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Assessment of radiological efficiency of countermeasures on peat-bog soils of Ukrainian Polissya

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ABSTRACT

In the field conditions, the long-term (2013–2015) small-plots experiment was carried out for evaluation of radiological efficiency of application of ameliorants as the countermeasures for reduction of the ^{137}Cs uptake to herbage at the Peat-boggy (Histosols) soils of Ukrainian Polissya. At the late stage after the Chernobyl accident, the average radiological efficiencies of application of sand (175–200 ton ha^{-1}) and ferrocyn (0.2 ton ha^{-1}) as the ameliorants were rather low ranging from 0.8 to 1.6. Application of 4 ton ha-1 of chalk and 5 ton ha-1 of peat ash decreased 1.7–1.9 times the ^{137}Cs activity concentrations in plans. The highest radiological efficiencies, 4.4 ± 2.0 and 7 ± 2, were reached at applications of chalk-ferrocyn ameliorant (4 + 0.2 ton ha^{-1}) and ferrocyn-bentonite absorbent HZH-90 (30 ton ha^{-1}), respectively.

1. Introduction

As a result of the Chernobyl accident on April 26, 1986, the vast territories in Ukraine, Belarus and Russian Federation were contaminated with radionuclides. The radionuclides of the fuel component of the Chernobyl release (^{90}Sr and transuranium elements (TUE), such as Pu, Am, Cm) deposited mainly in the near zone of the accident (Kashparov et al., 2001, 2003), while the volatile radioisotopes of cesium, iodine and tellurium spread to much longer distances. Population from the near zone (Exclusion zone) was evacuated in a few days after the accident. Being severe contaminated with the long-lived radioisotopes of Pu (especially ^{239}Pu and ^{240}Pu with the half-lives of approximately 24,100 years and 6560 years, respectively), about 500 km^2 in the Exclusion zone where the Pu deposition exceeds 4 kBq m^{-2} (United Nations, 2000) will remain unsuitable for inhabitance and economical utilization in the long-term. At the contaminated territories outside the Exclusion zone, the exposures to population after the acute phase of the accident were formed mainly by the long-lived ^{137}Cs ($T_{1/2}$ = 30.17 y). These territories were classified as the zones II - IV according to the radionuclide deposition levels and doses (or potential doses) to population (Verkhovna Rada of Ukraine, 1991). In the years followed the accident population was resettled from the zone II where the calculated effective equivalent dose from the Chernobyl radionuclides exceeded 5 mSv per year.

Major part of the zone III spread up to several hundred kilometers west of the ChNPP, at the territory called Ukrainian Polissya (Fig. 1). Until now, at the territory of the north-western Polissya of Ukraine, in Zhytomyr and Rivne regions, there are villages where the mean annual effective doses (MAED) of radiation to population exceed 1 mSv and the radionuclide specific activities in agriculture products are higher than the permissible levels (PL-2006) set by Government of Ukraine (Ministry of Health of Ukraine, 2006). According to the results of the latest dosimetric survey of 2012 (Likhtarov et al., 2013), in 25 most critical settlements MAED exceeded 1 mSv; the main source of the additional doses to population was consumption of milk with radiocesium specific activities above PL-2006 of 100 Bq L^{-1} (Fig. 2). In general, consumption of the local produced foodstuff with high ^{137}Cs specific activities, mainly milk and meat, contributes 80–95% of the doses to population of the villages in north-western Polissya. In up to 10 settlements radiocesium specific activities in milk and meat permanently are 3–10 times higher than PL-2006, and in up to 50

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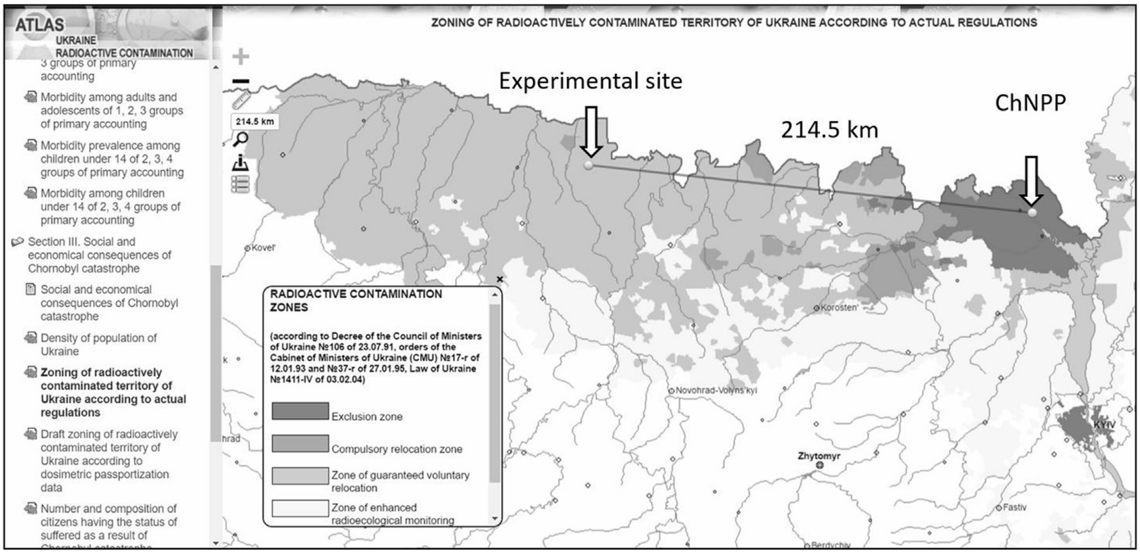

Fig. 1. Zones of radioactive contamination in Ukraine. Locations of the experimental site and the ChNPP and distance between them are added. Modified from Ministry of Emergencies of Ukraine, Intellectual systems GEO Ltd (2008).

settlements radiocesium specific activities in milk can exceed the permissible level (Likhtarov et al., 2013; Kashparov et al., 2011; Khomenko and Polishchuk, 2014; Maloshtan et al., 2015). In some villages in the north of Rivne region (Drozdyn', Vezhytsya, Stare Selo, Yelne, Grabun' of Rokytne district and Velykiy Cheremel' and Rizky of Dubrovytsya district) permissible levels for radiocesium can be also exceeded in vegetables and potato grown at the Peat-boggy soils (Histosols) (Fig. 2). The ^{137}Cs permissible level in milk is exceeded even at the territories with the relatively low, up to 100 kBq km^{-2}, levels of its deposition. For example, in May 2015, the ^{137}Cs activity concentrations in milk were as high as 330 ± 130 Bq L^{-1} in Stare Selo, 320 ± 140 Bq L^{-1} in Drozdyn', 420 ± 160 Bq L^{-1} in Vezhytsia and 470 ± 230 Bq L^{-1} in Perkhodychi (UIAR, 2015).

The reason of such situation is utilization of the non-cultivated natural pastures at the specific hydromorphic organic Peat-boggy soils (FAO-UNESCO classification - Histosols) of this area for the cattle grazing and hay harvesting. Physical-chemical and agrochemical properties of such soils facilitate the high bioavailability of ^{137}Cs (Marey et al., 1974; Perepelyatnikov and Ilyin, 1991; Ilyin and Perepelyatnikov, 1993, 1996; Perepelyatnikov, 2001; Prister et al., 2001; IAEA, 2009; Fesenko et al., 2013) for plants, and, consequently, cause its high activity concentrations in milk.

Therefore, development of the agrotechnical and agrochemical countermeasures for reduction of the ^{137}Cs transfer from soil to the pasture herbage is an important practical task aimed on support of production of the clean forage and decrease of the doses to population at this territory. Radiological efficiency of such countermeasures is characterized by the relative decrease of the ^{137}Cs activity concentration in plants. In the real soil and climate conditions of Ukrainian Polissya at the late stage after the Chernobyl accident, liming of the acid soils and application of the enhanced doses of mineral fertilizers enable 1.5–3 fold decrease of the ^{137}Cs in herbage (Fesenko et al., 2006, 2007). Radiological efficiency reaches 1.5–2 for liming at 4–6 ton ha^{-1} at organic soils, 1.5–3 for fertilization at the optimum ratio of$N_{60}P_{90}K_{120}$-1:1.5:2 ranges from 1.5 to 3, and 2.5–4 for the combined liming and fertilization (UIAR, 1998).

In the laboratory experiments we demonstrated very high radiological efficiency of application to the Peat-boggy soils of ferrocyn-bentonite absorbent at the rate of 100 ton ha^{-1} (520 ± 124) (Maloshtan and Polishchuk, 2015). Also, radiological efficiencies were as high as 3–5 at application of 200–400 ton ha^{-1} of sand, 9–23 at application of 1.5–3 ton ha^{-1} of wood ash, and 9–45 at their combined application (Kosarchuk et al., 2015). However, these experiments were carried out in the laboratory, where the actual soil moisture and climate conditions could not be adequately reproduced. It led to degradation and mineralization of soil in the vegetation cups and, as a result, to the non-typical dynamics of the soil-to-plant transfer of ^{137}Cs (Maloshtan et al., 2015; Maloshtan and Polishchuk, 2015; Kosarchuk et al., 2015).

In the present study we evaluate radiological efficiencies of the remediation actions (countermeasures) that were applied at the small fields in the real soil-climate conditions for reduction of the ^{137}Cs bioavailability for herbage at the Peat-boggy soils.

2. Material and methods

2.1. Description of the experimental site

The long-term experiment for evaluation of the remediation efficiency was performed since the summer of 2013 at the marshy land near the village Vezhytsia of Rokytne district of Rivne region (Galo marsh, 51.5752N, 27.1309E). This land is used as a pasture for the cattle of the local population. The Peat-boggy soil of the site is typical for Ukrainian Polissya; the pasture is waterlogged which facilitate the abnormal high transfer factors of ^{137}Cs into the natural herbage (Marey et al., 1974; IAEA, 2009; Fesenko et al., 2013). The radiocesium activity concentrations in the local agricultural production still exceed PL-2006 (Kashparov et al., 2011; Khomenko and Polischuk, 2014; UIAR, 2015), and the average annual effective equivalent dose to the village population, 2.18 mSv, exceed the dose limit of 1 mSv that is set by the Norms of Radiation Safety of Ukraine (Ministry of Health of Ukraine, 1997).

Within the experimental site, the soil samples were collected in 5 points to the depth of 20 cm for characterization of its contamination with ^{137}Cs (Khomutinin et al., 2001) and for determination of the agrochemical properties of soil according to the standard methods (Gorodniy et al., 2004). Also, soil from the 20-cm layer was collected for the laboratory vegetation experiment; the site