Appendix B: Chemicals

Appendix B: Chemicals

This appendix presents basic facts about chemicals. The information is intended to be a basis for understanding the dose or relative toxicity assessment associated with releases from the Oak Ridge Reservation (ORR), not a comprehensive discussion of chemicals and their effects on the environment and biological systems.

PERSPECTIVE ON CHEMICALS

The lives of modern humans have been greatly improved by the development of chemicals such as pharmaceuticals, building materials, housewares, pesticides, and industrial chemicals. Through the use of chemicals, we can increase food production, cure diseases, build more efficient houses, and send people to the moon. At the same time, we must be cautious to ensure that our own existence is not endangered by uncontrolled and overexpanded use of chemicals (Chan et al. 1982).

Just as all humans are exposed to radiation in the normal daily routine, humans are also exposed to chemicals. Some potentially hazardous chemicals exist in the natural environment. In many areas of the country, soils contain naturally elevated concentrations of metals such as selenium, arsenic, or molybdenum, which may be hazardous to humans or animals. However, exposures to many more hazardous chemicals result from the direct or indirect actions of humans. Building materials used for the construction of homes may contain chemicals such as formaldehyde (in some insulation materials), asbestos (formerly used in insulations and ceiling tiles), and lead (formerly used in paints and gasoline). Some chemicals are present as a result of application of pesticides and fertilizers to soil. Other chemicals may have been transported long distances through the atmosphere from industrial sources before being deposited on soil or water.

PATHWAYS OF CHEMICALS FROM THE ORR TO THE PUBLIC

Pathways refer to the route or way in which a person can come in contact with a chemical substance. Chemicals released to the air may remain suspended for long periods of time, or they may be deposited on plants, soil, and water. Chemicals may also be released as liquid wastes called effluents, which can enter streams and rivers.

People are exposed to chemicals by inhalation (breathing air), ingestion (eating exposed plants and animals or drinking water), or by direct contact (touching the soil or swimming in water). For example, fish that live in a river that receives effluents may take in some of the chemicals present. People eating the fish would then be exposed to the chemical. Less likely would be exposure by directly drinking from the stream or river.

The public is not normally exposed to chemicals on the ORR because access to the reservation is limited. However, chemicals released as a result of ORR operations can move through the environment to off-site locations, resulting in potential exposure to the public.

DEFINITIONS

Toxicity

Chemicals have varying types of effects. Generally, when considering human health, chemicals are divided into two broad categories: chemicals that cause health effects but do not cause cancer (noncarcinogens) and chemicals that cause cancer (carcinogens). The potential health effects of noncarcinogens range from irritation to life-shortening. Carcinogens cause or increase the incidence of malignant neoplasms or cancers.

Toxicity refers to an adverse effect of a chemical on human health. Not all chemicals are toxic: every day we ingest chemicals in the form of food, water, and sometimes medications. Even those chemicals that are usually considered toxic are usually nontoxic or harmless below a certain concentration.

Concentration limits or advisories are set by government agencies for some chemicals that are known or are thought to have an adverse effect on human health. These concentration limits can be used to calculate a chemical dose that would not harm even individuals who are particularly sensitive to the chemical.

Dose Terms for Noncarcinogens

Reference Dose (RfD)

An RFD is an estimate (with uncertainty spanning an order of magnitude or greater) of a daily exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime. Units are expressed as milligrams per kilogram per day (mg kg^{-1} day^{-1}).

Values for RfDs are derived from doses of chemicals that result in no adverse effect or the lowest dose that showed an adverse effect on humans or laboratory animals. Because these doses are in most cases derived from animal studies, safety factors are added for application to humans. Safety factors range from 10 to 1000 (i.e., safe doses for humans are set at 10 to 1000 times lower than doses showing no effect or a non-life-threatening effect in animals). This is thought to protect the most sensitive individuals. The Environmental Protection Agency (EPA) maintains the Integrated Risk Information System (IRIS) data base (EPA 1991), which contains verified RfDs and slope factors and up-to-date health risk and EPA regulatory information for numerous chemicals.

Primary and secondary maximum contaminant level

For chemicals for which RfDs are not available, national primary [maximum contaminant levels (MCLs)] and secondary drinking water regulation [secondary MCLs (SMCLs)] concentrations, expressed in milligrams per liter, are converted to RfD values by multiplying by 2 L (the average daily adult water intake) and dividing by 70 kg (the reference adult body weight). The result is a “derived” reference dose expressed in milligrams per kilogram per day (mg kg^{-1} day^{-1}).

Dose Term for Carcinogens

Slope Factor

A slope factor (SF) is a plausible upper-bound estimate of the probability of a response per unit intake of a chemical during a lifetime. The SF is used to estimate an upper-bound probability of an individual developing cancer as a result of a lifetime exposure to a particular level of a potential carcinogen. Units are expressed as risk per dose (mg kg^{-1} day^{-1}).

The SF converts the estimated daily intake averaged over a lifetime exposure to the incremental risk of an individual developing cancer. Because it is unknown whether a threshold (a dose below which no adverse effect occurs) exists for carcinogens, units for carcinogens are set in terms of risk factors. For potential carcinogens at the ORR, a specific risk of developing cancer over a human lifetime of 1 in 100,000 (10^{-5}) was used to establish acceptable levels of exposure. That is, EPA estimates that a certain concentration in food or water could cause a risk of one additional cancer case for every 100,000 exposed persons.

MEASURING CHEMICALS

Environmental samples are collected in areas surrounding the ORR and are analyzed for chemical constituents that are most likely to be released from the ORR. Typically, chemical concentrations in liquids are expressed in terms of milligrams or micrograms of chemical per liter of water; concentrations in solids (soil and fish tissue) are expressed in terms of milligrams or micrograms of chemical per gram or kilogram of sample material.

The instruments used to measure chemical concentrations are very sensitive; however, they have limits beyond which they cannot detect the chemicals of interest. Concentrations that are below the detection limits of the instruments are recorded as “less-than” (<) values or with tildes (~). Exposure calculations are given “less-than” values unless at least one sample exceeds the detection limit. The tilde indicates that estimated values and/or detection limits were used in estimating the average concentration of a chemical.

RISK ASSESSMENT METHODOLOGY

Exposure Assessment

To evaluate an individual’s exposure by way of a specific exposure pathway, the intake amount of the chemical must be determined. For example, chemical exposure by drinking water and eating fish from the Clinch River is assessed in the following way. It is assumed that individuals outside the ORR boundary are exposed to statistically significant concentrations of contaminants. It is also assumed that they drink 2 L (0.53 gal) of water per day directly from the river, which amounts to 730 L (193 gal) per year, and that they eat 94 g of fish per day (34 kg per year), which is based on a survey of recreational freshwater anglers about their fish consumption rates (EPA 1995). Estimated daily intakes or estimated doses to the public can be calculated by multiplying measured concentrations in water by 2 L or those in fish by 94 g. This intake is first multiplied by the exposure duration (30 years) and exposure frequency (350 days/year), and then divided by an averaging time (30 years for noncarcinogens and 70 years for carcinogens). These assumptions are conservative, and in many cases they result in higher estimated intakes and doses than an actual individual would receive.

Dose Estimate

Once the contaminant oral daily intake via exposure pathways is estimated, the dose can be determined. For chemicals, dose to humans is measured in terms of milligrams per kilogram per day (mg kg^{-1} day^{-1}). In this case, the “kilogram” refers to the body weight of an adult individual. When we calculate a chemical dose, the length of time an individual is exposed to a certain concentration is important. To assess off-site doses, it is assumed that the exposure duration occurs over 30 years. Such exposures are called "chronic" in contrast to short-term exposures, which are called "acute."

Calculation Methodology

In previous annual environmental reports, the "calculated daily intakes," based on chemical concentrations in water or fish, were divided by the "acceptable daily intake," which was based on the RfD. Both intakes were expressed in milligrams per day by multiplying by 70 kg for body weight. Current risk assessment methodologies use the term hazard quotient (HQ) to evaluate noncarcinogenic health effects. Therefore, in this environmental report the HQ methodology is used. Because intakes are calculated in milligrams per kilogram per day in the HQ methodology, they are expressed in terms of dose. The HQ compares the estimated exposure dose or intake (I) to the RfD as follows:

$$HQ = \frac{I}{RfD} \quad ,$$

where

HQ = hazard quotient (unitless),
I = estimated dose (mg kg^{-1} day^{-1}),
RfD = reference dose (mg kg^{-1} day^{-1}).

HQ values of less than 1 indicate an unlikely potential for adverse health effects, whereas HQ values greater than 1 indicate a concern for adverse health effects or the need for further study.

To evaluate carcinogenic risk, SFs are used instead of RfDs. In this report, we compare the estimated dose attributed from ingesting water or fish from rivers and streams surrounding ORR to the chronic daily intake (CDI) derived from assuming a human lifetime risk of developing cancer of 10^{-5} (1 in 100,000). The SF is converted to a CDI as follows:

$$CDI = \frac{1 \times 10^{-5}}{SF} \quad ,$$

where

CDI = chronic daily intake (mg kg^{-1} day^{-1}),
SF = slope factor, oral (risk per mg kg^{-1} day^{-1}).

In typical risk assessments, risks are generally derived; however, in this report we assume 10^{-5} as the level of acceptable risk. To estimate the risk of inducing cancers, from ingestion of water and fish, relative to the risk of 10^{-5}, the estimated dose (I) is divided by the CDI. A ratio greater than 1 indicates a risk greater than 10^{-5}. The tilde, "~," indicates that estimated values and/or detection limits were used in estimating the average concentrations of a chemical. This symbol is listed beside the estimated HQ or I/CDI values to indicate the type of data used.