Protactinium

Symbol:	Pa
Atomic Number: *(protons in nucleus)*	**91**
Atomic Weight: *(naturally occurring)*	**231**

What Is It? Protactinium is a malleable, shiny, silver-gray radioactive metal that does not tarnish rapidly in air. It has a density greater than that of lead and occurs in nature in very low concentrations as a decay product of uranium. There are three naturally occurring isotopes, with protactinium-231 being the most abundant. (Isotopes are different forms of an element that have the same number of protons in the nucleus but a different number of neutrons.) The other two naturally occurring isotopes are protactinium-234 and protactinium-234m (the "m" meaning metastable), both of which have very short half-lives (6.7 hours and 1.2 minutes, respectively) and occur in extremely low concentrations. Protactinium was first identified in 1913 by Kasimir Fajans and O.H. Gohring (as the isotope protactinium-234m), and protactinium-231 was identified in 1917. The name comes from the Greek work *protos* (meaning first) and the element actinium, because protactinium is the precursor of actinium.

Of the 20 known isotopes of protactinium, only protactinium-231 has a half-life greater than one year and is a concern for Department of Energy (DOE) environmental management sites. The half-lives of all other protactinium isotopes are less than a month. Protactinium-231 is a decay product of uranium-235 and is present at sites that processed uranium ores and associated wastes. This isotope decays by emitting an alpha particle with a half-life of 33,000 years to actinium-227, which has a half-life of 22 years and decays by emitting an alpha or beta particle. Actinium-227 and its decay products are included with the list of radionuclides associated with protactinium-231 in the table to the right for completeness, as these radionuclides are typically present with protactinium-231. Much of the hazard associated with protactinium-231 is attributable to actinium-227.

Radioactive Properties of the Key Protactinium Isotope and Associated Radionuclides

Isotope	Half-Life	Natural Abun-dance (%)	Specific Activity (Ci/g)	Decay Mode	Radiation Energy (MeV)		
					Alpha (α)	Beta (β)	Gamma (γ)
Pa-231	33,000 yr	>99	.048	α	5.0	0.065	0.048
Ac-227	*22 yr*		*73*	α, β	*0.068*	*0.016*	<
Th-227 (99%)	*19 days*		*31,000*	α	*5.9*	*0.053*	0.11
Fr-223 (1%)	*22 min*		*39 million*	β	-	*0.40*	*0.059*
Ra-223	*11 days*		*52,000*	α	*5.7*	*0.076*	*0.13*
Rn-219	*4.0 sec*		*13 billion*	α	*6.8*	*0.0063*	*0.056*
Po-215	*0.0018 sec*		*30 trillion*	α	*7.4*	<	<
Pb-211	*36 min*		*25 million*	β	-	*0.46*	*0.051*
Bi-211	*2.1 min*		*420 million*	α, β	*6.6*	*0.010*	*0.047*
Tl-207	*4.8 min*		*190 million*	β	-	*0.49*	*0.0022*

Ci = curie, g = gram, and MeV = million electron volts; a "<" means the radiation energy is less than 0.001 MeV, and 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.) Thorium-227 decays by both emitting an alpha particle (1%) and a beta particle (99%). Certain properties of additional radionuclides are included here because they accompany the protactinium decays. Values are given to two significant figures.

Where Does It Come From? Protactinium is widely distributed in very small amounts in the earth's crust, and it is one of the rarest and most expensive naturally occurring elements. It is present in uranium ores at a concentration of about 1 part protactinium to 3 million parts uranium. Of the three naturally occurring isotopes, protactinium-231 is a decay product of uranium-235, and protactinium-234 and protactinium-234m are decay products of uranium-238. Essentially all (99.8%) of the decays of thorium-234, which is the immediate decay product of uranium-238, are to protactium-234m; only about 0.2% are to protactinium-234. *(See the companion fact sheets on Uranium and Natural Decay Series for additional information.)*

How Is It Used? There are no industrial or commercial uses of protactinium due to its scarcity, expense, and radiotoxicity. Its only uses are associated with basic scientific research activities.

What's in the Environment? Protactinium is naturally present in soil, rocks, surface water, groundwater, plants, and animals in very low concentrations – on the order of one part per trillion, or 0.1 picocuries (pCi)/g. Higher levels are present in uranium ores and other geologic materials. Essentially all naturally occurring protactinium is present as protactinium-231. Protactinium preferentially adheres quite well to soil, and the concentration associated with sandy soil particles is typically 550 times higher than in interstitial water (water in the pore space between the soil particles); concentration ratios are even higher (about 2,000 and above) for loam and clay soils. Protactinium is generally not a major contaminant at DOE sites and is not a concern for groundwater.

What Happens to It in the Body? Protactinium can be taken into the body by eating food, drinking water, or breathing air. When protactinium is inhaled, a significant fraction can move from the lungs through the blood to other organs, depending on the solubility of the compound. Gastrointestinal absorption from food or water is a likely source of internally deposited protactinium in the general population. Most of the protactinium taken in by ingestion will promptly leave the body in feces; only about 0.05% of the amount ingested is absorbed from the gastrointestinal tract into the bloodstream. After leaving the intestine or lung, about 40% of the protactinium that does enter the bloodstream deposits in the skeleton, about 15% deposits in the liver, about 2% deposits in the kidneys, and the rest is excreted. The biological half-life in the skeleton is about 50 years. Of the protactinium deposited in the liver, 70% is assumed to be retained with a biological half-life of 10 days, with the remaining 30% having a biological half-life of 60 days. Of the protactinium deposited in the kidneys, 20% is assumed to be retained with a biological half-life of 10 days, with the remaining 80% having a biological half-life of 60 days. (This information is per simplified models that do not reflect intermediate redistribution.)

What Are the Primary Health Effects? Protactinium is generally a health hazard only if it is taken into the body, although there is a small external risk associated with the gamma rays emitted by protactinium-231 and a number of short-lived decay products of actinium-227. The main means of exposure are ingestion of food and water containing protactinium and inhalation of protactinium-contaminated dust. Ingestion is generally the exposure of concern unless there is a nearby source of contaminated airborne dust. Because protactinium is taken up in the body much more readily if inhaled rather than ingested, both exposure routes can be important. The major health concern is cancer resulting from the ionizing radiation emitted by protactinium deposited in the skeleton, liver, and kidneys. The health risks associated with protactinium-234m are included with those for uranium-238 *(see the companion fact sheet on Uranium)*. Protactinium-234m decays by emitting an energetic beta particle so precautions against this radiation are needed when handling uranium; for example, heavy rubber gloves are worn to protect the hands and forearms.

What Is the Risk? Lifetime cancer mortality risk coefficients have been calculated for nearly all radionuclides, including protactinium *(see box at right)*. The inhalation risk factor for protactinium-231 represents one of the largest risk factors for any radionuclide. Actinium-227 and its decay products account for more than 80% of this inhalation risk. While the risk factor for ingestion is much lower than for inhalation, ingestion is generally the most common means of entry into the body. Similar to other radionuclides, the risk coefficient for tap water is about 75% of that shown for dietary ingestion.

Radiological Risk Coefficients

This table provides selected risk coefficients for inhalation and absorption. Maximum values are given for inhalation as no default absorption types were provided, and dietary values were used for ingestion. These values include the contributions from the actinium-227 and its short-lived decay products. Risks are for lifetime cancer mortality per unit intake (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})*
Pa-231	2.5×10^{-7}	6.0×10^{-10}

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

In addition to risks from internal exposures, there is a risk from external gamma exposure to protactinium-231. Using the external gamma risk coefficients to estimate lifetime cancer mortality risks, if it is assumed that 100,000 people were continuously exposed to a thick layer of soil with an initial average concentration of 1 pCi/g protactinium-231, then 8 of these 100,000 people would be predicted to incur a fatal cancer. (This is in comparison to the 20,000 people from this group predicted to die of cancer from all other causes per the U.S. average.) As for internal exposures, much of this risk is from actinium-227 and its decay products.