

Using the Radium Thumb Rule

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Introduction

Like bad pennies, ^{226}Ra sources keep turning up. Scrap and waste dealers especially have to be vigilant to not accept a load containing a radium source. State regulators have taken the position that whoever is found to be in possession of the source is responsible for its disposal. And disposal isn't cheap! This article provides a method for determining the quantity of radium present in a source by measuring the exposure rate at a given distance. Then, using the "Radium Thumb Rule,"¹ the activity can be calculated based on this measurement. Determination of activity present is for purposes of shipping and disposing the source, since the activity is rarely indicated on the source itself.

Assumptions

Since most of these radium sources are old, we can assume the ^{226}Ra and all its daughter products are in equilibrium. The thumb rule assumes that a radium source under consideration has fully equilibrated. See Tables 1 and 2 for more information on ^{226}Ra and its daughters. It is worth noting that the ^{226}Ra itself emits only a small percentage of the radiation generally attributed to a "radium" source. The photon energies and yields for the radium daughters are not provided in this article, but are available from other sources.

Table 1. Radium-226 and daughter products.

Name	Modern Symbol	Historical Name	Half-Life
Radium-226	Ra-226	Radium	1600 years
Radon-222	Rn-222	Emanation Radon	3.82 days
Polonium-218	Po-218	Radium A	30.5 min
Lead-214	Pb-214	Radium B	26.8 min
Bismuth-214	Bi-214	Radium C	19.9 min
Polonium-214	Po-214	Radium C' (C Prime)	163.7 μ seconds
Thallium-210	Tl-210	Radium C'' (C Double Prime)	1.3 min
Lead-210	Pb-210	Radium D	22.26 years
Bismuth-210	Bi-210	Radium E	5.013 days
Polonium-210	Po-210	Radium F	138.38 days
Thallium-206	Tl-206	Radium E'' (E Double Prime)	4.20 min
Lead-206	Pb-206	Radium G	Stable

¹ *The Health Physics and Radiological Health Handbook*, Revised Edition, page 58. Scinta, Inc., Silver Spring, MD, 1992.

Table 2. ²²⁶Ra photon energies and fractional yields (f). Note the most predominant photon is 186 keV with only a 3.28% yield.

E (MeV)	Yield (f)
0.3097	6.7E-5
0.18621	0.0328
0.0949	0.001357
0.08378	0.002994
0.08107	0.001802
0.0117	0.008022

Since the original definition for the Curie was the activity in 1 gram of pure radium-226, we can still assume that 1 gram of radium equals 1 Curie of radium.²

The ²²⁶Ra Thumb Rule

The ²²⁶Ra thumb rule for a point source of radium-226 is:

$$\text{mR/h} = \frac{8400 \text{ a}}{d^2},$$

Where:

mR/h = exposure rate from ²²⁶Ra
 a = mass (or activity) of ²²⁶Ra in mg
 (or mCi)

and d = source-to-detector distance in cm.

Solving the equation for the unknown (mg), it ends up looking like this:

$$\frac{\text{mR/h} \times d^2}{8400} = \text{mass of } ^{226}\text{Ra in mg.}$$

² The actual specific activity of ²²⁶Ra is slightly different due to a more precise half-life measurement that was made after Marie Curie defined the curie. But it rounds off to 1 Ci/gm.

This thumb rule is derived from the more familiar³

$$\frac{0.53 C E n}{d^2}$$

Where:

C = Activity in Ci

E = Photon energy in MeV

n = photon yield per disintegration

and d = source-to-detector distance in meters.

Someone calculated the energy times the yield for all the ²²⁶Ra photons and all the daughters,⁴ accounted for the 0.53 factor, and converted the distance unit to cm. Exactly how this was done is beyond the scope of this article, but the Radium Thumb Rule has been used successfully for many years.

Instrument Selection

The best instrument to use for this measurement is an ionization chamber with the “beta window” open. A Bicron RSO-5, used to make the measurements for this article, is shown in Figure 1. The term “beta window” in this application is a misnomer. We are measuring gamma radiation (not beta) to apply the thumb

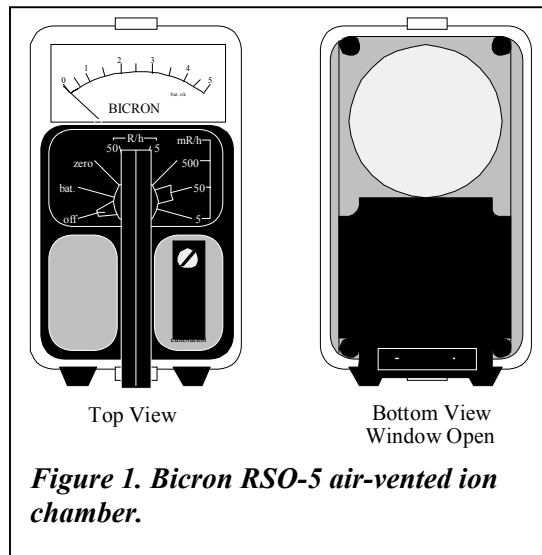


Figure 1. Bicron RSO-5 air-vented ion chamber.

³ *The Health Physics and Radiological Health Handbook, Revised Edition*, page 58. Scinta, Inc., Silver Spring, MD, 1992.

⁴ $(\sum E_{\gamma i} \cdot n_{\gamma i})$ for all ²²⁶Ra and all daughter photon energies and yields.

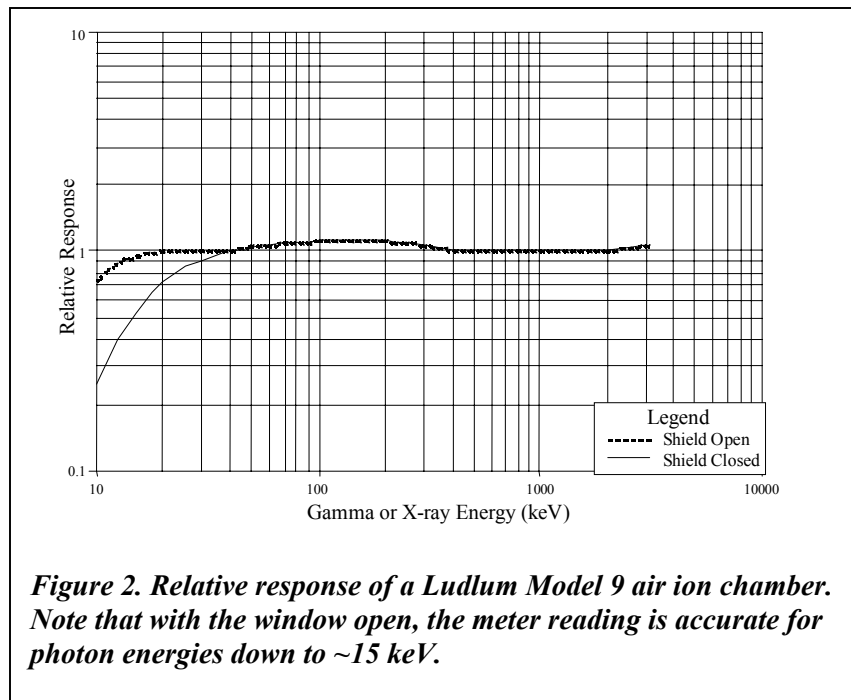
rule, and ion chambers have the best relative response⁵ characteristics of all the gas-filled detectors. This means that they don't read higher than the actual exposure rate in a certain photon energy range as standard Geiger-Mueller detectors do. Figure 2 shows a relative response curve for a typical ion chamber. Compare this to a typical G-M relative response in Figure 3, and to that of a sodium iodide micro-R meter in Figure 4.

The key here is to measure the maximum number of photons from the source by opening the window on the ion chamber, but also to eliminate or limit the number of betas that get to the detector. The thumb rule is based on photon response only. Therefore, we need to place the detector close enough to the source to minimize air attenuation of the numerous low-energy photons coming from ²²⁶Ra and its daughters, but not so close as to get significant beta response. See the results of the measurements below taken at varying distances.

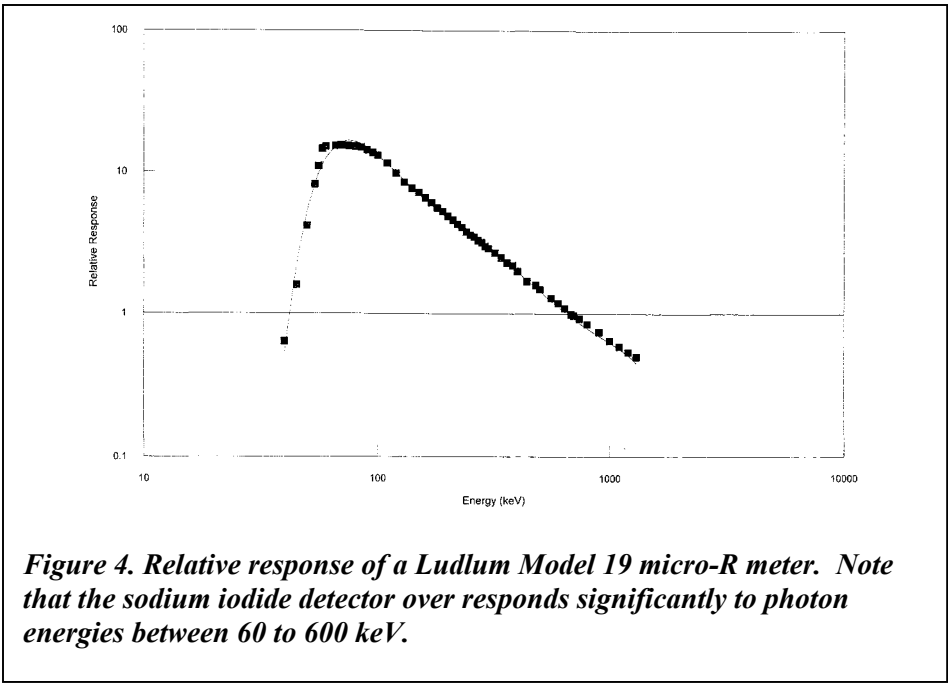
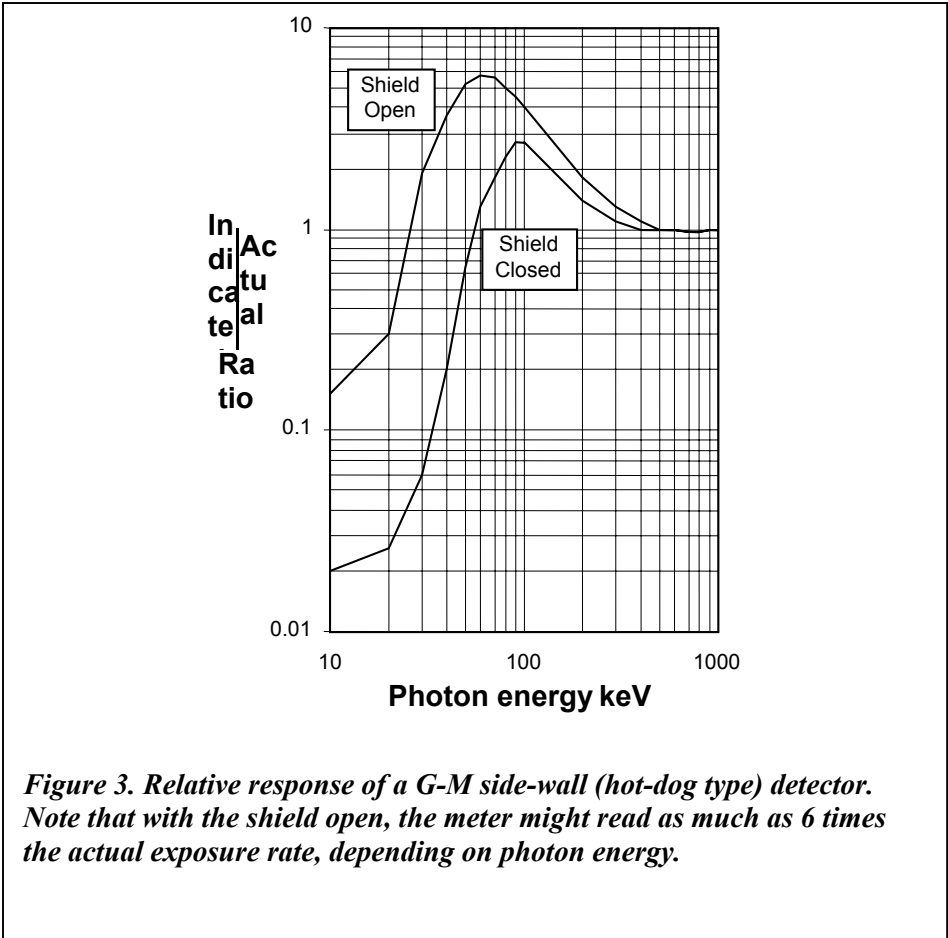
Survey Method

First, many of these radium sources are long and narrow and therefore, do not really meet the definition of a point source. Since the ²²⁶Ra thumb rule described above works *only* for point sources, some considerations need to be made in your survey method to emulate a point source. The easiest way is to measure the length of the source (L), and establish your source-to-detector measurement distance a minimum of one half that length $\left(\frac{L}{2}\right)$. If this is the case, a line source will emulate a point source and the equation should hold true.

Second, the source-to detector distance measurement must be made from the detector centerline to the source, not from the instrument case or from the face of the open detector window. The detector centerline is indicated on most ion chamber detectors by scribe marks or by dimples in the case.



⁵ Relative response is the indicated exposure rate divided by the true exposure rate. A 1.0 relative response is perfect.



Example

Calculate the exposure rate from a point source of a known quantity of ^{226}Ra (mg or mCi) that is in equilibrium with its daughters.

Solution for Activity Based on Exposure Rate

I made measurements on a ^{226}Ra source that was approximately 6 inches (15.24 cm) long using a calibrated Bicon RSO-5 ion chamber with the window open. The results obtained are given in Table 3.

Using the thumb rule from the previous page, I calculated the activity based on the readings at 6", 12" and 24" with the following results:

At 6 inches (15.24 cm)

$$\frac{(18) \times (15.24)^2}{8400} = \text{mg}$$

$$\frac{(18) \times 323.26}{8400} = \frac{4180.64}{8400} = 0.498 \text{ mg}$$

At 12 inches (30.48 cm)

$$\frac{(5) \times (30.48)^2}{8400} = \text{mg}$$

$$\frac{(5) \times 929}{8400} = \frac{4645.15}{8400} = 0.55 \text{ mg}$$

At 24 inches (60.96 cm)

$$\frac{(0.8) \times (60.96)^2}{8400} = \text{mg}$$

$$\frac{(0.8) \times 3716.12}{8400} = \frac{2972.9}{8400} = 0.35 \text{ mg}$$

Source-to-Detector CL Distance (inches)	Source-to-Detector CL Distance (cm)	mR/h
6"	15.24	18
12"	30.48	5
24"	60.96	0.8

Table 3. Gamma radiation measurements from a ^{226}Ra source.

Note that the calculated activity at 6 and 12 inches are in reasonably good agreement, which indicates that 6 inches of air is sufficient to attenuate the bulk of the beta emissions from the radium daughters. The approximately 35% decrease in calculated activity between 12 inches and 24 inches, however, illustrates the attenuation of some of the lower energy photons by the air between the source and the detector. The inverse square thumb rule, and this radium thumb rule, assume that there is *NO* air attenuation. The exponential reduction in exposure rate as distance increases is due to geometry, not any shielding provided by the air. This is a reasonable assumption when photon energies are moderate or high, but a fair number of ^{226}Ra and its daughters emit relatively low-energy photons. The lower photon energy is, the greater the likelihood of their interacting in whatever material they are passing through (i.e., air). Since with an equilibrated radium source we are starting out with a good number of low-energy gammas, the inverse square rule will underestimate calculated activities. And as distance increases this becomes more apparent.

Actual activity of this example source is judged to be approximately 0.6 mg ^{226}Ra . This is accurate enough to obtain disposal price quotes and to complete the shipping documents.

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