OAK RIDGE RESERVATION ANNUAL SITE ENVIRONMENTAL REPORT FOR 2011

APPENDIXES

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Appendix A. Glossary

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absorption, atomic—The process by which the number and energy of particles or photons entering a body of matter is reduced by interaction with the matter.

accuracy—The closeness of the result of a measurement to the true value of the quantity.

ACM—Asbestos-containing materials.

aliquot—The quantity of sample being used for analysis.

alkalinity—A measure of the buffering capacity of water, and because pH has a direct effect on organisms as well as an indirect effect on the toxicity of certain other pollutants in the water, the buffering capacity is important to water quality.

alpha particle—A positively charged particle emitted from the nucleus of an atom; it has the same charge and mass as that of a helium nucleus (two protons and two neutrons).

ambient air—The surrounding atmosphere as it exists around people, plants, and structures.

analyte—A constituent or parameter that is being analyzed.

analytical detection limit—The lowest reasonably accurate concentration of an analyte that can be detected; this value varies depending on the method, instrument, and dilution used.

anion—A negatively charged ion.

anthropogenic—Any effect caused by humans**.**

aquifer—A saturated, permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients.

aquitard—A geologic unit that inhibits the flow of water.

ash—Inorganic residue remaining after ignition of combustible substances.

assimilate—To take up or absorb into the body.

atom—The smallest particle of an element capable of entering into a chemical reaction.

atomic absorption spectrometry (AA)—Chemical analysis performed by vaporizing a sample and measuring the absorbance of light by the vapor.

Atomic Energy Commission (AEC)—A federal agency created in 1946 to manage the development, use, and control of nuclear energy for military and civilian applications. It was abolished by the Energy Reorganization Act of 1974 and was succeeded by the Energy Research and Development Administration (now part of the Department of Energy and the Nuclear Regulatory Commission).

base flow—The base flow of a spring or stream represents the normal day-to-day discharge of the spring or stream and is the result of groundwater seeping into the spring/stream.

base/neutral and acid extractables (BNA)—A group of organic compounds analyzed as part of Appendix IX of 40 CFR 264 and the Environmental Protection Agency (EPA) list of priority pollutants.

beta particle—A negatively charged particle emitted from the nucleus of an atom. It has a mass and charge equal to those of an electron.

biota—The animal and plant life of a particular region considered as a total ecological entity.

blank—A control sample that is identical, in principle, to the sample of interest, except that the substance being analyzed is absent. In such cases, the measured value or signal for the substance being analyzed is believed to be a result of artifacts. Under certain circumstances, that value may be subtracted from the measured value to give a net result reflecting the amount of the substance in the sample. EPA does not permit the subtraction of blank results in EPA-regulated analyses.

calibration—Determination of variance from a standard of accuracy of a measuring instrument to ascertain necessary correction factors.

carcinogen—A cancer-causing substance.

cation—A positively charged ion.

CERCLA-reportable release—A release to the environment that exceeds reportable quantities as defined by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

chain-of-custody—A form that documents sample collection, transport, analysis, and disposal.

chemical oxygen demand—Indicates the quantity of oxidizable materials present in water and varies with water composition, concentrations of reagent, temperature, period of contact, and other factors.

chlorocarbons—Compounds of carbon and chlorine, or carbon, hydrogen, and chlorine, such as carbon tetrachloride, chloroform, and tetrachloroethene. They are among the most significant and widespread environmental contaminants. Classified as hazardous wastes, chlorocarbons may have a tendency to cause detrimental effects, such as birth defects.

closure—Specifically, closure of a hazardous waste management facility under Resource Conservation and Recovery Act (RCRA) requirements.

compliance—Fulfillment of applicable requirements of a plan or schedule ordered or approved by government authority.

concentration—The amount of a substance contained in a unit volume or mass of a sample.

conductivity—A measure of water's capacity to convey an electric current. This property is related to the total concentration of the ionized substances in water and the temperature at which the measurement is made.

confluence—The point at which two or more streams meet; the point where a tributary joins the main stream.

contamination—Deposition of unwanted material on the surfaces of structures, areas, objects, or personnel.

cosmic radiation—Ionizing radiation with very high energies, originating outside the earth's atmosphere. Cosmic radiation is one source contributing to natural background radiation.

count—A measure of the radiation from an object or device; the signal that announces an ionization event within a counter.

curie (Ci)—A unit of radioactivity. One curie is defined as 3.7×10^{10} (37 billion) disintegrations per second. Several fractions and multiples of the curie are commonly used:

> **kilocurie (kCi)**—10^3 Ci, one thousand curies; 3.7×10^{13} disintegrations per second.
>
> **millicurie (mCi)**—10^{-3} Ci, one-thousandth of a curie; 3.7×10^7 disintegrations per second.
>
> **microcurie (µCi)**—10^{-6} Ci, one-millionth of a curie; 3.7×10^4 disintegrations per second.
>
> **picocurie (pCi)**—10^{-12} Ci, one-trillionth of a curie; 0.037 disintegrations per second.

DAPC—Division of Air Pollution Control (state of Tennessee).

daughter—A nuclide formed by the radioactive decay of a parent nuclide.

decay, radioactive—The spontaneous transformation of one radionuclide into a different radioactive or nonradioactive nuclide, or into a different energy state of the same radionuclide.

dense nonaqueous phase liquid (DNAPL)—The liquid phase of chlorinated organic solvents. These liquids are denser than water and include commonly used industrial compounds such as tetrachloroethene and trichloroethene.

derived concentration guide (DCG)—The concentration of a radionuclide in air or water that, under conditions of continuous exposure for 1 year by one exposure mode (i.e., ingestion of water, submersion in air, or inhalation), would result in either an effective dose equivalent of 0.1 rem (1 mSv) or a dose equivalent of 5 rem (50 mSv) to any tissue, including skin and lens of the eye. The guides for radionuclides in air and water are given in DOE Order 5400.5.

desorption—The process of removing a sorbed substance by the reverse of adsorption or absorption.

dilution factor—The mathematical factor by which a sample is diluted to bring the concentration of an analyte in a sample within the analytical range of a detector (e.g., 1 mL sample + 9 mL solvent = 1:10 dilution, or a dilution factor of 10).

disintegration, nuclear—A spontaneous nuclear transformation (radioactivity) characterized by the emission of energy and/or mass from the nucleus of an atom.

dissolved oxygen—A desirable indicator of satisfactory water quality in terms of low residuals of biologically available organic materials. Dissolved oxygen prevents the chemical reduction and subsequent leaching of iron and manganese from sediments.

dose—The energy imparted to matter by ionizing radiation. The unit of absorbed dose is the rad, equal to 0.01 joules per kilogram in any medium.

> **absorbed dose**—The quantity of radiation energy absorbed by an organ, divided by the organ's mass. Absorbed dose is expressed in units of rad (or gray) (1 rad = 0.01 Gy).

dose equivalent—The product of the absorbed dose (rad) in tissue and a quality factor. Dose equivalent is expressed in units of rem (or sievert) (1 rem = 0.01 sievert).

committed dose equivalent—The calculated total dose equivalent to a tissue or organ over a 50-year period after known intake of a radionuclide into the body. Contributions from external dose are not included. Committed dose equivalent is expressed in units of rem (or sievert).

committed effective dose equivalent—The sum of the committed dose equivalents to various tissues in the body, each multiplied by the appropriate weighting factor. Committed effective dose equivalent is expressed in units of rem (or sievert).

effective dose equivalent—The sum of the dose equivalents received by all organs or tissues of the body after each one has been multiplied by an appropriate weighting factor. The effective dose equivalent includes the committed effective dose equivalent from internal deposition of radionuclides and the effective dose equivalent attributable to sources external to the body.

collective dose equivalent/collective effective dose equivalent—The sums of the dose equivalents or effective dose equivalents of all individuals in an exposed population within a 50-mile (80-km) radius, and expressed in units of person-rem (or person-sievert). When the collective dose equivalent of interest is for a specific organ, the units would be organ-rem (or organ-sievert). The 50-mile distance is measured from a point located centrally with respect to major facilities or DOE program activities.

dosimeter—A portable detection device for measuring the total accumulated exposure to ionizing radiation.

dosimetry—The theory and application of principles and techniques involved in the measurement and recording of radiation doses. Its practical aspect is concerned with using various types of radiation instruments to make measurements.

downgradient—In the direction of decreasing hydrostatic head.

downgradient well—A well that is installed hydraulically downgradient of a site and may be capable of detecting migration of contaminants from a site.

DRH—Division of Radiological Health (state of Tennessee).

drinking water standard (DWS)—Federal primary drinking water standards, both proposed and final, as set forth by the EPA.

duplicate result—A result derived by taking a portion of a primary sample and performing an analysis on that portion identical to that performed on the primary sample.

duplicate samples—Two or more samples collected simultaneously into separate containers.

effluent—A liquid or gaseous waste discharge to the environment.

effluent monitoring—The collection and analysis of samples or measurements of liquid and gaseous effluents for purposes of characterizing and quantifying the release of contaminants, assessing radiation exposures of members of the public, and demonstrating compliance with applicable standards.

Environmental Restoration—A DOE program that directs the assessment and cleanup of its sites (remediation) and facilities contaminated with waste as a result of nuclear-related activities.

exposure (radiation)—The incidence of radiation on living or inanimate material by accident or intent. Background exposure is the exposure to natural background ionizing radiation. Occupational exposure is the exposure to ionizing radiation that takes place during a person's working hours. Population exposure is the exposure to the total number of persons who inhabit an area.

external radiation—Exposure to ionizing radiation when the radiation source is located outside the body.

falling limb—The falling limb is when discharge decreases and a spring or stream level falls. It has a gentler gradient than the rising limb as most overland flow has now been discharged, and it is mainly throughflow that makes up the spring/stream flow.

fecal coliform—The coliform group comprises all of the aerobic, non-spore-forming, rod-shaped bacteria. Testing determines the presence or absence of coliform organisms.

flux—A flow or discharge of a substance (in units of mass, radioactivity, etc.) per unit of time.

formation—A mappable unit of consolidated or unconsolidated geologic material of a characteristic lithology or assemblage of lithologies.

friable asbestos—Asbestos that is brittle or readily crumbled.

gamma ray—High-energy, short-wavelength electromagnetic radiation emitted from the nucleus of an excited atom. Gamma rays are identical to x-rays except for the source of the emission.

gamma spectrometry—A system consisting of a detector, associated electronics, and a multichannel analyzer that is used to analyze samples for gamma-emitting radionuclides.

genotoxicology—The study of the effects of chemicals or radioactive contaminants on the genetics of individual animals or plants.

grab sample—A sample collected instantaneously with a glass or plastic bottle placed below the water surface to collect surface water samples (also called dip samples).

groundwater, unconfined—Groundwater exposed to the unsaturated zone.

half-life, biological—The time required for a biological system, such as that of a human, to eliminate by natural processes half the amount of a substance (such as a radioactive material) that has entered it.

half-life, radiological—The time required for half of a given number of atoms of a specific radionuclide to decay. Each nuclide has a unique half-life; half-lives can range in duration from less than a second to many millions of years.

halogenated compound—An organic compound bonded with one of the five halogen elements (astatine, bromine, chlorine, fluorine, or iodine).

halomethane—Any compound that includes a methane group (CH_3) bonded to a halogen element (astatine, bromine, chlorine, fluorine, or iodine).

hardness—Water hardness is caused by polyvalent metallic ions dissolved in water. In fresh water, these are mainly calcium and magnesium, although other metals such as iron, strontium, and manganese may contribute to hardness.

heavy water—Water in which the molecules contain oxygen and deuterium, an isotope of hydrogen that is heavier than ordinary hydrogen.

hectare—A metric unit of area equal to 10,000 square meters or 2.47 acres.

herbaceous—Having little or no woody tissue.

hydrogeology—Hydrologic aspects of site geology.

hydrology—The science dealing with the properties, distribution, and circulation of natural water systems.

in situ—In its original place; field measurements taken without removing the sample from its origin; remediation performed while groundwater remains below the surface.

internal dose factor—A factor used to convert intakes of radionuclides to dose equivalents.

internal radiation—Internal radiation occurs when radionuclides enter the body by ingestion of foods, milk, and water, and by inhalation. Radon is the major contributor to the annual dose equivalent for internal radionuclides.

ion—An atom or compound that carries an electrical charge.

ion exchange—Process in which a solution containing soluble ions is passed over a solid ion exchange column that removes the soluble ions by exchanging them with labile ions from the surface of the column. The process is reversible so that the trapped ions are removed (eluted) from the column and the column is regenerated.

irradiation—Exposure to radiation.

isotopes—Forms of an element having the same number of protons in their nuclei but differing in the number of neutrons.

laboratory blank—An analyte-free matrix to which all reagents are added in the same volumes or proportions as used in sample processing. The laboratory blank should be carried through the complete sample preparation and analytical procedure. The laboratory blank is used to document contamination resulting from the analytical process.

lower limit of detection (LLD)—The smallest concentration/amount of analyte that can be reliably detected in a sample at a 95% confidence level.

maximally exposed individual—A hypothetical individual who, because of proximity, activities, or living habits, could potentially receive the maximum possible dose of radiation from a given event or process.

mercury—A silver-white, liquid metal solidifying at –38.9ºC to form a tin-white, ductile, malleable mass. It is widely distributed in the environment and biologically is a nonessential or nonbeneficial element. Human poisoning from this highly toxic element has been clinically recognized.

microbes—Microscopic organisms.

migration—The transfer or movement of a material through the air, soil, or groundwater.

millirem (mrem)—The dose equivalent that is one one-thousandth of a rem.

milliroentgen (mR)—A measure of x-ray or gamma radiation. The unit is one-thousandth of a roentgen.

minimum detectable activity—The smallest activity of a radionuclide that can be distinguished in a sample by a given measurement system at a preselected counting time and at a given confidence level.

monitoring—A process whereby the quantity and quality of factors that can affect the environment and/or human health are measured periodically in order to regulate and control potential impacts.

natural radiation—Radiation arising from cosmic and other naturally occurring radionuclide sources (such as radon) present in the environment.

nuclide—An atom specified by its atomic weight, atomic number, and energy state. A radionuclide is a radioactive nuclide.

outfall—The point of conveyance (e.g., drain or pipe) of wastewater or other effluents into a ditch, pond, or river.

parts per billion (ppb)—A unit measure of concentration equivalent to the weight/volume ratio expressed as micrograms per liter or nanograms per milliliter.

parts per million (ppm)—A unit measure of concentration equivalent to the weight/volume ratio expressed as milligrams per liter.

peak flow—Peak flow discharge occurs when a spring or stream reaches its highest level. The time difference between the peak of the rain event and the peak discharge is known as the basin lag.

person-rem—Collective dose to a population group. For example, a dose of 1 rem to 10 individuals results in a collective dose of 10 person-rem.

pH—A measure of the hydrogen ion concentration in an aqueous solution. Acidic solutions have a pH from 0 through 6, basic solutions have a pH > 7, and neutral solutions have a pH = 7.

piezometer—An instrument used to measure the potentiometric surface of the groundwater. Also, a well designed for this purpose.

precision—The closeness of approach of a value of similar or replicate results to a common value in a series of measurements.

priority pollutants—A group of approximately 130 chemicals (about 110 are organics) that appear on an EPA list because they are toxic and relatively common in industrial discharges.

process sewer—Pipe or drain, generally located underground, used to carry off process water and/or waste matter.

process water—Water used within a system process.

purge—To remove water prior to sampling, generally by pumping or bailing.

quality assurance (QA)—Any action in environmental monitoring to ensure the reliability of monitoring and measurement data.

quality control (QC)—The routine application of procedures within environmental monitoring to obtain the required standards of performance in monitoring and measurement processes.

quality factor—The factor by which the absorbed dose (rad) is multiplied to obtain a quantity that expresses, on a common scale for all ionizing radiation, the biological damage to exposed persons. It is used because some types of radiation, such as alpha particles, are more biologically damaging than others.

rad—The unit of absorbed dose deposited in a volume of material.

radioactivity—The spontaneous emission of radiation, generally alpha or beta particles or gamma rays, from the nucleus of an unstable isotope.

radioisotopes—Radioactive isotopes.

radionuclide—An unstable nuclide capable of spontaneous transformation into other nuclides by changing its nuclear configuration or energy level. This transformation is accompanied by the emission of photons or particles.

reclamation—Recovery of wasteland, desert, etc., by ditching, filling, draining, or planting.

reference material—A material or substance with one or more properties that is sufficiently well established and used to calibrate an apparatus, to assess a measurement method, or to assign values to materials.

regression analysis—A collection of statistical techniques that serve as a basis for drawing inferences about relationships among quantities in a scientific system.

release—Any discharge to the environment. "Environment" is broadly defined as any water, land, or ambient air.

rem—The unit of dose equivalent (absorbed dose in rads × the radiation quality factor). Dose equivalent is frequently reported in units of millirem (mrem), which is one one-thousandth of a rem.

remediation—The correction of a problem. See Environmental Restoration.

RFI Program—RCRA Facility Investigation Program; EPA-regulated investigation of a solid waste management unit with regard to its potential impact on the environment.

RFI/RI Program—RCRA Facility Investigation/Remedial Investigation Program; on the Oak Ridge Reservation (ORR), the expansion of the RFI Program to include CERCLA and hazardous substance regulations.

rising limb—The rising limb of the hydrograph represents the rapid increase resulting from rainfall causing surface runoff and later throughflow.

roentgen—A unit of radiation exposure equal to the quantity of ionizing radiation that will produce one electrostatic unit of electricity in one cubic centimeter of dry air at 0°C and standard atmospheric pressure. One roentgen equals 2.58×10^{-4} coulombs per kilogram of air.

screened interval—In well construction, the section of a formation that contains the screen, or perforated pipe, that allows water to enter the well.

seepage basin—An excavation that receives wastewater. Insoluble materials settle out on the floor of the basin, and soluble materials seep with the water through the soil column, where they are removed partially by ion exchange with the soil. Construction may include dikes to prevent overflow or surface runoff.

self-absorption—Absorption of radiation by the sample itself, preventing detection by the counting instrument.

sensitivity—The capability of a methodology or an instrument to discriminate among samples with differing concentrations or containing varying amounts of analyte.

settleable solids—Material settling out of suspension within a defined period.

settling basin—A temporary holding basin (excavation) that receives wastewater, which is subsequently discharged.

sievert (Sv)—The SI (International System of Units) unit of dose equivalent, 1 Sv = 100 rem.

slurry—A suspension of solid particles (sludge) in water.

specific conductance—The ability of water to conduct electricity; this ability varies in proportion to the amount of ionized minerals in the water.

spike—The addition of a known amount of reference material containing the analyte of interest to a blank sample.

spiked sample—A sample to which a known amount of some substance has been added.

split sample—A sample that has been portioned into two or more containers from a single sample container or sample-mixing container.

stable—Not radioactive or not easily decomposed or otherwise modified chemically.

stack—A vertical pipe or flue designed to exhaust airborne gases and suspended particulate matter.

standard deviation—An indication of the dispersion of a set of results around their average.

standard reference material (SRM)—A reference material distributed and certified by the National Institute of Standards and Technology.

statistical significance testing—A procedure for decision making and data evaluation based on mathematical probability that provides a consistent, scientific methodology for collecting, analyzing, and presenting data. Statistical significance testing reflects the mathematical likelihood of certain outcomes but says nothing about its environmental significance.

storm water runoff—Surface streams that appear after precipitation.

strata—Beds, layers, or zones of rocks.

substrate—The substance, base, surface, or medium in which an organism lives and grows.

surface water—All water on the surface of the earth, as distinguished from groundwater.

temperature—The thermal state of a body considered with its ability to communicate heat to other bodies.

terrestrial radiation—Ionizing radiation emitted from radioactive materials, primarily potassium-40, thorium, and uranium, in the earth's soils. Terrestrial radiation contributes to natural background radiation.

total activity—The total number of atoms of a radioactive substance that decay per unit of time.

total dissolved solids—Dissolved solids and total dissolved solids are terms generally associated with freshwater systems and consist of inorganic salts, small amounts of organic matter, and dissolved materials.

total organic halogens—A measure of the total concentration of organic compounds that have one or more halogen atoms.

total solids—The sum of total dissolved solids and suspended solids.

total suspended particulates—The concentration of particulates in suspension in the air irrespective of the nature, source, or size of the particulates.

transect—A line across an area being studied. The line is composed of points where specific measurements or samples are taken.

transmissive zone—A zone of sediments sufficiently porous and permeable to allow the flow of groundwater through the zone.

transuranic waste—Solid radioactive waste containing primarily alpha-emitting elements heavier than uranium.

transuranium elements—Elements with higher atomic weights than uranium; all 13 known transuranic elements are radioactive and are produced artificially.

trip blank—A sample container of deionized water that is transported to a sampling location, treated as a sample, and sent to the laboratory for analysis; trip blanks are used to check for contamination resulting from transport, shipping, and site conditions.

tritium (^{3}H)—The hydrogen isotope with one proton and two neutrons in the nucleus. It emits a low-energy beta particle (0.0186 MeV maximum) and has a half-life of 12.5 years.

t-test—Statistical method used to determine whether the means of groups of observations are equal.

turbidity—A measure of the concentration of sediment or suspended particles in solution.

unconsolidated zone—Soil zone located above the water table.

uncontrolled area—Any area to which access is not controlled for the purpose of protecting individuals from exposure to radiation and radioactive materials.

upgradient—In the direction of increasing hydrostatic head.

upper tolerance limit (UTL)—The upper endpoint of an interval that contains a specified fraction of a population with a specified probability (confidence level). Data points or calculated values that fall above a UTL indicate the existence of a statistical difference that is not explained by inherent random variation.

volatile organic compounds—Used in many industrial processes; the levels of these carcinogenic compounds must be kept to a minimum. They are measured by volatile organic content analyses. Common examples include trichloroethane, tetrachloroethene, and trichloroethene.

watershed—The region draining into a river, river system, or body of water.

wetlands—Lowland areas, such as a marshes or swamps, inundated or saturated by surface water or groundwater sufficiently to support hydrophytic vegetation typically adapted for life in saturated soils.

wind rose—A diagram in which statistical information concerning direction and speed of the wind at a location is summarized.

Appendix B. Climate Overview of the Oak Ridge Area

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Appendix B. Climate Overview of the Oak Ridge Area

B.1 Regional Climate

The climate of the Oak Ridge area and its surroundings may be broadly classified as humid subtropical. The term "humid" indicates that the region receives an overall surplus of precipitation compared to the level of evapotranspiration that is normally experienced throughout the year. The "subtropical" nature of the local climate indicates that the region experiences a wide range of seasonal temperatures. Such areas typically experience significant changes in temperature between summer and winter.

Local winters are characterized by synoptic weather systems that often produce significant precipitation events every 3 to 5 days. These wet periods are occasionally followed by arctic air outbreaks. Although snow and ice are not associated with many of these systems, occasional snowfall does occur. Winter cloud cover tends to be enhanced by the regional terrain (cold air wedging and trapping of moisture).

Severe thunderstorms are most frequent during spring but can occur at any time during the year. The Cumberland Mountains and the Cumberland Plateau often inhibit the intensity of severe systems that traverse the region, due to the downward momentum created as the storms move off the higher terrain into the Great Valley. Summers are characterized by very warm, humid conditions. Occasional frontal systems may produce organized lines of thunderstorms (and rare damaging tornados). More frequently, however, summer precipitation results from "air mass" thundershowers that form as a consequence of daytime heating, rising humid air, and local terrain features. Although adequate precipitation usually occurs during the fall, the months of August through October represent the driest period of the year. The occurrence of precipitation during the fall tends to be less cyclical than during other seasons but is occasionally enhanced by decaying tropical cyclones moving north from the Gulf of Mexico. During November, winter-type cyclones again begin to dominate the weather and continue to do so until May.

Decadal-scale climate change has recently affected the East Tennessee region. Most of these changes appear to be related to the hemispheric effects caused by the El Niño–Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), and the Atlantic Multidecadal Oscillation (AMO). The ENSO and PDO patterns, with cycles of 3 to 7 years and about 40 years, respectively, affect Pacific Ocean sea surface temperatures. The AMO, with a cycle of 30–70 years, affects Atlantic sea surface temperature. All of these patterns can collectively modulate regional temperature and precipitation trends with respect to East Tennessee (especially the AMO). The AMO shifted from a cold to a warm sea surface temperature phase (mid-1990s) and could continue in its present state for another 10 to 15 years. The PDO appears to have entered a cool sea surface temperature phase just after 2000. Also, the ENSO pattern has more frequently brought about warmer Eastern Pacific sea surface temperatures in the last couple of decades. Additionally, some evidence exists that human-induced climate change may be producing some effects (via an assembly of first-order influences such as well-mixed greenhouse gases, land cover change, carbon soot, and aerosols). Solar influences on the jet stream, via changes to the stratospheric temperature gradient with respect to the 11-year solar cycle, also play a role in inter-annual climate variability (Ineson *et al*. 2011). Largely due to the effects of the AMO and ENSO, the Oak Ridge climate warmed about 1.2ºC (34ºF) during the 1990s but has stabilized just above the 1990s values since then (little warming has occurred since 2000). The recent warming appears to have lengthened the growing season [i.e., the period with temperatures above 0ºC (32ºF)] by about 2 to 3 weeks over the last 30 years. In addition, a warming of minimum temperature has been noted over the last 30 years, this latter effect being presumably related to changes in the interaction of the surface boundary layer with greenhouse gases and/or aerosol concentration changes.

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B.2 Winds

Five major terrain-related wind regimes regularly affect the Great Valley of Eastern Tennessee: pressure-driven channeling, downward-momentum transport or vertically coupled flow, forced channeling, along-valley and mountain-valley thermal circulations, and down sloping. Pressure-driven channeling and vertically coupled flow affect winds on scales comparable to those of the Great Valley (hundreds of kilometers). Forced channeling occurs on similar scales but is also quite important at small spatial scales, such as those characterizing the ORR's ridge-and-valley terrain (Birdwell 2011). Along-valley and mountain-valley circulations are thermally driven and occur within a large range of spatial scales. Thermally driven flows are more prevalent under conditions of clear skies and low humidity.

Forced channeling is defined as the direct deflection of wind by terrain. This form of channeling necessitates some degree of vertical motion transfer, implying that the mechanism is less pronounced during strong temperature-inversion conditions. Although forced channeling may result from interactions between large valleys and mountain ranges (such as the Great Valley and the surrounding mountains), the mechanism is especially important in narrow, small valleys such as those on the Oak Ridge Reservation (Kossman and Sturman 2002).

Forced channeling within the Central Great Valley represents the most dominant large-scale wind mechanism, dominantly influencing 50–60% of all winds observed in the area. For up-valley flow cases, these winds are frequently associated with large wind shifts. At small-scales, ridge-and-valley terrain usually produces forced-channeled local flow (>90% of cases). Most forced-channeled winds prefer weak-to-moderate synoptic pressure gradients of less than 0.010 mb/km (Birdwell 2011).

Large-scale forced channeling occurs regularly within the Great Valley when northwest to north winds (perpendicular to the axis of the central Great Valley) coincide with vertically coupled flow. The phenomenon sometimes results in a split-flow pattern (winds southwest of Knoxville moving down-valley and those east of Knoxville moving up-valley). The causes of such a flow pattern may include the shape characteristics of the Great Valley (Kossman and Sturman 2002) but also may be associated with the specific location of the Cumberland and Smoky Mountains relative to upper level wind flow (Eckman 1998). The convex shape of the Great Valley with respect to a northwest wind flow may lead to a divergent wind flow pattern in the Knoxville area. This results in downward air motion. Additionally, horizontal flow is reduced by the windward mountain range (Cumberland Mountains), which increases buoyancy and Coriolis effects (also known as Froude and Rossby ratios). Consequently, the leeward mountain range (Smoky Mountains) becomes more effective at blocking or redirecting the winds.

Vertically coupled winds tend to occur when the atmosphere is unstably or neutrally buoyant. When a strong horizontal wind component is present, as in conditions behind a winter cold front or during strong cold air advection, winds tend to override the terrain, flowing roughly in the same direction as the winds aloft. This phenomenon is a consequence of the horizontal transport and momentum aloft being transferred to the surface. However, Coriolis effects may turn the winds by up to 40° to the left (Birdwell 1996).

In the Central Valley, vertically coupled winds dominate about 25 to 35% of the time; however, most such winds are turned toward an up-valley or down-valley direction when small-scale ridge-and-valley terrain is present. Wintertime vertically coupled flow is typically dominated by strong large-scale pressure forces, whereas the summertime cases tend to be more associated with deep mixing depths (>500 m). Most vertically coupled flows are associated with major wind shifts (90–135°) when such flow patterns begin or terminate (Birdwell 2011).

Pressure-driven channeling, in essence, is the redirection of synoptically induced wind flow through a valley channel. The direction of wind flow through the valley is determined by the pressure gradient superimposed on a valley axis (Whiteman 2000). The process is affected by Coriolis forces, a leftward deflection of winds in the Northern Hemisphere. Eckman (1998) suggested that pressure-driven channeling plays a significant role in the Great Valley. Winds driven purely by such a process shift from up-valley to down-valley flow or conversely as large-scale pressure systems induce flow shifts across the axis of the Great Valley. Since the processes involved in pressure-driven flow primarily affect the horizontal motion of air, the presence of a temperature inversion enhances flow significantly. Weak

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vertical air motion and momentum associated with such inversions allow different layers of air to slide over each other (Monti et al. 2002).

Within the Central Great Valley, especially the Oak Ridge Reservation, winds dominated by down-valley pressure-driven channeling range in frequency from 2 to 10%, with the lowest values in summer and the highest in winter. Up-valley pressure-driven channeling usually does not dominate winds in the Central Great Valley, but co-occurs with forced-channeled winds 50% of the time. Winds dominated by pressure driven channeling often result in large wind shifts (90–180°) before and after the occurrence of the wind pattern. These wind shifts occur about twice as frequently within and near the Oak Ridge Reservation when compared to other parts of the Great Valley (Birdwell 2011). Most pressure-driven channeled winds occurred in association with moderate synoptic pressure gradients (0.006–0.016 mb/km).

Thermally driven winds are common in areas of significantly complex terrain. These winds occur as a result of pressure and temperature differences caused by varied surface-air energy exchange at similar altitudes along a valley's axis, sidewalls, and/or slopes. Thermal flows operate most effectively when synoptic winds are light and when thermal differences are exacerbated by clear skies and low humidity (Whiteman 2000). Ridge-and-valley terrain may be responsible for enhancing or inhibiting such air flow, depending on the ambient weather conditions. Large-scale thermally driven wind frequency varies from 2 to 20% with respect to the seasons in the Central Great Valley. Frequencies are highest during summer and fall when more intense surface heating helps drive the flow patterns (Birdwell 2011).

Annual wind roses for each of the nine ORR meteorological towers during 2011 (Towers MT1, MT2, MT3, MT4, MT6, MT7, MT9, MT10, and MT11) have been compiled. These can be viewed online at http://www.ornl.gov/~das/web/page7.cfm. The wind roses represent large-scale trends and should be used with caution with respect to short-term variations.

A wind rose depicts the typical distribution of wind speed and direction for a given location. The winds are represented in terms of the direction from which they originate. The rays emanating from the center correspond to points of the compass. The length of each ray is related to the frequency at which winds blow from that direction. The concentric circles represent increasing frequencies from the center outward, given in percentages. Precipitation wind roses display similar information except that wind speed frequencies are replaced with data associated with the rate of hourly precipitation. Likewise, wind direction stability and wind direction mixing height roses replace wind speeds with data on stability class and mixing height respectively.

B.3 Temperature and Precipitation

Temperature and precipitation normals (1981–2010) and extremes (1948–2011) and their durations for the city of Oak Ridge are summarized in Table B.1. Decadal temperature and precipitation averages for the four decades of the 1970s to 2000s are given in Table B.2. Hourly freeze data (1985–2011) are given in Table B.3.

B.3.1 Recent Climate Change with Respect to Temperature and Precipitation

Table B.2 presents a decadal analysis of temperature patterns for the decades of the 1970s to 2000s. In general, temperatures in Oak Ridge rose in the 1990s but have leveled off during the 2000s. Based on these average decadal temperatures, temperatures have risen 2.5ºF or 1.4ºC between the decades of the 1970s and the 2000s from 13.7 to 15.2ºC (56.8 to 59.3ºF). More detailed analysis reveals that these temperature increases have been neither linear nor equal throughout the months or seasons.

January and February average temperatures have seen increases of 2.1ºC (3.8ºF) and 1.9ºC (3.5ºF), respectively. This significant increase is probably dominated by the effects of the AMO. Also, the Arctic has seen the largest increase in temperatures of anywhere in the Northern Hemisphere over the last 30 years. During the months of January and February, much of the air entering eastern Tennessee comes from the Arctic. As a result, Oak Ridge temperatures have warmed more dramatically during these months. Spring temperatures (March–April) have risen by about 1.4ºC (2.5ºF). Summer and fall temperatures have exhibited temperature rises of 1.6ºC (2.8ºF) and 1.4ºC (2.5ºF), respectively. December temperatures changed the least, +0.1ºC (+0.2ºF). Most of these average increases were driven by significant increases in minimum daily temperatures (which may be due to the redistribution of heat in the

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boundary layer resulting from increased presence of greenhouse gases and aerosols). Overall, annual minimum temperatures seem to have increased more dramatically (1.7ºC or 3.1ºF) than maximum temperatures (1ºC or 1.9ºF). For the most recent decade (2000s), August average temperatures are now slightly warmer than those of July.

Decadal precipitation averages suggest some important changes in precipitation patterns in Oak Ridge over the period of the 1970s to 2000s. Although overall precipitation has remained within a window of about 48 to 56 in. annually, there have been some recent decadal shifts in the patterns of rainfall on a monthly or seasonal scale. In particular, precipitation has tended to increase during the late winter and early spring (February through April) by about 2.54 cm/month (1 in./month). Conversely, the late summer and early fall months (August through October) have seen slight decreases in precipitation [about 1.27 cm/month (0.50 in./month)]. Overall, annual precipitation during the 2000s is consistent with the 30-year average [around 132 cm (52 in.)]. The year 2007 was the driest year on record in Oak Ridge (91.1 cm or 35.87 in.), which represented the core of a 4-year period of below-average precipitation (2005–2008). The year 2011 yielded precipitation totals around 40% above the 30-year mean. These statistics encompass the period from 1948 to 2011.

The previously discussed increase in winter temperatures has affected monthly and annual snowfall amounts until recently. During the 1970s and 1980s, snowfall averaged about 25.4–28 cm (10–11 in.) annually in Oak Ridge. However, during the most recent decade (2000s), snowfall has averaged only 6.6 cm (2.6 in). This decrease seems to have occurred largely since the mid-1990s. Although snowfall during 2010 reversed this trend with 11.1 in (28.2 cm), 2011 snowfall returned to the recent averages (4.3 in.). Concurrently with the overall decrease in snowfall, the annual number of hours of subfreezing weather has generally declined since the 1980s (Table B.3). However, the number of subfreezing hours during 2010 (1123) was the highest recorded since 1988.

Wind roses for all of the ORR towers that show wind direction for hours with and without precipitation have been compiled for 2011 and may be reviewed at http://www.ornl.gov/~das/web/page7.cfm.

Hourly values of subfreezing temperatures in Oak Ridge are presented in Table B.3 for the years 1985 through 2011. During the middle to late 1980s, a typical year experienced about 900 to 1000 h of subfreezing temperatures. In recent years, the value has fallen to approximately 500–700 h, though higher values occasionally occur.

B.4 Stability

The local ridge-and-valley terrain plays a role in the development of stable surface air under certain conditions and influences the dynamics of air flow. Although ridge-and-valley terrain creates identifiable patterns of association during unstable conditions as well, strong vertical mixing and momentum tend to reduce these effects. “Stability” describes the tendency of the atmosphere to mix or overturn. Consequently, dispersion parameters are influenced by the stability characteristics of the atmosphere. Stability classes range from “A” (very unstable) to “G” (very stable), with “D” being a neutral state.

The suppression of vertical motions during stable conditions increases the effect of local terrain on air motion. Conversely, stable conditions isolate wind flows within the ridge-and-valley terrain from the effects of more distant terrain features and from winds aloft. These effects are particularly true with respect to mountain waves. Deep stable layers of air tend to reduce the vertical space available for oscillating vertical air motions caused by local mountain ranges (Smith et al. 2002). This effect on mountain wave formation may be important with regard to the impact that the nearby Cumberland Mountains may have on local air flow.

A second factor that may decouple large-scale wind flow effects from local ones (and thus produce stable surface layers) occurs with overcast sky conditions. Clouds overlying the Great Valley may warm due to direct insolation on the cloud tops. Warming may also occur within the clouds as latent energy, which is released due to the condensation of moisture. Surface air underlying the clouds may remain relatively cool because it is cut off from direct exposure to the sun. Consequently, the vertical temperature gradient associated with the air mass becomes more stable (Lewellen and Lewellen 2002). Long wave cooling of fog decks has also been observed to help modify stability in the surface layer (Whiteman et al. 2001).

Table B.1. Climate normals (1981–2010) and extremes (1948–2011) for Oak Ridge, Tennessee (Town Site), with 2011 comparisons

Monthly variables	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Temperature, °C (°F)													
30-Year Average Max	8.1 (46.6)	11.1 (51.9)	16.3 (61.4)	21.4 (70.6)	25.7 (78.3)	29.8 (85.7)	31.3 (88.4)	31.1 (88.0)	27.6 (81.7)	21.7 (71.1)	15.3 (59.6)	9.8 (49.6)	20.8 (69.5)
2011 Average Max	6.8 (44.3)	13.1 (55.6)	16.8 (62.2)	23.8 (74.8)	25.9 (78.7)	31.3 (88.4)	32.8 (91.0)	33.1 (91.5)	26.3 (79.4)	20.9 (69.6)	16.6 (61.9)	11.8 (53.3)	21.6 (70.9)
64-Year Record Max	25 (77)	26 (79)	30 (86)	33 (92)	35 (95)	38 (101)	41 (105)	39 (103)	39 (102)	32 (90)	28 (83)	26 (78)	41 (105)
30-Year Average Min	-1.7 (28.9)	-0.2 (31.7)	4.1 (39.3)	8.3 (46.9)	12.9 (55.2)	18.1 (64.5)	20.3 (68.6)	19.6 (67.2)	15.4 (59.7)	8.9 (48.0)	3.5 (38.3)	-0.5 (31.1)	9.1 (48.4)
2011 Average Min	-2.7 (27.2)	0.8 (33.5)	5.8 (42.5)	9.7 (49.4)	13.9 (57.0)	19.4 (66.9)	21.8 (71.2)	19.7 (67.5)	15.3 (59.6)	8.2 (46.8)	4.8 (40.7)	0.4 (32.8)	9.8 (49.6)
64-Year Record Min	-27 (-17)	-25 (-13)	-17 (1)	-7 (20)	-1 (30)	4 (39)	9 (49)	10 (50)	1 (33)	-6 (21)	-18 (0)	-22 (-7)	-27 (-17)
30-Year Average	3.2 (37.7)	5.4 (41.8)	10.2 (50.4)	14.9 (58.8)	19.3 (66.8)	23.9 (75.1)	25.8 (78.5)	25.3 (77.6)	21.5 (70.7)	15.3 (59.5)	9.4 (48.9)	4.6 (40.3)	14.9 (58.9)
2011 Average	2.1 (35.8)	7.0 (44.6)	11.3 (52.4)	16.7 (62.1)	19.9 (67.9)	25.4 (77.7)	27.3 (81.1)	26.4 (79.5)	20.8 (69.5)	14.6 (58.2)	10.7 (51.3)	6.2 (43.1)	15.7 (60.3)
2010 Dep from Average	-1.1 (-1.9)	1.6 (2.8)	1.1 (2.0)	1.8 (3.3)	0.6 (1.1)	1.4 (2.6)	1.4 (2.6)	1.1 (1.9)	-0.7 (-1.2)	-0.7 (-1.3)	1.3 (2.4)	1.6 (2.8)	0.8 (1.4)
30-year average heating degree days, °C (°F)[a]													
	469 (845)	361 (650)	254 (458)	119 (215)	33 (59)	1 (2)	0	0	12 (21)	111 (199)	268 (483)	424 (764)	2053 (3696)
30-year average cooling degree days, °C (°F)[a]													
	0	0	2 (4)	15 (27)	63 (113)	169 (305)	232 (418)	217 (391)	107 (192)	17 (30)	1 (2)	0	823 (1482)
Precipitation, mm (in.)													
30-Year Average	115.4 (4.54)	116.1 (4.57)	128.6 (5.06)	106.2 (4.18)	109.0 (4.29)	108.7 (4.28)	133.9 (5.27)	70.1 (2.76)	93.8 (3.69)	74.2 (2.92)	114.1 (4.49)	123.5 (4.86)	1294 (50.91)
2011	101.4 (3.99)	144.8 (5.70)	169.0 (6.65)	232.0 (9.13)	54.4 (2.14)	185.5 (7.30)	122.0 (4.80)	23.1 (91.0)	257.4 (10.14)	116.6 (4.59)	276.9 (10.90)	122.0 (4.80)	1805.2 (71.05)
2011 Dep from Average	-14.0 (-0.55)	28.7 (1.13)	40.4 (1.59)	125.8 (4.95)	-54.6 (-2.15)	76.7 (3.02)	-11.9 (-0.47)	-47.0 (-1.85)	163.9 (6.45)	42.4 (1.67)	162.9 (6.41)	-1.5 (-0.06)	+511.7 (+20.14)
64-Year Max Monthly	337.2 (13.27)	324.7 (12.78)	311.0 (12.24)	356.5 (14.03)	271.9 (10.70)	283.0 (11.14)	489.6 (19.27)	265.8 (10.46)	257.4 (10.14)	176.6 (6.95)	310.5 (12.22)	321.2 (12.64)	1939 (76.33)
64-Year Max 24-hr	108.0 (4.25)	131.6 (5.18)	120.4 (4.74)	158.5 (6.24)	112.0 (4.41)	94.0 (3.70)	124.8 (4.91)	190.1 (7.48)	160.1 (6.30)	67.6 (2.66)	130.1 (5.12)	130.1 (5.12)	190.1 (7.48)
64-Year Min Monthly	23.6 (0.93)	21.3 (0.84)	54.1 (2.13)	22.4 (0.88)	20.3 (0.80)	13.5 (0.53)	31.3 (1.23)	13.7 (0.54)	Trace	Trace	34.8 (1.37)	17.0 (0.67)	911.4 (35.87)
Snowfall, cm (in.)													
30-Year Average	7.4 (2.9)	6.6 (2.6)	2.5 (1.0)	7.6 (0.3)	0	0	0	0	0	0	Trace	4.1 (1.6)	21.3 (8.4)
2011 Totals	10.4 (4.1)	5.1 (0.2)	Trace	0	0	0	0	0	0	0	Trace	Trace	15.5 (4.3)
64-Year Max Monthly	24.4 (9.6)	43.7 (17.2)	53.4 (21.0)	15.0 (5.9)	Trace	0	0	0	0	Trace	16.5 (6.5)	53.4 (21.0)	105.2 (41.4)
64-Year Max 24-hr	21.1 (8.3)	28.7 (11.3)	30.5 (12.0)	13.7 (5.4)	Trace	0	0	0	0	Trace	16.5 (6.5)	30.5 (12.0)	30.5 (12.0)
Days w/temp													
30-Year Max ≥ 32°C	0	0	0	0.1	0.3	5.9	11.3	10.4	2.9	0	0	0	30.9
2011 Max ≥ 32°C	0	0	0	0	5	14	22	24	3	0	0	0	68
30-Year Min ≤ 0°C	20.8	15.0	6.5	1.3	0	0	0	0	0	1.5	8.2	17.7	71.0
2011 Min ≤ 0°C	25	14	2	1	0	0	0	0	0	1	6	12	61
30-Year Max ≤ °C	2.8	0.5	0	0	0	0	0	0	0	0	0	0.8	4.1
2011 Max ≤ 0°C	4	0	0	0	0	0	0	0	0	0	0	0	4
Days w/precipitation													
30-Year Avg ≥ 0.01 in.	10.9	10.1	11.2	10.4	11.9	10.8	13.0	8.9	8.4	8.3	9.3	11.3	124.5
2011 Days ≥ 0.01 in.	12	9	10	5	13	13	12	8	10	6	11	13	118
30-Year Avg ≥ 1.00 in.	1.4	1.1	1.2	0.9	1.4	0.8	1.5	0.5	1.3	0.7	1.5	1.4	13.7
2010 Days ≥ 1.00 in.	1	2	2	3	1	4	2	2	2	1	5	2	27

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Table B.2. Decadal climate change (1970–2009) for Oak Ridge, Tennessee (Town Site), with 2011 comparisons

Monthly variables	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Temperature, °C (°F)													
1970-1979 Avg Max	6.6 (43.8)	9.7 (49.5)	15.6 (60.1)	21.4 (70.6)	24.8 (76.7)	28.5 (83.3)	30.0 (85.9)	29.7 (85.5)	26.8 (80.2)	20.8 (69.4)	14.5 (58.2)	10.0 (49.9)	19.9 (67.8)
1980-1989 Avg Max	6.9 (44.4)	10.2 (50.3)	15.9 (60.7)	21.0 (69.8)	25.6 (78.1)	29.8 (85.7)	31.6 (88.8)	30.7 (87.3)	27.1 (80.8)	21.3 (70.3)	15.6 (60.2)	8.6 (47.5)	20.3 (68.6)
1990-1999 Avg Max	9.4 (48.8)	12.3 (54.1)	16.2 (61.2)	21.9 (71.3)	26.2 (79.1)	29.7 (85.5)	32.1 (89.8)	31.4 (88.6)	28.4 (83.2)	22.6 (72.8)	15.2 (59.4)	10.4 (50.8)	21.3 (70.4)
2000-2009 Avg Max	8.8 (47.9)	11.2 (52.1)	17.0 (62.7)	21.4 (70.6)	25.8 (78.4)	29.8 (85.6)	30.8 (87.5)	31.4 (88.5)	27.6 (81.8)	21.8 (71.2)	15.9 (60.6)	9.8 (49.6)	21.0 (69.7)
Change (70s vs. 00s)	2.2 (5.1)	1.5 (2.6)	1.4 (2.6)	0.0 (0.0)	1.0 (1.7)	1.3 (2.3)	0.8 (1.6)	1.4 (2.5)	0.8 (1.6)	1.0 (1.8)	1.4 (2.4)	-0.2 (-0.3)	1.1 (1.9)
2011 Avg Max	6.8 (44.3)	13.1 (55.6)	16.8 (62.2)	23.8 (74.8)	25.9 (78.7)	31.3 (88.4)	32.8 (91.0)	33.1 (91.5)	26.3 (79.4)	20.9 (69.6)	16.6 (61.9)	11.8 (53.3)	21.6 (70.9)
1970-1979 Avg Min	-3.4 (25.8)	-2.4 (27.6)	3.0 (37.4)	6.7 (44.1)	11.6 (52.8)	15.7 (60.2)	18.3 (64.9)	18.1 (64.6)	15.5 (59.9)	7.5 (45.5)	2.6 (36.8)	-0.8 (30.5)	7.7 (45.8)
1980-1989 Avg Min	-4.1 (24.7)	-2.1 (28.3)	1.7 (35.0)	6.0 (42.9)	11.4 (52.4)	16.2 (61.2)	19.0 (66.2)	18.4 (65.1)	14.4 (57.9)	7.5 (45.4)	3.1 (37.5)	-2.3 (27.8)	7.4 (45.3)
1990-1999 Avg Min	-0.9 (30.3)	0.0 (32.0)	2.9 (37.1)	7.2 (45.0)	12.5 (54.5)	17.2 (63.0)	20.0 (67.9)	18.9 (66.1)	15.1 (59.2)	8.2 (46.8)	2.2 (36.0)	0.1 (32.2)	8.6 (47.6)
2000-2009 Avg Min	-1.4 (29.5)	0.0 (32.0)	4.4 (39.9)	8.6 (47.5)	13.6 (56.4)	18.0 (64.3)	20.0 (67.9)	20.0 (68.0)	16.1 (61.0)	9.5 (49.0)	3.9 (39.0)	-0.4 (31.4)	9.4 (48.9)
Change (70s vs. 00s)	2.0 (3.7)	2.4 (4.4)	1.4 (2.5)	1.9 (3.4)	2.0 (3.6)	2.3 (4.1)	1.7 (3.0)	1.9 (3.4)	0.6 (1.1)	2.0 (3.5)	1.3 (2.2)	0.4 (0.9)	1.7 (3.1)
2011 Avg Min	-2.7 (27.2)	0.8 (33.5)	5.8 (42.5)	9.7 (49.4)	13.9 (57.0)	19.4 (66.9)	21.8 (71.2)	19.7 (67.5)	15.3 (59.6)	8.2 (46.8)	4.8 (40.7)	0.4 (32.8)	9.8 (49.6)
1970-1979 Avg	1.6 (34.9)	3.7 (38.6)	9.3 (48.8)	14.1 (57.4)	18.1 (64.7)	22.1 (71.8)	24.1 (75.4)	23.9 (75.0)	21.1 (70.0)	14.2 (57.5)	8.6 (47.5)	4.6 (40.3)	13.8 (56.8)
1980-1989 Avg	1.4 (34.6)	4.1 (39.3)	8.8 (47.9)	13.5 (56.4)	18.5 (65.3)	23.0 (73.4)	25.3 (77.5)	24.6 (76.2)	20.8 (69.4)	14.4 (57.9)	9.4 (48.8)	3.1 (37.7)	13.9 (57.0)
1990-1999 Avg	4.2 (39.6)	6.2 (43.1)	9.6 (49.2)	14.5 (58.2)	19.4 (66.8)	23.5 (74.3)	26.0 (78.9)	25.2 (77.4)	21.9 (71.4)	15.5 (59.8)	8.8 (47.8)	5.3 (41.5)	15.0 (59.0)
2000-2009 Avg	3.7 (38.7)	5.6 (42.1)	10.7 (51.3)	15.3 (59.6)	19.7 (67.5)	23.9 (75.1)	25.4 (77.7)	25.7 (78.3)	21.9 (71.4)	15.6 (60.1)	9.9 (49.8)	4.7 (40.5)	15.2 (59.3)
Change (70s vs. 00s)	2.1 (3.8)	1.9 (3.5)	1.4 (2.5)	1.2 (2.2)	1.6 (2.8)	1.8 (3.3)	1.3 (2.3)	1.8 (3.3)	0.8 (1.4)	1.4 (2.6)	1.3 (2.3)	0.1 (0.2)	1.4 (2.5)
2011 Avg	2.1 (35.8)	7.0 (44.6)	11.3 (52.4)	16.7 (62.1)	19.9 (67.9)	25.4 (77.7)	27.3 (81.1)	26.4 (79.5)	20.8 (69.5)	14.6 (58.2)	10.7 (51.3)	6.2 (43.1)	15.7 (60.3)
Precipitation, mm (in.)													
1970-1979 Avg	143.4 (5.65)	94.6 (3.72)	169.4 (6.67)	118.3 (4.66)	149.8 (5.89)	120.5 (4.74)	130.4 (5.13)	109.8 (4.32)	107.2 (4.22)	99.8 (3.93)	129.6 (5.10)	145.3 (5.72)	1516.4 (59.68)
1980-1989 Avg	100.4 (3.95)	109.1 (4.29)	112.6 (4.43)	88.8 (3.49)	110.6 (4.35)	84.1 (3.31)	120.4 (4.74)	82.6 (3.25)	108.9 (4.29)	79.8 (3.14)	128.0 (5.04)	107.6 (4.23)	1236.2 (48.66)
1990-1999 Avg	141.4 (5.57)	136.5 (5.37)	149.0 (5.86)	126.3 (4.97)	113.4 (4.47)	110.0 (4.33)	134.8 (5.31)	83.6 (3.29)	71.9 (2.83)	67.3 (2.65)	109.8 (4.32)	161.0 (6.34)	1429.4 (56.26)
2000-2009 Avg	116.9 (4.60)	121.8 (4.80)	115.6 (4.55)	125.0 (4.92)	117.8 (4.64)	95.2 (3.75)	138.9 (5.47)	78.4 (3.09)	108.8 (4.28)	74.0 (2.91)	121.4 (4.78)	124.4 (4.90)	1333.4 (52.48)
Change (70s vs. 00s)	-26.5 (-1.04)	27.2 (1.07)	-43.8 (-1.72)	6.7 (0.26)	-32.0 (-1.26)	-25.3 (-1.00)	8.5 (0.33)	-31.4 (-1.24)	1.6 (0.06)	-25.8 (-1.02)	-8.2 (-0.32)	-20.9 (-0.82)	-183.0 (-7.20)
2011 Totals	101.4 (3.99)	144.8 (5.70)	169.0 (6.65)	232.0 (9.13)	54.4 (2.14)	185.5 (7.30)	122.0 (4.80)	23.1 (0.91)	257.6 (10.14)	116.6 (4.59)	276.9 (10.90)	122.0 (4.80)	1805.2 (71.05)
Snowfall, cm (in.)													
1970-1979 Avg	11.1 (4.4)	12.5 (4.9)	4.2 (1.7)	0.2 (0.1)	0	0	0	0	0	0	0.5 (0.2)	4.4 (1.8)	351 (13.8)
1980-1989 Avg	11.3 (4.5)	8.8 (3.5)	2.2 (0.9)	2.2 (0.9)	0	0	0	0	0	0	0	7.5 (3.0)	328 (12.9)
1990-1999 Avg	6.8 (2.7)	7.8 (3.1)	8.1 (3.2)	Trace	0	0	0	0	0	0	0.3 (0.1)	3.1 (1.2)	109 (4.3)
2000-2009 Avg	2.1 (0.8)	4.5 (1.8)	Trace	Trace	0	0	0	0	0	0	Trace	1.7 (0.7)	8.3 (3.3)
Change (70s vs. 00s)	-9.0 (-3.6)	-8.0 (-3.1)	-4.2 (-1.7)	-0.2 (-0.1)	0	0	0	0	0	0	-0.5 (-0.2)	-2.7 (-1.1)	-242 (-9.5)
2011 Totals	10.4 (4.1)	5.1 (0.2)	Trace	0	0	0	0	0	0	0	Trace	Trace	15.5 (4.3)

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Table B.3. Hourly subfreezing temperature data for Oak Ridge, Tennessee, 1985–2011 (Number of hours at or below 0, -5, -10, and -15 °C[a])

Year	January				February				March			April		May		October		November			December				Annual			
	≤0	<-5	<-10	<-15	≤0	<-5	<-10	<-15	≤0	<-5	<-10	≤0	<-5	≤0	<-5	≤0	<-5	≤0	<-5	<-10	≤0	<-5	<-10	<-15	≤0	<-5	<-10	<-15
1985	467	195	103	39	331	127	26	0	105	6	0	43	3	0	0	0	0	22	0	0	431	201	66	2	1399	532	195	41
1986	308	125	38	10	161	29	3	0	124	28	0	17	0	0	0	0	0	32	10	0	232	34	0	0	874	226	41	10
1987	302	53	7	0	111	19	3	0	95	0	0	55	4	0	0	36	0	103	18	0	151	16	0	0	853	110	10	0
1988	385	182	43	0	294	102	19	0	97	9	0	6	0	0	0	45	0	62	3	0	301	55	0	0	1190	351	62	0
1989	163	27	0	0	190	66	10	0	35	0	0	18	0	3	0	7	0	125	14	0	421	188	71	30	962	295	81	30
1990	142	13	0	0	115	5	0	0	35	0	0	35	0	0	0	19	0	62	1	0	172	43	5	0	580	62	5	0
1991	186	44	0	0	158	47	15	0	49	0	0	0	0	0	0	4	0	148	16	0	192	38	0	0	737	145	15	0
1992	230	65	8	0	116	22	0	0	116	4	0	27	2	0	0	7	0	100	0	0	166	9	0	0	762	102	8	0
1993	125	11	0	0	245	47	8	0	124	32	9	3	0	0	0	0	0	152	2	0	223	44	0	0	872	136	17	0
1994	337	191	85	26	196	46	3	0	66	0	0	18	0	0	0	0	0	53	1	0	142	0	0	0	812	238	88	26
1995	240	45	6	0	217	84	18	0	37	0	0	0	0	0	0	0	0	142	3	0	288	84	10	0	924	216	34	0
1996	301	91	0	0	225	110	62	27	182	49	6	23	0	0	0	3	0	101	0	0	194	40	4	0	1029	290	72	27
1997	254	101	24	0	67	0	0	0	25	0	0	6	0	0	0	6	0	96	10	0	232	14	0	0	686	125	24	0
1998	97	10	7	0	25	0	0	0	74	20	0	0	0	0	0	0	0	38	0	0	132	4	0	0	366	34	7	0
1999	181	68	0	0	113	14	0	0	62	0	0	0	0	0	0	4	0	41	0	0	177	23	0	0	578	105	0	0
2000	273	62	5	0	127	30	0	0	18	0	0	8	0	0	0	11	0	94	11	0	345	124	7	0	876	227	12	0
2001	281	60	5	0	79	9	0	0	53	0	0	2	0	0	0	18	0	28	0	0	137	35	0	0	598	104	5	0
2002	185	28	0	0	121	16	0	0	91	17	0	2	0	0	0	0	0	41	0	0	82	6	0	0	522	67	0	0
2003	345	123	26	0	117	12	0	0	19	0	0	0	0	0	0	0	0	37	0	0	102	9	0	0	620	144	26	0
2004	285	50	2	0	76	0	0	0	18	0	0	0	0	0	0	0	0	9	0	0	247	41	4	0	635	91	6	0
2005	151	65	6	0	52	1	0	0	81	1	0	0	0	0	0	1	0	55	0	0	176	28	0	0	516	95	6	0
2006	70	0	0	0	169	19	0	0	44	0	0	0	0	0	0	15	0	37	0	0	126	41	1	0	461	60	1	0
2007	189	30	5	0	283	70	0	0	29	0	0	32	0	0	0	0	0	60	0	0	83	8	0	0	673	111	5	0
2008	242	86	11	0	114	7	0	0	69	6	0	0	0	0	0	15	0	89	18	0	157	34	5	0	686	151	16	0
2009	238	93	29	0	178	64	5	0	55	15	0	5	0	0	0	0	0	8	0	0	178	22	0	0	662	194	34	0
2010	384	181	14	0	289	32	0	0	40	2	0	0	0	0	0	0	0	46	0	0	364	109	11	0	1123	324	25	0
2011	300	61	0	0	108	14	0	0	2	0	0	0	0	0	0	5	0	29	0	0	91	0	0	0	535	75	0	0
Avg.	247	76	16	3	158	37	6	1	65	7	1	11	0	0	0	7	0	67	4	0	205	46	7	1	760	171	29	5

[a]Source: 1985–2009 National Oceanic and Atmospheric Administration, Atmospheric Turbulence and Diffusion Division, KOQT Station, Automated Surface Observing System.

Stable boundary layers typically form as a result of radiational cooling processes near the ground (Van De Weil et al. 2002); however, they are also influenced by the mechanical energy supplied by horizontal wind motion, which is in turn influenced by the synoptic-scale "weather"-related pressure gradient. Ridge-and-valley terrain may have significant ability to block such winds and their associated mechanical energy (Carlson and Stull 1986). Consequently, radiational cooling at the surface is enhanced since there is less wind energy available to remove chilled air.

Stable boundary layers also exhibit intermittent turbulence, which has been associated with a number of the above factors. The process results from "give-and-take" between the effects of friction and radiational cooling. As a stable surface layer intensifies via a radiation cooling process, it tends to decouple from air aloft, thereby reducing the effects of surface friction. The upper air layer responds with an acceleration in wind speed. Increased wind speed aloft results in an increase in mechanical turbulence and wind shear at the boundary with the stable surface layer. Eventually, the turbulence works into the surface layer and weakens it. As the inversion weakens, friction again increases, reducing winds aloft. The reduced wind speeds aloft allow enhanced radiation cooling at the surface, which reintensifies the inversion and allows the process to start again. Van De Weil et al. (2002) have shown that cyclical temperature oscillations up to 4°C (7ºF) may result from these processes. Since these intermittent processes are driven primarily by large-scale horizontal wind flow and radiational cooling of the surface, ridge-and-valley terrain significantly affect these oscillations.

Wind roses for stability and mixing depth have been complied for all of the ORR tower sites in 2011. These may be viewed at http://www.ornl.gov/~das/web/page7.cfm. The wind roses in general reveal that both unstable conditions and/or deep mixing depths are associated with less channeling of winds, while stable conditions and/or shallow mixing depths tend to promote channeled flow.

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Appendix C. Reference Standards and Data for Water

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Table C.1. Reference standards for radionuclides in water

Parameter[a]	National primary drinking water standard[b]	4% of DCS[c]	DCS[d]
^{241}Am		6.8	170
^{214}Bi		10,400	260,000
^{109}Cd		640	16,000
^{143}Ce		1,040	26,000
^{60}Co		288	7,200
^{51}Cr		31,600	790,000
^{137}Cs		120	3,000
^{155}Eu		3480	87,000
Gross alpha[e]	15		
Gross beta (mrem/year)	4		
^{3}H	20,000[f]	76,000	1,900,000
^{131}I		52	1,300
^{40}K		192	4,800
^{237}Np		12.8	320
^{234m}Pa		2,840	71,000
^{238}Pu		6	150
$^{239/240}$Pu		5.6	140
^{226}Ra	5[g]	3.5	87
^{228}Ra	5[g]	1	25
^{106}Ru		164	4,100
^{90}Sr	8[f]	44	1,100
^{99}Tc		1,760	44,000
^{228}Th		13.6	340
^{230}Th		6.4	160
^{232}Th		5.6	140
^{234}Th		336	8,400
Thorium, natural		5.6	140
^{234}U		27.2	680
^{235}U		28.8	720
^{236}U		28.8	720
^{238}U		30	750
Uranium, natural		30	750
Uranium, total[h] (µg/L)	30	27.2	680

[a]Only the radionuclides included in the Oak Ridge Reservation monitoring programs are listed. Unless labeled otherwise, units are pCi/L.

[b]40 CFR Part 141, National Primary Drinking Water Regulations, Subparts B and G. The drinking water standards are presented strictly for reference purposes and have regulatory applicability only for public water supplies.

[c]Four percent of the derived concentration standard represents the DOE criterion of 4-mrem effective dose equivalent from ingestion of drinking water.

[d]DOE "*Derived Concentration Technical Standard, DOE-STD-1196-2011, April 2011*."

[e]Excludes radon and uranium.

[f]These values are not maximum contaminant levels but are concentrations that result in the effective dose equivalent of the maximum contaminant level for gross beta emissions, which is 4 mrem/year.

[g]Applies to combined ^{226}Ra and ^{228}Ra.

[h]Minimum of uranium isotopes.

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Table C.2. TDEC and EPA nonradiological water quality standards and criteria (µg/L)

Chemical	TDEC and EPA Drinking Water Standards[a]	TDEC Fish and Aquatic Life Criteria		TDEC recreation criteria water + organisms, organisms only[b]
		Maximum	Continuous	
Acenaphthene				670, 990
Acrolein				190, 290
Acrylonitrile (c)				0.51, 2.5
Alachlor	2 (E1, T)			
Aldrin (c)		3.0	–	0.00049, 0.00050
Aluminum	50 – 200 (E2)			
Anthracene				8300, 40,000
Antimony	6 (E1, T)			5.6, 640
Arsenic (c)	10 (E1, T)			10.0, 10.0
Arsenic(III)[c]		340[c]	150[c]	
Asbestos	7 million fibers/L (MFL) (E1)			
Atrazine	3 (E1, T)			
Barium	2000 (E1, T)			
Benzene (c)	5 (E1, T)			22, 510
Benzidine (c)				0.00086, 0.0020
Benzo(a)anthracene (c)				0.038, 0.18
Benzo(a)pyrene (c)	0.2 (E1, T)			0.038, 0.18
Benzo(b)fluoranthene (c)				0.038, 0.18
Benzo(k)fluoranthene (c)				0.038, 0.18
Beryllium	4 (E1, T)			
a-BHC (c)				0.026, 0.049
b-BHC (c)				0.091, 0.17
g-BHC (Lindane)	0.2 (E1, T)	0.95	–	0.98, 1.8
Bis(2-chloroethyl)ether (c)				0.30, 5.3
Bis(2-chloro-isopropyl)ether				1400, 65,000
Bis(2-ethylhexyl)phthalate (c)				12, 22
Bromoform (c)				43, 1400
Butylbenzyl phthalate				1500, 1900
Cadmium	5 (E1, T)	2.0[d]	0.25[d]	
Carbofuran	40 (E1, T)			
Carbon tetrachloride (c)	5 (E1, T)			2.3, 16
Chlordane (c)	2 (E1, T)	2.4	0.0043	0.0080, 0.0081
Chloride	250,000 (E2)			
Chlorine (TRC)	4000 (E1)	19	11	
Chlorobenzene	100 (E1, T)			130, 1600
Chlorodibromomethane (c)				4.0, 130
Chloroform (c)				57, 4700
2-Chloronaphthalene				1000, 1600
2-Chlorophenol				81, 150
Chromium (total)	100 (E1, T)			
Chromium(III)		570[d]	74[d]	
Chromium(VI)[c]		16[c]	11[c]	
Chrysene (c)				0.038, 0.18

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Table C.2 (continued)

Chemical	TDEC and EPA drinking water standards[a]	TDEC fish and aquatic life criteria		TDEC recreation criteria water + organisms, organisms only[b]
		Maximum	Continuous	
Coliforms	630/100 mL, *E. coli*, geometric mean (T); no more than 5% of samples per month can be positive for total coliforms (E1)	2880/100 mL, *E. coli* (single sample)	630/100 mL, *E. coli* (geometric mean)	126/100 mL, geometric mean, *E. coli* 487, maximum lakes/reservoirs, *E. coli* 941, maximum, other water bodies, *E. coli*
Color	15 color units (E2)			
Copper	1000 (E2) 1300 (E1 "Action Level")	13[d]	9.0[d]	
Cyanide (as free cyanide)	200 (E1, T)	22	5.2	140, 140
2,4-D (Dichlorophennoxyacetic acid)	70 (E1, T)			
4,4'-DDT (c)		1.1	0.001	0.0022, 0.0022
4,4'-DDE (c)				0.0022, 0.0022
4,4'-DDD (c)				0.0031, 0.0031
Dalapon	200 (E1, T)			
Dibenz(a,h)anthracene (c)				0.038, 0.18
1,2-dibromo-3-chloropropane (DBCP)	0.2 (E1, T)			
1,2-Dichlorobenzene (*ortho*-)	600 (E1, T)			420, 1300
1,3-Dichlorobenzene (*meta*-)				320, 960
1,4-Dichlorobenzene (*para*-)	75 (E1, T)			63, 190
3,3-Dichlorobenzidine (c)				0.21, 0.28
Dichlorobromomethane (c)				5.5, 170
1,2-Dichloroethane (c)	5 (E1, T)			3.8, 370
1,1-Dichloroethylene	7 (E1, T)			330, 7100
Cis-1,2-Dichloroethylene	70 (E1, T)			
trans 1,2-Dichloroethylene	100 (E1, T)			140, 10,000
Dichloromethane	5 (E1, T)			
2,4-Dichlorophenol				77, 290
1,2-Dichloropropane (c)	5 (E1, T)			5.0, 150
1,3-Dichloropropene (c)				3.4, 210
Dieldrin (c)		0.24	0.056	0.00052, 0.00054
Diethyl phthalate				17,000, 44,000
Di (2-ethylhexyl) adipate	400 (E1, T)			
Di (2-ethylhexyl) phthalate	6 (E1, T)			
Dinoseb	7 (E1, T)			
Dimethyl phthalate				270,000, 1,100,000
2,4-Dimethylphenol				380, 850
Di-n-butyl phthalate				2000, 4500
2,4-Dinitrophenol				69, 5300
2,4-Dinitrotoluene (c)				1.1, 34
Dioxin (2,3,7,8-TCDD) (c)	3 E-5 (E1, T)			0.000001, 0.000001
Diquat	20 (E1, T)			
1,2-Diphenylhydrazine (c)				0.36, 2.0
a-Endosulfan		0.22	0.056	62, 89
b-Endosulfan		0.22	0.056	62, 89
Endosulfan sulfate				62, 89
Endothall	100 (E1, T)			
Endrin	2 (E1, T)	0.086	0.036	0.059, 0.06

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Table C.2 (continued)

Chemical	TDEC and EPA drinking water standards[a]	TDEC fish and aquatic life criteria		TDEC recreation criteria water + organisms, organisms only[b]
		Maximum	Continuous	
Endrin aldehyde				0.29, 0.30
Ethylbenzene	700 (E1, T)			530, 2100
Ethylene dibromide	0.05 (E1, T)			
Fluoranthene				130, 140
Fluorene				1100, 5300
Fluoride	2000 (E2) 4000 (E1)			
Foaming agents	500 (E2)			
Glyphosate	700 (E1, T)			
Heptachlor (c)	0.4 (E1, T)	0.52	0.0038	0.00079, 0.00079
Heptachlor epoxide (c)	0.2 (E1, T)	0.52	0.0038	0.00039, 0.00039
Hexachlorobenzene (c)	1 (E1, T)			0.0028, 0.0029
Hexachlorobutadiene (c)				4.4, 180
Hexachlorocyclopentadiene	50 (E1, T)			40, 1100
Hexachloroethane (c)				14, 33
Indeno(1,2,3-cd)pyrene (c)				0.038, 0.18
Iron	300 (E2)			
Isophorone (c)				350, 9600
Lead	5 (T) 15 (E1 "Action Level")	65[d]	2.5[d]	
Manganese	50 (E2)			
Mercury (inorganic)[c]	2 (E1, T)	1.4[c]	0.77[c]	0.05, 0.051
Methyl bromide				47, 1500
2-Methyl-4,6-dinitrophenol				13, 280
Methylene chloride (Dichloromethane) (c)				46, 5900
Nickel	100 (T)	470[d]	52[d]	610, 4600
Nitrate as N	10,000 (E1)			
Nitrite as N	1000 (E1)			
Nitrobenzene				17, 690
N-Nitrosodimethylamine (c)				0.0069, 30
N-Nitrosodi-n-propylamine (c)				0.05, 5.1
N-Nitrosodiphenylamine (c)				33, 60
Odor	3 threshold odor number (E2)			
Oxamyl (Vydate)	200 (E1, T)			
Pentachlorophenol (c)	1 (E1, T)	19[e]	15[e]	2.7, 30
pH	6.5 to 8.5 units (E2) 6.0 to 9.0 units (T)		6.0 to 9.0 units, wade-able streams 6.5 to 9.0 units, larger rivers, lakes, etc	6.0 to 9.0 units
Phenol				21,000, 1,700,000
PCBs, total (c)	0.5 (E1, T)	–	0.014	0.00064, 0.00064
Pyrene				830, 4000
Selenium	50 (E1, T)	20	5	
Silver	100 (E2)	3.2[d]	–	
Simazine	4 (E1, T)			

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Table C.2 (continued)

Chemical	TDEC and EPA drinking water standards[a]	TDEC fish and aquatic life criteria		TDEC recreation criteria water + organisms, organisms only[b]
		Maximum	Continuous	
Styrene	100 (E1, T)			
Sulfate	250,000 (E2)			
1,1,2,2-Tetrachloroethane (c)				1.7, 40
Tetrachloroethylene (c)	5 (E1, T)			6.9, 33
Thallium	2 (E1, T)			0.24, 0.47
Toluene	1000 (E1, T)			1300, 15,000
Total dissolved solids	500,000 (E2)			
Total trihalomethanes	80 (E1)			
Toxaphene (c)	3 (E1, T)	0.73	0.0002	0.0028, 0.0028
2,4,5-TP (Silvex)	50 (E1, T)			
Tributyltin (TBT)		0.46	0.072	
1,2,4-Trichlorobenzene	70 (E1, T)			35, 70
1,1,1-Trichloroethane	200 (E1, T)			
1,1,2-Trichloroethane (c)	5 (E1, T)			5.9, 160
Trichloroethylene (c)	5 (E1, T)			25, 300
2,4,6-Trichlorophenol (c)				14, 24
Vinyl chloride (c)	2 (E1, T)			0.25, 24
Xylenes (total)	10,000 (E1, T)			
Zinc	5000 (E2)	120[d]	120[d]	

[a]E1 = EPA Primary Drinking Water Standards; E2 = EPA Secondary Drinking Water Standards; T = TDEC domestic water supply criteria.

[b]For each parameter, the first recreational criterion is for "water and organisms" and is applicable on the ORR only to the Clinch River because the Clinch is the only stream on the Oak Ridge Reservation (ORR) that is classified for both domestic water supply and for recreation. The second criterion is for "organisms only" and is applicable to the other streams on the ORR. TDEC uses a 10^{-5} risk level for recreational criteria for all carcinogenic pollutants (designated with "(c)" under "Chemical" column). Recreational criteria for noncarcinogenic chemicals are set using a 10^{-6} risk level. (Note: All federal recreational criteria are set at a 10^{-6} risk level.)

[c]Criteria are expressed as dissolved.

[d]Criteria are expressed as dissolved and are a function of total hardness (mg/L). Criteria displayed correspond to a total hardness of 100 mg/L.

[e]Criteria are expressed as a function of pH; values shown correspond to a pH of 7.8.

Abbreviations

TDEC = Tennessee Department of Environment and Conservation
EPA = US Environmental Protection Agency

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Appendix D. National Pollutant Discharge Elimination System Noncompliance Summaries for 2011

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Appendix D. National Pollutant Discharge Elimination System Noncompliance Summaries for 2011

D.1 Y-12 Complex

A. Noncompliance with Permit Effluent Limitations and Requirements

Analysis of water samples obtained at Outfall 125 during January 2011 revealed a noncompliance of the Y-12 National Security Complex NPDES Permit. A composite sample obtained on January 12, 2011, provided a cadmium concentration of 0.00186 mg/L, which is above the permit monthly average value of 0.001 mg/L. This value is the only cadmium value measured at Outfall l25 during January 2011. Outfall 125 typically receives water from the basement of Building 9204-1. The source is primarily spring water with some cooling waters and condensate. However, due to the failure of the pumping system, the basement area was flooded. Sampling and analysis of water contained in the flooded basement indicated the presence of cadmium. It is believed that cadmium is a contaminate remaining in the dirt areas of the basement.

Elevated readings of cadmium were also found in two composite samples taken at Outfall 200. The permit limits for cadmium at Outfall 200 are 0.001 mg/L for the monthly average and 0.025 mg/L for the daily maximum. The composite sample taken on December 5, 2010, indicated a cadmium level of 0.00118 mg/L, and a sample taken on January 19, 2011, showed cadmium to be 0.00104 mg/L. Outfall 200 is tied to a large drain system that includes most of the entire western half of the Y-12 Complex. In investigating potential causes for the two exceedances, it is believed that runoff from the newly cleaned Old Savage Yard (OSY) site, located upstream of Outfall 200, is a plausible cause. A stormwater sample taken from the OSY showed a concentration of cadmium of 0.072 mg/L.

B. Other Events and Observations

On January 26, 2011, verbal notification was made to personnel at the Tennessee Department of Environment and Conservation (TDEC), Division of Water Pollution Control (DWPC), of a possible leak in a cooling system that contains a mixture of 22 percent methanol in water. On January 27, 2011, verbal notification was made to TDEC DWPC personnel that water sampling at Outfall 135 indicated the presence of total organic carbon (TOC) caused by methanol. Location of the entry point of the leak into the storm drain system was located and isolated from reaching the outfall and East Fork Poplar Creek (EFPC) by using drain plugs. The water captured in the storm drain junction box was pumped to the sanitary sewer system for treatment by the city of Oak Ridge, or pumped to a tanker truck for on-site treatment. The situation was monitored by sampling TOC and methanol in the junction box and at the Outfall 135 location. Sampling and general observations of conditions on EFPC continued to indicate no adverse impact on the stream.

A second event was a fish kill that was discovered on July 21 in the upper portions of EFPC inside the boundaries of the Y-12 Complex, and TDEC was notified. Over a three-day period, a survey of the creek recovered a total of 650 minnow-sized fish (mostly stonerollers), crayfish, and clams. Surveys conducted July 23 identified living fish throughout the creek, and the overall impact to the creek was determined to be localized and insignificant. Follow-up checks of EFPC confirmed that aquatic life is doing well. A combination of a number of factors is believed to have caused the fish to die. These include stream conditions such as low flow, elevated water temperatures, and depressed dissolved oxygen as the result of flow management water being off and a discharge of cloudy water, which occurred on the afternoon of July 20. The discharge, which lasted about 1.5 hours, was from the storm drain system upstream of Outfall 200 and likely associated with discharges from the West End Mercury Area Storm Sewer Remediation Project. Analysis of the July 20 discharge indicated elevated levels of metals. Most

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notably was mercury measured at a concentration of 0.873 mg/L. Experts at the Aquatic Ecology Laboratory of the ORNL Environmental Sciences Division conducted external and internal examinations on stonerollers, the primary species involved in the incident. Examinations suggested respiratory distress. Gills were found to be frayed or damaged, causing a reduction in the exchange of respiratory gases. This factor, combined with low dissolved oxygen and relatively high water temperatures, could have resulted in respiratory failure.

D.2 East Tennessee Technology Park

On March 21, 2011, at approximately 3:00 p.m., an employee observed a discharge from sanitary sewer lift station K-1204-15 at the ETTP Central Neutralization Facility (CNF) entering into a nearby storm water inlet. This lift station collects sanitary sewage discharges from the CNF and from a break trailer located within the CNF area. Storm water from this area discharges to Mitchell Branch via storm water Outfall 170. This portion of the Outfall 170 storm water drainage network was flowing at the time the discharge into the catch basin was noticed. The discharge of sanitary sewage into the storm water outfalls is not permitted by ETTP NPDES Permit TN0002950. It was determined that this incident was a violation of the ETTP NPDES permit. A walkdown of Mitchell Branch was conducted, and no evidence of a fish kill or any other type of damage to the aquatic ecosystem of the stream was observed. No threat to human health or the environment occurred as a result of this discharge. No physical evidence of the discharge could be observed at the outfall.

On April 12, 2011, sampling subcontractor personnel were collecting routine NPDES permit compliance data at storm water Outfall 690. A pH reading of 9.6 standard units was measured at the designated NPDES monitoring location for that outfall. Sampling subcontract personnel then verified the calibration of the pH meter according to standard procedures. The pH meter calibration proved to be accurate. The pH reading of 9.6 standard units is outside the NPDES permitted range of 6.0–9.0 standard units for this outfall, which constitutes a noncompliance with the ETTP NPDES storm water permit. It is believed that storm water infiltrated through concrete debris and rubble that was generated during the demolition of the K-33 building. The pH of the storm water may have been elevated by the contact of the storm water with this material. No threat to human health or the environment occurred as a result of this incident.

D.3 Oak Ridge National Laboratory

Two missed compliance analyses (for pH and conductivity) were reported in January 2011 for the Steam Plant Wastewater Treatment Facility (SPWTF) (NPDES Outfall X02). The miss was due to an infrequent and irregular schedule of operation (the facility was only operated when an adequate batch of accumulated wastewaters necessitated treatment), which led to inadvertent oversight of communication protocol initiated by facility operators to compliance sampling technicians. Due to upgrades to the ORNL Steam Plant, the SPWTF is no longer needed and is expected to be taken out of service in 2012.

In March 2011, a construction contractor operating heavy equipment in a construction area accidentally breached an underground water supply pipe near the intersection of Fifth Street and Central Avenue. Water was released for approximately 35 minutes into Fifth Creek. Chlorine was measured at 1.1 mg/L, in excess of the maximum stream water quality standard of 0.019 mg/L. This event resulted in a small fish kill (nine stoneroller minnows were found) in both Fifth Creek and White Oak Creek. Aquatic biology staff concluded from their surveys that the detrimental impact on the fish was due to the water release but the toxicity was short lived.

Due to a sample-storage error at a contract laboratory that performs NPDES sample analyses for ORNL, the effluent Ammonia as N sample that was collected in August 2011 from Outfall X01 (ORNL Sewage Treatment Plant) was mistakenly stored for a time in an unrefrigerated area prior to analysis. This was reported as a technical nonconformance with the permit requirement that analyses be conducted per EPA protocols, which include refrigeration for ammonia samples. The sample in question was still analyzed, and the result fell within the expected range for ammonia at this facility based on historic data and was included in the calculation of the monthly average.

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Several instances have occurred at the ORNL Sewage Treatment Plant (STP) where, due to heavy rains that increase influent flow volume, pumping capacity operates at maximum, and as the facility was designed, the excess enters the disinfection contact chamber directly instead of first passing through the aeration chamber. Disinfection is operationally enhanced to treat the increased flow. In November 2011, during one such instance, the daily maximum concentration for *E. coli* bacteria measured greater than 5000 cfu/100 mL, which exceeded the NPDES permit limit of 941cfu/100 mL. ORNL is evaluating options to upgrade the existing STP system within the next few years.

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Appendix E. Radiation

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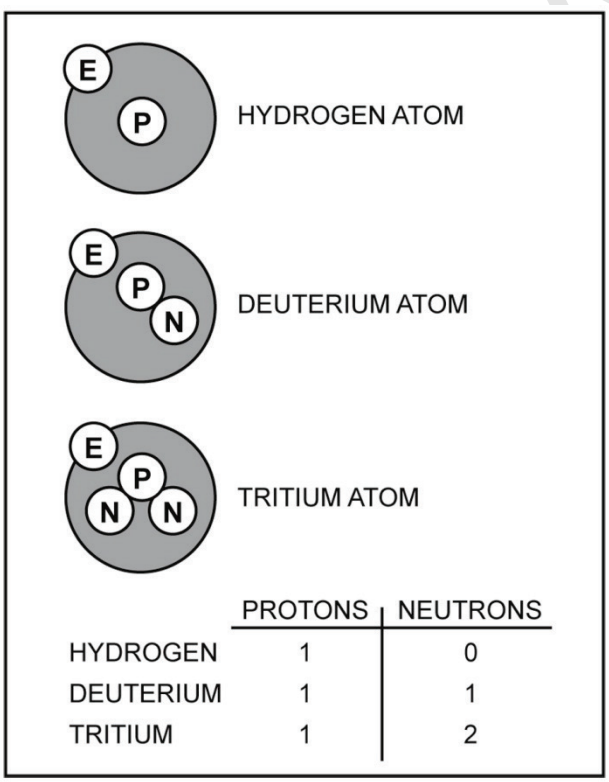
Appendix E. Radiation

This appendix presents basic facts about radiation. The information is intended to be a basis for understanding the potential doses associated with releases of radionuclides from the Oak Ridge Reservation (ORR), not as a comprehensive discussion of radiation and its effects on the environment and biological systems.

Radiation comes from natural and human-made sources. People are exposed to naturally occurring radiation constantly. For example, cosmic radiation; radon in air; potassium in food and water; and uranium, thorium, and radium in the earth's crust are all sources of radiation. The following discussion describes important aspects of radiation, including atoms and isotopes; types, sources, and pathways of radiation; radiation measurement; and dose information.

E.1 Atoms and Isotopes

All matter is made up of atoms. An atom is "a unit of matter consisting of a single nucleus surrounded by a number of electrons equal to the number of protons in the nucleus" (Alter 1986). The number of protons in the nucleus determines an element's atomic number or chemical identity. With the exception of hydrogen, the nucleus of each type of atom also contains at least one neutron. Unlike protons, the neutrons may vary in number among atoms of the same element. The number of neutrons and protons determines the atomic weight. Atoms of the same element that have different numbers of neutrons are called isotopes. In other words, isotopes have the same chemical properties but different atomic weights (Fig. E.1).



	PROTONS	NEUTRONS
HYDROGEN	1	0
DEUTERIUM	1	1
TRITIUM	1	2

Fig. E.1. The hydrogen atom and its isotopes.

For example, the element uranium has 92 protons. All isotopes of uranium, therefore, have 92 protons. However, each uranium isotope has a different number of neutrons:

- uranium-238 has 92 protons and 146 neutrons,
- uranium-235 has 92 protons and 143 neutrons, and
- uranium-234 has 92 protons and 142 neutrons.

Some isotopes are stable, or nonradioactive; some are radioactive. Radioactive isotopes are called "radionuclides" or "radioisotopes." In an attempt to become stable, radionuclides "throw away," or emit, rays or particles. This emission of rays and particles is known as radioactive decay. Each radioisotope has a "radioactive half-life," which is the average time that it takes for half of a specified number of atoms to decay. Half-lives can be very short (fractions of a second) or very long (millions of years), depending on the isotope (Table E.1).

Table E.1. Selected radionuclide half-lives

Radionuclide	Symbol	Half-life	Radionuclide	Symbol	Half-life
Americium-241	^{241}Am	432.2 years	Plutonium-238	^{238}Pu	87.75 years
Americium-243	^{243}Am	7.38E+3 years	Plutonium-239	^{239}Pu	2.41E+4 years
Antimony-125	^{125}Sb	2.77 years	Plutonium-240	^{240}Pu	6.569E+3 years
Argon-41	^{41}Ar	1.827 h	Potassium-40	^{40}K	1.2777E+9 years
Beryllium-7	^{7}Be	53.44 days	Promethium-147	^{147}Pm	2.6234 years
Californium-252	^{252}Cf	2.639 years	Protactinium-234*m*	^{234m}Pa	1.17 min
Carbon-14	^{14}C	5.730E+3 years	Radium-226	^{226}Ra	1.6E+3 years
Cerium-141	^{141}Ce	32.50 days	Radium-228	^{228}Ra	5.75 years
Cerium-143	^{143}Ce	1.38 days	Ruthenium-103	^{103}Ru	39.35 days
Cerium-144	^{144}Ce	284.3 days	Ruthenium-106	^{106}Ru	368.2 days
Cesium-134	^{134}Cs	2.062 years	Strontium-89	^{89}Sr	50.55 days
Cesium-137	^{137}Cs	30.17 years	Strontium-90	^{90}Sr	28.6 years
Cesium-138	^{138}Cs	32.2 min	Technetium-99	^{99}Tc	2.13E+5 years
Cobalt-58	^{58}Co	70.80 days	Thorium-228	^{228}Th	1.9132 years
Cobalt-60	^{60}Co	5.271 years	Thorium-230	^{230}Th	7.54E+4 years
Curium-242	^{242}Cm	163.2 days	Thorium-232	^{232}Th	1.405E+10 years
Curium-244	^{244}Cm	18.11 years	Thorium-234	^{234}Th	2.41E+1 day
Iodine-129	^{129}I	157E+7 years	Tritium	^{3}H	12.28 years
Iodine-131	^{131}I	8.04 days	Uranium-234	^{234}U	2.445E+5 years
Krypton-85	^{85}Kr	10.72 years	Uranium-235	^{235}U	7.038E+8 years
Krypton-88	^{88}Kr	2.84 h	Uranium-236	^{236}U	2.3415E+7 years
Manganese-54	^{54}Mn	312.7 days	Uranium-238	^{238}U	4.468E+9 years
Neptunium-237	^{237}Np	2.14E+6 days	Xenon-133	^{133}Xe	5.245E+9 years
Niobium-95	^{95}Nb	35.06 days	Xenon-135	^{135}Xe	9.11 h
Osmium-185	^{185}Os	93.6 days	Yttrium-90	^{90}Y	64.1 h
Phosphorus-32	^{32}P	14.29 days	Zirconium-95	^{95}Zr	64.02 days
Polonium-210	^{210}Po	138.378 days			

Source: DOE 1989. *Radioactive Decay Data Tables: A Handbook of Decay Data for Application to Radioactive Dosimetry and Radiological Assessments*, DOE/TIC-11026.

E.2 Radiation

Radiation, or radiant energy, is energy in the form of waves or particles moving through space. Visible light, heat, radio waves, and alpha particles are examples of radiation. When people feel warmth from sunlight, they are actually absorbing the radiant energy emitted by the sun.

Electromagnetic radiation is radiation in the form of electromagnetic waves. Examples include gamma rays, ultraviolet light, and radio waves. Particulate radiation is radiation in the form of particles. Examples include alpha and beta particles. Radiation also is characterized as ionizing or non-ionizing because of the way in which it interacts with matter.

E.2.1 Ionizing Radiation

Normally, an atom has an equal number of protons and electrons; however, atoms can lose or gain electrons in a process known as ionization. Some forms of radiation (called ionizing radiation) can ionize atoms by “knocking” electrons off atoms. Examples of ionizing radiation include alpha, beta, and gamma radiation.

Ionizing radiation is capable of changing the chemical state of matter and subsequently causing biological damage. By this mechanism, it is potentially harmful to human health.

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E.2.2 Non-ionizing Radiation

Non-ionizing radiation is described as a series of energy waves composed of oscillating electric and magnetic fields traveling at the speed of light. Non-ionizing radiation includes the spectrum of ultraviolet (UV), visible light, infrared (IR), microwave, radio frequency (RF), and extremely low frequency. Lasers commonly operate in the UV, visible, and IR frequencies. Microwave radiation is absorbed near the skin, while RF radiation may be absorbed throughout the body. At high enough intensities, both will damage tissue through heating. Excessive visible radiation can damage the eyes and skin (Department of Labor, OSHA Safety and Health Topics, www.OSHA.gov). However, in the discussion that follows, the term "radiation" is used to describe ionizing radiation.

E.3 Sources of Radiation

Radiation is everywhere. Most occurs naturally; a small percentage is human made. Naturally occurring radiation is known as background radiation.

E.3.1 Background Radiation

Many materials are naturally radioactive. In fact, this naturally occurring radiation is the major source of radiation in the environment. Although people have little control over the amount of background radiation to which they are exposed, this exposure must be put into perspective. Background radiation remains relatively constant over time and is present in the environment today much as it was hundreds of years ago.

Sources of background radiation include uranium in the earth, radon in the air, and potassium in food. Background radiation is categorized as cosmic, terrestrial, or internal, depending on its origin.

E.3.1.1 Cosmic Radiation

Energetically charged particles from outer space continuously hit the earth's atmosphere. These particles and the secondary particles and photons they create are called cosmic radiation. Because the atmosphere provides some shielding against cosmic radiation, the intensity of this radiation increases with altitude above sea level. For example, a person in Denver, Colorado, is exposed to more cosmic radiation than a person in New Orleans, Louisiana.

E.3.1.2 Terrestrial Radiation

Terrestrial radiation refers to radiation emitted from radioactive materials in the earth's rocks, soils, and minerals. Radon (Rn), radon progeny (the relatively short-lived decay products from the decay of the radon isotope ^{222}Rn), potassium (^{40}K), isotopes of thorium (Th), and isotopes of uranium (U) are the elements responsible for most terrestrial radiation.

E.3.1.3 Internal Radiation

Radionuclides in the environment enter the body with the air people breathe and the foods they eat. They also can enter through an open wound. Natural radionuclides that can be inhaled and ingested include isotopes of uranium and its progeny, especially radon (^{222}Rn) and its progeny, thoron (^{220}Rn) and its progeny, potassium (^{40}K), rubidium (^{87}Rb), and carbon (^{14}C). Radionuclides contained in the body are dominated by ^{40}K and ^{210}Po; others include ^{87}Rb and ^{14}C (NCRP 1987).

E.3.2 Human-Made Radiation

In addition to background radiation, there are human-made sources of radiation to which most people are exposed. Examples include consumer products, medical sources, fallout from atmospheric atomic bomb tests, and industrial by-products. No atmospheric testing of atomic weapons has occurred since 1980 (NCRP 1987).

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E.3.2.1 Consumer Products

Some consumer products are sources of radiation. The radiation in some of these products, such as smoke detectors, radioluminous products, and airport X-ray baggage inspection systems, is essential to the performance of the device. In other products, such as tobacco products and building materials, the radiation occurs incidentally to the product's function (NCRP 1987, NCRP 2009).

E.3.2.2 Medical Sources

Radiation is an important tool of diagnostic medicine and treatment and is the main source of exposure to the public from human-made radiation. Exposure is deliberate and directly beneficial to the patients exposed. In general, medical exposures from diagnostic or therapeutic X-rays result from beams directed to specific areas of the body. Thus, all body organs generally are not irradiated uniformly. Nuclear medicine examinations and treatments involve the internal administration of radioactive compounds, or radiopharmaceuticals, by injection, inhalation, consumption, or insertion. Even then, radionuclides are not distributed uniformly throughout the body. Radiation and radioactive materials also are used in the preparation of medical instruments, including the sterilization of heat-sensitive products such as plastic heart valves.

E.3.2.3 Other Sources

Other sources of radiation include emissions of radioactive materials from nuclear facilities such as uranium mines, fuel-processing plants, and nuclear power plants; transportation of radioactive materials; and emissions from mineral-extraction facilities.

E.4 Pathways of Radionuclides

People can be exposed to radionuclides in the environment through a number of routes (Fig. E.2). Potential routes for internal and/or external exposure are referred to as pathways. For example, radionuclides in the air could fall on grass in a pasture. The grass then could be eaten by cows, and the radionuclides deposited on the grass would show up in the cow's milk. People drinking the milk would be exposed to this radiation. People could also inhale the airborne radionuclides. Similarly, radionuclides in water could be ingested by fish, and people eating the fish would also ingest the radionuclides in the fish tissue. People swimming in the water would be exposed also.

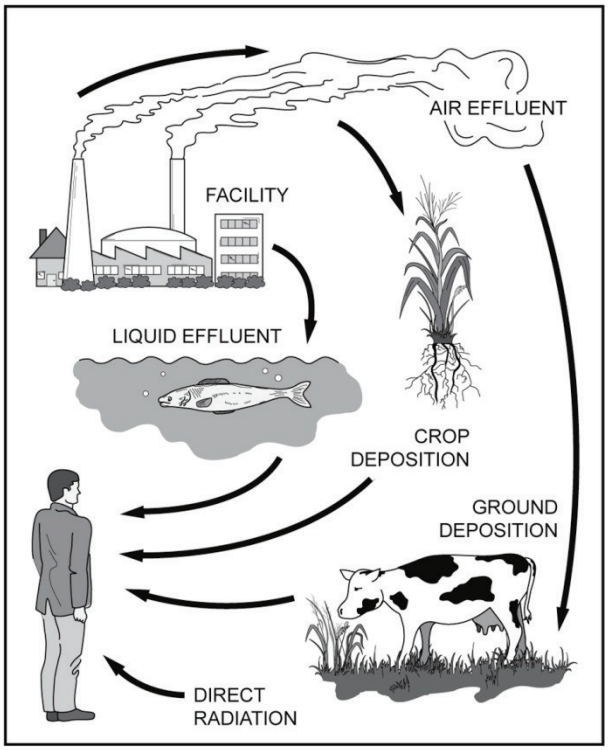

Fig. E.2. Examples of radiation pathways.

E.5 Measuring Radiation

To determine the possible effects of radiation on the health of the environment and people, the radiation must be measured. More precisely, its potential to cause damage must be ascertained.

E.5.1 Activity

When we measure the amount of radiation in the environment, what is actually being measured is the rate of radioactive decay, or activity. The rate of decay varies widely among the various radioisotopes.

For that reason, 1 g of a radioactive substance may contain the same amount of activity as several tons of another material. This activity is expressed in a unit of measure known as a curie (Ci). More specifically, 1 Ci equals 3.7×10^{10} (37,000,000,000) atomic disintegrations per second (dps). In the International System of Units, 1 dps equals 1 becquerel (Bq).

E.5.2 Absorbed Dose

The total amount of energy absorbed per unit mass of the exposed material as a result of exposure to radiation is expressed in a unit of measure known as a rad. It is the effect of the absorbed energy (the biological damage that it causes) that is important, not the actual amount. In the International System of Units, 100 rad equals 1 gray (Gy).

E.5.3 Effective Dose

The measure of potential biological damage to the body caused by exposure to and subsequent absorption of radiation is expressed in a unit of measure known as a rem. For radiation protection purposes, 1 rem of any type of radiation has the same total damaging effect. Because a rem represents a fairly large equivalent dose, it is usually expressed as millirem (mrem), which is 1/1000 of a rem. In the International System of Units, 1 sievert (Sv) equals 100 rem; 1 millisievert (mSv) equals 100 mrem. The effective dose (ED) is the weighted sum of equivalent dose over specified tissues or organs. The ED is based on tissue-weighting factors for 12 specific tissues or organs plus a weight factor for the remainder organs and tissues. In addition, the ED is based on the latest lung model, gastrointestinal absorption fractions, and biokinetic models used for selected elements. Specific types of EDs are defined as follows:

- committed ED—the weighted sum of the committed ED in specified tissues in the human body during the 50-year period following intake; and
- collective ED—the product of the mean ED for a population and the number of persons in the population.

E.5.4 Dose Determination

Determining dose is an involved process in which complex mathematical equations based on several factors, including the type of radiation, rate of exposure, weather conditions, and typical diet, are used. Basically, radioactive decay, or activity, generates radiant energy. People absorb some of the energy to which they are exposed. The effect of this absorbed energy is responsible for an individual's dose. Whether radiation is natural or human-made, it has the same effect on people.

Many terms are used to report dose. The terms take several factors into account, including the amount of radiation absorbed, the organ absorbing the radiation, and the effect of the radiation over a 50-year period. The term "dose" in this report means the committed ED, which is the ED that will be received during a specified time (50 years) from radionuclides taken into the body in the current year, and the ED due to exposure during the year to penetrating radiation from sources external to the body.

E.5.5 Dose Coefficient

A dose coefficient is defined as the ED received from exposure to a unit quantity of a radionuclide by way of a specific exposure pathway. There are two types of dose coefficients. One type gives the committed ED (rem) resulting from intake (by inhalation and ingestion) of a unit activity (1.0 µCi) of a radionuclide. The second gives the ED rate (millirem per year) per unit activity (1.0 µCi) of a radionuclide in a unit (cubic or square centimeters) of an environmental compartment (air volume or ground surface). In 2011 the Department of Energy replaced DOE O 5400.5 with DOE O 458.1. As part of this revision, dose coefficients were derived for a hypothetical Reference Person. The Reference Person is an aggregate of individuals in the US population (DOE 2011). The Reference Person effective dose coefficients are used for the ingestion pathway. For the airborne pathway, dose coefficients from

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Federal Guidance Report No. 13 were used, since these dose coefficients are used in the EPA-approved model CAP88PC, version 3 (EPA 1999).

E.5.6 Comparison of Dose Levels

Figure E.3 gives the 2006 percent contributions of various sources of exposure to total collective dose for the US population. As shown, the major sources are radon and thoron (37%), computed tomography (24%), and nuclear medicine (12%) (NCRP 2009). Consumer, occupational, and industrial sources contribute about 2% to the total US collective dose. This information is intended to help the reader become familiar with a range of doses that various individuals may receive.

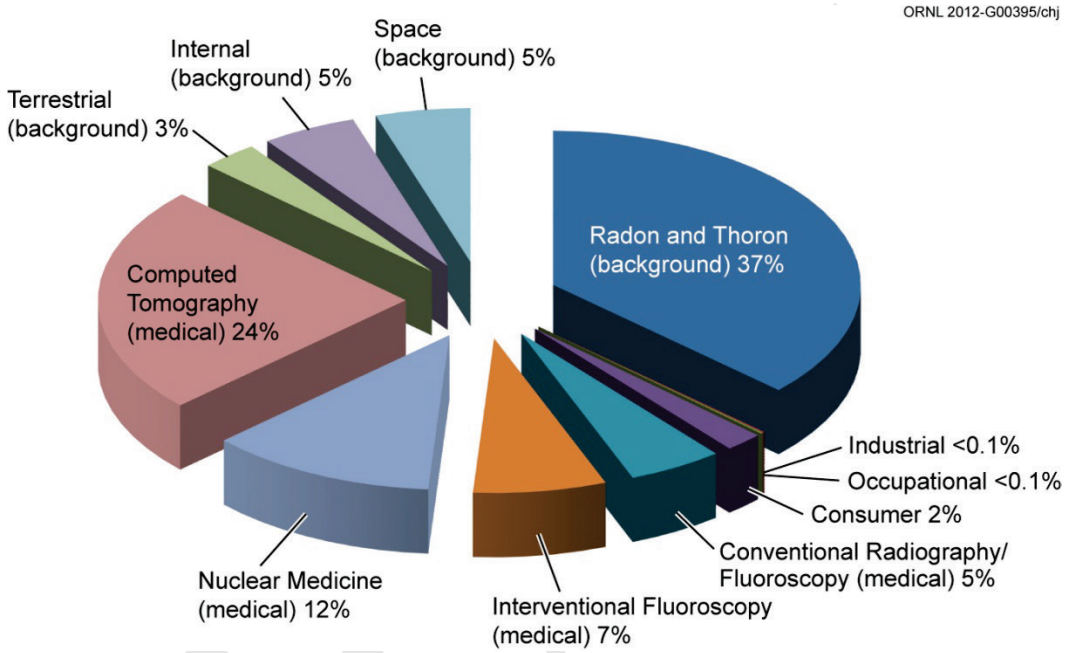

Fig. E.3. All exposure categories for collective effective dose (percent) for 2006.

E.5.7 Dose from Cosmic Radiation

The average annual dose equivalent to people in the United States from cosmic radiation is about 33 mrem (0.33 mSv) (NCRP 2009). The average dose equivalent caused by cosmic radiation in Tennessee is about 45 mrem per year (0.45 mSv per year) (Tsakeres 1980). When shielding and the time spent indoors are considered, the dose for the surrounding population is reduced to 80%, or about 36 mrem (0.36 mSv) per year.

E.5.8 Dose from Terrestrial Radiation

The average annual dose from terrestrial gamma radiation is about 21 mrem (0.21 mSv) in the United States but varies geographically across the country (NCRP 2009). Typical reported values are about 16 mrem (0.16 mSv) on the Atlantic and Gulf coastal plains and about 63 mrem (0.63 mSv) on the eastern slopes of the Rocky Mountains.

E.5.9 Dose from Internal Radiation

The major contributors to the annual dose equivalent for internal radionuclides are the short-lived decay products of radon, which contribute an average dose of about 228 mrem (2.28 mSv) per year. This dose estimate is based on an average radon concentration of about 1 pCi/L (0.037 Bq/L) (NCRP 2009).

The average dose from other internal radionuclides is about 29 mrem (0.29 mSv) per year, which is predominantly attributed to the naturally occurring radioactive isotope of potassium, ^{40}K. The concentration of radioactive potassium in human tissues is similar in all parts of the world (NCRP 2009).

E.5.10 Dose from Consumer Products and Activities

The US average annual dose to an individual from consumer products and activities is about 13 mrem (0.13 mSv), ranging between 0.1 and 40 mrem (0.001 and 0.4 mSv). Cigarette smoking accounts for about 35% of this dose. Other important sources are building materials (27%), commercial air travel (26%), mining and agriculture (6%), miscellaneous consumer-oriented products (3%), combustion of fossil fuels (2%), highway and road construction materials (0.6%), and glass and ceramics (<0.003%). Television and video, sewage sludge and ash, and self-illuminating signs all contribute negligible doses (NCRP 2009).

E.5.11 Dose from Medical Sources

Nuclear medicine examinations, which involve internal administration of radiopharmaceuticals, generally account for the largest portion of dose from human-made sources. However, the radionuclides used for specific tests are not distributed uniformly throughout the body. In these cases, the concept of ED, which relates the significance of exposures of organs or body parts to the effect on the entire body, is useful in making comparisons. The average annual ED from medical examinations is 300 mrem (3 mSv), including 147 mrem (1.47 mSv) from computed tomography scans, 77 mrem (0.77 mSv) from nuclear medicine procedures, 43 mrem (0.43 mSv) from interventional fluoroscopy, and 33 mrem (0.33 mSv) from conventional radiography and fluoroscopy (NCRP 2009). Not everyone receives such exams each year.

E.5.12 Doses from Other Sources

A few additional sources of radiation contribute minor doses to individuals in the United States. The dose to the general public from nuclear fuel cycle facilities, such as uranium mines, mills, fuel-processing plants, nuclear power plants, and transportation routes, has been estimated at less than 1 mrem (0.01 mSv) per year (NCRP 1987).

Small doses to individuals occur as a result of radioactive fallout from atmospheric atomic bomb tests, emissions of radioactive materials from nuclear facilities, emissions from certain mineral extraction facilities, and transportation of radioactive materials. The combination of these sources contributes less than 1 mrem (0.01 mSv) per year to an individual's average dose (NCRP 1987).

E.6 Water Pathway Dose Method

People can be exposed to radionuclides in the environment through a number of routes (Fig. E.2). Potential routes for internal and/or external exposure are referred to as exposure pathways. Several such pathways exist for exposures of humans to radionuclides in water. People may directly ingest (drink) the water. They may eat fish that were caught from the water that contain radionuclides taken in from the water. Also, people may swim in or boat on the water or use a shoreline that has absorbed radionuclides from the water. The following sections discuss the methodologies used to calculate potential radiological impacts to persons who drink water; eat fish; and swim, boat, and use the shoreline at various locations along the Clinch and Tennessee Rivers. The results of these calculations are summarized in Sect. 7.1.2.2.

Radionuclides discharged to surface waters from ORR enter the Tennessee River system by way of the Clinch River and various feeder streams (see Sect. 1.3.4 for the surface water setting of ORR). Discharges from the Y-12 Complex enter the Clinch River via Bear Creek and East Fork Poplar Creek, both of which enter Poplar Creek before it enters the Clinch River, and by discharges from Rogers Quarry into McCoy Branch and then into Melton Hill Lake. Discharges from ORNL enter the Clinch River via White Oak Creek and Melton Hill Lake via some small drainage creeks. Discharges from ETTP enter the Clinch River either directly or via Poplar Creek. For convenience, and to correspond to water sampling

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locations, surface waters around and below ORR are divided into seven segments (called water bodies in this appendix):

- Melton Hill Lake above all possible ORR inputs,
- Melton Hill Lake,
- Upper Clinch River from Melton Hill Dam to confluence with Poplar Creek,
- Lower Clinch River (from confluence with Poplar Creek to confluence with the Tennessee River),
- Upper Watts Bar Lake (from around the confluence with the Clinch River to below Kingston),
- Lower System (remainder of Watts Bar Lake and Chicamauga Lake), and
- Poplar Creek, including the confluence of East Fork Poplar Creek.

Since East Fork Poplar Creek is posted against water use, dose estimates for such uses are not reported.

The LADTAP computer code, Excel version (LADTAP XL; Hamby 1991), is used to calculate individual and population doses via waterborne exposure pathways. All dose calculations require definition of radionuclide concentrations in the medium of interest (water, fish, and shoreline) in the water body of interest.

Two methods, determined by the type of data used, are used to estimate potential radiation doses to the public. The first method uses radionuclide concentrations in the medium of interest (i.e., in water and fish) that were determined by laboratory analyses of actual water and fish samples (see Sects. 6.4 and 6.6). The second method estimates radionuclide concentrations in water and fish that were calculated from measured radionuclide discharges and known or estimated stream flows.

The advantage of the first method is the use of radionuclide concentrations actually measured in water and fish; disadvantages are the inclusion of naturally occurring radionuclides, especially in gross alpha- and beta-activity measurements, the possibility that some radionuclides of ORR origin might be present in quantities too low to be measured, and the possibility that the presence of some radionuclides might be misstated (e.g., present in a quantity below the detection limit). The advantages of the second method are that most radionuclides discharged from ORR will be quantified and that naturally occurring radionuclides will not be considered or will be accounted for separately; the disadvantage is the lack of complete river, discharge, and stream flow data. Both methods use models to estimate the concentrations of the radionuclides in water and fish, except at locations (water bodies) where actual measurements are made. Using the two methods should allow the potential radiation doses to be bounded.

For some water bodies, radionuclide concentrations are measured directly. These concentrations are used to calculate concentrations in fish and shoreline, as described below. Concentrations in the water body downstream of the measured water body are obtained by multiplying the measured water body concentrations by the ratio of the measured water body flow (liters per year) to the downstream water body flow (liters per year); in essence, the concentrations in the upstream water body are diluted by any additional water input to the downstream water body. This dilution calculation continues for all other downstream water bodies. Note that the dilution from Upper Watts Bar Lake to the Lower system (Lower Watts Bar Lake) is considered to be negligible.

For other water bodies, data are available on the activities of radionuclides discharged to a water body. These data may be in the form of (1) total activities discharged per year (curies per year) or (2) activities per unit volume of water (curies per liter) plus the total volume of water discharged per year (liters per year). Radionuclide concentrations in the receiving water body are calculated simply by dividing the measured discharge activities (curies per year) by the total annual flow of the receiving water body (liters per year). The process for calculating concentrations in downstream water bodies is the same as that described in the previous paragraph. The discharge flow rate is usually negligible with respect to the receiving water body flow rate.

Equations used to estimate water pathway doses from radionuclide concentrations in water are given in the following sections.

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E.6.1 Drinking Water

Several water treatment plants along the Clinch and Tennessee river systems could be affected by discharges from ORR. Because plant radionuclide concentration data are not available for these plants, the dose estimates given below likely are high because they are based on concentrations of radionuclides in water before it enters the water treatment plant. Most water treatment plants use flocculation/ sedimentation processes. The flocculant process produces a precipitate that helps to remove solids and also adsorbs dissolved metals. Many radionuclides would be adsorbed by the solids. However, the fraction removed depends on the radionuclide and initial concentration. For purposes of assessment, it was assumed that maximally exposed individuals drink 730 L/year of water and that the average person drinks 370 L/year.

Table E.2 is a summary of potential EDs from identified waterborne radionuclides around ORR and shows the variation in dose based on method used to estimate dose. The ED from ingestion of water is given by

$$D_{E,i,drink} = U_{drink} * C_{w,i} * DC_{i,ing} * EXP(-\lambda_{r,i} * t_{drink}) ,$$

where

$D_{E,i,drink}$	=	ED due to drinking water containing nuclide *i* (mrem/year),
U_{drink}	=	water consumption rate (L/year),
$C_{w,i}$	=	concentration of nuclide *i* in water (μCi/L),
$DC_{i,ing}$	=	dose coefficient for ingestion of nuclide *i* (mrem/μCi),
$\lambda_{r,i}$	=	radioactive decay constant for nuclide *i* (I/d), and
t_{drink}	=	time between entry of nuclide into plant and consumption (assumed 1 day).

E.6.2 Eating Fish

Fishing is quite common on the Clinch and Tennessee river systems. For purposes of assessment, it was assumed that avid fish consumers eat 21 kg/year of fish and that the average person consumes 6.9 kg/year. EDs were calculated from measured radionuclide contents in fish (see Sect. 6.6), measured concentrations of radionuclides in water, and calculated concentrations in water. The ED from consumption of fish containing nuclide *i* is given by

$$D_{E,i,fish} = U_{fish} * C_{w,i} * DC_{i,ing} * B_{i,fish} * EXP(-\lambda_{r,i} * t_{fish}) ,$$

where

$D_{E,i,fish}$	=	ED due to eating fish containing nuclide *i* (mrem/year),
U_{fish}	=	fish consumption rate (kg/year),
$C_{w,i}$	=	concentration of nuclide *i* in water (μCi/L),
$DC_{i,ing}$	=	dose coefficient for ingestion of nuclide *i* (mrem/μCi),
$B_{i,fish}$	=	bioaccumulation factor (L/kg),
$\lambda_{r,i}$	=	radioactive decay constant for nuclide *i* (I/d), and
t_{fish}	=	time between harvest and consumption (assumed 10 days).

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Table E.2. Summary of annual maximum individual effective dose equivalents from waterborne radionuclides (mrem)[a]

Type of sample	Drinking water	Eating fish	Other uses	Total of highest
Melton Hill Lake above ORR inputs, CRK 66				
Fish[b]		0.2		0.2
Water[c]	0.0	0.0	0.0	0.0
Maximum	0.0	0.2	0.0	0.2
Melton Hill Lake, CRK 58				
Water[c]	4E-09	<1E-12	5E-04	5E-4
Discharge[d]	2E-08	7E-08	2E-08	1E-07
Maximum	2E-08	7E-08	5E-04	5E-04
Upper Clinch River, CRK 23, Gallaher Water Plant, CRK 32				
Fish[b]		0.3		0.3
Water[c]	0.006	2E-04	2E-05	0.006
Discharge[d]	4E-05	9E-5	1E-05	2E-04
Maximum	0.006	0.3	2E-05	0.3
Lower Clinch River, CRK 16				
Fish[b]				
Water[c]	NA[e]	0.02	5E-05	0.02
Discharge[d]	NA[e]	1E-04	1E-05	1E-04
Maximum	NA[e]	0.02	5E-05	0.02
Upper Watts Bar Lake, Kingston Municipal Water Plant				
Water[c]	0.02	0.004	2E-05	0.02
Discharge[d]	3E-05	3E-05	5E-06	7E-05
Maximum	0.02	0.004	2E-05	0.02
Lower System (Lower Watts Bar Lake and Chickamauga Lake)				
Water[c]	0.01	0.004	1E-05	0.02
Discharge[d]	3E-05	3E-05	3E-06	5E-05
Maximum	0.01	0.004	1E-05	0.02
Lower East Fork Poplar Creek and Poplar Creek				
Water[c]	NA[e]	0.08	2E-04	0.08
Discharge[d]	NA[e]	0.4	0.02	0.4
Maximum	NA[e]	0.4	0.02	0.4

[a]1 mrem = 0.01 mSv.
[b]Doses based on measured radionuclide concentrations in fish tissue.
[c]Doses based on measured radionuclide concentrations in water.
[d]Doses based on measured discharges of radionuclides from on-site outfalls.
[e]Not at drinking water supply locations.
Abbreviations
CRK = Clinch River kilometer
ORR = Oak Ridge Reservation

Fish samples are collected from Melton Hill Lake above all ORR inputs [Clinch River kilometer (CRK) 70], from the upper part of the Clinch River (CRK 32), and from the Clinch River below all ORR inputs (CRK 16). Unidentified beta and alpha activities are often detected in many of the fish samples. Excess beta and alpha activities are estimated by subtracting activities of identified beta- and alpha-particle-emitting radionuclides from the corresponding unidentified activities. The excess unidentified beta and alpha activities are assumed to be from the naturally occurring radionuclides ^{234}Th and ^{226}Ra.

E.6.3 Other Uses

Other uses of the ORR area waterways include swimming or wading, boating, and use of the shoreline. A highly exposed "other user" was assumed to swim or wade for 30 h/year, boat for 63 h/year, and use the shoreline for 60 h/year. Measured and calculated concentrations of radionuclides in water and LADTAP XL were used to estimate potential EDs from these activities. The ED from swimming in water containing nuclide *i* (except tritium) is given by

$$D_{E,i,swim} = 0.142 * C_{w,i} * U_{swim} * DC_{i,WS} ,$$

where

$D_{E,i,swim}$	=	ED from swimming in water containing nuclide *i* (mrem/year),
0.142	=	unit conversion factor (1,000 L/m^3 divided by 8,760 h/year),
U_{swim}	=	time spent swimming (h/year),
$C_{w,i}$	=	concentration of nuclide *i* in water (µCi/L), and
$DC_{i,WS}$	=	dose conversion factor for submersion in water containing nuclide *i* (mrem-m^3/year-µCi).

Complete submersion is assumed while swimming. For tritium, the swimming dose equation is given by

$$D_{E,T,swim} = C_{W,T} * U_{swim} * I_T * DC_{T,ing} ,$$

where

$D_{E,T,swim}$	=	ED from swimming in water containing tritium (mrem/year),
U_{swim}	=	time spent swimming (h/year),
$C_{W,T}$	=	concentration of tritium in water (µCi/L),
I_T	=	absorption factor for tritium via whole body immersion in water (= 0.035 L/h), and
$DC_{T,ing}$	=	dose coefficient for ingestion of tritium (mrem/µCi).

The ED from boating on water containing nuclide *i* (except tritium) is given by

$$D_{E,i,boat} = 0.5 * (0.142 * C_{w,i} * U_{boat} * DC_{i,WS}) ,$$

where

$D_{E,i,boat}$	=	ED from boating on water containing nuclide *i* (mrem/year),
0.5	=	correction factor,
0.142	=	unit conversion factor (1,000 L/m^3 divided by 8,760 h/year),
U_{boat}	=	time spent boating (h/year),
$C_{w,i}$	=	concentration of nuclide *i* in water (µCi/L), and
$DC_{i,WS}$	=	dose coefficient for submersion in water containing nuclide *i* [mrem-m^3/year-µCi].

The 0.5 correction factor arises from the assumption used in LADTAP XL that doses per unit from boating equal one-half the doses from swimming. Any shielding by the boat's hull is ignored. The dose attributable to any tritium, which emits only very weak beta radiation, in the water is assumed to be 0.

The ED from using a shoreline containing nuclide *i* is given by

$$D_{E,i,shore} = C_{i,shore} * U_{shore} * (G_{shore} / 8760) * DC_{i,soil} ,$$

where

$D_{E,i,shore}$	=	ED due to use of shoreline containing nuclide *i* (mrem/year),
$C_{i,shore}$	=	annual average concentration of nuclide *i* in shoreline soil (µCi/m^2),
U_{shore}	=	duration of time spent on the shoreline (h/year),
G_{shore}	=	unitless shoreline width correction factor (0.2 for rivers),

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8760	=	number of hours in a year (h/year), and
$DC_{i,soil}$	=	dose conversion factor for infinitely thick soil containing nuclide (mrem-m^2/μCi-year).

The annual average concentration of nuclide *i* in shoreline soil is obtained by

$$C_{i,shore} = C_{W,i} * F_{i,W\text{-}S} * T_{1/2,i} * (1 - \mathrm{EXP}[-\lambda_{r,i} * 365 * t_{S\text{-}W}]) ,$$

where

$C_{W,i}$	=	annual average concentration of nuclide *i* in water (μCi/L),
$F_{i,W\text{-}S}$	=	water-to-sediment transfer coefficient nuclide *i* (= 100 L/m^2-day),
$T_{1/2,i}$	=	radioactive half-life of nuclide *i* (d),
$\lambda_{r,i}$	=	radioactive decay constant for nuclide *i* (1/d),
$t_{S\text{-}W}$	=	time over which shoreline soil is exposed to water containing nuclide *i* (= 50 years), and
365	=	number of days in a year (d/year).

It is assumed that the buildup and decay of nuclides in shoreline soil have occurred at the current year's rates for the past 50 years.

When compared with EDs from drinking water and eating fish from the same waters, the EDs from these other uses are relatively small. Refer to Table E.2 for a summary of potential EDs from identified waterborne radionuclides around ORR and the variation in dose based on the method used to estimate dose.

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Appendix F. Chemicals

Appendix F. 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 possible releases from the Oak Ridge Reservation (ORR), 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 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. Even some of the foods we eat contain natural toxins. Aflatoxin is a known toxin found in peanuts, and cyanide is found in apple seeds. 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.

F.2 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, 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 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 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.

F.3 Definitions

F.3.1 Toxicity

Chemicals have varying types of effects. Chemical health effects are divided into two broad categories: adverse or systemic effects (noncarcinogens) and cancer (carcinogens). Sometimes a chemical can have both a noncarcinogenic and a carcinogenic effect. The toxic effect can be acute (short-term severe health effect) or chronic (longer-term persistent health effect). Toxicity is often evident in a shorter length of time than the carcinogenic effect. The potential health effects of noncarcinogens range from skin irritation to fatality. 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 the form of food, water, and sometimes medications. Even those chemicals 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.

F.3.2 Dose Terms for Noncarcinogens

F.3.2.1 Reference Dose

A reference dose is an estimate 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 of chemical per kilogram of an adult's body weight per day (mg/kg-day). These values are given in Table F.1.

Values for reference doses 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. Uncertainty factors are typically used in deriving reference doses. Uncertainty adjustments may be made if animal toxicity data are extrapolated to humans to account for human sensitivity, extrapolated from subchronic to chronic no-observed-adverse-effect levels, extrapolated from lowest-observed-adverse-effect levels to no-observed-adverse-effect levels, and to account for database deficiencies. The use of uncertainty factors in deriving reference doses is thought to protect the sensitive human populations. The Environmental Protection Agency (EPA) maintains the Integrated Risk Information System database, which contains verified reference doses and up-to-date health risk and EPA regulatory information for numerous chemicals.

F.3.2.2 Primary Maximum Contaminant Levels

For chemicals for which reference doses are not available in the Integrated Risk Information System, national primary drinking water maximum contaminant levels, expressed in milligrams of chemical per liter of drinking water, are converted to reference dose 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-day). These values are given in Table F.1.

F.3.3 Dose Term for Carcinogens

F.3.3.1 Slope Factor

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 potential carcinogen. Units are expressed as risk per dose (mg/kg-day). These values are given in Table F.1.

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. Acceptable risk levels for carcinogens range from 10^{-4} (risk of developing cancer over a human lifetime of 1 in 10,000) to 10^{-6} (risk of developing cancer over a human lifetime is 1 in 1,000,000). In other words, a certain chemical concentration in food or water could cause a risk of one additional cancer for every 10,000 (10^{-4}) to 1,000,000 (10^{-6}) exposed persons, respectively.

Table F.1. Chemical reference doses and slope factors used in drinking water and fish intake analysis

Elements			Compounds		
Chemical	**Factor**	**Reference[a]**	**Chemical**	**Factor**	**Reference[a]**
Antimony	4.0E–04	RfD	Selenium	5.0E–03	RfD
Arsenic	3.0E–04	RfD	Silver	5.0E–03	RfD
	1.5E+00	SF	Strontium	6.0E–01	RfD
Barium	2.0E–01	RfD	Thallium	5.7E–05	*d,g*
Beryllium	2.0E–03	RfD	Uranium [h]	3.0E–03	RfD
Boron	2.0E–01	RfD	Vanadium[i]	9.0E–03	RfD
Cadmium	5.0E–04	RfD	Zinc	3.0E–01	RfD
Chromium(VI)	3.0E–03	RfD	Aroclor-1016	7.0E–05	RfD
Lead	1.4E–04	*d,e*	Aroclor-1254	2.0E-05	RfD
Manganese	1.4E–01	RfD	Aroclor-1260	2.0E–05	RfD[b]
Mercury	3.0E–04	RfD[f]	PCBs (mixed)	2.0E+00	SF[c]
Molybdenum	5.0E–03	RfD			
Nickel [h]	2.0E–02	RfD			

[a]RfD, reference dose (mg/kg-day); SF, slope factor (risk per mg/kg-day). Values obtained from US EPA, Integrated Risk Information System.

[b]The RfD for Aroclor-1254 is also used for Aroclor-1260.

[c]The cancer potency of PCB mixtures is determined using a three-tiered approach. This value is the upper bound slope factor for the High Risk and Persistence Tier.

[d]The water quality criteria (WQC) are given in units of micrograms per liter. To convert the concentration to an RfD (mg/kg-day), each was divided by 1000 (to convert to milligrams per liter), multiplied by the consumption rate (2 L/day), and divided by the mass of a reference man, 70 kg.

[e]This value is based on the 2008 Tennessee WQC (TDEC 2008) for lead for domestic water supplies which reflects the maximum contaminant level value (5 µg/L).

[f]An EPA-approved oral chronic RfD, SF, or other guideline for elemental mercury in water or aquatic organisms is not available. Most guidelines refer to "recoverable" or inorganic mercury. RfD values exist for several inorganic mercury salts. The EPA oral RfD for soluble mercuric chloride ($HgCl_2$) is 3.0×10^{-4} mg/kg-day.

[g]This value is based on the 2008 Tennessee WQC (TDEC 2008) for thallium for domestic water supplies, which reflects the maximum contaminant level value (2 µg/L).

[h]Soluble salts.

[i]Vanadium pentoxide.

F.4 Measuring Chemicals

Environmental samples are collected in areas surrounding the ORR and are analyzed for those chemical constituents 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 sensitive; however, there are limits below which they cannot detect chemicals of interest. Concentrations detected below the reported analytical detection limits of the instruments are recorded by the laboratory as estimated values, which have a greater uncertainty than those concentrations detected above the detection limits of the instruments. Health effect calculations that use these estimated values are indicated by the less than symbol (<), which indicates that the value for a parameter was not quantifiable at the analytical detection limit.

F.5 Risk Assessment Methodology

F.5.1 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. Clinch River surface water and fish samples are analyzed to estimate chemical contaminant concentrations. It is assumed that individuals drink 2 L of water per day directly from the river, which amounts to 730 L per year, and that they eat 0.06 kg of fish per day from the river (21 kg per year). Estimated daily intakes or estimated doses to the public are calculated by multiplying measured (statistically significant) concentrations in water by 2 L or those in fish by 0.06 kg. 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.

F.5.2 Dose Estimate

When the contaminant oral daily intake via exposure pathways has been estimated, the dose is determined. For chemicals, the dose to humans is measured as milligrams per kilogram-day (mg/kg-day). In this case, the "kilogram" refers to the body weight of an adult individual. When a chemical dose is calculated, 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."

The daily intake or dose from ingestion of water is estimated by the following equation:

$$I = \frac{CW \times IR \times EF \times ED}{BW \times AT},$$

where

I	=	intake (mg/kg-day),
CW	=	concentration in water (mg/L),
IR	=	ingestion rate (2 L/day),
EF	=	exposure frequency (350 days/year),
ED	=	exposure duration (30 years),
BW	=	body weight (70 kg),
AT	=	averaging time for noncarcinogens (365 days/year × ED) or for carcinogens (365 days/year ×70 years).

The daily intake rate or dose from consumption of fish obtained by recreational anglers is estimated by the following equation:

$$I = \frac{CW \times IR \times EF \times ED}{BW \times AT},$$

where

I	=	intake (mg/kg-day),
CW	=	concentration in fish tissue wet weight (mg/kg),
IR	=	ingestion rate (0.06 kg/day),
EF	=	exposure frequency (350 days/year),
ED	=	exposure duration (30 years),
BW	=	body weight (70 kg),
AT	=	averaging time for noncarcinogens (365 days/year × ED) or for carcinogens (365 days/year × 70 years).

F.5.3 Calculation Methodology

Current risk assessment methodologies use the term "hazard quotient" to evaluate noncarcinogenic health effects. Because intakes are calculated in milligrams per kilogram per day in the hazard quotient methodology, they are expressed in terms of dose. The hazard quotient is a ratio that compares the estimated exposure dose or intake (I) to the reference dose as follows:

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

where

HQ	=	hazard quotient (unitless),
I	=	estimated intake or dose (mg/kg-day),
RfD	=	reference dose (mg/kg-day).

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

To evaluate carcinogenic risk, slope factors are used instead of reference doses. In previous reports, the estimated dose from ingesting water or fish from rivers and streams surrounding the ORR is compared to the chronic daily intake I (10^{-5}) derived from assuming a human lifetime risk of developing cancer of 10^{-5} (1 in 100,000). However, as in typical human health risk assessments, risk levels are derived as follows:

$$R = I \times SF,$$

where

R	=	risk,
I	=	estimated intake or (mg/kg-day),
SF	=	slope factor, oral (risk per mg/kg-day).

To estimate the risk of inducing cancers from ingestion of water and fish, the estimated dose or intake (I) is multiplied by the slope factor (risk per mg/kg-day). As mentioned earlier, acceptable risk levels for carcinogens range from 10^{-4} (risk of developing cancer over a human lifetime of 1 in 10,000) to 10^{-6} (risk of developing cancer over a human lifetime is 1 in 1,000,000). The tilde (~) indicates that estimated values were used in estimating the average concentrations of a chemical.

F.6 References

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