A REVIEW ON BIOREMEDIATION OF RADIOACTIVE WASTE USING POND ALGAE FOR SUSTAINABLE WASTE MANAGEMENT

Manish Kumar[1], Deepika Davuluri[1], Anand Sharma[2]

[1]*Department of Nuclear Science and Technology, Pandit Deendayal Energy University, Gandhinagar, Gujarat – 382007*
[2]*Mody University of Science and Technology, Sikar Rajasthan*
****Corresponding author: Manish Kumar***
manishkumar087@gmail.com

Abstract:

Emission free electricity generation source has become the trivial necessity for sustenance on planet Earth. Nuclear energy can fulfil this need balancing our thirst for energy with reduced waste generation. Even this least waste generated can emerge as a bliss taking heavy toll if left without proper management. Many processing employed conventionally for reprocessing over years. Biosorption of Nuclear waste is expected to bring a silver lining. This work outlines the techniques employed by researchers in this field reviewing the algae adsorbent making methodology and procedure employed in using it for adsorption of Strontium that constitutes one of the most critical components of radioactive waste. Use the "Insert Citation" button to add citations to this document.

Key words: Nuclear energy, Biosorption, Algae Adsorbent, Radioactive waste, Strontium

Introduction

Nuclear energy being semi renewable with its high base load is critical for Sustainability on Earth. High base load energy and lower fuel cost being the salient features, the lowest per unit waste generation becomes prevalent for its wide acceptance. The waste generated in a nuclear power plant can be classified based on half-life - decay heat generation and also based on the radiation being emitted. Based on the amount of radiation, further classified as Low, Intermediate and High level wastes (Frimmel, 1993). Low-level wastes constitute all the stationeries used in Nuclear power plants like Cotton, Concrete etc. That are disposed of in stone trenches. Intermediate includes all the equipment utilized which are processed and disposable in near surface repositories (Hyslop, 2001). After ample processing, the Radioisotopes that are generated in the reactor constitute a major portion of the High level waste having higher half-life and also associated decay heat (Rollinson, 1997).

Objectives of reprocessing processes was to enhance efficiency of utilization of Natural Uranium resource, the basic raw material for nuclear fuels. Reducing the volume and long-term radio-toxicity and associated decay heat of high-level waste, by utilizing the minor actinides by recycling them will reduce the volume of High Level Waste and separating ^{90}Sr and ^{137}Cs, the major fission products in the spent fuel, reducing the long term radio-toxicity and decay heat associated with it before placing it in the Deep geological repository (Davuluri et al., 2023). Enhancing the proliferation –resistance of fissile and fertile materials thereby making their clandestine diversion difficult is another major objective (Hazen & Tabak, 2005).

Curtailing the waste emission, can be achieved by the processes of Partitioning and Transmutation processes. Partitioning is a series of physical and chemical processes of treatment of spent nuclear fuels for separation of major actinides Uranium and Plutonium, Fission products along with Minor actinides (Np, Am & Cm) in the uranium fuel cycle. Likewise in the backend of Thorium fuel cycles, based on ^{232}Th-^{239}Pu mixed fuels, partitioning is separation of major actinides Thorium (^{232}Th), Uranium (^{233}U) and Plutonium, Protactinium and Fission products. Minor actinides are absent in Th^{232} -^{233}U Fuel cycle but will be present in ^{232}Th- ^{239}Pu fuel cycle (Sengupta & Gupta, 2017). Transmutation is a process by which long lived radioisotopes, especially isotopes of actinides such as Plutonium and Minor actinides and selected fission products such as ^{99}Tc and ^{129}I are destroyed by conversion to short lived fission products, generally of low toxicity or stable isotopes by fission and/or neutron capture from neutrons generated in Fast reactor and Accelerated Driven system (Sengupta et al., 2016).

By these processes we are actually aiming to develop a nuclear fuel cycle that is safe, economically viable and attractive, environmentally benign, proliferation resistant and sustainable. Nuclear waste treatment can be performed by wet and dry processes. Wet processes include Solvent Extraction and Ion Exchange processes (Fan et al., 2012). These are believed to enhance the recovery of valuable radionuclides followed by permanent disposal in deep geological repositories after conditioning and immobilizing it in ceramic glass or Syn roc matrix. Dry processes include Electro reprocessing processes such as Pyro electric reduction and Pyro electric refining (Gupta et al., 2018). Pyro electric reduction is employed for Oxide fuels whereas Refining is especially for Metallic fuel that is produced by Injection Casting of Uranium- Zirconium fuels. Co-Extraction process is also demonstrated for Mixed Uranium and Plutonium nitrate and carbide fuel reprocessing (Das et al., 2010).

Solvent Extraction, widely practiced worldwide as PUREX and THOREX process for treatment of wastes. “Tri Butyl phosphate (TBP)” along organic solvents like kerosene is the concurrent methodology used in treatment of waste. Unfortunately, this combination suffers Radiation damage after few cycles forming degradation products like di butyl phosphoric acid (HDBP), hydro mono butyl phosphoric acid (H_2MBP) co-extracting other metal ions and affecting the selectivity of the process.in addition, non-degradability of TBP results in large volumes of organic waste from the process which requires excessive efforts for its safe disposal (Aytas et al., 2004).

Adsorption, the phenomenon of adhesion of atoms, ions or molecules from a gas, liquid or dissolved solid attached upon a surface. The phenomenon can be visualized as the deposition of molecular species that get adsorbed on the surface (Yıldız et al., 2011). Two types are Physical adsorption and Chemisorption. They are persistent in many natural, physical, biological and chemical systems that are widely used in Industrial applications such as Heterogeneous catalysts, activated charcoal, capturing and using waste heat. Pre concentration and separating actinides from radioactive nuclear wastes can often be achieved by adsorption, also clear from the very fact that, a lot of solid-phase adsorbents, either synthetic or natural are being utilized for the purpose (Krejci et al., 2011).

1. **Types of Bio-Adsorbent**

2.1 Algae Based: Photosynthetic Eukaryotic organisms ranging from Unicellular to Giant kelps. Mostly autotrophs, but certainly classified to be Green, brown and red algae. Prominently used for making biodiesel, dye extraction etc in industries. Studies have been closely conducted to observe the high adsorption capabilities of Algae due to higher cross-section it provides when properly treated with Functionalities such as $CaCl_2$. Recently, the scientists have discovered the remarkable abilities of Algae to separate long lived isotope ^{90}Sr from waste thereby, incredibly decreasing the amounts of nuclear waste

2.2 Bacteria Based: Prokaryotic microorganisms that are few micrometers in size yet, highly pathogenic sometimes and also very advantageous. Bioaccumulation and Biosorption of Heavy metals from waste waters have been in prominence with discovery of their usage serving the purpose. Carboxyl, phosphonate, hydroxyl and amine groups studded in the cell walls is said to be the major reason for adsorption activity being carried out by few of them like Mycobacterium, Anthrobacter etc (Taskaev & Apostolov, 1978).

2.3 Fungal Based: Encompassing enormous taxa within varied ecologies these are distinct from Plant and Animal kingdom with cell wall constituting substituents such as Chitin and anchored with Amine, Phosphate, sulphates that help in Metal Sequestration. Admirable for their easy availability, nonpathogenic nature and also approximated to be cheaper. Native Fungal biomass like Rhizomes, Trichoderma etc. is still being experimented upon for adoption as potential adsorbents (Sylwester et al., 2000).

2.4 Plant Based: Photosynthetic Eukaryotic organisms, predominantly forming the base of any food chain. Sustaining balance of life on earth, by providing oxygen along food for all organisms, also find their utility in Industries like pharmaceuticals etc.., The lignin and Cellulose make them viable adsorbents and a ray of hope is being looked upon for making these most economic and renewable sources of Adsorbents (Sengupta et al., 2015).

2.5 Animal Based: Metazoan Community with the ability of movement that have complex interactions and heterotrophic noticeably. These are being studied for removal of heavy metal ions from Industrial waste. Chitosan is attributed mainly for this adsorption phenomenon showcased in mainly aquatic animals like Shrimp shells, Starfish etc (Elsalamouny et al., 2017).

2. Methodology

Clostirium Moniliferum is a kind of green algae that occurs frequently in nature as pond algae and proved to be one of the effective solutions in partitioning waste mostly ^{90}Sr ion that constituted a higher percentage of High level waste constituted by fission products. The crescent shaped algae is highly effective in adsorbing ^{90}Sr ions and storing it as crystals in its tiny vacuoles forming complexes with natural organic ligands in humic substance. The salient features such as sustenance in acidic pH, calefaction and low nutrient availability and low light simulation probably made it most suitable for utilisation (Omar et al., 2007).

Initial processing

- The algae is washed and sun dried and later, it is dried in the oven at 343 k for up to 12 hours.
- Dry algal biomass formed be processed using different methods to manufacture the adsorbent that can be used for the bioremediation.

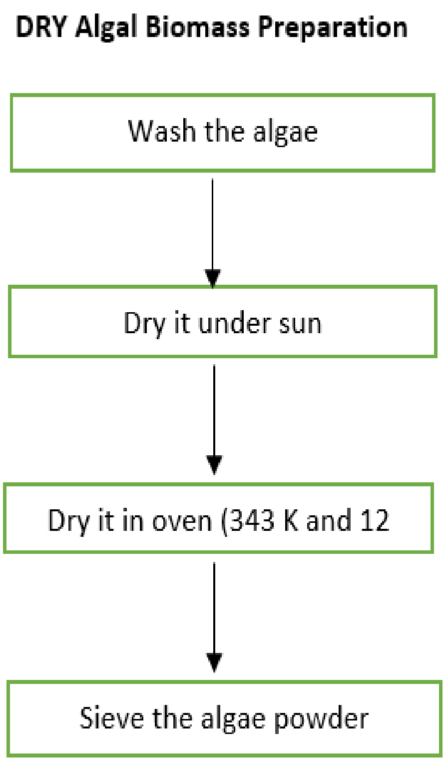

Fig 1. Dry algal biomass making process

3.1 First Method: - Ca^{2+} pretreated algal biomass

0.1 M $CaCl_2$ is added to the dry biomass maintaining the pH level between 4-5 at room temperature for 3 hours and obtained product can be used as Adsorbent (Pathak et al., 2000).

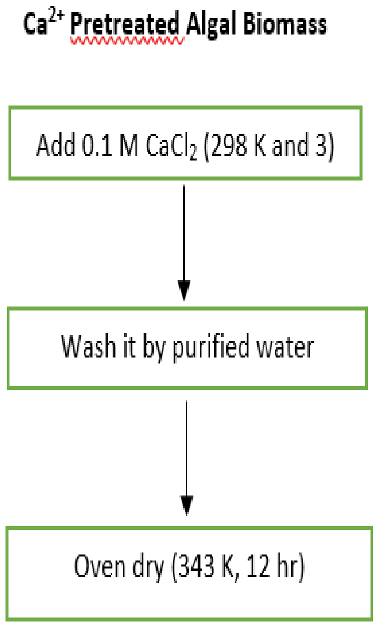

Fig 2. Calcium treatment of Algal biomass making it an adsorbent

3.2 Second Method: - Algae-Clay Composite

At first, a paste of the algal biomass and clay mineral is made. This paste is heated in the oven at approximately 375 K-385 K for 6 hours. The briquettes of the mixture obtained are further crushed and then are filtered out through the < 0.125 mm sieve and then the filtered mixture is dried in an electric oven at 380 K (Prabhu et al., 2015).

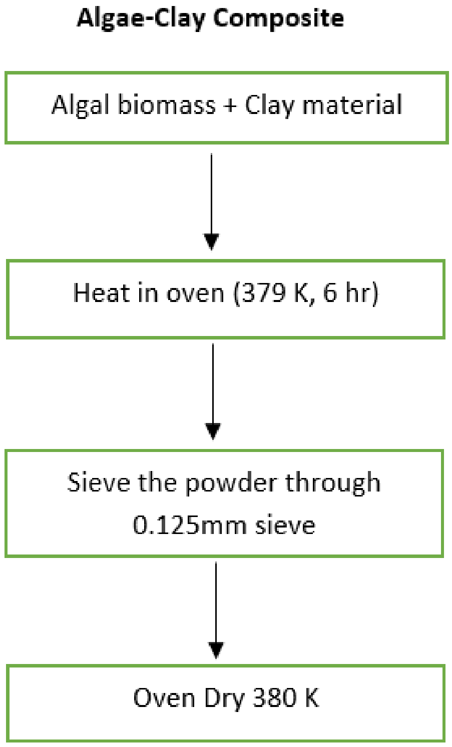

Fig 3. Algae–clay composite procedure for making adsorbent

3.3 Third Method: - CMC immobilized algal biomass

Take the mixture of algal biomass mixture and 2% Carboxymethyl cellulose in distilled water and drop some 0.2 M Calcium Chloride in the solution and then the solution is dried and thereby utilized as Adsorbent (Sengupta et al., 2014).

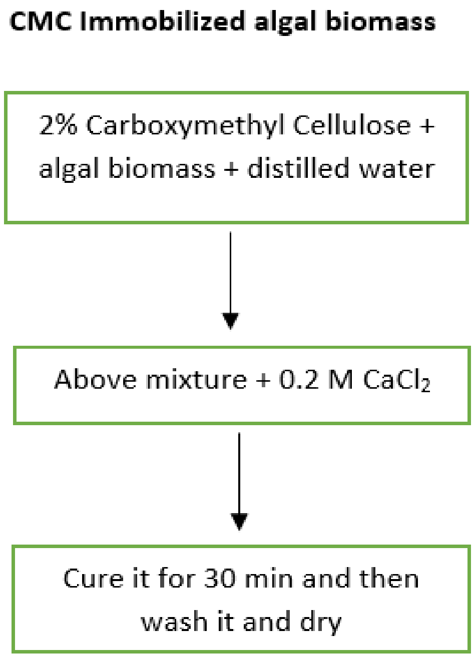

Fig4. Carboxymethyl cellulose immobilized methodology for making Algal adsorbent

Adsorbent manufactured are hereby used as a Permeable reactive membrane and can be applied differently under different scenarios (Horwitz et al., 1995).

Scenario 1: In the Partitioning processes, this can actually be used to separate the ^{90}Sr isotopes that form a part of 3% FISSION PRODUCTS produced by bombarding nuclear fuel. Having a half- life of 28 years these would take more than 100 years as usually believed to nullify their radioactivity. The Intermediate dry storage repository could be utilized for this purpose of accommodating Slurry Bioreactors where wastes can be exposed to Clostirium Moniliferum and adsorption occurs on the surface of this adsorbent bed, thereby separating ^{90}Sr in the form of Strontium Carbonate (Ojovan et al., 2008).

Scenario 2: In case of an uneven happening like Fukushima or a kind of repository failure like ground water intrusion in a near surface repository due to course change where the High level waste seem to get exposed following the phenomenon of Dispersion, Diffusion or Advection there by forming contaminated plumes above the surface or near to the surface mostly. Such contaminated plumes can thereby affect a larger cross section and need wider membrane coverage. Land farming is one way through which such scenarios could be dealt upon. Soil piles around the contaminated plume land can be prepared and tilling with the prepared adsorbent indeed helps in bio piling and composting off the radioactive isotope (Lee et al., 2006).

Fukushima incident that shook the world in 2011 and created havoc due to the intrusion of radioactive isotope into the environment. The released radiation’s impact probably can be reduced by using the Clostirium Moniliferum adsorbent as Membranes or probably sheets to cover the exposed area around the accident site (Farnan et al., 2007).

3. Mechanism of adsorption

Strontium exists in a valence state of +2. When it starts adsorbing on an Algal bed made of Closterium Moniliferum an organic ligand is formed in the presence of Barium. That organic ligand thereby gets stored in its Vacuoles in the cell wall of the organism in the form of Strontium Carbonate replacing the Calcium atoms. Henceforth explained in the picture below (Singh et al., 2008).

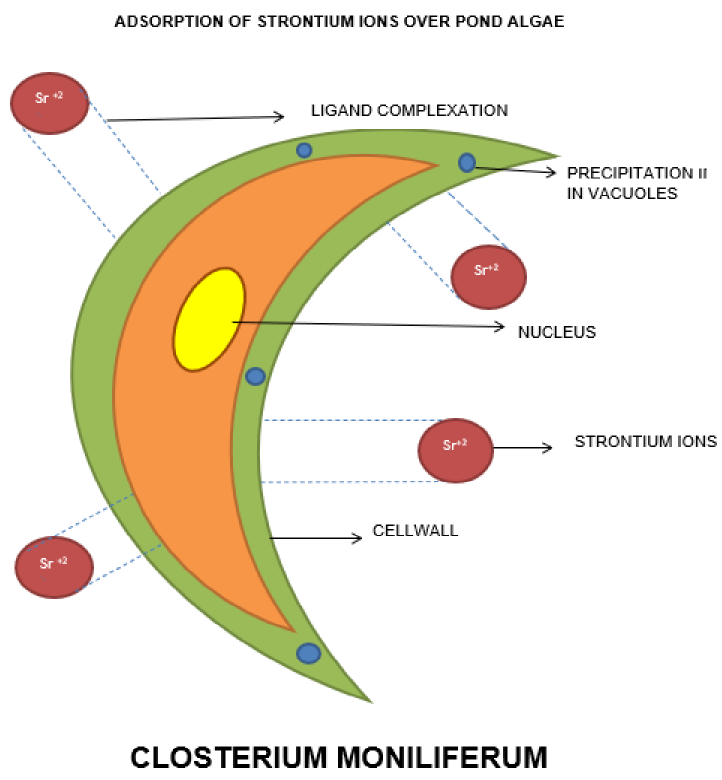

Fig 5. Adsorption of Strontium ions onto the Clostirium Moniliferum Pond Green algae

4. Conclusion :

The greatest facet of 21st century is the pollution of land, water, air and almost everything. Dumping of materials is the ultimate cause for all the grave climate issues. Bio based substances for capturing harmful substances and separating them thereby, reducing the probability of detrimental effect caused by them would improve the wholesomeness of our life. Algae is one of the hot favorite's and has been already explored as a befitting replacement of fuel, plastic etc.., to a great extent research is being performed to see its usage as a bio substituent of waste management technologies replacing the chemical based adsorbents. This is successfully being explored and we through this paper tried throwing some limelight upon the technologies.

References

Frimmel, F. H. (1993, May). Chemistry of the Solid-Water Interface. Processes at the Mineral-Water and Particle-Water Interface in Natural Systems. VonW. Stumm. Wiley, Chichester, 1992. X, 428 S., Broschur 32.50 £ - ISBN 0–471–57672–7. *Angewandte Chemie*, *105*(5), 800–800. https://doi.org/10.1002/ange.19931050543

Hyslop, E. (2001, February). P.C. Burns and R. Finch (Eds) Uranium: Mineralogy, Geochemistry and the Environment. Reviews in Mineralogy Volume 38. Washington, D.C. (Mineralogical Society of America) 1999, 679 pp. Price

US$32.00, US$24 for MSA members. ISBN 0 939950 50 2. *Mineralogical Magazine*, *65*(1), 149–150. https://doi.org/10.1180/s0026461x00025639

Rollinson, H. (1997, August). C. M. Bethke Geochemical Reaction Modeling. New York, Oxford (Oxford University Press). 1996, xvii + 397 pp. Price £37.95. ISBN 0-19-509475-1. *Mineralogical Magazine*, *61*(407), 611–612. https://doi.org/10.1180/minmag.1997.061.407.12

Davuluri, D., Kumar, M., Shukla, V., & Tiwari, R. (2023). Safety analysis of near surface nuclear waste repository constituting an aquifer in proximity. *Materials Today: Proceedings*, *77*, 382–388. https://doi.org/10.1016/j.matpr.2023.01.069

Hazen, T. C., & Tabak, H. H. (2005, August). Developments in Bioremediation of Soils and Sediments Polluted with Metals and Radionuclides: 2. Field Research on Bioremediation of Metals and Radionuclides. *Reviews in Environmental Science and Bio/Technology*, *4*(3), 157–183. https://doi.org/10.1007/s11157-005-2170-y

Sengupta, A., & Gupta, N. K. (2017, October). MWCNTs based sorbents for nuclear waste management: A review. *Journal of Environmental Chemical Engineering*, *5*(5), 5099–5114. https://doi.org/10.1016/j.jece.2017.09.054

Sengupta, A., Sk., J., Boda, A., & Ali, S. M. (2016). An amide functionalized task specific carbon nanotube for the sorption of tetra and hexa valent actinides: experimental and theoretical insight. *RSC Advances*, *6*(46), 39553–39562. https://doi.org/10.1039/c6ra07986e

Fan, F. L., Qin, Z., Bai, J., Rong, W. D., Fan, F. Y., Tian, W., Wu, X. L., Wang, Y., & Zhao, L. (2012, April). Rapid removal of uranium from aqueous solutions using magnetic Fe3O4@SiO2 composite particles. *Journal of Environmental Radioactivity*, *106*, 40–46. https://doi.org/10.1016/j.jenvrad.2011.11.003

Gupta, N. K., Sengupta, A., Gupta, A., Sonawane, J. R., & Sahoo, H. (2018, April). Biosorption-an alternative method for nuclear waste management: A critical review. *Journal of Environmental Chemical Engineering*, *6*(2), 2159–2175. https://doi.org/10.1016/j.jece.2018.03.021

Das, D., Sureshkumar, M. K., Koley, S., Mithal, N., & Pillai, C. G. S. (2010, May 30). Sorption of uranium on magnetite nanoparticles. *Journal of Radioanalytical and Nuclear Chemistry*, *285*(3), 447–454. https://doi.org/10.1007/s10967-010-0627-0

Aytas, S. O., Akyil, S., & Eral, M. (2004). Adsorption and thermodynamic behavior of uranium on natural zeolite. *Journal of Radioanalytical and Nuclear Chemistry*, *260*(1), 119–125. https://doi.org/10.1023/b:jrnc.0000027070.25215.92

Yıldız, B., Erten, H. N., & Kış, M. (2011, February 12). The sorption behavior of Cs + ion on clay minerals and zeolite in radioactive waste management: sorption kinetics and thermodynamics. *Journal of Radioanalytical and Nuclear Chemistry*, *288*(2), 475–483. https://doi.org/10.1007/s10967-011-0990-5

Krejci, M. R., Finney, L., Vogt, S., & Joester, D. (2011, March 29). Selective Sequestration of Strontium in Desmid Green Algae by Biogenic Co-precipitation with Barite. *ChemSusChem*, *4*(4), 470–473. https://doi.org/10.1002/cssc.201000448

Taskaev, E., & Apostolov, D. (1978, March). On uranium (VI) adsorption on activated carbon. *Journal of Radioanalytical Chemistry*, *45*(1), 65–71. https://doi.org/10.1007/bf02517111

Sylwester, E., Hudson, E., & Allen, P. (2000, July). The structure of uranium (VI) sorption complexes on silica, alumina, and montmorillonite. *Geochimica Et Cosmochimica Acta*, *64*(14), 2431–2438. https://doi.org/10.1016/s0016-7037(00)00376-8

Sengupta, A., Jayabun, S., Pius, I. C., & Thulasidas, S. K. (2015, December 17). Synthesis, characterization and application of metal oxides impregnated silica for the sorption of thorium. *Journal of Radioanalytical and Nuclear Chemistry*. https://doi.org/10.1007/s10967-015-4658-4

Elsalamouny, A. R., Desouky, O. A., Mohamed, S. A., Galhoum, A. A., & Guibal, E. (2017, November). Uranium and neodymium biosorption using novel chelating polysaccharide. *International Journal of Biological Macromolecules*, *104*, 963–968. https://doi.org/10.1016/j.ijbiomac.2017.06.081

Omar, H. A., Aziz, M., & Shakir, K. (2007, January 1). Adsorption of U(VI) from dilute aqueous solutions onto peat moss. *Radiochimica Acta*, *95*(1), 17–24. https://doi.org/10.1524/ract.2007.95.1.17

Pathak, P. N., Prabhu, D. R., & Manchanda, V. K. (2000, September). DISTRIBUTION BEHAVIOUR OF U(VI), Th(IV) AND Pa(V) FROM NITRIC ACID MEDIUM USING LINEAR AND BRANCHED CHAIN EXTRACTANTS. *Solvent Extraction and Ion Exchange*, *18*(5), 821–840. https://doi.org/10.1080/07366290008934709

Prabhu, D., Sengupta, A., Murali, M., & Pathak, P. (2015, December). Role of diluents in the comparative extraction of Th(IV), U(VI) and other relevant metal ions by DHOA and TBP from nitric acid media and simulated wastes: Reprocessing of U–Th based fuel in perspective. *Hydrometallurgy*, *158*, 132–138. https://doi.org/10.1016/j.hydromet.2015.10.011

Sengupta, A., Murali, M., Thulasidas, S., & Mohapatra, P. (2014, August). Solvent system containing CMPO as the extractant in a diluent mixture containing n-dodecane and isodecanol for actinide partitioning runs. *Hydrometallurgy*, *147–148*, 228–233. https://doi.org/10.1016/j.hydromet.2014.05.014

Horwitz, E., Dietz, M. L., Chiarizia, R., Diamond, H., Maxwell, S. L., & Nelson, M. R. (1995, June). Separation and preconcentration of actinides by extraction chromatography using a supported liquid anion exchanger: application to the characterization of high-level nuclear waste solutions. *Analytica Chimica Acta*, *310*(1), 63–78. https://doi.org/10.1016/0003-2670(95)00144-o

Ojovan, M. I., Juoi, J. M., Boccaccini, A. R., & Lee, W. E. (2008). Glass Composite Materials for Nuclear and Hazardous Waste Immobilisation. *MRS Proceedings*, *1107*. https://doi.org/10.1557/proc-1107-245

Lee, W. E., Ojovan, M. I., Stennett, M. C., & Hyatt, N. C. (2006, February). Immobilisation of radioactive waste in glasses, glass composite materials and ceramics. *Advances in Applied Ceramics*, *105*(1), 3–12. https://doi.org/10.1179/174367606x81669

Farnan, I., Cho, H., & Weber, W. J. (2007, January). Quantification of actinide α-radiation damage in minerals and ceramics. *Nature*, *445*(7124), 190–193. https://doi.org/10.1038/nature05425

Singh, S., Eapen, S., Thorat, V., Kaushik, C., Raj, K., & D'Souza, S. (2008, February). Phytoremediation of 137cesium and 90strontium from solutions and low-level nuclear waste by Vetiveria zizanoides. *Ecotoxicology and Environmental Safety*, *69*(2), 306–311. https://doi.org/10.1016/j.ecoenv.2006.12.004