NanoRem 3
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CL:AIRE

NanoRem Bulletin

CL:AIRE's NanoRem bulletins describe practical aspects of research which have direct application to the characterisation, monitoring or remediation of contaminated soil or groundwater using nanoparticles. This bulletin summarises one of the NanoRem outputs - "Generalised Guideline for Application of Nanoremediation".

Generalised Guideline for Application of Nanoremediation

1. Introduction

NanoRem (Taking Nanotechnological Remediation Processes from Lab Scale to End User Applications for the Restoration of a Clean Environment) was a research project, funded through the European Union Seventh Framework Programme. The NanoRem project focused on facilitating practical, safe, economic and exploitable nanotechnology for *in situ* remediation (Fig. 1). This was undertaken in parallel with developing a comprehensive understanding of the environmental risk-benefit, market demand, overall sustainability, and stakeholder perceptions of the use of nanoparticles (NPs). The NanoRem Toolbox, available at www.nanorem.eu, provides outputs which address all these issues.

This bulletin provides a summary of, and signposts to, one of the NanoRem outputs - a *Generalised Guideline for Application of Nanoremediation* (the "Guideline"). The Guideline gives a comprehensive overview on the successful implementation of nanoremediation.

The aim of the Guideline is to assist practitioners and consultants in screening nanoremediation as a possible remediation option for a given site. If nanoremediation is deemed beneficial, the Guideline provides design criteria and lists parameters to monitor in order to facilitate the successful application of the technology. In addition the Guideline may help regulators to evaluate a given nanoremediation scheme on its potential benefits or pitfalls.

The Guideline strictly focuses on the application of nanoremediation (Fig. 2). Prerequisites of a successful remediation such as a detailed site investigation, a conceptual site model (CSM), an overview of commercially available NPs and the corresponding operating windows (OWs) are not discussed in detail, however corresponding background material is offered in the appendices of the Guideline.

2. Pre-Screening

The Guideline contains a pre-screening tool that has been developed to quickly screen a contaminated site on the potential of nanoremediation. The pre-screening tool is a Microsoft Excel®-based application and matches commercially available NPs and their OWs with the requirements of a site as delineated in the CSM. It gives a quick indication of "favourable"/ "unfavourable" and indicates critical parameters to be investigated in more detail.

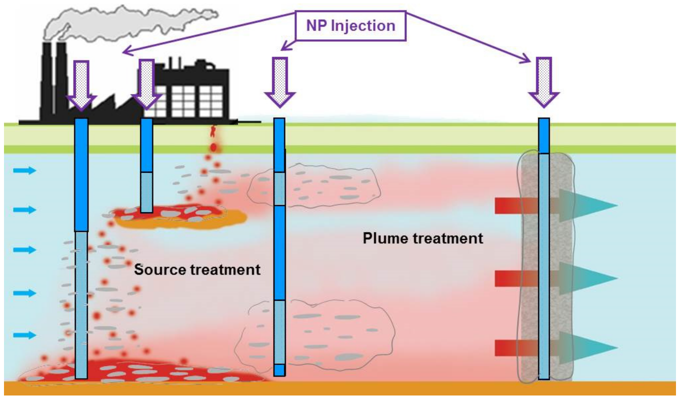

Figure 1. Schematic of *in situ* groundwater remediation using NPs. © VEGAS

3. Site and Contaminant Specific Particle Tests

Based on the outcomes of the pre-screening phase, one type of commercially available NPs is proposed to remediate a given contaminant type at a given site. The commercially available NPs are supplied by the producer as a ready-to-use suspension or with a protocol for preparation of a NP suspension. It is strongly recommended to verify the claims of the producer experimentally for each site since site-specific parameters such as pH, dissolved oxygen concentration, oxidation-reduction potential, dissolved inorganic ions and organic matter in groundwater as well as the mineral composition and natural organic matter content of the sediment may have substantial influence on NP reactivity, efficiency, longevity and (by)product formation. If a reactivity test of the NP suspension for a given contaminant proves successful, mobility (transport) experiments need to be conducted. These have the dual purpose of giving an indication of the radius of NP transport and in parallel yield parameters to calibrate a numerical model to eventually assist in the design of a remediation scheme.

4. Monitoring

As for all remediation the monitoring of a nanoremediation application may be divided into three phases: pre-, during, and post-deployment. For nanoremediation the deployment phase itself is critical since in this phase the distribution of the NPs (which in the end controls the success and efficiency of a given measure) in the subsurface is verified. The Guideline describes the monitoring phases in detail and suggests innovative and conventional monitoring devices and methodologies associated with each phase.

Taking Nanotechnological Remediation Processes from Lab Scale to End User Applications for the Restoration of a Clean Environment.
This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no. 309517.

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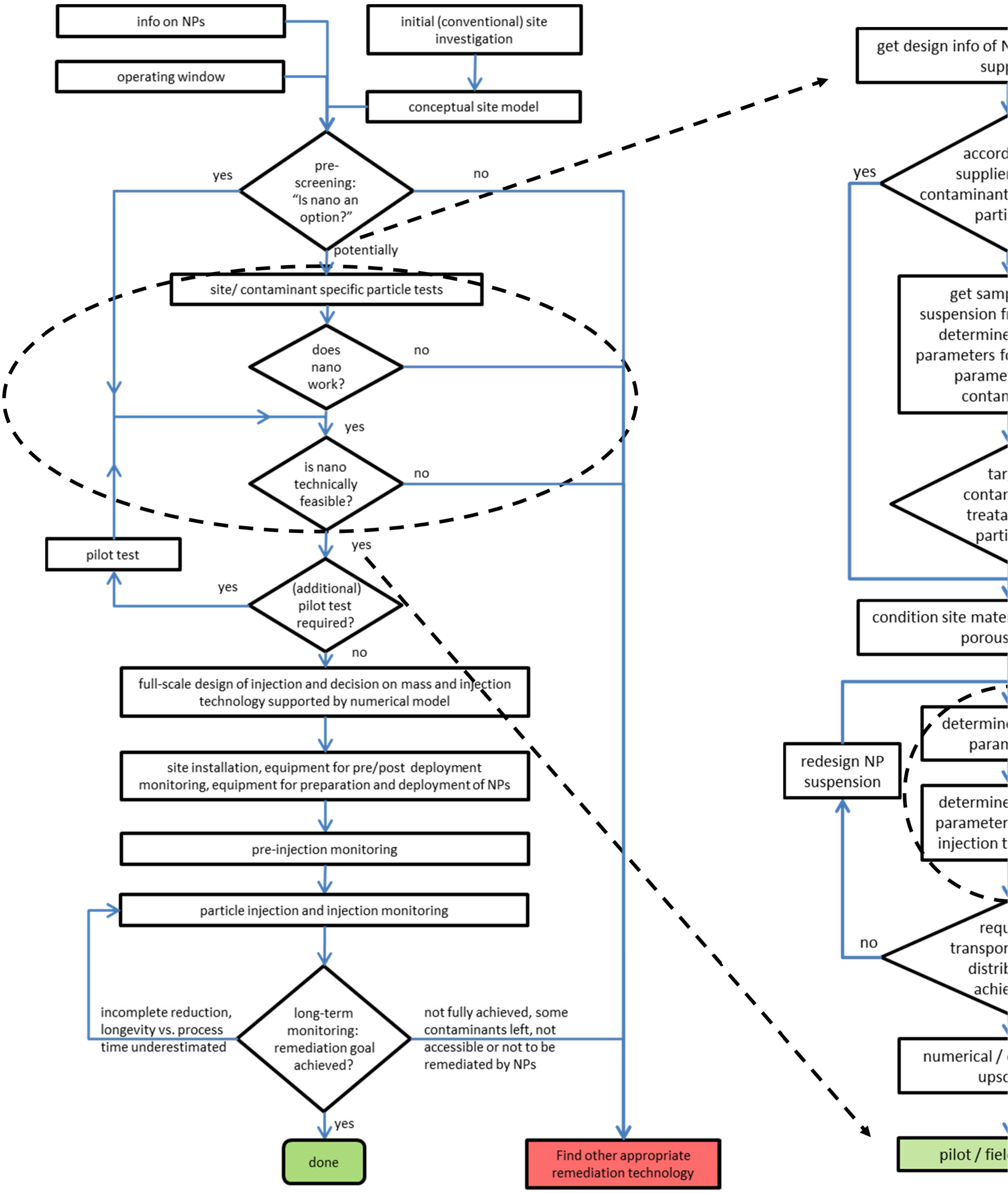

Figure 2. Flow chart delineating the structure of the Guideline.

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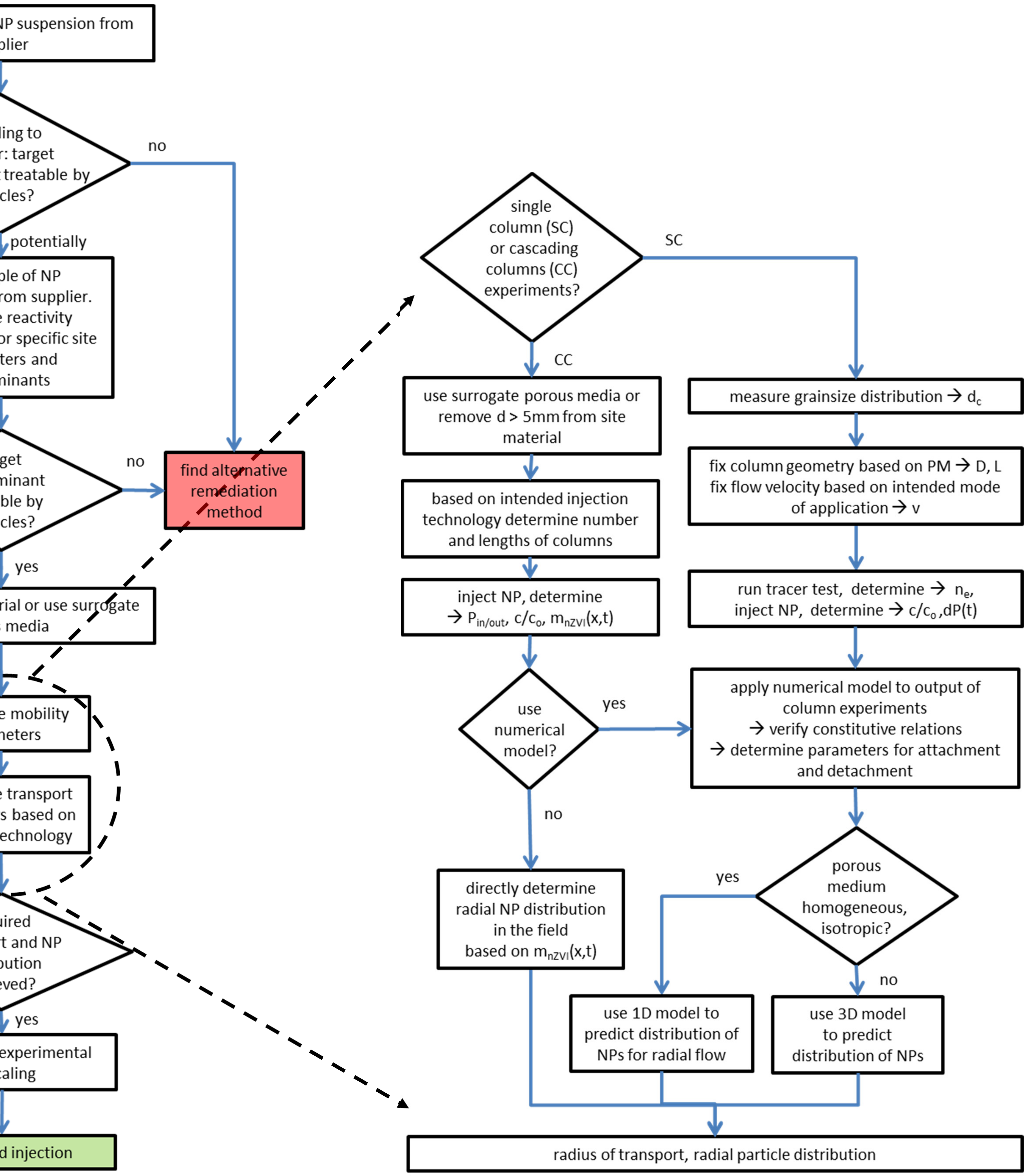

5. Model Assisted Upscaling of NP Mobility

The implementation of a NP-based remediation technology at a contaminated site usually requires the support of some form of quantitative modelling, to translate the results from laboratory column tests to estimated performance in the field. The main purpose of the modelling is to predict the NP mobility at different stages of the technology application, both in the planning and design stages (i.e. support the design of the injection plan), and later to predict the long-term NP mobility after injection (i.e. support the monitoring).

Within NanoRem, two macro-scale modelling tools were developed by Politecnico di Torino: MNMs, standing for Micro- and Nano-particles transport, filtration and clogging Model Suite, is used for the evaluation of laboratory-scale column tests, and the preliminary design of pilot NP injections in a simplified geometry (radial injection from a screened well); MNM3D, standing for Micro- and Nano-particles transport Model in 3D geometries, is a full 3D transport simulation of NP injection (in one or more injection points) in heterogeneous domains, and for the prediction of NP fate and transport at the field scale.

6. Pilot Tests

Pilot field tests are preferably designed based on the results of laboratory tests, or, if no such data are available, based on NP information from the supplier, on hydro-geo-chemistry and contaminant information obtained in the site investigation. The main aim of pilot field tests is the definition of specific conditions for the design and implementation of operational applications of NPs at the area of interest with respect to the selection of the right NP, evaluation of its efficiency and longevity of selected NPs, and thus to make a prediction of duration and technical as well as economic success of a given remediation scheme.

7. Full-Scale Design

Based on the pilot test and in conjunction with the numerical model a full-scale nanoremediation can be designed. The key part of the design is to match the contaminant distribution and inventory with a targeted deployment of NPs. The main challenge of the full-scale design is to balance technical and economical questions, i.e. homogeneous NP distribution vs. number of injection points.

8. Site Installations and Particle Deployment

Site installations necessary for a successful NP deployment comprise both above ground and below ground installations. Below ground installations may be emplaced beforehand if wells are being used or during NP deployment if the subsurface allows for the use of direct push injection technology. Above ground installations comprise mobile equipment containing mixing containers, dispersers, pumps etc. For the design of the above ground installations and especially during operation, as with other types of *in situ* remediation, worker's health and safety issues need to have top priority next to technical and economical questions (e.g. consult Material Safety Data Sheets for the NPs and follow good practice).

9. Long Term Performance

Test and confirmation of a successful nanoremediation is achieved via long term monitoring. During this phase contaminants, reaction products, metabolites and general environmental parameters of the groundwater are monitored on a regular (monthly) basis, in order to verify the success of the remediation. The main focus of the monitoring is to investigate the efficiency of the desired reaction in terms of reduction of concentrations of contaminants in the groundwater, reduction of emissions or contaminant masses. The criteria for the decision on the success of a nanoremediation have to be defined beforehand and a monitoring programme chosen accordingly (usually the success is measured against remediation goals, which are mutually agreed on with the responsible authorities prior to commencement of the remediation). The monitoring results will be compared to the status defined during the pre-injection phase. Eventually, the monitoring programme should be designed to give positive proof of a successful remediation or to decide if and when a reinjection of NPs is required.

10. Regulatory Issues

In order to implement nanoremediation at different locations within the European Union (and beyond) local regulatory requirements have to be fulfilled. It is beyond the scope of the Guideline to address these requirements in detail, however, most frequently or most likely asked questions posed by regulators are listed to facilitate communication between consultant and regulator.

11. Financial Issues

As for the application of any other remediation technology, there is no "generic" cost calculation for nanoremediation, rather the total cost will be a function of many parameters, such as the subsurface and contamination, geographic location and so on. Nevertheless, to facilitate a cost estimation the main cost drivers are listed in the Guideline.

12. Examples of Nanoremediation

Within the NanoRem project six pilot site studies have been conducted successfully. The descriptions of the sites, chosen remediation approach, monitoring and the outcomes are described in dedicated NanoRem Bulletins 7-12 (http://www.claire.co.uk/).

For further information on NanoRem please visit www.nanorem.eu

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The Guideline and its appendices will be available for download by the end of January 2017 at www.nanorem.eu.

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