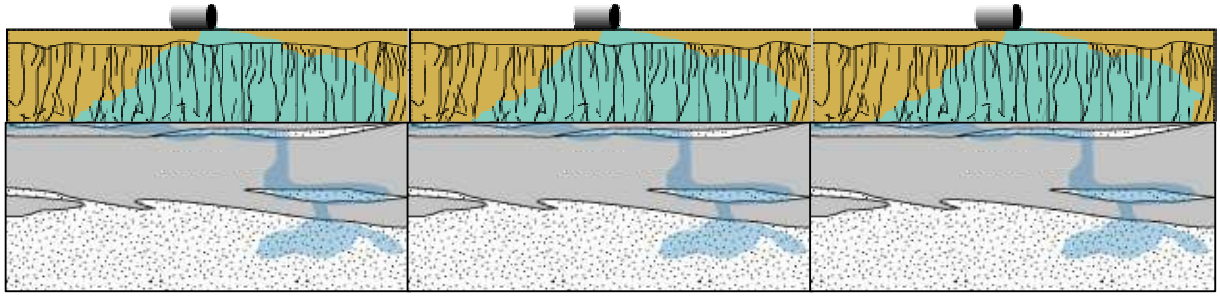
REMTEC

Innovative REMediation and assessment TEChnologies for contaminated soil and groundwater

PROJECT DESCRIPTION



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REMTEC

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Project description for REMTEC: Innovative REMediation and assessment TEChnologies for contaminated soil and groundwater

1) Summary

"Innovative REMediation and assessment TEChnologies for contaminated soil and groundwater" (REMTEC) provides a national platform for novel and applied research in soil and groundwater remediation. Given the extreme costs of cleaning up existing groundwater contamination problems and the immaturity of available technologies, a national focus on remediation technologies is required to ensure the continued development of new cost-effective clean-up methods. The project aims to develop a suite of new technologies to address gaps in currently available solutions. It aims to develop *in situ* remediation technologies for chlorinated solvents with emphasis on low permeability geologic media, bioremediation of mixed chlorinated ethenes/ethanes and sequential remediation of source zones with complex contaminant mixtures. In addition, research on concepts for risk reduction and innovative methods for stabilization of polycyclic aromatic hydrocarbons and heavy metal contamination will be conducted. The research project will advance environmental economic assessment tools and act as a focal point for the Danish remediation industry. The project aims to enhance their competitiveness in export of technologies, tools and holistic solutions for contaminated sites.

The REMTEC project team is truly interdisciplinary with leading Danish scientists from the Technical University of Denmark (DTU), the Geological Survey of Denmark and Greenland (GEUS), the National Environmental Research Institute at Aarhus University (NERI AU), and four consulting companies. The project is strongly coupled to a large and established network of leading international scientists. A Knowledge Exchange Group and an Innovation Advisory Group will be formed with leading consulting companies, contractors, regulators/stakeholders and project participants to ensure a focus on innovation, dissemination and application of research findings.

2) Objective of the project

The project brings together leading Danish and International expertise to address several outstanding issues in groundwater remediation of contaminated sites. It consists of 4 work packages related to specific contamination issues and 2 methodological work packages designed to provide state of the art tools for managing challenging remediation problems. Specifically, the project aims to: 1. Develop new techniques for accelerated removal of contaminants from clays and low permeability media; 2. Develop bioremediation methods for treatment of chlorinated solvents; 3. Optimise methods for the treatment of source zones contaminated with complex mixtures of chemicals; 4. Develop and test methods for the stabilization and risk control of polycyclic aromatic hydrocarbons (PAHs) and mobile heavy metals. These 4 aims will be complemented by two broader integrating aims: 5. To develop characterization and monitoring methods to improve site assessment and technology selection; and 6. To improve environmental-economic assessment tools.

The project addresses a growing societal need for effective technologies for removing or immobilizing toxic contaminants that threaten water resources and soil quality. It enhances the competitiveness of Danish industry. The technologies and tools will be applied by consulting companies and regulators both nationally and abroad. The project integrates research providers and industry to maintain a focus on societal relevant outcomes, and the fast transfer of technology into practice.

3) The project's expected main results

The REMTEC project is expected to produce new scientific findings, develop tools and technologies to be used in management and remediation and act as a national focal point for researchers, industry and end users. The activities will create a national focus for international researchers, post docs, PhD students and students, which will stimulate networking, and make Danish researchers and industry attractive partners on the international scene and market. The expected main results with respect to general scientific findings, tools and technologies will include:

- Accelerated "in situ" bioremediation technologies for low permeability deposits contaminated with chlorinated solvents.
- Advanced numerical and geostatistical model tools to be used in site characterization and design of remedial actions.
- New microbial tools that quantitatively combine DNA amplification of degrader bacteria with the actual activity of the functional genes for degradation of chlorinated solvents.
- Effective treatment methods for complex mixtures of chemicals, and tools to evaluate the effectiveness of treatments in terms of reduced toxicity.
- Evidence that *in situ* stabilization of PAHs and heavy metals can prevent transfer into field crops as well as exposure to the environment and humans.
- An operational procedure based on process insight for cost-efficient reduction of the risk related to sites contaminated by heavy metals.
- A new sampling approach for isolating the "non-accessible PAH-pool" that will facilitate: setting of (bio)remediation targets, selection of soil amendments for remediation, and risk assessment.
- Novel multi-disciplinary tools for characterization of contaminated sites in low permeability deposits, degradation of contaminants and toxicity testing of complex mixtures.
- Environmental-economic assessment tools for decision support to site remediation.

4) Concept and background of the project

The project will address several unresolved groundwater remediation problems. In Denmark, like in all developed countries, chlorinated solvents are viewed as a problem for indoor climate and the most serious threat to drinking water resources and other recipients (highlighted by the EU-Water Framework Directive). Another major problem is sites with mixtures of several contaminants with highly variable physical-chemical properties. At such sites a single remediation technology will probably fail and this motivates the aim to develop sequential technologies – often termed treatment trains. Soils at large sites are often contaminated with tens of tons of heavy metals (arsenic, chromium, copper) and residual PAHs, and this makes technologies such as efficient stabilization a necessary remedial measure.

The remediation technologies developed will be evaluated with respect to their cost-effectiveness, their effectiveness to reduce environmental and human exposure and for their overall environmental balance. In order to do this, methods for environmental-economic assessment will be developed and applied as an integrated part of the project.

Many remediation technologies have successfully been applied in permeable geologic media – but have not yet been developed for effective use in low permeability media. The main problem is mass transfer limitations that limit the contact between the reactant and the contamination /4,9/. Bioremediation is viewed as one of the best available technologies for environmentally sound site clean-up of chlorinated solvents and fuel hydrocarbons /13/. However, the slow rate of microbial degradation often makes it difficult to comply with environmental standards within a reasonable time. Recently, the introduction of novel Molecular Biological Tools (MBT) has increased interest in bioremediation. These tools can link presence and activity of specific microbial organisms with

degradation of specific contaminants /3,8/ and thereby help to accelerate microbial processes /8/ and improve performance of *in situ* bioremediation /13/.

Mathematical model tools have been developed significantly with respect to numerical performance and process description /15/. However, models are not widely applied for the prediction of time frames or design of remedial actions, particularly in low permeability media. A crucial point is comparison with reliable field scale data and microbial model parameters /15/. This may be solved by employing improved methods for site and contaminant characterization, microbial data provided by MBTs and improved process understanding in reactive solute transport models.

Large complex sources with a mixture of pollutants cause a challenge for remediation. Toxicity aspects and the presence of separate phases limiting microbial degradation are key problems. Stringent remediation goals can potentially be met by sequential application of aggressive technologies and biodegradation /5,7/. Advancement of treatment trains, however, may be limited by direct toxicity of treatment chemicals, possible sterilisation of the subsurface, or changes in environmental conditions causing adverse effects on degradation /5,7/.

For some contaminant classes, such as heavy metals, complete remediation is impractical by current approaches. In these cases there is an urgent need to exploit the potential of cost-efficient risk reduction technologies such as stabilization with waste products /6/. For PAHs, the accessible fraction of the contamination is expected to be available for degradation in soil organisms and uptake via the human diet. In contrast, the non-accessible fraction is recalcitrant to degradation, but will probably not lead to a significant exposure and risk /18/. A shift of paradigm is thus needed: remediation must be viewed as a cost-effective risk and exposure reduction technology, instead of being regarded simply as a contaminant removal process.

5) Innovative value, impact and relevance of the project

The cost of remediation of soil and groundwater contamination in Denmark is expected to exceed 14.3 billion DKK over a period exceeding 40 years. The proposed project will be economically and environmentally beneficial to society as it is expected to improve site characterization, risk assessment and remediation efficiency.

Establishment on REMTEC as a focal point for the Danish remediation industry will provide a platform for national technology development with an international dimension and a potential for export of technology. A collaborative approach with project consortia is necessary for technology development as well as technology transfer from especially North America. Good examples of previous successful development projects are bioremediation and chemical oxidation. DTU in particular has been an active player in this process by participation in several project consortia with consulting companies in parallel to dedicated research activities (e.g. 4, 7, 9). The collaboration in REMTEC between DTU, GEUS and NERI AU will strengthen such activities.

Consulting companies and Danish contractors have several activities in Eastern Europe and Asia in the water industry. However, the short term benefits for a site owner or an administrative body are small for soil and groundwater remediation. This contrasts with the large direct economic benefits experienced in other areas of the water industry. Thus, the expected markets are more difficult to enter and success will be strongly dependent on both legislation and economical growth in these countries. A holistic approach is one of the Scandinavian “brands”. The emphasis in the project is on the entire process: coordinated site characterization via development of monitoring tools, and remediation technologies to environmental assessment. Therefore, REMTEC will serve as a good example of a holistic approach which will have an export potential.

A prerequisite for growth in the area is the production of highly qualified candidates from Danish Universities. The spin-off in terms of production of national and international master thesis students and later PhD candidates from a large integrated research project is therefore of great value. This educational benefit is viewed as one of the strongest impacts of the project in addition to the expected scientific and innovative findings.

6) Project's methodology and expected results

The project will be truly interdisciplinary with participants having a background in environmental engineering, (hydro)geology, microbiology, soil science, environmental chemistry, ecotoxicology and numerical modelling. The work package structure (6 WP's in total) is strongly interlinked in order to strengthen integration and optimal use of knowledge, equipment and methods (Table 1). Research on processes, methods, and technologies is conducted in each work package. In order to ensure focus on innovative products, specific work packages are dedicated to the development of tools for monitoring and characterization of contaminants and contaminated sites, and for environmental economical assessment. The economic assessment will overarch technology development to ensure sustainable solutions and bring the need for prioritization into play. Will it be better for society and the environment to remediate 10 smaller contaminated sites instead of one large contaminated site like Cheminova at Høfde 42?

The research activities will be related to at least three field study sites, which will be used for the majority of activities. The field sites will be selected in order fulfil the overall goal of REMTEC: A clayey till site contaminated with chlorinated solvents, a large, complex source site and a contaminated soil site. The site scale is critical for evaluating the long-term benefit of the remedial action with respect to contaminant fluxes entering groundwater, and the source scale is the scale of relevance for evaluation of for example mass transfer limitations under realistic conditions (Figure 1). Laboratory and core scale research are essential for process understanding. The basic site characterization will be provided by two Danish Regions which will be administrative "site owners".

Table 1: Relationship between work packages, activities, tools, field sites and partners

WP 5 Characterization and monitoring toolss DTU, GEUS, NERI AU, Orbicon, COWI, Geosyntec, Neuchatel, UFZ

REMEDIATION TECHNOLOGIES	EXPERIMENTAL WORK	NUMERICAL MODELS	TOOLS	FIELD SITE/ CONTAMI-NANTS	INVOLVED INSTITUTIONS AND PARTNERS
WP1 Accelerating remediation of low permeable clay tills	Field scale and source scale	Design of enhance-ment proce-dures Performance Time frames	• Geological and hydraulic cha-racterization • Geostatistics	Clayey till/ Chlorinated solvents	GEUS, DTU, Orbicon, CSIRO, Clemson University, Danish Regions
WP2 Design and per-formance of bio-remediation	Field scale, source scale and laboratory scale	Quantifica-tion of proc-esses Design Time frames	• Stable isotope techniques • Molecular biological tools • Remedial design model	Clayey till/ Chlorinated Solvents	DTU, GEUS, Orbicon, Geo-syntec, University of Neuchâtel, CSIRO Danish Regions
WP3 Optimizing reme-diation at sites with complex sources	Laboratory scale – related to a specific field site		• Toxicity as-says • Treatability studies	Complex source/ Pharmaceuticals, pesticides,petro-leum hydrocar-bons, chlorinated solvents	DTU, NERI AU, Orbicon, Geo-syntec, Univer-sity of Neuchâtel Danish Regions
WP4 Innovative biore-mediation con-cepts Soil stabilization	Field scale, source scale and laboratory scale	Long term stability Contaminant mass flux	• Chemical accessibility • Bioavailability	Soil contamina-tion/ PAH's, heavy metals	NERI AU, DTU, COWI UFZ-Leipzig Danish Regions

WP6 Environmental-economic assessment NIRAS, DTU

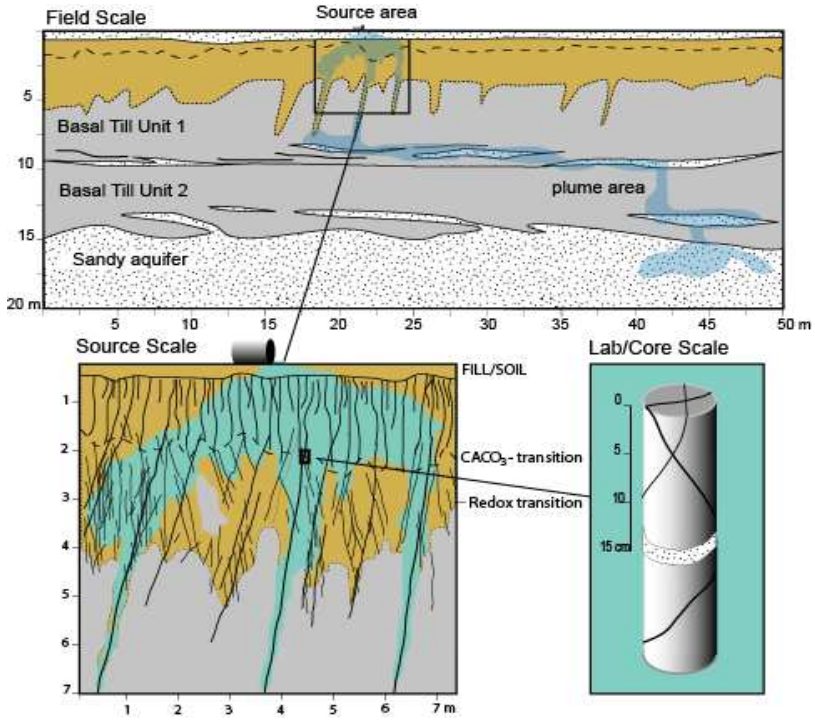

Figure 1: Relevant scales to be investigated in REMTEC. Example of multi scale characterization of a clay till site contaminated with chlorinated solvents.

In **WP1** we will conduct a field scale pilot experiment on a clayey till site contaminated with chlorinated solvents. The aim is to identify optimal enhancement technologies (hydraulic fracturing, pneumatic fracturing or other enhanced injection methods) for delivering of reactants, and increased bulk permeability in order to accelerate chemical and biological remediation processes /4,14/. State-of-the-art site characterization technologies will be applied (developed in WP5) in order to accurately evaluate the hydraulic/geological variability at relevant scales. Discrete/stochastic models will be constructed that realistically describe the spatial distribution of high permeability pathways (macropores, sand lenses) within low permeability clay till (Figure 1). The contaminant distribution will be identified at various scales. The conceptual model will supply input data for development of validated numerical modelling tools and for the optimization of the remediation experiment.

WP2 will primarily focus on bioremediation of chloroethenes and chloroethanes commonly found in groundwater, both within and outside Denmark. Chloroethanes are subject to both microbial and chemical degradation, and so degradation support tools are needed in order to deduce field-scale fate processes. Key questions and challenges pertaining to design and performance of the technology will be explored, including (i) methods for promoting biological treatment of chloroethanes via stimulated reductive dechlorination (SRD); (ii) quantification of chloroethane dechlorination and the presence and activity of functional genes for intermediate formation; (iii) potential merits of using bioaugmentation with *Dehalobacter* cultures for accelerating treatment via SRD; (iv) the role of competitive inhibition in application of bioremediation at sites impacted by chloroethanes and chloroethenes. Laboratory experiments mimicking field conditions will provide process understanding and support interpretation of field observations in WP1. New tools that allow us to measure the presence of degrader genes simultaneously with the actual activity of the functional genes are based on the co-extraction of mRNA and DNA directly from aquifer samples. Measurements of both the stable DNA and unstable compound mRNA will be a major step forward for monitoring of bioremediation. The process understanding developed will be incorporated into numerical models to quantify the distribution of degrading bacteria, electron donor and contaminants (closely related to WP1) and the governing processes occurring during anaerobic dechlorination in a clayey till. The models will be used for future bioremediation design.

Aggressive remediation technologies with sequential microbial degradation will be explored in **WP3**. Emphasis will be on approaches to optimize microbial degradation by adding/optimizing essential factors for microbial growth and, thus, achieve maximal removal of contaminants and toxicity reduction. WP3 will be strongly linked to technology development projects at large, complex sites in Denmark (Cheminova-Høfde 42/Ballerup, Kærgård Plantage). This involves treatment like chemical oxidation, thermal treatment and zero-valent iron treatment of complex source zones (pharmaceuticals, pesticides, petroleum hydrocarbons, chlorinated solvents). The effectiveness of the technologies will be evaluated by chemical analysis (biological/chemical oxidant demand; surplus of reactive agent, specific group(s) of chemicals and by bioassays (algae, crustaceans, light emitting bacteria (Microtox), nitrifying bacteria, yeast assay). A key issue will be optimal handling in relation to the analyses of samples with complex matrices (low O_2-contents, particles, precipitates, pH extremes). The chemical analyses and the biotests are expected to be a strong test battery for evaluation of sequential treatments.

New bioremediation concepts for the reduction of environmental and human risks will be developed in **WP4**. Emphasis will be on validation of approaches and attention will be paid to future concepts for risk assessment and soil remediation. We will introduce approaches for experimental isolation of the non-accessible pool of organic soil contaminants /12/. Experiments will then be conducted to demonstrate that the pool of non-accessible PAHs exceeding present threshold levels neither leads to a significant transfer into field crops nor to a significant environmental and human exposure /18/. This concept turns the limitation of existing bioremediation technology (limited bioavailability) into an advantage (low risk of the residual fraction). Finally, a number of soil amendments will be investigated for their potential to facilitate (bio)degradation or transfer into non-accessible forms while if possible at the same time improving other core functions of the disturbed soil (e.g. fertility, recreational value, protective barrier towards ground water).

The extent of, and the risk associated with As, Cr and Cu contaminated sites will also be part of WP4. If the risk can be lowered by stabilization in stable Fe-oxides /16/, so that exposure to and flux of contaminants approaches background values, this may be considered a true remediation measure. Mixing the ochre-sludge (waste) produced at water-works with soil has been found to be very efficient to bind heavy-metal pollutants /6/. The feasibility of developing this into a very cost-effective stabilization method has been confirmed through column studies at DTU. Geochemical processes and long-term stability will be studied in the laboratory and in the field, using aquatic, solid-phase, surface geochemical methods and models. Field application schemes and real-world efficiency are critical issues to be investigated.

In **WP 5** an integrated "toolbox" with a variety of methodologies will be developed. An important task of this WP will be analytical technology transfer to other work packages. Site characterization of clay till involves advanced geological and hydraulic characterization /11, 15/, however novel geostatistical scale-up procedures are needed. Stable isotopes are a rapidly evolving tool for evaluating degradation rates and pathways /10/. This approach will be used as an integrated part of the laboratory and field scale activities in WP2 and WP3. DNA and mRNA-based quantification methods /3/ will be further developed and applied to provide understanding of the key bacteria involved in bioremediation of chloroethanes and chlorethenes. Methodologies for toxicity testing will be developed in relation to WP3 and WP4 based on principles in /1,12,18/.

In **WP 6** an environmental economic analysis methodology will be developed to facilitate and support prioritization between remediation projects within a groundwater catchment area or a region. The methodology shall comply with EU Water Framework Directive requirements. Analysis will be based on welfare economic theory as well as state-of-the-art methods in order to identify the best remediation alternative for society. As part hereof an empirical valuation study (using stated preference methods) will be conducted, hereby valuing benefits from the remediation alternatives to society. The valuation will be closely linked to the other parts of the project both with respect to the description and quantification of the effects of remediation and especially with regard to the risk and uncertainty related to these effects concerning both environmental and human risk exposure in order to identify the best remediation alternative for society. The output will be a ranking of the best remediation alterna-

tive for society based the direct costs together with the potential value of the most important side effects from remediation. Uncertainties of remediation efficiency and the time lag from the time of source reduction to when groundwater is protected will be emphasised in the economic evaluation. The use of the output results will be discussed together with ethical aspects, especially for cases when effects of remediation include risk reduction and/or effects that occur after long periods of time (decades).

7) Project plan

The project plan is described in Figure 2. The PhD projects are expected to start from spring 2008 in order to have time for recruitment. All PhD projects will be initiated before October 2008 thereby allowing all projects to be completed autumn 2011. First part of 2008 is dedicated site identification and terms of collaboration. The primary experimental activities are focused in year 2009 and 2010. The last part of 2011 is dedicated to writing of papers, dissemination of knowledge and transfer of tools and technologies.

Senior scientists, associate professors and professors are assigned to all activities (see Participating parties) and consulting companies are fully integrated in projects tasks and management. Primary activities for PhD students and post docs are indicated on the Gantt diagram. The international dimension will be stimulated by knowledge exchange meetings (first meeting late summer 2008) and frequent contacts to international partners, conference participation and other networking activities. All PhD students are expected to stay with international research partners during their study.

WORK PACKAGE	ACTIVITY	PHD POST DOC	2008		2009		2010		2011	
WP1	Site characterization	PhD A/PhD B		M1						
	Design of experiment, validation	PhD A/PhD B			M2A				M2B	
	Field experiment	PhD A							M3	
	Modelling of geodata	PhD A				M4				
	Enhancement technologies	PhD A/PhD B							M5	
WP2	Microbial site characterization			M6						
	Field and laboratory experiments	Post doc C			M2A				M7	
	New microbial tools	Post doc C					M8			
	Conceptual model	PhD C				M9				
	Numerical model	PhD C							M10	
WP3	Toxicity methods: bioassay				M11					
	Laboratory experiments	Post doc A			M12					
	Integration with field test			M13					M14	
WP4	Experimental approach	PhD E/PhD F		M15						
	PAH transfer to field crops	PhD E		M16				M17		
	Exposure to PAH	PhD F							M18	
	Field site characterization	PhD D								
	Laboratory exp and modelling	PhD D					M19			
	Field application							M20		
WP5	Identification of tools	All								
	Development of tools	All				M21		M22	M23,24	
	Testing of tools	All								
	Transfer to end user	All								
WP6	Env. economic assessment					M25				
	Assessment of cont. sites	Post doc B							M26	
	Prioritization tool	Post doc B							M27	
	Environmental valuation								M28	
Project Management (PM)			Home	page						
PM	Leader group	Post doc B	x x	x x	x x	x x	x x	x x	x x	x x
	Kick off and budget follow up	Post doc B	x	x	x	x	x	x	x	x
	Knowledge exchange group		M29	x		x		x		x
	Innovation advisory board				x			x	x	x

Figure 2: Gantt diagram for REMTEC including primary activities for PhD students and post docs. VIP staff and consultants will participate in project tasks as well. The numbering of PhD student and post docs refer to budget form dsf4. The milestones (M1-M28) are further described on next page in Table 2. "x" indicates meetings.

Table 2: List of milestones (Mx) expected in REMTEC. Month indicates time since start of project.

MILESTONE	MILESTONE TITLE	WP	MONTH	LEAD PARTNER
M1, Note, data	Clay site characterization	WP1	6	GEUS
M2, Note, design tool	Design of experimental set up and validation, integrated between WP1 and WP2	WP1 WP2	15, 42	DTU
M3, Scientific paper	Multi scale enhancement of mass transfer limitations, field experiment	WP1	42	DTU
M4, Scientific paper	Field-scale geological/hydraulic model (geo-statistical approach)	WP1	24	GEUS
M5, Technology	Enhancement of remediation in low permeable settings	WP1	39	DTU
M6, Laboratory methods	Microbial characterization methods based on microbial ecosystem changes during remediation	WP2	12	GEUS
M7, Scientific paper	Lab and field scale experiments	WP2	39	DTU
M8, Scientific paper, tool	Microbial tool to quantify degradation genes based on co-extracted DNA mRNA	WP2	28	GEUS
M9, Note	Conceptual model for degradation of chlorinated solvents in low permeable settings.	WP2	24	DTU
M10, Scientific paper, tool	Numerical design model for bioremediation	WP2	40	DTU Orbicon
M11, Laboratory methods	Experimental approach and toxicity testing methodology	WP3	15	DTU
M12, Note	Field scale treatment technologies, state of the art	WP3	15	Geosyntec
M13, Note	Environmental and human risk assessment of key chemicals identified	WP3	12	DTU
M14, Scientific paper, tool	Identification of most sensitive bioassays	WP3	39	DTU
M15, Laboratory methods	Experimental approach	WP4	12	NERI AU
M16, Note	Commercial aspects of soil treatment and remediation	WP4	12	COWI
M17, Scientific paper	Transfer from non-accessible PAH pool into field crops?	WP4	36	DTU
M18, Scientific paper	Lack of environmental and human exposure from non-accessible PAH pool	WP4	42	NERI AU
M19, Scientific paper	Stabilization of mobile heavy metals	WP4	24	DTU
M20, Scientific paper, technology	Feasibility of field scale application	WP4	36	DTU COWI
M21, Scientific paper, tool	Analytical technique to isolate the non-accessible pool of organic soil contaminants	WP5	21	NERI AU
M22, Tool	Geological, hydraulic and geochemical characterization of contaminated sites	WP5	33	GEUS
M23, Scientific paper, tool	Analytical technique for measuring the chemical activity of the non-accessible PAH pool	WP5	37	NERI AU
M24, Tool	Advanced characterization tools for quantification of degradation in laboratory and field scale systems	WP5	39	DTU
M25, Note	Environmental economic assessment of remediation at contaminated sites	WP6	21	NIRAS
M26, Scientific paper	Comparative analysis of the efficiency and cost indices of the various remediation schemes at catchment scale	WP6	42	DTU
M27, Tool	Tool for prioritization of remediation at catchment scale	WP6	40	NIRAS
M28, Scientific paper	Environmental valuation (contingent valuation)	WP6	24	NERI AU
M29, Note	Plan for dissemination and publication strategy	PM	6	DTU

Table 2 describes the anticipated milestones indicated on the Gantt diagram in Figure 2. The developed tools/technologies will be disseminated to end users when they are ready. The milestones termed "Notes" and "Laboratory methods" will be accessible for project partners and used by the project leader group to monitor progress of the project and facilitate coordination of related project activities between work packages. The list of milestones with respect to scientific papers is not exhaustive, but the list highlights where we expect major findings. As described in our publication and promotional strategy we expect significant dissemination activities in addition to the scientific output.

8) Legal and ethical aspects

Research with contaminated soil and groundwater does not involve legal and ethical aspects at the level of laboratory investigation. However, for research work on contaminated sites, paragraph 8 of the Danish soil contamination law (Jordforureningsloven) requires formal approval of each project by the local community. Applications will be submitted during the planning phase of the project in order to avoid delays. The strong relationship with the Danish Regions and Danish EPA in combination with significant experience with legal aspects will help us in this matter. The WP project leaders will handle communication with site owners carefully to avoid misunderstandings and unnecessary delays.

Introduction of non-native biological species into the environment has been discussed in many parts of the world. A classical example is the introduction of plant-pathogenic microorganisms from one part of the world to another. For example, the introduction of commercial mixed bacterial culture (bioaugmentation) originating from North America into contaminated Danish aquifers could potentially raise some concern among regulators of groundwater contamination since the bacteria are not always known at the species level. However, bioaugmentation has been accepted by Danish authorities and approved by Danish Forest and Nature Agency (Skov- og Naturstyrelsen) in at least two cases in the former county of Funen. The current proposal will further address these ethical aspects by: 1) A detailed description of microbial cultures used in bioaugmentation; and 2) Improved performance of the naturally present microbial communities towards the bioremediation task (maybe removing the need for bioaugmentation).

9) Publication and promotional strategy

A plan for publication and dissemination strategy will be developed for REMTEC within 6 months from project start. Publications in different sources and for different target groups will be considered. The project partners have a tradition for knowledge exchange via collaboration projects, technical expert groups, papers in Danish journals and presentation at meetings in professional societies. In general, easy access to information for end users is a key point for REMTEC partners. DTU has for instance recently established a website for dissemination of reports from collaboration projects (sara.er.dtu.dk). This web page includes download facilities for both popular overview publications oriented towards end user and stake holders and detailed project reports. Specific outputs in terms of tools and articles are indicated as Milestones under “Project plan”.

The anticipated activities involve both national and international target groups:

- Establishment of a Knowledge Exchange Group (see also project organisation and management), where the publication and dissemination strategy will be presented.
- A common REMTEC web page will be launched within 6 month from project start. The site will involve information on project activities and materials in an open part of the site. The password protected part of the web site will be used for sharing project documents and presentations.
- Presentation of project results at national meetings (IDA-Miljø, ATV Jord og Grundvand, Knowledge Center for Soil Pollution).
- Articles in Danish conference proceedings and technical journals (Vand og Jord, Dansk Vand, Geologisk Nyt).
- Presentation of project results at international conferences (annual AGU meetings, CONSOIL, Batelle conferences, Groundwater Quality 2010, SETAC conferences).
- Articles in international Journals relevant for the area including Environmental Science and Technology, Journal of Contaminant Hydrology, Water Resources Research, Applied Environmental Microbiology, Environmental Toxicology and Chemistry. It is a dedicated success criteria for all project partners that articles are published in leading journals.
- Public access to methods and approaches including software.

10) Innovation

We see a general need for developing novel remediation technologies, innovative monitoring tools, new approaches for risk assessment, and better site characterization without significant increase in costs. It is relevant to focus on chlorinated solvents, PAHs and heavy metals because they are amongst the most prevalent and toxic contaminants in soil and groundwater. The development of innovative remediation technologies and investigative tools for low permeability settings is highly needed as a large part of Denmark is covered by clayey till. Advanced use of environmental economics including life-cycle assessment has just started nationally and internationally in the area of site remediation /2/. These approaches are of relevance for prioritization of contaminated sites in catchments and administrative regions or nationally, and for selection of a sustainable remediation for a specific contaminated site. The broad application is promising for development of innovative software tools based on the research project. The use of low cost waste products like ochre-sludge for stabilization of soil contaminants at large is also – if feasible - of great innovative value.

Ample field expertise at DTU and GEUS guarantees a professional approach with regard to management of field sites. The basic experience with the techniques, methods and processes to be applied by DTU, GEUS and NERI AU in the project has been gained in previous and on-going research and development activities. Thus, a strong platform for innovative laboratory and field research exists. In addition, the project participants have strong relations with administrative bodies and consulting companies. The strong link to end users will ensure timely dissemination of the results and significant impact of the project in engineering practice.

Software, analytical procedures and other tools will be available for all project partners during the project. After completion, the tools developed will be accessible for end users and stake holders. In most cases, inventions pertaining to the soil and groundwater remediation do not warrant patent applications, because of low economic returns. Additionally, the ultimate beneficiary of improved environmental technologies, besides the environment is the tax payer. Therefore, this proposal does not foresee patents, except in the case of benefits from project inventions to other sectors of industry. In such cases, the individual partner will hold the Intellectual Property Rights and will bear the cost and responsibility of patenting according to the rules set by the partner institutions. Collaboration contracts and other agreements will be established by the start of the project.

11) Participating parties

The core partners in the REMTEC project include 3 research groups from DTU, GEUS and NERI AU each with a strong team of scientists active in the area (Table 3). NIRAS, Orbicon, COWI, Geosyntec, four major consulting companies, are fully integrated in REMTEC. All institutions and companies as wells as project participants and their competencies are described below. The interaction and synergies between core partners and related partners are further explained in the section on Project organisation.

DTU is an institute within the Technical University of Denmark. The institute conducts science-based engineering research covering engineering, technology and management issues of environmental and resource-related problems in Denmark and internationally. The institute has a strong project related infrastructure including well equipped analytical, microbiological and ecotoxicological laboratories, experimental facilities and field equipment. Poul L. Bjerg is professor in environmental geochemistry and has an international recognised expertise in the area of risk assessment and remediation technologies. He has headed several research programmes and collaboration projects besides extensive experience with supervision of PhD and master thesis students. He has an outstanding national network including consulting companies, regulators (Regions) and the Danish Environmental Protection Agency. The multi disciplinary staff at DTU will contribute directly to the project activities and as supervisors for PhD students/post docs. Stefan Trapp is an associate professor with expertise in mathematical modelling and risk assessment. Philip Binning, associate professor, is expert on multiphase flow and transport in porous media, numerical methods and de-

Table 3: Competencies of scientists and WP participation of core research partners in REMTEC

PARTNER	NAME OF SCIENTIST	COMPETENCIES	PARTICIPATION IN WP
DTU	Poul L. Bjerg	Remediation and risk assessment, biogeochemistry, model application	Project leader of REMTEC WP1, WP2, WP3, WP6
	Stefan Trapp	Risk assessment, modelling,	WP4, WP5, WP6
	Philip Binning	Numerical modelling, multiphase flow	WP1, WP2, WP5
	Mette Broholm	Remediation of chlorinated solvents	WP1, WP2, WP5
	Kresten Ole Kusk	Toxicity testing, ecotoxicology	WP3, WP5
	Rasmus Jakobsen	Heavy metals, biogeochemical modelling	WP2, WP4, WP5
	Peter Kjeldsen	Heavy metals, remediation	WP4
	Charlotte Scheutz	Degradation of chlorinated solvents	WP2, WP5
GEUS	Knud Erik Klint	Geology, fracture characterization, risk assessment of low permeability settings	Deputy of REMTEC WP1, WP2, WP5
	Carsten S. Jacobsen	Microbiology, molecular biological tools	WP2, WP5
	Bertel Nilson	Hydrogeology, fracturing, geostatistics	WP1, WP2, WP5
NERI AU	Ulrich Gosewinkel Karlson	Soil remediation, bioavailability	WP4, WP5
	Philipp Mayer	Soil remediation, chemical analytical tools	WP3, WP4, WP5
	Berit Hasler	Environmental economics	WP6

sign of remediation technologies. Mette M. Broholm, associate research professor, will contribute with her expertise on chlorinated solvent migration, degradation, and *in situ* remediation in low permeable media. Rasmus Jakobsen, associate professor, is expert on sorption behaviour of heavy metals, biogeochemistry of redox processes, degradation of chlorinated solvents and geochemical modelling. Kresten Ole Kusk, associated professor with expertise in ecotoxicology and test methodology, and with an extensive experience in handling of polluted water samples from 10 years of consultant work. Peter Kjeldsen, associate professor, will provide expertise within remediation technology, chlorinated solvents and behaviour of heavy metals, while Charlotte Scheutz will contribute with insight about degradation of chlorinated solvents.

GEUS is an independent research and advisory institution under the Ministry of the Environment that conducts scientific research in three primary areas: environment, energy and exploration of minerals and raw materials. GEUS has a strong project related infrastructure including a well equipped molecular ecology laboratory. It has a unique experience in terms of multi-scale geological, hydraulic and chemical/microbiological characterization of contaminated, low permeability fractured deposits, and is a master of the science of quantifying complex geological heterogeneities for the estimation of realistic input parameters in numerical models. Knud Erik Klint is senior scientist and is internationally leading in characterization of heterogeneous glacigene deposits. He has a strong international network and is currently the coordinator the European FP6 Project STRESOIL. Carsten Suhr Jacobsen is professor in geomicrobiology and is an internationally recognised scientist in molecular, microbial ecology of contaminated soils. He has a large network and has formerly been head of Center for biological processes in contaminated soil and sediment (BIOPRO). Bertel Nilsson is senior scientist and has a strong international network in site characterization, geostatistical analysis and thermal remediation of contaminated clayey tills.

NERI AU is a department of the University of Aarhus. It is devoted to environmental research and monitoring, and consults the Danish environmental authorities. One of the major tasks of the Department of Environmental Chemistry and Microbiology is the development of monitoring tools for chemicals and microorganisms in the environment. NERI AU is excellently prepared for conducting the biological and chemical analyses required for this project, both in instrumentation and in highly qualified technical staff and researchers. Ulrich Gosewinkel Karlson, senior scientist, has coordinated international multidisciplinary research projects in bioremediation, phytoremediation and risk assessment. Philipp Mayer, senior scientist, has led collaborative research projects and par-

ticularly the recent project “Analytical Technology to Determine Contaminant Activity – Direct Measurement of (Bio)available Organic Contaminants in Soil, Sediment and Sludge (2003-2007)” that was funded by the Danish Technical Research Council. Berit Hasler, senior researcher and head of social section, has coordinated a number of valuation projects from 2002 until now regarding water and nature projects. NERI AU is among the leading actors in European research projects on remediation and environmental risk of soil pollution.

NIRAS is a leading Danish consulting company covering all aspects of civil and environmental engineering. They are a major player in the area of soil and groundwater remediation. The company has developed specific expertise in environmental economic assessment and cost-effectiveness of groundwater protection measures (e.g. WaterCost project, EU Interreg IIIb) and priority ranking of all point sources in Serbia EU "The European Agency for Reconstruction (EAR), 2007". Camilla K. Damgaard, MSc in Forestry and Environmental Economics, has extensive experience in conducting socio economics analysis from working seven years with the Danish EPA. She has recently joined NIRAS, where she is involved in consulting activities in the same area. Christian Seidelin Sørensen M.Sc in Economics is currently working on the EAR programme as well as WFD implementation projects in Eastern Europe. Tom Heron, hydrogeologist and division director, has initiated implementation of new remediation technologies in Denmark and he has acted as technical advisor for the Danish EPA on development projects.

COWI is a leading Danish Consulting company with a broad area of expertise in Denmark and abroad. They are a major player in the area of remediation technologies and soil contamination. Ninna Dahl Ravnsbæk, cand. tech. soc., has large expertise in soil contamination from projects in Denmark and Eastern Europa. He has significant experience as project leader and a very strong insight to commercial aspects of soil remediation projects. Jarl Dall Jepsen, hydrogeologist, has been involved in several large remediation projects (e.g. Kærgård Plantage and Høfde 42). Mia Ellegaard Munkøe, civilengineer, has extensive experience with soil treatment and commercial aspects of soil handling from major construction projects.

Orbicon is a leading Danish consulting company which has specialized in environmental engineering. The company has extensive experience in conducting investigations and risk assessments at contaminated sites as well as carrying out full-scale remediation technologies with innovative methods. Nina Tuxen, PhD, covers, fate of organic compounds in groundwater, microbiology, hydrogeology and remediation technologies. She has been project leader of research and innovation projects during her former employment at DTU and after she joined Orbicon. Thomas Hauerberg Larsen, PhD, has an interdisciplinary knowledge with special emphasis on physical and biological remediation technologies. He has been technical advisor for the Danish EPA on several development projects. Hans Christian Loer Linderoth is a consulting engineer within environmental management and numerical modelling of remedial actions.

Geosyntec Consultants is a premier provider of groundwater remediation design services, specializing in cleanup of chlorinated solvents and waste mixtures. Geosyntec has worked in Denmark since 2003 to design innovative remediation technologies, including assignments at Kærgård Plantage and Høfde 42. Neal Durant and Evan Cox, two recognized experts in chlorinated solvent bioremediation and Mega site remediation, will represent Geosyntec on the REMTEC project.

12) Project organisation and management

The project will be active for 4 years and will be organised by core research activities at DTU, GEUS and NERI AU (Figure 3). The project will be coordinated by a project leader (Poul L. Bjerg, professor, DTU) and a project leader deputy (Knud Erik Klint, senior scientist, GEUS). The project leader and deputy will be supported by a project manager which will be a part time post doc preferably working on the project. A group of professors/associate professors and senior researchers will be directly involved in the activities as indicated by Table 3. This contribution is a major strength of the project and viewed as a key point for scientific quality and institutional interaction and thereby the overall success of REMTEC.

The project will be divided into 6 interrelated work packages (WP1-WP6, Table 1), which each will be headed by a principal researcher (Table 4). Work package leaders and deputies have extensive experience with research and innovation projects and both research institutions and consulting companies are involved in project management. The project leader, project leader deputy and principal work package leader (Leader group) will meet frequently (4 meetings pr. year) in order to ensure coordination of the WP's. The time table (Figure 2), delivery of the anticipated milestones (Table 2), budget and resources will be monitored by the Leader group. The project leader and the project manager will solve daily management. A project homepage will be established with both internal and external access. Project results will be displayed and internal communication will be enforced by access to project information.

REMTEC will stimulate direct collaboration between consulting companies and research institutions. Four major consulting companies will participate in the project with key personnel, know-how and facilities. NIRAS will be heading WP6, while Orbicon and COWI will contribute to project management as deputies for WP3 and WP4. International knowledge sharing and business aspects are stressed by engagement of Geosyntec in the project. They will particularly contribute with expertise to WP2 and WP3. The industry engagement will promote fruitful synergy between the private and public sector with respect to research focus and commercial relevance of project activities.

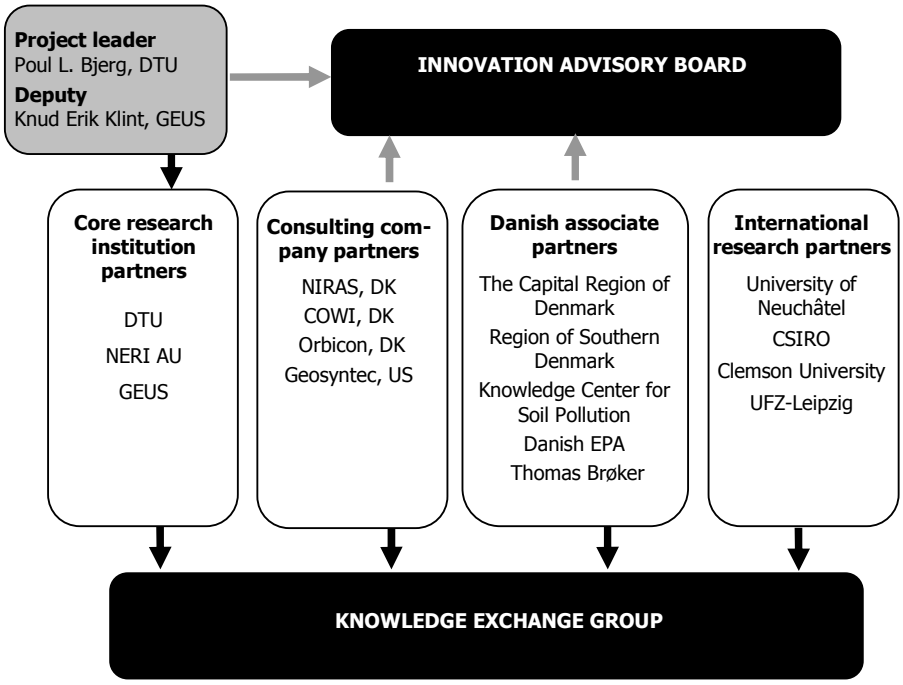

Figure 3: Project management and relation between partners, Innovation Advisory Board and Knowledge Exchange Group.

Table 4: Work package leaders and deputies in REMTEC.

WORK PACKAGE, WP		HEAD OF WP	DEPUTY OF WP
WP1	Accelerating remediation of low permeable clay tills	Knud Erik Klint, GEUS	Mette Broholm, DTU
WP2	Design and performance of bioremediation	Carsten Suhr Jacobsen, GEUS	Philip Binning, DTU
WP3	Optimizing remediation at sites with complex sources	Poul L. Bjerg, DTU	Nina Tuxen, Orbicon
WP4	Innovative bioremediation concepts, soil stabilization	Ulrich Gosewinkel Karlson, NERI AU	Ninna Dahl Ravnsbæk, COWI
WP5	Characterization and monitoring tools	Stefan Trapp, DTU	Bertel Nilson, GEUS
WP6	Environmental-economic assessment	Camilla K. Damgaard, NIRAS	Berit Hasler, NERI AU

International researchers will be directly related to the work packages (Table 1). The group will consist of leading scientists from Switzerland (Daniel Hunkeler, University of Neuchatel, WP2, WP3, WP5), Australia (Henning Prommer, CSIRO, WP2, WP5) and USA (Larry Murdoch, Clemson University, WP1), and Germany (UFZ Leipzig, Matthias Kästner, WP4, WP5) representing universities and research institutions with expertise in key topics for REMTEC. The international partners are active researchers performing parallel activities in their country. The strong links with international researchers are expected to result in co-supervision, exchange of PhD students and joint publications.

A Knowledge Exchange Group will be established with core project participants, international researchers, leading Danish consulting companies, a drilling contractor, two Danish Regions, Information Center for Soil pollution and the Danish Environmental Protection Agency. The knowledge exchange group will meet 4 times during the project period. Selected industry partners will participate in an Innovation Advisory Board, which will guide the project leadership with respect to innovation strategies and opportunities.

The project supports 6 PhD projects and three post doctoral research associates (51 month in total). The post docs will be recruited from national and international researchers with specialised qualifications within the area. The PhD positions will be partly financed by the Technical University of Denmark (2 full PhD scholarships) and Aarhus University (2*½ PhD scholarship). The core scientists have ample experience in PhD education. Candidates will obtain an internationally recognised education with a clear focus on dissemination of results in highly cited journals and at international conferences. The international group of scientist and consulting companies involved will guarantee a high standard of the work and form a strong basis for exchange and international networking. PhD A and PhD B will be jointly supervised by DTU and GEUS, while PhD C will supervised by DTU and CSIRO. PhD D will be supervised by DTU. PhD E and PhD F will be supervised by NERI AU in collaboration with DTU. A co-supervisor from industry will be affiliated to each PhD project.

The PhD students will be part of International research school of water resources (FIVA) or the Research School of Environmental Chemistry, Microbiology and Ecotoxicology (RECETO). The students will be able to take advantage of PhD courses regularly offered by these schools. PhD courses on topics of direct relevance to the project will be anticipated in relation to visits by the international scientists during meetings in the knowledge exchange group.

The project will be a major player in the development of remediation technologies in Denmark. The PhD students will interact directly with consulting companies and regulators which will be beneficial for efficient knowledge transfer and open new perspectives for development of remediation technologies and assessment tools.

13) Not relevant for minor strategic initiatives

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