Zirconium

Symbol:	**Zr**
Atomic Number: *(protons in nucleus)*	**40**
Atomic Weight: *(naturally occurring)*	**91**

What Is It? Zirconium is a lustrous, grayish-white, corrosion-resistant metal. When it exists in a finely divided form, zirconium can spontaneously ignite in air, especially at high temperatures; the solid metal is much more difficult to ignite. Zirconium occurs in nature as five stable isotopes. (Isotopes are different forms of an element that have the same number of protons in the nucleus but a different number of neutrons.) Zirconium-90 is the most prevalent form, comprising slightly more than half of natural zirconium. The other four stable isotopes and their relative abundances are zirconium-91 (11%), zirconium-92 (17%), zirconium-94 (17%), and zirconium-96 (2.8%). Zirconium occurs widely in the earth's crust, but not in concentrated deposits.

Of the six major radioactive zirconium isotopes, only one – zirconium-93 – has a half-life long enough to warrant potential concern at Department of Energy (DOE) environmental management sites such as Hanford. The half-lives of all other isotopes are less than three months. Zirconium-93 decays by emitting a beta particle with a half-life of 1.5 million years to niobium-93m (the "m" means metastable), which in turn decays by isomeric transition with a half-life of 14 years. Zirconium-93 is present in spent nuclear fuel and the wastes resulting from reprocessing this fuel. The low-specific activity and low energy of its radiations limits the radioactive hazards of this isotope.

Radioactive Properties of the Key Zirconium Isotope and an Associated Radionuclide

Isotope	Half-Life *(yr)*	Specific Activity *(Ci/g)*	Decay Mode	Radiation Energy *(MeV)*		
				Alpha (α)	Beta (β)	Gamma (γ)
Zr-93	1.5 million	0.0025	β	-	0.020	-
Nb-93m	*14*	*290*	*IT*	-	*0.028*	*0.0019*

IT =isomeric transition, 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.) Certain properties of niobium-93m are included here because this radionuclide can accompany zirconium-93 decays. Values are given to two significant figures.

Where Does It Come From? Zirconium is naturally present in a number of minerals, but it does not generally occur in concentrated deposits. The mineral zircon (zirconium orthosilicate), which is found in alluvial deposits in streambeds, ocean beaches, or old lake beds, is the only commercial source of zirconium. Commercial grade zirconium contains from 1 to 3% hafnium. The leading producers of zirconium are Australia and South Africa. Other producers include Ukraine, the United States, India, Brazil, and China. Annual worldwide production of zirconium is currently about 900,000 metric tons (MT) of which about 60 MT is produced domestically.

Zirconium-93 is produced by neutron activation of components in nuclear reactors and by nuclear fission. When a fissile nuclide such as an atom of 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. (The mass number is the sum of the number of protons and neutrons in the nucleus of the atom.) These neutrons can cause additional fissions (producing a chain reaction), escape from the reactor, or irradiate nearby materials. Zirconium is used in the cladding of nuclear fuel elements, and neutron irradiation of the cladding can produce zirconium-93. Zirconium-93 is also a fission product with a relatively high yield of about 6%. That is, about six atoms of zirconium-93 are produced per 100 fissions. Zirconium-93 is present in spent nuclear fuel, high-level radioactive wastes resulting from processing spent nuclear fuel, and radioactive wastes associated with nuclear reactors and fuel reprocessing plants.

How Is It Used? Zirconium is very resistant to corrosion that occurs in the presence of many common acids and alkalis as well as seawater. For this reason it is used extensively by the chemical industry where corrosive agents are employed. Zirconium is used in vacuum tubes, as an alloying agent in steel, in surgical appliances, photoflash bulbs, explosive primers, and lamp filaments. It is also used in poison ivy lotions in the form of the carbonate. The mineral zircon has a high index of refraction and is used as a gem material. The impure oxide zirconia is used for laboratory crucibles that can withstand heat shock, for the lining of metallurgical furnaces, and by the glass and ceramic industries as a refractory material. Zircaloy, an alloy of zirconium containing small amounts of tin, iron, chromium, and nickel, is used as a cladding material for nuclear fuel elements. Zirconium has a low absorption cross-section for neutrons, which makes it an ideal material for use in nuclear reactor applications. Its use in commercial nuclear power generation now accounts for as much as 90% of the zirconium metal that is produced.

What's in the Environment? Zirconium is present in the earth's crust at a concentration of about 130 milligrams per kilogram (mg/kg), and its concentration in seawater is about 0.026 micrograms (µg)/liter. Trace amounts of zirconium-93 are present in soil around the globe from radioactive fallout. It can also be present at certain nuclear facilities, such as reactors and facilities that process spent nuclear fuel. The highest concentrations at Hanford are in areas that contain waste from processing irradiated fuel, including the hardware associated with the spent fuel. Zirconium is generally one of the less mobile radioactive metals in soil, although certain forms can move downward some distance to underlying layers with percolating water. Zirconium preferentially adheres quite well to soil, and the concentration associated with sandy soil particles is typically about 600 times higher than in interstitial water (water in the pore space between soil particles), with higher concentration ratios (over 2,000) in loam and clay soils. Thus, zirconium is generally not a major contaminant in groundwater at DOE sites.

What Happens to It in the Body? Zirconium can be taken into the body by eating food, drinking water, or breathing air. Gastrointestinal absorption from food or water is the principal source of internally deposited zirconium in the general population. Zirconium is not well absorbed into the body, with only about 0.2% of the amount ingested being absorbed into the bloodstream through the intestines. Of the zirconium that reaches the blood, half deposits in the skeleton with a biological half-life of 8,000 days and the other half deposits in all other organs and tissues of the body where it is retained with a biological half-life of 7 days (per simplified models that do not reflect intermediate redistribution). Since zirconium is not a major constituent of mineral bone, the amount deposited in the skeleton is assumed to remain on the bone surfaces and not be absorbed into the volume of bone.

What Are the Primary Health Effects? Zirconium is a health hazard only if it is taken into the body. External gamma exposure is not a concern because zirconium-93 decays by emitting a beta particle with no gamma radiation, and niobium-93m decays by isomeric transition, in which only low-energy gamma radiation is emitted. While inside the body, zirconium presents a health hazard from the beta particles and gamma radiation, and the main concern is associated with the increased likelihood of inducing cancer.

What Is the Risk? Lifetime cancer mortality risk coefficients have been calculated for nearly all radionuclides, including zirconium *(see box at right).* While the coefficients for ingestion are somewhat lower than for inhalation, ingestion is generally the most common means of entry into the body. The risks shown here include the contribution from niobium-93m, even though it may not be in radioactive equilibrium with zirconium-93 (about ten niobium half-lives or 140 years are needed to establish equilibrium). Similar to other radionuclides, the risk coefficients for tap water are about 75% of those for dietary ingestion.

Radiological Risk Coefficients

This table provides selected risk coefficients for inhalation and ingestion. Recommended default absorption types were used for inhalation, and dietary values were used for ingestion. These values include the contribution from niobium-93m. Risks are for lifetime cancer mortality per unit intake (picocurie, pCi), averaged over all ages and both genders (10^{-12} is a trillionth). Other values, including for morbidity, are also available.

Isotope	Lifetime Cancer Mortality Risk	
	Inhalation *(pCi^{-1})*	**Ingestion** *(pCi^{-1})*
Zirconium-93	8.4×10^{-12}	1.7×10^{-12}

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