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ПРИМЕНЕНИЕ МЕЛИОРАТИВНЫХ ТЕХНОЛОГИЙ ДЛЯ СНИЖЕНИЯ ПОСТУПЛЕНИЯ РАДИОНУКЛИДОВ В РАСТЕНИЯ НА ЗАГРЯЗНЕННЫХ СЕЛЬСКОХОЗЯЙСТВЕННЫХ ЗЕМЛЯХ

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Сформулирована оценка масштаба загрязнения сельскохозяйственных земель радионуклидами в результате чернобыльской аварии, представлена классификация земель по степени загрязнения радионуклидами цезия-137 и стронция-90. Описаны наиболее распространенные технологии снижения поступления радионуклида в сельскохозяйственную продукцию, приведены нормы внесения извести и минеральных удобрений на загрязненных полях Брянской области. Рассмотрена последовательность расположения зерновых культур в порядке убывания коэффициентов перехода цезия-137 из почвы в растение. Приведены результаты оценки состояния зараженных сельскохозяйственных угодий Брянской области через 25 лет после аварии. Рассмотрены проблемы вторичного очагового загрязнения земель под действием ветровой и водной эрозии. Описан ряд новых технических решений, направленных на связывание цезия-137 почвенным поглощающим комплексом и перемещение его за пределы корнеобитаемого слоя почвы, а также предложены способы извлечения его из почвы, а именно: посев многолетних трав с последующим вывозом сена в специальные хранилища и глинование загрязненного верхнего слоя почвы с последующим перемещением его на более глубокое расположение относительно основной массы поглощающих корней растений. Рассмотрено несколько сорбентов, применяемых для удаления радионуклида цезия-137. Описана технология перемещения цезия-137 в сорбент посредством испарения и капельного орошения; изучена возможность промывки стронция-90 за пределы корнеобитаемого слоя почвы с последующим образованием слаборастворимой соли. Предложенные технические решения дают возможность снижения общего поступления нуклидов в сельскохозяйственную продукцию или ликвидации очагов локального накопления радионуклидов.

Ключевые слова*:* радиоактивное загрязнение, дозы внесения удобрений при радиоактивном загрязнении, глинование почвы, капельное орошение, сорбенты, промывка земель, загрязненных стронцием-90.

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USE OF RECLAMATION TECHNOLOGIES TO REDUCE THE INTAKE OF RADIONUCLIDES INTO PLANTS ON CONTAMINATED AGRICULTURAL LANDS

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The paper includes an assessment of the scope of agricultural land pollution with radionuclides caused by the Chernobyl accident, the classification of land by the degree of contamination with radionuclides Cesium (Cs) –137 and Strontium (Sr) –90. The paper describes the most common technologies for reducing the level of radionuclide intake by agricultural produce and provides the introduction rates for lime and mineral fertilizers on contaminated fields in the Bryansk region. The authors consider the descending -order sequence of grain crop according to their Cs-137 transfer coefficients. The paper also presents the assessment results of the contamination state of land in the Bryansk region 25 years after the accident. The problems of secondary local soil pollution caused by wind and water erosion are analyzed. A number of new technical solutions aimed at binding Cs-137 to the absorbing material, withdrawing it beyond the limits of the root layer (topsoil), as well as methods of extracting it from the soil, are also described in the paper, in particular, sowing perennial grasses with subsequent delivery of hay to special storage facilities; claying of the contaminated topsoil with its subsequent movement to a location deeper than the main mass of absorbing plant roots. The authors give account of several sorbents used for the removal of Cs-137 radionuclides. The technology of transferring Cs-137 to the sorbent by evaporation and drip irrigation is described. In addition, a possibility of flushing Sr-90 beyond the topsoil layer with the subsequent formation of slightly soluble salt is considered. The offered technical solutions provide for the decreased content of radionuclides in farm produce and the elimination of the localized pockets of radionuclide accumulation.

Key words: radioactive contamination, fertilizer doses for radioactive contamination, claying, drip irrigation, sorbents, flushing soil from Sr-90 extract.

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Introduction. The large-scale contamination by radionuclides Cs-137 and Sr-90 occurred as a result of the Chernobyl accident. The area polluted by Cs-137 with density above 1 Ci/km^2 includes 703 thousand ha of agricultural land in the Bryansk region, 146 thousand ha in the Kaluga region, 779 thousand ha in the Orel region, 669 thousand ha in the Tula region. The highest level of pollution was fixed in six districts of the Bryansk region and three districts of the Kaluga region. Reduction of the level of radionuclides Cs-137 to 37 kBq/m^2 by natural decay will happen only by 2090 in the Kaluga, Orel and Tula regions, and by 2180 in the Bryansk region [1].

In the past 25 years after the accident, in seven southwestern districts of the Bryansk region, six cycles of total radiological survey of farmland were performed, in the rest, less contaminated areas, two or three round of the survey were carried out. Monitoring results show that there has been no radical change towards improving. The density of soil contamination of farmland by Cs-137 was reduced just in 1.91 times.

Now soil of the Bryansk region farmlands have a weighted average density of pollution by Cs-137 – 1.87 Ci/km^2 that exceeds pre-emergency level in 50 times. In total, the density of pollution in the southwestern districts corresponds to 5.19 Ci/km^2, i.e. exceeding the limit in 137 times, in the Novozybkov district – in 238 times, in the Krasnaya Gora and Gordeyevka districts – in 198 times. Soils with the pollution density of more than 1 Ci/km^2 occupy an area of 422.4 thousand ha or 25.1% of all the farmland of the Bryansk region. Most of these land – 358.9 thousand ha (85% of the contaminated soils area) – is located in the southwestern districts. Soils with the pollution density of more than 5 Ci/km^2 are located on the 144.8 thousand ha (8.6%) of land; with the pollution density of more than 15 Ci/ km^2 – on 33 thousand ha (2%); with more than 40 Ci/km^2 – on 5.0 thousand ha (0.3%).

Therefore, farmland soils have improved insignificantly as compared to the radiation situation in 1986. Only 212.4 thousand ha – 13% of contaminated land, and in the Novozybkov, Gordeyevka and Krasnaya Gora – 1…3%, moved into the group of conditionally clean soils (up to 1 Ci/km^2). In the southwestern districts the dose-forming gamma radiation also decreased from 8 to 15 times. The analysis of radiation situation on agricultural lands of southwestern districts shows that the probability of harvesting produce, which do not meet the food safety and agricultural health standards is very high, and that risk can only be reduced through complex agrochemical rehabilitation activities [2].

The research purpose is to introduce agrotechnical and irrigation technologies and methods, allowing to reduce the impact of radionuclides on agricultural produce in the zone subjected to radioactive contamination as a result of the accident on the Chernobyl nuclear power plant.

Research methods. The results of patent research methods and devices for cleaning soil of radionuclides Sr-90 and Cs-137 are used, sources that contain description and evaluation of the effectiveness of technologies applied on the contaminated fields are analyzed.

Methodology. The main method to reduce the intake of radionuclides in agricultural produce widely used in production, is the application of high rates of fertilizers. Thus, the application of potassium (K_2O) in the amount of 160…240 kg reduces the intake of cesium in 1.5…2.7 times. Positive impact on the reduction of cesium intake by plants is made by soil liming technique. Comprehensive rehabilitation activities, such as soil liming, phosphating, adding potassium to the soil and conducting cultural-technical works were performed in Bryansk region on 17% of contaminated land [3].

The transition level of radionuclides into plants depends on their biological characteristics, as well as grain structure of the soil. Radionuclides accumulate in plants on the loams half as much as on the sandy soils. Depending on the kind of plants, the level of the radionuclides accumulation can differ by one or two orders of magnitude. Therefore, the least expensive intake reduction of the radionuclides content in the produce is the selection of cultivated crop varieties, that accumulate radionuclides in the least amount. So, according to the decreasing order of the Cs-137 transition coefficient in plants, a sequence of crops should be presented as follows: lupine, peas, vetch, colza, oats, millet, barley, wheat, winter rye. As a rule, potato and beet accumulate Cs in smaller amounts. In the cultivation of cereal grains, strontium accumulates in the straw and much less transfers into grain [4].

Technical solutions related to the removal or transfer of Cs-137 and Sr-90 beyond topsoil layer are based on the use of the interaction features of these radionuclides with absorbing complex of the soil. In the same soil, different radionuclides have different migration speed and different coefficients of migration. Migration coefficients of Cs-137 are one or two orders of magnitude lower than the migration coefficient of Sr-90. Soil migration coefficient of Sr-90 in descending order is as follows: sod-podzolic sandy> sod-podzolic loamy> peat bog > humus (black earth). Soil migration coefficient of Cs-137 is as follows: peat bog> sod-podzolic sandy> sod-podzolic loamy> humus (black earth). Maximum migration of radionuclides is in the sod-gley, sod-peat-gley and peat-bog soils, where strontium migrates more intense than Cs.

Bulk of radionuclides (90%) on the uncultivated land is located in the top layer – 0…5 cm – for loamy soil or 0…10 cm – for sandy loam. Migration in automorphic soils reaches 15…20 cm, on the moistened soil – more than 30 cm.

Migration of radionuclides in the soil profile occurs very slowly. On the arable soils, radionuclides are evenly mixed in a tillable layer (0…25 cm). In the subsurface horizon, the concentration of radionuclides is less than 1% of the total radionuclide content in the layer of 0…30 cm.

The content of Cs-137 and Sr-90 in soil is reduced only as a result of natural radioactive decay, which does not depend on external conditions, as well as the removal of radionuclides by vegetation. Due to radioactive decay, soil is annually cleaned of strontium and cesium by 2.2 and 2.1%, respectively [5].

However, along with a decrease in the level of radioactivity due to natural decay, the process of emerging zones with a high level of the radionuclide content may occur. This process is associated with wind and water erosion of the soil. In the drought periods, especially in spring when there is no vegetation, strong winds lift up dust clouds that settle near any obstacles. Each mote containing radionuclides forms the pockets of high pollution. The level of radioactivity in such pockets can be several times higher than the average level of the specific array of agricultural land. Due to water erosion, similar pockets form in the low relief places in the periods of floods. Flowing water takes suspended particles of sludge containing radionuclides in the area of settling.

A number of inventions in the field of reducing the content of radionuclides in the soil is based on a combination of reducing their mobility in the soil with their removal by vegetative plant mass. For example, the authors, who invented the method of soil cleaning from Sr-90 and Cs-137 contamination, suggest applying 5…6 tons of lime flour and at least 200 kg/ha of potash during the plowing process. After the soil preparation, perennial grasses are sown on the site and then harvested in autumn and placed in a special storage [6].

The VNIIGIM Research Institute named after A.N. Kostyakov patented the reclamation method for soil contaminated by Cs, which is based on claying technology used in irrigation of sandy, sandy-loam and light-loamy soils [7].

To develop this technology, properties of interaction between Cs-137 and absorbing soil complex were used. Most strong radionuclides are bound to the soils with heavy granulometric composition with the prevalence of a montmorillonite mineral group. In this case, bonding occurs with the inclusion of cesium ions into mineral crystal lattice. Therefore, it is almost excluded from the process of potassium or calcium ion exchange.

The proposed method of reducing the availability of Cs-137 for crops is carried out in a several steps: loosened soil is circumfused with clay solution, providing soil contact with the smallest fraction of clay. In this case conditions for the interaction of cesium ions with clay particles for a few days are made to achieve soil moisture sufficient for loosening. Then deep plowing is performed, when the layer of soil with bonded Cs-137 isotope are moved beyond the root layer of the majority of spring crops by a plow with a coulter. Thus, although the Cs-137 isotope is still located within the field, the probability of its intake into farm produce is limited.

The other way of preventing Cs-137 intake in agricultural products is its extraction from the soil with the help of sorbents able to attach it to their surface, with the following removal of these sorbents from the soil to the surface. Such inventions can find the application on small areas to eliminate localized pockets of radionuclides. According to a proposal developed by N.A. Ovchinnikov, the sorbent binding radionuclides is applied and mixed it with the soil. Then, after radionuclides are attached to the sorbent surface, it is separated from the soil by screening. The collected sorbent saturated with radionuclides is removed to the burial place [8].

Another technology of soil cleaning with hydrolyzed lignin (wood industry waste) as a sorbent is based on the placement of sacs filled with sorbent into the soil at 15…20 cm depth. After the fixation of radionuclides by sorbent, sacs are removed by potato digger [9].

The method of removing the Cs-137 isotope from the soil designed by the VNIIGIM Research Institute named after A.N. Kostyakov is based on the ability of Cs-137 isotope to transform into the gaseous state at a temperature lower than 38 C^0. In this state it is condensed on the surface of mats made from sorbent material and a membrane film screen (Fig. 1.). In the implementation of this method, biofuel storage clamps with drip irrigation pipelines are placed on the field. A specific feature of the drip irrigation system is a possibility of even moistening of biofuels with a specified amount of warm water with the addition of fertilizers and aerobic micro-organisms. Biofuel storage clamps with tubes are filled with soil containing cesium radionuclides and covered with mats containing sorbent, for example Synergy Sorb. A membrane film screen is placed on the top of mats. A specific feature of this screen is that it lets in the air, but at the same time condenses the radionuclide vapor at its surface. The radionuclide together with the moisture is absorbed by the sorbent. In the implementation of this method, the supply of warm water with nutrient solution and microorganisms causes the warm-up of biofuels and its “burning”. The released heat warms up soil layer up to 50°C, so Sc-137 transforms into gaseous state and is carried with heated air through the sorbent layer. There the air is cooled, and the radionuclide attaches to the surface of sorbent substances. After soil cleaning from radionuclide is finished, the film screen and sorbent mats are removed, and biofuels are plowed into the soil [10].

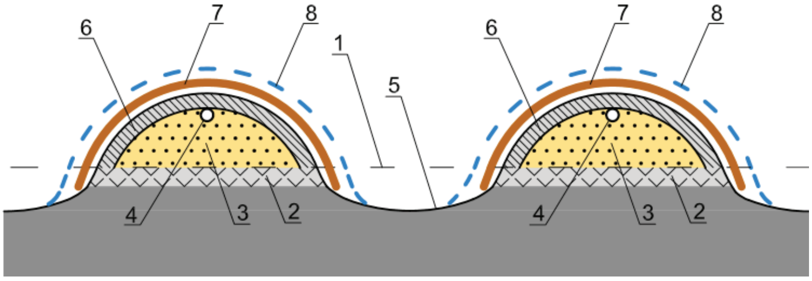

Fig. 1. Removal of Cs-137 isotopes by its transition into gaseous state:
1 – soil surface; 2 – loosened contaminated soil; 3 – sawdust; 4 – pipeline with drippers;
5 – the area from which the contaminated soil is moved to the roller; 6 – displaced soil; 7 – sorbent material;
8 – membrane screen

Рис. 1. Извлечение изотопа цезия-137 посредством перехода его в газообразное состояние:
1 – поверхность почвы; 2 – разрыхленная загрязненная почва; 3 – древесные опилки;
4 – трубопровод с капельницами; 5 – участок, с которого загрязненная почва перемещена на валик;
6 – перемещенная почва; 7 – сорбирующий материал; 8 – экран из мембранной пленки

When developing a method to clean the soil of Sr-90 radionuclide, its higher mobility and the ability to move into the soil solution while interacting with absorbing soil complex, as well as its ability to form slightly soluble salt in interaction with carbonic acid in certain conditions are taken into consideration. For the implementation of this method, a combination of several technologies used in the land reclamation was used. Speed of filtering was increased by loosening of soil and reducing the content of mobile salts by its washing with excess amount of water (Fig. 2).

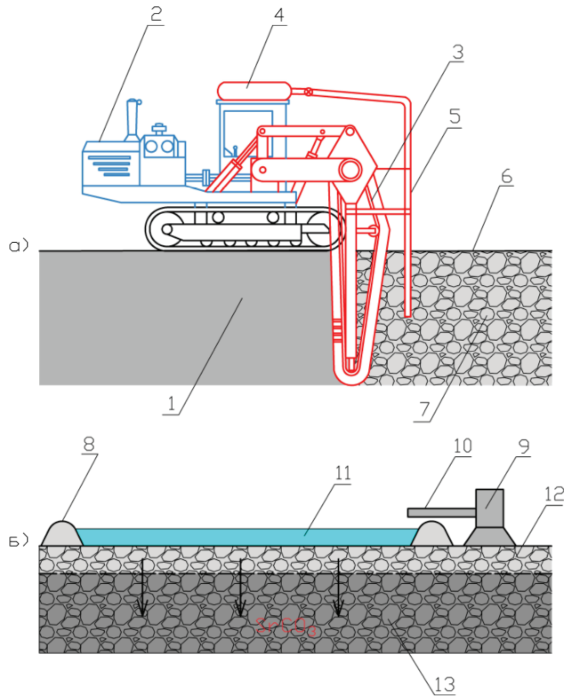

Fig. 2. Diagram of the technological process of cleaning the root zone soil from Sr-90:
a) preparing the soil: 1 – contaminated soil; 2 – tractor; 3 – deep ripper; 4 – carbon dioxide cylinder;
5 – pipe supplying carbon dioxide into loosened soil; 6 – loosened soil; 7 – soil saturated with carbon dioxide;
b) washing the soil from the cesium radionuclide with the formation of slightly soluble salt:
8 – rollers forming a sector for cleaning; 9 – pump for water supply; 10 – water release hose; 11 – water;
12 – tilted limed soil layer; 13 – zone of carbonic acid and Sr-90 interaction

Рис. 2. Схема технологического процесса очистки корнеобитаемого слоя почвы от Sr-90:
а) подготовка почвы: 1 – загрязненная почва; 2 – трактор; 3 – глубокорыхлитель;
4 – баллон с углекислым газом; 5 – труба подачи углекислого газа в разрыхленную почву;
6 – разрыхленная почва; 7 – зона насыщения почвы углекислым газом;
б) промывка почвы от радионуклида цезия с образованием слаборастворимой соли:
8 – валики формирующие чек; 9 – насос для подачи воды; 10 – водовыпускной шланг; 11 – вода;
12 – вспаханный заизвесткованный слой почвы; 13 – зона взаимодействия угольной кислоты с Sr-90

In the implementation of the proposed method soil moisture permeability is increased by tilling to the depth of 1.2…1.5 m. This depth can be achieved with modern deep tillage plows. An increased content of strontium radionuclides in the soil solution is achieved by the addition of high rates of lime. For the solution displacement beyond the root layer, a well-developed in arid zone method of soil flushing is used. At the same time, at the depth of the proposed strontium radionuclide fixation a zone saturated with carbon dioxide is pre-created, which, with its density exceeding that of the soil air, will remain in the pores and cavities made with deep tilling. In the implementation of the proposed method, water from the cleaned site moves the soil solution containing strontium to the depth of the tilled layer, where, with the dissolution of carbon dioxide in the soil solution, carbonic acid is formed, which interacts with strontium and forms slightly soluble $SrCO_3$ salt [11].

Results and discussion. From the reviewed methods, wide practical application is made of the selection of plant varieties with the least ability to absorb cesium radionuclides and the use of high amount of lime and fertilizers, first of all – potassium.

The implementation of the method including the sowing of perennial grasses that are able to accumulate an increased amount of radionuclides, followed by their disposal, is complicated by the need to bury very large amounts of hay. The method of radionuclide binding with claying is more affordable and economical, as it is based on the technology that has been already tested the irrigation; cleaning is performed once and provides a significant reduction of the Cs-137 content in the arable layer that allows to reduce the risk of its intake by the produce.

Flushing of Sr-90 with deep tilling and its converting into a slightly soluble salt in combination with the removal of Cs-137 with the help of sorbents is of interest in the elimination of localized pockets of radionuclide accumulation.

Conclusion

Currently the radioactive cesium isotope content in the soil is reduced mainly due to its natural decay. The reduction of its intake by farm produce is achieved mainly due to the selection of crops absorbing radionuclides in the least degree, by soil claying, and the addition of high amounts of fertilizers. Although technological methods of removing radionuclides beyond the root layer, described in the patents for inventions, are based on the well-known agricultural engineering and irrigation technologies, they still need more practical verification.

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