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Appendix F Chemicals

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

F.1. 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 into space. At the same time, we must be cautious to ensure uncontrolled and over-expanded use of chemicals does not endanger our own existence (Chan et al. 1982).

Just as all humans are exposed to radiation in their normal daily routines, 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. Even some of the foods we eat contain natural toxins. Aflatoxins are found in chili peppers, corn, millet, peanuts, rice, sorghum, sunflower seeds, tree nuts, and wheat. Cyanide is found in apple seeds. However, exposure to many more hazardous chemicals results from direct or indirect human actions. Building materials used in home construction may contain chemicals such as formaldehyde (in some insulation materials), asbestos (formerly used in insulation and ceiling tiles), and lead (formerly used in paints and gasoline). Some chemicals are present as a result of applying pesticides and fertilizers to soil. Other chemicals may have been transported long distances through the atmosphere from industrial sources and then deposited on soil or water.

F.2. Pathways of Chemicals from the Oak Ridge Reservation to the Public

Pathways are the routes or ways through which a person can come in contact with a chemical substance. Chemicals released to the air may remain suspended for long periods, or they may be rapidly 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 dermal contact (touching soil or swimming in water). For example, fish that live in a river that receives effluents may take in some of the chemicals present in the water. People eating fish and drinking water from the river would then be exposed to the chemicals. The public is not normally exposed to chemicals on 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 of the public.

F.3. Toxicity

Health effects from chemicals vary. Chemical health effects are divided into two broad categories: adverse or systemic effects from noncarcinogens and cancer from carcinogens. A chemical can have both carcinogenic and noncarcinogenic effects. The toxic effect can be acute (a short-term, possible severe health effect) or chronic (a longer-term, persistent health effect). Noncarcinogenic toxicity is often evident in a shorter length of time than a carcinogenic effect. The potential health effects of noncarcinogens range from skin irritation to death. Carcinogens cause or increase the incidence of malignant neoplasms or cancers.

Toxicity refers to an adverse effect of a chemical on human health. Every day we ingest chemicals in food and water, and sometimes in medications. Even chemicals typically 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 suspected to have adverse effects on human health. These concentration limits can be used to calculate chemical doses that would not harm even those individuals who may be particularly sensitive to the chemical.

F.3.1. Dose Terms for Noncarcinogens

A reference dose is an estimate of a daily exposure level for the human population, including sensitive subpopulations. These reference doses are likely to be without appreciable risk of deleterious effects during a lifetime. Units are expressed as milligrams of chemical per kilogram of an adult's body weight per day (mg/kg-day). Values for reference doses are derived from doses of chemicals that resulted in no adverse effect, or the lowest dose that showed an adverse effect, on humans or laboratory animals.

Uncertainty factors are typically used in deriving reference doses. Uncertainty adjustments may be made to account for (1) interspecies variability in response when extrapolating from animal studies to humans; (2) response variability in humans; (3) uncertainty in estimating a no-effect level from a dose where effects were observed; (4) extrapolation from shorter duration studies to a full life-time exposure; and (5) data deficiencies (Dankovic et al., 2015). The use of uncertainty factors in deriving reference doses is thought to help protect sensitive human populations. The US Environmental Protection Agency (EPA) maintains the Integrated Risk Information System (IRIS) database, which contains verified reference doses and up-to-date health risk and EPA regulatory information for numerous chemicals (EPA 2021).

For chemicals that do not have reference dose values available in IRIS, Tennessee Water Quality Criteria values for domestic water supply (TDEC 2019) may be used to calculate a reference dose by multiplying the chemical criteria in milligrams per liter by 2 liters (the average daily adult water intake) and dividing by 80 kg (the reference adult body weight). The result is a derived reference dose expressed in mg/kg-day.

F.3.2. Dose Term for Carcinogens

A slope factor is a plausible upper-bound estimate of the probability of a response per unit intake of a chemical during a lifetime. The slope factor 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 chemical. Units are expressed as risk per dose in mg/kg-day.

The slope factor converts the estimated daily intake averaged over a lifetime exposure to the incremental risk of an individual developing cancer. Because it is unknown for most chemicals whether a threshold (a dose below which no adverse effect occurs) exists for carcinogens, units for carcinogens are set in terms of risk factors. The standard cancer benchmarks used by EPA range from 1 in 1,000,000 to 1 in 10,000 (i.e., 10^{-6} to 10^{-4}) depending on the subpopulation exposed. In other words, a certain chemical concentration in food or water could cause a risk of one additional cancer for every 1,000,000 (10^{-6} risk level) to 10,000 (10^{-4} risk level) exposed persons.

F.4. Measuring Chemicals

Environmental samples are collected in areas surrounding ORR and are analyzed for those chemical constituents most likely to be released from ORR. Chemical concentrations in liquids are typically expressed in milligrams or micrograms of chemical per liter of water (mg/L or µg/L, respectively); concentrations in solids, such as soil and fish tissue, are expressed in milligrams or micrograms of chemical per gram or kilogram of sample material (e.g., mg/kg for soil or µg/g for fish tissue).

The instruments used to measure chemical concentrations are sensitive; however, there are limits below which they cannot detect chemicals of interest. Concentrations below the reported analytical detection limits of the instruments are recorded by the laboratory as estimated values, which have a greater uncertainty than concentrations detected above the detection limits of the instruments. Concentrations that use these estimated values are indicated by the less-than symbol (<), which indicates that the value for a parameter could not be quantified at the analytical detection limit.

F.5. Risk Assessment Methodology

The paragraphs below describe the method for assessing the risk of adverse health effects from a particular chemical.

Exposure Assessment

To estimate an individual's potential exposure via a specific exposure pathway, the intake amount of the chemical must be determined. For example, chemical exposure from drinking water and eating fish from the Clinch River is assessed in the following manner:

Clinch River surface water and fish samples are analyzed to measure chemical contaminant concentrations. For this assessment, it is assumed that individuals drink about 2 liters (0.5 gal) of water per day directly from the river, and that they eat 0.07 kg (roughly 0.2 lb) of fish per day from the river. Estimated daily intakes or estimated doses to the public are calculated by multiplying measured (statistically significant) chemical concentrations in Clinch River surface water by 2 liters, or those in fish from the Clinch River by 0.07 kg. This intake is first multiplied by the exposure duration (26 years) and exposure frequency (350 days per year) and then divided by an averaging time (26 years for non-carcinogens and 70 years for carcinogens) and an 80 kg adult body weight. These exposure assumptions are conservative, and in many cases result in higher estimated intakes and doses than an individual would actually receive.

Dose Estimate

Once the oral daily intake of a chemical contaminant has been estimated, the dose can be determined. The chemical dose to humans is measured in mg/kg-day. In this case, "kilogram" refers to the body weight of an adult. When a chemical dose is calculated, the length of time an individual is exposed to a certain concentration is important. To assess off-site chemical doses, it is assumed that the exposure duration occurs over 30 years. These are known as chronic exposures, in contrast to short-term exposures, which are called acute exposures.

Calculation Method

Current risk assessment methodologies use the term "hazard quotient" to evaluate non-carcinogenic health effects. Because intakes are calculated in mg/kg-day using the hazard quotient methodology, they are expressed in terms of dose. Hazard quotient values less than 1 indicate an unlikely potential for adverse noncarcinogenic health effects; hazard quotient values greater than 1 indicate a concern for adverse health effects or the need for further study.

Risk methods evaluating carcinogenic risk use slope factors instead of reference doses. To estimate the potential carcinogenic risk from ingestion of water and fish, the estimated dose or intake is multiplied by the slope factor (risk per mg/kg-day). As mentioned earlier, acceptable risk levels for carcinogens range from 10^{-6} (risk of developing cancer over a human lifetime is 1 in 1,000,000) to 10^{-4} (risk of developing cancer over a human lifetime is 1 in 10,000). Carcinogenic risks greater than 10^{-4} indicate a concern for adverse health effects or the need for further study.

F.6. References

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