The Utilization of Bioremediation to Reduce Soil Contamination: Problems and Solutions

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The Utilization of Bioremediation to Reduce Soil Contamination: Problems and Solutions

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PREFACE

Increasingly, modern society relies on a striking array of organic chemicals and the quantities of these compounds used on a yearly basis are staggering. As a direct consequence of their industrial, agricultural or domestic usage, occasionally as a result of accidents or negligence, ever-increasing amounts of these chemicals are released into the environment. There, they present risks to ecosystems and human health, since many organic pollutants are toxic to living organisms even in minute quantities. As a result, pollution in the atmosphere, seas and oceans, surface waters, and subsurface porous formations (soils, aquifers) by organic chemicals has become a cause of major societal concern in industrialized countries during the past forty years.

Since the seventies, public officials and the private sector have responded to this concern with a vigorous remediation effort. Various strategies have been adopted, largely based at first on *ex situ* treatments. For contaminated sediments, for example, they include incineration or disposal in landfills. "Pump-and-treat" (or "soil washing") procedures have also been developed, in which the polluted groundwater is pumped to the soil surface, treated to reduce the contaminant(s) concentration to an environmentally-acceptable level, and re-injected in the aquifer some distance away. The aboveground treatment of the pumped groundwater relies on physical, chemical or, occasionally, biological processes.

In the early eighties, interest shifted from above- to below-ground (or, more generally, from outside to inside polluted ecosystems) with the proposal that remediation might be carried out more directly in situ by fostering the growth of microorganisms capable of degrading targeted organic pollutants. These microorganisms may be indigenous to the polluted ecosystem, or may be injected specifically to carry out the in situ bioremediation. Compared with most physical or chemical procedures (like incineration, vitrification, or extraction), biologically mediated treatment strategies present the highly desirable feature of allowing, in principle, the complete eradication or mineralization of organic xenobiotics. In addition, they have generally lower capital and operational costs. These different advantages, combined with the enthusiasm of scientists, convinced a number of entrepreneurs to start bioremediation companies, or to reorient existing businesses in this promising direction.

Unfortunately, since that "pioneer" time in the mid-eighties, few of the original expectations seem to have been met by practitioners, and the initial euphoria has drastically subsided. The rate of adoption of in situ bioremediation strategies has been stagnating in recent years. In 1992, bioremediation was adopted in approximately 9 % of all Superfund remedial actions in the United States, with a little less than half of these actions taking place *in situ*. Two years later, in 1994, again at Superfund sites in the US, bioremediation was the technology of choice in 10 % of the cases. In situ bioremediation was used in 4% of all cases, i.e., at a mere 25 sites. Statistics are not available for more recent years, but it is generally agreed that the market share of bioremediation (*ex situ* and *in situ*) has only marginally increased since 1994, in the US as well as in Europe.

Some reasons for the disappointing rate of adoption of *in situ* bioremediation strategies are common to all the remediation strategies at the low end of the cost spectrum. Delays, whether because of disincentives to initiate remediation or because of bureaucratic inefficiency, substantially weaken the market for inexpensive, effective remediation technologies. Specifically, however, the key reasons for the stagnation of the bioremediation market (and for the ensuing bankrupcy of many start-up bioremediation companies over the last few years) seem to be the frequent inability of *in situ* bioremediation strategies to decrease contaminant concentrations below regulatory levels in a timely fashion. This may be caused by extreme pollution at the sites, with contaminant concentrations at or above levels that are toxic to microorganisms. However, even when conditions seem optimal for biodegradation of the pollutants to occur, the rate of the process often drops rapidly to inconsequential levels, allowing unacceptably high amounts of the contaminant(s) to remain in the system. In addition, in some well-documented cases where bioremediation had successfully decreased pollutant concentrations below regulatory levels, the clean-up turned out to be only temporary. After a few months, the contaminants were once again present in ground- and surface water at environmentally unacceptable concentrations.

In retrospect, it seems clear that bioremediation, *in situ* or *ex situ*, was promoted in the mid-eighties at a time when the basic knowledge needed to make it work in the field was woefully inadequate or even was entirely lacking. As is often the case under similar circumstances, and in spite of the fact that some of the required basic information was slowly but surely being produced by scientists, bioremediation lost much of its appeal and popularity in the nineties, and suffered a severe backlash, particularly in the US. This pendulum swing, in turn, contributed to distort somewhat in the minds of many the true usefulness of bioremediation strategies.

In that context, a NATO Advanced Research workshop was organized and held in Liblice (Czech Republic) in June 2000, to set the record straight. Specifically, this ARW was meant to provide to a group of specialists the opportunity to assess as accurately and objectively as possible the state of the science related to bioremediation, to point out areas where further research is vital, and to document and evaluate in detail a number of practical situations where bioremediation either failed or successfully met its intended objectives.

Even before the ARW was publicized, the organizers began receiving what eventually became a flood of applications, from several hundred individuals, practitioners as well as scientists. This enthusiastic response alone evinced that, paraphrasing Mark Twain, news of the demise of bioremediation may have been exaggerated, and that there was still a widespread belief that bioremediation remained a viable and promising technology. Of these hundreds of applicants, 47 participants and 11 observers were selected, representing 23 countries (Austria, Belarus, Belgium, Bulgaria, Canada, Czech Republic, Estonia, France, Germany, Greece, Israel, Italy, Latvia, Lithuania, The Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Ukraine, United Kingdom and United States).

Among the many topics addressed during the workshop, three were of particular significance. The first concerns the development of suitable toxicological tests to be used in conjunction with bioremediation strategies. Traditional reliance on chemical analysis to understand the direction and extent of treatment in a bioremediation process has been found to be inadequate. Whereas the goal of bioremediation is toxicity reduction, few direct, reliable measures of this process are as yet available. Toxicity measures in aquatic systems have been developed in recent years. However, equivalent methods for use in soils and sediments are direly needed. The efficacy of each method must be evaluated for application to soil. Test reliability, difficulties in the interpretation of the results, and lack of correlation among methods are the major hurdles limiting at present the utility of toxicology tests to determine suitable targets for bioremediation operations. Discussion of this concern led to heated debate among workshop participants.

Another area of intense discussion was the assessment of market forces contributing to the acceptability of bioremediation. Perspectives of the US and Czech Republic markets provided significant understanding of this poorly recognized factor.

Finally, another important component of the meeting was a series of lectures and lively exchanges devoted to practical applications of different bioremediation technologies. The range of subjects covered a wide spectrum, encompassing emerging technologies as well as actual, full-scale operations. Examples discussed included landfarming, biopiling, composting, phytoremediation and mycoremediation. Each technology was explored for its utility and capability to provide desired treatment goals. Advantages and limitations of each technology were discussed. The concept of natural attenuation was also critically evaluated since in some cases where time to remediation is not a significant factor, it may be an alternative to active bioreme-diation operations.

All of these themes are covered in the present book, which emanates from the 2000 NATO ARW and covers much of the same ground. Yet, in the intervening two years, the scope and content of the chapters have evolved in many cases compared to the lectures presented in Liblice, in part because of the insightful comments of reviewers and of the improved understanding of a number of issues as a direct result of the ARW itself. The result is a unique book that provides apparently for the first time an up-to-date, comprehensive assessment of bioremediation strategies, which we hope will be invaluable to scientists and practitioners alike.

Publication of this book would not have been possible without the extremely helpful assistance of Professor A. Kotyk, who polished the English of the various chapters authored by non-native English speakers, and of Dr. J. Cudlín and Dr. Č. Novotný, who prepared the final, camera-ready version of the text. Sincere gratitude is also expressed toward Dr. Alain Jubier, director of NATO's Scientific Affairs Division, and to his administrative assistant, Mrs. Lynn Campbell-Nolan, for their infaillible and stimulating support.

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