DESCRIPTION OF SOIL RECLAMATION AND REMEDIATION METHODS

Physical methods

Physical methods of soil reclamation are those that do not change the physico-chemical properties of the pollutants accumulated in the soil to be cleaned. Among this techniques are the simple engineering methods such as soil extraction and storage of polluted soil as well as complicated process technologies of electromigration. Within this group of techniques, isolation technologies based on the application of semi-permeable or impermeable barriers could also be discussed; however, the actual technological development of the barrier construction also enables the classification of these techniques into chemical methods.

The advantages of physical methods are the possibility of removal or disposal of a broad spectrum of pollutants and their wide practical application (usually on a small, local scale). However, their disadvantages are that they produce a considerable amount of wastes that need future management or utilization and have a relatively high cost of application on a large scale.

Physical methods of soil reclamation could be divided into

- *Ex-situ* methods – that require the transportation of the polluted soil to the place of cleaning.
    - mechanical separation
    - extraction and storage
- *In-situ* methods – that could be applied on-site, without the removal of the soil from the polluted site.
    - electrokinetic cleaning methods
    - cofferdam system
    - soil covering

Ex-situ techniques

Mechanical separation

The mechanical separation of soil is a physico-chemical process in which the contaminated parts of soil are separated. This process leads to a decrease in volume of contaminated soil. The techniques most often used for separation are: gravitational separation (based on differences in density between fractions) or in cyclones (based on the Coriolis effect), sieve analysis (different grain size of elements) or magnetic separation (based on magnetic induction). The separated fraction containing the pollutants must be cleaned up or neutralized in another process.

Method's advantages:

- Significant volume reduction of contaminated soil.
- For many years, this technique has been applied in municipal waste management.

Method's disadvantages:

- This technique could not be applied in the case of homogenous distribution of pollutants in soil. In that case, there is not a satisfactory decrease in volume.
- This method is not effective for some soils types.
- The separated part of the contaminated soil must be cleaned up using another method.

Extraction and storage

This method is the simple extraction of contaminated soil cover, using a digger or bulldozer, and its storage in an appropriate place for further clean-up using another method (e.g. biodegradation, vitrification or other). The storage site has to be sheltered to prevent wind and water erosion.

Method's advantages:

- Short time of excavation of contaminated soil (even one day)
- Does not require highly specialist equipment
- Could be applied in the case of emergency, when other methods are not effective or are too costly.

Method's disadvantages:

- Using a simple digger and bulldozer, the excavation is only possible up to a depth of 3 m.
- Not applicable in the case of small, local polluted sites because of high expenses.

In-situ techniques

Electroremediation

This method is based on the phenomenon of pollutant migration in an electric field. Migrating particles have to have a permanent electric charge or have to be polarized, so the technique is used to remove heavy metals or polar compounds. Electrodes are inserted into the ground on opposite sites of the contaminated area. Contaminants under the influence of an electromagnetic field migrate through the soil within the cathode or anode area, where they are removed in a few possible ways: chemical precipitation, adhesion to the electrodes' surfaces, removing and processing the contamination beyond the remediated site.

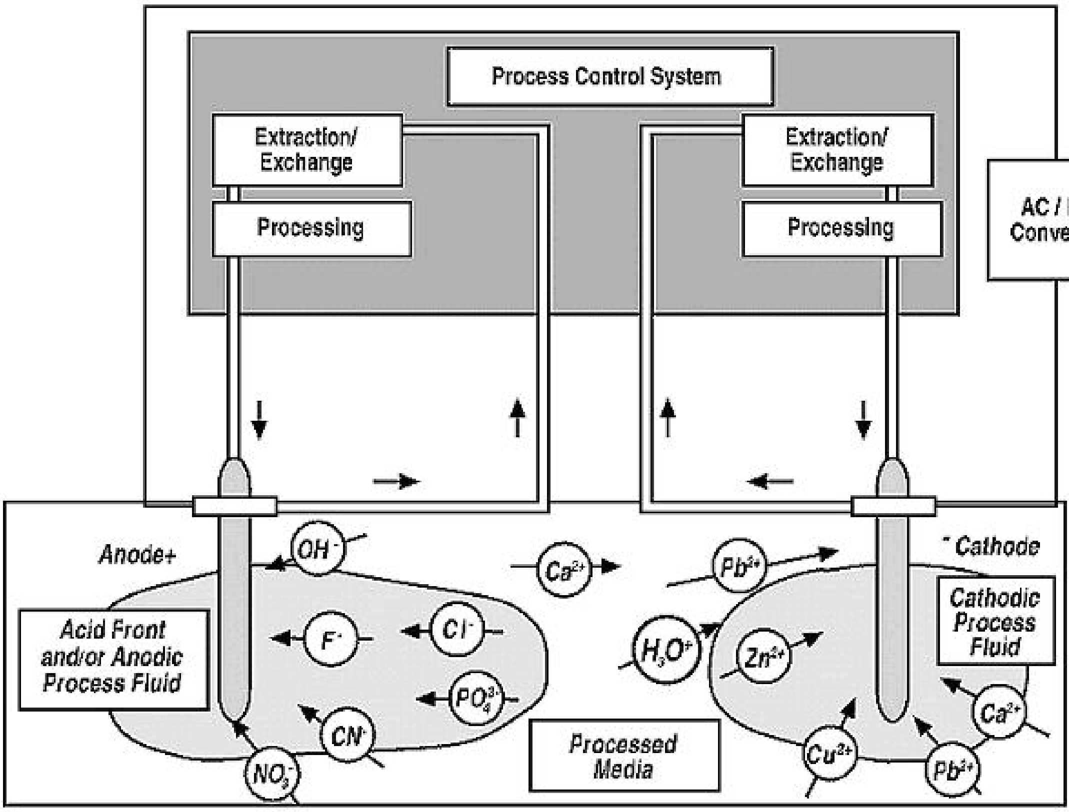

Figure 1. Chart of electroremediation process (US EPA Report 542-R-97-004).

Method's advantages:

- ❖ Electroremediation is practically the only method for *in-situ* removal of heavy metals from contaminated soil.
- ❖ This method is applicable to different metals.

Method's disadvantages:

- ❖ The method is still under development and its efficiency depends on so many features that in some cases the final results are unforeseeable.
- ❖ Any heterogeneity of the soil body decreases the effectiveness of the method.
- ❖ Considerable acidification of the remediated soil is a side effect of this method.

- Because of the complicated chemistry of this cleaning process, an on-site pilot test is necessary before application of this method.
- Oxidize-reduction processes can cause the development of unwanted compounds.

Cofferdam system

This is a system of barriers made from different substances placed under the soil's surface. The main role of the barriers is protection against the spreading of dangerous substances from the contaminated site. Thanks to the different chemical substances present in the barriers, the pollutants are transformed into environmentally friendly forms.

The main types of barrier construction are

- Semi-permeable barrier, which is placed perpendicularly to the direction of migration of contaminated ground waters. Contaminants are stopped and reduced (organic compounds) or immobilized (heavy metals).
- Non-permeable vertical barrier, which is placed under the ground and can stop groundwater or change its flow direction.
- Non-permeable horizontal barrier, which is placed above the groundwater level and stops the migration of contaminants down to a soil profile.

Chemical types of barrier:

- Barrier based on the redox process:
  - Fe^0, which lowers the mobility of ions of metals in the reduction process
  - FeS and $FeCO_3$, which reduce Cr (VI)
  - $Na_2S_2O_4$, which reduces heavy metals
- Precipitation barrier:
  - $Ca(OH)_2$, which has the ability to precipitate U, As, Mo, Se
  - $CaCO_3$, which has the ability to precipitate Cr (III)
  - $CaPO_4$, which has the ability to precipitate Pb
- Biological barrier – degradation and decomposition of pollutants using microorganisms
- Sorption barrier based on
  - active carbon,
  - bone char,
  - zeolite,
  - phosphate,
  - coal,
  - peat,
  - synthetic resin.

Method's advantages:

- A system of barriers is applicable to every kind of contamination (organic, inorganic)

- ❖ Fast effect

Method's disadvantages:

- ❖ Non-permeable barriers (without active factors) only limit the spread of the contamination (permanent monitoring is required)
- ❖ Any damage to the barrier decreases its efficiency
- ❖ The underground water flow direction must be well recognized.

Surface insulation

This is a physical method based on covering the contaminated soil to prevent toxic migration to the environment as a result of rainwater or wind erosion. The layers are comprised of combined material such as synthetic fibre, clay and concrete. The cover is usually made of synthetic fibre, heavy loam or concrete. The construction of the cover is comprised of four layers:

- ➢ protective layer with growing plants to reduce the erosion of surface cover;
- ➢ drainage layer, to drain rainfall water percolating through the surface layer;
- ➢ non-permeable barrier to protect the contaminated area against contact with precipitation waters;
- ➢ base layer, made from selected mineral material with a suitable grain size and mechanical parameters.

This technique is usually applied when

- ➢ the contaminated soil remains at the place of contamination;
- ➢ the underground contamination is so wide that it is impossible to extract and remove the contaminated soil;
- ➢ the physico-chemical properties of the pollutants do not exhibit any ability for release or migration;
- ➢ the removal of the contaminated soil would be more hazardous to the environment and human health than if it remained in place.

Removal of pollutants using the BAG method

This physico-chemical method is based on the sorption and ion-exchange properties of aluminosilicates (zeolites). This method is effective for cleaning up soils contaminated by heavy metals, including radio-nuclides and some of the organic compounds, as well as for their immobilization. Natural or synthetic zeolites (BAG) in the form of briquettes are placed in the soil layer. Their sorption ability is even higher than the soil's humus. Heavy metals presented in the soil are sorpted by minerals or are ion-exchanged and enriched the soil solution in Ca and K. Because of the selective activity of zeolites on heavy metals, different types of briquettes (BAG) are produced. After saturation with heavy metals, the briquettes are removed and regenerated. Recycled briquettes can be used repeatedly.

Method's advantages:

- Introducing into the soil natural materials which are friendly to the environment, and improving its physical and chemical properties.
- Selective sorption abilities for zeolites in respect to heavy metals.

Method's disadvantages:

- Limited sorption capacity of BAG briquettes.
- Necessity of maintenance of proper soil humidity during the process.

Chemical methods

Chemical methods of soil reclamation aim to degrade the pollutants accumulated in the soil or make such changes to their physico-chemical properties so as to reduce their ecological hazard.

Chemical methods are developed on the basis of the following chemical processes:

- Oxidation and reduction
- Extraction
- Precipitation of sparingly soluble chemical compounds
- pH stabilization

The main advantages of these methods are

- The broad spectrum of applicability
- High efficiency
- High specificity of application for individual pollutants

Their limitations and disadvantages are mainly related to their

- Usually high costs of application
- Production of a large amount of wastes, including hazardous waste
- Problems of process control, especially in the case of *in-situ* techniques.

Ex situ techniques

Soil washing

This *ex-situ* method is mostly used for removing inorganic contamination, such as heavy metals, radio-nuclides, toxic anions and others. In some cases, it can be applied to organic contamination. This method uses a wide spectrum of leaching solutions from water to strong inorganic acids.

There are two types of washing:

- separation of fine particles with adsorpted contaminants in a stream of dissolvent (water or solutions of inorganic salts Ca or Mg);
- extraction of contaminants.

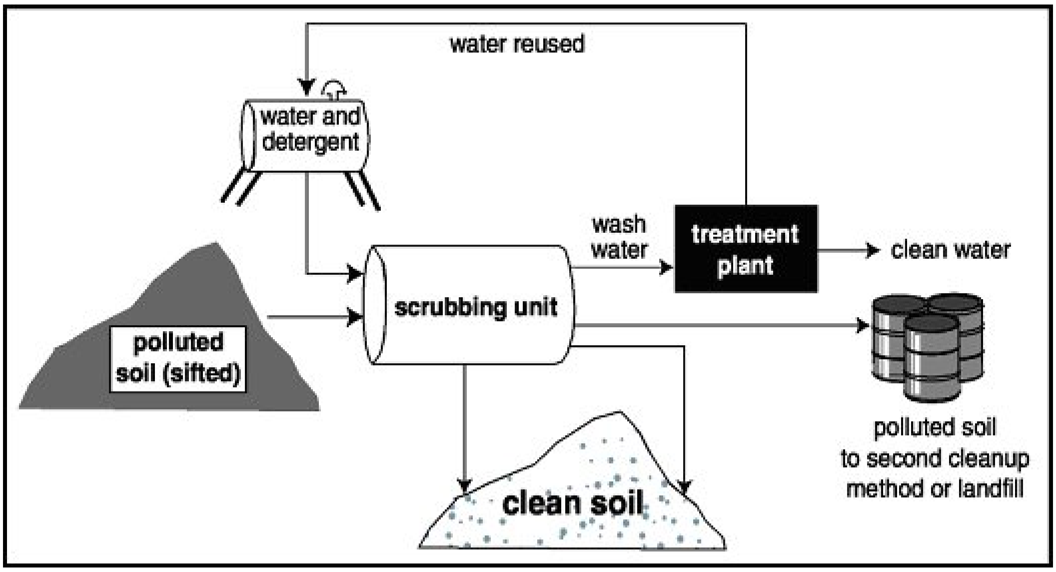

Figure 2. Chart of soil washing (US EPA Doc. EPA 542-F-01-008)

Method's advantages:

- Highly effective method for cleaning up strongly contaminated soils.
- Fast cleaning method.
- High efficiency (practically total removal of contamination from soil).

Method's disadvantages:

- High costs of construction of the cleaning installation and utilization.
- Generation of a large amount of solid and liquid wastes that need later management.
- Necessity for transportation of the clean-up soil.
- Highly invasive method for the environment (necessity of removal of soil from the contaminated site; soil after the clean-up can be used only as a construction material).
- Low level of community acceptance due to its invasivity.

Ex-situ immobilization of contaminants

This is a method for the neutralization of some organic and inorganic compounds in soil. For neutralization purposes, the contaminants' bonded substances are added (e.g. cement), which completely blocks the pollutants in the soil. This method is applied in areas where highly contaminated soil must be removed from its place of origin and its storage is connected with a high ecological risk (for example in the case of radio-nuclides).

Method's advantages:

- Fast and easily applicable method
- Relatively low costs of investment and operation

Method's disadvantages:

- High invasivity to the environment

- Generation of a significant amount of solid wastes (twice as large a volume after processing)
- The side product must be stored on a special landfill site
- In the case of changing of the physico-chemical condition in the side product or its surroundings, there is serious danger of the release of additional contaminants to the environment. Permanent control of the stored wastes is required.

Chemical and photochemical reduction

This method allows the total mineralization (by chemical reactions) of organic contaminants or the effective transformation of organic and inorganic contaminants into non-toxic, less-toxic or chemically inert forms. Theoretically, this method could be applied both *ex situ* and *in situ*; however, in practice, because of its high invasivity, only *ex-situ* techniques are used. The method is suitable for the removal of organic compounds (oil compounds, organic solvents, pesticides) and inorganic ones (ions or heavy metals, oxyanions). The reagents used in this method are: ozone, hydrogen peroxide, chlorates, chlorine monoxides and other oxidation or reduction reagents. In the case of the photochemical process, an additional factor is ultraviolet radiation.

Method's advantages:

- Wide range of applications
- Well-developed techniques with long-term use
- Special installation is not required
- Applicable for soil and groundwater cleaning
- Low costs of operation

Method's disadvantages:

- High invasivity to the soil and the environment.
- Detoxification of the soil can be incomplete because of the development of temporary products and antagonism effects in the case of complex contamination.
- Special safety rules required (caustic and explosive reagents).

In-situ techniques

Soil flushing

This method is a similar to soil washing and is used for the same group of pollutants (heavy metals), but is applied *in situ*. The most important differences are

- The contaminated soil is not removed from the site.
- The method is less invasive because of the application of mild extractors but is also less efficient so is not suitable for strong contamination.
- There is a necessity for insulation of the reclaimed area and the development of an effective system for the effluent's collection.
- Permanent monitoring of the surroundings is required.

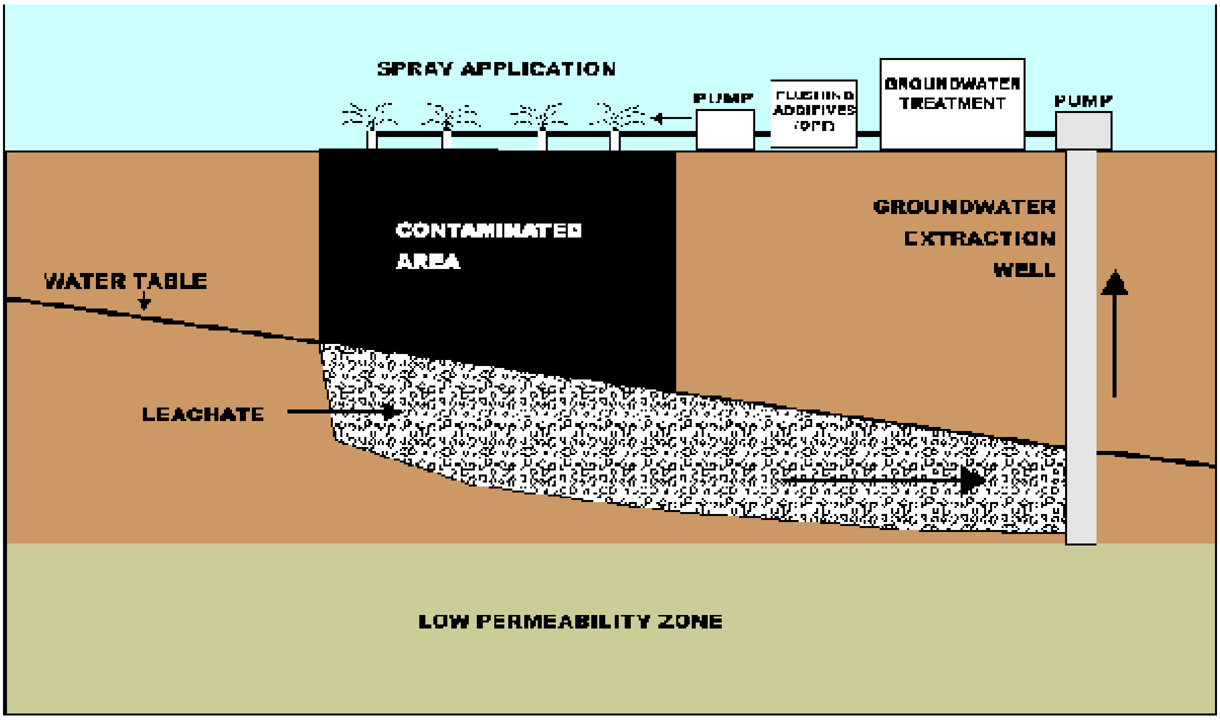

Figure 3. Chart of soil flushing process (US EPA Report 542-R-97-004).

Method's advantages:

- Relatively low invasive method.
- Applied *in situ*, without soil removal.
- Lack of solid wastes.
- Community acceptance is higher than in the case of soil washing.

Method's disadvantages:

- A large amount of liquid and semi-liquid wastes are generated.
- Incomplete removal of contaminants (strongly bounded heavy metals remain in the soil).

- ❖ Permanent monitoring during the process running, collection of effluents and insulation of the surrounding area is required.
- ❖ High costs of investment and post-reclamation monitoring and management.

In-situ immobilization of contaminants

This method is used for the immobilization of inorganic contaminants such as heavy metals (it is rarely applied to organic contaminants). The method is based on the introduction into the soil of different substances (cement, polyepoxide resin, zeolites) which bond strongly with the contaminants or create sparingly soluble chemical associations (carbonates or phosphates). The effects of this remediation technique are also the modification of the soil chemical properties, causing the immobilization of heavy metals or their chemical transformation into less mobile forms by pH changes (liming). This method is often used in emergency cases to prevent the contaminated area from spreading, often in connection with fitostabilization as a supporting technique. This method is applied to medium or low contaminated areas.

Method's advantages:

- ❖ Low invasive method
- ❖ Simple and fast method
- ❖ Relatively inexpensive
- ❖ Small amount of wastes
- ❖ Well accepted by the community
- ❖ Wide spectrum of inorganic pollutants

Method's disadvantages:

- ❖ Only a temporary solution (contaminants are still in the environment).
- ❖ In the case of physico-chemical properties changing, the pollutants would be activated.
- ❖ The reclamation process is applied only to the surface layer of soil (30–50 cm).
- ❖ Permanent monitoring is necessary.

Biological methods

Recently, biological methods of soil reclamation have received wide recognition. These methods are based on the biological activity of microorganisms and higher plants, which have the ability to degrade pollutants accumulated in the soil, including their mineralization, immobilization or removal.

Two categories of biological reclamation methods can be distinguished:

- ❖ Bioremediation methods based on microorganisms' activity, which are commonly used for the reclamation of soils polluted by organic compounds. However, recently there have also been many investigations into applying microorganisms for detoxication and cleaning soil polluted by inorganic substances (e.g. heavy metals).
- ❖ Fitoremediation methods, in which the higher plants are used for the degradation and removal of different contaminants (both organic and inorganic) from the soil. Among these methods, the most frequently used are

- fitostabilization;
- fitoextraction/fitodegradation.

Sometimes, in the literature, other biological methods, such as bioremediation in rhizosphere, rhizofiltration and fitovolatilization, are also mentioned. The first one is based on the same bases as the other kinds of bioremediation and therefore it will be discussed together with bioremediation methods. Rhizofiltration is, in most cases, applied for water purification, so it is not suitable for soil and mining wastes. Moreover, it is actually only in the stage of laboratory studies.

The advantages of biological methods of soil reclamation are

- wide application range;
- high efficiency but only in a limited concentration range (the concentrations could not exceed a tolerance level of organisms used for this purpose);
- cost-efficiency and simplicity during the initiation and process operation.

Among the limitations of these methods most frequently are mentioned

- dependency of process efficiency on bioavailability and contents of removing contaminants;
- sometimes, a long time is needed to obtain the expected effect;
- in some cases, production of highly toxic wastes.

Ex situ biological methods

Composting

Contaminated soil is explored and stored as a pile or a thin layer distributed over a larger area, for the degradation of contaminants. This process enables some organic contaminants (oil-origin compounds, non-halogen compounds and some of the halogen compounds and pesticides) to be removed from the soil, by way of biological degradation. The process is carried out by aerobic organisms, which mineralize organic compounds to simple compounds such as CO_2, H_2O and others.

Method's advantages:

- Simple and relatively cheap method that does not require specialist equipment, process controlling and trained staff.
- Some groups of contaminants can be totally removed.
- High level of community acceptance.

Method's disadvantages:

- Not applicable for some organic pollutants and inorganic pollutants (some metals can even inhibit the reaction).
- Not effective for strongly contaminated soils.
- A considerably large area for storage is required.
- Relatively long-lasting process.
- Necessity for effluents' collection and control.

Biological filters and bioreactors

Biological filters and bioreactors are based on the biological activity of microorganisms. During the first stage of the process, the contaminated soil is mixed with water and as a suspension is moved into a reaction chamber where a selected group of microorganisms removes the contaminants as a result of sorption and/or transformation. The transformation of organic compounds is based on total or partial degradation but in the case of inorganic compounds, the process leads to the precipitation of insoluble forms. The remediated soil is completely functional after drying.

Figure 4. Peat-based bioreactor in Quebec, Canada (www.quebecon.ca).

Method's advantages:

- ❖ Effective and relatively fast remediation technique (the fastest biological technique).
- ❖ Useful for the removal of both organic and inorganic contaminants.
- ❖ Wide range of applicability.
- ❖ Soil retains its properties and could be replaced on the reclaimed site.
- ❖ High level of community acceptance.

Method's disadvantages

- ❖ Construction of a special installation is required.
- ❖ Large amounts of wastes (solid, liquid) are generated.
- ❖ Efficiency strongly depends on soil properties.
- ❖ Relatively high costs depending on soil and contaminant properties.

In-situ biological methods

Bioremediation

This method is based on the physiological activity of microorganisms. Organic compounds are used by microorganisms as substrates in energetic processes or they are transformed into substances essential to proper functioning. Generally, this method is used to clean up soils contaminated by organic compounds; however, their availability for heavy metal removal is actually being tested as well.

A particular kind of bioremediation is rhizodegradation or biodegradation in the rhizosphere (the zone that surrounds the roots), where the higher green plants play a key role. The rhizosphere is mostly colonized by the microorganisms' zone of higher plants and therefore the efficiency of the remediation process here is higher. Additional higher plants protect the soil from erosion and the migration of contaminants. In the case of hardly degradable organic contaminants, the exogenic bacterial strains are not naturally occurring in the remediated area.

Method's advantages:

- ❖ The method is simple to apply and does not require any special installation or even specially trained staff.
- ❖ Low-cost method, compared with another techniques of bioremediation.
- ❖ Almost non-invasive to the environment.
- ❖ High efficiency in the case of organic pollutants.
- ❖ High level of community acceptance.

Method's disadvantages:

- ❖ Not applicable for highly contaminated soil.
- ❖ Method efficiency is highly dependent on weather and climatic conditions (low temperatures and humidity decreases the efficiency of the method).
- ❖ The efficiency of the method depends on access to feed substances (N, P, S and other micro- and macroelements).

Phytostabilization

This process is based on the ability of roots to immobilize pollutants. The process takes place on the surface of roots as an adsorption effect. Contaminants are absorbed into roots and precipitated in the roots' area. Additionally, the surface of the soil is stabilized and protected against water and eolian erosion, leaching and transportation of the contaminants into deeper soil horizons. Some plants have the ability to inactivate contaminants as a result of forming conditions to develop hardly soluble forms of the contaminants, both in the surface of the roots and inside their tissues. Some plant species are able to inactivate contaminants through the creation of special conditions from which non-soluble forms of pollutants arise. This process can take place in plant tissue and on the root surface.

Before the application of this technique, the soil needs special chemical treatment using compounds causing pollutant stabilization. Only soil prepared in such way could be sown with stabilizing plants.

Method's advantages:

- ❖ Low-cost method
- ❖ Positive influence on the environment, as an effect of the reconstruction of plant cover on the soil surface
- ❖ Practically no side effects

Method's disadvantages:

- ❖ Contaminants are not removed from the soil but only immobilized
- ❖ Plants and soil require long-term monitoring (controlling the release of metals and the leaching process)
- ❖ The applied plants usually require intensive fertilization
- ❖ The applied plant species could pick up minimal amounts of metals and transport them into overground parts.

Table 1. Most frequently used additives in process of phytostabilization of heavy metals and action mechanisms (Raskin and Ensley, 2000).

Kind of additives		Heavy metal stabilized	Probable action mechanism
phosphate compounds	apatite, calcium orthophosphate, Na_2HPO_4, K_2HPO_4, other phosphate fertilizers, wastes with high P content	Pb	formation of non-soluble phosphate compounds
hydrated iron compounds	wastes containing iron oxides	As, Cd, Cu, Ni, Pb, Zn	sorption of contaminants on oxygen surface, co-precipitation or formation of iron compounds with heavy metals
organic matter	manure, compost, sewage sludge, other organic and synthetic wastes	As, Cd, Cu, Pb	sorption of contaminants, ion exchange or formation of organometallic complexes
clay minerals	natural and synthetic aluminosilicates including zeolites, aluminosilicate wastes from coal combusion	As, Cd, Cu, Mn, Ni, Pb, Zn	sorption of contaminants and ion exchange

Plant species most suitable for metal stabilization:

- poplar hybrids (*Populus* sp.) are useful for arsenic stabilization (can tolerate As concentration in the soil up to 1250 mg/kg and Cd concentration up to 160 mg/kg);
- mustard (*Brassica juncea*) can reduce Cr^{6+} to Cr^{3-};
- some grass species (bentgrass – *Agrostis* sp., red fescue – *Festuca rubra*) are used for the stabilization of mining wastes and soils contaminated by copper lead and zinc.

Phytoextraction

In this method, contaminants are picked up by the roots of plants and transported to their overground parts, and then removed together with the crops.

There are two types of phytoextraction:

- Continuous phytoextraction using hyperaccumulators (plants with a high ability to accumulate metals in shoots with a few % in dry mass).
- Inducted phytoextraction used in the case of non-hyper accumulators when special substances are inserted into the soil to increase their accumulation properties.

This process is influenced by: soil pH, oxidize-reduction conditions and microbiological activity. The method is mostly applied for cleaning up soil, sludge and sediment deposits.

Method's advantages:

- Relatively low costs.
- The method is environmentally friendly.
- Low technical equipment requirements.
- High level of community acceptance.

Method's disadvantages:

- Contaminated biomass must be picked up, removed and properly managed.
- In the case of soil heavily contaminated by heavy metals, a phytotoxic effect can occur and make the process difficult to conduct.
- There is a risk of animals bringing contaminants into the food chain.

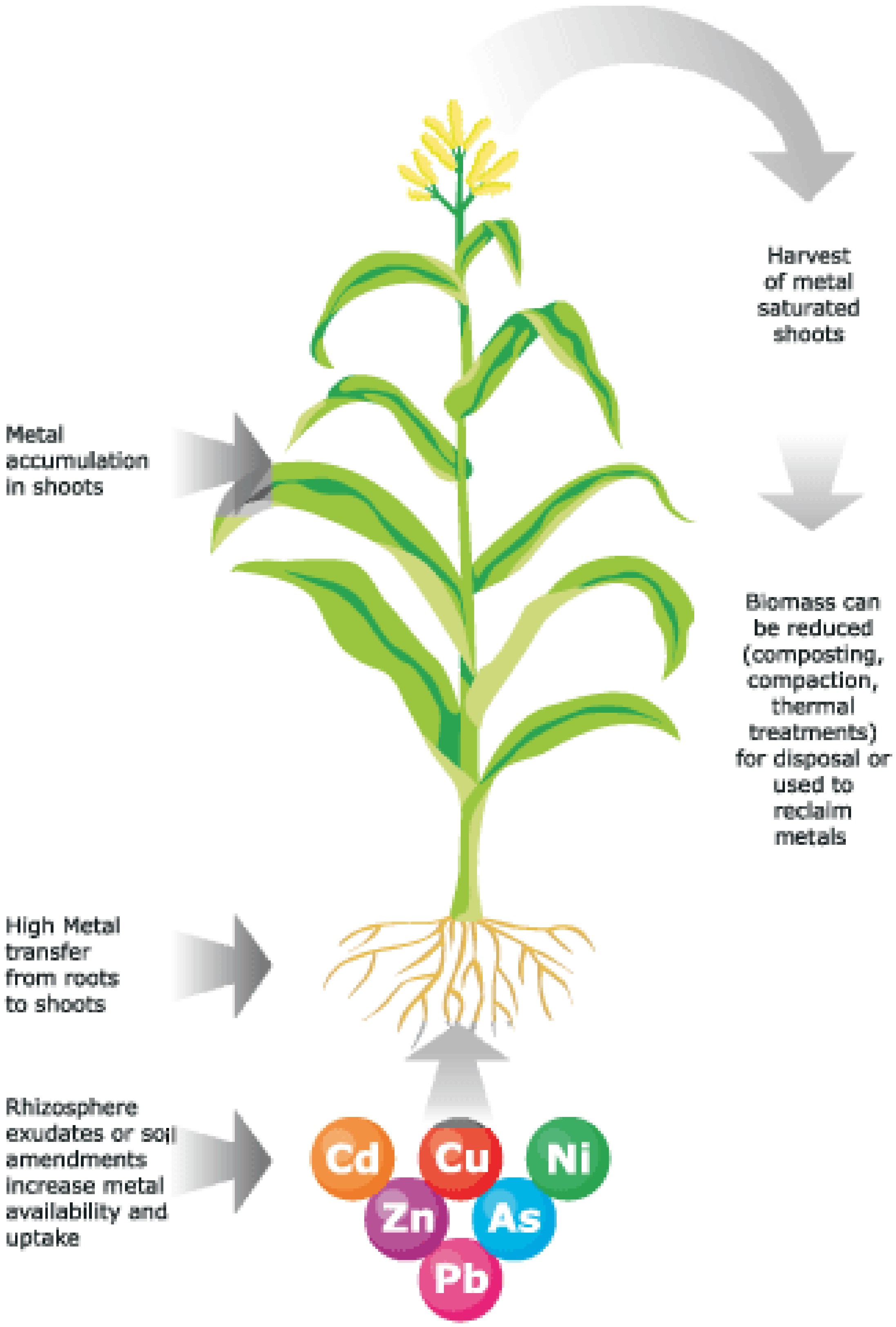

Figure 5. Schematic presentation of the process involved in phytoextraction of metals from soils.

Plant cover

Long-term, self-standing systems of cultivated plants that are introduced to the danger surface area. Plant cover can reduce the danger to an acceptable level and requires minimum conservation.

Types of plant cover:

- Evapotranspiration cover – plant cover of considerable thickness, consisting of plants growing in the soil or other ground. Its role is to decrease the evaporation and transpiration processes of plants and the infiltration of water.
- Phytoremediation cover – consists of soil and plants. Its role is to decrease the water infiltration and assist the process of degradation of the contaminants as well as to protect the environment.

The functioning of this cover is connected with aspects of phytodegradation and rhyzodegradation. In some cases, plant cover can be used alternatively as a non-permeable barrier. The main functions of plant cover are

- prevention of direct contact of people and animals with the contaminants;
- decrease of water percolation;
- long-term functioning without a big conservation effort;
- control of effluents and decrease of soil erosion;
- prevention of the contaminants' migration;
- prevention of the occurrence of large amounts of gases being releasing.

Method's advantages:

- Prevention and minimization of surface erosion by forming a self-sufficient ecosystem;
- Low cost;
- Plants can stimulate the activity of oxygen microorganisms (as an effect of the decomposition of toxic fumes);
- Supports the biodegradation of contaminants in soil.

Method's disadvantages:

- Necessity for long-term monitoring and maintenance of plant cover (natural succession can change the composition of species).
- Surface waters can infiltrate deeper horizons of the soil through macro-pores (decomposition of roots).
- Contaminants can be incorporated into the food chain through plants.
- The majority of covers are effective only in specific conditions (lack of universal cover).

Other innovative methods and technologies

Lasagna process

This is a physico-chemical process based on the electroosmosis phenomenon. An electric current causes a forced flow of water between electrodes, placed (10 m deep) in soil with low permeability (clay, fine grained sand). Screens and filtration layers placed in the way of the water flow are filters on which contaminants are collected. The method is applied *in situ* but is still in a development phase and the full control of the process has not, up to now, been successfully achieved.

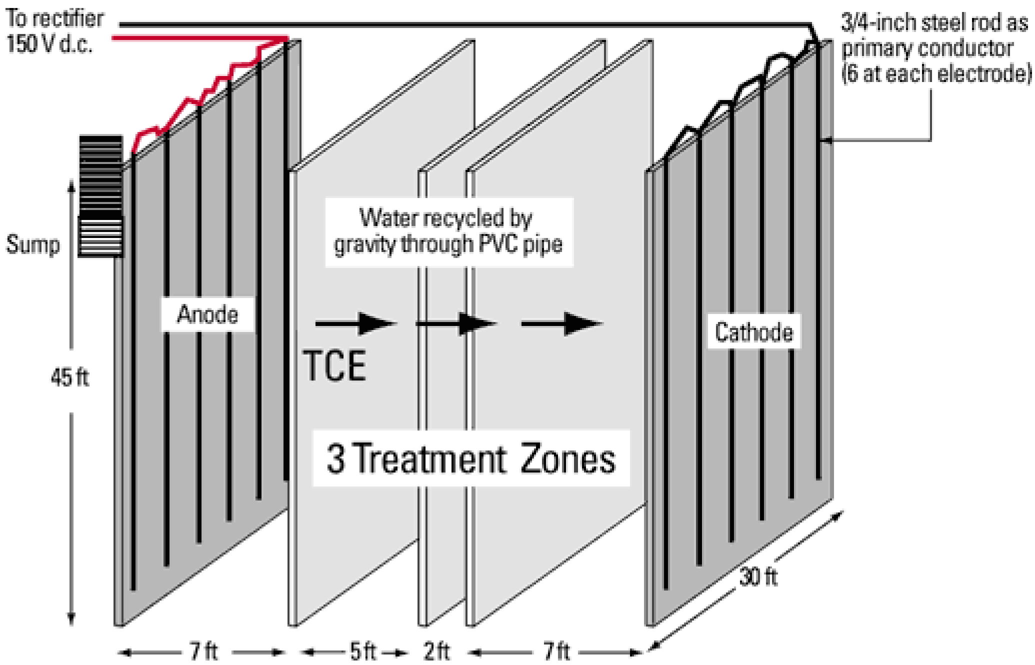

Figure 6. Conceptual droving of the vertical lasagna installation (www.epa.gov).

Method's advantages:

- ❖ For the individual remediated sites, appropriate methods of contaminant removal are selected, depending on the kind of contaminants.
- ❖ Contaminants are neutralized after the process by other methods.

Method's disadvantages:

- The negative effect of application of this method is die-back of the living organisms between electrodes.

Stabilization of contaminants on polymers

This technique uses polymers of a microbiological origin placed beneath the soil surface for contaminant stabilization. Contaminants (mostly heavy metals and their compounds) are absorbed onto specially produced mats, which capture and bond them, serving as biobarriers.

Additionally, biobarriers improve the mechanical properties of the soil and decrease their permeability. The method is applied *in situ*.

Method's advantages:

- The method is applied to soils contaminated by heavy metals and other chemical substances. The chemical composition of the biobarriers is selected individually depending on contamination character.
- It is a non-invasive method which is environmentally friendly.

Method's disadvantage:

- The method is actually in the developmental stage, so its practical efficiency is not fully described.

Vitrification

Vitrification of soil contaminants is a physico-chemical method, in which soil material is smelted. The high temperature necessary for smelting is achieved as a result of heat emitted by an electric current flowing in the soil. The process leads to a change in the structure of the soil from crystal to amorphous. Contaminants are bonded and immobilized in a glazed mass. The method is applied *ex situ*.

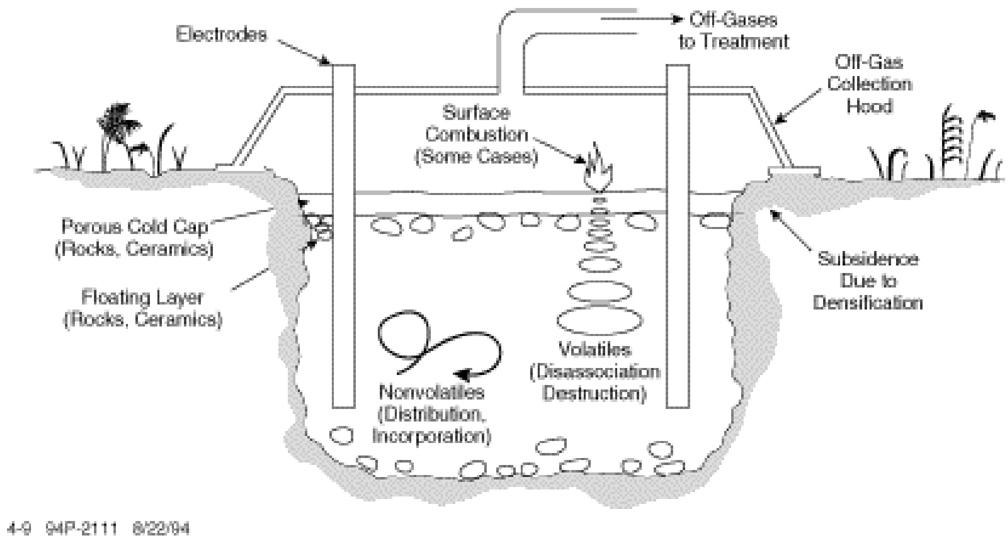

Figure 7. Typical in situ vitryfication system (www.frtr.gov)

Method's advantages

- The method can be applied for reclamation of heavily contaminated soils (Pb, Cd, Cr, asbestos and materials containing asbestos)
- In result of applying this method qualification of wastes (from hazardous to neutral) could be changed.

Method's disadvantages

- The method is very expensive so its applicability is limited to necessary cases.