
USEFUL INFORMATION

This section provides background information that may be useful to the reader in understanding and interpreting the results presented in this Annual Site Environmental Report (ASER). First, it presents brief summaries of concepts pertaining to radiation and radioactivity, including:

- radioactive decay;
- types of ionizing radiation;
- measurement of radioactivity;
- measurement of dose;
- background radiation; and
- potential health effects of radiation.

It describes how data are presented in the ASER, and presents tables of unit prefixes, units of measure, and conversion factors. It discusses limits applicable to air emissions and water effluents, and describes (and presents a table of) the dose-based United States (U.S.) Department of Energy (DOE) derived concentration guides (DCGs). It includes a discussion of CAP88-PC, the computer code used to evaluate compliance with the air dose standard. It also presents discussions of 1) water quality classifications, standards, and limits for ambient water; 2) potable water standards; 3) soil and sediment guidelines; and 4) evaluation of monitoring data with respect to limits.

Radiation and Radioactivity

Radioactivity is a property of atoms with unstable nuclei. The unstable nuclei spontaneously decay by emitting radiation in the form of energy (such as gamma rays) or particles (such as alpha and beta particles) (see inset on following page). If the emitted energy or particle has enough energy to break a chemical bond or to knock an electron loose from another atom, a charged particle (an “ion”) may be created. This radiation is known as “ionizing radiation.”

As used in this ASER, the term “radiation” refers only to ionizing radiation and does not include nonioniz-

ing forms of radiation such as visible light, radio waves, microwaves, infrared light, or ultraviolet light.

Radioactive Decay

An atom is the smallest particle of an element. It cannot be broken down by chemical means. An atom consists of a central core (the *nucleus*), composed of positively charged particles (*protons*) and particles with no charge (*neutrons*), surrounded by negatively charged particles (*electrons*) that revolve in orbits in the region surrounding the nucleus. The protons and neutrons are much more massive than the electrons, therefore most of an atom’s mass is in the nucleus.

An element is defined by the number of protons in its nucleus, its atomic number. For example, the atomic number of hydrogen is one (one proton), the atomic number of strontium is 38 (38 protons), and the atomic number of cesium is 55 (55 protons).

The mass number of an atom, its *atomic weight*, is equal to the total number of protons and neutrons in its nucleus. For example, although an atom of hydrogen will always have one proton in its nucleus, the number of neutrons may vary. Hydrogen atoms with zero, one, or two neutrons will have atomic weights of one, two, or three, respectively. These atoms are known as *isotopes* (or *nuclides*) of the element hydrogen. Elements may have many isotopes. For instance, the elements strontium and cesium have more than 30 isotopes each.

Isotopes may be stable or unstable. An atom from an unstable isotope will spontaneously change to another atom. The process by which this change occurs, that is, the spontaneous emission from the nucleus of alpha or beta particles, often accompanied by gamma radiation, is known as *radioactive decay*. Depending upon the type of radioactive decay, an atom may be transformed to another isotope of the same element or, if the number of protons in the

Note: Much of the background information in this section was taken from The Handbook of Health Physics and Radiological Health (Shleien, 1998), from the Environmental Protection Agency website (www.epa.gov/radiation/understand), and from The Health Physics Society website (<http://hps.org/publicinformation>).

Some Types of Ionizing Radiation

Alpha Particles. An alpha particle is a positively charged particle consisting of two protons and two neutrons. Compared to beta particles, alpha particles are relatively large and heavy and do not travel very far when ejected by a decaying nucleus. Therefore, alpha radiation is easily stopped by a few centimeters of air or a thin layer of material, such as paper or skin. However, if radioactive material is ingested or inhaled, the alpha particles released inside the body can damage soft internal tissues because their energy can be absorbed by tissue cells in the immediate vicinity of the decay. An example of an alpha-emitting radionuclide is the uranium isotope with an atomic weight of 232 (uranium-232). Uranium-232 was in the high-level radioactive waste (HLW) mixture at the West Valley Demonstration Project (WVDP) as a result of a thorium-based nuclear fuel reprocessing campaign conducted by Nuclear Fuel Services, Inc. Uranium-232 has been detected in liquid waste streams.

Beta Particles. A beta particle is an electron emitted during the breakdown of a neutron in a radioactive nucleus. Compared to alpha particles, beta particles are smaller, have less of a charge, travel at a higher speed (close to the speed of light), and can be stopped by wood or a thin sheet of aluminum. If released inside the body, beta particles do much less damage than an equal number of alpha particles because beta particles deposit energy in tissue cells over a larger volume than alpha particles. Strontium-90, a fission product found in the liquids associated with the HLW, is an example of a beta-emitting radionuclide.

Gamma Rays. Gamma rays are high-energy “packets” of electromagnetic radiation, called photons, that are emitted from the nucleus. Gamma rays are similar to x-rays, but are generally more energetic. If an alpha or beta particle released by a decaying nucleus does not carry off all the energy generated by the nuclear disintegration, the excess energy may be emitted as gamma rays. If the released energy is high, a very penetrating gamma ray is produced that can be effectively reduced only by shielding consisting of several inches of a dense material, such as lead, or of water or concrete several feet thick. Although large amounts of gamma radiation are dangerous, gamma rays are also used in lifesaving medical procedures. An example of a gamma-emitting radionuclide is barium-137m, a short-lived daughter product of cesium-137. Both barium-137m and its precursor, cesium-137, are major constituents of the WVDP HLW.

nucleus has changed, to an isotope of another element.

Isotopes (nuclides) that undergo radioactive decay are called *radioactive* and are known as *radioisotopes* or *radionuclides*. Radionuclides are customarily referred to by their atomic weights. For instance, the radionuclides of hydrogen, strontium, and cesium measured at the WVDP are hydrogen-3 (also known as tritium), strontium-90, and cesium-137. For some radionuclides, such as cesium-137, a short-lived intermediate is formed that decays by gamma emission. This intermediate radionuclide may be designated by the letter “m” (for metastable) following the atomic weight. For cesium-137, the intermediate radionuclide is barium-137m, with a half-life of less than three minutes.

The process of radioactive decay will continue until only a stable, nonradioactive isotope remains. Depending on the radionuclide, this process can take

anywhere from less than a second to billions of years. The time required for half of the radioactivity to decay is called the radionuclide’s *half-life*. Each radionuclide has a unique half-life. The half-life of hydrogen-3 is slightly more than 12 years, both strontium-90 and cesium-137 have half-lives of approximately 30 years, and plutonium-239 has a half-life of more than 24,000 years.

Knowledge of radionuclide half-lives is often used to estimate past and future inventories of radioactive material. For example, a 1.0 millicurie source of cesium-137 in 2006 would have measured 2.0 millicuries in 1976 and will be 0.5 millicuries in 2036. For a list of half-lives of radionuclides applicable to the WVDP, see Table UI-4.

Measurement of Radioactivity

As they decay, radionuclides emit one or more types of radiation at characteristic energies that can be

measured and used to identify the radionuclide. Detection instruments measure the quantity of radiation emitted over a specified time. From this measurement, the number of decay events (nuclear transformations) over a fixed time can be calculated.

Radioactivity is measured in units of curies (Ci) or becquerels (Bq). One Ci (based on the rate of decay of one gram of radium-226) is defined as the “quantity of any radionuclide that undergoes an average transformation rate of 37 billion transformations per second.” In the International System of Units (SI), one Bq is equal to one transformation per second. In this ASER, radioactivity is customarily expressed in units of Ci followed by the equivalent SI unit in parentheses, as follows: 1 Ci (3.7E+10 Bq).

In this report, measurements of radioactivity in a defined volume of an environmental media, such as air or water, are presented in units of concentration. Since levels of radioactivity in the environment are typically very low, concentrations may be expressed in microcuries per milliliter, with SI units (becquerels per liter) in parentheses, as follows: 1.00E-06 μ Ci/mL (3.7E+01 Bq/L). (One microcurie is equal to one millionth of a curie.)

Measurement of Dose

The amount of energy absorbed by a material that receives radiation is measured in rads. A rad is 100 ergs of radiation energy absorbed per gram of material. (An erg is the approximate amount of energy necessary to lift a mosquito one-sixteenth of an inch.) “Dose” is a means of expressing the amount of energy absorbed, taking into account the effects of different kinds of radiation.

Alpha, beta, and gamma radiation affect the body to different degrees. Each type of radiation is given a quality factor that indicates the extent of human cell damage it can cause compared with equal amounts of other ionizing radiation energy. Alpha particles cause 20 times as much damage to internal tissues as x-rays, so alpha radiation has a quality factor of 20, compared to gamma rays, x-rays, or beta particles, each of which have a quality factor of one.

The unit of dose measurement to humans is the *rem*. The number of rem is equal to the number of rads multiplied by the quality factor for each type of radiation. In the SI system, dose is expressed in sieverts. One sievert (Sv) equals 100 rem. One rem equals 1,000 millirem (mrem), the unit used to express stan-

dards for dose to man from air and water sources, as applicable to this ASER. This ASER expresses dose in standard units, followed by equivalent SI units in parentheses, as follows: 1 mrem (0.01 mSv).

Background Radiation

Background radiation is always present, and everyone is constantly exposed to low levels of such radiation from both naturally occurring and man-made sources. In the U.S. the average total annual exposure to low-level background radiation is estimated to be about 620 mrem or 6.2 millisieverts (mSv). About one-half of this radiation, approximately 310 mrem (3.1 mSv), comes from natural sources. The other half (about 310 mrem [3.1 mSv]) comes from medical procedures, consumer products, and other man-made sources (National Council on Radiation Protection and Measurements Report Number 160, 2009). (See Figure 3-1 in Chapter 3.)

Background radiation includes cosmic rays; the decay of natural elements, such as potassium, uranium, thorium, and radon; and radiation from sources such as chemical fertilizers, smoke detectors, and cigarettes. Actual doses vary depending on such factors as geographic location, building ventilation, and personal health and habits.

Potential Health Effects of Radiation

The three primary pathways by which people may be exposed to radiation are (1) direct exposure, (2) inhalation, and (3) ingestion. Exposure from radiation may be from a source outside the body (external exposure) or from radioactive particles that have been taken in by breathing or eating and have become lodged inside the body (internal exposure). Radionuclides that are taken in are not distributed in the same way throughout the body. Radionuclides of strontium, plutonium, and americium concentrate in the skeleton, while radioisotopes of iodine concentrate in the thyroid. Radionuclides such as hydrogen-3 (tritium), carbon-14, or cesium-137, however, will be distributed uniformly throughout the body.

Living tissue in the human body can be damaged by ionizing radiation. The severity of the damage depends upon several factors, among them the amount of exposure (low or high), the duration of the exposure (long-term [*chronic*] or short-term [*acute*]), the type of radiation (alpha, beta, and gamma radiations of various energies), and the sensitivity of the human (or organ) receiving the radiation. The human body has mechanisms

that repair damage from exposure to radiation; however, repair processes are not always successful.

Biological effects of exposure to radiation may be either somatic or genetic. *Somatic* effects are limited to the exposed individual. For example, a sufficiently high exposure could cause clouding of the lens of the eye or a decrease in the number of white blood cells. *Genetic* effects may show up in future generations. Radiation could damage chromosomes, causing them to break or join incorrectly with other chromosomes. Radiation-produced genetic defects and mutations in the offspring of an exposed parent, while not positively identified in humans, have been observed in some animal studies.

Assessing the biological damage from low-level radiation is difficult because other factors can cause the same symptoms as radiation exposure. Moreover, the body is able to repair damage caused by low-level radiation. Epidemiological studies have not demonstrated adverse health effects in individuals exposed to small doses (less than 10 rem) over a period of years. (For comparison, note that average natural background radiation in the U.S. is about 0.31 rem/year, and estimated annual dose from activities at the WVDP in 2010 was calculated to be about 0.000066 rem/year [0.066 mrem/year].)

The effect most often associated with exposure to relatively high levels of radiation appears to be an increased risk of cancer. However, scientists have not been able to demonstrate with certainty that exposure to low-level radiation causes an increase in injurious biological effects, nor have they been able to determine if there is a level of radiation exposure below which there are no adverse biological effects.

Data Reporting

In the text of this ASER, radiological units (e.g., rem, rad, curie) are presented first, followed by the SI equivalent in parentheses. Nonradiological measurements are presented in English units, followed by the metric unit equivalent in parentheses. See Tables UI-1, UI-2, and UI-3 for a summary of unit prefixes, units of measurement, and basic conversion factors used in this ASER.

Where results are very large or very small, scientific notation is used. Numbers greater than 10 are expressed with a positive exponent. To convert the number to its decimal form, the decimal point must be moved to the right by the number of places equal to the exponent. For example, 1.0E+06 would be expressed as 1,000,000 (one million). Numbers smaller than 1 are expressed with a

negative exponent. For example, 1.0E-06 would be expressed as 0.000001 (one millionth).

TABLE UI-1
Unit Prefixes Used in This ASER

| Multiplication factor | | Prefix | Symbol |
|-----------------------|----------------|--------|--------|
| Scientific notation | Decimal form | | |
| 1.0E+06 | 1000000 | mega | M |
| 1.0E+03 | 1000 | kilo | k |
| 1.0E-02 | 0.01 | centi | c |
| 1.0E-03 | 0.001 | milli | m |
| 1.0E-06 | 0.000001 | micro | μ |
| 1.0E-09 | 0.000000001 | nano | n |
| 1.0E-12 | 0.000000000001 | pico | p |

Radiological data are reported as a result plus or minus (\pm) an associated uncertainty, customarily the 95% confidence interval. The uncertainty is in part due to the random nature of radioactive decay. Generally, the relative uncertainty in a measurement increases as the amount of radioactivity being sampled decreases. For this reason, low-level environmental analyses for radioactivity are especially prone to significant uncertainty in comparison with the result. Radiological data are presented in the following manner:

Example: 1.04 \pm 0.54 E-09

Where: 1.04 = the result
 \pm 0.54 = plus or minus the associated uncertainty
 E-09 = times 10 raised to the power -09

Sources of uncertainty may include random components (e.g., radiological counting statistics) or systematic components (e.g., sample collection and handling, measurement sensitivity, or bias). Radiological data in this report include both a result and uncertainty term. The uncertainty term represents only the uncertainty associated with the analytical measurement which for environmental samples is largely due to the random nature of radioactive decay. When such radiological data are used in calculations, such as estimating the total curies released from an air or water effluent point, the other parameter used in the calculation (e.g., air volumes, water volumes), typically do not have an associated uncertainty value available. As such, the uncertainties in this report for such calculated values only reflect the uncertainty associated with the radiological re-

TABLE UI-2
Units of Measure Used in This ASER

| Type | Measurement | Symbol | Type | Measurement | Symbol |
|----------------------|--------------------|-------------------|-------------------------------|-------------------------|--------|
| Length | meter | m | Dose | rad (absorbed dose) | rad |
| | centimeter | cm | | rem (dose equivalent) | rem |
| | kilometer | km | | millirem | mrem |
| | inch | in | | sievert | Sv |
| | foot | ft | | millisievert | mSv |
| | mile | mi | | gray | Gy |
| Volume | gallon | gal | Exposure | roentgen | R |
| | liter | L | | milliroentgen | mR |
| | milliliter | mL | | microroentgen | μR |
| | cubic meter | m ³ | Concentration | parts per million | ppm |
| cubic feet | ft ³ | parts per billion | | ppb | |
| Area | acre | ac | | parts per trillion | ppt |
| | hectare | ha | | milligrams per L (ppm) | mg/L |
| | square meter | m ² | | micrograms per L (ppb) | μg/L |
| | square foot | ft ² | | nanograms per L (ppt) | ng/L |
| Temperature | degrees Fahrenheit | °F | milligrams per kg (ppm) | mg/kg | |
| | degrees Celsius | °C | micrograms per g (ppm) | μg/g | |
| Mass | gram | g | micrograms per mL (ppm) | μg/mL | |
| | kilogram | kg | milliliters per mL | mL/L | |
| | milligram | mg | microcuries per mL | μCi/mL | |
| | microgram | μg | picocuries per L | pCi/L | |
| | nanogram | ng | microcuries per g | μCi/g | |
| | pound | lb | becquerels per L | Bq/L | |
| | tonne (metric ton) | t | nephelometric turbidity units | NTU | |
| | ton, short | T | standard units (pH) | SU | |
| Radioactivity | curie | Ci | Flow rate | gallons per day | gpd |
| | millicurie | mCi | | gallons per minute | gpm |
| | microcurie | μCi | | million gallons per day | mgd |
| | nanocurie | nCi | | cubic feet per minute | cfm |
| | picocurie | pCi | | liters per minute | lpm |
| | becquerel | Bq | | meters per second | m/sec |

TABLE UI-3
Conversion Factors Used in This ASER

| To convert from | to | Multiply by |
|-----------------|-------------|-------------|
| miles | kilometers | 1.609344 |
| feet | meters | 0.3048 |
| inches | centimeters | 2.54 |
| acres | hectares | 0.4046873 |
| pounds | kilograms | 0.45359237 |
| gallons | liters | 3.785412 |
| curies | becquerels | 3.7E+10 |
| rad | gray | 0.01 |
| rem | sievert | 0.01 |
| cubic feet | mL | 28,316.85 |

Note: To convert from the units in column two to the units in column one, divide by the conversion factor.

sults used in the calculation. The actual (total propagated) uncertainty of such values would be larger if other components of uncertainty were available and included in these estimates.

Radiological results are calculated using both sample counts and background counts. If the background count is greater than the sample count, a negative result term will be reported. The constituent is considered to be detected if the result is larger than the associated uncertainty (i.e., a "positive" detection). Nonradiological data are not reported with an associated uncertainty.

In general, the detection limit is the minimum amount of a constituent that can be detected, or distinguished from background, by an instrument or a measurement technique. If a result is preceded by the symbol "<" (i.e., <5 parts per million [ppm]), the constituent was not measurable below the detection limit (in this example, 5 ppm).

The number of significant digits reported depends on the precision of the measurement technique. Integer counts are reported without rounding. Calculated values are customarily reported to three significant figures. Dose estimates are usually reported to two

significant figures. All calculations are completed before values are rounded.

Limits Applicable to Environmental Media

Dose Standards. The two dose standards against which releases at the WVDP are assessed are those established by the U.S. Environmental Protection Agency (EPA) for air emissions and that established by the DOE regarding all exposure modes from DOE activities.

Radiological air emissions other than radon from DOE facilities are regulated by the EPA under the National Emission Standards for Hazardous Air Pollutants (NESHAP) regulation (40 Code of Federal Regulation [CFR] 61, Subpart H), which establishes a standard of 10 mrem/year effective dose equivalent to any member of the public. See "CAP88-PC Computer Code" in inset.

DOE Order 5400.5 sets the DOE primary standard of 100 mrem/year effective dose equivalent to members of the public considering all exposure modes from DOE activities. (Currently there are no EPA standards establishing limits on the radiation dose to members of the public from liquid effluents.)

CAP88-PC Computer Code

The WVDP ASER summarizes the airborne radioactivity released (see Appendix C⁶⁹) and the effect from those releases (Chapter 3) in a manner consistent with that required by the U.S. Environmental Protection Agency (EPA). The computer code Clean Air Act Assessment Package-1988 for personal computers (CAP88-PC), Version 3.0, approved in February 2006, is used to perform radiation dose and risk calculations from WVDP airborne releases. According to the EPA website from whence the most recent release can be obtained, any approved version of the code can be used for compliance.

Version 3.0 of CAP88-PC (Trinity Engineering Associates, Inc., December 2007, which updates edits issued in November 2006, and March and October of 2007) was first approved by the EPA for use in February 2006 to demonstrate compliance with the 10-mrem/year National Emission Standards for Hazardous Air Pollutants (NESHAP) standard. Version 3.0 incorporates updated scientific methods to calculate radiation dose and risk. Version 3.0 also considers age and gender factors not considered in earlier versions. This version uses weighting factors that consider the sensitivity of various human organs to radiation. The model also calculates how long radioactive material will remain in a particular organ or system. Together, these factors are used to calculate dose and cancer risk. The net effect is that dose and risk estimates summarized in the ASER from using CAP88-PC Version 2.0 and Version 3.0 are slightly different, even if the radioactivity released from WVDP and meteorology both remain constant. However, test calculations with both versions have resulted in estimated doses far below the compliance limit.

At this juncture, the EPA accepts the use of any of the three approved versions of CAP88 for compliance purposes. The WVDP used Version 2.0 in 2009 for airborne dose assessment and has used the recommended Version 3.0 code in 2010.

Note that the EPA establishes a drinking water limit of 4-mrem/year (0.04-mSv/year) (40 CFR Parts 141 and 143, Drinking Water Guidelines). Corollary limits for community water supplies are set by the New York State Department of Health (NYSDOH) in the New York State Sanitary Code (Title 10 of the Official Compilation of Codes, Rules, and Regulations of the State of New York [NYCRR] 5-152). These limits are not applicable at the WVDP because no drinking water sources within the Cattaraugus Creek drainage basin are affected by the WVDP.

DOE Derived Concentration Guide (DCG). A DCG is defined as the concentration of a radionuclide in air or water that, under conditions of continuous exposure by one exposure mode (i.e., ingestion of water, immersion in air, or inhalation) for one year, would result in an effective dose equivalent of 100 mrem (1 mSv) to a "reference man" (DOE Order 5400.5). DCGs are applicable only at locations where members of the public could be exposed to air or water containing contaminants. DCGs for radionuclides measured at the WVDP are listed in Table UI-4. At the WVDP, DCGs are used as a screening tool for evaluating liquid effluents and airborne emissions. (DCGs are not used to estimate dose.)

State Pollutant Discharge Elimination System (SPDES) Permit Requirements. The site's SPDES permit defines points where sampling must be conducted, sampling frequency, the type of samples to be collected, nonradiological constituents for which samples must be analyzed, and the limits applicable to these constituents. Results are reported monthly to the New York State Department of Environmental Conservation (NYSDEC) in Discharge Monitoring Reports. Requirements of the CY 2010 SPDES permit are summarized in Appendix B-1⁶⁰. On July 1, 2011, a modified SPDES permit became effective for the WVDP.

Radionuclides are not regulated under the SPDES permit. However, special requirements in the permit specify that the concentration of radionuclides in the discharge is subject to requirements of DOE Order 5400.5, "Radiation Protection of the Public and the Environment."

Water Quality Classifications, Standards, and Limits for Ambient Water. The objective of the Clean Water Act of 1972 (CWA) is to restore and maintain the integrity of the nation's waters and ensure that, wherever attainable, waters be made useful for fishing and swimming. To achieve this goal, New York State is delegated with authority under Sections 118, 303, and 510 of

the CWA to (1) classify and designate the best uses for receiving waters, such as streams and rivers, within its jurisdiction, and (2) establish and assign water quality standards — goals for achieving the designated best uses for these classified waters.

In addition to achieving CWA goals for fishing and swimming, New York has further classified its jurisdictional waters and established ambient water standards, guidelines, and maximum contaminant levels (MCLs) to achieve objectives under the Safe Drinking Water Act for drinking water. These standards serve as the basis for periodic evaluation of the integrity of the receiving waters and identification of needed controls.

The definitions for best usage classification of New York's jurisdictional waters and the water quality standard goals for these classifications are provided in 6 NYCRR Parts 701–704. Mapping of the Cattaraugus Creek drainage basin and assignment of best usage designations and classification to each receiving water segment within this drainage basin are described in 6 NYCRR Part 838.

According to these regulations, Franks Creek, Quarry Creek, and segments of Buttermilk Creek under the influence of water effluents from the WVDP are identified as Class "C" receiving waters with a minimum designated best usage for fishing with conditions suitable for fish propagation and survival.

Cattaraugus Creek, in the immediate downstream vicinity of the Western New York Nuclear Service Center, is identified as a Class "B" receiving water with best designated usages for swimming and fishing. All fresh (nonsaline) groundwaters within New York are assigned a "GA" classification with a designated best usage as a potable water supply source.

Refer to Appendix B⁶⁰ for a summary of the water quality standards, guidelines, and MCLs assigned to these water classifications for those constituents that are included in the WVDP environmental monitoring program for ambient water.

Potable Water Standards. Standards for drinking water are established by the EPA and by NYSDOH. These standards are expressed as MCLs or MCL goals. See Appendix B-1⁶⁰ for a summary of these levels.

Soil and Sediment Concentration Guidelines. Contaminants in soil are potential sources for contamination of groundwater, surface water, ambient air, and plants and animals. No routine soil or sediment

samples were collected in 2010; therefore, no soil or sediment data were available for comparison with applicable guidelines (e.g., from the U.S. Nuclear Regulatory Commission, the EPA, and NYSDEC). Therefore, the guideline levels that were presented in the 2008 ASER have not been included in the 2010 ASER. The routine soil and sediment sampling is next scheduled for 2012.

Evaluation of Monitoring Data with Respect to Limits

Monitoring data for this report were evaluated against the limits presented in Table UI-4, and Appendices B^{6a} and D^{6a}. Those locations with results exceeding the limits are listed in Chapter 2, Table 2-4, and in Chapter 4, Table 4-10.

TABLE UI-4
U.S. Department of Energy Derived Concentration Guides (DCGs)^a for Inhaled Air or Ingested Water ($\mu\text{Ci}/\text{mL}$)

| Radionuclide | Half-life (years) ^b | DCG in Air | DCG in Water |
|--------------------------------------|--------------------------------|------------|--------------|
| Gross Alpha (as Am-241) ^c | NA | 2E-14 | 3E-08 |
| Gross Beta (as Sr-90) ^c | NA | 9E-12 | 1E-06 |
| Tritium (H-3) | 1.23E+01 | 1E-07 | 2E-03 |
| Carbon-14 (C-14) | 5.70E+03 | 6E-09 | 7E-05 |
| Potassium-40 (K-40) | 1.25E+09 | 9E-10 | 7E-06 |
| Cobalt-60 (Co-60) | 5.27E+00 | 8E-11 | 5E-06 |
| Strontium-90 (Sr-90) | 2.89E+01 | 9E-12 | 1E-06 |
| Technetium-99 (Tc-99) | 2.11E+05 | 2E-09 | 1E-04 |
| Iodine-129 (I-129) | 1.57E+07 | 7E-11 | 5E-07 |
| Cesium-137 (Cs-137) | 3.00E+01 | 4E-10 | 3E-06 |
| Europium-154 (Eu-154) | 8.59E+00 | 5E-11 | 2E-05 |
| Uranium-232 (U-232) | 6.89E+01 | 2E-14 | 1E-07 |
| Uranium-233 (U-233) | 1.59E+05 | 9E-14 | 5E-07 |
| Uranium-234 (U-234) | 2.46E+05 | 9E-14 | 5E-07 |
| Uranium-235 (U-235) | 7.04E+08 | 1E-13 | 6E-07 |
| Uranium-236 (U-236) | 2.34E+07 | 1E-13 | 5E-07 |
| Uranium-238 (U-238) | 4.47E+09 | 1E-13 | 6E-07 |
| Plutonium-238 (Pu-238) | 8.77E+01 | 3E-14 | 4E-08 |
| Plutonium-239 (Pu-239) | 2.41E+04 | 2E-14 | 3E-08 |
| Plutonium-240 (Pu-240) | 6.56E+03 | 2E-14 | 3E-08 |
| Americium-241 (Am-241) | 4.32E+02 | 2E-14 | 3E-08 |

^a DCGs are established in DOE Order 5400.5 and are defined as the concentration of a radionuclide that, under conditions of continuous exposure for one year by one exposure mode, would result in an effective dose equivalent of 100 mrem (1 mSv).

^b Nuclear Wallet Cards. April 2005. National Nuclear Data Center. Brookhaven National Laboratory. Upton, New York.

^c Because there are no DCGs for gross alpha and gross beta concentrations, the DCGs for the most restrictive alpha and beta emitters at the WVDP (americium-241 and strontium-90, respectively) are used as a conservative basis for comparison at locations for which there are no radionuclide-specific data, in which case a more appropriate DCG may be applied.