LOW-LEVEL RADIOACTIVE WASTE FORUM, INC.

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Disposition Options and Costs for Certain Radioactive Sealed Sources and Devices

Prepared by the Disused Sources Working Group of the Low-Level Radioactive Waste Forum

Radioactive sealed sources and devices that contain sealed sources are used in a variety of applications including, but not limited to, healthcare, manufacturing, construction and mineral exploration. When the radioactive sealed sources have decayed to a point where the source or device no longer functions as designed, the source can either be replaced or the entire source or device can be properly dispositioned through return of the device to the manufacturer, transfer to a licensed third party for reuse or recycle, or permanently disposed as low-level radioactive waste. Long-term storage is discouraged as a way to manage sealed sources or devices when disposition options are available.

The availability of these disposition options is dependent on the radionuclide and its activity. While commercial disposal is available for most sealed sources, higher activity sources may not meet the waste acceptance criteria at the licensed low-level radioactive waste disposal facilities. For such sources, return to the manufacturer or transfer to a third party for reuse or recycle may be the only viable disposition options. However, reuse and recycle are generally limited and will depend largely on the radionuclide and its activity. Furthermore, reuse and recycle often entail a significant expense to the user for transfer of the source or device to a licensed processor or distributor.

The following report is intended to assist stakeholders in understanding the likely options and estimated costs related to the disposition of common radioactive sealed sources and devices. These include industrial radiography devices, fixed industrial gauges, well logging and brachytherapy sources, portable gauges, teletherapy devices, and both self-contained and panoramic irradiators. Common characteristics of these devices are summarized in Table 1 at the end of this document.

Readers are cautioned that the information contained in this report is intended as a guide only, providing general information about the most common types of sources and devices. The identified costs are provided as estimates only based on current information and guidance and should not be relied upon as determinative of actual future disposal costs. Costs related to source transport and disposal, for example, may change over time and may vary significantly depending upon device specific features or logistical requirements.

For additional information, please visit the website of the Disused Sources Working Group (DSWG) of the Low-Level Radioactive Waste Forum (LLW Forum) at www.disusedsources.org.

Disposition Options Overview: Availability and Constraints

Source reuse involves transfer of the source material or device to another licensee for continued use. Its potential is largely a function of the remaining source activity. Higher activity sources have a greater reuse potential: they may still be useful for their original application, or for an application with lower activity requirements. Lower activity sources, or sources without adequate documentation, have a minimal reuse potential.

Source recycle, by contrast, involves destruction of the original source by a licensed processor in order to harvest the source material for re-encapsulation in an entirely new source. Due to the costs involved in this process, activity constraints for source recycle are even greater than for source reuse. However, the activity threshold at which source reuse or source recycle is possible will vary, depending upon prevailing market condition, such as new source availability and user demand.

When evaluating disposition alternatives, licensees should consider the long-term liability associated with the available options. If the source or device is to be transferred to a third party for reuse or recycle, the licensee should seek verification prior to transfer of material as required by 10 CFR 40.51(c) or equivalent Agreement State regulations. This includes obtaining written assurance or confirmation from the receiving party of the transfer of the source to the recipient's license. This will limit or eliminate the future financial liability of the user for the source or device. Transfer to a third party for reuse or recycle without this formal verification leaves the user potentially liable for future expense related to the source. Disposal in a licensed disposal facility provides the user with the most certain reduction in long-term liability.

The following sections provide more detailed information on the potential options and costs for disposition of the different source types under consideration. Additional information regarding the current commercial sealed source disposal landscape is contained in Table 2.

Industrial Radiography

Industrial radiography is a non-destructive inspection technique used to determine the integrity of pipes, vessels and other components and identify manufacturing defects and other flaws that may impact system performance. Defects including cracks, incomplete welds and porosity in tubes can be identified. Radiography can be accomplished using gamma or x-rays.

The primary radionuclides used in industrial radiography are Ir-192 and Co-60. The source is housed in a shielded storage container when not in use. When used, the source is advanced to the item being inspected through a tube using a cable drive system. The gamma rays passing through the item are recorded on film placed on the other side from the source or detected electronically.

Ir-192 has a relatively short half-life of 75 days. As a result, these devices require frequent source replacement with the used sources being returned to the manufacturer, the cost of which is included in the price of the new source. When the source reaches the end of its useful life, the source can typically be returned to the manufacturer or disposed as low-level radioactive waste.

Due to the short half-life, there are very few, if any, reuse or recycle options for Ir-192 radiography sources. Reuse or recycle of the relatively high activity Co-60 sources may be possible. The cost to dispose of an Ir-192 industrial radiography source is approximately $200 to $500 while the cost to dispose of a Co-60 radiography source is approximately $3,000 to $10,000.

Fixed Industrial Gauges

Fixed industrial gauges are used throughout industry to monitor and control process equipment. Examples include devices to measure thickness, density, specific gravity, flow rate or tank fill level. The primary radionuclides used in fixed industrial gauges are Cs-137 and Am-241/Be. The source activity ranges from a fraction of a curie to tens of curies.

When the device is no longer needed, the source/device can typically be returned to the manufacturer (usually associated with the purchase of a new source/device), transferred to a source distributor/recycler or disposed as low-level radioactive waste. Due to both high demand and limited supply, reuse or recycle are often available for Am-241 sources. The cost to transfer these sources to a source recycler range from approximately $1,500 to $5,000 not including removal, packaging and transportation. Technician costs to package and transport can add approximately $6,000 to $8,000, depending on the number of sources and the transportation distance. The cost to dispose of an industrial fixed gauge ranges from approximately $1,000 to $30,000. Disposal of some higher activity sources can be difficult due to the waste acceptance criteria at the operating disposal facilities. Sources that exceed those limits must be disposed through the National Nuclear Security Administration's Off-Site Source Recovery Program (OSRP). The cost to remove a fixed industrial gauge is a function of how hard it is to remove the gauge from service. For example, gauges that are mounted high on a vessel are more labor intensive, and therefore more expensive to remove, than a gauge mounted at floor level, resulting in a higher cost.

Well Logging Sources

Well logging is a technique used to measure the properties of geologic strata by inserting specialized instruments down a borehole. Most downhole well logging occurs in the oil and mineral exploration industry. Some of these instruments use radioactive sealed sources.

Primary radionuclides used in well logging include Am-241/Be sources in the 5 Ci to 20 Ci range and 1 Ci to 3 Ci Cs-137 sources. The cost to transfer these sources to a distributor will range from approximately $2,250 to $6,750 per source. This does not include packaging or transportation. The fee for a service technician to package and transport the sources to the distributor is approximately $6,000 to $8,000, depending on the number of sources and transportation distance. Disposal of some higher activity sources can be difficult due to the waste acceptance criteria at the operating disposal facilities. Sources that exceed those limits must be disposed through the OSRP.

Brachytherapy

Brachytherapy or internal radiation therapy involves placing small radioactive sealed sources in or near the tissue to be treated or injecting radioactive material in the bloodstream or body cavity. The type of radioactive material and delivery method is determined based on the tissue being treated and the required dose to be administered. Placement of the sources can be temporary or permanent. In temporary brachytherapy, the source is placed inside a catheter or tube that has been inserted in or near the tissue to be treated for a short period of time and then withdrawn. Permanent brachytherapy involves placing the source in or near the tissue to be treated and leaving it there permanently.

Table 1 identifies the radionuclides associated with brachytherapy. Some of the radionuclides have short half-lives and can be decayed in storage until they are no longer radioactive. Disposal and recycling of the longer-lived radionuclides range from approximately $5 per Ir-192 seed to $1,500 to $4,500 for the Cs-137 and Co-60 sources. The cost range for disposal of a Sr-90 beta eye applicator is approximately $2,000 to $3,000.

Portable Gauges

Portable gauges are primarily moisture/density gauges used in the construction industry to measure soil, asphalt and concrete density, as well as soil and rooftop moisture. The American Portable Nuclear Gauge Association describes the devices as follows:

> Mechanically, all soils and asphalt moisture density gauges work the same. The gauges have a source rod that lowers into the ground to measure wet density and another stationary source contained in the base of the gauge that measures moisture.

The gauges use Cs-137 sources to measure density and Am-241/Be sources to measure moisture. When purchasing a new gauge, most gauge manufacturers will accept back an old gauge as part of the purchase price. The cost to return a gauge to the manufacturer without purchase of a new gauge ranges from approximately $750 to $1,500 plus shipping.

Teletherapy

External beam teletherapy devices use ionizing radiation to treat diseases such as cancer throughout the body. These devices use either linear accelerators or 5,000 to 15,000 curies of Co-60 to generate the treatment doses. The use of teletherapy devices that use Co-60 has decreased over time as the use of linear accelerators has increased.

However, a radiosurgery device called a Gamma Knife remains in wide use. It uses 201 Co-60 sealed sources of roughly 30 Ci each arranged hemispherically to focus the gamma rays on a specific locus in the brain. The patient can be moved so that the tissue to be treated can be located at this locus. This device is limited to treating tissue in the brain only.

The cost to return these items to the manufacturer is approximately in the $200,000 to $400,000 range due to shipping and handling expenses. Site-specific conditions may dramatically impact the cost. For example, because these units require shielding, some building dismantlement may be needed to remove the units from the facility.

Irradiators

Irradiators fall in to 2 basic categories based on the amount of material that can be irradiated at one time. Panoramic irradiators are used to treat large quantities of material in either a batch or continuous mode. Self-contained irradiators are used to treat small quantities of material in a batch mode.

<u>Panoramic Irradiators:</u>

Panoramic irradiators are used for the bulk sterilization of medical supplies and equipment, consumer goods (such as cosmetics) and some food products. These devices use millions of curies of cobalt-60, a gamma emitter. The sources are typically stored below floor level and are raised into a room level processing chamber when in use. Source storage is either in a dry shielded storage container or in a pool of water. The irradiator room has access controls to prevent the sources from being raised while personnel are in the room.

The panoramic irradiator can be operated in either batch mode or in a continuous mode. When operated in batch mode, the items to be sterilized are placed in the irradiator room in an arrangement where they will be exposed to the sources when the sources are raised. In a continuous mode, the items to be irradiated are passed in front of the raised sources via an automated conveyor system. Exposure time is determined based on the desired dose the products are to receive.

Due to the large quantity of sealed sources, the most viable disposition path is to return the sources to the manufacturer or to a recycler. Disposing of this quantity of radioactive material may not be viable at the existing low-level radioactive waste disposal facilities due to the disposal facility's waste acceptance criteria, license conditions limiting the inventory or other access limitations.

There are many cost components in decommissioning a panoramic irradiator. These components include onsite source removal, equipment rental, Type B shipping container rental, transportation charges and source disposal fee. As a reference for the total cost to decommission, the aggregate costs can range from $750,000 to $2,500,000. Source disposal costs represent approximately 50% of the total cost to decommission. The remainder of the cost is associated with onsite work and transportation. Costs may vary due to location, distance for transportation and total source activity.

Self-Contained Irradiators:

Self-contained or self-shielding irradiators are used to irradiate small quantities of material in a batch mode process. These irradiators can use radioactive material (Cs-137 or Co-60) or x-rays to provide the required dose. The size of these irradiators will vary, but they typically have a footprint of 8 to 15 square feet and can weigh two thousand to six thousand pounds.

A Cs-137 blood irradiator is the most common type of self-contained irradiator. These irradiators typically have a 15 to 20-year operating life and don't require re-sourcing during this time due to the 30-year half-life of the material. Total activity of the sources range from 600 to 3,000 curies or more. Disposal of Cs-137 at the existing low-level radioactive waste disposal facilities can be complex due to the waste acceptance criteria at the disposal facilities. Another consideration is that these items require transportation in a Type B shipping container, which currently costs approximately $80,000 to $100,000 to rent. Some irradiator manufacturers and recyclers maintain their own Type B shipping containers so the Type B rental cost might not be incurred when returning the device to the manufacturer or a recycler.

The cost to return the device to the manufacturer ranges from approximately $75,000 to $200,000. This cost is reduced if the device is being exchanged for a new irradiator. Since a new irradiator would have been shipped in a Type B container, the container is returned to the manufacturer carrying the old irradiator. This practice eliminates the cost associated with the shipment of an empty Type B container to the facility. In addition, there is a cost savings since manufacturer staff is onsite to perform the removal and loading of the old irradiator.

There are larger self-contained irradiators in use, primarily in research applications. These irradiators will use tens of thousands of curies of Co-60 to achieve a higher dose rate. Costs to return these irradiators to the manufacturer are approximately $100,000 to $200,000, but transfer to a recycler may be less.

Table 1 – Widely Used Radioactive Sealed Sources[1]

Device	Radionuclide	Typical Activity in Curies (Ci) Range	IAEA Source Category[a]	Waste Class[b]
Panoramic irradiators used to irradiate single-use medical devices and products, cosmetics, food, and plastics.	Cobalt-60[c]	150,000 - 5,000,000	1	B
Self-shielded irradiators/blood-tissue irradiators.	Cesium-137	2,500-42,000	1,2	B, C, GTCC
	Cobalt-60[c]	1,500-50,000	1	
Gamma knife (fixed, multibeam teletherapy).	Cobalt-60[c]	4,000-10,000	1	B
Teletherapy, which uses radiation directed at a human or animal body to treat many serious diseases, most notably cancer.	Cesium-137	500-1,500	2	B, C
	Cobalt-60[c]	1,000-15,000	1	
Calibration sources, generally used to calibrate various radiation measuring and monitoring instruments	Americium-241	1-25	2,3,4	A, B, C, GTCC
	Cesium-137	1.5-14,000	1,2,3,4	
	Cobalt-60[c]	0.55-16,000	1,2,3,4	
	Plutonium-239/ Beryllium	2-25	2,3	
	Strontium-90	0.05-2	4	
Industrial radiography widely used in the chemical, petrochemical, and building industries for radiographic inspection of pipes, boilers, and structures where consequences of failure can be severe.	Cesium-137	5-12	3	A, B, C, GTCC
	Cobalt-60[c]	11-330	2	
	Iridium-192	5-290	2,3	
	Selenium-75	80	2	
	Thulium-170	20-200	4	
	Ytterbium-169	2.5-20	3,4	
Fixed industrial gauges (level, dredger, conveyor, blast furnace, and spinning pipe) used for a wide variety of industrial and manufacturing purposes, primarily to monitor production processes.	Cesium-137	0.1-40	2,3,4	A, B, C, GTCC
	Cobalt-60[c]	0.1-20	2,3,4	
	Plutonium-238	20	2	
	Californium-252	0.034	4	
	Krypton-85	0.05-1	5	
Well-logging sources used for characterizing subsurface properties such as density and moisture percentages. Most commonly associated with oil and mineral exploration.	Americium-241/ Beryllium	0.5-20	2,3,4	A, B, C, GTCC
	Californium-252	0.027-1.61	3,4	
	Cesium-137	0.5-20	3,4	
	Cobalt-60[c]	1-20	2,3	
	Plutonium-238/ Beryllium	5-70	2,3	
	Radium-226	20	2	
	Tritium	1-20	5	

[1] Excerpted and adapted from *Sealed Source Disposal and National Security – Problem Statement and Solution Set,* which was a deliverable of the Removal and Disposition of Disused Sources Focus Group of the Radioisotopes Subcouncil of the Nuclear Government and Sector Coordinating Councils, dated December 9, 2009. This table identifies some of the sealed source devices and uses, the radionuclides and activity, categorization by the International Atomic Energy Agency (IAEA) and waste classification for disposal purposes.

Device	Radionuclide	Typical Activity in Curies (Ci) Range	IAEA Source Category[a]	Waste Class[b]
Brachytherapy (high, medium and low dose rate), which uses either beta or gamma sources to irradiate tumors over a very small area and thickness of tissues.	Cobalt-60[c]	1-20	2,3	A, B, C, GTCC
	Cesium-137	0.1-8	3,4,5	
	Iridium-192	0.02-15	3,4,5	
	Radium-226	0.005-0.05	4,5	
	Iodine-125	0.005-1.3	4,5	
	Gold-198	0.08	4	
	Californium-252	0.083-0.54	3,4	
	Strontium-90	0.02-0.12	4,5	
	Ruthenium/ Rhodium-106	0.00022-0.0006	5	
	Palladium-103	0.03-0.0056	5	
Cardiac pacemakers.	Plutonium-238	2.9-8	3	B, C GTCC
Research reactor startup sources.	Americium-241/ Beryllium	2-5	3	B, C, GTCC
Static eliminators used in the production of paper, textiles, plastic and electrical circuits. They are particularly useful in hazardous areas where electrical devices cannot be used.	Americium-241	0.03-0.11	4	A, B, C, GTCC
Portable gauges (moisture and density) used in the field at construction sites and on farms. The gauges are typically used to determine the moisture and density of a material such as soil or asphalt.	Americium-241/ Beryllium Cesium-137	0.01-3	3,4,5	A, B, C, GTCC

a. The International Atomic Energy Agency (IAEA) categorization system is based on “the potential for radioactive sources to cause deterministic health effects. This potential is due partly to the physical properties of the source, especially its activity, and partly to the way in which the source is used.” See, IAEA Safety Guide No. RS-G-1.9, Categorization of Radioactive Sources 2005, Annex I, page 37, available at http:// www-pub.iaea.org/MTCD/publications/PDF/Pub1227_web.pdf.

b. Refers to Nuclear Regulatory Commission’s (NRC’s) classification of LLRW for land disposal found in 10 CFR Part 61. Activity per unit mass or volume classification limits are related to relative hazard and necessity for waste isolation. Class A represents the least hazard, Class B represents a greater hazard, and Class C the greatest hazard appropriate for near surface disposal. Waste with an activity concentration Greater- Than-Class-C (GTCC) must be disposed of in a geologic repository unless NRC approves an alternate disposal site.

c. There are no limits established for cobalt-60 in Class B or C wastes. Practical considerations such as the effects of external radiation and internal heat generation on transportation, handling, and disposal will limit the concentrations for these wastes. These wastes shall be Class B unless the concentrations of other nuclides in Table 2 in 10 CFR § 61.55 determine the waste to be Class C independently of these nuclides.

Table 2 – The Current Commercial Sealed Source Disposal Landscape[2]

	Maximum Limit Allowed[a]			
	Non-GTCC			GTCC Sources
	Barnwell, SC Facility (3 States)[b]	Richland, WA Facility (11 States)	Andrews, TX Facility (36 States)	GTCC Facility[c]
Americium-241 Plutonium-238 Plutonium-239	500 µCi/container	100 nCi/gm	30 mCi/55-gal container	>100 nCi/gm
Californium-252	10 Ci[d]	13 Ci[e]	13 Ci[e]	NA[f]
Curium-244	500 µCi/container[d]	100 nCi/gm	100 nCi/gm	>100 nCi/gm
Cobalt-60	10 Ci[d]	([g])	([g])	NA[f]
Cesium-137	10 Ci[d]	976 Ci	976 Ci	>976 Ci
Iridium-192	10 Ci[d]	13 Ci[e]	13 Ci[e]	NA[f]
Strontium-90	10 Ci[d]	1,486 Ci	1,486 Ci	>1,486 Ci
Radium-226	50 µCi/container	1.2 Ci	100 mCi/55-gal container	
	Disposal of radium-226 is available to all states at the Richland facility up to 1.2 Ci per source.[h]			NA[f]

General Notes:

1. Disposal available commercially for Compact states up to maximum Class C limits for applicable radionuclides, considering concentration averaging unless otherwise noted in this table.
2. Access to the commercial LLRW disposal facilities is described in the report "Compact Export and Import Permit Requirements" which can be found on the LLW Forum Disused Sources Working Group's website at: http://www.disusedsources.org/wp-content/uploads/2014/12/Compact-Export-Import-Permit-Requirements-Report-3.26.17.pdf.

Specific Table Footnotes

a The maximum curie or activity limit allowed for an individual sealed source containing the specified radionuclide based on site-specific administrative limits, waste acceptance criteria, application of concentration averaging, or license conditions.

b The minimum package size at the Barnwell facility is a 5-gallon drum.

c A GTCC LLRW disposal facility does not currently exist; DOE is preparing an Environmental Impact Statement analyzing potential disposal alternatives for this waste. The maximum limit for the facility will be determined during the implementation and licensing phase for the selected alternative and will be greater than the Class C waste classification values shown in the Table (which assumes application of concentration averaging).

d The Barnwell facility operator approves source disposal up to 10 Ci for 10 CFR 61.55 Table 2 radionuclides. Greater than 10 Ci for Table 2 radionuclides requires SC DHEC approval.

e The facility may accept sources in excess of this limit on a case-by-case basis based on worker exposure and other site-specific considerations.

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[2] Excerpted from *Sealed Source Disposal and National Security – Problem Statement and Solution Set" which was a deliverable of the Removal and Disposition of Disused Sources Focus Group of the Radioisotopes Subcouncil of the Nuclear Government and Sector Coordinating Councils,* dated December 9, 2009. This table was updated to reflect the acceptance criteria for the Texas Low-Level Radioactive Waste Disposal Compact facility located in Andrews County, Texas since the facility was not operational when the report was published.

f	Sealed sources consisting of these radionuclides are not classified as GTCC LLRW when sent for disposal because there is no maximum Class C limit for the radionuclide or the radionuclide is not included in the list of radionuclides in 10 CFR § 61.55, Tables 1 and 2 that determine LLRW classification.
g	There is no Class C limit for Co-60. Acceptance at the operating disposal facility is subject to the facility's waste acceptance criteria and operational considerations such as occupational exposure dose rate and waste inventory limits.
h	Diffuse radium-226 is still considered naturally occurring radioactive material (NORM) for purposes of disposal, but discrete Ra-226 sources are now considered "byproduct material" per the NRC and compatible Agreement State regulations. However, the *2005 Energy Policy Act* has excluded radium-226 sources as LLRW, and some compact regulations still consider radium-226 containing waste as NORM. Disposal options are therefore still available to all states.