5. PRODUCTION, IMPORT/EXPORT, USE, AND DISPOSAL

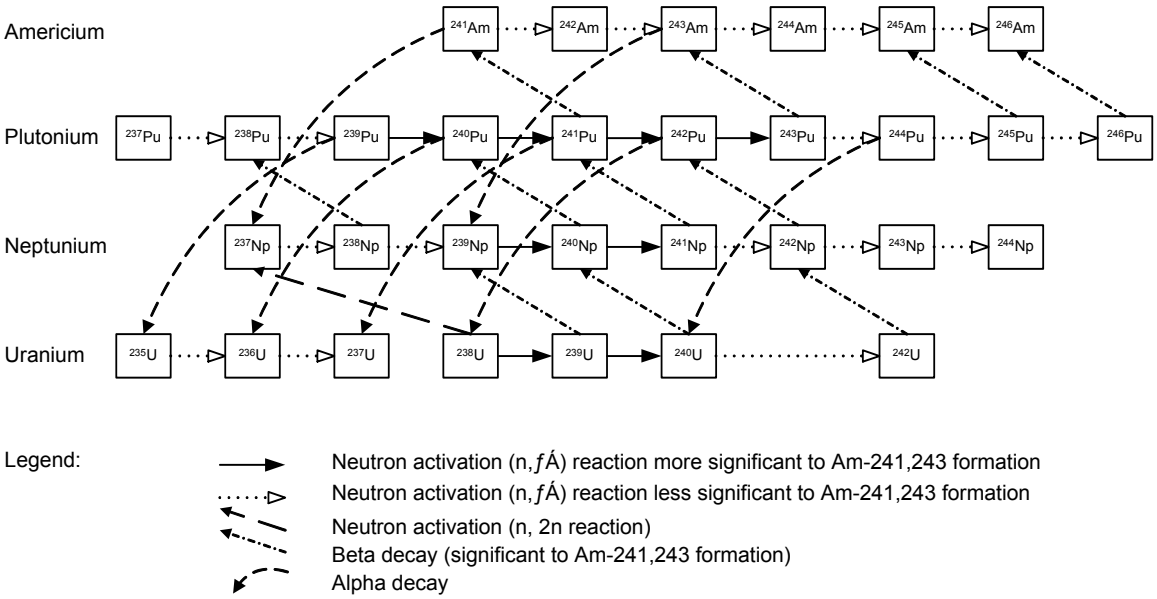
5.1 PRODUCTION

Americium does not occur in nature. Although the amount of ^{241}Am produced is believed to be several kilograms a year, the only isotope produced for commercial use is ^{241}Am. No production figures were available in the published literature. The amount of ^{243}Am available ranges from 10 to 100 g (Seaborg and Loveland 1990).

^{241}Am and ^{243}Am can be made from ^{239}U or ^{239}Pu by neutron activation involving an operating nuclear reactor or nuclear bomb detonation. In this process, neutron activation of ^{238}U can produce uranium isotopes up to at least ^{241}U, and each of these beta decays to a neptunium isotope of the same mass. Neutron activation of neptunium can produce isotopes starting with ^{239}Np up through at least ^{244}Np, and each of these isotopes beta decays to a plutonium isotope of the same mass. Neutron activation of plutonium isotopes starting with ^{239}Pu can produce isotopes through at least ^{246}Pu, and of these, ^{241}Pu, ^{243}Pu, ^{245}Pu, and ^{246}Pu beta decay to americium isotopes of the same mass. ^{241}Am can be produced more directly through alpha bombardment of ^{238}U to ^{241}Pu (^{238}U [α,n] ^{241}Pu), and its subsequent beta decay. Each of these americium isotopes can also be neutron activated to isotopes up through at least ^{246}Am. The amount of any product is a function of the starting mass of either ^{238}U or ^{239}Pu and the neutron fluence over the activation period balanced by the natural radioactive decay of the isotopes being formed. For example, an atom of ^{239}Pu will naturally decay to ^{235}U, unless it is first neutron activated to ^{240}Pu. ^{240}Pu will alpha decay to ^{236}U, unless first activated to ^{241}Pu. ^{241}Pu will beta decay to ^{241}Am, unless first neutron activated to ^{242}Pu. These processes can be managed through focused radiochemical separation or by the addition of special processing (proton bombardment) to help direct the effort toward a particular isotopic product (Parrington et al. 1996). In general, lower mass isotopes are preferentially produced in the relatively low fluxes available inside nuclear reactors, while higher masses are more feasibly produced in extreme flux conditions present inside a nuclear detonation. These processes are summarized in Figure 5-1.

The relative activities of americium isotopes for a typical pressurized-water reactor (PWR) fuel assembly are 1,500, 7.2, and 20 Ci (56, 0.27, and 0.74 TBq) for ^{241}Am, ^{242}Am, and ^{243}Am, respectively (DOE

Figure 5-1. Production Table for ^{241}Am



*developed from Parrington et al. (1996)

2002a). The respective activity ratios for a typical boiling water reactor (BWR) are 370, 2.1, and 4.8 Ci (14, 0.078, and 0.18 TBq). There are 78 PWRs and 40 BWRs in the United States, several of which have ceased operation. Total projected inventories of these three radionuclides for all reactors are $2.2x10^8$, $1.6x10^6$, and $1.9x10^6$ Ci ($8.1x10^6$, $5.9x10^4$, and $7.0x10^4$ TBq), respectively. The post-irradiation americium content of typical PWR and BWR fuel assemblies are 600 g (0.09%) and 220 g (0.07%), respectively.

The ratio of plutonium isotopes to ^{241}Am is often reported in monitoring studies as it is an important tool in dose assessment by enabling a determination of plutonium concentrations. ^{243}Am is produced directly by the capture of two neutrons by ^{241}Am. The parent of ^{241}Am is ^{241}Pu, which constitutes about 12% of the 1% content of a typical spent fuel rod from a nuclear reactor, and has a half-life of 14.4 years. Separation of ^{241}Am from its parent, ^{241}Pu, and the other isotopes present can be effected by precipitation, ion exchange, or solvent extraction.

Americium metal has been obtained by heating americium oxide, Am_2O_3, with lanthanum at 1,200 EC; americium, which is more volatile than other actinides, volatilizes and can readily be separated from other actinides. AmO_2 can be obtained by igniting most trivalent americium compounds (Budavari 1996; Cotton and Wilkinson 1980; UIC 1997).

5.2 IMPORT/EXPORT

No U.S. import or export information is available for americium.

5.3 USE

^{241}Am has a long half-life and a predominant gamma ray energy of 59.5 keV, which makes it useful for a wide range of industrial gauging applications and for diagnosing certain thyroid disorders (Seaborg 1991). The most common application of americium is in ionization smoke detectors, and most of the several kilograms of americium produced each year are used for this purpose. Smoke detectors today typically contain approximately 1 µCi (37 kBq) of ^{241}Am (EPA 2004b). One gram of americium dioxide, AmO_2, provides enough active material for more than 5,000 smoke detectors. In the 1980s, annual sales of smoke detectors approached 12 million units. A mixture of ^{241}Am and beryllium known as ^{241}Am-Be is used as a neutron source in non-destructive testing of machinery and equipment, and as a thickness gauge

in the glass industry (UIC 1997). ^{241}Am is used worldwide to measure the rate of production by oil wells (Seaborg 1991). No commercial uses for other americium isotopes were found. However, ^{243}Am can be used as a target material for the production of transcurium elements in high neutron flux reactors (Budavari 1996). ^{243}Am is also the preferred isotope for investigating the chemical properties of americium, because its lower specific activity and gamma emissions relative to ^{241}Am, which produce a lower radiation field for researchers and a lower radiation dose to experimental animals.

5.4 DISPOSAL

Radioactive wastes are categorized according to their origin, the type of waste present, and their level of activity. The first distinction is between defense waste and commercial waste. The former was generated during and after World War II, principally at DOE's facilities at Hanford, Washington; Savannah River, South Carolina; and Idaho Falls, Idaho where plutonium and other isotopes were separated from production reactor or nuclear-powered naval vessel spent fuel. Commercial waste is produced by nuclear power plants, except for the long defunct commercial reprocessing facility at West Valley, New York. Nuclear waste is classified as transuranic waste (TRU), high-level waste (HLW), spent nuclear fuel (SNF), uranium and thorium mill tailings (UMT), and low-level waste (LLW). LLW is further differentiated into four classes, A, B, C, and greater than class C, according to increasing level of activity (listed in Tables 1 and 2 of 10 CFR 61.55 for long and short half-life radionuclides, respectively), with specific disposal requirements (USNRC 2004a). SNF, HLW, TRU, and greater than class C (GTCC) waste are not generally suitable for near-surface disposal (EPA 2004d). Class C waste would include much of the operating and decommissioning waste from nuclear power plants, typical radioactive material licensee facilities, and sealed radioisotope sources. LLW (less GTCC) is currently accepted at three sites (Barnwell, South Carolina; Envirocare, Utah; and Richland, Washington). Defense TRU is currently being buried at the Waste Isolation Pilot Plant (WIPP) 2,150 feet below ground in a geologically inactive salt deposit near Carlsbad, New Mexico (EPA 2004e). GTCC, HLW, and SNF are destined for disposal at a HLW site, which is likely to be at Yucca Mountain, Nevada (USNRC 2004b). Yucca's 25-foot diameter main access tunnel and test disposal drifts have been bored, and research is underway to test and reduce uncertainties associated with various modeling parameters used to provide assurance that isolation of the waste from the biosphere for 10,000 years will be feasible (DOE 2004). If LLW also contains hazardous material (i.e., toxic, corrosive, inflammable, or oxidizing), it is termed low level mixed waste (LLMW). EPA is considering the feasibility of disposing of some LLMW in RCRA-C landfills, and the EPA public comment period ended in April, 2004. Large volumes of mixed chemical and radioactive

liquid waste at the Hanford Reservation are slated for disposal at the future HLW repository; however, Hanford is considering managing the waste in a way that destroys the volatile organics and PCBs, separating the resulting waste into low and high level component streams, vitrifying each, disposing of the low activity waste on site in a virtual LLW facility, and holding the vitrified HLW until Yucca or the selected facility opens. UMT waste does not concern americium (DOE 1999a; Murray 1994).

TRU contains radionuclides, like ^{241}Am and ^{243}Am, which follow uranium in the periodic table and have half-lives >20 years. If its level of activity is less than 100 nanocuries (nCi) (3.7 kBq) of alpha-emitters per gram of waste material (up from 10 nCi/g in 1982), the waste can be disposed of by shallow burial. Wastes with TRU concentrations >100 nCi/g go to WIPP. TRU generally has low levels of radioactivity, generates very little heat, contains volatile organics, and is grouped as contact handled (CH) with surface radiation levels not exceeding 200 mrem per hour, or remote handled (RH) waste with surface levels above 200 but not exceeding 1,000 mrem per hour (EPA 2004d).

HLW includes spent fuel that is contained in fuel rods that have been used in a nuclear reactor and fuel reprocessing liquids, concentrates, and solids. These fuel rods will contain some level of transuranic elements. After removal, these rods are placed in pools adjacent to the commercial nuclear power plants and DOE facilities where they were produced. It was originally intended that the fuel rods remain in these pools for only about 6 months to allow for a reduction in radioactivity and temperature, and then be transferred to a reprocessing or storage facility. There is no commercial reprocessing facility or permanent disposal facility for HLW operating in the United States. The USNRC has issued standards for the disposal of HLW (10 CFR 61), and the DOE is pursuing the establishment of an HLW facility. Efforts to establish an HLW facility, which began over 2 decades ago, have experienced many delays. However, in July 2002, the U.S. Congress and the President selected Yucca Mountain, Nevada as the nation's first long-term repository for HLW. The underground tunnel system and several of its operational facilities have been completed through 2004. The facility is projected to begin operation (accept HLW) in 2010, and efforts are underway to consider establishing a nearby interim storage facility should that date need to be extended beyond the capacity of utilities to provide onsite storage of their SNF (DOE 2002b, 2004).

LLW is officially defined as radioactive waste other than those previously defined. These wastes come from reactors and institutions such as hospitals, universities, and research centers. Most LLW contains very little or low concentrations of primarily short-lived radioactivity and essentially no transuranic elements. It requires little or no shielding or special handling, and may be disposed of by shallow burial.

However, some LLW contains sufficient quantities of radioactivity as to require special treatment. USNRC regulations for LLW disposal (10 CFR 61) permit shallow land burial, and the three states with licensed LLW disposal facilities (South Carolin, Utah, and Washington), as USNRC agreement states, have enacted more stringent regulations (Eisenbud 1987; Murray 1994; USNRC 2004c). The EPA is developing cleanup regulations as well as general environmental standards for LLW disposal that would apply to DOE facilities (EPA 2001d). The standards will facilitate planning and reduce costs for cleanup and disposal. There are currently 23 DOE and commercial LLW disposal sites in the United States (EPA 2001d). While some LLW facilities are closed, they are continuously monitored to detect releases of radioactivity into the environment. The Manifest Information Management System (MIMS), maintained by the Idaho National Environmental and Engineering Laboratory (INEEL), contains information on low-level radioactive waste shipments received at commercial low-level radioactive waste disposal facilities at Barnwell, South Carolina (January 1, 1986–present); Beaty, Nevada (April 1, 1986–December 31, 1992); Richland, Washington (January 1, 1986–present); and Envirocare, Utah (January 1, 1998–December 31, 1999). In 1999, 3.67 Ci (136 GBq) of ^{241}Am and <0.01 Ci (<0.4 GBq) of ^{243}Am LLW was received at these facilities from academic, industrial, government, and utility generators throughout the United States (INEEL 2000).

The USNRC and EPA each have responsibilities for regulating the cleanup of radioactivity and decommissioning of USNRC licensed sites. USNRC and EPA reached an agreement in 2002, in response to Congressional mandate, to preclude double regulation of these efforts. The agreement provides that EPA will defer exercise of authority under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) for the majority of facilities decommissioned under USNRC authority. It also contains provisions for joint consultation when certain EPA parameters are exceeded, including groundwater exceeding EPA-permitted levels, USNRC contemplation of restricted release or alternate release criteria, and residual soil radioactivity concentrations exceeding those in the agreement (USNRC 2002).

At present, DOE stores most of its spent fuel and HLW at three primary locations: the Hanford site in Washington, the INEEL in Idaho, and the Savannah River Site in South Carolina, representing 86% of the volume and 98% of the metal mass. Some HLW/SNF is also stored at Oak Ridge National Laboratory in Tennessee, the West Valley site in New York, and the dry storage facility at Fort St. Vrain in Colorado (DOE 2002c). Much smaller amounts of spent nuclear fuel stored at other sites were to be shipped to the three prime sites for storage and preparation for ultimate disposal (DOE 1999a). The DOE National Spent Fuel Program maintains a spent nuclear fuel database that lists the total volume, mass, and metric

tons of heavy metal (MTHM) of 16 DOE categories of spent nuclear fuel stored in each of the three locations. The categories having the highest ^{241}Am activities per spent nuclear fuel canister (decayed to 2030) are 'uranium metal', 'mixed oxides', and 'plutonium/uranium carbide, nongraphite'. The ^{241}Am solid waste stored on the Hanford site in 1998 included 2.3 Ci (85 GBq) as LLW and 11 Ci (410 GBq) as TRU (Hanford 1999). Between 1945 and 1970, the Farallon Islands Nuclear Waste Dump Site (FINWDS), approximately 30 miles west of San Francisco, received at least 500 TBq (14,000 Ci) of reportedly low-level nuclear waste, concrete-encapsulated in at least 47,500 55-gallon, 16-gauge steel drums (life-expectancy ~30 years in sea water) (Suchanek et al. 1996). These were deposited at three sites 100, 900, and 1,800 m deep.

According to EPA (2004a), smoke detectors (with the batteries removed) can be disposed of in the trash. However, EPA also notes that state and local practices for the safe disposal of smoke detectors vary. Some state radiation control programs conduct annual collection programs for smoke detectors, while other state and local governments recommend that the smoke detector be returned to the supplier (EPA 2004b).