

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

5.1 PRODUCTION

Cobalt is the 33rd most abundant element, comprising approximately 0.0025% of the weight of the earth's crust. It is often found in association with nickel, silver, lead, copper, and iron ores and occurs in mineral form as arsenides, sulfides, and oxides. The most important cobalt minerals are: linnaeite, Co_3S_4 ; carrolite, CuCo_2S_4 ; safflorite, CoAs_2 ; skutterudite, CoAs_3 ; erythrite, $\text{Co}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$; and glaucodot, CoAsS (Hodge 1993; IARC 1991; Merian 1985; Smith and Carson 1981). The largest cobalt reserves are in the Congo (Kinshasa), Cuba, Australia, New Caledonia, United States, and Zambia. Most of the U.S. cobalt deposits are in Minnesota, but other important deposits are in Alaska, California, Idaho, Missouri, Montana, and Oregon. Cobalt production from these deposits, with the exception of Idaho and Missouri, would be as a byproduct of another metal (USGS 2004). Cobalt is also found in meteorites and deep sea nodules.

The production of pure metal from these ores depends on the nature of the ore. Sulfide ores are first finely ground (i.e., milled) and the sulfides are separated by a floatation process with the aid of frothers (i.e., C_5 – C_8 alcohols, glycols, or polyethylene or polypropylene glycol ethers). The concentrated product is subjected to heating in air (roasting) to form oxides or sulfates from the sulfide, which are more easily reduced. The resulting matte is leached with water and the cobalt sulfate leachate is precipitated as its hydroxide by the addition of lime. The hydroxide is dissolved in sulfuric acid, and the resulting cobalt sulfate is electrolyzed to yield metallic cobalt. For the cobalt-rich mineral cobaltite, a leaching process with either ammonia or acid under pressure and elevated temperatures has been used to extract cobalt. The solution is purified to remove iron and is subsequently reduced by hydrogen in the presence of a catalyst under elevated temperature and pressure to obtain fine cobalt powder (Duby 1995; Nagaraj 1995; Planinsek and Newkirk 1979).

Except for a negligible amount of byproduct cobalt produced from some mining operations, no cobalt is presently mined or refined in the United States. In addition to byproduct production, U.S. production is derived from scrap (secondary production). In 2003, an estimated 2,200 metric tons of cobalt were recycled from scrap (USGS 2004). Since 1993, production has been supplemented by sales of excess cobalt from the National Defense Stockpile (NDS), which the government maintains for military,

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industrial, and essential civilian use during national emergencies. In fiscal year 2002, 2,720 metric tons of cobalt were released from the NDS. In 2001, the United States did not mine or refine cobalt, with the exception of small amounts of byproduct cobalt produced from mining operations in Missouri and Montana. The 2002 U.S. consumption of cobalt metal, organic and inorganic cobalt compounds, and purchased scrap (in terms of cobalt content) was 3,870, 1,270, and 2,800 metric tons, respectively (USGS 2002).

Current U.S. manufacturers of selected cobalt compounds are given in Table 5-1. Table 5-2 lists facilities in each state that manufacture, process, or use cobalt or cobalt compounds, the intended use, and the range of maximum amounts of these substances that are stored on site. In 2000, there were 618 reporting facilities that produced, processed, or used cobalt or cobalt compounds in the United States. The data listed in Table 5-2 are derived from the Toxics Chemicals Release Inventory (TRI) (TRI01 2004). Only certain types of facilities were required to report. Therefore, this is not an exhaustive list.

^{60}Co is produced by irradiating stable cobalt, ^{59}Co , with thermal neutrons in a nuclear reactor: $^{59}\text{Co}(n,\gamma)^{60}\text{Co}$. The neutron flux employed is 10^{12} – 10^{15} $n/\text{cm}^2\text{-sec}$ and the conversion is 99%. The maximum specific activity obtained is 3.7×10^{13} Bq/g (1,000 Ci/g). Commercial ^{60}Co sources used for bacterial sterilization are made into rods with double metal shielding. The individual sources have an activity of about 2×10^{14} – 6×10^{14} Bq (6–15 kCi). The annual output of ^{60}Co was about 2×10^{18} – 3×10^{18} Bq (50–80 MCi) in the early 1990s. In 1991, there were 170 gamma irradiation systems operating in 45 countries having a total activity of about 6×10^{18} Bq (160 MCi) (Zyball 1993). Producers of ^{60}Co include MDS Nordion in Canada, AEA Technology (formerly Amersham QSA) in the United Kingdom, and Neutron Products in Dickerson, Maryland.

^{58}Co is not produced commercially. It can be produced by irradiating ^{58}Ni , a stable isotope, with neutrons, followed by positron decay: $^{58}\text{Ni}(n,\gamma)^{58}\text{Co}$. It can be produced in a nuclear reactor or a cyclotron. Both ^{60}Co and ^{58}Co may be produced unintentionally in reactors. These are the dominant sources of residual radiation in the primary circuit outside the reactor core of nuclear plants and are formed by neutron absorption of ^{59}Co and ^{58}Ni , both stable isotopes commonly used in plant construction materials (Taylor 1996). ^{60}Co is commonly found as one of the radionuclides present in the low-level radioactive waste discharges from many nuclear power plants; however, amounts rarely make a significant contribution to the radiation exposure of the public (Leonard et al. 1993a). The geometric

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Table 5-1. Current U.S. Manufacturers of Cobalt Metal and Selected Cobalt Compounds^a

Company	Location
Cobalt metal ^b :	
Kennametal, Inc.	Latrobe, Pennsylvania
OM Group, Inc.	Cleveland, Ohio
Cobalt (II) acetate:	
The IMC Group	Shelby, North Carolina
McGean-Rohco, Inc., McGean Specialty Chemicals Division	Cleveland, Ohio
OM Group, Inc.	Franklin, Pennsylvania
The Shepard Chemical Company	Cincinnati, Ohio
Cobalt (II) carbonate:	
The IMC Group	Shelby, North Carolina
McGean-Rohco, Inc., McGean Specialty Chemicals Division	Cleveland, Ohio
OMG Apex	St. George, Utah
OM Group, Inc.	Franklin, Pennsylvania
The Shepherd Chemical Co.	Cincinnati, Ohio
Cobalt (II) chloride:	
The IMC Group	Shelby, North Carolina
Johnson Matthey, Inc., Alfa Aesar	Ward Hill, Massachusetts
McGean-Rohco, Inc., McGean Specialty Chemicals Division	Cleveland, Ohio
OM Group, Inc.	Franklin, Pennsylvania
The Shepard Chemical Company	Cincinnati, Ohio
Cobalt (II) hydroxide:	
McGean-Rohco, Inc., McGean Specialty Chemicals Division	Cleveland, Ohio
OM Group, Inc.	Franklin, Pennsylvania
The Shepard Chemical Company	Cincinnati, Ohio
Cobalt (II) nitrate:	
The IMC Group	Shelby, North Carolina
Johnson Matthey, Inc., Alfa Aesar	Ward Hill, Massachusetts
McGean-Rohco, Inc., McGean Specialty Chemicals Division	Cleveland, Ohio
OMG Apex	St. George, Utah
OM Group, Inc.	Franklin, Pennsylvania
The Shepard Chemical Company	Cincinnati, Ohio
Umicore USA, Inc., Cobalt Products	Laurinburg, North Carolina
Cobalt (II) oxide:	
OMG Apex	St. George, Utah
The Shepard Chemical Company	Cincinnati, Ohio

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Table 5-1. Current U.S. Manufacturers of Cobalt Metal and Selected Cobalt Compounds^a

Cobalt (III) oxide:	
Johnson Matthey, Inc., Alfa Aesar	Ward Hill, Massachusetts
Mallinckrodt Baker, Inc.	Phillipsburg, New Jersey
McGean-Rohco, Inc., McGean Specialty Chemicals Division	Cleveland, Ohio
OM Group, Inc.	Franklin, Pennsylvania
Osram Sylvania Inc.	Towanda, Pennsylvania
Cobalt (II) sulfate:	
The IMC Group	Shelby, North Carolina
McGean-Rohco, Inc., McGean Specialty Chemicals Division	Cleveland, Ohio
OMG Apex	St. George, Utah
OM Group, Inc.	Franklin, Pennsylvania
The Shepard Chemical Company	Cincinnati, Ohio

^aDerived from Stanford Research Institute (SRI) 2003, except where otherwise noted. SRI reports production of chemicals produced in commercial quantities (defined as exceeding 5,000 pounds or \$10,000 in value annually) by the companies listed

^bU.S. members of The Cobalt Development Institute that are listed as producers of cobalt powder or hard metal products

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Table 5-2. Facilities that Produce, Process, or Use Cobalt and Cobalt Compounds

State ^a	Number of facilities	Minimum amount on site in pounds ^b	Maximum amount on site in pounds ^b	Activities and uses ^c
AK	2	10,000	999,999	1, 5, 7, 12
AL	22	100	999,999	1, 2, 3, 4, 5, 6, 7, 8,9, 10, 12, 13
AR	9	100	99,999	1, 5, 7, 8,9
AZ	12	1,000	49,999,999	1, 2, 3, 5, 7, 8,9, 10, 12, 13, 14
CA	28	0	9,999,999	1, 2, 3, 5, 6, 7, 8,9, 10, 11, 12
CO	1	10,000	99,999	12
CT	9	0	999,999	2, 3, 7, 8
DE	2	1,000	9,999	1, 5,9, 13
FL	11	0	99,999	1, 2, 3, 4, 5, 6, 7, 8,9, 12, 13, 14
GA	17	100	999,999	1, 2, 3, 4, 5, 6, 7, 8,9, 11, 12, 13
IA	6	100	99,999	3, 4, 7, 8, 12
ID	2	100,000	999,999	1, 3, 5, 12
IL	24	100	9,999,999	1, 2, 3, 4, 5, 6, 7, 8,9, 10, 11, 12, 13, 14
IN	42	100	999,999	1, 2, 3, 4, 5, 6, 7, 8,9, 10, 11, 12, 13, 14
KS	5	10,000	99,999	1, 3, 5, 6, 7, 8,9, 10, 11, 12, 13
KY	22	100	999,999	1, 2, 3, 4, 5, 6, 7, 8,9, 12, 13, 14
LA	15	1,000	999,999	1, 2, 3, 4, 5, 6, 8, 10, 12, 13, 14
MA	11	100	99,999	1, 5, 8,9, 12
MD	6	1,000	99,999	1, 2, 3, 4, 5, 6, 7,9, 13
ME	2	100	99,999	1, 5, 8
MI	24	0	999,999	1, 2, 3, 4, 5, 7, 8,9, 11, 12, 13, 14
MN	6	100	99,999	1, 2, 5, 7, 8,9, 10, 12, 13, 14
MO	5	1,000	999,999	1, 2, 3, 4, 5, 6, 8,9, 12, 13, 14
MS	7	100	99,999	1, 5, 6, 7, 8, 10
MT	1	10,000	99,999	1, 5, 12, 14
NC	24	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8,9, 10, 12, 13, 14
ND	4	1,000	99,999	1, 5, 7, 12, 13, 14
NE	1	1,000	9,999	8, 11
NH	1	100	999	8
NJ	14	1,000	9,999,999	1, 3, 4, 5, 6, 7, 8, 10, 12, 14
NM	6	1,000	9,999,999	1, 3, 4, 5, 7, 8,9, 11, 12, 13
NV	8	1,000	10,000,000,000	1, 5, 6, 8, 12, 13, 14
NY	12	1,000	99,999	1, 2, 3, 4, 5, 7, 8,9, 11, 12
OH	44	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8,9, 11, 12, 13, 14
OK	14	100	999,999	1, 2, 3, 5, 6, 7, 8,9, 10, 11, 12
OR	6	1,000	99,999	1, 5, 7, 8, 12
PA	44	100	9,999,999	1, 2, 3, 4, 5, 6, 7, 8,9, 10, 11, 12, 13, 14

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Table 5-2. Facilities that Produce, Process, or Use Cobalt and Cobalt Compounds

State ^a	Number of facilities	Minimum amount on site in pounds ^b	Maximum amount on site in pounds ^b	Activities and uses ^c
PR	2	1,000	99,999	8,9
RI	1	100,000	999,999	8
SC	26	100	9,999,999	1, 2, 3, 4, 5, 6, 7, 8,9, 10, 11, 12, 13
SD	1	10,000	99,999	7
TN	18	0	999,999	1, 2, 3, 4, 5, 6, 7, 8,9, 10, 12, 13
TX	45	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8,9, 10, 11, 12, 13, 14
UT	6	1,000	9,999,999	1, 3, 4, 5, 7, 8,9, 12, 13
VA	9	10,000	999,999	1, 2, 3, 4, 5, 6, 7, 8
VI	1	10,000	99,999	10
WA	2	10,000	99,999	1, 3, 4, 5,9, 10, 11, 12, 13
WI	20	100	999,999	1, 3, 4, 5, 7, 8,9, 11, 12, 13, 14
WV	13	100	999,999	1, 2, 3, 4, 5, 7, 8,9, 11, 12, 13, 14
WY	2	0	99,999	1, 5,9, 12, 13

Source: TRI01 2004

^aPost office state abbreviations used^bAmounts on site reported by facilities in each state^cActivities/Uses:

- | | | |
|--------------------------|--------------------------|-----------------------------|
| 1. Produce | 6. Impurity | 11. Chemical Processing Aid |
| 2. Import | 7. Reactant | 12. Manufacturing Aid |
| 3. Onsite use/processing | 8. Formulation Component | 13. Ancillary/Other Uses |
| 4. Sale/Distribution | 9. Article Component | 14. Process Impurity |
| 5. Byproduct | 10. Repackaging | |

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mean release of ^{60}Co in liquid effluents of light-water nuclear power stations was reported as in the early 1970s as 0.0805 Ci/year (3.0 GBq) (Morgan 1976).

The ^{60}Co activities for a representative pressurized-water reactor (PWR) and boiling water reactor (BWR) fuel assemblies are 1,100 and 170 Ci (41 and 6.3 TBq), respectively. There are 78 PWR and 40 BWR reactors in the United States, several of which have ceased operation. The postirradiation cobalt content of typical PWR and BWR reactor fuel assemblies are 38 g (0.01%) and 26 g (0.01%), respectively (DOE 2002).

^{55}Co may be produced by applying 12 MeV indirect deuteron energy to ^{54}Fe ($^{54}\text{Fe}(\text{d},\text{n})^{55}\text{Co}$), 40 MeV protons to natural iron ($^{56}\text{Fe}(\text{p},2\text{n})^{55}\text{Co}$), or 20 MeV protons to natural nickel foil ($^{58}\text{Ni}(\text{p},\alpha)^{55}\text{Co}$) followed by separation of the ^{55}Co on an ion exchange column (Wolf 1955). Due to the short half-life (17.5 hours), however, ^{55}Co would not be persistent in the environment or in waste sites. ^{57}Co (half-life of 270 days) is produced by AEA Technology (formerly Amersham QSA) in the United Kingdom (Web Research Co. 1999).

5.2 IMPORT/EXPORT

In 2002, 8,450 metric tons of cobalt were imported into the United States compared with 7,670, 8,150, 8,770, and 9,410 metric tons in 1998, 1999, 2000, and 2001 (USGS 2002). Between 1999 and 2002, Finland, Norway, Russia, and Canada supplied 24, 18, 13, and 10% of cobalt, respectively (USGS 2004). Imports for 2002 by form included (form, metric tons cobalt content): metal, 6,800; oxides and hydroxides, 936; acetates, 84; carbonates, 60; chlorides, 22; and sulfates 545. Cobalt exports for 1999, 2000, 2001, and 2002 were 1,550, 2,630, 3,210, and 2,080 metric tons, respectively; exports estimated in 2002 are 2,500 metric tons (USGS 2002; 2004).

^{60}Co and ^{57}Co are produced in Canada and in the United Kingdom and are imported from these countries. No import and export quantities for cobalt radioisotopes were available.

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5.3 USE

The United States is the world's largest consumer of cobalt. Cobalt is used in a number of essential military and industrial applications. The largest use of metallic cobalt is in superalloys that are used in gas turbines aircraft engines. Superalloys are alloys developed for applications where elevated temperatures and high mechanical stress are encountered. It is also used in magnetic alloys and alloys that are required for purposes requiring hardness, wear resistance, and corrosion resistance. Cobalt is used as a binder for tungsten carbide (cemented carbides) cutting tools to increase impact strength. Cobalt compounds are used as pigments in glass, ceramics, and paints; as catalysts in the petroleum industry; as paint driers; and as trace element additives in agriculture and medicine.

Over 40% of nonmetallic cobalt is used in catalysis, and most cobalt catalysts are used in hydrotreating/desulfurization in the oil and gas industry, the production of terephthalic acid and dimethylterephthalate, and the production of aldehydes using the high pressure oxo process (hydroformylation). Cobalt chemicals primarily used as catalysts include cobalt(III) acetate, cobalt(II) bromide, carbonate, manganate, oxalate, and sulfide, cobalt carbonyl, and cobalt naphthenate. Cobalt carbonate and chromate are mainly used as pigments and cobalt(II) acetate, 2-ethylhexanoate, linoleate, naphthenate, nitrate, oleate, and stearate are mainly used as driers. Cobalt has been used for hundreds of years as a blue colorant in glass, ceramics, and paints (Richardson 1993).

A growing use for cobalt is as an addition to the Ni/Cd, Ni-metal hydride battery or as the main component of the lithium ion cell (LiCoO_2). In 2002, the reported U.S. cobalt consumption was 7,930 metric tons with a use pattern of (end use, metric tons cobalt content, percent): superalloys, 3,700, 46.7%; steel alloys, 555, 7.0%; other alloys, including magnetic alloys, 1,050, 13.2%; cemented carbides, 617, 7.8%; chemical and ceramic use, 1,950, 24.6%; and miscellany, 63, 0.8%. Cobalt is also used a target material in electrical x-ray generators (Cobalt Development Institute 2004; Donaldson 1986; Hodge 1993; IARC 1991; Richardson 1993; USGS 2002).

Gamma rays from ^{60}Co are used medically to treat cancer and industrially to sterilize medical and consumer products, to crosslink, graft and degrade plastics, and as an external source in radiography and radiotherapy. ^{60}Co , along with iridium 192 (^{192}Ir), are the most commonly used isotopes in industrial radiography. In this application, ^{60}Co is used for nondestructive testing of high-stress alloy parts, such as pipeline weld joints, steel structures, boilers, and aircraft and ship parts. Radiography may be conducted

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at permanent, specially shielded facilities or temporary sites in the field (USNRC 1999). ^{60}Co is used in chemical and metallurgical analysis and as a tracer in biological studies. In 1990, about 95% of installed ^{60}Co activity was used for the sterilization of medical devices; about 45% of medical devices were sterilized using radiation. ^{60}Co is also a source of gamma rays used for food irradiation; depending on the dose levels, irradiation may be used to sterilize food, destroy pathogens, extend the shelf-life of food, disinfest fruits and grain, delay ripening, and retard sprouting (e.g., potatoes and onions). Sludge, waste water, and wood may also be treated with gamma rays to kill harmful organisms.

^{57}Co decays to an excited state of ^{57}Fe , the most widely used x-ray source in Mössbauer spectroscopy (Hodge 1993; Richardson 1993). It is also made into standards and sources for dose calibrators, gamma cameras, and gauges, and is used as markers and rulers to help estimate organ size/location. It is also used in *in vitro* diagnostic kits for the study of anemia related to vitamin B₁₂ deficiency/malabsorption (MDS Nordion 2000). ^{55}Co -bleomycin has been used for scanning malignant tumors (e.g., lung and brain cancer) and is a practical isotope for positron emission tomography (PET) studies because it mainly (81%) decays by positron emission.

5.4 DISPOSAL

There is a paucity of data on the methods of disposal of cobalt and its compounds. Due to the lack of natural sources of economically extractable ores in the United States, cobalt is entirely imported in the United States, and it is considered a strategic mineral. It is economical to recycle certain cobalt wastes rather than to dispose of them. Recycling of superalloy scrap is an important method for the recovery of cobalt. About 2,200 metric tons of cobalt were recycled from purchased scrap in 2003. This was about 28% of reported consumption for the year (USGS 2004). According to TRI (TRI01 2004), 7.14 and 1.42 million pounds of cobalt and cobalt compounds combined were recycled onsite and offsite, respectively, in 2001. Waste containing cobalt dust and, presumably, waste containing cobalt in the solid state may be placed in sealed containers and disposed of in a secured sanitary landfill (HSDB 1989). Waste water containing cobalt can be treated before disposal, for instance, by precipitation of carbonate or hydroxide of cobalt or by passage through an ion-exchange resin (Clifford et al. 1986). According to TRI (TRI01 2004), 1,619,874 pounds of cobalt and cobalt compounds, were transferred offsite for disposal, in processes such as solidification/stabilization and waste water treatment, including publicly operated treatment plants (POTWs). The amount of cobalt so transferred by state is shown in Table 6-1.

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In August 1998, EPA issued a final rule listing spent hydrotreated and hydrorefined catalysts as hazardous waste under the Resource Conservation and Recovery Act (USGS 1998). Listing under this act requires that releases of these substances will be subject to certain management and treatment standards and emergency notification requirements. Information regarding effluent guidelines and standards for cobalt may be found in Title 40 of the Code of Federal Regulations, Parts 421.230, 421.310, and 471.30.

⁶⁰Co sources used for irradiation purposes are valuable and are not to be discarded. However, some radioactive cobalt isotopes may occur in waste material from nuclear reactors. Radioactive waste is categorized according to origin, type of waste present, and level of activity. Radioactive cobalt isotopes may be commingled with other radioactive isotopes. The first distinction in radioactive waste is between defense waste and commercial waste, the former being generated during and after World War II principally at the Department of Energy (DOE) facilities at Hanford, Washington; Savannah River, South Carolina; and Idaho Falls, Idaho, where plutonium and other isotopes were separated from production reactor spent fuel or nuclear-powered naval vessels. Commercial wastes are produced predominantly by nuclear power plants as well as the long defunct commercial reprocessing facility at West Valley, New York and manufacturers of radioisotopes used in nuclear medicine for the treatment and diagnosis of disease. Nuclear waste is also classified as high-level waste (HLW), transuranic waste (TRU), and low-level waste (LLW). LLW is further differentiated into three classes, A, B, and C, according to increasing of the level of activity. A fourth category, commercial greater-than-class-C LLW (listed in 10 CFR 61.55 Tables 1 and 2 for long and short half-life radionuclides, respectively) is not generally suitable for near-surface disposal. This could include operating and decommissioning waste from nuclear power plant and sealed radioisotope sources. The final disposition for this waste has not been determined. If LLW also contains nonradioactive hazardous material (i.e., that which is toxic, corrosive, inflammable, or explosive), it is termed mixed waste. Mine tailings from uranium mining is yet another category of radioactive waste (DOE 1999; Murray 1994). While radioactive cobalt would not ordinarily be found in HLW or TRU, the definitions of these are included below for completion.

TRUs are those containing isotopes, like plutonium, that are above uranium in the periodic table and whose half-lives are >20 years. If their level of activity is <100 nanocuries (nCi) (<3,700 becquerels[Bq]) of alpha-emitters per gram of waste material (up from 10 nCi/g in 1982), the waste could be disposed of by shallow burial. Otherwise, the waste must be placed in retrievable storage for eventual transfer to a

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permanent repository. The level of radioactivity in TRUs is generally low; they generate very little heat and can be handled by ordinary means without remote control (Eisenbud 1987, Murray 1994).

HLW includes spent fuels that are contained in fuel rods that have been used in a nuclear reactor. These may contain small amounts of transuranic elements. After removal from the reactor, these rods are placed into 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 short-lived radioactivity and rate of heat production 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 U.S. Nuclear Regulatory Commission (USNRC) has issued standards for the disposal of HLW (10 CFR 60), and the DOE is pursuing the establishment of an HLW facility in Yucca Mountain, Nevada. Efforts to establish an HLW facility, which began over 2 decades ago, have experienced many delays (Eisenbud 1987; Murray 1994). 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 facility is projected to begin operation in 2010, and efforts are underway to consider establishing a nearby interim facility (DOE 2002b).

LLWs are officially defined as wastes other than those previously defined. These wastes come from certain reactor operations and from manufacturers of radioisotopes used in nuclear medicine and institutions such as hospitals, universities, and research centers. Most LLW contain very little radioactivity and contain practically 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 radioactivity as to require special treatment. Although USNRC regulations for LLW disposal (10 CFR 61) permit shallow land burial, many states have enacted more stringent regulations that require artificial containment of the waste in addition to natural containment (Eisenbud 1987; Murray 1994). The EPA has the authority to set generally acceptable environmental standards for LLW that would be implemented by the US NRC and DOE (EPA 2004). The Manifest Information Management System (MIMS), maintained by the Idaho National Engineering and Environmental Laboratory (INEEL), contains information on low-level radioactive waste shipments received at commercial low-level radioactive waste disposal facilities at Barnwell, South Carolina (1/1/86–present), Beatty, Nevada (4/1/86–12/31/92), Richland, Washington (1/1/86–present), and Envirocare, Utah (1/1/98–12/31/99). In 1999, 17 Ci (0.63 TBq) of ^{57}Co , 1,300 Ci (48 TBq) of ^{58}Co , and 1.08×10^6 Ci (4.00×10^4 TBq) of ^{60}Co contained in LLW was received at these facilities from academic, industrial, government, and utility generators throughout the United

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States (INEL 2000). In addition, 4.26 Ci (0.158 TBq) of ^{57}Co of NARM (“naturally occurring and accelerator-related waste”) was received.

At present, DOE stores most of its spent fuel at three primary locations: the Hanford site, Washington, the Idaho National Engineering and Environmental Laboratory (INEEL), Idaho, and the Savannah River site, South Carolina. Some spent fuel is also stored at the dry storage facility at Fort St. Vrain in Colorado. 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 1999). The DOE National Spent Fuel Program maintains a spent nuclear fuel database that lists the total volume, mass, and metric tons heavy metal (MTHM) of 16 DOE categories of spent nuclear fuel stored in each of the three locations. The categories having the highest ^{60}Co activities per spent nuclear fuel canister (decayed to 2030) are ‘naval surface ship fuel’ and ‘naval submarine fuel’. The ^{58}Co and ^{60}Co solid wastes stored on the Hanford site in 1998 as LLW were 2,600 and 6,900 Ci (96 and 260 TBq), respectively (Hanford 1999). In addition, 40 Ci (1.5 TBq) of ^{60}Co was included in TRU.

In commercial irradiators, additional quantities of ^{60}Co are added, usually once a year to maintain preferred radiation levels of the source (MDS Nordion 2000). ^{60}Co sources are removed from the facility at the end of their useful life, which is typically 20 years. In general, manufacturers of ^{60}Co sources guarantee to accept the sources they originally supplied. These old sources may be reencapsulated, reprocessed, or recycled when technically, environmentally, and economically feasible.