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2/25/97

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Michael Thompson
Department of Energy

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Dear Mike:

As you requested in our meeting of 1/31/97 (also attended by Drs Milt Gordon and Lee Newman), I am sending you a summary of our ideas on groundwater remediation at Hanford using phytoremediation.

We believe that using plants to remove metals and organic contaminants from groundwater pumped from polluted aquifers is an effective and economical approach to these problems that have proved so difficult for conventional technologies. We look forward to your response and comments.

Sincerely yours,

Stuart E Strand

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enclosed: 4 page summary
cc: Milt Gordon and Lee Newman

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Practical Applications of Phytoremediation to Groundwater Remediation at Hanford

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University of Washington
Paul Heilman, Washington State University

Background of Groundwater Remediation Problems at Hanford

The main problem of groundwater remediation at Hanford is high cost, compounded by a lack of technically feasible alternatives. In this proposal we present a low cost alternative groundwater treatment that provides long life with lower maintenance and a more ecologically acceptable outcome.

There are three types of groundwater remediation sites on the Hanford reservation. The first type, area 200-West, is contaminated with carbon tetrachloride, CT, nitrate, and tritium. Presently the extent of the CT problem is being reduced by vapor extraction from the soil and by pumping of groundwater at the perimeter of the plume.

The other types of groundwater remediation sites at Hanford are contaminated with toxic metals. The second type of site is area 100 near the N reactor, with a high level of radioactive strontium, ^{90}Sr, in a plume near the river. The ^{90}Sr plume is being contained by pumping, but the cost of operating the aboveground adsorption units is very high. A buried adsorption barrier for ^{90}Sr has been proposed, but its location on the bank of the Columbia River has met with resistance from stakeholders because it would leave this radioactive metal in place near the river.

The third type of groundwater remediation site is in area 300: a plume of hexavalent chromium which is leaching into salmon spawning grounds in the Columbia River. Injection of a chemical reductant into the plume would immobilize the chromium and reduce its toxicity, but uncertainties about long-term stability of the chromium and the impact of the reductant on the groundwater quality remain.

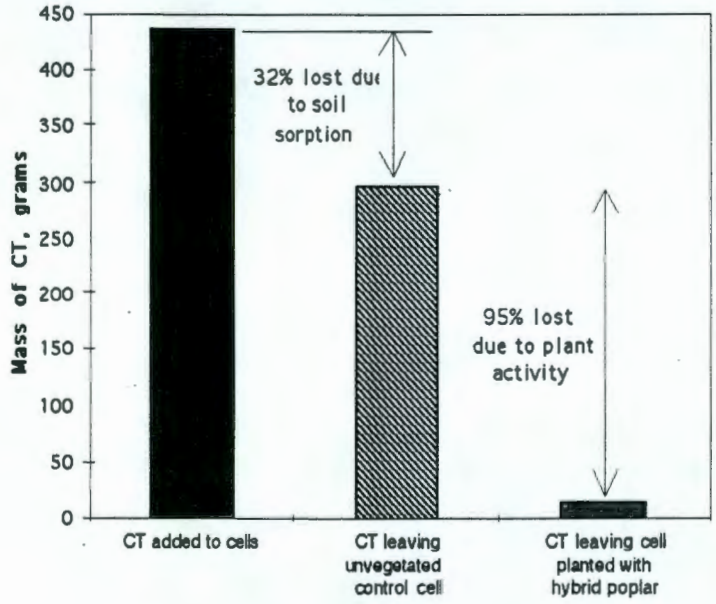
Although pumping of the seriously contaminated groundwaters at Hanford is relatively inexpensive, subsequent treatment of the water is costly ($2-3M/year). Remediation will require decades, so the costs over the long haul will be exorbitant. A new remediation technology can provide a solution to these problems: phytoremediation, the use of plants to take up and destroy or sequester pollutants.

Recent findings from our labs at the University of Washington have shown that CT is readily taken up by hybrid poplar trees and degraded with no measurable air emissions (see Figure, below). Uptake and destruction of toxic organics like CT by trees is an elegant approach to groundwater remediation, because the tree are long-lived, self-maintaining, and economical. We propose that this approach, combined with pumping, can be applied to the cleanup of groundwater from the 200-ft deep aquifers of the Hanford plateau.

Other research groups have demonstrated the abilities of a variety of plants to take up and concentrate chromium and ^{90}Sr in plant tissues where they can be harvested and used for recycling or safe disposal of the metal. For example, chromium can be accumulated in Indian mustard up to 5000 times more concentrated than in the water to which it is exposed. Sunflower has been used to preferentially remove ^{90}Sr from water at Chernobyl. By hyperaccumulating metals in plant tissue to levels higher than in the water, it is possible to economically remove the metals from a contaminated environment and either safely dispose of the toxic metal in a contained landfill or to recycle appropriate metals by using the plant material as a supplement to ore in a smelter. No other metal remediation technology offers such a desirable outcome.

Carbon Tetrachloride Uptake by Hybrid Poplar

15 trees in a lined cell (12x20x4.5 ft, filled with soil and sand) were exposed to an artificial groundwater flow for 4 months. The water entering the cells contained 15 ppm CT and water leaving the tree-planted cell contained virtually no CT. A cell that was not planted with trees absorbed some CT in the soil, but most passed through unchanged. Measurements of CT in the air around leaves of the trees detected no CT emitted into the atmosphere.



Proposed Uses of Phytoremediation at Hanford

We propose that groundwater be pumped from contaminated aquifers and applied to plants that can take up and destroy (CT) or concentrate (Cr(VI) and ^{90}Sr) contaminants. In the 200 W area, CT-contaminated water from groundwater control wells would be drip-irrigated onto a plantation of poplar planted on the site. During the growing season the trees would take up the CT along with the water and the CT would be destroyed by metabolic processes in the tree tissue. During the winter, when the trees are dormant, the pumps would be off. Resumption of pumping in the spring will draw back any advances the contaminated groundwater would make during the winter. We estimate that roughly 100,000 trees, planted on 230 acres would be needed to treat the water that will ultimately be pumped annually from the 200 W aquifer. The advantages of phytoremediation over the present CT-treatment system are:

- CT would be destroyed on site without air emissions or need to ship adsorbent off site for destruction of CT and regeneration of the adsorbent
- Trees would also readily take up nitrate, which is also a contaminant
- Vapor extraction requirements would be minimized, since tree roots would remove CT adsorbed in the upper part of the soil

- Strippers and activated carbon processing presently used to treat the groundwater would be eliminated, substantially reducing costs

Phytoremediation is also more economical than proposed *in situ* bioremediation methods, which use anaerobic bacteria, while avoiding the residual chloroform that the bacterial methods produce.

For phytoremediation of the metals, Cr(VI) and ^{90}Sr, water will be pumped from the polluted aquifers and applied to hydroponic ponds of harvestable plants capable of hyperaccumulation of the target metal. The double-lined hydroponic ponds will support the growth of plants on a shallow bed of gravel which can support harvesting equipment. The contaminated water will flow through the ponds allowing uptake of the metals in plant roots, stems and leaves. The use of ponds avoids problems with binding of metals on soil. These ponds will be located well away from the Columbia River. The ponds will be enclosed in greenhouses to allow operation year-round and to protect the plants from wildlife. Periodically the metal-rich plants will be harvested, dried, and placed in the Environmental Restoration Disposal Facility (ERDF) or, in the case of Cr(VI), taken to an off-site smelter for Cr recycling. The advantages of phytoremediation of Cr(VI) and ^{90}Sr over existing and proposed treatment methods are:

- Metal treatment would be relocated away from the vicinity of the river
- The risk of future releases of Cr from the aquifer would be eliminated
- The uncertain effects of an anaerobic leachate on the salmon spawning beds near the Cr site would be eliminated
- The possibility that Cr could be removed from the site altogether and recycled
- Lower cost than for the extra pumping and treatment equipment required by the existing and proposed treatment technologies

Proposed Demonstration

Given the striking potential advantages of phytoremediation over conventional groundwater remediation technologies, we propose a three year demonstration of these methods at Hanford. This inexpensive, short-term demonstration will provide an on-site evaluation of which approaches are the most practical, economical, and effective.

In the 200 W area, a test plot will be set up with a hybrid poplar selected for rapid water uptake. The plot will be drip irrigated with part of the pumped well water from the plume containment system. The plot will be equipped to monitor CT and nitrate in soil water leachates and methods developed at the UW will be used to monitor air emissions of CT. Plant tissue will analyzed for CT metabolites and the accumulation of chlorinated organics in plant tissue.* The ecological effects of the plant material will be determined by feeding to animal and insect species representative of those at Hanford. The data from the test plot will be used in the design of a full-scale treatment plantation for CT contaminated groundwater pumped from the 200 W aquifer.

Hyperaccumulating plant species will be set out in 3-4 hydroponic test ponds under greenhouses uphill from the Cr(VI) plume in the 300 area and in similar ponds and greenhouses set back from the Columbia River near the ^{90}Sr-contaminated plume in the 100 area. Indian

* No accumulation of chlorinated organics has been observed in the tissue of poplar that have taken up CT at the UW test bed facility.

mustard, tobacco, and sunflower are candidates for use as Cr(VI) and ^{90}Sr hyperaccumulators. These test ponds will be filled with gravel to support the plant root systems and with groundwater from wells in the contaminated plumes. Monitoring will consist of water sampling to be determine whether all of the Cr(VI) or ^{90}Sr is taken up by the plants, of plant tissue analysis to determine the extent to which Cr and ^{90}Sr are accumulated in the plant tissues, and of analysis of potential ecological toxicity with insect and animal feeding tests. The level of Cr(VI) or ^{90}Sr in the plant tissue will be used to compare the efficiency of these methods to conventional methods, to determine whether Cr can be economically recovered from the Cr-accumulators, and to determine the volumes required in the ERDF facility for Cr and Sr loaded plant tissue. We will also use the monitoring data to design the processing facilities needed to dry the plant tissue and to calculate the total planted area needed for phytoremediation of Cr(VI) and ^{90}Sr.

Summary

Present methods for remediation of groundwater problems at Hanford are expensive and of uncertain effectiveness. Recent research has shown that phytoremediation, the use of plants to take up and degrade or concentrate toxics, provides an economical, low-risk, long-lived and ecologically acceptable alternative method for groundwater cleanup. We propose that groundwater be pumped from the contaminated aquifers and used to irrigate plantations of plant species selected to degrade carbon tetrachloride or to accumulate and concentrate hexavalent chromium or radioactive strontium. Long-lived trees would be used to degrade CT while Cr(VI) and ^{90}Sr would be accumulated in tissues of plants that will be harvested and used to reclaim Cr or to be stored in the upland containment facility. A three year phytoremediation project is proposed which will demonstrate a solution to many of Hanford's groundwater cleanup problems that will be economical, low risk, long-term, and acceptable to the stakeholders.