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MICROBIAL BIOREMEDIATION OF RADIONUCLIDES

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ABSTRACT

The extent of the pollution, produced by the rapid release of radionuclides into environment, has prompted public and scientific concern in last few decades. Their removal is a challenge for scientists as, like other contaminants, they cannot be purified and reintroduced into the environment in a short time period. The perceived high environmental and economic costs of invasive physico-chemical degradation, technologies are emerging for bioremediation of nuclear waste. The basis of these approaches is the efficient usage of radioactive elements and fission products via natural nutrition cycles. Sequestrants, siderophores, cytochromes, organic acids, and hydrogenase complexes have all been shown to be effective in the degradation pathways. Recent advances have been made in comprehending microbial colonisation. Several discoveries are on record for understanding the metal-microbial interactions in radioactive habitats as well as the biological foundation of radioactive waste conversion in these situations. In-depth investigations have shown the positive results in this domain. This review presents a quick overview of nuclear energy and waste creation, followed by applications, health impacts, nuclear waste management, and the significance of microbial radioactive waste breakdown.

Keywords: environment, nuclear waste, radionuclides, health, microbial degradation.

INTRODUCTION

Researchers genuinely began to make advancements in atomic structure in the late eighteenth century. While Dmitri Mendeleev came up with the periodic systems of elements in 1869, Henry Becquerel introduced the term radioactivity to the Academy of Sciences in Paris after discovering the radioactive characteristics of uranium. Wilhelm Roentgen accidentally discovered the property of X-rays in 1895 that led to a number of discoveries and the prospect of utilising X-rays in the field of medicine. Following investigations on the properties of uranium, Marie Curie proposed the word "radioactivity" in 1898. New hazards accompany new discoveries, and the debt of discovery was fully paid when a researcher died while working inadvertently (Rodriguez-Achach, 2017).

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On April 26 (1986), the year was considered as the Soviet Union government's failure to avoid the Chernobyl nuclear accident. Following the incident, a large area terrestrial land in Belarus, Ukraine and Russia were found contaminated. The "exclusion zone," which stretches over 30 kilometers around the facility, has become largely uninhabitable (Cardis and Hatch, 2011). Furthermore, the nuclear tragedy in Fukushima Daiichi around 2011, strongly approached the International Scientific Community to seek a firm treatment for this incidence. It was also realized that the earlier basic physicochemical approaches were ineffective and expensive as well. The United States spent trillions of dollars on nuclear waste refining and containment, whereas the United Kingdom spent about 50 million pounds. Consequently, George M. Robinson, a petroleum engineer for Saint Maria, California, who was working on bioremediation at this time, came up with some promising results and received the attention of the researchers. Building of microbial consortia to improve degrading efficiency was proposed at this time (Prakash et al., 2013; Rodriguez-Achach, 2017).

THE CONCEPT OF BIOREMEDIATION

George M. Robinson created and invented the phrase bioremediation in the early 1960s. The first large-scale application of bioremediation occurred in 1972, when it was executed to clean up an oil spill by Sun Oil Pipeline Company in Ambler, Pennsylvania. Therefore, nuclear bioremediation may be considered as a technique that uses natural or genetically modified biological agents, e.g., microorganisms and plants, to catalyse the reaction of radioactive materials or radionuclides to break them down into simpler forms, thereby decreasing their half-life period or stabilising the unstable nuclear atoms (Vandana et al., 2021).

Depending on the atomic structure of the radionuclide, the microorganisms utilised in the experiments are either electron gainers or electron losers. These procedures can be in-situ or ex-situ, based on a variety of parameters, including site circumstances, the kind and quantity of pollutants, and most significantly, the cost. Maintenance of on-site systems and the difficulties of appropriately observing and regulating the subsurface of polluted regions in in-situ bioremediation process were the major limitations in their implementation (Azubuike et al., 2016). On the other side, due to the additional cost of excavation, ex-situ operations were considered relatively expensive in comparison to the in-situ approaches. Selection of a suitable bioremediation technology that efficiently can reduce the concentration of pollutants to an permissible condition is therefore critical for success of a bioremediation project (Azubuike et al., 2016; Vandana et al., 2021).

HEALTH CONCERNS OWING TO RADIONUCLIDES

The influence of radioactivity is likely to be based on the quantity of radiation received in a given location, resulting in statistical variance in radio-ecological impact assessment. A lethal dose of radiation is around 400 REM (Roentgen Equivalent Man)—the amount of radiation absorbed by the body in 60 min of exposure to a field of 400 Roentgen (Prakash et al., 2013). Although reports on the 25-year-long Chernobyl accident research led to a greater understanding, it was without the complete knowledge on the long-term health problems. It was realized that the health data can only be stored up once the victims of the nuclear calamity had fulfilled their normal life span. The uranium fuel and graphite from reactor 4 alone released 20,000 Roentgen/h, much above the lethal dosage. The core surrounding region emitted 30,000 Roentgen/h (Cardis and Hatch, 2011; Rodriguez-Achach, 2017). It only took 48 sec for a deadly amount to be absorbed, which is why the

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initial responders, such as the fire fighters and the Reserve Ukrainian army, perished within the first few weeks. Exposure to this quantity of radiation might lead to death within a few weeks or have long-term consequences on future generations (Cardis and Hatch, 2011). The common diseases in such conditions include growth reduction, leucopenia, burned tissues exposed to radiation, cancer (particularly leukaemia), DNA damage, chromosome aberrations, and reproductive deficiencies and mortality, leading to both lethality as well as reduced life span (Prakash et al., 2013).

MECHANISM OF RADIONUCLIDE BIOREMEDIATION

The radioactive resistance phenomenon of microorganisms emerged from the survivability of *Deinococcus radiodurans* cultured from a canned meat that was sterilized by giving high doses of X-rays in 1956 (Manobala et al., 2019). It is used by US Department of Energy (DOE) for radioactive waste degradation initiative. Many other microorganisms such as *Shewanella putrefaciens, S. putrefaciens, Desulfovibrio vulgaris, Escherichia coli, Desulfovibrio desulfuricans,* and *Rhodoferax ferrireducens, Geobacter sulphurreducens* have successfully been applied for biological reduction of radionuclides (Lloyd and Renshaw, 2005; Manobala et al., 2019). Microorganisms possess the capacity to affect radionuclide solubility through various methods (Fig.1), either directly through interactions with the biological system (enzymatic degradation) or indirectly by creating variations in the chemistry of the environment exposed to the microbial activity (Biosorption, bioaccumulation or biostimulation) (Prakash et al., 2013). The periplasm is known to play a key role in microbial reduction. Uranium (VI) is reduced to insoluble uranium (IV) by *Shewanella putrefaciens, Desulfovibrio vulgaris, Desulfovibrio desulfuricans,* and *Geobacter sulphurreducens* and requires periplasmic cytochrome (Lloyd and Renshaw, 2005; Prakash et al., 2013).

Wildung et al. (2000) studied the degradation of technetium (VII) to technetium (IV) by *S. putrefaciens*. The sulfur reducers *D. desulfuricans, Geobacter metallicreducens*, and *Escherichia coli* require the formation of hydrogenase complex present in their cellular compartments. Other radioactive actinides such as thorium, plutonium, neptunium and americium have been reported for degradation by *Rhodoferax ferrireducens* (Wildung et al., 2000; Kim et al., 2012).

Other reduction phenomena include indirect enzymatic reduction, which is typically done by sulfate-reducing and heterometallic bacteria through the secretory response of metabolites and breakdown products (Lloyd et al., 2003; Lloyd and Renshaw, 2005). The oxidation of these heterotrophic secretions' organic acids requires the reduction of iron or other metals and radionuclides to make insoluble compounds that can precipitate into oxide and hydroxide minerals. Hydrogen sulphide is produced by sulfate-reducing bacteria, which improves the solubility of contaminated radionuclides and facilitates biological alkalinization (Francis, 1998; Kim et al., 2012).

Specific chelators are produced by a variety of microorganisms, including indirect siderophores and sequestrants. These sequestrants serve a key function in complexing radionuclides and improving their solubility and bioavailability. *Microbacterium flavescens,* for example, develops in the presence of radioactive isotopes such as thorium, plutonium, americium, or uranium, creating organic acids and siderophores that facilitate radionuclide breakdown and mobility through soil

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(John et al., 2001). Siderophores on the bacterial surface appear to help these components and enter the cell as well. When cultivated in uranium and thorium-containing medium, *Pseudomonas aeruginosa* has been reported to chelate as well. Enterobactin siderophores have been shown to be particularly successful in dissolving plutonium actinide oxide citrate complex trials (Francis, 1998; Lloyd et al., 2003).

The development of genetically engineered (GE) microorganisms emerged as a breakthrough in the bioremediation research. These can be formed via certain procedures such as linking multiple protein constructions to membrane bound proteins that are tethered via metal-binding polypeptides (Valls et al., 2000); changing the transporter genes merTP (from *Serratia marcescens*), and nixA (from *Helicobacter pylori*), respectively. A transgenic strain of *E. coli* was cultured with enhanced sorption ability for U(VI) radionuclides (Beckwith et al., 2001) and cloning the *E. coli* gene (merA) in *D. radiodurans* which enables the utilisation of carbon and energy from degradation of toluene and mercury (Brim et al., 2000). GE microorganisms certainly have potential in bioremediation, however more experimental research needs to be performed to create environmentally acceptable cleanup methods.

CONCLUSION AND FUTURE PROSPECTS

The microbial bioremediation of radionuclides is critical to the development of new environmental strategies and technologies. Microbial mechanisms that are likely to impact the environmental behaviour of redox sensitive radionuclides are of considerable interest, while understanding on the underlying redox reactions is critical for the safe management of radioactive wastes. During the past century, advancement in the knowledge on the biogeochemical controls on important radionuclides have been made possible by using the tools available in various scientific disciplines. However, there is a significant gap between the knowledge of radionuclide-microbe interactions obtained in-vitro utilising bacterial cultures through well circumstances and detailed explanations of the underlying systems of key radionuclides in microbial communities. As a result, it is critical to comprehend the method by which bacteria remove radionuclides from polluted areas. Use of omics-based methodologies to discover the molecular basis in complex ecological processes will be critical in supporting the establishment of bioremediation programmes that can have a beneficial influence on environmental contamination.

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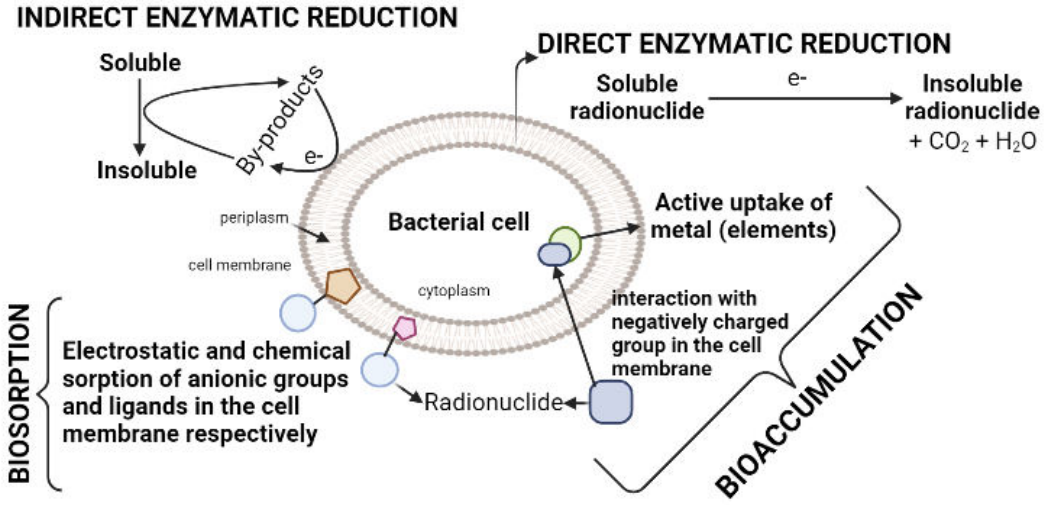

Fig.1. Various Mechanisms of Microbial Bioremediation