3

Contaminants

CONTAMINANTS

3.1 Introduction to Contaminants

Environmental contaminants are potentially harmful agents that have been released into the ecosystem and have entered our food, water, air, or soil. For ease of presentation, contaminants in the environment have been grouped into the three following categories:

- chemicals, in organic or inorganic forms;
- micro-organisms, including bacteria, protozoa, viruses and fungi; and
- radiation, including ionizing and non-ionizing types.

Some substances that degrade slowly and remain in the environment for a long time are called **persistent contaminants**. When contaminants are released into the environment, their persistence becomes an important concern. A substance that is relatively toxic may be a minor hazard if it breaks down quickly into non-hazardous substances before people can be exposed to it. Conversely, a mildly toxic contaminant that remains for a long time in environmental media to which humans are exposed can accumulate in human tissues and become a significant concern. Elements such as lead or cadmium do not break down. Some organic chemicals such as DDT, dioxins and furans, and polychlorinated biphenyls break down very slowly in the environment and in human tissue even though they can be destroyed under extreme conditions, i.e., high temperature incineration. Radionuclides are a special class of contaminants that cannot be broken down by physical or chemical processes; they gradually decay with half-lives varying from a few minutes to thousands of years.

Contaminants can enter the environment in many different ways. **Point** sources of contaminants are localized and are often easily identified. Such point sources can include:

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

Non-point sources of contaminants are also important. These sources are more diffuse and not as easily identified as point sources are. They can include:

- run off from land that has been treated with pesticides or fertilizers;
- car exhausts;
- contaminated sediments;
- storm-water run off from built-up areas; and
- atmospheric deposition, which is the transfer of contaminants out of the atmosphere onto the land and into the water. For example, metals or organic chemicals on dust particles can fall on water. Often these contaminants have travelled long distances and reacted with other chemicals in the air (e.g., acid rain).

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

- the major types of contaminants in the environment;
- the origins of these contaminants;
- their movement and persistence in the environment;
- how people can be exposed to them;
- some health effects that have been associated with exposure to these contaminants; and
- regulation of these contaminants.

3.2 Major Types of Contaminants

Thomas Rahn

Chemicals

Since the Second World War, there has been an enormous increase in the number of and amount of chemical products manufactured and used. Hundreds of new chemicals are being introduced into the global marketplace each year. Manufactured chemicals are a part of all aspects of modern life. The benefits of using chemicals are wide ranging — increased food production and food quality, improved drugs and medicines, increased efficiency in industrial production processes, and increased variety of consumer products and building materials. While most commercial chemicals are of significant benefit, many manufacturing by-products and wastes can cause problems in the environment if they are not handled or disposed of properly. For example, in recent years there has been a lot of concern about the levels of persistent toxic chemicals in the Great Lakes basin ecosystem.

Chemicals in the environment can be in organic and inorganic forms. Organic chemicals are composed of carbon in combination with other elements such as hydrogen, nitrogen, oxygen or sulphur, or halogens such as chlorine. Inorganic chemicals do not contain carbon, and can be single elements such as chlorine, or elements (other than carbon) in combination such as sodium chloride. Metals can be inorganic when in elemental form such as lead (Pb^{++}) and cadmium (Cd^{+}), or in organic form such as methyl mercury.

The building blocks for all chemicals come from the Earth. All life is made up of and depends on chemicals. Whether naturally occurring or manufactured, a chemical's origin does not predetermine its toxicity, which can range from low to high toxicity. Through industrial activities, however, living organisms, including humans, have become exposed to a large number of chemicals that were not a significant part of their environment in the past. These substances were either buried in the ground and released through human activity (e.g., mining), or were created by industrial processes, either deliberately or as by-products.

Many chemicals, such as PCBs, persist in the environment for long periods and can bioaccumulate in the tissues of living organisms. As a result, concentrations of some chemicals get increasingly higher, i.e., biomagnify, as they go up the food chain (see Figure 3.1).

Once released, chemical contaminants 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 may evaporate into the air and then be washed out by rain and deposited onto soil and vegetation. The contaminated plants could then be eaten by different species of animals. Chemicals can also 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 many contaminants that come from Europe, Asia and the Americas.

For information on exposure and health considerations for individual chemicals, see *Contaminant Profiles*.

BIOACCUMULATION

MOST CHEMICALS THAT ENTER THE HUMAN BODY ARE METABOLIZED AND/OR EXCRETED. THE SPEED WITH WHICH AN ORGANISM ALTERS AND/OR EXCRETES THE CHEMICAL DETERMINES HOW LONG IT WILL REMAIN IN THE BODY. CHEMICALS THAT ARE TAKEN IN AT A GREATER RATE THAN THEY CAN BE EXCRETED CAN "BIOACCUMULATE" IN THE ORGANISM. FAT SOLUBLE SUBSTANCES SUCH AS DDT, DIOXINS, FURANS, AND PCBS WILL BIOACCUMULATE IN BODY FAT, FATTY TISSUES SUCH AS LIVER, AND BODY FLUIDS SUCH AS PLASMA. SOME METALS SUCH AS LEAD, MERCURY AND CADMIUM BIND TO PROTEIN AND ARE STORED IN THE LIVER, KIDNEY AND BONE. PERSISTENT RADIONUCLIDES OFTEN ACCUMULATE IN THE KIDNEY, TEETH AND BONE. HUMANS EXPOSED TO HIGHLY PERSISTENT CONTAMINANTS FOR A LIFETIME WILL BIOACCUMULATE THESE SUBSTANCES IN THEIR BODIES.

Measurements

Concentrations of chemicals and metals can be expressed in many ways using different units of measurement. In **liquids**, such as water, contaminants are most commonly expressed in milligrams per litre (mg/L) or micrograms per litre (µg/L). One milligram is 1/1000 of a gram, and 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 particulates in **air** are usually expressed as milligrams or micrograms per cubic metre (mg/m^3, $\mu g/^3$). 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 in Table 3.2.

Critical Great Lakes Pollutants

In 1985, 11 of the most persistent and widespread toxic contaminants were identified as critical Great Lakes pollutants by the International Joint Commission (IJC). (Great Lakes Water Quality Agreement 1987) These were:

- PCBs, DDT and its metabolites, dieldrin, toxaphene, dioxin (2,3,7,8-TCDD, furan (2,3,7,8-TCDF), mirex, hexachlorobenzene (HCB), mercury, alkylated lead, and benzo[a]pyrene (B[a]P).

All of these compounds are widely distributed and persist for long periods of time in the environment. The IJC has recently concluded that organochlorines are pollutants of growing concern and that they should be addressed as a class because they are potentially so harmful, numerous and widespread.

In addition to these compounds of primary concern, the IJC has identified over 1000 additional toxic compounds. Many of the these are classified as volatile organic compounds that tend to evaporate or degrade rapidly. They are still widespread and some are very toxic.

POINT SOURCES OF CONTAMINANTS IN THE ENVIRONMENT

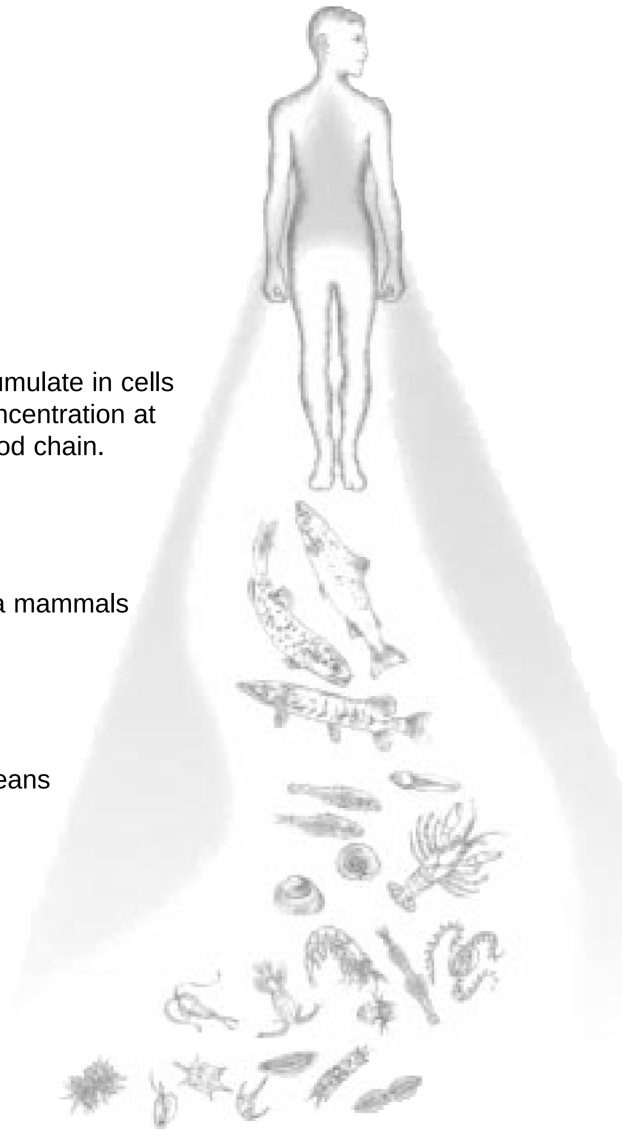
IN ONTARIO THERE ARE ABOUT 300 INDUSTRIAL SITES THAT DISCHARGE DIRECTLY INTO RIVERS AND LAKES, AND THERE ARE ANOTHER 12 000 THAT DUMP THEIR WASTE INTO MUNICIPAL SEWAGE SYSTEMS THAT CANNOT ADEQUATELY TREAT TOXIC CHEMICALS.

NON-POINT SOURCES OF CONTAMINANTS IN THE ENVIRONMENT

MORE THAN 90 PERCENT OF THE PCBS, DDT AND LEAD ENTERING LAKE SUPERIOR ANNUALLY COME FROM "NON-POINT" SOURCE ATMOSPHERIC DEPOSITION.

Figure 3.1

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.

Standards, Criteria, Guidelines, and Levels — What's the difference?

The differences between the terms are important especially from a legal perspective.

A **standard** is a **legally enforceable limit** on the amount or concentration of a substance. Exceeding the standard could result in unacceptable harm to human health or the environment and could also lead to penalties such as fines. Standards, such as those for different air pollutants and the penalties for exceeding them are usually set out in a legally enforceable **regulation**.

Criteria and **guidelines** are advisory limits, but they are **not legally enforceable**. When the concentration of a substance exceeds the limit, there are grounds for concern. Criteria and guidelines are useful guides for managing the risks associated with exposures to environmental contaminants.

Levels are simply amounts or concentrations of a substance in various media, such as, air, water, human tissue.

Pesticides

The term pesticides includes a large variety of classes of compounds. Pesticides have attracted a great deal of attention over the years. Because of such interest, a selected number of important chemical pesticides are described in this section. These include organochlorine, organophosphate, carbamate, triazine, and chlorophenoxy compounds.

Origin

A pesticide is any registered product (chemical or non-chemical) that controls pests such as insects, rodents, weeds, bacteria, viruses, algae and fungi. The term **pesticides** generally describes several categories of compounds including herbicides, fungicides, insecticides, rodenticides, algaecides, disinfectants and several others. Pesticide compounds can either be organic (i.e., containing carbon) or inorganic in composition. Biological pesticides include microbial agents (e.g., *Bacillus thuringiensis*) and pheromones (hormones released by animals).

Table 3.1

BASIC UNITS

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

Table 3.2

SOIL, FOOD AND WATER

SI Units in Liquids	Equivalent in Parts Per Unit				SI 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 µg/L	10^{-3}	1	10^3	10^6	1 µg/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

Table 3.3

AIR

Converting from equivalent in parts per unit to metric SI units
µg/^{3} = ppm x molecular weight of the contaminant x 40.9

Pesticides are used widely in agriculture and forestry where they have become essential to conventional (non-organic) farm practices and to the post-harvest protection of food. The kind of intensive high yield farming practised in Canada currently relies on the use of fertilizers and pesticides. Correct pesticide use can help protect croplands, resulting in an abundant supply of reasonably priced food that is free of infection and disease, and control pests that transmit disease to people or animals.

There are over 500 active ingredients registered for use as pesticides in Canada. In an effort to maximize the benefits of pesticides and reduce harmful side effects of their use, Ontario has implemented an initiative to reduce the use of all pesticides by 50 percent by the year 2000. Integrated pest management (IPM) will be used to achieve this goal.

Sustainable Pest Management

The World Commission on Environment and Development, better known as the Brundtland Commission, defined sustainable development as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." Sustainable development addresses the interdependence of social, environmental, and economic systems. Under the umbrella of sustainable development, integrated pest management (IPM) combines all available techniques needed to manage pests effectively, economically and in an environmentally sound manner. IPM programs are knowledge-based, and are developed for particular crops and pests. To be implemented successfully, IPM programs require active involvement of growers and expert advisors. Various federal, provincial and academic institutions support the research and operational needs of IPM. IPM includes a broad range of farming techniques such as strategic use of chemical and natural pesticides, and natural predators.

Organic agriculture is another farming technique. It is a holistic production system that promotes biodiversity, biological cycles and soil biological activity to eliminate the need for toxic chemicals. The aim is to produce nutritious food through responsible stewardship of the Earth. Soil fertility is maintained through the use of compost, catch crops (crops which "catch" nutrients that might be lost after a crop is harvested), and green manures (crops that return nutrients to the soil when incorporated). A preventive approach is used for pest and disease management that encourages balanced host/predator relationships, and when necessary, uses biological or mechanical control methods that have the least ecological impact. Occasionally, and as a last resort, botanical pesticides such as rotenone may be used.

In 1996, organic food was 0.5 percent of the U.S. retail food sales. Figures for Canada are not available but the sector has been growing steadily as more people have become concerned about the environmental effects of conventional agriculture. Health is the reason some consumers purchase organically growth food, especially those suffering from allergies or environmental illness. Health is also one of the reasons farmers give for converting to organic methods, in that it reduces their exposure to toxins.

Organochlorine pesticides are chlorine-containing compounds and include DDT, aldrin, dieldrin, endrin, chlordane, heptachlor, toxaphene, hexachlorobenzene and lindane. The organochlorines act on pests by interfering with the transmission of nerve impulses, disrupting primarily the functioning of the nervous system. Because they often persist in the environment, many organochlorine compounds have been banned, deregistered, or had their use severely curtailed since the mid-1970s. They are still used in many developing countries to control plant pests and insects that can transmit diseases.

USE OF THE TERMS "ORGANIC" OR "ORGANICALLY GROWN" WHEN APPLIED TO FARMING OR FOOD PRODUCTS, SHOULD NOT BE CONFUSED WITH THE USE OF THE TERM "ORGANIC" AS APPLIED TO COMPOUNDS (INCLUDING MANUFACTURED PESTICIDES) CONTAINING CARBON.

Organophosphorus compounds and carbamates are nerve poisons that are used as insecticides. They were developed to replace the more persistent organochlorines. Organophosphorus compounds are now the most widely used group of pesticides in the world and include parathion, malathion, diazinon, chlorpyrifos and many others. Carbamates include compounds such as aldicarb, aminocarb, carbaryl, carbofuran and methiocarb. Farmers find these pesticides useful because there are many to choose from to control different pests and they are highly effective. The organophosphorus pesticides do not persist in the environment. The carbamates, although more persistent than the organophosphorus compounds, also tend not to bioaccumulate in the environment. Both of these groups act on pests by inhibiting acetylcholinesterase, an enzyme essential for nerve function, and thereby damaging the nerve function. They are acutely toxic to insects, animals and humans.

Triazines are a group of compounds that include such herbicides as atrazine, simazine, propazine and cyanine. They act as inhibitors of photosynthesis in nuisance plants. Worldwide, atrazine has been one of the most widely used herbicides in the past 30 years and has been particularly effective in treating corn crops.

Chlorophenoxy herbicides include 2,4-D and related compounds such as MCPA. 2,4-D is widely used as an herbicide because of its low cost, its effectiveness on broad-leaf plants and because it does not persist or bioaccumulate in the environment. It is acutely toxic in plants, animals, and humans. Chlorophenoxy herbicides act by inhibiting the formation of adenosine triphosphate, thus stopping energy supply to the cell. (See also *Contaminant Profiles*.)

In addition to the active ingredients described above, most pest control products contain additional components, called **formulants**. These components possess chemical or physical properties that serve useful purposes in the pesticide (e.g., by acting as stickers, spreaders, emulsifiers and solvents). Although they are not responsible for the pesticidal activity of the product, formulants may pose toxicological or environmental hazards.

Persistence and Movement in the Environment

Pesticides can enter the environment through their manufacture, use and disposal. Pesticides can be transported long distances in the atmosphere and deposited far from their original place of use. Atmospheric deposition is considered an important source of pesticide contamination of the Great Lakes and in the North. For example, several persistent organochlorine pesticides are commonly found in the tissues of polar bears and seals in the Canadian Arctic even though these substances have not been used in this region. These pesticides were deposited there by long range atmospheric transport from their use in more southerly parts of the world. Similarly, toxaphene has contaminated fish in the Yukon and the Northwest Territories even though it has never been used there. In Ontario, pesticide use is particularly heavy in southern Ontario and residues of several pesticides can be found in drainage basins where large quantities are routinely applied to crops.

Pesticides may enter the water supply when they are accidentally spilled, are siphoned into wells when they are being mixed, are disposed of incorrectly, are sprayed over water for control of mosquitoes and blackflies, or are leached from soil into groundwater. Pesticides may also drift off the target during aerial spraying and contaminate water run off from fields, hydro, highway, and railroad borders. Pesticide residues in food are usually very low but can result from misapplication on crops before or after harvest or mistreatment of food to prevent spoilage or insect infestation.

Because of their very stable chemical structure, **organochlorines** such as DDT and toxaphene do not break down easily and remain in the environment for a long time. Some organochlorines are persistent and tend to accumulate in the food chain, possibly causing concentrations in the fatty tissues of higher animals and humans to reach levels that may pose risks to health. Even though their use has largely been banned in Canada since the mid-1970s, many of these compounds still persist in the environment and are considered carefully in establishing the Great Lakes fish consumption advisories.

Most **organophosphorus and carbamate pesticides** tend to break down readily by the action of enzymes present in living organisms or by other processes in the environment. Their half-lives range from days to months, although generally they last longer in dry climates and at low temperatures. Because they are less persistent, they are less likely than organochlorine pesticides to bioaccumulate in animal and human tissue. However, they are more water soluble than organochlorines and in some cases more likely to reach water supplies.

As a group, **triazine herbicides** are moderately persistent in the environment as they are quite insoluble in water, with half-lives measured in months. The movement of atrazine in the environment is a major concern and it has been found in both surface water and groundwater due to its mobility in soil. Atrazine is degraded in soil and water by photolysis (exposure to light) and by microbial processes in soil.

Exposure

The general public is exposed to pesticides from home pesticide use, from minute residues in food, and to an even smaller extent, from minute quantities in drinking water.

For pesticides currently registered for use in Canada, factory, farm workers and others who handle pesticides have a high potential for exposure even though all stages of pesticide manufacture, transport, sale, and application and disposal are tightly controlled through regulatory standards and safety certification courses. Workers in chemical manufacturing, transportation and clean-up sectors, and those who apply and sell pesticides may be exposed to these chemicals by inhaling them or having their skin come in contact with them. The risk of exposure is greatest when workers do not adhere to safety codes, proper hygiene, and when some is spilled or there is an accident. The improper use of pesticide containers as drinking or cooking utensils by field workers and contamination of open water containers during aerial pesticide spraying has resulted in high levels of exposure.

The pesticide formulation type will affect the amount of exposure and penetration. Pesticides are available in different formulations — liquids, solids or gasses. Certain formulations can penetrate the skin more easily than others; some are more volatile and can pose a greater inhalation hazard. For example, aerosol formulations are difficult to confine to the target area and can present an inhalation hazard to the applicator. Understanding how exposure occurs will help pesticide users to understand by which routes a pesticide is likely to be absorbed, and they can therefore select the appropriate protective clothing, equipment, and working procedures to reduce exposure to various pesticide formulations.

People are exposed to persistent organochlorine pesticide contaminants primarily by eating fatty foods containing small amounts of these compounds. Since the ban of many organochlorine pesticides in the mid-1970s, their levels in crops have been decreasing and are expected to continue to fall. Residue levels in the Canadian food supply are among the lowest in the world.

Large, top of the food chain fish from the Great Lakes basin and inland waters can be a food source of organochlorine exposure. Fish consumption advisories have been developed for sport-caught fish. Commercially caught fish from the Great Lakes are routinely monitored and pose little risk to consumers.

(See also Chapter 8. "Food Quality.")

Health Considerations

There is well-documented historical evidence of pesticide toxicity among farm workers and manufacturing formulating workers who have been exposed to high levels of these chemicals. Some pesticides are harmful on direct contact with eyes and skin, causing irritation and rash. They may also cause respiratory tract irritation. Other effects depend on the particular pesticide and the type of exposure. It is important to read the label and follow all label directions to avoid exposure.

In the case of persistent **organochlorine pesticides** (e.g., DDT) that accumulate in the food chain, health effects due to chronic (long-term) exposure are of more concern than the effects due to acute exposures. In fish and wildlife, there is evidence of reproductive and developmental effects as a consequence of chronic exposure to environmental levels of these pesticides. Laboratory animal studies have shown interruptions in breeding cycles and birth defects. While there is concern that similar effects may occur in humans exposed to the same pesticides in the environment, the scientific evidence to date is not clear. Acute human exposure to large amounts of some organochlorine pesticides can result in nausea, vomiting, diarrhea, stomach pains, excitability, headache, dizziness, and disorientation. Rarely, convulsions and death may ensue. Several organochlorine pesticides are possibly carcinogenic to humans and have been removed from the Canadian marketplace.

In contrast to organochlorine pesticides, **organophosphorus and carbamate pesticides** degrade rapidly in the environment and do not accumulate or concentrate as readily in the food chain. Consequently, there is far less concern for health effects resulting from chronic exposure to these pesticides than for organochlorine pesticides. However, organophosphorus and carbamate compounds have a greater potential for acute toxicity in humans than do organochlorine compounds.

Organophosphorus and carbamate pesticides are absorbed readily following inhalation, ingestion, and skin contact. Because these compounds are distributed rapidly throughout the body, they are typically associated with rapid onset of symptoms minutes to hours after exposure. Some of the more lipid-soluble organophosphorus pesticides can initially be stored in the body's fat and may not produce symptoms for several days. Many organophosphorus and carbamate compounds are considered acutely toxic at relatively low doses. Carbamates tend to be less toxic than organophosphorus pesticides but poisoning symptoms are similar. Nevertheless, the most acutely toxic pesticide when ingested orally is the carbamate, aldicarb. Both organophosphorus and carbamate pesticides interfere with nerve impulses in the body by inhibiting the enzyme acetylcholinesterase. Toxic doses, usually as a result of large occupational or accidental exposure in humans, produce symptoms of sweating, vomiting, weakness, paralysis and in extreme cases, death, usually from respiratory failure.

Many organophosphorus and carbamate compounds, either alone or in combination with other pesticides, account for most pesticide related poisonings. Poisoning incidents include suicides, homicides, and accidental exposures, especially in children. Pesticides usually contain solvent carriers such as toluene or xylene that may also produce toxic effects.

Infants under six months of age may be particularly susceptible to organophosphorus and carbamate pesticides, because they have incompletely developed acetylcholinesterase systems and immature livers unable to metabolize and detoxify these compounds as readily as adults. People with asthma are at increased risk following organophosphorus pesticide exposure, because many of these compounds cause narrowing of the airways, which can exacerbate breathing difficulties.

Triazine compounds have low acute toxicity but have been implicated with contact dermatitis (skin irritation) and eczema in workers who have been in contact with the herbicides.

Regulations

The major federal legislation regulating pesticides in Canada is the *Pest Control Products Act* and Regulations, administered by the Pest Management Regulatory Agency, Health Canada. The registration process involves in-depth assessment of scientific studies pertaining to toxicology, environmental impact, and product performance. The intent of the legislation is to ensure the safety, merit and value of pest control products used in Canada.

Manufacturers are required to inform the federal government regarding the composition of their products, including the identity and concentration of all formulants. Acute toxicology tests must be conducted on the formulated product; these tests are used to assess the acute hazards posed by the formulants in combination with the active ingredient(s), and may indicate if further toxicity testing is required on the formulants.

With regard to food, the *Food and Drugs Act* and Regulations prohibits the sale of both domestic and imported foods that contains any harmful or poisonous substance. The *Guidelines for Canadian Drinking Water Quality* set acceptable levels of many chemical contaminants in drinking water and the Ontario Drinking Water Surveillance Program routinely monitors for chemicals. Most chemicals are removed during municipal water treatment processes and levels of those remaining are generally minimal and not considered a risk to human health.

Other federal legislation regulates different aspects of pesticide use. The *Migratory Birds Convention Act* protects water fowl and other migratory birds, and the *Fisheries Act* protects fish and fish habitat. The *Transportation of Dangerous Goods Act* and Regulations permits the transport of potentially dangerous goods only by people who are properly trained and use the appropriate procedures.

Legislation at the provincial and municipal levels may further restrict pesticide use with respect to provincial conditions, and public health. Provincial governments are responsible for regulating the post registration sale, storage, use and disposal of pesticides. This includes training and licensing of commercial pesticide operators, vendors and exterminators, imposing risk reduction measures, post registration monitoring for adverse impacts, compliance and enforcement. Risk reduction measures encompass a variety of activities such as permits for high risk uses (i.e., building fumigations, treatment of weeds in aquatic environments), posting of signs following spraying in urban areas and dealing with spills and clean-up (Ontario Ministry of Environment and Energy October 1995). (For more information on individual pesticides, see *Contaminant Profiles*.)

Other Chemicals

Origin

Many chemicals that have been used and released into the environment are of concern to people and their health. Among these are polychlorinated biphenyls (PCBs), dioxins and furans, polycyclic aromatic hydrocarbons (PAHs), and chlorinated naphthalenes. These compounds were never used as pesticides, but they are current problems in the environment because of their persistence.

PCBs are mixtures of 209 similar chemicals, called congeners, that were widely used in electrical and hydraulic equipment and lubricants because they are chemically stable and heat resistant. In 1980, the use of PCBs in Canada was restricted to existing electrical and mechanical equipment. Importing or manufacturing PCB filled equipment was also prohibited.

Dioxins and furans are a group of chemicals (75 dioxins and 135 furans) that are unwanted by-products of some industrial processes, such as the manufacture of some pesticides and the bleaching of wood pulp with chlorine. They are also by-products of fuel combustion, such as occurs in vehicle engines and furnaces, and during waste incineration.

Some Types of Pesticides

Herbicides

These are used to control unwanted weeds. The most commonly used herbicides in Canada are 2,4-D and related compounds, such as MCPA, which are used to control broad-leafed weeds.

Insecticides

These are used to control undesirable insects. Common insecticides include parathion, diazinon, malathion and fenitrothion. Other types of insecticides include synthetic pyrethroids, synthetic insect growth regulators and pheromones (such as sex attractants).

Fungicides

These are used to prevent rot on fruits and vegetables. Captan is a common fungicide used on crops in Canada. Fungicides are also used as wood preservatives in the timber, wood products, and building industries.

Rodenticides

These are used to combat rodents and other small mammals. Common rodenticides include strychnine, red squill and warfarin.

PAHs are a large group of chemicals formed from incomplete combustion of fossil fuels, organic matter and garbage. They are found in soot and many petroleum products including creosote, tar, and vehicle exhausts, and are by-products of the metal smelting industries. As well, PAHs are present in foods prepared through methods such as smoking, grilling, frying and barbecuing. Of the many PAHs in the environment, benzo[a]pyrene or B[a]P has been the most studied to date.

Chlorinated naphthalenes are a group of chemicals made up of many isomers. They are used in electrical insulation and are by-products of industrial manufacturing processes that release them into the environment.

Persistence and Movement in the Environment

PCBs, dioxins and furans, and chlorinated naphthalenes are slow to break down in the environment. They are also very soluble in fat and consequently tend to accumulate in living organisms including human tissues. PAHs break down more easily but are continuously produced by various sources and released into the environment. These contaminants can be transported in the atmosphere along wind currents, in water or by living organisms.

Exposure

The most important route of exposure to PCBs, dioxins and furans in the general population is through the consumption of foods contaminated with trace amounts of these substances. All Canadians have trace amounts of these contaminants in their bodies. Because PCBs, dioxins and furans accumulate in fatty tissues, including breast milk, nursing infants are potentially at increased risk of exposure. However, the documented health benefits of breast-feeding outweigh the risks posed by these contaminants. The greatest sources of PAH exposure for the general population are inhalation of tobacco smoke, wood smoke and contaminated air, and the ingestion of PAHs through food. Inhalation and skin contact are the two most important routes of exposure to chlorinated naphthalenes in the occupational setting. Exposure through the consumption of contaminated foods is likely the most important route of exposure for the general population.

Health Considerations

The various **PCB congeners** have slightly different chemical structures and vary mainly in the number and the positions of chlorine atoms they possess. Higher chlorine content generally produces a higher level of toxicity. Effects seen in studies with laboratory animals have included decreased longevity, developmental effects in the offspring, reproductive effects and cancer. Occupational exposure to high levels of mixtures of PCBs has occasionally been associated with skin irritation and liver effects. Long-term reproductive toxicity is not associated with chlorine content, but rather with the way in which the chlorine atoms are arranged in the compound.

One particular dioxin, known as **2,3,7,8-TCDD** is extremely toxic. Animal laboratory studies have shown that prolonged exposures result in weight loss and damage to the liver, the reproductive system and the immune system. Accidental exposures of humans to 2,3,7,8-TCDD have resulted in skin lesions, but have not been fatal. Studies indicate that there may be detectable increases in cancer rates as a long-term result of high occupational or high accidental exposures to dioxin.

Health effects that have been attributed to exposure to **PAHs** include bronchitis, dermatitis and other skin conditions. Lung and skin cancer have been reported in occupationally exposed workers.

Common effects in people exposed to **chlorinated naphthalenes** are chloracne of the skin arising primarily from direct contact and liver damage as a result of inhalation in the industrial workplace. The liver is the primary internal organ directly damaged by chlorinated naphthalenes.

The effects of the above contaminants on health have been observed following high occupational or accidental exposures or in laboratory animals treated with large doses of these chemicals. The general population is exposed, by comparison, to very low levels found in the environment. The effects that prolonged exposure to low environmental levels may have on people's health are not as apparent or clearly understood.

Regulations

PCBs, dioxins and furans, and other organochlorines are monitored in domestic and imported foods by Health Canada under a variety of programs and are subject to or regulated under the *Food and Drugs Act* and Regulations.

The *Guidelines for Canadian Drinking Water Quality* set acceptable levels of many chemical contaminants in drinking water and the Ontario Drinking Water Surveillance Program routinely monitors for chemicals. Most chemicals are removed during municipal water treatment processes and levels of those remaining are generally minimal and not considered a risk to human health.

The *Hazardous Products Act* also regulates the levels of chemical contaminants in many consumer products.

In 1992, the Ontario Ministry of Environment and Energy introduced regulations under its Municipal-Industrial Strategy for Abatement (MISA) program to reduce or eliminate the formation of all dioxins and furans by altering industrial practices, particularly in pulp and paper mills. As well, Regulations under the *Canadian Environmental Protection Act* have reduced the amount of dioxins and furans being emitted from pulp and paper mills that use chlorine bleaching.

For more information on individual chemicals see *Contaminant Profiles*.

Q. What is the status of contaminant levels in the Great Lakes basin?

A. In general, levels of contaminants in air, water and wildlife have declined. Metals and persistent chlorinated substances decreased rapidly from the early 1970s to the early 1980s. Declines since then have been much slower. Contaminant levels in human breast milk have also decreased and continued to do so slowly, up to the last time levels were measured in 1992. Contaminant levels in food in the Canadian marketplace are extremely low and in general well below the current internationally accepted action levels. The levels of some persistent toxic substances (e.g., dioxins and PCBs) are sufficiently high in some fish and wild game that they may pose a health risk to those exceeding health-based consumption guidelines.

Metals

Several metals and their compounds found in the environment are a potential health concern. These metals and their compounds are relatively abundant in the environment and are of toxicological concern.

Aluminum is found in the Earth's crust, many consumer products and other manufactured products.

Arsenic is widely distributed in nature and found mainly in groundwater where the bedrock is high in arsenic.

Cadmium in the environment is from many sources including incinerators, batteries and long- range transport. Cadmium is used in a wide variety of industrial processes.

Chromium is abundant in the Earth's crust and is used in the metals industry.

Lead in the environment is from the former use of leaded gasoline, from incinerators and some current and old industrial processes, and also from removal of old paint during renovations.

Mercury residues result from old industrial practices, pesticides no longer in use, incinerators and long-range transport.

Nickel is mainly used in the steel industry and is found in some consumer products.

Other metals such as antimony, beryllium, iron, manganese, selenium, and zinc are found in the environment and can be a concern to health.

Origin

Metals have a multiplicity of industrial applications. In the metallic form, they may appear in structures, pipes, solders, and electrical supplies. In organic and inorganic compounds, they appear in pigments, paints, drugs, fuel additives, and pesticides.

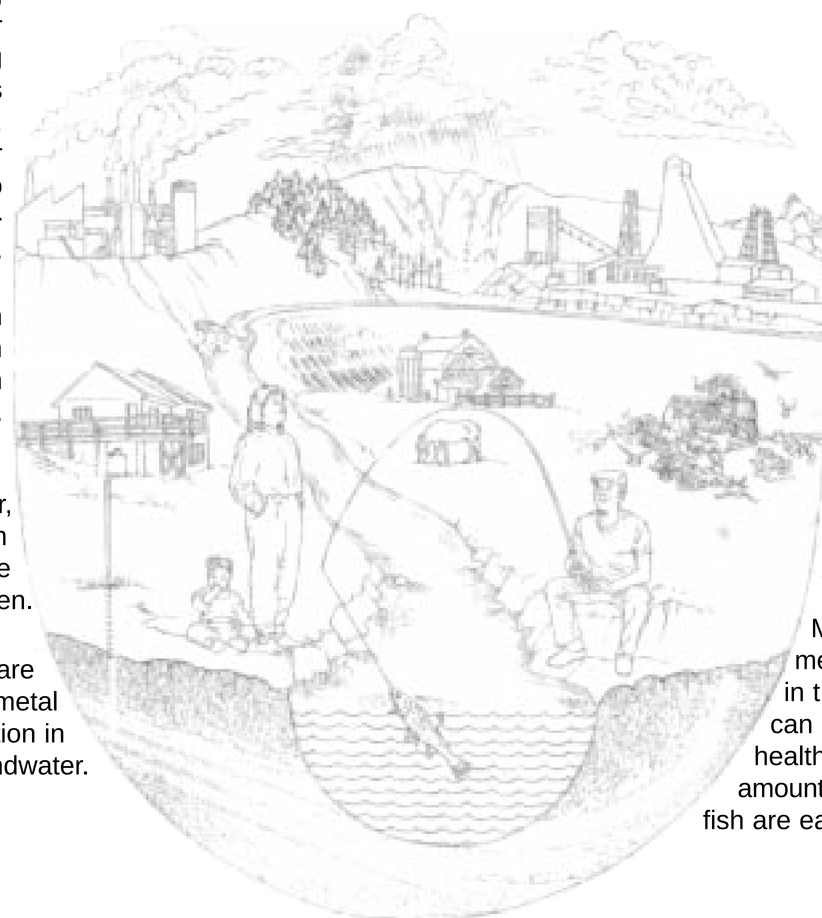
Persistence and Movement in the Environment

Metals are neither created nor destroyed, but they may be changed from one form to another, such as from solid metal to a metal salt. Furthermore, human use influences their potential to affect health in two major ways: 1. by movement through the environment; and 2. by altering their chemical form. Metals move naturally in the environment both by geological and biological cycles. In the geological cycle, rainwater dissolves rocks and ores and transports material to streams and rivers, adding to and removing from adjacent soil. The metals may precipitate as sediments at the bottom of the rivers and lakes or may be taken up in rainwater to be relocated elsewhere on Earth. The biological cycles include accumulation by plants and animals and incorporation into food chains and food cycles.

Human activities (such as mining and smelting, burning of fossil fuels and uncontrolled industrial waste discharge) and the use of metal-containing products by the public are the major contributors to increased levels of metals in the environment. Mining can result in the release of metals such as mercury, arsenic and lead into lakes and streams. Metals from discarded consumer products (e.g., lead and cadmium from batteries) can be leached into groundwater or emitted into the air during incineration. Lead solder in older pipes can result in lead leaching into drinking water. The flooding of land for hydroelectric dams and acid rain helps to dissolve metals, such as magnesium, lead, nickel, cadmium and especially mercury, that occur naturally in soil and rocks. These metals can accumulate to significant levels in fish and wildlife.

Figure 3.2

THE RELEASE OF METALS INTO THE ENVIRONMENT



Exposure

In certain occupational settings, such as welding, people may be exposed directly to metals by inhaling their fumes. Incinerators release significant amounts of metals as combustion products, however, their concentrations are rarely high enough to pose an airborne health hazard. Metals from incinerators do end up being deposited on soil and vegetation. Because of the accumulation of metals in the food chain, the consumption of wild fish and game may be a significant route of exposure to these contaminants. Consumption advisories are in effect in parts of Canada because of mercury levels in fish and cadmium levels in organ meats of deer, moose and caribou.

For children the major route of exposure to many metals is through ingestion. Children consume more calories per body weight than adults and have greater gastro-intestinal absorption of metals, particularly lead. Metals in dust and dirt can be ingested by young children who suck their fingers and put toys and other objects in their mouths. Lead in paints was a historical source of exposure but now has very limited presence in Canadian paints and coatings (levels are regulated under the *Hazardous Products Act*). In older buildings, paint chips may be around for children to put in their mouths. Children have also chewed toys and furniture painted with lead-based paints. It has recently been discovered that inexpensive horizontal PVC mini-blinds made in several countries contain lead (see also Lead in *Contaminant Profiles* for more information).

Lifestyle factors contribute significantly to exposure to metals. For example, smoking leads to elevated levels of cadmium in people, depending on the tobacco supply.

Health Considerations

Most toxic metals have multiple effects and interfere with specific biochemical and cellular processes. A metal's chemical form can influence its absorption, distribution in the body, and toxicity. For example, mercury in the environment can be found in its elemental form, inorganic forms, or it can be methylated and found as methyl mercury (an organic form). Inorganic mercury is not easily absorbed by plants or animals. However, methyl mercury is readily absorbed by living organisms and is known to affect the human nervous system. Such factors as diet, age, smoking, alcohol ingestion, and interaction with other metals influence toxicity and the health effects observed.

Scientific knowledge about the health effects of metals continues to broaden. Historically, medical concerns about metals centred around acute exposures and health effects such as abdominal colic from lead toxicity or bloody diarrhea and suppression of urine formation from ingestion of mercury. Concerns now focus more on long-term exposure to low levels of metals, which may produce subtle, subclinical health effects. Human immune system suppression, behavioural changes and learning disabilities from interference with neurological development are examples of such subtle effects.

There is some concern that metals may play a role in promoting or initiating certain cancers. According to the International Agency for Research on Cancer (IARC), the metals that are known human carcinogens are beryllium, cadmium, chromium, and nickel.

Regulations

Metals are monitored in both domestic and imported foods by Health Canada under a variety of programs and are subject to or regulated under the *Food and Drugs Act* and Regulations.

The *Guidelines for Canadian Drinking Water Quality* set acceptable levels of many metals in drinking water and the Ontario Drinking Water Surveillance Program routinely monitors for metals. Most metals are removed during municipal water treatment processes and levels of those remaining are generally minimal and not considered a risk to human health.

The *Hazardous Products Act* also regulates the levels of metals in many consumer products. For example, the act regulates the content of lead, cadmium, and mercury in paints to levels that pose little risk to human health.

For more information on individual metals see *Contaminant Profiles*.

Micro-organisms

Micro-organisms include bacteria, protozoa, viruses and fungi. These microscopic organisms are an integral part of the natural environment and exist in air, water, soil, food, and in and on our bodies. While most of these organisms are harmless and are considered desirable, many are capable of causing discomfort and producing severe illness and death in humans and other animals. Historically, infectious diseases were the most common cause of death until developments in sanitation and antibiotics.

Bacteria, Viruses, Fungi and Protozoa

Origin

Bacteria are small, single-cell living organisms that lack a nucleus to enclose the genetic material. They reproduce by dividing in half and often grow best when nutrients are abundant and temperatures are warm. Bacteria are common in the environment and are frequently found in raw food such as meats, poultry, eggs, and unpasteurized milk; water; humidifiers; air-conditioners; and air ventilation systems. Common types of bacteria include *Salmonella*, *Campylobacter*, *Escherichia coli* (*E. coli*), *Streptococcus*, *Staphylococcus* and *Clostridium*. The innate properties of some bacteria have also been exploited for a variety of commercial uses. For example, certain bacteria have been used as insecticides (*Bacillus thuringiensis*) and to clean up oil spills (*Pseudomonas spp.*).

Viruses are extremely small non-cellular entities, with no intrinsic metabolism. They consist of genetic material (DNA or RNA) that may be wrapped in a protein coat. Unlike true organisms, viruses do not reproduce by cell division. Rather, they reproduce by replication, invading a host cell and diverting the cell's reproductive capacity toward the production of new viruses. Often, the reproduction of a virus within a host cell will lead to the death of that cell. Fortunately, viruses tend to be host-specific so that other animal and plant viruses rarely affect humans. The specificity of the virus-host relationship has led to the development of viruses for use in pest control. Baculoviruses have been used to control pest insects on crops. Other viruses have been used to control pest animals, such as the myxoma virus which was used to control rabbit populations in Australia.

Fungi are a group of widespread, unicellular and multicellular organisms that lack chlorophyll and usually bear spores and often form filaments. Fungi need moist conditions in which to grow. Moulds, a type of fungi, are capable of growing on many substances and surfaces depending on the conditions. Many moulds are beneficial. Cultivated varieties enhance the flavour and appearance of cheeses. One of the most important beneficial moulds is *Penicillium*. The discovery of its ability to kill harmful bacteria led to the development of Penicillin and the discovery of antibiotics. Moulds may also produce toxic metabolites (by-products) known as mycotoxins that can be harmful if eaten or inhaled.

Protozoa are one-celled organisms, mostly free-living in water or soil, which reproduce by cell division. They differ from bacteria in that their genetic information, in the form of chromosomes, is contained within a nuclear envelope. The common types to infect drinking water are the parasites *Giardia lamblia* and *Cryptosporidium spp*. Other important protozoan parasites known to be transmitted by food are *Entamoeba histolytica* and *Toxoplasma gondii*.

The micro-organisms in the environment that can 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 material such as animal wastes and animal carcasses.

Measurement

Microbiological agents, including bacteria and viruses are usually expressed as the number of organisms present in a given volume, for example, 100 organisms/litre of water or 100 organisms/cubic metre of air. Bacteria are typically detected and/or measured by extracting them from the sample and growing them on suitable cultural media. Some assays (measuring techniques) involve detection of a component part of a bacterium, such as a protein in the cell membrane, or a specific metabolite. Viruses are very difficult to detect and measure, and few methods currently exist.

Persistence and Movement in the Environment

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

Exposure

People come into contact with harmful micro-organisms mainly by eating contaminated food, drinking contaminated water, breathing indoor air, and using water for recreation. Fecal contamination of water or fertilizers, insects and animals, and unsanitary handling of crops and food will favour the spread of micro-organisms. Inadequate ventilation in buildings and homes, and the inappropriate maintenance of humidifiers, air-conditioners and air ventilation systems can enhance the growth of bacteria, moulds and fungi in these dwellings. Micro-organisms can be found in raw foods such as meat, poultry, eggs, shellfish, and unpasteurized milk. Unprocessed raw fruits and vegetables are seldom a concern for exposure to harmful micro-organisms.

Giardia lamblia is a protozoan that infects the intestinal tract of humans and is the pathogen most often identified in waterborne disease outbreaks. Cysts enter the water supply when contaminated human or animal feces are deposited in or near the water. Many animals such as beaver and muskat act as reservoirs of the parasite. *Giardia* cysts isolated from humans, dogs, cats, muskrats and beaver do not appear to be host specific. *Giardia* outbreaks are rare but have occurred when contaminated drinking water receives inadequate treatment. In May 1996, there was an outbreak of giardiasis in the town of Dauphin, Manitoba, due to contamination of the town water supply. *Giardia* can also be spread by food or person-to-person contact. Day-care centres are prime sites for outbreaks where the cysts are spread among children and staff. Infected individuals can then spread the parasites to their parents and siblings.

Cryptosporidium parvum is another protozoan parasite that can infect humans through contaminated drinking water or by the fecal-oral route from human to human or animals to humans. The parasite has been isolated from a number of sources including cattle and pigs which in turn are responsible for infections in man. British Columbia experienced two separate waterborne outbreaks of cryptosporidiosis during the summer of 1996. The presence of cattle grazing in the watersheds is thought to have been the source of the outbreaks in Cranbrook and Kelowna. A waterborne outbreak also occurred in Collingwood, Ontario, in March 1996.

Giardia and *Cryptosporidium* are resistant to most disinfectants. The only practical way for municipalities to remove the pathogens is filtration.

Aflatoxins are an important type of mould mycotoxin implicated in human disease. Certain crops, grown or stored in humid climates are susceptible to mould contamination that can produce aflatoxins. These crops include corn, tree nuts and peanuts. The fungus *Aspergillus flavus* is the organism principally responsible for the production of aflatoxins on crops. Aflatoxins are rarely found in Canadian field crops because of the cooler, drier climate. However, imported crops from susceptible areas and their processed goods are monitored to ensure that they do not contain aflatoxins.

Health Considerations

Thousands of Canadians each year are affected by food poisoning caused by bacteria, viruses, parasites and seafood toxins. Symptoms commonly include stomach cramps, nausea, vomiting and diarrhea. Children and older persons may be especially affected and serious cases can lead to death. The most common types of bacteria associated with food poisoning are *Salmonella*, *Campylobacter*, *Escherichia coli* (*E. coli*), *Staphylococcus* and *Clostridium*. *Salmonella* is the best known with an estimated 600 000 cases of poisoning occurring each year. Most such cases are unreported, as the symptoms, which can start between eight to 24 hours after eating, resemble the common flu. *Salmonella* occurs most commonly in raw milk, eggs and poultry and can be transmitted through water.

In the case of food poisoning, bacteria can cause their effects either by intoxication or infection.

- Intoxication is brought about by the production of toxins by the bacteria and can happen in either of two ways:
  - Some bacteria such as *Staphylococcus aureus* and *Clostridium botulinum* produce toxins while they are growing and multiplying in the food. Bacterial toxins can remain in food even though cooking has killed the bacteria responsible for producing them. The toxins are released from the bacteria into the food and if the food is ingested, the toxins can act very quickly. The main symptom of food poisoning due to *Staphylococcus aureus* is acute vomiting followed by abdominal pains and diarrhea.
  - Other bacteria such as *Clostridium perfringens* grow and multiply in food but the toxins they produce remain inside the bacterial cells. The toxins are only released from the cells when the bacteria sporulate and/or die. When contaminated food is eaten, the bacteria establish themselves in the intestinal tract but no ill effects are felt until a sufficiently large number of bacteria have released the toxins. Symptoms of this type of poisoning due to *Clostridium perfringens* include abdominal pain, diarrhea, nausea, and sometimes vomiting.
- Infection by food poisoning is caused by the ingestion of contaminated food containing live bacterial cells, viruses or parasites. The bacteria grow and multiply in the intestine where they produce the toxin that causes illness. *Salmonella* and *E. coli* are among the bacterial organisms responsible for this type of food poisoning, and the main symptoms they cause are abdominal pain and diarrhea and a general feverish condition sometimes accompanied by vomiting.

Many viral infections are not apparent, some cause only local infections such as skin disease, whereas others spread rapidly throughout the body to produce systemic diseases, such as the common cold, measles, polio and viral hepatitis. Some viruses implicated in food-borne illness include Poliovirus, Hepatitis A virus, Coxsackie group A viruses, and Echovirus. Some viruses can contaminate drinking water if it is not properly protected and treated. For example, Norwalk viruses in drinking water can cause diarrhea in humans. In the case of Hepatitis A, outbreaks have been related to food preparation by infected food handlers, raw or undercooked shellfish from sewage-contaminated water and by contaminated drinking water. The course of viral infection depends on factors such as the virulence of a particular strain of virus, the dose absorbed, and the resistance of the host. Individual host resistance can be affected by specific immunity, age, stress or nutritional status.

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. Other mycotoxins, such as aflatoxins and penicillic acid, are poisonous at high concentrations, and lower levels eaten over a longer time can cause liver cancer. Certain varieties of mushrooms, which are a type of fungi, are toxic when eaten and can cause severe illness (e.g., amanita poisoning) or death. Other fungi can grow in the lung (*Aspergillus spp.* in granary and aviary workers) or on the skin (the most common in humans is athlete's foot).

When the protozoan parasite *Giardia lamblia* infects drinking water, it causes giardiasis, also known as "beaver fever" because animals such as beaver act as a reservoir for this pathogen. Giardiasis is characterized by diarrhea, loss of appetite, dehydration, cramps and, in some cases vomiting. The parasitic protozoa *Entamoeba histolytica* and *Cryptosporidium spp.* also cause enteritis or dysentery.

Regulations

Guidelines for Canadian Drinking Water Quality set limits protective of human health for the levels of biological contamination of drinking water. Fecal coliform bacteria such as *E. coli*, a group normally found in the intestines of animals and humans, serve as the general indicator of harmful micro-organisms in the water. Since they are generally the most abundant contaminating organisms, their absence indicates that the levels of disease-causing organisms are also probably low. The guidelines set limits of total coliform bacteria in drinking water, at a maximum of 10 organisms per 100 millilitres, none of which are to be fecal coliforms (as indicated by the presence of *E. coli*). According to the 1996 edition of the *Guidelines for Canadian Drinking Water Quality*, the confirmed presence of *E. coli* in drinking water should trigger an immediate "boil water" advisory.

Guidelines for Canadian Recreational Water Quality set limits for the concentration of micro-organisms that are safe in recreational water. The goal of the guidelines is to ensure that water used for recreational purposes is sufficiently free from fecal contamination, disease-producing micro-organisms, and other hazards that may pose a risk to the public. Fecal coliform bacteria serve as the general indicator of harmful micro-organisms in the water. The guidelines set limits of fecal coliforms, in fresh water, at less than 2000 organisms per litre, and suggest that beaches be closed if these levels are frequently exceeded.

Health Canada, under the *Food and Drugs Act* and Regulations, is responsible for assessing the microbial hazards in food, for setting standards for acceptable microbial content, and for setting regulations for the control of microbial hazards in both domestic and imported food.

For more information on individual micro-organisms see *Contaminant Profiles*.

Radiation

All people are exposed to radiation. The greatest part of our total radiation exposure comes from natural sources. Light and heat from the sun are two examples. Certain naturally occurring elements, such as radium and uranium, also emit radiation. The remainder comes from the various sources of radiation artificially produced by humans, including nuclear power reactors, nuclear medicine, X-rays, radio and television waves, and microwaves.

Radiation is energy in the form of waves or particles. A distinction needs to be made between ionizing radiation, i.e., radiation emitted by radioactive substances, and non-ionizing radiation, such as radio waves, microwaves, and the low frequency electromagnetic waves emitted by power transmission lines. Although both types of radiation can have harmful biological consequences, their mechanism of action and possible health effects are quite different.

Ionizing Radiation

Origin

Ionizing radiation is found everywhere and comes from both natural and artificial sources. Natural radiation sources have always existed, and all living organisms are continually exposed to them. These sources include cosmic rays, and radiation emitted from naturally occurring radionuclides found in the Earth's crust (e.g., uranium, radium, potassium-40), in the air (i.e., radon and its decay products), and those produced in the atmosphere by the interaction of cosmic rays with some components of air.

In addition to natural sources, artificial sources of ionizing radiation have contributed to total radiation doses over the last 50 years. These sources include the radioactive fall-out from nuclear weapons detonations; discharges of radionuclides to the environment from nuclear technologies employed in industry, hospitals, research facilities, consumer products such as smoke detectors; and the medical use of X-rays and radioactive materials.

The largest source of artificial radioactivity released into the environment has come from atmospheric nuclear weapons tests conducted in the 10-year period immediately prior to the 1963 Limited Test Ban Treaty on atmospheric detonations. Non-signatories to the treaty carried out a limited number of above-ground tests from 1963 to 1980. Some testing has continued underground, and although small amounts of radioactive material have occasionally been vented to the atmosphere, increases in environmental fall-out have been insignificant. Levels of fall-out radionuclides peaked shortly after the cessation of atmospheric testing in 1963, and have declined to levels approaching background. The dose resulting from the majority of radionuclides produced during testing has almost all been received, and currently averages about 0.005 m*Sv* per year, compared with about 0.14 m*Sv* per year in 1963 (Atomic Energy Control Board 1995).

The widespread use of nuclear technologies in power generation, medical diagnosis and treatment, and consumer and industrial applications also results in the release of radioactivity into the environment. The release of this radioactivity is controlled and regulated (see "Regulations" for more information). The components of the nuclear fuel cycle (uranium mining and processing, fuel fabrication, nuclear power generation, and waste management) are all potential sources of radioactivity. On average, radiation exposures of the public from these activities represent a minor increase above natural sources. The large quantities of highly radioactive waste generated during power production, however, remains a significant disposal problem. Discharges from facilities such as hospitals, research facilities and industry contribute minimally to total radiation exposure from natural and artificial sources.

Concepts

Atoms are composed of three major constituent particles: positively charged protons, negatively charged electrons, and neutral neutrons. The protons and neutrons comprise the relatively small nucleus, around which the electrons revolve, and their number characterizes the species of atom, or nuclide.

Some nuclides are stable, many are unstable. These unstable nuclides, or **radionuclides**, become stable by ejecting subatomic particles and high-energy photons, and transforming into lighter, more stable nuclides. This process is known as **radioactive decay**, and the energy released is referred to as **ionizing radiation**. A simple definition of ionization is that the radiation detaches electrons from the atoms of the medium it passes through and leaves a trail of high-density electrical charge in its wake. If the medium is a living cell, the electrical charge can lead to biological damage. Examples of ionizing radiation include alpha particles, beta particles, gamma rays, X-rays, and neutrons.

Alpha particles are energetic, positively charged particles (helium nuclei) that rapidly lose energy when passing through matter. They are commonly emitted in the decay of the heaviest radioactive elements, such as uranium and radium. Alpha particles are the least penetrating type of ionizing radiation; they can scarcely penetrate the dead, outer layer of skin, and are seldom a hazard outside of the body. However, if an alpha radiation source is ingested or inhaled, it could be retained in the body, and subject various internal tissues to alpha radiation.

Beta particles are fast moving positively or negatively charged electrons emitted from the nucleus of some radionuclides. Beta particles are more penetrating than alpha particles, but are less damaging over equally travelled distances. Energetic beta particles may penetrate a centimetre or so of tissue, although most are absorbed in the first few millimetres. As with alpha emitters, beta emitters are generally more hazardous if ingested or inhaled.

Gamma radiation and **X-rays** are discrete quantities of electromagnetic energy, without mass or charge. Gamma rays often accompany the emission of alpha or beta particles from a nucleus. X-rays originate from processes occurring outside the nucleus of the atom. Gamma rays are highly penetrating, and can easily pass through the body, or be absorbed by body tissues, thus constituting a radiation hazard for the entire body. X-rays are generally lower in energy and therefore less penetrating than gamma rays.

The strength or **activity** of a radioactive source is a measure of its rate of decay. The time taken for the activity of a quantity of radionuclide to lose half of its value by decay is called the *half-life*, which is unique to each radionuclide. The activity of a radionuclide is expressed in a unit called the **becquerel** (*Bq*). One becquerel is defined as one atomic transformation or disintegration per second. Activity was formerly expressed in a unit called the **curie**.

Table 3.4

COMPARISON OF ABSORBED AND EQUIVALENT DOSE

Radiation Type	Absorbed Dose	Equivalent Dose
Gamma radiation	1 *Gy*	1 *Sv*
Beta radiation	1 *Gy*	1 *Sv*
Alpha radiation	1 *Gy*	20 *Sv*

Table 3.5

RADIOACTIVE HALF-LIVES OF SELECTED RADIONUCLIDES

Radionuclide	Half-life	Radionuclide	Half-life
Uranium-238	4.5 billion years	Strontium-90	29 years
Plutonium-239	24 390 years	Tritium	12.5 years
Radium-226	1 600 years	Iodine-131	8.5 days
Cesium-137	30 years	Radon-222	3.8 days

Dose Quantities

The hazards of radioactive substances are related to the fact that they emit ionizing radiation. When ionizing radiation passes through matter, including living tissue, some of the energy is deposited in the material as a result of electrical interactions. This electrical charge results in chemical changes in the irradiated cells that can lead to biological damage. The damage to the cell depends on the amount of energy absorbed per kilogram of living tissues. This amount is the **absorbed** dose and the corresponding SI unit is the **gray** (*Gy*) where 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 rad = 1 *Gy*).

Not all absorbed doses of radiation are equal in their ability to damage living cells. One *Gy* to tissue from alpha radiation, for example, is more harmful than one *Gy* from beta radiation. To put all ionizing radiation on an equal basis with regard to potential for causing harm, the absorbed dose is multiplied by a radiation weighting factor to give an **equivalent dose** to the exposed organ. The weighting factors take account of the way the particular radiation distributes energy in tissue, and range from 1 for beta radiation to 20 for alpha radiation. The SI unit for the equivalent dose is the **sievert** (*Sv*). One sievert is equal to one joule of energy absorbed per kilogram of body weight. The sievert is actually a very large unit. Several sieverts of radiation delivered in a short period can be lethal. For radiation protection purposes, doses are generally measured in millisieverts, where one sievert equals 1000 millisieverts (m*Sv*).

The harm induced by radiation exposure has been found to vary in both magnitude and kind, from one tissue or organ to another for the same equivalent dose. In other words, some body tissues can be damaged by radiation more easily than others. For example, the risk of fatal lung cancer is greater than the risk of fatal bone cancer for the same equivalent dose. Another type of harm that must be taken into account is the risk of serious hereditary damage that could result if a sperm or egg cell is irradiated. These complications are dealt with by multiplying the equivalent dose in each of the major organs and tissues by a factor related to the risk associated with the organ or tissue. The sum of these weighted equivalent doses is then called the **effective dose**, also measured in sieverts. For low levels of radiation, the harm resulting from a given effective dose will be approximately the same regardless of the type of radiation or the tissues irradiated.

Radionuclides taken into the body by inhalation, ingestion, or absorption through the skin may remain in certain tissues and organs for extended periods of time; in some cases, the resulting dose to the internal organs may occur over several days or years. The **committed effective dose** is the total effective dose received from a radioactive substance in the body during the remainder of an individual's life, taken to be 50 years for an adult, and 70 years for a child.

Table 3.6

RADIOLOGICAL UNITS

Quantity	SI Unit	Symbol	Old Unit	Symbol	Relationship
Activity	becquerel	*Bq*	curie	Ci	1 Ci = 3.7 x 10^{10} *Bq*
Absorbed dose	gray	*Gy*	rad	rad	1 rad = 0.01 *Gy*
Equivalent dose Effective dose	sievert	*Sv*	rem	rem	1 rem = 0.01 *Sv*

The committed dose is included in any calculations of effective dose. The effective dose therefore serves as a broad indicator of the risk to human health from any type of radiation and any distribution of dose in the body, whether received internally or externally, from natural or artificial sources.

Persistence and Movement in the Environment

Radionuclides released into the environment can be in gaseous, liquid, or particulate form. With few exceptions, they become involved in a complex series of physical, chemical, and biological processes that may ultimately lead to irradiation of humans. Some of these processes result in progressive dilution, others lead to physical or biological concentration through the food chain.

The movement of radionuclides in the environment is driven by atmospheric, aquatic, and terrestrial processes. Material released into the atmosphere is transported and dispersed by normal mixing in the atmosphere and may be removed through wet (i.e., rain) and dry (i.e., dust) deposition. Deposited radionuclides may also accumulate in soil, or be leached into groundwater. Radionuclides released into aquatic systems may be transported and diluted, may be adsorbed onto suspended particles, or may accumulate in aquatic animals and plants. Radionuclides entering groundwater are transported slowly, which may lead to the contamination of well and surface waters. As a result of the long half-life of most radioactive elements, radionuclide contamination may continue long after a source has been removed.

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 is often much less than its radioactive half-life due to other environmental and biological processes.

Exposure

Human exposure to radioactivity may be through either internal or external irradiation. Internal doses can result from the inhalation of radionuclides in air, or consumption of food and water. The duration of exposure is dependent on both the radioactive half-life of the material, and on the persistence of the source in the body, or biological half-life. External exposure can occur from irradiation by cosmic rays, or from radionuclides in the air or after they have been deposited on the ground, and is dependent on the proximity of the source. Solid matter often has a shielding effect because it absorbs radiation, thus preventing or reducing human exposure to external radiation. The removal of an external source usually leads to the cessation of exposure.

In general, naturally occurring radiation accounts for more than 98 percent of the total ionizing radiation to which people are exposed (United Nations Scientific Committee on the Effects of Atomic Radiation 1993). The majority of this exposure comes from breathing radon gas and its short-lived radioactive decay products, and from internal and external exposure to radioactive potassium. The average background level dose in Canada is about 2 m*Sv* per year (AECB 1995), although this value varies across the country.

A potentially significant source of radiation for certain people is medical X-rays used for diagnostic purposes, and radioactive materials used in medical diagnosis or treatment, such as radiotherapy of cancers. Levels of medical radiation dose vary greatly between individuals and types of medical procedures, but efforts are taken to limit any unnecessary exposure.

Radiation from all aspects of nuclear power including mining and processing and final disposal of the fuel, though very low, is becoming increasingly important as the remaining fall-out radionuclides decay. A priority over the next few decades will be the management of substantial amounts of nuclear waste products. Based on environmental models and actual monitoring data, estimates of annual doses received by hypothetical critical groups living near the boundaries of Ontario nuclear generating stations are less than the limit of 0.05 m*Sv* per radionuclide group (about 0.01 m*Sv* in 1994). Doses to populations residing further away from these facilities are smaller still.

Health Considerations of Ionizing Radiation

The radiological impact of a particular radionuclide, whether natural or artificial in origin, depends on its environmental, biological, and radiological properties. Physical, chemical, and biological parameters control the processes that may ultimately lead to human exposure through inhalation, ingestion, or direct irradiation. Because these processes tend to move materials through the ecosystem, the effective half-life of a radionuclide in a particular medium is often less than its radioactive half-life.

If ingested or inhaled, the health impact of the radionuclide will depend on its behaviour in the body, for example, its ability to accumulate in specific tissues, and how quickly it is cleared from the body. Radionuclides that are chemically and metabolically similar to essential nutrients will tend to behave in a similar manner. For example, strontium-90, barium-140, and radium-226 behave like calcium, and will accumulate in bone; radioiodines behave like stable iodine, and accumulate in the thyroid. Radionuclides that will be distributed throughout the body include potassium-40 and cesium-137, which follow the general movement of stable potassium, and tritium, which resembles stable hydrogen and is usually found as tritiated water.

The health effects of ionizing radiation are divided into two classes: **threshold** effects and **non-threshold** effects. Threshold effects are characterized by a generally accepted minimum level of dose (or threshold) below which they are not expected to occur. These effects occur only at exposure rates thousands of times higher than normal background radiation, and with few exceptions, appear shortly after exposure. Acute radiation syndrome includes nausea, fatigue, vomiting, blood cell changes, diarrhea, temporary sterility, and, at very high exposure levels, death. Skin burns are also a threshold effect of high radiation exposure. The **severity** of these effects is related to the amount of radiation received. The threshold for clinically observable effects such as nausea, or temporary blood changes such as depression of the white blood cell count, is about 250–500 m*Sv* received in a few hours. The doses received from natural background radiation or routine exposures from regulated practices are significantly below the threshold for these effects.

Non-threshold effects may not show up until years after the exposure has occurred, and unlike threshold effects, there is no clear minimum level of dose for them. Furthermore, the **likelihood** of experiencing these effects is related to the amount of radiation received. Authorities generally assume that there is no safe level of radiation, and that the risk of non-threshold effects is directly proportional to the dose received. This is referred to as the **linear no-threshold hypothesis** in the radiation protection literature. The most significant non-threshold effect for human exposure to ionizing radiation is an increased incidence of cancer in exposed persons. There is also the possibility of genetic or hereditary effects to future generations.

Non-threshold effects result from damage to DNA in the irradiated cells. If cellular damage occurs and is not adequately repaired, it may result in a modified cell that is capable of producing a cancer after a prolonged and variable period of time. Specific types of cancers observed in exposed populations include leukemia and cancers of the thyroid, lung, breast, and bone. Damage to sperm or egg cells may result in effects that are expressed in the offspring of the exposed individual. Although hereditary effects have been observed in experimental animals, there is no direct evidence of their occurrence in humans. The effects of various doses of radiation are indicated below.

Table 3.7

EFFECTS OF VARIOUS DOSES OF RADIATION

Dose in millisieverts		Effects: Description	Effects: Cancer Risk *
10 000	in a few hours	survival unlikely	—
5 000	in a few hours	50% survival dose in humans	one in 4
1 000	in a few hours	onset of acute radiation illness	one in 20
20	per year	occupational dose limit	one in 1 000
2	per year	background radiation dose	one in 10 000
1	per year	public dose limit for nuclear facilities	one in 20 000
0.1	per year	basis for Health Canada drinking water guidelines	one in 200 000

* based on linear extrapolation from effects observed in populations exposed at doses greater than 100 m*Sv*, such as the A-bomb survivors

Radiation is a known human carcinogen. Estimates of cancer risk are based mainly on epidemiological studies of human populations exposed to high doses of radiation. These include the Japanese survivors of the 1945 atomic bombings of Hiroshima and Nagasaki, occupationally exposed persons, and patients treated with ionizing radiation for various medical conditions. The atomic bomb survivors have shown increased deaths from leukemia, from cancers of the oesophagus, stomach, colon, lung, liver, breast, and ovary, and from multiple myeloma. There is also a possible association for cancers of the bladder, gallbladder, pancreas, uterus, and prostate and for lymphoma.

Effects other than cancer, such as neurological, developmental, and immunological damage, have been observed at only high doses of radiation and are generally assumed to be threshold effects. It has been suggested that radiation weakens the immune system, and that exposure even at low levels may lower one's resistance to infectious diseases. The basis for this theory probably arises from the observed depression in the white blood cell count at high levels of radiation exposure. This leaves a person susceptible to infections. However, there is no clear mechanism linking low level radiation exposure with immune system damage. Nor is there any clear empirical evidence that such an effect exists.

Risk estimates have been derived from these studies by the U.S. Committee on the Biological Effects of Atomic Radiations (BEIR-V), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and the International Commission on Radiological Protection (ICRP). The ICRP has established a lifetime fatal cancer risk of 0.05 per sievert and a total risk coefficient of 0.073 per sievert for fatal and non-fatal cancers, and hereditary effects. The fatal cancer risk coefficient has been used to predict the number of radiation-induced cancers in Table 10.

Q. How are radiation guidelines established?

A. Establishing radiation exposure guidelines and regulations that are protective of public health has generated a great deal of scientific debate. Current guidelines, which have been adopted in most countries for protecting public health from everyday low-level radiation exposures

> resulting from human activity, have been developed based primarily on long-term studies of Japanese atomic bomb survivors and radiation therapy cases in the United Kingdom using cancer as the principal health endpoint. Both of these study populations were exposed to high doses of radiation delivered in a short period of time. Extrapolating the findings to low doses spread over a number of years has generated considerable debate and competing models of interpretations since the 1970s. A number of research studies are now focussing on large populations of workers in the nuclear industry who have been exposed to low levels of radiation for many years in order to provide more direct data on the health effects at low doses. These long-term studies will add to our knowledge and eventually help to develop better protective guidelines.

Others have argued as to whether, in fact, a threshold exists for radiation-induced cancer for exposures up to about 100 m*Sv*. They point to the fact that cells possess DNA repair mechanisms, and suggest that it is only at higher radiation doses that the repair mechanisms become overwhelmed, with the consequence of radiation-induced cancer.

It is virtually impossible to prove or disprove the existence of a such a threshold. Radiation-induced cancers are indistinguishable from cancers caused by other factors. At low exposures, the radiation-induced cancers would be so few as to become lost in the large number of normally occurring cancers.

A number of research studies are now focussing on large populations of workers in the nuclear industry who have been exposed to low levels of radiation for many years in order to provide more direct data on the health effects at low doses. One such study has been conducted recently by the International Agency for Research on Cancer (IARC) on several hundred thousand atomic radiation workers in Canada, the United States, and the United Kingdom. In the range of 100 to 400 *mSv* lifetime exposure, they did find a slight excess of leukemia which was consistent with the ICRP risk coefficient, including the dose rate reduction factor.

In Ontario, three separate epidemiological studies have been conducted in populations living near Ontario Hydro nuclear reactors to respectively address childhood leukemia, birth defects and leukemia among children of reactor workers. A study on the incidence of childhood leukemia near Pickering Nuclear Generating Station did not find any correlation between incidence and radiation dose (Clarke et al. 1989; Clarke et al. 1991). Studies on the incidence of birth defects and infant mortality did not find any effects in populations living near the Pickering station that were statistically different than the Ontario averages (Johnson and Rouleau 1991). Finally, a study of the association between childhood leukemia and the occupational exposure of fathers to ionizing radiation before the child's conception did not find support for this hypothesis (McLaughlin et al. 1993).

At present, Health Canada considers that the main effect associated with low-level exposures is cancer, with a small risk of hereditary effects. There is not enough evidence to reject the linear no-threshold hypothesis or to conclude that the true risks are significantly higher than predicted by ICRP. Health Canada applies the ICRP dose limits and risk factors in setting guidelines for radioactivity in food and drinking water. It is recognized that the true risk at low doses could be as low as zero, and the application of the linear no-threshold hypothesis is more likely to **over**estimate than to **under**estimate the true risk.

Environmental Radionuclides of Concern

Cesium-137 is one of the more important artificial radionuclides due to its relatively high yield as a fission product and its ability to bioconcentrate in some food chains. Nuclear fission is a process in which the nucleus of an atom splits into two or more nuclei and energy is released. It is produced during the fissioning of uranium and plutonium fuels, and has a radioactive half-life of about 30 years. Cesium-137 is found in the environment primarily as a result of the worldwide fall-out from atmospheric weapons tests conducted prior to 1963. It is also released during normal nuclear reactor operations, primarily in liquid releases. If ingested, it is readily absorbed and becomes uniformly distributed in the soft tissues and muscles of the body.

Radioactive iodine has been extensively studied due to its mobility in the environment, and its selective irradiation of the thyroid when taken into the body. It is found in the environment mainly as a result of nuclear weapons testing and nuclear reactor operation, although iodine-129 and iodine-131 are naturally present as a result of spontaneous fission of natural uranium. Of the many isotopes of iodine produced by fission in nuclear reactors, iodine-129 and iodine-131 are the most important. Although iodine-129 is not identified in routine reactor emissions, almost all of it is still present in the environment owing to its long half-life (1.6×10^7 years), whereas virtually all of the short-lived iodine-131 has decayed (half-life of about eight days).

Once released to the atmosphere, radioactive iodine may return via precipitation to land used for pasture, where it may appear in vegetation and, ultimately, the food and milk supply. If ingested, radioiodine is selectively concentrated in the thyroid gland, and may result in doses 1000-fold that in other tissues in organs. However, because of its short half-life, iodine-131 is only of concern immediately following a significant, accidental release to the environment.

Plutonium-239 is an anthropogenic element used as fuel in some nuclear power reactors and as an explosive in nuclear weapons. Plutonium-239 has a radiation half-life of 24 390 years. Nuclear weapons testing programs have placed more than 5000 kilograms of plutonium, mostly as insoluble particles of oxide, into the stratosphere, which has resulted in worldwide deposition. Actual concentrations in the environment are extremely low. If ingested, plutonium concentrates in the thoracic lymph nodes and in bone.

Radium-226 is a member of the decay series of uranium-238. It is present in trace amounts in all rocks and soils, and may be found in elevated amounts in the waste rock from uranium mines. Radium-226 is an alpha emitter with a half-life of 1600 years. It is an alkaline Earth element, similar to calcium.

The primary route of exposure to radium-226 is from food or water, depending on the location of residence. Typical concentrations in drinking water average 0.001–0.013 *Bq*/L. In general, the higher end of this range can be expected in areas containing uranium mining and milling operations, or where rock containing high concentrations of the natural radionuclides is in contact with water.

If ingesting food or water containing radium-226, 20 percent will be absorbed by the gastro-intestinal tract. Once ingested, it tends to accumulate in bone where it may remain for many years, with the potential of causing bone cancer. In the early part of this century, an increased incidence of bone cancer was found among painters in the radium dial industry. A very definite threshold exists for radiation-induced bone cancer, with no cancers occurring for bone doses less than 20 sieverts (20 000 m*Sv*).

Radon-222 is a colourless, odourless, chemically inert gas that is present in the environment as a result of the radioactive decay of radium-226. Radon, itself an alpha emitter, decays in a relatively short time (half-life=3.82 days) through a series of short-lived radioactive particles which also emit alpha radiation. In air, these products attach to dust, which may be inhaled and retained in the lungs and respiratory tract.

Elevated concentrations of radon and its decay products can accumulate in indoor air if the soil surrounding the buildings contain excess radium. The principle health effect associated with radon exposure is lung cancer. Excess lung cancers have been observed in uranium miners exposed to high levels of radon in the past. A recent study on the association between lung cancer and elevated household levels of radon in Winnipeg did not show any effect (Létourneau et al. 1994). Tobacco smoking, the chief cause of lung cancer, has always been a confounding factor in studies of this nature.

Strontium-90 has been extensively monitored in the environment and in various food chains. It has a radioactive half-life of 29 years, and is metabolically similar to calcium. The majority of environmental strontium-90 has come from nuclear weapons fall-out. Strontium-90 is also part of the normal emissions from nuclear power reactors, although releases are very small and indistinguishable from fall-out. The most important route of exposure is from the air, to vegetation, livestock and, ultimately, milk. When ingested, it is retained largely in bones.

Tritium (hydrogen-3) is one of the most significant radioactive releases from Canadian CANDU reactors. It is a hydrogen atom whose nucleus contains two neutrons, and it decays with a radioactive half-life of 12.3 years. It is produced naturally in the upper atmosphere, and artificially in nuclear detonations and nuclear reactors. Nuclear weapons tests have produced quantities of tritium far exceeding the natural inventory. Tritium produced during nuclear power generation is released in liquid and gaseous effluent as tritiated water, which is its most common form. Slightly elevated levels of tritium in air and water are found in the vicinity of CANDU nuclear reactors, although these levels are low.

Airborne tritium can be inhaled or absorbed through the skin. Ingested tritiated water is completely absorbed from the gastro-intestinal tract and is then rapidly distributed throughout the body by the blood. Only rarely does tritiated water specifically concentrate in particular cells. The majority of the tritium is removed from the body with a biological half-life ranging from 2.4 to 8 days, representing the turnover of body water. The remainder is removed with a half-life of one month to one year, representing the turnover of tritium incorporated in organic compounds. Tritium is excreted with water, in breath and in urine.

Uranium is normally present in rocks and soil at levels of about one to two parts per million. It consists primarily of uranium-238 (half-life of $4.47(10^9$ year), which is the parent radionuclide of the uranium radioactive decay series. Both radium-226 and radon-222 are a part of this series. Uranium- 234 and uranium-235 are present in much smaller proportions.

Uranium can enter the body through inhalation or ingestion. Ingested uranium must be in soluble form before it can be absorbed by the body. Even then, studies carried out at Health Canada have shown that only about 1 percent of dissolved uranium is absorbed by the human intestine. Most of this absorbed uranium is excreted through the kidneys in a few days. A small fraction of the uranium finds its way to bone where it can replace calcium. It may remain there for many years.

Although uranium is both chemically and radiologically toxic, its primary hazard arises from its properties as a toxic heavy metal, rather than from its radioactivity. In this respect uranium is similar to other heavy metals such as lead, mercury, or cadmium. These metals are presumed to be harmless in small amounts. Damage does not occur until the levels rise above a certain toxic threshold. Uranium administered to laboratory animals has been observed to produce kidney damage.

Uptake in food is the principal route of exposure, although uranium is one of the more important natural radionuclides that may be found in water supplies. In general, levels of uranium in both surface and groundwaters are low, typically less than 1 µg/L. However, substantially higher concentrations have been measured in both private and community groundwater sources across Canada.

Regulatory Control of Ionizing Radiation

The primary aim of radiological protection is the provision of an appropriate standard of human protection against the risks of ionizing radiation exposure without unduly limiting the uses of nuclear products that benefit society. In Canada, laws governing the use of radioactive materials, radiation emitting devices and ionizing radiation exposures exist at both the federal and provincial levels.

The Atomic Energy Control Board (AECB) is the federal agency responsible for the regulation of nuclear facilities and the use of nuclear materials. As in most countries of the world, its system of radiological protection is based on the recommendations of the ICRP. Legal dose limits have been established for occupational and public radiation exposures arising from all regulated practices. These limits do not apply to radiation exposures received from natural sources, those received by patients medically exposed, or to persons carrying out lifesaving procedures in an emergency.

The ICRP (1991) has recommended dose limits of 20 millisievert per year (m*Sv*/year) for occupational exposures and 1 m*Sv*/year for public exposures, from all regulated (i.e., artificial) sources combined. The public dose limit is about half the average exposure to radiation from natural sources. At present, the current legal limits in Canada are 50 m*Sv*/year for occupational exposures, and 5 m*Sv*/year for public exposures. The AECB is adopting the latest ICRP recommendations on dose limits.

As a condition of licensing, the AECB requires that the total dose at the site boundary of nuclear facilities may not exceed 0.05 m*Sv* per year for all radionuclides and pathways combined. In addition to the monitoring conducted by nuclear facilities, independent environmental monitoring is carried out by various agencies, including Health Canada, the Ontario Ministry of Environment and Energy, and the Ontario Ministry of Labour.

Although natural background radiation exposure is not specifically regulated at the federal or provincial level, standards and guidelines do exist for specific types of exposure, for example, to radon in air or from radionuclides in drinking water. The provinces may also set general environmental quality standards for radiation. For example, Ontario Drinking Water Objectives for radionuclides are used to evaluate the acceptability of water supplied to the Ontario public and are legally enforceable on agencies supplying communal water.

Health Canada administers the federal *Radiation Emitting Devices (RED) Act* pertaining to specific classes of radiation emitting devices used both occupationally (e.g., X-ray equipment, lasers, ultrasound therapy devices) and residentially (e.g., microwave ovens, television receivers). However, the responsibility for controlling the use of radiation emitting devices belongs to the provinces, which regulate and monitor exposures that may result from these devices (but not radioactive material), as well as non-nuclear fuel cycle activities, which give rise to occupational exposure to radionuclides.

In 1996, Health Canada issued guidelines for radionuclides in drinking water. Maximum acceptable concentrations (MAC) for radionuclides in drinking water are 0.1 mSv from one year's consumption of drinking water. This level of dose corresponds to a theoretical risk of about five extra cancer deaths per million people exposed. The guideline reference dose is based on the total activity in a water sample, whether the radionuclides appear singly or in combination, and includes the dose due to both natural and artificial radionuclides.

Table 3.8

SUMMARY OF GUIDELINES FOR SELECTED RADIONUCLIDES IN DRINKING WATER

Natural Radionuclides	MAC (*Bq*/L)	Artificial Radionuclides	MAC (*Bq*/L)
Lead-210	0.1	Antimony-125	100
Radium-224	2	Cerium-141	100
Radium-226	0.6	Cerium-144	20
Radium-228	0.5	Cesium-134	7
Thorium-228	2	Cesium-137	10
Thorium-230	0.4	Iodine-125	10
Thorium-232	0.1	Iodine-131	6
Thorium-234	20	Iron-59	40
Uranium-234	4[1]	Manganese-54	200
Uranium-235	4[1]	Molybdenum-99	70
Uranium-238	4[1]	Niobium-95	200
		Ruthenium-103	100
		Ruthenium-106	10
		Strontium-90	5
		Tritium[2]	7000
		Zinc-65	40
		Zirconium-95	100

1. The activity concentration of natural uranium corresponding to the chemical guideline of 0.1 mg/L is about 2.6 *Bq*/L
2. Tritium is also produced naturally in the atmosphere in significant quantities

Source: *Guidelines for Canadian Drinking Water Quality, Sixth Edition*. Health Canada, 1996.

Origin

Ultraviolet radiation (UV radiation) is part of the sunlight spectrum and is invisible to the naked eye. In addition to the sun's natural rays, ultraviolet is also emitted by UV lamps in tanning salons and spas, germicidal lamps, ultraviolet lasers, certain kinds of industrial inspection lamps, and welding arcs.

Solar ultraviolet radiation can be divided into three regions according to wavelength.

UVC (wavelength 200-280 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. When produced by an artificial source, it travels through the air and can cause injury to the eyes and skin. The transmission of UV radiation depends on the wavelength, and also the different areas of human skin. Short wavelengths such as UVC are mostly absorbed by a protective dead-cell layer of skin.

UVB (wavelength 280-315 nm) is the wavelength most affected by the concentration of the ozone layer. Ozone absorbs UVB between 280 and 297 nm and reduces the amount reaching the Earth's surface. Due to its wavelength, UVB is primarily absorbed by the epidermis. UVB is carcinogenic and erythemogenic (causing sunburn) and is thought to be responsible for most of the adverse effects of sun exposure.

UVA (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. Even though UVA has the least energy, it tends to penetrate deeper into the dermis and reach cells that are less protected. This is because longer wavelengths penetrate more deeply into the dermis. It takes one thousand times more UVA than UVB to produce erythema in sensitive individuals. UVA affects the immune system and triggers photo-allergies to, and photo-toxicity of, certain chemicals and products.

Persistence and Movement in the Environment

Ozone (O_3) is a form of oxygen occurring naturally in the stratosphere, located between 15 and 35 kilometres above ground level. The stratosphere contains 90 percent of all ozone present on Earth and its distribution varies around the globe reflecting season, latitude and other complexities of meteorology. Even though ozone is fairly rare in the atmosphere, it acts as a screen against ultraviolet radiation from the sun. If all the ozone in the atmosphere was brought to sea level, it would form a layer only a few millimetres thick. By absorbing ultraviolet radiation, ozone protects life forms on the Earth from dangerous levels of UV radiation.

Human activity has modified the total amount and distribution of stratospheric ozone. Ozone "holes," or thinning of the ozone layer, occurs when normal stratospheric chemical reactions involving oxygen and ozone are disrupted.

There are many chemicals present in the stratosphere that are capable of disrupting these reactions and thus destroying ozone; chlorofluorocarbons (CFCs) and halons degradations are key examples.

Exposure

The amount of ultraviolet radiation reaching people at any moment is extremely variable and depends on many factors. Clouds shelter a large proportion of the UV radiation. The season of the year affects UV radiation; it is lowest in the winter and highest in the summer. UV radiation generally increases with altitude and decreases with latitude; it is higher at the equator. The thickness of the ozone layer also plays a role that is yet to be quantified precisely, as the ozone thickness is naturally variable. The presence of reflective surfaces, such as snow and water, can greatly increase the amount of UV radiation exposure.

Tanning beds are an additional source of UV radiation exposure. The intensity of UV radiation, especially UVA, can be significantly higher in tanning beds than in sunlight. An indoor tanning bed does not produce a "healthier" tan and presents the same dangers as tanning outdoors via sunlight. In other words, one suntan is not safer than the other.

Ultraviolet radiation is part of the normal spectrum of sunlight. Although most of the sun exposure occurs before the age of 20, there is no age at which one can escape further damage. The health risks associated with exposure can be reduced significantly through the following simple measures:

- Decrease sun exposure between 10 a.m. and 4 p.m., when the sun is strongest.
- Wear protective non-transparent clothing and decrease the amount of skin exposed to the sun. Hats with brims and sunglasses that block both UVA and UVB decrease the UV radiation reaching the eyes.
- Avoid sunburn by decreasing the amount of time spent in the direct rays of the sun, and by using a sunscreen with a sun protection factor (SPF) of 15 or greater. Reapply the sunscreen after two hours of sun exposure and after swimming or bathing in water.
- Teach children sun protection early in life, as sun damage adds up over the years. Have children begin using sunscreens by 6 months of age, and teach children about wearing adequate clothing and using shade to protect themselves from the sun.
- Use sunscreens on cloudy days. There is still considerable UV radiation reaching the Earth on these days.
- Avoid tanning parlours. There is no healthy tan.
- Be aware of reflective surfaces such as snow and water while in the sun.

These precautions are even more important for people in higher risk categories, i.e., people with susceptible skin types, those taking medications with photosensitive or photo-allergic properties and the very young.

ENVIRONMENT CANADA'S UVB ADVISORY

Health departments and the media across Canada receive daily city-specific UVB Reports issued by Atmospheric Services of Environment Canada. It is intended to rate the amount of UVB an individual may receive on a specific day. The UV radiation dose received by an individual varies depending on time of day, season, solar cycles, weather conditions, pollution index, altitude, latitude, clothing, and length of time unprotected out in the sun. The specific reaction to exposure to ultraviolet radiation depends on the individual skin type or sensitivity.

Environment Canada translates energy values to a UVB index measured from 0 to 10; the higher the index, the more intense the UVB exposure and the shorter the sunburn time. Sunburn times are based on the sensitivity of individuals of skin type II (see below). Six skin types have been defined as follows:

I. Always burns easily and never tans;

II. Always burns easily but tans minimally;

III. Burns moderately, tans gradually and uniformly (light brown);

IV. Burns minimally, always tans well (moderate brown);

V. Rarely burns and tans profusely (dark brown); and

VI. Never burns, deeply pigmented (black).

Table 3.9

THE UV INDEX AND MAIN UV CATEGORIES

UV Index	Category	Recommended Actions
Below 4	Low	Minimal precautions are necessary for normal activity. Low values can still be a concern if there is a prolonged period of exposure and/or significant reflection, especially off fresh snow.
4 – 7	Moderate	Take precautions to limit UV exposure, especially if outside for one hour or more: 1. the time spent in the sun by re-arranging activities or finding shade. 2. Wear proper clothing including a wide brimmed hat, a shirt that blocks the sun and sunglasses. 3. Use sunscreen with SPF 15 or greater and UVA/UVB protection. Apply 15–20 minutes before going out in the sun.
7+	High	Burns and skin damage can occur quickly. Reducing the time spent in the sun is most important. Follow precautions above, even if you will only be in the sun for a short period of time.

Source: *Sun Protection and the UV Index*, Government of Canada.

Health Considerations

UVA, which is able to penetrate more deeply into the skin than UVB, causes changes in blood vessels and premature aging of skin. UVB causes sunburn and makes the skin more susceptible to UVA. Altered DNA, the result of damage by UVB radiation, can lead to various forms of skin cancer. Individuals with skin types I and II, particularly those who freckle and who have a large number of moles on their body, are at greatest risk for adverse health effects.

For non melanoma skin cancers, such as basal and squamous cell carcinoma, an estimated 90 percent are related to UV radiation exposure. The relationship of the more serious malignant melanoma to UV radiation exposure is more difficult to quantify. It tends to occur on body sites not routinely exposed to sun, although severe occasions of sunburn, particularly in childhood, appear to be a causative factor. Melanoma is related to genetic predisposition and dysplastic naevi (i.e., moles) but solar exposure is the major external factor. Most of the factors identified in high risk individuals relate to the sensitivity of the skin to acute effects of UV radiation.

UVB can also damage the eye. Prolonged exposure can cause "snow blindness" which affects the conjunctiva and cornea; chronic keratopathy, which affects the cornea; and cataracts, which develop in the lens. The retina may also be damaged by UVA when the lens has been surgically removed. All of these afflictions affect vision, and not all are amenable to remedial treatment.

Damaging exposure to UV radiation may also affect the immune system. Immunosuppression may be due to UV radiation effects on dermal T-lymphocytes resulting in potential increased risk of infection and cancer. For example, persons receiving immunosuppressive drugs have been shown to be at greater risk of developing squamous cell carcinoma. Herpes simplex virus can be exacerbated by UV radiation exposure.

Even brief exposure to sunlight in warm or cold weather can cause intense skin reactions in persons who have used photosensitizing agents. Such agents include drugs — phenothiazines, thiazides and related sulfonamide diuretics — and antibiotics such as demethylchlortetracycline. Some persons may remain sensitive to sunlight long after ceasing use of these agents. The most frequent reactions involve phototoxicity, a chemical injury to the skin resulting in a sunburn reaction with redness, swelling, blisters, hyperpigmentation and peeling. Less commonly, these agents can cause photoallergy, resembling contact allergy with immediate wheal (slighly elevated area which is redder or paler than surrounding skin) and flare (an area of redness on the skin, spreading out around a point of irritation) reactions or delayed papular (pimply), erythematous (reddening of the skin) or eczematous rashes.

Non-ionizing Radiation: Electromagnetic Fields (EMFs)

Origin

The electricity generated in power stations is transmitted to homes, offices and factories by various systems ranging from high-voltage transmission lines to distribution lines (both commonly known as power lines). High-voltage lines can have voltages ranging from 110 to 735 kilovolts (kV). Distribution lines have lower voltages. The generation, transmission and use of electricity creates two kinds of invisible fields — electric and magnetic. An electric field is produced whenever two objects are at different potential (voltage). The electric field strength is expressed in units of volts per metre (V/m) or kilovolts per metre (kV/m). A magnetic field is produced whenever there is a current flowing in a conductor, for instance a high-voltage conductor, or a power cord for appliances. The magnetic field is frequently expressed in various units such as tesla (T) or gauss (G), where 1 tesla is equal to 10 000 gauss. Together, electric and magnetic fields are referred to as "electromagnetic fields" or EMFs.

Persistence and Movement in the Environment

Electromagnetic fields are strongest close to the source and rapidly decrease in strength as the distance from the source increases. These fields are not persistent but are continuously being generated as long as electricity is flowing through the line.

Exposure

On a daily basis, most Canadians are exposed to electromagnetic fields through the use of electrical appliances such as hair dryers, can openers, vacuum cleaners, electric shavers, electric blankets, kitchen ranges, other electrical devices (e.g., power tools), as well as their proximity to power lines. Another source of exposure are video display terminals (VDTs). These are television sets, used as display terminals for computers.

In Canada, the strongest electric field normally encountered by the public is about 10 kilovolts per metre and is found under high-voltage transmission lines. By comparison, the electric fields created by electric blankets usually have a strength of about 0.2 to 2 kilovolts per metre. Workers in some electrical occupations, such as power line maintenance, may be exposed to stronger electric fields. Over the last decade, Health Canada has tested VDTs and at no time did they emit EMFs that exceeded the recommended exposure limits. Anti-radiation shields (a transparent screen placed in front of a VDT) do decrease the electric fields emitted, but had no effect on the magnetic fields.

Unlike electric fields, the strongest magnetic fields are usually not associated with high-voltage transmission lines but occur in occupational situations involving use of high currents such as arc-welding, induction heating, some electric motors and power transformers. These processes typically expose workers to magnetic fields ranging in strength from 1 to 1000 microtesla. In the home, the strongest magnetic fields are found close to some appliances.

Health Considerations

The impact of EMFs on health has become a topic of considerable scientific debate. Studies to investigate the health effects of EMFs have been ongoing for more than 20 years. Research has focused on laboratory studies concerning effects on cells, tissues and animals, as well as studies on human exposure and epidemiology. The results to date have not established a clear link between ill health and exposure to electromagnetic fields. Extensive research internationally is currently attempting to address unresolved questions.

Figure 3.3

Electric Fields in the Home Near Some Appliances and Power Lines

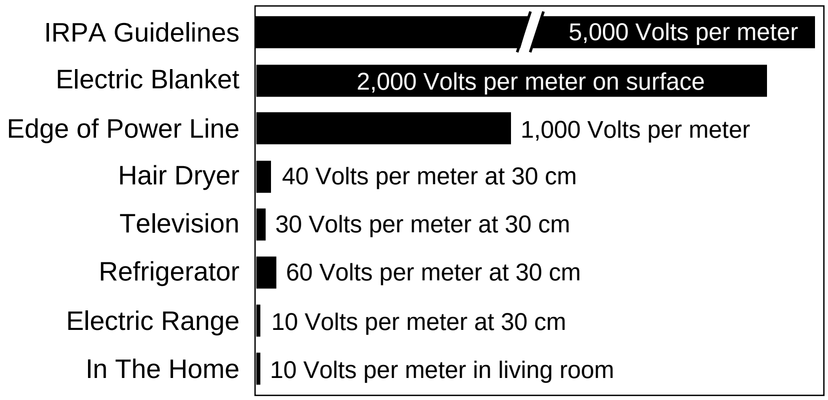
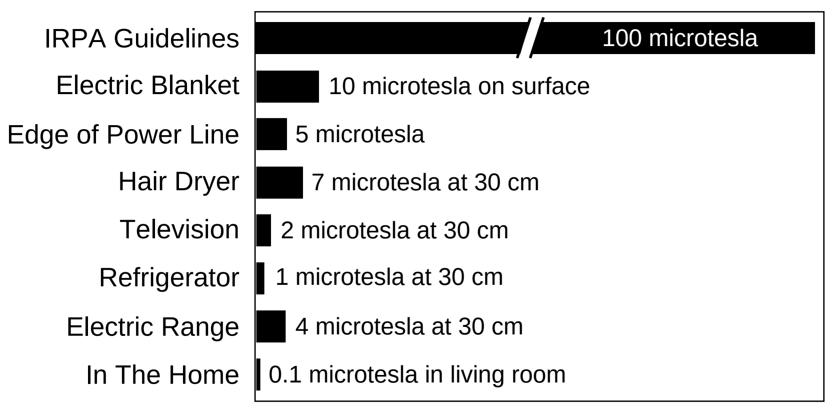


Figure 3.4

Magnetic Fields in the Home Near Some Appliances and Power Lines



1 microtesla = 10 milligauss

When a human body is in the presence of either electric or magnetic fields, electric currents are induced within the body. Electric fields stronger than 10 kilovolts per metre may also cause body hair to vibrate and a tingling sensation on the skin, both of which can be perceived by most people.

A number of epidemiological studies have suggested a possible association between exposure to EMFs and increased cancer rates, particularly childhood leukemia and brain cancer. For example, an occupational study of over 30 000 Ontario Hydro male workers showed an increased risk of leukemia from exposure to electric and magnetic fields (Miller 1996). It should be noted that there are controversies surrounding EMF related studies. To date, no clear picture has emerged from epidemiological investigations.

There has been increased public concern regarding exposure to EMFs from VDTs. Scientific evidence, both from people and animals, does not support the claim of adverse health effects from VDTs. The majority of epidemiological studies show no increased risk of spontaneous abortion or fetal malformation. Similar results were found from animal experiments.

Some laboratory studies have shown that EMFs can affect the functioning of cells, but these conditions do not necessarily lead to health effects. A few animal studies have suggested that magnetic fields may speed up the development of tumours in animals exposed to cancer-causing chemicals. However, these findings have yet to be confirmed. At present, there is not a full understanding of how these biological effects occur, nor are the implications of these findings on human health known.

Standards

There are no governmental health standards in Canada for exposure to electric and magnetic fields at a frequency of 60 Hz. This is due to the lack of a sufficient scientific basis to establish what such standards should be. Exposure of Canadians to 60 Hz fields from high-voltage transmission lines is generally limited because of design and siting criteria adopted by utility companies in Canada. Exposure standards recommended by some organizations such as the International Radiation Protection Association (IRPA) are well above levels to which Canadians are exposed.

Standards are in place for metal fencing and other structures to prevent exposure to dangerous shocks from strong EMFs under high-voltage transmission lines.

Origin

Noise (or sound) is considered a form of non-ionizing acoustical radiation as it is energy emanating from a source. Noise is defined as unwanted or objectionable sound. Occupational noise has been a controlled health hazard for about 25 years. Environmental noise is now emerging as a health concern as a result of the growth, over the last three decades, of noise sources that are affecting more people. A noise source is defined as an emitter that creates a noise high enough to annoy people, and to affect a significant proportion of the population. Three distinct types of environmental noise sources can be identified in the community:

- Stationary sources such as air conditioners and industrial equipment can be of concern to residential and other sensitive land uses.
- Mobile sources are mostly transportation related. Transportation is by far the major source of noise, with road traffic the chief offender. According to a national survey by Transport Canada, 19 percent of respondents complained that road-traffic noise was the most disliked feature in their neighbourhood. The most prevalent sources are motor vehicles, including cars, trucks, buses and motorcycles. Aircraft and trains can also be locally significant sources.
- Noise generated by people and animals, including children playing, outdoor parties, loud music, and dogs barking.

Noise from industry, construction and demolition work can also create a very high level and a serious disturbance to people. Consequently, many municipalities restrict construction to between the hours of 7:00 a.m. and 7:00 p.m.

HOW WE HEAR

THE EAR CONSISTS OF THREE DISTINCT REGIONS: OUTER, MIDDLE, AND INNER EAR. WHEN SOUND ENTERS THE EAR, AIR WAVES PASS ALONG AN AUDITORY CANAL IN THE OUTER EAR TO THE EARDRUM. EACH WAVE VIBRATES THE EARDRUM, WHICH CONDUCTS THE SOUND TO THE OSSICLES OF THE MIDDLE EAR, THE THREE SMALLEST BONES IN THE BODY. THE OSSICLES TRANSMIT THE VIBRATIONS TO A FLUID CONTAINED IN A TINY SNAIL-SHAPED STRUCTURE CALLED THE COCHLEA IN THE INNER EAR. MICROSCOPIC NERVE ENDINGS, CALLED HAIR CELLS, WITHIN THE COCHLEA RESPOND TO FLUID VIBRATIONS. ELECTRIC IMPULSES FROM NERVE ENDINGS ARE TRANSMITTED TO THE BRAIN AND INTERPRETED AS SOUND.

Measurement

Sound is a travelling pressure wave produced by small compressions and expansions of the air next to a vibrating object. **Frequency** (or pitch) and **intensity** are two basic characteristics of sound. Frequency describes the number of waves radiated per second. Common everyday sounds tend to be made up of frequencies ranging from about 40 hertz (Hz) to 10 000 Hz, where one hertz is equal to one wave cycle per second. Most people can hear sounds within a frequency range from 20 to 20 000 Hz. There is a great deal of individual variation in people's ability to perceive very low or very high frequency sounds.

The intensity of sound is measured in terms of its sound pressure level (SPL). All SPL is measured in decibels (dB). A sound-level meter, a small microphone connected to special electronic circuitry, is used to measure SPL. A sound pressure level of 0 dB is approximately the threshold of normal hearing. Every increase in sound pressure levels of 10 dB corresponds to a tenfold increase in intensity which is, in turn, perceived as twice as loud by people. The loudness of a sound also varies with its frequency. Maximum sensitivity to sound occurs in the 1000 to 3000 Hz range. Sounds at very low or very high frequencies seem fainter to the human ear than those in the middle frequencies, even at equal intensities.

Table 3.10

NOISE LEVELS IN DECIBELS (dB)

Noise Level (dB)	Description	Examples
140 dB	Human ear pain threshold	Shotgun blast, jet plane at take-off
120 dB	Uncomfortably loud	Amplified rock music, hockey game crowd, severe thunder, pneumatic jackhammer
100 dB	Extremely loud	Powered lawn mower, farm tractor, subway train (interior), motor- cycle, snowmobile
80 dB	Moderately loud	Window air-conditioner, crowded restaurant, diesel-powered truck/tractor
60 dB	Quiet	Singing birds, normal conversation
40 dB	Very quiet	Rustle of leaves, faucet dripping, light rainfall
10 dB	Just audible	Whisper

Exposure

Noise can vary considerably from region to region, from town to town, and even from one district to another within the same town. Factors such as population density can be important. In general, noise levels are higher in urban areas that are more densely populated and have higher traffic density. Motor vehicle traffic affects the most people, followed by aircraft noise. Aircraft noise around airports is loudest during take-off and landing, and is most disturbing over the more densely populated parts of the country. Railway noise and noise from stationary sources, such as industrial establishments, generally affect a more limited proportion of the population.

Many noise sources such as power tools, home appliances, subways, and trains could cause hearing damage if a person were continually exposed for a long time. Fortunately, the number of people receiving such a high exposure is limited. Certain occupational groups, such as those working with loud machinery, may be exposed to excessively loud noise, particularly if they fail to wear protective equipment. Some people participating in certain recreational activities may also be exposed to damaging noise. These include those who target shoot, hunt, listen to loud music for prolonged periods, and people who use snowmobiles, motorcycles and power boats.

Health Considerations

The degree to which people can tolerate noise is relative. Excessive noise is harmful to the health and well-being of many people. One major effect is permanent hearing loss. However, even at exposures too low to cause permanent hearing loss, noise can significantly affect health and well-being by interfering with listening, startling people, disturbing sleep and rest, and causing severe annoyance and stress.

Hearing Loss: There is considerable variation in the effect of noise on an individual. Some people are very susceptible to noise-induced hearing loss and some very resistant. Hearing loss caused by noise results from overexposure to sound, which can cause direct physical damage to the hair cells of the inner ear. There are two categories of hearing loss: temporary or permanent.

Temporary hearing loss may occur when a person who is exposed to a period of loud noises has trouble hearing for some time. Normal hearing returns after a rest period which varies from a few minutes to a few days, depending on the person, and how long and severe the exposure was.

Permanent hearing loss resulting from exposure to loud noises is usually very gradual. This cumulative effect depends on the total sound energy to which the ear is exposed, regardless of the cause of the noise. However, sometimes the noise exceeds a critical level and a single exposure can cause permanent hearing loss.

Present industrial noise standards do not protect every worker from developing hearing losses. For example, the 90-decibel limit on noise for a 40-hour weekly exposure in industrial settings results in about 10 percent of workers suffering hearing impairment solely due to noise exposure after 30 years. There is evidence to support lowering the occupational noise limits, and recently Labour Canada lowered its occupational noise limit to 87 decibels.

Sleep: Annoyance from noise can keep a person from falling asleep, and noise may awaken that person during the night, thus disturbing the cyclical pattern of sleep. These effects lead to a decrease in sleep quality which, in turn, can lead to increased tiredness and decreased performance the next day, with the possibility of more serious effects on health and well-being for long-term exposure. The elderly are particularly sensitive to sleep loss from noise.

Annoyance and Stress: Excessive noise can cause severe annoyance and can result in stress. The effects of the annoyance alone can significantly reduce the well-being of people in exposed communities. In addition, while studies are inconclusive, there are concerns that excessive noise can indirectly affect the cardiovascular system.

Control: Noise from almost any source can be controlled. Noise-control measures should be directed primarily at reducing noise at the source, and secondarily at the receiver or on the path of transmission between the source and receiver.

Problems in controlling noise should be anticipated at the design stages of a new building or plant. Engineers and architects should consider the acoustics and incorporate noise control measures in their design work, to ensure that noise problems are handled before they develop. Special acoustical treatment of roofs and walls with double-layer construction helps cut down on noise. Equipment producing high levels of noise should be kept away from areas such as offices or conference rooms. Noisy equipment should also be located at grade levels to minimize vibration and noise transmission to other areas of a building. Special enclosures and free-standing barriers are other methods to consider in overall noise control.

Barriers and enclosures are an effective technique in reducing sound levels. For a barrier to be effective, it should be high enough to intercept the line of sight from the source to the receiver. Free-standing noise barriers require a minimum of space, allow easy maintenance, and physically separate a person from the noise source. The surface features of a region, such as hills or ravines, can be exploited to act as natural barriers.

Generally, it is less expensive to buy quiet equipment than it is to silence noisy equipment. By providing noise emission data for equipment, manufacturers can facilitate the use of quieter machinery and the design of quieter workplaces. Mufflers can control low-frequency noise. Mid- to high-frequency noise in ducts and openings can be controlled by lining the walls with sound-absorbing material.

Devices to protect personal hearing are physical barriers that reduce the amount of sound energy transmitted to receptors in the inner ear. These devices are either earplugs inserted in the external ear canal, or protective devices resembling earmuffs that cover the ears to seal them from unwanted sound.

Regulations

Federal Government: The primary responsibilities of the federal government in noise control are to establish and to ensure compliance with standards for noise emission labelling and maximum noise emission for a variety of products, equipment and vehicles. However, these regulations do not extend to "after sale" situations where products deteriorate and exceed sound levels required at the time of manufacture. The federal government also establishes guidelines for noise control over interprovincial transportation systems including aircraft, trains and navigable waterways. In addition, Health Canada has a legal requirement to provide expert advice on the health effects of environmental noise to environmental assessments involving other federal departments.

Provincial Government: Provincial governments establish guidelines for noise control in land use planning. They authorize and assist municipalities in creating and implementing municipal plans and noise control by-laws to abate individual sources of noise. Provincial governments are also responsible through various provincial statutes for controlling the operational noise levels of many products, equipment and vehicles.

Municipal Government: Most environmental noise control legislation has been passed at the municipal level. Municipalities exercise environmental noise control through municipal noise control by-laws, municipal land use plans and zoning, traffic management and road noise barrier retrofit programs.