due to the penetrating nature of the probe and emitted radiation used in NAA. Instrumental NAA (INAA) were used for those elements which have a neutron capture product that is radioactive; Prompt Gamma NAA (PGNAA) was used in the case of cadmium because the most favorable reaction in cadmium (neutron capture by $^{113}Cd$ which has a capture cross section of 19,896 barns [1 barn $= 10^{-24}$ cm$^2$]) yields non-radioactive $^{114}Cd$. It was found that the neutron flux from a small plutonium–beryllium neutron source is adequate for the analysis of cadmium in large samples at the ppm concentration level.

A large sample irradiation facility for PGNAA using isotopic (plutonium–beryllium) neutron sources has been constructed and characterized. Results of the PGNAA work will be presented along with various issues of concern in the analysis of large, inhomogeneous samples and in particular, the analysis of municipal solid wastes.

A large sample irradiation facility is being planned for installation and evaluation at the Texas A&M Nuclear Science Center to irradiate samples of municipal solid waste for the analysis of heavy metals by INAA. Preliminary multielement results of the analysis of small samples of composted municipal solid waste will be presented along with a brief comparison of INAA results to atomic absorption results (performed according to procedures in EPA SW-846).

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# Development of bioreactors for the destruction of chlorinated solvents

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**Abstract**

Aerobic bioreactors for the removal of chlorinated solvents in groundwaters are a promising alternative to conventional treatment methods. Biodegradation is advantageous because in one step the contaminants are destroyed in addition to being removed from the treated waters. Chloroform, 1,2-dichloroethane, and trichloroethylene (TCE), for example, are degraded at concentrations of 1 to 1000 $\mu$g/L by certain heterotrophic bacteria, yielding innocuous end products. The nonspecific oxygenase enzymes of the bacteria enable the cometabolism of the chlorinated solvents.

Cometabolism of chlorinated solvents has been reported for several species and consortia of microorganisms including methanotrophs, pseudomonads, and nitrifiers. This research, with the objective of developing a small-scale bioreactor, has focused on microorganisms grown with aromatic substrates (pseudomonads). These organisms degrade chlorinated solvents, in particular TCE, at a fairly high rate and readily form biofilms.

Most of the relevant literature for the aromatic degraders has focused on the performance of pure cultures, which may be impractical to maintain in a wastewater treatment process. To assess the performance of mixed indigenous organisms, microbial populations from several sources including industrial and municipal activated sludges, commercial innoculum, and contaminated soil were acclimated with phenol, toluene, *o*-cresol, or 2,4-dichlorophenol in batch reactors. Radiochemical methods were used to measure the ability of the cultures to degrade TCE after a one month acclimation period. All cultures degraded TCE at a concentration of 100 $\mu$g/L to some extent as compared to the controls, and some degraded TCE to nondetectable levels. TCE carbon was converted to cell mass (15%), carbon dioxide (70%), and undegraded metabolites (15%). The undegraded metabolites were not volatile.

The batch degradation appeared to be first-order for an initial TCE concentration of 100 $\mu$g/L and cell concentrations of 100 to 500 mg-protein/L. The first-order TCE degradation rate constant for the aromatic cultures varied from 12 to 480 L/mg-protein·day, not including the culture grown on 2,4-DCP which did not degrade TCE. Literature rates for pure and mixed cultures ranged between 15 to 180 L/mg-protein·day, with the exceptionally high rate constant of 2900 for *Pseudomonas cepacia* G4. Otherwise, the mixed culture rates appear to be of the same order of magnitude as the pure culture rates. The highest mixed culture rates were obtained when batch cultures were intermittently fed phenol at 100 mg/L. TCE degradation was delayed or occurred at a slower initial rate when the growth substrate was present. Higher initial concentrations of phenol gave lower percent removals of TCE for a two hour incubation period.

Preliminary data for removal of TCE across continuous flow columns containing the phenol degraders on glass beads has been inconsistent. The largest removal has been 40% for a 1.5 cm diameter by 20-cm long column operating at a flow rate of 1.2 mL/minute. Modeling of the column TCE removal using the measured biomass distributions and batch degradation rates predicted that the organisms in the column were degrading TCE at rates 5–10 times less than observed in the batch experiments. Ongoing efforts are focusing on improved biodegradation rates and a better understanding of continuous-flow reactor operation.