust the thickness of the slices. The saw blade usually has to be cooled with water, but at this point the samples contain sufficient amounts of water to grease/cool during the slicing process. As the samples are deep frozen the slices keep their parallel-side circular disc shape and even stones in the samples are cut through. The reproducibility of this 'precision engineered' technique has been evaluated through an examination of the sectioned core samples, which shows that the variations in thickness have a standard deviation of about 1 %.

Since the samples stay in the plastic tube during the slicing process, the sliced tube sections form rings around the sample slices. These rings support the samples during the different analysis sequences (drying, weighing and γ-measurement). Further, a removal of the whole soil core from the tube would introduce an unnecessary cross-contamination hazard.

The samples are then dried in 3 days at 60°C. After drying, the density of the samples is established through a weighing, where the mass of the plastic ring is subtracted. Stones and grass roots are not removed. This enabled a determination of the bulk soil density as a function of depth. The density of the sample is also used to allow for the attenuation of gamma-rays through the soil slice while measuring the gamma-activity.

The photopeak count rate of ^{137}Cs (661.6 keV) in each sample is measured in a lead shielded gamma spectrometer which includes a 15.6 % efficiency Ge(Li) detector. In this calibrated detector system the sample was placed directly on top of the upward facing detector end cap.

Finally, the photopeak net count rate is converted to a contamination level (Bq/cm^3 of ^{137}Cs) in the sample, taking into account differences in slice thickness and densities relative to the calibration standard.

RESULTS/DISCUSSION

The above described method was applied in situ in the Gävle area of Sweden in the summer of 1994. This area received high levels of contamination after the Chernobyl accident in 1986. Thus, soil core samples from the area contain sufficient amounts of radiocaesium to perform analyses with good accuracy. The soil profiles were sampled at five different locations in the area. At each location a series of 5 cores was sampled: one in each corner of a square with a side length of 1.40 m and one in the centre of the square.

Measurements of the soil density at the 5 different locations showed almost identical profiles. The bulk density of the surface layer (ca. 1cm) was found to range from 0.36 to 0.47 g/m^3. It was found that the bulk density increases almost linearly with depth through the top 10 cm layer. Below 10 cm, the soil has a nearly constant density, ranging from 1.2 to 1.5 g/cm^3. This is approximately the value that has been used as a default value for the whole profile in existing biospheric transfer models (1,2). Only the top layers of the beach samples were found to differ significantly from the rest. Here, the top layer density was found to be only 0.24 g/m^3, which can hardly surprise since this top layer was sand. The generally lower density of the top layers of the other samples must be attributed to a high content of organic matter, which has previously been recorded by textural analysis of soil from the area (3). This lower density in the top layers is expected to influence not only the shielding against radiation from penetrated radiocaesium, but also the downward migration of radiocaesium in the soil.

Figure 1 shows the recorded vertical soil profiles (averages over 5 cores). Although the total amounts of contamination were found to vary by as much as a factor of 1.5 between the individual cores, the shape of the profile was found to be fairly consistent. The counting uncertainties were less than 1 %. Samples were taken from the lawn in front of the city hall, a local surveyor's office in the city area (Land C.), a lawn in an industrial area (Gevalia), a lawn about 13 km to the north-east of the town centre (cottage) and a beach area about 11 km to the north of the town centre. Also shown is an estimate made with the computer model MLSOIL (1) of the profile, assuming a k_d value of 37 ml/g, which is actually the minimum value that has been used so far by the model for uncertainty analysis.

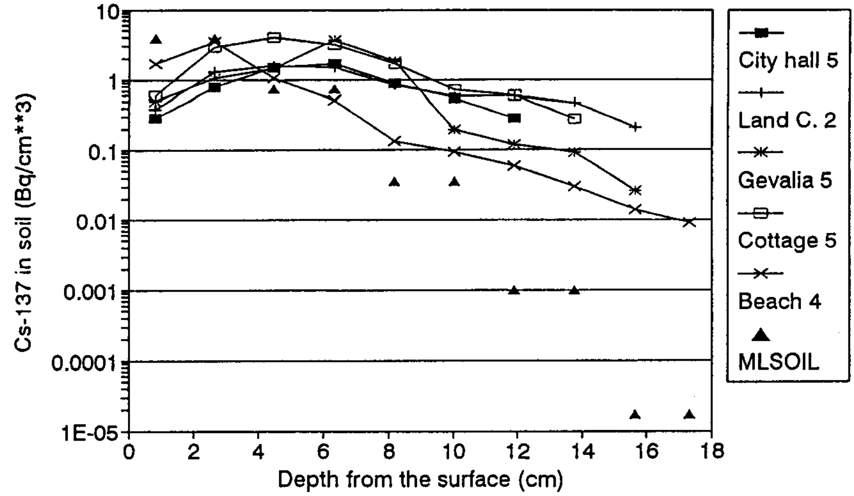

Figure 1. Vertical ^{137}Cs profiles in soil in 5 different lawns in the Gävle area. The sampling results are compared with estimates obtained with the MLSOIL model.

As could be expected from the density measurements, the higher content of organic matter and consequently higher macro-porosity and smaller fixation potential of the top soil layer is reflected in the radiocaesium profile. However, compared with previous investigations in the same area (the lawns termed 'Gevalia' and 'Cottage') in 1988 and 1990 (3), the average depth of the contamination has increased rather much. In 1990 the profile of the 'Gevalia' soil peaked at a depth of about 1 cm. Anyway, it has certainly been demonstrated that the assumption that soil contaminant content decreases exponentially with depth is not generally valid. After longer periods of time, the contaminant content in the uppermost layer can be depleted.

CONCLUSIONS

A specially adapted technique for soil sampling was established and tested in the field in the Gävle area of Sweden. By this method, the sectioning of soil cores can be performed with very good accuracy (ca. 1 %). The gamma analysis of trace amounts of radiocaesium in the soil slices from Gävle (initial contamination level ca. 200 kBq/m^2) was performed with an uncertainty of less than 1 %. Although the total contents of radiocaesium differed between the individual samples taken at a site, the shape of the vertical caesium profile was found to be relatively consistent. The radiocaesium concentration was found to peak at a depth of several centimetres in the investigated sandy loam type soil.

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