Calculating the Estimated Dose for Exposure to Ionizing Radiation

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

$$\mathbf{ED} = \mathbf{ED_{external} + ED_{internal}}$$

$$= \mathbf{ED_{external} + ED_a + ED_w + ED_s + ED_f}$$

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

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

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

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

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

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

$$\mathbf{ED_x = C \times CR \times CF \times EF \times DCF}$$

where,

ED_x = Estimated Committed Dose over 50 years (adults) or 70 years (children) from a specific radionuclide taken into the body in the current year (*Sv*) for a specific pathway "x" (air inhalation, and water, soil or food ingestion).

C = Concentration of the radionuclide in the exposure pathway being considered (e.g., *Bq*/L for radionuclides in water).

CR = Contact Rate: The amount of water, food, air, etc., which is taken into the body in one day. Typical units for food are grams per day (g / day) and litres per day (L / day) for water.

CF = Conversion Factor: The factor of 365 days is required to convert the Contact Rate (CR) from units/day to units/year.

EF = Exposure Factor: This factor indicates how often the individual is exposed during a year. It is needed especially when exposure does not occur daily, such as at work (only five days a week) or when related to seasonal activities (swimming in the summer).

DCF = Dose Conversion Factor: This factor converts the amount of radionuclide taken into the body via inhalation or ingestion, in becquerels, to the extended 50-year (adults) or 70-year (children) dose in sieverts. DCFs are usually expressed as *Sv*/*Bq*.

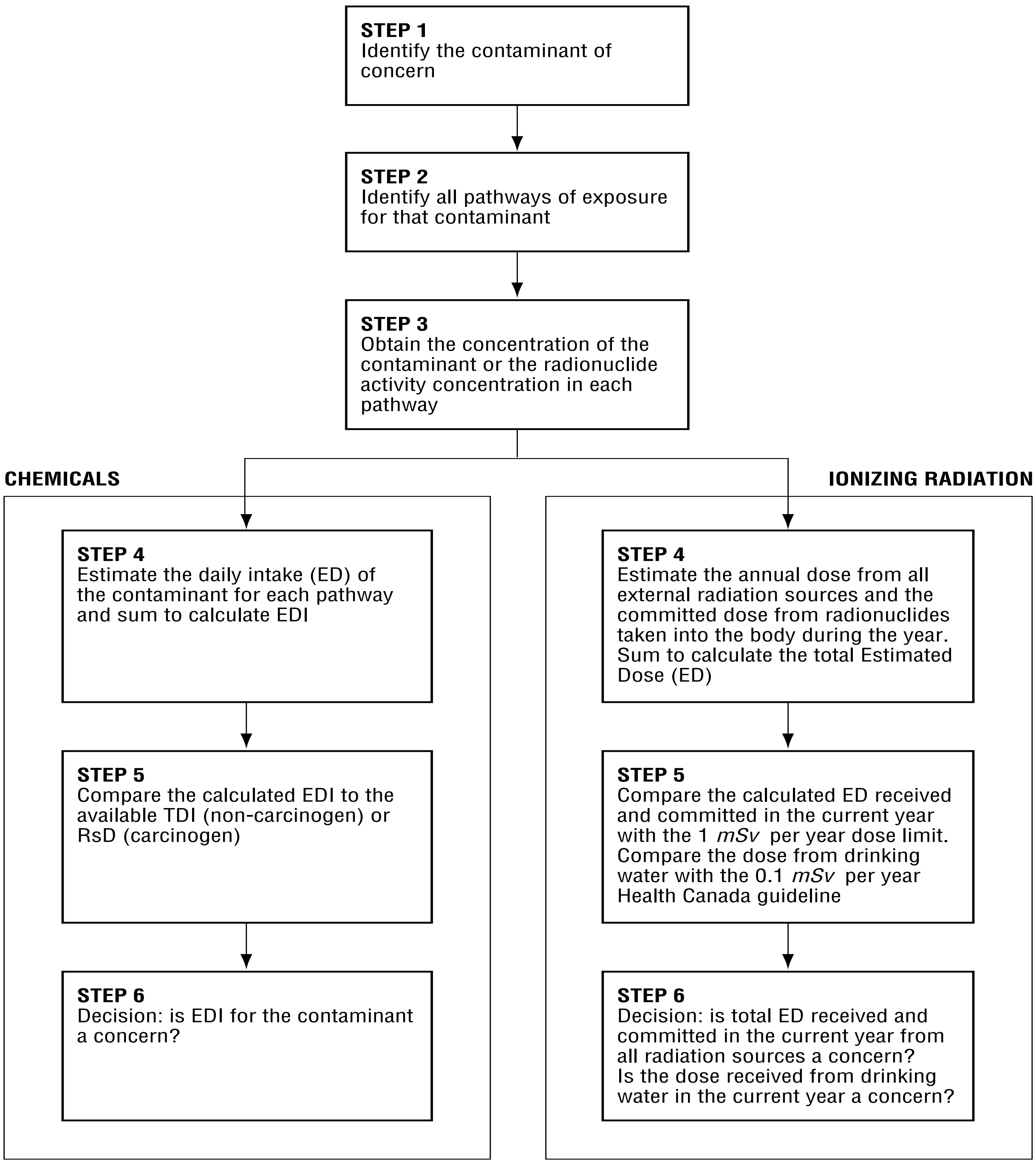
What Are the Recommended Limits to Radiation Exposure?

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

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

5. THE STEP-BY-STEP APPROACH FOR ESTIMATING EXPOSURE TO ENVIRONMENTAL CONTAMINANTS

This handbook focuses on steps four, five and six - calculating the Estimated Daily Intake of chemicals and the total Estimated Dose of radiation - of the following flow chart. For more information on steps one through three, see the companion “Community Handbook”.



6. ESTIMATED DAILY INTAKE FOR CHEMICALS: EQUATIONS AND EXAMPLES

This section describes how to carry out the calculations for the Estimated Daily Intake of a chemical contaminant. It also gives advice on what values to use in the equations and includes tables of average values that can be used when you have no specific, local information available.

The equations and calculations in this section can be onerous. Consult an experienced scientist for help.

Assumptions and Inferences

Many subjective judgements are made in the process of calculating exposures using the many precise formulas available. This happens because some of the information for equations is not available, or values that are available do not accurately reflect the real variations in areas such as the concentration of contaminants in the air, soil, water and food. Many of the assumptions and judgement calls that may be made during an exposure assessment are highlighted below:

- How should the movement of contaminants through the environment be predicted? A specific example of this question is: How should the dispersion of air pollutants in the atmosphere due to wind currents be predicted?
- How should the size and nature of the population potentially exposed to the contaminant be estimated? Can the exposure measurements taken from a small segment of the community be applied to the entire community and, if so, how should this done?
- How should patterns of human activity, such as variations in diet, lifestyle and hobbies, be taken into account?
- How should differences in exposure to the contaminant, such as timing, duration and age at first exposure, be estimated?
- How should the breathing rate, water and food consumption, body weight and surface area of the potentially exposed population be estimated?
- How should exposures of special risk groups, such as pregnant women and small children, be estimated?

Because these judgement calls often change the results of an exposure assessment, it may be necessary to seek professional advice before performing these calculations.

It is important that the units of measurement used in the equations be compatible when calculating exposures.

Exposure Factors

The exposure factor is a value that must be calculated in each of the examples that follow. Its calculation also involves a judgement call.

Exposure to contaminants may occur intermittently or not necessarily on a daily basis. In these cases, an exposure factor (EF) can be calculated to estimate an average dose over the exposure period. The exposure factor is calculated by multiplying the number of days in the year on which exposure occurs by the number of years that this pattern has been repeating itself. This number is then divided by the time period over which the dose is to be averaged. For example, if a child comes into contact with contaminated soil three times a week over a four-year period, the exposure factor would be calculated as follows:

$$EF = \frac{(3\ \text{days/week}) \times (52\ \text{weeks/year}) \times (4\ \text{years})}{(4\ \text{years}) \times (365\ \text{days/year})}$$

$$EF = 0.43$$

In this example, the dose resulting from one day on which the child was exposed would be multiplied by 0.43 to yield the average daily dose over the four-year period.

In calculating the exposure factor, a judgement call is required in choosing the time period over which the exposure is averaged. The time period chosen depends on the expected health effects of the contaminant. In most cases, the expected health effects will be those such as cancer, or injury to organs that result from a continuous low level of exposure over a long period of time. In such cases, researchers generally average all exposures over a lifetime of 70 years.

In cases where children are exposed to contaminants, such as lead, that affect their development, a shorter period (4-12 years) can be chosen as the period over which exposure is averaged. When calculating the exposure factor for a child, the total exposure factor can be broken into three parts to allow changes in the child's body weight, and food, water and air consumption to be included in the final calculation. Researchers generally divide a child's life into three stages: the first six months, six months to 5 years, and 5 to 12 years old. To calculate a child's lifetime exposure, the exposure in each of these periods must be calculated separately. The separate exposures are then added together. The examples that follow show how this is done.

As a rule of thumb then, calculating the EDI requires averaging the exposure over a lifetime of 70 years, unless the contaminant can affect human development in a critical life stage such as childhood. Once again, if you are not sure, consult someone with a background in toxicology or epidemiology.

Estimating Exposures from Air Pollution

Air is an important pathway for contaminants and inhalation is the major route of exposure to contaminants that exist as atmospheric gases or are attached to airborne particles or fibres. In order to estimate an inhalation dose, an estimate of the amount of air a person breathes in a day is required. Standard values for the amount of air inhaled by various age groups are presented in TABLE 1. A person's sex, age, and the amount of physical activity are major factors affecting the volume of air breathed. Other factors influencing the volume of air breathed include: temperature, altitude, background air pollution, and a person's weight, height, whether or not they smoke, and whether they have suffered from heart disease.

To calculate the inhalation dose, it is assumed that 100% of the contaminant is absorbed after contact.

The amount of a contaminant absorbed into the body through inhalation (ED_a) can be estimated with the equation:

$$ED_a = \frac{C \times IR \times EF}{BW}$$

where:

ED_a = Estimated Dose through air inhalation: The air inhalation dose is expressed as milligrams of the contaminant inhaled per kilogram of body weight per day (mg/kg/day).

C = Concentration of the contaminant in the air, in milligrams per cubic metre of air (mg/m^3).

IR = Inhalation Rate: The amount of air a person breathes in a day, in cubic metres (m^3/day). Standard values are given in TABLE 1. If contaminated air is breathed for only part of a day, then inhalation rate is adjusted accordingly.

EF = Exposure Factor: Indicates how often the individual has been exposed to the contaminant over a lifetime (unitless). See previous discussion of exposure factors.

BW = Body Weight: The average body weight in kilograms (kg) based on an individual's age group. Standard values are given in TABLE 2.

EXAMPLE:

Estimate the exposure for an 11-year-old child (just prior to the 12th birthday) who has been exposed, for two hours per day every day since birth, to lead in outdoor air at a concentration of 8×10^{-6} mg/m^3. Exposure ended at age 12 when the family moved to another area. Remember to calculate exposures for three age periods: 0 - < 0.5 years, 0.5 - < 5 years, and 5 - < 12 years. In this case the inhalation rate (IR) of contaminated air is a fraction of the total amount of air breathed in a day. It is calculated as follows:

$$\frac{\textbf{2 hours of exposure/day}}{\textbf{24 hours in a day}} \quad \textbf{X} \quad \textbf{total daily amount of air inhaled}$$

The total daily amount of air inhaled changes as a child grows (see TABLE 1 for the values for each stage of a child's life). Multiplying each of these values by 2/24 (= 0.083) gives an IR of 0.166 m^3/day, 0.415 m^3/day, and 0.996 m^3/day for each of the three age periods. The Exposure Factors for these periods are calculated as follows:

Age (yrs)	Exposure Factor
0 - < 0.5	183 days of exposure in first six months/4380 days in lifetime (12 years) = 0.042
0.5 - < 5	1642 days of exposure in second period/4380 days in lifetime (12 years) = 0.375
5 - < 12	2555 days of exposure in second period/4380 days in lifetime (12 years) = 0.583

Age (yrs)	Concentration	IR	EF	BW	Daily Inhalation Dose (mg/kg/day)
0 - < 0.5	8×10^{-3}	0.166	0.042	7	0.79×10^{-5}
0.5 - < 5	8×10^{-3}	0.415	0.375	13	9.58×10^{-5}
5 - < 12	8×10^{-3}	0.996	0.583	27	17.21×10^{-5}
ED_a					2.76×10^{-4}

The estimated daily dose of lead, which this child absorbs through the lungs, is estimated to be 2.76×10^{-4} mg/kg/day.

Modified from ATSDR, 1992.

Note: This example consists of fictitious data.

Estimating Water Ingestion Exposures

Drinking contaminated water can lead to significant exposures of hazardous substances. In order to estimate the exposure to contaminants from drinking water, the amount of water people drink must be determined. Ingestion of water includes straight water, water in coffee, tea or other drinks made with tap water, and water in cooked food. If precise values for your community are not available, the standard values for the daily ingestion of water, which are presented in TABLE 1, can be used.

To calculate the water ingestion dose, it is assumed that 100% of the contamiant is absorbed after ingestion.

The amount of a contaminant absorbed into the body through drinking water (ED_w) can be estimated with the following equation:

$$ED_w = \frac{C \times IR \times EF}{BW}$$

where:

ED_w = Estimated Dose from drinking water: The water ingestion dose is expressed as milligrams of the contaminant ingested, per kilogram of body weight per day (mg/kg/day).

C = Concentration of the contaminant in the water, in milligrams per litre of water (mg/L).

IR = Ingestion Rate: The amount of water a person drinks in a day, in litres (L/day). Standard values are given in TABLE 1. If the person drinks from the contaminated water source for only a part of the day (for example, only at work), then the ingestion rate is adjusted accordingly.

EF = Exposure Factor: Indicates how often the individual has been exposed to the contaminant over a lifetime. See previous discussion of exposure factors (unitless).

BW = Body Weight: The average body weight in kilograms (kg) based on an individual's age group. Standard values are given in TABLE 2.

EXAMPLE:

Calculate human exposure to contaminants in the drinking water at work. The water is contaminated with 367 mg/L methylchloride. To calculate an adult exposure dose over a lifetime, assume a body weight of 70 kg (TABLE 2) and a 30-year career, with 5 working days per week, and 50 work weeks per year. Assume a water ingestion rate (IR) of 1.5 L/day (TABLE 1).

$$EF = \frac{\text{30 work years x 50 work weeks/year x 5 work days/week}}{\text{70 years/lifetime x 365 days/year}}$$

$$= 0.29$$

Then, $$ED_w = \frac{C \times IR \times EF}{BW}$$

$$= \frac{\text{367 mg/L x 1.5 L/day x 0.29}}{\text{70 kg}}$$

$$= \text{2.28 mg/kg/day}$$

Assuming that the workplace is the only source of exposure, the lifetime exposure to methylchloride of the adult in the above conditions is calculated to be 2.28 mg/kg/day.

Modified from ATSDR, 1992

Note: This example consists of fictitious data.

Estimating Soil Ingestion Exposures

Soil can be eaten unintentionally, when soil sticks to hands or to food. Soil can also be ingested when other objects are put in the mouth or swallowed. All children do this to some extent. How often children swallow and mouth objects varies. Children between the ages of one and three years, and children with neurologic disorders develop a "swallowing object habit" (known as pica) more often than other children.

Standard values for the daily ingestion of soil by children who do not swallow objects regularly, and adults are presented in TABLE 1. To calculate the soil ingestion dose, it is assumed that 100% of the contaminant ingested with soil is absorbed.

The amount of a contaminant absorbed into the body by eating soil (ED_s) can be estimated with the equation:

$$ED_s = \frac{C \times IR \times EF \times 10^{-6}}{BW}$$

where:

ED_s = Estimated Dose through eating soil: The soil ingestion dose is expressed as milligrams of the contaminant eaten, per kilogram of body weight per day (mg/kg/day).

C = Concentration of the contaminant in the soil in milligrams per kilogram of soil (mg/kg).

IR = Ingestion Rate: The amount of soil a person eats in a day, in milligrams (mg/day). Standard values are given in TABLE 1. If the individual can only eat contaminated soil for part of the day (for example, a child exposed to contaminated soil at a daycare centre attended only in the morning), then the ingestion rate can be adjusted accordingly.

EF = Exposure Factor: Indicates how often the individual has been exposed to the contaminant over a lifetime. See previous discussion of exposure factors (unitless).

BW = Body Weight: The average body weight in kilograms (kg) based on an individual's age group. Standard values are given in TABLE 2.

NOTE: The equation includes a conversion factor of 10^{-6}, which is required to convert the concentration of the contaminant in the soil (C) from mg/kg of soil to mg/mg of soil. In this way, the units for soil concentration are the same as those for soil ingestion (both now in milligrams of soil).

EXAMPLE:

Calculate the exposure of an adult to soil at the workplace. The soil is contaminated with 0.9 mg/kg of cadmium. To calculate an adult exposure dose over a lifetime, assume a body weight of 70 kg (TABLE 2) and a 30-year career, with 5 working days per week, and 50 work weeks per year. Assume a soil ingestion rate (IR) of 20 mg/day (TABLE 1).

$$\mathbf{EF} = \frac{\text{30 work years x 5 work days/week x 50 work weeks/year}}{\text{70 years/lifetime x 365 days/year}}$$

$$= 0.29$$

Then,

$$\mathbf{ED_s} = \frac{C \times IR \times EF \times 10^{-6}}{BW}$$

$$= \frac{0.9\ \text{mg/kg} \times 20\ \text{mg/day} \times 0.29 \times 10^{-6}}{70\ \text{kg}}$$

$$= 7.46 \times 10^{-8}\ \text{mg/kg/day cadmium}$$

Assuming that the workplace is the only source of exposure, the exposure to cadmium of the adult in the above conditions is calculated to be 7.46 x 10^{-8} mg/kg/day, averaged over a lifetime.

Modified from ATSDR, 1992

Note: This example consists of fictitious data.

Estimating Food Ingestion Exposures

How much of a contaminant is eaten with food requires a knowledge of eating habits of the group or population being studied, and the concentration of the contaminant in different kinds of food. Eating habits - the amount of each different kind of food eaten - in your community may differ from the national average. For example, in some communities, far more fish is eaten than the average for all Canadians. Groups within the community may also vary from national averages. In general, older people eat more fish, as do sport fishermen. When values for local eating habits are available, they should be used to calculate the exposure dose. The average amount of various food groups eaten by Canadians are shown in TABLE 3, and can be used when local values are not available.

The amount of a contaminant taken into the body with food (ED_f) requires a separate calculation for each kind of food (or food group) that is eaten. That makes the equation look more complicated, but the extra steps are just a repetition of the basic equation used in calculating all other estimated doses (ED). The total estimated dose from food can be calculated with the following equation:

$$ED_f = \underbrace{\frac{CF \times CR \times EF}{BW}}_{\text{(food group 1)}} + \underbrace{\frac{CF \times CR \times EF}{BW}}_{\text{(food group 2)}} + \ldots + \underbrace{\frac{CF \times CR \times EF}{BW}}_{\text{(last food group)}}$$

where:

ED_f = Estimated Dose from food: The food ingestion dose is expressed as milligrams of the contaminant eaten per kilogram of body weight per day (mg/kg/day).

CF = Concentration in food groups: The concentration of the contaminant in the food group is expressed in milligrams of contaminant per gram of food (mg/g).

CR = Consumption Rate: The amount of food from that food group eaten, expressed in milligrams per day (mg/day). Standard values are given in TABLE 3.

EF = Exposure Factor: Indicates how often the individual has eaten the contaminated food in a lifetime (unitless). See previous discussion of exposure factors.

BW = Body Weight: The average body weight in kilograms (kg) based on an individual's age group. Standard values are given in TABLE 2.

NOTE: It is assumed that 100% of the contaminant eaten with the food is absorbed into the body.

The calculation of the food ingestion dose of a contaminant in home-grown foods is similar, but takes into account the percentage of contaminated food that is home-grown:

$$ED_f = \underbrace{\frac{CF \times CR \times EF \times PH}{BW}}_{\text{(food group 1)}} + \underbrace{\frac{CF \times CR \times EF \times PH}{BW}}_{\text{(food group 2)}} + \ldots + \underbrace{\frac{CF \times CR \times EF \times PH}{BW}}_{\text{(last food group)}}$$

where,

PH = percentage of that food group that is home-grown

Agricultural lands: assume that 50% of the meat, milk, fruit and vegetables eaten by residents in agricultural areas are grown on the farm.

Residential lands: assume that 7% of the fruit and vegetables are grown in the backyard garden. No meat or milk is produced at home.

EXAMPLE:

Estimate the exposure of a child, between the ages of 5 and 11 years, to lead from food that is produced on the farm where she lives. Since she lives on a farm (i.e., agricultural land), assume that 50% (i.e., PH = 0.5) of the meat, milk, and fruit and vegetables eaten by this child are produced on the farm. To calculate exposure dose through food, assume a body weight of 27 kg (TABLE 2) and a consumption rate (CR) of meat, dairy products, fruit and vegetables to be 120 g/day, 609 g/day and 198 g/day respectively (TABLE 3). Assume an exposure factor (EF) of 1.0 since the child eats every day. This estimate is only for lead from the locally grown food. It does not consider other sources of lead such as from purchased food.

Food Group	CF	CR	PH	EF	BW	Daily Intake of Contaminant (mg/kg/day)
Meat	0.01	120	0.5	1.0	27	0.022
Dairy Products	0.005	609	0.5	1.0	27	0.056
Vegetables	0.002	198	0.5	1.0	27	0.007
ED_f						0.085

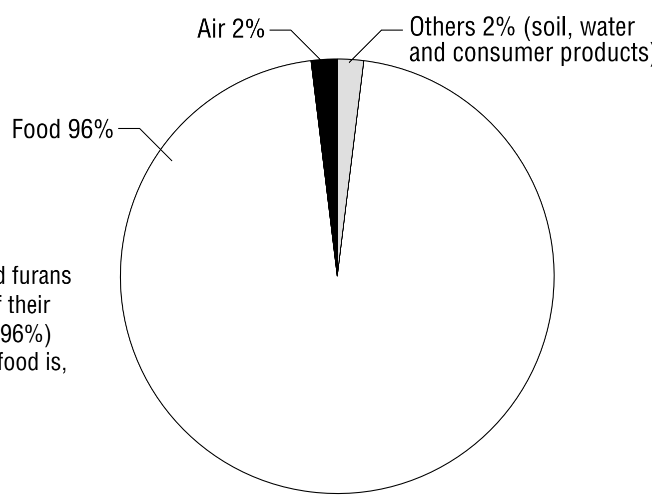
The daily intake of lead from home-grown food, by this child between the ages of 5 and 11 years, is estimated to be 0.085 mg/kg/day.

Modified from ATSDR, 1992.

Note: This example consists of fictitious data.

FIGURE 3:

Food Ingestion as the Major Exposure Route for Dioxins and Furans in Canadians



While few people are exposed to dioxins and furans at levels considered a risk to health, most of their exposure is from some contaminated food (96%) rather than from air or other sources. Most food is, in fact, free of dioxins and furans.

Estimating Skin Exposure Doses (Water and Soil)

The absorption of contaminants through the skin depends on a number of factors, including:

- the total surface area of the exposed skin;
- what part of the body was in contact with the contaminant;
- length of contact;
- concentration of the chemical on the skin;
- the ability of the specific contaminant to move through the skin into the body. This is called the "chemical-specific permeability";
- the type of substance through which the contaminant comes into contact with the skin. For example, is the contaminant dissolved in water, or in soil, when it comes into contact with the person? and
- whether the skin is damaged in any way before coming into contact with the contaminant.

The area of the skin that is exposed will be influenced by the activity being performed and the season of the year. Total skin surface area also varies with age. TABLE 2 provides values for skin surface area of different parts of the body for adults and for children.

Skin Exposure Dose from Contaminated Water

The absorption of contaminants in water through the skin occurs during bathing, showering or swimming. Worker exposure via this route depends on the type of work performed, protective clothing worn, and the extent and length of water contact. How quickly a chemical travels through the skin is affected by the physical and chemical properties of the substance, including:

- the weight, size and shape of the molecules of the chemical;
- its electrostatic charge; and
- whether or not it can be dissolved in water, and in fats.

In general, chemicals that travel quickly through the skin have low molecular weights, no electrostatic charge, and can be dissolved in fat. How fast a chemical travels can be measured and expressed as a value, called the permeability constant. This constant is different for every chemical. Absorption through the skin can go more quickly where skin cuts and abrasions, or skin conditions such as psoriasis or eczema, are present.

To estimate the absorption of a contaminant in water through the skin, a permeability constant (P) should be used. However, such constants have been established for only a few chemicals. Even for chemicals that have been tested, the value of the constant can depend to a very large degree on the design of the experiment used to test the chemical. Skin permeability constants for some contaminants in water are shown in TABLE 4. To be on the safe side and not underestimate the exposure, a permeability of 1.0 cm/hour can be used in the calculations. This is done by a number of government agencies, rather than using the constants such as those in TABLE 4.

The amount of a contaminant in water absorbed into the body through skin contact (ED_{ws}) can be estimated with the equation:

$$ED_{ws} = \frac{C \times P \times SA \times ET \times EF \times 10^{-3}}{BW \times AT}$$

where:

ED_{ws} = Estimated Dose through water on the skin: The skin exposure dose is expressed as milligrams absorbed through the skin per kilogram of body weight per day (mg/kg/day).

C = Concentration of the contaminant in the water in milligrams per litre of water (mg/L).

P = Permeability Constant: expressed as the number of centimetres the chemical will travel through the skin in an hour (cm/h). A cautious approach assumes a constant of 1.0 cm/h rather than the constants shown in TABLE 4. See previous discussion.

SA = Surface Area: The surface area is the skin that is exposed to the contaminated water, expressed in square centimetres (cm^2). TABLE 2 contains the average surface areas for various parts of the body.

ET = Exposure Time: The number of hours per day that the contaminated water is in contact with the skin.

EF = Exposure factor: Indicates how often the individual has been exposed to the contaminated water over a lifetime (unitless).

BW = Body Weight: The average body weight in kilograms (kg) based on an individual's age group. Standard values are given in TABLE 2.

NOTE: The factor of 10^{-3} is required to convert the volume units of water from litres (L) to cubic centimetres (cm^3) (1L = 1,000 cm^3). This conversion is necessary, so that the contaminant concentration (C) uses the same units as the permeability constant (P) and the surface area (SA).

EXAMPLE:

Calculate the exposure through the skin of a contaminant in the water for a woman who lives in an area where the benzene concentration (C) has been found to be 0.002 mg/L. She has been living in her house for 25 years and has bathed every day. Ignore other skin contact with the water. Assume that the whole body (SA = 18,200 cm^2) is exposed for a quarter of an hour (ET = 0.25) during bathing. Benzene moves through the skin at a rate of 0.11 cm/h (P). Calculate the daily skin exposure of this woman, averaged over her lifetime which is assumed to be 70 years.

$$\mathbf{EF} = \frac{\text{25 years x 365 days/year}}{\text{70 years x 365 days/year}}$$

$$= \mathbf{0.36}$$

Then,

$$ED_{ws} = \frac{C \times P \times SA \times ET \times EF \times 10^{-3}}{BW}$$

$$ED_{ws} = \frac{0.002 \text{ mg/L} \times 0.11 \text{ cm/hour} \times 18{,}200 \text{ cm}^2 \times 0.25 \text{ hours/day} \times 0.36 \times 10^{-3}}{70 \text{ kg}}$$

$$= 5.1 \times 10^{-6} \text{ mg/kg/day}$$

The skin exposure of this woman to benzene from bathing water, averaged over her lifetime, is 5.1 x 10^{-6} mg/kg/day.

Modified from ATSDR, 1992.

Note: This example consists of fictitious data.

Skin Exposure Dose through Contaminated Soil

The absorption of contaminants from soil or dust through the skin depends on a number of factors:

- the area of contact;
- the duration of contact;
- the chemical and physical attraction between the contaminant and the soil;
- the ability of the contaminant to penetrate the skin;
- the weight of individual molecules of the particular contaminant; and
- how well the contaminant dissolves in water and fats.

Often, not all of the contaminant in the soil is available to the skin for absorption. Many organic chemicals are firmly attached to organic matter in soil so that they can move through the skin only with difficulty. In addition, only the contaminant molecules that are in direct contact with the skin can be absorbed. The amount of a contaminant that can be absorbed from the soil can be tested. The results of such an experiment gives a "bioavailability factor" specific to the contaminant, such as those shown in TABLE 5. These bioavailability factors may also vary according to the experimental method used to determine them. The most cautious approach is to use a bioavailability factor of 1.0 (= 100% absorption) in the calculations.

Another variable factor in calculating absorption through the skin is how well the soil sticks to the skin. Data on dust and soil adherence to the skin are limited. Standard values for the total soil adhered (A) to the skin for various age groups are presented in TABLE 1.

The amount of a contaminant that is absorbed through skin contact with contaminated soil (ED_{ss}) can be estimated using the following equation:

$$ED_{ss} = \frac{C \times A \times BF \times EF \times 10^{-6}}{BW}$$

where:

ED_{ss} = Estimated Dose through skin contact with soil: This dose is expressed as milligrams of the contaminant absorbed through the skin per kilogram of body weight per day (mg/kg/day).

C = Concentration of the contaminant in the soil, in milligrams per kilogram of soil (mg/kg).

A = Total soil Adhered: The amount of soil that will stick to a person, expressed in milligrams per day (mg/day). Standard values that can be used here are found in TABLE 1.

BF = Bioavailability Factor: The percentage of the contaminant in the soil that is actually free to move out of the soil and through the skin (unitless). A cautious approach is to use a factor of 1.0 (= 100% availability) instead of the factors shown in TABLE 5. See previous discussion.

EF = Exposure Factor: Indicates how often the individual has been exposed to the contaminant over a lifetime (unitless). See previous discussion of exposure factors.

BW = Body Weight: The average body weight in kilograms (kg) based on an individual's age group. Standard values are given in TABLE 2.

NOTE: The equation includes a conversion factor of 10^{-6}, which is required to convert the concentration of the contaminant in the soil (C) from mg/kg of soil to mg/mg of soil. In this way, the units for soil concentration are the same as those for total soil adhered to the skin (both now in milligrams of soil).

EXAMPLE:

Estimate the exposure for an 11-year-old child (just prior to the 12th birthday) who has had skin contact with a contaminated soil every day since birth. The concentration of the contaminant in the soil (C) is 100 mg/kg. Assume that the bioavailability factor (BF) is 1.0 (= 100% availability). Remember to calculate exposures for three age periods: 0 - < 0.5 years, 0.5 - < 5 years, and 5 - < 12 years. In this case the total soil adhered (A) to the child is 2200 mg/day, 3500 mg/day, and 5800 mg/day respectively for each of the three age periods (see TABLE 1). The exposure factors for each age period are calculated as follows:

Age (yrs)	Exposure Factor		
0 - < 0.5	183 days of exposure in the first period/4380 days in lifetime	=	0.042
0.5 - < 5	1642 days of exposure in the second period/4380 days in lifetime	=	0.375
5 - < 12	2555 days of exposure in the third period/4380 days in lifetime	=	0.583

Age (yrs)	C	A	BF	EF	Conversion Factor	BW	Daily Skin Exposure (mg/kg/day)
0 - < 0.5	100	2200	1.0	0.042	10^{-6}	7	0.001
0.5 - < 5	100	3500	1.0	0.375	10^{-6}	13	0.010
5 - < 12	100	5800	1.0	0.583	10^{-6}	27	0.013
ED_{ss}							0.024

The daily intake of contaminant by this child is estimated to be 0.024 mg/kg/day, averaged over a lifetime of 12 years.

Modified from ATSDR, 1992.

Note: This example consists of fictitious data.

Calculating the Estimated Daily Intake (EDI)

Once you have calculated each of the separate Estimated Doses, you can add them all together to get the total Estimated Daily Intake (EDI) for the contaminant. The following example shows how it is done.

Estimated Daily Intake (EDI) = $ED_a + ED_w + ED_s + ED_f + ED_{ws} + ED_{ss}$

where, ED_a is the estimated inhalation dose,
ED_w is the estimated water ingestion dose,
ED_s is the estimated soil ingestion dose,
ED_f is the estimated food ingestion dose,
ED_{ws} is the estimated water skin exposure dose,
ED_{ss} is the estimated soil skin exposure dose.

EXAMPLE:

Calculate the EDI of pentachlorophenol of a person living near a suspected contaminated site. Assume you are averaging exposure over a lifetime of 70 years. The Estimated Dose for each possible combination of exposure pathway and exposure route are given below. Note that each Estimated Dose has been calculated separately for each of the five life stages. This can increase the accuracy of the total estimate. Each Estimated Dose was calculated using the equations described on the preceding pages. All values are expressed in nanograms of pentachlorophenol per kilogram of body weight per day (ng/kg/day).

	AGE (years)					
PATHWAY	**0 - < 0.5**	**0.5 - < 5**	**5 - < 12**	**12 - < 20**	**20+**	**Daily Exposure (ng/kg/day)**
Air Inhalation	0.079	0.823	1.430	1.634	6.786	ED_a = 10.752
Water Ingestion	0.001	0.007	0.005	0.006	0.029	ED_w = 0.048
Soil Ingestion	0.007	0.012	0.014	0.016	0.064	ED_s = 0.113
Food Ingestion	0.705	6.771	4.990	5.703	19.786	ED_f = 37.955
Water Skin Exposure	0.003	0.003	0.002	0.002	0.014	ED_{ws} = 0.024
Soil Skin Exposure	0.004	0.071	0.009	0.010	0.036	ED_{ss} = 0.013
	0.799	7.687	6.450	7.371	26.715	EDI = 49.022

The daily intake of pentachlorophenol by this person is estimated to be 49.022 ng/kg/day (equivalent to 0.049 µg/kg/day), averaged over a lifetime of 70 years.

Note: This example consists of fictitious data.

Comparing EDI to TDI or RsD

To determine whether or not the Estimated Daily Intake (EDI) you have calculated is at a level associated with increased risk to health, compare it to the Tolerable Daily Intake (TDI) or the Risk-specific Dose (RsD), whichever is appropriate for that contaminant.

Non-carcinogen

EXAMPLE:

Consider the exposure of a commercial fisherman to methyl mercury, whose EDI has been estimated at 0.61 μg/kg/day. How does this compare with the known TDI?

The TDI for methyl mercury from TABLE 6 is 0.47 μg/kg/day. The EDI of 0.61 μg/kg/day is about 1.3 times above the TDI. This indicates that the exposure exceeds the level considered a risk to health. Steps should be taken to reduce exposure to methyl mercury in this situation.

Carcinogen

EXAMPLE:

The EDI for pentachlorophenol, calculated in the example on the previous page, is found to be 49.022 ng/kg/day (=4.9 x 10^{-5} mg/kg/day). Assume a slope factor (SF) of 0.12 $(mg/kg/day)^{-1}$ for pentachlorophenol and that the level of risk for cancer that was considered acceptable was one excess cancer death per 100,000 people exposed (i.e., 1 x 10^{-5}). How does the EDI compare with the RsD?

1. Calculate the RsD for pentachlorophenol.

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

$$= \frac{1 \times 10^{-5}}{0.12\ (mg/kg/day)^{-1}}$$

$$= \mathbf{8.3 \times 10^{-5}\ mg/kg/day}$$

2. Compare EDI to RsD

The EDI for pentachlorophenol exposure is 4.9 x 10^{-5} mg/kg/day which is about one-half the RsD calculated at 8.3 x 10^{-5} mg/kg/day. This indicates that the exposure is within the level of risk of cancer considered acceptable.

Note: These examples consist of fictitious data.

Another Way to Support Your Results

Guidelines have been prepared for many chemical contaminants found in soil and water. If contaminated levels in soil or water exceed the guidelines, then further investigation of the contamination is recommended. The guidelines, called Interim Assessment Criteria for Soil and Water, were prepared by the Canadian Council of Ministers of the Environment (CCME), and are shown in TABLE 8. If the contaminant concentrations in the soil or water of your community exceed these levels, you can use them to support your request for more detailed study of the problem.

7. ESTIMATED DOSE FOR IONIZING RADIATION: EQUATIONS AND EXAMPLES

Exposure to sources of ionizing radiation outside the body will result in direct external exposure. Inhaling air, or ingesting food, water, or soil, which contains natural or human-made radionuclides can lead to an internal radiation exposure which may be received over an extended period following inhalation or ingestion. As with chemical contaminants, the amount of air, food, water, and soil taken into the body must be determined in order to estimate the dose received from one year of inhalation or ingestion.

Standard values for daily inhalation and ingestion rates are the same as presented in TABLE 1 and TABLE 3. Dose conversion factors (DCF) for children and adults can be obtained from publications issued by the International Commission on Radiological Protection, the National Radiation Protection Board (U.K.), or by contacting the Radiation Protection Bureau, Health Canada, which can provide expertise in this area. DCFs for selected radionuclides are presented in TABLE 7.

Exposure Factors

For radionuclides, the averaging period over which exposure is estimated is taken to be one year (365 days), since exposure limits are expressed on an annual basis. For example, if a worker is exposed four times a week over a work year of 50 weeks, the exposure factor would be calculated as follows:

$$EF = \frac{(50 \text{ work weeks/year}) \times (4 \text{ work days/week})}{(365 \text{ days/year})}$$

$$EF = 0.55$$

Estimating Air Inhalation Radiation Exposures

The committed dose from internal radiation exposure as a result of air inhalation (ED_a) can be estimated with the equation:

$$ED_a = C \times IR \times CF \times EF \times DCF$$

where:

ED_a = Estimated Dose over 50 years (for adults) or 70 years (children) through air inhalation in one year: The air inhalation dose is expressed as sieverts (*Sv*) or millisieverts (*mSv*).

C = Radionuclide activity concentration in air, in becquerels per cubic metre of air (*Bq*/m^3).

IR = Inhalation Rate: The amount of air a person breathes in a day, in cubic metres (m^3/day). Standard values are given in TABLE 1. If contaminated air is breathed for only part of a day, then inhalation rate is adjusted accordingly.

CF = Conversion Factor: The factor of 365 days is required to convert the Inhalation Rate (IR) from units/day to units/year.

EF = Exposure Factor: Indicates how often the individual has been exposed to the contaminant over the year (unitless).

DCF = Dose Conversion Factor (specific for each radionuclide): The extended 50-year or 70-year dose resulting from the inhalation of 1 *Bq* of a given radionuclide (*Sv*/*Bq*). Selected DCFs are presented in TABLE 7.

EXAMPLE:

Estimate the committed dose of radiation for an adult male from one year of inhalation of tritium in air at the workplace. Assume a 50-week work year, a 5-day work week with an 8-hour work day. Air inhalation rate is assumed to be 23 m^3 over 24 hours (see TABLE 1) so that the air inhalation rate (IR) attributable to 8 hours at the workplace is 7.67 m^3. The tritium activity concentration (C) in the air at the workplace was measured at 0.1 *Bq*/m^3 and the DCF for tritium via inhalation is 1.80×10^{-11} *Sv*/*Bq* (see TABLE 7).

$$EF = \frac{\text{1 work year x 50 work weeks/year x 5 work days/week}}{\text{365 days/year}}$$

$$= 0.68$$

Then,

$$ED_a = C \times IR \times CF \times EF \times DCF$$

$$= 0.1\ Bq/m^3 \times 7.67\ m^3/day \times 365\ days \times 0.68 \times 1.8 \times 10^{-11}\ Sv/Bq$$

$$= 3.4 \times 10^{-9}\ Sv$$

$$= 3.4 \times 10^{-6}\ mSv$$

The estimated 50-year committed dose from tritium, as a result of one year of inhalation at the workplace, is 3.4×10^{-6} *mSv*.

Note: This example consists of fictitious data.

Estimating Water Ingestion Radiation Exposures

The committed dose from internal radiation exposure as a result of water ingestion (ED_w) can be estimated with the equation:

$$ED_w = C \times IR \times CF \times EF \times DCF$$

where:

ED_w = Estimated Dose over 50 years (for adults) or 70 years (children) through water ingestion in one year: The water ingestion dose is expressed as sieverts (*Sv*) or millisieverts (*mSv*).

C = Radionuclide activity concentration in drinking water, in becquerels per litre of water (*Bq*/L).

IR = Ingestion Rate: The amount of water a person drinks in a day, in litres (L/day). Standard values are given in TABLE 1. If the person drinks from the contaminated water source for only a part of the day (for example, only at work), then the ingestion rate is adjusted accordingly.

CF = Conversion Factor: The factor of 365 days is required to convert the Ingestion Rate (IR) from units/day to units/year.

EF = Exposure Factor: Indicates how often the individual has been exposed to the contaminant over the year (unitless).

DCF = Dose Conversion Factor (specific for each radionuclide): The extended 50-year or 70-year dose resulting from the ingestion of 1 *Bq* of a given radionuclide (*Sv*/*Bq*). Selected DCFs are presented in TABLE 7.

EXAMPLE:

Estimate the committed dose of radiation for an adult male from one year of ingestion of strontium-90 in water at the workplace. Assume a 50-week work year and a 5-day work week. The total daily water ingestion rate is assumed to be 1.5 L/day (see TABLE 1) with one-half (IR = 0.75 L/day) being consumed at the workplace. The strontium-90 activity concentration (C) in the water at the workplace was measured at 5.0×10^{-3} *Bq*/L and the DCF for strontium-90 via ingestion is 2.80×10^{-8} *Sv*/*Bq* (see TABLE 7).

$$\mathbf{EF} = \frac{\text{1 work year x 50 work weeks/year x 5 work days/week}}{\text{365 days/year}}$$

$$= 0.68$$

Then,

$$ED_w = C \times IR \times CF \times EF \times DCF$$

$$= 5.0 \times 10^{-3}\ Bq/L \times 0.75\ L/day \times 365\ days \times 0.68 \times 2.8 \times 10^{-8}\ Sv/Bq$$

$$= 2.6 \times 10^{-8}\ Sv$$

$$= 2.6 \times 10^{-5}\ mSv$$

The estimated 50-year committed dose from strontium-90, as a result of one year of water ingestion at the workplace, is 2.6×10^{-5} *mSv*.

Note: This example consists of fictitious data.

Estimating Soil Ingestion Radiation Exposures

The committed dose from internal radiation exposure as a result of soil ingestion (ED_s) can be estimated with the equation:

$$ED_s = C \times IR \times CF \times EF \times DCF$$

where:

ED_s = Estimated Dose over 50 years (for adults) or 70 years (children) through soil ingestion in one year: The soil ingestion dose is expressed as sieverts (*Sv*) or millisieverts (*mSv*).

C = Radionuclide activity concentration in soil, in becquerels per kilogram of soil (*Bq*/kg).

IR = Ingestion Rate: The amount of soil a person eats in a day, in milligrams (mg/day). Standard values are given in TABLE 1. If the person ingests contaminated soil for only a part of the day (for example, only at work), then the ingestion rate is adjusted accordingly.

CF = Conversion Factor: The factor of 365 days is required to convert the Ingestion Rate (IR) from units/day to units/year.

EF = Exposure Factor: Indicates how often the individual has been exposed to the contaminant over the year (unitless).

DCF = Dose Conversion Factor (specific for each radionuclide): The extended 50-year or 70-year dose resulting from the ingestion of 1 *Bq* of a given radionuclide (*Sv*/*Bq*). Selected DCFs are presented in TABLE 7.

EXAMPLE:

Estimate the committed dose of radiation for an adult male from one year of accidental ingestion of cesium-137 in soil at the workplace. Assume a 50-week work year, a 5-day work week with an 8-hour work day. The soil ingestion rate is assumed to be 20 mg over 24 hours (see TABLE 1) so that the soil ingestion rate (IR) attributable to 8 hours at the workplace is 6.67 mg. The cesium-137 activity concentration (C) in the soil at the workplace was measured at 10.0 *Bq*/kg, which is equivalent to 1×10^{-5} *Bq*/mg. The DCF for cesium-137 via ingestion is 1.30×10^{-8} *Sv*/*Bq* (see TABLE 7).

$$EF = \frac{\text{1 work year} \times \text{50 work weeks/year} \times \text{5 work days/week}}{\text{365 days/year}}$$

$$= 0.68$$

Then,

$$ED_s = C \times IR \times CF \times EF \times DCF$$

$$= 1 \times 10^{-5}\ Bq/\text{mg} \times 6.67\ \text{mg/day} \times 365\ \text{days} \times 0.68 \times 1.3 \times 10^{-8}\ Sv/Bq$$

$$= 2.2 \times 10^{-10}\ Sv$$

$$= 2.2 \times 10^{-7}\ mSv$$

The estimated 50-year committed dose from cesium-137, as a result of one year of accidental soil ingestion at the workplace, is 2.2×10^{-7} *mSv*.

Note: This example consists of fictitious data.

Estimating Food Ingestion Radiation Exposures

The committed dose from internal radiation exposure due to food consumption (ED_f) requires a separate calculation for each kind of food (or food group) that is eaten. The extra steps are just a repetition of the basic equation used in calculating all other estimated doses. The total estimated dose from food can be calculated with the following equation:

		(food group 1)		(food group 2)		(last food group)
ED_f	**=**	**(C x CR x CF x EF x DCF)**	**+**	**(C x CR x CF x EF x DCF)**	**+ .... +**	**(C x CR x CF x EF x DCF)**

where:

ED_f = Estimated Dose over 50 years (adults) or 70 years (children) from food ingestion in one year: The food ingestion dose is expressed as sieverts (*Sv*) or millisieverts (*mSv*).

C = Radionuclide activity concentration in the food group, in becquerels per kilogram (*Bq*/kg) or per gram (*Bq*/g) of food.

CR = Consumption Rate: The amount of food from that food group eaten, expressed in grams per day (g/day). Standard values are given in TABLE 3.

CF = Conversion Factor: The factor of 365 days is required to convert the Consumption Rate (CR) from units/day to units/year.

EF = Exposure Factor: Indicates how often the individual has been exposed to the contaminant over the year (unitless).

DCF = Dose Conversion Factor (specific for each radionuclide): The extended 50-year or 70-year dose resulting from the ingestion of 1 *Bq* of a given radionuclide (*Sv*/*Bq*). Selected DCFs are presented in TABLE 7.

EXAMPLE:

Estimate the committed dose of radiation for an adult male from one year of ingestion of cesium-137 and radium-226 in food at the workplace. Assume a 50-week work year, and a 5-day work week with one meal eaten from food prepared at the workplace so that approximately one third of the average amount of food eaten, presented in TABLE 3, is consumed in the workplace. The radionuclide activity concentrations (C) is measured in three food groups and their DCFs via ingestion (see TABLE 7) are presented below.

$$\mathbf{EF} = \frac{\textbf{1 work year x 50 work weeks/year x 5 work days/week}}{\textbf{365 days/year}}$$

$$= \mathbf{0.68}$$

Food Group	Radionuclide	C	CR	CF	EF	DCF	ED_f for each food group (*Sv*)
Meat	cesium-137	2×10^{-2} *Bq*/g	61	365	0.68	1.3×10^{-8}	3.9×10^{-6}
Dairy Products	cesium-137	5×10^{-5} *Bq*/g	94	365	0.68	1.3×10^{-8}	1.5×10^{-8}
Vegetables	radium-226	2×10^{-3} *Bq*/g	83	365	0.68	2.2×10^{-7}	9.1×10^{-6}
ED_f							1.3×10^{-5}

The estimated 50-year committed dose from cesium-137 and radium-226, as a result of food consumption at the workplace over one year, is 1.3×10^{-5} *Sv* (1.3×10^{-2} *mSv*).

Note: This example consists of fictitious data.

Calculating the Estimated Dose (ED) for Ionizing Radiation

Once you have estimated the committed doses for each pathway and radionuclide resulting in internal radiation exposure, you can add them all together to get the total Estimated Dose for all radionuclides taken into the body in one year ($ED_{internal}$). This value is then added to the Estimated Dose measured from external sources ($ED_{external}$) to obtain the total Estimated Dose (ED) for ionizing radiation. The following example shows how it is done.

Estimated Dose (ED) $= ED_{external} + ED_{internal}$

$= ED_{external} + ED_a + ED_w + ED_s + ED_f$

where,

$ED_{external}$ is the estimated dose from external radiation received during the year,
ED_a is the estimated committed dose from radionuclides inhaled through the air during the year,
ED_w is the estimated committed dose from radionuclides taken in by drinking water during the year,
ED_s is the estimated committed dose from radionuclides taken in by eating soil during the year,
ED_f is the estimated committed dose from radionuclides taken in by eating food during the year.

EXAMPLE:

Estimate the ED for exposure to ionizing radiation from artificial sources for an adult male in the workplace. Assume a 50-week work year, and a 5-day work week and an 8-hour work day with one meal eaten from food prepared and consumed at the workplace. The ED for internal exposure via each possible pathway have been calculated in the four previous examples (air: 3.4×10^{-6} *mSv*; water: 2.6×10^{-5} *mSv*; soil: 2.2×10^{-7} *mSv*; food: 1.3×10^{-2} *mSv*). The $ED_{external}$ for radiation exposure from artificial sources has been measured by instruments and estimated to be 2.0×10^{-2} *mSv* above the natural background radiation.

$$\mathbf{ED} = ED_{external} + ED_a + ED_w + ED_s + ED_f$$

$$= 2.0 \times 10^{-2} + 3.4 \times 10^{-6} + 2.6 \times 10^{-5} + 2.2 \times 10^{-7} + 1.3 \times 10^{-2}$$

$$= 3.3 \times 10^{-2}\ mSv$$

The Estimated Dose from both internal and external radiation exposure to ionizing radiation during one year at the workplace is estimated to be 3.3×10^{-2} *mSv*.

Note: This example consists of fictitious data.

Comparing ED with Radiation Exposure Limits

To determine whether or not the Estimated Dose (ED) from all artificial sources you have calculated is at a level associated with increased risk to health, compare it to the radiation exposure limit of 1 *mSv* issued by the International Commission on Radiological Protection (ICRP). In addition, compare the estimated annual dose you have calculated for the drinking water pathway (ED_w) to the drinking water guideline of 0.1 *mSv* issued by Health Canada. The drinking water guideline applies to the total dose from all radionuclides in drinking water, both natural and artificial in origin.

EXAMPLE:

Consider the workplace exposure to ionizing radiation of the man described in the previous examples, whose total ED (external + internal) is estimated at 3.3×10^{-2} *mSv* and whose internal exposure from drinking water (ED_w) is 2.6×10^{-5} *mSv*. How do these compare with the ICRP and Health Canada limits?

The ICRP public dose limit applies to the total dose to an individual from all sources during the year, excluding the natural background radiation and exposures for medical purposes. The workplace exposure of 3.3×10^{-2} *mSv*, described in the above example, is well below the public dose limit of 1 *mSv* received or committed in one year.

In the case of drinking water, assuming that the total dose received from the water supply is from strontium-90, as given in the previous example, the ED_w of 2.6×10^{-5} *mSv* is well below the Health Canada guideline of 0.1 *mSv* for the total dose from all radionuclides in the water supply.

Note: This example consists of fictitious data.

8. WHAT DO YOU DO NEXT?

Before Proceeding Further

Chemicals

- Have all pathways of exposure been identified?
- Have the daily intakes from all pathways of exposure been calculated?
- Have the EDIs been estimated by adding up the exposures calculated from each pathway?
- Have the EDIs been compared to the TDI or RsD, if they are known for those contaminants?

Ionizing Radiation

- Have all pathways of exposure been identified?
- Have the estimated committed doses from all pathways of exposure been calculated?
- Has the total ED been estimated by adding up the exposures calculated from each pathway, including radiation from sources external to the body?
- Has the total ED been compared to the 1 *mSv* dose limit and has the dose from the drinking water pathway been compared to the 0.1 *mSv* guideline? Are exposures as low as reasonably achievable?

What's Next?

Once the exposure to a contaminant has been estimated and compared to the appropriate Tolerable Daily Intake (TDI), Risk-specific Dose (RsD), or the dose limit or drinking water guideline for radiation exposure, it is time to decide what action to take on the results. If the EDI is below the TDI or RsD, or if the radiation ED is below the dose limit or drinking water guideline, the risk to people's health may be considered small because the potential exposure to the contaminant is low. No further actions may be considered necessary. However, if the estimated exposures exceed the guidelines, the following options may be considered:

- Providing information to the public on how to minimize exposure. This could include advice on which changes in habits and lifestyle would reduce exposure;
- Recommending measures to reduce the release of the contaminants into the environment;

- Recommending voluntary standards for manufacturers; and
- Setting standards and guidelines at levels that protect human health.

The options considered will depend on the major pathway of exposure, the number or sensitivity of people exposed, and the possible interaction between different contaminants.