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THE NICOLE/NOBIS CONFERENCE ON *IN SITU* BIOREMEDIATION

Review of the Meeting at:

Golden Tulip Barbizon Palace Hotel, Amsterdam, Netherlands
on Friday 10 October 1997

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Abstract

Two European contaminated land networks NICOLE and NOBIS held a joint conference on recent advances in the state of the art of bioremediation. NICOLE is a concerted action of the EC Environment and Climate Research Programme. NOBIS is a national programme of the Netherlands. Four technical areas were considered:
- natural attenuation/extensive remediation,
- intensive remediation,
- remediation monitoring
- decision support systems.

Projects were presented from the following programmes: EC Environment and Climate, NOBIS and the US Remediation Technology Development Forum (RTDF) focusing on the state of the art in bioremediation across these four areas.

NICOLE and NOBIS outlined their interests, membership, activities and opportunities for collaboration. Each network has a considerable basis of expertise and information. (Contact points for further information are given in the body of the paper).

At the meeting, NICOLE and NOBIS agreed to collaborate at a strategic level on information dissemination; including through their web sites, newsletters and conferences. In addition, three specific technical areas of collaboration are to be explored.

1. Natural attenuation
2. Decision support systems
3. Field testing of NOBIS technologies by NICOLE members

NICOLE and NOBIS will also collaborate with the RTDF Bioremediation of Chlorinated Solvents Consortium in their work on natural attenuation.

Introduction

NICOLE, the Network for Industrially Contaminated Land in Europe, is a Europe wide initiative by industry and the European Commission to provide a forum for problem holders and researchers to come together to find workable solutions to the problems of contaminated land. Its initial budget (1996) was 650,000ECU. The network as presently constituted will run to the beginning of 1999, [Annex 1].

NOBIS, the Dutch Research Programme on *In Situ* bioremediation is a Public – Private partnership. Its objective is to develop, evaluate and demonstrate innovative strategies, methods and techniques, which will effectively deal with contaminated land using *in situ* bioremediation. The programme will run until the end of 1998 and has a budget of 37.5 million Dutch Guilders, one third of which is contributed by the Private sector. [see Annex 2].

Both NICOLE and NOBIS aim to foster public/private sector collaboration in research, development and demonstration projects. These similarities in interest led to a joint conference on *in situ* bioremediation in Amsterdam during October 1997.

The objectives of this conference were to:

1. Explore the activities and general outlook of each organisation;
2. Review progress and research findings to date in each organisation;
3. Identify opportunities for future collaboration.

The conference also sought to draw upon the state of the art in the USA, in particular the Remediation Technologies Development Forum – RTDF [see Annex 3] and general progress in bioremediation [see Annex 4].

This summary paper presents overview of NICOLE, NOBIS and the RTDF. It describes the type of work taking place in NICOLE and NOBIS and outlines the common views from the October meeting. It also draws upon the fundamental contaminated land research projects of the EC Environment and Climate Programme. A detailed meeting report is available from the NICOLE secretariat at TNO (see contacts table). The meeting was divided into four themes:

- Natural Attenuation/Extensive Remediation
- Intensive Remediation
- Remediation Monitoring
- Decision Support Systems

NB Extensive and Intensive Treatments. Many remedial treatments operate over the shorter term and require relatively high cost and energy inputs. These are referred to as “intensive” treatment technologies. Extensive technologies operate over a longer period with low maintenance, cost, and energy requirements. Effective treatment may reduce contaminant concentrations, environmental mobility, availability/toxicity, or enhance natural attenuation processes. Techniques include hyper-accumulator plants/enhanced rhizosphere mediated biodegradation, and fixation by minerals.

A range of oral papers and posters were presented for each theme followed by a discussion to draw common threads from these papers. These presentations drew on projects from NOBIS and NICOLE, although several EC Environment and Climate Programme and US RTDF Bioremediation of Chlorinated Solvents Consortium projects were also presented.

Natural Attenuation/Extensive Remediation

Seven papers were presented:-

1. Natural Attenuation, in Controlling Leachate Landfills
2. Bioremediation of Sediments in Combination with Beneficial Land Use
3. Processes Underlying Remediation of Creosote Contaminated Groundwater in Fractured Sandstone
4. Intrinsic Bioremediation at Six Laundry Sites
5. *In situ* Bioscreens
6. Strategies for rehabilitation of Metal Polluted Soil, *In Situ* Remediation, Immobilization and Revegetation
7. The Natural Attenuation of Chlorinated Ethenes at Dover Airforce Base, Delaware, USA

1. The first paper of the session proposed an evaluation of the capacity of natural attenuation processes to limit the migration of landfill leachate plumes. Field scale work is scheduled to begin in 1998. Natural attenuation is seen as an important prospect for reducing the cost of dealing with the estimated 3,000 abandoned landfill sites in the Netherlands.

2. Dredged harbour and river sediments are a major disposal problem in the Netherlands. A significant proportion of this material is polluted with polynuclear aromatic hydrocarbons (PAH) and mineral oils. These sediments are typically treated by landfarming, however some PAH’s persist for several years. The use of willow coppicing is to be investigated, both to accelerate the degradation of these contaminants and to achieve productive use of the land. Root zone enhancement of biodegradation is postulated, with energy recovery from the harvested willow bromass.

3. An EU supported project has been investigating the degradation of contaminants in a sandstone aquifer beneath a coking plant. Despite intensive sampling, the expected contamination by organics (phenols) in the UK was not apparent. However, ammonium compounds revealed that extensive contamination had taken place, and they remain in the vicinity of the site.

4. Contamination by chlorinated solvents, such as those used by the dry cleaning industry, has typically been considered an intractable problem under natural conditions. However, evidence accumulated over recent years demonstrates that intrinsic biodegradation processes can take place depending on the availability of sufficient and suitable organic matter co-substrate. The exact nature of some of these processes and how they might be enhanced is currently an important research and development issue.

5. *In situ* bioscreens represent a new and emerging technology for *in situ* isolation and remediation of contaminated sites. An *in situ* bioscreen is a local zone in a natural porous medium such as soil that has a high contaminant retention capacity (isolation) and an increased biodegradation activity of hazardous organics and/or the immobilisation of dissolved heavy metals. Thus, contaminants are removed from groundwater flowing through such a bioscreen. Laboratory bench scale tests with bioscreens made from activated carbon particles with attached microbes supplied with various electron donors/acceptors are being studied.

6. In another EU project, two extensive approaches are being evaluated and compared for the rehabilitation of metal polluted soils. The first approach is metal/metalloid immobilisation with metal/metalloid binding soil additives, either with or without revegetation. In the second strategy, metal bioextraction use of accumulator plant is being investigated.

7. Interim findings for an RTDF project at Dover Air Force Base are strongly indicative of processes of intrinsic biodegradation of chlorinated ethenes. The degradation of these chlorinated solvents is mediated by a complex interaction of biological and geo-chemical processes combining sequential anaerobic-aerboc degradation of chloroethenes.

Intensive Remediation

Seven papers were presented:-

1. Microbial Adaptation to Degradation of Natural and Synthetic Organohalogens
2. NOBIS Biosparging and Bioventing: design and monitoring
3. Demonstration of Accelerated Anaerobic Bioremediation for Tetrachloroethene (PCE) and Trichloroethene (TCE) Contaminated Groundwater at Dover.
4. *In situ* Remediation of Poorly Permeable and Layered Soils
5. Degradation of Xenobiotics by Thermophilic Micro-organisms
6. Laboratory and Field Pilot Evaluation of Co-Metabolic Bioventing for the Remediation of Soil Contaminated with (TCE) and Trichloroethane (TCA)
7. Stimulation of Reductive Dechlorination for Complete Biological *In situ* Remediation of Soils Contaminated with Chlorinated Ethenes.

1. Synthetic organohalogen compounds are environmental pollutants of major concern. However, a wide range of organohalogens is also naturally produced, suggesting that there may be micro-organisms and enzymes for their degradation. New dehalogenating organisms have been isolated and characterised in this EU project, both biochemically and genetically. A group of mutually identical haloalkane dehalogenases that degrade various and synthetic organohalogens was identified. New mono-oxygenase-like halogenating enzymes were studied by genetic analysis.

2. The main goal of the NOBIS Biosparging and Bioventing project is to generate design principles and to evaluate extensive remediation strategies in which biosparging and bioventing plays an important role. The project is focused on improving design, monitoring and the prediction of the remediation process.

Demonstrating the effectiveness of biosparging and bioventing for biodegradable compounds in practice is one of the main issues in this project. The results of the research will be used in a decision support tool (ESS: Expert Support System)

3. Past use of solvents for degreasing, has resulted in a plume of PCE and other chlorinated aliphatics in the sandy aquifer at Dover Air Force Base, USA. Initial findings of laboratory scale work being carried out under the RTDF indicate that partial dechlorination can take place under anaerobic conditions mediated by the microbial community. Complete dechlorination took place following bioaugmentation with a specialist consortium obtained from another site. Initial field scale testwork indicates that this bioaugmentation also appears active in the field.

4. Poorly permeable and layered soils present particular problems for both enhancing and monitoring bioremediation. Initial results from the use of biosparging to create a "bioscreen" were presented. A key problem is determining the extent, location and impact of preferential pathways of air and water flow.

5. The potential of a range of thermophilic organisms to degrade organic compounds was examined in this EU project. A range of *Bacillus* strains has been isolated able to dechlorinate TCE and other solvents at 65^0C, although identification of the strains is not complete. However, the usefulness of thermophilic organisms in bioremediation is thought likely to be particularly advantageous for compounds with lower solubility and bioavailability under ambient temperatures.

6. Labscale cometabolic bioventing studies using soils from the same site as Paper 3 indicate that aerobic biodegradation of TCE and TCA is possible in the vadose zone using toluene, methane or propane as co-substrates. Field scale testing of this approach has recently begun.

7. Observations of degradation products in groundwater around the site of a former blender of chemicals indicated that some dehalogeneration of PCE and other solvents was already taking place under natural conditions. Laboratory column tests were demonstrated partial dechlorination under anaerobic conditions with the addition of various organic electron donors (methanol, lactate etc). Dechlorination of chlorinated ethanes and ethenes was observed with 'natural' organic amendments based on a mixture of organic acids and humic substances.

<u>Remediation Monitoring</u>

Six papers were presented:

1. Optimising the selection of monitoring parameters for bioremediation
2. Phased Flexible Emission Control (FEC): a New Cost Effective, Fail-Safe Approach for (Large Scale) Soil and groundwater Remediation
3. Seismic Tomography to Characterise Subsurface Lithology and Permeability
4. A project to develop Fiber Optic Chemical Sensors for the Determination of BTEX and Chlorinated Solvent Concentrations in Soils
5. Bioassays as Monitoring Instrument

6. Optimization of Bioventing by On-Line process Monitoring and Control

1. A structured protocol (PIQQ) has been developed to optimise the selection of monitoring parameters for bio-remediation. Its objective is to focus efforts on key parameters that provide maximum information. Parameters are divided into four classes *Process conditions* (e.g. pH), *Indicative parameters* for biodegradation (eg biomass), *Quantitative parameters* for biodegradation (eg O_2 consumption) and *Quality parameters* (eg bioassays of residual toxicity).

2. In the Netherlands isolation, containment and monitoring (ICM) has usually been required where the treatment of hazardous contamination is not considered feasible. A more flexible approach has been proposed, with efforts focusing on monitoring. Isolation and containment measures would only be employed if shown to be necessary by monitoring data.

3. Seismic tomography is being investigated as tool to provide detailed information about heterogeneity in subsurface conditions. Field scale test work around a former rubbish dump is currently underway in the Netherlands.

4. One of NOBIS' major monitoring R&D projects is the development of an optical sensor for BTEX compounds and chlorinated ethenes. Similar sensors have already been devised and one product is commercially available for measuring total hydrocarbon concentration. Two types of instruments are foreseen, an improved version of the currently available total hydrocarbon probe and a totally new instrument: a penetrometer based device that can be pushed into the soil.

5. Bioassays are intended to provide a direct assessment of toxicity for determining potential impacts on and risks to human health and the environment, and so supplement chemical analyses. However, problems with their use include: lack of consensus on representative test organisms, lack of agreed assessment criteria and reference values. Efforts are underway to develop bioassays as a monitoring instrument for bio-remediation, along with a set of reference data on toxicity values.

6. Optimisation of bioventing based on monitoring data has been tested at a site with heterogeneous ground conditions and contaminated with a petrol spill. *In situ* respiration measurements were found to be a useful tool. Two basic operational tests were distinguished: stop tests (i.e. the *in situ* respiration measurement), and start tests where the response of volatile contaminants in the soil to airflow could be determined.

Decision Support Systems

Six papers were presented:

1. REC: a Decision Support System to Increase Efficiency and Effectiveness of Soil Remediation
2. A Proposed Guidance Document on Intrinsic Remediation of Chlorinated Solvents and an Associated Training Package

3. Restrisk: Risks of the Residual Contamination in Soil after Remediation
4. The Netherlands Decision Support System for Natural Attenuation
5. Contaminated Site Assessment: measurement and testing with VOCs sensors
6. Risk Assessment of Spreading: a Concept

1. Decision support systems for soil remediation have typically focussed on immediate project related needs such as cost, available time and space and desired remediation objectives for a site. They tend to discount broader factors that are often important, in particular "environmental merit". Environmental merit describes the broad environmental costs and benefits of a process such as use of resources such as clean water and energy, and broad environmental impacts such as air emissions of greenhouse gases. REC is a system that incorporates an environmental merit index into its decision-making algorithm, with a view to encouraging more sustainable remediation practice.

2. The importance of adequate training for decision-makers was highlighted by a presentation from the RTDF. They have developed a training course to raise awareness and understanding of natural attenuation in collaboration with the Interstate Technology and Regulatory Co-operation Workgroup (ITRC) of the Western Governors Association. The primary audience for the course is regulators and other professionals working with contaminated land. The course has been delivered to a number of groups across the USA and it is planned to make this available to interested parties in Europe. In addition, a document entitled "Natural Attenuation of Chlorinated Solvents: Principles and Practices" has been developed to assist in providing information on the natural attenuation of chlorinated solvents and its assessment.

3. Pump and treat is increasingly seen as a technology able to bring about an initial reduction and then control of contaminant migration, but is not generally regarded as able to effect a complete removal of contaminants. The RESTRISK methodology is intended to help determine whether pump and treat is of continuing effectiveness in controlling the spread of contamination, or whether the treatment should be terminated.

4. As previously discussed, intrinsic processes of natural attenuation can often be demonstrated on sites. The critical issues for selection of a remedial approach are whether the observed processes are able to effect acceptable remediation or control on their own, and, if not how they might be enhanced to do so. A joint NICOLE/NOBIS consortium is developing a draft decision support system to objectively assess their issues drawing on existing protocols from the USA.

5. Laboratory investigations of potential *in situ* sensors for volatile organic compounds are being carried out in in an EU project, with a view to collecting an information base to support the selection of suitable sensors for use in the field.

6. An important strategic influence on prioritising remediation is the context of both the pollution and the desired treatment. NOBIS propose that at the planning stage a series of underpinning decisions will influence both assessment and remediation strategy. These decisions are:
   - Distinction between solutions that allow for preventative measures (soil protection) or curative measures (soil remediation);
   - The basic principles of the remediation: should the removal of contaminants be planned with regard to the intrinsic value of soil and groundwater or for their practical value.

GENERAL OUTLOOK

Each theme of the conference included a discussion period and a number of common threads emerged from these discussions.

Natural attentuation/extensive remediation

1. At the most fundamental level, knowledge of the capacity of intrinsic natural processes to destroy contamination or render them immobile is not complete. Each year, new evidence emerges of degradation or attenuation problems previously thought intractable. A good example of this is the development in understanding of processes leading the degradation of ‘problem’ solvents. A feature of this new understanding is the importance of interactions of processes and of organisms, often in unexpected or complex ways, but often also quite elegantly. The capacity of these intrinsic processes to eliminate or at least restrict the spread of contamination is becoming better understood but in several areas is contentious. Equally there is much debate about how such processes can be enhanced and/or accelerated and findings tend to be site specific, implying that fundamental factors remain undiscovered.

   Natural attenuation is becoming more acceptable as a remedial strategy, as fundamental knowledge of mechanisms is improved, and as risks related to natural are better understood.

2. Two general propositions were put forward:

   - Wherever possible it is worth investigating processes of natural attenuation/intrinsic remediation on a site. These may already be a significant limiting factor on risks from the contamination. An environmentally optimal approach to site remediation is to do the minimum necessary to stimulate “Nature” to achieve a desired goal.

   - In time all mobile contaminants will attenuate.

3. So far as extensive remediation technologies are concerned, delegates felt that there is an urgent need for field testing bioscreens. Many delegates see “phytostabilisation” (ie the immobilisation in plant biomass *in situ*) as “proven technology”. The use of “phytoextraction”, such as the use of metal

hyperaccumulator plants remains a lot more contentious, with a particular concern being what to do with the harvested biomass.

Intensive Remediation

The distinction made at the conference between 'intensive' and 'extensive' remediation is based on the level of input to soil processes, rather than the processes themselves. As in the extensive remediation session, new developments continue to extend the range of contamination problems whose treatment by bio-remediation now seems feasible. For a long time bio-augmentation has often been considered of limited effectiveness in the field. Initial (emphasis on initial) findings indicate that introduced organisms may be able to exert a positive effect under field conditions.

There are good prospects for extending the range of treatable problems through exploring new groups of organisms. Understandably the majority of work to date has focused on mesophilic organisms. However, new organisms may offer new opportunities, for example the use of extracellular degradation by lignolytic fungi to also degrade large and poorly available organic compounds. Exploration of the activities of thermophilic organisms is a natural extension of this search, which offers the possible prospect of co-treatment with organic wastes.

As mentioned previously the prospects for bioremediation of chlorinated solvents such as PCE and TCE now seem much more encouraging. However, there remains a lot of fundamental work to be undertaken. Of particular interest is the role of hydrogen in anaerobic systems where dehalogenation is taking place, both for remedial treatments and in the context of natural attenuation.

The problems of heterogeneity in soil and ground continue to pose obstacles to both the implementation and the monitoring of bio-remediation. However some researchers feel that heterogeneity should be seen as much as an opportunity as a problem, increasing the range of ecological niches for micro-organisms and hence possibly the diversity of possible degradation processes. The meeting considered that a major need was to increase the reliability of field scale monitoring – yet also drive down its cost to allow more monitoring to take place.

Remediation Monitoring

Process monitoring is a vital part of any bioremediation approach, and should be viewed as an integral part of the process rather than before and after snapshots. Its importance was questioned within the meeting with a view expressed that contaminant disappearance was the only key monitoring issue. The majority view was that a range of operational parameters also needed to be assessed as well as intermediate breakdown products and 'residual toxicity'. Monitoring of these is necessary to:

1. Determine fate of contaminants;
2. Optimise the process being applied including its use of energy, reagents and other resources;
3. Monitor environmental impacts of the process;

4. Ensure that the treatment is operating correctly;

This last bullet point was hotly debated, with some delegates not accepting the need for such monitoring. At a practical level the general view was that regulators and communities often required such confirmation. At a more fundamental level the view was expressed that on many occasions site specific factors have had an unpredicted effect on process outcome. The effect was not always a problem. On many occasions it was beneficial resulting in better than expected performance and/or new technology developments.

The importance of a monitoring strategy to focus effort and obtain the maximum possible information on a limited budget was strongly emphasised.

Two real problems for bioremediation monitoring are:
- dealing with heterogeneity;
- the reliability of measurements

An important opportunity for bioassays may be their strategic integration with chemical analysis protocols. One possibility suggested is that bioassays may permit a reduced suite of 'general' chemical analyses, with a broader range of chemical analyses being applied where bioassay indicated a problem (ie toxic) sample.

Decision Support Systems

There has been a proliferation of decision support systems in recent years. The selection of appropriate decision support can be regarded as fast becoming in need of decision support itself. It must always be borne in mind that a decision support system is, at its absolute best, only as good as:

1. the information base it relies on;
2. the fundamental science and logic behind it;
3. and the ability of the user to use it both correctly and appropriately.

Decision support tools should not be used as a final arbiter in themselves, but are better used to explore and classify options, and to illustrate a defensible, consistent and logical framework for any final decision taken. This final decision must always be based on an adequate understanding of site specific as well as general factors, and the context of the decision needs to be made clear, i.e. does the decision include an assessment of environmental merit; what was the original range of considered options; what decision support tools were used and why; and finally as emphasised by NOBIS what is the "policy" context of the remediation decision.

Concluding Remarks

NICOLE delegates were impressed by the NOBIS programme, and congratulated its delegates. A number of projects are to discuss collaboration with the other network (ie NICOLE or NOBIS). At a strategic level NICOLE and NOBIS intend to collaborate on information dissemination; including through their web sites, newsletters and conferences. Three specific technical areas of collaboration are to be explored.

1. Natural attenuation
2. Decision support systems
3. Field testing of NOBIS technologies by NICOLE members.

NICOLE and NOBIS will also collaborate with the RTDF Bioremediation of Chlorinated Solvents Consortium in their work on natural attenuation.

Compared to the NOBIS programme, the budget for EU projects on *in situ* remediation is limited. However, the meeting concluded that the EU projects presented made and will make a substantial contribution to the understanding of more fundamental aspects of land remediation.

Annex 1. WHAT IS NICOLE?

The problem of land and groundwater contaminated by industrial activity is a significant one that affects all industrialised societies. Whilst companies are striving to identify and manage such problems responsibly and cost-effectively, they are often doing so without a clear understanding of the complexities or the scientific and technological aspects of the problem. There was thus the need to create NICOLE as a forum to bring together the problem holders and those who are well placed to assist them.

Established as a Concerted Action of the EU Environment & Climate RTD Programme in February 1996, NICOLE is an alliance of industrial problem holders, research performers, technology developers, service providers and research planners.15 countries are represented. Its three fundamental aims are:

- to provide a European forum for the dissemination and exchange of scientific and technological knowledge and ideas relating to all aspects of contaminated land arising from industrial and commercial activities;

- to identify research needs and thereafter to promote co-ordinated, multidisciplinary, collaborative research that will enable European industry to identify, assess and manage contaminated sites more efficiently and cost-effectively;

- and to inform relevant EU and Member State planners of publicly funded research of needs and priorities for future research.

Participation in ***NICOLE*** is open to the following individuals & organisations:

- Companies and organisation with potential contaminated land problems.
- Researchers in universities and independent research organisations.
- Technology developers or service providers.
- National and European Industrial Trade Associations
- National and EU research funding bodies.

NICOLE Membership (September, 1997)	
Research Performers (universities & independent research organisations)	77
Industrial Companies (problem holders)	28
Technology Developers/Service Providers	3
Research Enablers (research planning/funding agencies)	17
Consultants	2
Total Organisations	127

Membership of NICOLE costs 3,500 ECU per year (February to February) for Private Sector organisations. Membership for research organisations and research enablers is free, however, those bodies are changed for meeting attendance. Unlike NOBIS, NICOLE does not provide funding support for projects, rather it encourages collaborative venturers, where individual NICOLE companies may offer support in kind or by funding.

As of September 1997 11 projects, across six themes, were being prepared by NICOLE as summarised below:-

I. BIOAVAILABILITY

- The Bioavailability of Lead, Mercury and Petroleum Residuals in Contaminated Soils and Sediments.

II FATE & TRANSPORT

- Exposure Assessment Tools for use in Risk Based Decision making at Contaminated Sites.

III LOW-COST, RAPID, ON-SITE MEASUREMENTS

- Rapid Site Assessment for Petroleum Contaminated Sites.
- Good Survey Practice

IV NATURAL ATTENUATION

- Natural Attenuation: Guidelines for Acceptance.

V REMEDIATION

- Phytoremediation of Petroleum Hydrocarbons Phase II Field Demonstration.
- Demonstration Sites for Novel Cleanup Technologies.
- Beneficial Applications.

VI RISK MANAGEMENT

- A Risk Management Framework for Contaminated Land.
- Risk Communication.
- Model for Comparing/Optimising Remediation Technologies.

NICOLE also holds a research directory covering research performers with active contaminated land interests across Europe. NICOLE also produces a regular newsletter: *NICOLE News.*

More information and *NICOLE News* on line are available from the NICOLE website: www.nicole.org. Enquiries can also be made to:

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Tel + 31 55 5493 927
Fax +31 55 5493 410
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Annex 2. WHAT IS NOBIS?

NOBIS is Public-Private partnership in which both the demand and the supply side of the soil clean-up market, the Research & Development branch and the government sector are represented. NOBIS incorporates: landowners, consulting firms and contractors, institutes for fundamental and applied scientific research, universities and the government (national, provincial and municipal).

The objective of NOBIS is to develop, evaluate and demonstrate innovative strategies, methods and techniques that will effectively help to control in-situ remediation by means of biotechnology (biorestoration).

NOBIS will also help to improve the export position of the Netherlands in the field of knowledge-based soil clean-up products and services.

NOBIS was founded in December 1994 after its initiators of NOBIS had presented an investment programme for research in the field of biotechnological soil remediation to the Ministry of Economic Affairs. NOBIS was founded in December 1994. For the execution of the tasks, the administrative facilities and infrastructure of the CUR (Centre for Civil Engineering Research and Codes) in Gouda are used. The activities are grouped in the CUR/NOBIS organisation.

NOBIS pursues development in technology based on the market demand. The contents of the programme are based on project proposals, sent in by consortia, in which problem owners co-operate with nationally and internationally operating consultancy firms, scientific institutes and contractors. The experience and know-how acquired is exchanged among the participants and results of evaluated remediation projects are made accessible to all NOBIS members.

Participation in NOBIS is open to all parties who want to support NOBIS structurally and who wish to contribute substantially with funds and know-how in the realisation of the programme.

The NOBIS programme is realised through selection of project proposals offered by the market sector. The projects selected are eligible for a NOBIS-contribution towards 60% of the costs of research. NOBIS asks the participants for an annual contribution of 15.000 guilders.

Participants in NOBIS are entitled to have:

- access to the general know-how developed within NOBIS;
- access to specific know-how when participating in separate projects;
- a representative in the Supervisory Board and thereby participating in the policy of NOBIS and the structure of both the Board of Directors and the Scientific Advisory Board.

Investors in the programme are entitled to have a representative on the Supervisory Board. The Board of Directors of NOBIS is advised by the Scientific Advisory Board (WAR) on the contents of the NOBIS programme. A Knowledge Integration Team (KIT) consists of representatives from the different projects. The KIT initiates innovative ideas and takes care of the coherence within the programme according to identified research lines. The KIT also advised on NOBIS supporting projects.

<u>NOBIS Membership</u>
<u>(September 1995)</u>

<u>From the demand side</u>

Akzo Nobel Chemicals B.V.
Du Pont de Nemours (Nederland) B.V.
ICI Holland
The Port of Rotterdam
The Port of Amsterdam
Nederlandse Philips Bedrijven B.V.
Dutch Railways
SHELL International Petroleum Company B.V.
Foundation: Europort/Botlek Interests
VNO-NCW (Confederation of Dutch Employers)

<u>From the supply side</u>

DHV Environment and Infrastructure B.V.
The municipality of Rotterdam, Consulting Engineers
Grontmij Consulting Engineers (Environmental Division)
Heidemij Realisatie B.V.
Consulting Engineers Oranjewould B.V.
IWACO B.V.
Dutch Association of Soil Cleansing Companies
Tauw Environmental Services

<u>From the R & D sector</u>

Delft Geotechnics
TNO Milieu, Energie en Procesinnovatie

<u>From the government sector</u>

Inter Provincial Association (IPQ)
Ministry of Economic Affairs
Ministry of Housing, Spatial Planning and Environment
Association of Dutch Local Governments (VNG)

As of October 1997 NOBIS included 42 projects in the following themes:

Theme	**Number of Projects**
Risk and risk assessment	3
Bioscreens	7
Measurement and monitoring	13
Extensive concepts	16
Intensive concepts	6
Decision support systems	2

(Note: some projects deal with more than one theme)

More information is available on the NOBIS website: http://www.NOBIS.org

A project listing was published by NOBIS in October 1997, which is available from the NOBIS contact given below:-

ir. H.J. Vermeulen
CUR/NOBIS
PO Box 420
2800 AK GOUDA

Telephone: 31 (0) 182-540680
Fax: 31 (0) 182-540681
e-mail: harry.vermeulen@cur.nl

Annex 3 THE RTDF BIOREMEDIATION OF CHLORINATED SOLVENTS CONSORTIUM

The Bioremediation of Chlorinated Solvents Consortium is one of the Action Teams of the Remediation Technologies Development Forum (RTDF). The Consortium was established in 1993 when representatives from six companies, the US Environmental Protection Agency (EPA) and the Department of Energy (DOE) met to discuss their mutual interest in developing *in situ* bioremediation technologies to degrade chlorinated solvents in soils and groundwater. The original industrial partners of the Bioremediation Consortium (DuPont, Dow, General Electric, Monsanto, Novartis, and Zeneca) were later joined by two more: ICI and Beak International.

The industrial partners signed a research agreement in 1994 and agreements were then negotiated with the EPA, the DOE and the US Air Force (USAF) to facilitate collaboration between the public and private sectors on the planned research projects. These legal arrangements were time-consuming but have proved flexible and practical. There is a mechanism for sharing proprietary technology such that consortium members can use shared or developed technology at their own sites.

The rationale for creation of this consortium (and of the RTDF initiative as a whole) was to enable the efficient leverage of resources for technology development and implementation in a non-competitive area for the problem holders. This has enabled elimination of duplication of effort and collaboration on a defined work-plan for the common good. Key elements of the work processes include a resource commitment: members must commit approximately one person-year per annum of in-house effort over four years and support some fieldwork. A steering committee on which all of the members are represented provides policy and ratifies technical strategies. A technical conference is held once per year and *ad hoc* technical groups meet regularly. The total cost of the work-plan is currently forecast to be US$ 16 million.

The mission of the Consortium is to accelerate the development of the most cost-effective *in situ* bioremediation processes for degrading chlorinated solvents. To accomplish this mission, Consortium members jointly participate in the research, development, demonstration, evaluation and dissemination efforts necessary to achieve public and regulatory acceptance of these biological processes. Consortium members contribute personnel, equipment, laboratory facilities and the funding needed to complete the mission.

The Consortium focuses on three *in situ* bioremediation processes: cometabolic bioventing (for treatment in the vadose zone), intrinsic bioremediation (for treatment of large ground water plumes) and accelerated anaerobic bioremediation (for treatment of concentrated areas within plume. Each technology is being demonstrated at two sites. The first site for all three technologies has been Dover Air Force Base, Dover, Delaware, USA; the second sites for testing differ for the different technologies.

Further information on the RTDF is available on their web site: http://www.rtdf.org

Annex 4 In Situ Bioremediation – Lessons Learned and Future Direction

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As early as 1913, researchers realised that organic contaminants could be degraded by microorganisms. In the 1960's citizens of the United States and elsewhere discovered that industrial practices over the previous century had caused contamination of shallow soil and ground water. By the late 1970's however, researchers were observing that many contaminant plumes, especially those composed of fuel hydrocarbons, were not migrating an appreciable distance downgradient from the spill. In the 1980's and into the 1990's, researchers conducted numerous microcosm studies with aquifer material from contaminated sites to help determine the fate of organic contaminants. These researchers discovered that fuel hydrocarbons could be used as electron donors and oxidized to innocuous compounds such as carbon dioxide and water under aerobic, denitrifying, manganese (IV)-reducing, iron(III)-reducing, sulfate-reducing, and methanogenic conditions.

Whereas the biodegradation of fuel hydrocarbons involves oxidation of the contaminant, the biodegradation of chlorinated solvents is more complicated. For example, the common chlorinated solvents such as perchloroethene, trichloroethene, and carbon tetrachloride can only be degraded in most ground water systems via biologically-mediated reductive dechlorination, a process that requires large quantities of organic carbon to drive the redox potential of the system into the sulfate-reducing to methanogenic range. The lightly chlorinated solvents and daughter products such as dichloroethene and vinyl chloride, on the other hand, can be degraded via oxidative or reductive pathways, and appear to be degraded more rapidly via the oxidative reaction.

The differences in biological degradation mechanisms causes fuel hydrocarbons to behave differently than chlorinated solvents in the shallow subsurface. For example, intrinsic bioremeditaion is occurring at all 50 of the sites contaminated with fuel hydrocarbons studied by the author, and it is estimated that natural attenuation will be protective of human health and the environment at about 80% of these sites. These observations are confirmed by studies conducted by Lawrence Livermore National Laboratory and the State of Texas Bureau of Economic Geology. On the other hand, intrinsic bioremediation of chlorinated solvents occurs much less frequently, and natural attenuation is likely protective at less than 20% of these sites. This suggests that engineered systems will be required for remediation of sites contaminated with chlorinated solvents. The addition of low molecular weight organic compounds such as benzoate and propionate, or perhaps even molecular hydrogen appears to hold promise but additional research is needed to determine which compounds provide the best substrate for the generation of the molecular hydrogen required for halorespiration. In addition, additional research into cost-effective delivery systems would be beneficial.