6

Trends in Technologies to Combat Contaminated Soil Environments

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6.1 Introduction

In the 1960s, pollution problems such as the Itai-itai Disease, Minamata Disease and Yokkaichi Asthma emerged to become major social issues. To cope with this, preparations were advanced such as 1967's Basic Law for Environmental Pollution Control, Air Pollution Control Law and Water Pollution Control Law, and countermeasure technologies have also progressed in tandem with these.

Nevertheless, in the case of soil contamination, the seriousness of contamination had not become apparent, and for this and other reasons, legislation had not yet been enforced. Meanwhile in recent years, there have been many cases where soil contamination became evident in soil surveys attendant to land redevelopment and sale, and independent surveys that businesses conduct as part of environmental management relating to ISO14001 (certification), and along with increasing concern, measures to combat this have become a pressing issue.

Looking at recent trends, the Council for Regulatory Reform's "Interim Report on Regulatory Reform in Six Priority Areas" (July, 2001), highlights the necessity for legislation concerning soil and ground water contamination, and the Council for Science and Technology Policy (CSTP), Cabinet Office's "Promotion Strategies for Prioritized Areas" (September, 2001), notes the necessity for technological development concerning soil and ground water contamination. Furthermore, the Central Environment Council released a report in January 2002 entitled, "On the Desired State of Systems concerned with Measures to Preserve Soil Environments." According to the report, a mechanism is being planned whereby governors of Tokyo, Hokkaido, and all the prefectures can oblige land owners to conduct soil contamination surveys in instances where factories and businesses handling hazardous substances terminate their business or change (land) usage to residential areas, etc., or where the possibility of serious soil contamination is recognized. Furthermore, funding, the corner-stone of this mechanism, and how expenses should be borne when persons responsible for contamination can not be specified and so forth, are set to be discussed in future.

Against this kind of backdrop, this paper analyzes the latest technological trends concerning measures to combat soil and ground water contamination, and takes up the themes that should be resolved, with a focus on technical aspects.

6.2 The current state of soil contamination and laws and regulations

6.2.1 Soil contamination within Japan

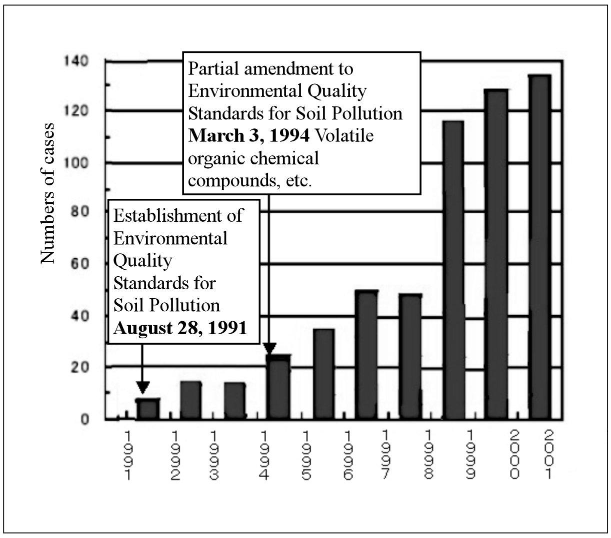
The "Overview of Soil Contamination Surveys and Countermeasure Examples, and Survey Results on Countermeasure Effectiveness in the Year 2000" (February, 2002, Ministry of the Environment), reports on the numbers of proven cases of soil contamination until the end of March, 2001, ascertained by Tokyo, Hokkaido and all the prefectures. Figure 1 shows the numbers of proven cases of soil contamination by year that exceeded Environmental Quality Standards (EQS) for Soil Pollution values *[1], and we can see that in recent years in particular, the number of proven cases of soil contamination has risen dramatically.

The cumulative number of cases since the establishment of the Environmental Quality Standards for Soil Pollution (1991), is 574.

Factors cited for this are that the number of soil surveys has increased due to (1) companies' efforts towards gaining ISO14001 (certification) and (2) soil surveys, etc., based on the ordinances and outlines of local autonomous bodies. It is conceivable that the growth trend in cases of excessive soil contamination will continue in the future as well.

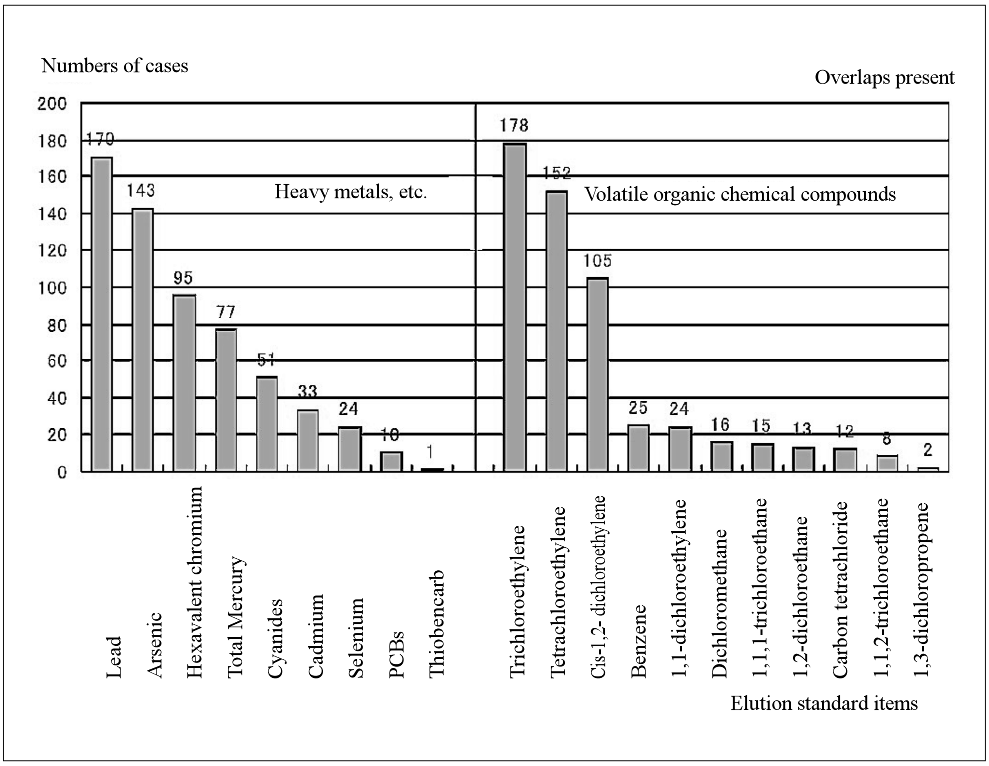
Figure 2 shows the cases exceeding the Environmental Quality Standards for Soil Pollution *1 of Figure 1 by substance targeted for regulation. Among heavy metals, etc., lead and arsenic account for approximately 60%, and there are many proven cases of contamination in metal products manufacturing industries and chemical industries. And among volatile organic chemical compounds, chloroethylenes that were being used in semiconductor manufacturing processes, etc., account for about 80%, and there are numerous proven cases of contamination from electrical machinery and devices manufacturing industries and the cleaning industry. These are harmful substances that are causing concerns about health-related problems, and there is also a strong need for combative measures.

Figure 1: Numbers of proven cases of soil contamination by year



Source: Composed from Ministry of Environment data, "Overview of Soil Contamination Surveys and Countermeasure Examples, and Survey Results on Countermeasure Effectiveness in the Year 2000" Feb., 2002

Figure 2: Numbers of excessive cases by substances targeted for regulation (cumulative)



Source: Ministry of the Environment "Overview of Soil Contamination Surveys and Countermeasure Examples, and Survey Results on Countermeasure Effectiveness in the Year 2000" (Feb., 2002)

6.2.2 Current state of soil contamination regulations in developed countries

In European and American countries such as the United States and Holland, countermeasures concerning conservation of soil environments were adopted from an early stage, and reports of soil contamination from businesses and land owners are compulsory under law; surveys by administrative organs are also being conducted. Table 1 shows an outline of systems to combat soil contamination enacted in Europe and America.

6.2.3 Current situation in Asian countries

Environmental problems in developing countries present a variety of aspects. For example, in Asian countries that are undergoing rapid industrialization and urbanization, it is necessary to deal with the environmental issues of industrial pollution, urban pollution and global-scale environmental deterioration while advancing development. In Thailand for instance, principally arsenic-based groundwater and soil contamination from the manufacture and use of agrochemicals is a serious problem. Similar problems are also being reported in China and other Asian countries. Furthermore, in West India and Bangladesh, an estimated 17 million people are drinking groundwater contaminated with arsenic eluted from geologic strata, and the situation is acute [1]. Looking at systems of environment-related laws in place in Asian countries, in the same way as Japan almost all laws apart from those concerning soil have been established. But even if a system is in place, its effectiveness is an issue. Reasons indicated for this are (1) even if a law is

Table 1: Overview of soil contamination countermeasure systems in Europe and America

Name of country	System concerning soil contamination countermeasures and overview
Holland	**1983: Provisional Soil Purification Law** **1987: Soil Conservation Law (revised in 1994 in a form including the Provisional Soil Purification Law)** **1997: BEVER Project (goal to repair contamination) commences** Began with the commencement of soil purification resulting from disclosure of the Lekkerkerk incident (ground water contamination) in 1980. Currently it establishes two levels of standards concerning soil contamination: target value and intervention value.
Germany	**1998: German Federal Soil Protection Act** A framework for formulating unified standards of regulation concerning soil contamination countermeasures established in each province of Germany. Objective is to permanently conserve or recover soil functions. Establishes fundamental obligations towards land users such as the (1) obligation to prevent the ecological functions of soil from being damaged; (2) obligation to act in such a manner that harmful soil changes do not occur; (3) obligation to unseal sealed ground when it can be requested so as to recover soil functionality; (4) obligation of purification; (5) obligation to perform contamination surveys, and so on.
Denmark	**1999: Contaminated Land Law** Began with the disposal of uncovered waste materials in the 1970s. Revises the Waste Materials Disposal Law and the Environmental Protection Law. Stipulates the introduction of a registration system for contaminated sites; setting of the order of priority for carrying out purification measures; obligation of administrative agencies to carry out surveys and purification measures.
England	**1990: Environmental Protection Law** **1999: Environment Law** Using the concept of comprehensive contamination regulations, promotes control of the total amount by unified management of contaminants discharged into the air, water and soil from industrial facilities, the number one source of contamination. Establishes liability to purify contamination; a system for registering contaminated land and specific facilities; administrative procedures to protect the lives of private citizens; and provisions of requesting court injunctions, etc.
United States	**1980: The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, commonly known as Superfund)** **1999: Superfund Redevelopment Initiative** Soil and groundwater contamination problems became conspicuous in the latter half of the 1970s. Support is being given to formulate national guidelines and boost funding, etc. Contaminated areas that exceed a certain level of risk are registered on the National Priority List (809 locations as of February, 2002).

Source: Author's own compilation

formulated, the establishment of its enforcement ordinance is lagging behind or has not been established, (2) compared to developed countries, the budget, human talent and technology to implement environmental measures are inadequate.

6.3 Current state of measures to combat soil contamination

6.3.1 Features of soil contamination

Compared to water and air, soil has a complex composition, and reacts in various ways to hazardous substances.

Heavy metals, one type of general pollutant, resist dissolving in water and are easily adsorbed by soil. Therefore, heavy metals and so on that have penetrated into the ground exist in the soil close to the surface, and often do not diffuse to deeper levels. But when they surpass the absorbing capabilities of soil, hexavalent chromium, cyanide and so forth, which are highly mobile and highly soluble in water, spread to deep subterranean levels along with rain water percolation, and there is a possibility that the range of contamination will expand by the flow of groundwater.

Among volatile organic chemical compounds on the other hand, organic chlorine compounds are indecomposable in the natural world, and are degradation resistent substances that remain for long periods in the environment. Furthermore, since they have extremely strong permeability, they penetrate deep underground while contaminating the soil, mixing in and diffusing in groundwater to cause groundwater contamination. Furthermore, since they are also volatile, some of them vaporize and resolve from the groundwater, and there is a possibility that they will once again contaminate the upper layers of geologic strata. Therefore, even if the contamination source is confined to a small area, the contamination often diffuses and reaches a wide area along with groundwater flow.

6.3.2 Soil contamination treatment technology

In the "Guidelines and Standards for Research and Countermeasures Concerning Soil and Groundwater Pollution" (Environment Agency, 1999), measures to combat soil contamination are classified into the following types of contamination: "heavy metals" *2 and "volatile organic chemical compounds"*3. In addition, pollution countermeasures are classified as "emergency measures" and "permanent measures." Emergency measures are measures for cases where permanent measures can not be implemented, and consist of measures to prevent ingestion by humans and measures to prevent diffusion of contamination. The latter are measures to ensure that target substances that elute due to rain water do not spread to the surrounding soil and groundwater in the future. Table 2 shows an overview of emergency measures among the measures to combat soil contamination

As for permanent measures, the following are treatment technologies for which a considerable number of cases have been executed so far:

1) With heavy metals, etc., use is often made of landfill disposal, transporting them to a final place of disposal; and solidifying and making them insoluble using cement, etc., at the site.
2) With volatile organic chemical compounds,

Table 2: Emergency measures for soil and groundwater contamination

Technique	Overview
Measures to prevent ingestion by humans	Installation of keep out fences and bulletin boards
	Instruction to prevent drinking of groundwater, switching of water source
Measures to prevent spread of contamination	Installation of collecting channels, settling basins, etc.
	Covering of contaminated soil by paving, tree planting
	Covering with sheets, etc.; installation of windproof nets; installation of barrier wells
Monitoring	Observation of soil and water quality, air, etc.

Source: Author's own compilation

in many cases contaminants are adhered to active carbon using the soil vapor extraction method and the groundwater pumping-up method, and this active carbon is finally treated in meltdown furnaces.

In recent years it has become even more difficult to secure a final place of disposal, and there is a growing need for treatment technology that enables low cost, in on-site treatment (soil treatment at the contamination site).

6.4 Trends in the development of new technologies to treat soil contamination

Table 3 shows permanent measures for soil contamination that are currently at the stage of practical application, including technologies that have a record of little usage. As it stands, all the technologies require further improvements in terms of cost and labor saving. In particular, the following technologies are cited as those for which R&D is being vigorously undertaken: technology for treatment at the contamination site; technology for treatment in a short time frame; technology to reuse contaminated soil rather than just contain it; and technology that uses the decomposing power of organisms.
Below, we show technologies from among the countermeasure technologies show in Table 3 that are attracting particular attention of late.

6.4.1 Physical and chemical treatments

(1) In-site oxidation decomposition method
A technique that decomposes volatile organic chemical compounds and renders them harmless by directly injecting an oxidizer (potassium permanganate, etc.) into a contaminated groundwater system. Since it utilizes a chemical reaction in site, the purification treatment can be completed at low cost and in a short time frame compared to the ground water pumping-up method and soil vapor extraction method, etc. What is more, since the injected oxidizer reacts and resolves the contaminants in a short time frame, injection of a solvent for recovery is not required.

(2) Permeable reactive barrier
A method that purifies contaminated groundwater by installing a permeable reactive barrier in the contaminated groundwater downstream area (site boundary, etc.) that contains iron powder, which has the ability to purify contaminants. When groundwater contaminated with volatile chlorine compounds passes through the permeable reactive barrier, it causes a reduction reaction with the iron powder in the permeable reactive barrier, and ethylene and even ethane are resolved and rendered harmless. Since power for maintenance is not required after installing the permeable reactive barrier, it is anticipated that a significant reduction in maintenance and management work and expenses is possible compared to the groundwater pumping-up method, the representative purification method.

6.4.2 Biological treatment

(1) Bioremediation
A soil and groundwater contamination repair technology that utilizes the substance-decomposing capabilities of microorganisms, it is classified into two according to the method by which microorganisms are utilized :

1) Method that gives nitrogen and other nutrient salts to microorganisms inhabiting contaminated areas, propagates micro-organisms at the site, and increases purification activity (biostimulation)
2) Method that introduces cultivated microorganisms into contaminated areas, and purifies contamination (bioaugmentation).

International interest is also high, and recently, the Fifth International Environmental Biotechnology Symposium was held in Kyoto in July, 2000, and in June, 2001, the 8th Bioremediation International Symposium was held in San Diego. Since subterranean soil and groundwater that requires environmental repair are generally anaerobic conditions, research on the utilization of anaerobic microorganisms is also being carried out. Microorganisms are being discovered that can decompose even substances resistant to degradation like highly chlorinated PCBs, by dehalogenation reaction under anaerobic

Table 3: Permanent countermeasure technologies for soil and groundwater contamination

◎: Treatment technologies with many cases of employment

Technique	Technology classification	Name of technology	Target substance		Overview, etc.
			VOC	Heavy Metals	
In site treatments	Physical and chemical treatments	Electrokinetic separation method		○	Removes heavy metals using electrodes inserted in the ground
		Soil vapor extraction method	◎		Treatment that pressure fits air, etc., into the ground and adheres contaminants to active carbon, etc.
		Groundwater pumping-up method	◎	○	Treatment that adheres contaminants from pumped-up groundwater to active carbon, etc.
		In site oxidation resolution method	○		Technology that directly injects an oxidizer into a groundwater system, resolves VOCs and renders them harmless
		Permeable reactive barriers	○		Technology that installs a permeable reactive barrier containing iron powder in a contaminated groundwater downstream area and purifies it
		High-pressure Jet-propelled Agitation, Displacement, Solidification	○	○	Injects cement at high pressure into the ground, and replaces contaminated soil with a concrete hardening body
		Containment	○	○	Containment with sheet pile and an impermeable layer (clay layer).
	Thermal treatment	Thermal desorption and volatilization		○	Treatment that thermally resolves contaminants and adheres them to active carbon, etc.
		Glass solidifying		○	High-temperature melting by an electrothermal source. Requires exhaust gas treatment.
	Biological treatment	Bioremediation	○		Utilizes the resolving power of injected microorganisms and resolves and renders trichloroethylene, etc., harmless (uses non-genetically modified microorganisms)
Excavation treatments (Ex site)	Physical and chemical treatments	Soil classification and washing		○	Classifies by soil viscosity and dissolves target substances in washing liquid.
		Chemical treatment	○		Treatment that resolves target substances by oxidation, reduction and catalytic reactions, etc., and adheres them to active carbon.
		Solidification and solubility retardation		◎	Makes insoluble by cement solidification, use of solubility retardants, etc.
		Containment	○	○	Containment with impermeable sheet, continuous underground wall, sheet pile, etc.
		UV irradiation		○	Dechlorination of PCBs by UV rays.
	Thermal treatment	Thermal decomposition (incineration)	○	○	Heats contaminated soil in an incineration furnace, etc., and removes volatile metals.
		Pyrolysis (Molten solid processing)	○	○	Heats contaminated soil in a melt furnace, treats volatile substances with exhaust gas and solidifies heavy metals, etc., in slag
	Biological treatment	Slurry treatment		○	Adds water to soil to form slurry, and after oxidation-decomposition, completely decomposes PCBs by microorganisms (non-genetically modified).
	Other	Land fill disposal	○	◎	Landfill disposal at final place of disposal

(Note) VOC: volatile organic compound; PCB: polychlorinated biphenyl

Source: Author's own compilation

conditions.

Furthermore, in the "Development of Remedial Technologies for Soil Contamination" project (conducted by NEDO: New Energy and Industrial Technology Development Organization) carried out from 1995 to 2000, empirical tests were conducted to confirm the effectiveness of bioremediation and to investigate effects on the environment. From 2001 NEDO began developing technology to use microorganisms to purify soil contaminated by heavy oil, etc.

(2) Phytoremediation

Phytoremediation is a contamination repair and purification technology that utilizes the ability of plants to store and decompose environmental contaminants. In addition to the feature that it can be applied to purifying low concentration, broad-ranging contamination, its scope of application is confirmed to be extremely broad, from organic chemical compounds to radioactive substances.

In technological development the US leads the way, and the discovery of a type of fern that efficiently absorbs arsenic[2] and technology that enhances plants' resistance and amount of accumulation in respect to heavy metals by genetic manipulation[3] have been reported. Venture companies that deal with Phytoremediation are also appearing, but cases of practical application are few.

(3) Cost of biological treatment

Since the circumstances of pollution cases (scale and concentration of contamination, target substances, etc.) are diverse, it is difficult to quantitatively compare and discuss phyto-remediation and conventional technologies such as physical and chemical techniques. For this reason, we compared treatment costs and other limited items. The results are shown in Table 4.

For the cost of phytoremediation treatment, we look at overseas cases of trial calculation reports. According to a trial calculation carried out by D.J. Glass of the per-ton cost of treating contaminated soil, the phytoremediation treatment cost is $25-100, whereas chemical treatment and incineration treatment is $100-500, the cost of treatment being about five times higher[4]. And looking at a case conducted by F. Chris comparing phyto-remediation and bioremediation, the per-square yard cost of treating of soil contaminated with pesticides is about $80 in the case of phyto-remediation and $8.4-197 for bioremediation [5].

However, to carry out a detailed comparison of these costs, it is necessary to study costs such as expenses required for the land during the period necessary for soil purification.

Table 4 : Performance comparison of soil contamination treatment technologies

○ Fexcellent, △ Faverage, × inferior

Item for comparison	Phytoremediation	Bioremediation	Chemical treatment	Heat treatment
Target substances for treatment	• Heavy metals • VOC	• VOC	• Heavy metals • VOC	• Heavy metals • VOC
Cost (initial cost)	○	○	△~× differs for each technology	△~× differs for each technology
Need for external energy	○	△	×	×
Speediness (Purification in short time frame)	×	△	×	×
Effect of soil temperature and humidity, etc., on treatment capability	×	×	○	○
Application to areas contaminated at low concentration over a wide area	○	○	×	×

(Note) VOC: volatile organic compound

Source: Author's own compilation

6.5 Conclusion

In this paper we have examined the current state of overseas soil contamination regulations and the current state and developmental trends, etc. in soil contamination countermeasure technologies in regard to soil contamination, which has numerous technically difficult aspects compared to air and water contamination and whose legislation had been lagging behind.

Looking at the current state of technologies to combat domestic soil environment contamination, there is a problem of having insufficient places of final disposal, and investing efforts into technological development for treating contaminated soil on site and at low cost is considered to be vital.

Furthermore, with the introduction of laws and regulations, it is conceivable that the numbers of cases requiring purification of contaminated soil will increase, and it will become even more important to be able to treat at low cost and in a short time frame.

In addition, measures are also being sought to combat environmental contamination that is being caused by endocrine disrupting chemicals (so-called environmental hormones) that exist in trace amounts over wide areas. The treatment of contamination extending over wide areas, typified by environmental hormones, is a difficult field to deal with using conventional technology such as physical and chemical treatments.

Considered in this way, the promotion of research towards establishing biological treatment technologies taken up in Section 6.4.2, is desired. Also, in terms of dealing with the treatment of soil contaminated with heavy metals, etc., the development of technologies of the type that combine bioremediation and phytoremediation, will probably be necessary also.

The above mentioned types of issues are themes that neighboring Asian countries are also facing. The development of technologies to combat soil environment contamination, including bio-remediation mentioned above, is something that from the perspective of international contribution, this country also must surely position politically and promote.

Glossary

*1 Among investigation cases, cases that were proven not to meet Environmental Quality Standards for Soil Pollution. Environmental Quality Standards for Soil Pollution concerning dioxins, and cases of farmland soil contamination based on the Agricultural Land Soil Pollution Prevention Law, are excluded from this target.

*2 15 items: cadmium, cyanides, organic phosphorus, lead, hexavalent chromium, arsenic, mercury, alkyl mercury, PCBs, thiuram, simazine, thiobencarb, selenium, fluorine and boron.

*3 11 items: Dichloromethane, Carbon tetrachloride, 1,2-dichloroethane, 1,1-dichloroethylene, Cis-1,2-dichloroethylene, 1,1,1-L trichloroethane, 1,1,2-trichloroethane, Trichloroethylene, Tetrachloroethylene, Benzene, 1,3-dichloropropene.

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