Environmental Toxicology (ET)

Course: ES 535

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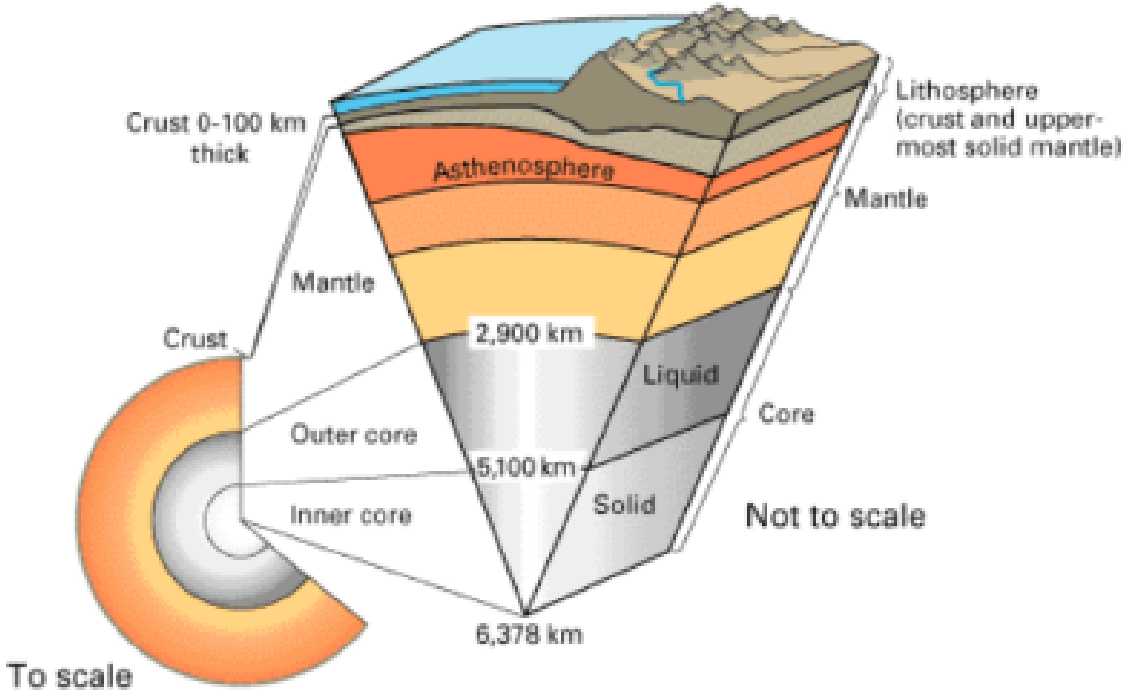
Soil and Water Pollution – Environmental Metals and Metalloids: Sources of Metals in the Environment

Metals found in the environment are derived from a variety of sources:

- Natural weathering of the earth's crust
- Mining
- Soil erosion
- Industrial Discharge
- Urban runoff
- Sewage effluents
- Pest or disease control agents applied to plants
- Air pollution fallouts and
- Other sources also

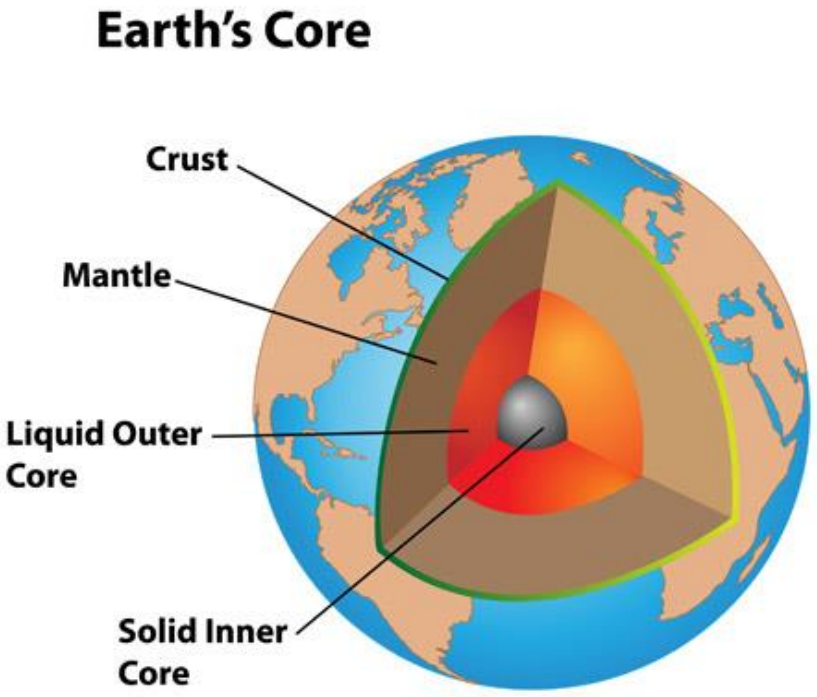
Weathering of Earth's crust

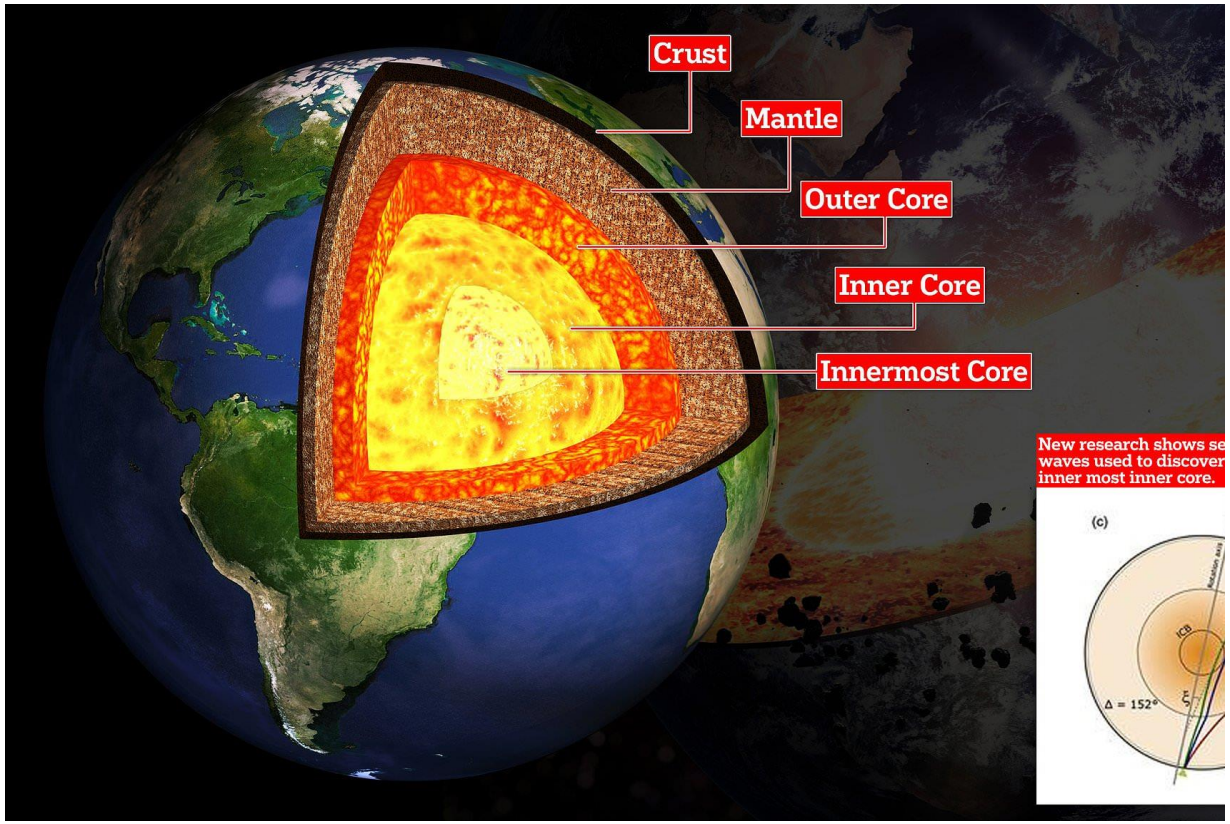
Inside the Earth



The Earth's Crust is like the skin of an apple. It is very thin in comparison to the other three layers. The crust is only about 3-5 miles (8 kilometers) thick under the oceans(oceanic crust) and about 25 miles (32 kilometers) thick under the continents (continental crust). The temperatures of the crust vary from air temperature on top to about 1600 degrees Fahrenheit (870 degrees Celcius) in the deepest parts of the crust

Scientists have detected evidence of another core at the center of the earth





Weathering of Earth's crust

Weathering & Erosion

Weathering:

- **Physical**
- **Chemical**
- **Biological**

- **<u>Weathering</u> – a natural process that breaks down and wears away rocks to create sediments**
- **Erosion is the movement of small rock particles by wind, water and ice**

Sources of Metals in the Environment (Contd.)

- Since industrial revolution, the use of metal has been increased, precisely in the developed countries
- This has led to the health hazards
- A group of metallic elements, which are present in the environment are heavy metals
- After absorption, these metals tends to bind to bio-molecules such as protein and nucleic acids impairing their functions

Heavy Metals

- A **heavy metal** is a member of a loosely-defined subset of elements that exhibit metallic properties.
- It mainly includes the transition metals, some metalloids, lanthanides, and actinides.
- Many different definitions have been proposed—some based on density, some on atomic number or atomic weight, and some on chemical properties or toxicity.
- Heavy metal can include elements lighter than carbon and can exclude some of the heaviest metals.

Heavy Metals

- Most of the heavy metals are extremely toxic because, as ions or in certain compounds, they are soluble in water and can be readily absorbed into plants and or animal tissue.
- We shall discuss the sources of the following metals and their health and biological effects on living beings:
- Lead, (Pb)
- Cadmium (Cd)
- Mercury (Hg)
- Nickel (Ni), and
- Arsenic (As)

These and a number of other metals are widely used in industry, and Pb, Cd, and Hg, in particular, are generally considered the most toxic to humans and animals

Lead (Pb)

- Lead is a soft gray metal element that occurs naturally in the earth.
- For many years, lead was added to

I. paint,
II. gasoline,
III. historic monuments
IV. mining, and
V. commercial or
VI. industrial operations.
VII. Battery (Lead-Acid)

Lead

Sources of Lead Exposure:

Airborne Lead

- About 90% of the atmospheric lead is due to automobile exhaust. While atmospheric Pb pollution has decreased in the U.S and other developed countries due to use of unleaded gasoline , a similar trend has not occurred in many developing countries.
- In Bangladesh government has issued order in 2006 and 2008 for the Lead-Acid battery management

Waterborne Lead

- Once emitted into the atmosphere or soil, lead can find its way into the aquatic systems. Both surface water and ground water may contain significant amounts of Pb derived from these sources.

Lead in Food

- Food is a major source of Pb intake for humans and animals. Plant food may be contaminated with lead through its uptake from ambient air and soil, animals may then ingest the Pb- contaminated vegetation. In humans, Pb ingestion may arise from eating Pb-contaminated vegetation or animal foods.

What products may cause lead exposure?

Past product exposures

- Leaded gasoline

Present product exposures

- Canned food,
- Jewelry, and
- Some products used in home remedies.

What are the sources of lead in the environment?

- Homes that have cracked and peeling old lead paint on their walls.

- Home renovations that disturb old lead paint can spread invisible lead dust.

- Lead from old lead paint may contaminate household dust and nearby soil.

What are the sources of lead in the environment? (continued)

- Soil may still have high lead levels
- Lead enters the dust or air in businesses that involve lead.
- Lead mines or smelters may contaminate nearby soil or water.

Lead in drinking water

- Lead can enter water by leaching from
  - Lead-containing pipes
  - Taps
  - Solder
- Boiling water from the faucet (tap) does not get rid of lead.
- Running cold water before using may reduce exposure.

Lead in commercial products

- Lead is still used in products such as:
  - Bridge paint
  - Computers
  - Solder
  - Pewter
  - Costume jewelry

Lead in contaminated products (continued)

- ✓ Ceramic tableware used for storage or serving food or beverages may cause exposure.
- ✓ Lead-glazed pottery is a potential source often overlooked.

How are people exposed to lead?

- Ingestion of foods, water, alcohol may be significant for certain populations.

- Ingestion- primary way by which the general population, especially children, are exposed to lead.

- Inhalation of lead dust contributes to build up led content in the body.

How are people exposed to lead? (continued)

- Inhalation may be the major route for workers in lead-related occupations.

- Ingestion of certain home remedies.

- Ingestion of lead paint or inhalation of lead dust or fumes is a major source for children in the Developed world.

What happens when lead enters the body?

- Lead is stored for long periods in mineralizing tissue such as teeth and bones.
- Lead is can be released again into the bloodstream from these sources during times of bodily stress, such as

  -pregnancy

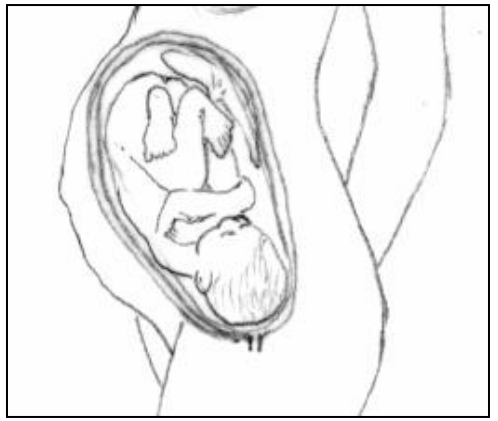
  -breastfeeding

  -calcium deficiency

  -osteoporosis (thinning of the bones)

Who is most at risk of lead exposure?

- Children living in older housing
- Pregnant women and developing fetus
- Certain occupations



What levels of lead cause health effects?

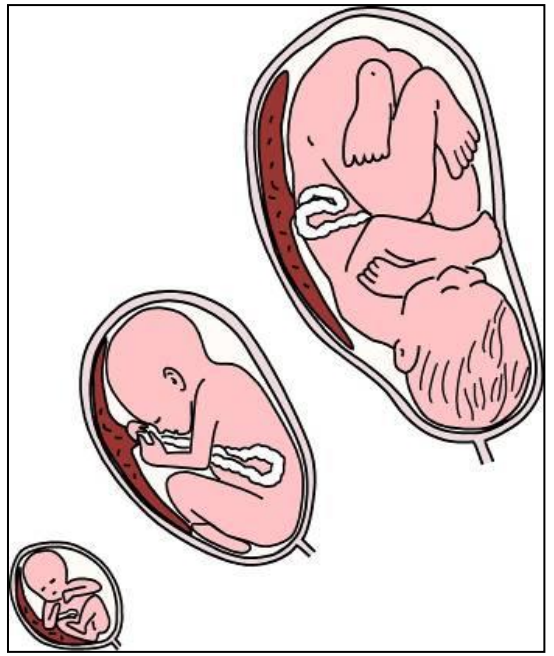
- Lead can cause harm even at very low levels, especially in young children.
- There is no safe threshold for lead.
- At very high levels, lead can brain damage, coma
- Adults experience similar effects, but generally at higher levels of exposure.

What are the effects of lead exposure on young children?

- Lowered IQ
- Learning disabilities
- Attention deficit and hyperactivity
- Other behavioral issues
- Impaired hearing
- Anemia
- Decreased growth

What are the effects of lead on adults?

- Similar to children, although generally at higher lead levels.
- Long-term exposure may affect thyroid.
- Problems with pregnancy and offspring.
- May also affect reproduction/fertility.



Prevention of exposure to lead in home Environment

- Make sure all paint is in good condition.
- Wet-clean all surfaces, especially window sills, at least every week.
- Wash children’s hands frequently.
- Cover bare soil in the yard.
- Learn about lead-safe work practices when doing work on your home that disturbs paint.

Prevention of exposure to lead in workplace

- If someone works around lead paint, solder, or other products that contain lead:
- Ask doctor to test blood for lead.
- Talk to workplace health and safety officer.
- Wear protective clothing and use a respirator as appropriate.
- Wash hands carefully and change clothing before going home.

Cadmium (Cd)

- In 1945, Japanese farmers living downstream from the Kamioka Zinc-Cadmium-Lead mine began to suffer from pains in the back and legs, with fractures, decalcification, and skeletal deformation in advanced cases.
- The first documented case of mass cadmium poisoning in the world - in Toyama Prefecture, Japan in 1950 – itai-itai-byo disease (river polluted with waste from factory, water used on rice fields – poisoning from rice).
- The drinking water of the residents was also highly polluted

Cadmium - Cd

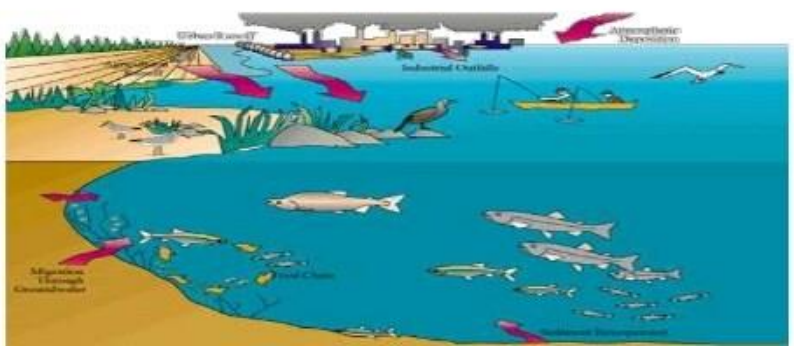
- Cadmium is a nonessential trace element and is present in air, water, food, plants and animals
- No constructive purpose in the body
- Extremely toxic even in low concentrations, accumulates in organisms and ecosystems
- Chemical properties similar to zinc
- Sources: earth crust, fossil fuels, plastic materials industry, electronic industry, tobacco fume
- Absorption after digestion or less by inhalation

Cadmium (Cd) Toxicity_Summary

- Cadmium is a byproduct of the mining and smelting of lead and zinc.
- It does not corrode and is primarily used for electroplating activities.
- Cadmium can gather and concentrate in plants.
- It has also contaminated irrigation waters and is found in fertilizers.
- Shellfish represent a major source of cadmium in the diet (100-1,000 [µg/kg]).
- Cadmium is also found in tobacco, each cigarette has approximately 1-2 µg of cadmium.
- Approximately 1 µg of cadmium may be found in one liter of breast milk.
- Very little cadmium is absorbed through the ingestion route, and it is not easily absorbed.
- Acute toxicity from cadmium exposure occurs primarily through ingestion of contaminated beverages or food. This could result in nausea, vomiting, and abdominal pain.
- Acute toxicity through inhalation may result in chemical pneumonia and fluid in the lung. Irritation of the nose and throat, coughing, dizziness, weakness, chills, fever, chest pains, and labored breathing are also symptoms.
- Chronic toxicity may result in chronic obstructive pulmonary disease, emphysema, and kidney disease. It may also result in adverse affects to the cardiovascular system and the skeleton.

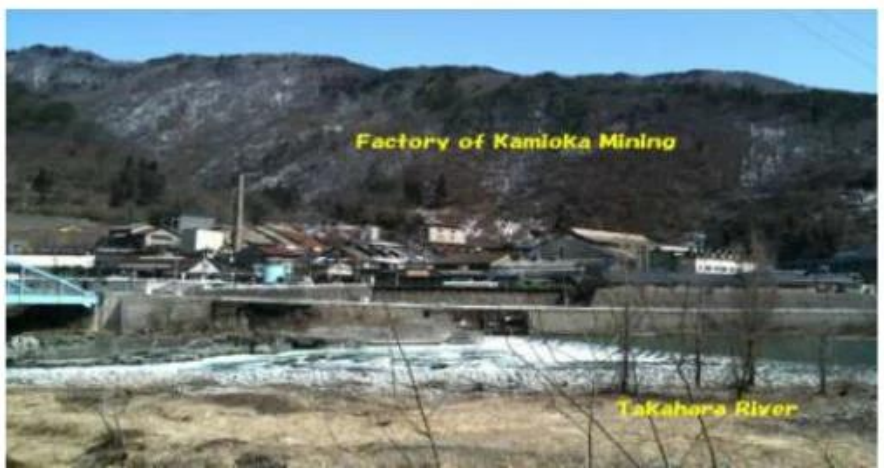
CADMIUM POISONING

- Caused by excessive exposure to cadmium
- No constructive purpose in the human body.
- Extremely toxic even in low concentrations, and will bioaccumulation in organisms and ecosystems
- The McDonalds Shrek Glasses are contaminated with Cadmium



Cadmium epidemics/case studies

- Japan (1950s) "***Itai-Itai***" is Japanese for "**ouch-ouch**"-refers to bone pain related to **calcium loss**
- Renal failure,Anemia, severe muscle pain
- River polluted with waste from factory, water used on rice fields for many years
- Rice accumulated high level of Cd Community was poor (and therefore malnourished with respect to calcium)



Sources of Cadmium Exposure

Airborne Cadmium

- Human exposure to Cd occurs both in the occupational and general environment
- Tobacco smoke is one of the largest single source of Cd exposure in humans

Cadmium in Food

- Cd exposure in the general environment comes from food. Food consumption accounts for the largest source of Cd exposure by animals and humans, mainly because plants can bioaccumulate the metal. Leafy vegetables, grains, and cereals often contain particularly high amounts of Cd.

Effects of Cadmium on Humans

- Human exposure to Cd occurs from airborne emissions, ingestion of contaminated foods, and through smoking.
- The adverse heath effects caused by ingestion or inhalation of Cd include renal tubular dysfunction due to high urinary Cd excretion, high blood pressure, lung damage and lung cancer. Cd and Cd compounds are “known to be human carcinogens”.

Clinical signs

- Acute exposure:
  - Cadmium fumes may cause flu like symptoms including chills, fever, and muscle ache
  - More severe exposures can cause tracheo-bronchitis, pneumonitis, and pulmonary oedema. Symptoms of inflammation may start hours after the exposure and include cough, dryness and irritation of the nose and throat, headache, dizziness, weakness, fever, chills, and chest pain.
  - Ingestion of any significant amount of cadmium causes immediate poisoning and damage to the liver and the kidneys. Also CNS disturbances occur and changes in blood count

Mercury (Hg) Toxicity

Mercury

- Only metal which is liquid at room temperature
- Vapours are much more dangerous
- Both organic and inorganic compounds, all toxic
- Sources: earth’s crust and industry, accumulation in water environment
- Water micro-organisms transform pure mercury into methylmercury – most common source of poisonings – incorporation into food chain (fish)

ANTHROPOGENIC
SOURCES OF MERCURY

- Artisanal and small-scale gold mining (ASGM)
- Biomass burning (domestic, industrial and power-plant energy production)
- Cement production (raw materials and fuel, excluding coal)
- Cremation emissions
- Chlor-alkali production (mercury process)
- Large-scale gold production
- Mercury production
- Oil refining

- Pig iron and steel production (primary)
- Secondary steel production

- Mercury-containing waste
- Waste incineration (controlled burning, including burning waste for energy, burning medical waste, burning corpses with amalgam)

FORMS OF MERCURY
AND THEIR CHARACTERISTICS

Mercury form	Sources into environment	Exposure pathways	Main excretion pathways	Health endpoints
Elemental (metallic) mercury Hg^0	Natural: volcanoes, rock weathering Anthropogenic: mining of mercury, gold and other metal; fuel combustion; industrial processes; waste incineration; spills (for example, broken products)	Inhalation	Urine Faeces	Central and peripheral nervous systems, kidneys, lungs
Inorganic mercury Hg^{2+}	Natural: can occur naturally in the environment Anthropogenic: some industrial processes and production of other chemicals; cosmetics (skin-lightening creams); ritual and folk medicine	Ingestion Dermal	Urine	Central nervous system, kidneys, gastrointestinal tract, immune system, skin (acrodynia in children)
Organic mercury **MeHg** (methylmercury)	Environmental conversion	Ingestion Parenteral Transplacental	Faeces	Central nervous system, cardiovascular system

MERCURY IN WATERS

- In waters (marine and fresh), mercury can be transformed into methylmercury, which is more toxic for humans.
- Metallic mercury is heavy and not easily transported through watersheds, but it becomes more mobile following its association with small particles or the formation of organic mercury.
- Direct spills into aquatic environments can cause significant local contamination that can lead to elevated population exposures, for example, through the consumption of fish.
- Releases into waters are of a greater local concern than contamination solely due to atmospheric mercury emissions.

Mercury can be transformed into more toxic methylmercury in waters

Mercury (Hg) Poisoning

- Mercury is the third most toxic substance in the environment.
- Approximately half of all mercury is used to produce vapor lamps, fluorescent tubes, thermometers, and electrical products.
- It exists in a number of forms, which may affect different parts of the body. Organic mercury primarily affects the brain.
- Methyl mercury is the most toxicological form of the element and, by its accumulation in the central nervous system (CNS), may result in neurotoxic effects in adults and toxicity in the fetuses of mothers exposed to methyl mercury during pregnancy.
- Metallic mercury is slowly absorbed by the gastrointestinal system and is not as toxic as methyl mercury.
- Inorganic mercury (mercury salts) primarily affects the kidneys. Exposure to mercuric salts may lead to abdominal cramps and bloody diarrhea.
- Chronic mercury exposure may lead to tremor and personality disturbances and permanent CNS damage may result from methyl mercury exposure.
- Acute mercury exposure can be assessed by measuring the level of mercury in blood.
- Chronic exposure is best assessed by measuring the amount of mercury in urine.

Biotransformation of Mercury

- Conversion of environmental mercury of one form to other occurs in sediment, water, and air and is catalysed by various biological systems.
- The elemental mercury deposited in lakes and seas are converted into methylmercury,CH_3Hg by micro-organisms through a process called methylation.

DENTAL AMALGAM (I)

- Mercury dental amalgams are **used globally.**
- The risk for patients and dental professionals is **evaluated as low.**
- Amalgam is a **source of mercury release** into the environment.
- The European Commission found **insufficient evidence of negative health effects** to prevent the use of dental amalgam in the general population

There is a political commitment to phase down use of dental amalgams (the Minamata Convention on mercury)

HEALTH EFFECTS OF EXPOSURE TO METHYLMERCURY:

MINAMATA DISEASE (II)

Symptoms include:

- ataxia
- numbness in the hands and feet
- general muscle weakness
- narrowing in the field of vision
- impaired hearing and speech.

Extreme cases lead to:

- insanity
- paralysis
- coma
- death.

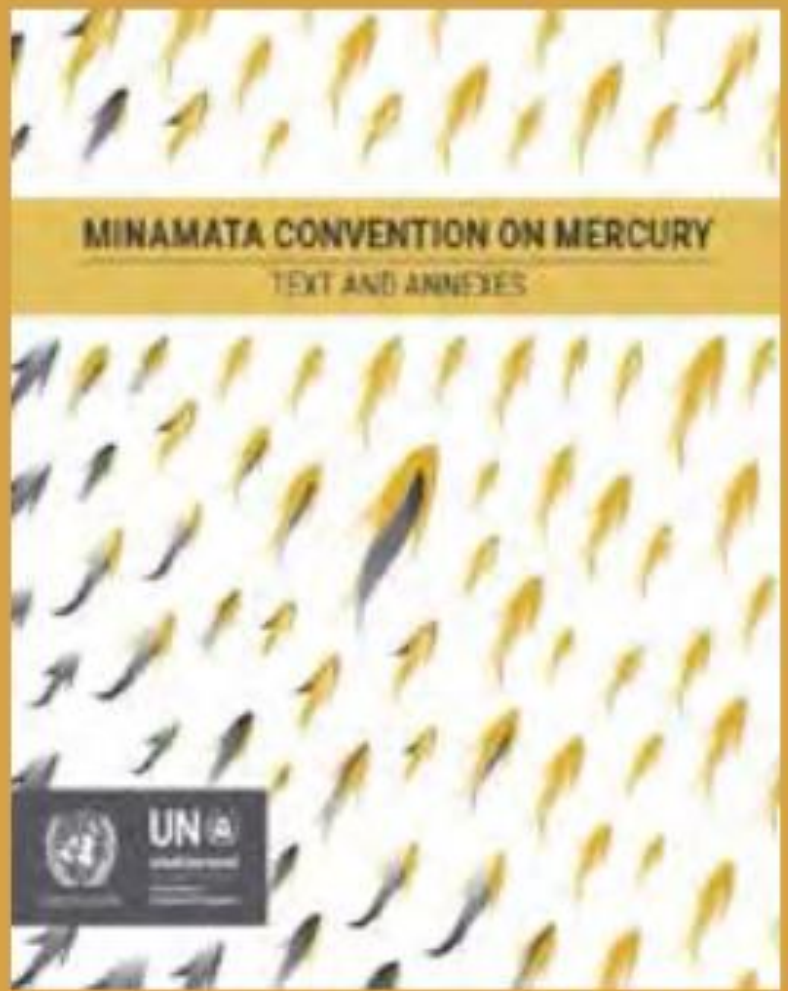
The symptoms of Minamata disease range from motor impairments such as difficulty walking and speaking to sensory constraints in seeing and hearing. In very extreme cases, insanity, paralysis, coma and death can occur.

MAIN CONCERN RELATED TO **DENTAL AMALGAM**

- Dental amalgam is the primary source of exposure to inorganic mercury for most people with mercury-containing dental fillings.
- Workers in dental offices (dentists, dental hygienists) can be exposed to mercury through the preparation and use of mercury fillings. An elevated body burden of mercury in dentists and dental hygienists has been observed.
- Dental amalgam is a source of mercury into the environment (soil, air and water).

THE MINAMATA CONVENTION ON MERCURY

- The Minamata Convention is a global treaty to protect human health and the environment from the adverse effects of mercury.
- The text was adopted and opened for signature at a Diplomatic Conference (Conference of Plenipotentiaries), held in Kumamoto, Japan, from 10 to 11 October 2013.
- The Convention entered into force on 16 August 2017, the 90th day after the date of deposit of the 50th instrument of ratification, acceptance, approval or accession.



Nickel

- Nickel (Ni) is a white metal, with a faint tinge of yellow.
- Although it is the fifth most abundant element in the biosphere, Ni was only discovered through the mining of other metals.
- It is quite mobile through the air, water, and soil.

Health Effect of Nickel

- The most common type of Ni exposure for the public is through direct skin contact with Ni plating.
- $Ni(CO)_4$ gas, the most toxic of the Ni compounds, was the first to cause deaths in refineries.
- Nickel carbonyl is a volatile liquid with extraordinary toxicity, particularly to the lungs. It is an intermediate produced in refining nickel ore.

ARSENIC

Occurrence and properties of Arsenic

- Arsenic (As) is a ubiquitous element present in various compounds.
- Some micro-organism can oxidise or reduce As; these include strains of *Bacillus* and *pseudomonas. Penicillin brevicaule, called arsenic fungi,* can produce toxic and highly volatile arsenes.
- Arsenic is present in urban air at levls of about 0.02 µg/m3, and in soil at levels from 0.2 to 40µg/l.
- In Bangladesh the drinking water from shallow tube wells in many districts contain arsenic more than the allowable limit of 500µg/l.
- For the general population, the main exposure to inorganic As is through ingestion. Fish contains relatively high concentrations of organic arsenic.

Toxicity of Arsenic to Animals and Humans

- The toxicity of As to mammals is related to its absorption and retention in the body, and varies with chemical form.
- The toxicity of arsenicals is decreasing order is: inorganic arsenites> organic trivalent compound (arsenoxides) > inorganic arsenates > arsonium compounds > elemental arsenic.

Toxicity of Arsenic to Animals and Humans

- Toxicity appears to be related to the solubility of the arsenical in water. The low toxicity of elemental arsenic is attributed to its near insolubility in water and body fluids.
- Trivalent arsenic is much more toxic than pentavalent arsenic
- Arsenate is well absorbed and rapidly eliminated, mainly by urine.
- Inorganic As compounds are" known to be human carcinogens”, based on sufficient evidence of carcinogenicity in humans.
- An association between environmental exposure to As through drinking water and skin cancer has been observed and confirmed.