NORM Measurements

Round Table 225

Controlling NORM Hazards

(Naturally Occurring Radioactive Material)

AIHce, Montreal, Canada

Tuesday, May 21, 2013,   2 – 5 PM

Presented by

Ray Johnson, MS, SE, PE, FHPS, CHP

Director

Radiation Safety Counseling Institute
16440 Emory Lane
Rockville, MD 20853
ray@radiationcounseling.org
301-370-8573

Abstract

NORM Measurements*

Ray Johnson, MS, SE, PE, FHPS, CHP,
Director, Radiation Safety Counseling Institute,
16440 Emory Lane, Rockville, MD 20853
301-370-8573. ray@radiationcounseling.org

Measurements for Naturally Occurring Radioactive Materials can be difficult for many reasons, including: 1) most radiation instruments in common use by industrial hygienists are calibrated in response to cesium-137 at 662 keV. The primary radioactive materials in NORM are part of the uranium-238 decay chain and potassium-40. These materials emit gamma energies from about 100 keV to about 1,500 keV. Instruments such as Geiger Counters (GM) and Sodium Iodide (NaI) scintillators do not respond well to this range of energies. 2) All radioactive materials in NORM also emit beta particles. Thus open window GM, ion chambers, or plastic scintillators will over respond by as much as 95% when taking readings of exposure in milliroentgen per hour (mR/hr) due to beta interference. The best measurements of NORM will use an instrument calibrated for radium-226 and all measurements for mR/hr should be sure to shield out all beta particles. Data will show how a variety of common radiation instruments respond to several sources of NORM.

- Raymond H. Johnson, ***Radioactivity in Granite Countertops***, Chapter 10 in Naturally Occurring Radioactive Material (NORM) and Technologically Enhanced NORM (TENORM), Edt. by P. Andrew Karam and Brian J. Vetter. A textbook for the Health Physics Society Professional Development School, Minneapolis, MN July 16-18, 2009. Medical Physics Publishing, Madison, WI.

NORM MEASUREMENTS

RT 225
AIHce, Montreal, Canada
Tuesday, May 21, 2013

Ray Johnson, MS, SE, PE, FHPS, CHP
Director
Radiation Safety Counseling Institute
ray@radiationcounseling.org

Do You Really have a NORM Hazard ?

- Do you work with materials coming from the ground ?
  - Everything from the ground has NORM
- How do you measure NORM ?
- Do you have the right instrument ?
- Is it calibrated properly ?
- Are you using it properly ?
- What do the measurements mean ?
- How can your instruments mislead you ?

Radiation Safety Counseling Institute 2

NORM Measurements - Difficulties

- 1. Calibration error
  - Calibration for Cs-137 at 662 keV
  - vs NORM gamma energies at 100 – 1,500 keV
  - Geometry errors
- 2. Beta particle interference
  - Meters that include beta, may over respond by 95 % for mR / hr

Radiation Safety Counseling Institute 3

Choice of Instruments ?

- Factors to consider
  - Activity or exposure ?
  - What is measured ? α, β, γ
  - Sensitivity ?
  - Speed ?
  - Ruggedness ?
  - Cost ?
  - Calibration ?
  - Proper use ?

Radiation Safety Counseling Institute 4

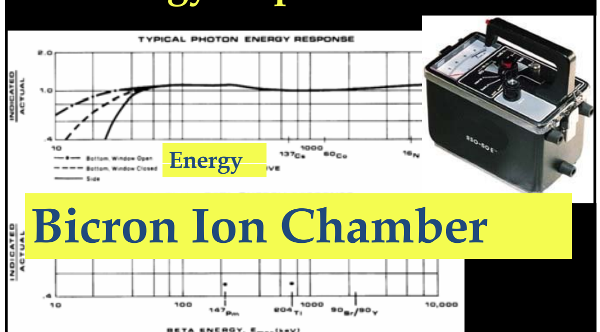
Calibration Errors

- Energy dependence
  1. Most meters are calibrated for Cs-137 at 662 keV
  2. Most gammas from NORM – Ra decay products

Isotope	Energy	%
Pb-214	295	19
	352	36
Bi-214	609	47
	1,120	15
	1,765	16
	2,204	5

Radiation Safety Counseling Institute 5

Energy Dependence



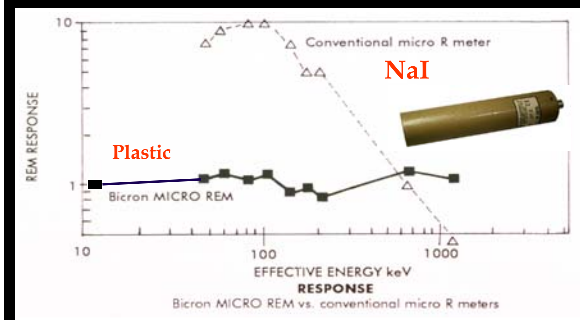
Radiation Safety Counseling Institute 6

Ion Chambers

- Ionization in air
- Good for X – and γ - rays
- True measure of "exposure" in units of Roentgen, R, mR, μR (normal is 10 μR / hr)
- No audio
- Slow, erratic, not very sensitive
  - Only use when you know the source
- Standard and Pressurized

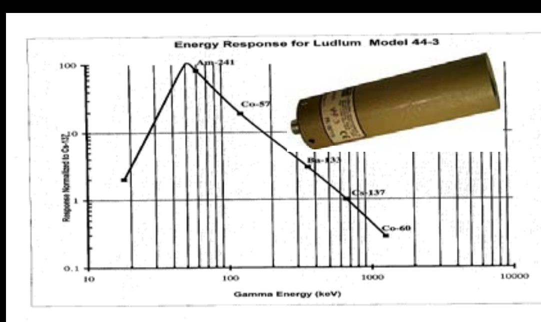
Radiation Safety Counseling Institute 7

NaI and Plastic Scintillator Response



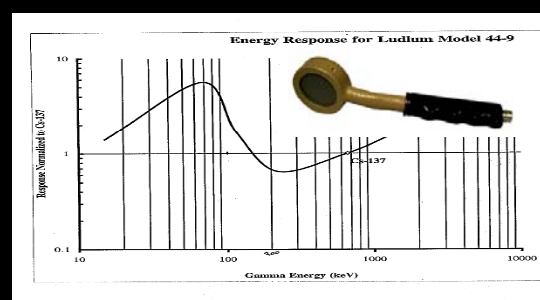
Radiation Safety Counseling Institute 8

Thin Window – Thin NaI



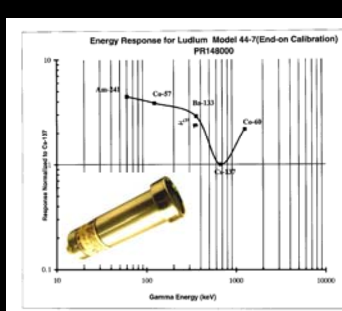
Radiation Safety Counseling Institute 9

Pancake GM



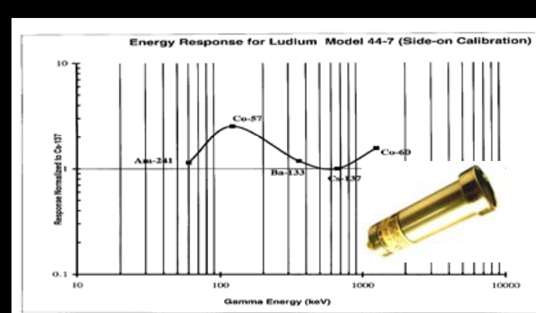
Radiation Safety Counseling Institute 10

Response from End of End-Window GM



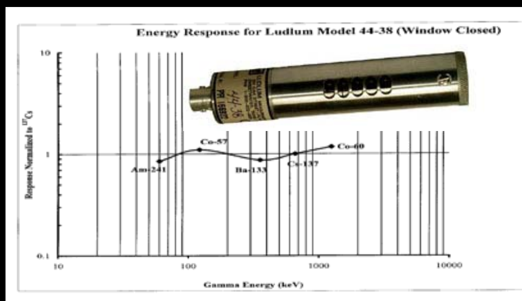
Radiation Safety Counseling Institute 11

Response from Side of End-Window GM



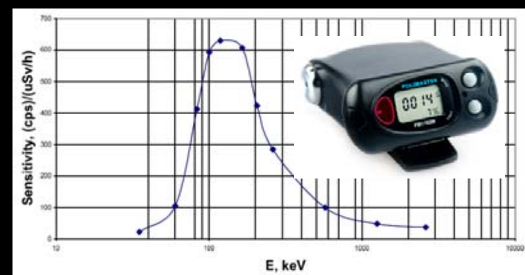
Radiation Safety Counseling Institute 12

Energy Compensated – Model 44-38 Thin Wall GM - Window Closed



Radiation Safety Counseling Institute 13

PM 1703 M



Radiation Safety Counseling Institute 14

Scintillation Detectors

- Common to use 1 x 1 inch NaI
  - Ludlum Model 19, Micro R meter
- Also in use, Thermo Fisher Scientific
  - PM 1703M
  - Small CsI detector
- Will over respond to energies < 662 keV

Radiation Safety Counseling Institute 15

Beta Interference for mR / hr

- Pancake GM used for granite countertops
  - Measurements in air ?
  - Measurements on granite ?
  - Report readings 10 x – 100 x background ?
- What is the problem here ?
- Effects of beta interference ?
- What to do ?
- Shield to block beta signal

Radiation Safety Counseling Institute 16

Inappropriate use of GM Detectors

- Granite Measurements
  - Pan GM used for exposure readings
  - In air – measure cosmic and terrestrial gamma
  - In contact – measure mainly beta
  - Interpreted as exposure in mR / hr
  - Reported as multiples of background
- Easy to misinterpret - since GM detectors have mR / hr and cpm scales
- Need beta shield

Radiation Safety Counseling Institute 17

Instrument Comparison (see Table 3)

- Noted large differences when beta included or blocked
  - GM from 3 x to 100 x with beta
  - Ion chamber from 3 x to 10 x higher
- PIC and plastic gave similar readings
- Readings in contact vs 30 cm
  - 5 to 25 x higher

Radiation Safety Counseling Institute 18

Choice of Instruments for NORM

- NaI – fast, sensitive, fragile, expensive
  - May over respond relative to Cs-137
- Plastic – fast, sensitive, fragile, expensive
  - Energy independent
- Ion chamber – slow, insensitive, erratic
  - Pressurized is more sensitive, energy independent
- Sidewall GM – sensitive, rugged, cheap
  - energy independent
- End Window GM – sensitive, rugged, cheap
  - Energy dependent end window

Better Instruments

- Sidewall GM, window closed
  - Metal housing will block beta signal
- Plastic scintillator
  - Not low range option, which will show beta
- MicroR meter may be close
  - Similar response of Ra-226 vs Cs-137
- Standard or pressurized ion chamber

Testing Protocols

- None published
- Great variation in testing procedures
- Variation in instruments, geometry
  - Measure distance to center of detector
  - Big differences for point sources
- Most people have used contact readings
  - To estimate risk
- Recommend 30 cm
  - I in. vs 12 in,
  - for point source, inverse square law, 1 / 144
- For ground measurements
  - 1 meter to represent whole body exposure

Misunderstanding NORM Measurements

- Radioactivity in Granite
  - According to measurements made:
  - Some say U is natural and small
  - Some report “hot spots,” tests needed ?
  - Some say they do not know, tests needed?
  - Nuclides of U-238, U-235, Th-232
    - Many beta emitters in decay chains
  - Internal exposures – not likely
  - Could be source of radon
    - AARST says not much, ground is greater

Perceptoions of Radioactivity in Granite

- Over 1,000 varieties and colors
  - Desirable for perceived quality and value
- Much questionable data

Media Reports

- What’s lurking in your countertop?
- Is your kitchen cooking you?
- It might heat up your cheerios!
- Public fears lead to removal of tops
- 100s of websites show
  - Misinformation / misunderstanding
- Misunderstandings abound due to -
  - Misinformation, measurement errors, different testing protocols, lack of understanding of health risks, and few guidelines for safety

More Information

- MARSSIM – Multi Agency Radiation Survey and Site Investigation Manual
  http://www.epa.gov/rpdweb00/marssim/obtain.html
- Egidi, Phil. "Characteristics of Routine Radiation Safety Measures of NORM and TENORM Nuclides," (Chapter 5, 43 pages) In: Naturally Occurring Radioactive Materials (NORM) and Technologically Enhanced NORM (TENORM). P. Andrew Karam and Brian J. Vetter, Editors. A Textbook for the Health Physics Society Professional Development School, Minneapolis, MN July, 16-18, 2009. Medical Physics Publishing, Madison, WI (549 pages).

Radiation Safety Counseling Institute 25

More Information

- ANSI N323-B (2003)
  - Installed Radiation Protection Instrumentation Test and Calibration - Portable Survey Instruments for Near Background Operation
- Glenn F. Knoll (2010)
  - Radiation Detection and Measurement

Radiation Safety Counseling Institute 26

Radioactivity in Granite Countertops*

Ray Johnson, MS, SE, PE, FHPS, CHP
VP Training Programs, Dade Moeller & Associates

A New York Times article in July 2008 was titled "What's Lurking in Your Countertop" (Murphy 2008)? Should your beautiful granite countertop come with a radiation warning? "Just when you thought it was safe to cook in your kitchen, it turns out your kitchen may be cooking you" (Detrick 2008). "Its not that all granite is dangerous, but I've seen a few that might heat up your Cheerios a little" (Murphy 2008). News media across the country publicized the dangers of radon and radioactivity in granite countertops during 2008. As a result some homeowners have had their countertops removed and replaced with other materials at an expense of many thousands of dollars. A web search on the words "radioactivity in granite" yielded 120,000 hits. Only about 100 were reviewed for this article, but that was enough to show that misinformation and misunderstanding abound.

Since concerns for radioactivity in granite countertops have become a matter of considerable public interest over the past year, a review of incidental NORM would be incomplete without at least some discussion of this matter. The following material is not intended to be an in depth review, but rather it is intended to touch on some highlights that health physicists and others may want to know more about. In particular, I would like to address 1) misinformation and misunderstanding of radioactivity in granite, 2) measurements, 3) testing protocols, 4) health risks, and 5) guidelines for safety.

Radioactivity in Granite

Ethington and Karam have noted that much of what is sold as "granite" is not a true granite as defined by a geologist (Ethington 2009, Karam 2009). Apparently the countertop industry calls any durable igneous or crystalline rock "granite." Granite is characterized by a coarse grained crystalline structure formed by the cooling of molten magma from deep within the earth as it intrudes into surface rocks. The chemical makeup of most of the rock called granite is primarily: oxides of silica (Si), aluminum, (Al), potassium (K), sodium (Na), calcium (Ca), iron (Fe), magnesium (Mg), and oxygen (O). Of course, a small fraction of all potassium is radioactive K-40 (0.012%). Radioactive uranium (U), radium (Ra), and thorium (Th) are only trace elements. Also, since these radioactive elements are large ions, they remain in the melt and tend to be in the minerals that crystallize last, after the darker minerals have formed. Thus, a rough rule of thumb is that the lighter-colored rocks will tend to have the higher levels of radioactive elements. True granite - with elevated levels of U, Th, and K - is typically white, gray, or pink. Black "granite" is not a true (i.e. geological) granite and is not expected to have as much radioactivity. In this chapter any natural stone used for countertops will be called granite.

---

* **Radioactivity in Granite Countertops** (Chapter 10, 21 pages) In: Naturally Occurring Radioactive Materials (NORM) and Technologically Enhanced NORM (TENORM). P. Andrew Karam and Brian J. Vetter, Editors. A Textbook for the Health Physics Society Professional Development School, Minneapolis, MN July, 16-18, 2009. Medical Physics Publishing, Madison, WI (549 pages).

The fact that granite may contain trace amounts of the elements uranium, radium, thorium, and potassium is not news to health physicists. All materials which come from the ground typically contain these elements in varying amounts and this has been known for at least 70-80 years within our profession. However, what is common knowledge to us becomes alarming information for homeowners when they hear this for first time as the media proclaims the dangers of a popular household material, namely granite countertops. This information is especially unsettling for homeowners who hear the virtues of granite touted by builders, remodelers, and home designers on TV as a very desirable upgrade to increase the value of their homes. With over 1,000 varieties and colors to choose from, granite is now readily available all around the country and often selected by homeowners because of its desirable variety of colors and perceived quality and value.

All granite is radioactive. While all granite is radioactive to some extent, the amount varies widely according to where the granite came from and varying concentrations of the elements listed above. The content of these elements also varies a great deal even within a single slab of granite. A given piece of granite may easily have small spots of radiation readings that are 10 to 20 times higher than average across the stone. Unfortunately, much of the reported data are questionable because of the radiation instruments used, how the measurements were made, and how the data were interpreted. Therefore, there is not a lot of good radioactivity data published for granite. It appears that describing radioactivity in granite is equivalent to how the blind men each described an elephant differently according to the part they examined, see Figure 1.

Figure 1 - Six Blind Men Examine an Elephant

Reproduced by permission of John Robertson (Robertson 2009)

The Blind Men and the Elephant (Paraphrased from Saxe,1873)

It was six men of Indostan, to learning much inclined,
Who went to see the elephant, (though all of them were blind),
That each by observation, might satisfy his mind…
"It's very like a snake"

“It’s very like a spear”
“It’s very like a fan”
“It’s very like a tree”
“It’s very like a wall”
“It’s very like a rope”

And so these men of Indostan disputed loud and long,
Each in his own opinion, exceeding stiff and strong
Though each was partly in the right, and all were in the wrong.

Actually, the response of the six blind men is an issue for all of science. This could be called attention or perception blindness. Cognitively we are primed to look for data that support our theories (Simons 1999). While attending to one task we may miss really obvious things that we are not attentive to.

As with the six blind men, according to measurement data, some may say that homeowners do not need to be concerned for radioactivity in granite because it is naturally occurring and the amounts are small. Others will say they found a “hot spot” and all granite should be tested before purchase. Others may admit that they do not really know, which implies that homeowners should be cautious about choosing various types of granite.

The primary radiation emitted from granite countertops is due to radionuclides from the uranium-238 decay chain, including thorium-234, radium-226, and short lived decay products of radon-222, namely lead-214 and bismuth-214, and also potassium-40 as shown in Table 1.

Table 1 - Primary Radioactive Components of Granite

Nuclide	Alpha Energy keV	Alpha Abundance %	Beta Energy keV	Beta Abundance %	Gamma Energy keV	Gamma Abundance %
U-238	4,150	23				
	4,200	77				
Th-234			96	19	63	4
			189	73	92	6
Pa-234m			2,280	99		
Pa-234			up to1,260	22 betas	132	20
					570	11
					883	12
					926	11
					946	12
U-234	4,720	27				
	4,770	72				
Th-230	4,621	23				
	4,688	76				
Ra-226	4,600	6				

	4,780	94				
Rn-222	5,490	100				
Po-218	6,000	100				
Pb-214			670	48	295	19
			730	42	352	36
			1,030	6	786	1
Bi-214			1,420	8	609	47
			1,505	18	1,120	15
			1,540	18	1,765	16
			3,270	18	2,204	5
Po-214	7,687	100				
Pb-210			16	80		
			63	20		
Bi-210			1,161	100		
Po-210	5,305	100				
K-40			1,310	89	1,460	11

(Note: isotopes from the thorium-232 and uranium-235 decay chains may also be present in natural stone materials). The radiation of potential concern for external exposures from these radionuclides is primarily gamma radiation from Pa-234, Pb-214, and Bi-214. Gamma radiation is of concern because of its ability to penetrate the skin and body tissues. Many radionuclides in granite also emit beta particles including Th-234, Pa-234m, Pa-234, Pb-214, Bi-214, and Bi-210. In contrast to gamma radiation, however, beta particles are of less concern because they may be blocked by clothing, the skin, or a thin layer of tissue.

Internal exposures from ingestion of uranium, thorium, radium, or potassium are not very likely because these elements are not very soluble or removable in significant quantities from the granite surface. While several radionuclides in the decay chain of uranium-238 emit alpha particles, these are only of significance for either ingestion or inhalation. While ingestion is not likely, inhalation of radon and its short-lived decay products is a possibility.

Radon from Granite

Since all granite contains trace amounts of radium, then all granite may also be a source of radon. The concerns for radon in houses are addressed earlier in this book (Johnson 2009). The big question is how much radon may emanate from granite countertops? Because radon testing companies are routinely conducting radon measurements in homes, homeowners are asking them about the dangers of radon from granite countertops. The American Association of Radon Scientists and Technologists published a position statement on that issue (AARST 2008). This statement noted that “materials in buildings such as concrete, granite, slate, marble, sand, shale, and other stones can contain traces of radium that release radon with varying intensities.” However, radon from these sources will not usually cause high radon levels in a building. The soil beneath a house is the primary source for radon because of the enormous surface area of the ground in contact with the house. The next largest source of radon would likely be from the concrete used in the foundation, walls, and floors of buildings (Brodhead 2008).

Measurements of radon that may emanate from granite are not a reliable method to predict indoor radon levels, because of variations of radon emanation across the surface of granite, variable ventilation rates, and the large dilution volume of air in a house (AARST 2008).

Granite Measurements

Perhaps the greatest source of misinformation regarding radioactivity in granite is the result of the inappropriate use of radiation detectors and misinterpretation of measurement results. With the recent publicity about granite as a radioactive material, many people across the country have attempted to make measurements to determine the levels of radiation with the common pancake Geiger Mueller (GM) detector. Unfortunately, pancake GM detectors are not very well suited for such measurements. In particular, the pancake GM probe, which many people have used with their radiation meter, is not very good for measuring gamma radiation. It is best suited for measuring medium to high energy beta particles (Johnson, 2004 and 2008).

There are several issues observed with regard to reported measurements of radioactivity in granite; 1) using an inappropriate detector, 2) confusion of beta vs gamma measurements, 3) misunderstanding exposure readings, 4) calibration and energy dependence, 5) using contact readings to estimate risks.

Using Inappropriate Detectors

Since a pancake or end-window GM detector is best suited for medium-high energy beta radiation, this is the primary signal that will be detected from uranium and radium decay products. What this means is that the signal from granite with a pancake GM detector will be 95% or more due to beta particles. On this basis alone, exposure readings in mR/hr are too high by a factor of at least 20 to 30, not counting further problems discussed below.

Confusion of Beta and Gamma Readings

Many people have reported results with pancake GM detectors in terms of a multiple of the background reading (such as twice or five times background), without knowing what their meter is actually detecting. They have determined a normal background reading by holding the GM detector in the air at some location away from the granite countertop. Such background readings will consist of gamma rays from outer space (cosmic radiation) and gamma rays from the ground (terrestrial radiation from uranium, radium, and potassium that are natural components of soil everywhere). Background readings in the air are then compared to readings taken on the granite surface, which are primarily due to beta particles as noted above. The granite surface readings are then reported as multipliers of the background. For example, if the background reading in air is 50 counts per minute, and the granite surface reading is 150 counts per minute, this would be reported as three times background. Such reports are also typically presented with an emphasis on how bad the granite readings appear.

Misunderstanding Exposure Readings (Interference of Beta Particles)

Since the meter dial for many GM detectors has dual scales that provide readings either in units of counts per minute (cpm) or in units of exposure in milliroentgens per hour (mR/hr), many people believe those scales can be used interchangeably. What many people do not understand is that the word “exposure,” in the language of radiation safety, has a very specific meaning related to ionization in air from x-rays or gamma rays. Thus, exposure is not defined for a beta particle signal and the exposure scale on a GM meter is not calibrated for measurements of beta particles. Therefore, exposure readings on a granite countertop taken with an end-window or pancake GM meter (which is measuring primarily beta particles) have no meaning in units of mR/hr. Thus, measurements of exposure readings in air, compared with exposure readings on granite surfaces and reported as 5 or 10 times background are completely wrong.

You could compare readings from one piece of granite to another or at different points on a single slab as relative values, preferably in units of counts per minute, not in units of mR/hr. Energy transfer from beta particles can be measured in units of millirad/hour (mrad/hr), if your meter is calibrated, and a correction factor determined, with a known standard source of beta particles.

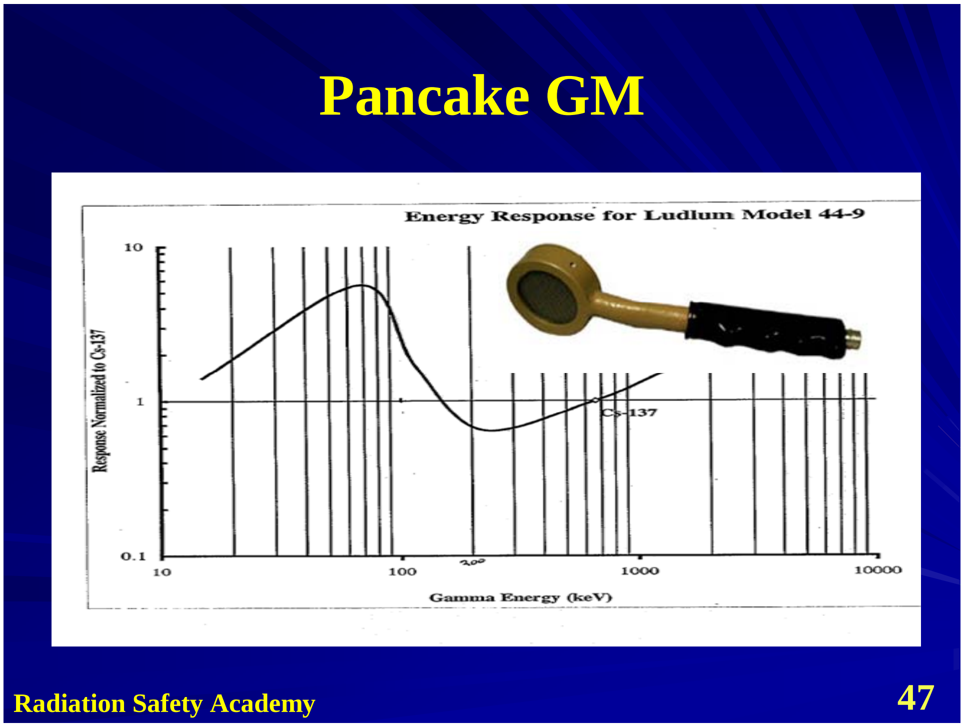
If your pancake, or end-window, GM detector is calibrated for exposure readings in mR/hr, then in order to measure only gamma rays (which is what an exposure calibration is for), you would need to block out the beta particle signal with about 1/4 inch of plastic. This will eliminate the beta component or interference with gamma measurements in mR/hr. However, exposure readings of only gamma rays would still be in error because of the energy dependence of GM detectors (see below).

Calibration and Energy Dependence

Eliminating the beta signal will only resolve one problem with GM detectors. The other problem has to do with how the meter was calibrated for exposure readings in mR/hr. The normal practice is to calibrate exposure reading instruments by comparison with a standard or known exposures from gamma rays emitted by a calibration source of cesium-137 at an energy of 662 keV. This means that measurements of gamma radiation at any other energy may not be accurate. The gamma energies from uranium-238 and radium decay products and potassium-40 are shown in Table 1.

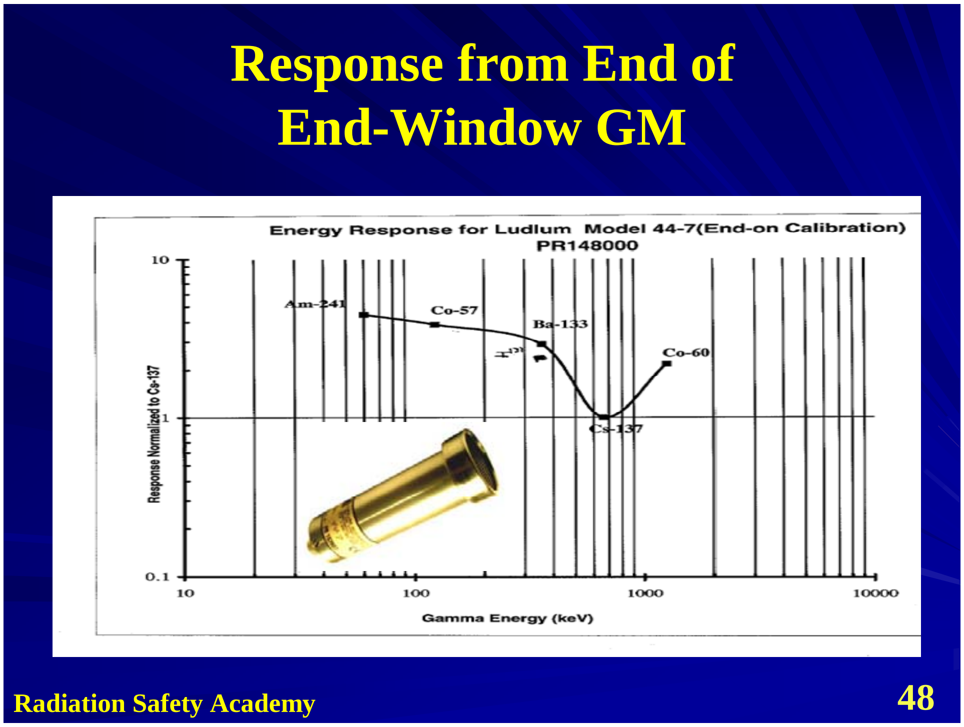
Based on the gamma energies from the uranium series shown in Table 1, it would appear from the energy response show in Figure 2 that a pancake GM detector will respond 30 to 40% too low for the gamma energies below 662 keV, which make up 75% of the total. About 25% of the total gammas above 662 keV may read too high by about 5%. Overall, even if you block the beta signal by shielding, the pancake GM will likely under respond by 30% or more for exposure readings in mR/hr.

Figure 2 – Energy Response of a Pancake GM Detector



Perhaps the worst possible choice of detector for evaluating granite countertops would be an end-window GM detector as shown in Figure 3. The energy response of this detector shows that it would read too high by at least 100% (a factor of two) for all of the gammas shown in Table 1. Furthermore, since the end window is made of mica, it will allow measurement of the beta particle signal at the same time. Thus, any readings through the end window for granite will be high by a factor of at least ten or more.

Figure 3 - Energy Response of an End Window GM



Thus, accounting for the influence of the beta signal and the energy response of pancake or end-window GM detectors, means that these detectors should never be used to accurately quantify exposure readings from granite countertops. As noted above, however, these GM detectors could be used to identify spots of higher count rate along the surface of a granite countertop, in terms of relative count rate readings.

Scintillation Detectors May Also Have Problems

Two types of scintillation detectors are also being used for granite measurements. These include the Ludlum Model 19 microR meter (which contains a one inch by one inch cylindrical sodium iodide crystal (NaI) detector inside an aluminum housing within a metal carrying case). The other detector is the Thermo Fisher Scientific PM 1703M. This uses a very small cesium iodide (CsI) crystal within a plastic housing the size of a pager. Since both detectors are contained in metal or plastic housings, they will not register a signal from beta particles. Both are also fast and very sensitive, however, the responses of both are very energy dependent as shown in Figures 4 and 5. Both detectors will over respond for gamma rays with energy less than the cesium-137 calibration energy of 662 keV and under respond for gamma energies greater than 662 keV.

Figure 4 - Energy Response of a NaI Detector

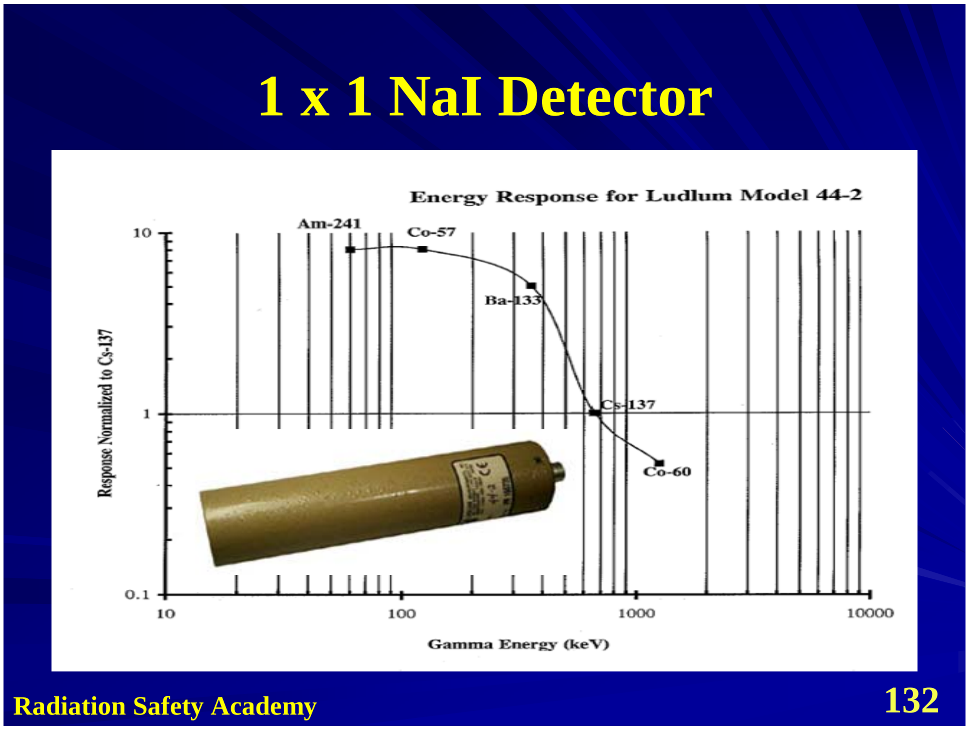
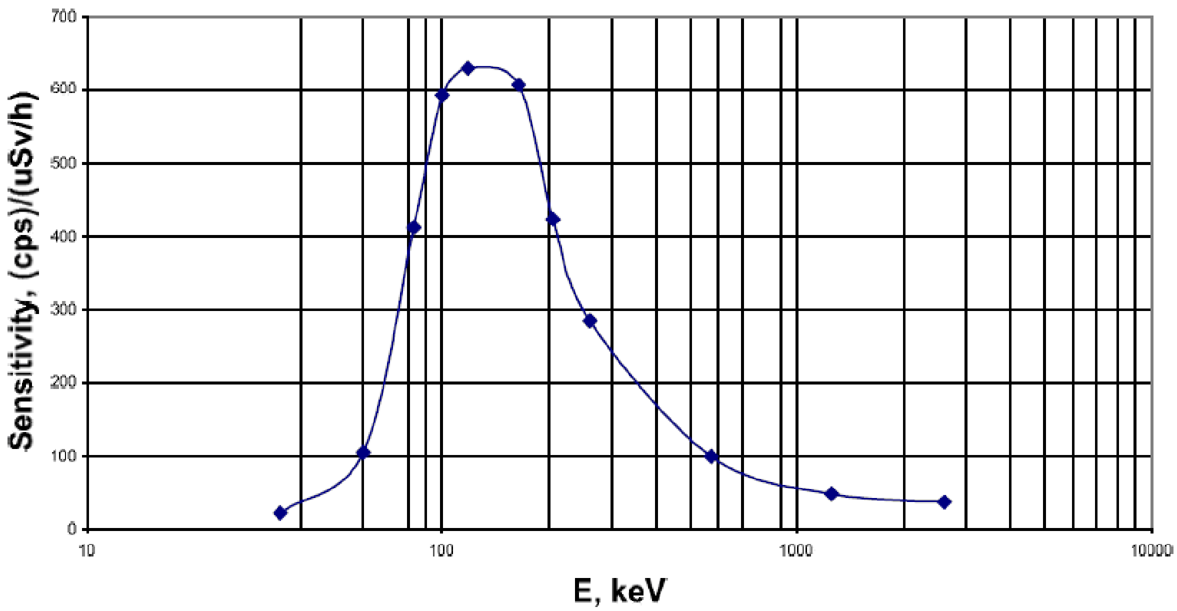


Figure 5 - Energy Response of PM 1703 M

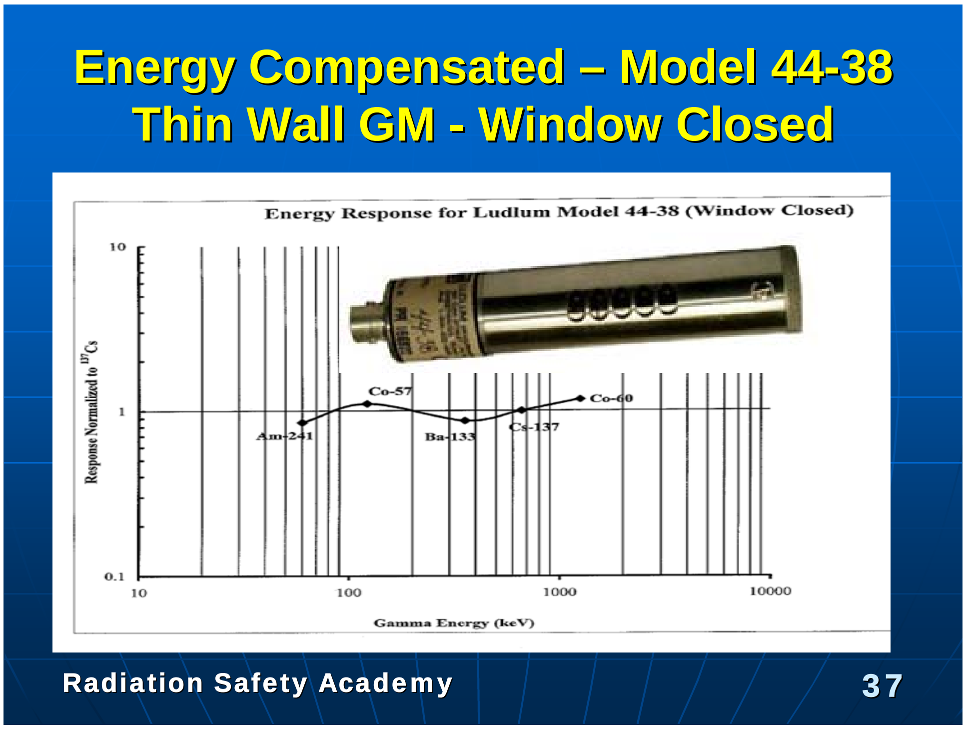


The PM 1703M is designed as an alarming ratemeter for efficient searching, detection, and location of gamma-emitting radioactive sources for homeland security. It is not energy compensated and so it has a high sensitivity at low energies (60-300 keV), which allows efficient detection of nuclear materials. Note: energy compensation is achieved by shielding the detector to reduce the over response at energies below 662 keV. Since the PM1703M is calibrated for a collimated Cs-137 radiation source, it may be used to measure dose rate for collimated Cs-137 sources. However, it may not give the same readings for other gamma sources and may differ from readings of energy compensated dosimeters. Since both NaI and CsI are very energy dependent detectors, if quantitative exposure readings are wanted, the best answer would be to calibrate the detectors for known radium exposures.

More Appropriate Detectors for Granite Measurements.

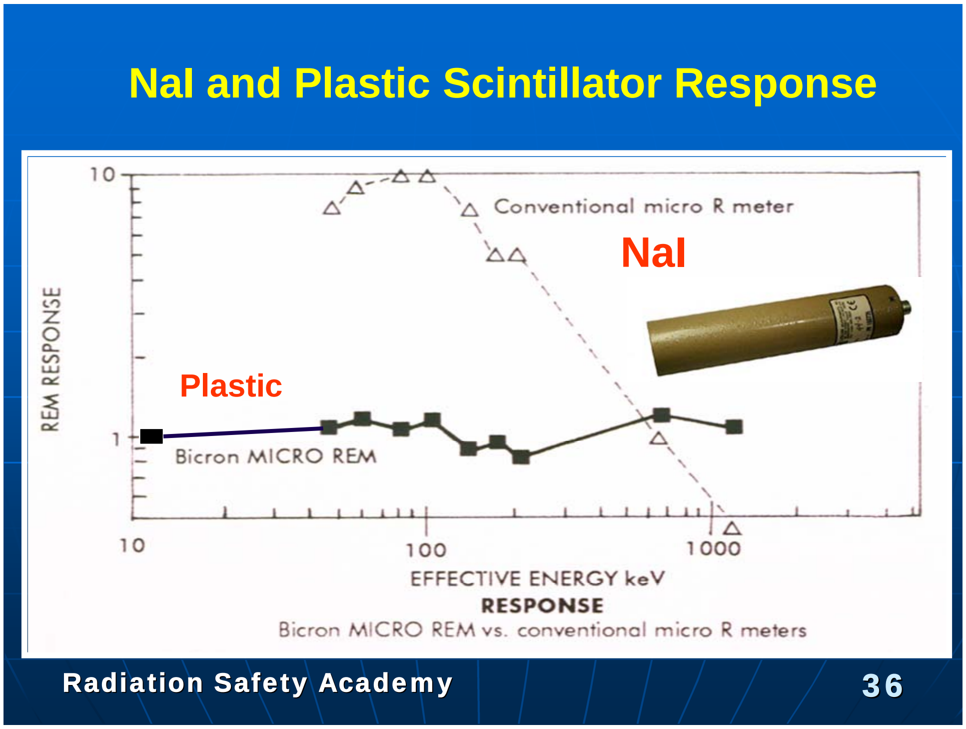
Sidewall GM. Better readings of gamma ray exposure could be achieved with a thin sidewall GM with the window closed as shown in Figure 6. According to the energy response of this detector, the readings in mR/hr for the gamma rays noted in table 1 should be fairly consistent with the Cs-137 calibration. Another advantage of this sidewall GM is that the metal housing will block signals from beta particles and therefore eliminate that source of interference.

Figure 6 - Energy Response of a Side-Wall GM



Plastic Scintillator. Another detector that could be used to measure radioactivity in granite is a plastic scintillator. This detector has a fairly flat or energy independent response as shown in Figure 7.

Figure 7 Energy Response of a Plastic and NaI Scintillators



The energy response for a Bicron microrem plastic scintillator as shown is for the extended low range option which has an opening through the housing to allow measurements of very low energy gamma or x-rays. Unfortunately, this is not suitable for measuring granite countertops because it will pick up beta particle interference. A better model would be the microrem without the low energy option. This has the plastic scintillator within a solid metal housing that will block any beta signal (these meters are now manufactured by Thermo Fisher Scientific).

Brodhead has compared several instruments for various samples of granite as shown in Table 2 (Brodhead 2008). From these data it appears that the PM1703M over reports exposure readings in uR/hr by 20% to 57% compared to the Bicron micro-rem meter. This is what would be expected as a result of the difference in energy dependence of the two instruments. Assuming the Bicron micro-rem plastic scintillator gives the true reading, the CsI (PM 1703M) is reading too high because most of the gamma energies from granite are below 662 keV in the region where the detector over responds.

Table 2 Instrument Comparisons (Brodhead 2008)

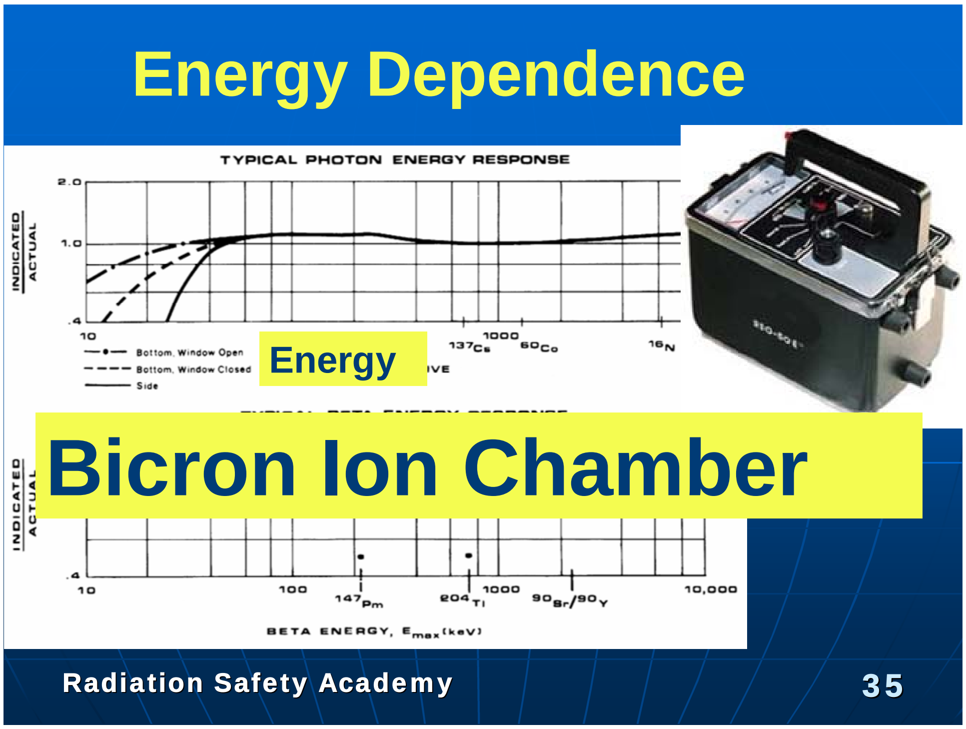
Granite type	Bicron μrem / hr above background	PM1703M μR / hr above background	Granite emanation pCi/ft^2/hr	pCi/ft^2/hr per Bicron μR / hr	PM1703M vs Bicron
NG granite	99	140	490	4.9	+ 40%
FS granite	25	30	508	20.3	+ 20%
JB granite	12.7	20	125	9.8	+ 57%
CB granite	3.4	3.0	8.6	2.5	n/a

The other reason for the differences could be a matter of geometry, which has to do with the distance from the detector to the source. The Bicron plastic scintillator detector inside the metal housing would be about one inch away from the source when placed on a granite surface. The PM 1703M CsI detector would be less than ½ inch away from the source when placed on the same surface. The difference of ½ inch could be very significant for a small area (point) source. Gamma rays diverge from a point source such that doubling the distance reduces the exposure rate by a factor of four.

Brodhead also reported that he found the PM1703M responded faster and was more stable than the Bicron (lots of needle movement on the Bicron). The PM1703M measured very close to the Bicron when measuring uranium ore and thoriated welding rods. In comparison the Ludlum Model 19 microR meter (NaI scintillator) read about double the Bicron for these sources. Again this is what would be expected from an NaI detector which over responds for energies below 662 keV. When measuring higher energy gammas, such as the K-40 gammas at1,460 keV, both the PM1703M (CsI) and microR (NaI) detectors under responded in comparison to the Bicron plastic scintillator.

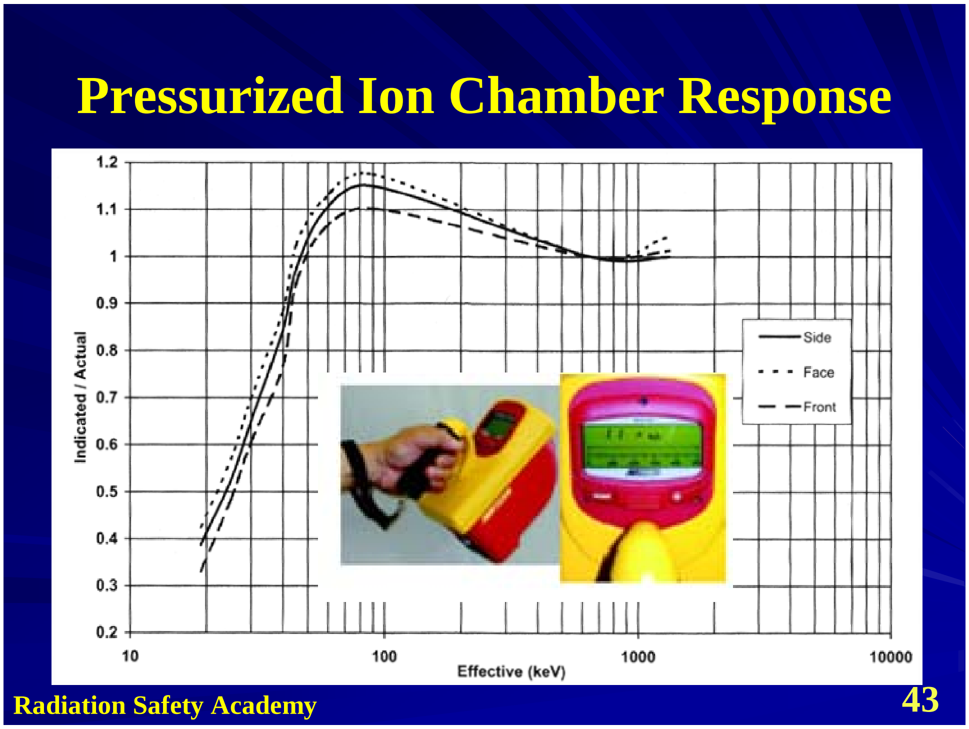
Standard or Pressurized Ion Chambers. Ion chambers could also give good energy independent readings on gamma radiation from granite countertops as shown in Figures 8 and 9.

Figure 8 Energy Response of a Standard Ion Chamber



Of all the detectors discussed above, perhaps the best detectors for measuring radiation or exposure levels from granite would be either a closed-window standard ion chamber or a pressurized ion chamber. Both are designed to block out the beta particle signal and also have good energy response over the range of gamma ray energies that come from radium decay products. Ion chambers also give a true measure of exposure in mR/hr. All other instruments for measuring exposure are surrogates and not a true measure of exposure.

Figure 9 Energy Response of a Pressurized Ion Chamber



Intercomparison of Radiation Instruments

To show how various radiation detectors would respond to several naturally occurring radionuclides an intercomparison study was done as shown in Table 3. This intercomparison was to illustrate not only differences between radiation instruments, but also differences related to measuring a combined beta-gamma signal vs a gamma-only signal and differences related to source contact readings vs readings at 30 cm (1 ft). In particular, you will note that very large differences are shown between an open GM and one where beta particles are blocked by ¼ in. of plastic. Depending on the sample, the open GM readings (combined beta-gamma signal) are from 3 to more than 100 times higher than the gamma only readings. Likewise the 450 B ion chamber showed differences of about 3 to 10 times higher readings with the window open to include both beta and gamma signal (compared to window closed gamma-only readings). In most cases it appears that the pressurized ion chamber (PIC) and Microrem plastic scintillator gave similar readings. For some samples these instruments gave lower readings than the 450B with a closed window (they would also be expected to be similar).

Table 3 Radiation Instrument Comparisons

	Sample	Pan GM Open Kcpm	Pan GM ¼" Plastic	End GM Open Kcpm	End GM ¼" Plastic	450B IC Closed μR/hr	450 B IC Open μR/hr	PIC μR/hr	Microrem Plastic Scint. μR/hr	NaI 1 x 1 μR/hr
1	U Ore 3#	60 3	2.5 1.0	22 1.3	9 0.6	230	670	200	200	300
2	U Ore 4#	220 12	70 4	65 5.5	29 3.5	1,100	2,500	900	950	-
3	U Ore 1#	60 3	6 1	14 1	2.2 0.3	70	190	40	40	110
4	U Ore 1.5#	110 5	20 1	30 1.3	0.9 0.5	290	800	180	200	300
5	DU 4 oz.	220 14	3 0.4	80 4.5	1.5 0.2	230	2,400	38	50	100
6	ThO 99%	180 7	60 3	60 3	24 1.8	500	1,400	400	400	400
7	UO Glaze	28 5	0.2 0.1	4.5 1.5	0.06 0.06	70	660	30	30	70
8	UO Glaze	32 6	0.2 0,1	6 1.5	0.1 0.1	110	1,000	30	30	70
9	Ra Clock	120 2	1 0.15	30 0.5	0.7 0.1	60	320	30	30	-
10	KCl	0.6 0.1	0.15 0.05	0.2 0.1	0.1 0.05	-	-	-	-	-
11	ThO Mantles	30 0.7	0.8 0.15	5 0.3	0.3 0.1	50	140	8	10	-
12	Vaseline Glass	5 0.3	0.15 0.1	1 0.15	0.1 0.05	30	80	-	-	-

Table 3 Continued

	Sample	Thin NaI Kcpm	1 x 1 NaI Kcpm	2 x 2 NaI Kcpm	ZnS Kcpm	Alpha Proportional Kcpm
1	U Ore 3#	5	6	20	35	200
2	U Ore 4#	22	35	> 500	23	120
3	U Ore 1#	2.9	2	60	3	20
4	U Ore 1.5#	6	7	170	5	50
5	DU	8	2	60	0.1	15

	4 oz.					
6	ThO 99%	8	15	270	100	200
7	UO Glaze	2.5	35	35	3	20
8	UO Glaze	3	12	42	1	8
9	Ra Clock	1.2	1.3	33	8	100
10	KCl	-	-	5	-	-
11	ThO Mantles	-	-		4	20
12	Vaseline Glass	-	1	-	-	-

Notes for Table 3: None of these samples would be considered a point source. All would represent an area greater than 100 square centimeters. For GM instruments, two readings are shown, the upper reading is in contact with the source, the lower number is measured at 30 cm or 1 foot. The GM Open readings will include both beta and gamma signal. A ¼ inch piece of plastic was also used to block the beta signal for GM gamma only readings. The 450 B is a standard ion chamber with readings of window closed vs window open. The open window readings would include any beta and gamma signal. The closed window readings are for gamma only. The readings in kcpm are count rates (thousands of counts per minute). The PIC is a pressurized ion chamber. The microrem meter is a 3/8 by 1 inch plastic scintillator with the extended low-range option (all readings were taken through a ¼ plastic shield to remove interference from beta particles). The NaI μR/hr is an internal sodium iodide (1 in. x 1 in.) microroentgen (microR) meter. Thin NaI is a thin-window, thin-crystal NaI detector. The other NaI detectors are crystals of 1 in. x 1 in. and 2 in. by 2 in. All of the exposure readings in μR/hr (1,000 μR/hr = 1 mR/hr) were taken at 30 cm (1 ft). The count rate readings for all NaI detectors were taken also at 30 cm (1 ft). ZnS is a zinc sulfide alpha particle detector of about 100 square centimeters. The alpha proportional detector has an area of about 80 square centimeters. All alpha readings were taken in contact with the source. No background subtractions were done. The backgrounds for pan GM = 40 – 50 cpm, for end Gm = 3-40 cpm, for thin NaI = 200 cpm, for NaI 1 x 1 = 1,200 cpm, and for NaI 2 x 2 = 2,000 cpm. For readings in μR/hr, the background was about 10 μR/hr.

Unfortunately, no granite samples with sufficient activity were available for this intercomparison. However, since the samples selected all contained high concentrations of uranium, thorium, radium, or potassium they should represent the worst case possibilities for granite countertops. It is important to note that readings in contact with the sources ranged from about 5 to 25 times higher than readings at 30 cm (1 ft). Thus, readings in contact with granite countertops may overestimate the risks by these amounts.

Radiation Testing Protocols and Geometry

At the time of writing this chapter, no testing protocols were yet published. Consequently, a great deal of variation in testing procedures exists for radiation measurements of granite countertops, both in terms of instruments used and in the locations for readings (how far is the detector away from the surface). The orientation or location of a detector relative to the source is called geometry. Most measurements reported on the internet are for readings taken in contact with the granite surface. However, it should be noted that while the outer housing of an instrument may be in contact with the granite surface, the center of the detector will usually be some distance from the surface. Measurements for distance from a source are always measured to the center of the detector. For example, for a pancake GM detector in contact with the surface, the actual center of the detector would be about ¼ to ½ inch from the surface. In contrast, for ion chambers with the housing in contact with the surface, the center of the detectors are from 1 to 2 inches away from the surface. For the microrem plastic scintillator and the NaI microR meter the center of the detectors are about 1 inch from the outer housing of the instruments. Thus, for measuring small areas of activity (point sources) on a granite countertop, even placing the detectors in contact could result in substantial differences of readings because of differences in the location of the center of the detector within the instruments. For example, for a point source, a change in geometry or distance from ½ to 1 inch away from the source will reduce the reading by a factor of four (400%).

Using Contact Readings to Estimate Risk. All of the video clips which demonstrate the use of radiation detectors for evaluating granite show readings being taken in contact with the granite surface. While surface measurements may help to find spots of higher radioactivity in terms of count rates, measurements of exposure would normally be taken at various distances away from the surface. A common distance for evaluating other sources of radiation, such as sealed source nuclear gauges and x-ray machines, is 30 centimeters (one foot)

For example, 10 CFR 20.1003 (NRC 2009) defines a *radiation area* as an area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 5 mrem (0.05 mSv) in 1 hour at 30 centimeters from the radiation source or from any surface that the radiation penetrates. Similarly a *high radiation area* means an area, accessible to individuals, in which radiation levels from radiation sources external to the body could result in an individual receiving a dose equivalent in excess of 100 mrem (1 mSv) in 1 hour at 30 centimeters from the radiation source or 30 centimeters from any surface that the radiation penetrates.

Thus, the distance for judging how to post warnings for radiation is based on readings at 30 cm or 1 foot from the source or surface for licensed or registered sources of radiation. This distance is likely to be more representative of a person's proximity to the countertop on the average, than a contact reading. Contact readings would only be useful to estimate the exposure to a part of person's body in direct contact with the granite surface, such as a person's hand or arm. Even then such readings would be more representative of a skin dose, rather than a deeper whole body dose. Since a person's hands, arms, and surface tissues are less sensitive parts of the body, regulatory limits allow ten times higher dose to those parts of the body. Since exposure rates usually go down very quickly with distance from a localized source of gamma rays, exposure readings at a distance of one foot are likely to be much lower than contact readings.

For a true point source measured at one inch, the reading at 12 inches would be reduced to 1/144 of the reading a one inch. Thus, a contact reading could overestimate the risk by as much as 144 times. For sources that are larger in area, the readings will also go down with distance, but not as dramatically as for a true point source.

Radon Testing Protocols

Because homeowners may have concerns about granite countertops as a source of radon in their homes, many people have attempted to measure radon emanation from granite. The normal procedure is to seal a large container (such as a large bowl) on the granite surface and then measure the accumulation of radon in the container. Other methods include placing a sample of granite inside a sealed container and measurement of the radon in the container, either with a radon detector in the container or by pulling an air sample into a scintillation cell (Kitto 2009 and Brodhead 2008). The results of such measurements can be reported as an emanation or flux rate, such as pCi ft^{-2} hr^{-1} or as a concentration in pCi Kg^{-1}. As with radiation measurements discussed above, measurements of radon emanation rates have to be done carefully and reported responsibly.

One video clip available on the internet shows a direct reading radon detector inside a clear plastic box sealed to a granite countertop. The detector, visible from outside the box, is showing about 14 pCi and the narrator is exclaiming that this is almost four times the EPA action level. This is one example of purposeful misinformation intended to show how bad granite countertops could be. No consideration was given to the fact that no one would be breathing the air in the box, or to account for normal ventilation rates and dilution in the volume of air throughout the house.

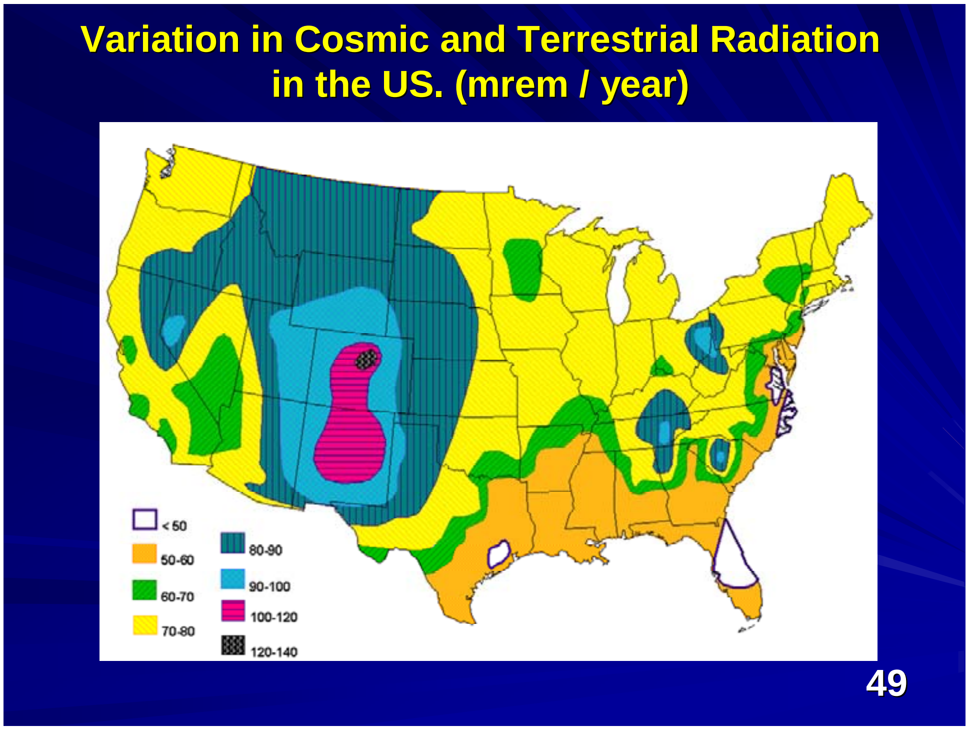
As noted earlier in this chapter, the American Association of Radon Scientists and Technologists has indicated that granite countertops are unlikely to result in high radon levels in a home (AARST 2008). AARST notes that measurement of radon emanation is also not a reliable indicator of indoor radon levels. To check for radon that may emanate from a granite countertop, AARST recommends placing a radon test device in the kitchen, in the lowest lived-in level of the house, and in another highly occupied room (such as the bedroom), using standard radon testing protocols. Comparisons of these three radon tests should help determine the source of radon. In virtually all cases, the expectation would be for the highest readings to occur in the lowest lived-in level, or the basement of a house. Thus, if radon is a concern to the homeowner, the normal mitigation of radon with a sub-slab suction system will likely produce lower radon levels throughout the home, rather than removing the granite countertop (HPS 2008).

Health Risks

Since a whole chapter (or book) could be written on radiation and radon health risks, for the purposes of evaluating granite countertops, I would like to say that I have not yet seen any measurement data that show granite countertops would likely result in health effects. The fact that granite may be a source of radiation and radon, that was not expected by homeowners, is not a sufficient basis to assume that any particular health effects will result.

Concerns for radiation risks from granite are more a matter of public perception and understanding, than about reality as understood by specialists in radiation safety (Johnson 2009b). While increases in radiation levels above normal background seem alarming to many people, most do not realize that normal background in the US can easily vary by factors of 2 to 3 or more depending the region of the country (see Figure 10).

Figure 10



For example, a person could receive an extra 100 mrem yr^{-1} by moving from Orlando to Denver, due to an increase in cosmic radiation from higher altitude and due to increases in terrestrial radiation from greater content of uranium and radium in the ground. Furthermore, while the average exposure to natural radiation in the US is about 300 mrem yr^{-1}, there are regions in other countries where the normal background radiation is from 3,000 to more than 20,000 mrem yr^{-1} (Johnson 2009a).

Part of the public's fears of radiation from granite countertops may also be due to the way people have identified so-called "hot spots" or "hot stones." Even people who should understand radiation measurements seem prone to using the words "hot spots" to describe points or areas on a granite countertop where the radiation readings are above normal background. For the public, use of the word "hot" implies danger or health risk. While specialists in radiation safety may understand that "hot" simply means a reading higher than normal, for most people this means something dangerous.

To assess health risks there are several questions that need to be answered, as follows:

1. What kind of radiation and how much? (beta or gamma radiation and the amount)
2. What are the exposure conditions? (external beta or gamma radiation)

3. Where is the radiation relative to occupancy? (how far from the granite and for how long).
4. How much radiation energy will be deposited in a person's body? (Exposure rate times time)
5. What is the expected effect of the energy deposition? (based on observations of exposed people, such as survivors of Hiroshima and Nagasaki).

While the debate continues and will likely go on forever about effects of low radiation doses (typical of granite countertops), I like to offer a new message. Namely, it is actually very difficult to seriously harm someone with radiation. This conclusion is based upon the quantity of radiation that is required to kill sensitive tumor cells for cancer treatment. It typically takes from 3,000,000 to 6,000,000 mrem delivered directly to the tumor cells to stop cancer growth. Cancer cells can be killed by radiation without killing the person, because the cancer cells are more sensitive to harmful effects of radiation than other healthy cells.

Guidelines for Safety

Unfortunately, there are no guidelines for safety to evaluate radiation from granite countertops. Those who sell products that compete with granite would like homeowners to believe that any additional radiation in their homes is bad, and many homeowners may agree. Also, many homeowners upon hearing a clicking Geiger Mueller detector on their granite countertop will assume they are at significant risk.

As an evaluation of health risk, exposure rate measurements, such as milliroentgen per hour (mR hr^{-1}), or concentration measurements for radon in units of pCi L^{-1} are not enough by themselves. Health risk is related to radiation energy deposited in our bodies, which is a function of exposure rate or concentration times exposure time. For example, EPA's radon action level of 4 pCi L^{-1} is incomplete without considering exposure time. For radon risks estimates, EPA assumes a lifetime of 70 years with 70% of a person's time spent in a home at the action level. Thus, a person's radon risks would be proportionally much smaller for exposure times of only a few years. Likewise to estimate risks and make decisions for safety, we need to know not only exposure rates (measured with appropriate instruments and protocol, as described above), but also how long a homeowner may spend in proximity to their granite counter top in a year.

Regulations for NORM

Even if you take radiation readings carefully as described above, you still need a reference value or guideline to interpret the readings. Unfortunately, there is no regulation or guideline value in microR/hour (uR/hr) or milliroentgen/hour (mR/ hour) that applies to granite countertops.

States primarily have jurisdiction for regulations of NORM, except for discrete sources of radium-226, such as radium illuminated instruments, which are now regulated by the Nuclear Regulatory Commission. The few states with NORM regulations have adapted the Conference of State Radiation Control Directors "Suggested State Regulations." (SSRCR 2008). Section N of these suggested regulations provides guidance for Technologically Enhanced Naturally Occurring Radioactive Material (TENORM), which means "naturally occurring radioactive material whose radionuclide concentrations are increased by or as a result of past or present human practices. TENORM does not include background radiation or the natural radioactivity of rocks or soils." Thus clearly, regulations for TENORM should not apply to granite countertops. The regulation does say that it applies for concentrations of radium-226 above 185 Bq Kg^{-1} (5 pCi g^{-1}), excluding natural background. Since any radium in granite would be considered natural background, then it appears that this requirement would not apply either.

Section N.5 says that if the TENORM is licensed then the licensee shall conduct operations with TENORM so that individual members of the public will not exceed 1 millisievert (100 mrem or 100,000 microrem) TEDE (total effective dose equivalent) annually. This does not include inhalation of indoor radon and its short half-life (less than 1 hour) progeny. The limit of 100 mrem in a year is the same limit applied by the US Nuclear Regulatory Commission (NRC) for limiting radiation exposures to members of the public from licensed radioactive materials in unrestricted areas. The NRC also imposes an hourly limit of 2 mrem (NRC 2008).

For lack of any specific guidelines for safety of granite countertops, many people have attempted to apply the annual and hourly limits for members of the public as described above. However, there does not appear to be any regulatory basis for using these limits. Unfortunately also, when these limits are used, many people are interpreting them in terms of safety. Thus, homeowners have been told that if they might exceed 100 mrem in a year from their granite countertop, that this is unsafe and the granite should be removed (as noted earlier, because of misinterpretation of radiation instruments, estimates of annual mrem are probably high by as much as at least 10 or more). One woman who claimed to sit at her granite countertop for several hours every day was counseled that she should have the granite moved because of "hot spots" detected with a pancake GM detector.

In fact, no one should expect any adverse effects at a level of 100 mrem in a year. As noted above, a homeowner could gain this amount by moving to Colorado. Also, if a person is really concerned about exposures at a level of 100 mrem, then they really need to consider radon in their home first. As noted by the author earlier in this book, 1 pCi L^{-1} is equivalent to 200 mrem in a year (Johnson 2009b). Thus, the EPA action level of 4 pCi L^{-1} is equivalent to 800 mrem in a year.

References

AARST. Position Statement. Granite Countertops and Radon Gas. American Association of Radon Scientists and Technologists, 14 Pratt Road, Alstead NH 03602. August 4, 2008.

Brodhead, B, Measuring radon and thoron emanation from concrete and granite with continuous radon monitors and e-perms. Proceedings of the American Association of Scientists and Technologists International Symposium, Las Vegas, NV September 14-17, 2008. AARST,14 Pratt Road, Alstead NH 03602, September 2008

Brodhead, B. personal communication on comparative instrument readings, October 25, 2008.

Detrick, P. 'Early Show' fuels granite countertop radiation fears. NewsBusters.org. July 25, 2008.

E.H.&.E. Assessing exposure to radon and radiation from granite countertops, Environmental Health and Engineering, Inc., Needham, MA November 21, 2008

Ethington, personal communication on the definition and composition of true granite, 2009,

HPS, Radiation from granite countertops. Health Physics Society, McLean, VA, 2008.
Johnson, R.H. Radon in houses: in NORM and TENORM. Ed. by Karam, A. 2009 Health Physics Society Professional Development School, Minneapolis, MN. July 16-18, 2009a.
Johnson, R. H. To help first responders - its time for us to become radiation myth busters. Proceedings of the HPS Midyear meeting in San Antonio, TX, Jan. 31 – Feb. 3, 2009, Health Physics Society, McLean, VA 2009b.
Johnson, R. H., Neslon, N.S., Golden, A. S., and Gesell, T.F., Natural radiation quality of the environment in the United States, Proceedings of the 2nd Special Symposium on Natural Radiation Environment, Bhabha Atomic Research Center, Bombay, India, January 19-23, 1981.
Karam, A. personal communication on the definition and composition of true granite, 2009
Kitto, M.E, Haines, D.K, and Arauzo, H.D., Emanation of radon from household granite, Health Physics, 96, 4, pagr 477-482, April 2009.
Murphy, K. "What's lurking in your countertop? New York Times, Home Section, July 24, 2008.
NRC, Title 10 Code of Federal Regulations, Part 20, US. Nuclear Regulatory Commission, Washington, DC, 2008
Robertson, John, Image of six blind men reproduced with permission of John Robertson, compiler of the dictionary site of Word Information located at http://www.wordinfo.info where this illustration and the other related images may be seen by doing a search for Blind Men. The complete poem and images can be found at http://www.wordinfo.info/words/index/info/view_unit/1/?letter=B&spage=3. January 26, 2009.
Saxe, J.G. The blind men and the elephant from The POEMS of John Godfrey Saxe. James R. Osgood and Company, Boston, 1873
Simons, D.J. Gorillas in our midst: sustained inattentional blindness for dynamic events. Perception, 28, pages 1059-1074, 1999.
SSRCR, Suggested state regulations, Conference of Radiation Control Program Directors, Inc. Frankfort, KY, Volume I, May 2008.
Toohey, R. Radioactive Ghosts, Letter to the Editor, The New York Times, August 1, 2008.
Turner, A. Be wary of granite that glows. Houston Chronicle, July 25, 2008

Raymond H. Johnson, MS, SE, PE, FHPS, CHP

Director, Radiation Safety Counseling Institute 301-370-8573

- BS, Civil Engineering (1961) University of Vermont
- MS, Sanitary Engineering (1963) Massachusetts Institute of Technology (MIT)
- SE, Professional Sanitary Engineer Degree (1963) MIT and Harvard University
- PhD Studies, Radio and Nuclear Chemistry (1966–1972), Rensselaer Polytechnic Institute
- Greater Washington Institute for Transactional Analysis - Counseling (1977–1979)
- American Board of Health Physics Certification (CHP) (1983–present)
- Licensed Professional Engineer (PE, Sanitary) in Vermont since 1965
- Johns Hopkins Fellow, Organizational Systems and Communications (1984–1985)
- Past President and Fellow of the Health Physics Society (FHPS) (2000)
- President, American Academy of Health Physics (2013)
- Commissioned Stephen Minister – Counselor, United Methodist Church (2003–pres)

Experience

2010 – pres.	Director , Radiation Safety Counseling Institute. Workshops, training, and counseling for individuals, companies, universities, or government agencies with concerns or questions about radiation safety. Specialist in helping people understand radiation, risk communication, worker counseling, psychology of radiation safety, and dealing with fears of radiation and nuclear terrorism for homeland security.
2007 – 2012	VP, Training Programs, Dade Moeller Radiation Safety Academy, training and consulting in radiation safety.
1984 - 2007	Director, Radiation Safety Academy. Providing x-ray and radiation safety training, audits, and consulting to industry (nuclear gauges and x-ray), universities, research facilities, and professional organizations.
1988 - 2006	Manager and Contractor to National Institutes of Health (NIH) for radiation safety audits of 3,500 research laboratories and 2,500 instrument calibrations a year, along with environmental monitoring, hot lab and analytic lab operations, and three accelerators and over 100 x-ray machine inspections.
1990 - 2005	President of Key Technology, Inc. a manufacturer and primary laboratory for radon analysis with over 1,500,000 measurements since 1985. Primary instructor at Rutgers University 1990-1998 for radon, radon measurements, radiation risks, radiation instruments, and radon risk communication courses.
1986 - 1988	Laboratory Director, RSO, Inc. Directed analytical programs and Quality Assurance for samples from NIH, Aberdeen Proving Ground, radiopharmaceutical companies, and the nuclear industry.
1972 - 1985	Chief, Radiation Surveillance Branch, EPA, Office of Radiation Programs. Directed studies of radiological quality of US, coordinated 7 Federal agencies for nuclear fallout events, QA officer 8 years. Head of US delegations to I.A.E.A and N.E.A. on radioactive waste disposal. ANSI N-13, (1975-1985). Retired PHS Commissioned Officer (0-6) in 1985 with 29 years of service.
1963 - 1972	U.S.P.H.S. Directed development of radiation monitoring techniques at DOE National Labs, nuclear plants, and shipyards in the US and Chalk River Nuclear Laboratory in Canada.

Health Physics and Professional Activities

Health Physics Society (HPS) plenary member 1966; President-elect, President, Past President (1998-2001), Fellow (2000), Treasurer (1995-1998); Secretary (1992-1995); Executive Cmte. (1992-2001), Chair, Finance Cmte. (1996-1998); Head of U.S. delegation to IRPA X (2000); RSO Section Founder and Secretary/Treasurer (1997-2000); Co-founder and President, Radon Section (1995-1996). Co-Chair Local Arrangements Cmte. Annual Meeting in DC (1991); Public Info. Cmte. (1985-1988); Summer School Co-Chair (2004); Chair, President's Emeritus, Cmte (2006); Chair, Awards Cmte. (2002); Chair, History Cmte. (2005-2012); Historian (2012-pres.), Continuing Education Cmte. (2005-2012). Academic Dean for HPS Professional Development School on Radiation Risk Communication (2010); PEP, CEL and AAHP Instructor; Journal Reviewer; AAHP Treasurer (2008 – 2011). AAHP President (2013). Baltimore-Washington Chapter: President (1990-1991) and Honorary Life Member; Newsletter Editor (1983-2005); Public Info. Chair (1983-1991), Science Teacher Workshop Leader (1995 – Pres.). New England Chapter: Newsletter Editor, Board of Directors, Education Chair (1968-1972). American Association of Radon Scientists and Technologists Charter Member (1986), President (1995-1998), Honorary Life Member (2000), Board of Directors; Newsletter Editor (1990-1993). Founder and first President, National Radon Safety Board (NRSB) (1997-1999). Member of American Industrial Hygiene Association (1997 – Pres.) (Secretary, Vice Chair, Chair, Ionizing Radiation Committee, 2009-2012), Conference of Radiation Control Program Directors (1997-Pres.), Studied H.P. communication styles and presented Myers-Briggs seminars to over 3500 H.P.s since 1984. Over 30 professional society awards. Registered Professional Engineer since 1965. Certified Health Physicist since 1983.

Publications

Authored over 500 book chapters, articles, professional papers, training manuals, technical reports, and presentations on radiation safety. Author of monthly column, "Insights in Communication" HPS Newsletter 1984 – 1989, 1994 -2001, and 2012 – Pres.

Contact at: 301-370-8573, ray@.radiationcounseling.org or 301-990-6006, ray.johnson@moellerinc.com