**Characterization of
Greater-Than-Class C
Sealed Sources
Volume 2: Sealed Source
Characterization and Future
Production**

***Greater-Than-Class C
Low-Level Waste Management Program***

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**Characterization of
Greater-Than-Class C Sealed Sources
Volume 2: Sealed Source Characterization
and Future Production**

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ABSTRACT

Sealed sources are small, relatively high-activity radioactive sources typically encapsulated in a metallic container. The activities can range from less than 1 mCi to over 1,000 Ci. They are used in a variety of industries and are commonly available. Many of the sources will be classified as Greater-Than-Class C low-level radioactive waste (GTCC LLW) for the purpose of waste disposal. The U.S. Department of Energy is responsible for disposing of this class of low-level radioactive waste.

The characterization of a sealed source is essentially a function of the type of radiation it emits, the principal use for which it is applied, and the activity it contains. The types of radiation of most interest to the GTCC LLW Program are gamma rays and neutrons, since these are emitted by the highest activity sources. The principal uses of most importance are gamma irradiators, medical teletherapy, well logging probes, and other general neutron applications.

Current annual production rates of potential Greater-Than-Class C (PGTCC) sources sold to specific licensees were estimated based on data collected from device manufacturers. These estimates were then adjusted for current trends in the industry to estimate future annual production rates. It is expected that there will be approximately 8,000 PGTCC sealed sources produced annually for specific licensees.

SUMMARY

This report, the second of three volumes investigating sealed sources that may eventually become Greater-Than-Class C (GTCC) low-level radioactive waste (LLW), characterizes sealed sources and estimates current and future production rates of sealed sources sold to specific licensees. Information on which to base the production estimates were obtained from the U.S. Nuclear Regulatory Commission's Sealed Source and Device database and by contacting sealed source and device manufacturers.

This report comprises three parts. The first part, comprising Chapters 1 and 2, presents the purpose and scope of the report and summarizes concepts of radioactivity relevant to the uses of sealed sources. The second part, comprising Chapters 3 through 5, discusses the uses and construction of sealed sources. The final part, comprising Chapters 6 and 7, estimates the annual production of potential GTCC (PGTCC) sources, discusses current trends in the industry, and presents conclusions of this report. Because this report focuses on characterizing sealed sources and estimating annual production rates of sealed sources sold to specific licensees, the following paragraphs summarize the results and conclusions contained in Chapters 3–6.

Chapter 3, Source/Device General Descriptions, describes the function of the source/device, the isotopes and activities of the sources, and the major manufacturers. It identifies nine categories of sealed sources: calibration devices, medical sources, well logging sources, portable gauges, irradiation sources, fixed gauges, general neutron application sources, x-ray fluorescence sources, and other sources or gauges.

While there is a wide variety of sealed source applications, both the principles governing those applications and the designs of the sources are similar. There are two broad radiation techniques: irradiation and gauging. In irradiation techniques, radiation is used to change the properties of the material being irradiated (e.g., kill bacteria, sterilize products, modify polymer properties). In gauging applications, properties of the material being examined (e.g., thickness, density) are assessed by the effect they have on the transmitted or scattered radiation.

Chapter 4, Sealed Source Construction, discusses general sealed source construction and also describes American National Standards Institute (ANSI) and U.S. Nuclear Regulatory Commission (NRC) performance requirements that sealed sources must meet.

For the user, the importance of a sealed source is not so much what the source contains as what it emits. Hence, source construction is designed to allow radiation to be emitted while containing the radioactive isotope. The design of the source must meet three general criteria: (a) the radiation emission from the source must be satisfactory for the ultimate application, (b) there should be no release of radioactive material due to loss of integrity of the source seal even after prolonged service life, and (c) the sealing material must be compatible with the prospective environment of the source.

Several typical designs are illustrated in this chapter.

Chapter 5, Source/Device Characterization (SDC) Database, describes the development of the SDC database. It is based on the NRC's Sealed Source and Device Registry (SSD) database. The SSD database includes company names, addresses, model numbers, isotopes, and maximum activity levels. However, the SSD does not include other information that is needed by the GTCC LLW Program, such as source volumes or whether the source is welded or soldered. The SSD also does not list specific activities of multiple models listed on the same registration certificate. Because of this lack of specificity on some models and lack of information relevant to the GTCC LLW Program, the Program modified the SSD to gather some of the above information, and produced the DOE SDC database.

Chapter 6, Annual Production Estimation, discusses what information was requested from manufacturers, the methods applied to estimate the annual production of PGTCC sources sold to specific licensees by isotope and device type (i.e., the incremental numbers of sources), and the results.

The annual production estimates are for *PGTCC sources, as opposed to GTCC sources*.

- *PGTCC sources* exceed the Class C concentration limits when the concentration of radioactive isotopes is calculated over the source capsule volume.
- *GTCC sources* exceed the Class C concentration limits when current disposal practices are used. Current disposal practices allow concentration averaging to occur over the disposal container, with some restrictions. That is, of those PGTCC sources, concentration averaging removes the sources with the lowest activities and averages their radionuclide activity over the volume or mass of encapsulation media filling an entire waste container, thereby reducing the concentration to a level acceptable to a near-surface LLW disposal facility.

This report deals almost exclusively with PGTCC sealed sources. *Most of the PGTCC sources will not become GTCC LLW*. The PGTCC values represent the most basic estimates, and can be used as a foundation on which to apply any assumptions regarding packaging or concentration averaging. The impacts of packaging volumes and concentration averaging practices on these estimates are explored in other studies.

Manufacturers were contacted by phone and by letter. The quality of the data was influenced by the response rate and response quality, both of which were less than satisfactory. The response rate was low. Many manufacturers did not want to release past production rates, claiming justifiably that this data was proprietary; others determined that the level of effort to retrieve past production data was too great, therefore, it was not worth their time. Some manufacturers claimed that they had no PGTCC material. The response quality was also less than satisfactory; some companies sent general instead of actual production figures, claiming again that the information was proprietary.

Because data gathered from manufacturers were of limited value, survey results from specific licensees were also used to make estimates of the annual production of sealed sources held by specific licensees for the low, base, and high cases. The low case estimates production of 4,700 sources annually, the base case estimates 8,000, and the high case estimates 11,500. The isotopes Am-241 and Cs-137 account for the majority of the sources. While there is a moderate amount of uncertainty in these estimates, manufacturers felt the estimates were reasonable.

While particular companies or device types may be experiencing growth, overall the markets for devices containing PGTCC sources are either stable or shrinking. Companies are moving toward less toxic substances, for example, using x-ray tubes instead of gamma sources. Also, companies are replacing isotopes that are difficult to dispose of with those that can be more easily disposed of. And in some applications, nonradioactive techniques are replacing methods that use radioactive isotopes. These factors are reflected in the estimates for future production.

Extrapolations to All Licensees

This report is the second of three volumes. This report and Volume 1 discuss sealed sources held by specific licensees, while Volume 3 concerns sealed sources held by general licensees. These reports give estimates of the total number of PGTCC sources (those whose activity is averaged over the source capsule) and the number of GTCC sources (assumed here to be those remaining after concentration averaging has been performed over the disposal container, as explained in Appendix D of Volume 1).

Volume 1 estimates that, in 1992, the number of PGTCC sources held by specific licensees was 89,000; the estimated 1992 number of GTCC sources is 28,400. In this report, Volume 2, it is estimated that 8,000 PGTCC sources are sold per year to specific licensees.

Volume 3 estimates that the general licensee population possesses roughly 36% of the total 1992 number of GTCC sealed sources. Together with the GTCC sources held by specific licensees (from Volume 1), this yields about 44,000 total GTCC sources held by all licensees. The results presented in Volume 1 and Volume 3 for GTCC sealed sources are summarized in Table ES-1.

Volume 3 estimates that the general licensee population possesses roughly 63% of the total 1992 number of PGTCC sealed sources. Together with the PGTCC sources held by specific licensees (from Volume 1), this yields about 250,000 total PGTCC sources held by all licensees. The results presented in Volume 1 and Volume 3 for PGTCC sealed sources are summarized in Table ES-2.

For general licensees, Volume 3 extrapolates the estimated annual number of GTCC sources sold to the number of PGTCC sources sold. When those results are added to the number of PGTCC sources sold to specific licensees (reported here in Volume 2), the resulting estimate is 24,000 PGTCC sources sold to all licensees per year. This is shown in Table ES-3.

Table ES-1. Base case estimates of the number of GTRC sources held by specific and general licensees. Numbers rounded to two significant digits.

Device type	Am-241	Cm-244	Cs-137	Pu-238	Pu-239	Pu-241	U-238	Subtotal
Calibration	1,900	14	10	45	250	14	—	2,300
Medical	93	—	10	—	—	—	24	130
Well logging	3,700	—	—	—	—	—	—	3,700
Portable gauge	14,000	—	—	—	—	—	—	14,000
Irradiation	110	—	590	—	—	—	—	700
Fixed gauge	16,000	3	—	45	—	—	—	16,000
General neutron applications	1,300	—	—	110	460	—	—	1,900
XRF	1,300	1,300	—	180	—	—	—	2,800
Other	550	21	10	1,500	480	21	28	2,600
Subtotal	39,000	1,300	620	1,900	1,200	35	52	44,000

Table ES-2. Base case estimates of the number of PGTEC sources held by specific and general licensees. Numbers rounded to two significant digits.

Device type	Am-241	C-14	Cm-244	Cs-137	Ni-63	Np-237	Pu-238	Pu-239	Pu-241	Se-90	Tc-99	U-238	Subtotal
Calibration	3,000	24	34	3,400	110	10	41	280	17	1,900	17	34	8,960
Medical	340	—	—	1,300	—	—	—	—	—	34	3	28	1,600
Well logging	4,300	—	—	2,300	—	—	170	—	3	—	—	—	6,700
Portable gauge	13,000	—	—	110	—	—	—	—	—	—	—	—	13,000
Irradiation	160	—	—	1,700	—	—	—	—	—	10	—	—	1,800
Fixed gauge	17,000	30	17	170,000	—	—	3	—	—	270	—	—	190,000
General neutron applications	1,500	—	—	—	—	—	110	530	—	—	—	—	2,100
XRF	3,300	—	1,400	3	—	—	180	—	—	—	—	—	4,900
Other	1,100	62	34	11,000	3,900	3	1,600	650	21	300	500	80	19,000
Subtotal	46,000	120	1,500	190,000	4,000	13	2,100	1,500	41	2,500	520	140	230,000

Table ES-3. Base case estimates of the number of PuTCC sealed sources sold annually to both specific and general licensees. The numbers are rounded to at most two significant digits.

Device type	Am-241	C-14	Cm-244	Cs-137	Ni-63	Np-237	Pu-238	Pu-239	Pu-241	Sr-90	Tc-99	U-238	Total
Calibration	290	2	3	330	11	1	4	30	2	190	2	3	860
Medical	30	0	0	110	0	0	0	0	0	2	0	3	150
Well logging	130	0	0	60	0	0	5	0	0	0	0	0	190
Portable gauge	1,500	0	0	11	0	0	0	0	0	0	0	0	1,500
Irradiation	15	0	0	120	0	0	0	0	0	1	0	0	140
Fixed gauge	1,700	3	2	17,000	0	0	0	0	0	27	0	0	19,000
General neutron applications	140	0	0	0	0	0	11	50	0	0	0	0	210
XRF	310	0	135	0	0	0	14	0	0	0	0	0	460
Other	110	6	3	1,100	370	0	15	60	2	30	40	8	1,700
Total	4,200	12	140	19,000	390	1	50	140	4	250	50	14	24,000

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FOREWORD

This report is the second of three volumes investigating sealed sources that may eventually become Greater-Than-Class C (GTCC) low-level radioactive waste (LLW). Volume 1 estimates the number, volume, and activity of sealed sources held by specific licensees. This volume, Volume 2, estimates current and future annual production rates of PGTC sealed sources sold to specific licensees. It also provides a physical characterization of sealed sources that are currently produced. Volume 3 characterizes sealed sources held by general licensees.

ACRONYMS

ANSI	American National Standards Institute
AS	agreement state
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
GNA	general neutron application
GTCC	greater-than-Class C
LLW	low-level radioactive waste
NRC	U.S. Nuclear Regulatory Commission
PGTCC	potential greater-than-Class C
TRU	transuranic
RCRA	Resource Conservation and Recovery Act
RSO	Radiation Safety Officer
TIG	Tungsten inert gas
SDC	Source/Device Characterization (database)
SSD	Sealed Source and Device Registry (database)
XRF	x-ray fluorescence

Characterization of Greater-Than-Class C Sealed Sources Volume 2: Sealed Source Characterization and Future Production

1. INTRODUCTION

By enacting the Low-Level Radioactive Waste Policy Amendments Act of 1985, the U.S. Congress made the U.S. Department of Energy (DOE) responsible for ensuring the safe disposal of greater-than-Class C low-level radioactive waste (GTCC LLW). A need was identified by the GTCC LLW Program to better characterize sealed sources (and devices containing sealed sources) that have the potential to become GTCC LLW. This report and its associated database are written to meet that need.

Sealed sources are typically small metallic containers encapsulating relatively high-activity radioactive material. Source activities can range from less than 1 mCi to over 1,000 Ci. However, most sources have activities less than 100 mCi. The source is often placed in a device intended for a specific purpose, typically for performing some type of measurement. Sealed sources and devices containing sealed sources have a wide variety of uses in medicine, construction, manufacturing, research, and other fields.

In the report "Characterization of Greater-Than-Class C Low-Level Radioactive Waste Sealed Sources; Volume 1: Sealed Sources Held by Specific Licensees" (DOE/LLW-163), hereafter referred to as "Volume 1," the number of potential GTCC sources held by specific licensees in 1992 is estimated to be 89,000. By "potential GTCC" (PGTCC), it is meant that when concentration averaging over the volume of the source capsule, the activity would exceed the limits given in Code of Federal Regulations, 10 CFR 61. This does not, however, necessarily mean that the source will be disposed of at a GTCC LLW disposal facility, as qualification for disposal is dependent upon the packaging and concentration averaging criteria of the disposal site.

A need was later identified for more information about the physical construction of the sources and devices, to help plan for storage and disposal facilities. Additionally, there is a need for estimating the number of PGTCC sealed sources that will be produced in the future.

This report comprises three parts. The first part, making up Section 2, summarizes concepts of radioactivity relevant to the uses of sealed sources. The second part, comprising Sections 3 through 5, discusses the uses and construction of sealed sources. The final part estimates the annual production of PGTCC sources sold to specific licensees and discusses current trends in the industry.

1.1 Sealed Sources

Sealed sources come in a variety of shapes and sizes. Typical sources that are PGTCC LLW range in volumes from 1 to 100 cm³, with most being under 10 cm³. The radioactive material is typically composed of a single radionuclide and only makes up a small percentage of the source volume (1 to 10%). Most sources are cylindrical, though annular sources are also common. Some sources (such as those used in gas chromatographs) are small metal plates supporting a thin foil of radioactive material.

Sources can be either singly or doubly encapsulated, depending upon the stress or environment the source is expected to encounter. A doubly encapsulated source is better able to withstand physical abuse (but at a higher expense). Doubly encapsulated sources are also favored when the activity of the material in the

source is large. In a doubly encapsulated source, a singly encapsulated source is placed inside a slightly larger capsule, and then a plug is typically welded onto the open end.

The capsules are generally constructed of high-grade stainless steels. The thickness of the capsule walls and plugs varies depending upon the application.

The radioactive material can be in a powder, ceramic, or metal foil form. The ceramics are commonly formed by adding a silicate to the radioactive material, mixing, and then applying either heat or pressure to produce the ceramic. In neutron-emitting sources, beryllium is often mixed with the active material or a beryllium "window" is added to the source.

The use to which the source is applied determines the type of isotope, activity, and physical composition employed. More details about sources are given in Section 4.

1.2 Devices

Most sealed sources are contained in devices when sold to a licensee. There are many uses for such devices, as discussed in Section 3. The device typically controls the radiation emitted from the source by shielding all but a small portion of the source. The device may just focus the radiation for irradiation or calibration, but more commonly, the device will also have a detector aligned with the source to allow a measurement of the amount of radiation reaching the detector.

Generally, the licensee or owner of the device does not have easy access to the source (most licensees are not authorized to access the source, anyway). However, the manufacturer can extract the encapsulated source from the device when the device is no longer useful. In fixed gauges, a source may be placed in a source holder that is easily removed and replaced on the device.

Apart from the specific application that the device provides (as discussed in Section 3), devices commonly serve two control purposes with respect to the source. First, the device provides shielding from the radiation emitted by the source. This protects the user from receiving dangerous exposures. Second, the device frequently "collimates" the radiation. Collimation is the process whereby the radiation is focused or directed toward the target, eliminating radiation that is scattered away from the target. Collimation is particularly important for gamma ray sources.

Devices come in a wide variety of sizes and shapes. They can be the size of a pencil (an ophthalmic applicator) or as large as a room (an irradiator). While there are only about a half-dozen source manufacturers, there are dozens of device manufacturers. Each manufacturer has its own market niche and device designs.^a Therefore, a description of devices must cover a wide array of possibilities. This is given in Section 3.

1.3 PGTC Sealed Sources

As in Volume 1 of this series, this report deals with sources that are PGTC LLW. The distinction between PGTC sources and GTC sources is important.

- *PGTC sources exceed the Class C limits when the concentration of radionuclides is calculated over the source capsule. This is a conservative concentration averaging*

a. Mention of specific products and/or manufacturers in this document implies neither endorsement or preference, nor disapproval by the U.S. Government, any of its agencies, or EG&G Idaho, Inc. of the use of a specific product for any purpose.

assumption in that it results in much lower activity limits than currently acceptable methods.

- *GTCC sources* exceed the Class C limits when concentration averaging is implemented over the disposal container, with certain volume, density, and surface radiation restrictions. That is, of those PGTC sources, concentration averaging removes the sources with the lowest activities and averages their radionuclide activity over the volume or mass of encapsulation media filling an entire waste container, thereby reducing the concentration to a level acceptable to a near-surface LLW disposal facility. Concentration averaging over the disposal container is a currently accepted practice.

Many of the PGTC sources will likely be disposed of at near-surface LLW facilities rather than at a DOE GTCC LLW facility. This is because a conservative approach was taken in assessing the number of PGTC sources, thereby allowing flexibility in applying various concentration averaging and packaging scenarios used for planning such a facility. Hence, by design, the information given in this report essentially overstates the true scope of the GTCC sealed source population.

Table 1-1 shows the sealed source activity limits used in the base case of Volume 1 to classify sources as PGTC LLW. A source with the given isotope and in the given device type that exceeds the activity limits given in Table 1-1 is considered PGTC LLW. The derivation of these limits is based on concentration averaging over an assumed source volume, and is discussed in Section 3.1 of Volume 1.

As a point of reference, the U.S. Nuclear Regulatory Commission (NRC) has recently provided proposed guidelines for maximum activities of sealed sources that may be disposed of in a single 0.2 m³ (55-gal) container at LLW disposal facilities (NRC 1993). These are shown in Table 1-2 and illustrate the impact that disposal practices might have on the quantity of sealed sources that DOE may have to dispose of; obviously, if the Table 1-2 limits are used, there will be significantly fewer sources classified as GTCC than if the Table 1-1 limits are used.

While the remainder of this report discusses PGTC sources, there is an emphasis on sources that are most likely to become GTCC LLW. These are large cesium sources used in gamma irradiators and medical teletherapy devices, and sources with transuranics of more than 30 mCi activity, with an emphasis on large neutron sources.

Table 1-1. Lower activity limits (mCi) for PGTC sources.^a

Device Type	Am-241	C-14	Cm-244	Cs-137	Ni-63	Np-237	Pu-238	Pu-239	Pu-241	Sr-90	Tc-99	U-238
Calibration	1.0	1.0	1.0	9.2	1.4	1.0	1.0	1.0	1.0	14.0	1.0	1.0
Medical	1.0	—	—	92.0	—	—	—	—	—	140.0	1.0	1.0
Well logging	1.0	—	—	115.0	—	—	1.0	—	1.0	—	—	—
Portable gauge	1.0	—	—	92.0	—	—	—	—	—	—	—	—
Irradiation	1.0	—	—	194.0	—	—	—	—	—	280.0	—	—
Fixed gauge	1.0	1.0	1.0	13.8	—	—	1.0	—	—	21.0	—	—
General neutron applications	1.0	—	—	—	—	—	1.0	1.0	—	—	—	—
X-ray fluorescence	1.0	—	1.0	2.3	—	—	1.0	—	—	—	—	—
Other	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

a. Sources with activity limits exceeding those stated in this table are PGTC material. Reference: Volume 1 of DOE/LIW-163.

Table 1-2. Proposed guidelines for the maximum activity of sources in a 0.2 m³ (55-gal) container that can be disposed of at a near-surface LLW facility (NRC 1993).

Isotope	Activity
Cs-137	30 Ci
Alpha-emitting TRU	30 mCi ^a
Pu-241	1.05 Ci ^b
C-14	1.6 Ci
Ni-63	140 Ci
Sr-90	1,400 Ci
Tc-99	0.6 Ci

a. Assumes the density of the encapsulating mass is 1.3 g/cm³. The maximum density allowed is 2.5 g/cm³, which would result in an activity limit of 58 mCi.

b. Assumes the density of the encapsulating mass is 1.3 g/cm³. The maximum density allowed is 2.5 g/cm³, which would result in an activity limit of 2,020 mCi.

2. RADIATION INTRODUCTION

Sealed sources have a wide variety of applications in the medical, industrial, agricultural, research, and other fields. These uses are derived from the nature of radiation and its interaction with matter. In some applications, the effect of matter on radiation is of interest, such as in gauging devices. In other applications, it is the effect of radiation on matter that is of interest, such as in irradiation.

To better understand the types and uses of radioactive material in sealed sources, a brief background on selected topics in radiation science will be useful. The following sections focus on topics in radiation chemistry that may improve the reader's understanding of radioactive sealed sources. The first few sections give an overview of the types of radiation used in sealed sources. The final section introduces some basic uses of radiation, which are explored in more detail in Section 3. These sections summarize the excellent introduction to radioactivity given by Edmonds (1986a).

2.1 Basics of Radioactivity

Atoms are composed of three fundamental particle-types. These are protons, neutrons, and electrons. The protons and neutrons make up the nucleus, while electrons orbit outside the nucleus, forming "shells." Protons are positively charged; electrons are negatively charged; and neutrons are electrically neutral. The number of protons in the nucleus is the atomic number of the element. The number of protons and neutrons in the nucleus is the mass number, since these particles make up the majority of the element's mass.

An element with a fixed atomic number may have different atomic masses due to different numbers of neutrons. These are called "isotopes" of the element. When the number of neutrons and protons is unstable, radioactivity will result. That is, the unstable isotope will tend to seek a more stable configuration through the process of radioactive decay.

Radioactive decay involves the emission of charged particles from the nucleus or the capture or ejection of an orbital electron. The particles that are emitted by the nucleus are either an alpha (α) or beta (β) particle. Additionally, there is commonly electromagnetic radiation which accompanies the decay. The electromagnetic radiation is in the form of x-rays or gamma (γ) rays.

The decay of the nucleus is also associated with a loss of energy. The amount of energy lost is measured in electron volts (eV). Most energy transitions from decay are on the order of thousands of electron volts (keV) or millions of electron volts (MeV). Each isotope has characteristic energy levels that it gives off during decay.

The amount of energy lost from particle emission decay depends upon the speed at which the particle leaves the nucleus. Photons (packets of electromagnetic radiation), on the other hand, all travel at the speed of light; the energy of the photon is dependent on its momentum (Edmonds 1986a).

As a simple example, C-14 undergoes the loss of a beta particle to become N-14. The beta particle is associated with a loss of 0.159 MeV of energy. A slightly more complex example is shown in Figure 2-1, in which Cs-137 decays to form the stable isotope Ba-137. In this example, two decay schemes are possible. In the first decay scheme, a beta particle of 0.51 MeV is emitted to form the "metastable" isotope Ba-137m (the "m" after the atomic mass indicates the isotope is metastable), followed by a transition to stable Ba-137 in which a gamma ray of 0.66 MeV is given off. The second decay scheme involves the emission of a beta particle of 1.17 MeV.

Figure 2-1. Example of the decay scheme for Cs-137 (Edmonds 1986a).

The activity of a radioactive substance indicates the number of nuclear transformations the material undergoes per unit of time. The common unit for activity is the curie (Ci), which represents 3.7×10^{10} disintegrations per second.

As a radioactive material decays, its activity is reduced. The amount of time it takes for a radioactive material to decay to half its original activity is called the half-life. The decay of radionuclides can be described through statistical models, which allows accurate assessment of how much activity is lost over time and quantification of the half-life.

When the photons or particles are emitted, the effect they have on surrounding material occurs at the atomic level. Of concern in this report are the effects of "ionization" and "excitation." When an atom is ionized, it loses an electron and an "ion pair" results. The ion pair consists of the residual atom (which now has a positive charge) and a free electron. When an atom is excited, electrons are not in their lowest energy configuration (shell). In this situation, the electrons will seek the lowest energy configuration (shell), in the process giving off energy.

All of the radionuclide properties discussed above are important considerations in the use of sealed sources. These properties are the type of decay, the energy emitted during decay, the activity, and the half-life. Each of these properties is an important factor in selecting a source for a particular application. The following sections discuss the nature of radionuclide transformations in more detail.

2.2 Types of Decay

Since the instability of a radioactive isotope is due to an excess or shortage of neutrons in a nucleus, it would be reasonable to expect the nucleus to reach stability by ejecting some neutrons or protons. And, in fact, that is essentially what happens during alpha decay. However, beta decay and electromagnetic radiation do not involve the emission of neutrons or protons.

2.2.1 Beta Particle Decay

While it would seem reasonable for the nucleus to eject a proton or neutron to reach a more stable configuration, in light elements the nuclear forces binding the protons and neutrons are strong enough to prevent the emission of relatively large particles like neutrons or protons. One strategy for achieving a more stable mix of neutrons and protons without emitting a neutron or proton is to change a neutron to a proton or vice versa.

Since a proton is a positively charged particle, an electron or positron (a positively charged electron) is produced in the conversion to maintain the original charge. If there are too few protons, then a neutron will convert to a proton and an electron is produced and emitted from the nucleus. If there are too few neutrons, then a proton will convert to a neutron, and a positron is produced and emitted. The electron or positron is the beta particle.

For a given isotope, the energy associated with the beta particle may vary due to the way energy is released in beta decay, as shown in Figure 2-1. Along with the beta particle, other particles and energy are also released during decay. Thus, beta decay from a particular isotope is associated with a range of energy levels.

The energy associated with a beta particle is generally less than 3 MeV, though larger energies are possible (Tait 1980). Both positrons and electrons strongly ionize the matter in which they travel as the particles interact with the electrons of the media. Since beta particles are quite light, they bounce around violently in the surrounding media causing randomly distributed "hot spots" where they interact with other atoms. Inevitably, the energy is burned off over a short range (i.e., it is not very penetrating), with the degree of penetration being directly proportional to its energy. The beta particles will eventually be captured by atoms and ions of the medium.

Positive beta decay is characterized by the emission of two 0.511 MeV photons. This is because a positron, which cannot exist for long, is almost immediately annihilated. This occurs when the positron combines with an electron.

2.2.2 Alpha Particle Decay

In atoms of low atomic number, the neutrons and protons are bound together through nuclear forces. For elements of large atomic number, however, these nuclear forces can be overcome by the greater force exerted from the repulsion of the protons from one another. The nuclear forces act only over a very short range, while the repulsion caused by like electrical charge operates over a large distance (Edmonds 1986a). In large, unstable nuclei, then, enough energy can easily be obtained to cause large particles to be emitted.

In alpha particle decay, two protons and two neutrons bound together are emitted. This configuration of two neutrons and two protons is called an alpha particle and is equivalent to a He-4 nucleus. These particles are quite stable and form the basic building block for nuclei. The alpha particle is about 7,500 times more massive than a beta particle (Edmonds 1986a). The alpha particle eventually picks up two electrons to become helium.

The daughter product of an alpha decay is also commonly unstable and so a chain of alpha and beta decays may occur before a stable daughter product is reached. For example, the Th-232 decay chain involves six alpha decays and four beta decays before the stable Pb-208 isotope is produced (Friedlander et al. 1981).

The energy associated with an alpha particle ranges from 4 to 9 MeV (Tait 1980). Additionally, the half-life of an alpha emitter is related to the energy of the alpha particle. An isotope with a short half-life emits particles with less energy.

Alpha particles are highly energetic and ionizing when in contact with other matter because of the positive charge from the protons. However, they are not very penetrating. To see this, the analogy given by Edmonds (1986a) is quite descriptive. Consider a parking lot with cars regularly spaced apart. These cars represent the nuclei of the material bombarded by an alpha particle. Since the alpha particle is roughly the size of the nuclei of the material to be ionized, this particle can also be represented by a small car.

Now if the car was fired into that parking lot it would cause a wreck. The amount of damage and number of parked cars affected would depend upon the speed of the car (i.e., the energy of the alpha particle) upon impact. While the resulting mayhem may be quite severe, it is localized—cars parked on the other side of the parking lot are completely unaffected.

In this same analogy, a beta particle would be roughly equivalent to a tennis ball. Fire the ball into the parking lot and it will bounce around between cars until it finally comes to rest. The ball will “penetrate” the parking lot a bit further than the alpha particle, but will not cause as much damage due to its smaller mass.

2.2.3 Gamma Rays and X-Rays

Gamma rays and x-rays are both forms of electromagnetic energy that have essentially the same properties and are highly penetrating. The major difference between the two is in their point of origination, with gamma rays originating from the nucleus and x-rays originating from the electron shells. While there are low energy forms of x-rays, called “soft” x-rays, the high energy forms, called “hard” x-rays, can have energies similar to gamma rays.

Both gamma rays and x-rays are forms of electromagnetic energy. Electromagnetic energy includes visible light, infra-red, and ultra-violet. While infra-red light is a form of heat (caused by the excitation of the atoms), gamma-rays and x-rays can have far more catastrophic effects on atoms because of their higher energy state.

Briefly, x-rays are emitted due to changes in the orbits of the electrons. Each electron orbit in a given atom/element has an associated energy level. When an electron leaves an orbit to fill a lower orbit that has been vacated by another electron, a photon or packet of energy is emitted. This photon is an x-ray; and depending upon the shell and element, it has a characteristic quantum of energy. That is, the energy emitted is a discrete amount and is characteristic for that element.

The same concepts are true for gamma rays. The nucleus which emits a gamma ray does so in packets of energy characteristic of that element. Gamma rays, however, are associated with alpha and beta decay. When an alpha or beta particle is emitted, it takes energy away from the original nucleus. Often, however, more energy must be emitted in order for the daughter nucleus to be in its lowest energy state.

The photons (both x-rays and gamma rays) emitted have energy levels uniquely characteristic of the parent element; a fact that is useful in analyzing samples through x-ray fluorescence.

Photons will interact with matter in one of three ways: photoelectric absorption, Compton scattering, and pair production. In all cases, the photon ejects an electron from the target atom (causing ionization). In photoelectric absorption and pair production, the photon is fully absorbed in the process.

In photoelectric absorption, the photon imparts all of its energy to the electron. The electron is ejected from the atom at high speed. The product is an ionized atom and a free energetic electron.

In Compton scattering, the photon imparts only a portion of its energy to the electron. This results in an ionized atom, a free energetic electron, and a photon of reduced energy. The photon can continue to ionize other atoms.

In pair production, the photon interacts with the electromagnetic field of the nucleus and is converted into an electron-positron pair of particles. The mass of the particle pair is created from the photon's energy. Since each particle is 0.511 MeV, the photon must have at least 1.022 MeV energy. As mentioned previously, the positron annihilates with an electron almost immediately, forming two 0.511 MeV photons. These photons are then free to interact with other atoms.

In all three cases, the resulting electrons will interact with other electrons in the medium and can produce secondary ionizations. This energy transfer can cascade along until all of the original energy of the photon is deposited in the medium.

2.3 Neutrons

Neutrons can also be emitted from nuclei as particle radiation. The neutron is a fundamental particle with a mass number of 1 and no electrical charge. It may, however, be viewed as a combination of a proton and an electron. Indeed, in its free state, it does decay with a half-life of 12 minutes. The result of the decay is a proton, a beta particle, and a neutrino.

Some elements spontaneously emit neutrons. Cf-252 is one isotope that spontaneously emits neutrons and is frequently used in sealed sources. More commonly, however, an alpha emitter is mixed with a light "target" element to produce neutrons. The most common mixture used is Am-241 and Be. The neutrons produced by this mixture are called "fast" neutrons.

Similar to photons, neutrons can be divided between low-energy, "thermal" neutrons and high-energy, "fast" neutrons. The low-energy neutrons are, like gas molecules, in thermal equilibrium with their environment. Thermal neutrons have energies of about 0.025 eV. Fast neutrons are extremely energetic, with energy up to tens of mega-electronvolts (Tait 1980).

Thermal neutrons have the important ability to activate (to make radioactive) the materials they pass through. While other decay products can do this, neutrons are much more effective. Indeed, many commercially available radioisotopes are produced through neutron bombardment. Activation occurs when the neutrons are absorbed into nuclei through simple random, thermal motion.

Being electrically neutral, neutrons do not interact with the electric fields of atoms, and hence, do not ionize. They are slowed primarily through collisions with light nuclei, such as the hydrogen nucleus. As such, fast neutrons are extremely penetrating.

2.4 Sealed Source Radiation Methods

As should now be apparent, there are a variety of types of radiation. Each type of radiation has been exploited for useful purposes in fields such as medicine, industry, mining, and construction. The following sections briefly discuss the primary ways that radiation from sealed sources are used. In the next section, many of the uses are described in detail.

2.4.1 Backscattering

As noted in the above discussions of decay types, beta particles and gamma rays can be scattered around in the target media. In backscatter techniques, a beam of radiation is directed at the substance of interest and the amount of radiation returning to a detector located near the source is measured. The measured radiation is then used to determine certain properties of the medium, most commonly density and thickness.

Gamma rays can be backscattered by both Compton scattering and photoelectric absorption. In Compton scattering, the photon's energy and direction are changed by interactions with electrons. Hence, the amount of scattering is proportional to the electron density of the substance of interest. In photoelectric absorption, the photon causes a high energy electron from an inner shell to be ejected. When the ionized atom fills that inner shell, an x-ray is emitted; the x-rays emitted are considered backscattered radiation.

Gamma backscattering is used for thickness gauging where beta sources are not suitable. Additionally, it has a number of applications in measuring densities of materials, including well logging and construction applications. It also forms the basis for the chemical analysis method known as x-ray fluorescence.

The backscatter of beta particles is also caused by their interaction with electrons in the substance of interest. Assuming a fairly uniform density of the substance, the amount of beta particles scattered is proportional to the atomic number of the substance. Since beta rays do not penetrate deeply, the substance must be of fairly uniform density.

Beta backscattering is used to measure the thickness of thin samples. It can also be used to measure coating thickness providing that there is sufficient difference in the atomic number between the coating and the substrate.

Although not typically considered a backscatter technique, neutron thermalization is similar in that the neutrons are measured by a detector located near the source. When fast neutrons collide with light elements, they become thermalized. By measuring the amount of thermal neutrons returning to the detector, the amount of light elements can be determined.

Neutron thermalization is most commonly used in moisture measurement—the neutrons being thermalized by the hydrogen in water. Additionally, it is used in well logging and oil exploration.

Another neutron scattering technique is neutron activation analysis. Absorbed neutrons cause elements in the sample to emit gamma rays. These gamma rays are characteristic of the elements which emit them, and so can be used to measure the concentrations of these elements.

The major drawback to backscatter techniques is their acute sensitivity to geometrical effects (Edmonds 1986b). The amount of radiation backscattered is dependent upon the relative positions of the source, detector, and sample.

2.4.2 Transmission

In backscattering methods, the source and detector are typically next to one another. In transmission methods, the source and detector are located on opposite sides of the sample; the radiation reaching the detector is essentially that radiation that has not been scattered or has been lightly scattered. Because of their high penetration, gamma rays and neutrons are most useful in transmission methods, though beta sources are sometimes used.

Transmission methods are some of the most commonly used. They form the basis of radiography techniques and have a wide variety of gauging application, including thickness and density gauging, mass flow measurements, and level control.

Transmission methods using gamma sources come about because the intensity of the beam reaching the detector is a function of the sample density and the distance travelled. For methods using beta sources, the number of beta particles reaching the detector is a function of the sample's density and the distance travelled. And for neutron sources, it is a function of the distance travelled and the concentration of elements that have high neutron absorption and scattering ability.

2.4.3 Irradiation

The prior two general methods are based on the idea that matter changes the properties of the incident radiation. For irradiation and related techniques, the idea is to use radiation to change the properties of the

matter. Irradiation techniques rely on the ionizing ability of the radiation to change the irradiated material in some way.

Irradiation is primarily done with gamma ray sources because of their high ionizing potential and deep penetration. However, beta irradiators are used in certain medical therapy applications.

Irradiation is used to kill viruses and bacteria for food preservation, provide cancer therapy, catalyze chemical reactions, and modify material properties.

2.4.4 Conclusion

Since there are a wide variety of uses, there is also a wide variety of isotopes used. This report is concerned only with those identified in Volume 1 as being FGTC material. These isotopes are Am-241, C-14, Cm-244, Cs-137, Np-237, Ni-63, Pu-238, 239, and 241, Sr-90, Tc-99, and U-238. Table 2-1 provides information on the properties of these radionuclides.

Finally, recognize that the above discussions are looking at individual atoms. When radioactive material is used in sealed sources, there are a vast number of atoms of the isotope. To put the decay processes into perspective, a 1 μ Ci source of Cs-137 will generate approximately 3.7×10^4 beta particles and 3.5×10^4 photons per second (Tait 1980). Next, consider that the activity levels of interest to the GTCC LLW Program are on a millicurie to kilocurie magnitude per source, and one will realize the magnitude of the problem these sources can pose.

Table 2-1. Properties of PCTCC material isotopes [Friedlander, et al. (1981) and Tait (1980)].

Nuclide	Atomic mass	Atomic number	Half-life (y)	Type of decay	Particles		Gamma rays ^a	
					Energy (MeV)	Transition probability	Energy (MeV)	Intensity ^b
Am	241	95	433	α	5.387	1.6%	0.026	2.5%
					5.442	12.5%	0.0593	35.3%
					5.484	85.2%		
					5.511	0.2%		
					5.543	0.34%		
					Others	Low		
C	14	6	5.730	β^-	0.156	100%		
Cs	137	55	30.17	β^-	0.512	94.6%	0.6616 ^c	85.1%
					1.174	5.4%		
Cm	244	96	18.11	α	5.763	23.6%		
					5.806	76.4%		
					Others	Low		
Np	237	93	2.14×10^6	α	4.638	6%	0.029	12%
					4.663	3.3%	0.087	13%
					4.765	8%		
					4.770	25%		
					4.787	47%		
					4.802	3%		
					4.816	2.5%		
					4.872	2.6%		
					Others	<2%		
Ni	63	28	100	β^-	0.066	100%		

Table 2-1. (continued).

Nuclide	Atomic mass	Atomic number	Half-life (y)	Type of decay	Particles			Gamma rays ^a	
					Energy (MeV)	Transition probability	Energy (MeV)	Intensity ^b	Intensity ^b
Pu	238	94	87.74	α	5.445	28.7%			
					5.449	71.1%			
					Others	0.2%			
Pu	239	94	2.44×10^4	α	5.103	11%			
					5.142	15%			
					5.153	73%			
					Others	<0.05% each			
Pu	241	94	14.4	β^-	0.0208	99+%			
				α	4.9	0.0024%			
Sr	90	38	28.8	β^-	0.546	100%			
Tc	99	43	2.14×10^5	β^-	0.204	Low			
					0.293	100%			
U	238	92	4.468×10^9	α	4.143	23%			
					4.195	77%			

a. Only gamma rays with an intensity of 1% or more are listed.

b. The intensity is given as a percentage of disintegrations.

c. Gamma ray emitted by the metastable daughter nuclide Ba-137.

3. SOURCE/DEVICE GENERAL DESCRIPTIONS

The following sections give a brief overview of the various device and source types that have the potential to be GTCC material. Each section describes the function of the device/source, the isotopes and activities of the sources, and the major manufacturers. The descriptions ignore cobalt and other sources that cannot be GTCC material. Much of the information presented in this section is taken from IAEA (1990).

3.1 Calibration Devices

Calibration sources and devices are generally used to calibrate various radiation measuring and monitoring instruments. The source is constructed to emit a specified amount of radioactivity within a small degree of error. In this sense, a calibration device is very similar to an irradiation device as far as its method of application is concerned. Calibration sources are often traceable to some standard, such as from the National Institute of Standards and Technology (formerly the National Bureau of Standards).

There are a wide variety of isotopes and activities available for calibration sources. The primary PGTCC isotopes are Am-241, Cs-137, and Sr-90. Most of the source activities are under 1 Ci. The largest activity calibration source in the NRC Sealed Source and Device (SSD) Registry is a 5,500 Ci Cs-137 source produced by Oak Ridge National Laboratory. The remaining PGTCC calibration sources in the Registry are all less than 250 Ci.

The major manufacturers of calibration sources and devices that are PGTCC material are Monsanto (who is no longer producing sealed sources) and Amersham. GNI, 3M, and ABB Process Automation have also been significant sellers of calibration sources or devices.

3.2 Medical Sources

Sealed sources are used for both diagnosis and treatment of diseases. Uses include x-ray imaging, brachytherapy, and teletherapy. The latter two uses involve irradiating damaged tissue. Medical teletherapy devices treat disease with gamma radiation from a controlled source of radiation located at a distance from the patient. Additionally, there are numerous medical reference sources used as instrument check sources and spot markers. Radioactive materials in unsealed form also have a variety of uses in medicine, including tracer studies and therapeutic applications; however, these unsealed sources generally do not use PGTCC isotopes and are not discussed here.

The isotopes most likely to be found in PGTCC sources or devices are Am-241 and Cs-137, though there are a few high-activity Sr-90 sources also. In the past, Ra-226 sources were extensively used in brachytherapy. Cobalt and iridium sources are probably the most common but are not PGTCC material. Most medical sources have activities well below the PGTCC limits. The majority of medical sources are well below 100 mCi, though there are some sources in the kiloCurie range—used in medical teletherapy devices.

The major manufacturer of medical sources that are PGTCC material was 3M. Since 3M no longer produces sealed sources, other companies such as Amersham and Isotope Products Laboratories will have increasing shares of this market. Nuclear Associates also has a significant market share, specializing in medical reference sources.

3.2.1 Medical Diagnostic Imaging (X-Ray Imaging)

Diagnostic imaging includes a range of radiographic and fluoroscopic techniques, with new techniques still being developed. In general, a beam of radiation is directed through the part of a patient's body under

examination. A short intense beam may be used with the resulting image being recorded on a photographic plate. Alternatively, a continuous, low intensity, beam may be used with the image being viewed on a monitor and/or recorded to video tape. Radionuclide-based instruments are useful for only a limited range of body parts, such as teeth and extremities.

Some radiography systems use Am-241 sources, though I-125 and x-ray tubes are more common. The NRC SSD Registry has only three medical radiography device models with Am-241. The devices have maximum activities of 9 mCi, 15 mCi, and 28.6 Ci, the latter being a thyroid scanner.

3.2.2 Brachytherapy

Brachytherapy, or radiotherapy, uses either a beta or gamma source to irradiate tumors. The irradiation occurs over a very small area and thickness of tissue. There are three categories of brachytherapy, interstitial, intracavitary, and surface, depending upon how the radioactive source is positioned (IAEA 1990).

3.2.2.1 Interstitial Radiotherapy. In interstitial radiotherapy, the source is introduced directly into the tumorous tissue. There are three techniques used.

The first technique uses a needle. The needle typically has a point and eyelet. The size of the needle, particularly the length, depends upon the required activity. These sources commonly use Cs-137 or Co-60. The NRC SSD Registry has registered a large number of needle sources, particularly from 3M. The maximum activity is 500 mCi, though most applications use less than 10 mCi.

The other two techniques do not use isotopes that are PGTC material. The first of these techniques, permanent implantation, uses a radionuclide with a short half-life, such as Rn-222 or Au-198, in small millimeter size cylinders. The other technique uses iridium in the form of a wire. In this technique a small plastic tube is inserted into an incision in the tumor and the radioactive wire is introduced through the tube (this reduces exposure to the medical personnel).

3.2.2.2 Intracavitary Radiotherapy. In intracavitary radiotherapy, the source is entered into a natural body orifice, most commonly the cervix uteri. This technique uses more powerful gamma sources than the interstitial method. Common isotopes are Cs-137 and Co-60. The cesium sources in the NRC SSD Registry are registered for over 1 Ci for remote after-loading units. Remote afterloaders have a tube that delivers the source to the applicator located in the area to be irradiated. This technique eliminates doses to medical personnel, and, when high dose rates are used, occurs in fully shielded rooms.

3.2.2.3 Surface Radiotherapy. In surface applications, the source is applied to the surface of the body part, typically either the skin or the eye. The most common therapy uses a Sr-90 ophthalmic applicator. The activity of these sources are relatively small, usually 40 mCi, and generally these applicators will not be PGTC LLW.

3.2.3 Teletherapy

Teletherapy, or radiation beam therapy, uses gamma rays, x-rays, or electrons directed onto the site of a tumor. Of all the medical therapy applications of sealed sources, teletherapy uses the largest source activities, up to 2,500 Ci of Cs-137; unlike the other applications, however, there are very few teletherapy units in this country—in 1989 there were only 13 that met the GTCC definition.^a

The technique concentrates the radiation at the tumor site both on the surface (skin) of the body or deep within the body. The radiation is concentrated such that it does minimal damage to the surrounding healthy

a. Letter from Steve Baggett (NRC) to Roger Scott (EG&G Idaho), December 30, 1992.

tissue, but kills the tumor. The patient is located on a table in a shielded room that the medical personnel cannot access during the irradiation.

3.3 Well Logging Devices

Well logging sources are used to do geophysical surveys. They are most commonly associated with oil and mineral exploration but are also used by others interested in characterizing subsurface properties, such as matrix density and percent moisture. The source is commonly placed in a pressure vessel before being lowered into the well. This vessel protects the source from the well environment, which can have extremely high pressures and temperatures.

There are generally two techniques used in well logging—neutron thermalization and gamma scattering. Neutron thermalization is used for moisture measurement and oil prospecting. Figure 3-1 shows an example neutron probe. Gamma scattering in well logging has a variety of uses based on density measurements. This use is illustrated in Figure 3-2.

Well logging sources are typically neutron emitters, though gamma sources (typically Cs-137) are also used. The neutron emitters use either Am-241 or Pu-238 mixed with beryllium or other light elements (lithium, boron, or fluorine). The americium or plutonium is typically present as an oxide (AmO_2 , PuO_2) in a powder and mixed with the target light element (also in powder form). The resulting powder is pressed into the inner capsule and plugged. Virtually all well logging sources are doubly encapsulated. The activities range from 100 mCi to 20 Ci, with the larger activities associated with neutron sources; the cesium sources can have activities up to 5 Ci.

The source, pressure vessel, and detector are placed in a borehole or well. The detector is typically wired to instruments on the surface that record or display results. For neutron logging, the alpha particles from the americium or plutonium interact with the target material, causing the target material to emit neutrons. The neutrons travel at a high speed, but are slowed down by interacting with certain elements, particularly hydrogen. The intensity of the slowed down neutrons give a measure of the concentration of the interacting element. Hence, in oil well logging, the neutron source measures the hydrogen content of oil deposits.

The cesium sources are used to determine matrix density. This application of gamma rays, called “gamma scattering” is discussed in Section 3.4, Portable Gauges, and shown in Figure 3-2. The cesium sources are typically around 500 mCi.

In the past, the major well logging source manufacturers were Gulf Nuclear, Inc., Monsanto, and 3M, all of which have since stopped source production. Amersham has recently become more involved in manufacturing cesium and americium sources for well logging applications. Other manufacturers include Tuboscope Inc., Gammatron (also known as Nuclear Sources and Services, Inc.), and Gearhart-Owen Industries, Inc.

3.4 Portable Gauges

Portable gauges or, more specifically, moisture/density gauges, are used in the field at construction sites and on farms. The gauges are typically used to determine the moisture or density of a material such as soil or asphalt. The gauges are relatively small and light so they can be carried to the site (in a transport case similar to luggage). The gauge usually has a long cylindrical probe that is placed into the matrix of interest. The probe most commonly contains the detector, though it may contain the source.

Figure 3-1. Neutron thermalization: well logging with a neutron probe [Lorch (1979)].

Figure 3-2. Gamma scattering: two density measurement applications. The first application measures density in a borehole. The second application gives a surface density measurement such as for asphalt [Lorch (1979)].

The gauge typically contains two sources, a neutron emitter and a gamma emitter. The neutron source is used under the same principal as for well logging. The neutrons travel at a high speed, but are slowed down by interactions with hydrogen. The intensity of the slowed down neutrons gives a measure of the moisture of the matrix. See Figure 3-1. The gamma source provides a measure of the matrix density through gamma scattering. The high energy gamma rays are backscattered from a medium; the resulting intensity provides a measure of the bulk density and porosity of the medium. See Figure 3-2.

Portable gauges (and well logging sources) should be of particular interest to the DOE GTCC LLW Program because they are widespread and almost always use Am-241 sources with significant activities. Many of the sources are Americium-241/Beryllium (Am/Be) sources. A typical gauge contains both an

Am/Be source and a Cs-137 source. The Am/Be source is typically 40 to 50 mCi and the Cs-137 source is 15 mCi. These small Cs-137 sources are likely not of interest to the GTCC LLW Program.

There are essentially two players in this market: Troxler Electronic Laboratories and CPN. They have over 90% of the market. Humboldt Scientific and Seaman Nuclear have small segments of this still very active market.

3.5 Irradiation Devices

Irradiation devices are commonly used in research, food, and medical applications. Medical teletherapy and brachytherapy are forms of irradiation covered in section 3.2. The irradiators discussed in this section are used to irradiate blood, biological samples, and other substances for sterilization. As reported in IAEA (1990), there are a number of uses of ionizing radiation, including:

- Killing or inactivating viruses or bacteria (sterilization)
- Modifying polymer properties by inducing chemical links between individual macromolecules (cross-linking)
- Initiating polymerization in special coatings (curing)
- Activating surfaces so as to induce bonding (grafting).

Specific medical applications include

- Sterilizing products such as disposable syringes, bandages, etc.
- Sterilizing of cell culture media and mixed lymphocyte cultures.
- Irradiating blood. Blood irradiation inactivates lymphocytes to prevent graft versus host disease in patients given transfusions who have severely weakened immune systems.

Industrial applications (IAEA 1990) include:

- Upgrading wire and cable insulation for use at higher temperatures
- Producing of heat shrinkable materials for packaging
- Radiation cross-linking of unvulcanized rubber
- Producing wood-plastic composites to improve mechanical properties
- Curing inks and adhesives on, for example, paper, metal, wood and plastics
- Coating or laminating paper, film, and foil
- Curing magnetic coating for audio and video tapes.

Additionally, irradiation has a variety of uses in food preservation. It can be used to protect food from insects and other spoilage processes such as ripening and sprouting. It can be applied to bulk material or individually packaged units. Some uses (IAEA 1990) include:

- Inhibiting sprouting in root crops
- Insect disinfestation in a variety of crops

- Delay of ripening, particularly in fruit
- Extending shelf-life, particularly in meats
- Reducing microbial load in a variety of foods
- Improving technological properties of food.

Irradiators are broken into four categories as follows.

Category I. Self-contained, dry-source-storage irradiators. These are the most common irradiators. The device completely encloses the source within a shield. Human access to the source and the space subject to irradiation is impossible.

Category II. Panoramic, dry-source-storage irradiators. The device completely encloses the source within a shield when not in use. Irradiations occur in air within a room accessible to personnel only while the sources are shielded. This category also includes certain beam-type irradiators in which the source remains partially shielded.

Category III. Underwater irradiators. The sealed sources are stored in a pool and shielded at all times. Human access to the sources and the space subject to irradiation is not physically possible without entering the pool.

Category IV. Panoramic, wet-source-storage irradiators. The sealed sources are in a storage pool containing water and are full shielded when not in use. Irradiations occur in air within a room made inaccessible to personnel by an entry control system while the sources are exposed.

Category III and IV irradiators are room-sized and larger, and relatively infrequent (compared to Category I and II irradiators). Recent regulations from the NRC essentially ban the use of Cs-137 in Category III and IV irradiators (58 FR 7715, February 9, 1993), due to its solubility. Previously, very few Category III and IV irradiators used Cs-137, opting instead for the higher energy and insoluble Co-60 sources.

Irradiation devices vary considerably in the activity of their sources, with upper limits on the order of 15,000 to 20,000 Ci. The most common isotope of interest to the GTCC LLW Program is Cs-137, though cobalt sources are the most common. The sources tend to be shaped in long narrow tubes, reaching lengths of a foot or more. Large irradiators often use multiple sources.

There are three major manufacturers of irradiation devices, Nordion International, CIS-US, and J. L. Shepherd. Nordion is a Canadian company. Nordion takes back and disposes of all its sources/devices (in Canada) as a service to the customer. J.L. Shepherd will also take back devices and reuse sources. Hence, while these devices do have extremely high activities, the impact of these devices on the GTCC LLW Program may not be so significant.

3.6 Fixed Gauges

Fixed gauges have a wide variety of industrial and manufacturing uses, primarily to monitor production processes. They can monitor moisture, thickness, and density. Additionally, they are used as level monitors (e.g., monitor the fill level of a can of soup). Radioactive sealed sources have become popular in this area because of their ease of use and noncontact/nondestructive method of operation, matched with essentially real-time results. The source is typically encased in a "source housing" that protects the source from extreme environments.

There are a number of major manufacturers in this market, with TN Technologies, Kay-Ray, and Ohmart being the largest. Other significant manufacturers include ABB Process Automation, Ronan Engineering, and Berthold Systems. Discussions with these manufacturers did not indicate much concern on their part with disposing of sources; notably, these companies are shifting away from using Am-241 and, to a lesser extent, Cs-137.

There are a variety of gauging techniques that can be broken into nine categories:

1. Transmission gauges (beta and photon)
2. Gamma backscatter gauge
3. X-ray fluorescence gauge
4. Photon switching (level gauge)
5. Selective gamma absorption
6. Beta backscatter gauge
7. Gamma scattering
8. Thermalization of neutrons
9. Neutron transmission.

The first five techniques are discussed in the following sections. Beta backscatter gauges typically do not use sources that are PGTC material (though Sr-90 with up to 5 mCi can be used). Gamma scattering, used to measure density, is discussed under Section 3.4, Portable Gauges. Neutron scattering (i.e., thermalization of neutrons), used to measure moisture or other hydrogen and light element-rich substances, is discussed in Section 3.3, Well Logging Devices. Neutron transmission is discussed in Section 3.7, General Neutron Applications Sources. The descriptions are from IAEA (1990).

3.6.1 Transmission Gauges (Beta and Photon)

Transmission gauges are typically used to determine sample thickness. The source and detector are arranged on opposite sides of the sample and the radiation penetrates the sample and proceeds to the detector. The degree of absorption provides a measure of the sample thickness or density. Two applications are shown in Figure 3-3. Both beta and gamma sources can be used. Beta sources are used to

- Measure the thickness of plastic, paper, thin metal sheet, rubbers, textiles, etc.
- Determine the tobacco content of cigarettes
- Measure the dust and pollutant levels on filter paper samples.

Gamma sources are used to

- Measure the thickness of metal sheets (steel rolling mills), glass, plastics, rubber, etc., at thicknesses that are too large for beta gauges
- Monitor bulk flow of material on conveyors or in pipes
- Measure bone density to diagnose osteoporosis.

Figure 3-3. Beta and gamma transmission: two gauging applications. The left application measures the thickness or density of a continuous sheet. The right application weighs the load in the conveyor [Lorch (1979)].

The beta sources include Sr-90, with activities ranging from 1 to 1,000 mCi. The gamma sources include Am-241 and Cs-137, with activities ranging from 10 to 1,000 mCi. The actual source strength and type is fit to the application.

In some applications, when measuring over a wide band of material, a long source strip or assembly will be used. In other applications, a small circular source is used to measure a narrow band of material. In the latter case, the source and detector may be moved along the primary axis of the sample, such as a cigarette.

3.6.2 Gamma Backscatter Gauges

In gamma backscatter gauging, both the source and detector are located on the same side of the sample. Because of this, the detector must be shielded from direct radiation from the source. The method is most suitable for measuring material thicknesses (beyond the sensitivity of transmission gauges) and mean atomic number (the larger the atomic number, the more backscatter). Two applications are shown in Figure 3-4. Specific applications include

- Determine thickness of light alloys, glass, plastics, rubbers, etc., beyond the measurement range of beta sources
- Measuring the wall thickness of pipes, tanks, process vessels, etc.
- Measuring the ash content of coal (the ash increases the mean atomic number)
- Acting as coal sensing probes on automatic coal cutting machines.

The sources include Am-241 (100 mCi), Cs-137 (50 mCi), and Pu-238 (25 mCi). The actual isotope and activity are tailored to the particular application.

Figure 3-4. Gamma backscatter technique in fixed gauging. The gauge on the left measures the density of the glass. The gauge on the right determines the ash content of the coal based on the mean atomic weight [Lorch (1979)].

3.6.3 X-Ray Fluorescence Gauge

An x-ray fluorescence gauge uses a low-energy gamma, x-ray, or bremsstrahlung source to excite x-rays from the sample. The resulting x-rays can be used to measure the thickness of coatings. X-ray fluorescence is also used for chemical analysis. This application is discussed in Section 3.8. Example applications of x-ray fluorescence gauges include measuring the thickness of metals on other metals where there is only a small difference in atomic number between the metals.

PGTCC sources include Pu-238 (25 mCi) and Am-241 (100 to 1,000 mCi). The actual isotope and activity are tailored to the particular application.

3.6.4 Photon Switching (Level Gauge)

In photon switching a gamma or x-ray source emits radiation through a container to a detector located on the opposite side of the container. The intensity of the radiation is changed depending upon whether the contained material has reached the level of the radiation. See Figure 3-5. Example applications include

- Packaging monitors, providing automatic rejection of partially filled cans, bottles, etc.
- Process control of the contents of large vessels, hoppers, etc., e.g., liquids in vessels, coal in hoppers
- Alignment of pusher and container on coke ovens.

PGTCC sources include Am-241 (100 mCi) and Cs-137 (50 to 2,000 mCi). The actual isotope and activity are tailored to the particular application.

Figure 3-5. Gamma transmission in level gauges: two types of photon switching gauges. In the first application, only one detector is used to monitor when the level is too high [Lorch (1979)].

3.6.5 Selective Gamma Absorption

In selective gamma absorption, the source and detector are located on opposite sides of the sample. The source is selected to emit a specific energy, based on the element in the sample being measured. Typically the element being measured has high atomic weight and is contained in a matrix with low mean atomic weight. Example applications include

- Measurement of sulfur in oils
- Measurement of lead in gasoline
- Measurement of ash in paper.

PGTCC sources include Am-241 with 10 mCi activity.

3.7 General Neutron Application Sources

General neutron application (GNA) sources are neutron emitters used in a variety of applications, including moisture/density gauges, explosives detectors, neutron activation analysis, neutron radiography, and bulk sample analyzers. Moisture/density gauges are discussed under portable gauging in Section 3.4. This category excludes well logging and reactor startup sources. The three most common applications are discussed below.

Most of these sources use either Am/Be, Pu/Be, or Cf-252 to generate neutrons, though other alpha or gamma emitters can be used. Other target neutron generators include lithium, boron, and fluorine. In cases where the radioactive element is a gamma emitter, the target is often kept separate from the active material in a window configuration; but due to the short range of alpha particles, alpha emitters (including Am-241 and Pu-239) are thoroughly mixed together with the target light element. They can have source activities up to 10 Ci, with most being about 100 mCi. Cf-252 sources can have similar activities, but because the half-life is less than 5-years, these sources will not be GTCC LLW.

Troxler Electronic Laboratories and Monsanto (no longer in the sealed source business) have produced the most GNA sources and devices. Most Am/Be and Pu/Be sources that fall into the GNA category will need to be handled by a GTCC LLW disposal facility.

3.7.1 Neutron Radiography

In neutron radiography, a beam of thermal (slow) neutrons is projected through a sample. The emerging neutron radiation is measured or recorded to film. Changes to the beam of neutrons indicate either scattering of the neutrons by low atomic number material or absorption of neutrons in material having a high neutron cross-section. Cf-252 is the most commonly used source isotope, and hence, these sources are not likely to be GTCC material.

3.7.2 Neutron Capture and Activation Analysis

When neutrons, either fast or thermal, interact with a material, gamma rays and nuclear reaction products are emitted. These products can be analyzed in terms of energy, rate of decay, and intensity to provide qualitative and quantitative identification of the elements in the sample. The idea is similar to that in x-ray fluorescence in that the radiation causes an emission from the sample that identifies the elements in the sample. Typical uses include

- Trace element analysis to the ppm level
- Pollution analysis
- Measurement of silicon, chromium, aluminum, etc., in the analysis of ores
- Production control measurement of oxygen in steel
- Borehole analysis.

These devices can use Am/Be neutron sources with activities between 1 and 100 Ci.

3.7.3 Neutron Transmission

Neutron transmission is quite similar to neutron radiography in that a beam of thermal neutrons is transmitted through a sample of interest. The intensity of the emerging beam gives a measure of elements with either low atomic number or high neutron cross-sections. Typical uses include:

- Measurement of boron content of detergents, glass, etc.
- Bulk element analysis in process control, e.g., water, lithium, boron, cadmium
- Weighting of explosives.

These devices can use Am/Be neutron sources with activities between 250 to 1,000 mCi.

3.8 X-Ray Fluorescence

This category refers to the application of x-ray fluorescence (XRF) to analyze samples to determine their chemical composition. The source emits radiation which in turn causes atoms in the sample to emit characteristic x-rays which are then measured. XRF devices can either be small portable instruments that can be used in the field, or large, laboratory-based instruments. The method is illustrated in Figure 3-6.

Most of the sources of interest to the GTCC LLW Program will have Am-241 sources, though there are some Cm-244 and Pu-238 sources. The activities are typically 30 mCi, but can be upwards of 10 Ci.

TN Technologies and Oxford Analytical Instruments produce the large XRF devices. Oxford Analytical Instruments, Outokumpu Engineering, and Asoma Instruments are manufacturers of portable x-ray fluorescence devices.

Figure 3-6. X-ray fluorescence analysis in which a photon source is used to excite fluorescent x-rays in the sample [Lorch (1979)].

3.9 Other Uses

The above categories cover the most widespread uses of radioactivity that use PGTCC sealed sources. In this section, brief note is made of two other techniques. The first, radiography, is widely applied but does not use PGTCC sources. The second technique, thermal generation, used to power heart pacemakers among other things, can utilize large Pu-238 sources. However, lithium batteries are now more commonly used in pacemakers.

3.9.1 Radiography

In radiography, a beta, gamma, x-ray, or neutron beam is passed through the material of interest. Changes in the radiation beam after passing through the material will indicate imperfections, voids, or corrosion in the material. The resulting radiation is commonly recorded as an image. These devices are commonly used to check the integrity of pipes, joints, or other structures. Additionally, x-rays and gamma rays are used in medical diagnostic radiography. The sources typically do not use PGTCC isotopes, or if they do, they are of activities lower than the PGTCC limits.

3.9.2 Nuclear Batteries (Pacemakers)

Applications which require batteries that must produce electricity over long periods of time without interruption can use radioactive sources. The sources generate heat which, when a sufficient temperature gradient is achieved, will produce electricity. These nuclear batteries are used in heart pacemakers and in low power lights and transmitters (e.g., navigational aids). Heart pacemakers can use Pu-238 in activities up to 35 kCi, though usually less than 10 kCi. Low power lights and transmitters may use Sr-90 in activities up to 20 kCi.

3.10 Summary of Devices

This section has covered the wide variety of applications of the principles and techniques of radioactivity introduced in Section 2. Transmission and backscatter methods have led to gauging devices and chemical analysis. Irradiation methods have many medical, industrial, and manufacturing applications.

Table 3-1 summarizes the radiation methods and isotopes used in devices that contain PGTCC sealed sources. Of particular note (due to their activity levels) are cesium sources used in irradiators and medical teletherapy devices, and large neutron sources used in well logging and general neutron applications. On the

Table 3-1. Summary of radiation methods and isotopes used in devices that contain FGTC sealed sources. The isotopes and activities reflect the most common applications. Other isotopes and larger activities can be expected, but should not commonly occur.

Device type	Radiation Method	Isotope	Typical activity	Maximum activity
Calibration	NA	Am-241	<500 mCi	1 Ci
		Cs-137	<1 Ci	2 kCi
Medical	Radiography	Am-241	<100 mCi	30 Ci
	Teletherapy	Cs-137	1.25-2.5 kCi	2.5 kCi
	Brachytherapy	Cs-137	1-10 mCi	500 mCi
Well logging	Neutron thermalization	Am-241	6-16 Ci	20 Ci
		Pu-238	6-16 Ci	20 Ci
	Gamma scattering	Cs-137	<500 mCi	5 Ci
Portable gauge	Neutron thermalization	Am-241	40-50 mCi	5 Ci
	Gamma scattering	Cs-137	5-15 mCi	1 Ci
Irradiation	NA	Cs-137	1-5 kCi	20 kCi
Fixed gauge	Beta transmission	Sr-90	<500 mCi	1 Ci
	Gamma transmission	Am-241	0.01-0.5 Ci	1 Ci
		Cs-137	0.01-0.5 Ci	1 Ci
	Gamma backscatter	Am-241	100 mCi	1 Ci
		Cs-137	50 mCi	1 Ci
		Pu-238	25 mCi	1 Ci
	Photon switch	Am-241	100 mCi	1 Ci
		Cs-137	0.05-2 Ci	2 Ci
	XRF	Am-241	0.1-0.5 Ci	1 Ci
		Pu-238	25 mCi	100 mCi
	Gamma absorption	Am-241	10 mCi	NA
General neutron applications	Neutron capture and activation analysis	Am-241	1-100 Ci	100 Ci
	Neutron transmission	Am-241	0.25-1 Ci	1 Ci
X-ray fluorescence		Am-241	1-1,000 mCi	1 Ci
		Pu-238	1-1,000 mCi	1 Ci
Other	Nuclear battery	Pu-238	4-6 Ci	35 Ci
		Sr-90	NA	20 kCi

other hand, certain small neutron sources used in portable gauges and gamma sources used in fixed gauges, while not having excessively high activities, are quite common and may make up the largest volume of material the GPCC LLW Program may expect.

In this section, the devices and applications that use sealed sources were discussed. In the following section, the sealed sources themselves are considered in detail.

4. SEALED SOURCE CONSTRUCTION

In the previous sections, the uses of sealed sources are discussed. As part of that discussion, there are descriptions of the isotopes and activities used. In the following sections, a more detailed look at sealed source construction is given. The first section discusses general sealed source construction. The second section describes various performance requirements that sealed sources must meet, in particular, the American National Standards Institute (ANSI) standard for the classification of sealed sources. This classification system states conditions that a source should be able to withstand. Appendix A shows specifications for a representative selection of PGTC sources.

4.1 General Principles

To a user, the importance of a sealed source is not so much what the source contains as what it emits. Hence, source construction is designed around allowing radiation to be emitted while containing the radioactive isotope. The design of the source must meet three general criteria (Engelbert 1971):

1. The radiation emission from the source must be satisfactory for the ultimate application, taking into account the influence of the selected mounting and sealing method on the type, intensity, spectrum, and uniformity of the emitted radiation.
2. There should be no release of radioactive material due to loss of integrity of the source seal, even after prolonged service life.
3. The sealing material must be compatible with the prospective environment of the source.

4.1.1 Radiation Emission

The first criteria is important in determining the types of materials that may be used in the source capsule, as well as the overall shape of the capsule. Alpha and beta sources commonly have "windows" that allow these less penetrating forms of radiation to be emitted. The window may be made of a material that does not interfere greatly with the particles or it may be just a thinner area in the wall of the capsule.

4.1.2 Containment of Radioactive Material

There are three general ways that radioactive material may be incorporated into the source (Engelbert 1971):

1. Incorporate the radioactive material into a metallic matrix. These are so-called "foil" sources. They are used extensively in smoke detectors, static eliminators, and electron capture detectors (gas chromatography).
2. Form a ceramic compound in which the radioactive material is firmly bound. This is commonly used to produce Cs-137 "beads." In this production, silicates are replaced with cesium so that the isotope becomes a permanent part of the ceramic's structure. The beads are then commonly sealed in metallic cylinders.
3. Encapsulate the radioactive material into one or more containers of acceptable protective properties. The capsule material is typically a high-grade stainless steel.

For PGTC sealed sources, the third containment type, metallic capsules, is the only one of interest. The first two containment methods are utilized in sources with activity levels and/or isotopes that are not PGTC material.

The radioactive material contained in the source actually makes up a very small fraction of the overall source mass and volume. Typically, the isotope is in a chemical form that is either safe to handle or has low reactivity with the source environment.

Plutonium and americium are almost always present in sources as oxides, PuO_2 or AmO_2 . In a neutron source, the oxide powder is intimately mixed with a beryllium (or other light element target) metal powder. The powder may also be mixed with some other neutral filler, such as aluminum. The mixed powder is typically sintered or pressed to form a solid pellet.

In PGTC sources, cesium is most commonly incorporated into a cermet or ceramic by replacement of silicates. The ceramic is generally in a pellet shape. Pressed and sintered cesium salts may also be used. Sr-90 is also commonly incorporated in a source as a ceramic.

4.1.3 Capsule Design

Sealed sources come in a variety of shapes and sizes. The source is, of course, designed around the type of radiation required and the specific application (e.g., brachytherapy, well logging). The shapes include foils, wires, needles, disks, rods, and rings. Source volumes vary from less than 1 cm^3 to over $2,000 \text{ cm}^3$ for large gamma irradiation sources.

For PGTC sealed sources, there are two general shapes: the cylinder and ring (annular). Cylindrical sources are the most frequently used. The cylinder may be a long rod (commonly used in large gamma irradiators) or a short tuna can shape. Additionally, there may be threading or eyelets or other appendages to the basic cylinder allowing the source to be secured in the device. The annular shapes are used in low energy photon sources. Figures 4-1 through 4-4 show examples of each type.

The size and style of the source is a function of the activity and type of radiation. All high activity gamma and neutron sources will be doubly encapsulated. Alpha and beta sources are commonly "foil" sources; that is, thin, generally metallic, strips with active material coated on them. This is because the alpha and beta particles do not penetrate deeply. However, these foil sources have low activities and are not considered PGTC material.

Beta and certain low energy gamma sources commonly have "windows." A window is an area through which the radiation is expected to pass. For a beta source, the beta particles are shielded except through a thinner area in the wall—this thinner area of the capsule wall is the window. For low energy gamma sources, the window is usually associated with a light element, generally beryllium, which attenuates the gamma energy. The window area of the source may be constructed of different material, material that is less opaque to radiation, than the remainder of the capsule.

The performance requirements for sealed sources, discussed in Section 4.2, limit the types of metals used in capsules to a narrow scope. High grade stainless steel is the most frequent capsule material used; the most common grades include 304, 316, 316L, 321, 410, and 17-4 PH. Monel is also a fairly common capsule material. Aluminum may be used in beta sources, but is not likely to be used in sources that are PGTC LLW. Titanium and tantalum are used in special applications. For well logging, where the source must withstand pressures of up to 25,000 psi, some capsules are made from nitronic metals or ARMCO NP-30 precipitation hardened stainless steels.

A study was undertaken in 1993 to establish whether neutron sources could be come Resource Conservation and Recovery Act (RCRA) hazardous waste (Kimer, 1994). There was concern that either the silver solder or the neutron generating beryllium would exceed RCRA hazardous waste limits. It was concluded that these sources are not hazardous waste under current RCRA definition.

LF94 0094

Figure 4-1. Example of a neutron disk source with Am-241 and a beryllium window. Courtesy of Amersham Corporation.

LF94 0093

Figure 4-2. Example of large gamma sources using Cs-137 with activities of up to 2.2 kCi. Courtesy of Amersham Corporation.

LF84 0085

Figure 4-3. Example of an annular Cm-244 source, with a brazed beryllium window. Courtesy Amersham Corporation.

4.1.4 Sealing of Sources

Virtually all PGTCC sealed sources produced today use welds to seal the capsules. To provide a quality seal that meets the performance requirements discussed in Section 4.2, welds provide the most cost-effective method. The most common weld methods are heliarc and tungsten inert gas (TIG) welds. The weld penetration depth is usually under 0.05 inches, depending upon wall thickness.

Solders may be used to attach windows or when the capsule is aluminum. For example, Amersham's AMCL, CLCL, and PPCL series of sources for fixed gauges uses a silver solder to attach a beryllium window to the source. Similarly the AMCD1 Amersham XRF source uses vacuum brazing to attach a beryllium window to a monel capsule. In both cases, the actual sealing of the capsule containing the radioactive source material is by welds. There are also some sources which use solders to seal the inner capsule, but weld the outer capsule lid, such as TN Technologies fixed gauge Cs-137 source model 696833 and many of the older 3M doubly encapsulated sources.

LFSA 0066

Figure 4-4. Example of large, doubly encapsulated gamma irradiation tube sources containing Cs-137 (information from NRC Sealed Source and Device Registration).

Sealing of the source capsule by solders, however, is not considered an acceptable practice by most source manufacturers and the NRC. Indeed, the NRC recently imposed a penalty on a source manufacturer for just such a practice. This company shortly thereafter ceased source production. This regulatory action should further discourage the use of solders for sealing sources.

4.2 Performance Classification

To provide manufacturers of sealed sources a set of tests to evaluate the safety of their products and to assist users of such sources to select types which suit their applications, the American National Standards Institute has developed a system of classification of sealed radioactive sources based on performance

specifications related to safety (ANSI 1978). Tests are prescribed for temperature, external pressure, impact, vibration, and puncture over a range of severity to which a source can reasonably be subjected.

Among other things, this standard includes a source classification that is commonly used by manufacturers and by the NRC to determine whether a source meets the requirements under 10 CFR 32.210(d) for registration. The classification is based on the performance of the source in the five tests. The performance classifications of the tests are shown in Table 4-1.

Part of the source classification is a five-digit code that describes the performance on each of the tests. The digits are in the order of temperature, external pressure, impact, vibration, and puncture. The five digit code is preceded by the year of approval of the American National Standard used to determine the classification followed by a letter.

The letter will be either a C or an E. The letter is assigned based on the toxicity and activity of the isotope contained in the source. The letter C indicates a lower toxicity and/or activity than an E.

Additionally, the Standard establishes performance requirements for a variety of common device types. These requirements are shown in Table 4-2.

For example, a large Category I gamma irradiator Cs-137 source may be designated "ANSI 77E43323." This indicates that the source designation is based on the standard approved in 1977, the source contains either highly toxic or high activity amounts, the source meets class 4 requirements for temperature, class 3 requirements for external pressure, class 3 requirements for impact, class 2 requirements for vibration, and class 3 requirements for puncture.

There is another classification of sources that manufacturers use, independent of the the ANSI standard. This is whether the source is "Special Form" material or not. The International Atomic Energy Agency established the Special Form tests to determine the maximum acceptable activities for various types of transport containers. The tests evaluate sources under impact, percussion, bending (applicable only to long, slender sources), and heat. Source owners may prefer a Special Form Source because it is less expensive than a non-Special Form Source together with a corresponding transport container.

In addition to the above performance requirements, there are requirements for specific device types and sources contained in those devices. ANSI has standards for certain radiography devices (ANSI N432-1980), certain brachytherapy sources (ANSI N44.1-1973), and self-luminous light sources (ANSI N540). The NRC has issued specific requirements for well logging devices in 10 CFR 39.41 (which requires that the source meet the ANSI classification 56522) and brachytherapy sources in 10 CFR 35.400. It has recently issued requirements for sources used in Category II through IV irradiators in 58 FR 7715, February 9, 1993 (which requires double encapsulation and stainless steel, and bans the use of Cs-137) for Category III and IV irradiators.

Table 4-1. Classification of sealed source performance standards by ANSI N43.6-1977. These performance standards for sealed sources are generally used by the NRC as part of their source registration procedure (58 FR 7715). There is also a Class X, not included in this Table, for sources that will be subject to unique conditions; this Class requires custom testing protocols.

Test	Class					
	1	2	3	4	5	6
Temperature	No test	-40°C (20 min) +80°C (1 hr)	-40°C (20 min) +180°C (1 hr)	-40°C (20 min) +400°C (1 hr) and thermal shock +400°C to +20°C	-40°C (20 min) +600°C (1 hr) and thermal shock +600°C to +20°C	-40°C (20 min) +800°C (1 hr) and thermal shock +800°C to +20°C
External pressure	No test	25 kN/m ² abs. (3.6 lbf/in ²) to atmosphere	25 kN/m ² abs. to 2 MN/m ² (290 lbf/in ²) abs.	25 kN/m ² abs. to 7 MN/m ² (1,015 lbf/in ²) abs.	25 kN/m ² abs. to 70 MN/m ² (10,133 lbf/in ²) abs.	25 kN/m ² abs. to 170 MN/m ² (24,656 lbf/in ²) abs.
Impact	No test	50 g (1.8 oz) from 1 m (3.28 ft) and five drop ten times to a steel surface from 1.5 m (4.92 ft)	200 g (7 oz) from 1 m	2 kg (4.4 lb) from 1 m	5 kg (11 lb) from 1 m	20 kg (44 lb) from 1 m
Vibration	No test	30 min 25 to 500 Hz at 5 g peak amp	30 min 25 to 50 Hz at 5 g peak amp and 500 to 900 Hz at 0.635 mm amp peak to peak and 90 to 500 Hz at 10 g	90 min 25 to 80 Hz at 1.5 mm amp peak to peak and 80 to 2,000 Hz at 20 g	Not used	Not used
Puncture	No test	1 g (15.4 gr) from 1 m (3.28 ft)	10 g (154 gr) from 1 m	50 g (1.76 oz) from 1 m	300 g (10.6 oz) from 1 m	1 kg (2.2 lb) from 1 m

Table 4-2. ANSI N43.6-1977 sealed source minimum performance requirements for the device types discussed in this report. The test requirements are shown in the previous table.

Device type	Test				
	Temperature	Pressure	Impact	Vibration	Puncture
Calibration	2	2	2	1	2
Medical	3	2	3	1	2
Radiography					
Gamma teletherapy	3	3	3	2	4
Well logging	3	6	3	2	2
Portable gauge	4	3	3	3	3
Irradiation	4 ^a	3	4	2	4
Categories II, III, and IV					
Category I	4	3	3	2	3
Fixed gamma gauge--- medium and high energy	4	3	3	3	3
Unprotected source					
Source in device	4	3	2	3	2
Fixed gamma gauge--- low energy	3	3	2	2	2
Fixed beta gauge	3	3	2	2	2
General neutron applications	4	3	3	2	3
X-ray fluorescence	3	3	2	2	2

a. ANSI N43.10 revised the temperature requirement to test level 3 for category II, III, and IV irradiators.

5. SOURCE/DEVICE CHARACTERIZATION DATABASE

The results of the source/device characterization are contained in the Source/Device Characterization (SDC) database. This is a dBase IV file, SDC.DBF, available from Don Fischer or Gerry Harris of the National Low-Level Waste Management Program, P.O. Box 1625, Idaho Falls, ID 83415-2420. It is based on the U.S. NRC Sealed Source and Device Registry (SSD) database. The following describes the SDC database.

The SDC database is essentially a subset of the U.S. NRC Sealed Source and Device Registry database (Version 2.0, July 1992) with some additional information. Unlike the NRC's Registry database, the SDC database has information for PGTCC sources only. The NRC Registry was implemented to

- Generate a registry that will assist the license reviewer and inspector in the licensing and inspection of sealed sources and devices
- Protect public health and safety by preventing inadequate sealed sources and devices from being distributed and used by the public
- Help identify lost or abandoned sources and devices.

When a company manufactures a new device or source model, it must first get the model registered through the NRC or the competent authority in an Agreement State (AS). The company fills out forms that describe the source or device and these forms are sent for review to the NRC. The forms ask for source and device characterization information, safety considerations, conditions of normal use, etc. This registration system was formalized in 1982, with the registrations being stored in a hard copy format.

More recently, the NRC has put a subset of the information contained in the registration certificates into an electronic database. This database was developed to allow regulators to quickly retrieve information pertaining to sources and devices. The electronic database is described in the documentation that accompanies the NRC's SSD database.

The electronic registry contains information relevant to the characterization of PGTCC sources and devices that will be of use to the DOE in disposing of sources. Specifically, company names, addresses, model numbers, isotopes, and maximum activity levels are included. However, the SSD does not include other information that is needed for the GTCC LLW Program, such as source volumes and whether the source is welded or soldered.

Another problem with the Registry is that multiple models may be included under the registration certificate. This leads to problems from lack of specificity. For example, the Registry gives a maximum activity of 300 mCi of Cs-137 to Amersham's CDC.700 series; yet most of the source models in this series have activities well below the PGTCC limits (e.g., CDC.701 has 1 mCi of Cs-137).

Because of the lack of specificity for some registered models and the lack of information relevant to the GTCC LLW Program, the SSD was modified to produce a database that more closely fits the DOE's needs. This is the SDC database. Modifications include the deletion of some fields not relevant to the DOE, addition of fields relevant to the DOE, and addition of records that are incompletely specified in the original SSD database.

The SDC is broken into two distinct database files. The major file is SDC.DBF, which contains the source/device specification information. The other file, ADDRESS.DBF, contains addresses of source and device manufacturers.

6. ANNUAL PRODUCTION ESTIMATION

In Volume 1, the current inventory of PGTC sealed sources held by specific licensees is estimated. In that report, it was estimated that there are 89,000 PGTC sources under the base case. The report found that Cs-137 and Am-241 sources were the most frequently observed. The estimated number of sources, broken down by principal use and isotope, is shown in Appendix B for the base case.

However, Volume 1 did not attempt to estimate the number of sources produced in the future. GTCC sealed sources produced in the future may significantly impact the planning and requirements for a GTCC LLW disposal facility. The GTCC Inventory and Projection System for sealed sources (GIPSSS) program, which this document supports, is used to estimate the amount of GTCC LLW sealed sources the DOE will be required to dispose of. Part of the data requirements for the GIPSSS program is future production of sealed sources sold to specific licensees broken down by principal use and isotope.

As a result of this need, a survey of manufacturers of sealed sources or devices containing sealed sources was implemented to collect production data. In this section, the results of that data collection and analysis activity are given.

The following discusses what information was requested from manufacturers, the methods applied to estimate the annual production of PGTC sources by isotope and device type (i.e., the incremental numbers of sources), and the results. Due to the proprietary nature of the information asked for from the companies, the raw data and intermediate results are not presented.

6.1 Survey Methodology

In order to model future yearly production of sealed sources, yearly past production records of sources/devices was needed. Thus, manufacturers and distributors of sources/devices were contacted by phone and by letter to obtain this data. Since it was infeasible to contact every manufacturer of sources/devices, manufacturers were contacted that accounted for at least 50% of the number of PGTC sources/devices in each principal use as determined from the NRC and AS surveys. Appendix E has tables showing the most common companies and models observed in the survey results by principal use. The companies were initially contacted through a phone call and then sent a letter of request for information.

6.1.1 Phone Calls

The source/device industries are highly competitive and past production records are considered proprietary information by many companies. Thus, to increase the response rate, manufacturers and distributors were contacted by phone to explain EG&G Idaho's and the DOE's involvement with the GTCC LLW Program before a letter requesting past production data and other information was sent. Calling companies before hand also established a contact to send a letter to and helped further identify those companies who produced sources/devices that are PGTC material.

Radiation Safety Officers (RSOs), the majority of the company contacts, answered questions over the phone very thoroughly and often provided additional information about their companies and industries. The following information was requested during the phone conversation:

- A brief history of the company's name changes and takeovers. This information is useful for tracking past production and for correlating this data to results from the NRC and AS specific licensee surveys.

- The type of sources/devices the company primarily produces, and uses of the devices.
- The sources primarily used in the devices and the isotopes associated with them and the range of activities.
- Average life span of the sources/devices. This information was requested to see if a "turnover rate" of sources/devices could be determined. Such a rate may be a useful way of estimating future production.
- Information on storage, disposal and recycling of unwanted or unusable sources/devices. This information was requested to determine whether there is a significant number of sources that are being reused, thus reducing the distribution of new radioactive material.
- The company's customer return policies once the sources/devices are no longer wanted.
- Willingness to release past production records.
- Expectations about future production.

6.1.2 Survey Letter

Most RSOs seemed willing to release past production records and other data provided a letter was sent to them listing the information needed, the general purpose of the request and a statement that confidentiality would be maintained. The following was requested in the letter:

- A product catalog with specifications (dimensions, source activity, and isotope) of the source/device models that the company manufactured or distributed
- Recommended useful life of the source or device
- The company's current return or recycle policies
- Past production or sales records specifying the number of sources or devices sold per year
- In some cases, estimates of yearly future production.

6.1.3 Problems Encountered

While it was hoped that the contacted companies would be cooperative, it was recognized that some of the information being asked for is sensitive and proprietary. The degree of cooperation, however, was far less than expected. Some of the major problems encountered are briefly discussed in the following.

6.1.3.1 Nonresponse. Although many RSOs indicated over the phone that they would be willing to send past production estimates, the response rate was disappointing in that few companies have responded. Of those that have responded, some sent everything except past production records or very general past production estimates. Follow-up phone calls indicated several reasons for the nonresponse:

- Superiors were not willing to release past production information.
- The level of effort to retrieve past production data is too great; essentially, it was not worth their time.

- Several potential respondents were adamant that they had no PGTC material or did not produce PGTC material. While our information indicates otherwise, they were not willing to respond.

With respect to the last bullet, it should be noted that there is validity to the companies' concerns. First, many companies are no longer producing high-activity sources or sources with transuranic (TRU) isotopes as they may have done in the past when concerns about waste disposal were not as much an issue. Second, information was being requested on sources that can currently be disposed of at LLW facilities. As discussed in Section 1, the GTCC Management Program distinguishes between PGTC sources and sources that will be handled by the DOE for disposal. Most PGTC sources will quite likely not be handled by the DOE; however, uncertainty in the future regulation of LLW concentration averaging requires the DOE GTCC LLW Program to be conservative in its planning. On the other hand, the recent proposed NRC technical position on concentration averaging (released at the time this Volume was being written) may go a long way to removing some of that uncertainty, if the position is adopted.

6.1.3.2 Quality of Past Production Data. The quality of past production data received has also been less than satisfactory. Instead of sending actual past production figures, some companies opted to send general estimates such as "produced 500 devices per year over the past 10 years." This type of estimate was not the best to base future estimates on. For proprietary reasons companies may have chosen to send this type of information.

6.1.3.3 Well Logging. Many of companies in this industry were unwilling to send past production records because they felt the past was not representative of the future. Between 1975 and 1985 the oil industry experienced a boom. Now, however, the industry expects little growth in the near future.

6.2 Analysis Methods and Results

The number of responses to the request for past production information was extremely small. While many companies did provide source/device characterization information, most did not include past sales data. Because of this, the methods used to estimate the future annual production of sealed sources rely as much on information gained from the survey of specific licensees as they do on the manufacturers' data. While the method is straightforward, it does not allow for a quantitative uncertainty analysis. Qualitative discussions of the accuracy of the estimates are given in Section 6.4.

The method initially estimates the current production rate and then adjusts this rate (for known and expected market trends) to determine future annual production rates. Because there is a great deal of uncertainty in quantifying future market trends, future annual production rates are assumed to follow a steady-state. Unless major changes occur in the market, the assumption of steady-state production should give reasonably accurate results.

6.2.1 General Methodology to Compute Extrapolated Past Production of Sources by Principal Use and Isotope

Extrapolations of past production of sources for specific licensees are based on the NRC and AS specific licensee survey results and past production data from the manufacturers and distributors. However, due to the vendors' requests that the data they released be kept confidential, this section presents only general methodology, formulas, and final results.

Initially, the base case annual production rates were estimated as follows. Given the number of sources/devices produced per year by company c in principal use i , the total number of sources produced for a particular year for principal use i is estimated by

$$N_l = \frac{N_{lc}}{MS_{lc}} \quad (1)$$

where

- N_l = number of sources produced per year for principal use l
 N_{lc} = number of sources produced per year by company c for principal use l
 MS_{lc} = estimate of company c 's market share in principal use l from the NRC and AS specific licensee survey results.

This estimate is used to approximate the number of sources produced per year for other principal uses with the following formula.

$$N_i = \frac{N_l P_i}{P_l} \quad (2)$$

where

- N_i = number of sources produced for principal use i , $i \neq l$
 N_l = number of sources produced for principal use l .
 P_i = percentage of sources for principal use i , $i \neq l$
 P_l = percentage of sources for principal use l .

Table 6-1 lists the percentage of sources for each principal use.

Table 6-1. Percentage of sources for each principal use. These are the P_i and P_l values in Equation (2).

Principal Use	Percentage of Sources
Calibration	10.03
Medical	1.78
Well logging	7.46
Portable gauge	17.32
Irradiation	2.05
Fixed gauge	36.07
General neutron applications	2.38
X-ray fluorescence	1.25
Other	21.66

The approximate number of sources of a particular isotope within a principal use under the base case is found using

$$N_{ij} = N_i P_{ij} \quad (3)$$

where

N_{ij} = number of sources produced for principal use i and isotope j

N_i = number of sources produced for principal use i

P_{ij} = proportion of sources of isotope j within principal use i .

Table 6-2 displays the percentages of isotopes within each principal use.

The low case and high case estimates for the annual production rates of sealed sources sold to specific licensees are found by adjusting the base case estimates. The base case estimates are derived in part from the results of the 1992 surveys. The survey results are subject to some degree of uncertainty. The low and high case annual projection estimates were derived to account for this uncertainty.

The low case annual production is calculated such that it is proportional to the uncertainty, as represented by the lower confidence limit, of the current inventory estimates. Similarly, the high case annual production estimate is calculated to be proportional to the uncertainty, as represented by the upper confidence limit, of the current inventory estimates.

To calculate the low case annual production, the base case annual production is multiplied by the ratio of the lower confidence limit of the estimated current inventory to the estimated current inventory. To calculate the high case annual production, the base case annual production is multiplied by the ratio of the upper confidence limit of the estimated current inventory to the estimated current inventory. The current inventories and confidence limits are shown in Appendix B.

For example, the base case estimated annual production of Am-241 calibration sources is 290 sources per year. From Appendix B, the estimated current inventory is 3,000 sources with upper and lower confidence limits of 1,319 and 4,682, respectively. Hence, the estimated low case annual production of americium calibration sources is $290 \times (1,319/3,000) = 128$; and the estimated high case annual production of americium calibration sources is $290 \times (4,682/3,000) = 453$.

This method for calculating the low and high case estimates was selected to reflect the uncertainty in the base case estimates. However, the low and high case estimates do not form a valid confidence interval on the annual production because not all uncertainties are accounted for. Some other uncertainties include estimated market shares of the companies providing production data and uncertainties in the provided production data.

Also, there are general trends in the industries that use sealed sources that are not accounted for in these estimates. These trends are discussed and the estimates are adjusted for some of these trends in Section 6.3.

6.2.2 Results

Past production records were received from six companies in three principal use markets. Of the six, two provided inadequate information on which to base the projections. The first of these two companies was only able to provide information on the total activity of material shipped, including waste material. The

Table 5-2. The percentage of isotopes of PCTCC LLW sources within each principal use. For example, 32.68% the PCTCC calibration sources use Am-241. When divided by 100, these values are the P_{ij} of Equation (2).

Device Type	Am-241	C-14	Cm-244	Cs-137	Ni-63	Np-237	Pu-238	Pu-239	Pu-241	Sr-90	Tc-99	U-238
Calibration	33.62	0.27	0.39	38.43	1.27	0.12	0.46	3.08	0.19	21.59	0.19	0.39
Medical	21.74	—	—	74.78	—	—	—	—	—	1.52	0.22	1.74
Well logging	64.92	—	—	32.44	—	—	2.59	—	0.05	—	—	—
Portable gauge	99.26	—	—	0.74	—	—	—	—	—	—	—	—
Irradiation	8.52	—	—	90.91	—	—	—	—	—	0.57	—	—
Fixed gauge	7.10	0.11	0.05	92.38	—	—	0.01	—	—	0.35	—	—
General neutron applications	69.81	—	—	—	—	—	5.36	24.84	—	—	—	—
X-ray fluorescence	61.73	—	21.60	0.31	—	—	16.36	—	—	—	—	—
Other	5.84	0.32	0.18	57.57	20.08	0.02	8.18	3.39	0.11	1.55	2.36	0.41

second of these companies is no longer producing devices containing sealed sources and much of its production was of sources that were not PGTC material.

The four remaining companies provided the total number of sources produced per year for at least the past five years (one company gave 11 years of data). Since there was no obvious trend in the data, the average annual production was computed for each company. These averages formed the N_c of Equation (1). The results from applying Equations (2) and (3) to these averages are shown in Tables 6-3, 6-4, and 6-5 for the low, base, and high cases, respectively.

6.3 Adjusted Estimates of Future Annual Production

As mentioned previously, there are general trends in the production rates for certain of the device types. While particular companies or device types may be experiencing growth, overall the markets for devices containing PGTC sources are either stable or shrinking. Companies are moving toward less toxic substances, for example, using x-ray tubes instead of gamma sources as photon sources. Also, companies recognize the disposal problems with certain isotopes and are replacing these isotopes with those that can be more easily disposed, for example, using Co-60 in place of Cs-137 in irradiators. And in some applications, nonradioactive techniques are replacing methods that use radioactive isotopes; for example, using ultrasonic methods in certain gauging applications.

While it is impossible to accurately assess the rate at which sources will be produced in the future, the production rates given in the previous section can be adjusted for current trends. The estimates given in the previous section were in part based on the current estimated inventory of sources held by specific licensees. This inventory has been built up over decades and is likely not sensitive to more recent trends in radioisotope production.

In this section, the estimates given in Section 6.2 are adjusted to better reflect current trends. The adjustment factors are based on qualitative assessments of the degree to which the trend will impact production over the near future. Generally the adjustments are believed to be conservative—that is, the actual effect of the trends is more likely to result in lower production rates over those given here.

In each of the following sections, some of the major trends identified through discussions with manufacturers are further discussed, with an emphasis on determining adjustment factors for the annual production rates given in Section 6.2.

Finally, it should be noted that the production rates given here do not take into account reuse and recycling. Recycling of longer-lived radioisotopes is on the increase, particularly for large neutron sources. Recycling will, however, be accounted for by the GIPSSS program, which is using the data reported here.

6.3.1 Impacts on Future Production

Major impacts on future production are the reuse and recycling of sources, new technologies, and the full cost recovery program. For the most part, these impacts will most likely cause a decrease in production. In addition, little production of well logging sources is expected, due to the decline in the oil sector. In Section 6.3, the results are adjusted for some of these trends.

6.3.1.1 Reusing and Recycling. Because of growing awareness of the difficulty of disposing of sources, the expense of some forms of isotopic material, and the general emphasis on waste reduction, there is increasing reuse and recycling of radioactive sources.

A source is reused if the radioactive material is not removed from the capsule. In this situation the source will need to be retested to assure that performance requirements are met. In some cases, a reused

Table S-3. Unadjusted estimates of the annual production of PGIOC sealed sources sold to specific licensees, low case. The numbers are rounded to at most two significant digits.

Device type	Am-241	C-14	Cm-244	Cs-137	Ni-63	Np-237	Pu-238	Pu-239	Pu-241	Sr-90	Tc-99	U-238	Total
Calibration	130	1	1	240	1	0	1	10	0	0	0	0	380
Medical	18	0	0	50	0	0	0	0	0	1	0	1	70
Well logging	100	0	0	40	0	0	0	0	0	0	0	0	140
Portable gauge	1,200	0	0	6	0	0	0	0	0	0	0	0	1,200
Irradiation	0	0	0	120	0	0	0	0	0	0	0	0	120
Fixed gauge	160	0	0	2,400	0	0	0	0	0	6	0	0	2,560
General neutron applications	100	0	0	0	0	0	4	30	0	0	0	0	140
X-ray fluorescence	40	0	5	0	0	0	3	0	0	0	0	0	50
Other	80	2	1	80	1	0	0	40	0	15	0	4	200
Total	1,900	3	7	2,900	2	0	8	80	0	20	0	5	4,980

Table 5-4. Unadjusted estimates of the annual production of PGTC sealed sources sold to specific licensees, base case. The numbers are rounded to at most two significant digits.

Device type	Am-241	C-14	Cm-244	Cs-137	Ni-63	Np-237	Pu-238	Pu-239	Pu-241	Sr-90	Tc-99	U-238	Total
Calibration	290	2	3	330	11	1	4	30	2	190	2	3	860
Medical	30	0	0	110	0	0	0	0	0	2	0	3	150
Well logging	420	0	0	210	0	0	17	0	0	0	0	0	640
Portable gauge	1,500	0	0	11	0	0	0	0	0	0	0	0	1,500
Irradiation	15	0	0	160	0	0	0	0	0	1	0	0	180
Fixed gauge	220	3	2	2,900	0	0	0	0	0	11	0	0	3,100
General neutron applications	140	0	0	0	0	0	11	50	0	0	0	0	210
X-ray fluorescence	70	0	20	0	0	0	18	0	0	0	0	0	110
Other	110	6	3	1,100	370	0	150	60	2	30	40	8	1,900
Total	2,800	12	30	4,800	390	1	200	140	4	230	50	14	8,800

Table 8-3. Unadjusted estimates of the annual production of PRT/C sealed sources sold to specific licensees, high case. The numbers are rounded to at most two significant digits.

Device type	Am-241	C-14	Cm-244	Cs-137	Ni-63	Np-237	Pu-238	Pu-239	Pu-241	Sr-90	Tc-99	U-238	Total
Calibration	450	4	6	430	20	2	7	40	4	400	3	6	1,400
Medical	50	0	0	180	0	0	0	0	0	4	1	4	240
Well logging	730	0	0	380	0	0	40	0	1	0	0	0	1,200
Portable gauge	1,700	0	0	16	0	0	0	0	0	0	0	0	1,700
Irradiation	30	0	0	200	0	0	0	0	0	2	0	0	230
Fixed gauge	280	9	3	3,300	0	0	1	0	0	16	0	0	3,600
General neutron applications	190	0	0	0	0	0	20	70	0	0	0	0	270
X-ray fluorescence	90	0	40	1	0	0	30	0	0	0	0	0	170
Other	140	10	6	2,100	750	1	360	90	4	40	100	12	3,600
Total	3,700	20	60	6,600	770	4	480	200	9	460	110	20	12,000

source is placed in a tertiary capsule for further assurance that performance criteria are met. A source is recycled when the radioactive material is removed from the capsule (i.e., the capsule is cut open), typically mixed with other recycled or virgin material, and then encapsulated.

Sources with long half-lives such as Am-241 often outlive the devices they are installed in. Thus, these sources may be reused, if they pass safety and integrity tests, reducing the need for future production. However, one major source manufacturer lists a 10- or 15-year recommended working life (depending upon the environment the source is used in) for Am-241 sources it manufactures, even though many are used in the field much longer. Not only does this reduce the company's liability, it reminds a user that a source has a finite useful life that is a function not only of the nuclide's half-life, but also of the source construction and its environment. Even though a source may appear unharmed on the outside, its interior may be significantly damaged. Moreover, due to technological changes, a source constructed 15 years ago may no longer be as efficient or effective as sources constructed today.

Some manufacturers feel that sources with shorter half-lives, such as Cs-137, are not worth the expense to reuse or recycle. Thus, these sources are stored until they can be disposed of. For example, some portable gauge manufacturers will accept another portable gauge manufacturer's device and extract the source. However, one portable gauge manufacturer's source is not compatible with another portable gauge manufacturer's device. Because no agreement exists among portable gauge manufacturers to swap sources, the source is put in storage rather than reused.

A fixed gauge manufacturer stated that recycling sources, extracting radioactive material and reencapsulating it into another source, can cost as much as 80% of the cost of a new source. Some manufacturers, however, believe this is the right thing to do versus disposing of the source by burying.

In any case, reuse and recycling of old sources appears to be an option in the gauging and well logging sectors of the sealed source market. As such, the estimated production for these device types may reflect a significant number of reused or recycled sources.

6.3.1.2 Disposing of Unusable or Unwanted Sources. Disposing of some sources, such as Am-241 and Pu-238, is an expensive problem for many licensees. Many disposal sites, such as at Bamwell, South Carolina, are slated to close or have closed, and no other facilities are opening to replace them. Thus, licensees are forced to store sources. This problem may deter many customers from purchasing devices with radiation sources.

Some manufacturers do take back devices or sources from customers. However, due to the disposal problem, some manufacturers may no longer do so or take them back at a very high cost. One source manufacturer mentioned that in the future they may take sources back at a cost of \$30,000 per source. Another manufacturer is asking its customers to store devices with the sources in cold storage until the company can take the devices back and extract the source for a fee, when a facility becomes available to dispose of them.

6.3.1.3 New Technologies. In the gauging industry, one of the selling points for sealed sources is that they can measure properties of material nondestructively. However, because of increasing costs for disposing of sources and potential safety concerns, other nonnuclear technologies are being considered, further decreasing demand for future production of sealed sources. A nonnuclear x-ray tube device is replacing x-ray fluorescence devices with nuclear sources. Optical, ultrasonic, and microwave technologies may replace some nuclear devices used in the gauging industry.

However, new technologies may also require new types of sources, increasing future production. For example, in the medical industry there are new Co-57 flood sources for Gamma Head Cameras. Ni-63 is used in a new aerosol deionizing technology in the industrial sector.

6.3.1.4 Licensing Fees. Some manufacturers mentioned that the NRC and some agreement states are imposing annual fees, in addition to licensing fees. These fees range from \$1,200 to \$10,000 depending on the amount of licensed material. One manufacturer felt that this would restrict growth in the gauging industry to simply replacing devices, and that it would be difficult for sealed source owners to pass these fees onto their customers. These fees allow the NRC to recover their full cost of administration of the license, including inspections.

A portable gauge manufacturer, who manufactures road construction gauges, stated that many small contractors are giving their gauges to laboratories in exchange for analyses of materials that they would normally analyze themselves had they retained the gauge. The manufacturer felt that laboratories would do the work more efficiently and that fewer gauges would be manufactured as a result.

6.3.1.5 Decommissioning Costs. The NRC has recently implemented regulations that require licensees to certify that they can cover the costs associated with future decommissioning of their sealed sources. The financial assurance of costs can either be prepaid or a surety or insurance method can be used. These regulations appear in 10 CFR 30.35. The effect is to make owning a specific license and radioactive material more expensive. This policy has been in place for NRC specific licensees since 1990; it is going to be in place in all Agreement States in the near future. These regulations are expected to cause some licensees to drop their license and hence result in lower demand for sources in the future.

6.3.2 Well Logging

The well logging industry has experienced a significant drop in production due to the decline in the oil business. Domestic growth is currently not expected. This industry has a large inventory of neutron sources that are currently not being used. Indeed, these are the companies that are most in need of a GTCC LLW disposal facility.

This, however, is not to say that no well logging sources are being produced. Well logging sources are subject to extreme environments and commonly need replacement from aging. Production for replacement sources is expected to proceed at a slow rate. Additionally, some of the companies operate in the more active international market where sources are still needed. Any increase in the production of sources is expected to be countered by disposal of sources. Moreover, many well logging sources contain Am-241 and are reused when possible.

For the base case, it is assumed that well logging sources are produced at 30% the rate of previous years. For the low case, then, it is assumed that production is at 10% of past rates. And for the high case, it is assumed to be at 50% of past rates.

6.3.3 Irradiation

Large gamma irradiators are turning to Co-60 over Cs-137 as the isotope of choice. One manufacturer of irradiation devices stated that while in the past 80% of the irradiators they sold used cesium sources, it is now closer to 50%. Cobalt has become a more valid alternative for large-activity irradiators. Issues of cost and availability are favoring cobalt. Additionally, the NRC has recently proposed banning the use of cesium in Category III and IV irradiators; though this will have little impact since cesium was very rarely used in these wet-storage irradiators due to its relatively high solubility.

For the base case, the annual production rates are adjusted by reducing the estimate for cesium irradiators by 25%. The reduction noted above (from 80% to 50%) is approximately a 37% reduction. Since some of this reduction is probably already accounted for in the estimates (due to the currency of the data the estimate is based on), a 25% reduction is reasonable. For the low case, a 50% reduction is assumed. And for the high case, no adjustment is made.

6.3.4 X-Ray Fluorescence

The x-ray fluorescence device manufacturers we spoke to were in unanimous agreement that the use of x-ray tubes (which do not use radioactive sources) is replacing the use of radioactive sources. The tubes can provide roughly the same accuracy and measure a similar range of elements as older analyzers using radioactive photon sources. However, they do still sell analyzers with radioactive sources, and expect to continue to do so—particularly supplying replacement sources.

For the base case, the rates given in section 6.2 are reduced by 25% for the x-ray fluorescence sources. While this assessment trend indicates that there will be even further reductions in the use of radioactive sources in the long term, 25% is chosen as a conservative near-future estimate. For the low case, the x-ray fluorescence estimates are reduced by 50%; no reduction is implemented for the high case.

6.3.5 Nuclear Pacemakers

Many of the Pu-238 sources in the "Other" use category are nuclear pacemaker batteries. Nuclear batteries for pacemakers are being replaced by nonradioactive lithium batteries. Production of nuclear batteries for pacemakers has essentially ceased. While these batteries do have other uses, the survey results found this to be the most frequent.

In all three cases (low, base, and high), the production rate for Pu-238 "Other" use sources is reduced by 90%. This figure is based on the 90% occurrence of plutonium pacemaker batteries in the survey results.

6.3.6 Results

The result of applying the above adjustments are shown in Tables 6-6, 6-7, and 6-8 for the low, base, and high cases, respectively. The adjustments result in approximately a 5% reduction in the low case total annual production, and a 7% reduction for the base and high cases.

As discussed in section 6.3.1, increases in licensing costs, advent of new technologies, and other issues may impact the future production of PGTC sealed sources. However, there is not currently sufficient information available on the effect of these issues on production to allow the current estimates to be adjusted. So the estimated production rates are not adjusted for these trends to retain a degree of conservatism.

6.4 Validity of the Estimates

The estimates given in the previous sections are based on a number of assumptions. Violation of these assumptions may affect the validity of the estimates. Probably the most important assumption is that the estimated number of sources currently produced per year is an adequate predictor of future production. Because it is impossible to know the situation in the future, this assumption cannot be validated. The following briefly discusses some other important assumptions.

- The relative proportion of PGTC sources between principal uses based on past licensee data from the NRC and AS survey, adequately portrays the current and future production. The results were adjusted for trends based on conversations with manufacturers. So at least currently, this assumption is fairly valid after taking adjustments into account. The device types that will account for the largest number of sources is still the gauges, both portable and fixed.

Table 6-6. Adjusted estimates of the annual production of PCTTC sealed sources sold to specific licensees, low case. The numbers are rounded to at most two significant digits.

Device type	Am-241	C-14	Cm-244	Cs-137	Ni-63	Np-237	Pu-238	Pu-239	Pu-241	Sr-90	Po-210	U-238	Total
Calibration	130	1	1	240	1	0	1	10	0	0	0	0	380
Medical	18	0	0	50	0	0	0	0	0	1	0	1	70
Well logging	10	0	0	4	0	0	0	0	0	0	0	0	14
Portable gauge	1,200	0	0	6	0	0	0	0	0	0	0	0	1,200
Irradiation	0	0	0	60	0	0	0	0	0	0	0	0	60
Fixed gauge	160	0	0	2,400	0	0	0	0	0	6	0	0	2,600
General neutron applications	100	0	0	0	0	0	4	30	0	0	0	0	140
X-ray fluorescence	20	0	3	0	0	0	2	0	0	0	0	0	20
Other	80	2	1	80	1	0	0	40	0	15	0	4	200
Total	1,700	3	4	2,800	2	0	7	80	0	20	0	5	4,700

Table 6-7. Adjusted estimates of the annual production of PGTOC sealed sources sold to specific licensees, base case. The numbers are rounded to at most two significant digits.

Device type	Am-241	C-14	Cm-244	Cs-137	Ni-63	Np-237	Pu-238	Pu-239	Pu-241	Sr-90	Tc-99	U-238	Total
Calibration	290	2	3	330	11	1	4	30	2	190	2	3	800
Medical	30	0	0	110	0	0	0	0	0	2	0	3	150
Well logging	130	0	0	60	0	0	5	0	0	0	0	0	190
Portable gauge	1,500	0	0	11	0	0	0	0	0	0	0	0	1,500
Irradiation	15	0	0	120	0	0	0	0	0	1	0	0	140
Fixed gauge	220	3	2	2,900	0	0	0	0	0	11	0	0	3,100
General neutron applications	140	0	0	0	0	0	11	50	0	0	0	0	210
X-ray fluorescence	50	0	17	0	0	0	14	0	0	0	0	0	80
Other	110	6	3	1,100	330	0	15	60	2	30	40	8	1,700
Total	2,500	12	30	4,600	390	1	50	140	4	230	50	14	8,000

Table 6-8. Adjusted estimates of the annual production of PCTCC sealed sources sold to specific licensees, high case. The numbers are rounded to at most two significant digits.

Device type	Am-241	C-14	Cm-244	Cs-137	Ni-63	Kp-237	Pu-238	Pu-239	Pu-241	Sr-90	Po-210	Total
Calibration	450	4	6	430	20	2	7	40	4	400	3	1,400
Medical	50	0	0	180	0	0	0	0	0	4	1	240
Well logging	370	0	0	190	0	0	20	0	1	0	0	580
Portable gauge	1,700	0	0	16	0	0	0	0	0	0	0	1,700
Irradiation	30	0	0	200	0	0	0	0	0	2	0	230
Fixed gauge	280	9	3	3,300	0	0	1	0	0	16	0	3,600
General neutron applications	190	0	0	0	0	0	20	70	0	0	0	270
X-ray fluorescence	90	0	40	1	0	0	30	0	0	0	0	170
Other	140	10	6	2,100	750	1	36	90	4	40	100	3,300
Total	3,300	20	60	6,400	770	4	120	200	9	460	110	11,500

- The relative proportion of isotopes within the principal uses based on past licensee data from the NRC and AS survey, adequately portrays the current and future production. The two most common GTCC material isotopes (Am-241 and Cs-137) in the survey results are currently still the isotopes most commonly used that can be GTCC material. As noted previously, large gamma irradiators are turning to Co-60 over Cs-137. Also, some of the less frequent isotopes may not be used as much; for example, at least two companies related that while they did use Pu-238 isotopes in the past, they no longer do so.
- The companies that did provide past production data are representative of manufacturers in general. This assumption is difficult to validate. Of the four companies whose data was used to calculate the results, three would be considered major players in their respective markets. Two of the companies have also experienced significant growth over the past 5 to 10 years; hence they may not represent other companies as well.

Based on current knowledge, the sealed source market looks fairly stable, though some decline can be expected. The decline would be primarily associated with increases in the cost of maintaining a license to hold by-product material. Specifically, the fees that the NRC has recently implemented will likely be implemented by the Agreement States in the near future. The decline will also be due to increased recycling, implementation of nonnuclear technologies, and, for potential GTCC LLW sources, a reduction in the use of highly toxic or high activity sources. Offsetting these factors for declining production will be production of replacement sources and the additional sources used in newly developed applications.

The annual production estimates are believed to adequately characterize the expected annual production of PGTC sources sold to specific licensees. The unadjusted estimates were discussed with several manufacturers, who concluded that the estimates for their segment of the market were reasonable. The adjusted estimates take into account some of the aforementioned declines that can be expected. Thus, while a quantitative uncertainty analysis is impossible, based on our current knowledge, the estimated production rates appear to be realistic.

7. CONCLUSIONS

While there are a wide variety of applications of radioactivity contained in sealed sources, both the principles governing those applications and the designs of the sources are fairly similar. In irradiation techniques, the radioactivity is used to change the properties of the material. In gauging application, properties of the material are assessed by the effect they have on the transmitted or scattered radiation.

Sealed sources are designed to contain the isotopic material under severe conditions. They are generally made of high grade stainless steel with welds designed to prevent leakage of the material. As such, the capsule itself is a safe containment device that will prevent its contents from leaching into the soils at a disposal facility. The degree of safety can be assessed by the source's ANSI performance classification.

There is some concern about the possibility of sealed sources being mixed waste; that is, whether the source is both a low-level radioactive waste and a hazardous waste under the Resource Conservation and Recovery Act (RCRA). Of particular interest were americium/beryllium sources as beryllium is known to be highly toxic. A recent study conducted for the DOE concluded that these sources will not be mixed waste because they are neither characteristic nor listed wastes (Kirner 1994). A similar concern was whether devices containing sealed sources could be mixed wastes. Discussions with manufacturers indicated that this would not occur.

Sources of most interest to the GTCC LLW Program will be the large gamma irradiation sources used in irradiators and medical teletherapy units, large neutron sources used in well logging and other general neutron applications. While these sources are not the most common, they do have the largest activities.

However, the future appears to rely less heavily on PGTC sources. Both manufacturers and end-users have become aware of the problems of disposing of certain isotopes with high activity levels. In gamma irradiators, cobalt-60 is becoming the isotope of choice over cesium-137. Cobalt is not GTCC material. In x-ray fluorescence applications, users are favoring the use of nonradioactive x-ray tubes over radioactive sources. The well logging industry is currently inactive, and there is no revival in sight.

After taking these trends into account, it is estimated that about 8,000 PGTC sources will be produced for specific licensees each year. Over half of those sources will be Cs-137 sources, and about a third will be Am-241 sources. This report did not estimate future production of sealed sources sold to general licensees.

Additionally, increases in licensing costs, advent of new technologies, and other trends expected in the future may further reduce the use of PGTC sources. However, there is not currently sufficient information available on the effect of these issues on production to allow the current estimates to be adjusted. So the estimated production rates are not adjusted for these trends to retain a degree of conservatism.

8. REFERENCES

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Appendix A

Specifications of Selected PGTCC LLW Sealed Sources

Appendix A

Specifications of Selected PGTCC LLW Sealed Sources

The following tables, broken down by principal use, show specifications on selected sources that are PGTCC material. The sources were selected to be representative of the range of sources available within a particular device type. However, this does not mean that the listings are of the most popular models. Indeed, sources used in devices are often custom made and are generally not included in the tables since these source designs tend to be proprietary.

Included in the following tables are the isotope, maximum activity, manufacturer, model, number of capsules, source dimensions, capsule material, sealing method, and ANSI classification (as per Section 4.2 of this report). Within each principal use, the sources are sorted by isotope and maximum activity. If a field in the table is blank, no data was available for that model.

The information contained in the appendix is from either the NRC Sealed Source and Device Registry or from the manufacturer's catalog and can be found in the SDC database. Many of the sources listed in the tables are no longer being produced.

The "activity" column usually lists maximum activity, but may instead indicate a "nominal" activity. The nominal activity is the most common activity loading of the isotope.

In some cases, under the "model" column, multiple models are given under the same listing. This generally reflects the fact that the models use the same capsule but have different loadings of radioactive material. Many of the Amersham sources with multiple models under the same listing are preceded by the model number under which the sources are registered.

For the dimensions, it is assumed that the source is a cylinder. The first dimension given is the diameter and is appended with a "D" to make this clear. The second dimension is the length. If the source is not in the general shape of a cylinder, this is noted in the table.

For capsule materials, the notation "SS" means stainless steel. If the source is doubly encapsulated and the capsules are made of different materials, this is noted in the table by specifying the "outer" and "inner" capsule materials.

The closure indicates the type of weld or braze used to seal the cap of the source. If the source is doubly encapsulated and the closure is different for the two capsules, this is noted in the table by specifying the "outer" and "inner" closure method. Note that the TIG, heliarc, and argon-arc welds likely refer to the same method of welding. However, the nomenclature used in the Registry or catalog is retained.

Table A-1. Specifications of selected sealed sources used in calibration.

Isotope	Maximum Activity	Manufacturer	Model	Number of capsules	Outer Dimensions	Capsule Material	Outer Closure	ANSI classification
^{241}Am or ^{228}Fr	0.1 Ci	Monnate	2417 ^a	1	$0.2053 \times 0.719 \text{ in.}$	304 SS	TIG	77C6545
Cs-137	165 mCi	Amerstham	77302	2	$63 \times 8 \text{ mm}$	SS	weld	77C66545
Co-137	143 Ci	PERMAFORM NL	ORNL 2339 A ORNL DSR-2384	2		316 SS	weld	77E43525 (DSK)
Cs-137	220 Ci	EON Corp./ORNL	ORNL Dog. 926-175	2				

a. It is not clear whether this is a neutron source; while the Registration miniature neutrons, there is no mention of the target element. Also, this model is singly encapsulated; however, the capsule is intended to be put into a secondary capsule that acts as a holder-adaptor to allow it to properly fit into the instrument to be calibrated.

Table A-2. Specifications of selected sealed sources used in medical applications.

Isotope	Maximum Activity	Manufacturer	Model	Number of capsules	Outer Dimensions	Capsule Material	Outer Closure	ANSI classification
Cs-137	10 mCi	Amersham	CDC-K1	1	3.2D x 8 mm	SS	weld	
	30 mCi		CDC-K2					
	100 mCi		CDC-K3					
Cs-137	15 mCi	Amersham	CDC-G1	1	4.0SD x 20 mm	inert-platinum	weld	
	30 mCi		CDC-G2					
	45 mCi		CDC-G3					
	60 mCi		CDC-G4					
	75 mCi		CDC-G5					
Cs-137	100 mCi	ICN Biomedicals	76005	2	0.210 x 0.154 in.	300 series SS	helium weld ^a	C & E 32333
	500 mCi		76006					
Cs-137	2 Ci	ICN Biomedicals	76007	2	3.75 x 0.575D x 1.5 in. ^b 3.78 x 1.27 x 0.575	375: N/A ^c 378: 17-4PH SS	375: helium weld 378: helium weld ^d	375: C33333 378: C33333
	5 Ci		76008					
Cs-137	10 Ci	ICN Biomedicals	76009	2	0.492D x 1.97 in.	321 SS	helium weld	C & E 33333
	20 Ci		76010					
	50 Ci		76011					
	100 Ci		76012					
	150 Ci		76013					
Cs-137	1.0 mCi	Amersham	CDC-30	2	3.0D x 70 mm	SS	sewn arc weld	
	1.5 mCi		CDC-31					
	2.0 mCi		CDC-32					
Sr-90	100 mCi	Amersham	SIA-10	2	2.5D x 25 mm ^d	outer: niocol inner: silver foil		

a. The inner capsule may be sealed by either a helium weld or a silver braze.

b. Models 76007 and 76008 can use either capsule type 375 or 378.

c. N/A = data not available.

d. Length dimension given does not include the 120-mm handle that is attached to the source. The device is a nasopharyngeal applicator.

Table A-3. Specifications of selected sealed sources used in well logging applications.

Isotope	Maximum Activity	Manufacturer	Model	Number of capsules	Outer Dimensions	Capsule Material	Outer Closure	ANSI classification
Am-241/Ba	1 mCi 3 mCi 10 mCi 30 mCi 100 mCi 300 mCi	Amersham	AMN-PES-1; AMN-11 AMN-13 AMN-15 AMN-16 AMN-17 AMN-18	2	17.40 × 19.2 mm	SS	weld	E66646
Am-241/Ba	30 mCi	Amersham	AMN-PES-5; AMN-168	2	7.80 × 15 mm	SS	weld	C65545
Am-241 or Am-241/Ba	500 mCi	Comarcon	AN-RF, dwg 20P2	2	0.50 × 0.5 in.	17-4 SS (disc use 304, 316 SS) heat treat B-1300 form B-1100	helium weld	C or B 56536
Am-241 or Cs-137	51 Ci 51 Ci	GNH Inc.	VL-1	2	0.125-1.0 × 0.25-3 in.	SS	helium weld	C43335
Am-241 or Cs-137	52 Ci 510 Ci	GNH Inc.	ENV	2	0.2-1.0 × 0.5-3 in.	SS	helium weld	C6516 (7)
Am-241 or any β-γ emitter	2 Ci (Am) 20 Ci (other)	Gamma Industries	VD	2	inner: 0.125-2.0 N 0.25-6 in. outer: varies	304 or 316 SS	helium (TIG)	33434
Am-241 or any β-γ emitter	2 Ci (Am) 20 Ci (other)	Gamma Industries	VD (RP)	2	inner: 0.125-2.0 N 0.25-6 in. outer: varies	304 or 316 SS	helium (TIG)	46515
Am-241/Ba	3 Ci	Amersham	AMN-PES-3; AMN-23	2	22.40 × 48.5 mm			
Am-241/Ba	3 Ci 3 Ci	Amersham	AMN-CY3; AMN-2643 AMN-2645	2	0.750 × 2.0 in.	outer: 17-4PH SS inner: 316L SS	TIG weld	E66544

Table A-3. (continued).

Isotope	Maximum Activity	Manufacturer	Yield	Number of capsules	Order Dimensions	Capsule Material	Outer Closure	ASST classification
Am-241/Be	3 Ci 5 Ci	Amersham	AMN CY4 AMN 2673 AMN 2675	2	0.750 × 2.0 in.	outer: 17-4PH SS inner: 316L SS	TIG weld	E66544
Am-241/Be	3 Ci 5 Ci	Amersham	AMN CY7 AMN 2673 AMN 2675	2	0.660 × 2.5 in.	outer: 17-4PH SS inner: 316L SS	TIG weld	E66544
Am-241/Be	5 Ci	Amersham	AMN CY5 AMN 2665	2	0.750 × 3.0 in.	outer: 17-4PH SS inner: 316L SS	TIG weld	E66544
Am-241 or Am-241/Be	5 Ci	Camstream	AN-38P, dog 2008	2	0.750 × 2.0 in.	17-4 SS (also use 304, 316 SS) heat treat H-1000 thru H-1100	bellows weld	C or E 56535
Am-241/Be	5.2 Ci	GM Inc.	71-1	2	0.75-1.25D × 1.5-3.125 in.	SS	TIG	77C58522
Am-241/Be or Pu-238/Be	10 Ci	Moconite	H-245258 (NSR-M)	2		inner: 304 SS outer: 18% Ni and managing steel	inner: weld outer: TIG weld	77C66545
Am-241/Be	10 Ci 20 Ci	Amersham	AMN CY10 AMN 2671 AMN 2672	2	1.00 × 3.0 in.	outer: 17-4PH SS inner: 316L SS	TIG weld	E66544
Am-241/Be	20 Ci	Amersham	AMN CY1		0.750 × 2.75 in.	316L		
Am-241 or Am-241/Be	20 Ci	Camstream	AN-38P, dog 2012	2	1.000 × 4.3 in.	17-4 SS (also use 304, 316 SS) heat treat H-1000 thru H-1100	bellows weld	C or E 56535

Table A-3. (continued).

Isotope	Maximum Activity	Manufacturer (General Nuclear)	Model	Number of capsules	Capacitor Dimensions	Capacitor Material	Outer Closure	ANSI classification
Am-241/Be or Pu-238/Be ^a	20 Ci	General Nuclear	CS-1000 (GP) GM-CS-1000	2	0.343D x 1.483 in.	304 or 316 SS	TIG	68146515
Am-241/Be	20 Ci	QNB Inc.	AmBe-71-2A	2		SS	laser weld	C66515
Am-241/Be or Pu-238/Be ^a	45 Ci ^b	Monasanto	24183	2	1.06D x 5.113 in.	inner: 304 SS outer: 17-4 pH SS	TIG	77E66546
Am-241/Be or Pu-238/Be ^a	51 Ci ^b	Monasanto	24174	2	1.235D x 2.562 in.	inner: 304 SS outer: 17-4 pH SS	TIG	77E66546
Am-241/Be or Pu-238/Be ^a	57 Ci ^b	Monasanto	24183	2	1.02D x 3.0 in.	inner: 304 SS outer: 17-4 pH SS	TIG	77E66546
Am-241/Be or Pu-238/Be ^a	70 Ci ^b	Monasanto	24113	2	1.16D x 5.81 in. ³	inner: 304 SS outer: 17-4 pH SS	TIG	77E66546
Co-137	200 mCi	Ameroham	CDC-CY8	2	0.247D x 0.74 in.	outer: 17-4 pH SS inner: 316L SS	TIG weld	C66534
Co-137	2.3 Ci nom. 2 Ci	Ameroham	CDC-CY4	2	0.492D x 0.75 in.	outer: 17-4 pH SS inner: 316L SS	TIG weld	C66534
Pu-238/Be	5 Ci	Monasanto	24112	2	0.82D x 1.4 in.	inner: 304 SS outer: 17-4 pH SS	weld	68C66525

Table A-3. (continued).

Isotope	Maximum Activity	Manufacturer	Model	Number of capsules	Outer Dimensions	Capsule Material	Outer Closure	ANSI classification
Pu-238/Be	20 Ci	Monsanto	24120	2	0.751 x 2.957 in.	inner: 304 SS outer: 17-4 pH SS	weld	68L66523

a. The target element, given as beryllium in the table, could be any of the following light elements: beryllium, lithium, boron, fluorine, or carbon.

b. The maximum activity depends upon the "Packing Fraction." The Monsanto registrations identify three packing fractions, though others are available "upon request." The three fractions used are 0.5, 0.68, and 0.8 with 0.5 corresponding to the largest activities. The maximum activities given in this table for Monsanto sources correspond to the 0.5 packing fraction. It is assumed that the "packing fraction" is reflective of the volume of neutral filler material in the source.

c. Typical application uses 16 Ci of Am-241/Be.

d. Dimensions are approximate; exact dimensions are not given.

Table A-4. Specifications of selected sealed sources used in portable gauging applications.

Isotope	Maximum Activity	Manufacturer	Model	Number of capsules	Outer Dimensions	Capsule Material	Outer Closure	ANSI classification
Am-241/Be	50 mCi	CPS	CPN 131 in MC, 500, 503, and AC-1	2	0.356D x 0.5 in.	316L	double fusion weld	C64444
Am-241/Be	50 mCi	CPS	CPN 131 in MC, 500, 503 ^a	2	0.356D x 0.6 in.	316L	double fusion weld	C64444
Am-241 or Am-241/Be	50 mCi 100 mCi	Isotope Products Laboratories	PRI-153-50 PRI-153-100	1	0.312D x 0.21 in.		fusion weld	645-45 (w Be) 33232 (w Be)
Am-241/Be	100 mCi	CPS	CPN 131 in AC-2, AC-2R	2	0.356D x 0.5 in.	316L	double fusion weld	C64444
Am-241	3 Ci	Amerstham	AKCK-580		2.25D x 0.3125 in.	SS	helium weld	
Am-241/Be and Cs-137	50 mCi (Am) 10 mCi (Cs)	Amerstham	AKM-6002	2	0.35D x 0.57 in.	316 SS	argon arc weld	
Am-241/Be and Cs-137	50 mCi 10 mCi	CPS	CPN 131 in BRC, MC-5	2	0.356D x 0.572 in.	316L	double fusion weld	C64444
Am-241/Be and Cs-137	125 mCi (Am) 10 mCi (Cs)	Amerstham	AKM-6003	2	0.35D x 0.57 in.	316	argon arc weld	
Am-241/Be and Cs-137	1 Ci 0.1 Ci	GMI Inc.	AMC-1	2	0.356-0.5D x 0.572-0.625 in. ^b	SS	helium weld	C72222

a. Be-encapsulated source.

b. Source may have a threaded fitting at one end that extends about 0.6 in.

Table A-5. Specifications of selected sealed sources used in irradiation applications.

Isotope	Minimum Activity	Manufacturer	Model	Number of capsules	Outer Dimensions	Capsule Material	Outer Closure	ANSI classification
Am-241	3.6 Ci	GMI Inc.	AT-1	2	1.910 × 0.094 in.	titanium	beadarc weld	77C33312
Cs-137	414 Ci	Isomedix	R458CQ-50	2		316L SS		
Cs-137	600 Ci	Radion International	C-1000	2	0.50 × 0.69 in.	316L SS	fusion weld	77E55346
Cs-137	720 Ci	Isomedix	ISO-1000	2		304L		
Cs-137	max: 210 Ci nominal: 590 Ci	Radion International	C-1001	2	0.50 × 0.69 in.	316L SS	fusion weld	77E55346 ^a
Cs-137	1,270 Ci	Radion International	C-3000	2	0.6870 × 0.69 in.	316L SS	fusion weld	77E55346 ^a
Cs-137	max: 1,650 Ci nominal: 1,270 Ci	Radion International	C-3001	2	0.6870 × 0.69 in.	316L SS	fusion weld	77E55346 ^a

a. ANSI designation inferred due to similarity to C-1000 source capsule.

Table A-6. Specifications of selected sealed sources used in fixed gauge applications.

Isotope	Maximum Activity	Manufacturer	Model	Number of capsules	Source Dimensions	Capable Material	Quench Source	ANSI classification
Am-241	1 mCi 3 mCi 10 mCi	Amer sham	AMC-2 AMC-3 AMC-4	1	8D x 5 mm	SS	argon arc weld	
Am-241/Be	10 mCi 30 mCi 100 mCi 100 mCi	Amer sham	AMC-1 AMC-13044 AMC-13145 AMC-13146 AMC-13446	1	8D x 5 mm 10.8D x 5 mm 10.8D x 5 mm 13D x 5 mm	mixed	weld	C64344
Am-241	10 mCi 100 mCi	Amer sham	AMC-36 AMC-34 AMC-36	1	2.8D x 30 mm	SS		C64344
Am-241	14 mCi	Amer sham	AMC-1064		8.35D x 12.6 mm	SS		
Am-241	30 mCi 100 mCi	Amer sham	AMC-5 AMC-6	1	10.8D x 5 mm	SS	argon arc weld	
Am-241/Be	60 mCi	Amer sham	AMN W254		6D x 10 mm	316L	argon arc weld	C34444
Am-241	100 mCi	Amer sham	AMC-16	1	10.8D x 6 mm	SS		C64444
Am-241	200 mCi 100 mCi	Industrial Dynamics/ Amer sham	IN-240 capsule AMCQ-306	1		304 SS	weld	77C64634
Am-241	300 mCi	Amer sham	AMC-7	1	13D x 5 mm	SS	argon arc weld	
Am-241	500 mCi	Amer sham	AMC-18	1	22D x 6 mm	SS		C64444
Am-241	1 Ci	Amer sham	AMC-19	1	30D x 6 mm	SS		C64444
Am-241	2 Ci	Amer sham	AMC-K316			SS	argon arc weld	

Table A-6. Specifications of selected sealed sources used in fixed gauge applications.

Isotope	Maximum Activity	Manufacturer	Model	Number of capsules	Outer Dimensions	Capable Material	Outer Closure	ANSI classification
Am-241	1 mCi 3 mCi 10 mCi	Amer sham	AMC-2 AMC-3 AMC-4	1	8D x 5 mm	SS	argon arc weld	
Am-241/Be	10 mCi 30 mCi 100 mCi 100 mCi	Amer sham	AMC-1 AMC-13044 AMC-13145 AMC-13146 AMC-13446	1	8D x 5 mm 10.8D x 5 mm 10.8D x 5 mm 13D x 5 mm	mixed	weld	C64444
Am-241	10 mCi 100 mCi	Amer sham	AMC-36 AMC-34 AMC-36	1	2.8D x 30 mm	SS		C64444
Am-241	14 mCi	Amer sham	AMC-1064		8.35D x 12.6 mm	SS		
Am-241	30 mCi 100 mCi	Amer sham	AMC-5 AMC-6	1	10.8D x 5 mm	SS	argon arc weld	
Am-241/Be	60 mCi	Amer sham	AMN W254		6D x 10 mm	316L	argon arc weld	C34444
Am-241	100 mCi	Amer sham	AMC-16	1	10.8D x 6 mm	SS		C64444
Am-241	200 mCi 100 mCi	Industrial Dynamics/ Amer sham	IN-240 capsule AMCQ-306	1		304 SS	weld	77C64634
Am-241	300 mCi	Amer sham	AMC-7	1	13D x 5 mm	SS	argon arc weld	
Am-241	500 mCi	Amer sham	AMC-18	1	22D x 6 mm	SS		C64444
Am-241	1 Ci	Amer sham	AMC-19	1	30D x 6 mm	SS		C64444
Am-241	2 Ci	Amer sham	AMC-K316			SS	argon arc weld	

Table A-6. (continued).

Isotope	Maximum Activity	Manufacturer	Model	Number of capsules	Order Dimensions	Capsule Material	Order Closure	ANSI classification
Am-241	2.5 Ci	Monsanto/Orion	249FD-12328	2	0.4950 × 5 in.	inner: 321 SS outer: 304 SS	TIG weld	
Cs-244/Bz		Amersham	CCL	1	8D × 3.1 max. mm	inoxel	weld	C64344
	12 mCi		CDC 13074					
	35 mCi		CDC 13075					
	220 mCi		CDC 13076					
Cs-244/Bz		Amersham	CCL	1	10.8D × 5 mm	inoxel	weld	C64343
	12 mCi		CDC 13144					
	35 mCi		CDC 13145					
	100 mCi		CDC 13146					
	230 mCi		CDC 13147					
Cs-244/Bz	300 mCi	Amersham	CCL		8 to 15D × 5 mm	SS	argon arc weld	
Cs-137	100 mCi	Amersham	CDC 15	2	6D × 8 mm	SS	weld	
	300 mCi		CDC 16					
Cs-137	100 mCi	Amersham	CDC 100M	1	10D × 28.4 mm*	inoxel	freeze	
	250 mCi		CDC 250M					
	500 mCi		CDC 500M					
	300 mCi max		CDC 700 series	1	4.5D × 6 mm	SS	weld	C66343
Cs-137	300 mCi max	Amersham	CDC 800 series	2	8D × 8 mm	SS	weld	C66346
Cs-137	300 mCi max	Amersham	CDC 700	2	8D × 12 mm	SS	weld	C66346
			CDC 316 series					
Cs-137	300 mCi max	Amersham	CDC 700	2	9D × 25.4 mm	SS	weld	C66346
			CDC 311 series					

Table A-6. (continued).

Isotope	Maximum Activity	Manufacturer	Model	Number of capsules	Outer Dimensions	Capsule Material	Outer Closure	AECB classification
Cs-137	300 mCi max	Amersham	CDC-700; CDC-252 series	2	6.4D × 15.9 mm	SS	weld	C66-445
Cs-137	300 mCi max	Amersham	CDC-700/CDC-711mc; CDC-3801, b; CDC-3811	2	12.7D × 19.1 mm	SS	weld	C66-446
Cs-137	0.5 Ci 1.0 Ci 2.0 Ci 3.0 Ci 4.0 Ci 5.0 Ci	Amersham	CDC-27; CDC-90 CDC-91 CDC-92 CDC-93 CDC-94 CDC-95	2	8D × 12 mm	SS	weld	C66-446
Cs-137	1 Ci	3M	AP6M	2	0.28D × 0.92 in.	304 SS	TIG weld	77C66-545
Cs-137	1 Ci 2 Ci 5 Ci 10 Ci	Amersham	CDC-1C CDC-2C CDC-5C CDC-10C	2	18D × 29.1 mm ^b	incoel	brass	
Cs-137	1 Ci 3 Ci 10 Ci	Amersham	CDC-17 CDC-18 CDC-19	2	8D × 12 mm	SS	weld	
Cs-137	2 Ci	3M	AP6E	2	0.28D × 0.75 in.	304 SS	TIG weld	77C66-545
Cs-137	3 Ci	Giannini Industries	S-17	1	0.25-0.5D × 1.25-4 in.	SS	be flare	
Cs-137	4 Ci 8 Ci 10 Ci	TN Technologies	37137C	2	0.5D × 0.75 in. 0.40 × 1.0 in. 0.50 × 1.5 in.	SS	TIG weld	C65-545

Table A-6. (continued)

Isotope	Maximum Activity	Manufacturer	Model	Number of capsules	Outer Dimensions	Capsule Material	Cover Closure	ANSI classification
Co-137	5 Ci	3M	4P68T	3	0.625D × 0.91 in.	inner: titanium middle: tantalum outer: 304 SS	TIG weld	77C66346
Co-137	5 Ci	3M	4P68	2	0.5D × 0.75 in.	304 SS	TIG weld	77C66346
Co-137	5 Ci	American	CDC 492; CDC 4024	2	12.45D × 17.85 mm	SS	weld	86C6635
Co-137	10 Ci	3M	4P6P	2	0.5D × 1 in.		TIG weld	77C66346
Co-137	10 Ci	3M	4P6D	2	0.375D × 0.437 in.		inner: silver bronze outer: weld	
Co-137	10 Ci	3M	4P6P	2	0.5D × 2.5735 in.	304 and 410 SS	inner: silver bronze outer: weld	
Co-137	10 Ci max	Amersham	CDC 711m; CDC 3620 w; CDC 3821B	2	12.7D × 19.1 mm	SS	weld	C6646
Co-137	10 Ci; 20 Ci; 30 Ci	Amersham	CDC 492; CDC 4025 CDC 4080 CDC 4081	2	12.45D × 17.85 mm	SS	weld	86C6635
Co-137	20 Ci	3M	4P6T	2	0.75D × 1 in.	304 SS	weld	68C66414
Co-137	20 Ci	3M	4P6L	2	0.5D × 1.5 in.		TIG weld	77C66346
Co-137	30 Ci (0.5 Ci per inch)	TY Technologies	656033	2	0.5D × 3.5 to 61.5 in.	SS	inner: silver solder outer: weld	

Table A-6. (continued).

Isotope	Maximum Activity	Manufacturer	Model	Number of capsules	Outer Dimensions	Capsule Material	Order Closure	ANSI classification
Cs-137	50 Ci	Amersham	CDC PER: CDC 631	2	14.6D × 20.1 mm	SS	weld	ES3335
Cs-137	100 Ci	Amersham	CDC PER: CDC 631	2	17.4D × 22.7 mm	SS	weld	ES3335
Cs-137	200 Ci	Amersham	CDC PER: CDC 631	2	21.2D × 26.2 mm	SS	weld	ES3335
Cs-137	400 Ci	Amersham	CDC PER: CDC 631	2	27.8D × 28.5 mm	SS	weld	ES3335
Cs-137	1,200 Ci	Amersham	CDC PER: CDC 631	2	34.0D × 70 mm	SS	weld	ES3335
Cs-137	2,200 Ci	Amersham	CDC PER: CDC 631	2	36.1D × 65 mm	SS	weld	ES3335
Po-210	100 mCi	Amersham	PPCL		8 to 15D × 5 mm	SS	argon arc weld	
Po-210/Be	750 mCi	Monozeto	2445	2	3.25 × (0.75 ± 0.612) in.	monel (2)	TIG	C2242
Sr-90	50 mCi 100 mCi	Amersham	SIR 31: SIR 1175 SIR 1177	2	19D × 12 mm	SS		ES4343
Sr-90	0.5 Ci 1.0 Ci 2.0 Ci 4.0 Ci	Amersham	SIR 30 SIR 31 SIR 32 SIR 33	1	0.3 × 50 × 40 mm ² 0.3 × 50 × 40 mm ² 0.3 × 65 × 30 mm ² 0.3 × 100 × 30 mm ²	silver foilplate		

Table A-6. (continued).

Isotope	Maximum Activity	Manufacturer	Model	Number of capsules	Outer Dimensions	Capsule Material	Outer Closure	ANSI classification
Sr-90	1 Ci 5 Ci	Aurethane	SRE-21 SRE-22	2	150 × 20 mm ²	SS	argon arc weld	
<p>a. Source capsule includes a cylinder containing the radioactive material and a flat tag about 11 mm long.</p> <p>b. Source capsule includes a cylinder containing the radioactive material and a flat tag about 12 mm long.</p> <p>c. Older models may have been helium welded.</p> <p>d. Silver Cad Free Allstate 155 base.</p> <p>e. Older models may have had inner capsule silver soldered and outer capsule helium welded.</p> <p>f. These are metal plate sources with the strontium "firmly bonded within the metal."</p> <p>g. Length dimension does not include the approximately 4 mm appendage with threadings.</p>								

Table A-7. Specifications of selected sealed sources used in general neutron applications.

Isotope	Maximum Activity	Manufacturer	Model	Number of capsules	Outer Dimensions	Capsule Material	Outer Closure	ANSI classification
Am-241/Ba	1 mCi 3 mCi 10 mCi 30 mCi 100 mCi 300 mCi	Amer sham	AMN 1M AMN 3M AMN 10M AMN 30M AMN 100M AMN 300M	2	17.4D x 19.4 mm	SS	argon-on weld	
Am-241/Ba	40 mCi	Amer sham	AMN V997	2	7.8D x 9.8 mm	316 SS	TIG	68C34443
Am-241/Ba	100 mCi	Amer sham	AMN 37 AMN 170	2	31.3D x 19 mm ^b			C64444
Am-241/Ba or Pu-238/Ba ^c	190 mCi ^d	Monacato	24195	2	0.389D x 0.4 in.	304 SS	TIG	77C66443
Am-241/Ba or Pu-238/Ba ^c	340 mCi ^d	Monacato	24194	2	0.346D x 0.515 in.	304 SS	TIG	77C66443
Am-241/Ba	350 mCi	Amer sham	AMN V349	2	12.7D x 12.7 mm	inner: AISI 316L outer: 316L	inner: weld outer: TIG	68C34443
Am-241/Ba or Pu-238/Ba ^c	See note d. 0.4 Ci 1.4 Ci 2.4 Ci 6.0 Ci 10.5 Ci 16.8 Ci 48.0 Ci 78.0 Ci 34.7 Ci	Monacato	2720 Series 2721A, B, or C 2722A, B, or C 2723A, B, or C 2724A, B, or C 2725A, B, or C 2726A, B, or C 2727A, B, or C 2728A, B, or C 2729C	2	0.5D x 0.5 in. 0.5D x 0.7 in. 0.7D x 0.87 in. 1.0D x 1.12 in. 1.0D x 1.5 in. 1.0D x 2.0 in. 1.3D x 2.5 in. 1.5D x 3.5 in. 1.5D x 2.076 in.	304 SS	TIG weld	68E64525
Am-241/Ba or Cs-137 ^e	0.5 Ci 0.1 Ci	General Industries/ General Nuclear	NRG	2	0.2-2D x 0.25-4 in.	SS	helium (TIG)	33545

Table A-7. (continued).

Isotope	Maximum Activity	Manufacturer	Model	Number of capsules	Outer Dimensions	Capsule Material	Outer Closure	ANSI classification
Am-241/Be	0.5 Ci 1.0 Ci	Amerstham	AMN.PE2 AMN.19 AMN.22	2	22.40 x 31 mm			
Am-241/Be	0.95 Ci	Monsanto	2722-BT	2	0.50 x 0.93 in.	304 SS	TIG	68C64525
Am-241/Be	1 Ci	Amerstham	AMN.1C	2	22.40 x 31 mm	SS ^a	argon-on weld	
Am-241/Be	1 Ci	General Radiological Products	7022	2	0.750 x 1.0 in.	304 SS	helium fusion weld	
Am-241/Be or Pu-238/Be ^a	1 Ci	Monsanto	24154-A 24154-B 24154-C	2	1.360 x 0.5 in. f	SS	TIG	A, B: 68C31443 C: 77C96544
Am-241/Be or Pu-238/Be	1.3 Ci	Tetra Nuclear	Dwg. No. 570-579103	2	≤ 1.1250 x ≤ 1.375 in.	304 or 316 SS	TIG	68C32232
Am-241/Be	3 Ci	Amerstham	AMN.3C	2	22.40 x 48.5 mm	SS ^a	argon-on weld	
Am-241/Be or Pu-238/Be ^a	4.5 Ci ^d	Monsanto	24107	2	1.250 x 2.85 in.	inner: 304 SS outer: 304 SS	TIG	68C64525
Am-241/Be	5 Ci	Amerstham	AMN.5C	2	30.0 x 60 mm	SS ^a	argon-on weld	
Am-241/Be	5 Ci 10 Ci	Amerstham	AMN.PE4 AMN.24 AMN.25	2	30.0 x 60 mm			
Am-241/Be or Pu-238/Be ^a	14 Ci	Monsanto	2726-BX	2		304 SS	TIG	77C64525
Am-241/Be or Am-241/Ba or Pu-238/Be ^a	25 Ci 5 Ci 20 Ci	Gamma Industries/ General Nuclear	NH, NB (HP)	2	0.2-0.3 x 0.25-4 in.	SS	helium (TIG)	NB: 35545 NB (HP): 46515

Table A-7. (continued).

Isotope	Maximum Activity	Manufacturer	Model	Number of capsules	Outer Dimensions	Capsule Material	Outer Closure	AEC classification
Am-241/Be	25 Ci	Amerham	A324.36	2	490 x 85 mm			
Po-210/Be	4.73 Ci	Monsanto	#461		10 x 2.51 in.			
<p>a. Stainless steel is composed in part of 18% Cr, 8% Ni, and 1% Mn.</p> <p>b. Annular source with inner diameter of 26.2 mm.</p> <p>c. The target element, given as beryllium in the table, could be any of the following light elements: beryllium, lithium, boron, fluorine, or carbon.</p> <p>d. The maximum activity depends upon the "Packing Fraction." The Monsanto registrations identify three packing fractions, though others are available "upon request." The three fractions used are 0.5, 0.68, and 0.8 with 0.5 corresponding to the largest activities. The maximum activities given in this table for Monsanto sources correspond to the 0.5 packing fraction. It is assumed that the "packing fraction" is reflective of the volume of neutral filter material in the source.</p> <p>e. When the source contains cesium, it is used for a non-general neutron application, probably for a fixed gauging application.</p> <p>f. Annular source with inner diameter of 1.63 in.</p>								

Table A-8. Specifications of selected sealed sources used in x-ray fluorescence applications.^a

Isotope	Maximum Activity	Manufacturer	Model	Number of capsules	Outer Dimensions	Capsule Material	Outer Closure	ANSI classification
Am-241	2 mCi	Ameribon	AMC-21	1	2D × 10 mm	SS	weld	C64444
Am-241	10 mCi	Ameribon	AMC-2164	1	37D × 32 mm	SS	argon arc weld	C6C43326
Am-241	10 mCi 100 mCi 1,000 mCi	Ameribon	AMC-42; AMC-2504 AMC-8506 AMC-8509	1	38OD × 6.5 mm 22.5 mm ID	SS	weld	C64444
Am-241	14 mCi	Ameribon	AMC-24	1	3D × 10 mm	SS	weld	C64444
Am-241	30 mCi 100 mCi	Ameribon	AMC-13; AMC-45 AMC-56	1	10ND × 5 mm	SS	weld	C66544
Am-241/Be	30 mCi 100 mCi 500 mCi	Ameribon	AMC-41; AMC-8728 AMC-8726 AMC-8728	1	38OD × 6.5 mm 22.5 mm ID	SS	weld	C34343
Am-241	45 mCi 100 mCi	Ameribon	AMC-25/AMC-P1; AMC-25 AMC-10236	1	4D × 10 mm	SS	weld	C64444
Am-241	50 mCi 100 mCi	Isotope Products Laboratories	AN-241-50 AN-241-100	1	2.5 in. OD 2.0 in. ID	SS	weld	33232
Am-241	200 mCi	Ameribon	AMC-26	1	7D × 10 mm	SS	weld	C64444
Am-241	300 mCi	Ameribon	AMC-17	1	15D × 6 mm	SS		77C64444

Table A-8. (continued).

Isotope	Maximum Activity	Manufacturer	Model	Number of capsules	Outer Dimensions	Capsule Material	Outer Closure	ANSI classification
Am-241	3 Ci	Amersham	AMC-30	1	38D x 8 mm	SS		ES4444
Am-241	4 Ci	Amersham	AMC-D1	2	17 to 24D mm	outer: monel inner: SS	outer: argon arc weld inner: vacuum brazed	77C64344
Am-241	5 Ci	Amersham	AMC-50	1	45D x 8 mm	SS		ES4444
Cs-244/Be	12 mCi	Amersham	CLC-A1:	1	38D x 6.5 mm ^a	monel/SS	weld	CS4343
	35 mCi		CLC-8724					
	110 mCi		CLC-8725					
	230 mCi		CLC-8726					
	500 mCi		CLC-8727 CLC-8728					
Cs-244/Be	550 mCi	Amersham	CLC-B1:	1	23D x 6 mm	monel	weld	CS4344
	1,200 mCi		CLC-1338 CLC-1339					

a. Some of these sources are used to generate x-rays and are not necessarily used in x-ray fluorescence devices.

b. Invalid ANSI classification as given in the model's NRC registration.

c. Dimensions are for an annular source holder assembly, AND and ANT series. No length specification is given.

Table A-9. Specifications of selected sealed sources used in other applications.

Isotope	Maximum Activity	Manufacturer	Model	Number of capsules	Outer Dimensions	Capsule Material	Outer Closure	ANSL classification
Am-241	100 mCi	Amersham	AMCK 200		27 mm outer diam.*	SS	argon arc weld	
Am-241	100 mCi	Monanto	MRC-A-SS-P-AM		0.25 in I.D. 0.25 in. L.	SS	solder, weld, or no seal	
Am-241	150 mCi	Amersham	AMCP3	1	30 × 10 mm	316L SS	argon arc weld	
Am-241	0.15 Ci 0.24 Ci 0.63 Ci 1.43 Ci 1.98 Ci 2.39 Ci	Monanto	2300 Series 2701 2702 2703 2704 2705 2706	2	0.4375 × 0.715 in. 0.50 × 0.715 in. 0.750 × 0.715 in. 1.00 × 0.715 in. 1.250 × 0.715 in. 1.250 × 0.715 in.	304 SS	TIG	68C-3334
Cs-137	1 Ci	3M	4D6M	2	0.4743 × 0.875 in. ^b	SS or monel	inner: silver bronze outer: bellare weld	
Cs-137	1 Ci	3M	4D6F	2	0.50 × 2.12 in.		inner: silver bronze outer: weld	
Cs-137	1.2 Ci	Monanto	23149-AC 24149	1 2	0.2180 × 0.365 in. 0.3120 × 2.0 in.	321 SS	TIG	
Cs-137	2 Ci	3M	4F6D	2	0.750 × 1.474 in.	SS	inner: silver bronze outer: bellare weld	
Cs-137	12 Ci	Monanto	24149	2	0.50 × 0.75 in.	304 or 316 SS	TIG	68C-4334
Po-210	2.5 Ci	Alamos/Nuclear Battery Corp.	Eng. B990C408	2	0.340 × 0.315 in.	outer: Hastelloy C-276 inner: TA-10W Tungsten tungsten	weld	

Table A-9. (continued).

Isotope	Maximum Activity	Manufacturer	Model	Number of capsules	Outer Dimensions	Capsule Material	Outer Closure	ANSI classification
Po-210	4.27 Ci	Bismuth/Chemtronics	Dwg. C-4101-17c "X" type fuel capsule	2	0.360 × 0.150 in.	outer: 99.9% Pb inner: T-222 inner: tantalum		
Sr-90	30 mCi	Amersham	SR-1.5 SR-324%	1	22D × 6 mm	SS	silver arc weld	C43324

a. This is an annular source. No inner diameter nor height dimensions are given.

b. Source may have a threaded fitting at one end that extends 0.5 in.

c. Nuclear battery (for pacemaker).

Appendix B

Current Inventory of PGTCC Sealed Sources Held by Specific Licensees

Appendix B

Current Inventory of PGTCC Sealed Sources Held by Specific Licensees

The following table shows the base case projected number of PGTCC sealed sources currently held by specific licensees. The table is taken directly from Appendix B of Volume 1. A description of the methods used to calculate the table entries is given in that Appendix. The table is repeated here to support calculations made in Chapter 6 of this report.

Table B-1. Summary statistics for the base case projection of the number of PGTC sources.

Device Type	Isotope	Total Number of Sources	Standard Error of Total	Lower 95% Confidence Limit	Upper 95% Confidence Limit
Calibration	Am-241	3,000	858	1,319	4,682
Calibration	C-14	24	9	7	41
Calibration	Cm-244	34	11	13	56
Calibration	Cs-137	3,430	508	2,434	4,427
Calibration	Ni-63	114	52	12	215
Calibration	Np-237	10	9	0	27
Calibration	Pu-238	41	15	12	70
Calibration	Pu-239	275	86	106	444
Calibration	Pu-241	17	14	0	46
Calibration	Sr-90	1,927	1,118	0	4,118
Calibration	Tc-99	17	8	2	32
Calibration	U-238	34	16	2	67
Medical	Am-241	344	84	179	509
Medical	Cs-137	1,184	355	489	1,879
Medical	Sr-90	24	8	9	39
Medical	Tc-99	3	3	0	9
Medical	U-238	28	9	10	45
Well logging	Am-241	4,311	1,652	1,073	7,549
Well logging	Cs-137	2,154	886	417	3,891
Well logging	Pu-238	172	145	0	456
Well logging	Pu-241	3	3	0	9
Portable gauge	Am-241	15,294	1,288	12,770	17,819
Portable gauge	Cs-137	114	29	56	171
Irradiation	Am-241	155	79	0	310
Irradiation	Cs-137	1,652	204	1,252	2,051
Irradiation	Sr-90	10	5	0	20
Fixed gauge	Am-241	2,278	319	1,654	2,902
Fixed gauge	C-14	34	29	0	91
Fixed gauge	Cm-244	17	9	0	34
Fixed gauge	Cs-137	29,649	2,392	24,961	34,338
Fixed gauge	Pu-238	3	3	0	9
Fixed gauge	Sr-90	114	26	63	164
General neutron applications	Am-241	1,480	226	1,037	1,922
General neutron applications	Pu-238	114	39	37	190

Table B-1. (continued).

Device Type	Isotope	Total Number of Sources	Standard Error of Total	Lower 95% Confidence Limit	Upper 95% Confidence Limit
General neutron applications	Pu-239	526	99	332	721
X-ray fluorescence	Am-241	688	141	413	964
X-ray fluorescence	Cm-244	241	97	51	431
X-ray fluorescence	Cs-137	3	3	0	9
X-ray fluorescence	Pu-238	182	77	31	334
Other	Am-241	1,125	173	786	1,465
Other	C-14	62	18	26	98
Other	Cm-244	34	12	10	59
Other	Cs-137	11,097	5,261	786	21,408
Other	Ni-63	3,871	1,968	13	7,729
Other	Np-237	3	3	0	9
Other	Pu-238	1,576	1,085	0	3,703
Other	Pu-239	654	144	372	935
Other	Pu-241	21	10	1	40
Other	Sr-90	299	73	156	442
Other	Tc-99	454	308	0	1,058
Other	U-238	79	21	39	120
Calibration	Total	8,925	1,630	5,730	12,121
Medical	Total	1,583	365	867	2,298
Well logging	Total	6,641	2,440	1,859	11,423
Portable gauge	Total	15,408	1,289	12,882	17,934
Irradiation	Total	1,817	220	1,385	2,249
Fixed gauge	Total	32,096	2,453	27,283	36,908
General neutron applications	Total	2,120	251	1,628	2,611
X-ray fluorescence	Total	1,115	204	715	1,515
Other	Total	19,275	5,853	7,804	30,746
Total	Am-241	28,676	2,846	23,097	34,254
Total	C-14	120	37	49	192
Total	Cm-244	327	99	134	520
Total	Cs-137	49,282	6,216	37,100	61,465
Total	Ni-63	3,984	1,969	125	7,844
Total	Np-237	14	9	0	32

Table B-1. (continued).

Device Type	Isotope	Total Number of Sources	Standard Error of Total	Lower 95% Confidence Limit	Upper 95% Confidence Limit
Total	Pu-238	2,089	1,101	0	4,247
Total	Pu-239	1,455	302	1,000	1,851
Total	Pu-241	41	18	6	76
Total	Sr-90	2,374	1,121	177	4,571
Total	Tc-99	475	308	0	1,079
Total	U-238	141	29	84	198
Total	Total	68,979	7,742	73,805	104,153

Appendix C

Common PGTCC LLW Sources and Devices

Appendix C

Common PGTC LLW Sources and Devices

The following tables list the most common potential GTCC devices and sources by principal use, as observed in the NRC and AS surveys. These tables are given to inform the reader of the major manufacturers in a given principal use and their most popular models. In order to be included in the tables, a model must have accounted for at least 10 sources. That is, the cut-off for inclusion is that at least 10 sources used in the given model were observed in the survey. The exception to this is Table C-6, fixed gauges, in which the model was included if it made up at least 1%, or about 80, of the observed fixed gauges.

Description of the Tables.

Due to the nature of the quality of the responses to the surveys, a number of disclaimers must be made about the following tables. Rather than footnoting every table, the reader is advised to keep the following issues in mind when perusing the tables. The following describes the content of each column of the tables and their limitations.

Manufacturer or distributor—MODEL:

This column gives the manufacturer or distributor of the given model. In some cases, the model number is for the source (constructed by a different manufacturer) inside the device assembled by the named manufacturer. Occasionally the named manufacturer may be a distributor. The model may represent a series of models observed in the surveys, though this is typically noted in the table.

Isotope:

This is the isotope associated with the model. If there is more than one isotope listed, then either the device may have more than one potential GTCC source in it or, more commonly, the isotope used in the device can vary.

Activity:

The observed activities often varied considerably. This is not unexpected as the activity will commonly be fit to the particular application. The activity given in the table represents a reasonable maximum activity of the observed sources.

% of records, % of sources:

The "% of records" values are the proportion of responses within the principal use that had the particular model. The value reflects the number of specific licensees who have that model. Since a given record could represent multiple sources or devices of the same model held by the licensee, a separate column, "% of sources," is given for the proportion of sources or devices within the principal use of the particular model. This last column determines the order of listing of the information in the tables.

Table C-1. Calibration sources and devices.

Manufacturer or distributor—MODEL	Isotope	Activity	% of reconfs	% of sources
Dept. of the Army—AN/VDM-2	Sr-90	190 mCi	0.13	18.05
Monsanto—NSR-GB	Am-241	500 mCi	0.13	10.79
Amersham—AMC-21	Am-241	2 mCi	1.02	7.45
Amersham ^a —773	Cs-137	165 mCi	15.14	5.75
GNI—71-1	Am-241	300 mCi	8.14	3.58
FEMA ^b —CDV-794 MODEL 2	Cs-137	130 Ci	0.13	3.49
FEMA ^b —CDV-790 MODEL 1	Cs-137	16 mCi	0.51	2.54
3M—6503	Cs-137	28 mCi	0.25	2.12
ABB Process Automation—U-6	Am-241	3 Ci	3.05	1.98
	Sr-90	700 mCi		
Tech/Ops ^c —64773	Cs-137	150 mCi	0.38	1.98
3M—6D6C	Cs-137	30 mCi	0.64	1.60
Gammatron—ANHP	Am-241	1 Ci	1.40	1.51
Amersham—M1A1	Am-241	10 mCi	0.13	1.46
ABB Process Automation—C-7	Sr-90	100 mCi	0.51	1.27
Nuclear Associates ^d —64-764	Cs-137	100 mCi	3.18	1.23
ABB Process Automation—U-3	Am-241	3 Ci	2.80	1.04
	Sr-90	70 mCi		
Monsanto—NSR-N	Am-241	50 mCi	0.25	0.99
Molins—MODIC or MAID N	Sr-90	25 mCi	0.13	0.75
BZ Wire—67-601	Cs-137	17 mCi	0.13	0.75
Amersham—AMN-PE8	Am-241	550 mCi	0.13	0.75
New England Nuclear—NER-401H	Cs-137	90 mCi	1.53	0.57
ABB Process Automation—U-4	Am-241	1 Ci	1.53	0.57
	Sr-90	700 mCi		
Amersham—8488	Cs-137	100 mCi	0.76	0.57
Dept. of the Army—AN/VDM-1A	Cs-137	130 Ci	0.13	0.57
ICN Biomedical—375	Cs-137	120 mCi	1.40	0.52
New England Nuclear—SPCGB	Am-241	30 mCi	0.13	0.52
FEMA ^b —CDV-797	Cs-137	15 mCi	0.13	0.52
Monsanto—NSR-G	Am-241	135 mCi	0.13	0.47
3M—6D6C-6500	Cs-137	450 mCi	0.13	0.47

a. Also manufactured or distributed by Tech/Ops and Nuclear Associates.

b. FEMA is the Federal Emergency Management Agency.

c. Also manufactured or distributed by Nuclear Associates. This model may be the Amersham model 773.

d. Also manufactured or distributed by Eon Corporation.

Table C-2. Medical sources and devices.

Manufacturer or distributor—MODEL	Isotope	Activity	% of records	% of sources
3M—6D6C	Cs-137	150 mCi	5.93	21.74
3M—6B6G - 6530	Cs-137	150 mCi	0.85	14.73
Nucletron—MICROSELECTRON-HDE	Cs-137	314 mCi	0.85	9.66
Monsanto—MRC2704	Am-241	50 mCi	0.85	4.83
Siemens—SS10244	Am-241	24 mCi	9.32	4.35
Amersham—CDCT1	Cs-137	360 mCi	1.69	4.35
Kelex—6600	Am-241	21 mCi	8.47	4.11
3M—6B6G	Cs-137	200 mCi	0.85	3.86
Kelex—6700, 6700B, 6700PS	Am-241	21 mCi	6.78	3.62
3M—6502	Cs-137	400 mCi	1.69	3.38
Siemens—035-4300C	Am-241	12 mCi	5.08	2.66
3M—6H6E	Cs-137	300 mCi	1.69	2.66
3M—6505	Cs-137	105 mCi	5.08	2.42
Nuclear Associates—67-611	Cs-137	140 mCi	0.85	2.42

Table C-3. Well logging sources and devices.

Manufacturer or distributor—MODEL	Isotope	Activity	% of records	% of sources
Monsanto—NSR-F	Am-241	16 Ci	0.26	19.68
GNI ^a —CSV	Am-241	0.5 Ci	7.65	14.06
	Cs-137	2 Ci		
GNP ^b —71-1	Am-241	5 Ci	32.91	13.20
Monsanto—NSR-M	Am-241	10 Ci	0.51	9.35
Gammafron ^c —ANHP	Am-241	18.5 Ci	13.27	7.70
	Pu-238	5.2 Ci		
Monsanto—NSR-D	Am-241	5 Ci	0.51	6.97
GNI ^d —VDHP	Am-241	50 mCi	4.59	5.26
	Cs-137	2 Ci		
Monsanto—NSR-L	Am-241	16 Ci	0.26	3.67
Monsanto—MRC-PU-8-BE	Pu-238	16.7 Ci	11.22	2.69
Amersham—GSR-Z	Cs-137	1.7 Ci	0.36	2.36
GNI—71-2A	Am-241	20 Ci	4.34	2.20
GNI ^e —NBHP	Am-241	3 Ci	3.57	1.83
Gammafron—NSR-T	Am-241	7.5 Ci	0.51	1.34
Amersham—AMN-PE8	Am-241	23 mCi	0.26	0.98
Century—9030	Am-241	250 mCi	0.36	0.92
Amersham—CDC-CYN	Cs-137	2 Ci	0.51	0.86
Gearhart-Owen ^f —VL-1	Am-241	1 Ci	1.02	0.73
	Cs-137	125 mCi		

a. Also manufactured or distributed by Gearhart-Owen and Tuboscope.

b. Also manufactured or distributed by Gearhart-Owen and Century.

c. Also manufactured or distributed by Nuclear Sources and Services, Amersham, and ARMCO.

d. Also manufactured or distributed by Amersham, Gamma Industries, and Comprobe.

e. Also manufactured or distributed by Amersham and Gamma Industries.

f. Also manufactured or distributed by Century.

Table C-4. Portable gauge sources and devices.^a

Manufacturer or distributor—MODEL	Isotope	Activity	% of records	% of sources
Troxler Electronic Labs—3411B	Am-241	40 mCi	33.52	39.11
Troxler Electronic Labs—3440	Am-241	40 mCi	13.36	11.85
Troxler Electronic Labs—3411	Am-241	40 mCi	5.89	8.90
CPN—MC-1	Am-241	50 mCi	6.20	6.41
Troxler Electronic Labs—3401-B	Am-241	40 mCi	2.84	5.78
Troxler Electronic Labs—2401	Am-241	50 mCi	8.18	4.22
Troxler Electronic Labs—3401	Am-241	40 mCi	1.27	3.27
CPN—MC-3	Am-241	50 mCi	2.23	1.85
Humboldt Scientific—5001	Am-241	40 mCi	1.52	1.85
Troxler Electronic Labs—3400	Am-241	40 mCi	1.32	1.85
Troxler Electronic Labs—3440A	Am-241	40 mCi	3.35	1.58
CPN—MC-2	Am-241	50 mCi	2.44	1.51
CPN—503	Am-241	50 mCi	1.68	1.38
Troxler Electronic Labs—3216	Am-241	40 mCi	2.03	1.02
Troxler Electronic Labs—3430	Am-241	40 mCi	1.37	0.95
Humboldt Scientific—5001P	Am-241	40 mCi	0.76	0.54
CPN—131	Am-241	50 mCi	0.71	0.50
Seaman Nuclear—C-75BP	Am-241	40 mCi	0.10	0.45
Troxler Electronic Labs—2400	Am-241	50 mCi	0.15	0.38
Humboldt Scientific—5001-C	Am-241	40 mCi	0.76	0.34
CPN—MC SERIES	Am-241	50 mCi	0.46	0.27
Troxler Electronic Labs—2140	Am-241	2 mCi	0.05	0.27
Troxler Electronic Labs—3216A	Am-241	40 mCi	0.51	0.25
Troxler Electronic Labs—1257	Am-241	110 mCi	0.30	0.23
Troxler Electronic Labs—3440B	Am-241	40 mCi	0.15	0.23

a. Most of these devices also have a Ce-137 source. These sources are not included in the tabulation because they have activities around 10 mCi which is below the potential GTCC limits.

Table C-5. Irradiation sources and devices.

Manufacturer or distributor—MODEL	Isotope	Activity	% of records	% of sources
Nordion International—GAMMACELL 40	Cs-137	3,900 Ci	10.94	14.06
Nordion International—GAMMACELL 1000 ^a	Cs-137	2,900 Ci	14.06	12.08
3M—686GLH-FI	Cs-137	200 mCi	0.31	9.51
J.L. Shepherd and Assoc.—28-6A	Cs-137	1.2 Ci	4.69	2.97
GNI—AT-1	Am-241	800 mCi	0.94	2.77
CIS-US ^b —IBL-437C	Cs-137	5,100 Ci	3.13	2.57
GNI Incorporated—AT-2	Am-241	5 Ci	1.25	2.38
Radiation Machinery—GAMMATOR M-38	Cs-137	2,500 Ci	1.88	2.18
Radiation Machinery ^c —GAMMATOR 50B	Cs-137	400 Ci	3.13	1.98
J.L. Shepherd and Assoc.—MARK I 68A	Cs-137	600 Ci	2.81	1.98
J.L. Shepherd and Assoc.—78-2M	Cs-137	400 Ci	2.50	1.98
Fletcher Tandem & Ovoids—6502	Cs-137	400 mCi	0.63	1.98
Amersham—67-612 SERIES	Cs-137	204 mCi	0.31	1.98

a. Includes Nordion's 1000 Elite, 1000B, 1000D, and Isomedix' Gammacell 1000B.

b. Also manufactured or distributed by Compagnie Cris Industrie.

c. Also manufactured or distributed by Isomedix.

Table C-6. Fixed gauge sources and devices.

Manufacturer or distributor—MODEL	Isotope	Activity ^a	% of records	% of sources
TN Technologies—5197	Cs-137	100 mCi	3.51	6.80
TN Technologies—5192	Cs-137	200 mCi	3.54	5.77
Kay-Ray/Sensall—7062P	Cs-137	100 mCi	1.81	4.68
Kay-Ray/Sensall—7062BP	Cs-137	100 mCi	2.57	4.59
TN Technologies—5200	Cs-137	100 mCi	5.59	3.83
Kay-Ray/Sensall—7063P	Cs-137	1 Ci	1.84	3.00
TN Technologies—5190	Cs-137	200 mCi	1.84	2.67
Kay-Ray/Sensall—7062	Cs-137	100 mCi	2.11	2.26
TN Technologies—5202	Cs-137	500 mCi	3.86	2.25
Ohmart—SHRM-PA	Cs-137	100 mCi	0.35	1.99
ABB Process Automation—SH-301	Cs-137	50 mCi	0.06	1.97
Ohmart—A-2102	Cs-137	1.5 Ci	1.84	1.65
Kay-Ray/Sensall—7062B	Cs-137	100 mCi	1.43	1.59
TN Technologies—5191	Cs-137	1 Ci	0.99	1.55
Kay-Ray/Sensall—7063	Cs-137	200 mCi	3.01	1.52
TN Technologies—5205	Cs-137	100 mCi	2.78	1.43
TN Technologies—5201	Cs-137	100 mCi	2.78	1.33
TN Technologies—5193	Cs-137	1 Ci	1.05	1.22
Kay-Ray/Sensall—7080	Cs-137	100 mCi	0.26	1.15

a. The activity of each model can vary considerably depending upon the application. The activities given here are reflective of the typical observed activity.