Towards the fourth generation site remediation technology
Vers la quatrième génération de technologie de recupération des sites

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SYNOPSIS: Within a decade soil remediation developed in the leading countries (USA, the Netherlands, FRG) from an ad hoc reaction on public pressure to a systematic soil protection policy. For the USA and the European Community (EC), estimated remediation costs exceed 430 billion US$. Soil quality standards and legislation force industry into large scale soil remediation of present and former sites and dumps. This incites large (petro)chemical companies to the development of more specific and cheaper remediation technologies, specifically suited for their own types of contamination: i.e. in-situ and off-site treatment of contaminated soil. This may bring sophisticated chemistry and microbiology in this traditionally civil engineering field, and might cut remediation costs down to 50%, but might also reduce considerably the market share of the building industry. Early R & D cooperation of contractors with chemical industry could benefit both, but particularly the contractors.

1 THE RAPID GROWTH OF THE REMEDIATION MARKET

Soil pollution was recognized as a public concern in the nineteen seventies in the USA and U.K., and in the early eighties in the Netherlands and the FRG. Public pressure gave the impetus to remedial measures for now "famous" sites like Love Canal (USA), Lekkerkerk (the Netherlands) and Georgwerder (Hamburg, FRG) where the remediation costs up to now are about 250, 100 and 70 million US$, respectively. Due to these incidents a completely new view has developed with respect to the hazards of polluted soil and groundwater, and the value of clean soil, resulting in large scale soil remediation and protection programs. The estimated public and industrial spendings range up to 430 billion US$ for the USA and the European Community (EC). Estimated public budgets in the USA, the Netherlands and the FRG now already exceed 26 billion US$, whereas allocated budgets already exceed 15 billion US$. Simultaneously the costs for waste disposal and for soil protection measures (e.g. for industrial sites, petrol stations) increase rapidly. Up to now still almost all this money is spent at the building industry.

2. HISTORY OF SITE REMEDIATION TECHNOLOGY

The first generation. The first large scale remediations took place under large public pressure. In all those cases direct health effects and health risks were recognized or strongly suspected: sickness of workers or inhabitants, or children playing amidst very hazardous waste. The first generation site remediation technology consisted of traditional geotechnics: excavation, encapsulation and pumping, accompanied with worker protection measures (Mischgofsky et al. 1981).

The second generation. In a reaction on the first large scale incidents and the public pressure, governments started to inventarize potential hazardous sites. In the USA, the Netherlands and the FRG with populations of 240, 15 and 61 million, respectively, up to now over 25,000, 6,000 and 40,000 suspectedly hazardous sites, respectively, were identified, and the numbers still are increasing. For the whole EC (320 million inhabitants) Gieseler (1987) expects 120-160,000 suspect sites with over 1 billion m^3 contaminated soil and waste.

At the beginning only the pollution cases which posed a direct threat to public health by direct uptake of toxics (contaminated dust, vegetables, drinking water) were addressed. The contaminated sites were closed for the public and priority lists were drawn for remediation. Simultaneously, in the early eighties by adaptation and modification of the existing techniques a second generation techniques was developed: adapted excavation and transport equipment, less permeable and more durable encapsulation materials, better pumping strategies and water treatment installations.

The third generation. In the mid eighties in several highly industrial countries soil remediation has become a regular environmental issue. Laws are being developed for soil remediation and protection. Soil quality and remediation standards are being developed.

Large soil investigation and remediation programs are running in the USA and the Netherlands. These formed the basis for a large scale involvement of consultancy firms and contractors in the field of civil engineering. So in the mid eighties (Mischgofsky 1985, 1986ab, 1988) a much more advanced, third generation of field investigation, encapsulation and in-situ treatment techniques, and of installations for the treatment of excavated contaminated soil and hazardous waste was developed specifically for the remediation and monitoring of contaminated sites, but simultaneously also for the protection of soil, that is: for the safe disposal of wastes ranging from household refuse and dredged material to fly ashes and hazardous waste. Although the influence of chemical engineers and biologists is rapidly increasing, the vast majority of the work still is done by building companies.

3. THE INFLUENCE OF SOIL STANDARDS

The dutch soil quality standards for the dutch Soil Protection Bill are intended to protect the quality of soil and groundwater. These values validate everywhere, irrespective of the specific use of the soil. The **reference values** (De Bruijn & De Walle 1988, Moen 1988) (figure 1a) are based on contaminant concentrations of which no hazardous effects are known, and are close to the background levels in clean soil. One can expect in future **target values** intended to improve the general present quality in the long term, and **limits**, i.e. concentration levels of which hazardous effects are known. According to the present dutch minister of the environment mr. Nijpels (Moen 1988) already 20% of dutch terrestric and underwater soils exceed the reference values.

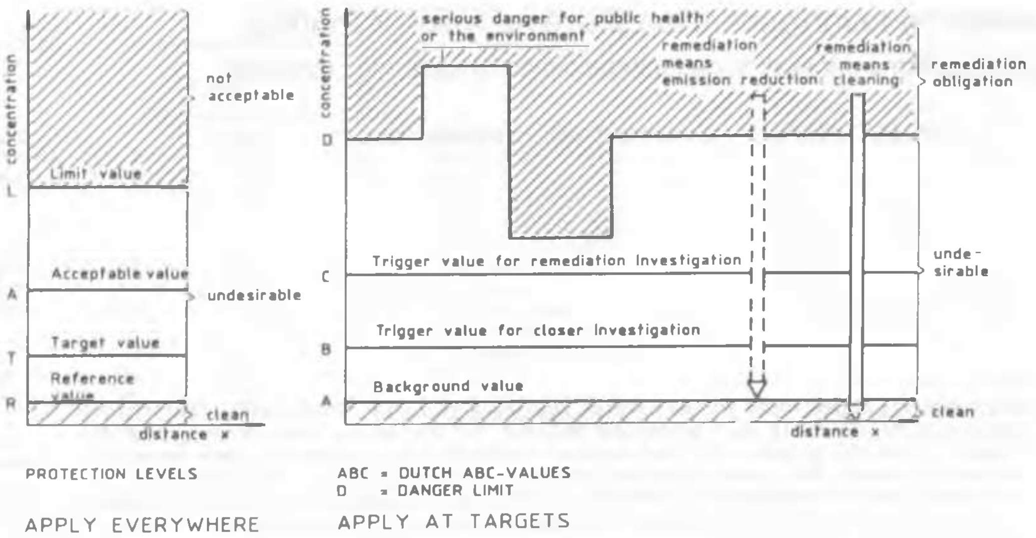

Figure 1a (left): Soil quality standards are intended to **protect the general quality of the soil** and **apply everywhere**.

Figure 2b (right): The dutch ABC-values are action levels for contaminated sites, and intend to **protect** the presently (or potentially) **threatened targets**.

The dutch ABC-values (De Bruijn & De Walle 1988) (figure 1b) for the (older) dutch Soil Remediation Bill are action levels. The A-level is close to the reference value for clean soil and groundwater. Soils at this level are considered clean. If at a site for any substance the 5-10 times higher B-value is found, this means that a **closer investigation** is required. If then for any substance the 5-10 times higher C-value is found, a **remediation investigation** is required, in which the hazards of the site have to be assessed. If then a serious danger for public health (or the environment) is found, remediation is obligatory.

4. REMEDIATION TARGETS

Whereas **the soil quality values** apply **everywhere** and are intended to **prevent** (further) soil and groundwater pollution, the **ABC-values apply only to contaminated sites** and are intended to indicate the need for action. The concentration values in the risk assessment apply to the soil and groundwater **at the targets** which already are (or in future will be) **threatened** by the contamination **source** (figure 2). The concentration levels which exert a direct (or potentially) serious danger could be called D- or Danger levels. It is clear that they depend on the actual use of the (potentially) contaminated soil: the D-value will be lowest in a childrens sand box or a drinking water well and much higher in a parking area or a chemical production site (see figure 1b).

Having found levels (potentially) exceeding the D-value, the important question arises to which extent remediation is required. The **ideal** would be to clean all contaminated soil to below the A- or reference-values. Such action only can be called **soil clean-up** properly (figure 1b). The dutch Technical Soil Committee (TCB 1986), however, established that in nearly all cases this could be achieved only by complete removal of all contaminated soil exceeding the A-value.

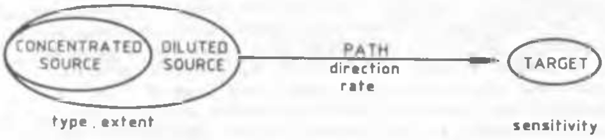

Figure 2: The (contaminated) **source** - (potential migration) **path** - (threatened) **target model** (Mischgofsky et al. 1981, 1986a, 1988).

The **minimal** remediation, fulfilling the above criteria, would be to remove selectivily only so much of the contaminants, that **at the threatened** targets the D-value never would be attained. Such remediation means in fact **emission-reduction** of the pollution-source (figure 1b).

Whereas the dutch government in the past focussed on proper **soil-cleaning**, one now sees the industry to focus on cost-effective **emission-reduction**, i.e. **excavation of "hot spots"** (the "concentrated source" in figure 2) and **in-situ treatment** of the remaining area.

5. IMPACT OF SOIL STANDARDS AND TIGHTENING LEGISLATION ON REMEDIATION SPENDINGS

The **soil quality standards** label large areas as contaminated:
- most abandoned and former industrial sites
- most former waste dumps and disposal sites containing industrial waste, dredging sludge, etc.
- many of the present industrial sites and waste dumps
- many river and lake sediments
- large agricultural areas due to too high pesticide, metal or nutrient concentrations
- large areas polluted by air deposition of heavy metals due to e.g. metal melting industry
- a large number of small sites polluted at various commercial activities, like petrol stations, dry-cleaners, garages, printers, shunting-yards etc.

Governments (will) use soil quality standards and soil legislation for identification of contaminated areas and for the enforcement of measures to:
- prevent a further deterioration of soil quality, i.e.:
  . soil protection measures for a.o. industrial activities and waste disposal
  . emission reduction measures to prevent a further migration of pollutants from contaminated sites and uncontrolled (hazardous) waste dumps
- remediate the soil quality of contaminated areas, i.e.:
  . remediation of sites which impose a direct threat to human health or the environment, and moreover:
  . reduction of the average contamination level in general.

The **dutch industry** recently had made a general cost estimate to bring **all its sites** in a state conform to the new dutch reference values for clean soil: roughly 10 billion US$ would be needed in the next 25 years (and an additional 0.4 billion US$/year for soil protection measures).

In a recent report for the EC, Gieseler (1987, 1988) calculated that on the same criteria the EC would need 110-130 billion US$ to remediate **present and former industrial and waste sites**. For two sets of more lenient criteria he calculated that the EC would need 55-72 and 45-55 billion US$, respectively. In another report for the EC, Haines (1988) estimates that the EC will need 24 billion US$ for the remediation of **merely those industrial sites** which are already **abandoned** or **will be abandoned** in the next decade.

A similar trend is visible from the soil remediation budgets of the Superfund Program of the USA Environmental Protection Agency (Kovalick, 1988). It spended 1.6 billion US$ directly and US industry had to remediate for another 0.7 billion US$ in the period 1981-1985. Its budget for the period 1986-1991 is 9 billion US$, but US industry expects to have to spend 3-6 billion US$/year on remediation for at least 50 years.

Looking at the general world wide development in the last decade of the soil problem, one sees a rapid increase of the budgets in the leading countries, and a simultaneous decrease of the time needed by other countries to formulate similar soil policy and soil remediation and protection programs. Since the costs for the disposal of hazardous waste are rapidly increasing, waste export firms try to find the cheapest countries for disposal, recently resulting in various scandals which have induced now also several african countries to develop laws against import and uncontrolled disposal of hazardous waste. Evidence is clear: (hazardous) waste disposal, soil remediation and soil protection are developing into the fastest growing world wide market for the building industry.

6. DEVELOPMENT POTENTIAL OF REMEDIATION TECHNOLOGY

The polluted area in the USA and EC can be classified as:

1. Some tens square kilometers containing high concentrations pollutants, e.g. uncontrolled hazardous waste and/or dumps and lagoons; "hot spots" of hazardous waste and/or accumulated chemicals in mixed dumps and in former and present industrial sites
2. Many hundreds square kilometers containing elevated contaminant concentrations, such as large proportions of former and present industrial sites, agricultural areas and areas contaminated by air deposition.

6.1 Remediation of "hot spots"

For the first category enormous cost savings can be expected if only the "hot spots" need to be addressed, i.e. there is a development potential for:

1. **Cheap reliable survey instruments** to identify the "hot spots" in industrial sites and waste dumps. Surface surveys with improved electromagnetic (groundprobing radar, geoelectric and magnetometric methods) and shallow seismic tests are suited to identify suspect spots in rather undisturbed, original stratifications. For the identification of "hot spots" in more complicated situations ("mixed dumps") the development of push-away ground-radar-, seismic-, geoelectric- and chemical probes could provide more reliable information. All electromagnetic and seismic techniques require data banks and improved signal processing in order to discriminate between the signals of potential harmfull and harmless spots. Although this technology is in development, e.g. at Delft Geotechnics, still many years are required before complex situations may be analysed reliably.
2. The most cost-effective way in the long term to remediate "hot spots" (U.S. Congress 1985, Mischgofsky & Kabos 1988), is not encapsulation and monitoring, but excavation. Presently methods are being developed to remove safely "hot spots" (even deep under the surface) without removing the surrounding less contaminated waste or soil (Hannink et al. 1989).
3. The most expensive part of excavation is the treatment of the excavated material: incineration, immobilization, extraction, detoxification, controlled disposal etc. Present costs range from 1000 US$/ton for the incineration of dioxin containing material down to about 100 US$/ton for oil and tar contaminated soils. A large market can be expected for cheaper methods designed for the treatment of specific types of pollutants. This, however, will require a large research input of chemical, microbiological, combustion and mechanical engineers.
4. Due to lack of budgets and/or the impossibility to detect the "hot spots", many uncontrolled hazardous waste dumps are planned to be (or are being) encapsulated. This requires high investment and monitoring costs whereas the expected life time of encapsulation materials is estimated to be a mere 20-50 years. Within this span of time either the "hot spots" have to be removed or treated, or the expensive encapsulation measures have to be replaced. Therefore there exists a development trend towards more durable and more impermeable encapsulation materials.

6.2 Remediation of large areas with elevated pollutant concentrations: trend towards in-situ treatment

Of all the available remediation techniques, the **in-situ treatment techniques** offer the most economic prospects. These are methods, with which contaminants can be isolated, removed or treated without having to remove the soil itself. Their effect is emission reduction (and thus risk reduction) by reduction of the amount and/or mobility of the contaminants. This can be achieved by heating, pumping, flushing, dissolving, extracting, immobilizing or transforming the pollutants and by so removing, destroying or immobilizing them or making them less harmfull. Transformation reactions may be e.g. oxydation, reduction, hydrolysis, polymerization, biodegradation, precipitation, immobilization, chelation and other neutralisation, detoxification or destruction reactions.

In-situ treatment techniques require a gaseous or liquid medium which can be extracted or added. Gaseous media can be air, steam and/or gases (oxygen, ozone, H_2O_2 etc.). Liquids can be water with or without additives, or other viscous media (solvents, injection media etc.). Also heat and electric fields or currents may be used. The methods can be applied separately, subsequently or simultaneously, depending on the situation.

In-situ treatment techniques offer many **advantages**:

- low investment and implementation costs *
- less extensive apparatus required **
- (contribution to) removal of the contaminants
- little influence on existing and future constructions**
- particularly cost-effective for large sites with low contaminant concentrations
- less dangerous for residents and remediation personnel as regards contact with contaminants and chemicals
- rapid initial emission reduction and so a rapid risk reduction.

These techniques also may exhibit **disadvantages**:

- only suited for permeable soils
- lengthy operation *
- side effects can occur and must be examined
- additives and conversion (or by-)products can be harmful and may require constant monitoring or even additional temporary isolation provisions
- permeability heterogenities may cause short-cut flows or uneven through-flow effects
- durability monitoring may be necessary for immobilization and precipitation reactions.

The (dis)avantages marked with an *) indicate that the costs for in-situ treatment are rather low and can be spread rather evenly over a longer period, which is very favourable for industry. The advantages marked with an **) indicate that in-situ techniques are particularly suitable for use on sites which are still in operation (industry, railways, service stations etc.).

Although in-situ treatments such as pumping and flushing are widely applied, and although progress is made with the application of biodegradation, nearly all the other potential applications are still in the laboratory stage. Of these only a few have reached the field trial stage. Further development will require a large research input of soil physicists and -chemists, physical and organical chemists, microbiologists, chemical and mechanical engineers. Elaborate field tests will be needed with appopriate effect prediction and -evaluation, and in many cases also risk assessments because of the potential hazardous effects of additives and transformation- and degradation compounds.

7. COSTS AND BENEFITS OF R & D

The largest opportunities for cheaper remediation techniques are in the following fields (Haines 1988, Gieseler 1988, Mischgofsky 1986ab, 1988):

- **cheaper** methods to clean excavated soils and wastes
- methods to clean **more types** of excavated polluted soils
- in-situ techniques suited to treat **more types** of contaminated soils.

Haines (1988) states that savings on remediation costs might be up to 30% by these new developments. Gieseler in a reaction to his publication (1988) even expects savings up to 50%.

In the early eighties, due to lack of legislation and jurisdiction, governments paid for the site remediations. Nowadays it has become easier to find the responsible firms and to have them to do the remediation. The trend is that in future the major part of remediations will be done by industry itself. So saving on remediation costs benefits both the industry and the government. The largests budgets for soil research (Quakernaat & Mischgofsky 1986) are spent by the US EPA (exceeding 50 million US$/year) and the FRG (about 20 million US$/year of which 50% is paid by the research contractors themselves). Substantial smaller R & D budgets are spent by the governments of the Netherlands (5 million US$/year) and the U.K. However, many of the larger oil and chemical companies in the US, Netherlands and FRG seem to have realized that they can save tens to hundreds millions of dollars by developing cheaper remediation techniques specifically aimed on those contaminants which are typical for the hundreds of hectares under their own responsibility. Many of them now are cooperating with research institutes and consultants for R & D and for field trials and demonstration projects on their own premises (Wolf et al. 1988). Some are considering or even starting subsidiaries or joint-ventures to exploit their new experiences. In this way they might benefit twice from the R & D results: by saving on their own remediation costs and by earning from the remediation budgets of others. An additional advantage, which should not be underestimated, would be that they can treat their own contaminated sites (always a delicate affair) without too many outsiders.

8. CONCLUSIONS: SHIFTING POSITION OF BUILDING INDUSTRY

Up to now the remediation market is completely dominated by building industry. Exceptions are mainly the treatment of hazardous waste (immobilization, incineration) and a few installations for the high temperature treatment of excavated soil.

However, the (petro)chemical multinationals dispose over large R & D departments, extensive and highly specialized knowledge on the chemicals in their branch, large funds for R & D and soil remediation, and over polluted areas to test out new or improved remediation techniques and strategies. The emerging cooperation with institutes covering soil science and civil engineering may lead to just the required teams of research specialists and the required R & D funds and facilities needed to tackle successfully the highly complex field of in-situ and off-site treatment of contaminated soil and hazardous waste. The management and marketing skills of the multinationals, together with their investment resources might enable them to take a large share of the future soil remediation market.

The research for in-situ treatment of industrial sites might also yield cheap treatment techniques for the vast areas (e.g. several hundred square kilometers for just the Netherlands) with polluted river and lake sediments or with polluted top layers due to agricultural use or air deposition. One can easily imagine that such treatments would be well suited for land development companies, which from this position might also penetrate the site remediation market.

If the building industry would wish to reserve its prominent position on the remediation market, extensive R & D cooperation with selected chemical companies would benefit both, but particularly the building industry.

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