Sources and Remediation Technologies of Soil Radioactive Contamination

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Abstract: Soil is an important part of the human environment. With the development of nuclear industry, soil radioactive pollution has aroused widespread concern in society. With the continuous expansion of the field of nuclear energy utilization and the rising risk of nuclear accidents, a series of nuclear safety problems and hidden dangers need to be resolved urgently. In the process of nuclear energy development and utilization, improper use of radioactive materials or irresistible factors will lead to leakage of radionuclides into the natural environment. After radioactive pollutants enter the atmosphere and water bodies, radioactive nuclides contaminate the soil through sedimentation and water flow, or sudden nuclear accidents directly cause radioactive contamination of the soil. Radionuclides in soil not only cause harm to the ecological environment, but also endanger human safety through food chain enrichment. By analyzing the sources of radioactive contamination in soil and remediation technologies, suitable remediation technologies can be screened to reduce radioactive contamination in soil. The research summarizes the sources and hazards of soil radioactive pollution, and reviews the current soil radioactive pollution remediation technology, providing reference for the control of soil radioactive pollution.
***Keywords*:** soil, radioactive contamination, source, remediation technology

1. Introduction

With the development of science and technology, phenomena such as artificial radioactivity have been discovered, and nuclear technology has been widely used. While nuclear energy brings convenience to human life, it also causes some environmental problems. Radionuclides produced by uranium mining, nuclear tests, uranium tailings pools, isotope production, and crop breeding cause radioactive pollution to the environment, and enter into the environment through diffusion and migration. The soil ecological environment has various effects on human health. Radioactive pollutants make the soil radioactive level higher than the natural background value, and produce α, β, γ rays through decay to penetrate human tissues and damage cells. Radioactive pollution is difficult to detect but easy to accumulate in organisms, and enters the human body through bioaccumulation, eventually harming Human health and even the health of the next generation are affected by genetics, so we must pay attention to the remediation of radioactively contaminated soil, and it is of great significance to use reasonable remediation technology to remediate radioactively contaminated soil.

2. Sources and hazards of soil radioactive contamination

Soil is an important material environment for plants to survive and an important medium for environmental transfer of radioactive pollutants. The radioactive pollutants from the mining of nuclear materials mainly exist in the soil for a long time in the form of 90Sr and other radioactive elements. Soil radioactive pollution mainly comes from contaminated fallout, which is polluted to the soil through rainwater washing and surface runoff [1]. It is difficult for the soil ecosystem to be eliminated by radioactive element pollution. Soil radioactive element contamination entering the food chain will cause various diseases in animals, and even endanger life. Soil radioactive pollution poses a huge threat to the ecological environment and social and economic development. Restoration technology has important practical significance.

2.1 Sources and characteristics of soil radioactive contamination

Radioactive pollution is a phenomenon in which the discharge of radioactive substances in production changes the environmental radiation level and destroys the ecological environment. The extensive use of radionuclides by humans has caused potential pollution risks to the soil environment. Nuclear raw material mining and nuclear energy production are the main reasons for the increase in the concentration of radioactive substances in the soil. [2-3]. Soil radioactive pollution sources are divided into natural and man-made radioactive sources, the main sources are uranium mining, nuclear energy production and nuclear accidents. Common radioactive pollutants in soil include 238U, 210Po, 89Sr, etc. The radioactive pollution in soil is characterized by the fact that most nuclides are more toxic than common chemical poisons, radioactivity cannot be directly detected by human sensory organs, and radionuclides are variable, gaseous radionuclides can be transformed into solid daughter deposits through respiration.

The natural radioactivity of the soil refers to the radioactivity existing in the soil, and the primary radioactivity refers to the background radioactivity existing in the soil during the formation of the earth. There are at least 22 non-serial primary radionuclides with low isotopic abundance in the soil, the most important ones for humans are 40K and 87Rb. Cosmogenic radioactivity is the generation of natural radionuclides in the atmosphere that fall to the surface to produce radioactivity. The natural radioactivity of the soil is basically constant to the irradiation of human beings, and the artificial radioactivity of the soil is the additional radioactivity caused by human activities, mainly including the radioactivity produced by nuclear experiments, nuclear power plant related activities and nuclear accidents. Atmospheric tests of nuclear weapons caused a large amount of radionuclides to be released into the air, and the radionuclides fell to the surface with the atmospheric circulation [4-5]. Nuclear power plant accidents released radionuclides and deposited in the soil, which is an important source of radioactive pollution. The Chernobyl nuclear accident released 1.2×107 TBq of radioactivity, and the Fukushima nuclear accident caused a large area of soil radioactive pollution. Uranium mining, processing of uranium-containing raw materials, discharge of three wastes, disposal of spent fuel and other nuclear power plant-related processes generate radioactivity. Due to the strict safety shielding measures adopted by nuclear power plants, the release of radionuclides produced by nuclear power plants to the external environment is not large.

2.2 Harm of soil radioactive contamination

Human production and living activities produce substances with radioactive hazards, which are not conducive to the harmonious development of the ecological environment. Soil is the foundation of biological growth and the medium for the transmission of radioactive pollutants. The appearance of man-made radioactive substances changes the state of radioactive pollutants in soil [5-7]. The hazards of soil radioactive pollution are directly reflected in the environmental and ecological effects. Radioactive substances such as 137Cs enter the human body and accumulate locally to induce cancer. Long-term low-dose soil radioactive element radiation causes species variation and endangers food safety, reduces soil fertilizer efficiency and the purification function of toxic substances, and plutonium-210 inhalation will cause irreversible radioactive damage to the human body. The hazards of soil radioactive pollution include affecting the soil ecosystem and causing harm to animals, plants and human health.

Radionuclides enter the soil and enter the human body through the biological chain. The alkali group elements and some non-metallic elements where Cs are located are radionuclides that enter the human body from the digestive tract, and their absorption rate is relatively high. Radionuclides have different distribution and metabolism characteristics after being absorbed by the human body. 131I has a short half-life and is easy to concentrate in the thyroid gland. Radioactive Sr and Cs are the most concerned. 90Sr and 137Cs are common long-lived artificial radionuclides. 137Cs is an important part of fission products. The radioactive Cs in the human body is mainly caused by the release of radioactive Cs into the environment by nuclear tests and nuclear fuel reprocessing industries [8-9]. Cs can be rapidly absorbed in the human gastrointestinal tract, and it is evenly distributed in the human body, mainly in the muscle and soft tissue. Radioactive Cs is a moderately toxic nuclide, and its irradiation can cause soft tissue tumors. Radioactive pollution endangers the safety and stability of the soil ecosystem. The ecological effects of long-term low-dose radiation include increasing the specific activity of radionuclides in agricultural products; affecting the survival and population structure of soil microorganisms; radionuclides in the soil will participate in the water-air cycle to pollute water bodies and atmosphere. In the soil environment, species in the same community form a complex relationship of mutual influence through evolution. Different species have differences in radiation sensitivity. The response of a population to environmental radiation stress is indirectly affected by the radiation response of other populations.

3. Soil radioactive pollution remediation technology

The development and utilization of nuclear energy promotes the development of society and economy, and the development and utilization of nuclear technology by humans produces radioactive pollution to the environment, posing a potential threat to the living environment and life and health [10]. Atmospheric nuclear tests cause radioactive substances to settle and pollute the soil, and the discharge of radioactive waste from the mining and refining of nuclear fuel in the development of the nuclear industry pollutes the soil environment. It is very urgent to control soil radioactive pollution. There are great differences in the ways of radioactive soil pollution. Nuclide decay produces heavy ions that penetrate human tissues and damage cells. At present, a variety of remediation methods are used for soil radioactive contamination, which are mainly divided into traditional remediation and biological remediation methods.

3.1 Traditional remediation methods for soil radioactive contamination

Traditional remediation methods for soil radioactive contamination include physical remediation and chemical remediation. Soil radioactive contamination is usually caused by the contamination of the surface soil, so the physical remediation methods such as the guest soil method and the shovel method, which are mainly aimed at the treatment of surface contaminated soil, have certain applicability. The alien soil method is to cover the contaminated soil with non-radioactively contaminated soil, and cover the bottom layer of non-radioactively contaminated soil with the surface soil [11-12]. Part of the remediation of soil contaminated by the Fukushima nuclear accident in Japan uses deep plowing to treat soils with radioactive concentrations less than 500Bqkg-1. The foreign soil method is to shield the radionuclides in the contaminated soil through the foreign soil. Although it can prevent the radionuclides from entering the biological chain, the radionuclides diffuse into the foreign soil and transfer to the ground. The shoveling method is to remove radionuclides from contaminated soil by eradicating the surface soil. It can be eradicated after adding soil curing agent or in-situ vitrification treatment. It is often used first in severe pollution cases.

Chemical remediation methods for soil radioactive pollution include agricultural improvement and leaching. Agricultural improvement is a method to reduce the availability of soil radionuclides. For example, adding lime can increase the pH value of acidic soil and reduce the mobility of heavy metal elements. It is widely used in the treatment of heavy metal contaminated soil, and has the advantages of low cost and quick effect. The leaching method is a restoration method that collects radionuclides from the leaching solution to remove nuclides by applying a leaching agent to the soil. Its disadvantage is that the removal of radionuclides is not thorough enough, which may cause damage to the soil structure and cause secondary pollution to groundwater. Soil radioactive pollution electrochemical remediation method applies a direct current electric field to the contaminated soil, so that the radionuclides in the soil solution can be enriched and removed near the electrode. The electric remediation technology is currently in the laboratory research stage in my country, and certain pilot experiments have been carried out in the United States. The electric restoration technology does not need to excavate the soil, the operation is simple, and usually requires the addition of an enhancement solution. Water molecules will decompose during electrokinetic restoration, resulting in changes in soil pH. At the same time, the restoration efficiency has a strong dependence on soil texture. Before using electrokinetic restoration, it is necessary to fully investigate the soil properties. Electrodynamic repair technology combined with physical and chemical repair technology has been widely used. The heat treatment repair technology is to remove harmful components in the damaged waste by means of electric resistance, etc., and the repair efficiency of the heat treatment repair technology can reach more than 90%. Table 1 Key parameters of heat treatment repair technology.

Table 1. Key parameters of heat treatment repair technology

	Small polluted site	Large polluted site		
	Simple	Complex	Simple	Complex
Soil type	Silt, silty clay	Sand, gravel sand	Silt, silty clay	Sand, gravel sand
Hydraulic conductivity c/m	0.1	5.0	0.1	5.0
Polluted area m2	464	464	1393	1393
Pollution thickness m	4.572	4.572	4.572	4.572
Total Cost/USD	282755	341336	485745	626602

3.2 Soil radioactive contamination bioremediation technology

Bioremediation is a remediation method that uses natural biological activities to remove pollutants. At present, it mainly includes animal, plant and microbial remediation. The research on bioremediation of soil radioactive contamination mainly focuses on plant and microbial remediation. Since high radioactivity has a strong radiation effect on organisms, bioremediation is suitable for remediation of low radioactive contamination. It is a soil remediation method for uniform treatment by planting plants in polluted soil to absorb polluted nuclides in the soil. After the Chernobyl nuclear accident, soil restoration by planting sunflowers has achieved certain results. Soil radioactive contamination phytoremediation can be repaired only by planting plants in contaminated soil with proper management, and it is very environmentally friendly due to the use of the natural growth process of plants. The cost of phytoremediation is low, and it is considered as a green phytoremediation technology. Phytoremediation has attracted great attention in the field of soil radioactive contamination remediation.

The remediation of contaminated soil by macrofungi is called microbial remediation. Microbial remediation of radioactively polluted water is a good method. Since no microorganisms have been found that can completely metabolize radionuclides into harmless substances, the possibility of separate application of soil radioactively contaminated microbial remediation is currently small. Microbial remediation technology cannot fundamentally eliminate soil radioactive pollution. The combination of phytoremediation and microbial remediation has good prospects for soil remediation. Screening and cultivating microorganisms with strong tolerance to radionuclides can enhance the effect of phytoremediation. The synergistic remediation of soil radioactive plants and microorganisms is in the research stage. Mycorrhizal fungi form symbiotic mycorrhizas with plant roots. Mycorrhizal fungi have certain selectivity for host plants, and there may be cases where enriched plants cannot form mycorrhizas. There are some problems to be solved in the application of plants and microorganisms in the collaborative remediation of radioactively contaminated soil, such as competition between inoculated microorganisms and indigenous microorganisms. The principle of macrofungal remediation is similar to that of phytoremediation. Because it is more complicated to artificially cultivate fungi in a large area of soil, there are relatively few studies on macrofungal remediation. According to the radionuclides such as 137Cs, 238U and 40K in the soil at home and abroad, it has been found that broad-leaved bean and eucalyptus seedlings are plants with high accumulation of 90Sr; soybean and sunflower are plants with high accumulation of U.

4. Soil radioactive pollution remediation and control methods

Soil is the basic element of the human environment. Soil is in the transition zone between the atmosphere, lithosphere and biosphere. Soil pollution is the discharge of harmful substances from production activities into the soil, endangering environmental safety and human health. There are many kinds of soil pollutants, mainly including biochemical and radioactive pollution. Radioactive pollutants emit and settle in the atmosphere, some directly enter the soil and endanger the stability of the ecosystem, and enter the human body through the food chain to threaten human health. The traditional remediation methods of radionuclide-contaminated soil damage the environment, and the prevention and control of soil radioactive pollution should be determined according to the actual situation. Currently adopted methods include direct treatment and indirect control methods.

4.1 Selection of remediation technology for soil radioactive contamination

The indirect prevention and control of soil radioactive pollution is to decontaminate water sources and vehicles, and the decontamination mechanisms include mechanical physical methods, electrochemical methods, etc. Mechanical and physical methods currently include vacuuming, wiping, and high-pressure spraying; chemical methods use chemical cleaning agents to dissolve radioactive dirt on the surface of loose glass equipment, and the chemicals used include inorganic acids, redox, etc. The electrochemical method removes the components as anodes, and the polluted surface layer is uniformly dissolved under the action of electric current. The electrochemical method has high decontamination efficiency and less secondary waste. The combined physical and chemical decontamination method uses the dissolution of chemical agents and mechanical force to remove radioactive pollutants, and adds chemical agents to high-pressure jet water. At present, the direct control methods of soil radioactive pollution include physical landfill method and natural decay reduction method. The chemical treatment method is fast and effective in the treatment of small-scale radioactively contaminated soil. The cost of chemical treatment is high and cannot be used alone for the treatment of large-scale radioactive soil pollution cases. The cost of chemical treatment for large-scale radioactive contaminated soil treatment in nuclear test site areas is high. The soil replacement method is also an effective treatment method for radioactively contaminated soil. It is to cover the contaminated site with a clean soil layer to reduce its further pollution to the surrounding environment. The physical landfill method can effectively isolate the contaminated soil from the ecosystem and reduce its impact on the environment.

Soil radioactive pollution remediation and treatment need to choose the appropriate treatment method according to the actual situation. Large-scale radioactive pollution refers to nuclear explosion test sites, etc. With the gradual opening of my country's nuclear weapon test explosion sites to the outside world, the problem of radionuclide-contaminated sites has begun to emerge. At present, the most commonly used methods for soil radioactive pollution control are physical and chemical methods, microbial removal methods, etc., but the treatment costs are high and it is easy to cause secondary pollution. The physical landfill method is suitable for large-scale pollution control in the nuclear test site area. The advantage of the physical landfill method is that the technical principle is simple and the construction period is short, and it is suitable for high-concentration concentrated areas and surface pollution areas. A large area of radioactively contaminated soil is an experimentally polluted area of the atmosphere. Phytoremediation of large-area and low-concentration contaminated sites has certain advantages. It mainly uses roots to absorb water and transform radionuclides in the body. Phytoremediation is suitable for the control of low-dose radioactive pollution. Phytoremediation technology has the advantage of low cost, and it is currently moving from laboratory cultivation to field experiments. The research on phytoremediation in the atmospheric nuclear test site can solve the problems encountered in large-scale application, but environmental factors such as drought in the nuclear test site that affect plant growth are problems that need to be solved urgently in phytoremediation.

4.2 Development of soil radioactive contamination control technology

With the development of the nuclear industry, the problem of soil radioactive pollution has aroused widespread concern in the society. At present, the physical, chemical, and biological remediation methods that have been studied more for the treatment of radioactive pollution cannot be used to solve the problem of radioactive pollution caused by sudden nuclear accidents [13-15], on-site vitrification technology is an ideal treatment method for α-contaminated soil in nuclear test sites. Microwave sintering utilizes the special wave band of microwave to couple with the fine structure of materials to generate heat, with fast heating speed and high energy utilization rate, which makes it have great advantages in increasing material density, energy saving and environmental protection. Compared with the traditional solidification method, microwave sintering technology has strong advantages in the sintering of soil vitrified body, such as fast heating rate, short sintering time, low sintering temperature, superior performance of solidified body, simultaneous solidification of multiple polluting nuclides, etc., especially in small Areas with serious pollution and complex pollution conditions have unique advantages in emergencies such as nuclear accidents that require rapid and efficient treatment.

Soil pollution remediation decision-making is oriented towards remediation based on pollution risk assessment, from a single remediation technology to multi-technical joint remediation; in terms of application, it has developed from remediation of heavy metal-contaminated soil and persistent organic compound-contaminated soil to combined remediation technology of mixed contaminated soil. The development trend of soil radioactive pollution remediation technology is from ex-situ to in-situ remediation technology, to green and environment-friendly soil bioremediation technology, and to soil remediation technology based on environmental functional remediation materials. The research and development of soil pollution prevention and restoration technology in my country needs to formulate soil pollution prevention and restoration action plans according to the characteristics of different domestic soil pollution and the current situation of national economic and social development, and vigorously support the research on soil pollution prevention and restoration technology. The characteristics of pollutants in soil are difficult to move and dilute Site-specific restoration techniques need to be developed.

5. Conclusion

Soil radioactive pollution is characterized by a wide range of hazards and complex types of nuclides, such as 137Cs, 90Sr, and 238U, 239Pu, 240U, 131I, etc.; environmental factors such as mineral content and organic matter composition in soil affect radionuclides. The rate of migration of nutrients in soil. Animals and plants are affected by radiation due to soil radioactive contamination. The remediation technologies for radioactively contaminated soil include physical, chemical, biological remediation and mixed remediation technologies. The radioactive level can be reduced by more than 99% through remediation of radioactively contaminated soil. The cost of remediation technology and environmental factors affect the remediation effect, and choosing the best remediation technology can reduce the soil radioactivity level to an environmentally acceptable level. Physicochemical methods cannot deal with low-radioactive nuclide pollution in soil. Phytoremediation technology is an effective method with low cost, and the ability of microorganisms to overwhelm is fast. Microorganisms have great advantages in controlling soil radioactive contamination, and microbial remediation has great potential. With the development of biotechnology, more attention will be paid to bioremediation technology.

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