4.5 Calibration and Reference Sources

4.5.1 Introduction

Calibration and reference sources may be made from solid byproduct material that is either encapsulated, embedded in another material, or plated on a metal surface, and from liquid byproduct material that is contained in sealed glass vials to prevent leakage or dispersion of the materials during normal handling and usage. A person who acquires, receives, possesses, owns, uses, or transfers such sources may be exempted from licensing under conditions discussed in 10 CFR 30.15(a)(9), Ionizing Radiation Measurement Instruments (see Section 2.10) or 10 CFR 30.18, Exempt Quantities (see Section 2.13). Other calibration and reference sources are used under either a general license or a specific license as described in 10 CFR 30.31. This section deals with the potential exemption of certain calibration or reference sources that are currently being distributed for use under a general or specific license.

A general license is granted in 10 CFR 31.5 to acquire, receive, possess, use, or transfer byproduct material contained in devices designed and manufactured for a number of specific purposes, including measuring radiation or producing light. Included in the general license are requirements for labeling, leak testing, and proper storage and disposition of the device. The licensee is also subject to terms and conditions set forth in 10 CFR 31.2 dealing with general license requirements, transfer of byproduct material, reporting and recordkeeping, and inspection. Leak testing is required except for devices containing only krypton, devices containing only tritium or not more than 3.7 megabecquerel (MBq) (100 microcurie (μCi)) of a beta- and/or gamma-emitting material or 0.37 MBq (10 μCi) of an alpha-emitting material, and devices held in storage in the original container prior to installation.

Examples of byproduct materials being distributed for use under 10 CFR 31.5 are sealed 133Ba or 152Eu sources for calibration of a liquid scintillation counter and 14C contained in a phosphor for use as a reference light source. There are no limits in 10 CFR 31.5 on the amount of byproduct material that may be used in a calibration or reference source in a device. However, an applicant for a specific license to manufacture or initially transfer such devices for use under 10 CFR 31.5 must demonstrate that they will meet certain requirements contained in 10 CFR 32.51. These requirements are described below:

- The device can be safely operated by persons without training in radiological protection.
- Under ordinary conditions of handling, storage, and use of the device, the byproduct material contained in the device will not be released or inadvertently removed from the device, and it is unlikely that any person will receive in any 1-year period a total effective dose equivalent (EDE) in excess of 5 millisieverts (mSv) (500 mrem), or the sum of the deep-dose equivalent and committed dose equivalent to any individual organ or tissue other than the lens of the eye in excess of 50 mSv (5 rem); an eye dose equivalent in excess of 15 mSv (1.5 rem); or a shallow-dose equivalent in excess of 50 mSv (5 rem) to the skin or to any extremity (i.e., hand, elbow, arm below the elbow, foot, knee, or leg below the knee).
• Under accident conditions (such as fire and explosion) associated with handling, storage, and use of the device, it is unlikely that any person would receive an external dose equivalent or committed internal dose equivalent in excess of 0.15 Sv (15 rem) to the whole body, head and trunk, active blood-forming organs, gonads, or lens of the eye; 2 Sv (200 rem) to the hands and forearms, feet and ankles, or localized areas of skin averaged over areas no larger than 1 cm²; and 0.50 Sv (50 rem) to any other organs.

A specific license under 10 CFR 30 is required when a device containing an internal calibration or reference source does not meet the above conditions (e.g., the device cannot be operated safely by persons without training in radiological protection) or the calibration or reference source is not incorporated within a device and contains more than a quantity of byproduct material as defined in 10 CFR 30.71, Schedule B (e.g., the loose calibration or reference source contains more than 0.037 MBq (1 µCi) of ⁶⁰Co, 0.37 MBq (10 µCi) of ¹³⁷Cs, etc.). Exposures to individuals working near such devices and sources are monitored routinely, any excessive doses to these individuals are detected and appropriate action taken to reduce unwarranted exposures.

Some calibration or reference sources (either loose or internal to a device) are potential candidates for exemption from the general and specific licensing requirements set out in 10 CFR 30 through 36 and 39. This assessment evaluates the potential radiation doses that could result if the acquisition, receipt, possession, use, and transfer of certain of these calibration and reference sources were exempt from licensing. The assumed conditions for this potential exemption are loose or internal calibration and reference sources in the form of sealed or plated sources containing not more than 10 times a quantity of byproduct material as defined in 10 CFR 30.71, Schedule B. For devices with internal sources, the limit of 10 times a quantity is assumed to apply to both the individual sources and the total within a device.

The quantity of a long half-life radionuclide commonly used in either calibration or reference sources is determined primarily from considerations of the internal dose from intake (see Section 2.13.1). The external dose rate from a single exempt quantity of a long half-life radionuclide is typically less than 0.01 mSv/h (<1 mrem/h) at a distance of 10 cm and less than 0.1 mSv/h (<10 mrem/h) at 10 cm from a source containing 10 quantities. For example, the dose rates as calculated by CONDOS (Computer Codes, O'Donnell et al., 1975) at 10 cm from a source containing 10 quantities of either ¹⁴C, ¹³³Ba, or ¹⁵²Eu are approximately 1×10⁻⁵ mSv/h (0.001 mrem/h)¹⁷, 0.01 mSv/h (1 mrem/h), and 0.004 mSv/h (0.4 mrem/h), respectively. Also considered was a generic source containing 10 quantities with a dose rate of 0.1 mSv/h (10 mrem/h) at a distance of 10 cm to assess potential doses from external exposure during routine use of a single calibration or reference source (or a combination of sources within a single device) under this potential exemption.

Reports of leaking sources, submitted by licensees under the requirement of 10 CFR 31.5(c)(5) between 1990 and 1996 and contained in the Nuclear Materials Events Database (NMED) (Nuclear Regulatory Commission (NRC) Databases, NMED, Reports), do not include any cases of leaking sources in liquid scintillation counters or thermoluminescent dosimetry readers.

¹⁷ CONDOS calculations for ¹⁴C have been reduced by a factor of 20 to correct for its over estimation for low energy bremsstrahlung radiation. (Refer to Appendix A.4).
Examples of thermoluminescent materials include thallium-doped lithium fluoride, LiF(Tl), used in personnel dosimeters, and dysprosium-doped calcium sulfate, CaSO$_4$(Dy), used in environmental dosimeters.

Thus, external exposures to gamma rays, X-rays, and bremsstrahlung from the sources dominate except in cases such as accidents, in which the source integrity may be compromised. Similarly, for byproduct material contained in loose calibration sources, there is no inhalation or ingestion concern during routine usage. The principal exposure pathway is external irradiation of the whole body.

4.5.2 Description of Items Considered for Exempt Distribution

The calibration and reference sources that may be distributed under this potential exemption include: (1) reference light sources contained in thermoluminescent dosimeter readers, (2) calibration sources contained in liquid scintillation counters, and (3) loose calibration and reference sources for general usage in instrument work or in research and teaching.

4.5.2.1 Thermoluminescent Dosimetry Readers

Thermoluminescent dosimetry (TLD) readers determine the radiation dose to an exposed piece of thermoluminescent material\(^\text{18}\) by measuring the light output as the material is heated (Duftschmid et al., 1986). Reference lights, described in a safety evaluation provided by one manufacturer, contain either 2.2-MBq (60-$\mu$Ci) or 8.9-MBq (240-$\mu$Ci) sources of $^{14}$C and are used for verifying instrument gain and stability and for troubleshooting. More sophisticated TLD readers may contain up to four of the smaller (2.2-MBq (60-$\mu$Ci)) reference lights, but no more than one of the larger (8.9-MBq (240-$\mu$Ci)) lights is used in a reader. TLD reader systems incorporating these $^{14}$C reference lights have been manufactured since the early 1970s with no reports of fracturing of the light source or inadvertent release of the hermetically sealed radioactive material.

It is assumed that a nominal 60 TLD readers are sold annually by a manufacturer. The number of instruments distributed annually by other manufacturers is believed to be about one-third of this quantity. Since the TLD readers are configured to hold either a single 8.9-MBq (240-$\mu$Ci) source or up to four 2.2-MBq (60-$\mu$Ci) sources, we assume that the configurations are equally distributed among the five possibilities (those containing a single large source or one, two, three, or four of the smaller sources). The maximum amount of $^{14}$C in a reader is 8.9 MBq (240 $\mu$Ci), and the average amount under these assumptions is 6.3 MBq (170 $\mu$Ci). In this assessment, however, it is assumed that each of the 80 TLD readers distributed annually contains 10 times a quantity (see 10 CFR 30.71, Schedule B) or 37 MBq (1000 $\mu$Ci) of $^{14}$C (see Table 4.5.1).

Reference lights containing $^{90}$Sr/$^{90}$Y are reportedly used in another TLD reader (Spanne, 1973), but the source activity is not reported, and there is no evidence that this design is still used or that the instrument was sold in the United States. Exposure from the $^{90}$Sr/$^{90}$Y light sources was observed as the thermoluminescent response of quartz components in the sample chamber of the readers. No such thermoluminescence was reported in components of readers in which $^{14}$C was used in the light source. The increased exposure potential from $^{90}$Sr/$^{90}$Y is explained by the ability of their more energetic beta particles to escape the scintillator matrix and impart radiation.

\(^\text{18}\) Examples of thermoluminescent materials include thallium-doped lithium fluoride, LiF(Tl), used in personnel dosimeters, and dysprosium-doped calcium sulfate, CaSO$_4$(Dy), used in environmental dosimeters.
dose to the surrounding materials, whereas the less energetic beta particles of $^{14}$C are unable to escape the scintillator matrix to any appreciable degree.

4.5.2.2 Liquid Scintillation Counters

Liquid scintillation counters (LSCs) measure light emitted by a scintillator medium in which radioactive materials are intimately dispersed and estimate the concentration of the radioactive material from the light intensity. One manufacturer uses an LSC in which an external gamma-ray source containing 0.74 MBq (20 $\mu$Ci) of $^{152}$Eu is brought into close contact with the sample vial containing the scintillating medium to provide a reproducible calibration and reference light. The byproduct material is sealed within a 0.35-mm stainless steel capsule. The capsule is further contained within a stainless steel cable cap by crimping the cap around a stainless steel plug and, behind the plug, to a steel cable. The sealed source can only be used in the LSC for which it was designed and not as part of another product. The source is normally stored in a lead shield (40-mm wall thickness), except when extended into the LSC sample chamber by the steel cable. The sample chamber is also enclosed by a lead shield, so that the only time that the source is unshielded (except by the instrument housing) is during transit from storage to the sample cell. Another manufacturer of LSCs uses a $^{133}$Ba or $^{137}$Cs source in a similar configuration.

It is assumed that a nominal 600 LSCs using 0.37 to 0.74 MBq (10 to 20 $\mu$Ci) of $^{133}$Ba are distributed annually by one manufacturer. The average unit quantity of $^{133}$Ba is assumed to be the approximate arithmetic average of these values, or 0.56 MBq (15 $\mu$Ci). LSCs using 0.74 MBq (20 $\mu$Ci) of $^{152}$Eu are not as prevalent in the United States, with only 20 to 25 distributed annually by a single manufacturer. In this assessment, however, it is assumed that each of the LSCs contains 10 times an exemption quantity (see 10 CFR 30.71, Schedule B), which is either 0.37 MBq (10 $\mu$Ci) of $^{152}$Eu or 3.7 MBq (100 $\mu$Ci) of $^{133}$Ba (see Table 4.5.1).

The two different LSC manufacturers report that both $^{226}$Ra and $^{241}$Am were once used in calibration sources for these devices, but that $^{241}$Am is no longer in use and no $^{226}$Ra has been distributed for this purpose for the past 6 or 7 years.

4.5.2.3 Loose Calibration Sources

Loose calibration sources that could be distributed under this potential exemption are primarily gamma-ray emitters such as $^{60}$Co or $^{137}$Cs/$^{137m}$Ba and beta-particle emitters such as $^{90}$Sr/$^{90}$Y or $^{204}$Tl (NCRP 112). The sources are small in physical size, namely, less than a few centimeters in maximum dimensions. The byproduct material is either encapsulated or plated on metal and covered with a thin window to prevent the spread of contamination during normal usage. For calibration sources emitting beta particles, a thin window is necessary to permit the emergence of a useful fraction of the radiation from the source. Extreme care in handling is vital to prevent window damage to a beta-particle source.

The estimates in Table 4.5.2 for the number of loose calibration sources and the amount of byproduct material distributed annually under this potential exemption were obtained as follows. First, it was assumed that the amount of byproduct material distributed annually for use under an exemption would be the same as that distributed annually for use under 10 CFR 30.18 (see Section 2.13, Table 2.13.1). Second, it was assumed that the amount of byproduct material per source would be 10 times a quantity as specified in 10 CFR 30.71, Schedule B. Third, it was
assumed that the number of calibration sources for beta particles (i.e., $^{90}\text{Sr}$ and $^{204}\text{Ti}$) would be the same since very little $^{90}\text{Sr}$ appears to be used under 10 CFR 30.18 (see Section 2.13, Table 2.13.1). Fourth, it was assumed that two manufacturers produce an equal number of the various loose calibration sources.

Assuming a quality factor of 1 for beta particles and photons (International Commission on Radiological Protection (ICRP) 26), the dose rates from photons at 10 cm from the center of a small encapsulated source containing 0.37 MBq ($10^{-1}$ Ci) of $^{60}\text{Co}$ or 3.7 MBq ($100\mu$Ci) of $^{137}\text{Cs}^{137m}\text{Ba}$ are approximately 0.01 mSv/h (1 mrem/h) and 0.03 mSv/h (3 mrem/h), respectively (as derived from Table 4.3 in National Council on Radiation Protection and Measurements (NCRP 112)). Dose rates from beta particles at 10 cm from the radioactive surface of a small plated source containing 37 kBq ($1\mu$Ci) of $^{90}\text{Sr}/^{90}\text{Y}$ or 3.7 MBq ($100\mu$Ci) of $^{204}\text{TI}$ are approximately 0.08 mSv/h (8 mrem/h) and 4.5 mSv/h (450 mrem/h), respectively (as derived from Table 5.1 in NCRP 112).

**4.5.3 Summary of Previous Analyses and Assessments**

There are no known previously published analyses or assessments of the radiation doses to personnel using calibration or reference sources (either loose or internal to a device). However, each applicant for a specific license to manufacture or initially distribute devices containing a calibration or reference source for use under 10 CFR 31.5 is required to submit information (i.e., a safety analysis) to the NRC to show that their product will meet the dose criteria summarized in Section 4.5.1.

**4.5.4 Present Assessment for Calibration and Reference Sources Distributed Internal to a Device**

Table 4.5.3 presents the results of the present assessment of the potential doses to members of the public from calibration or reference sources distributed internal to a device under a general license. Results are based on the annual distribution data in Table 4.5.1 and the following useful lifetimes for the various devices and sources. The useful lifetime was assumed to be 10 years for devices with internal sources containing $^{133}\text{Ba}$ or $^{152}\text{Eu}$ and 15 years for devices with internal sources containing $^{14}\text{C}$.

The amount of activity per device in Table 4.5.1 is set equal to 10 times a quantity of a byproduct material as defined in 10 CFR 30.71, Schedule B. These data are used to estimate potential doses to individuals exposed to multiple sources during transport and disposal and to estimate collective doses from all potential exposure pathways. Dose rates from photons at a distance of 10 cm from the sources in Table 4.5.1 are less than the potential dose rates allowed by this general license. Hence, also considered was a generic source containing 10 quantities with a dose rate of 0.1 mSv/h (10 mrem/h) at a distance of 10 cm to assess the potential doses from external exposure during routine use of a single source (or combination of sources within a single device) as a potential exemption (see Section 4.5.1).

**4.5.4.1 Distribution and Transport**

A relatively small number of internal calibration and reference sources are expected to be distributed under this potential exemption (see Table 4.5.1). Hence, the sources were
considered to be fabricated on demand and shipped directly to the user without intermediate storage in a warehouse.

The individual and collective doses are based on the generic distribution methodology in Appendix A.3 and the following assumptions. The distribution involves five steps: (1) express delivery (small truck) from the manufacturer to a nearby airport, (2) processing at airport freight terminal and loading on the outbound plane, (3) transport by plane, (4) unloading of the plane and processing at the receiving airport, and (5) local delivery (small truck, within 400 km of the airport) to the user.

Individual doses were evaluated based on the greatest annual quantity shipped by a single manufacturer. A single driver is assumed to transport all sources in a small truck from a given manufacturer to the same outbound airport. It is further assumed that the shipments are distributed equally to 25 regional airports and that the sources are picked up at the receiving airports and delivered to users by many local delivery drivers.

For calibration and reference sources distributed internal to devices, the shipment of sources, individual doses, and collective doses can be summarized as follows:

- Sixty $^{14}\text{C}$ sources containing 37 MBq (1000 $\mu$Ci) each are distributed annually by a single manufacturer (see Section 4.5.2.1), and the total distributed annually by all manufacturers is 80 sources (see Table 4.5.1). The annual EDE to a local express-delivery driver would be less than $1 \times 10^{-5}$ mSv (<0.001 mrem). Individual doses to other truck drivers, terminal workers, and members of the public would also be less than $1 \times 10^{-5}$ mSv (<0.001 mrem). The annual collective EDE to all truck drivers, terminal workers, and members of the public is estimated to be $1 \times 10^{-6}$ person-Sv ($1 \times 10^{-4}$ person-rem).

- Six-hundred $^{133}\text{Ba}$ sources containing 3.7 MBq (100 $\mu$Ci) each are distributed annually by a single manufacturer (see Section 4.5.2.2). The annual EDE to a local express-delivery driver could be 0.02 mSv (2 mrem). Individual doses are less to other truck drivers, terminal workers, and members of the public. The annual collective EDE to all drivers, terminal workers, and members of the public is estimated to be 0.001 person-Sv (0.1 person-rem).

- Twenty-five $^{152}\text{Eu}$ sources containing 37 kBq (10 $\mu$Ci) each are distributed annually by a single manufacturer (see Section 4.5.2.2). The annual EDE to a local express-delivery driver could be $3 \times 10^{-4}$ mSv (0.03 mrem). Individual doses are less to other truck drivers, terminal workers, and members of the public. The annual collective EDE to all drivers, terminal workers, and members of the public is estimated to be $2 \times 10^{-5}$ person-Sv (0.002 person-rem).

4.5.4.2 Routine Use

Devices such as thermoluminescent dosimeter readers and liquid scintillation counters distributed for use under the general license provided in 10 CFR 31.5 are used primarily by technicians, educators, researchers, and students. The sources of byproduct material in these devices are kept in a normally shielded storage position, reducing exposure to an estimated 1% of the unshielded values, except when specifically employed for calibration or to provide a
reference light, which is assumed to be the case about 10% of the time. These devices are relatively large and the sources of byproduct material typically are found near the center, well away from the cabinet enclosure, even when in use. Thus, the shielding by the cabinet enclosure and other parts of the device are assumed to reduce the radiation dose from the internal source in its calibration or reference-light position to 10% of that from an unshielded source at the same distance.

Operation is typically automatic and initiated from a computer console, so that the operator’s closest proximity to the radioactive sources is during sample loading and unloading. Other duties may usually be performed after loading samples and initiating the analyses as the device performs without operator intervention. This evaluation assumes that 20% of the operator’s time is spent loading and unloading samples with both the whole body and hands at 0.5 meter from the shielded reference source, and that an additional 20% of the operator’s time is spent 1 meter from the source at the computer console, with the source in the calibration or reference-light position half of the time. The remainder of the operator’s time is spent performing other tasks at an average distance of 2 meters from the shielded source. Two other room occupants are also assumed to perform tasks at an average distance of 2 meters from the source in either its storage and calibration or reference-light positions.

If the radiation doses at various distances from an unshielded source are calculated with CONDOS (Computer Codes, O’Donnell et al., 1975), so that bremsstrahlung is taken into account in the calculations and both the operator and other two room occupants spend 1000 h/yr working close to the device, then the following results are obtained:

- For a device with an internal 37-MBq (1000-μCi) source of 14C, the annual EDE to the operator and to each of the other two occupants of the room would be less than 1×10^{-5} mSv (<0.001 mrem). For the yearly distribution of 80 such devices, it is estimated that the collective EDE is 2×10^{-7} person-Sv (2×10^{-5} person-rem) over the first year of routine use and 3×10^{-6} person-Sv (3×10^{-4} person-rem) over the estimated 15-year lifetime of these devices.

- For a device with an internal 3.7-MBq (100-μCi) source of 133Ba, the annual EDE could be 0.003 mSv (0.3 mrem) to the operator and 6×10^{-4} mSv (0.06 mrem) to each of the other two occupants of the room. For the yearly distribution of 600 such devices, it is estimated that the collective EDE is 0.003 person-Sv (0.3 person-rem) over the first year of routine use and 0.02 person-Sv (2 person-rem) over the estimated 10-year lifetime of these devices.

- For a device with an internal 0.37-MBq (10-μCi) source of 152Eu, the annual EDE could be 9×10^{-4} mSv (0.09 mrem) to the operator and 2×10^{-4} mSv (0.02 mrem) to each of the other two occupants of the room. For the yearly distribution of 25 such devices, it is estimated that the collective EDE is 3×10^{-5} person-Sv (0.003 person-rem) over the first year of routine use and 2×10^{-4} person-Sv (0.02 person-rem) over the estimated 10-year lifetime of these devices.

The above results give a potential collective dose of about 0.02 person-Sv (2 person-rem) from routine use of 1 year’s distribution of devices under this potential exemption (see Table 4.5.3). To assess the potential individual dose from routine use of a single device, a device containing a generic source with a dose rate of 0.1 mSv/h (10 mrem/h) at a distance of 10 cm (see Section
4.5.1) was considered. If the dose rate varies inversely with the square of the distance from the source, then the potential individual dose to an operator of a device containing such a source could be 0.02 mSv/yr (2 mrem/yr) and the potential dose to each of the other two occupants in the room could be 0.005 mSv/yr (0.5 mrem/yr) (see Table 4.5.3).

4.5.4.3 Disposal

Although these calibration and reference sources would be discarded as radioactive waste under the current regulatory scheme, for purposes of evaluating a possible exemption, all sources distributed are assumed to be disposed as ordinary waste, as there are usually no controls over disposal under an exemption.

To estimate the potential doses from the disposal of these sources as ordinary waste in landfills and incinerators, the generic disposal methodology in Appendix A.2 is used along with the following assumptions: (1) each $^{14}$C source is discarded at the end of 15 years and contains essentially its full initial activity of 37 MBq (1000 µCi), (2) each $^{133}$Ba source is discarded at the end of 10 years and contains 50% of its initial activity of 3.7 MBq (100 µCi), and (3) each $^{152}$Eu source is discarded at the end of 10 years and contains 60% of its initial activity of 0.37 MBq (10 µCi). Thus, the 80 sources of $^{14}$C would contain 3 GBq (80 mCi) at the time of disposal, the 600 sources of $^{133}$Ba would contain 1.1 GBq (30 mCi), and the 25 sources of $^{152}$Eu would contain 56 MBq (1.5 mCi). It is assumed that 80% of the sources are disposed in a landfill and 20% are incinerated. Since the number of sources disposed of annually is less than 3500, the assumed number of landfills, the applicable dose-to-source ratio (DSR), for individual dose in Appendix A.2 are multiplied by the ratio of 3500 to the number of items annually disposed. A similar correction is made for incineration.

4.5.4.3.1 Landfill Disposal

In applying the methodology of Appendix A.2 to disposal at landfills, it is further assumed that (1) the byproduct material in the calibration and reference sources is in a form that is not readily dispersible and (2) the sources are not handled directly by waste collectors or by workers during landfill operations. Thus, the following adjustments are made to the dose-to-source ratios in Appendix A.2: (1) there is no exposure from inhalation or ingestion by waste collectors or landfill workers, (2) there is no exposure to off-site members of the public during landfill operations, (3) there is a reduction by a factor of 10 in the exposure to off-site members of the public from groundwater releases, and (4) there is a reduction by a factor of 10 in the exposure to future on-site residents by inhalation and ingestion.

Estimates of potential individual and collective doses from landfill disposal of $^{14}$C can be summarized as follows:

- The annual EDE to off-site members from groundwater releases, waste collectors, workers at landfills, off-site members of the public exposed to airborne releases during landfill operations, and future on-site residents, would be less than $1 \times 10^{-5}$ mSv (<0.001 mrem).

- The total collective EDE could be $4 \times 10^{-6}$ person-Sv ($4 \times 10^{-4}$ person-rem), due almost entirely to exposure to off-site members of the public from groundwater releases.
Estimates of potential individual and collective doses from landfill disposal of $^{133}$Ba can be summarized as follows:

- The annual EDE to waste collectors could be $6\times10^{-4}$ mSv (0.06 mrem). For workers at landfills, off-site members of the public near landfills, and future on-site residents, the individual doses would be less.

- The total collective EDE could be $5\times10^{-4}$ person-Sv (0.05 person-rem), due about equally to exposure to waste collectors and landfill workers.

Estimates of potential individual and collective doses from landfill disposal of $^{152}$Eu can be summarized as follows:

- The annual EDE to waste collectors could be $2\times10^{-4}$ mSv (0.02 mrem). For workers at landfills, off-site members of the public near landfills, and future on-site residents, the individual doses would be less.

- The total collective EDE could be $1\times10^{-5}$ person-Sv (0.001 person-rem), due about equally to exposure to waste collectors, landfill workers, and future on-site residents.

### 4.5.4.3.2 Incineration

In applying the methodology of Appendix A.2 to disposal by incineration, it is also assumed that there is no exposure to waste collectors by either inhalation or ingestion. However, it is assumed that all of the various pathways of exposure to workers and off-site members of the public are fully operative.

Estimates of potential individual and collective doses from incineration of $^{14}$C can be summarized as follows:

- The annual EDE to workers at incinerators, collectors at incinerators and off-site members of the public near landfills could be less than $1\times10^{-5}$ mSv (<0.001 mrem).

- The total collective EDE could be $2\times10^{-9}$ person-Sv ($2\times10^{-7}$ person-rem), due almost entirely to exposure to off-site members of the public from airborne releases during incinerator operations.

Estimates of potential individual and collective doses from incineration of $^{133}$Ba can be summarized as follows:

- The annual EDE to waste collectors could $6\times10^{-4}$ mSv (0.06 mrem). For workers at incinerators and off-site members of the public near incinerators, the individual doses would be less.

- The total collective EDE could be $6\times10^{-5}$ person-Sv (0.006 person-rem), due almost entirely to exposure to waste collectors at incinerators.
Estimates of potential individual and collective doses from incineration of $^{152}$Eu can be summarized as follows:

- The annual EDE to waste collectors could be $2 \times 10^{-4}$ mSv (0.02 mrem). For workers at incinerators and off-site members of the public near incinerators, the individual doses would be less.
- The total collective EDE could be $1 \times 10^{-6}$ person-Sv ($1 \times 10^{-4}$ person-rem), due almost entirely to exposure to waste collectors at incinerators.

### 4.5.4.4 Accidents and Misuse

Devices containing byproduct material in either calibration or reference sources are used primarily in industry and education, rather than in homes or small businesses. Thus, the following exposure scenarios are considered: (1) transportation accidents involving fires, warehouse fires, and laboratory fires, and (2) misuse of a calibration or reference source during repair or attempted modification of a device by an unqualified individual.

Doses for transportation accidents involving fires, warehouse fires, and residential fires can be estimated by using the generic accident methodology in Appendix A.1. Doses from a laboratory fire can be estimated by using dose-to-source ratios for a residence and correcting for different volumes and air exchange rates. Inhalation and submersion doses for a laboratory fire are essentially equal to those for a residential fire, whereas resuspension doses are approximately three times greater for the laboratory. It is assumed here that only a single device is involved and that the release fraction is 0.01%, since the byproduct material is enclosed within the device as a sealed source and the sealed source may be further encased within another subassembly of the device. Based on these assumptions and the generic accident methodology in Appendix A.1, estimates of individual dose are summarized as follows:

- For a firefighter wearing a respirator at a transportation fire, the individual EDEs would be less than $1 \times 10^{-5}$ mSv (<0.001 mrem) from a source containing 37 MBq (1000 $\mu$Ci) of $^{14}$C, 3.7 MBq (100 $\mu$Ci) of $^{133}$Ba, or 0.37 MBq (10 $\mu$Ci) of $^{152}$Eu. For a worker who is involved in the cleanup following the fire and who does not wear a respirator, the individual EDEs would be less than $1 \times 10^{-5}$ mSv (<0.001 mrem) for all sources.

- For a firefighter wearing a respirator at a laboratory fire, the individual EDEs would be less than $1 \times 10^{-5}$ mSv (<0.001 mrem) from a source containing 37 MBq (1000 $\mu$Ci) of $^{14}$C, 3.7 MBq (100 $\mu$Ci) of $^{133}$Ba, or 0.37 MBq (10 $\mu$Ci) of $^{152}$Eu. For a worker who is involved in the cleanup following the fire and who does not wear a respirator, the individual EDEs would be less than $1 \times 10^{-5}$ mSv (<0.001) mrem for all sources.

Misuse of the calibration or reference source contained in a device might entail removal of a source or subassembly, followed by close hand work for repair or modification by an unqualified individual. If it is assumed that the person spends 1 week (40 hours) attempting the repair or modification, with the trunk of the body located at an average distance of about 50 cm and the hands located at an average distance of about 10 cm from the source, then the following results are obtained:
For a 37-MBq (1000-μCi) source of $^{14}$C, the EDE from irradiation of the whole body could be about $2 \times 10^{-5}$ mSv (0.002 mrem) and the dose equivalent to the hands could be about $4 \times 10^{-5}$ mSv (0.004 mrem).

For a 3.7-MBq (100-μCi) source of $^{133}$Ba, the EDE from irradiation of the whole body could be about 0.02 mSv (2 mrem) and the dose equivalent to the hands could be about 0.4 mSv (40 mrem).

For a 0.37-MBq (10-μCi) source of $^{152}$Eu, the EDE from irradiation of the whole body could be about 0.007 mSv (0.7 mrem) and the dose equivalent to the hands could be about 0.2 mSv (20 mrem).

For a generic source with a dose rate of 0.1 mSv/h (10 mrem/h) at a distance of 10 cm, the EDE from irradiation of the whole body could be about 0.2 mSv (20 mrem) and the dose equivalent to the hands could be 4 mSv (400 mrem).

### 4.5.5 Present Analysis for Loose Calibration and Reference Sources

Table 4.5.4 shows the results of the present assessment of potential radiation doses to the public from loose calibration and reference sources. Results are based on the annual distribution data in Table 4.5.2 and following effective lifetimes for these various sources. Lifetimes are assumed to be 5 years for the $^{60}$Co and $^{204}$Tl sources and 15 years for the $^{85}$Sr and $^{137}$Cs sources.

The amount of activity per source is set equal to 10 times a quantity of a byproduct material as defined in 10 CFR 30.71, Schedule B. These data are used to estimate potential doses to individuals exposed to multiple sources during transport and disposal and to estimate collective doses for all exposure pathways. Dose rates from photons at a distance of 10 cm from the sources in Table 4.5.2 are less than the potential dose rates allowed by an exemption. Hence, we also consider a generic source with a dose rate of 0.1 mSv/h (10 mrem/h) at 10 cm to assess the doses from routine use of a single source under this potential exemption (see Section 4.5.1).

The sources will probably be shipped and stored in shielded containers that provide some protection against photons from the sources. No credit is taken, however, for any shielding against photons from the sources. As a result, dose estimates for distribution and transport and for routine use of these loose calibration and reference sources will be conservative.

#### 4.5.5.1 Distribution and Transport

A relatively small number of loose calibration and reference sources is expected to be distributed under an exemption. The same assumptions are applied here as applied in Section 4.5.4.1 for reference or calibration sources shipped internal to a device.

For loose calibration and reference sources, the shipment of sources, individual doses, and the collective doses are summarized as follows:
Two hundred $^{137}$Cs sources containing 3.7 MBq (100 $\mu$Ci) each are distributed annually by a single manufacturer (see Section 4.5.2.3), and the total distributed annually by all manufacturers is 400 sources (see Table 4.5.2). The annual EDE to a local express-delivery driver could be 0.01 mSv (1 mrem). Individual doses are less to other truck drivers, terminal workers, and members of the public. The annual collective EDE to all truck drivers, terminal workers, and members of the public is estimated to be 0.001 person-Sv (0.1 person-rem).

Forty-five $^{60}$Co sources containing 0.37 MBq (10 $\mu$Ci) each are distributed annually by a single manufacturer (see Section 4.5.2.3), and the total distributed annually by all manufacturers is 90 sources (see Table 4.5.2). The annual EDE to a local express-delivery driver could be 0.001 mSv (0.1 mrem). Individual doses are less to other truck drivers, terminal workers, and members of the public. The annual collective EDE to all truck drivers, terminal workers, and members of the public is estimated to be $1\times10^{-4}$ person-Sv ($1\times10^{-2}$ person-rem).

Ten $^{204}$Tl sources containing 3.7 MBq (100 $\mu$Ci) each are distributed annually by a single manufacturer (see Section 4.5.2.3), and the total distributed annually by all manufacturers is 20 sources (see Table 4.5.2). The annual EDE to all delivery drivers, other truck drivers, terminal workers, and members of the public would be less than $1\times10^{-5}$ mSv (<0.001 mrem). The annual collective EDE to all truck drivers, terminal workers, and members of the public is estimated to be $2\times10^{-7}$ person-Sv ($2\times10^{-5}$ person-rem).

Ten $^{90}$Sr sources containing 37 kBq (1 $\mu$Ci) each are distributed annually by a single manufacturer (see Section 4.5.2.3), and the total distributed annually by all manufacturers is 20 sources (see Table 4.5.2). The annual EDE to all delivery drivers, other truck drivers, terminal workers, and members of the public would be less than $1\times10^{-5}$ mSv (<0.001 mrem). The annual collective EDE to all truck drivers, terminal workers, and members of the public is estimated to be $2\times10^{-9}$ person-Sv ($2\times10^{-7}$ person-rem).

### 4.5.5.2 Routine Use

While the dose rate from photons at 10 cm from an unshielded reference or calibration source is typically less than 0.1 mSv/h (<10 mrem/h), the dose rate from beta particles may be much greater and result in a significant dose to the hands, even if the hands are only in close proximity to the sources for very brief periods of time. Thus, potential doses from external irradiation of the hands, by beta particles are considered first, then potential doses from external irradiation of the whole body by photons (i.e., X-rays, gamma rays, and bremsstrahlung) are considered.

To assess the potential beta-particle doses to the hands during routine use of loose calibration or reference sources, the following exposure scenario was adopted: (1) an individual uses a pair of forceps to handle the source for 1 min/day for 150 day/yr (i.e., 2.5 h/yr), and (2) the hands are located at a distance of 10 cm from the source while using the forceps. For a source containing 10 times the quantity of $^{204}$Tl, the dose rate from beta particles could be 4.5 mSv/h (450 mrem/h) at 10 cm from the source (see Section 4.5.2.3), and the annual dose equivalent to the hands could be 10 mSv (1 rem). The annual dose equivalent to the hands could easily
be 100 times greater, or 1 Sv (100 rem), if the source was handled routinely using fingers instead of forceps.

To assess the potential photon doses to the public from routine use of loose calibration or reference sources containing 10 times the quantity of a byproduct material, the following exposure scenario was adopted: (1) an individual is located in the same room as the source for 1000 h/yr, and (2) the average distance between the source and exposed individual is 2 meters (see Section 2.13.4.1). Exposure time is based on the assumption that the individual spends half of his or her working hours during the year in the room with the source, and the assumed distance from the source would be representative of the average distance in a typical laboratory. Based on these assumptions and on calculations with CONDOS (Computer Codes, O'Donnell et al., 1975), the following results were obtained:

- For a $^{60}$Co source containing 0.37 MBq (10 $\mu$Ci), the annual EDE to a user could be 0.002 mSv (2 mrem). For a yearly distribution of 90 such sources, the collective EDE could be 0.002 person-Sv (0.2 person-rem) over the first year of use or 0.01 person-Sv (1 person-rem) over the estimated 5-year lifetime of these sources.

- For a $^{90}$Sr/$^{90}$Y source containing 37 kBq (1 $\mu$Ci), the annual EDE to a user could be $2\times10^{-5}$ mSv (0.002 mrem). For a yearly distribution of 20 such sources, the collective EDE could be $5\times10^{-7}$ person-Sv ($5\times10^{-5}$ person-rem) over the first year of use or $7\times10^{-6}$ person-Sv ($7\times10^{-4}$ person-rem) over the estimated 15-year lifetime of these sources.

- For a $^{137}$Cs source containing 3.7 MBq (100 $\mu$Ci), the annual EDE to a user could be 0.06 mSv (6 mrem). For a yearly distribution of 400 such sources, the collective EDE could be 0.02 person-Sv (2 person-rem) over the first year of use or 0.3 person-Sv (30 person-rem) over the estimated 15-year lifetime of these sources.

- For a $^{204}$Tl source containing 3.7 MBq (100 $\mu$Ci), the annual EDE to a user could be $2\times10^{-5}$ Sv (0.2 mrem). For a yearly distribution of 20 such sources, the collective EDE could be $4\times10^{-6}$ person-Sv (0.004 person-rem) over the first year of use or $1\times10^{-4}$ person-Sv (0.01 person-rem) over the estimated 5-year lifetime of these sources.

The above results suggest a total collective dose of about 0.3 person-Sv (30 person-rem) from routine use of 1 year's distribution of loose calibration and reference sources under an exemption (see Table 4.5.4). To assess the potential individual dose from photons during routine use of a single loose calibration or reference source, a generic source of high-energy photons with a dose rate of 0.1 mSv/h (10 mrem/h) at a distance of 10 cm was considered. If dose rates vary inversely with the square of the distance from the source, then the estimated potential individual dose to a user could be 0.3 mSv/yr (30 mrem/yr).

The photon dose estimates given above could be somewhat conservative, because it does not take into account any shielding between the source and the user. The common practice of storing calibration sources in a shielded container could result in some reduction to dose. In addition, the assumed exposure time could be a very conservative overestimate for a realistic exposure situation, because the source could be stored in rooms such as teaching laboratories that any individual would occupy infrequently.
In contrast, rooms in which calibration or reference sources are stored could be occupied on a continuous basis for up to twice as long as the time assumed here, and the average distance from the source to the individual could be less than 2 meters. For a maximum exposure to 2000 h/yr and an average distance from the source of 1 meter, estimated individual doses could be increased by a factor of 8, although such doses should be less likely to occur. In addition, multiple calibration and reference sources of byproduct material could be located in the same room, in which case the external dose would increase in proportion to the number of sources.

Considering all of the above factors, the following conclusions seem warranted about potential individual dose from calibration and reference sources containing 10 times a quantity of a byproduct material from Schedule B. First, by invoking reasonable assumptions about exposure conditions, the annual EDE to an individual from photons could be as much as 0.3 mSv (30 mrem). Second, the annual photon dose could be higher if multiple sources were stored essentially without shielding in locations occupied by an individual during a substantial portion of a year. Third, by invoking very pessimistic assumptions about exposure conditions that could occur only in unusual circumstances, the annual photon dose from exposure to either single or multiple sources could approach or exceed 1 mSv (100 mrem). Finally, annual beta-particle doses to the hands of an individual could be as much as 10 mSv (1 rem) if an individual handles a source with forceps and as much as 1 Sv (100 rem) or more if an individual routinely handles a source using fingers instead of forceps.

4.5.5.3 Disposal

Although these loose calibration and reference sources would be discarded as radioactive waste under the current regulatory scheme, for purposes of evaluating a possible exemption, all sources distributed are assumed to be disposed as ordinary waste, as there are usually no controls over disposal under an exemption.

To estimate potential doses from the disposal of these sources as ordinary waste in landfills and incinerators, the generic disposal methodology in Appendix A.2 is applied with the following assumptions: (1) each 60Co source is discarded at the end of 5 years and contains 50% of its initial activity of 0.37 MBq (10 μCi), (2) each 90Sr source is discarded at the end of 15 years and contains 70% of its initial activity of 37 kBq (1 μCi), (3) each 137Cs source is discarded at the end of 15 years and contains 70% of its initial activity of 3.7 MBq (100 μCi), and (4) each 204Tl source is discarded at the end of 5 years and contains 40% of its initial activity of 3.7 MBq (100 μCi). Thus, at the time of disposal, the 90 sources of 60Co would contain 17 MBq (450 μCi), the 20 sources of 90Sr would contain 0.52 MBq (14 μCi), the 400 sources of 137Cs would contain 1.04 GBq (28 mCi), and the 20 sources of 204Tl would contain 30 MBq (800 μCi). It is assumed that 80% of the sources are landfill disposed and 20% are incinerated. Since the number of sources disposed of annually is less than 3500, the assumed number of landfills, the applicable DSRs for individual dose in Appendix A.2 are multiplied by the ratio of 3500 to the number of items annually disposed. A similar correction is made for incineration.

4.5.5.3.1 Landfill Disposal

In applying the methodology of Appendix A.2 to disposal at landfills, it is further assumed that (1) the byproduct material in the calibration and reference sources is in a form that is not readily dispersible and (2) the sources are not handled directly by waste collectors or by workers during landfill operations. Thus, the following adjustments to the dose-to-source ratios in
Appendix A.2: (1) there is no exposure from inhalation or ingestion by waste collectors or landfill workers, (2) there is no exposure to off-site members of the public during landfill operations, (3) there is a reduction by a factor of 10 in the exposure to off-site members of the public from groundwater releases, and (4) there is a reduction by a factor of 10 in the exposure to future on-site residents by inhalation and ingestion.

Estimates of potential individual and collective doses from landfill disposal of $^{60}$Co can be summarized as follows:

- The annual individual EDE to waste collectors could be $2 \times 10^{-4}$ mSv (0.02 mrem). For workers at landfills, off-site members of the public near landfills, and future on-site residents, the individual doses would be less.

- The total collective EDE could be $2 \times 10^{-5}$ person-Sv (0.002 person-rem), due almost entirely to exposure to waste collectors and landfill workers.

Estimates of potential individual and collective doses from landfill disposal of $^{90}$Sr can be summarized as follows:

- The annual EDE to future on-site residents, collectors and workers at landfills and off-site members of the public exposed to airborne releases during landfill operations or to groundwater releases from the landfill, would be less than $1 \times 10^{-5}$ mSv (<0.001 mrem).

- The total collective EDE could be $1 \times 10^{-11}$ person-Sv ($1 \times 10^{-9}$ person-rem), due almost entirely to exposure to future on-site residents.

Estimates of potential individual and collective doses from landfill disposal of $^{137}$Cs can be summarized as follows:

- The annual EDE to waste collectors could be $6 \times 10^{-5}$ mSv (0.06 mrem). For workers at landfills, off-site members of the public near landfills, and future on-site residents, the individual doses would be less.

- The total collective EDE could be $3 \times 10^{-4}$ person-Sv (0.03 person-rem), due almost entirely to exposure to waste collectors and landfill workers.

Estimates of potential individual and collective doses from landfill disposal of $^{204}$Tl can be summarized as follows:

- The annual EDE to waste collectors, workers at landfills, off-site members of the public near landfills, and future on-site residents, would be less than $1 \times 10^{-5}$ mSv (<0.001 mrem).

- The total collective EDE could be $2 \times 10^{-8}$ person-Sv ($2 \times 10^{-6}$ person-rem), due almost entirely to exposure to waste collectors and landfill workers.
4.5.5.3.2 Incineration

In applying the methodology of Appendix A.2 to disposal by incineration, it is also assumed that there is no exposure to waste collectors by either inhalation or ingestion. However, it is assumed that all of the various pathways of exposure to workers and off-site members of the public are fully operative.

Estimates of potential individual and collective doses from incineration of $^{60}\text{Co}$ can be summarized as follows:

- The annual EDE to waste collectors could be $3\times10^{-4}$ mSv (0.03 mrem). For workers at incinerators and off-site members of the public near incinerators, the individual doses would be less.
- The total collective EDE could be $4\times10^{-6}$ person-Sv ($4\times10^{-4}$ person-rem), due almost entirely to exposure to waste collectors at incinerators.

Estimates of potential individual and collective doses from incineration of $^{90}\text{Sr}$ can be summarized as follows:

- The annual individual EDE to workers at incinerators, waste collectors at incinerators and off-site members of the public near landfills, would be less than $1\times10^{-5}$ mSv (<0.001 mrem).
- The total collective EDE could be $1\times10^{-11}$ person-Sv ($1\times10^{-9}$ person-rem), due almost entirely to exposure to off-site members of the public from airborne releases during incinerator operations.

Estimates of potential individual and collective doses from incineration of $^{137}\text{Cs}$ can be summarized as follows:

- The annual EDE to waste collectors could be $8\times10^{-4}$ mSv (0.08 mrem). For workers at incinerators and off-site members of the public near incinerators, the individual doses would be less.
- The total collective EDE could be $6\times10^{-5}$ person-Sv (0.006 person-rem), due almost entirely to exposure to waste collectors at incinerators.

Estimates of potential individual and collective doses from incineration of $^{204}\text{Tl}$ can be summarized as follows:

- The annual EDE to waste collectors, workers at incinerators and off-site members of the public near incinerators, would be less than $1\times10^{-5}$ mSv (<0.001 mrem).
- The total collective EDE could be $6\times10^{-9}$ person-Sv ($6\times10^{-7}$ person-rem), due almost entirely to exposure to waste collectors at incinerators.
4.5.5.4 Accidents and Misuse

Exposure scenarios for accidents or misuse involving loose calibration and reference sources based on actual experience are almost unlimited. The ones considered here are: (1) a laboratory fire involving the release of byproduct material from a source, (2) accidents or misuse involving the crushing or rupture of a source followed by subsequent ingestion of some of the released byproduct material, and (3) a misplaced or lost source in the folds of a desk chair.

In the case of a laboratory fire, the generic accident methodology developed in Appendix A.1 is applied. Potential doses from a laboratory fire can be estimated using dose-to-source ratios for a residence and correcting for different volumes and air exchange rates. Inhalation and submersion doses for a laboratory fire are essentially equal to those for a residential fire, whereas resuspension doses are approximately three times greater for the laboratory. It is assumed here that only a single source is involved and that the release fraction is 0.1%. Based on these assumptions and the generic accident methodology in Appendix A.1, the estimates of individual dose are summarized as follows:

- For a firefighter who wears a respirator at a laboratory fire, the EDE would be less than $1 \times 10^{-5}$ mSv (<0.001 mrem) from a single 0.37 MBq ($10^{-6}$ Ci) $^{60}$Co source, a single 37 kBq ($1 \times 10^{-4}$ Ci) $^{90}$Sr source, a single 3.7 MBq ($100 \times 10^{-6}$ Ci) $^{137}$Cs source, or a single 3.7 MBq ($100 \times 10^{-6}$ Ci) $^{204}$Tl source.

- For a worker who is involved in the cleanup following the fire and who does not wear a respirator, the EDE could be less than $1 \times 10^{-5}$ mSv (<0.001 mrem) for all sources.

In the case of accidents or misuse involving the crushing or rupture of a loose calibration or reference source, the potential doses to the user of the source and to a waste collector were considered. To estimate the potential dose to the user of the source, the generic accident methodology developed in Appendix A.1 is applied for ingestion of radioactivity following a spill of a radioactive material in the form of a powder. First, it is assumed that 10% of the material is deposited on the skin of an individual and, second, that 0.1% of this deposited material would be ingested before bathing removed the material from the body. Based on these assumptions and the generic accident methodology of Appendix A.1 (see Table A.1.8), the individual dose to a user could be about $3 \times 10^{-4}$ mSv (0.03 mrem) for a 0.37-MBq ($10^{-6}$ Ci) source of $^{60}$Co, $1 \times 10^{-4}$ mSv (0.001 mrem) for a 37-kBq ($1 \times 10^{-4}$ Ci) source of $^{90}$Sr/$^{90}$Y, 0.005 mSv (0.5 mrem) for a 3.7-MBq ($100 \times 10^{-6}$ Ci) source of $^{137}$Cs/$^{137m}$Ba, and $3 \times 10^{-4}$ mSv (0.03 mrem) for a 3.7-MBq ($100 \times 10^{-6}$ Ci) source of $^{204}$Tl.

To estimate the radiation dose to a waste collector, the generic disposal methodology in Appendix A.2 (see Table A.2.1) is used. Because the dose-to-source ratios are divided by the number of landfills in the United States, the first thing to do is multiply by 3500 (i.e., the estimated number of U.S. landfills), then by the amount of activity in the various sources. Thus, the potential individual dose to a waste collector from both ingestion and inhalation of byproduct material from a crushed source would be less than $1 \times 10^{-5}$ mSv (<0.001 mrem) for a 0.37-MBq ($10^{-6}$ Ci) source of $^{60}$Co, a 37-kBq ($1 \times 10^{-4}$ Ci) source of $^{90}$Sr/$^{90}$Y, a 3.7-MBq ($100 \times 10^{-6}$ Ci) source of $^{137}$Cs/$^{137m}$Ba, or a 3.7-MBq ($100 \times 10^{-6}$ Ci) source of $^{204}$Tl.
In the case of a misplaced or lost source in the folds of a desk chair, it is assumed that an individual sits in the desk chair for 20 hours before the source is retrieved from the chair, and that the distance from the source to the surface of the body is about 1 cm during this time. Based on calculations with MicroShield (Computer Codes, Grove Engineering, 1996), the EDE rates from photon irradiation of the whole body are estimated to be $9 \times 10^{-5}$ mSv/h (0.009 mrem/h) and 0.02 mSv (2 mrem/h) for the 3.7-MBq (100-$\mu$Ci) sources of $^{204}$Tl and $^{137}$Cs/$^{137m}$Ba, respectively. Dose equivalent rates from photon irradiation of the skin are estimated to be 0.005 mSv/h (0.5 mrem/h) and 3 mSv/h (300 mrem/h) for the 3.7-MBq (100-$\mu$Ci) source of $^{204}$Tl and $^{137}$Cs/$^{137m}$Ba, respectively. In addition, the dose equivalent rate from beta-particle irradiation of the skin by a 3.7-MBq (100-$\mu$Ci) source of $^{204}$Tl over an area of 10 cm² is estimated to be 0.26 Sv/h (26 rem/h), based on calculations using VARSKIN MOD2 (Computer Codes, Durham, 1992).

The dose equivalent rates to skin are from calculations for a separation distance of 1 cm between the source and skin and a 0.7 mm cloth cover with a density of 0.4 g/cm². The EDE rates are from calculations at a body depth of 10 cm, which is considered a reasonable approximation for the average depth of the body organs relative to a small source on the surface of the body. (Refer to modeling in Appendix A.4). Because of the small area of skin irradiated by a small source on the body's surface, the contribution of the skin dose to the EDE is quite small. Assuming an exposed area of 10 cm² and a skin weighting factor of 0.01, the EDE is estimated to be 0.03 mSv (3 mrem) and 0.4 mSv (40 mrem) for the $^{204}$Tl and $^{137}$Cs/$^{137m}$Ba sources, respectively. However, the dose equivalent to a small area of skin on the body's surface could be as much as 60 mSv (6 rem) for the $^{137}$Cs/$^{137m}$Ba source and 5 Sv (500 rem) for the $^{204}$Tl source, assuming minimal shielding by articles of clothing or other materials between the source and skin surface.

4.5.6 Summary

Results of the assessment of potential doses for an exemption involving calibration and reference sources either internal to a device or loose are presented in Tables 4.5.3 and 4.5.4. It is assumed that an exemption would allow some calibration and reference sources (either loose or internal to a device) to contain as much as 10 times a quantity of a byproduct material as defined in 10 CFR 30.71, Schedule B. For devices with internal sources, the limit of 10 times a quantity is assumed to apply to both the individual sources and the total within a device.

In the case of internal sources in devices, estimated doses are based on typical designs for devices distributed under the requirements applicable to distributors and applicants for license to distribute such devices for use under 10 CFR 31.5. The details of the designs are important in ensuring control of exposure. For the radiation doses resulting under an exemption of these devices to be comparable to those estimated, similar controls over the distributors would be necessary to ensure that the designs are comparable in minimizing exposures to users and members of the public. Removal of some requirements of a general license would not be likely to significantly increase the number of thermoluminescent dosimetry readers and liquid scintillation counters that are distributed annually because the specialized application of the devices is assumed to be the limiting factor. However, the amount of byproduct material distributed annually under this proposed exemption for sources internal to a device may increase because some devices may incorporate sources containing 10 times the quantity of a byproduct material such as $^{14}$C or $^{133}$Ba.
The annual EDEs to individuals from internal sources in devices could be 0.02 mSv (2 mrem) for distribution and transport, 0.02 mSv (2 mrem) for routine use, and $6 \times 10^{-5}$ mSv (0.006 mrem) for disposal in landfills or by incineration. For all of these activities combined, the collective EDE to all users and members of the public could be 0.02 person-Sv (2 person-rem). This collective dose estimate assumes the annual distribution data in Table 4.5.1 and an effective lifetime of 10 years for devices containing $^{133}$Ba or $^{152}$Eu and 15 years for devices containing $^{14}$C. For accidents involving fire, the individual EDE could be less than $1 \times 10^{-5}$ mSv (<0.001 mrem). For misuse of an internal source in a device during repair or attempted modification of a device by an unqualified individual, the EDE could be 0.2 mSv (20 mrem). Also, the estimated dose equivalent to the hands from misuse during repair or attempted modification of a device by an unqualified individual could be 4 mSv (400 mrem).

The assessment suggests that the quantity of a long half-life radionuclide commonly used in either calibration or reference sources is determined primarily from considerations of the internal dose due to inhalation (see Section 2.13.1), and the external dose rate from a single quantity of a long half-life radionuclide is typically less than 0.01 mSv/h (<1 mrem/h) at a distance of 10 cm and less than 0.1 mSv/h (<10 mrem/h) at 10 cm from a source containing 10 quantities as specified in Schedule B (see Section 4.5.1). For example, the dose equivalent rate at 10 cm from a source containing 10 quantities of $^{155}$Eu is about 0.004 mSv/h (0.4 mrem/h). Sources are already being distributed under the general license granted in 10 CFR 31.5 that contain 20 times the quantity of $70$ kBq (1 $\mu$Ci) for $^{152}$Eu (see Section 4.5.2.2).

In the case of loose calibration or reference sources, the sources will probably be shipped and stored in containers that provide some protection against photons from the sources. No credit is taken, however, for any shielding against photons from the sources in the current dose estimates. As a result, individual and collective dose estimates for distribution and transport and for routine use of these loose calibration and reference sources will be conservative.

The annual EDEs to individuals from loose calibration and reference sources could be 0.01 mSv (1 mrem) for distribution and transport, 0.3 mSv (30 mrem) for routine use of a single source, and $8 \times 10^{-4}$ mSv (0.08 mrem) for disposal in landfills or by incineration. For all of these activities combined, the collective EDE to all users and members of the public could be 0.3 person-Sv (30 person-rem). This collective dose estimate assumes the annual distribution data in Table 4.5.2 and an effective lifetime of 5 years for sources containing either $^{60}$Co or $^{204}$Tl and 15 years for sources containing either $^{90}$Sr/$^{90}$Y or $^{137}$Cs/$^{137}$mBa. For accidents and misuse, it is estimated that the individual EDE from a lost or misplaced source could be 0.4 mSv (40 mrem) and that the dose equivalent to a small area of skin on the individual's whole body from the lost or misplaced source could be 5 Sv (500 rem).

The assessment also suggests that such an exemption may not provide enough protection in limiting exposure to loose calibration or reference sources for a couple of reasons. First, the EDE during routine use could be greater than 0.3 mSv (30 mrem) if multiple sources were stored essentially without shielding in locations occupied by an individual during a substantial part of the year. By invoking conservative assumptions about exposure conditions that could occur only in unusual circumstances, the annual EDE from exposure to either single or multiple sources during routine use could approach or exceed 1 mSv (100 mrem) (see Section 4.5.5.2). An annual EDE of 1 mSv (100 mrem) is equivalent to the annual dose limit for a member of the public under the requirements of 10 CFR 20.1301. Second, such an exemption fails to control the dose equivalent rates from sources of beta particles during routine use (see Section

4–71
or misuse (see Section 4.5.5.4), and a lost or misplaced source could deliver a dose equivalent of several Sv (several hundred rem) to a small area of the skin on the whole body (see Section 4.5.5.4). Such a skin dose could cause minor radiation burns to the skin if delivered over a short time (Potten, 1985).
### Table 4.5.1 Estimated Annual Distribution of Calibration and Reference Sources Contained Internal to Devices

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Devices/yr</th>
<th>$\mu$Ci/device$^b$</th>
<th>$\mu$Ci/yr$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{14}$C</td>
<td>80</td>
<td>1,000</td>
<td>80,000</td>
</tr>
<tr>
<td>$^{133}$Ba</td>
<td>600</td>
<td>100</td>
<td>60,000</td>
</tr>
<tr>
<td>$^{152}$Eu</td>
<td>25</td>
<td>10</td>
<td>2,500</td>
</tr>
</tbody>
</table>

$^a$ See Section 4.5.2.

$^b$ 1 $\mu$Ci = 0.037 MBq.

### Table 4.5.2 Estimated Annual Distribution of Loose Calibration and Reference Sources

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Sources/yr</th>
<th>$\mu$Ci/source$^b$</th>
<th>$\mu$Ci/yr$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{60}$Co</td>
<td>90</td>
<td>10</td>
<td>900</td>
</tr>
<tr>
<td>$^{90}$Sr</td>
<td>20</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>$^{137}$Cs</td>
<td>400</td>
<td>100</td>
<td>40,000</td>
</tr>
<tr>
<td>$^{204}$Tl</td>
<td>20</td>
<td>100</td>
<td>2,000</td>
</tr>
</tbody>
</table>

$^a$ See Section 4.5.2.

$^b$ 1 $\mu$Ci = 0.037 MBq.
<table>
<thead>
<tr>
<th>Exposure Pathway</th>
<th>Individual Annual Effective Dose Equivalent (mrem)a</th>
<th>Collective Effective Dose Equivalent (person-rem)b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution and transport</td>
<td>2c</td>
<td>0.1</td>
</tr>
<tr>
<td>Routine use</td>
<td>2d</td>
<td>2</td>
</tr>
<tr>
<td>Disposal as ordinary waste</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landfills</td>
<td>0.06e</td>
<td>0.05</td>
</tr>
<tr>
<td>Incinerators</td>
<td>0.06f</td>
<td>0.006</td>
</tr>
<tr>
<td>Accidents and misuse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accidents involving fire</td>
<td>&lt;0.001g</td>
<td></td>
</tr>
<tr>
<td>Repair by unqualified person</td>
<td>20h</td>
<td></td>
</tr>
</tbody>
</table>

a 1 mrem = 0.01 mSv; 1 person-rem = 0.01 person-Sv.
b Collective doses over effective lifetime of product for 1 year’s distribution. Refer to text for time period of collective dose assessment.
c Dose estimate applies to an express-delivery driver; dose estimates would be less for other local parcel-delivery drivers, terminal workers, and members of the public (see Section 4.5.4.1).
d Dose estimate applies to an operator of a device containing a generic source with a dose rate of 0.1 mSv/h (10 mrem/h) at a distance of 10 cm; dose estimates are for operators using devices with $^{14}$C, $^{133}$Ba, or $^{152}$Eu sources and for other persons casually exposed to these devices (see Section 4.5.4.2).
e Dose estimate applies to waste collectors at landfills; dose estimates are less for workers at landfills, off-site members of the public, and future on-site residents at landfills (see Section 4.5.4.3.1).
f Dose estimate applies to waste collectors at incinerators; dose estimates are less for workers at incinerators and off-site members of the public near incinerators (see Section 4.5.4.3.2).
g Dose estimate applies to all individuals for a laboratory or transportation fire. (See Section 4.5.4.4).
h Dose estimate applies to a generic source with a dose rate of 0.1 mSv/h (10 mrem/h) at a distance of 10 cm and to whole-body irradiation of an unqualified person who removes source from a device in an attempt to repair or modify device; dose estimate for irradiation of hands during repair or modification of devices by an unqualified person is 4 mSv (400 mrem) (see Section 4.5.4.4).
Table 4.5.4 Potential Radiation Doses From Loose Calibration and Reference Sources

<table>
<thead>
<tr>
<th>Exposure Pathway</th>
<th>Individual Annual Effective Dose Equivalent (mrem)(^a)</th>
<th>Collective Effective Dose Equivalent(^b) (person-rem)(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution and transport</td>
<td>1(^c)</td>
<td>0.1</td>
</tr>
<tr>
<td>Routine use</td>
<td>30(^d)</td>
<td>30</td>
</tr>
<tr>
<td><strong>Disposal as ordinary waste</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landfills</td>
<td>0.06(^e)</td>
<td>0.2</td>
</tr>
<tr>
<td>Incinerators</td>
<td>0.08(^f)</td>
<td>0.006</td>
</tr>
<tr>
<td><strong>Accidents and misuse</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accidents involving fire</td>
<td>&lt;0.001(^g)</td>
<td></td>
</tr>
<tr>
<td>Crushing of a source</td>
<td>0.5(^h)</td>
<td></td>
</tr>
<tr>
<td>Misplaced or lost source</td>
<td>40(^i)</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) 1 mrem = 0.01 mSv; 1 person-rem = 0.01 person-Sv.
\(^b\) Collective doses over effective lifetime of source for 1 year’s distribution. Refer to text for time period of collective dose assessment.
\(^c\) Dose estimate applies to an express-delivery driver; dose estimates are for other local parcel-delivery drivers, terminal workers, and members of the public (see Section 4.5.4.1).
\(^d\) Dose estimate for external irradiation of whole body by photons from a single source; depending upon particular byproduct material, annual individual dose could be as much as 0.3 mSv (30 mrem). Higher annual photon doses could result from exposure to multiple sources, and more pessimistic, but relatively unlikely, assumptions about exposure conditions to either single or multiple sources could result in annual photon doses approaching or exceeding 1 mSv (100 mrem). Annual beta-particle doses to hands of an individual could be as much as 10 mSv (1 rem) if an individual handles a source with forceps and as much as 1 Sv (100 rem) or more if a person handles a source without forceps (see Section 4.5.5.2).
\(^e\) Dose estimate applies to waste collectors at landfills; dose estimates are less for workers at landfills, off-site members of the public, and future on-site residents at landfills (see Section 4.5.4.3.1).
\(^f\) Dose estimate applies to all individuals for a laboratory fire (see Section 4.5.4.3.2).
\(^g\) Dose estimate applies to workers involved in cleanup following a laboratory fire; dose estimates for firefighters at a laboratory fire would be less (see Section 4.5.5.4).
\(^h\) Dose estimate applies to a user who ingests byproduct material from a crushed or ruptured source; dose estimates for ingestion or inhalation of byproduct material from a crushed or ruptured source by a waste collector are substantially less (see Section 4.5.5.4).
\(^i\) Dose estimate applies to whole-body irradiation of a person from a misplaced or lost \(^{137}\)Cs source in the folds of a desk chair; dose estimates for a small area of skin on the whole body are 60 mSv (6 rem) from a \(^{137}\)Cs source and 5 Sv (500 rem) from a \(^{204}\)Tl source (see Section 4.5.5.4).