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Transfer of chlorine from the environment to agricultural foodstuffs

V. Kashparov [a], C. Colle [b,*], S. Levchuk [a], V. Yoschenko [a], N. Svydynuk [a]

[a] *Ukrainian Institute of Agricultural Radiology (UIAR), Mashinostroiteley Strasse 7, Chabany, Kiev Region 08162, Ukraine*
[b] *Institute for Radioprotection and Nuclear Safety (IRSN/DEI/SECRE), Cadarache bat 159, BP 3, 13115 Saint Paul-Lez-Durance, France*

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Abstract

The factors governing chlorine transfer from Phaeozem and Greyzem soils to various important crop species (foodstuff and forage) were determined in natural conditions in the Kiev region of Ukraine. The stable chlorine concentration ratio (CR) values were the lowest in apple (0.5 ± 0.3) and strawberry (2 ± 1), higher in vegetables (5 ± 3), seeds (15 ± 7) and reached a maximum in straw (187 ± 90). The average CR values of ^{36}Cl were estimated for the most important crops using all experimental data on ^{36}Cl and stable chlorine transfer into plants from various soils.

It was experimentally shown that boiling potatoes in water leads to an equilibrium between ^{36}Cl specific content in the water and moisture in the cooked potato. The ^{36}Cl processing factor (PF) for boiling various foodstuffs is equal to the ratio of water mass in the cooked foodstuff to the total water mass (in the food and the decoction). ^{36}Cl PF for cereal flour can be estimated as 1. The ^{36}Cl processing factor for dairy products is equal to the ratio of residual water mass in the product to initial water mass in milk.

At a ^{36}Cl specific activity in soil of 1 Bq kg^{-1}, the estimated annual dietary ^{36}Cl intake into human organism (adult man) is about 10 kBq. Sixty to seventy percent of the above amount will be taken in via milk and dairy products, 7–16% via meat, 14–16% via bread and bakery items and 8–12% via vegetables. The highest annual ^{36}Cl intake, 10.7 kBq, is predicted for 1-year-old children. The expected

* Corresponding author. Tel.: +33 0442199471; fax: +33 0442199151.
E-mail address: claude.colle@irsn.fr (C. Colle).

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effective doses from annual ^{36}Cl intake are higher for younger age groups, increasing from 0.008 mSv in adults to 0.12 mSv in 1-year-old children.

Keywords: Halogens; Chlorine radioisotopes; Chlorine-36; Chlorine; Concentration ratio; Transfer factor; Root uptake; Processing factor; Radioecology

1. Introduction

The Chernobyl accident led to the radioactive contamination of large geographical areas. The highest contamination levels are found up to 30–50 km around the ChNPP, in the immediate vicinity of the accident (Kashparov et al., 2001, 2003). Within this area, numerous storage facilities were built to temporarily and permanently store radioactive waste. However, many of these storage facilities do not meet existing safety requirements (Dewiere et al., 2004). There is also a plan to relocate the radioactive materials from the destroyed ChNPP unit 4 and the spent nuclear fuel from the other three units of ChNPP. With this in mind, discussions are underway as to the possibility of creating some facilities, including deep storage, in the ChNPP Exclusion Zone, to house radioactive waste from the Exclusion Zone and from other nuclear enterprises in Ukraine.

Long-lived ^{36}Cl ($T_{1/2} = 0.3$ Ma) potentially makes a major dose contribution to humans (Sheppard et al., 1996, 1999; White and Broadley, 2001). The average value of ^{36}Cl specific activity in graphite samples taken from ChNPP unit 2 after 13 years of reactor operation was 1.2 MBq kg^{-1} (Bobro et al., 2003). The active zone of each Chernobyl unit contains 1700 tons of graphite. ^{36}Cl has a high capacity for migration and is not absorbed by the mineral part of the soil. Chlorine transfer from soil to plants is extremely high. Another important factor to be taken into account is the water pathway from the Chernobyl zone. The Pripyat River, a tributary of the Dnieper River, crosses the center of the Exclusion Zone. The Dnieper River is Ukraine's main waterway and supplies more than half of the Ukrainian territory with water. It is therefore vital to comprehensively assess the long-term storage of radioactive materials in the ChNPP zone.

The behavior of radioactive chlorine in soil–plant systems has recently been studied under laboratory conditions (Bostock et al., 2002; Colle et al., 2002; Shaw et al., 2004; Kashparov et al., 2005, in press). The root uptake of chlorine-36 in root vegetables (radish), leafy vegetables (lettuce) and fruit vegetables (bean) was determined using pot experiments (Colle et al., 2002). The experiments were performed on three soil types with contrasting properties: acidic, calcareous and organic. The values of the soil–plant concentration ratio (CR) expressed with respect to the dry weight of vegetables were very high, varying between 18 and 377 according to plant organ and soil type. The highest ^{36}Cl root uptake values were obtained with the calcareous soil and the lowest with the organic soil.

The root uptake of ^{36}Cl by grass swards in undisturbed forest soil columns (podzol with well-developed organic surface layers) has been shown to be very substantial, with soil–plant transfer factors (activity concentration ratios) exceeding 100, and inventory ratios exceeding 1.0 (Bostock et al., 2002). The vertical distribution of ^{36}Cl has also been presented by using deep and shallow lysimeters above artificially controlled water tables for a 4-year experiment in late summer, when a winter wheat crop was harvested (Shaw et al., 2004). After harvest, the activity concentrations in different organs of the crops were determined and crop uptake quantified in order to give differential root and radionuclide distributions within the soil profile. The