1. Source and Special Fissionable Material

1.1. Uranium containing the mixture of isotopes occurring in nature; uranium depleted in the isotope 235; thorium; any of the foregoing in the form of metal, alloy, chemical compound or concentrate and any other goods containing one or more of the foregoing.

1.2. Low Enriched Uranium (LEU), or plutonium as follows:
Uranium enriched to less than 20% of the isotopes 233, 235, or both; plutonium with an isotopic concentration of Pu-238 exceeding 80%; any of the foregoing in the form of metal, alloy, chemical compound or concentrate and any other goods containing one or more of the foregoing, other than irradiated nuclear fuel (see item 1.4).

1.3. *Highly Enriched Uranium (HEU) or plutonium, as follows:
Uranium enriched to 20% or more in the isotopes 233, 235, or both; plutonium containing less than 80% plutonium 238; any of the foregoing in the form of metal, alloy, chemical compound or concentrate and any other goods containing one or more of the foregoing, other than irradiated nuclear fuel (see item 1.4), <u>except for the following items which are not prohibited, but are controlled:</u>

Sub-gram amounts of the special fissionable material specified in 1.3 above in the form of:

(a) certified reference material;

(b) instrument calibration source; or

(c) sensing component in instruments.

1.4. *Irradiated nuclear fuel

<u>EXPLANATORY NOTE:</u>
The prohibition applies only to the transfer of irradiated nuclear fuel to Iraq.

Typical Appearance

As Manufactured: Natural uranium consists of three isotopes: ^{238}U (99.27%), ^{235}U (0.72%), and ^{234}U in trace amounts. Natural thorium consists almost entirely of the isotope ^{232}Th. The isotopes ^{238}U and ^{232}Th, which constitute the bulk of these elements occurring naturally, when irradiated by a neutron flux, produce the isotopes ^{239}Pu and ^{233}U, respectively.[a]

Ore deposits of uranium- and thorium-containing minerals occur in nature. Commercially mined uranium minerals include uraninite, pitchblende, autunite, tobernite, coffinite, and carnotite; those for thorium include monazite, thorite, and thorianite. Depending on the nature of the deposit, various chemical processes are used for the extraction, conversion, and purification of these elements. These processes often require several intermediate steps, at each of which the desired element may exist as a different compound. The important uranium compounds and their properties resulting from these processes, as well as from various enrichment techniques, are listed in Table 1.1; Table 1.2 lists those for thorium. Selected uranium compounds are also shown in Figure 1.1. Table 1.3 lists the main compounds existing at various stages during the processes used for the separation of plutonium from irradiated uranium source material and the fabrication of plutonium metal. It should be kept in mind that although these tables cover the intermediate compounds formed during what are believed to be the most widely used and easily accessible processes, competing processes may involve additional compounds not listed in the tables.

[a] Pu is not a naturally occurring element.

Table 1.1. Uranium compounds of interest.

Compound	Appearance[†]	Properties/Handling
Ammonium, magnesium, or sodium diuranite; "yellow-cake"	Bright yellow solid	Packaged and shipped in steel drums with a polyethylene liner
Uranyl nitrate ($UO_2(NO_3)_2$)	Yellow crystalline solid	m.p. 118°C[††]
Uranium trioxide (UO_3)	Orange solid	Stable in air up to 450 - 600°C
Uranium dioxide (UO_2)	Dark brown cinnamon-colored powder	m.p. 2827°C
Uranium tetrafluoride (UF_4) "green salt"	Emerald-green solid	m.p. 1036°C; insoluble in water
Uranium hexafluoride (UF_6)	Colorless crystalline solid	m.p. 64°C; reacts violently with water and oils; corrosive to many metals; sublimates at 56.4°C; shipped as a solid in specially designed cylinders
Uranium tetrachloride (UCl_4)	Dark green solid	m.p. 590°C; soluble in water
Uranium trihydride (UH_3)	Black powder	Highly reactive, pyrophoric
Uranium carbide (UC)	Gray-black solid	m.p. 2525°C; reactive with moist air, steam, or water
Uranium nitride (UN)	Gray-black solid	m.p. 2805°C; reactive with moist air, steam, or water

[†] At ambient temperature and atmospheric pressure.

[††] m.p. = melting point.

Table 1.2. Thorium compounds of interest.

Compound	Appearance[†]	Properties
Thorium dioxide (ThO_2)	White solid	m.p. 3390°C[††]; stable, refractory
Thorium tetrafluoride (ThF_4)	White crystalline solid	m.p. 1110°C; hygroscopic
Thorium nitrate ($Th(NO_3)_4$)	White crystalline solid	Decomposes at 500°C; hygroscopic; very soluble in water; very reactive with oxidizers
Thorium dicarbide (ThC_2)	Yellow solid	m.p. 2650°C
Thorium tetrachloride ($ThCl_4$)	Gray-white crystalline solid in the form of needles	m.p. 770°C; hygroscopic; very soluble in water
Thorium hydride (ThH_2)	Gray to black powder	Highly reactive, pyrophoric

[†] At ambient temperature and atmospheric pressure.
[††] m.p. = melting point.

Table 1.3. Plutonium compounds of interest.

Compound	Appearance[†]	Properties
Plutonium nitrate ($Pu(NO_3)_4$)	Aqueous solution Pu(IV) in weak nitric acid solution: brown with a tinge of red Pu(IV) in strong nitric acid solution: green Pu(III) in nitric acid solution: blue	Calcined at 350°C Radioactive, neutron and gamma; extremely toxic
Plutonium dioxide (PuO_2)	Yellow-black to green solid; powder or shiny particles	m.p. 2390°C[††]; stable
Plutonium trifluoride (PuF_3)	Blue-violet solid	m.p. 1425°C; insoluble in water
Plutonium tetrafluoride (PuF_4)	Pink-brown solid	m.p. 1027°C
Plutonium trichloride ($PuCl_3$)	Blue-green crystalline solid	m.p. 760°C; soluble in water
Plutonium oxalate ($Pu_2(C_2O_4)_3 \cdot (10H_2O)$)	Bright green solid	Calcined at 450°C

[†] At ambient temperature and atmospheric pressure.
[††] m.p. = melting point.

Pure metallic forms of uranium and plutonium are most useful for constructing nuclear weapons. Metallic uranium is ductile with a density of 19.07 g/cm^3. It is lustrous silvery-white when polished but quickly tarnishes when exposed to air, becoming coated with a dark-colored layer of oxide. Figure 1.2 shows a dime-sized sphere of highly enriched uranium (HEU) covered with a dark oxide layer. Note its similarity in appearance to the deformed lead sphere also shown in the figure. Unenriched uranium metal has been produced in ingots with dimensions up to 25 cm in diameter and a height of 25 cm. The amount of both low enriched uranium (LEU) and HEU metal or its compounds that can be produced and stored in a given locale is limited by criticality concerns. (See Cautions below.)

Plutonium metal is silvery when polished, similar to nickel. It has a density of 19.86 g/cm^3. When exposed to air, plutonium first takes on a yellow tarnish when slightly oxidized and eventually becomes coated with a powdery green layer of plutonium dioxide (PuO_2) (Figure 1.3). Plutonium metal is produced by reducing either PuO_2 or plutonium fluoride, yielding a button similar to that shown in Figure 1.4. Figure 1.5 shows a high-purity (greater than 99.99%) plutonium ring produced by electrorefining. Criticality concerns again place limits on the amount of plutonium metal or its compounds that may be produced and stored.

Pure thorium metal is soft and very ductile, with a density of 11.7 g/cm^3. It is silvery-white when polished and air-stable, retaining its luster for several months. When exposed to air, thorium tarnishes, becoming gray and finally black. Procedures for thorium purification may yield either solid metal billets or a powder. There are no criticality concerns associated with the amount of thorium metal or its compounds that may be produced and stored.

As Packaged: Dry uranium ore concentrate, known as "yellowcake," is typically shipped from a mill in polyethylene-lined steel drums. Once converted into uranium hexafluoride (UF_6) (see Chapter 6), it is shipped as a solid in specially designed steel cylinders. Figure 1.6 shows a large cylinder (diameter 1.2 m,

Figure 1.1. Uranium compounds formed at various processing steps.

Figure 1.2. From left to right, clad plutonium pellet, highly enriched uranium sphere, and deformed lead sphere.

Figure 1.3. Plutonium dioxide.

length 3 m) used for transporting UF_6 enriched to a maximum of 4.5% ^{235}U. Because of criticality concerns, much smaller cylinders are used to transport highly enriched UF_6. Two such cylinders are shown in Figure 1.7. Because of its intense radioactivity, irradiated spent nuclear fuel is shipped in specially designed shipping casks like the one shown in Figure 1.8. (See Section 49.8.d.) These casks provide both shielding and protection against insult.

Because of its chemical reactivity, metallic plutonium is normally packaged in an inert atmosphere, such as dry argon or nitrogen using glove box techniques or remote handling equipment. Because it is primarily an alpha (α) emitter, plutonium metal can be transported without shielding. In plutonium compounds with light elements, especially fluorides, the (α, n) reaction can produce significant neutron dose rates, and shielding is required. Transport of such compounds, many of which are highly volatile, would require great care.

Special containers known as “pigs” are used to transport highly enriched special fissionable materials to guard against possible nuclear criticality. These containers are fabricated into special geometries using neutron-absorbing materials. Criticality concerns place limits on the quantities of these materials that can be transported safely.

Uranium and thorium metal should require a shipping label of “Radioactive, Spontaneously Combustible.” Uranylnitrate (solid) and thorium nitrate require a shipping label of “Radioactive, Oxidizer.”

Cautions: Uranium, plutonium, and their compounds pose significant chemical and radiological health hazards. Neither thorium nor its compounds present significant chemical hazards. Because thorium is an α-emitter, it is classified as an industrial health hazard. Actually, with a long half-life (1.41×10^{10} yr) and low activity, it poses only minimal radiological hazards. In powdered or finely divided form, pure uranium, plutonium, and thorium metals are all pyrophoric and can spontaneously ignite in the presence of air at room temperature.

Figure 1.4. Metallic plutonium button produced by direct oxide reduction.

Figure 1.5. Plutonium ring (~14 cm in diameter) produced by electrorefining.

Figure 1.6. Cylinder for transporting uranium hexafluoride.

There are several cautions associated with UF_6. Chemically, it is extremely reactive with both water and many organic compounds, such as oils and lubricants. For this reason, all systems used for carrying and processing UF_6 must be extremely clean and free of leaks. When being loaded for transport, a cylinder is typically filled with liquid UF_6 that is then allowed to cool and solidify, resulting in an eccentric center of gravity. For large cylinders, this may add to the normal hazards of handling heavy loads.

Because plutonium is a strong α-emitter, there is concern about radiotoxicity through inhalation of airborne particles or from contamination injuries. For kilogram quantities of weapons-grade plutonium, the α-radiation dose rates at the surface can be substantial (0.025 Gy/hr), and the use of lead-lined gloves is recommended if the material is to be handled. When substantial fractions of plutonium isotopes other than ^{239}Pu are present, the γ- and x-ray dose rates necessitate radiation shielding to protect workers.

A mass of metallic plutonium is warm because of its intense α activity, with larger pieces producing enough heat to boil water.

Extreme caution must be exercised when handling quantities of special nuclear materials approaching critical mass, i.e., the mass of a substance at which a fission chain reaction becomes possible. This critical mass depends on several factors: the form and concentration of the material, the geometry of the system, the presence of moderators (particularly water or other hydrogen-containing compounds), the proximity of neutron reflectors, and the potential interaction of neighboring fissile systems. Increasing the distance between neighboring fissile substances and eliminating moderating materials both serve to reduce the chance of criticality.

Nuclear Uses

Metal or compounds enriched in any of the fissile isotopes ^{235}U, ^{233}U, and ^{239}Pu are of immediate concern for possible nuclear

Figure 1.7. Cylinders (12.7 cm diameter, 1 m length) used for transporting highly enriched uranium hexafluoride.

Figure 1.8. Shipping cask for transporting spent nuclear fuel.

explosive applications. Ceramic oxide forms of uranium or a mixture of uranium and plutonium oxides is used as a fuel in commercial nuclear power reactors. Both ^{232}Th and ^{238}U have been used as blanket materials in nuclear reactors, producing, via neutron irradiation, ^{233}U and ^{239}Pu, respectively. Depleted uranium, i.e., uranium with a ^{235}U concentration less than that of naturally occurring uranium, is used as a shielding material and as a target material for the production of high-energy x-rays.

Plutonium-238 is used in radioisotope thermal generators, providing electrical power for space missions.

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