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Phytoremediation of Radioactive Metals

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Abstract : **Humans have been constantly exploiting nature in the name of development, since the inception of Earth. Industrial growth, scientific experiments, and destruction of habitats are the leading causes of degradation of ecosystem and deterioration of soil quality. Radioactive matter, industrial effluents, domestic refuse and many other forms of waste is constantly being discharged into the soil and water, and thus jeopardizing the environment. This paper explores the potential of a novel technique, phytoremediation, to resolve the issues of waste management, especially radioactive waste. This technique makes use of green plants to clean up and treat radioactive contaminated sites. Radionuclides such as U-238, Th-232, Ra-226 and Am-241 are extremely dangerous and exposure to them can pose serious health risks. The radiation from these radionuclides can penetrate the cells and tissues of human body and mutate the genetic material, leading to malignant forms of cancers and birth defects. Plants have remarkable features- both anatomical and morphological- that help them suck the contaminants out from the source and accumulate them in their stalks, leaves, and flowers. Use of plants to clean a radioactive site is a cheaper, environmentally friendlier and a more effective way as compared to the existing techniques which are tedious and expensive. The efficiency to phytoremediate a contaminated site depends on many critical factors, such as biochemistry of plant, environmental conditions (temperature, pH, and humidity), nature of plants used, the area of contaminated site, and many other mechanisms which are yet to be fully understood. This review evaluates some of the research that has been done on phytoremediation of radioactive metals, explains the general mechanisms of how plants and mushrooms accumulate radionuclides in their system and discusses the advantages and disadvantages of the technique.**

1. INTRODUCTION

Radioactive pollution, like any other pollution is something that is unwanted and exploits the ecosystem. Radiation from the radionuclides can mutate the DNA, cause abnormalities, birth defects and cancer [1]. Radiation stays in the environment for billions of years and diminishes very slowly. The leading causes of radioactive pollution are human activities involving production of nuclear weapons, mining of radioactive ore, waste from the medical surgeries and treatments, and production of nuclear energy. Sardinia, a beautiful small island in Italy used to be a nuclear bomb and weapon testing facility for US military. Years of constant bomb experiments and nuclear weapons being fired has exposed Sardinia to huge amounts of radiation and is now causing birth defects in the people of Sardinia [2].

Over the past years, several methods have been used to deal with the radioactive waste from contaminated sites. However these methods are costly and inefficient in their performance. The chemical methods generate large volumes of sludge and increase the cost of maintenance. Thermal methods are technically difficult and adversely affect the valuable component of soil by degrading it [3]. Two major methods that are conventionally used to remediate the radioactive contaminated sites are: [4]

- ***Ex-situ methods:*** this requires the removal of contaminated soil for treatment on or off site and then returning the treated soil to the site. The example of these methods are; vitrification, solidification, immobilisation, soil leaching, heap leaching, sea disposal, ground disposal, incineration or destruction and etc.
- ***In-situ methods:*** in this method excavation of contaminated site is not needed. The examples are; bottom sealing, de-chlorination, electromagnetic heating and etc.

Phytoremediation is a novel solution that effectively and affordably extracts out the contaminants from the site and cleans up the wasteland [5]. Phytoremediation makes use of green plants to clean up and treat radioactive contaminated sites such as soil, water and sediments. Plants have remarkable features that help them absorb contaminants into their systems with the help of their uptake capabilities such as translocation, bioaccumulation and contaminant degradation.

Many plant species have been successful in efficiently accumulating the radionuclides in their stems and leaves and hence remediating the contaminated site [3]. This review evaluates some of the research that has been done on phytoremediation of radioactive metals and aims to discuss the potential of phytoremediation, highlight the general mechanisms of plant uptake, give a brief overview on radioactive metals (especially: Uranium-238, Thorium-232, Radium-226) uptake by plants, and address the advantages and limitations associated with this method.

2. RADIONUCLIDES: SOURCES, HALF-LIFE, HEALTH AND ENVIRONMENTAL EFFECTS

A radionuclide can be largely defined as any unstable nucleus that possesses additional energy, which can be imparted to a newly created radiation particle. A radionuclide constantly undergoes radioactive decay in form of sub-atomic particles such as alpha-particle and beta-particle or in form of gamma rays [4].

A confirmed count of total existing radionuclides is unquantifiable because radionuclides generally have half-lives of more than thousands of years and their decay is difficult to measure experimentally. Radiation consists of radionuclide undergoing decay in form of alpha, beta, gamma particles that travel at very fast speeds and penetrate deep through the human body and into the cells and tissues [5]. Once inside the body, the radiation from these radionuclide can stay in cells for years and get accumulated causing serious health risks. The damage is in form of changes in the genetic makeup leading to cancer and also causing birth defects in later generations of offspring. The sources, effects and half-lives of various radionuclides (see Table 1).

2.1 Uranium-238: Nearly 99.9% of natural Uranium is in form of Uranium 238, and it is the most common type of isotope of Uranium. The half-life of Uranium 238 is 4.468 billion years. The health effects associated with Uranium 238 are cancer, birth defects and mutation in the genetic makeup of the body [6].

2.2 Thorium-232: It is the most stable and longest lived isotope which accounts for all the naturally occurring Thorium. The half-life of Th-232 is 14.05 billion years which is longer than the age of Earth. Thorium has colouring properties that has made it useful in ceramic glazes, and is an alloying agent in certain metals used in the aerospace industry. If thorium is inhaled as dust it stays in the lungs and enters the bloodstream causing cancer. [7].

2.3 Radium-226: Radium is a naturally occurring radioactive element. The most common isotope of Radium is Ra-226. It was discovered in the Pitchblende ore by Madame Curie. Radium-226, is an alpha emitter, with subsequent gamma radiations, and has a half-life of about 1600 years. A long-term exposure to radium increases the risk of developing several diseases such as lymphoma, bone cancer, and diseases that affect the formation of blood, such as leukaemia and aplastic anaemia [8].

Radionuclide	Uses	Effects	Half Life
Uranium (238)	Bombs, Weapons, Nuclear fuel	Mutations, cancer, birth defects	4.5 billion years
Thorium (232)	Alloying Agent, Nuclear fuel	Carcinogenic	14 billion years
Radium (226)	Luminous paints, dials of watches	Lymphoma, leukaemia, bone cancer	1601 years

Table 1: Comparison of properties of Radionuclide

3. PHYTOREMEDIATION- A NOVEL TECHNOLOGY

The roots of the term “phytoremediation” can be traced back to Greek and Latin texts. The term can be bifurcated as: *phyto*(plant) which comes from Greek roots and *remedium*(to correct or remove an evil) from Latin [9]. But phytoremediation simply means to clean a site contaminated with heavy metals, radionuclides, toxic chemicals or any harmful contaminant from soil, sludge, water, groundwater, wastewater and etc. depending on how well a plant survives in that medium. Remediation using various plants relies on the plants ability to suck the contaminant out of the soil through their roots and up into their stems, leaves and flowers. Some plants are particularly adroit at leeching heavy metals while some are adept in accumulating radionuclide from soil and water [10]. There are different methods by which a plant can use its anatomical and morphological features and return a site free from the contaminants(see Table 2) [11, 12].

Table 2: Uptake Mechanisms of Phytoremediation

Phytotechnology	Mechanism	Pollutants	Plants
Phytostabilization	binding contaminants	Inorganics: As, Cd, Cu	Hemp, *Brassica juncea*

Phytoextraction	Hyperaccumulation	radionuclides, Metals like Ni and Zn	*Brassica juncea*, *Helianthus annus*
Phytovolatilization	Transpiration through leaves	Organics: TCE, Hg, Se	Poplars, Alfalfa
Rhizofiltration	Rhizosphere accumulation	Radionuclides, organic solvents.	Sunflower, Spinach

4. EFFECTIVENESS OF RADIONUCLIDE UPTAKE BY PLANTS

Several studies have described the performance of radioactive metals uptake by plants. It is suggested that phytoremediation technology is a substitute to treat radionuclide contaminated soil which will be more admitted in order to remediate the environment [13].

Activity concentrations in soil and in plants from contaminated (see Table 3). The highest activity concentration of ^{226}Ra (35 times higher compared to the control site) was found in J. Effuses. Soil-to-plant transfer factors increase in the following order: C. palustris < M. arundinacea < J. Effuses. Similarly low content of U in soil resulted in low activity concentrations of ^{238}U in all three plant species. Soil-to-plant transfer factors increase in the following order: M. arundinacea = C. palustris < J. Effuses. The lowest activity concentration of ^{230}Th was found in M. arundinacea which is probably related to low thorium mobility in soil. Soil-to-plant transfer factors increase in the following order: M. arundinacea < J. effusus < C. Palustris [14] [15].

Uranium uptake in sandy soil by Acacia sp. showed a highly considerable difference in the ability of the Acacia seedlings (*Acacia albida*and *Acacia nilotica*) to absorb different concentrations of uranium. *Acacia nilotica*registered the highest absorption of uranium in dry weight roots in different concentrations (202, 339, 1175, and 1477 µg.g-1) respectively of the concentrations 50, 100, 200, and500 mgkg-1). Compared to the root of *Acacia albida*, the absorption of uranium was (60, 54, 133, and 526 µg.g-1) in the concentrations of the same samples. It can be concluded that the percentage of uranium *A. albida*accumulated in roots ranged between 50-66% and in shoots between 33-50%, while in *Acacia nilotica*the percentage was different and ranged between 63.5-73% in roots and 28-36.5 % in shoots (see Table 4). This explains that *A. nilotica*could accumulate higher uranium rates in its roots, up to 2/3 of the whole uranium uptake from soil, but in *Acacia albida*only about ½ [16].

Radionuclide	Concentration in Contaminated Soil (Bq kg $^{-1}$)	*Calthapalustris*	*Juncuseffusus*	*Moliniaarundinacea*
^{238}U	536 ± 270	0.4 ± 0.1	2.4 ± 0.2	1.2 ± 0.2
^{226}Ra	446 ± 282	3.2 ± 0.3	22.0 ± 2.2	16.3 ± 1.2
^{230}Th	1055 ± 789	1.0 ± 0.1	1.2 ± 0.1	0.45 ± 0.08

Table 3: Activity concentration in soil and plant

Uranium Concentration mg.kg-1	*Acacia albida*		*Acacia nilotica*	
%	U in Root	U in Shoot %	U in Root %	U in Shoot %
100	66.19	33.81	66.95	33.05
500	51.03	48.97	71.93	28.67
1000	55.71	44.29	72.71	27.28
2000	51.54	48.46	63.48	36.52

Table 4: % ^{238}U concentration in soil, plants

5. FACTORS AFFECTING THE UPTAKE MECHANISMS

There are several factors which can affect the uptake mechanisms of radioactive metals. These are:

1.1. *Plant Species*: Plant species with superior remediation ability are screened and selected. The success of phytoremediation technique depends upon the ability of the plant to accumulate [17].

1.2. *Properties of Medium*: Factors such as temperature, moisture content, pH, organic matter affect the rate of uptake by plants [18].

1.3. *The Root Zone*: It can absorb contaminants and store or metabolize it inside plant tissue. An increase in root diameter and reduced root elongation as a response to less permeability of the dried soil [19].

1.4. *Addition of Chelating Agents*: The increase of the uptake by crops can be influenced by increasing the bioavailability of radionuclides through addition of biodegradable physiochemical factors such as chelating agents, and micronutrients [20].

6. ADVANTAGES

Phytoremediation technique may be more acceptable than other remediation techniques which involve physical and chemical processes. Advantages of phytoremdiation are its effectiveness in contaminant reduction which leads to reusability of the land, low cost, covers wide variety of contaminants and is an environment friendly method [21].

Phytoremediation is low cost option and inexpensive approach for remediating contaminated media, particularly suited for large sites that have low levels of contamination. It is inexpensive when compared to conventional physiochemical techniques (see Figure 1). Another advantage of phytoremediation is the generation of radioactive metal rich plant residue [22].

7. LIMITATIONS

On the other hand, there are many limitations to this technique such as it being a very time consuming and cumbersome technique, the amount of biomass produced, the age of plant, impact of contaminants on vegetation. (See Figure 2).

It is also limited by growth rate of plants. More time may be required when compared to conventional clean-up techniques [23]. Other matter of concern is excavation and disposal or incineration of the plants used takes a lot of time to accomplish, while phytoextraction and degradation may take several years. Also, success of phytoremediation may be limited by factors such as growing time, climate, root depth, soil quality and level of contamination [24].

8. CONCLUSIONS

Phytoremediation is fast developing field and radioactive metals uptake by plants seems to be prosperous way to remediate contaminated soil.

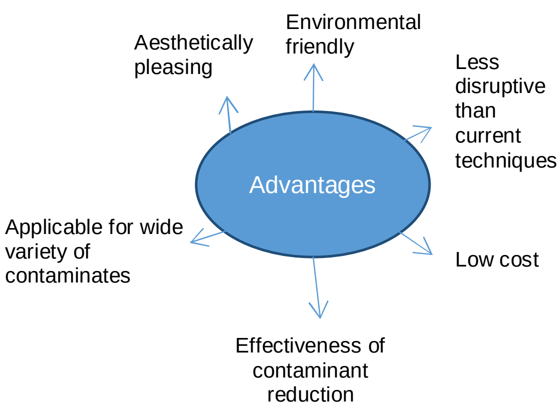

Figure 1: Advantages of Phytoremediation

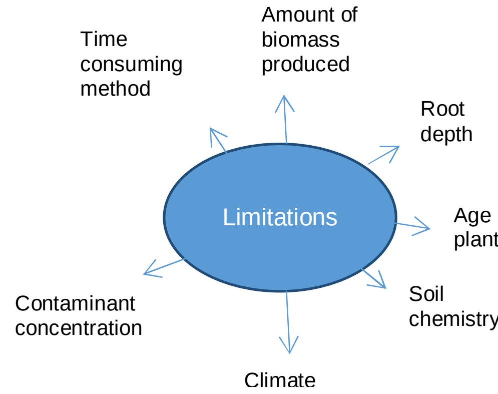

Figure 2: Limitations of Phytoremediation

This sustainable and inexpensive process is fast emerging as viable alternative to convention remediation techniques. Several factors must be considered in order to accomplish a high performance of remediation result. However, several methods of plant disposal have been described but data regarding these methods are scarce. Composting and Compaction can be treated as a pre-treatment step for volume reduction. Prolong research needs to be conducted to minimize the limitations in order to apply this technique effectively.

9. REFERENCES

[1] Messenger, George C., and Milton S. Ash. "The effects of radiation on electronic systems." 1986.

[2] A. Gaur and A. Adholeya, "Prospects of arbuscular mycorrhizal fungi in phytoremediation of heavymetal contaminated soils," *Current Science*, 86. 4, pp. 528–534, 2004.

[3] Pavel, Lucian Vasile, and Maria Gavrilescu. "Overview of ex situ decontamination techniques for soil cleanup." *Environmental engineering and management journal 7*.6, pp 815-834, 2008.

[4] Ghosh, M., and S. P. Singh. "A review on phyto remediation of heavy metals and utilization of it's by products." *Asian J Energy Environ* 64.18, 2005.

[5] Salt, David E., et al. "Phytoremediation: a novel strategy for the removal of toxic metals from the environment using plants." *Nature Biotechnology* 13.5, pp 468-474, 1995.

[6] Jadia, Chhotu D and Madhusudan H. Fulekar. "Phytoremediation: the application of vermicompost to remove zinc, cadmium, copper, nickel and lead by sunflower plant." *Environmental Engineering and Management Journal* 7..5, pp 547-558, 2008.

[7] Erdtmann, Gerhard, and Werner Soyka, "The gamma rays of the radionuclides," 1979.

[8] Spinks, John William Tranter, and Robert James Woods, "An introduction to radiation chemistry," 1990.

[9] Molinari, J., and W. J. Snodgrass, "The chemistry and radiochemistry of radium and the other elements of the uranium and thorium natural decay series," *The environmental behaviour of radium*, 1990.

[10] A. Erakhrumen and A. Agbontalor, "Review Phytoremediation: an environmentally sound technology for pollution prevention, control and remediation in developing countries," Educational Research and Review, 2. 7, pp. 151–156, 2007.

[11] U. S. Environmental Protection Agency, "Introduction to Phytoremediation," National Risk Management Research Laboratory, EPA/600/R-99/107, 2000, http://www.clu-in.org/download/remed/introphyto.pdf.

[12] Berti, William R., and Scott D. Cunningham, "Phytostabilization of metals,"*Phytoremediation of toxic metals: using plants to clean-up the environment. New York, John Wiley & Sons, Inc*, pp71-88, 2008.

[13] Kumar, PBA Nanda, et al. "Phytoextraction: the use of plants to remove heavy metals from soils." *Environmental Science & Technology*, 29.5, pp 1232-1238, 1995.

[14] BeibyVoijantTangahu, SitiRozaimah Sheikh Abdullah, Hassan Basri, MushrifahIdris, NurinaAnuar and Muhammad Mukhlisin, "A Review on Heavy Metals (As, Pb and Hg) Uptake by Plants through Phytoremediation" *International Journal of Chemical Engineering*, Article ID 939161, doi:10.1155/2011/939161, 2011.

[15] Černe, Borut Smodiš, Marko Štrok and Radojko Jaćimović, "Accumulation of ^{226}Ra, ^{238}U and ^{230}Th by wetland plants in a vicinity of U-mill tailings at Žirovskivrh (Slovenia)," *Journal of Radioanalytical and Nuclear Chemistry*, 2010.

[16] Marko Černe, BorutSmodiš, "Estimation of Absorbed Dose Rates to Wetland Plants From the Vicinity of the Former Uranium Mine at ŽirovskiVrh, Slovenia Using ERICA Tool," in proceesdings of *International Conference Nuclear Energy for New Europe*, 2010.

[17] Riyad Abdullah Fathi, Douglas L. Godbold, Hana S. Al-Salih and Davey Jones, "Potential of Phytoremediation to clean up uranium-contaminated soil with Acacia species ," *Journal of Environment and Earth Science*, 4, pp.4, 2014.

[18] L. Rodriguez, F. J. Lopez-Bellido, A. Carnicer, F. Recreo, A.Tallos, and J. M.Monteagudo, "Mercury recovery from soils by phytoremediation," in *Book of Environmental Chemistry*, pp.197–204, Springer, Berlin, Germany, 2005.

[19] Y-G. Zhu and E. Smolders, "Plant uptake of radiocaesium: a review of mechanisms, regulation and application,"*Journal of Experimental Botany*, 51, pp. 351, 2000.

[20] Ehlken Sabine, and Gerald Kirchner, "Environmental processes affecting plant root uptake of radioactive trace elements and variability of transfer factor data," *Journal of Environmental Radioactivity*, 58, pp. 97–112, 2002.

[21] R. Rakhshaee, M. Giahi, and A. Pourahmad, "Studying effect of cell wall's carboxyl-carboxylate ratio change of *Lemna minor* to remove heavy metals from aqueous solution," *Journal of Hazardous Materials*, 163. 1, pp. 165–173, 2009.

[22] A. Erakhrumen and A. Agbontalor, "Review Phytoremediation: an environmentally sound technology for pollution prevention, control and remediation in developing countries," *Educational Research and Review*, 2. 7, pp. 151–156, 2007.

[23] W. J. S. Mwegoha, "The use of phytoremediation technology for abatement soil and groundwater pollution in Tanzania: opportunities and challenges," *Journal of Sustainable Developmentin Africa*, 10. 1, pp. 140–156, 2008.

[24] A. L. Salido, K. L. Hasty, J. M. Lim, and D. J. Butcher, "Phytoremediation of arsenic and lead in contaminated soil using Chinese Brake ferns (*Pterisvittata*) and Indian mustard (*Brassica juncea*)," *International Journal of Phytoremediation*, 5. 2, pp. 89–103, 2003.