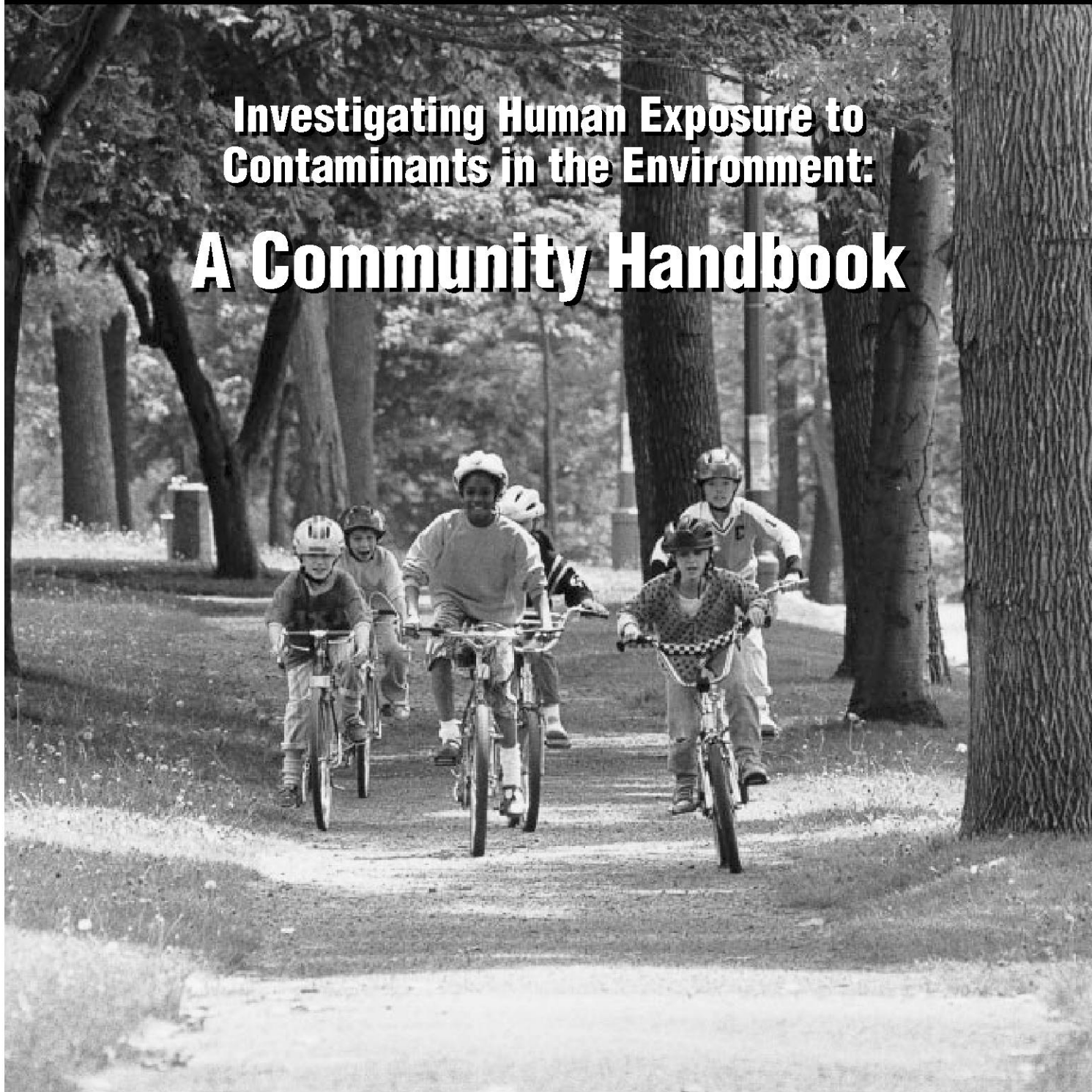




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Investigating Human Exposure to Contaminants in the Environment: A Community Handbook



This document has been divided into a series of files for easier downloading from our web site.

Part 3 of 4

Canada

Investigating Human Exposure to
Contaminants in the Environment:

A Community Handbook

PART B: BACKGROUND INFORMATION

This part of the handbook contains basic information about contaminants in the environment and some of their potential health effects. Specifically, it describes:

- the major types of contaminants in the environment;
- how people can be exposed to them;
- the scientific approaches that are commonly used to investigate the relationships between exposure and health effects; and
- some of the health effects that have been associated with exposure to some contaminants.



1. MAJOR TYPES OF CONTAMINANTS

Contaminants in the environment can be categorized into four major types. These are:

- chemicals, including organic and inorganic ones;
- microorganisms, including bacteria, viruses, fungi and protozoa;
- radiation, including ionizing and non-ionizing types; and
- physical hazards, especially dust (also called particulate matter).

These are described in more detail below.

1.1 Chemicals

There are two basic types of chemicals in the environment; organic and inorganic. Organic chemicals are composed of carbon, usually in combination with other elements such as hydrogen, oxygen or chlorine. Inorganic chemicals include metallic elements such as lead and cadmium, as well as non-metallic ones, such as silica and nitrogen. The building blocks for all chemicals come from the earth. All life depends on chemicals. However, through industrial activities, living organisms, including humans, have come to be exposed to a large number of chemicals which have not been a part of their environment in the past. These “new” chemicals were either substances that were buried in the

ground or chemicals created by industrial production, either deliberately or as a by-product.

Since the Second World War, there has been an enormous increase in the amount and number of chemicals manufactured, used and disposed. While there are beneficial uses for most chemicals, by-products from manufacturing and wastes can cause problems in the environment, as can chemicals that are not treated or handled properly.

Manufactured chemicals are a part of all aspects of modern life. Some of their uses are:

- as pesticides and fertilizers;
- to preserve or colour food and to enhance food flavours;
- in drugs and cosmetics;
- in many different manufacturing industries;
- in paints, varnishes and glues; and
- as disinfectants and cleaning agents.

In recent years, there has been a lot of concern about the levels of persistent toxic chemicals in the Great Lakes Basin. Concern has focused on some organochlorine chemicals. These are chemicals that contain carbon, hydrogen, sometimes oxygen, and chlorine. The persistent toxic organochlorine chemicals of concern can include:

- PCBs - now banned, used in electrical transformers, hydraulic equipment and lubricants;
- dioxins and furans - now restricted, by-products of pesticide manufacturing, waste incineration and pulp and paper manufacturing;
- DDT and the substances it breaks down into (its metabolites) - a pesticide, now banned, that affects wildlife health; and
- aldrin, dieldrin, chlordane, endrin, etc. - other pesticides whose use is now banned or restricted.

Although the manufacture and use of most of these chemicals has been greatly reduced, they remain a health concern because those that were used in the past have not broken down and remain in the environment.

Metals of concern can include:

- mercury - naturally occurring and from industrial sources;
- lead - from industrial sources and once used in leaded gasoline; and
- cadmium - used in a variety of industrial processes.

These metals cannot break down. The only way that their hazard can be reduced is when they move to a part of the environment where they are not available to living organisms.

1.2 Microorganisms

Microorganisms exist in air, water, soil, food and in and on our bodies. These microscopic organisms include bacteria, viruses, fungi and protozoa. While most of these organisms are harmless and many are beneficial, some do cause discomfort or illness in humans, ranging from allergies to infections. On rare occasions, they can cause death.

Bacteria are small, single-cell organisms that require nutrients to survive, produce waste products and reproduce by dividing in half. They often grow best when there is an abundance of nutrients and warm temperatures. Bacteria are frequently found in raw foods, such as meats, poultry, eggs and unpasteurized milk, and in water, humidifiers, air conditioners and air ventilation systems. Bacteria can cause many health problems, including infections, food poisoning and upset digestion. *Salmonella*, *Campylobacter*, *Escherichia coli* (*E. coli*), *Staphylococcus*, *Streptococcus*, *Clostridium* and *Shigella* are common types of bacteria that cause illness in people.

Viruses are microscopic organisms that consist of genetic material (DNA or RNA) wrapped in a protein coat. Unlike bacteria, they can only reproduce inside the living cells of another living organism. Often, the reproduction of a virus within a host cell will lead to the death of that cell. Many viruses cause diseases, including the common cold, measles, polio and viral hepatitis. Some viruses can contaminate drinking water if it is not properly protected and treated. For example, Norwalk viruses in contaminated drinking water can cause diarrhea in humans. Some viruses implicated in food-borne illness include Poliovirus, Hepatitis A virus, Coxsackie group A viruses and Echovirus.

Fungi are a group of widespread, unicellular and multicellular organisms that need warm, moist conditions in which to grow. Many of the products of fungi - spores, mycotoxins and volatile chemicals - can be harmful to human health. Spores can cause allergies, lung disease or diminish the response of the immune system in some people. Mycotoxins and the volatile compounds produced by fungi can cause lung and other respiratory problems. Certain varieties of mushrooms, which are a type of fungi, are toxic when eaten and can cause severe illness or death. Other fungi can grow in the lungs (*Aspergillus* spp. in granary and aviary workers) or on the skin (the most common in humans is athlete's foot).

Protozoa are one-celled parasitic organisms, mostly free-living in water or soil. The most common types of parasites to infect drinking water

are *Giardia lamblia* and *Cryptosporidium spp.* *Giardia lamblia* causes giardiasis, also known as “beaver fever,” and is characterized by diarrhea, loss of appetite, dehydration, cramps and in some cases, vomiting. *Giardia* may enter the water supply from human or animal waste. *Cryptosporidium* and *Entamoeba histolytica*, which is another important protozoan parasite known to be transmitted by food, also cause enteritis or dysentery.



1.3 Radiation

Radiation is a form of energy that can be classified as either ionizing (high energy) or non-ionizing (low energy). Ionizing radiation is normally referred to as radioactivity whereas non-ionizing radiations are associated with optical radiation, such as ultraviolet and visible light and electromagnetic fields, such as microwave and radio frequency. In general, non-ionizing radiation is less harmful than ionizing radiation.

Ionizing radiation is found everywhere in the environment as a result of cosmic radiation produced in outer space and radioactive nuclides in the earth. Most nuclides in nature are stable, maintaining their form and composition indefinitely, but many others are unstable. Unstable nuclides (*radionuclides*) return to stability by spontaneous disintegration (*radioactive decay*), thus forming different nuclides by releasing energy (i.e., radiation) in the form of an alpha particle or a beta particle.

The new nuclide formed may still be radioactive and emit further alpha or beta radiation, or it may be in an excited state and return to stability by emitting gamma radiation. The radiation released by the decay of radionuclides, as well as the cosmic radiation from outer space, is referred to as *ionizing radiation* because it is capable of producing electrical charge in the matter through which it passes. If ionization occurs in living tissue, it can lead to biological damage.

Radionuclides are found in the environment as naturally occurring elements in the earth's crust and as products or by-products of nuclear technologies. The biological consequences of ionizing radiation exposure are the same regardless of the origin of the radionuclide. By far, the greatest contribution to the average public radiation exposure is from naturally occurring radionuclides.

Ultraviolet radiation is part of the sunlight spectrum and is invisible to the naked eye. It can be divided into three regions according to wavelength. UVC radiation (wavelength 200 - 280 nanometres - nm) has the highest energy and is potentially the most destructive ultraviolet radiation. However, it is all filtered by the ozone layer in the upper atmosphere. UVB radiation (wavelength 280 - 315 nm) is thought to be responsible for most of the adverse effects of sun exposure and is most affected by the concentration of the ozone layer. UVA radiation (wavelength 315 - 400 nm) has the least energy and is not absorbed by the ozone layer so that it easily reaches the earth's surface. UVA can enhance the effects of UVB.

Electromagnetic fields (EMFs) are associated with all electrical power and consist of two kinds of fields, electric and magnetic fields. Electric fields result from the strength (voltage) of the charge. A high-voltage power line usually produces stronger electric fields than a low-voltage power line. An electric field can exist even if a current is not flowing in an object, as long as it is plugged in. For example, an electric blanket that is plugged in, but not operating, may still produce an electric field. Magnetic fields result from the motion (current) of the charge. Since magnetic fields are created only when current is flowing, appliances that are plugged in, but turned off, do not produce magnetic fields.

1.4 Particulate Matter (Dust)

Particulate matter refers to a wide variety of minute particles and fibres carried along in the air. While there have always been particles in the air, in the form of dust, pollen, ash and smoke, in more recent times industrial activity has added to the measured levels of particulate matter. These particles vary in size, shape and chemical composition. From the perspective of human health, size may be the most significant of the three, because the smaller the particle, the greater the chance for penetration into the lungs. Particle size is measured in microns (or micrometres), one of which equals one millionth of a metre. Particles larger than about 10 microns are large enough to settle to a nearby surface after being emitted from a source. Anything smaller can remain suspended in the air for long periods and they constitute what is called "suspended particulate matter."

2. SOURCES, MOVEMENT AND PERSISTENCE

2.1 Chemicals

Sources of Chemicals

Chemicals can enter the environment in many different ways. “Point” sources of chemicals can include:

- industrial discharges;
- waste incinerators;
- sewage treatment plants;
- waste disposal sites.

“Non-point” sources of chemicals can include:

- runoff from land that has been treated with pesticides, fertilizers or herbicides;
- car exhausts;
- contaminated sediments;
- stormwater runoff from built-up areas; and
- atmospheric deposition, which is the transfer of contaminants out of the atmosphere onto the land and into the water. Often these contaminants have travelled long distances and reacted with other chemicals in the air. An example is acid rain.

For example, in Ontario there are about 300 industrial sites that discharge directly into rivers and lakes, and there are another 12,000 that dump their wastes into municipal sewage systems that cannot adequately treat toxic chemicals. Non-point sources are also important. For example, more than 90% of the PCBs, DDT and lead in Lake Superior come from atmospheric deposition.

There are natural sources of contaminants as well as human sources. For example, cadmium and mercury can be released into the environment from soil and rock by erosion due to wind and rain. Natural events, such as forest fires, floods and volcanoes, can also release contaminants into the environment.

Movement of Chemicals in the Environment

Once released, toxic chemicals can be found in different parts of the environment, including air, water, soil and living organisms. They are often “mobile” and can move from one part of the environment to another. For example, a chemical in water may evaporate into the air and then be condensed into rain and be deposited onto soil and vegetation. The contaminated plants could then be eaten by different species of animals.

As well as moving through different parts of the environment, chemicals can be carried long distances by wind and water currents and by organisms that have absorbed them. For example, the tissues of wildlife in the Canadian arctic contain traces of PCBs and pesticides that come from the industrial countries of Europe, Asia and America. Although the concentrations found in the arctic are lower than those in such areas as the Great Lakes Basin, it is clear that there is no way of avoiding exposure completely.

Persistence in the Environment

Many chemicals, such as PCBs, are quite stable in the environment and this allows them to persist for long periods without breaking down.

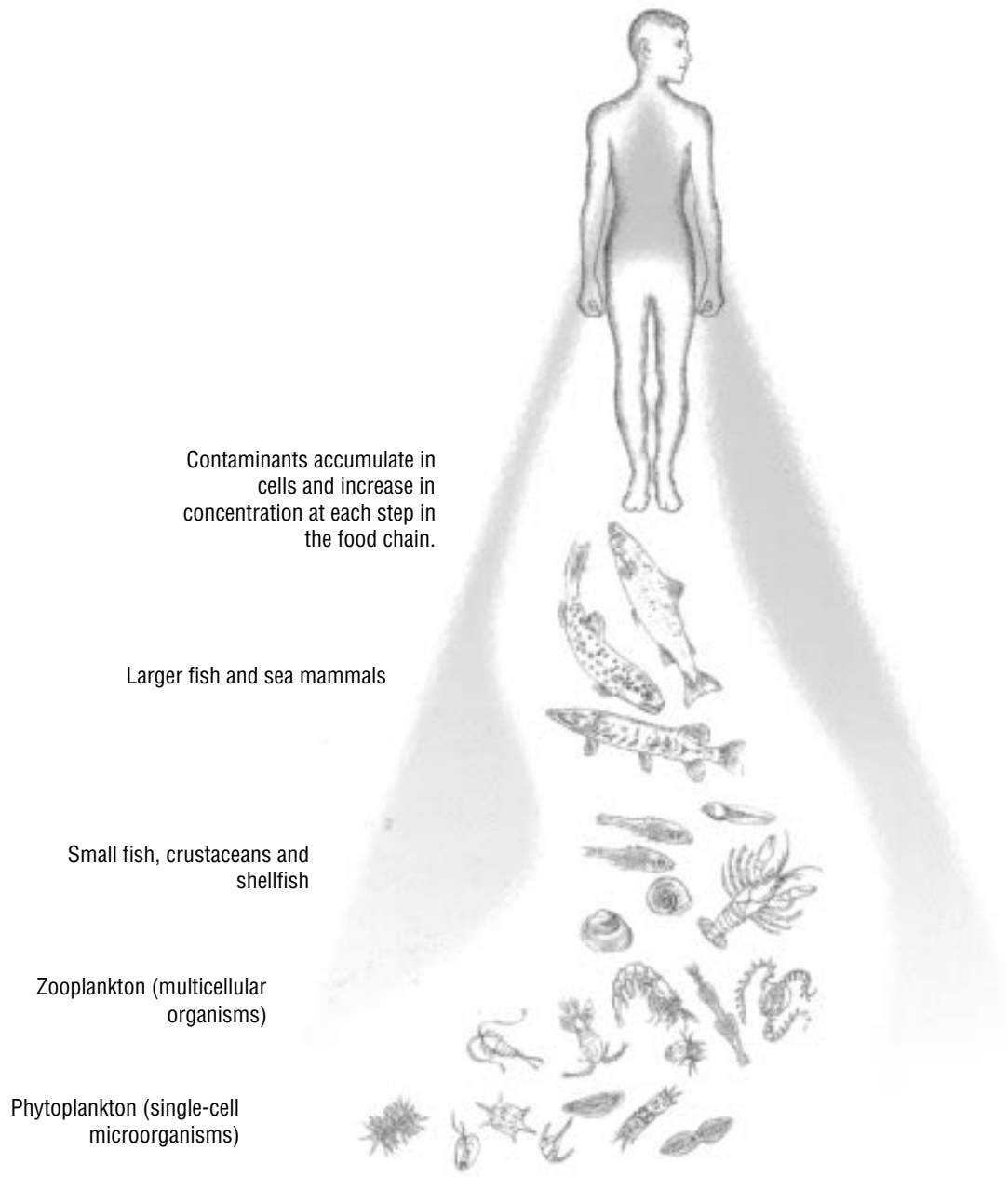
When absorbed or eaten by living organisms, some chemicals gradually accumulate in their tissues. Organochlorines, for example, tend to accumulate in fat because they can be dissolved in fat. Through this process - called bioaccumulation - contaminant levels in living organisms can build up to harmful levels. Organisms can also pass on their accumulated load of contaminants onto other animals that feed on them. This is known as biomagnification. As a result, concentrations of some contaminants get increasingly higher as one goes up the food chain. Biomagnification is shown in FIGURE 3.



Thomas Rehn

FIGURE 3:

Biomagnification of Contaminants in the Food Chain



Biomagnification

A persistent contaminant present at very low concentrations in water can bioaccumulate in plankton or small fish. When a larger organism, such as a fish, eats many of these small creatures over its lifetime, it in turn bioaccumulates the contaminants already bioaccumulated in its food, and the contaminant becomes even more concentrated. At each level of the food chain, the concentration increases or “biomagnifies.” The accumulated level of persistent trace chemicals in fish or other animals high in the food chain can pose a significant risk to health.

2.2 Microorganisms

Sources of Microorganisms

Those microorganisms in the environment which affect human health have several important sources. These include contaminated or poorly prepared food, untreated or partially treated waste water and other rotting or decaying biological wastes such as animal and human wastes and carcasses.

Movement of Microorganisms in the Environment

Bacteria, protozoa, viruses and fungi can be carried quite long distances by other organisms or by water or wind currents. For example, migrating birds can carry bacteria and viruses many thousands of kilometres in or on their bodies.

Persistence in the Environment

Unlike many chemicals, microorganisms are often not very persistent in the environment, and will die out unless they can reproduce. However, some microorganisms can form “spores” which are extremely resistant to environmental change and are very persistent. Mycotoxins produced by moulds are persistent substances and may remain in a product even after the moulds that produced them are killed. The cysts formed by the protozoans *Giardia lamblia*, *Entamoeba histolytica* and *Cryptosporidium* spp. may persist for long periods in natural waters.

2.3 Radiation

Sources of Radiation

The major sources of ionizing radiation are natural. We are all exposed to ionizing radiation from space (i.e., cosmic), as well as from the earth itself (e.g., uranium, radium, potassium-40). Atmospheric nuclear weapons tests have contributed most of the artificial radioactivity released to the environment to date. Radiation from all aspects of nuclear power including uranium mining, processing and final disposal of the fuel, though very low, is becoming increasingly important. The products of nuclear energy are also used in medicine (e.g., radiotherapy of cancers) and in consumer products (e.g., smoke detectors). In addition to benefiting society, these applications release radioactivity into the environment, thus adding to the existing levels of radiation from natural sources.

We are also exposed to different kinds of non-ionizing radiation from many sources. Examples are:

- ultra-violet (UV) radiation from the sun, from UV lamps in tanning salons and spas, from germicidal lamps, from ultraviolet lasers, from certain kinds of industrial processes and UV radiation given off by welding arcs; and
- electromagnetic fields (EMFs) through use of electrical appliances such as hair dryers, can openers, vacuum cleaners, electric shavers, electric blankets, computers, other electrical devices (e.g., lighting) and proximity to electric power lines.

Movement of Radiation in the Environment

Radiation is unique among the contaminants discussed in this handbook in that it is capable of penetrating or travelling through matter. Just as non-ionizing radiation such as light, heat or microwaves are transmitted through the air, so too is ionizing radiation. However, because ionizing radiation is generally more energetic than the other forms of radiation, it can also penetrate matter. The degree to which ionizing radiation can penetrate matter depends on both the material and the type of radiation. For example, alpha radiation can be stopped by a piece of paper or the outer layer of the skin on the body, whereas several inches of lead are required to stop gamma radiation.

Radionuclides, or radioactive material, can be released into the environment as a gas, liquid or particle. Material released into the atmosphere is transported and dispersed by wind currents and may be removed by rain or settle as dust. The deposited radionuclides may also accumulate in soil or be leached into groundwater, which may lead to the contamination of well and surface water. Radionuclides may also enter and move through the food chain. Some of these processes result in progressive dilution, others lead to concentration in the environment.

Persistence in the Environment

Radiation can be generated continuously by natural and artificial sources. In some cases, the half-life (the time required for a material to lose one half of its radiation) of some radionuclides is very long. However, the persistence of a radionuclide in an environmental medium, such as water, is often much less than its radioactive half-life due to environmental and biological processes which lead to their progressive dilution.

The sun continuously emits ultraviolet radiation, much of which is absorbed by the Earth's ozone layer, which is situated between 15 and 35 kilometres above ground level. Electromagnetic fields are being generated continuously as long as electricity is being transmitted through a line. They are strongest close to the source and rapidly decrease in strength as one moves away from the source.

2.4 Particulate Matter (Dust)

Sources of Particulate Matter

The principal sources of particulate matter released into the air, as a result of human activity, are:

- industrial processes;
- fuel combustion;
- transportation; and
- solid wastes.

Industrial operations, such as power stations, solid waste incinerators, smelters, mills, refineries and factories, can release very fine particles containing a wide range of compounds into the air. Particulates can contain such compounds as acid mist, arsenic, asbestos, beryllium, cadmium, lime, mercury and silica.

The principal sources of particulate matter released into the air, from naturally occurring events, are:

- volcanoes;
- wind erosion;
- forest fires; and
- pollens from plants.

Movement of Particulate Matter

Particulate matter is dispersed in the air and can be carried long distances by the wind. Particles can be deposited on soil and plants where some contaminants can be taken up by the plants. They can be deposited on water where the contaminants can enter the food chain. For example, even though DDT has been banned in North America for several years, it is still used elsewhere in the hemisphere, and may be entering the Great Lakes through long-range atmospheric transportation and deposition.

Persistence in the Environment

Particulate matter eventually settles out of the air and is deposited on a surface. In itself, a particle may not be persistent, but contaminants adsorbed on the particle may be persistent. Therefore, the origin and composition of the particle will determine its persistence.

3. EXPOSURE

Exposure is any contact between a substance and an individual who has touched, breathed dust or fumes, or swallowed material or liquid from a contaminated source. Contaminants must follow pathways from the point of release into the environment to the point of contact with humans in order for exposure to take place.

Exposure Pathways

An **exposure pathway** describes how a contaminant travels through the environment from its source to humans or other living organisms. An exposure pathway consists of the five following elements:

- source of contamination;
- environmental media;
- point of exposure;
- receptor person or population; and
- route of exposure.

Source of Contamination

Sources of environmental contaminants are numerous. They include exhaust from vehicles, emissions from smokestacks, wastewater released by factories and mills, waste disposal sites, closed factories and storage sites, consumer products (e.g., paints, household cleaning products) and numerous other sources, both indoors and outdoors. A number of substances are also released into the environment from natural sources.

Environmental Media

Once released from its source, a contaminant will travel through environmental media to points where human exposure can occur. For human exposure, the major environmental media include water, air, food and soil.

Water

- drinking water, whether from a surface water source (e.g., a lake or river) or a groundwater source (e.g., a municipal or private well);
- recreational use, such as swimming, boating, windsurfing; and
- industrial or agricultural use.

Water is an important exposure pathway for chemicals and microorganisms.

Air

- indoor air, including air quality at home, work and school; and
- outdoor air.

Both indoor and outdoor air are important environmental media for exposure to a variety of contaminants, including microorganisms. In many instances, some contaminants may be more concentrated indoors than outdoors.

Food

- foods grown with contaminated water or grown in areas where the soil is contaminated. This would include food grown for personal consumption;
- contaminated fish and wildlife;
- foods containing pesticide residues;
- foods packaged in containers which contaminate the contents (e.g., lead-soldered cans used in some imported goods); and
- mother's milk (for nursing infants), where the mother has been exposed to chemicals which accumulate in fat in tissues (breast milk has a high fat content).

Food can be an important medium for exposure to many environmental contaminants, including microorganisms.

Soil

- bare ground (exposure of workers to soil, swallowing soil or skin contact with soil);
- contaminated soil blown as dust in the air and particles deposited on other surfaces (such as food);
- soil below the surface (workers involved in digging and excavating); and
- contaminated sediments at the bottom of lakes, rivers and ponds.

Soil is an important exposure pathway for small children who often put contaminated objects in their mouths. Contaminants can settle and accumulate in sediments where people can become exposed while playing and swimming. Exposure to chemicals and microorganisms can occur through soil and sediments.

Point of Exposure

The point of exposure is the location where contact with a contaminant occurs. For example, people can be exposed to contaminants in the home, a business, a playground, a lake, river or other body of water.

Receptor Person or Population

The receptor person or population is the one exposed to the contaminant at the point of exposure. For example, swimmers may be exposed while bathing in a contaminated river; anglers may be exposed by consuming contaminated sport-caught fish.



Thomas Rahn

Routes of Exposure

People can be exposed to contaminants in water, air, food and soil in several different ways. The exposure route is the final link in the chain from the contaminant source through the exposure pathway to human beings. The exposure route describes how the contaminant enters the body. The three main routes are:

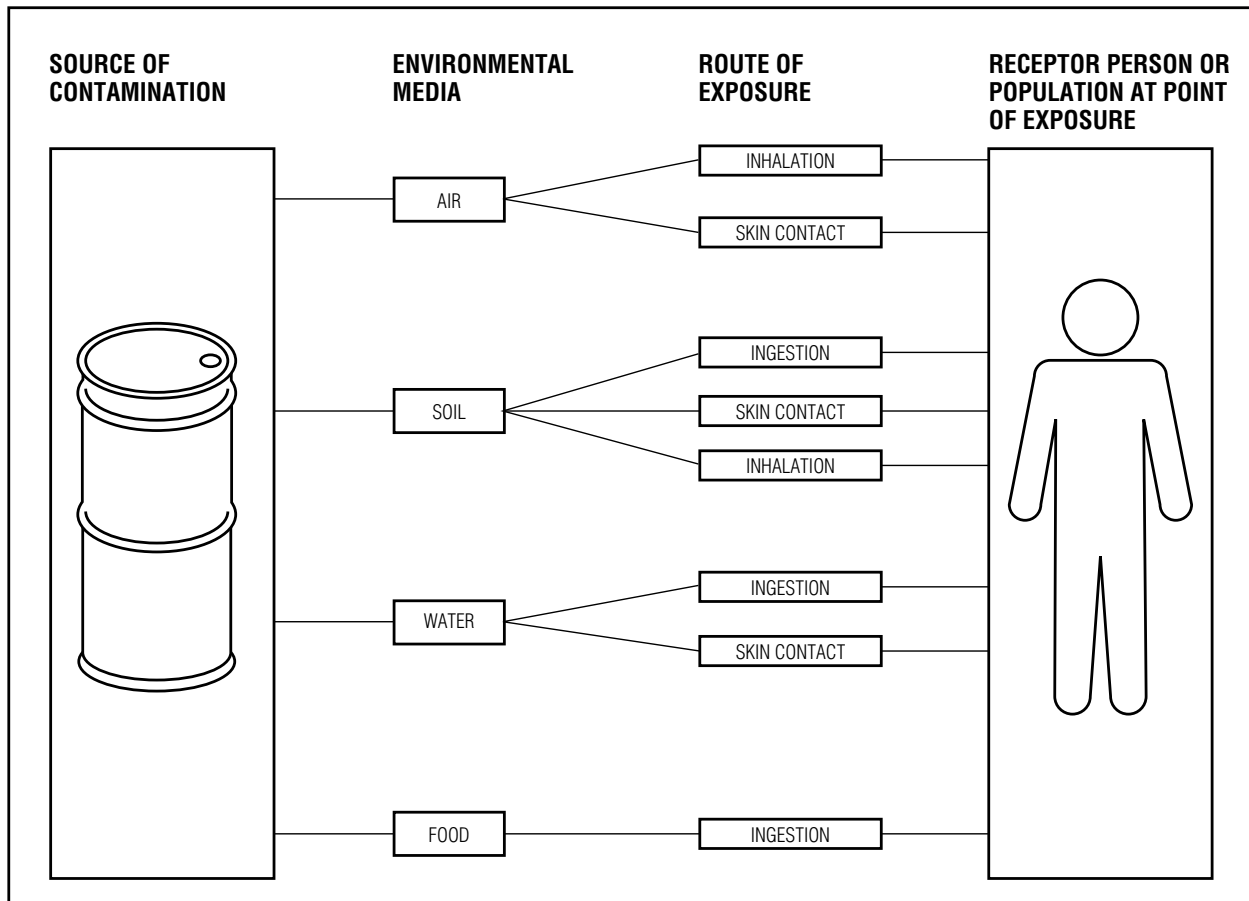
- *Ingestion* - Swallowing food, water, small amounts of soil and accidental ingestion of objects or other liquids containing the contaminant. The mouth, throat, stomach and intestines can absorb ingested materials rapidly and at different rates, depending on the material.
- *Inhalation* - Breathing in a contaminant such as a gas, vapour or airborne particles. This includes small amounts of soil and dust that can be inhaled into the lungs. The lungs often absorb gases and vapours quickly and efficiently.
- *Skin Contact* - Some contaminants in water, soil or air can be absorbed through the skin. The skin is usually an efficient barrier to most contaminants. In the case of radioactivity, exposure can occur through penetration of the skin by radioactivity in the atmosphere or released from radionuclides that are in the air or on the ground. The radionuclide does not actually need to be in contact with the skin.

The major pathways of human exposure to environmental contaminants are shown in FIGURE 4. Food ingestion is the major exposure pathway for many persistent chemicals such as DDT, PCBs and some metals such as mercury, with air, water and soil products contributing only small amounts to the total human exposure. Based strictly on environmental contaminants, ingestion of untreated drinking water is the most important exposure pathway for microorganisms. However, due to improper storage and handling, food is an important pathway for exposure to microorganisms causing illness.

For exposure to radiation, there does not have to be physical contact with a radioactive substance, because radiation can travel through matter. Exposure can occur through penetration of the skin by radioactivity in the atmosphere or released from radionuclides that are in the air or the ground.

FIGURE 4:

Major Pathways of Human Exposure to Environmental Contaminants



Exposure to ionizing radiation from radionuclides in environmental media may also occur by direct external irradiation.

It is important to remember that exposure to contaminants does not always result in their absorption into the body. The lungs, digestive system and especially the skin can present very effective barriers to many substances. For instance, inhaled substances can be swept out of the lungs and expelled. Absorption of chemicals may vary depending on the route of exposure. For example, a substance that is readily absorbed through the respiratory tract may not be as readily absorbed through the gastrointestinal tract or skin, and vice versa. The absorption of a chemical will also be affected by its chemical and physical properties. In general, the more a chemical is soluble in fat, the more easily it will be absorbed into the body.

Substances that are absorbed can be transported throughout the body by the bloodstream. Once in the body, these substances can be either broken down into other substances, stored in the body or excreted. In many cases, the liver breaks the substance down, so that it can be excreted as waste material through the bile, urine or feces. When the intake exceeds excretion, build-up of these substances in the body can occur.

Many contaminants, such as microorganisms, are not absorbed into the bloodstream but can cause adverse health effects where they contact the body. For example, drinking water contaminated with microorganisms can cause diarrhea, nausea and cramps; detergents and dust can cause dermatitis where they contact the skin. Radionuclides do not need to be in contact with the body to cause their effects since the radiation emitted can travel through matter to result in an exposure.

Estimated Daily Intake for Exposure to Chemical Contaminants

People are exposed to low levels of chemical contamination in the air they breathe, in the food they eat and in the water they drink. In detailed exposure assessments, this exposure is quantified and called the Estimated Daily Intake (EDI). A separate EDI is calculated for each contaminant of concern. The EDI is the sum of exposures from all known or suspected exposure pathways for an average person. Numerous other factors must be considered, making these types of estimates complex - especially because assumptions are used that require a great deal of professional judgement. The information in the box below gives a basic overview of the type of calculations involved.

CALCULATING THE ESTIMATED DAILY INTAKE

Estimated Daily Intake (EDI) of a chemical can be calculated by adding up all the exposures from various pathways. The EDI of one contaminant can be represented by the following equation:

$$EDI = ED_a + ED_w + ED_s + ED_f + ED_{ws} + ED_{ss}$$

Each ED (Estimated Dose) is the amount of the contaminant taken in through a different combination of exposure pathway and exposure route. Specifically:

ED_a is the amount inhaled through the air,

ED_w is the amount taken in by drinking water,

ED_s is the amount taken in by eating soil,

ED_f is the amount taken in with food,

ED_{ws} is the amount absorbed through skin contact with water,

ED_{ss} is the amount absorbed through skin contact with the soil.

To calculate the estimated amount of the contaminant taken in through these combinations of exposure pathway and route requires a different equation for each combination. However, all the equations are somewhat similar. The general equation for each estimated dose is:

$$ED = \frac{C \times CR \times EF}{BW}$$

where,

ED = Estimated Dose is generally the number of milligrams of the contaminant that enter the body for each kilogram of body weight (mg / kg / day).

C = Concentration of the contaminant in the exposure pathway being considered.

CR = Contact Rate: The amount of water, food, air, etc., which is swallowed, inhaled or comes into contact with the skin in one day. Typical units for food eaten are grams per day (g / day).

EF = Exposure Factor: This number indicates how often the individual is exposed during a year and the number of years that this pattern has been repeating itself. This factor is needed especially when exposure does not occur daily, such as exposures at work (only five days a week) or exposures related to seasonal activities (swimming in the summer in contaminated water).

BW = Body Weight: The average body weight of an individual in kilograms (kg).

Estimated Dose for Exposure to Ionizing Radiation

Exposure to ionizing radiation is treated somewhat differently than exposure to chemical contaminants. Because the effects of radiation exposure are well understood, radiation experts express exposure in a unit called the sievert (*Sv*), which is a measure of the total harm that may be caused in a human exposed to ionizing radiation from any radiation source. Unlike chemical contaminants, it is the total exposure from all sources that is controlled, rather than the exposure from individual radionuclides. This is done since it is the total exposure that determines the risk of a health effect occurring.

Furthermore, the dose rate is expressed on a yearly basis, rather than a daily basis. This dose is calculated to include all direct **external**

irradiation received in the year, and the dose that will continue to be received **internally** from all radionuclides ingested or inhaled in the current year. The period over which this extended dose, due to internal radiation, is calculated has been standardised to 50 years for exposures in adults (18 years of age and older) and 70 years for exposures in children (under 18 years of age). Unlike the approach taken for chemical contaminants, this approach accounts for the radiation dose that will continue to be received from radionuclides that are retained in the body.

CALCULATING THE ESTIMATED DOSE FOR EXPOSURE TO IONIZING RADIATION

The Estimated Dose (ED) for exposure to ionizing radiation can be calculated by adding up all exposures received in a year from various pathways and can be represented by the following equation:

$$\begin{aligned} \text{ED} &= \text{ED}_{\text{external}} + \text{ED}_{\text{internal}} \\ &= \text{ED}_{\text{external}} + \text{ED}_a + \text{ED}_w + \text{ED}_s + \text{ED}_f \end{aligned}$$

$\text{ED}_{\text{external}}$ is the direct external irradiation received in a year. $\text{ED}_{\text{internal}}$ is the dose that will be received over the next 50 years (adults) or 70 years (children), from all radionuclides taken into the body in the current year, specifically:

ED_a is the estimated committed dose from radionuclides inhaled through the air,

ED_w is the estimated committed dose from radionuclides taken in by drinking water,

ED_s is the estimated committed dose from radionuclides taken in by eating soil,

ED_f is the estimated committed dose from radionuclides taken in by eating food.

To calculate the estimated committed dose from internal radionuclides, an equation of the following general form is used for each radionuclide for each pathway:

$$\text{ED}_x = C \times \text{CR} \times \text{CF} \times \text{EF} \times \text{DCF}$$

where,

- ED_x = Estimated Committed Dose over 50 years (adults) or 70 years (children) from a specific radionuclide taken into the body in the current year (Sv) for a specific pathway “x” (air inhalation, and water, soil or food ingestion).
- C = Concentration of the radionuclide in the exposure pathway being considered (e.g., Bq/L for radionuclides in water).
- CR = Contact Rate: The amount of water, food, air, etc., which is taken into the body in one day. Typical units for food are grams per day (g / day) and litres per day (L / day) for water.
- CF = Conversion Factor: The factor of 365 days is required to convert the Contact Rate (CR) from units/day to units/year.
- EF = Exposure Factor: This factor indicates how often the individual is exposed during a year. It is needed especially when exposure does not occur daily, such as at work (only five days a week) or when related to seasonal activities (swimming in the summer).
- DCF = Dose Conversion Factor: This factor converts the amount of radionuclide taken into the body via inhalation or ingestion, in becquerels, to the extended 50-year (adults) or 70-year (children) dose in sieverts. DCFs are usually expressed as Sv/Bq.

4. DOSE AND RESPONSE

The relationship between the amount of a contaminant that is given (the dose) and the health effect (the response) is referred to as the dose-response relationship. The relationship between the two is a key consideration in understanding how contaminants can cause adverse health effects. The main factors that influence any dose-response relationship are the amount of a contaminant received and its toxicity, the route of exposure (i.e., inhalation, ingestion, dermal contact), and the frequency and duration of exposure. Is it short term (e.g., minutes, hours) or long term (e.g., years)? Short-term exposures are often referred to as acute exposures, whereas long-term exposures are called chronic exposures.

The dose is the amount of a contaminant that a test animal is administered or an individual is exposed to. It is usually expressed as the weight of the substance (g, mg) per unit of body weight (e.g., mg/kg).

Because every individual reacts differently to a contaminant, the dose-response relationship cannot be used to predict exactly when a particular health effect will begin in a particular individual. Instead, researchers speak of the chance or risk that a health effect will occur as a result of exposure. As the dose increases, the chance or risk of health effects for any particular individual also increases.

Different kinds of hazardous substances can vary widely in their toxicity or ability to cause adverse health effects. Theoretically, there is no compound that cannot produce a toxic response if the amount is large enough. For example, ordinary table salt might be toxic to humans, but only if a very large amount was to be eaten all at once (i.e., around 300 g for an adult). If a very small dose causes an effect, a contaminant is said to be more toxic than a substance that causes health effects only when the dose is very large. Botulinum toxin, for example, is extremely dangerous even in minute amounts (the lethal dose is about 0.00001 mg/kg body weight), and causes several food poisoning deaths each year in Canada. Fortunately, only a few substances are very toxic and choices can be made as to what risk of health effects we want to tolerate.

The acute toxicity of different substances is often expressed as a LD_{50} (Lethal Dose - 50). This is the amount of a substance that will kill 50% of test animals, such as rats. It should be noted that LD_{50} 's are usually

calculated using a single oral (by mouth) dose to an experimental animal. In real life, exposure levels are always much lower and exposure can occur over days, weeks, months or even years (i.e., not a single dose) and may involve different or even multiple routes of exposure. As well, although there are many similarities between the way rat and human bodies function, they are not identical. Thus, it is always necessary to interpret the results for human health. Nevertheless, LD₅₀'s are a useful means of judging how acutely toxic one substance is relative to another, but are not very useful when trying to determine the long-term effects of exposure to lower non-lethal doses of chemicals. Other laboratory animal tests can be used to assess the effects of long-term exposure. Some examples of the LD₅₀'s of substances are shown in TABLE 1 below.

TABLE 1:

Examples of LD₅₀'s of Several Common Substances in Laboratory Rats

Substances	LD ₅₀ 's*	Toxicity
Table salt	3000	Low
Aspirin	1500	↓
Phenobarbital	660	
DDT	150	
Lead	100	
Tetraethyl lead	35	
Potassium cyanide	10	

* LD₅₀'s are usually expressed as the number of milligrams of the substance per kilogram of body weight.

For more information on measuring ionizing radiation, see **Appendix D.**

The concept of the LD₅₀ can also be applied to doses from ionizing radiation, although it is defined slightly differently than for chemical contaminants. Rather than being expressed as the amount of a substance ingested per kilogram of body weight, the LD₅₀ for ionizing radiation is defined as the amount of energy imparted to tissue by ionizing radiation, measured in joules per kilogram of body weight. This quantity is called the *absorbed dose* of radiation and is measured in grays (Gy, 1 Gy = 1 joule per kilogram). The LD₅₀ for acute, whole-body exposures in the absence of medical care is about 3 to 5 Gy, although with modern medical treatment, lives can often be saved following doses as high as 8 to 10 Gy. Doses of this magnitude are exceptionally high and could be received only under severe emergency situations.

Most of the time, chemical contaminants are excreted in a slightly modified form or as metabolic byproducts. If they are not excreted, contaminants or their byproducts are stored in the body where they can bioaccumulate in tissue. Health effects may not become obvious until a certain level is reached. Sometimes, contaminants can take many years to cause health effects. The time between the first exposure and the observation of a health effect is called the **latency period**. Many types of cancer can have latency periods of 20 to 30 years.

Many persistent toxic organochlorine chemicals, such as PCBs, are stored in fat tissue, whereas some metals, such as lead, are stored mostly in the bone. Other tissues and organs that often store chemicals include the liver, kidney and brain. Some chemicals can also build up in mother's milk, which can be an important exposure pathway for nursing infants.

Methods of Investigating Dose-Response Relationships

The dose-response relationships of chemical contaminants are investigated primarily by toxicological studies using laboratory animals. In some instances, when the data are particularly clear and convincing, human epidemiological studies can be used to provide information on dose-response relationships. Such human studies include occupational health and clinical studies, and those on accidental poisonings. In most other studies on humans, there is not enough information to establish actual dose-response relationships, because of the difficulty in controlling and quantifying the exact exposure and the consequent response. Toxicological and epidemiological studies are described below.

Toxicological Studies

Toxicological studies provide indirect information about the potential health effects of toxic substances in humans. These studies are carried out on laboratory animals or use other models to approximate the effects on human health. Exposures and doses of the contaminants can be carefully controlled in these studies.

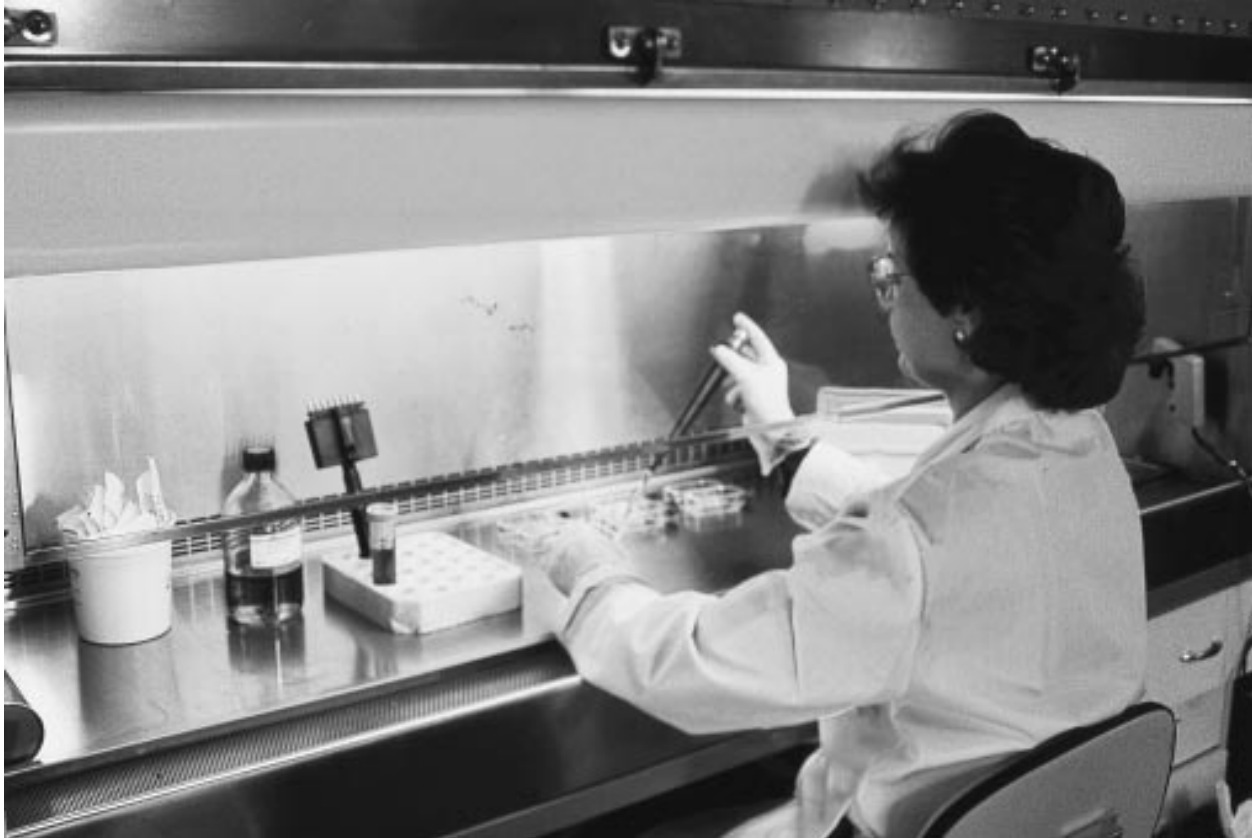
Some of the more common types of toxicological studies are outlined below:

- *Acute toxicity studies* examine the health effects of a single large dose of a substance given to the test animal. They are used mostly to determine what short-term specific health effect a substance produces in order to compare it with the acute toxicity of other substances, and to help determine lower dosages to be used in long-term studies.

- *Subchronic toxicity studies* examine the health effects of longer exposure to smaller doses of a substance. Periods of 90 days or longer are generally chosen. By using several exposure levels, the exact relationship between dose and the health effect is explored.
- *Chronic toxicity studies* and *carcinogenicity bioassays* look for health effects that occur only after a very long exposure to a substance. Most health effects become evident during the subchronic studies, but certain effects that develop very slowly (e.g., cancer) may appear only after exposures which last most of a lifetime. Chronic toxicity studies are the most important in assessing potential health risks to humans, since the experimental conditions are similar to those in which the general population is routinely exposed, that is, long-term, low-level exposure to chemicals and radioactivity.
- *Metabolic and pharmacokinetic studies* determine what happens to a substance inside a living organism, that is, how quickly it is absorbed and metabolized, transported through and excreted by the organism. The results of such studies are used to help interpret the results of other studies and to compare tests on different kinds of living organisms.
- *Genetic toxicological studies* look for genetic changes in bacteria, fungi, plants, insects, small mammals or cells of mammals that have been grown in a special culture. Although the tests are short-term, they can identify genetic mutations.
- *Structure-activity analyses* take the chemical structure of a contaminant, and attempt to predict toxic or carcinogenic effects based on the chemical and physical properties of the contaminant and its molecular structure. Examples of such properties include the types of chemical bonds or the number of chlorine atoms in organochlorine compounds. Such studies have had some limited success, but they are far from perfect.

Epidemiological Studies

Epidemiology is the study of disease patterns in populations and what factors influence these diseases. The simplest form of an epidemiological study looks at the patterns of illness (morbidity) and death (mortality) in a defined human population, and examines the possible factors that could be contributing to them. For obvious ethical reasons, people cannot be used to test the health effects of most environmental contaminants. Therefore, observational studies are generally used to investigate the health effects caused by past or ongoing exposures to environmental contaminants.



The most common types of observational epidemiology studies are summarized below:

- *Ecologic studies* examine the distribution of a particular health effect across areas or regions. They make use of existing large databases like cancer registries or disease incidence databases. In an ecologic study, information about the health and exposure of each individual is not known. Instead, the study compares disease rates in the entire population in each region and can identify unusual excesses of disease by area. Ecologic studies cannot adequately control for possible confounding factors, such as lifestyle (e.g., smoking or diet), that can contribute to disease. Therefore they cannot, by themselves, establish a cause and effect relationship. Rather, the studies are useful for identifying differences in disease rates, and can lead to hypotheses about the reasons for the differences. The hypotheses may then be investigated more rigorously in further studies.
- *Cross-sectional studies* determine the presence or absence of health problems, and the presence or absence of exposure in a subset of the population in the study. They are often carried out using questionnaire surveys, and confounding factors, such as

lifestyle (e.g., smoking, diet), can be evaluated for each individual, providing a better understanding of the factors affecting the disease being investigated. If the disease is very rare, the number of people required to adequately study the relationships becomes very large.

- *Case-control studies* look at the relationship between a disease and possible causes by comparing a group of individuals who have, or have had, the disease with a group which do not. For each individual in each group, the study obtains information about past exposure to contaminants and other lifestyle factors, and then compares the groups to see if there are differences in exposure rates while considering all other factors. Case-control studies are among the most common form of epidemiological study.
- *Cohort studies* compare a group exposed to an agent to a non-exposed or less exposed group, and determine the difference in disease incidences between the two groups. The population groups are called cohorts. The prospective study follows the individuals in that cohort forward in time, recording the incidences of disease as they occur. A retrospective study compares the disease outcomes in the two cohorts, backwards in time, long after the exposure has occurred. Cohort studies are commonly used to examine the effects of occupational exposures on groups of workers.

Epidemiological studies can collect new information or they can be based on historical data. Records from hospitals, disease registries, health insurers and Statistics Canada all provide data for large-scale epidemiological studies, once personal information has been removed. Similarly, useful information can be obtained by linking existing computerized databases (e.g., comparing records of cancer mortality to those for occupational exposure to radiation).

Epidemiological studies have drawbacks. Even with sound methods and a statistically significant association between exposure and incidence, a cause-and-effect relationship cannot be categorically stated. Epidemiological studies, even relatively large ones, can be insensitive to small effects. Also, studies may have to continue for many years to adequately assess disease development in exposed populations (e.g., studies of suspected carcinogens). Although these studies have drawbacks, it is always preferable to have good epidemiological studies when assessing the toxicological risks to humans. Even with good quality data from animal studies, there is still uncertainty in extrapolating the potential risks to human health.

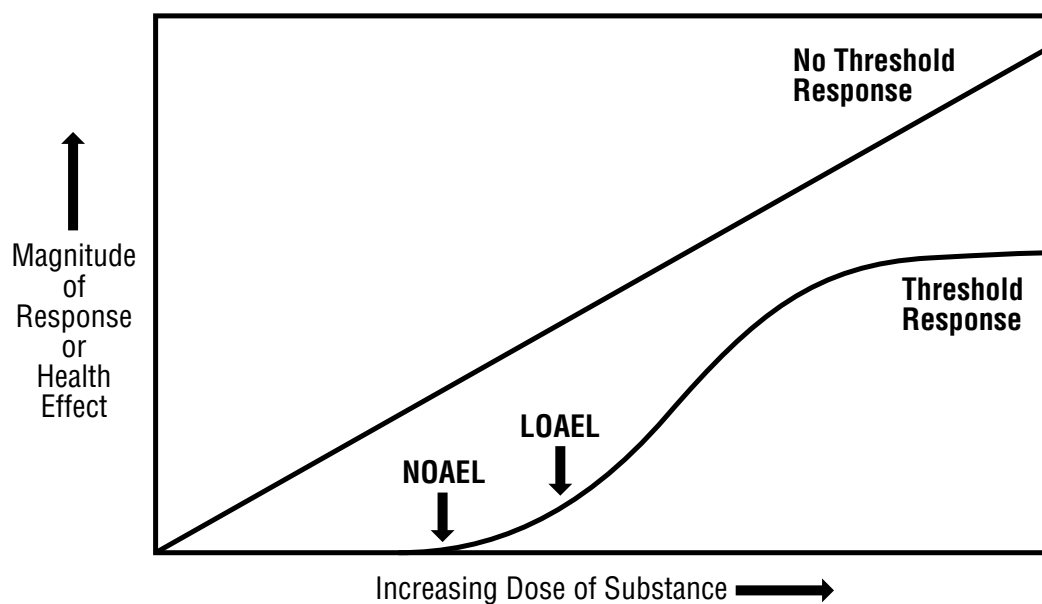
The results of toxicological and epidemiological studies are used to determine the dose-response relationship of individual chemicals. For

*For more information on understanding the risk of disease from exposure to contaminants, as described in epidemiological studies, see **Appendix B**.*

some substances, no health effects can be observed when the exposure dose falls below a certain level. This level is called the threshold dose. For others, especially some substances which cause cancer by directly affecting the genetic material of the cell, there is thought to be no threshold dose. In these cases, there is assumed to be a risk, though extremely minute, of developing cancer even at very low doses. Threshold and non-threshold types of dose-response relationships are shown in FIGURE 5 below.

FIGURE 5:

Dose-Response Relationships



NOAEL - No Observed Adverse Effect Level - The level of exposure to a chemical at which no adverse effects are observed during studies with laboratory animals or in human epidemiological studies.

LOAEL - Lowest Observed Adverse Effect Level - The lowest level of exposure to a chemical at which adverse effects are observed during studies with laboratory animals or in human epidemiological studies.

For substances that do not cause cancer, or for the non-carcinogenic effects of substances that cause cancer, a level of exposure can be estimated below which effects on human health are not expected. For these substances, toxicological studies on laboratory animals and epidemiological studies are used to establish what is called the No Observed Adverse Effect Level (NOAEL), where the concentration of the substance does not lead to any adverse health effects, or the Lowest Observed Adverse Effect Level (LOAEL), which is the lowest

concentration of contaminant at which adverse health effects are observed. This threshold dose is then converted to a dose considered tolerable by humans by using an uncertainty factor (UF). The uncertainty factor takes into account the difficulty of applying animal test results to humans, the differences between individuals in the way they react to and process substances, and the amount of experimental data available to assess these substances. By dividing the animal NOAEL or LOAEL by the uncertainty factor - usually by 100, sometimes as high as several thousand - a tolerable daily intakes (TDI) for humans is calculated. The tolerable daily intake is a value that implies that exposure over a lifetime above this level may lead to increased risk to health, based on the best existing scientific evidence. The risk from short-term exposures above the TDI is likely to be minimal.

$$\text{TDI} = \frac{\text{NOAEL or LOAEL}}{\text{UF}}$$

A different approach than the TDI is required for chemicals known to cause cancer. Contaminants which are known carcinogens are generally assumed to have a non-threshold dose-response, so that there may be no level of exposure to these contaminants that does not present some risk to health. For these substances, a decision must be made as to how large a risk of cancer can be accepted, in order to set acceptable intake levels. Various acceptable levels of risk are currently being used around the world, depending on specific circumstances. Such levels often vary between one extra cancer death per 10,000 people exposed to the contaminant over their entire lifetime, to one extra cancer death per million people exposed.

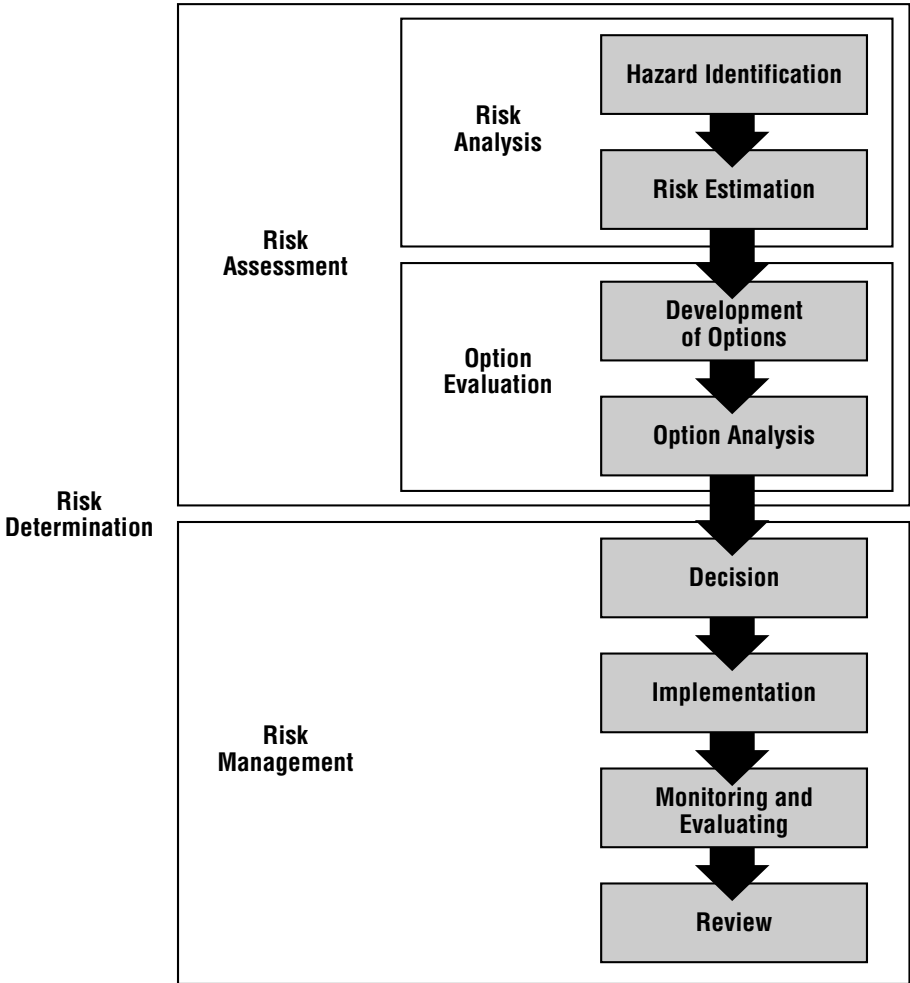
Once an acceptable level of risk has been established, it is possible to calculate a dose that people can be exposed to on a daily basis over their entire lifetime that will not exceed the accepted level of risk of cancer. In other words, if people are exposed to an amount of a carcinogen every day of their life that lies below this calculated dose, then their risk of cancer will lie below the acceptable level of risk. Because this “acceptable” dose is related directly to the decision about an acceptable level of risk, it is called the Risk-specific Dose (RsD). The Risk-specific Dose is calculated by dividing the accepted level of risk by a slope factor. Each carcinogen has its own slope factor which is determined from the results of laboratory and epidemiological studies. In essence, the slope factor states what the cancer risk is for every possible dose of the contaminant. The straight line in FIGURE 5 represents such a slope factor.

$$\text{Risk-specific Dose} = \frac{\text{Acceptable Level of Risk}}{\text{Slope Factor}}$$

When humans are exposed to chemical amounts that exceed the tolerable daily intake or the Risk-specific Dose, then there may be an unacceptable level of risk. Calculating and comparing such risk levels is called “risk analysis.” Risk analysis is the first step in a larger study called “risk determination.” Risk determination studies are used to weigh the health risks of contaminants against the benefits to society of the industrial processes or products that cause the contamination. The steps that Health Canada goes through in carrying out a risk determination are shown in Figure 6.

FIGURE 6:

Risk Determination: Steps in Risk Assessment and Management



If you want to know more about risk, refer to the following books:

Health Canada. 1993. Health Risk Determination: The Challenge of Health Protection. Health Protection Branch. Catalogue number: H49-40/1993E.

Paustenbach D. J. (ed.). 1989. The Risk Assessment of Environmental and Human Health Hazards: A Textbook of Case Studies. John Wiley and Sons, Toronto, Ont..

Recommended Limits to Radiation Exposure

Limits for radiation exposure from artificial sources, in the public, have been issued by the International Commission on Radiological Protection (ICRP), and have been set at 1 *mSv* per year. Implicit in this limit is the understanding that exposures must be as low as reasonably achievable. This limit is in the process of being adopted by the Atomic Energy Control Board (AECB) of Canada. It applies to the total dose received from all internal and external sources, but does not include the natural background radiation that everyone is exposed to or exposures received for medical purposes. Actual doses received by the public from artificial sources are much lower than this limit. Artificial sources include levels of natural radionuclides that have been enhanced due to human practices such as uranium mining. In addition, the total dose at the site boundary of nuclear facilities may not exceed 0.05 *mSv* in a year as stipulated by the AECB. By comparison, the dose received from the natural background radiation is about 3 *mSv* per year.

Health Canada has issued guidelines for radionuclides in drinking water. The total dose received from the consumption of drinking water should not exceed 0.1 *mSv* per year, and this includes the dose from all radionuclides that exist naturally in the environment, as well as those that are artificial. This level of dose corresponds to a theoretical risk of about five extra cancer deaths per million people exposed.

5. WHAT EFFECTS DO CONTAMINANTS HAVE ON HEALTH?

This section summarizes some of the major health effects that have been associated with selected contaminants in the environment. A good overall reference is: *Toxic Chemicals in the Great Lakes and Associated Effects*. 1991. Volumes I, II and Synopsis. Environment Canada, Department of Fisheries and Oceans and Health and Welfare Canada. Catalogue number: En 37-95/1990-1E (Volumes I and II), En 37-94/1990E (Synopsis).

5.1 Chemicals

PCBs

PCBs have been found in human fat and milk of Canadians and people living in other countries around the world. However, there is not enough information to tell whether levels are increasing or decreasing. It is known that levels in people living in the Great Lakes Basin are about the same as those in people living elsewhere.

PCBs are actually a family of chemicals with very similar structures. Individual members of the family are called congeners. Not all PCBs are equally toxic. In animals, short-term high exposures can shorten the lifespan, be toxic to the liver, prevent normal growth and development, suppress the immune system, and cause reproduction problems and cancer. The actual effect depends on the dose and type of PCB. It is unlikely that PCBs actually “start” cancer. It is more likely that they act as “promoters” once a cancer has already started to grow.

Until about 10 years ago, researchers thought that all PCBs were similar and were about equally toxic, so that only the total amount of all PCBs were measured. It is now known that different PCB “congeners” are not equally toxic. Therefore, it is difficult to tell how toxic the “total PCBs” of old studies really are. Today, PCB research is focusing on measuring levels of individual PCB congeners and understanding their effects.

General Reference: Kimbrough R.D. 1987. Human health effects of polychlorinated biphenyls (PCBs) and polybrominated biphenyls (PBBs). *Annual Review of Pharmacology and Toxicology* 27:87-111.

Dioxins and Furans

Like PCBs, dioxins and furans have been found in human fat and mother’s milk. The most toxic type of dioxin/furan is called 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), but its toxicity is different in different species. Guinea pigs are the most sensitive species found so far, and hamsters the least. High exposures in animals cause a skin

disease called chloracne, weight loss, effects on the thymus gland (used to keep the immune system functioning correctly) and death. Longer term exposures can cause liver damage, weight loss, effects on reproduction, the immune system and normal development. Lifetime exposure of laboratory rats and mice has resulted in increased occurrence of cancer in the liver and other organs. However, like PCBs, it is thought that dioxins and furans “promote” cancer that has already started to grow.

Accidental exposures of people to dioxins and furans, such as at Seveso, Italy and in Vietnam, have caused chloracne, but reports of cancer and developmental effects have been called into question. Dioxins and furans usually come as mixtures of different types. Since 2,3,7,8 - TCDD is the most toxic form, the toxicity of all other types of dioxins and furans is calculated by comparing them with the toxicity of 2,3,7,8 - TCDD. The toxicity of other dioxins and furans varies from about 0.001 (a thousand times less toxic) to 1.0 (equal toxicity).

General Reference: International Programme on Chemical Safety (IPCS). 1989. *Environmental Health Criteria 88: Polychlorinated dibenzo-para-dioxins and dibenzo furans*. World Health Organization, Geneva.

DDT and Its Breakdown Products

DDT and its breakdown products are found throughout the environment. DDT breaks down to DDE and other compounds. DDE is less toxic to humans than DDT, but it is more stable. DDE also has a stronger attraction to fat than DDT. Therefore DDE, rather than DDT, is the major contaminant stored in human tissues.

DDT and DDE cause several effects in animals including: liver enlargement and death of the liver, effects on the nervous, immune and reproductive systems and cancer. There is much less information about effects in humans. Only a few incidents of DDT poisoning have been reported. However, exposure to quite high levels of DDE in mother's milk may cause babies to have slower reflexes than normal.

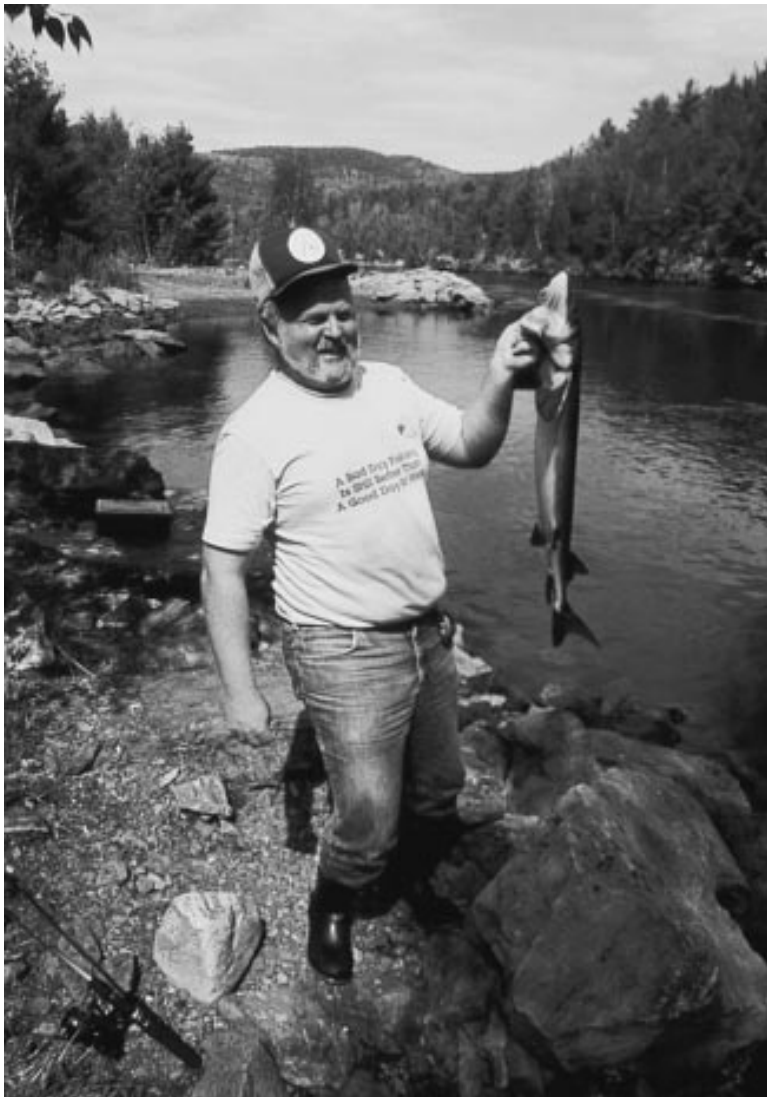
General Reference: International Programme on Chemical Safety (IPCS). 1989. *Environmental Health Criteria 83: DDT and Its Derivatives — Environmental Aspects*. World Health Organization, Geneva.

Cadmium

Most cadmium is stored in the liver and kidneys. Because it cannot break down and is not easily expelled from the body, levels of cadmium tend to increase with age. The main long-term effects of low-level exposure to cadmium are reduced lung function, emphysema and

kidney disease. There may also be effects on the circulatory system and skeleton. A disease called “itai-itai,” first noticed in Japan, has been associated with eating low levels of cadmium over the long term. Itai-itai victims typically experience a softening of the bones, pain in the back and spontaneous bone fractures. There are also indications that cadmium can be carcinogenic. One study of battery workers in England found a relationship between exposure to cadmium and prostate cancer. Cadmium has been shown to be carcinogenic in several species of laboratory animals, including rats.

General Reference: Friberg L., Elinder C-G., Kjellström T., Nordberg G.F. (eds.). *Cadmium and Health: a Toxicological and Epidemiological Appraisal. Volume I: Exposure, Dose, and Metabolism* (1985) and *Volume II: Effects and Response* (1986). CRC Press, Boca Raton, Florida.



Mercury

Mercury can exist in three forms: as pure metallic mercury; in inorganic compounds such as mercuric chloride; and in organic compounds, like alkyl mercury. Inorganic mercury can be converted to organic mercury by bacteria and other living organisms, especially in lakes and rivers. The organic form can concentrate in fish and make the fish poisonous to humans.

Organic mercury is more toxic than either pure metallic or inorganic mercury. Two major epidemics of organic mercury poisoning have occurred in Japan, in Minimata Bay and in Niigata. Both were caused by mercury pollution from industry, and the subsequent build-up of mercury in fish which were then eaten. The largest recorded incident of organic mercury poisoning was in Iraq in 1971-72 when seed grain, coated with a mercury-based pesticide to keep it from rotting, was made into

bread and eaten. Over 6,000 people went to hospital and there were over 500 deaths. In Canada, the health effects of mercury have been investigated in Indian and Inuit communities, where contaminated fish and wildlife were eaten. Although severe organic mercury poisoning was not found, many of the reported symptoms suggested mild poisoning.

The early symptoms of mercury poisoning include a prickling or tingling feeling in the hands or feet, tunnel vision and slurred speech. In animals, inorganic mercury has been associated with kidney damage and abnormal growth and development. Both inorganic and organic forms of mercury are thought to affect the immune system.

General Reference: Goyer R.A. 1991. Toxic effects of metals. In Amdur M.O., Doull J., Klaassen C.D. (eds.). *Casarett and Doull's Toxicology: The Basic Science of Poisons, 4th ed.* Pergamon Press, New York.

5.2 Microorganisms

Bacteria, viruses, protozoa and fungi can cause a wide variety of health effects that range from being insignificant, such as a runny nose, to being fatal. Bacterial, viral, protozoan and fungal infections can occur almost anywhere in the body. However, bacteria, protozoa, and perhaps viruses, in contaminated water are associated with ear, eye, nose and throat infections, skin problems and upset digestion.

General Reference: Burton G.R.W. 1992. *Microbiology for the Health Sciences, Fourth Edition.* Lippincott, Philadelphia.

5.3 Radiation

The health consequences of ionizing radiation depend on the size of the dose received and the duration of exposure. For exposure to radiation at the low levels generally found in the environment, the duration of exposure is of most concern. The main health effects associated with chronic (long-term) exposures at these levels are the development of various cancers such as in the bone, thyroid or lung, as well as cataracts of the eye. Cancers caused by radiation may not appear for several decades after exposure. Radiation-induced cancers are indistinguishable from those that occur for other reasons. Although there is a small risk of hereditary effects, no conclusive evidence for these effects, attributable to either natural or artificial radiation, have been found in human offspring.

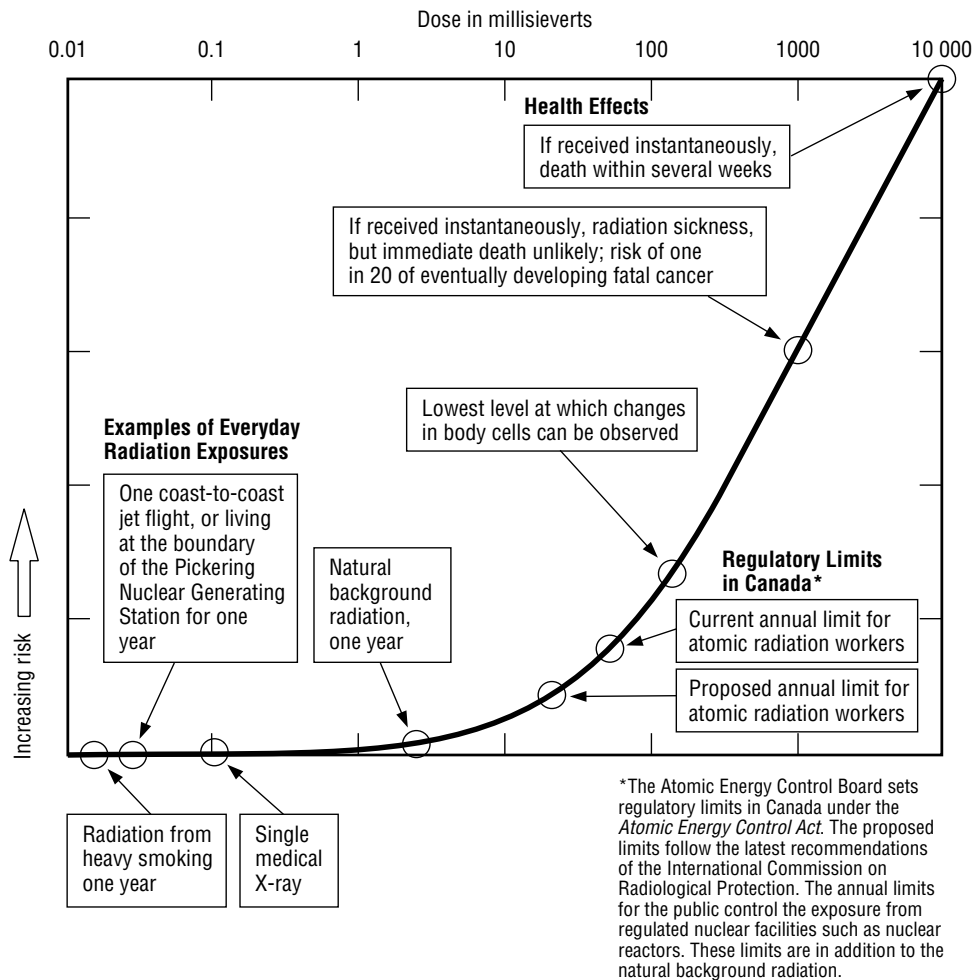
It is generally assumed that even the smallest dose of ionizing radiation poses a potential risk of cancer, and that this risk is proportional to the dose received. However, this assumption is simple and there is considerable evidence that it is also conservative.

Ultra-violet radiation can cause skin cancer and cataracts. There is some evidence that the increase in UV radiation caused by the thinning of the ozone layer is resulting in more cases of skin cancer and cataracts. The effects of electromagnetic fields on health are not clearly understood. Some studies suggest a weak association between increased risk of certain cancers (e.g., leukemia, brain cancer) and exposure to electromagnetic fields.

General Reference: Hendee W.B. 1984. *Health Effects of Low-level Radiation*. Appleton-Century-Crofts, Norwalk, Connecticut.

FIGURE 7:

Radiation Exposure and Limits



5.4 Particulate Matter (Dust)

There seem to be three ways that particulate matter is harmful:

- some of the particles themselves may be toxic or have toxic elements adsorbed onto the particle;
- too many particles within a short time can tax or overwhelm the ability of the lung to clear itself of unwanted substances; and
- the particles may interact with other pollutants in the air and act synergistically, that is, the effect of two or more contaminants acting together is greater than the sum of effects attributable to each contaminant.

In general, particulates deposited in the respiratory system are thought to aggravate already existing lung and heart disease. Some researchers claim that other body defence mechanisms are also affected. Children, the elderly, asthmatics, smokers, people suffering from heart disease and those with the flu or bronchitis may be at particular risk when particulate levels are high.

5.5 Health Effects of Special Concern

In most epidemiological and toxicological studies of environmental contaminants, only a relatively small range of health effects have been investigated. Many studies have examined the ability of contaminants to cause cancer, either in human populations or in experimental animals. As well, mutagenicity (i.e., a contaminant's ability to change the inheritable genetic material, DNA) is often studied using bacterial cultures.

To date, the public has been most concerned about the ability of toxic chemicals, such as PCBs and dioxins, to cause cancer. However, a growing amount of scientific evidence suggests that contaminants can be associated with many other less noticeable health effects.

Within the last 20 years, studies on wildlife in the Great Lakes Basin and elsewhere have shown that newborn animals were less healthy after their parents had been exposed to mixtures of persistent chemicals. The health effects observed include behavioural changes, weight loss and deformities. There is also some information on human populations exposed to contaminants that partially agrees with the wildlife studies.

The scientific research now suggests that as well as studying mortality and cancer, other health effects should be investigated, particularly those that are related to growth and development - both physical and behavioural. There have been some efforts to investigate birth defects, and greater emphasis is being placed on less noticeable developmental changes, including learning ability, memory and behaviour as well as physical effects.

In many communities in the Great Lakes Basin and elsewhere, a growing concern is the increase in respiratory problems and allergies, particularly in children. For example, more cases of asthma and related conditions in children living in urban areas have been documented. While it can be difficult to prove that specific contaminants in the environment cause specific health effects, it will be important to monitor these types of health problems in relation to the presence of environmental contaminants.

TABLE 2 summarizes some of the health effects that are of special concern for environmental contaminants.

TABLE 2:

Health Effects of Special Concern for Environmental Contaminants

HEALTH EFFECTS	DESCRIPTION
Cancer	<ul style="list-style-type: none"> • over a hundred different types • contaminants are cancer “initiators,” others “promoters”
Mutagenicity	<ul style="list-style-type: none"> • changes in the inheritable genetic material
Teratogenicity	<ul style="list-style-type: none"> • affects the growth and development of the children of the person who has been exposed (e.g., acute exposure to PCBs)
Reproductive Impacts	<ul style="list-style-type: none"> • reduced fertility: reduced ability to produce healthy eggs or sperm. For example, the men working in a plant producing the pesticide dibromochloropropape (DBCP) became sterile • effects on reproductive organ development expressed during childhood or post-adolescence (e.g., dioxin) and reproductive tract disorders
Neurotoxicity	<ul style="list-style-type: none"> • affects the central and/or peripheral nervous systems, leading to adverse development and behavioural effects (e.g., the effect of lead on childhood learning) • direct effects on the nervous system (e.g., mercury affects vision and causes peripheral neuropathy)
Immunological Toxicity	<ul style="list-style-type: none"> • reduction of the body’s ability to fight disease; allergies; auto-immune diseases
Respiratory Effects	<ul style="list-style-type: none"> • affects the respiratory system (i.e., the nose, throat and lungs)
Microorganism-related Effects	<ul style="list-style-type: none"> • affects the gastrointestinal system, respiratory system, eyes, ears and skin

6. DESIGNING AND CONDUCTING A COMMUNITY HEALTH SURVEY

A community health survey is one possible part of developing a community health profile. Surveys are undertaken only when existing data are inadequate or new information is needed. It is very important to check with experts and verify all sources of information before you decide to conduct a survey. Surveys require a great deal of time and effort, especially if many people are being surveyed.

To minimize the work and ensure results that are scientifically sound, health surveys must be well designed, thoroughly planned and thought through before proceeding. Seek some expert advice and try to consult with others who have done similar types of surveys. The following steps are usually considered when carrying out epidemiological surveys:

- designing the survey;
- planning for the survey;
- conducting the survey;
- interpreting the survey results; and
- disseminating the survey results.

Some of the main points addressed under each of these headings are summarized below:

Designing the Survey

A community health survey should follow basic scientific methods. These include defining the survey objective or the problem to be studied, defining the geographic area to be investigated and selecting the study sample, defining a control population and designing the survey tools such as questionnaires.

Defining Survey Objectives

- What are you investigating in this survey? Is there a particular health effect or disease to be investigated? Is it a specific type of cancer, reproductive condition or other illness? Do you want to find out what your community's health status is?
- What type of survey would be best? There are two main types of survey - interview and self-administered. In interview surveys, a trained person interviews people either in person or over the telephone. In self-administered surveys, the people being surveyed fill out the survey form themselves and return it. The self-administered approach avoids concerns about possible biases of the interviewer. On the other hand, an interview survey usually gets a higher proportion of the people to respond.

CONFIDENTIALITY OF INFORMATION

Information collected in health surveys are often sensitive and personal. It is the responsibility of the investigators to ensure that the data collected from each survey respondent be kept confidential. For example, each respondent can be assigned with an identification number and the name and address can be kept separately from the questionnaire. All data should be kept under lock and key with designated people only having access.

Area and Sample Selection

- What area do you include in your survey? Depending on the nature of the health concerns, geographic boundaries that make sense must be established.
- Who do you survey? Will all the people in the study area be surveyed or will a representative group (known as a sample) be selected? For practical reasons, it is not likely that every person can be surveyed, especially in large communities. The focus of the survey must be established and could, for example, include households, people working at the same place, people living in the same neighbourhood or children attending the same school.
- How will you select the sample? The people in the sample must be chosen in a way that does not make your survey biased. In other words, the people in the study area who will be interviewed should be picked randomly, rather than choosing all those who you know are unhealthy.

Defining a Control Population

- Who will you compare your survey results against? Do you want to survey a second group of people (control group) that resembles your survey population in every way, except for the suspected environmental contaminant or factor? This control group should have the same age and sex distribution and socio-economic makeup as your survey population. Such a population may be difficult to find within your community, but its inclusion will add to the strength of the survey.
- Health statistics collected by government and private agencies can also be used as a basis for comparing your survey data to standardized health. These data are usually analysed for major causes of death or illness and are often presented by age, sex and by various geographical areas (national, provincial, county or census subdivision).

Designing the Questionnaire

A questionnaire is often the primary tool used to collect information in a health survey. It is important that the survey questionnaire be well designed, specific to the problem being investigated, and thoroughly tested prior to starting the survey. It is recommended that questions from previously used standardized questionnaires be used. These can be adapted for your specific circumstance. An epidemiologist can be extremely helpful in designing questionnaires and health surveys.

Health surveys try to collect the following four types of information:

- demographic characteristics;

- exposure history;
- health effects; and
- confounding factors.

The types of questions which can be used to collect this information are presented below. This list is lengthy but not exhaustive and should be adapted to the objectives of the study.

Demographic characteristics

- age and sex of the respondent;
- ethnic or cultural group (English, French, Native, Asian, African, etc.);
- occupation or type of work;
- total household income (usually in ranges of \$10,000 to \$15,000);
- type of neighbourhood (urban, suburban, rural, etc.);
- type of housing (single-family, multiple family, mobile home, etc.);
- number of years living at the present address and in the community;
- number of people living in the household; and
- education level of the respondent (last grade of school completed, college, university, etc.).

Exposure history

These include questions related to exposure pathways and routes such as:

- the source of drinking water (city, well, bottled);
- eating habits; and
- exposure at work and at home, and information on the extent of exposure to contaminants.

Occupational Information

- list of jobs, places of employment, the department and years of employment;
- list of main activity of the company or organization, the products and the industrial or production processes used;
- the type of place usually worked at (factory or plant, laboratory, vehicle, warehouse, outdoors, office, restaurant, hotel);
- specific tasks and materials used;
- the work surroundings (number of people, noise, temperature, machines, dust, fumes, smoke, gases);

- the use of oils, solvents, acids and detergents; and
- exposure to X-rays or microwaves.

Exposure to chemicals at work

- Acrylonitrile
- Arsenic
- Asbestos
- Benzene
- Beryllium
- Bis(chloromethyl)ether
- Ceramic dust or talc
- Coal tar pitch, volatiles
- Oils, asphalt
- Chemical fertilizers
- Coke oven emissions
- Dyes
- Lacquers, varnishes
- Lead
- Fibreglass
- Cotton, textile, wood, grain or metal dust
- Paints, glues
- Isopropyl oils
- Other petroleum products
- Radioisotopes or radioactive materials
- Insecticides, pesticides
- Herbicides, fungicides
- Chromium or chromate



Exposure to chemicals at home

- Plastics
- Metals
- Clay
- Wood
- Paper
- Stone
- Glazes
- Enamels
- Pastels
- Dyes
- Plaster
- Pigments
- Feathers
- Wax
- Glass
- Fixatives
- Oil paints
- Acrylic paints
- Alkyd paints
- Epoxy paints
- Aerosol or spray paints
- Lacquer, varnish
- Acid, caustics
- Solvents - turpentine, paint thinner, paint removers
- Glues, adhesives, resins
- Solder
- Photography chemicals
- Pesticides, insecticides, fungicides, herbicides, fumigants

Neighbourhood Information

- Water:
 - Unusual taste or smell
 - Corrosive
 - Hard
 - Use of water softener
 - Use of charcoal filter or ion exchanger
- Outdoor air quality:
 - Clear
 - Haze
 - Light smog
 - Moderate smog
 - Heavy smog
 - Occasional dust or smoke
 - Frequent dust or smoke
 - Occasional or frequent chemical smell
- Indoor air quality in household:
 - Tobacco smoke in the house
 - Use of floor wax, furniture polish and oven cleaners
 - Use of gas stoves, wood-burning stoves and unvented gas space heaters for heating
 - Use of roach spray, insecticides and foggers

Health effects

Questions to detect health effects that could be related to exposure can be asked. Questions about unrelated health effects can also be asked to determine whether the people being interviewed on average tend to report more or fewer health effects than people in other communities.

Family medical history

Questions concerning the medical history of the respondent's close relatives, such as grandparents, parents, siblings and cousins, can be asked. These can include the incidence of allergies, asthma, diabetes, heart trouble, stroke, thyroid problems, ulcers and many other conditions among the respondent's family.

Respondent's medical history

Questions concerning the respondent's medical history which could include symptoms and diagnosed conditions of the following:

- Respiratory system:
 - Tuberculosis
 - Pneumonia
 - Persistent bronchitis
 - Emphysema
 - Pneumoconiosis
 - Lung disease
 - Persistent cough
 - Productive cough (phlegm, sputum)
 - Chest pain
 - Coughing up blood
 - Difficult or laboured breathing
 - Wheezing or asthma
- Cardiovascular system:
 - Heart attack
 - Heart disease
 - Low blood pressure
 - High blood pressure
 - Stroke
 - Hardening of the arteries
 - Other disease of veins or arteries
 - Vasculitis
 - Thrombophlebitis
 - Rapid or irregular heartbeat
 - Heart murmur
- Blood:
 - ITP
 - Anemia
 - Infectious mononucleosis
 - Malaria
 - Condition of the spleen
 - Dialysis or pheresis
 - Abnormal blood count
 - Blood transfusion
 - Coagulation or clotting disorder

- Digestive system:
 - Gallstones
 - Ulcers
 - Hepatitis
 - Jaundice
 - Cirrhosis of liver
 - Other conditions of liver or pancreas
 - Esophageal atresia
 - Frequent nausea or vomiting
 - Urinary tract:
 - Kidney condition
 - Bladder disease
 - Protein in urine
 - Endocrine/glandular system:
 - Diabetes
 - Thyroid condition
 - Any hormonal condition
 - Skin:
 - Psoriasis
 - Eczema
 - Dermatitis
 - Unusual rashes
 - Red, scaly, dry or itching skin
 - Unusual acne
 - Immune system:
 - Hay fever
 - Asthma
 - Food allergies
 - Allergic dermatitis or skin rashes
 - Head and neck:
 - Excessively oily or brittle hair
 - Unusual loss of hair
 - Nasal soreness, sinus troubles or infections
 - Excessive salivation
 - Prolonged sore throat
 - Dry throat
 - Difficulty in swallowing
 - Unusual taste in mouth
 - Excessive dental cavities
- Chronic indigestion
 - Colic or abdominal cramps
 - Frequent diarrhea
 - Frequent constipation
 - Loss of appetite
 - Loss of weight
 - Alcohol or food intolerance
 - Frequent or painful urination
 - Blood in urine
 - Excessive sweating
 - Hypoglycemia
 - Hives, unusual flushing
 - Patches of greater or less pigmentation
 - Easy or spontaneous bruising
 - Small, round purple or red spots
 - Frequent colds or infections
 - Chemical intolerance
 - Excessive tooth loss
 - Swollen or sore gums
 - Ears (itching, pain or discharge)
 - Head injuries
 - Eyes (red, itchy, watery, sore, dry, inflamed, blurred vision, constricted pupils, cataracts, glaucoma)

- Nervous system:
 - Epilepsy or seizures
 - Headaches
 - Dizziness
 - Weakness, fatigue
 - Lethargy, drowsiness
 - Decreased sensory perception (smell, taste, hearing, vision, touch)
 - Colour vision
 - Numbness, tingling, prickling, other sensations on skin
 - Tremors, cramps, spasms
 - Problems with balance, coordination, reaction time, clumsiness
 - Anxiety
 - Depression
 - Trouble sleeping
 - Irritability
 - Hyperactivity
 - Restlessness
 - Learning disorder
 - Memory or personality changes
 - Frequent nightmares
 - Meningitis
 - Peripheral neuropathy
- Muscles and bones:
 - Arthritis/rheumatism
 - Limb pain, hand or foot
 - Stiffness in joints
 - Broken bones
 - Numbness, weakness in feet and arms
 - Leg cramps
 - Muscular dystrophy
 - Multiple sclerosis
- Other symptoms or diagnosed conditions:
 - Cancer
 - Leukemia
 - Hodgkin's disease
 - Any metabolic disorder
 - Fever
 - Chills
 - Unexplained loss or gain in weight
 - Overweight or underweight
 - Frequently feel warmer or colder
 - Cysts
 - Accidents that required medical care (including athletic injuries)
 - Serious infections
- Female diagnosed conditions:
 - Menopause
 - Irregular periods
 - Premenstrual syndrome
 - Female hormones (estrogen) prescribed
 - Disorder of cervix
 - Disorder of uterus
 - Disorders of ovaries
 - Venereal disease
 - Infertility
- Male diagnosed conditions:
 - Sterility
 - Abnormal sperm count
 - Sexual disturbances or problems
 - Venereal diseases

- Reproductive history (women):
 - Past and current pregnancies
 - Number of pregnancies
 - Number of babies born
 - Ability to become pregnant
 - Sterility and menopause
 - Current use of birth control
 - The gender of each baby
 - Normal vaginal birth
 - Cesarean
 - Stillbirth
 - Abortion (induced)
 - Twins (both live), twins (one live, one stillborn)
 - Other multiple outcome
 - Tubal pregnancy
 - Low birth weight baby (less than 5 1/2 pounds or 2500 grams)
 - Premature birth (less than 37 weeks)
 - Miscarriage

The condition of each baby at birth or apparent shortly after ward that involved:

- Extremities (arms, legs, hands, feet)
- Skin rashes or darkened skin
- Moles and birthmarks
- Molding (head)
- Eyes
- Cleft lips
- Cleft gums
- Cleft palate
- Ears (abnormalities)
- Thorax (large, small)
- Lungs (not fully inflated, difficulty breathing)
- Heart (abnormal rhythm, murmur, valve defect)
- Liver (jaundice)
- Spleen
- Kidneys
- Skeletal muscles
- Bones
- Joints
- Stomach
- Intestines
- Throat
- Genitals
- Brain (cerebral palsy, spinal or nervous system condition)
- Mental condition
- Reflexes – abnormal
- Metabolic disorder
- Chromosomal disorder

Children's health (persons through 18 years of age)

- General health (excellent, good, fair or poor)
- Resistance to illness
- Previous serious illnesses
- Nervousness
- Anxiety
- Restlessness
- Depression or moodiness
- Hyperactivity
- Ability to concentrate
- Learning or reading disorders
- Allergies
- Asthma
- Metabolic conditions
- Height, weight
- Speech
- Coordination

Children's health cont'd. (persons through 18 years of age)

- Reading
- Physical and mental development at various ages
- Limits to amounts of play or vigorous activity due to health

Confounding factors

These are other factors that could also lead to similar health effects as exposure to a contaminant. Such factors "confound" the study because they make it difficult to prove that the reported health effects were caused by the contaminant. They include smoking, alcohol consumption, use of medications and pre-existing health problems. Some examples are provided below.

Major medications

- Allergy shots
- Atrovent
- Diazepan
- Halcion
- Insulin
- Levothyroxin
- Propanolol
- Provera
- Prozac
- Salbutamol
- Tetracyclin
- Tylenol
- Ventolin

Radiation history

- Screening (chest, mammography, dental)
- Diagnostic (what body part, how many, when)
- Therapeutic (what type, what underlying condition, how many treatments, when)

Lifestyle information

- Special or restricted diet
- Smoking cigarettes, pipes and cigars, chewing tobacco, snuff
- Use of recreational drugs (e.g., amphetamines, barbiturates, marijuana)
- Alcohol use (e.g., beer, wine, spirits)

Planning for the Survey

- What kind of people do you need? Typically, the following types of people are needed to carry out a survey: project managers or team leaders, statisticians or epidemiologists, toxicologists, interviewers, people to deal with the media and to perform communication activities, data entry clerks and clerical help.
- Where will the survey office be located? In someone's home, in a community centre or at the local college? You will need a phone

number for people to contact to obtain information and an address to receive correspondence.

- What kind of materials and equipment do you need? Items may include desks, telephones, facsimile machines, photocopiers, computers (hardware and software), vehicles.
- What will the budget be for the survey? What will the expenses be for each aspect of the study? Will you have to pay for people's time or will they be volunteers? Budget for expenses such as telephones, printing and photocopying, postage, equipment rentals, etc.
- Who will pay for the expenses? Will the money be raised from the community? Will there be some funds available from any government or community agency?

Conducting the Survey

Conducting a community health survey involves a series of steps, including:

- Public consultation and information activities include making an initial announcement in the community that a survey will be conducted and answering any questions from potential participants.
- Recruit survey participants and obtain their informed consent to participate.
- Recruit and train the survey workers to ensure the quality and consistency of the data being collected. This could involve training the interviewers on how to ask questions and how to fill out the questionnaires. Interviewers should be trained to remain non-biased, not to ask leading questions and to be consistent between interviews.

All workers are made familiar with the study objectives and methods, and the process of data collection (questionnaires), as well as the entry of the data on computers.

- Administer the survey (either interview or self-administered). It is important that enough people respond to the survey. The level of participation in the community may be critical in the survey's success. Some scientists feel that an 80% level of participation of the chosen sample is necessary, while others believe that only 60% is adequate. However, with more responses you can have more confidence in your results.

Interpreting the Survey Results

Once the data collection phase is completed and all questionnaires have been received, the survey results are transferred to a master

sheet. This is usually done by entering all the data on a computer file using a spreadsheet program or a statistical computer program, such as SAS or SPSS. All questionnaire data on the computer file should be verified to ensure that no data entry errors have been made.

The data that has been collected may not be easy to interpret and will require statistical analysis by someone with a background in epidemiology or statistics. In-depth data analysis can require a great deal of effort and can be time consuming. The outcome of this analysis could include the following:

- **Summary data:** The data are usually tabulated to give a summary of the results and tell you such things as how many people responded to the survey compared to the selected sample, how many people are in each age group, the number of male and female respondents, and the frequency of responses for each question. Specific health effects from questions asked in the survey will be tallied simply as the number of positive responses recorded.
- **In-depth analysis:** The summary data may provide some insights for further analysis. Analysis should be kept specific to the objectives identified in the planning stages of the survey. The incidence of health symptoms or diseases from the surveyed sample may be compared to the incidence in a control group or incidence in the county, province or country.

At this stage, associations between health symptoms and possible causes may be examined. For example, the frequency of a particular respiratory symptom may be compared to levels of air pollutants in a community. These corresponding trends do not necessarily prove cause and effect, but may show where more detailed investigations are needed. Confounding factors such as smoking, alcohol and drugs should also be carefully considered in these analyses, since they can lead to many of the same symptoms or illnesses as environmental contaminants.

Disseminating the Survey Results

A study report is prepared after the survey is completed and the data analysed. The following are some items that can be included in the report:

- a description of the study's objectives, the methods followed and the population sampled;
- a summary of the data and the results obtained;
- a discussion of your findings, which includes the interpretation of your results;

- the conclusions drawn from the survey results;
- an executive summary of the study; and
- a public summary report on highlights of the study, written in lay language.

Once prepared, the report can serve as the basis for disseminating the results of the survey. Some of the people you might consider sending the results to could include:

- all the survey participants;
- the community at large in the area surveyed;
- the local public health unit;
- government officials (local, provincial, federal);
- all the people who have contributed to the study; and
- the media (radio, television, newspaper).

7. REMEDIAL ACTION PLANS (RAPs)

7.1 Overview

In 1985, the International Joint Commission's (IJC) Great Lakes Water Quality Board identified 42 Areas of Concern (AOCs) around the Great Lakes with an additional site designated in 1991. Sites have been listed as AOCs if one or more of 14 standard beneficial uses of the water resource, such as beach quality, restrictions on dredging due to levels of contaminants in sediments, etc., are impaired (see TABLE 3).

TABLE 3:

Restriction of Beneficial Uses in Areas of Concern

The impairment of beneficial uses with direct relevance to human health

- restrictions on fish and wildlife consumption;
 - tainting of fish and wildlife flavour;
 - restrictions on drinking water consumption, or taste and odour problems; and
 - beach closings.
-

The impairment of beneficial uses with secondary relevance to human health

- degradation of fish and wildlife populations;
 - restrictions on dredging activities;
 - eutrophication or undesirable algae;
 - degradation of esthetics; and
 - added cost to agriculture and industry.
-

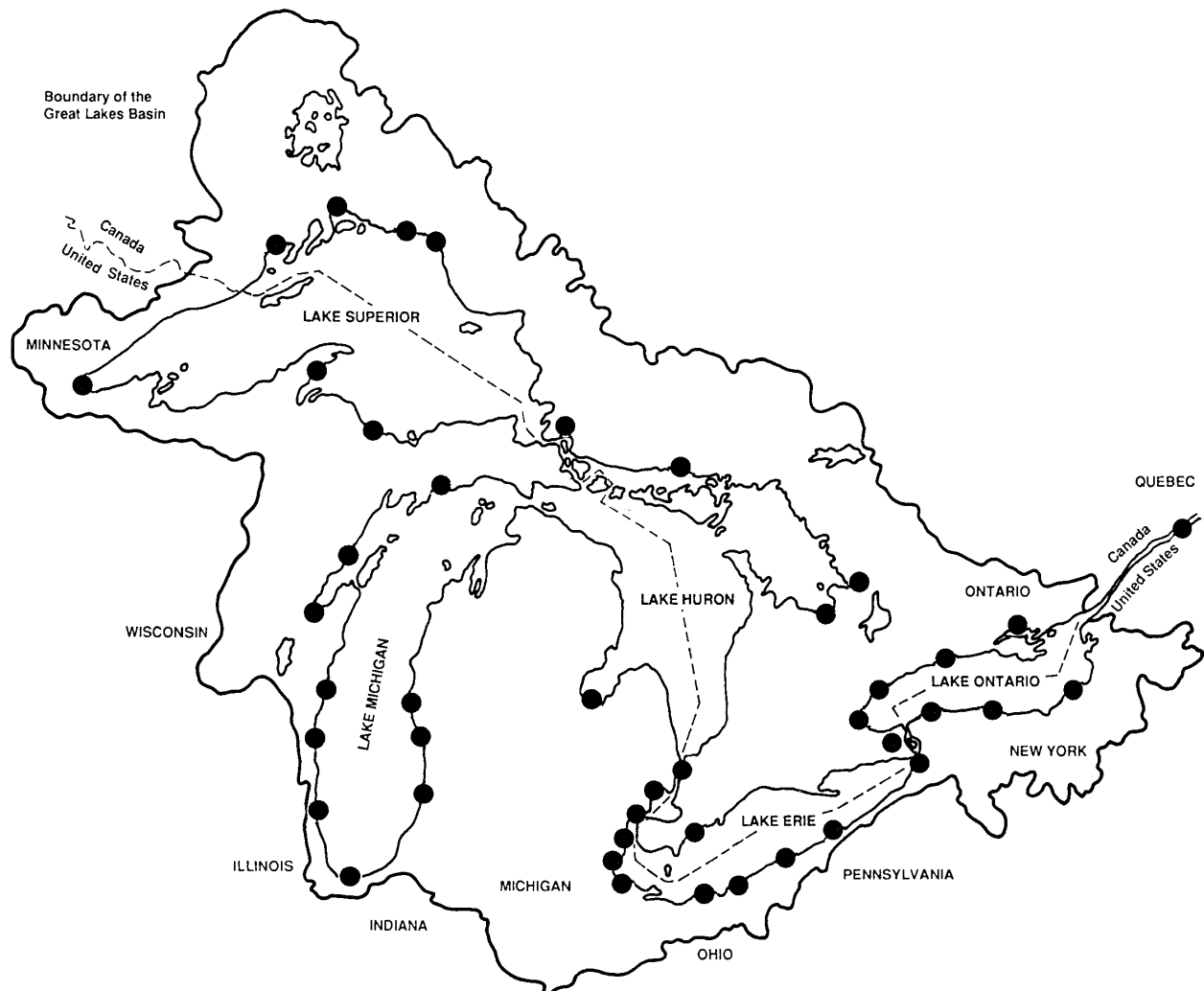
The impairment of beneficial uses that could be sentinel or early warning indicators of relevance to human health

- fish tumours or other deformities;
 - bird or animal deformities or reproductive problems;
 - loss of fish and wildlife habitat;
 - degradation of benthos; and
 - degradation of phytoplankton and zooplankton populations.
-

Seventeen of the AOCs are located in Canada, 12 bordering on Canadian waters and 5 shared with the United States on river systems which connect with the Great Lakes. Canada and Ontario are committed to developing and implementing Remedial Action Plans (RAPs) for these AOCs under the provisions of the Canada-Ontario Agreement Respecting Great Lakes Water Quality (COA). For each of the 17 RAPs, there is a RAP technical team composed of representatives from federal and provincial agencies and a public advisory committee (PAC) involving community stakeholders (industry, business, interest groups, citizens). Overall coordination of Canadian RAPs is achieved through a COA/RAP Steering Committee. Final plans are submitted to the IJC, where progress and implementation of all 43 RAPs are monitored.

FIGURE 8:

Areas of Concern in the Great Lakes Basin



RAPS are developed in three stages using a comprehensive ecosystem approach. Plans must describe the environmental problems (Stage 1), how they can be cleaned up, by whom and by when (Stage 2), and a final report when clean-up is complete and programs for long-term monitoring are in place (Stage 3).

7.2 RAPs and Human Health

The Great Lakes Water Quality Agreement provides little guidance to RAP teams on ways to address health issues. The IJC and participating agencies have been struggling to develop a standard, practical approach. The issue is complicated, however, by a lack of appropriate scientific or socioeconomic data for assessing human exposure to, or pinpointing health effects caused by, environmental contaminants. In addition, most RAP teams have no representation from the health sector of the community to provide the link between community health expertise and RAPs.

The fact remains, however, that before remedial measures are undertaken, it is as important to have a clear picture of the general health status of the AOC human population as it is for the other members of that ecosystem such as fish and wildlife.

Data on human exposure to contaminants through air, water and soil/sediment, and on quantities and species of fish and wildlife actually consumed by people in the AOC are necessary. In addition, potential “at-risk” populations such as consumers of large amounts of Great Lakes fish, the very young, the elderly, asthmatics and others should be identified. Locations of beaches, marinas, sport fishing areas, etc., should be mapped. Information on the geology of the area, groundwater sources, landfill sites or other potential sources of human contaminant exposure is also important.

One of the main reasons for the development of this handbook was to provide RAP communities with a tool for assessing issues of health and environment. These issues could be public concerns over cancer incidence, for example, as occurred in Wheatley Harbour and St. Lawrence River AOCs, and/or technical issues such as dermal exposure to polycyclic aromatic hydrocarbons (PAHs) in the St. Marys River AOC. The information presented in this handbook will guide you, step by step, through the process of determining exposures to contaminants, identifying data gaps and planning secondary health studies.

APPENDIX A: UNDERSTANDING RATES OF DISEASE

Whether health data are obtained from existing sources or from a community health survey, rates of disease will often be presented or will have to be calculated. Different terms used to express rates of disease are explained below.

Rate of Disease

The *Rate of Disease* is the number of cases relative to a population in a defined time period. The three components of a rate include:

- the absolute number of cases of a disease (numerator);
- the population in which these cases occur (denominator); and
- the time period in which these cases occur (e.g., one year).

$$\text{Rate} = \frac{\text{number of cases within a time period}}{\text{population in which the cases occur}}$$

For example, if 46 cases of leukemia were diagnosed in a city of 387,000 in one year, then the rate of leukemia **for that year** is:

$$\begin{aligned} \text{Rate} &= \frac{46}{387,000} \\ &= 0.000119 \end{aligned}$$

Rates of disease are often presented in terms of number of cases per 1000, 10,000, 100,000, etc., people. In the above example, the rate (0.000119) can be multiplied by 100,000 to obtain an equivalent rate of 11.9 cases per 100,000 population.

Incidence Rate and Prevalence Rate

The rate just described is the *Incidence Rate*, that is, the number of **newly** diagnosed cases of a disease in a specific time period and population. On the other hand, the *Prevalence Rate* is the number of people in an area who have the disease at any one point in time, **regardless** of when they have been diagnosed.

Crude Rate and Category Specific Rate

The rate of leukemia described above is a *Crude Rate* which does not take into account differences in rates between different ages, gender or ethnic make-up of a population. The rates of disease broken down for specific categories of the population are known as *Category Specific Rates*.

Standardized Mortality (or Morbidity) Ratio (SMR)

In order to make it easier to compare rates of disease (morbidity) and death (mortality) between different populations, *Standardized Mortality Ratios* (SMR) are often calculated. The Standardized Mortality Ratio is defined as the number of events observed in a study population divided by the number that would be expected if the study population had the same specific rates as a standard or comparison population. In Ontario, provincial norms are most often used as the standard population rates. The events in the SMR can be either death (i.e., mortality) or incidence of disease (i.e., morbidity).

$$\text{SMR} = \frac{\text{Total observed events in a study population}}{\text{Total expected events in that population}}$$

If the SMR is greater than 1, it means that more events (i.e., mortality or morbidity) are observed in the study population than would be expected on the basis of rates in the standard population. Conversely, if the ratio is less than 1, fewer events are observed than expected.

SAMPLE CALCULATION OF A STANDARDIZED MORTALITY RATIO FOR LEUKEMIA IN MALES

Four deaths from leukemia have been observed in a male study population of 36,000 over the course of a year, which is equivalent to 11.1 leukemia deaths for a population of 100,000 (4 cases/36,000 = 11.1 cases/100,000). The death rate of the standard male population for leukemia in Ontario is 6 per 100,000 males.

$$\begin{aligned} \text{SMR} &= \frac{\text{Total observed events in a study population}}{\text{Total expected events in that population}} \\ &= \frac{11.1}{6} \\ &= 1.85 \end{aligned}$$

Therefore, the mortality rate from leukemia in the male study population is 1.85 times (or 85%) greater than would be expected if the Ontario standard rate applied to the study population.

Note: This example comprises fictitious data.

APPENDIX B: UNDERSTANDING RISK

Risk

In the context of human exposure to environmental contaminants, *Risk* is the probability or likelihood that an adverse health effect (i.e., disease) will occur in a person or group that is exposed to a particular concentration or dose of a hazardous agent. The greater the level of exposure, the higher the risk.

Relative Risk

In assessing the association between an environmental contaminant and disease, a commonly used technique in epidemiological studies is the estimation of the *Relative Risk* of the disease for people who are exposed to the agent, as compared to people who are not exposed. The relative risk is defined as the ratio of the disease incidence rate among exposed people to the disease incidence rate among unexposed people. A disease incidence rate is typically expressed as the number of new cases per year per 100,000 persons (see **Appendix A** for more information on disease incidence rates)

$$\text{Relative Risk} = \frac{\text{Disease Incidence Rate for Exposed Population}}{\text{Disease Incidence Rate for Unexposed Population}}$$



Thomas Rahn

Relative risk is a measure of the strength of association between exposure and disease. A relative risk of 1 corresponds to no association between exposure to a contaminant and disease, that is, exposed people get the disease at the same rate as unexposed people. A relative risk of 2, for example, means that exposed people in the study get the disease at twice the rate observed for unexposed people. On the other

hand, a relative risk less than 1 indicates that the rate of disease for the exposed population is less than that for the unexposed population.

SAMPLE CALCULATION OF RELATIVE RISK

Consider a fictitious study comparing the incidence of liver cancer in farmers who use pesticide BRANDX to farmers who do not use this pesticide. The incidence rate of liver cancers among farmers who use the pesticide is 140 per 100,000 and for farmers who do not use the pesticide, 80 per 100,000. The relative risk for farmers who use the pesticide is:

$$\frac{140}{80} = 1.75$$

Therefore, the incidence of liver cancers in farmers who use the pesticide BRANDX is 1.75 times (or 75%) greater than in farmers who do not use the pesticide.

Attributable Risk

When examining the associations between exposure to environmental contaminants and the incidence of disease, it is important to separate the risk of disease that can be attributed to exposure to an agent from the total risk of disease. Therefore, *Attributable Risk* is defined as the incidence rate of disease in exposed individuals that can be attributed to the exposure. This measure is derived by subtracting the disease incidence rate among the unexposed population from the rate among the exposed population. It also assumes that causes other than the one under investigation have had equal effects on the exposed and unexposed groups. These can include diet, smoking, age and heredity.

$$\text{Attributable Risk} = \frac{\text{Disease Incidence}}{\text{Rate for Exposed Population}} - \frac{\text{Disease Incidence}}{\text{Rate for Unexposed Population}}$$

SAMPLE CALCULATION OF ATTRIBUTABLE RISK

Consider the above fictitious study comparing the incidence of liver cancer in farmers who use pesticide BRANDX to farmers who do not use this pesticide.

In assessing the individual risk of liver cancer attributable to BRANDX pesticide use in farmers, we must subtract out liver cancers that would have occurred even without pesticide use. Only the risk above this baseline value is attributed to the pesticide.

The incidence rate of liver cancers among farmers who use the pesticide is 140 per 100,000 and for farmers who do not use the pesticide, 80 per 100,000. The attributable risk for farmers who use the pesticide is:

$$140 - 80 = 60$$

Therefore, for every 100,000 farmers who use the BRANDX pesticide, 60 cases of liver cancer per year out of a total of 140 cases can be attributed the pesticide itself. The other 80 cases can be attributed to other factors assumed to be equal in both exposed and unexposed groups, such as diet, smoking and heredity.

APPENDIX C: SAMPLE MATERIAL SAFETY DATA SHEET

As mentioned earlier, every facility storing or using a hazardous substance must have a copy of the Material Safety Data Sheet (MSDS) for that substance on file. To give a sense of what kind of information an MSDS contains, a sample MSDS for the chemical 2,4-D follows.

2,4-D is a herbicide whose uses include keeping dandelions and other plant species out of lawns. The use of 2,4-D in park areas has become controversial in some communities because of fears about health and environmental effects.

As is typical for MSDSs, this example contains a good number of technical terms and acronyms. The sections of the MSDS most relevant to an exposure assessment are:

1. Ingredients;
2. Physical Data;
5. Environmental and Disposal Information;
6. Health Hazard Data;
8. Handling Precautions; and
9. Additional Information.

The Ingredients and Health Hazards Data will give you some background information on how toxic the substance is. The ingredients will obviously be helpful only if you recognize the substances listed.

The Physical Data and Additional Information give some clues as to what exposure pathways the substance will likely take. In this case, because 2,4-D decomposes when it boils, has a low vapour pressure and no vapour density, you can rule out the air pathway, except as dust. However, it is soluble in water and could conceivably be found in solid form on food or in the soil, if it has been spilled. From the Additional Information you may get a better sense of where and how the substance is meant to be used, and thus clues on where it will turn up in the environment. The section on Environmental and Disposal Information and on Handling Procedures allow you to evaluate whether the substance is being handled properly. If the instructions are not being followed, then it is more likely that this substance will be an environmental contaminant of concern.

If an MSDS leaves you baffled, the Canadian Centre for Occupational Health and Safety is the best source of information on MSDSs. They also provide, at a small charge, the following publications on MSDSs:

Material Safety Data Sheets: A basic guide for users; and

Material Safety Data Sheets: An explanation of common terms.

These publications can be ordered from the CCOHS Inquiry Service: 1-800-263-8466.

Alternatively, try asking a toxicologist for assistance.

MATERIAL SAFETY DATA SHEET (MSDS) FOR 2,4-D

Generic Chemical Company

Phone: 123-456-7890

Product Code: 12345

PRODUCT NAME: 2,4-DICHLOROPHENOXYACETIC ACID, FLAKE

Effective Date: 06/30/92 Date Printed: 05/25/93 MSDS: 001

1. INGREDIENTS: (% w/w, unless otherwise noted)

2,4-Dichlorophenoxyacetic acid, min.	CAS# 000094-75-7 97.0%
4-Chlorophenoxyacetic acid, max.	CAS# 000122-88-3 1%
2,6-Dichlorophenoxyacetic acid, max.	CAS# 006575-24-2 1%

2. PHYSICAL DATA:

BOILING POINT:	Decomposes
VAPOUR PRESSURE:	(mmHG @ 20C) very low
VAPOUR DENSITY:	Not applicable
SOLUBILITY IN WATER:	0.09gm/100gm
SPECIFIC GRAVITY:	Powder 1.416 (35C)
APPEARANCE:	White powder
ODOUR:	Phenolic odour

3. FIRE AND EXPLOSION HAZARD DATA:

FLASH POINT:	None
METHOD USED:	TCC, TOC
FLAMMABLE LIMITS:	
LFL: Not applicable.	UFL: Not applicable.
EXTINGUISHING MEDIA:	Water fog, foam, CO ₂ , dry chemical.
FIRE AND EXPLOSION HAZARDS:	Noxious fumes produced when exposed to fire conditions.
FIRE-FIGHTING EQUIPMENT:	Wear positive-pressure self-contained breathing apparatus.

4. REACTIVITY DATA:

STABILITY: (CONDITIONS TO AVOID)	Decomposes above 302F (150C) when dry.
INCOMPATIBILITY: (SPECIFIC MATERIALS TO AVOID)	Alkaline or oxidizing materials.
HAZARDOUS DECOMPOSITION PRODUCTS:	HCl under fire conditions.
HAZARDOUS POLYMERIZATION:	Will not occur.

5. ENVIRONMENTAL AND DISPOSAL INFORMATION:

ACTION TO TAKE FOR SPILLS/LEAKS:	Sweep up spills.
DISPOSAL METHOD:	If wastes cannot be disposed of by use according to label instructions, contact your provincial pesticide or environmental control agency, or the hazardous waste representative for guidance.

6. HEALTH HAZARD DATA:

EYE: May cause pain. May cause severe irritation with corneal injury. Effects may be slow to heal. Dust may irritate eyes.

SKIN CONTACT: Prolonged or repeated exposure may cause skin irritation.

SKIN ABSORPTION: A single prolonged skin exposure is not likely to result in the material being absorbed through the skin in harmful amounts. Repeated skin exposure may result in absorption of harmful amounts. The LD₅₀ for skin absorption in rabbits is 1400 to >2000 mg/kg.

INGESTION: Single dose oral toxicity is moderate. The oral LD₅₀ for rats is 375 to >1000 mg/kg. Amounts ingested incidental to industrial handling are not likely to cause injury; however, ingestion of larger amounts may cause injury. Ingestion may cause gastrointestinal irritation or ulceration.

INHALATION: Vapours are unlikely due to physical properties.

SYSTEMIC AND OTHER EFFECTS: Excessive exposure may cause liver, kidney, gastrointestinal and muscular effects. Signs and symptoms of excessive exposure may be nausea and/or diarrhea. Various animal cancer tests have shown no reliably positive association between 2,4-D exposure and cancer. Epidemiology studies on herbicide use have been both positive and negative with the majority being negative. Birth defects are unlikely. Exposures having no effect on the mother should have no effects on the fetus. Did not cause birth defects in animals; other effects were seen in the fetus only at doses which caused toxic effects to the mother. Excessive dietary levels caused toxic effects (weight and viability reduction) in rats on a reproduction test. Results of mutagenicity tests in animals have been inconclusive. Has been shown to be negative in some in vitro (test tube) mutagenicity tests and positive in others.

7. FIRST AID:

EYES: Irrigate with flowing water immediately and continuously for 15 minutes. Consult medical personnel.

SKIN: Wash off in flowing water or shower.

INGESTION: If swallowed, induce vomiting immediately as directed by medical personnel. Never give anything by mouth to an unconscious person. Seek medical attention immediately.

INHALATION: Remove to fresh air if effects occur. Consult a physician.

NOTE TO PHYSICIAN: No specific antidote. Supportive care. Treatment based on judgement of the physician in response to reactions of the patient.

8. HANDLING PRECAUTIONS:

EXPOSURE GUIDELINE(S): ACGIH TLV and OSHA PEL are 10mg/m³.

VENTILATION: Good general ventilation should be sufficient for most conditions. Local exhaust ventilation may be necessary for some operations.

RESPIRATORY PROTECTION: Atmospheric levels should be maintained below the exposure guideline. When respiratory protection is required for certain operations, use an approved air-purifying respirator.

SKIN PROTECTION: Wear clean, long-sleeved, body-covering clothing. Use impervious gloves when prolonged or repeated contact could occur.

EYE PROTECTION: Use chemical goggles.

9. ADDITIONAL INFORMATION

SPECIAL PRECAUTIONS TO BE TAKEN IN HANDLING AND STORAGE: See label. Keep out of reach of children. Do not swallow. Avoid eye and skin contact. Do not store near seeds, fertilizers, insecticides or fungicides.

APPENDIX D: UNITS OF MEASUREMENT

Units of measurement can often be quite confusing, especially as each thing being measured seems to use different units. In this section, the various units and how to convert them from one to another will be described.

1. Chemicals

In *liquids* such as water, levels or concentrations of contaminants are most commonly expressed in milligrams per litre (mg/L) or micrograms per litre ($\mu\text{g/L}$). One milligram equals one thousand micrograms. In *soil, food and other solids*, contaminant levels are usually expressed in milligrams per kilogram (mg/kg). Concentrations of chemicals and dust in *air* are usually expressed as milligrams or micrograms per cubic metre (mg/m^3 , $\mu\text{g/m}^3$). Occasionally, the units for chemical concentrations in water, soil, food and air are expressed in parts per million (ppm), parts per billion (ppb), parts per trillion (ppt) or parts per quadrillion (ppq). The relationship of the various expressions of concentration are shown below.

BASIC UNITS	
g (gram)	μg (microgram) = 10^{-6} gram
kg (kilogram) = 10^3 gram	ng (nanogram) = 10^{-9} gram
mg (milligram) = 10^{-3} gram	pg (picogram) = 10^{-12} gram

SOIL AND WATER					
Metric Units in Liquids	Equivalent in Parts per Unit				Metric Units in Solids
	ppm	ppb	ppt	ppq	
1 g/L	10^3	10^6	10^9	10^{12}	1 g/kg
1 mg/L	1	10^3	10^6	10^9	1 mg/kg
1 $\mu\text{g/L}$	10^{-3}	1	10^3	10^6	1 $\mu\text{g/kg}$
1 ng/L	10^{-6}	10^{-3}	1	10^3	1 ng/kg
1 pg/L	10^{-9}	10^{-6}	10^{-3}	1	1 pg/kg

AIR

Converting from ppm in Air to Its Equivalent in $\mu\text{g}/\text{m}^3$

Converting air contaminant values from ppm to $\mu\text{g}/\text{m}^3$ is not as straightforward as similar conversions in water or soil. In this case, the conversion is dependent on the atomic molecular weight of the contaminant. Atomic weights are found in most chemistry textbooks. To convert from ppm to $\mu\text{g}/\text{m}^3$ in air, the following equation is used:

$$\text{Contaminant Concentration } (\mu\text{g}/\text{m}^3) = \frac{\text{Contaminant concentration (ppm)} \times \text{Molecular Weight of the Contaminant}}{40.9}$$

EXAMPLE: Convert the pollutant ozone, at 0.08 ppm in air, to its equivalent in $\mu\text{g}/\text{m}^3$. The molecular weight of ozone is 48.

$$\begin{aligned} \text{Contaminant Concentration } (\mu\text{g}/\text{m}^3) &= 0.08 \text{ ppm} \times 48 \times 40.9 \\ &= 157 \mu\text{g}/\text{m}^3 \end{aligned}$$

157 $\mu\text{g}/\text{m}^3$ ozone is equivalent to 0.08 ppm ozone.

2. Microorganisms

Microorganisms, including bacteria, viruses and protozoa, are usually measured by the number of organisms present in a given volume. For example,

- 100 organisms/100 millilitres (mL) and
- 100 organisms/cubic centimetre (cm^3)

3. Radiation

Different characteristics of radiation can be measured as it travels from its source into living organisms. The three characteristics described below are: the activity, the absorbed dose and the equivalent dose. For each characteristic of radiation, at least two different units exist. These different units are simply older and newer descriptions of the same thing, just as, for example, feet and metres both measure distance.

RADIOLOGICAL UNITS

Quantity	Metric Unit	Symbol	Old Unit	Symbol	Relationship
Activity	becquerel	<i>Bq</i>	curie	<i>Ci</i>	1 <i>Ci</i> = 3.7×10^{10} <i>Bq</i>
Absorbed dose	gray	<i>Gy</i>	rad	<i>rad</i>	1 <i>rad</i> = 0.01 <i>Gy</i>
Dose equivalent	sievert	<i>Sv</i>	rem	<i>rem</i>	1 <i>rem</i> = 0.01 <i>Sv</i>

Activity

Radioactive elements (radionuclides) decay or break down into lighter substances. As they decay, they emit energy which is called ionizing radiation. The more decay, the more radiation is produced. The energy released during radioactive decay is in the form of alpha, beta or gamma radiation. The activity of a radionuclide is a measure of its rate of decay. The becquerel (*Bq*) is the International System (S.I.) unit for measuring this activity. The older unit of measurement is the curie (*Ci*). One curie equals 3.7×10^{10} becquerels.

Absorbed Dose

When ionizing energy from a radioactive substance moves into a living organism, energy is given off to the cells of the organism. That energy damages the cells and interferes with their functioning. The damage to cells depends on the amount of energy given off per kilogram of living tissue. This amount is the absorbed dose and the S.I. unit is the gray (*Gy*). One gray equals one joule (J) of energy absorbed per kilogram of living tissue. The older unit for the absorbed dose is the *rad* ($100 \text{ rad} = 1 \text{ Gy}$).

Equivalent Dose

Not all absorbed doses of radiation are equal in their ability to cause damage to living cells. This is because radioactivity produces different kinds of energy, such as alpha, beta and gamma. The damage caused by each radiation type is directly related to how quickly each type gives off its energy as it travels through living tissue. Alpha radiation, for example, causes the most damage because it loses its energy very quickly along its path. On the other extreme, gamma radiation causes the least damage because it loses little of its energy.

To give a more accurate picture of the damage caused by an absorbed dose of radiation, a new unit of measurement is calculated: the equivalent dose. The equivalent dose is directly related to the absorbed dose, but takes into account the type of radiation involved. To calculate equivalent dose, the absorbed dose for each radiation type is multiplied by a factor that reflects its ability to do damage. This factor, called the *radiation weighting factor*, ranges from 1 for beta radiation to 20 for alpha radiation.

COMPARISON OF ABSORBED AND EQUIVALENT DOSE

Radiation Type	Absorbed Dose	Equivalent Dose
Beta radiation	1 <i>Gy</i>	1 <i>Sv</i>
Alpha radiation	1 <i>Gy</i>	20 <i>Sv</i>

The S.I. unit for the equivalent dose is the sievert (*Sv*). One sievert is equal to one joule of energy absorbed per kilogram of body weight (J/kg). The older unit of measurement for the equivalent dose is the *rem* ($100 \text{ rem} = 1 \text{ Sv}$).

Further Complications:

Does the equivalent dose imply that alpha radiation is always more dangerous than beta or gamma radiation? The answer is not that simple. Gamma radiation can be a greater hazard to health because it travels furthest into the body. Alpha radiation is stopped by the skin. It becomes a hazard only when the source of the alpha radiation has been swallowed or breathed into the body. Gamma radiation, on the other hand, is a hazard from any kind of source, whether inside or outside the body.

To complicate matters further, some body tissues can be damaged more easily by radiation than others. For example, the risk of fatal lung cancer is greater than the risk of fatal bone cancer, for the same equivalent dose. In other words, the effect of an equivalent dose depends on what part of the body is exposed. To account for these differences, scientists have developed another factor, called the *tissue weighting factor*. By multiplying the equivalent dose by this factor for each organ in the body, and then adding the results of all the organs, a new quantity can be calculated: the *effective dose*. The effective dose gives an overall measure of the risk to health of any type of radiation, no matter which parts of the body are exposed, and regardless of whether the source is inside or outside the body.

APPENDIX E: GLOSSARY

Attributable Risk

Attributable risk is defined as the rate of disease in exposed individuals that can be attributed to the exposure. This measure is derived by subtracting the disease rate among the unexposed population from the rate among the exposed population. It also assumes that causes other than the one under investigation have had equal effects on the exposed and unexposed groups.

Bioaccumulation

Some pollutants are not excreted quickly, but rather are stored in parts of the body for long periods of time. Total pollutants in the body (the “body burden”) may build up if the organism is exposed to the substance for a long period of time.

Biomagnification

Pollutants “biomagnify” when they build up to higher levels as they move through the food chain. For example, when pollutants in plants are passed on to animals feeding on the plants, the animals may be exposed to higher levels because the plants have collected and concentrated pollutants, and the animals eat many plants.

Carcinogen

A substance (e.g., a chemical) or an agent (e.g., ionizing radiation) that causes cancer.

Congener

A different configuration or mixture of a single chemical where some of the atoms occupy different positions in the molecule.

Contaminant

A substance foreign to a natural system or present at unnatural concentrations.

Control group

In an experimental or follow-up study, the control group comprises subjects being observed who have not been exposed to the contaminant being studied, for comparison with exposed groups. In a case-control study, the control group is made up of subjects without the disease under study, for comparison with a group that has the disease.

DDT

An insecticide, also called dichlorodiphenyl trichloroethane. DDT can break down to DDE (dichlorodiphenyl dichloroethylene), which is very persistent in the environment.

Demography

The study of populations, especially with reference to size and population density, fertility, mortality, growth, age distribution, migration and vital statistics, and the interaction of all these with social and economic conditions.

Detection limit

The lowest concentration of a substance that can be detected with certainty by the measuring technique being used.

Dioxin

A group of about 75 chemicals, also called polychlorinated dibenzodioxins (PCDDs). The most toxic is 2,3,4,5-TCDD (tetrachlorinated dibenzodioxin).

Disease cluster

A series of cases of disease or other health effects that all occur around the same time or in the same place or both.

Dose-response curve

A mathematical relationship between exposure to a toxic chemical and some health effect (“end point”). Often, higher doses will produce larger numbers of adverse effects or more severe reactions. For example, the more alcoholic beverage a person consumes, the more likely the person is to show signs of intoxication. Since there is a mathematical relationship between the amount of exposure (the “dose”) and the effects observed (the “response”), the relationship can be shown on a graph or “curve.”

Epidemiology

The science that studies statistical relationships between patterns of disease and the occurrence of possible causing or contributing factors.

Excess risk

An increased risk of disease above the background rate.

Exposure

Exposure is any contact between a substance and an individual who

has touched, breathed dust or fumes, or swallowed material or liquid from a contaminated source. It is quantified as the amount of the substance, that can be absorbed, available at the exchange boundaries of the organism (e.g., skin, lungs, digestive tract).

Exposure assessment

Measurement or estimation of the magnitude, frequency, duration and route of exposure of individuals or populations to substances in the environment.

Exposure pathway

The pathway a contaminant may take to reach humans or other living organisms. Exposure pathways include all the elements that link the source of a contaminant to the exposure route (ingestion, inhalation, skin contact) by which the contaminant enters the body.

Exposure route

The means by which contaminants enter the body, such as by ingestion (swallowing), by inhalation (breathing) and by skin contact (touching).

Food web

A food web consists of different species of plants and animals that are dependent on each other for food. It usually contains green plants (primary producers), herbivores that eat the plants and one or more level of carnivorous or predatory species. Humans are at the top of many food webs.

Guideline

A recommended limit for a substance or an agent intended to protect human health or the environment. It is not legally enforceable.

Half-life

The amount of time required for half of a particular pollutant to degrade (change to another chemical form) in the environment, so that only half of the amount of the original pollutant is left in the environment.

Hepatic

To do with the liver.

Incidence

The number of new cases of a disease occurring in a defined population, within a specified period of time. It is frequently presented as the

number of new cases per 1,000 or 100,000 per year. The incidence rate can provide a direct estimate of the risk of developing a disease during a specified time period.

LD₅₀

The LD₅₀ is the dose of a substance fed to rats (unless otherwise specified) that will cause death in 50% of the test animals. LD stands for lethal dose.

Latency period

The period of time between exposure to a disease-causing agent and the appearance or manifestations of the disease.

Mutagen

A substance or agent which can alter the genetic material (DNA or RNA), resulting in changes that may be inherited.

Objective

A preferred or desired level of a substance or an agent in the environment, often zero or the detection limit.

PCBs

A group of 209 chemical compounds, also called polychlorinated biphenyls, made up of carbon, hydrogen and chlorine.

Persistent

A pollutant that takes a long time to break down or be rendered harmless in the environment. Under the Great Lakes Water Quality Agreement, a persistent pollutant is one with a half-life of eight weeks or longer.

Prevalence

The number of existing cases of a given disease or other condition in a given population at a designated point in time.

Radionuclide

An unstable nuclide (nucleus of an atom) that undergoes spontaneous radioactive decay, emitting radiation as it does so, and changing eventually from one element into another.

Relative risk

Relative risk is a measure of the strength of association between exposure and disease. The relative risk is defined as the ratio of the

disease rate among exposed people to the disease incidence rate among unexposed people.

Renal

To do with the kidney.

Risk

Risk is the probability or likelihood that an adverse health effect (i.e., disease) will occur in a person or group that is exposed to a particular concentration or dose of a hazardous agent.

Risk assessment

Techniques for systematically measuring and estimating the likely health impacts and other results of releasing or discharging specified amounts of pollutants.

Risk management

Making decisions with regard to release of a pollutant on the issue of how much risk, and to whom, will be considered acceptable.

Standard

A legally enforceable limit for a substance or an agent intended to protect human health or the environment. Exceeding the standard could result in unacceptable harm to whatever it is intended to protect.

Standardized Mortality (or Morbidity) Ratio

The Standardized Mortality Ratio (SMR) is the number of deaths (or disease) observed in a population divided by the number that would be expected in a standard or comparison population. The events in the SMR can be either death (i.e. mortality) or incidence of disease (i.e., morbidity).

Teratogen

A substance or agent which can cause effects (e.g., birth defects) in the offspring of exposed adults.

Tolerable Daily Intake (TDI)

The Tolerable Daily Intake is an estimate of the quantity of a chemical that humans can consume every day for their whole life without threatening their health. It is usually expressed in milligrams of chemical per kilogram of body weight per day (mg/kg/day).

Toxic substance

A substance capable of causing harm to humans, animals or other living things at some level of exposure. In common usage, the term refers to chemical substances that are capable of causing harm at very low levels of exposure, while providing little or no benefit to the organism in question.

Toxicology

A science that studies the effects of poisons on humans, animals or other organisms.