4. CHEMICAL, PHYSICAL, AND RADIOLOGICAL INFORMATION

4.1 CHEMICAL IDENTITY

Information regarding the chemical identity of plutonium and selected plutonium compounds is located in Table 4-1.

4.2 PHYSICAL, CHEMICAL, AND RADIOLOGICAL PROPERTIES

Information regarding the physical and chemical properties of plutonium and selected plutonium compounds is located in Table 4-2. Information regarding the radiological properties of selected plutonium isotopes is located in Table 4-3. The decay schemes for ^{239}Pu and ^{241}Pu are summarized in Figures 4-1 and 4-2, respectively.

Plutonium is a member of the actinide series and is a human-made element (atomic number 94). Actinides are the 15 elements starting with actinium, atomic number 89, and extending to lawrencium, atomic number 103. All of the isotopes of the actinide elements are radioactive. Plutonium was the first human-made element to be synthesized in weighable amounts. ^{238}Pu was discovered in 1940 by Seaborg and co-workers; it was synthesized by the bombardment of uranium with deuterons (^{2}H). Isotopes with mass numbers 228–247 have been identified for plutonium; all are radioactive. The most important isotope is ^{239}Pu, which has a half-life that is sufficiently long (24,100 years) to permit its preparation in large amounts, making it possible to perform chemical studies. Metallic plutonium exists in six allotropic modifications under ordinary pressure; a seventh phase exists under high pressure. Five oxidation states, Pu(III), Pu(IV), Pu(V), Pu(VI), and Pu(VII), are known to exist in compounds and solution (Clark et al. 2006). Plutonium(III) and plutonium(IV) are considered to be the reduced forms of plutonium, while plutonium(V) and plutonium(VI) are the oxidized forms (DOE 1987a). While the atomic mass of plutonium depends on the isotope, 244 is frequently listed as the mass of plutonium on periodic tables. ^{244}Pu is the isotope with the longest half-life.

Table 4-1. Chemical Identity of Plutonium and Selected Plutonium Compounds

Characteristic	Information[a]		
Chemical name	Plutonium	Plutonium dioxide	Plutonium nitride
Synonym(s)	No data	Plutonium(IV) oxide	No data
Registered trade name(s)	No data	No data	No data
Chemical formula	Pu	PuO_2	PuN
Chemical structure	Metallic plutonium exhibits seven allotropic modifications[b]	$Pu^{4+}(O^{2-})_2$	$Pu^{3+}N^{3-}$
Identification numbers:			
CAS registry	7440-07-5[c]	12059-95-9	12033-54-4
NIOSH RTECS	No data	No data	No data
EPA hazardous waste	No data	No data	No data
OHM/TADS	No data	No data	No data
DOT/UN/NA/IMDG shipping	No data	No data	No data
EINECS	231-117-7	235-037-3	No data
HSDB	6465	No data	No data
NCI	No data	No data	No data

Table 4-1. Chemical Identity of Plutonium and Selected Plutonium Compounds

Characteristic	Information[a]			
Chemical name	Plutonium nitrate	Plutonium hexafluoride	Plutonium Oxalate	Plutonium tetrafluoride
Synonym(s)	Nitric acid, plutonium(4+) salt	Plutonium(VI) fluoride	No data	Plutonium(IV) fluoride
Registered trade name(s)	No data	No data	No data	No data
Chemical formula	$Pu(NO_3)_4$	PuF_6	$Pu\ C_4O_8$	PuF_4
Chemical structure	$Pu^{4+}(NO_3^-)_4$	$Pu^{6+}(F^-)_6$	$Pu^{4+}(C_2O_4^{2-})_2$	$Pu^{4+}(F^-)_6$
Identification numbers:				
CAS registry	13823-27-3	13693-06-6	14448-76-1 13278-81-4[b]	13709-56-3
NIOSH RTECS	No data	No data	No data	No data
EPA hazardous waste	No data	No data	No data	No data
OHM/TADS	No data	No data	No data	No data
DOT/UN/NA/IMDG shipping	No data	No data	No data	No data
EINECS	238-979-3[d]	No data	No data	No data
HSDB	No data	No data	No data	No data
NCI	No data	No data	No data	No data

[a]All information obtained from ChemIDplus 2007, ChemFinder 2007, Lide 2005, and HSDB 2007 except where noted.
[b]Clark et al. 2006
[c]This is the generic CAS Registry Number for plutonium (unspecified form). Each isotope has an individual CAS Registry Number (Table 4-3).
[d]This EINCES number refers to plutonium nitrate (CAS Registry No. 14913-29-2) with a chemical formula of $Pu(NO_3)_x$.

CAS = Chemical Abstracts Service; DOT/UN/NA/IMDG = Department of Transportation/United Nations/North America/International Maritime Dangerous Goods Code; EINECS = European Inventory of Existing Chemical Substances EPA = Environmental Protection Agency; HSDB = Hazardous Substances Data Bank; NCI = National Cancer Institute; NIOSH = National Institute for Occupational Safety and Health; OHM/TADS = Oil and Hazardous Materials/Technical Assistance Data System; RTECS = Registry of Toxic Effects of Chemical Substances

Table 4-2. Physical and Chemical Properties of Plutonium and Selected Plutonium Compounds

Property	Information[a]		
Chemical name	Plutonium	Plutonium dioxide	Plutonium nitride
Molecular weight[b]	244	276	258
Physical description	Silver, white metal Six allotropic modifications under ordinary pressure[c]	Yellow-brown cubic crystals	Gray cubic crystals
Melting point	640 °C	2,400 °C	2,550 °C
Boiling point	3,228 °C	No data	No data
Density	19.7 g/cm^3	11.5 g/cm^3	14.4 g/cm^3
Odor	No data	No data	No data
Odor threshold:			
Water	No data	No data	No data
Air	No data	No data	No data
Solubility:			
Water	No data	No data	No data
Organic solvents	No data	No data	No data
Other	Soluble in hydrochloric acid; insoluble in nitric acid, concentrated hydrogen sulfide	No data	No data
Partition coefficients:			
Log K_{ow}	No data	No data	No data
Log K_{oc}	No data	No data	No data
Vapor pressure	No data	No data	No data
Henry's law constant	No data	No data	No data
Autoignition temperature	No data	No data	No data
Flashpoint	No data	No data	No data
Flammability limits	No data	No data	No data
Conversion factors	No data	No data	No data
Explosive limits	No data	No data	No data

Table 4-2. Physical and Chemical Properties of Plutonium and Selected Plutonium Compounds

Property	Information[a]			
Chemical name	Plutonium nitrate	Plutonium hexafluoride	Plutonium oxalate	Plutonium tetrafluoride
Molecular weight[b]	No data	358	No data	320
Physical description	No data	Red-brown orthorhombic crystals	Green-yellow solid[d]	Red-brown monoclinic crystals
Melting point	No data	52 °C	No data	1,027 °C
Boiling point	No data	No data	No data	No data
Density	No data	5.08 g/cm^3	No data	7.1 g/cm^3
Odor	No data	No data	No data	No data
Odor threshold:				
Water	No data	No data	No data	No data
Air	No data	No data	No data	No data
Solubility:				
Water	No data	No data	No data	No data
Organic solvents	No data	No data	No data	No data
Other	No data	No data	No data	No data
Partition coefficients:				No data
Log K_{ow}	No data	No data	No data	No data
Log K_{oc}	No data	No data	No data	No data
Vapor pressure	No data	No data	No data	No data
Henry's law constant	No data	No data	No data	No data
Autoignition temperature	No data	No data	No data	No data
Flashpoint	No data	No data	No data	No data
Flammability limits	No data	No data	No data	No data
Conversion factors	No data	No data	No data	No data
Explosive limits	No data	No data	No data	No data

[a]All information obtained from HSDB 2007; ChemFinder 2007, and Lide 2005, except where noted.
[b]Molecular weights will be dependent on the isotope of plutonium.
[c]α-phase, simple monoclinic; β-phase, body-centered monoclinic; γ-phase, face-centered orthorhombic; δ phase, face-centered cubic; δ'' phase, body-centered tetragonal; $\varepsilon\varepsilon$ phase, body-centered cubic (Clark et al. 2006)
[d]$Pu(C_2O_4)_2 \cdot 6H_2O$ (CAS No. 26588-74-9) (Clark et al. 2006)

Table 4-3. Radiological Properties of Plutonium Isotopes

Isotope	CAS Registry No.	Half-life	Decay mode(s)/ Energy (MeV)	Decay product(s)	Specific activity (Ci/g)
^{236}Pu	15411-92-4	2.87 years 1.5×10^{9} years	α/ 5.867 MeV SF/1.9×10^{-7} MeV	^{232}U	540
^{237}Pu	15411-93-5	45.7 days	EC/ 0.220(99.9%) α/ 5.747 (0.003%)	^{233}U	12,100[a]
^{238}Pu	13981-16-3	87.7 years 4.75×10^{10} years	α/ 5.593 SF/ 1.8×10^{-7}	^{234}U	17
^{239}Pu	15117-48-3[b] 19257-39-7[c]	2.410×10^{4} years 8×10^{15} years	α/ 5.244 SF/ 3×10^{-10}	^{235}U	0.063
^{240}Pu	14119-33-6	6.56×10^{3} years 1.14×10^{11} years	α/ 5.255 SF/ 5.7×10^{-6}	^{236}U	0.23
^{241}Pu	14119-32-5	14.4 years <6×10^{16} years	β^-/ 0.0208 (99+%) α/ 5.139 (0.002%) SF/ >2.4×10^{-14}	^{241}Am ^{237}U	100
^{242}Pu	13982-10-0	3.75×10^{5} years 6.77×10^{10} years	α/ 4.983 SF/ 5.5×10^{-4}	^{238}U	0.0040
^{243}Pu	15706-37-3	4.956 hour	β^-/ 0.582	^{243}Am	2.6×10^{6}[c]
^{244}Pu	14119-34-7	8.00×10^{7} years 6.6×10^{10} years	α/ 4.665 (99.9%) SF/ 0.12	^{240}U	1.8×10^{-5}

[a]Calculated values
[b]Another CAS Registry number listed for ^{239}Pu is 97918-67-7
[c]CAS Registry Number for $^{239}Pu^{4+}$ ion

α = alpha particle emission; β^- = negative beta emission; SF = spontaneous fission

Sources: Baum et al. 2002; ChemIDplus 2007; Clark et al. 2006; DOE 2005a; Lide 2005