Cadmium

Symbol: Cd

Atomic Number: 48
(protons in nucleus)

Atomic Weight: 112
(naturally occurring)

What Is It? Cadmium is a soft, silvery gray metal that is malleable and ductile, similar to zinc. When heated, it burns in air with a bright light to form the oxide CdO. In nature, essentially all cadmium exists as seven stable isotopes and one radioactive isotope. (Isotopes are different forms of an element that have the same number of protons in the nucleus, but a different number of neutrons.) The seven stable isotopes and their approximate abundances are cadmium-106 (1.3%), cadmium-108 (0.9%), cadmium-110 (12%), cadmium-111 (13%), cadmium-112 (24%), cadmium-114 (29%), and cadmium-116 (7.5%). The primary radioactive isotope, cadmium-113, comprises about 12% of natural cadmium and has an extremely long half-life.

Nine major radioactive isotopes of cadmium exist, of which only three – cadmium-109, cadmium-113, and cadmium-113m – have half-lives long enough to warrant potential concern. The half-lives of the other six are less than 45 days. Cadmium-109 decays by electron capture with a half-life of 1.3 years, so any that was produced more than 20 years ago has long since decayed away. The other two cadmium isotopes decay by emitting a beta particle. The very low specific activity of cadmium-113 limits its radioactive hazards. Thus, cadmium-113m (the "m" means metastable) is the isotope of most concern at Department of Energy environmental management sites such as Hanford. Cadmium-113m decays by emitting a beta particle with no gamma radiation.

Radioactive Properties of Key Cadmium Isotopes

Isotope	Half-Life *(yr)*	Natural Abundance *(%)*	Specific Activity *(Ci/g)*	Decay Mode	Radiation Energy *(MeV)*		
					Alpha (α)	Beta (β)	Gamma (γ)
Cd-109	1.3	<<1	2,600	EC	-	0.083	0.026
Cd-113	9.3 million billion	12	0.34 trillionth	β	-	0.093	-
Cd-113m	14	<<1	240	β	-	0.019	-

EC = electron capture, Ci = curie, g = gram, and MeV = million electron volts; a dash means the entry is not applicable. (See the companion fact sheet on Radioactive Properties, Internal Distribution, and Risk Coefficients for an explanation of terms and interpretation of radiation energies.) Values are given to two significant figures.

Where Does It Come From? Cadmium is found in rare ores such as sphalerite and greenockite, and it is formed as a byproduct during production of zinc, copper, and lead. The United States is among the top ten producers, refining over 1,000 metric tons of cadmium a year. The majority of cadmium that enters the environment is from mining, smelting, oil and coal combustion, and waste incineration. Cadmium-113m is produced by neutron activation of the stable isotope cadmium-112 and as a fission product. When a fissile nuclide such as uranium-235 fissions, it generally splits asymmetrically into two large fragments – fission products with mass numbers in the range of about 90 and 140 – and two or three neutrons. In a nuclear reactor, these neutrons can cause additional fissions (producing a chain reaction), escape from the reactor, or irradiate nearby materials. Cadmium is used in reactor components such as control rods and shields to absorb neutrons, resulting in the formation of various isotopes including cadmium-113m. The fission yield of cadmium-113m is very low (about 0.0002%). This radioactive isotope is present in spent nuclear fuel and radioactive wastes associated with operating nuclear reactors and fuel reprocessing plants.

How Is It Used? Most cadmium in the United States (about 75%) is used in nickel-cadmium batteries. It has also been used as an anticorrosive coating for steel and cast iron, and it is a component of certain specialty alloys. Cadmium is used in semiconductors (such as cadmium selenide and telluride), in dyes and pigments, as a stabilizer in plastics such as polyvinyl chloride, and as a neutron absorber in nuclear reactor control rods and shields. Its use in the United States has recently decreased by about 50% in response to environmental concerns.

What's in the Environment? Nonradioactive cadmium is present in U.S. soil at an average concentration of about 0.15 milligram per kilogram (mg/kg). Trace amounts of cadmium-113m are present in soil around the world from radioactive fallout due to past atmospheric weapons tests. It may also be present at certain nuclear facilities, such as reactors and facilities that process spent nuclear fuel. Cadmium is usually relatively immobile, with concentrations in sandy soil estimated to be 80 times higher than in interstitial water (water in the pore space between the soil particles); it is even less mobile

in clay soils, with estimated concentration ratios above 500. The typical ratio of the concentration of cadmium in plants to that in soil is estimated at 0.15 (or 15%). (Cadmium-113m is generally not a major contaminant in groundwater at DOE sites like Hanford because of its relatively low concentration in wastes as a result of its low fission yield.)

What Happens to It in the Body? Cadmium can be taken into the body by eating food, drinking water, breathing air, or smoking a cigarette. Children, and to a lesser extent adults, can also be exposed by ingesting soil. Gastrointestinal absorption from food or water is the principal source of internally deposited cadmium in the general population. Gastrointestinal absorption is generally quite low, with only about 5% of the amount ingested being transferred to the bloodstream; the unabsorbed cadmium is excreted in the feces. Cadmium absorption via inhalation exposure is higher, estimated at 30 to 60%. Little metabolic conversion of cadmium compounds occurs in the body, but cadmium does bind to proteins and other components of macromolecules. Thirty percent of cadmium that reaches the blood deposits in the liver, another 30% deposits in the kidneys, and the rest distributes throughout all other organs and tissues of the body (per simplified models that do not reflect intermediate redistribution). Absorbed cadmium is excreted primarily in the urine, but because daily excretion is only about 0.01% of the total body burden, the biological half-life is about 25 years. Dermal contact is not usually of concern because the amount absorbed is small (about 0.1%).

What Are the Primary Health Effects? Cadmium-113m is a health hazard only if it is taken into the body. It does not pose an external hazard because it decays by emitting a relatively low-energy beta particle with no gamma radiation. While it concentrates in the liver and kidneys, cadmium can also deposit in other organs and tissues depending on its chemical form. The main concern is cancer induction from the beta particles associated with its radioactive decay, but cadmium also exhibits chemical toxicity, with health effects following inhalation exposure to high levels that can include damage to the respiratory system (bronchial and pulmonary irritation), headache, chest pains, muscular weakness, pulmonary edema, and death. Chronic exposure may result in emphysema and chronic bronchitis. Repeated low exposures may also cause permanent kidney damage, leading to kidney stones and other health problems. In its narrative for the cancer weight of evidence, the U.S. Environmental Protection Agency (EPA) states that occupational studies of cadmium smelter workers developing lung cancer provide limited evidence for the carcinogenicity of cadmium in humans following inhalation exposure, and that there is sufficient evidence of carcinogenicity in rats and mice by inhalation and intramuscular and subcutaneous injection. Cadmium was classified as a probable human carcinogen under the EPA 1996 cancer guidelines. In contrast, cadmium has not been shown to cause cancer when ingested. Information on the joint toxicity of cadmium with other metals is provided in the companion chemical mixtures fact sheet.

What Is the Risk? Lifetime cancer mortality risk coefficients have been calculated for nearly all radionuclides, including cadmium *(see box at right).* While the coefficients for ingestion are lower than for inhalation, ingestion is generally the most common means of entry into the body. Similar to other radionuclides, the risk coefficients for tap water are about 80% of those for dietary ingestion. The EPA has also developed toxicity values to estimate the risk of developing cancer or other adverse health effects as a result of inhaling or ingesting cadmium. The toxicity value for estimating the risk of cancer for inhalation exposure is called a unit risk (UR), which is an estimate of the chance that a person will get cancer from continuous exposure to a chemical in air at a concentration of 1 milligram per cubic meter (mg/m^3). The value for the non-cancer effect following oral exposure is a reference dose (RfD), which is an estimate of the highest dose that can be taken in every day without causing an adverse non-cancer effect. The UR is based on studies of humans exposed to cadmium in the workplace. Oral RfDs for food and water, shown at right, were developed using a toxicokinetic model that relates cadmium intake to concentrations in the kidney. To illustrate how the RfD is applied, a 150-pound (lb) person could safely ingest food containing 0.068 mg or drink water containing 0.034 mg of cadmium every day without expecting any adverse effects (2.2 lb = 1 kg, or 1,000 g, or 1 million mg). In contrast to the RfD, which represents a "safe daily dose" (and so is compared to the amount an individual takes in, as a ratio), the UR is multiplied by the air concentration to estimate the cancer risk. Using the UR, the EPA estimates that a person would have a one-in-a-million chance of developing cancer if exposed to air containing 0.0006 microgram (μg)/m^3 every day over a lifetime. (A microgram is one millionth of a gram.)

Radiological Risk Coefficients

The following table provides selected radiological risk coefficients for inhalation and ingestion. Maximum values are given for inhalation (no default absorption types were provided), and dietary values were used for ingestion. Risks are for lifetime cancer mortality per unit intake (picocurie, pCi), averaged over all ages and both genders (10^{-9} is a billionth, and 10^{-12} is a trillionth). Other values, including for morbidity, are also available.

Isotope	Lifetime Cancer Mortality Risk	
	Inhalation (pCi^{-1})	Ingestion (pCi^{-1})
Cadmium-109	2.0×10^{-11}	4.2×10^{-12}
Cadmium-113	8.1×10^{-11}	2.0×10^{-11}
Cadmium-113m	9.3×10^{-11}	2.5×10^{-11}

For more information, see the companion fact sheet on Radioactive Properties, Internal Distribution, and Risk Coefficients and the accompanying Table 1.

Chemical Toxicity Values

Cancer Risk	Non-Cancer Effect	
Inhalation UR	***Oral RfD: Water***	***Oral RfD: Food***
1.8 per mg/m^3	0.0005 mg/kg-d	0.001 mg/kg-d