Phytoremediation of $^{137}$Cs from low level nuclear waste using *Catharanthus roseus*

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Remediation of radionuclides has been carried out using the phytoremediation technology. The green plants have been screened for the uptake potential of radionuclide and found that *Catharanthus roseus* has the high potential for radionuclides in particular $^{137}$Cs. Low level nuclear waste (LLNW) collected from effluent treatment plant, BARC has been characterized for physico-chemical and the presence of traces of radionuclides. LLNW was spiked with $3.7 \times 10^4$ kBq L$^{-1}$ activity level of $^{137}$Cs. The plants of *C. roseus* were grown in (i) LLNW, (ii) $^{137}$Cs spiked LLNW and (iii) with the control. The radio activities were measured in the solution at the intervals of 0, 1, 2, 3, 6, 8 and 15 days in triplicate set of the experiment. The plants were harvested after the growth. The depletion of $^{137}$Cs in LLNW was found to be 19, 21, 24, 38, 60 and 76% at intervals of 1, 2, 3, 6, 8 and 15 days, respectively. The bio-accumulation of $^{137}$Cs has been measured in the roots and shoots of the harvested plants. The activity of $^{137}$Cs was found higher in shoots (998 kBq g$^{-1}$ dw) as compared to the roots (735 kBq g$^{-1}$ dw). The uptake of radionuclide-$^{137}$Cs, bio-accumulation in the shoot via the active transport from the root, shows the high efficiency and potentiality of *C. roseus* for the remediation of radionuclide. The bio-accumulation of $^{137}$Cs in the shoot will remediate the radionuclide contamination from LLNW. *C. roseus* can also be made applicable for effective remediation of radionuclides present in the LLNW.

**Keywords:** Radionuclides, Low level nuclear waste, Phytoremediation, Potential, *Catharanthus roseus*

1 Introduction

The contamination of soil and water with radionuclides present in low level nuclear waste (LLNW) is an increasing environmental concern. Radioactive contamination of the environment can be due to emissions and accidental spills from operations such as, nuclear fuel cycle like mining, milling and fallout from nuclear testing. Accidents like Chernobyl disasters also add up to the radionuclide contamination. Naturally occurring radionuclides may be brought to the surface of the earth by the process of oil drilling. Soil contamination with radiocaesium has a long-term radiological impact due to its long physical half-life (30 years for $^{137}$Cs) and its high biological availability. Consumption of agricultural produce contaminated with radiocaesium represents the principal route of human exposure to this radionuclide. Remediation of sites contaminated with radionuclides is particularly challenging. Remediation of soils contaminated with radiocaesium using present physical and chemical technologies may entail high costs. Phytoremediation is an emerging, green plant based, low-cost, environmental-friendly alternative technology, potentially effective and applicable to a number of radionuclides. Plants take up essential and non-essential elements from soils in response to concentration gradients induced by selective uptake of ions by roots, or by diffusion of elements in the soil. The technology relies on plants that translocate radionuclides from soil or water to their aboveground parts-shoots. The plant biomass is removed from the field and can be burned to reduce its volume. It is then disposed in an appropriate area for the safe environment.

LLNW contains the traces of radionuclides in particular $^{137}$Cesium, is among the most important constituents, chosen for the present study, which affects environment adversely at fairly low concentrations.

The green plants have been screened to check the uptake efficiency of radionuclide and found that *Catharanthus roseus* has the high potential for radionuclides in particular $^{137}$Cs. *Catharanthus roseus* L. belongs to the family Apocynaceae and is a
cosmopolitan evergreen herbaceous subshrub commonly known as Sadabahar and being rich in indole alkaloids. The plant, though can be cultivated in gardens as a flowering plant, is known for its robust growth in wastelands and toxic due to the presence of toxic alkaloid. Pandey et al.² have studied the impact of cadmium and lead on C. roseus. Zheng and Wu⁷ reported that cadmium treatment enhanced the production of alkaloid, secondary metabolites in C. roseus. There is no report on uptake potential of this plant for remediation of 137Cs from low level waste. The present study portrays the uptake potential of Catharanthus roseus for radionuclides with special reference to 137Cs present in LLNW.

2 Experimental Details

The uniform size of juvenile plants of Catharanthus roseus were collected from the vicinity of Bhabha Atomic Research Centre, Mumbai and acclimatized in Hoagland’s liquid medium¹, containing various plant nutrients, for a period of 15 days. Healthy plants with well developed root system were selected for uptake of 137Cs present in LLNW. LLNW was collected from effluent treatment plant, BARC, Mumbai. This waste is generated during cleaning/decontamination operations of intermediate level waste treatment facilities and needs remediation before its final discharge to sea. LLNW was characterized for physico-chemical properties. Initial activity (gross β, γ) in the LLNW was 42.88 kBq L⁻¹ with 99% of the activity contribution from 137Cs and 1% of 90Sr. The pH of the solution was 6.5. Elemental analysis of the waste was carried out and sodium was found to be the major constituent having concentration of 125 mg L⁻¹. The total dissolved salt of the waste solution was found to be less than 0.05% (w/v) (Table 1). Plants were cultivated in (i) LLNW, (ii) 137Cs spiked LLNW and (iii) with the control for a period of 15 days. The initial pH of the solutions was adjusted to 5.6. The radio activities were measured in the solution at the intervals of 0, 1, 2, 3, 6, 8 and 15 days in triplicate set of the experiment. Figure 1 demonstrates the experimental set up of phytoremediation of radionuclides.

After 15 days of the experiment, plants were removed from the solution, thoroughly washed with distilled water, manually divided into roots and shoots and oven-dried at 60°C to constant weight and dry weight measured. The dried plant materials were digested with HNO₃:HClO₄ (5:1 v/v) acid mixture and analyzed for radioactivity using GM counter.

Radioactivity analysis was carried out by plancheting known volume of the samples during under infra ray (IR) lamp followed by determination of radioactivity using GM counters. GM counter was calibrated with standard sources prior to estimation of samples. Accuracy of GM counter was estimated using standard sources of 137Cs and 90Sr and was found to be 5% expressed in terms of percentage error. Coefficient of variance was found to be in order of 1.5-2% indicating the reproducible nature of the work. For experiments with LLNW, gross β, γ activity was determined using a GM counter⁶.

3 Results and Discussion

Phytoremediation of radionuclide present in LLNW with special reference to 137Cs was carried out under controlled conditions. The remediation technology developed for decontamination of radionuclides using potential green plants Catharanthus roseus is shown in Fig. 2. The findings of the present research work shows that when the plants of C. roseus have been cultivated in

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Table 1 — Physio-chemical analysis of low level nuclear waste
the LLNW as well as Cs spiked LLNW, only 25 and 27% of activity was remained after 15 days, which shows that 75 and 73% of activity was remediated from LLNW, Cs spiked LLNW, respectively (Fig. 3). The bioaccumulation of radionuclide in the root and shoot of C. roseus is shown in Fig. 4. The activity of $^{137}$Cs in shoots was 998 kBq g$^{-1}$ dw and in roots was 735 kBq g$^{-1}$ dw.

The mechanism of uptake of $^{137}$Cs by C. roseus highlights that Caesium (Cs) is a weakly hydrated alkaline metal with chemical similarities to potassium (K). Caesium is predominantly present in solution as the free hydrated cation Cs$^+$ with little or no tendency to form soluble complexes. Caesium can be readily absorbed by plant roots from solution and can be translocated to the above-ground plant parts. Plants grown in nutrient solution typically concentrate Cs in their tissue compared to the outer solution. Caesium has a high mobility within a plant.

The present studies have shown the potential of C. roseus as a good remediator of $^{137}$Cs from the solutions. Phytoremediation result obtained is in concurrence with the study of Chromolaena odorata$^5$.

In case of C. odorata, at the lowest Cs activity ($1 \times 10^3$ kBq L$^{-1}$), accumulation of Cs was found to be higher in roots compared to shoots, while at higher Cs activities ($5 \times 10^3$ and $10 \times 10^3$ kBq L$^{-1}$), Cs accumulation was more in shoots than roots. The advantage of high concentration of $^{137}$Cs in shoots of C. roseus is that the shoot can be cut, removed, buried and ashed to disposed off in safe environment.

C. roseus grown in aquatic environment could remove most of the radionuclides within 15 days from LLNW, which makes it an ideal plant for remediation of $^{137}$Cs from LLNW.

4 Conclusions

The radioactive waste contaminants namely $^{137}$Cs have been remediated by using Catharanthus roseus. The potential of C. roseus to take up the radionuclides has been established by screening the plants and studying the phytoremediation of $^{137}$Cs at various concentrations by an eco-friendly, solar-energy driven, in situ remediation technology that utilizes the inherent abilities of living plants to clean up the environment. Our experimental data elucidated that Catharanthus roseus plant (Apocynaceae family) is suitable for phytoremediation of radioesium from contaminated environment.
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