Soil Contamination

Takeshi KOMAI, Ph D.
Institute for Geo-resources and Environment,
Geological Survey of Japan, AIST

Abstract

The problems of soil and groundwater contamination are of great concern regarding to risk management and sustainable development of industries. Risk and exposure assessment for subsurface environment is very important for both aspects of health and environmental protection as well as making decision of remedial goal for engineering activities. Exposure due to hazardous chemicals in the subsurface environment is essential to assess risk level to individual person, especially from soil and groundwater environmental media. In this seminar, the status of soil and groundwater contamination is presented to discuss on the problem for environmental risk assessment. The methodologies of fate and exposure models are also discussed by conducting the case studies of exposure assessment for heavy metals, organic compounds, and dioxin compounds. In addition, the structure of exposure models and available data for model calculation are examined to make clear more realistic exposure scenarios and the application to the practical environmental issues. Three kinds of advanced remediation techniques for soil and groundwater contamination are described in this paper. These are evaluated by using the process of risk assessment. It is very important to study the methodology of MNA, monitored natural attenuation, into account for conducting risk assessment of long-term contamination and low concentration in groundwater. MNA is one of the effective methods to make decision to the clean-up actions for soil and groundwater contamination, to which risk assessment can be conducted scientifically. Risk assessment is an essential process of corrective actions for soil and groundwater contamination, regarding for the problems of risk benefit, cost effectiveness, and information disclosure.

AIST

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Soil and Groundwater Contamination

For Environmental Risk Management
and Site Assessment Techniques

Takeshi Komai, Ph.D.

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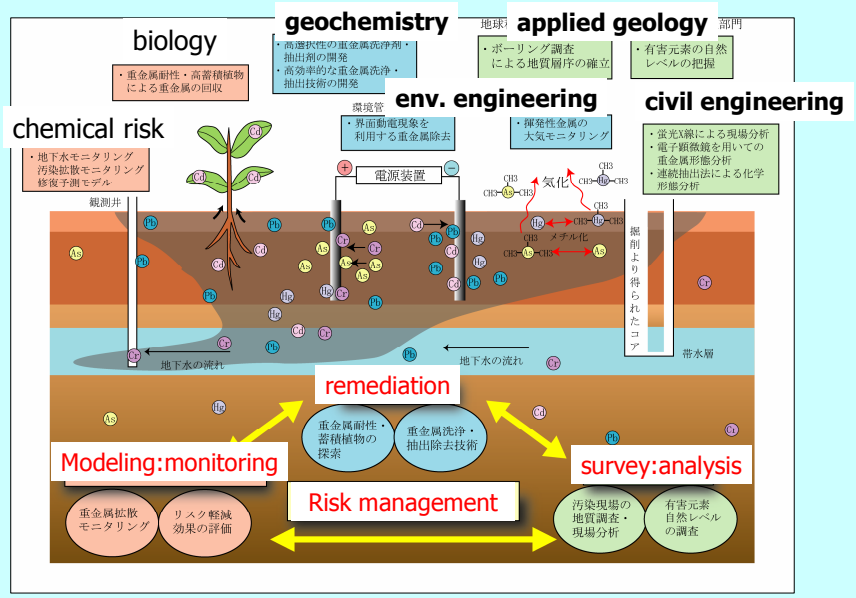
Deputy Director and Group Leader
Geo-analysis Group
Affiliate Professor, Tohoku University
Institute for Geo-resources and Environment
& Center for Chemical Risk Management
National Institute of Advanced Industrial
Science and technology (AIST), Japan

16-1 Onogawa, Tsukuba, 305-8569 Japan
E-mail: koma@ni.aist.go.jp

Contents of my talk

1. Soil and Groundwater Contamination in Japan
   (1) Fact of subsurface contamination
   (2) New regulation of soil contamination
2. Risk Assessment Methodologies for Site Assessment
   (1) Exposure scenario of contaminated soil
   (2) Exposure and risk assessment models
3. Monitored Natural attenuation of contaminants
4. Remediation Techniques of Soil and Groundwater Contamination
5. Risk Management of Subsurface Contamination

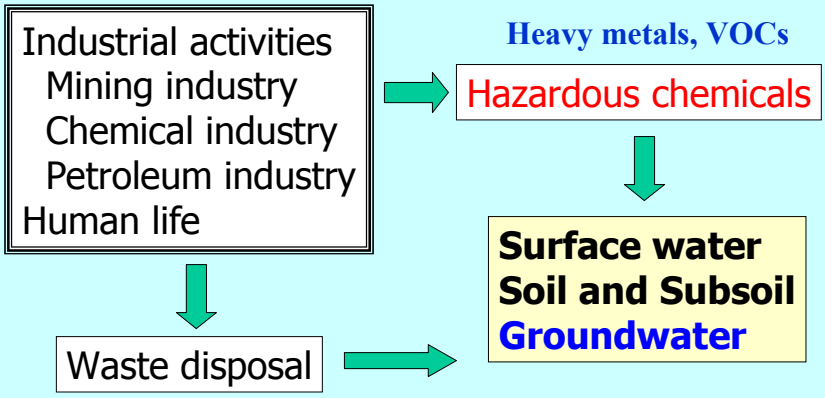
Soil contamination and remediation



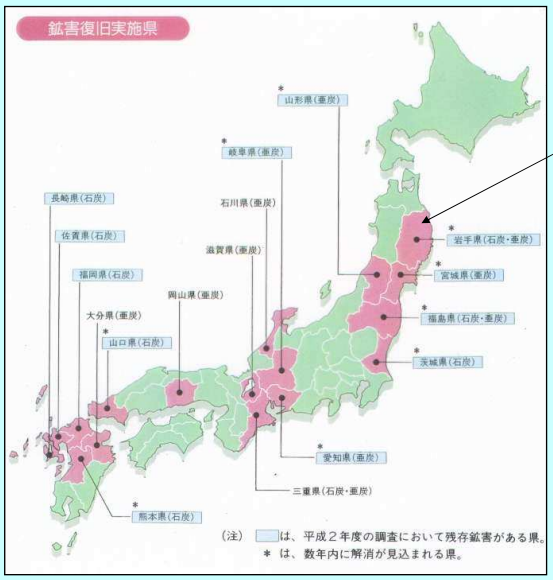
1. The status of Soil and Groundwater Contamination in Japan

Subsurface contamination in Japan

There are a lot of problems on subsurface contamination in soil and groundwater with hazardous chemicals, such as heavy metals and volatile organic compounds (VOCs).



The effects of mining activities in Japan

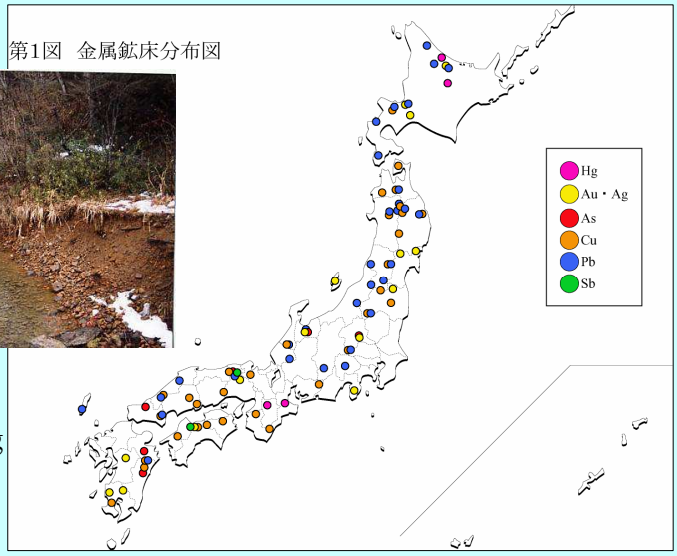


Heavy effects due to mining

(1) Pollution of air, water and soil
(2)Groundwater problems
(3)Acidity
(4)Subsidence
(5)other mining geo-hazards

Distribution of Metal Deposits in Japan

Effluent including heavy metals



Heavy metals emitted from Volcanic Activity

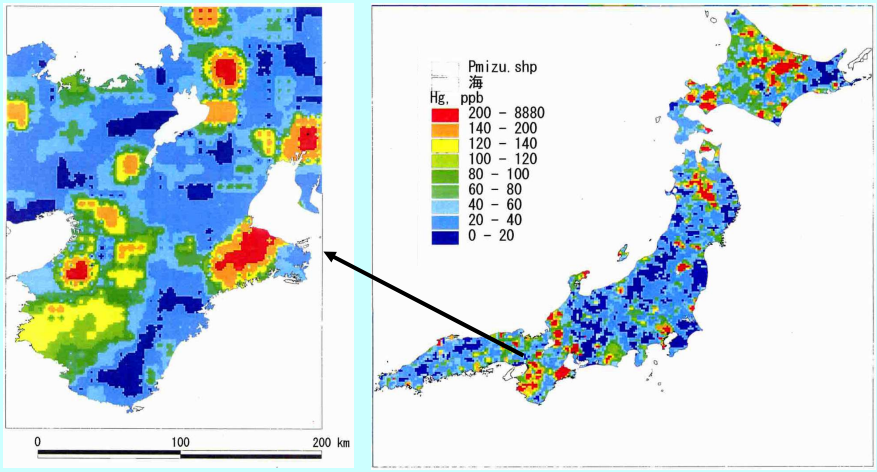
Kusatsu (Hot spring)
pH1.62
As 10.68mg/L
Pb 0.071mg/L

Yukawa (River)
pH2.08
As 2.08mg/L
Pb 0.021mg/L

Shinaki (Lake)
pH5.06
As 0.007mg/L
Pb 0.000mg/L

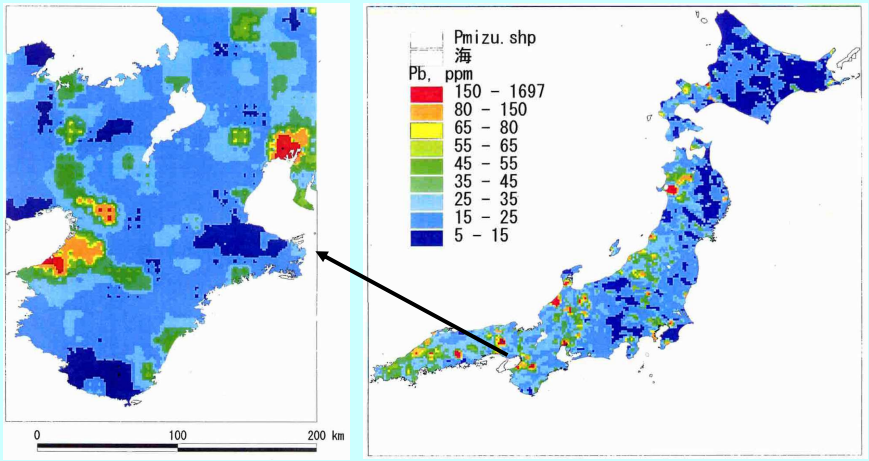
PH2 : Fe2+
pH5 : Fe3+

Spatial Distribution of Hg as Background Level (Imaging configuration)



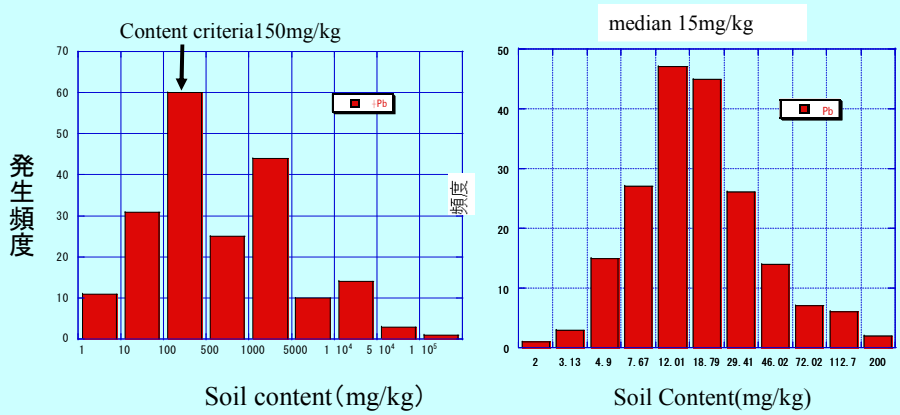
Points of survey: Sediments in major river
Chemical analysis: Total content for sediment substances

Spatial Distribution of Pb as Background Level (Imaging configuration)



Points of survey: Sediments in major river
Chemical analysis: Total content for sediment substances

Distribution of Soil Content (Pb)



Remediation Sites
(industrial lands)

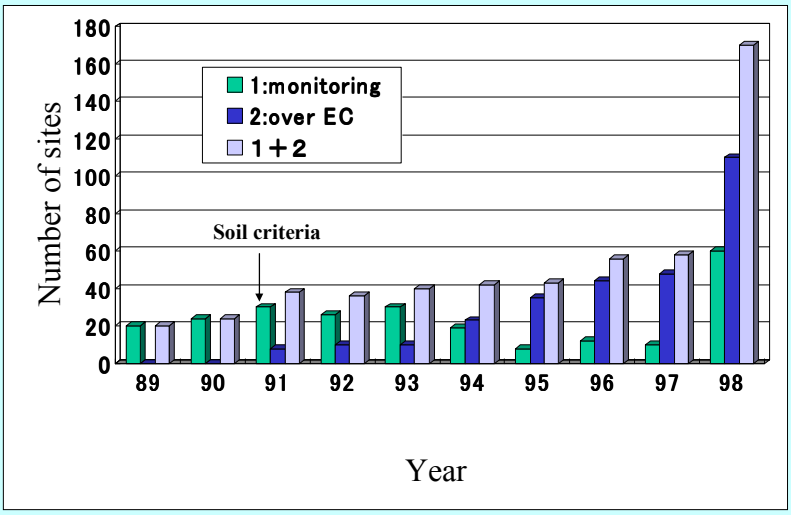
Background Level
(large cities in Japan)

Features of subsurface contamination

- Social background
  Difficult to appear, Site specific, Property of land
- Survey and monitoring
  Few monitoring data, Difficulty of detailed survey
- Assessment methods and models
  No official methods, Uncertainty of parameters
- Management
  Criteria, Remediation goal, Risk management

Soil and GW contamination in Japan

－Number of exceeding criteria－



Fact of subsurface contamination
－Kind of contaminants－

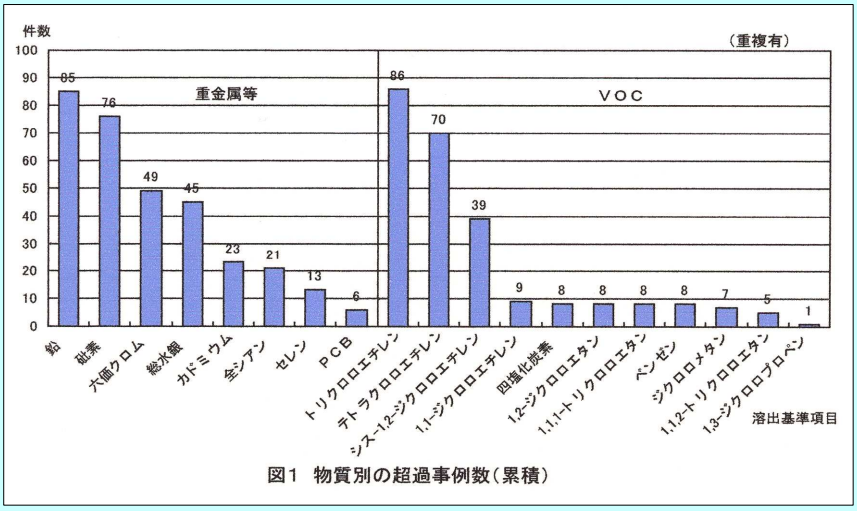


図1　物質別の超過事例数（累積）

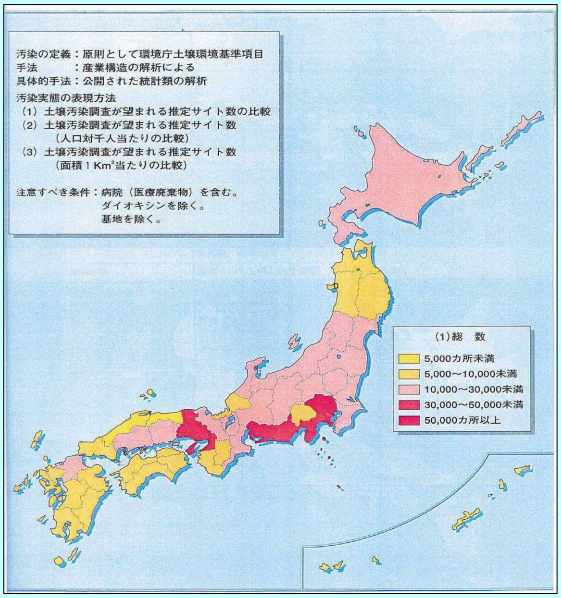
The Estimation of Contaminated Sites in Japan

Kind of industrial site	Number of sites	References
Total number of operating site	387,645	from industrial data of METI
Non contamination site	90,507	industies of food, cloth and others
Large factory	1,850	more than 500 enployees
Gas station	60,421	from industrial data of METI
Cleaning factory	24,700	from industrial data of METI
Scientific laboratory	392	from industrial data of METI
Waste treatment site	13,705	from waste treatment data of MOE
Abandonded factory	48,352	in five years
Abandonded large factory	100	more than 500 enployees
Estimated number of sites needed for contamination	442,758	not including school, hospilal, airport, railway, and other facilities
		Chemical substances related to Environmental criteria of soil and groudwater

Estimated by Inter-Risk Co. Ltd.

Potential sites: more than 400,000 soil contamination in Japan
Severe sites: more than 4,000 soil contamination

Distribution of Soil Contamination in Japan



Potential number of contamination sites in Japan

Oil and VOCs
300,000 sites
Heavy metals
100,000 sites
Others (PCB,DXN)
50,000 sites

New regulation of soil contamination

Soil environment law and regulations will be established in 2002-2003. We are discussing the framework and details.

The background of the regulations are based on the rapid increase of subsurface contamination and dealing of lands.

New environmental criteria:
(1) Leaching ability of soil; Existence
(2) Content of contaminant in soil; New criteria for Heavy metals and related substances and VOCs, PCB, Dioxin compounds, F and B.

Environmental criteria in Japan
- groundwater quality -

Heavy Metals
- Hg : 0.0005 mg/L
- Cd : 0.01 mg/L
- Pb : 0.01 mg/L
- As : 0.01 mg/L
- Cr : 0.05 mg/L
- Se : 0.01 mg/L

Others
- CN : non-ditection
- F : 0.8 mg/L
- B : 1.0 mg/L

Organic compounds
- Benzene : 0.01 mg/L
- TCE : 0.03 mg/L
- PCE : 0.01 mg/L
- DCE : 0.02 mg/L
- cis-DCE : 0.04 mg/L
- DCM : 0.02 mg/L

Others
- DXNs : investigating
- PCB : non-detection

Environmental criteria in Japan
- criteria of soil quality-

Heavy Metals Leaching
- Hg : 0.0005 mg/L
- Cd : 0.01 mg/L
- Pb : 0.01 mg/L
- As : 0.01 mg/L
- Cr : 0.05 mg/L
- Se : 0.01 mg/L

Others
- CN : non-ditection
- F : 0.8 mg/L
- B : 1.0 mg/L

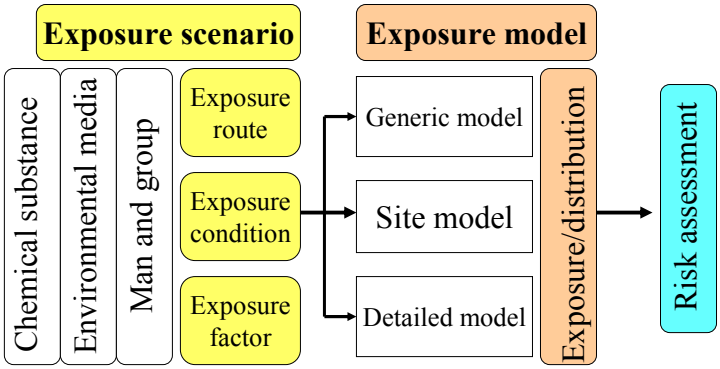
Heavy Metals Content
- Hg : 9 mg/kg
- Cd : 150 mg/kg
- Pb : 150 mg/kg
- As : 150 mg/kg
- Cr(VI) : 250 mg/kg
- Se : 150 mg/kg

Others
- CN : 50 mg/kg-free
- F : 4000 mg/kg
- B : 4000 mg/kg

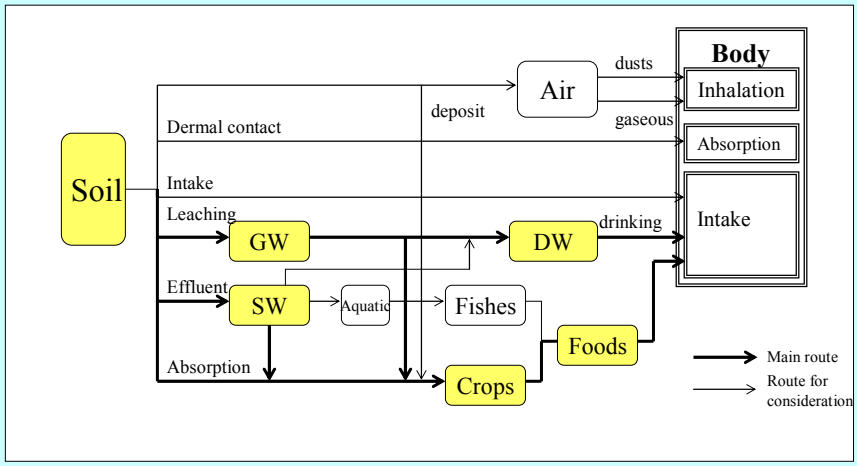
2. Risk Assessment Methodology for Soil and Groundwater Contamination

Methodology of Exposure/Risk Assessment

- From exposure scenario to risk assessment

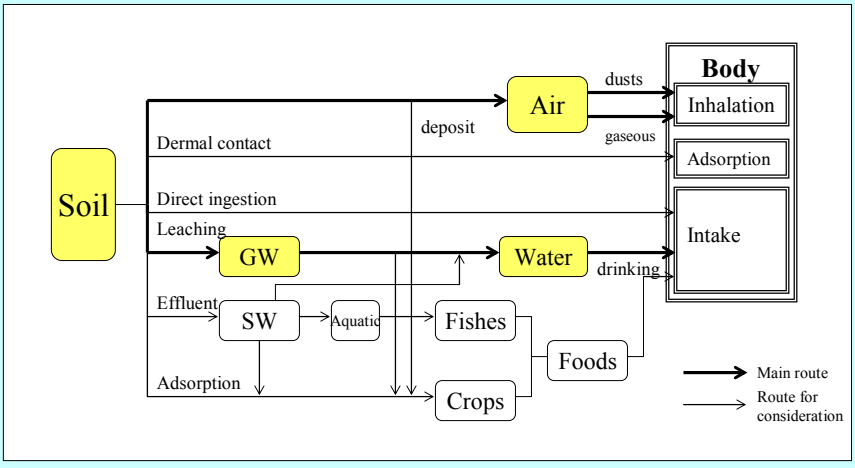


Exposure from contaminated soil
- Heavy metals -



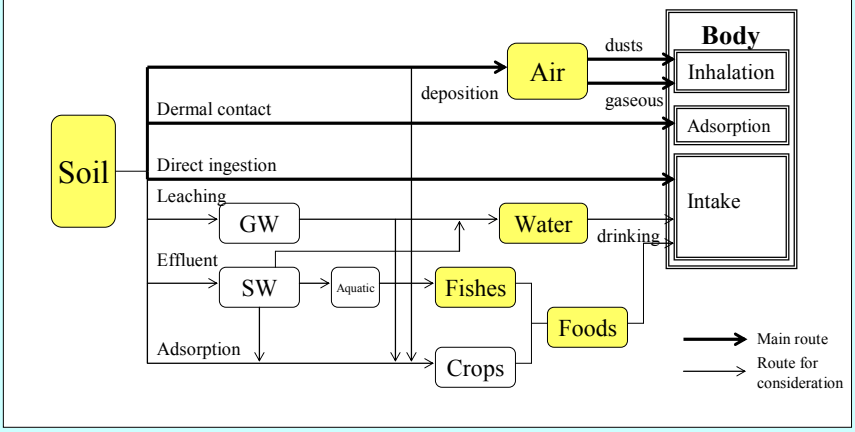
(a) Exposure route of heavy metals

Exposure from contaminated soil
- organic chloride compounds -



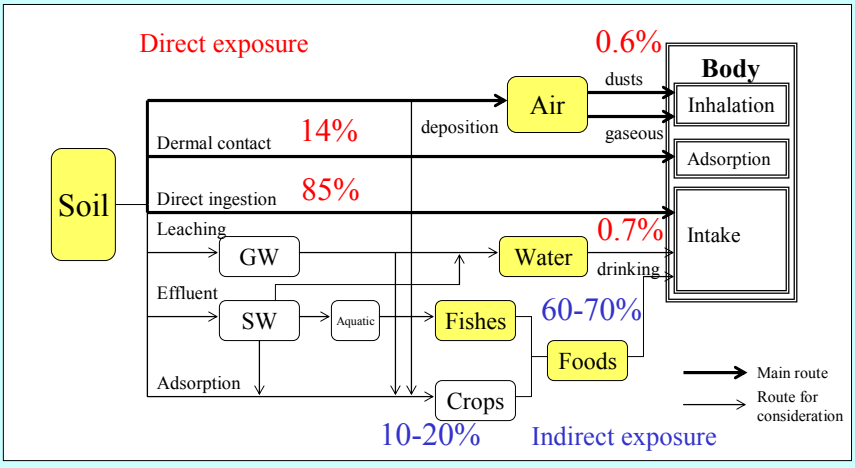
(b) Exposure routes of organic chloride compounds

Exposure from contaminated soil
- DXNs and PCBs -



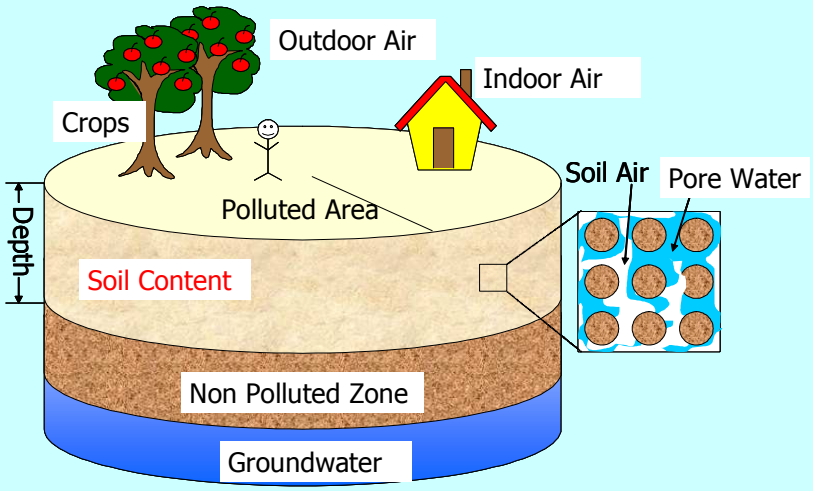
(c) Exposure route of DXNs compounds

Exposure assessment for DXNs compounds



(c) Exposure route of DXNs compounds

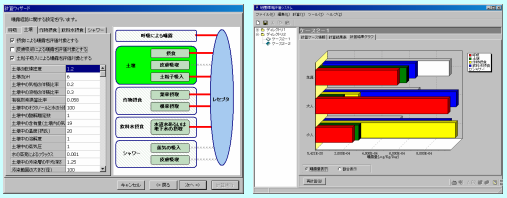
Comprehensive Assessment Model (Tier1)



Risk Assessment of As and Pb

ARSENIC
LEAD ⇨ **Major contaminant in soil and groundwater environment in Japan**

Artificial pollution: Industrial activity
Natural pollution : Volcano, Mine
⇒Higher background level



Exposure rates
Distribution of their path
Risk level
Specific to Japanese situation

Geo-environmental risk assessment system

Methodology of Risk Assessment

Risk Assessment of Arsenic and Lead in Japan

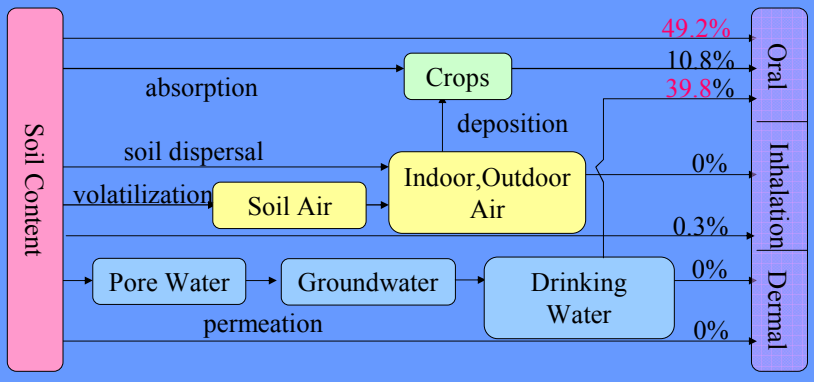
- What is major exposure pathway?
  Direct ingestion of soil, Inhalation of soil,
  Drinking water intake and Crops intake

- How is the risk level of arsenic and lead for human
  living in the general environment (background level)?
  the polluted area (soil environmental criteria)?
  TDI, Cancer risk (arsenic),
  Blood lead concentration

Evaluated

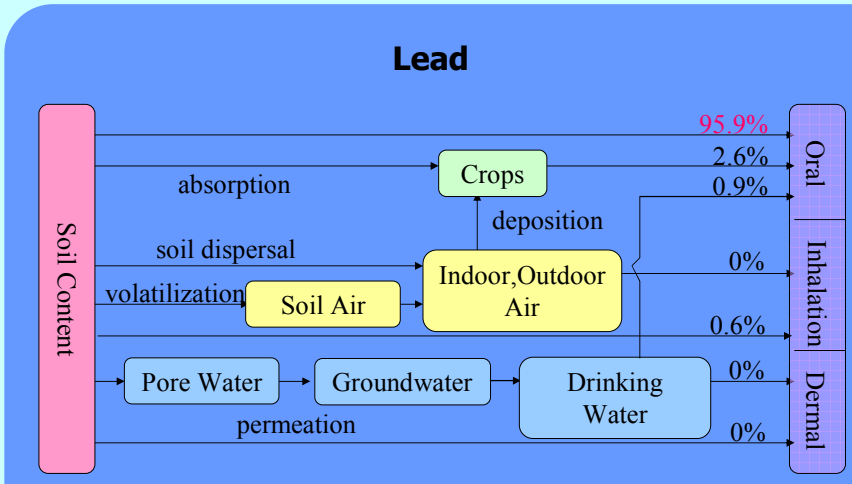
Exposure Pathways and Distribution

Arsenic



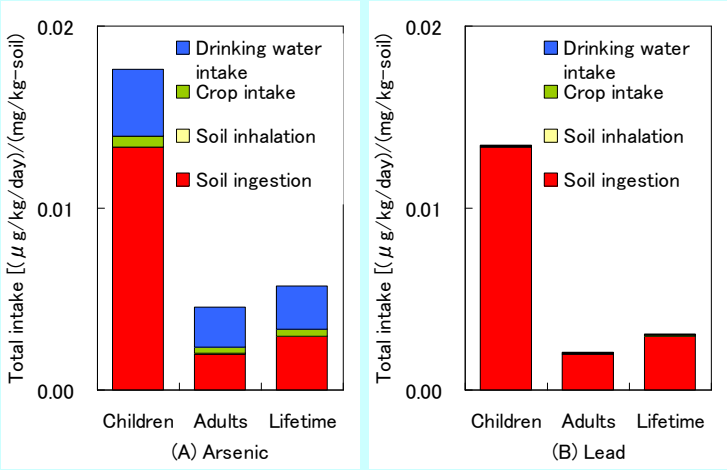
Exposure paths and the distribution of the exposure paths (Lifetime aged 0 to 70)

Exposure Pathways and Distribution



Exposure paths and the distribution of the exposure paths (Lifetime aged 0 to 70)

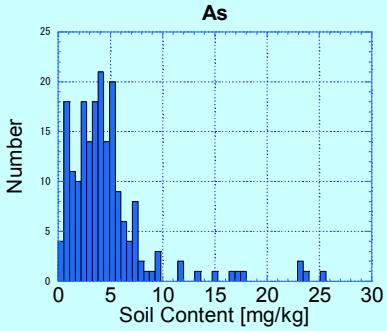
Results of Exposure Assessment



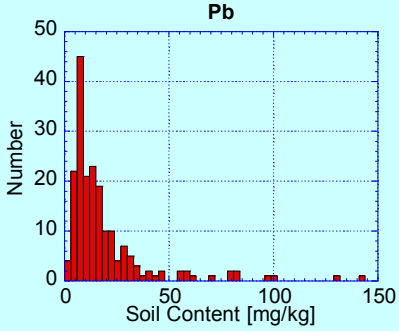
The exposure rates and contribution of the different exposure paths of children (aged 0 to 6), adults (aged 7 to 70) and lifetime (aged 0 to 70).

Results of Risk Assessment

Log normal distribution
GM 3.4 mg/kg
GSD 2.3



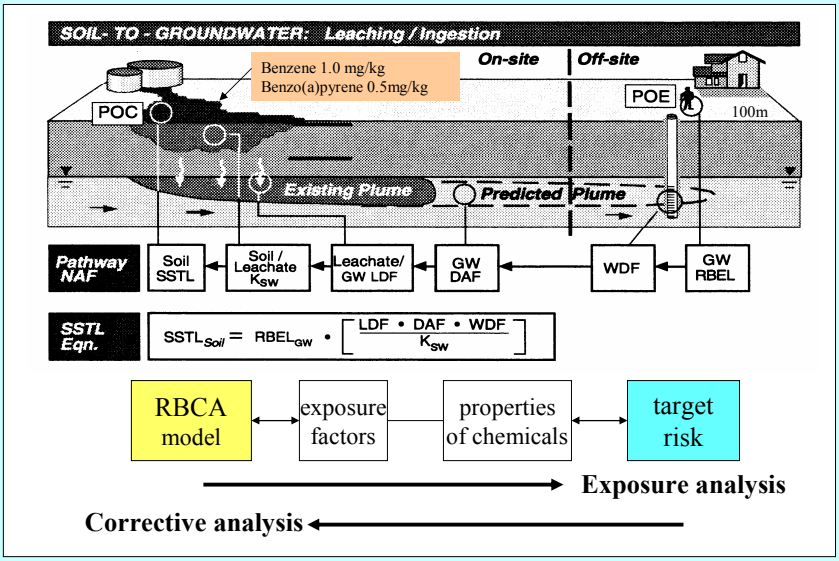
Log normal distribution
GM 13 mg/kg
GSD 2.2



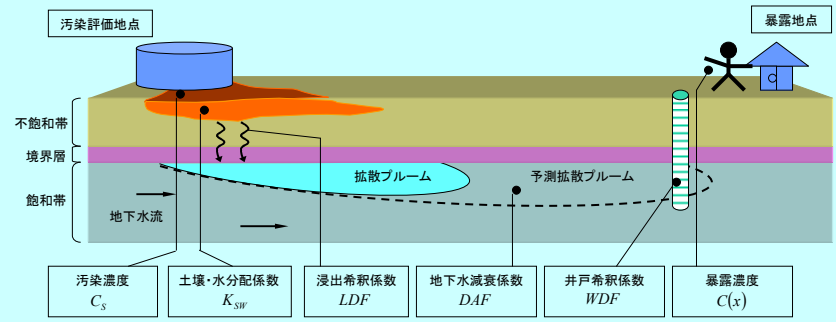
Background concentration of arsenic and lead

10000 trials the Monte Carlo simulation

Methodology of site assessment
—Risk Based Corrective Action(RBCA)—



Site Assessment Model (Tier2)



$$C_S = C(x) \cdot \frac{LDF \cdot DAF \cdot WDF}{K_{SW}}$$

計算手順

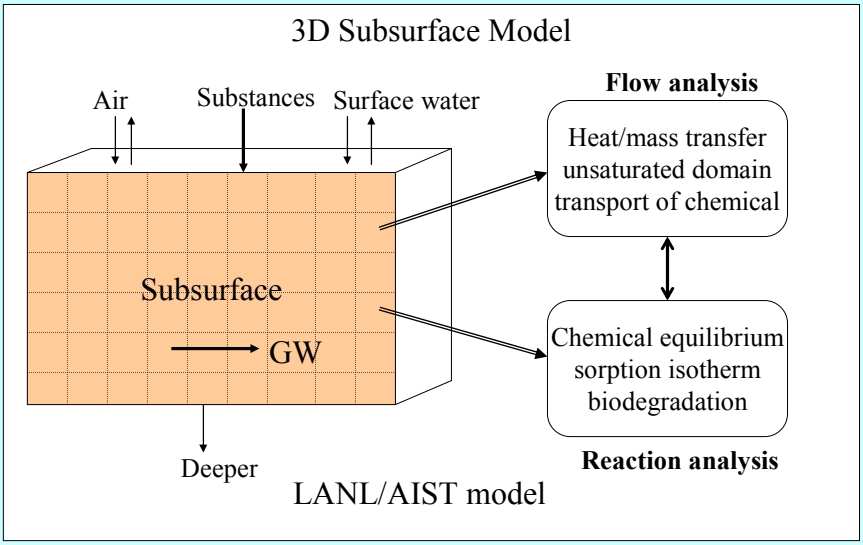
前進方向計算

汚染濃度 → (希釈減衰係数) → 暴露地点濃度 → (毒性データ) → リスク予測

後進方向計算

目標浄化濃度 ← (希釈減衰係数) ← 目標暴露地点濃度 ← (毒性データ) ← 目標リスク設定

Structure of detailed numerical model



3. Monitored Natural Attenuation (MNA) for Groundwater Contamination

Monitored natural attenuation (MNA) methodology

(1) Increase of contamination sites in soil and groundwater environment

(2) Limitation of remediation costs

400,000 contamination sites are estimated in Japan.

(3) From environmental criteria to risk assessment

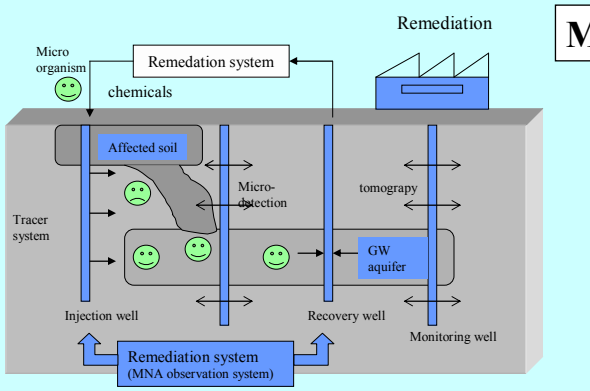
for more realistic and reasonable assessment

(4) Scientific knowledge and background

organic chemicals may take degradation in the environment

MNA application to groundwater problem

Methodology of MNA



Investigation
chemical analysis
monitoring system

Remediation
biotechnology
functioning act

Evaluation
in-situ observation
remediation effect

Optimization
technology
biology

Risk assessment

Groundwater monitoring

Data compilation by analysis
Environmental assessment
Numerical simulation of fate
Optimization of acts

Risk assessment
Exposure analysis
Risk analysis
Risk reduction in future

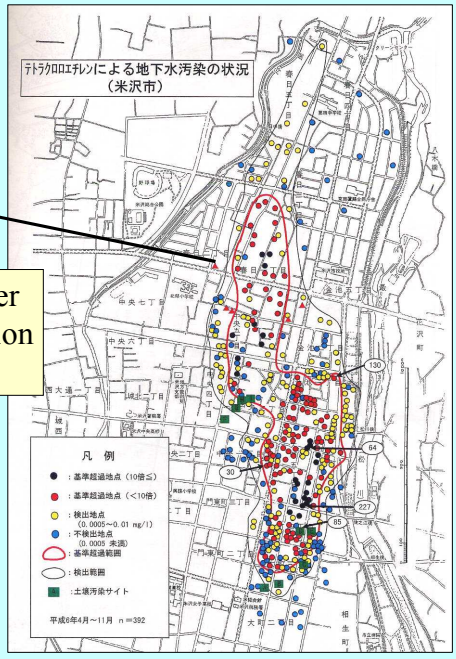
•Shift to MNA
stop of remediating acts
•Risk communication
Information free

Monitoring MNA sites

Yonezawa
TCE, PCE
(contamination)
Iwaki
BTEX, Oil
Takatsuki
TCE, PCE

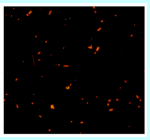
Kumamoto
Gasoline, Oil
Tokyo bay
Oil, Coal tar

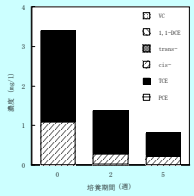
Groundwater contamination sites

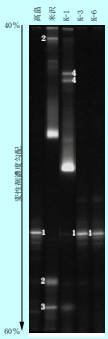


Fundamental study for MNA approach

Fundamental study on microbiology
Bio-degradation factor, attenuation
Parameters for assessment

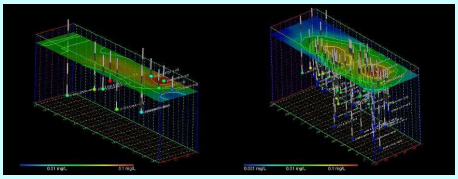






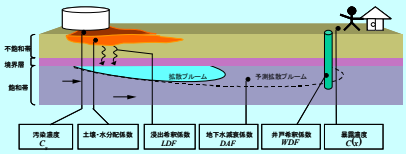
DNA analysis
Microbiological study

Modeling environmental fate



Attenuation and decay factors
Estimation of transport

Exposure/risk analysis



Modeling health effect

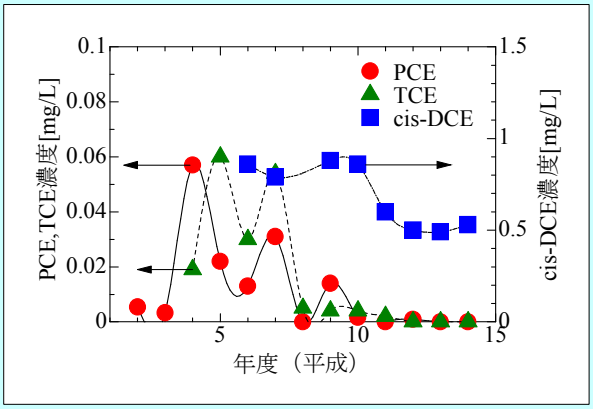
Mechanism of attenuation and monitoring articles

Organic chloride compounds
1. Aerobic degradation
TCE → Dichlorobenzene
→ CO_2, organic acids
2. Anaerobic degradation
TCE → cis- dichloroethylene
→ vinyl chloride
Polycyclic aromatic hydrocarbons
1. Aerobic degradation
PAHs → low aromatics
→ alcohol, water, CO_2
2. Anaerobic degradation
degradation rate may be low

Needed monitor

Temperature
pH
Dissolved O_2
Electrode potential
Electric conductivity
Inorganic / Organic
Number of microorganism
DNA analysis

Trend curve of contaminant Concentration level



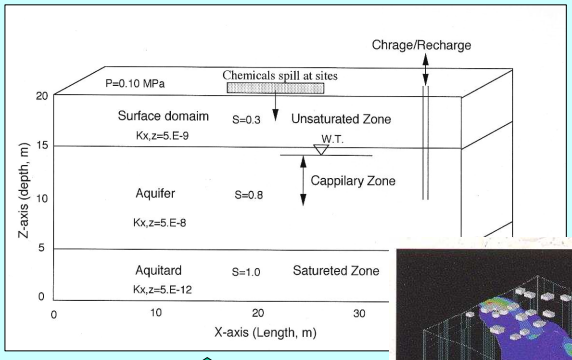
VOCs contamination at Yamagata sites
1988～2003

Attenuation of VOCs
rate of attenuation
concentration level
Degradation product
TCE/PCE/cisDCE
Estimation of MNA

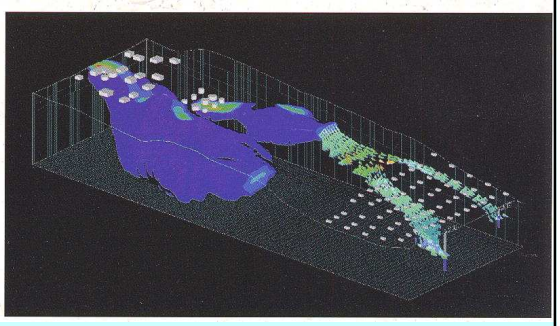
MNA decision

Stop remediation

Simulation of Groundwater Transport

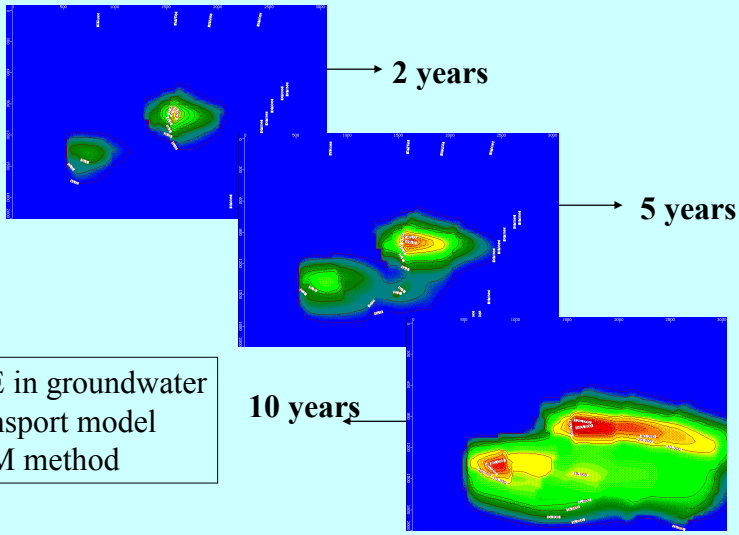


Flow of groundwater
Contaminant transport
Estimation of fate



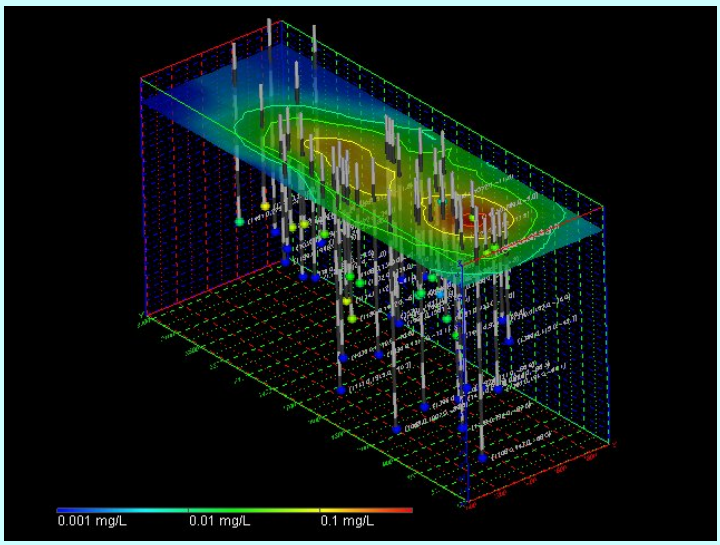
Modeling contaminated site conditions
Monitoring data

Results of model analysis
-time growth of contaminant-



TCE in groundwater
Transport model
DEM method

3-D transport of DNAPLs(PCE) in subsurface environment at Yamagata Pref.



4. Remediation Techniques for Soil and Groundwater Contamination

Advanced remediation techniques in Japan

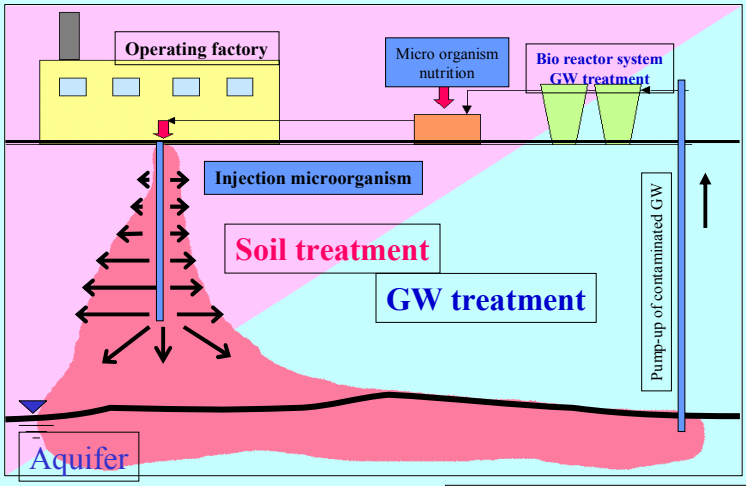
National project for soil remediation method
Ministry of the Environment, 2002-2004

(Heavy metals)
1. In-site soil flushing using functional solutions
2. Electro-kinetics and/or electro-chemical methods
3. Biological treatment by phyto-remediation

(VOCs)
1. In-site air injection and vapor extraction system
2. Bio-reactor system using microbiology consortium
3. Chemical treatment using activated iron powder

(DXNs and PCBs)
1. Geo-melting reactor system and glass consolidation
2. Electro-photochemical reaction system
3. Ultra-violet chemical treatment

A: In-site biological remediation for VOCs (TCE, PCE)



Bio-rangers Co. and AIST

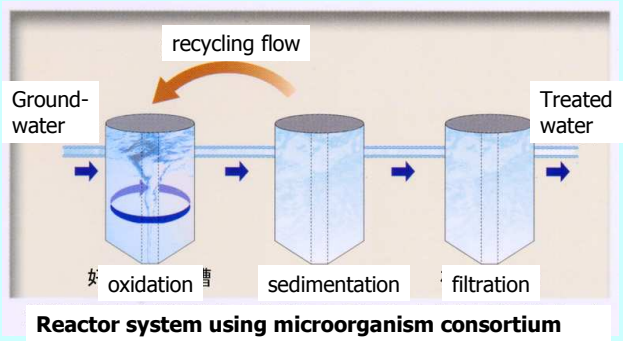
1) Bioreactor system for groundwater

Objective : Treatment of groundwater contaminated by oils and TCE using microorganism consortium

Target : below environmental criteria of VOCs

TCE concentration in contaminated GW

1 ppm, 10 ppm, 100 ppm



Reactor system using microorganism consortium

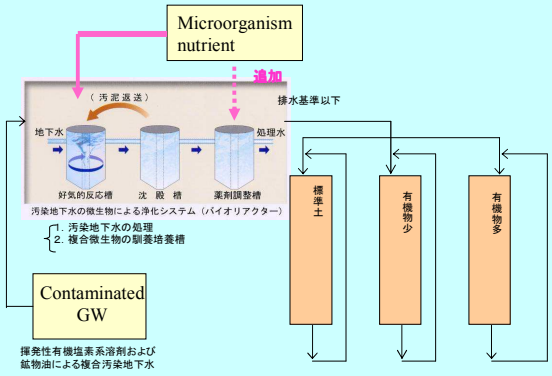
2) Soil remediation system

Experiment2: Soil column test by microorganism consortium

Objective: Development of soil clean-up system by bio-reactor and treated water By microorganism consortium

We make some modeled soil columns in which TCE and other contaminants exist in porous media, and do experiment on bioremediation of soils using bioreactor system and microbe consortium.

We also have test on the details of remedial efficiency, depending on the type of soils and other environmental conditions. In addition, the mechanism of bio-degradation and risk assessment of treated water and bi-products will be conducted.



Model soil column

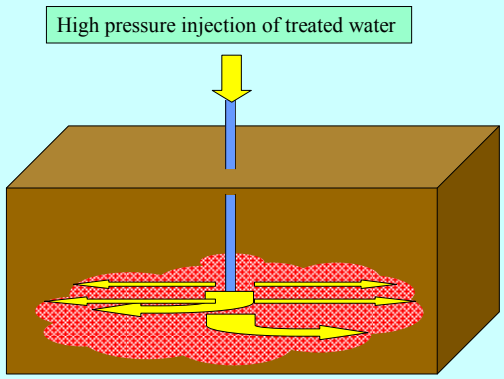
3) Microbiology injection system

Experiment 3: High pressure injection system of bio-treated water

Objective: Development of injection system of treated water with microorganism consortium into contaminated soil

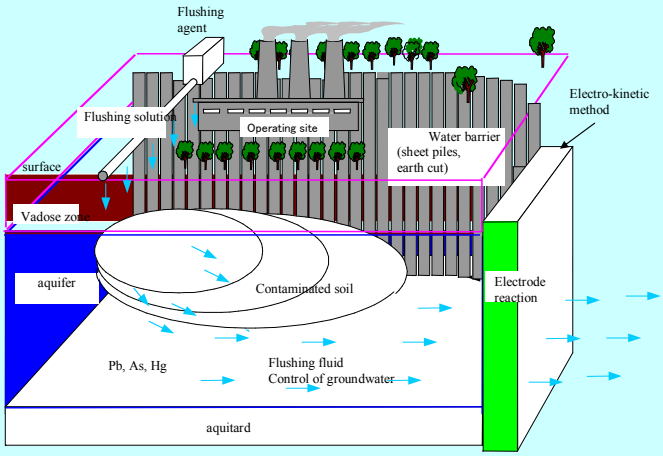
We develop the system of bio-agents injection into contaminated soil and aquifer for more quick remediation

By the way, we make clear the engineering data for in-situ bio-remediation technique, including the rate of dispersion in subsurface area and the degradation rate by bio-agents.



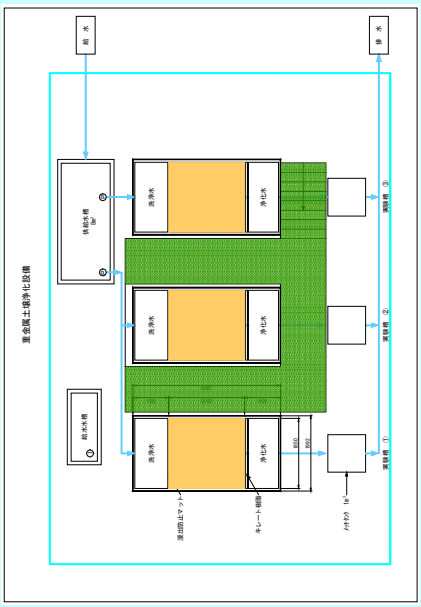
Contaminated soil

B: In-site soil flushing technique for heavy metals (Pb, As, Cr(VI))

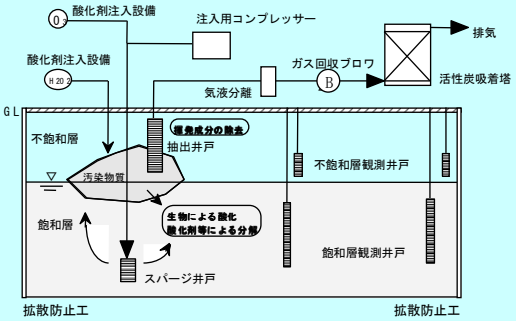


Shimizu construction Co. and AIST

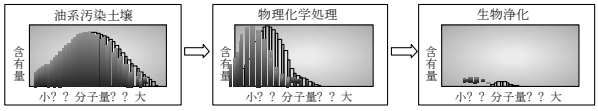
Soil flushing and measurement system



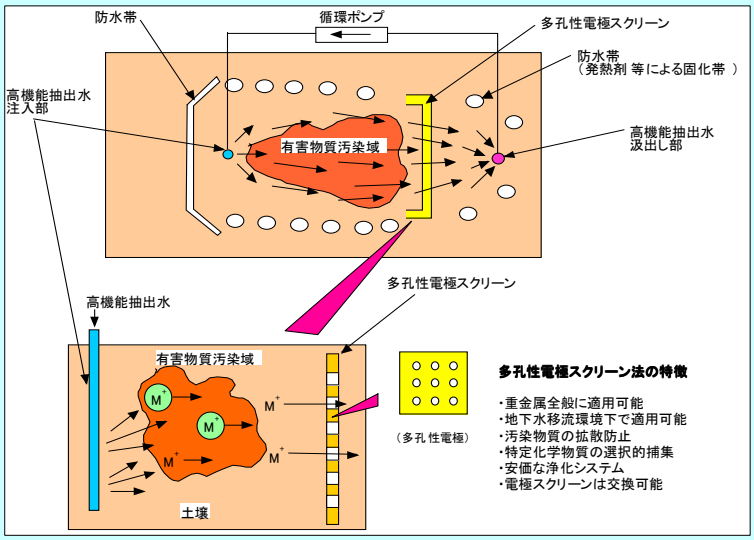
Bio-stimulation and flushing technique



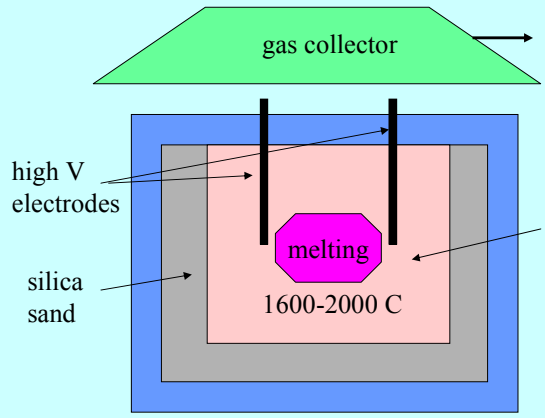
Bio-sparging method for remediation



Electro-chemical barrier using electrodes



C: Geo-melting technique for DXNs and PCBs



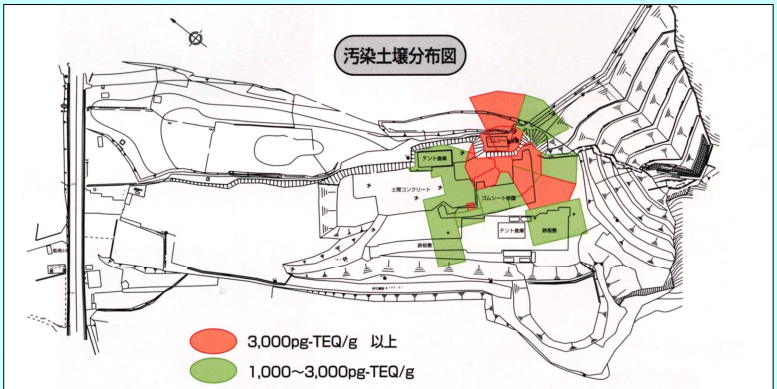
geo-melting reactor ($100m^3$ chamber)

Consolidation + Decomposition for DXNs

Konoike-Gumi Co. Ltd.

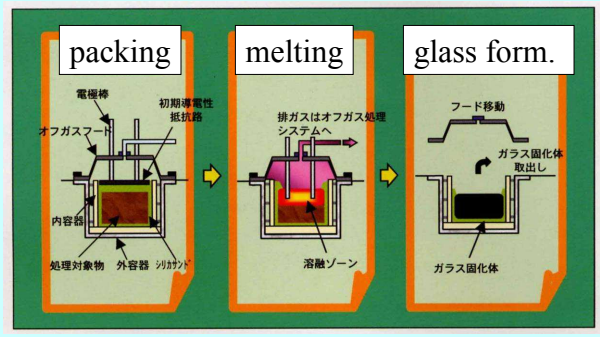
Remediation site in Wakayama Pref. by geo-melting technique

Site characterization of contaminated soil



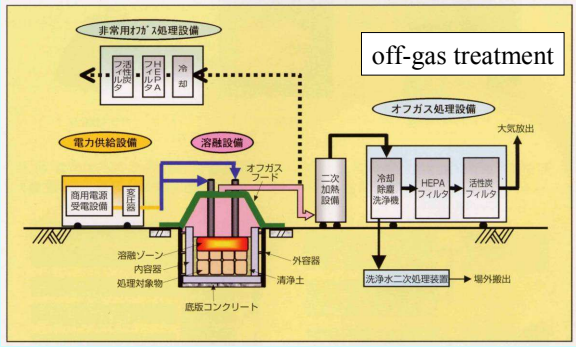
	ダイオキシン類濃度	対策
*高濃度汚染土壌	3,000pg-TEQ/g以上	現地無害化処理
*低濃度汚染土壌	1,000~3,000pg-TEQ/g	現地封じ込め

Abandoned waste treatment site contaminated by DXNs



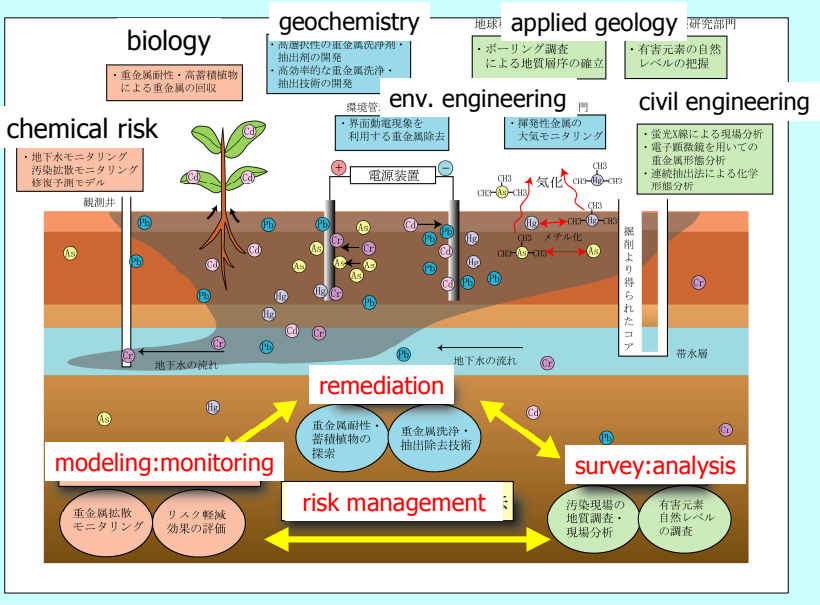
Remediation process

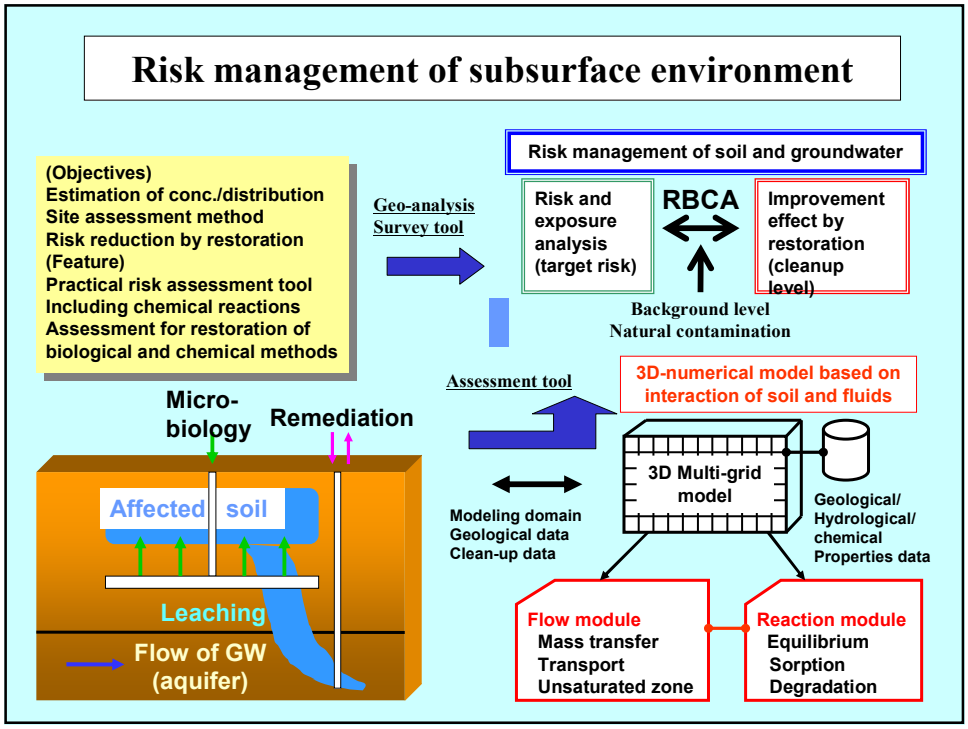
Remediation system

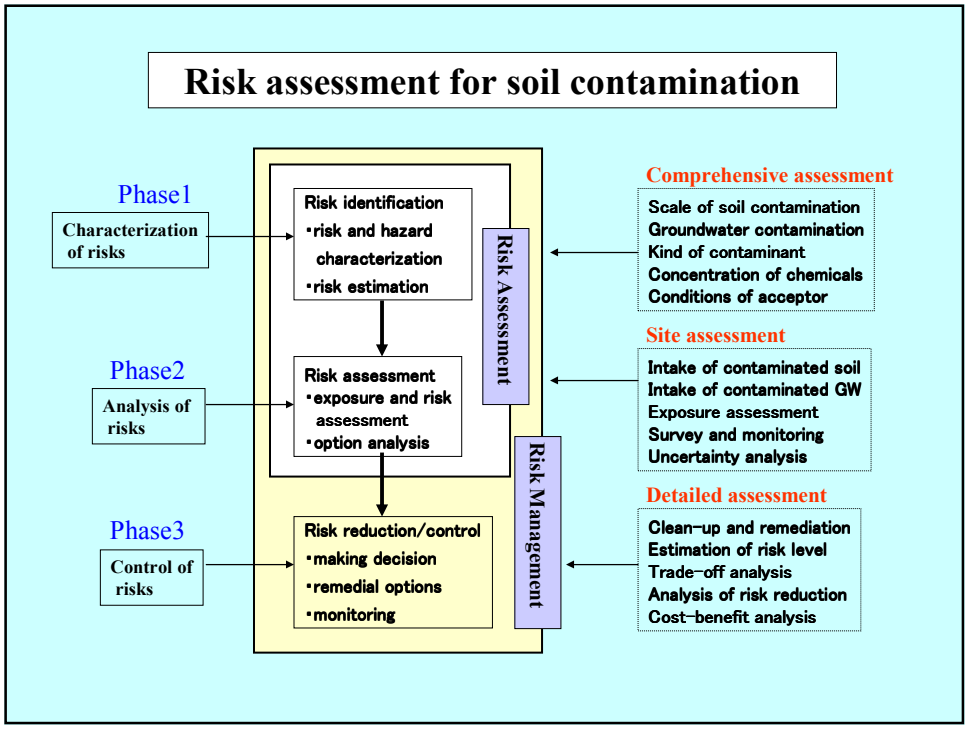


5. Risk Management for Soil and Groundwater Contamination

Soil and groundwater contamination




Risk management of subsurface environment
(Objectives)
Estimation of conc./distribution
Site assessment method
Risk reduction by restoration
(Feature)
Practical risk assessment tool
Including chemical reactions
Assessment for restoration of
biological and chemical methods
Geo-analysis
Survey tool
Risk management of soil and groundwater
Risk and exposure analysis (target risk)
RBCA
Improvement effect by restoration (cleanup level)
Background level
Natural contamination
Micro-biology
Remediation
Affected soil
Leaching
Flow of GW (aquifer)
Assessment tool
3D-numerical model based on interaction of soil and fluids
3D Multi-grid model
Modeling domain
Geological data
Clean-up data
Geological/ Hydrological/ chemical Properties data
Flow module
Mass transfer
Transport
Unsaturated zone
Reaction module
Equilibrium
Sorption
Degradation


Risk assessment for soil contamination
Phase1
Characterization of risks
Risk identification
•risk and hazard characterization
•risk estimation
Phase2
Analysis of risks
Risk assessment
•exposure and risk assessment
•option analysis
Phase3
Control of risks
Risk reduction/control
•making decision
•remedial options
•monitoring
Risk Assessment
Risk Management
Comprehensive assessment
Scale of soil contamination
Groundwater contamination
Kind of contaminant
Concentration of chemicals
Conditions of acceptor
Site assessment
Intake of contaminated soil
Intake of contaminated GW
Exposure assessment
Survey and monitoring
Uncertainty analysis
Detailed assessment
Clean-up and remediation
Estimation of risk level
Trade-off analysis
Analysis of risk reduction
Cost-benefit analysis

Remediation goal and target risk

- How much level we should clean up? (Remediation goal)

  Evaluation of clean-up
  Natural attenuation
  Environment economy
  Industrial policy

Survey monitor Clean-up

Exposure and risk assessment

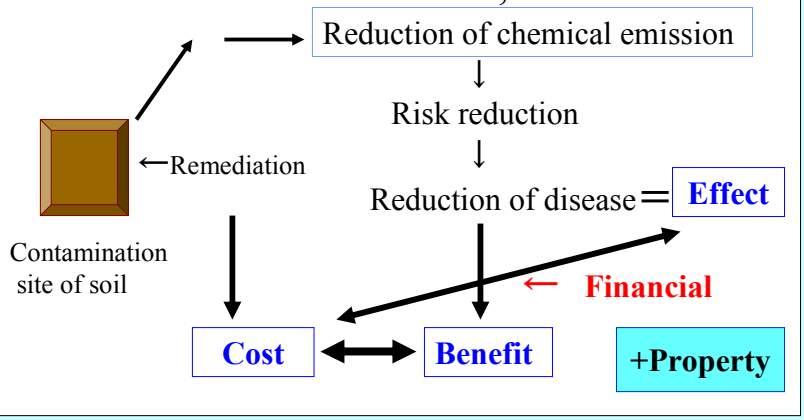
- How much level we should reduce risk? (Target risk)

  End points
  Uncertainty
  Acceptable risk
  Social consensus

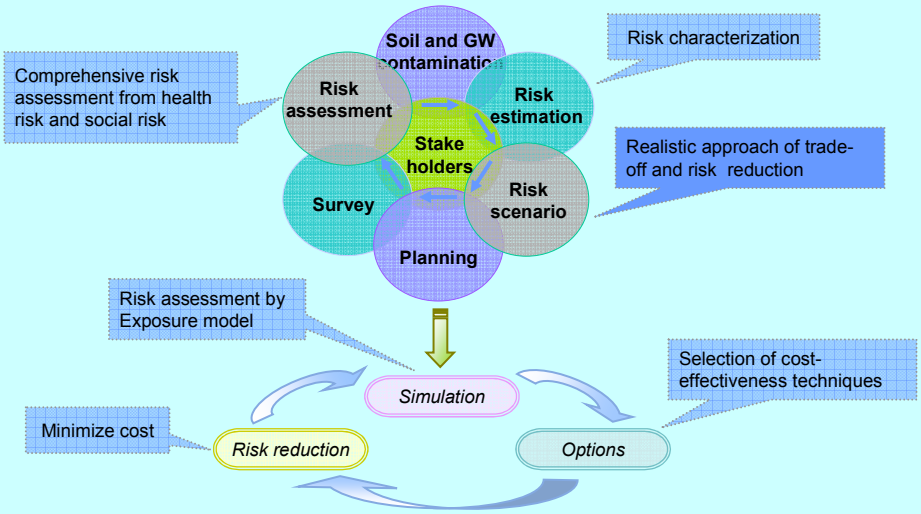
Risk management

Cost / Effectiveness / Benefit
- The case of soil remediation -

The case of soil remediation;



Strategy of environmental risk management



Risk management strategy with risk communication in each step

Advanced risk assessment

Advanced framework of risk assessment with information disclosure and participation of all stakeholders

・regulatory management by criteria and guideline	・realistic risk management based on risk assessment
・closure of information	・disclosure of information
・luck of scientific evidence	・a lot of scientific data
・assessment by government	・assessment by all persons
・who should make decision	・stakeholders make decision

Conclusion Remarks

1) Risk management procedure including contamination survey, risk and environmental impact assessment is very important for soil and groundwater protection.
2) The status of subsurface contamination of Japan and remediation is presented to discuss on how we can reduce risks of soil and groundwater contamination.

Thank you for your attention!