Transuranic Radionuclides

What Are They? Taking their name from being *trans-* or beyond uranium, transuranic radionuclides have atomic numbers greater than that of uranium, which is 92. All transuranic isotopes are radioactive. (Isotopes are different forms of an element that have the same number of protons in the nucleus but a different number of neutrons.) Those associated with americium, californium, curium, neptunium, and plutonium are generally of concern for U.S. Department of Energy (DOE) environmental management sites such as Hanford. More information on these five radionuclides and their decay products is presented in the separate radionuclide-specific fact sheets. An additional transuranic radionuclide that can be found at DOE sites is berkelium-247; summary radioactive properties for this transuranic isotope is given in the green box on the back of this page.

Where Do They Come From? Most transuranic radionuclides at DOE sites were produced in nuclear reactors by neutron capture, with the remainder being produced in particle accelerators. Because multiple neutron capture reactions are usually needed to produce higher-numbered isotopes for a given element, the relative number of individual isotopes decreases with increasing atomic number. For example, after nuclear fuel is discharged from a plutonium production reactor, more plutonium-238 and plutonium-239 would generally be present than the higher-numbered isotopes such as plutonium-242. Transuranic radionuclides typically do not occur naturally in the environment, although very minute amounts can be present with some uranium ores. The underground, natural sustained nuclear reactions estimated to have occurred about 1.9 billion years ago in Gabon, Africa, also produced some transuranic radionuclides, including neptunium and plutonium.

Like certain other radioactive isotopes such as those of naturally occurring uranium, radium, and thorium, the transuranic radionuclides undergo radioactive decay to create typically long chains of decay products. Radioactive decay occurs when an unstable atom transforms to a more stable isotope by emitting an alpha or beta particle, although some isotopes also decay by spontaneous fission. During spontaneous fission, the atom self-disintegrates into two smaller atoms accompanied by a release of energy. The radioactive decay series for several key transuranic radionuclides are shown in Figures T.1 through T.3 at the end of this fact sheet. These figures illustrate the relationships among isotopes in terms of radioactive decay and ingrowth. They also identify the major decay modes and show which isotopes emit significant gamma radiation. A number of these transuranic decay series eventually transition into the decay series for the naturally occurring radionuclides, which are shown separately in Figures N.1 through N.3 within the companion fact sheet: *Natural Decay Series: Uranium, Radium, and Thorium*. Many concepts relevant to decay series, such as secular equilibrium, are discussed in that companion fact sheet and are therefore not repeated here. Interested readers are encouraged to refer to that sheet for more information.

What Are Transuranic Wastes? Radioactive wastes containing more than 100 nanocuries per gram (nCi/g) of alpha-emitting transuranic radionuclides with half-lives greater than 20 years are termed "transuranic wastes." (100 nCi/g is one tenth of a microcurie or one ten-millionth of a curie per gram.) This term technically applies to radioactive wastes generated after 1970. Prior to 1970, no specific considerations were identified for radioactive wastes containing transuranic radionuclides. At that time, these wastes were managed in the same manner as other low-level radioactive wastes regardless of the concentration of transuranic radionuclides, and all these wastes were generally disposed of by shallow land burial. Today, transuranic wastes are segregated from other low-level radioactive wastes and managed separately because the hazards associated with the higher concentrations of long-lived alpha-emitting radionuclides are believed to warrant more stringent handling and disposal considerations.

Radioactive wastes that would meet today's definition of transuranic wastes but were disposed of before 1970 by shallow land burial and other similar techniques at DOE sites are often referred to as "buried transuranic wastes." The DOE is currently evaluating the most appropriate manner to manage these wastes over the long term on a site-specific basis. Transuranic (or TRU) wastes generated by more recent defense-related activities, including a substantial inventory in controlled storage, are currently being sent to the Waste Isolation Pilot Plant located near Carlsbad, New Mexico, for deep underground disposal. This facility began accepting wastes in 1999 and has a permitted capacity of about 175,600 m^3.

The following table summarizes key properties of selected transuranic radionuclides. (For americium, californium, curium, neptunium, and plutonium, this information is also given in the radionuclide-specific fact sheets and the supporting Table 2.) The table below includes radionuclides beyond those that define transuranic wastes, i.e., those with half-lives <20 years or that decay by means other than alpha emission. (These are indicated by regular green shading, while those that define TRU wastes are in yellow-green.)

Radioactive Properties of Selected Transuranic Radionuclides

Isotope	Half-Life	Specific Activity *(Ci/g)*	Decay Mode	Radiation Energy *(MeV)*		
				Alpha *(α)*	Beta *(β)*	Gamma *(γ)*
Americium-241	430 yr	3.5	α	5.5	0.052	0.033
Americium-242m	150 yr	9.8	IT	0.025	0.044	0.0051
Americium-242	*16 hr*	*820,000*	*β, EC*	-	*0.18*	*0.018*
Americium-243	7,400 yr	0.20	α	5.3	0.022	0.056
Neptunium-239	*2.4 days*	*230,000*	*β*	-	*0.26*	*0.17*
Berkelium-247	1,400 yr	1.1	α	5.6	0.061	0.11
Californium-248	330 days	1,600	α	6.3	0.0060	0.0013
Californium-249	350 yr	4.1	α	5.8	0.043	0.33
Californium-250	13 yr	110	α	6.0	0.0057	0.0012
Californium-251	900 yr	1.6	α	5.8	0.020	0.13
Californium-252	2.6 yr	540	α	5.9	0.0056	0.0012
Curium-242	160 days	3,400	α	6.1	0.010	0.0018
Curium-243	29 yr	52	α	5.8	0.14	0.13
Curium-244	18 yr	82	α	5.8	0.086	0.0017
Curium-245	8,500 yr	0.17	α	5.4	0.065	0.096
Curium-246	4,700 yr	0.31	α	5.4	0.0080	0.0015
Curium-247	16 million yr	0.000094	α	4.9	0.021	0.32
Curium-248	340,000 yr	0.0043	α	4.7	0.0060	0.0012
Curium-250	6,900 yr	0.21	α, β	1.3	0.0016	-
Plutonium-246 (25%)	*11 days*	*49,000*	*β*	-	*0.13*	*0.14*
Berkelium-250 (14%)	*3.2 hr*	*3.9 million*	*β*	-	*0.29*	*0.89*
Americium-246 (25%)	*39 min*	*20 million*	*β*	-	*0.66*	*0.70*
Neptunium-235	1.1 yr	1,400	EC	<0.001	0.010	0.0071
Neptunium-236	120,000 yr	0.013	β, EC	-	0.21	0.14
Plutonium-236 (9%)	*2.9 yr*	*540*	*α*	*5.8*	*0.013*	*0.0021*
Neptunium-237	2.1 million yr	0.00071	α	4.8	0.070	0.035
Protactinium-233	*27 days*	*21,000*	*β*	-	*0.20*	*0.20*
Plutonium-238	88 yr	17	α	5.5	0.011	0.0018
Plutonium-239	24,000 yr	0.063	α	5.1	0.0067	<0.001
Plutonium-240	6,500 yr	0.23	α	5.2	0.011	0.0017
Plutonium-241	14 yr	100	β	<0.001	0.0052	<0.001
Plutonium-242	380,000 yr	0.0040	α	4.9	0.0087	0.0014
Plutonium-244	83 million yr	0.000018	α	4.6	0.0071	0.0012

Decay products are in italics. Values are given to two significant figures. EC = electron capture, IT = isomeric transition, Ci = curie, g = gram, and MeV = million electron volts. A dash indicates that the entry is not applicable. (See radionuclide-specific fact sheets and the companion fact sheet on Radioactive Properties, Internal Distribution, and Risk Coefficients for further information, including on terminology and interpretation of radiation energies.)

What Are the Health Risks? Transuranic wastes pose a concern for environmental management because of the relatively long half-lives of the transuranic radionuclides, combined with their emission of alpha particles (and to a lesser degree beta particles). Because the alpha particles cannot penetrate the outer layer of skin, these radionuclides pose a hazard primarily if they are taken into the body. Some isotopes also emit gamma radiation, which results in an additional hazard from external exposure. The main concern is cancer induction due to energy deposited in tissues during radioactive decay. Lifetime cancer mortality risk coefficients have been calculated for nearly all radionuclides, including transuranic

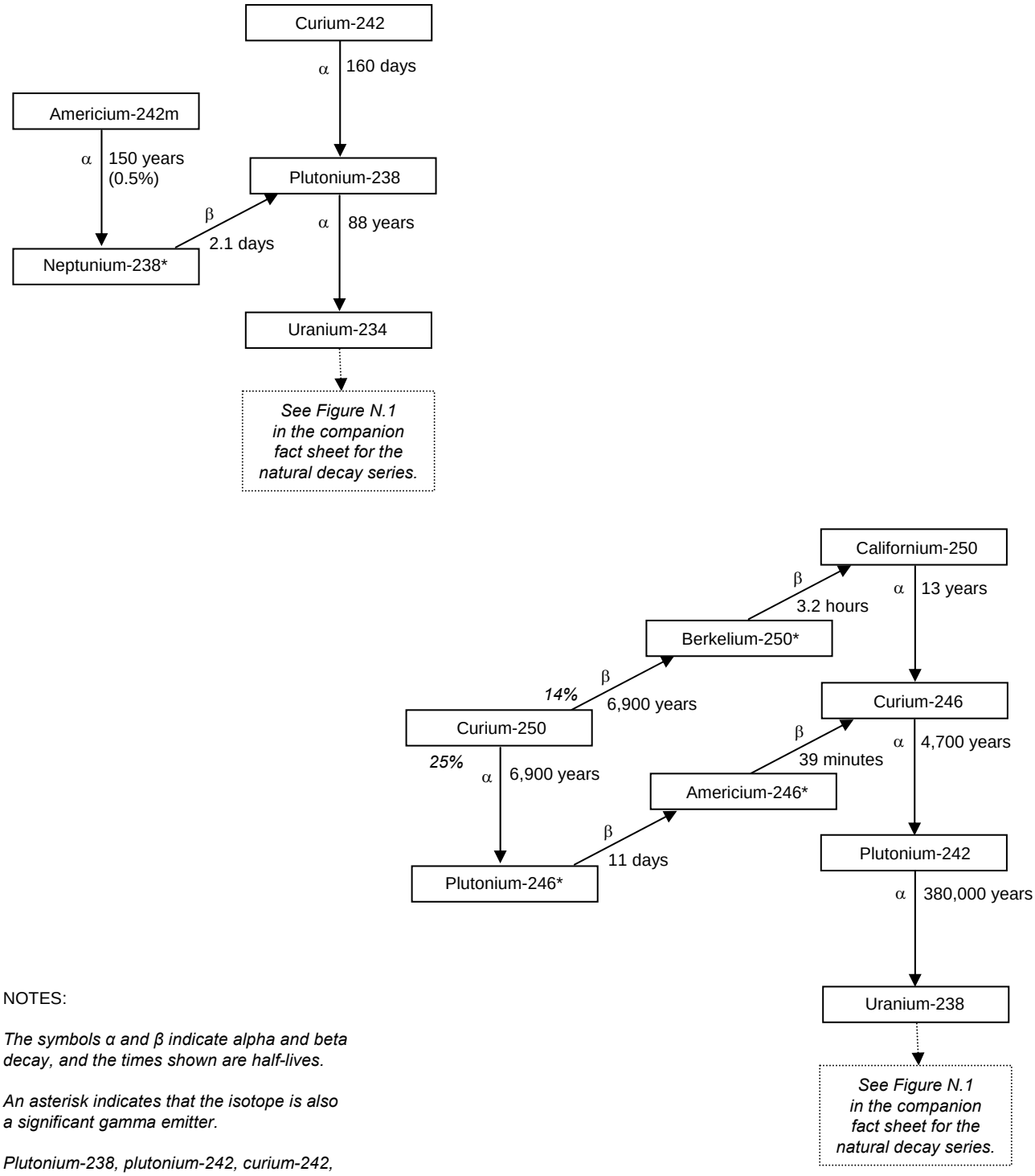
isotopes. Selected radiological risk coefficients are summarized in the yellow box below. This summary includes information presented on the radionuclide-specific fact sheets for americium, californium, curium, neptunium, and plutonium and the supporting Table 1. Information for berkelium-247 is taken from the same source reference used for that table. Shown below are selected risk coefficients of various transuranic radionuclides for inhalation and dietary ingestion, and for external gamma irradiation where that entry is appropriate. The mortality risk represents the lifetime risk of incurring a fatal cancer, and the morbidity risk represents the risk of incurring both fatal and non-fatal cancers.

Mortality and Morbidity Risk Coefficients for Selected Transuranic Radionuclides

Isotope	Lifetime Cancer Risk					
	Mortality			Morbidity		
	Inhalation	Ingestion	External	Inhalation	Ingestion	External
Americium-241	2.4×10^{-8}	9.5×10^{-11}	1.9×10^{-8}	2.8×10^{-8}	1.3×10^{-10}	2.8×10^{-8}
Americium-242m	1.3×10^{-8}	6.8×10^{-11}	-	1.6×10^{-8}	9.0×10^{-11}	-
Americium-243	2.3×10^{-8}	9.8×10^{-11}	4.3×10^{-7}	2.7×10^{-8}	1.4×10^{-10}	6.4×10^{-7}
Berkelium-247	4.0×10^{-8}	1.2×10^{-10}	2.1×10^{-7}	4.8×10^{-8}	1.6×10^{-10}	3.1×10^{-7}
Californium-248	2.4×10^{-8}	3.8×10^{-11}	-	2.6×10^{-8}	6.2×10^{-11}	-
Californium-249	4.0×10^{-8}	1.2×10^{-10}	9.3×10^{-7}	4.8×10^{-8}	1.6×10^{-10}	1.4×10^{-6}
Californium-250	3.5×10^{-8}	8.0×10^{-11}	-	3.7×10^{-8}	1.1×10^{-10}	-
Californium-251	4.1×10^{-8}	1.3×10^{-10}	2.6×10^{-7}	4.9×10^{-8}	1.7×10^{-10}	3.8×10^{-7}
Californium-252	2.1×10^{-8}	4.1×10^{-11}	-	2.2×10^{-8}	5.7×10^{-11}	-
Curium-242	1.4×10^{-8}	3.2×10^{-11}	-	1.5×10^{-8}	5.5×10^{-11}	-
Curium-243	2.4×10^{-8}	8.5×10^{-11}	2.9×10^{-7}	2.7×10^{-8}	1.2×10^{-10}	4.2×10^{-7}
Curium-244	2.3×10^{-8}	7.5×10^{-11}	-	2.5×10^{-8}	1.1×10^{-10}	-
Curium-245	2.4×10^{-8}	9.5×10^{-11}	1.6×10^{-7}	2.8×10^{-8}	1.3×10^{-10}	2.4×10^{-7}
Curium-246	2.4×10^{-8}	9.3×10^{-11}	-	2.8×10^{-8}	1.3×10^{-10}	-
Curium-247	2.2×10^{-8}	9.0×10^{-11}	8.9×10^{-7}	2.5×10^{-8}	1.3×10^{-11}	1.3×10^{-6}
Curium-248	8.8×10^{-8}	3.4×10^{-10}	-	1.0×10^{-7}	4.8×10^{-10}	-
Curium-250	5.0×10^{-7}	2.0×10^{-9}	9.7×10^{-7}	5.8×10^{-7}	2.8×10^{-9}	1.4×10^{-6}
Neptunium-235	1.0×10^{-12}	2.8×10^{-13}	-	1.2×10^{-12}	5.1×10^{-13}	-
Neptunium-236	2.6×10^{-9}	1.5×10^{-11}	2.2×10^{-7}	3.0×10^{-9}	2.3×10^{-11}	3.2×10^{-7}
Neptunium-237	1.5×10^{-8}	5.8×10^{-11}	5.4×10^{-7}	1.8×10^{-8}	9.1×10^{-11}	8.0×10^{-7}
Plutonium-238	3.0×10^{-8}	1.3×10^{-10}	-	3.4×10^{-8}	1.7×10^{-10}	-
Plutonium-239	2.9×10^{-8}	1.3×10^{-10}	-	3.3×10^{-8}	1.7×10^{-10}	-
Plutonium-240	2.9×10^{-8}	1.3×10^{-10}	-	3.3×10^{-8}	1.7×10^{-10}	-
Plutonium-241	2.8×10^{-10}	1.9×10^{-12}	-	3.3×10^{-10}	2.3×10^{-12}	-
Plutonium-242	2.8×10^{-8}	1.3×10^{-10}	-	3.1×10^{-8}	1.7×10^{-10}	-
Plutonium-244	2.7×10^{-8}	1.3×10^{-10}	-	3.1×10^{-8}	1.6×10^{-10}	-

Source: *Cancer Risk Coefficients for Environmental Exposure to Radionuclides*, Federal Guidance Report 13, U.S. Environmental Protection Agency, EPA 402-R-99-001, September 1999. Values are averaged over all ages and both genders and include the contributions from short-lived decay products, i.e., those with half-lives less than one year. (For context, 10^{-9} is a billionth, 10^{-12} is a trillionth, and a pCi is a picocurie, or a trillionth of a curie.) To convert to standard international units, multiply by 27 pCi per becquerel (Bq). For ingestion and inhalation, units are risk per pCi. For inhalation, the values corresponding to the recommended default absorption type for particulates are shown; the maximum value is given if no absorption type was recommended. For ingestion, the dietary values shown are the highest for ingestion exposures; values for tap water ingestion are typically 70 to 80% of those for diet. For external exposure, risk coefficients are given for those radionuclides with gamma-ray energies >0.03 MeV per decay, accounting for the fraction of time that the radioactive decay results in the emission of gamma rays. A dash indicates the radionuclide or its decay products does not emit significant gamma radiation (see the fact sheet for Radioactive Properties, Internal Distribution, and Risk Coefficients). Units for external gamma risk coefficients shown in the table are risk per pCi/g soil for one year of exposure. Risk coefficients do not exist for curium-248, curium-250, or plutonium-244, so values shown have been derived (see the *Curium* and *Plutonium* fact sheets for derivation approach); the external value for curium-250 is attributable to its short-lived decay products.

Two parent radionuclides are shown here.



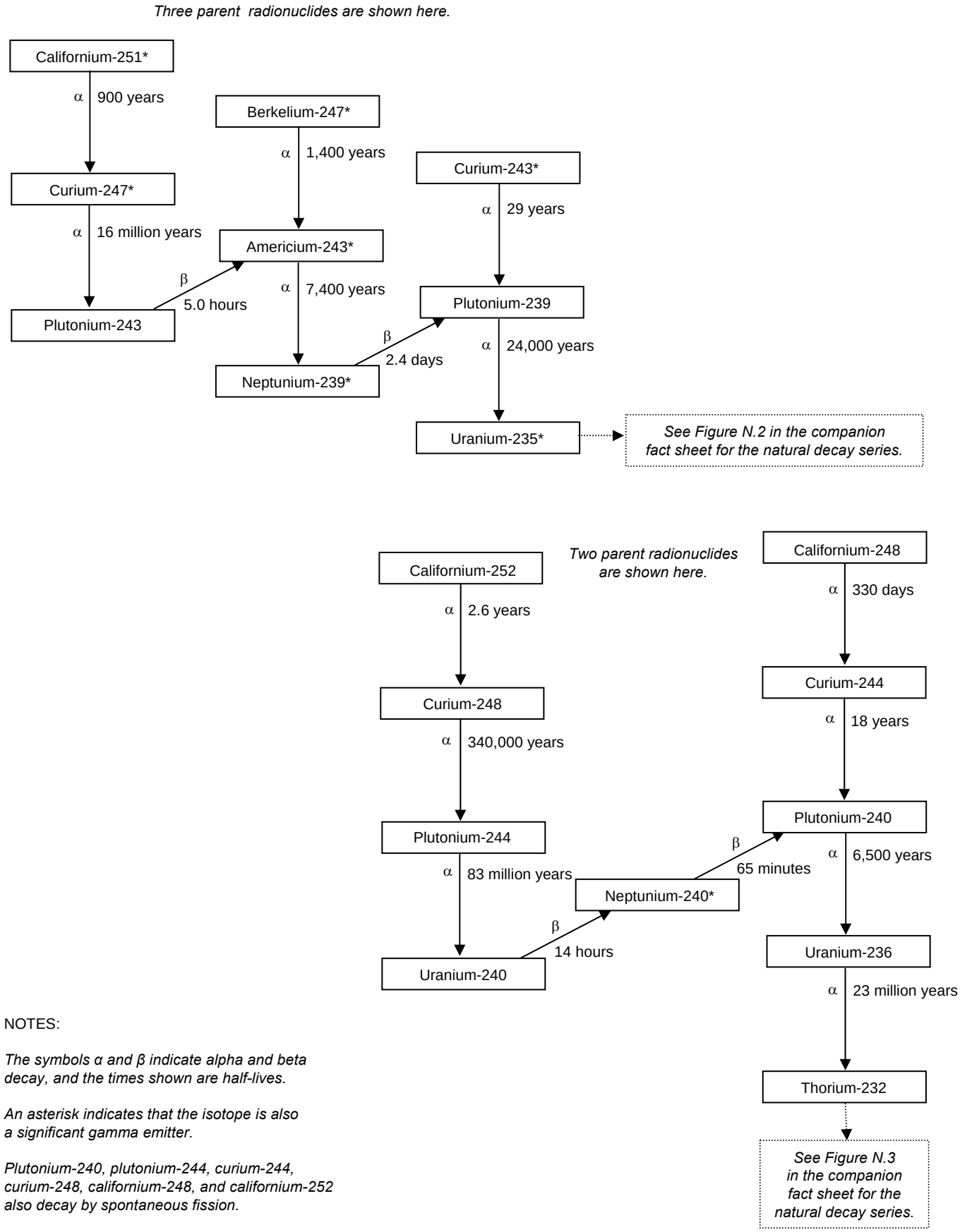
NOTES:

The symbols α and β indicate alpha and beta decay, and the times shown are half-lives.

An asterisk indicates that the isotope is also a significant gamma emitter.

Plutonium-238, plutonium-242, curium-242, curium-246, curium-250, and californium-250 also decay by spontaneous fission.

FIGURE T.1 Transuranic Decay Series: Americium-242m and Curium-242, and Curium-250



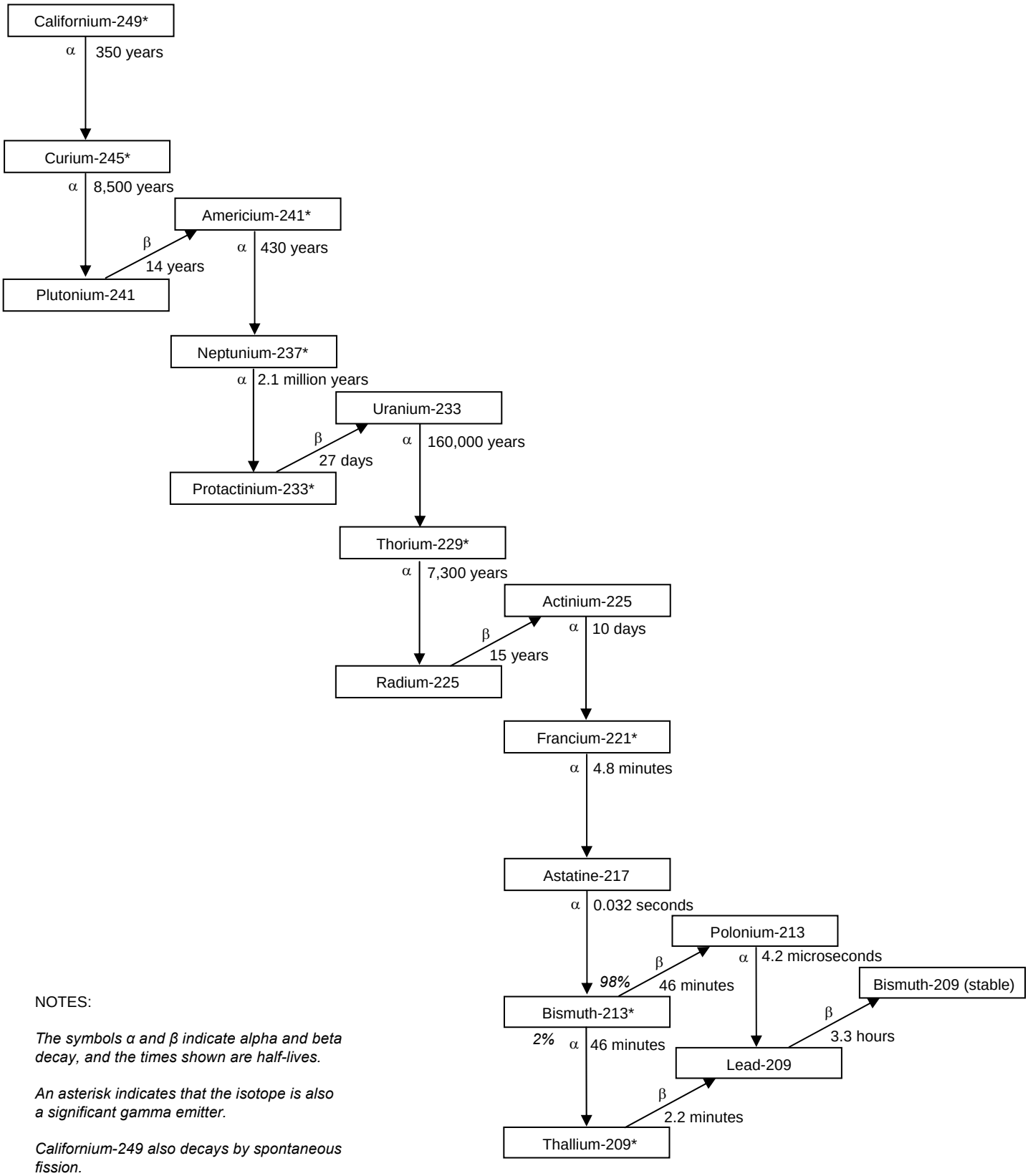
NOTES:

The symbols α and β indicate alpha and beta decay, and the times shown are half-lives.

An asterisk indicates that the isotope is also a significant gamma emitter.

Plutonium-240, plutonium-244, curium-244, curium-248, californium-248, and californium-252 also decay by spontaneous fission.

FIGURE T.2 Transuranic Decay Series: Californium-251, Berkelium-247, and Curium-243; Californium-252 and Californium-248



NOTES:

The symbols α and β indicate alpha and beta decay, and the times shown are half-lives.

An asterisk indicates that the isotope is also a significant gamma emitter.

Californium-249 also decays by spontaneous fission.

FIGURE T.3 Transuranic Decay Series: Californium-249