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The management of contaminated soil remediation programmes

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Abstract

This paper summarizes the management system for the control of soil remediation programmes in Taiwan. This system includes subsystems which are linked together in order to make the remediation process more cost-effective and efficient. The subsystems include: (1) site discovery and identification using a monitoring and information system; (2) a preliminary assessment and site inspection system to establish a national priority list (NPL) for remedial action; (3) a response and control system; (4) a remedial investigation and feasibility study (RI/FS) and detailed evaluation of remedial action alternatives; (5) responsibility for financial support; and (6) the release of sites from the NPL and their transfer to other land uses. In other words, the key components of this management system include soil remediation law and related legislation, alternative techniques for soil remediation, financial support, and guidelines or criteria for soil remediation. For cost-effectiveness and efficiency in the selection of soil remediation techniques, key factors are considered, including initial contaminant concentrations and soil characteristics, materials handling and preprocessing techniques, treatment goals, and mixtures of organic and inorganic contaminants. An acceptable solution may involve the use of several treatment technologies in a treatment train. Some case studies of soil remediation management of sites in Taiwan polluted by trace elements, particularly cadmium and lead and organic pollutants, are discussed.

1. INTRODUCTION

When a contaminated site is identified by the government, the next step is to consider what action should be taken. Many developed countries have experience of the techniques of soil remediation for different kinds of soil pollutants, especially organic pollutants (US EPA 1988, 1989, 1990, 1991; Mench *et al.* 1994; Yaron *et al.* 1996; Iskandar and Adriano 1997). In order to manage the soil remediation programme in Taiwan, there is a need to establish guidelines or processes to be followed, based on what has been learned from developed countries. This will save cost and time in the restoration of soil and environmental quality.

The objectives of this paper are: (1) to discuss the management of soil remediation programmes and the key components of such programmes; (2) to explain how to evaluate soil remediation techniques which are cost-effective and efficient for contaminated sites; and (3) to present some case studies of soil remediation management for some sites in Taiwan polluted by trace elements, especially cadmium and lead as well as organic pollutants.

2. MANAGEMENT SYSTEMS FOR SOIL REMEDIATION PROGRAMMES

In order to manage the complete soil remediation programme, we must establish a management system to control the remediation process. Four sectors/groups of people are included in this management system:

- local people;
- local or national government;
- Environmental Protection Agency (EPA); and
- soil remediation consultancies.

In brief, these sectors/people must communicate with each other to reduce the possibility of risks to human health and the environment (Figure 1). Local people may inform local government about sites with a high risk of contamination. Local and national governments also have responsibility for organizing a routine monitoring system to locate such sites. After a contaminated site has been found, the EPA has responsibility for controlling the situation, supporting local government in carrying out a pre-

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liminary survey, making a risk assessment and determining the state of the pollution. Then, the EPA must decide whether or not the site will be included in the National Priority List (NPL) for remediation. If the site has been included in the NPL, a proposed change to another land use must be announced. Then, local government can invite environmental consultants to propose remedial action alternatives which will be evaluated by soil remediation experts from the EPA. After approval of the remedial action plan, local government must control and monitor the whole remedial process until it is completed, based on the guidelines or criteria for the clean-up of soil pollutants. Once the site has been cleaned up, the EPA can release it from the NPL.

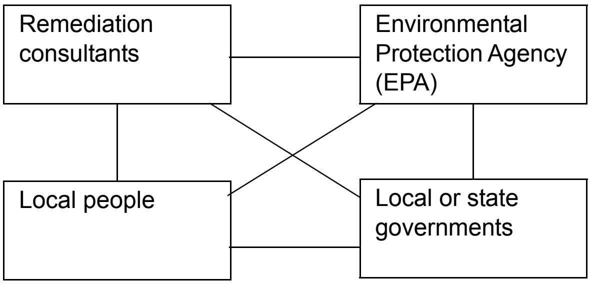

Figure 1. The people and agencies involved in the management of remediation sites

In the USA, under section 105 of the 'Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)', the United States Environmental Protection Agency (US EPA) has established a procedure for discovering releases, evaluating remedies, determining the appropriate extent of the response, and ensuring that the remedies selected are cost-effective (US EPA 1985*c*). The US EPA has also established the 'National Contingency Plan (NCP)' for controlling soil remediation programmes (US EPA 1985*a*, 1990).

Based on this remediation management concept and also on some study reports (US EPA 1985*a*, 1985*b*, 1985*c*, 1988, 1990, 1991; Chen 1997*a*; Iskandar and Adriano 1997; Lin 1997; Yeh 1997), the management system controlling the soil remediation programme includes six subsystems which are linked together in order to make the remediation process more cost-effective and efficient (Figure 2):

- site discovery and identification by a monitoring and information system;
- a preliminary assessment and site inspection system for establishing national priority lists for remedial action;
- a response and control system;
- a remedial investigation and feasibility study (RI/FS) system;
- responsibility for financial support;
- a control of land use action system for the release of contaminated sites and their transfer to other land uses; and
- a detailed evaluation of remedial action alternatives design and construction.

In summary, four key systems are included in this management system:

- soil remediation law or related legislation;
- alternative techniques for soil remediation;
- financial support; and
- guidelines or criteria of remediation.

2.1 Site discovery and identification using a monitoring and information system

In order to identify sites with a high risk of contamination, a monitoring and information system should be established by government in the same way as a fire emergency information system. The monitoring system is operated by the state or county government based on the distribution of plants or industries. This system can find the majority of the contaminated sites, but not all. Other contaminated sites should be identified through the information system with support from local people living around the pollution sources or industrial private plants especially in developing countries (US EPA 1985*a* 1990).

The information system must be established by state governments or by a central government agency such as the EPA, and must be the link between local and central governments. In Taiwan, such a system has been set up to collect information relating to air, water, solid waste and toxic substance pollution sources, with the exception of the sources of soil pollution (EPA/Taiwan 1997). The benefits derived from this information system include saving time and money in the identification of sites with a high risk of contamination.

2.2 Preliminary assessment and site inspection system

After a site with a high risk of contamination is identified, local government must conduct a preliminary assessment and site inspection. This must be done as soon as possible to avoid serious negative effects on human health, or serious contamination of the groundwater, soil, and crops.

2.3 Response and control system

A response and control system for local people is set up after the preliminary results of the soil survey and risk assessment of the potentially contaminated site have been obtained. Then essential official actions are undertaken, e.g.:

- a report is made to the government agencies concerned, including the Department of Agriculture,

Department of Health, EPA, and related departments on the control of use of the site and the quality of crops there;
- if the preliminary evaluation shows that a site is seriously polluted, a detailed survey and assessment must be made to be able to include the site in the NPL by EPA. An announcement will then be made;
- if a site is evaluated as slightly polluted, local government must carry out essential treatment to remove or reduce the toxic substances, the mobility of the pollutants or reduce the effects on the quality of local environmental conditions.

2.4 The National Priority List (NPL) for remedial action

The EPA announces that the contaminated site will be included in the NPL after a detailed survey of the soil pollution has been carried out and a risk assessment for human health and environmental quality has been made. Then the EPA controls the remediation programme until the site is released from the NPL.

2.5 Controlling land use

After the EPA has announced a national priority site, any use of the site is prohibited. This control process is the responsibility of the EPA and the Department of the Interior until that particular site has been released from the NPL.

2.6 Detailed evaluation of remedial action alternatives and soil remediation action

In the USA, after a site has been included in the NPL, a remedial action selection process is undertaken (US EPA 1985*a*, 1985*b*, 1985*c*). In accordance with section 105 of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the US EPA has established a standard procedure for discovering a release, evaluating and determining the appropriate extent of the response, and ensuring that the remedial action selected is cost-effective (US EPA 1988, 1990, 1991; Iskandar and Adriano 1997) (Figure 3). This process is commonly referred to as the remedial investigation and feasibility study (RI/FS). The RI emphasizes data collection and site characterization. Its purpose is to define the nature and extent of contamination of a site as well as the evaluation, selection, and design of cost-effective remedial action. On the other hand, the FS focuses on data analysis and decision making. It uses the data from RI to develop response objectives and alternative remedial responses. The alternatives are then evaluated in terms of their engineering feasibility, public health protection, environmental impact and cost.

For the selection of a suitable remedial technology, the following steps are necessary (US EPA 1991):

- **Step 1. Determination of remedial objectives and identification of response action**: This step identifies existing site problems using preliminary remedial investigation data and it determines the categories of remedial technology that are applicable. More than one technology category may be applied to a given site.
- **Step 2. Technology screening**: This step identifies and screens potential applicable remedial technologies from general remedial technology categories already selected. It focuses on eliminating those technologies which have severe limitations for a given set of waste- and site-specific conditions.
- **Step 3. Development and screening of remedial action alternatives**: These alternatives represent a workable number of options that appear to adequately address all site problems. These alternative actions undergo screening to eliminate those which are an order of magnitude more costly than others, and those which do not provide adequate public health protection or have adverse environmental impacts.
- **Step 4. Detailed evaluation of remedial action alter-**

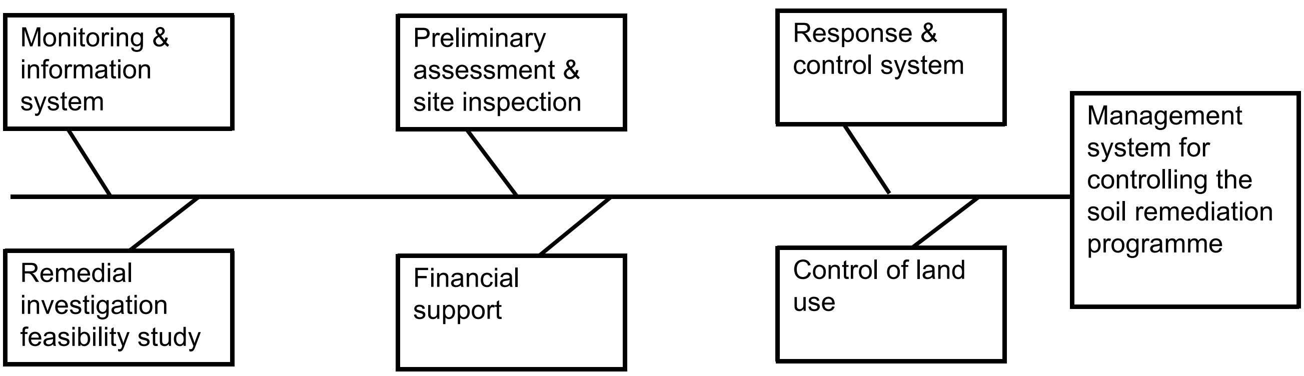

Figure 2. The management system for controlling the soil remediation programme

natives, and remedial alternative selection: The alternative technologies are then subjected to detailed evaluation. For each remedial alternative, the following factors are analysed:

- *Technical considerations*. Suitability is evaluated in terms of performance, reliability, implementability, time, and safety.
- *Environmental concerns*. The environmental assessment will generally consider the environmental effects of each alternative technology, including any adverse impact on environmentally sensitive areas, exceedance of the environmental standard of pollutants, short and long-term effects, irreversible commitments of resources, and mitigative measures and their costs (Adriano 1986).
- *Public health concerns*. The items that must be considered include: site evaluation; analysis of the extent and duration of human exposure to the site; comparisons between the projected clean-up level and the standard level; and the ability to remove contaminants from the site (Jackson and Alloway 1992).
- *Institutional concerns*. The effects of federal, state and local standards, and other institutional considerations, on the implementation and operational time of each alternative technique should be determined.
- *Costs.* These include operation and maintenance (O&M) costs. The manual for remedial action cost procedure provides a detailed procedure for evaluating costs in remediation.

- **Step 5. Remedial alternative selection**: After detailed evaluation of action alternatives, each of the alternatives is summarized relative to each of the criteria described above. This summary is generally in the form of tables which allow the alternatives to be compared easily and decision-makers can select the most appropriate technique.

The EPA or local government organize third party evaluation and monitoring of the results of the soil remediation and make a final assessment to decide whether or not the site can be released from the NPL.

2.7 Release and transfer of contaminated sites

After the sites have been cleaned up, the government, through the EPA, releases them from the NPL and they may be transferred to other land uses.

3. EVALUATION OF THE MAIN SOIL REMEDIATION TECHNIQUES

The sources of soil pollution can be mainly classified into two groups: organic and inorganic pollutants. Recently, remediation techniques have been developed for soil pollution (US EPA 1991; Adriano *et al.* 1997; Chen 1997*a*; Iskandar and Adriano 1997; Lo and Che 1997; Yang 1997).

3.1 US EPA classification of soil remediation techniques (US EPA 1991)

Under the US EPA Superfund Innovative Technology Evaluation (SITE) programme, remediation techniques can be divided into three categories (US EPA 1991) as shown in Figure 4.

The different soil remediation techniques proposed by the US EPA (1990) are summarized in Figure 5.

- Chemical extraction and soil washing

  Chemical extraction and soil washing are physical

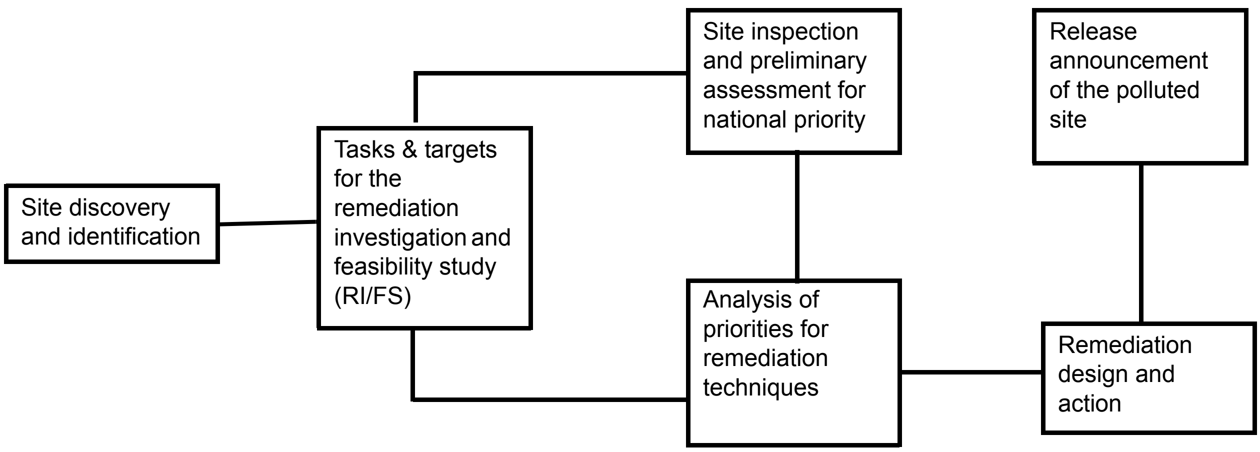

Figure 3. The standard flow chart for the National Contingency Plan (NCP) under the Superfund (1991)

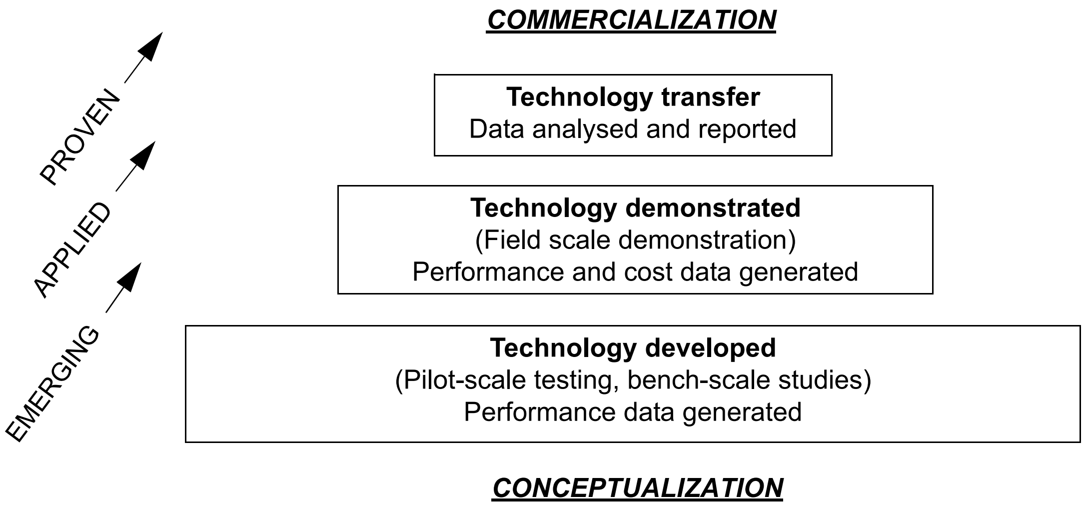

Figure 4. Development of innovative technologies for soil remediation

transfer processes in which contaminants are disassociated from soils, becoming dissolved or suspended in a liquid solvent. This liquid waste stream then undergoes subsequent treatment to remove the contaminants and, if possible, the solvent is recycled. Soil washing uses water as the solvent to separate the clay particles, which contain the majority of the contaminants, from the sand fraction. Chemical extraction processes use a solvent which separates the contaminants from the soil particles and then dissolves the contaminants in the solvents. If the selection of the solvent is optimized, with the addition of surfactants or chemical agents, chemical extraction and soil washing can successfully treat many organic and inorganic contaminants, particularly those which are more soluble in the solvent of choice.

- Immobilization (or stabilization and solidification)

  Immobilization processes reduce the mobility of contaminants by stabilizing or solidifying them within the soil matrix, without causing the destruction or transfer to another medium of significant contaminants. Volatile organics may volatilize during treatment, and an emission control system may be required. Leaching of contaminants can be significantly retarded by selecting optimal formulations and proportions of stabilized materials, such as cement and/or lime materials to the waste. For the immobilization processes, contaminant concentrations in treated soils are typically measured in terms of EP toxicity, toxicity characteristic leaching procedure (TCLP), or similar extraction protocols performed on the untreated and treated soils.

- Bioremediation

  Bioremediation is a destructive process that uses soil microorganisms to chemically degrade organic contaminants. These microorganisms include bacteria, fungi, and yeast. Biodegradation of hazardous wastes can occur both as an intracellular and an extracellular activity. Both intracellular and extracellular biodegradation can occur in the presence or in the absence of oxygen. In the presence of oxygen (aerobic), bacteria, fungi, and yeasts biodegrade organics to carbon dioxide, water, and cell protein. In the absence of oxygen (anaerobic), they biodegrade the waste to generate methane, carbon dioxide, and cell protein.

- Low temperature thermal desorption

  Low temperature thermal desorption is a physical transfer process that uses air, heat, and/or mechanical agitation to volatilize the contaminants into a gas stream, where they are subjected to further treatment. This method moves the contaminants into a medium which is easier to treat than soil. This technology is most effective on the more volatile organic compounds, and it is limited in its ability to volatilize metals (with the exception of mercury) and semi-volatile organic compounds.

- Thermal destruction

  Thermal destruction uses high temperature to incinerate and destroy hazardous waste materials, usually by converting the contaminants to carbon dioxide, water, and other combustion products in the presence of oxygen. Thermal destruction is a proven technology which can effectively and rapidly treat all organic compounds. It consistently achieves the best overall results for these contaminants, usually accomplishing well over 99% removal. This technology is equally effective on halogenated, non-halogenated, aliphatic, aromatic, and polynuclear compounds. However, incineration of nitrated compounds may release large quantities of nitrous oxide into the air.

- Dechlorination
  Dechlorination is a destructive process that uses a chemical reaction to replace chlorine atoms in chlorinated aromatic molecules with an ether or hydroxyl group. This converts the more toxic compounds into less toxic, more water-soluble products. Field and laboratory tests have identified several types of solutions that can dechlorinate PCBs, dioxins, furans, and other aromatic compounds.

3.2 Key factors to be considered in the evaluation of soil remediation

The effectiveness of available soil remediation technologies can vary widely due to the unique characteristics of contaminated soils. Key factors affecting selection and effectiveness include the following (US EPA 1990, 1991; Chen 1997*b*; Iskandar and Adriano 1997):

- *initial contaminant concentrations and soil characteristics*: these two factors may limit the ability of a technology to treat the waste. Concentrations must be characterized before and during the remediation;
- *material handling and preprocessing techniques*: these two factors may be necessary to homogenize the contaminant concentrations and particle size before the waste is subjected to a particular technology;
- *treatment goals*: the remediation goals vary depending on the levels of acceptable risks. These goals affect the selection of processes, with some technologies, such as thermal destruction, capable of removing contaminants down to the part per billion range while others achieve treatment goals in the part per million range;
- *mixtures of organic and inorganic contaminants*: mixed contaminants may preclude the use of some treatment processes due to the potential for undesirable cross-media impacts. An acceptable solution may involve the use of several treatment technologies in a treatment train.

3.3 Case studies of management of contaminated soil remediation in Taiwan

Five well known contaminated sites have been announced by the Taiwan EPA since 1984 (Chen 1991; Chen 1992; Chen 1994*a* and 1994*b*; Chen *et al.* 1996; Chen and Lee 1997; Chen 1997*a*). These sites are contaminated by organic pollutants and heavy metals, as follows:

- Site A: 17 ha of sandy rural soils (more than 80% sand) in northern Taiwan contaminated by Cd and Pb announced by EPA/Taiwan in 1984.
- Site B: 80 ha of clayey rural soils (more than 40% clay) in northern Taiwan contaminated by Cd and Pb announced by EPA/Taiwan in 1988.
- Site C: 3.6 ha of silty rural soils (more than 70% silt) in central Taiwan contaminated by Cd, Pb, Cu, Zn, and Ni announced by EPA/Taiwan in 1992.
- Site D: 8 ha of rural soils in northern Taiwan contaminated by organic pollutants. These include 1,1-dichloroethane, 1,2-dichloroethane, tetrachloroethene, trichloroethene, and cis-1,2-dichloroethene.
- Site E: 20 ha of rural soils in northern Taiwan contaminated by oil announced by EPA/Taiwan in 1997.

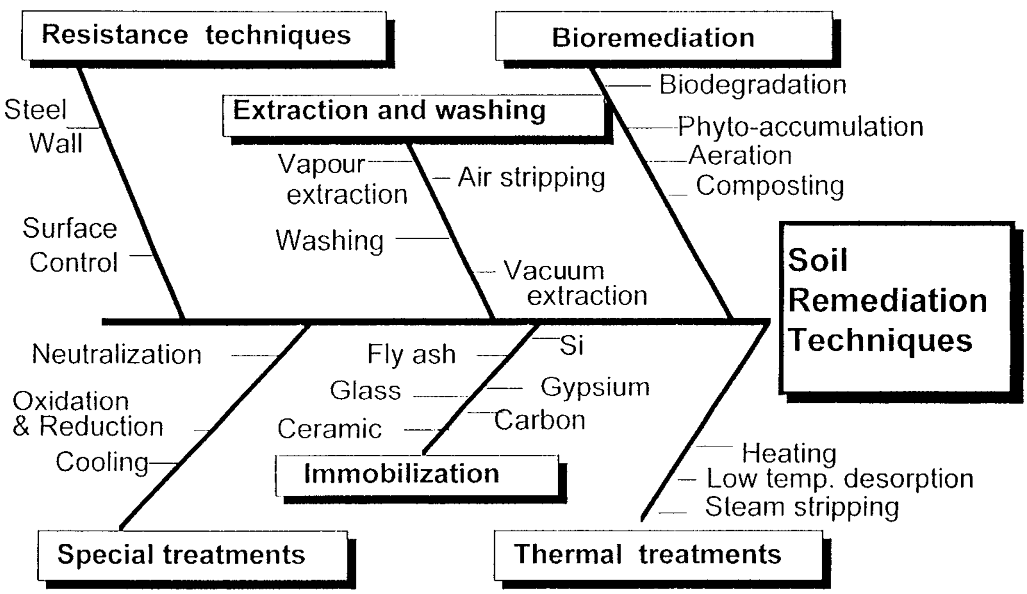

Figure 5. The main soil remediation techniques used in contaminated sites

Sites A and B were contaminated by waste water discharged from the chemical engineering plants which produce the stabilizing materials for plastics. The Cd contents of brown rice grown in the contaminated soil ranged from 2.4 to 4.9 mg/kg (Chen 1991; Chen *et al.* 1996). This was higher than the allowable control limits of 0.5 mg/kg issued by the Taiwan Department of Health.

Different soil remediation techniques including engineering, chemical, and biological treatments were proposed and tested to clean up these two sites (Chen *et al.* 1992*a*; Chen 1994*a*; Chen *et al.* 1994; Lee and Chen 1994; Wang *et al.* 1994*a*; Cheng 1996; Chen and Lee 1997; Lo and Che 1997).

Two technical consultant committees on soil remediation were set up in 1997 to manage and supervise the soil remediation programme in these polluted sites. One committee's remit is the remediation of organic pollutants and the other's the remediation of heavy metal pollution. Each committee is composed of 14 members. These committees are appropriate third parties to liaise between local governments, local people and the EPA, and to communicate the concepts and techniques involved.

3.3.1 *Engineering remediation techniques*

Engineering remediation techniques are effective and save time when changing the use of contaminated sites (Chen *et al.* 1994). The most effective engineering remediation technique is the removal of the polluted surface soil and replacing it with uncontaminated soil. The contaminated soil removed is then washed by chemical extraction or chelating reagents (Chen *et al.* 1994).

3.3.2 *Chemical remediation techniques*

Chemical remediation techniques include adding chemical material to polluted soil to reduce the concentration of Cd and Pb soluble in the soil solution. For example:

- lime materials, manures, or composts to increase soil pH and reduce the solubility of trace elements;
- hydrous oxides of iron or manganese or zeolite to increase the adsorption sites of trace elements;
- large quantity of phosphate to increase the precipitation of metal ions and phosphate ion.

Some chemical materials have been tested in field experiments to treat contaminated soils. Examples include lime material, manure or composts, phosphate, hydrous oxides of iron and manganese, and zeolite (Gworek 1992; Mench *et al.* 1994; Chen and Lee 1997; Chen *et al.* 1997*a*; Pierzynski 1997; Mench *et al.* 1997; Sappin-Didier *et al.* 1997; Liu *et al.* 1998). The application of lime can significantly reduce the solubility of heavy metals in contaminated sites (McBride and Blasiak 1979; Sommers and Lindsay 1979; McBride 1980; Kuo *et al.* 1985; Mench *et al.* 1997; Sappin-Didier *et al.* 1997; Chen *et al.* 1998; Liu *et al.* 1998).

Some reports also indicated that the application of hydrous oxides of iron or manganese or zeolite in contaminated soils could reduce the concentration of Cd or Pb soluble in the soils (McKenzie 1980; Kuo and McNeal 1984; Tiller *et al.* 1984; Khattak and Page 1992; Mench *et al.* 1994; Mench *et al.* 1997; Sappin-Didier *et al.* 1997; Liu *et al.* 1998). Application of a large quantity of phosphate to polluted soils also can reduce the solubility of Zn in the soil solution by precipitation (Saeed and Fox 1979).

3.3.3 *Phyto-remediation techniques*

Some vegetation species (flowers and trees of high economic value), may be planted in polluted soils to remove heavy metals or to allow the contaminated soils to continue to be used for agricultural production (Lee and Liao 1993; Lee and Chen 1994; Brooks 1997; Chen and Lee 1997). Brooks (1997, 1998) reported that some plant super-accumulators of heavy metals have been defined as taxa containing more than 0.1% (1000 mg/kg) Cu, Pb, Ni, or Co in dried tissues. In the case of Zn, a threshold of 1% (10 000 mg/kg) is proposed.

3.3.4 *Evaluation of remediation of heavy metal contaminated soils in Taiwan*

The criteria for detailed evaluation of soil remedial action alternatives are based on the following considerations (US EPA 1990; Adriano *et al.* 1997; Chen 1997*b*; Iskandar and Adriano 1997; Lo and Che 1997; Pierzynski 1997):

- short-term effectiveness;
- long-term effectiveness and performance of technology;
- reduction of toxicity, mobility, or volume;
- implementation;
- costs;
- compliance with standards or guidelines;
- overall protection;
- national or state acceptance; and
- community acceptance.

The conclusions of the detailed evaluation of remedial action alternatives in rural soils contaminated with Cd and Pb in Taiwan are as follows (Chen 1997*a*; Lo and Che 1997):

- chemical extraction can be used for sites with medium concentrations of Cd or Pb;
- chemical immobilization can be used for sites with serious contamination by Cd or Pb, on or off site;
- engineering methods, involving removal of polluted soil and replacement with clean soil, can be used for sites with serious contamination by Cd or Pb, on or off site;
- engineering methods using the acid-leaching process can be used for sites with serious contamination by Cd or Pb, on or off site;

- phytoremediation can only be used for sites with slight contamination of Cd and Pb. Some plant species were selected to be planted in the polluted sites.

3.4 Case studies of remediation of organic pollutants in Taiwan

There have been several cases involving organic pollutants in recent years in Taiwan. These include: the disposal in soils of oil, organic toxic compounds and organic waste materials; oil pollution from underground tanks in gasoline stations; and JP4 oil pollution discharged from an air force base (Chen *et al.* 1997*b*; Ding 1997; Yang 1997).

3.4.1 Soil remediation techniques for organic pollutants

Some of the technologies demonstrated by the US EPA for sites with organic pollution (US EPA 1988, 1990) have been tested in Taiwan. They are:

- soil vapour extraction;
- biodegradation and composting;
- air stripping;
- immobilization (solidification or stabilization);
- thermal desorption; and
- chemical oxidation.

3.4.2 Evaluation of remediation of organic pollutants in Taiwan

The effectiveness of soil remediation techniques were evaluated for soils contaminated by organic pollutants (US EPA 1990; Yang 1997). Some case studies and field remedial studies in the vadose zone indicated that soil vapour extraction (SVE) system in sites contaminated by volatile organic compounds (VOCs) is a cost-effective process for soil contaminated with gasoline, diesel, solvent, methane, or other relatively volatile compounds found in Taiwan (Che *et al.* 1997; Chen *et al.* 1997*b*; Huang *et al.* 1997). The whole system was automatically controlled, being switched on and off periodically every day, in order to reduce the cost of the operation (Huang *et al.* 1997).

4. GUIDELINES OR CRITERIA FOR REMEDIATION OF SOIL POLLUTION

4.1 Critical concentrations used to assess heavy metal polluted sites and monitoring sites in developed countries

Various approaches to assessing contaminated soils are used internationally especially in developed countries including the USA, Germany, the UK, Australia, Canada, the Netherlands and Japan (Asami 1981; Moen *et al.* 1986; ICRCL 1987; USEPA 1989; Alloway 1990; Denneman and Robberse 1990; Jacobs, 1990; ANZECC/NHMRC 1992; Tiller 1992). Many national governments and their state, provincial or local authorities without their own formal guidelines or regulations have used the 'Dutch Standards' to support their decisions on assessing contaminated sites or monitoring sites. Some national authorities have also made modifications to develop their

Table 1. Dutch standards for soil contamination assessment for total concentrations of heavy metals in soils

Elements	Target values	Intervention value
	mg/kg soils	
As	29	55
Ba	200	625
Cd	0.8	12
Cr	100	380
Co	20	240
Cu	36	190
Hg	0.3	10
Pb	85	530
Mo	10	200
Ni	35	210
Zn	140	720

Notes:
1. Target values are specified to indicate desirable uncontaminated pollutant content of soils.
2. B value: the former B values required investigation to identify whether risks were actually likely (Moen *et al.* 1986). The former B values are now replaced by the average of the intervention and target values, or (where no target value is listed) by half the intervention values.
3. Intervention value: intervention values are available to identify serious contamination of soils and to indicate when remediation is necessary.
4. For heavy metals, the target and intervention values are dependent on clay/silt and organic matter contents and the standard soil values must be modified by the formula:
   $Ib = Is\{(A + B\%\ clay/silt + C\%\ organic\ matter)\}/(A + 25B + 10C)$
   where: Ib = Intervention values for a particular soil; Is = Intervention values for a standard soil (10% organic matter and 25% clay); A, B, and C = compound dependent constants (Table 1-1 shows the detailed values).

Table 1-1. Compound related constants for metals in soils (Source: Ministry of Housing – The Netherlands 1994)

Elements	A	B	C
As	15	0.4	0.4
Ba	30	5	0
Cd	0.4	0.007	0.021
Cr	50	2	0
Co	2	0.28	0
Cu	15	0.6	0.6
Hg	0.2	0.0034	0.0017
Pb	50	1	1
Mo	1	0	0
Ni	10	1	0
Zn	50	3	1.5

Table 2. Standard total concentration for soil contamination in developed countries

Elements	Germ.#	France#	U.K.#	USA+	Australia ##	Canada +	Dutch#	Japan*	Taiwan&	Range in the world
	mg/kg									
As	20	20	10	5.6	20	----	55	15	20	5.6-30
Cd	3	2	3.5	2	----	----	12	1	4	1-5
Cu	100	100	140	45	60	----	190	125	150	45-150
Cr	100	150	600	212	50	120	380	----	200	50-600
Hg	2	1	1	----	----	----	10	----	2	1-2
Ni	50	50	35	31	60	32	210	----	120	31-120
Pb	100	100	550	68	----	----	530	----	100	68-550
Zn	300	300	280	50	200	----	720	----	300	50-500

#Alloway (1990)
+US EPA (1989)
++Jacobs (1990)
* Asami (1981)
ANZECC/NHMRC (1992), Tiller (1992) & Wang *et al.* (1994*b*)
Ministry of Housing – The Netherlands (1994)

Table 3. The control pollution total concentration of heavy metals in rural soils in Taiwan

Items to be considered	Zn	As	Cd	Cu	Cr	Hg	Ni	Pb
	Total concentration, mg/kg soils							
Soil database of heavy metals	300	25	4	200	200	1	100	200
Soil chemical properties	150	15	2	70	250	2	50	200
Groundwater quality	1000	375	10	100	13	0.21	50	1500
Soil micro-organism activity	100	800	2	100	50	1	125	100
Food quality, safety and health	300	20	0.5 (brown rice)	180	200	0.5	120	100
Overall consideration	300	20	4	150	200	1	120	100

Wang *et al.* (1994*b*) with permission.

own regulations based on the soil qualities they require. The Dutch authorities are progressively upgrading their soil quality criteria in light of new scientific work, especially in relation to the ecotoxicology of listed substances and experience with impacts on species in ecosystems (Denneman and Robberse 1990). They consider two values for making decisions on the regulation of heavy metals in soils, including a target value (normal or natural level) and intervention values (for cleaning up) (Ministry of Housing – the Netherlands 1994). The Dutch standards for soil contamination assessment for total concentrations of heavy metals in soils are listed in Tables 1 and 1-1.

In the UK, a similar approach was developed based on two trigger concentrations for selected pollutants, one designated as 'threshold' below which sites are considered 'uncontaminated' (similar with the B-value in Dutch standard) and the other as an 'action' concentration above which remedial action is required (ICRCL 1987). Many

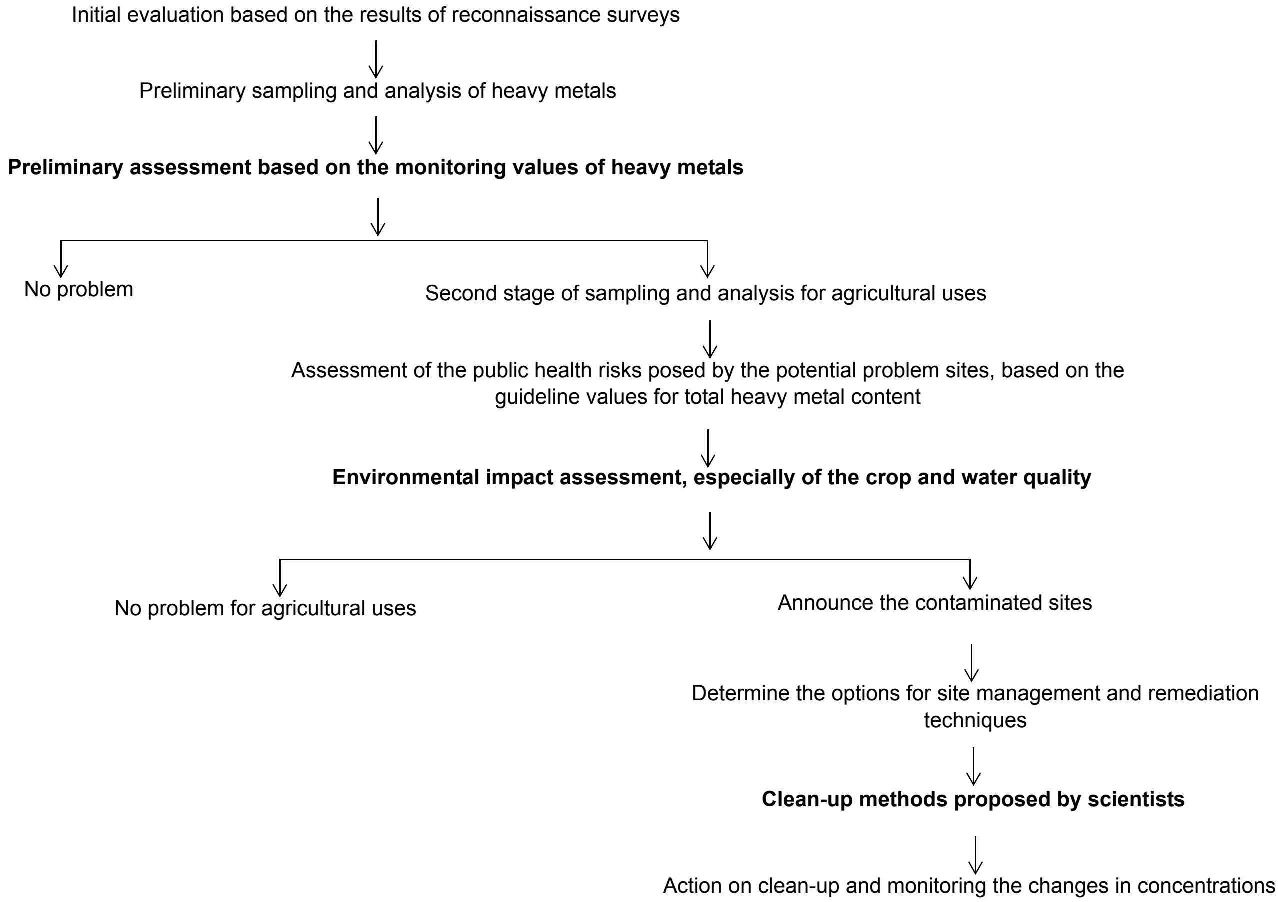

Figure 6. Recommended processes for the assessment and management of sites potentially contaminated by heavy metals in Taiwan

Table 4. The control pollution concentration of heavy metals extracted by 0.1 M HCl in Taiwan rural soils

Items to be considered	**Zn**	**Cd**	**Cu**	**Cr**	**Ni**	**Pb**
	0.1 M HCl extractable,* mg/kg soils					
Soil database of heavy metals	80	1	100	20	40	120
Soil chemical properties	14.5	0.3	21	4.2	3.4	50.4
Groundwater quality	200	2.3	32	2	–	500
Soil micro-organism activity	20	0.45	32	18	25	34
Food quality, safety, and health	60	0.5 (crops)	50	8	15	40
Overall consideration	60	1	50	30	22	40

*: phyto-availability concentration for crops
Wang *et al.* (1994*b*) with permission

Table 5. The A, B, and C values of heavy metals in polluted rural soils proposed by EPA/Taiwan

Elements	A value		B value		C value	
	0.1 M HCl extractable	Total conc.	0.1 M HCl extractable	Total conc.	0.1 M HCl extractable	Total conc.
	mg/kg soils					
As	–	10	–	14	–	20
Cd	0.43	2	0.58	2.5	1	4
Cr	12	100	15	101	30	200
Cu	26	35	27	89	50	150
Hg	–	0.49	–	0.55	–	1
Ni	10	60	12	63	22	120
Pb	18	50	23	58	40	100
Zn	25	120	33	163	60	300

A value: Reference top value of background range
B value: Indicative value for further investigation or monitoring
C value: Indicative value for cleaning up
(Chen *et al*. 1996, with permission)

Table 6. The control concentration of heavy metals proposed for different land uses in Taiwan

Elements	Rural soils A value [#1]	Rural soils C value [#2]	Residence area C value [#3]	Industrial and commercial area C value [#3]
	mg /kg soils			
As	10	20	40	50
Cd	2	4	20	20
Cr	100	200	200	625
Cu	35	150	500	500
Hg	0.49	1	5	10
Ni	60	120	1000	1000
Pb	50	100	500	1000
Zn	120	300	1000	1000

[#1] Chen *et al.* (1996)
[#2] Wang *et al.* (1994*b*)
[#3] EPA/Taiwan (1997)

developed countries have also developed regulated threshold values as listed in Table 2.

4.2 Guideline values in Taiwan

The EPA/Taiwan organized a working group from 1991 to 1994 to develop investigation guidelines for assessing heavy metal polluted sites and monitoring sites (Wang *et al.* 1994*b*; Chen *et al.* 1996). These guidelines are primarily based on basic soil properties and the effects of heavy metals on:

- water quality;
- activity of soil microorganisms;
- human health; and
- plant productivity and crop quality.

Final guideline values for soil quality were proposed by a working group organized by EPA/Taiwan in 1994 (Wang *et al.* 1994*b*; Chen *et al.* 1996).

Final guideline values for soil quality were proposed by this working group, based primarily on the effects of heavy metal concentrations on human health, plant productivity and crop quality (Tables 3 and 4). The top values of the background concentrations (A values), the proposed monitoring values (B values), and the proposed clean-up values (C values) (total concentration) of heavy metals extracted with 0.1 M HCl developed rural soils in Taiwan are listed in Table 5. The proposed clean-up values (C values) (total concentration) of heavy metals in soils in different uses are listed in Table 6.

4.3 Recommended processes for the assessment of sites potentially contaminated by heavy metals in Taiwan

The recommended processes to assess sites potentially contaminated by heavy metals that have been established in Taiwan are shown in Figure 6 (Chen *et al.* 1996). The key processes can be divided into four stages as follows:

First stage

(1) Initial evaluation based on the results of reconnaissance surveys of the sites.

(2) Preliminary sampling and analysis of heavy metals at the sites. Twenty soil samples were sampled using an 8 cm auger and mixed to one representative sample in each 100 ha or 25 ha soils.

(3) Preliminary assessment based on the monitoring values of heavy metals.

Second stage

(4) Second stage of sampling and analysis of soil samples in only one ha for the areas where heavy metal concentrations are higher than the monitoring values.

(5) Assessment of the public health risks from the potential problem sites.

(6) Environmental impact assessment with emphasis on soil, crop, and water quality.

Third stage

(7) Announcement of the contaminated sites, determination of options for site management, and determination of remediation techniques or clean-up methods proposed by scientists.

Fourth stage

(8) Implementation of clean-up and monitoring of concentration changes at the sites.

4.4 Prioritization of contaminants in Taiwan

Hazardous heavy metals are recognised as first priority contaminants by EPA/ROC in designated or potentially contaminated sites in Taiwan (especially As, Cd, Cr, Cu, Hg, Ni, Pb and Zn). Guideline values, including reference background level, monitoring level, and clean-up level of heavy metals have been developed in the last decade to assess potentially contaminated rural and urban sites. Recommended processes for the assessment and management of contaminated sites have also been developed. Some remediation techniques have been tested in heavy metal-contaminated rural sites in Taiwan including: (1) mechanical methods which involve the removal of the contaminated soils and replacement with clean soils, or mixed operation to dilute the concentration of Cd in soils (Chen *et al.* 1994; Chen and Lee 1997); (2) chemical methods whereby the soil is treated with non-toxic chemical materials to immobilize the heavy metals and to decrease the solubility of heavy metals in polluted soils (Chen *et al.* 1992*a*; Chen and Lee 1997; Chen *et al.* 1998; Liu *et al.* 1998); and (3) phyto-remediation (or biological) methods which involve screening the candidate non-diet plants, ornamental flowers and woody seedlings, for Cd polluted soils for sustainable land uses (Chen *et al.* 1992*b*; Lee and Chen 1994; Wang *et al.* 1994*a*). Some remediation techniques have been applied on a field-scale to clean up contaminated sites from June 1998, but a few contaminated sites will be cleaned up by other remediation techniques in the coming years.

The second priority contaminants recognised by EPA/ROC are hazardous organic waste materials including medical chemical compounds, oil chemical products, pesticide products and formulations, and polychlorodibenzene (PCBs). Some surveys of these hazardous organic waste materials have been conducted since 1990. Guideline values for these contaminants will be proposed by a working group.

5. REFERENCES

Adriano, D.C. (1986) Trace elements in the terrestrial environment. Springer-Verlag, New York.

Adriano, D.C., Albright, J., Whicker, F.W., Iskandar, I.K. and Sherony, C. (1997) Remediation of soils contaminated with metals and radionuclide-contaminated soils. pp. 27-46. In: A. Iskandar, and D.C. Adriano (eds.). *Remediation of Soils Contaminated with Metals*. Science Reviews, Northwood, UK.

Alloway, B.J. (1990) *Heavy Metals in Soils*. Blackie and Son Ltd., London, UK. 339p.

ANZECC/NHMRC (1992) *Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites. January 1992.* Australian and New Zealand Environment and Conservation and National Health and Medical Research Council, Canberra.

Asami, T. (1981) Maximum allowable limits of heavy metals in rice and soils. pp 257-274. In: K. Kahuzo and I. Yamane (eds.) *Heavy Metal Pollution in Soils of Japan*. Japan Scientific Societies Press, Tokyo, Japan.

Brooks, R.R. (1997) Plant hyper-accumulation of metals and their role in mineral exploration, archaeology, and land remediation. pp. 123-134. In: A. Iskandar, and D.C. Adriano (eds.) *Remediation of Soils Contaminated with Metals*. Science Reviews, Northwood, UK.

Brooks, R.R. (ed.) (1998) *Plants That Hyperaccumulate Heavy Metals*. CAB International, Oxon, UK.

Che, M.D., Chang, H.D. and Chin, M.S. (1997) A treatability study of biopile/composting techniques for remediation on diesel contaminated soils. pp. 415-433. In: Z. S. Chen (ed.) *Proceedings of 5th Workshop on Soil Pollution and Prevention: Symposium on Soil Remediation Technologies on Contaminated Soils*. (In Chinese, with English abstract and tables), June 18, 1997. Taipei, Taiwan.

Chen, Z.S. (1991) Cadmium and lead contamination of soils near plastic stabilizing materials producing plants in northern Taiwan. *Water, Air, & Soil Pollu.*, **57-58**, 745-754.

Chen, Z.S. (1992) Metal contamination of flooded soils, rice plants, and surface waters in Asia. pp. 85-107. In: Domy C. Adriano (ed.) *Biogeochemistry of Trace Metals*. Lewis Publishers Inc., Florida, USA.

Chen, Z.S. (1994*a*) Soil properties of soil contaminated with Cd and Pb and their remediation tests in Taiwan. pp. 3-1 to 3-17. In: *Proceedings of Remediation of Polluted Soils and Sustainable Land Use*. Taipei, Taiwan. In Chinese, with English abstract and tables.

Chen, Z.S. (1994*b*) Sampling design for studying the relationships between heavy metals in soils, sediments, and discharged waste waters. pp. 365-378. In: B. Markert (ed.) *Sampling of Environmental Materials for Trace Analysis*. Chapter 19, VCH Publisher, Weinheim and New York.

Cheng, H.F. (1996) *Remediation of Soils Contaminated with Heavy Metals by Soil Conditioners: Cd, Zn, and Cu*. Project report of Council of Agriculture of Taiwan (in Chinese, with English abstract and tables), Taipei, Taiwan.

Chen, Z.S. (1997*a*) Assessment and experience on the soil remediation techniques used in the soils contaminated with cadmium and lead in Taiwan. pp. 75-88. In: Z. S. Chen (ed.) *Proceedings of 5th Workshop on Soil Pollution and Prevention: Symposium on Soil Remediation Technologies on Contaminated Soils*. (In Chinese, with English abstract and tables). June 18, 1997. Taipei, Taiwan.

Chen, Z.S. (1997*b*) *Comments on the Revision of Contaminated Soils Remediation Act of EPA/Taiwan*. (Grant No. EPA-87-H104-03-04). Taipei, Taiwan.

Chen, Z.S. and Lee, D.Y. (1997) Evaluation of remediation techniques on two cadmium polluted soils in Taiwan. pp. 209-223. In: A. Iskandar, and D.C. Adriano (eds.) *Remediation of Soils Contaminated with Metals*. Science Reviews, Northwood, UK.

Chen, Z.S., Lee, D.Y., Huang, D.N. and Wang, Y.P. (1992*a*) The effect of chemical methods treated in polluted soils on the Cd uptake by the vegetables. pp. 277-292. In: *Proceedings of 3rd Workshop on Soil Pollution and Prevention*. Taipei, Taiwan. (In Chinese, with English abstract and tables.)

Chen, Z.S., Lee, D.Y., Lin, T.K. and Wang, Y.P. (1992*b*) Suitable vegetation for growing in soils contaminated with Cd in northern Taiwan. pp. 247-259. In: *Proceedings of 3rd Workshop on Soil Pollution and Prevention*. Taipei, Taiwan. In Chinese, with English abstract and tables.

Chen, Z.S., Lo, S.L. and Wu, H.C. (1994) *Summary Analysis and Assessment of Rural Soils Contaminated with Cd in Taoyuan*. Project report of Scientific Technology Advisor Group (STAG), Executive Yuan. Taipei, Taiwan. In Chinese, with English abstract and tables.

Chen, Z.S., Lee, D.Y., Lin, C.F., Lo, S.L. and Wang, Y.P. (1996) Contamination of rural and urban soils in Taiwan. pp. 691-709. In: R. Naidu, R.S. Kookuna, D.P. Oliver, S. Rogers, M.J. McLaughlin (eds.), Contaminants and the soil environment in the Australasia-Pacific Region. *Proceedings of the First Australasia-Pacific Conference on Contaminants and Soil Environment in the Australasia-Pacific Region. Adelaide, Australia, Feb. 18-23, 1996*. Kluwer Academic Publishers, Boston, London.

Chen, Z.S., Lee, G.J. and Liu, J.C. (1997*a*) Chemical remediation treatments for soils contaminated with cadmium and lead. pp. 421-422. In: *Proceedings of the Fourth International Conference on the Biogeochemistry of Trace Elements*, June 22-26, 1997, Berkeley, California, USA.

Chen, C.Y., Wei, Y.T. and Wu, S.C. (1997*b*) In-situ soil vapor extraction: Field study in Taiwan. pp. 553-563. In: Z.S. Chen (ed.) *Proceedings of 5th Workshop on Soil Pollution and Prevention: Symposium on Soil Remediation Technologies on Contaminated Soils*, June 18, 1997, Taipei, Taiwan. In Chinese, with English abstract and tables

Chen, Z.S., Lee, J.C. and Liu., J.C. (1998) Chemical remediation treatments' effect on the change of speciation of cadmium and lead in contaminated soils. In: M. H. Wong (ed.) *Proceedings of International Conference on Environmental Contamination, Toxicity and Health*. Sep. 23-25, 1998. Hong Kong Baptist University, Hong Kong (in press).

Denneman, P.R.J. and Robberse, J.G. (1990) Ecotoxicological risk assessment as a base for a development of soil quality criteria. pp.157-164. In: *Contaminated Soils '90*. F. Arendt, H. Hinsenfeld, and W. J. van den Brink (eds.). Kluwer, Dordrecht.

Ding, L.L. (1997) Tao-Yuan RCA site soil contamination case studies. pp. 343-374. In: Z.S. Chen (ed.) *Proceedings of 5th Workshop on Soil Pollution and Prevention: Symposium on Soil Remediation Technologies on Contaminated Soils*, June 18, 1997, Taipei, Taiwan. In Chinese, with English abstract and tables.

EPA/Taiwan (Environmental Protection Administration of Taiwan) (1997) *Soil pollution Information System*. Taipei, Taiwan.

Gworek, B. 1992. Lead inactivation in soils by zeolites. *Plant Soil*, **143**, 71-74.

Huang, C.Y., Juang, Y.C. and Shu, K.C. (1997) Case study of remedial feasibility by soil vapor extraction system in Taiwan. pp. 523-540. In: Z.S. Chen (ed.) *Proceedings of 5th Workshop on Soil Pollution and Prevention: Symposium on Soil Remediation Technologies on Contaminated Soils*, June 18, 1997, Taipei, Taiwan. In Chinese, with English abstract and tables

ICRCL (1987) *Guidance on the Assessment and Redevelopment of Contaminated Land*. ICRCL paper 59/83. Department of the Environment, London, UK.

Iskandar, I.K. and Adriano, D.C. (1997) Remediation of soils contaminated with metals – A review of current practices in the USA. pp. 1-26. In: A. Iskandar, and D.C. Adriano (eds.) *Remediation of Soils Contaminated with Metals*. Science Reviews, Northwood, UK.

Jackson, A.P. and Alloway, B.J. (1992) The transfer of cadmium from agricultural soils to the human food chain, pp. 109-158. In: D.C. Adriano (ed.) *Biogeochemistry of Trace Metals*. Lewis Publication, Boca Raton, FL., USA.

Jacobs, L.W. (1990) Potential hazards when using organic materials as fertilizers for crop production. In: Food and Fertilizer Technology Center of Asia and Pacific Regions (FFTC/ASPAC). *FFTC Extension Bulletin*, No. 313.

Khattak, R.A. and Page, A.L. (1992) Mechanism of manganese adsorption on soil constituents, pp. 383-400. In: D.C. Adriano (ed.) *Biogeochemistry of Trace Metals*. Lewis Publ., Boca Raton, FL., USA.

Kuo, S. and McNeal, B.L. (1984) Effects of pH and phosphate on cadmium sorption by a hydrous ferric oxide. *Soil Sci. Soc. Am. J.,* **48**, 1040-1044.

Kuo, S., Jellum, E.J. and Baker, A.S. (1985) Effects of soil type, liming, and sludge application on Zn and Cd availability to swiss chard. *Soil Sci*., **139**, 122-130.

Lee, D.Y. and Chen, Z.S. (1994) Plants for cadmium polluted soils in northern Taiwan, pp. 161-170. In: D.C. Adriano, Z.S. Chen, and S.S. Yang (eds.) Biogeochemistry of trace elements, *Environmental Geochemistry and Health*, **16**. Science and Technology Letters, Northwood, UK.

Lee, F.Y. and Liao, C.T. (1993) Removal of Cd and Cu from the polluted soils by vegetation, pp. 471-481. In: *Proceedings of 4th Workshop on Soil Protection and Remediation*. Taipei, Taiwan. In Chinese, with English abstract and tables.

Lin, C. (1997) Remedial investigation and feasibility study of a halogenated solvent contaminated Superfund site, pp. 501-522. In: Z.S. Chen (ed.) *Proceedings of 5th Workshop on Soil Pollution and Prevention: Symposium on Soil Remediation Technologies on Contaminated Soils*, June 18, 1997. Taipei, Taiwan.

Liu, J.C., Looi, K.S., Chen, Z.S. and Lee, D.Y. (1998) The effects of composts and calcium carbonate on the uptake of cadmium and lead by vegetables grown in polluted soils. *J. Chinese Insti. Environ. Engineering*, **8**, 53-60.

Lo, S.L., and Che, P.T. (1997) Site remediation alternatives and assessment for soils contaminated by heavy metals in Taiwan. pp. 19-46. In: Z. S. Chen (ed.) *Proceedings of 5th Workshop on Soil Pollution and Prevention: Symposium on Soil Remediation Technologies on Contaminated Soils*, June 18, 1997, Taipei, Taiwan. In Chinese, with English abstract and tables.

McBride, M.B. and Blasiak, J.J. (1979) Zinc and copper solubility as a function of pH in an acid soil. *Soil Sci. Soc. Am. J.,* **43**, 866-870.

McBride, M.B. (1980) Chemisorption of Cd (II) on calcite surfaces. *Soil Sci. Soc. Am. J*., **44**, 26-28.

McKenzie, R.M. (1980) The adsorption of lead and other heavy metals on oxides of manganese and iron. *Aust. J. Soil Res*., **18**, 61-73.

Mench, M., Didier, V.L., Loffler, M., Gomez, A. and Masson, P. (1994) A mimicked in-situ remediation study of metal-contaminated soils with emphasis on cadmium and lead. *J. Environ. Qual*., **23**, 58-63.

Mench, M., Amans, V., Sappin-Didier, V., Fargues, S., Gomez, A., Loffler, M., Masson, P. and Arrouays, D. (1997) A study of additives to reduce availability of Pb in soils to plants. pp. 185-202. In: A. Iskandar, and D.C. Adriano (eds.) *Remediation of Soils Contaminated with Metals*. Science Reviews, Northwood, UK.

Ministry of Housing – the Netherlands (1994) *Dutch Intervention Values of Heavy Metals and Organic Pollutants in Soils, Sediments, and Groundwater*. Physical Planning and Environmental Conservation Report HSE 94.021.

Moen, J.E.T., Cornet, J.P. and Evers, C.W.A. (1986) Soil protection and remedial actions: criteria for decision making and standardisation of requirements, pp. 441-448. In: J. W. Assink, and W. J. van den Brink (eds.) *Contaminated Soil.* Martinus Nijhoff, Dordrecht.

Pierzynski, G.M. (1997) Strategies for remediating trace elements contaminated sites, pp. 67-84. In: A. Iskandar, and D.C. Adriano (eds.) *Remediation of Soils Contaminated with Metals*. Science Reviews, Northwood, UK.

Saeed, M., and Fox, R.L. (1979) Influence of phosphate fertilization on zinc adsorption by tropical soils. *Soil Sci. Soc. Am. J*., **43**, 683-686.

Sappin-Didier, V.L., Mench, M.J., Gomez, A.N. and Lambrot, C. (1997) Use of inorganic amendments for reducing metal bioavailability to ryegrass and tobacco in contaminated soils, pp. 85-98. In: A. Iskandar, and D.C. Adriano (eds.) *Remediation of*

Soils Contaminated with Metals. Science Reviews, Northwood, UK.

Sommers, L.E. and Lindsay, W.L. (1979) Effect of pH and redox on predicted heavy metal-chelate equilibria in soils. *Soil Sci. Soc. Am. J.*, **43**, 39-47.

Tiller, K.G. (1992) Urban soil contamination in Australia. *Aust. J. Soil Res.*, **30**, 937-957.

Tiller, K.G., Gerth, J. and Bruemmer, G.W. (1984) The relative affinities of Cd, Ni, and Zn for different clay fractions and goethite. *Geoderma*, **34**, 17-35.

US EPA (United States Environmental Protection Agency) (1985*a*) *Guidance on Remedial Investigations under CERCLA*. Hazardous Waste Engineering Research Laboratory, Cincinnati, OH and Office of Emergency and Remedial Response, Washington, DC.

US EPA (United States Environmental Protection Agency) (1985*b*) *Guidance on Feasibility Studies under CERCLA*. Hazardous Waste Engineering Research Laboratory, Cincinnati, OH and Office of Emergency and Remedial Response, Washington, DC.

US EPA (United States Environmental Protection Agency) (1985c) *The Remedial Action Costing Procedures Manual*. Hazardous Waste Engineering Research Laboratory, Cincinnati, OH and Office of Emergency and Remedial Response, Washington, DC.

US EPA (1988) *Technology Screening Guide for Treatment of CERCLA Soils and Sludges*. EPA/540/2-88/004, Washington, DC.

US EPA (1989) Standards for the disposal of sewage sludge: proposed rules. *Federal Register*, **54**, 5778-5902.

US EPA (1990) *Summary of Treatment Technology Effectiveness for Contaminated Soils*. EPA/540/2-89/053, Washington, DC.

US EPA (1991) *The Superfund Innovative Technology Evaluation Program: Treatment Profiles*. EPA/540/5-91/008, Cincinnati, OH.

Wang, Y.P., Huang, Y.M., Li, G.C., Liu, C.L. and Chen, Z.S. (1994*a*) Assessment and remediation techniques for soil contamination sites in Taiwan. Project reports of EPA/ROC (Grant No. EPA-83-H105-09-04). In Chinese, with English abstract and tables.

Wang, Y. P., Chen, Z.S., Liu, W.C., Wu, T.H., Chaou, C.C., Li, G.C. and Wang, T.T. (1994*b*) *Criteria of Soil Quality – Establishment of Heavy Metal Contents in Different Categories (Final Reports of Four Years Projects)*. Project reports of EPA/ROC (Grant No. EPA-83-E3H1-09-02). In Chinese, with English abstract and tables.

Yang, G.C.C. (1997) Remediation technology for soils contaminated by organic compounds. pp. 47-74. In Z.S. Chen (ed.) *Proceedings of 5th Workshop on Soil Pollution and Prevention: Symposium on Soil Remediation Technologies on Contaminated Soils*, June 18, 1997. Taipei, Taiwan. In Chinese, with English abstract and tables.

Yaron, B., Calvet, R. and Prost, R. (1996) *Soil Pollution: Processes and Dynamics*. Springer-Verlag, Berlin Heidelberg, Germany.

Yeh, C.T. (1997) *The Revision of Soil Remediation Act. Project reports of EPA/Taiwan*. (Grant No. EPA-87-H104-03-04). Taipei, Taiwan (in Chinese).

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