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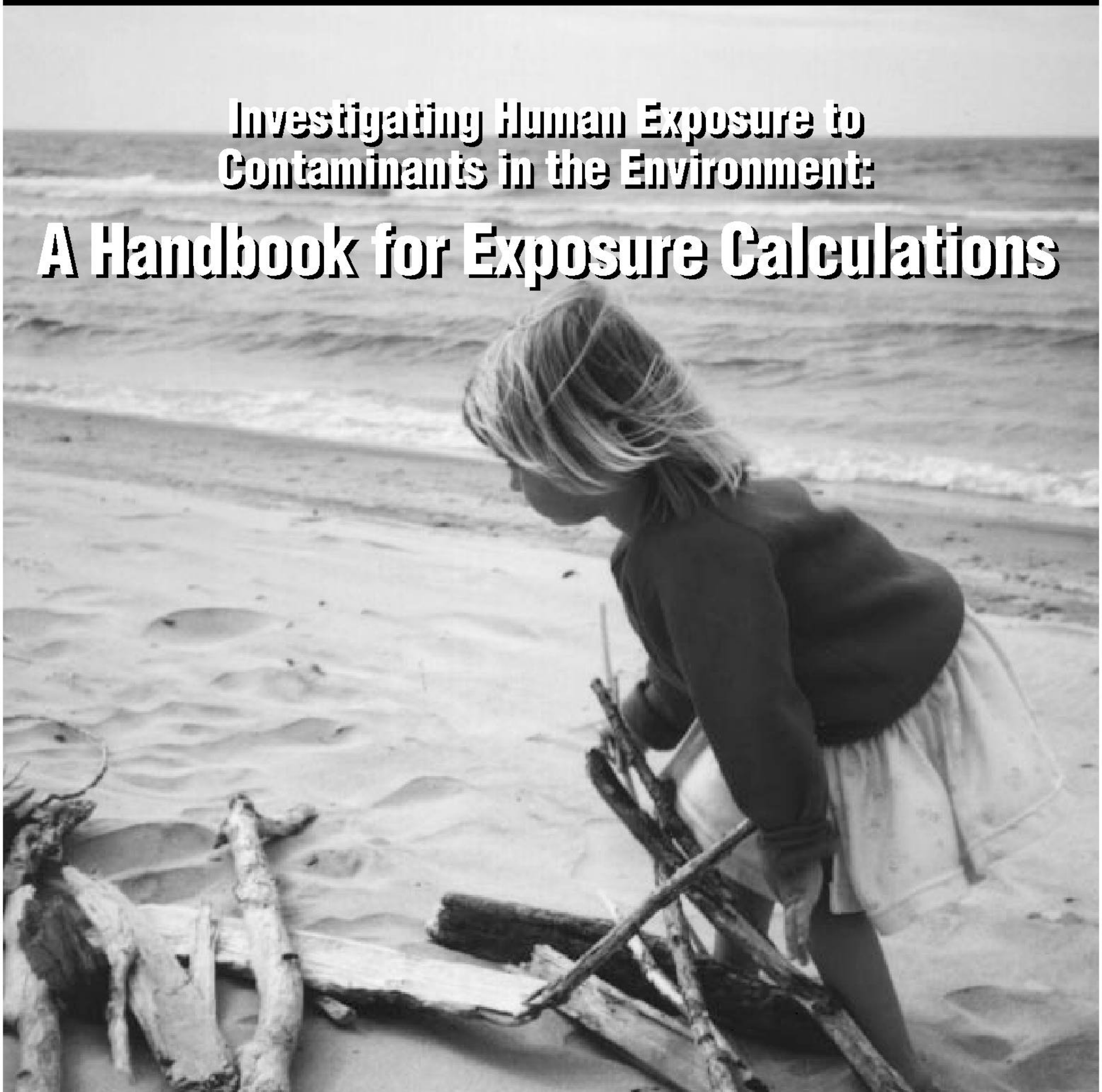
Investigating Human Exposure to Contaminants in the Environment:

A Handbook for Exposure Calculations



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Part 1 of 3

Canada

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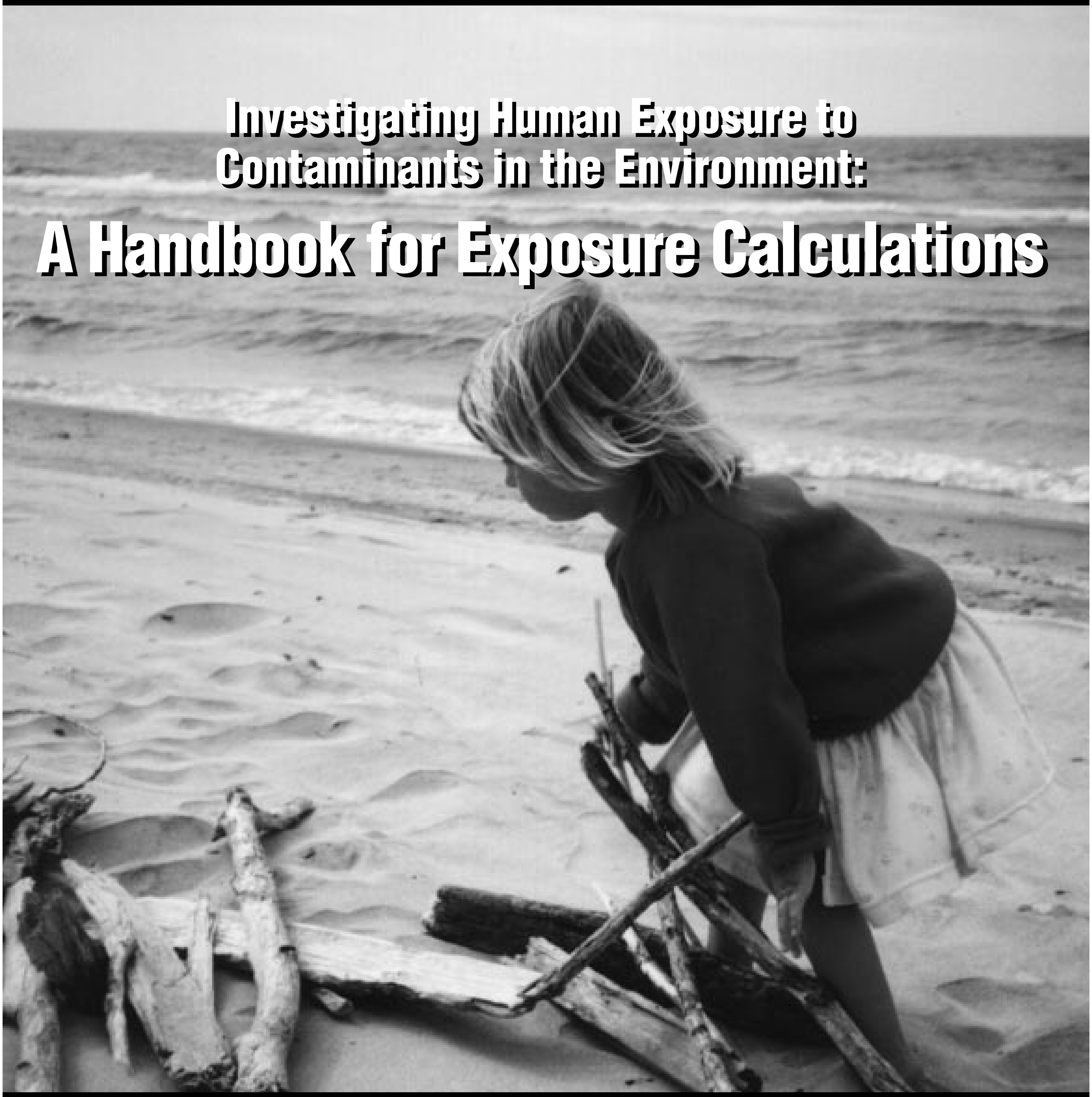

Our mission is to help the people of Canada maintain and improve their health.

Health Canada

Published by authority of the Minister of National Health and Welfare

Cat. No. H49-96/1-1995E
ISBN-0-662-23543-6

Également offert en français sous le titre, *Enquête sur l'exposition des êtres humains aux contaminants dans le milieu : Un guide pour les calculs de l'exposition*

Printed on recycled paper.

FOREWORD

People and communities are becoming more aware of the relationship between their health and the environment. *Investigating Human Exposure to Contaminants in the Environment* consists of two handbooks that provide information to assist communities in understanding this relationship. *A Community Handbook* will help you carry out a descriptive exposure assessment and develop a health profile of your community. *A Handbook for Exposure Calculations* describes the general methods followed for calculating human exposure to environmental contaminants. These handbooks have been prepared by the Great Lakes Health Effects Program of the Health Protection Branch, Health Canada.

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ACKNOWLEDGEMENTS

Investigating Human Exposure to Contaminants in the Environment: A Handbook for Exposure Calculations has been prepared by the Great Lakes Health Effects Program of the Health Protection Branch, Health Canada. A number of people have contributed to the preparation of this handbook. These people are: Douglas Haines, Jennifer Rae, Andy Gilman, Mary Hegan and Lynn Andrews of the Great Lakes Health Effects Program; Brian Ahier of the Environmental Radiation Hazards Division; and Rod Raphael and Barry Jessiman of the Monitoring and Criteria Division; all of whom are with the Environmental Health Directorate of Health Canada. The following people have reviewed this handbook: Elaine Easson, Danny Epstein, Bev Huston, David Kane, Mark Richardson, Keith Rodgers, and Ron Newhook.

The figures and photos in the handbook are from a variety of sources. Figures 1 and 2 were created for this handbook. Figure 3 is from *A Vital Link*, published by Health and Welfare Canada in 1992. Except where individually credited, all photographs were provided by Health Canada. Doug Haines provided the cover photo.

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1. ABOUT THIS HANDBOOK

Why Was This Handbook Developed?

In recent years, there has been a tremendous increase in people's awareness of environmental issues and a growing concern over how their health is affected by their environment. Health professionals who respond to public demands need more tools to help them assess the risks posed by environmental contaminants in their communities. The public, on the other hand, want to know how these assessments are done.

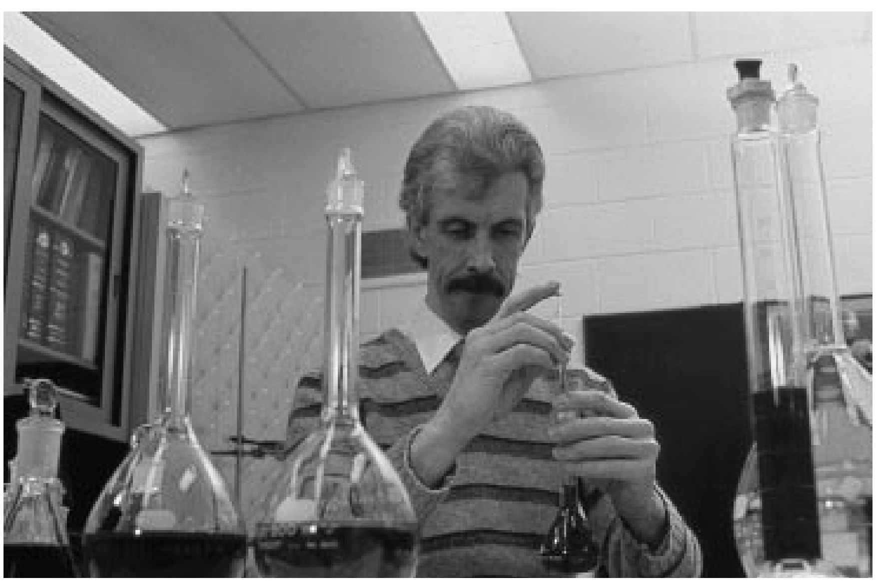
Radionuclide

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

This handbook describes a step-by-step process for calculating exposures to **chemicals and radionuclides** present in the environment. The methods presented in this handbook may be of use to health professionals performing exposure assessments. This information may also help the public understand the process and methods generally followed for performing exposure assessments.

What Is in This Handbook?

This handbook provides the technical information necessary for calculating exposure to environmental contaminants. It includes a brief description of the exposure model and the general method used to estimate exposure to contaminants. Equations used to calculate exposure, along with specific examples showing how the calculations are performed, are included. To solve the equations, numerous measurements and values are needed. Because all of these values may not be available for your situation, the handbook contains tables of standard values that can be substituted instead.



How Can the Results Be Used?

What can you do with the results of the calculations described in this handbook? Firstly, your results will help identify which exposure pathways are important for each contaminant of concern in your community. Knowledge of the main exposure pathways can be useful in designing strategies to reduce exposure. The results of exposure calculations can also help to determine whether more detailed studies are necessary before actions to reduce exposure are taken.

A Word of Caution

Many assumptions and judgements are made when calculating people's exposure to environmental contaminants. Some of these include using average values for body weight, the amount of food and water people consume, the amount of air people breathe, and the number of times people are exposed to contaminants over their lifetime. Different groups performing the same calculations may use different assumptions or have more or less information to work with. Therefore, the results obtained by one group or agency may be different from the results of others.

This handbook is not intended as a substitute for professional expertise. Instead, it describes the general approach taken in estimating exposure to environmental contaminants. If you want to calculate exposures in your community, be sure to consult with professionals whenever you feel unsure about gathering and analysing data, drawing conclusions and making recommendations.

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

Units of Measurement for Contaminants in the Environment – Terminology

The concentrations of chemicals and radionuclides can be expressed in many ways using different units of measurements. When calculating exposure, it may be necessary to convert contaminant concentrations from one unit to another.

In *liquids* such as water, chemical contaminants are most commonly expressed in milligrams per litre (mg/L) or micrograms per litre (µg/L). One milligram equals one thousand micrograms. Similarly, radionuclide activity concentrations are expressed in becquerels per litre (*Bq*/L). In *soil*, *food and other solids*, chemical contaminant levels are usually expressed in milligrams per kilogram (mg/kg) while radionuclide activity concentrations are expressed in becquerels/kilogram (*Bq*/kg). Concentrations of chemicals and particulates in *air* are usually expressed as milligrams or micrograms per cubic metre (mg/m^3, $\mu g/m^3$) or as becquerels per cubic metre (Bq/m^3) for radionuclide activity. Occasionally, the units for chemical and radionuclide 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 on the opposite page.

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

The basic unit for radionuclide activity is the becquerel (*Bq*).

SOIL AND WATER

Metric Units in Liquids*	Equivalent in Parts Per Unit ppm	ppb	ppt	ppq	Metric Units in Solids*
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

* The radionuclide activity concentration is usually expressed as *Bq*/L in liquids and *Bq*/kg in solids.

AIR

Converting from ppm in Air to Its Equivalent in μg/m³

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

Contaminant Concentration (μg/m^3) = Contaminant concentration (ppm) x Molecular Weight of the Contaminant x 40.9

EXAMPLE: Convert the pollutant ozone, at 0.08 ppm in air, to its equivalent in μg/m^3. The molecular weight of ozone is 48.

Contaminant Concentration (μg/m^3) = 0.08 ppm x 48 x 40.9

= 157 μg/m^3

157 μg/m^3 ozone is equivalent to 0.08 ppm ozone

The radionuclide activity concentration in air is usually expressed as *Bq*/m^3.

2. THE EXPOSURE MODEL

What Is Exposure?

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

What Is an Exposure Pathway?

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

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

Source of Contamination

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

Environmental Media

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

i. WATER

Groundwater (water below ground, such as from aquifers and wells)

- drinking water from wells (municipal or domestic), bathing, showering;
- industrial, agricultural or recreational use of groundwater; and
- recreational and other use of natural springs and sink holes.

Surface water (water from lakes, rivers, and ponds)

- drinking water (municipal or domestic), bathing, and showering;
- recreation, such as boating, canoeing, and swimming; and
- industrial or agricultural use.

ii. AIR

- indoor air, including air quality at home, work and school;
- outdoor air; and
- contaminant gases from industrial production or other processes (e.g., car exhaust, home heating).

iii. FOOD

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

iv. SOIL

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

Point of Exposure

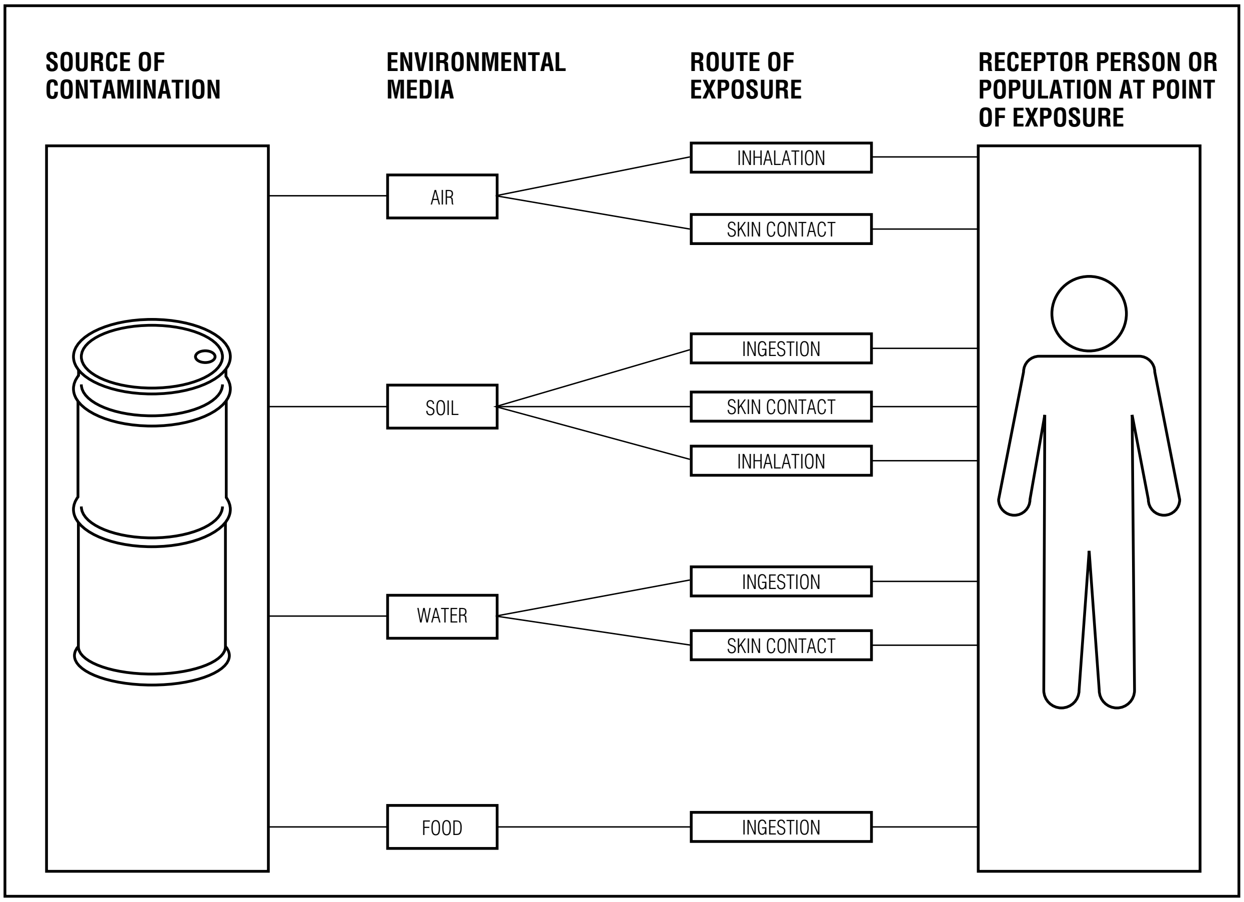
The point of exposure is the location where contact with a contaminant occurs. For example, people can be exposed to contaminants in the home, a business, a playground, a lake, river or other body of water.

Receptor Person or Population

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

FIGURE 1:

Major Pathways of Human Exposure to Environmental Contaminants



Routes of Exposure

An **exposure route** is how a contaminant enters the human body. There are three general routes by which humans may take contaminants into their bodies. These include:

i. *Ingestion*

- Swallowing something containing the contaminant. This can include food, water, small amounts of soil, and accidental ingestion of objects or other liquids containing the contaminant. The mouth, throat, stomach, and intestines can absorb certain ingested materials rapidly.

ii. *Inhalation*

- Breathing in a substance as a gas or vapour, or as airborne particles. This includes small amounts of soil and dust that can be inhaled into the lungs. The lungs often absorb gases and vapours quickly and efficiently.

iii. Skin Contact

- Some contaminants in water, soil and air can be absorbed through the skin.

In addition to the above three exposure routes, exposure to ionizing radiation (from radionuclides on the ground, in the air, or from radiation sources outside the body) may also occur by direct external irradiation.

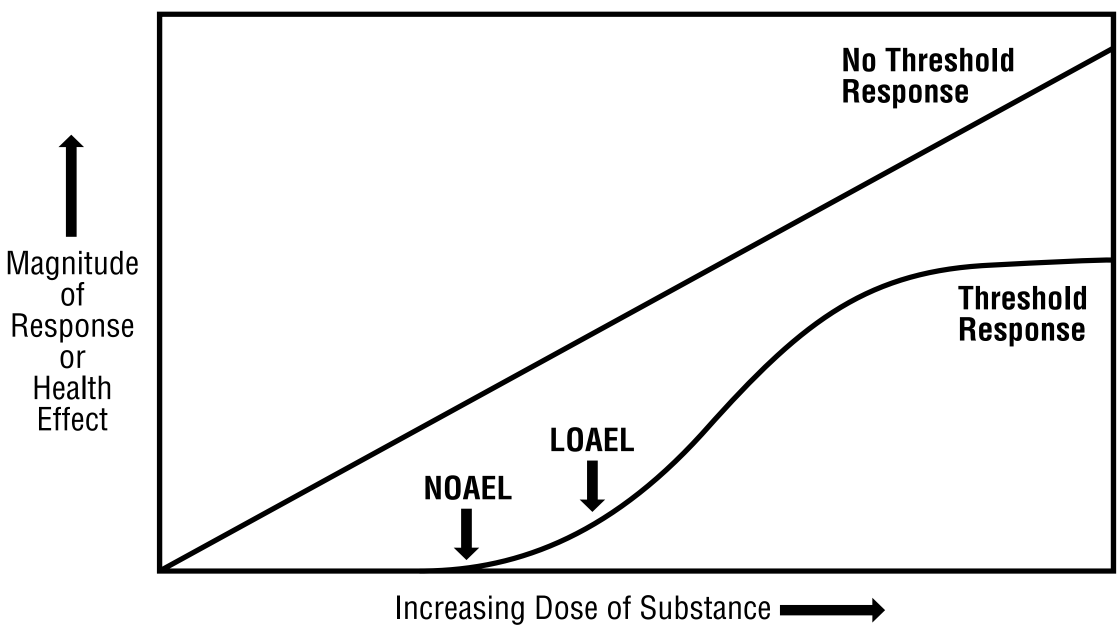
The elements of an exposure pathway are shown in FIGURE 1.

What Is the Dose-Response Relationship?

The relationship between the amount of a contaminant that is given (the dose) and the health effect (the response) is referred to as the dose-response relationship. Dose-response relationships are usually determined in laboratory experiments using animals and, in some instances, from results of epidemiological studies in humans.

FIGURE 2:

Dose-Response Relationship



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

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

For most contaminants, no adverse health effects can be observed when the dose falls below a certain level. This level is called the threshold dose. Whether or not adverse health effects occur below the threshold cannot be known conclusively because of the limitations of toxicological studies.

Based on the knowledge of how cancer develops, it is generally assumed that contaminants which cause cancer (carcinogens) can potentially do so even at the very lowest levels of exposure. In other words it is assumed that most carcinogens have no threshold concentration. A typical dose-response relationship for carcinogens is shown by the straight line titled "No Threshold Response" in FIGURE 2.

For health effects other than cancer, it is assumed that the health effect will not occur when the dose of the contaminant falls below a certain threshold. A typical dose-response relationship for such contaminants is shown by the curved line titled "Threshold Response" in FIGURE 2.

3. ESTIMATING EXPOSURE TO CHEMICALS

What Is the Estimated Daily Intake (EDI)?

We are all exposed to a low level of contamination in the air we breathe, in the food we eat, and in the water we drink. The Estimated Daily Intake (EDI) for a chemical contaminant represents the total exposure from all known or suspected exposure pathways for an average person. Examples of how to calculate the EDI are shown in Section 6 - Estimated Daily Intake: Equations and Examples.

CALCULATING THE ESTIMATED DAILY INTAKE

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

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

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

- ED_a is the amount inhaled through the air,
- ED_w is the amount taken in by drinking water,
- ED_s is the amount taken in by eating soil,
- ED_f is the amount taken in with food,
- ED_{ws} is the amount absorbed through skin contact with water,
- ED_{ss} is the amount absorbed through skin contact with the soil.

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

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

where,

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

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

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

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

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

What Is the Tolerable Daily Intake (TDI)?

The tolerable daily intake (TDI) is an estimate of the quantity of a non-cancer causing chemical that humans can be exposed to every day for their whole life without threatening their health. The TDI can also apply to the non-cancer effects of chemicals which cause cancer. It is usually expressed in milligrams of chemical per kilogram of body weight per day (mg/kg/day). The term "acceptable daily intake" (ADI) has also been used instead of TDI. However, the two terms describe the same value.

TDIs for humans are usually based on studies carried out on laboratory animals. In these studies, researchers establish what is called the No Observed Adverse Effect Level (NOAEL), where the concentration of the chemical does not lead to any adverse health effects in animals, or the Lowest Observed Adverse Effect Level (LOAEL) which is the lowest concentration of contaminant at which adverse health effects are observed. This level is then divided by an uncertainty factor (UF) to calculate the TDI. Depending on how exhaustive the studies have been, how confident the researchers are in transferring their conclusions to humans, and the adverse effects that the substance can cause, the uncertainty factor may range from 10 to several thousand.

$$\text{TDI} = \frac{\text{NOAEL (LOAEL)}}{\text{UF}}$$

TDIs are used by governments to establish guidelines to protect human health from the potential health effects of exposure to environmental contaminants. These guidelines are reviewed and revised periodically, especially when new scientific information is obtained. As a result of new information, or of different ways of estimating NOAEL, LOAEL and UF, different governments may set different Tolerable Daily Intake levels.

THE UNCERTAINTY FACTOR

The uncertainty factor (UF), also known as the safety factor, reflects the uncertainty associated with the variety of scientific data used to estimate the TDI. An uncertainty factor of 10 is used when TDIs are based on epidemiological studies of prolonged exposure of healthy humans or when no serious adverse effects are known to occur. This factor accounts for differences in people's sensitivity to contaminants. If the TDI is not based on studies of prolonged human exposure, this basic UF of 10 is multiplied by another 10 for each of the following conditions that apply:

- When TDIs are based on experimental studies using long-term exposure to laboratory animals. This factor accounts for the uncertainty involved in applying animal data to humans.
- When TDIs are based on scientific studies using shorter exposures of the animals to the contaminants. This factor accounts for the uncertainty in extrapolating from short-term to long-term exposures.
- When TDIs are based on a LOAEL rather than a NOAEL. This factor accounts for the uncertainty in calculating NOAELs from LOAELs.
- Additional uncertainty factor (up to 10, and in some cases greater than 10) may be applied depending on the seriousness of the adverse health effect observed.

What Is the Risk-specific Dose?

A different approach than the Tolerable Daily Intake is required for contaminants known to cause cancer. This is because there may be no level of exposure to these contaminants that does not present any risk to health. In these cases, "zero risk" can be achieved only by eliminating all possible human exposure. However, this may not be possible with many contaminants, such as naturally occurring carcinogens that may be widespread in the environment. Therefore, it is desirable to reduce exposure to carcinogens to as low a level as possible, while recognizing that "zero" exposure is impossible.

For such substances, a decision must be made as to how large a risk of cancer can be accepted, in order to set acceptable intake levels. Various acceptable levels of risk are currently being used around the world, depending on specific circumstances. Such levels often vary between one extra cancer death per 10,000 people exposed (1×10^{-4}) to the contaminant over their entire lifetime, to one extra cancer death per million people exposed (1×10^{-6}).

Once an acceptable level of risk (R) has been established, it is divided by a factor (known as the Slope Factor: SF), which has been determined from the results of laboratory and epidemiological studies, to obtain a Risk-specific Dose (RsD). The Risk-specific Dose is the amount of contaminant that people can be exposed to on a daily basis, over their entire lifetime, that will not exceed the accepted level of risk of cancer. It is usually expressed in milligrams of chemical per kilogram of body weight per day (mg/kg/day).

$$\mathbf{RsD} = \frac{\mathbf{R}}{\mathbf{SF}}$$

Example: Calculate the Risk-specific Dose (RsD) for a contaminant known to cause cancer. The Slope Factor* (SF) for this contaminant is 4.3×10^{-3} $(mg/kg/day)^{-1}$ and the accepted level of risk (R) is one extra cancer death per year per one million people exposed (10^{-6}).

$$\mathbf{RsD} = \frac{1 \times 10^{-6}}{4.3 \times 10^{-3}\ (mg/kg/day)^{-1}}$$

$$= 2.3 \times 10^{-4}\ mg/kg/day$$

* *Slope Factors (SF) can be obtained from on-line toxicological databases such as the Integrated Risk Information System (IRIS) available from the United States Environmental Protection Agency. The IRIS registry contains regulatory information on more than 400 chemicals with more added to the database each year. IRIS is available in disc format for use on microcomputers.*

How Does EDI Compare with TDI or RsD?

Once an EDI has been calculated for a contaminant, it is then compared to the TDI or to the RsD, depending on whether it is a non-carcinogen or a carcinogen. As a general rule, if the TDI or RsD is exceeded, exposure to the contaminant is a potential health concern. In some instances, additional medical and toxicological information may indicate that exposures exceeding the TDI or RsD are not a health concern. In other instances, exposures below the TDI or RsD could be a health concern because of interactions between chemicals or because certain individuals in the exposed population are more sensitive. Therefore, it should be recognized that the TDI and RsD are estimates of exposures at which adverse health effects are not expected to occur for the majority of the population. They do not describe a level at which we are absolutely certain that no risk to health will occur for every individual. TDIs and RsDs for a number of environmental contaminants are shown in TABLE 6.

COMPARING EDI TO TDI OR RsD

Non-carcinogens

- If the EDI is well below the TDI, it indicates that exposure to that contaminant likely does not pose a significant risk to human health.
- As the EDI approaches the level of the TDI, the concern regarding the risk to human health increases.
- If the EDI is above the TDI, then exposure and potential risk to people's health should be considered important. Action may be necessary to reduce the exposure.

Carcinogens

- If the EDI is well below the RsD, it indicates that the risk of cancer from exposure to that contaminant is minimal for that situation.
- As the EDI approaches the RsD, the concern regarding the risk to human health increases.
- If the EDI is above the RsD, then exposure and potential risk to human health should be considered important. Action may be necessary to reduce the exposure.