AN UNIVERSITY INTERNSHIP PROGRAM IN RADIOACTIVE WASTE MANAGEMENT

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ABSTRACT

There is a critical shortage of trained technical personnel entering the fields of environmental restoration of previously contaminated Federal facilities and radioactive waste management. To remedy this shortage, an internship program in these areas has been developed at Vanderbilt University. Outstanding students, primarily environmental and chemical engineers, are enrolled in the program where they take, in addition to their specialties, courses in modern physics, instrumentation for detection and measurement of ionizing radiation, and health physics and environmental transport of radioactive waste.

At the end of the first of two years, they are assigned to a DOE-owned contractor-operator facility or to a DOE prime contractor to get first-hand experience in the field. Their summer internships have been at sites as diverse as Savannah River, Hanford, Oak Ridge, Grand Junction, Colonnie, Niagara Falls, etc. By the time they go into the field, they understand the fundamentals of the radiation, can handle the monitoring equipment, can make dose calculations and do risk assessments of the fate and transport of wastes in the environment. They are required to present the results of their summer's work to the Project's Advisory Board, which consists of high-ranking personnel from DOE and the contractor-operated laboratories.

Since its inception, the Program has enrolled 43 students with a grade point average of over 3.5 out of 4. An average of one paper per year has been presented at a national meeting by one of the interns and one published article per year in refereed journals. The interns are much sought after by their host organizations and most have gone to work on DOE related projects at either the national laboratories, DOE facilities or for consultants working on DOE problems. Some are still doing advanced studies at prestigious universities.

BACKGROUND

In August 1984, Vanderbilt University's Department of Civil and Environmental Engineering was awarded a grant by the U.S. Department of Energy to fund a Pilot Internship Program in Radioactive Waste Management with emphasis on the decontamination and decommissioning of radioactive waste sites. The Internship Program provides technical education and training for gifted undergraduate and graduate students to prepare them for leadership positions in environmental restoration and waste management. This is accomplished by a rigorous educational program and a supervised practicum, both subject to peer review. Key to the success of the program is the quality of the students (average grade point average of greater than 3.5 out of 4.0) and the practicum in the summer between the two academic years. In the practicum the student gets hands-on experience in waste management. The summer work must result in a senior paper or part of a master's thesis. The initial grant was for three years with the intent for an initial enrollment of six students (four graduates and two undergraduates) and an equilibrium level of twelve students for the two-year program. Having this many students at one site allows more detailed direct supervision, quality control and special lectures and courses. The grant has since been renewed for another three years.

The number of properly prepared professionals entering the environmental restoration and waste management field is inadequate to supply the demand. This need is highlighted in the Department of Energy's Five-Year Plan, where it is stated "Preliminary results indicated a significant work force growth over current levels by 1995". This is part of a national problem as noted by Erich Bloch, Director of the National Science Foundation, "It is now widely understood that the nation faces a serious problem in science and engineering education and that we are not mobilizing the human resources we need to compete effectively in the modern world". These statements only reinforce the trends forecast by the University of California at Los Angeles' Cooperative Institutional Research Program. They showed a decline from 11.5 to 5.8% between 1966 and 1988 of college freshman preparing to major in the sciences and mathematics. Perhaps most surprising is the decline in women's interest in science and mathematics in that period, from 8.8 to 5.1%, considering the strong efforts to encourage young women to enter these fields. Added to this dismal picture is the fact that Black and Hispanic students, while showing increasing interest, in 1988 only accounted for 11.5% and 2.1% respectively, of the entering freshman planning careers in science and engineering. Equally depressing is the fact that for the 1982 entering freshman, more than 60% of biological science majors did not get their degree in that field, for engineering it was about 50% and for the physical sciences approximately 70%. Though the entering science and engineering majors contain almost twice as many academically able students (45.3% vs 26.3% with high school grade point averages of A- or better) as those entering other major courses of study, the total pool of students entering college will continue to decrease by four to five percent per year for the next four to five years.

Further exacerbating the problem is the decline in the number of Ph.D.s graduating in science and engineering and the fact that over 50% of the Ph.D.s in engineering and mathematics are foreign born. Federal funding for basic and applied research in universities in 1989 was only 20% higher (in constant dollars) than in 1968 despite the fact that there are more than twice as many Ph.D. scientists and engineers at universities. These dismal statistics only reinforce the necessity for programs such as this to motivate students into scientific and engineering fields where they are desperately needed and to provide adequate funding for them.

EDUCATION AND TRAINING

The undergraduate students, primarily from environmental and chemical engineering, pursue their own individual curriculum, adding courses in Elements of Modern Physics, Atomic and Nuclear Physics Laboratory, and Radiological Aspects of Environmental Engineering (Radioactive Waste Management). The graduate students are enrolled in the Solid and Hazardous Waste concentration within the Environmental Engineering graduate program. A suggested curriculum is shown in Table I. As can be seen, such a study program would be equally applicable to a degree in hazardous waste engineering.

Vanderbilt did, in 1980, offer one of the earliest courses in hazardous waste engineering in the country. Since that time, most engineering schools that offer environmental engineering options offer a course in hazardous waste engineering. A more recent review of educational offerings in Hazardous Waste Management shows that only three universities offer a Master's Degree (New Jersey Institute of Technology, Newark, New Jersey; Tufts, Medford, Massachusetts; and Wayne State, Detroit, Michigan)

Our course in Hazardous Waste Management is similar to those offered at other institutions except that we put

TABLE I
Environmental and Water Resources Engineering
Solid and Hazardous Waste Option

First Year			
EWRE 260	Solid Waste Management	-	3
EWRE 269	Radiological Aspects of Environmental Engineering	-	3
EWRE 271	Environmental Chemistry	3	-
EWRE 276	Ground Water Hydrology	-	3
EWRE 277	Open Channel Hydraulics	3	-
EWRE 278	Hydrology	3	-
EWRE 300	Water Quality Management	-	3
EWRE 318	Systems Analysis for Environmental Engineers	3	-
		12	12
Second Year			
EWRE 272	Microbiology of Water, Waste-water, and Air	--	4
EWRE 273	Environmental Chemistry Lab	3	-
EWRE 279	Economics and Law of Air and Water Resources	3	-
EWRE 280	Atmospheric Pollution	-	3
EWRE 355	Hazardous Wastes Engineering	3	-
Math 233	Introduction to Statistics	3	-
	Electives	-	6
		12	13

greater emphasis on the environmental transport of hazardous materials. Laboratory work is lacking in this course. This is true for most university courses. This lack is due to liability problems, the availability of other courses where some of these techniques are taught and the lack of proper instrumentation to carry out the necessary testing. In the course on radioactive waste management, one-third of the time is spent on Nuclear Physics with emphasis on fission product, induced activity and transuranic isotope generation and decay, one-third on dose calculations using both the methods of ICRP2 and ICRP26 and ICRP30. The final third is spent on environmental transport and fate of the isotopes and design of waste disposal facilities. In parts two and three, the regulatory and institutional constraints are emphasized. By the time they go into the field, the interns understand the fundamentals of radiation, can handle the monitoring equipment, can make dose calculations and do risk assessments of the fate and transport of wastes in the environment.

The students spend two semesters at the university (20 August - 15 May) and twelve weeks at the work site (mid May - mid August) and then return for the final two semesters. In addition to the annual Technical Advisory Committee overview of the entire program, a system of checks has been installed to assure the quality of the program. At the beginning of the school year, each intern meets with the Program Director to review their course of study and career goals. Shortly after the beginning of the school year, all interns meet with the Program Director to review the program for the year and so that the second-year students can help counsel the first-year students on course choices and summer work choices. Approximately 2 months after school begins, the fall colloquium is held where the second year interns present the results of their summer work to the Technical Advisory Committee and the rest of the interns. After the second semester begins, the likely practicum sites send in their proposed work scopes for the interns. After discussions with the program director and representatives of the sites, the students make their choices. Within two weeks after the student begins his summer assignment, he and his supervisor prepare a description of the summer project. This may reaffirm or modify the initial work scope proposal received at the beginning of the second semester. After receipt of the proposal, the Program Director reviews it to be sure that the topic and scope of the work are compatible with the objectives of the program. Shortly after receipt of the modified proposal, the Program Director visits the site to discuss with the intern and his supervisor the summer work program and any difficulties there may be in implementing it. At the end of the summer work period, the intern and his supervisor prepare, if appropriate, a proposal for further work on the summer project. During the course of the summer program, the intern is encouraged to seek advice from the appropriate faculty members at Vanderbilt University. If work is continued at Vanderbilt, then the appropriate faculty member is encouraged to continue to work with the student.

The Technical Advisory Committee, composed of high-ranking officials at the major sites and with whom we have students doing their practicum, meet in conjunction with the fall colloquium at which the interns present the results of their summer's work. They also meet the new interns at that time. Prior to the meeting, the annual report of the internship program and vitae of the new interns are distributed to members of the committee.

RESEARCH

The changes in our understanding of waste management disposal, treatment and remediation are so rapid that participation in research projects is essential for the student to learn how to keep abreast of such changes. The work of some of the interns, as well as the work of some of the other students in radioactive and hazardous chemical wastes management at Vanderbilt University is summarized:

Probabilistic Risk Assessment

Methodology Development

The Ph.D. dissertation of Robert Broshears examined the risks presented by three hazardous chemical waste sites in Tennessee that are on the National Priority List. Broshears developed a risk algorithm, shown in Fig. 1, to determine what degree of treatment or more accurate quantification of the parameters, if any, was required to meet ingestion standards. In some cases, none of the above would be sufficient and then institutional controls would be necessary. To illustrate the methodology, the results of the groundwater pathway at the Velsicol Disposal site in Hardeman County, Tennessee are utilized. A cross section of the site is shown in Fig. 2. From the mid-60s to the early 1970s, the corporation buried 300,000 drums of wastes from the manufacture of organochlorine pesticide wastes in near-surface trenches. The wastes included heptachlor, dieldrin, heptachlor epoxide, endrin, as well as other organic constituents, including carbon tetrachloride. Only the heptachlor analysis will be dealt with in this paper.

The hydraulic conductivity at the site was taken to be 1.2×10^{-4} m/s; hydraulic gradient, 0.0034; dispersivity, 100 m, and porosity, 0.08. Standard, simplified first-order deterministic models of degradation, solubilization, and leaching of the waste and dilution of the waste stream with ground water and by advection, dispersion, retardation and degradation and ingestion of drinking water were used to calculate maximum individual risks for worst case analysis. A conceptual diagram is shown in Fig. 3. The risks at 1000 m for times of 100, 1000, and 10,000 years were greater than 10^{-6} per lifetime, except for the risks at 100 years for hydraulic conductivities of 1.2×10^{-4} m/s and for 100 and 1000 years

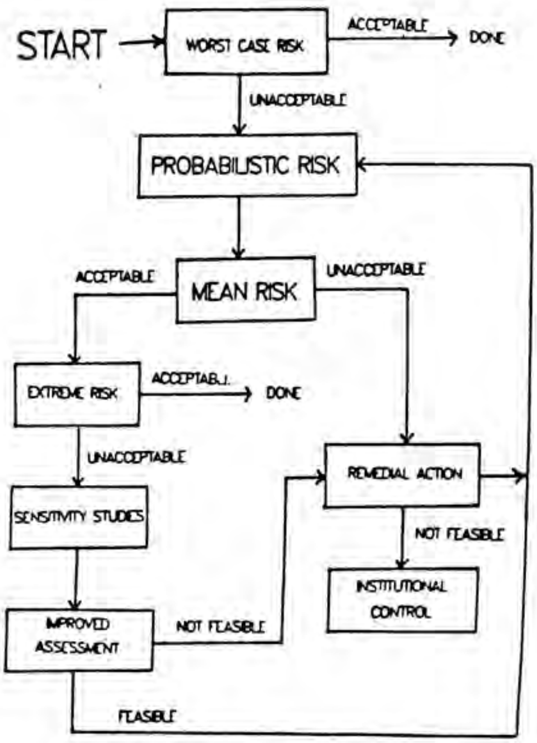

Fig. 1. Risk assessment algorithm for hazardous waste sites (after Broshears, 1986).

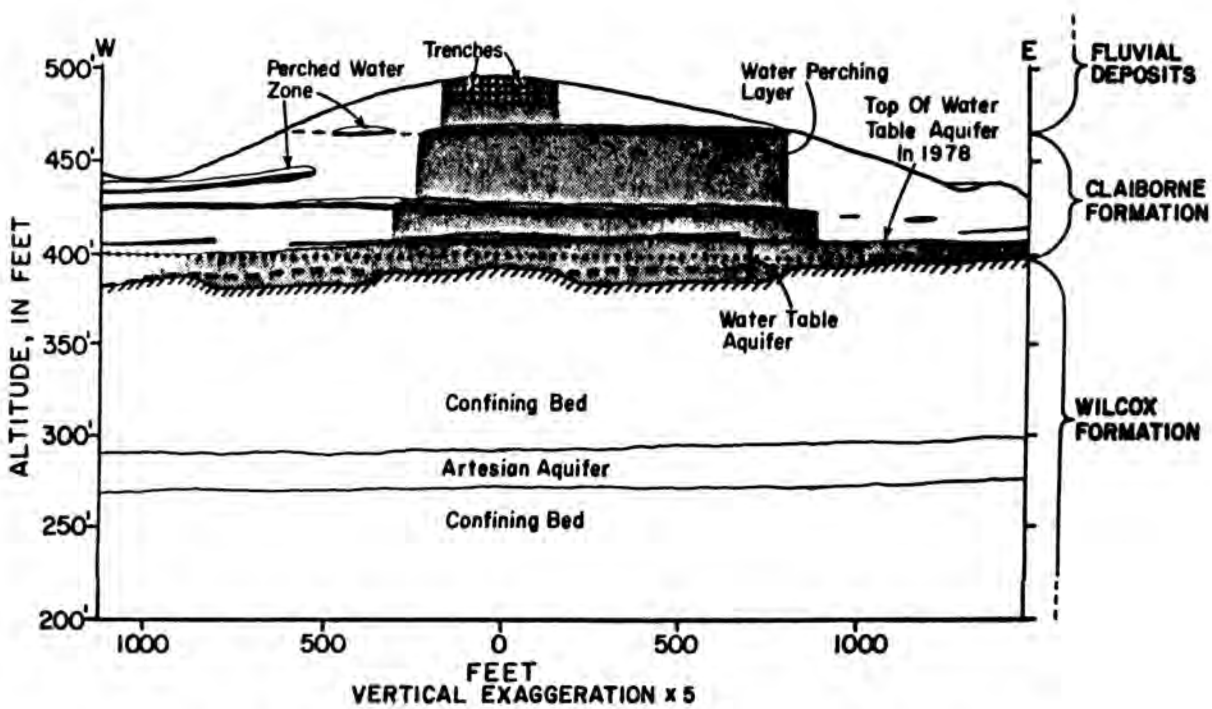

Fig. 2. Profile beneath the Hardeman County disposal site (after USGS).

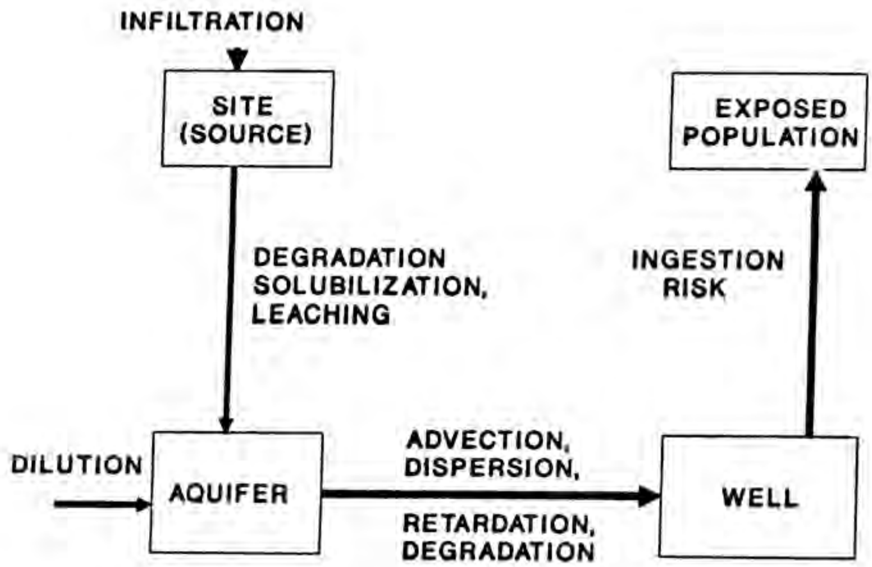

Fig. 3. Contaminant transport scheme for groundwater pollution scenarios at a hazardous waste landfill.

at hydraulic conductivities of 1.2x10-5 m/s, where the plume had not yet reached the sampling point as shown in Fig. 4. For individual risks, collective risks were also calculated. Based upon the previous work of Starr (11) and the guidance of the Environmental Protection Agency, a risk of 1 in a million per lifetime is generally regarded as "de minimis" non curat lex (the law does not concern itself with trifling matters) and 10^{-3} to 10^{-6} risk of death per lifetime is regulated. Therefore, a probabilistic risk analysis was carried out. One would have to improve the estimates (i.e., reduce the uncertainties) of the solubility and partitioning coefficient by further experimentation. This would lead to reduced risks, but not necessarily low enough to meet the risk criteria.

It can be seen from this study that, depending upon the time interval utilized and the accuracy of the input data and the criterion of acceptable risk utilized, the releases of heptachlor may or may not be acceptable. If institutional control of drinking water supplies can be maintained over a period of centuries, then, the risks would meet the criteria.

Efficacy of Synthetic Liners

The Resource Conservation and Recovery Act of 1976 (RCRA) and its amendments specify the use of synthetic membrane liners to prevent contamination below a hazardous waste landfill. Some of these wastes, heavy metals for example, suffer no degradation and therefore, have an infinite half-life. Others, organic chemicals, have half-lives that vary from near infinite to very short half-lives. This study by Connor Haugh, an intern, was carried out for the environmental conditions at the Hardeman County Velsicol site and the same parameters, described above, hold (14). The containment of an organic solvent, benzene which is easily biodegradable, a pesticide, heptachlor, which is less easily degradable and a heavy metal, lead, which is not degradable was studied. The manufacturer of a high density polyethylene liner that meets RCRA requirements guarantees a life of 20 years and expects an effective life in the range of 50 to 100 years (15). Despite this disparity in lifetimes of the wastes and liners no probabilistic risk analyses was carried out to determine the likely years of effective use. The effectiveness of the liners is most pronounced for short periods of time up to 100 years. At 1000 years there is virtually no difference in the risks between lined and unlined landfills with heptachlor and lead. Even with a liner, the risk from heptachlor was only acceptable for a 30-year period. For lead, which does not degrade, a liner only redistributes the risk over time. Only with benzene, which degrades rapidly, does the liner reduce the risk over all time periods. The risks from a deterministic analysis were also calculated where the acceptable risk for lead, a non-carcinogen, is taken as the drinking water standard, 0.05 mg/l. A summary of the results are shown in Table II.

Land Filling Versus Land Farming of Hazardous Wastes

Land farming of hazardous wastes may be an acceptable treatment depending upon the waste characteristics. The primary mechanism of degradation in a landfarm is aerobic as apposed to anaerobic under reducing conditions in a landfill. Clearly, landfarming is unacceptable for heavy metals which do not degrade. A comparison of the unac-

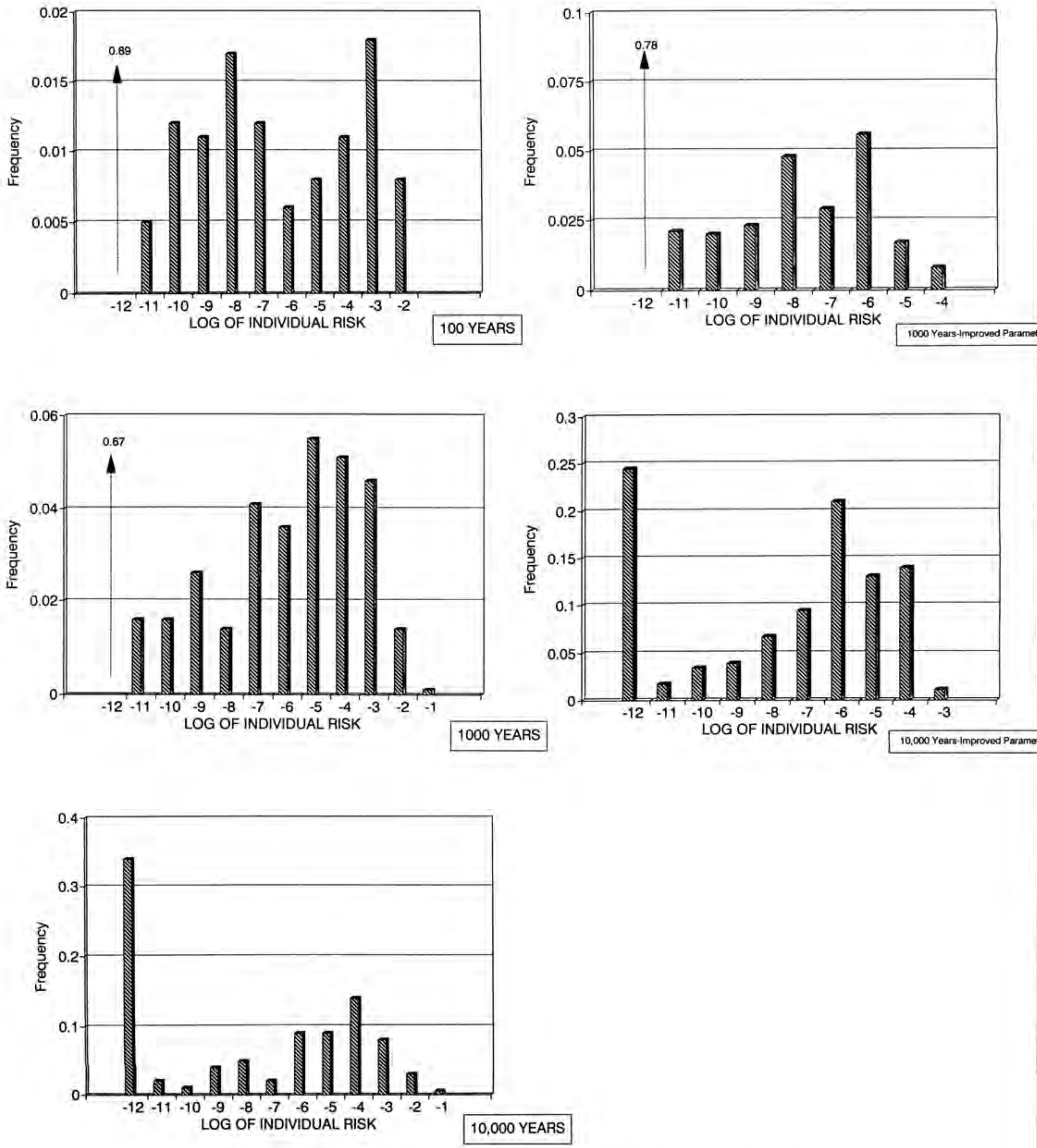

Fig. 4. Histograms for individual risk due to Heptachlor at Velsicol disposal site.

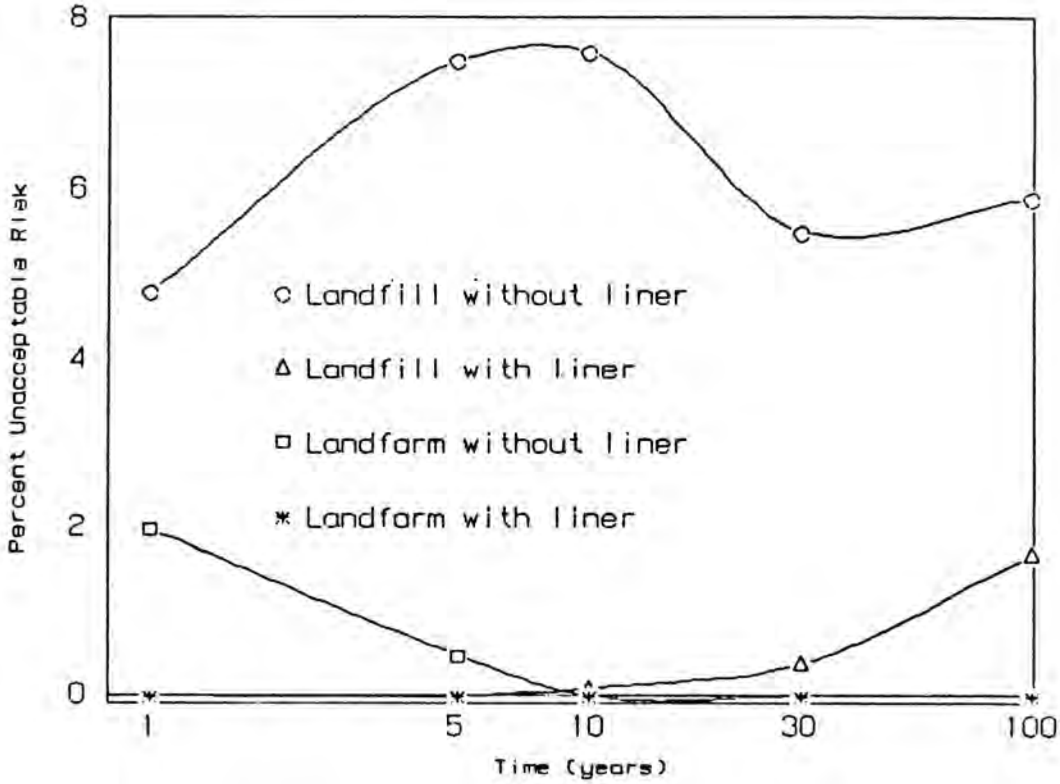

Fig. 5a. A comparison of individual risks from Benzene.

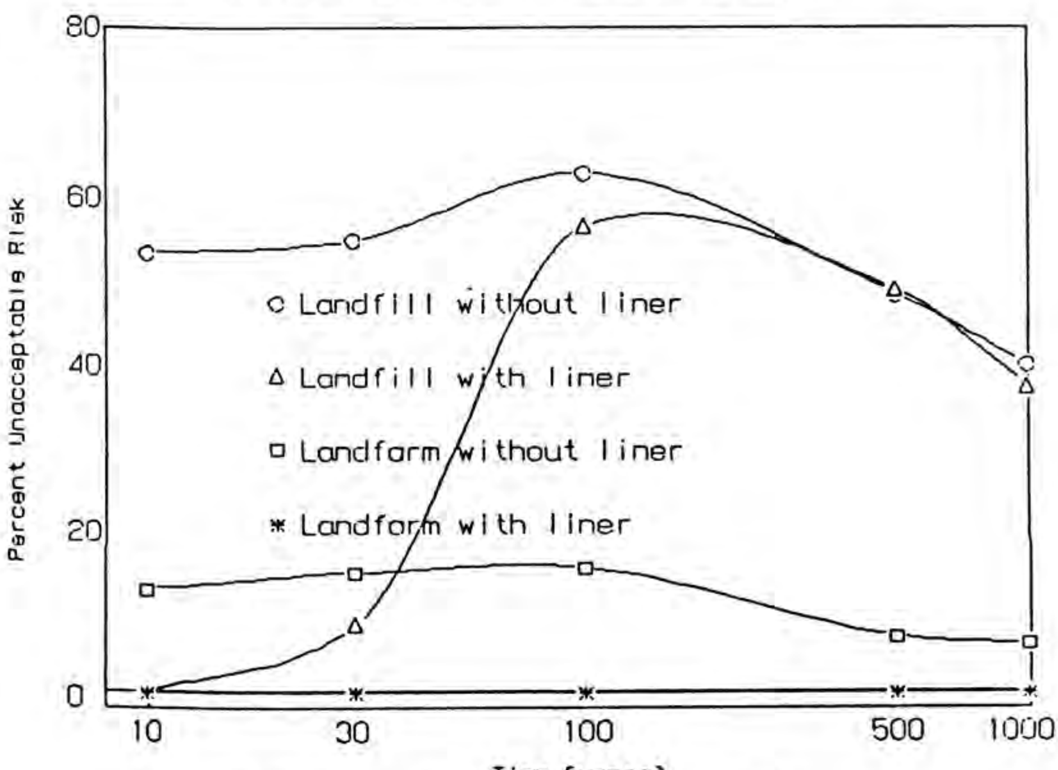

Fig. 5b. A comparison of individual risks from CCL4.

TABLE II

Summary of Results

Trial Period/Liner		Deterministic Median Values	Deterministic Extreme Values	Probabilistic 95% level Confidence	Probabilistic Percent Unacceptable
Benzene			Log Individual Risk		
5 yrs	No	No Risk	-0.13	-3.5	7.2
5 yrs	Yes	No Risk	No Risk	No Risk	0.0
100 yrs	No	No Risk	No Risk	No Risk	2.0
100 yrs	Yes	No Risk	No Risk	No Risk	0.8
Heptachlor			Log Individual Risk		
30 yrs	No	No Risk	-1.55	-4.2	8.4
30 yrs	Yes	No Risk	-2.33	No Risk	0.8
100 yrs	No	No Risk	-1.51	-4.0	8.8
100 yrs	Yes	No Risk	-1.51	-4.8	7.2
500 yrs	No	No Risk	-1.51	-5.0	5.8
500 yrs	yes	No Risk	-1.51	-5.2	4.4
Lead			Log Concentration (g/l)		
30 yrs	No	-10.67	-2.25	-3.1	21.2
30 yrs	Yes	No Risk	-2.25	-5.8	2.4
1000 yrs	No	-3.74	-2.25	-2.4	55.6
1000 yrs	Yes	-3.74	-2.25	-2.6	44.8

ceptable risks for benzene, heptachlor and carbon tetrachloride was carried out by Rinko Ghosh (16). The results for benzene and carbon tetrachloride and are shown in Figs. 5a and 5b. respectively. Risks by deterministic algorithms using median values were also calculated. Contaminants that are volatile can lose material to the atmosphere where the dilution factors are great. Aerobic degradation, in general, is more rapid than anaerobic degradation . For carbon tetrachloride, landfills without liners were unacceptable for all time periods and with liners were only acceptable at times less than 100 years. For both benzene and heptachlor deterministic calculations gave acceptable risks for both landfills, with or without liners, and land farms. For the probabilistic case, land farming would be preferred to landfilling for benzene and heptachlor. Even though land farming is more effective for carbon tetrachloride than landfilling, it is still not effective enough and incineration would be required.

Cutoff Walls at Hazardous Waste Sites

Yen-Chung Huang tested the efficacy of cutoff walls combined with synthetic membrane caps to remediate CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act) landfills. He showed that the solubility, degradation, and geotechnical characteristics of the wastes dominated the results. For all four combinations, benzene had the highest unacceptable risk at five years. Within 30 years, its risk was acceptable. Heptachlor's risk was highest at about 100 to 150 years, but by 1000 years its risk was acceptable for all cases. Because of lead's low mobilization, its risk was low to begin with, but progressively increased with time.

Mixed Waste Treatment

Mixed hazardous chemical and radioactive wastes are presently orphan wastes. No commercial landfill will accept

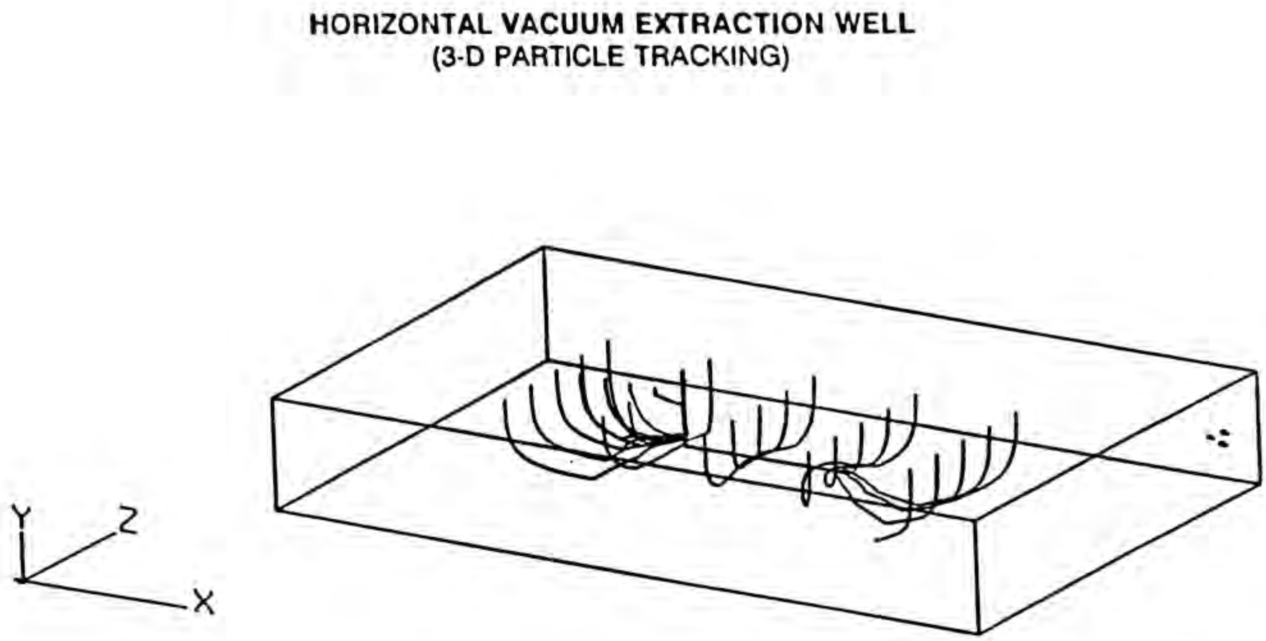

Fig. 6. 3-D particle tracking (full view).

them. In the cleanup of the FUSRAP (Formerly Utilized Sites Remedial Actions Program) Colonnie Interim Storage Site the waste was depleted uranium contaminated with an oil and water emulsion, i.e., a mixed waste. Mike Vick, an intern, with the help of Professor Alan Bowers developed a treatment system to separate the oil and the uranium from each other and from the water so that the water could be disposed of in the town's sewer system and the oil and uranium solidified and shipped to their respective disposal sites (18). First, the tramp oils on the water surface in the tank were sorbed. The oil-water emulsion was broken by an acid-alum split (pH < 2.0). Then, alum [$Al_2(SO_4)_3$] was added to act as a coagulant and adsorbent. Finally, sodium hydroxide was added to raise the pH to 6.7, causing the precipitation of the aluminum hydroxide. The supernatant was then, raised to a pH > 10 by further addition of sodium hydroxide to cause the precipitation of uranic oxide (UO_3). The process worked successfully and, of the initial 1000 gallons of waste, 860 gallons of decontaminated water were deemed safe for discharge to the sewer, and the 30 gallons of tramp oil, 40 gallons of uranic oxide slurry and the 70 gallons of aluminum hydroxide slurry were individually solidified with a gypsum cement and disposed of.

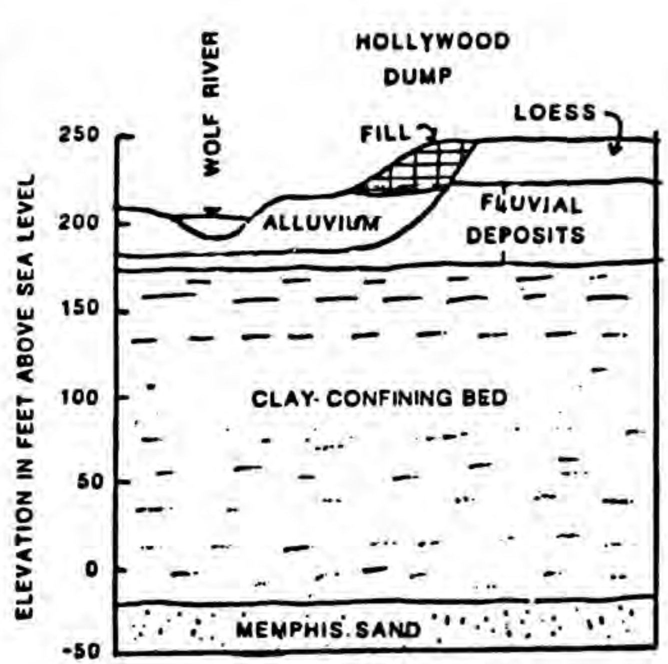

Fig. 7. Profile beneath North Hollywood Dump (after Broshears, 1986).

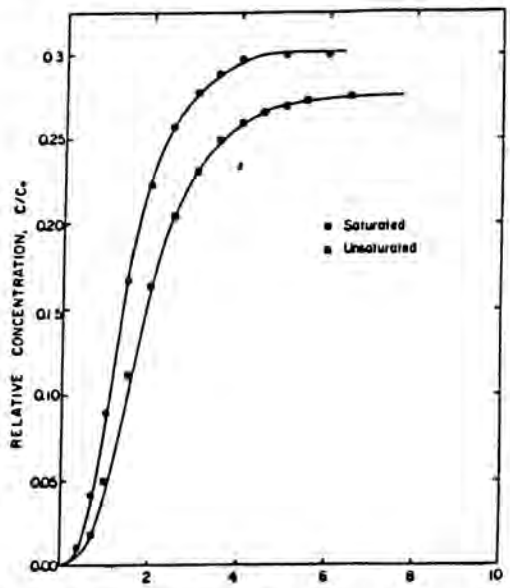

Fig. 8. Relative concentration vs. time, Hollywood Dump, at x = 400 m.

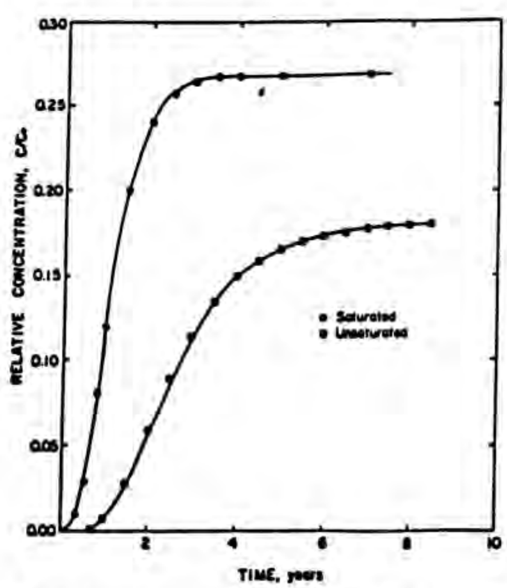

Fig. 9. Relative concentration vs. time, Hardeman County site, at x = 1000m.

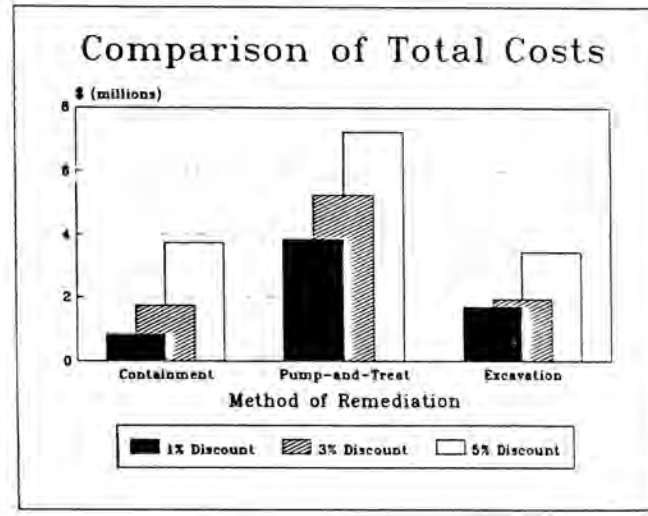

Fig. 10. Comparison of total costs.

Waste Minimization

Alpha Waste

Plutonium-238 is used for specialized energy sources. In the course of the manufacture of the energy sources, waste is generated. Waste disposal is expensive, but the loss of the plutonium is even more expensive. The production of Pu-239 and the wastes must be handled within glove boxes, hermetically sealed, to prevent the loss of the extremely toxic alpha-producing wastes. Bill Crawford, an intern, designed a pyrohydrolysis incinerator (to maintain temperatures low enough to extract the Pu after incineration), that would fit into a glove box (19). The cost of the system was $300,000 and the avoided costs of waste disposal of plutonium-contaminated waste was $400,000 the first year alone. This ignores the value of the estimated 10 kg of Pu-238 per year that will also be recovered.

Radioactive Waste Tank Farms

Chris McKee, an intern, worked at the Tank Farms in 200 East Area at the Hanford, Washington site. He devised means to minimize three different waste streams (20). Deintrainment sprays presently utilize 2 gpm of uncontaminated water which is then added to the waste stream. By recycling process condensate to the spray, this added waste stream is eliminated. Including disposal costs, there will be a net savings of $75,000 per year. Vacuum pumps used for air sampling now use water seals. By replacing these pumps which must operate continuously, even when the evaporator is not operating, with electrical oil-sealed pumps, the water consumed is reduced by 4 gpm. This should result in savings of about $200,000 per year. The third minimization project would replace the steam ejectors used to transfer wastes with an oil-sealed pump and would eliminate 3 gpm of process waste. It is estimated that this would result in a savings of $260,000 per year. (The savings are not linear with volume as it is also a function of the quality of the waste and the treatment required for it.)

Similar savings would result from making these changes at all the waste farms. It would be worthwhile to make the changes for the dollar savings alone, but in addition, it will meet legal requirements, reduce wastes, reduce potential liabilities, and would enhance the corporate image.

Solar Distillation of Well Water

When groundwater is sampled for RCRA (Resource Conservation and Recovery Act) contaminants the well must first be purged to get a representative sample. The purged water cannot be reinjected or disposed of on the ground surface. When the well is in a remote location, then the problem of disposal of the discarded well water can become formidable. Consequently, low cost, locally applicable methods must be sought. Scott Thompson, an intern, investigated the use of solar stills to reduce the volume of the extracted ground water (21). Scott found that relative humidity had no effect on the evaporation rate while the rate was linearly proportional to the area and approximately exponentially proportional to temperature. He further found that the evaporation rate did not decrease significantly until the dissolved solids reached a concentration of 180 grams per liter and salt crystals did not form until a concentration of 7.2 gm/l was reached. The effect of the crystals on the evaporation rate (shielding of the black bottom area of the still) has not been investigated. As a result of the success of these experiments, a prototype still will be built to determine the efficiencies and costs of such stills and their applicability to remote sites.

Innovative Remediation Techniques

Horizontal Wells to Extract Organic Vapors from Groundwater and the Vadose Zone

At the M area at the Savannah River site, an area along the sewer line is contaminated with trichloroethylene and tetrachloroethylene. The integrated experiment (a cooperative project of a number of labs) will inject air from a horizontal well into the ground water below the contaminated zone. As the air rises through the ground water and into the vadose zone, it strips the volatile organics. Above the contaminated zone, an horizontal well will create a negative pressure and vacuum the stripped organics out of the soil matrix. Jonathan Huddleston, an intern, modelled the air flow around the vacuum extraction well with a 3-D particle tracking program (22). A schematic of the movement after 5000 days is shown in Fig. 6. Testing of the single horizontal well system showed that it was more effective than an eleven vertical well system in the same area.

Bioremediation

Angela John, an intern, used a benchtop continuous-flow liquid-culture bioreactor, inoculated with a trichloroethylene (TCE) degrading species of bacteria to conduct a series of experiments dealing with the biodegradation of TCE (23). Time varying pulses of TCE-contaminated groundwater were introduced to assess the effect of TCE. The optimum pulse length of TCE introduction:

1. did not negatively affect the microbial culture, no toxicity or starvation effects,as measured by absorbance and direct count techniques.
2. did result in a decrease in TCE concentration in the reactor which could not beaccounted for by dilution, off-gassing, or absorption to physical components ofthe system. Ambient TCE concentration in the system was measured by gas chromatography.

This methodology could provide a first approximation of optimum pulse length for a continuous-flow pump-and-treat systems to be used for biodegradation at the integrated demonstration site. Before the methodology can be used practically, however, more work must be done to establish the statistical validity of the data collected and to further understand the processes occurring within the biological system.

Groundwater Contamination Assessment

Vadose Zone Approximation

In most hazardous and low-level radioactive waste burial grounds, the waste trenches are above the water table. When a risk assessment is made of the travel of the wastes to the point of use, the conservative assumption is made that there is no vadose zone, i.e., that the zone beneath the trenches is always saturated. However, the degree of this conservatism is unknown. To determine the relative conservatism, Lance Cooper, an intern, utilized the SUTRA model (developed by Clifford I. Voss) of the USGS in both the saturated and unsaturated mode (24).

SUTRA (for Saturated-Unsaturated TRAnsport) is a groundwater transport model that allows simulation of either totally saturated systems or combined saturated-unsaturated systems. It may be used for either areal or cross-sectional saturated simulation or cross-sectional unsaturated simulation. It was applied to two of the National Priority List sites in Tennessee-Hardeman County, already discussed, and North Hollywood.

Though there were many chemicals placed in the North Hollywood site, shown in cross-section in Fig. 7, the calculations were carried out for chlordane alone. The site has 3.5 m. of unsaturated soil. (Chlordane is moderately soluble and has a half-life of approximately ten years.) The results are shown in Fig. 8, where it can be seen that the saturated solution is conservative. Seven years after emplacement the leachate profiles had reached steady state. As is to be expected, due to lack of dilution, the concentrations directly beneath the site are greater for the unsaturated condition than for the saturated condition by about 35%. The resultant concentrations are shown at 400 m from the waste site. It can be seen that the concentrations for saturated conditions are higher than for conditions with an unsaturated zone. At steady state, the safety factor is about 10%.

For Hardeman County, similar calculations were carried out. There the unsaturated zone is about 15 m, as shown previously, and the pollutant of concern is carbon tetrachloride, which is highly soluble but is deemed to be non-biodegradable. The results are shown in Fig. 9, where it can be seen that steady state is approached in five years for the saturated case and ten years for the unsaturated case. Here it can be seen that the saturated case is conservative by about 50%.

The factor of safety was less than two for both waste sites considered in this study. That is, at the same offsite location and at steady state, the saturated concentration was less than twice the unsaturated concentration. The uncertainties that are involved in parameter estimation for the system may cause variances this great, or greater. Though there is no generic solution to this problem, based on these two cases, it would appear that the inclusion of the unsaturated zone is not warranted in cases where the disposal facility is located in humid regions. This may not be true in arid regions where the depth to the water table is frequently considerably greater than either of the two cases that were considered in this work.

Pump and Treat Efficacy

Over two-thirds of Records of Decision for Superfund (CERCLA) site cleanup select extraction of the contaminated groundwater by wells and treatment of the groundwater at the surface to achieve aquifer restoration (25). Recently, a number of prominent geohydrologists and risk assessors have challenged the efficacy of this method. Therefore, Philip Johnson, an intern, did a study (26) of this option by utilizing a finite difference model developed by David Wilson (27). TCE has a maximum permissible concentration of 2.7 parts per billion in drinking water. For this study it was assumed that the concentration in the plume was 27 parts per million. Therefore, one barrel of TCE (55 gallons) could contaminate over 100,000 cubic meters of ground water to this level. To reach drinking water standards, 99.999 percent of the mass of the pollutant must be removed. The model indicated it would take 42 years of pumping and treating to reduce the TCE concentrations to drinking water standards. (This was based upon using a 3-spot well pattern having a pumping rate of 15 gpm, a K_D value of 4.0 ml/g, porosity of 0.3 and a TCE half-life of 20 years and treating 10.7 pore volumes per year). This "high tech" option was compared with pumping for (265 years before natural degradation reduces the concentration to drinking water standards) containment purposes only and with excavation and landfill. These options were compared and a sensitivity analyses carried out. The results are shown in Fig. 10. Though containment was least expensive, it was only slightly less expensive than excavation and land filling but which was less expensive at the 5% true discount rate. Pump-and-treat was at least twice as expensive at all discount rates. Perhaps more importantly, this modelling of the pump-and-treat method treats TCE as totally miscible with water when in fact it will sink to the bottom of the aquifer (density equals 1.46) and will only slowly (solubility product) be incorporated into the fluid flow in the aquifer.

CONCLUSIONS

These research results represent only a small fraction of the work in environmental remediation and waste management of hazardous chemical and radioactive wastes done by students at Vanderbilt University. Though the Internship Program was initiated prior to the new commitment of the Department of Energy to education, it has fulfilled DOE's desire to bring bright, talented young people, including women and minorities into this new and exciting field.

Last year among the interns there were three women including one minority student. This year there are two women including one minority student. Of the 43 students who have participated in the program, 14 are still at Vanderbilt University. Of the remainder, 90% are in the environmental restoration and waste management field including graduate school, 15% are working for DOE contractors, 30% for DOE consultants, and 5% are in military service. Their summer work and proposed theses have resulted in one paper each year presented at a national conference and one paper each year published in a peer-reviewed journal.

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