Is Your Radiation Instrument Telling You What You Think It Is?

A Technical Presentation

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by

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A 15 Minute Technical Paper Presentation for the
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Misunderstandings abound when it comes to the interpretation of radiation measurements. There are two key factors governing such interpretations:

1) measurements have no meaning until interpreted and
2) measurements only have meaning in terms of how they are interpreted.

Thus, recorded or reported radiation measurements have no inherent meaning by themselves, they are just numbers. Interpretation of radiation measurements may have as much to do with attitudes and perceptions of radiation risks as it does about technology. For example, a worker at an industrial facility observed the RSO taking readings with a Geiger counter and saw the meter go off scale. That was enough information for this worker to start an uproar that eventually involved several hundred other workers, the union, and management. Another worker at a food production facility heard a GM meter in use for surveying the installation of a new x-ray machine for product quality control. He raised concerns and when the company manager heard there was radiation in his facility, he told the x-ray company to remove their machine. This resulted in the loss of a $4 million sale for 20 x-ray machines.

Radiation safety specialists have the advantage for interpreting radiation measurements based on knowledge of comparative readings from background and other sources. Most people without this specialized knowledge do not know that we live in a sea of radiation which surrounds us all the time. Furthermore, a screaming Geiger counter may sound alarming, but radiation risks depend on many other factors, such as the type of radiation, the proximity of people, the duration of exposure, and dose actually delivered. A Geiger counter reading is only one piece of information which specialists would use for assessing potential risks. Unfortunately, all radiation measurements have many potential sources for errors which people may not know about and may therefore assume the measurements represent the real world. For interpreting radiation measurements, how much do we rely on technical understanding and how much or our interpretation is an emotional reaction regarding safety?

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- BS - Civil Engineering, University of Vermont (1961)
- MS - Sanitary Engineering, Massachusetts Institute of Technology (MIT) (1963)
- PSE - Professional Sanitary Engineer Degree, MIT and Harvard University (1963)
- PE – Licensed Professional Engineer, Vermont (1965 – present)
- PhD Studies, Radio and Nuclear Chemistry, Rensselaer Polytechnic Institute (1966–1972)
- Greater Washington Institute for Transactional Analysis – Counseling (1977–1980)
- CHP – Certified Health Physicist, American Board of Health Physics (1983–present)
- Johns Hopkins Fellow, Organizational Systems and Communications (1984–1985)
- FHPS - Fellow of the Health Physics Society and Past President (2000)
- DAAHP – Diplomate and Past President, American Academy of Health Physics (2015)
- Commissioned Stephen Minister – Counselor, United Methodist Church (2003–present)

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 and x-ray safety. Specialist in helping people understand radiation, what is safe, risk communication, worker counseling, psychology of radiation safety, and dealing with fears of radiation and nuclear terrorism for homeland security.
2007 – pres.	VP, Training Programs and consultant to Dade Moeller Radiation Safety Academy, training and consulting in x-ray and radiation safety, safety program audits, radiation instruments, NORM, and regulatory requirements.
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 inspections of three accelerators and over 100 x-ray machines.
1990 - 2005	President of Key Technology, Inc. a manufacturer and primary laboratory for radon analyses with over 1,500,000 measurements since 1985. Primary instructor at Rutgers University for radon, radon measurements, radiation risks, radiation instruments, and radon risk communication courses (1990-1998).
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.
1970 - 1985	EPA program manager and Chief, Radiation Surveillance Branch, EPA, Office of Radiation Programs. Directed studies of radiation exposures from all sources of radiation in the 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 delegate (1975-1985). Retired as PHS Commissioned Officer (0-6) in 1985 with 29 years of service.
1963 - 1970	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. Conducted doctoral research.

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); 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). Chair, Professional Development School Cmte (2014-Pres.), Academic Dean for HPS Professional Development School on Radiation Risk Communication (2010) and Radiation Instruments School (2014). PEP, CEL and Journal Reviewer. AAHP Instructor; Treasurer, AAHP (2009 – 2012). AAHP President-elect, President, Past President (2012-2015). Baltimore-Washington Chapter: President (1990-1991) and Honorary Life Member; Newsletter Editor (1983-2005); Public Info. Chair (1983-1989), Science Teacher Workshop Leader (1995 – Pres.). New England Chapter HPS, Newsletter Editor, Board of Directors, Education Chair (1968-1972). President, American Association of Radon Scientists and Technologists (1995-1998) and Honorary Life Member, Charter Member; 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.), Taught 3,500 RSO students since 1985. Studied H.P. communication styles and presented Myers-Briggs seminars to over 4,000 H.P.s since 1984. Over 35 professional society awards. Licensed Professional Engineer since 1965. Certified Health Physicist since 1983.

Publications

Authored over 600 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- 2013.

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Is Your Radiation Instrument Telling you What you Think it Is?

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Since radiation does not give us any physical sensation, we have to rely on radiation instruments to tell us what is happening. Thus, we turn on a radiation instrument and look at the reading as a basis for making decisions for safety. The challenge at this point is to determine if the instrument is telling us the truth. There are at least twenty pitfalls that can affect the quality of radiation measurements. Several questions to consider, include:

1) Have we chosen the appropriate instrument for the type of radiation and safety decision which we want to make?

2) After choosing an instrument, how do we know if it is working properly?

3) After verifying operation, are we prepared to use the instrument properly (the way it was calibrated)? Assuming we have answered these questions appropriately, we then proceed to gather measurement data. The next question has to do with evaluating the quality of our measurement data.

4) What do these measurements mean and are they defensible?

5) Do these measurements support expensive decisions for safety, such as evacuation, clean up, or other actions?

The Ionizing Radiation Committee has presented a PDC on radiation instruments to answer these questions for the past two AIHce's and also for 2012. The 2011 PDC was rated 8 out of 58. The instructors (authors of this article) have more than 60 years of radiation instrument experience. The focus of the PDC is not about theory or math, but rather about practical things to know about radiation instruments to allow industrial hygienists to do their jobs well and stay out of trouble. We will briefly review the fundamentals of radiation to better understand how instruments work and what they measure. We will bring a variety of radiation instruments to the PDC and pass them around to allow attendees to see how they respond to several exempt quantity radioactive sources. Our mode of instruction is primarily show-and-tell, including a laboratory exercise for everyone to observe which instruments are fast or slow, stable or erratic, more or less sensitive, and analog versus digital readouts. The following are some of the topics and points we will discuss during the PDC.

Choice of Instruments for Exposures. Before choosing an instrument, you first have to decide on your purpose for making a radiation measurement. For example, are you wanting to determine someone's external exposure to gamma radiation or x-rays? If so the first choice could be a standard or pressurized ion chamber. These are the only instruments that give a true reading of exposure (transfer of energy through the air) in milliroentgens per hour (or microSieverts per hour). All other instruments with roentgen scales are surrogate or secondary measurements. This does not necessarily mean they are not acceptable, as long as you understand their limitations. Standard ion chambers are slow, erratic, not very sensitive (not able to measure normal background radiation), and may be affected by air pressure (altitude) or temperature. Pressurized ion chambers are more sensitive, but only if the signal has a high enough energy to penetrate the heavy walled pressure chamber. For example, part of any x-ray signal will always have energies at 50 keV or below and most of this signal will not be measured by a pressurized ion chamber. The rule-of-thumb is that the bulk of an x-ray signal will have energies at about 1/3 of the applied voltage in the direct beam. Scattered x-rays, which we measure for safety decisions to protect people nearby, will have lower energy.

Radioactivity or Contamination Measurements. If you want to measure radioactivity (or activity,) then you should choose an instrument which will give the best response for the type of signal (alpha, beta, or gamma). The most common instrument for beta and gamma activity measurements is a Geiger-Mueller (GM) detector. There are several designs for GM detectors. The most sensitive design is called a pancake GM (a heavy metal housing of about 2 inches in diameter and ¾ inch thick). About 1/3 as sensitive is an end-window GM (a metal tube usually about 1 inch in diameter and about 5 inches long). Even less sensitive is a sidewall GM (a metal or plastic tube usually 1 inch in diameter and about 4 inches long). The least sensitive is the internal GM (tube about ½ inch in diameter and 2 inches in length. This design is the least sensitive because of its small size and because it is located internally within the meter base housing (thus, it will not detect any beta or low energy x-ray (below about 50 keV)).

The pancake and end window GM detectors are most sensitive to beta particles. If you want to measure beta radiation, either of these GM detectors could be a good choice.

However, if you want to measure gamma radiation, the beta sensitivity could be a problem. Since all gamma emitters also emit beta particles, you will always have a mixed signal unless the beta particles are shielded within a source capsule. Lack of understanding about the response of a pancake GM led to huge measurement errors a couple years ago when people were concerned about radiation from granite counter tops. A person would hold a pancake GM probe in the air to measure normal background radiation (10 microroentgens per hour is a typical reading of gamma rays from the ground (terrestrial) and from outer space (cosmic)). The person would then place the GM probe on the granite surface and show readings of 500 microroentgen per hour. This measurement was then interpreted as 50 times above normal, often with a dramatic flare to imply danger.

There are multiple errors in this reading. When a GM probe is held in the air, it will only measure gamma radiation which can be interpreted as a true measure of exposure in microroentgens per hour. However, when the same probe is brought near a granite countertop, it will pick up beta radiation from the uranium decay products. Typical sources of naturally occurring radiation from uranium, radium, and thorium (found in all materials coming from the ground) will give a reading on a GM detector which is about 90% to 95% due to beta particles. There are two issues when a GM probe is responding to a beta signal. First, readings in roentgens per hour are only defined for ionization in air for x-rays and gamma rays. Thus, the transfer of beta energy cannot be measured in units of roentgen. Second, associating risk to beta particle exposure can be very misleading because beta particles do not travel very far in the air and do not penetrate into the body. Beta particle energy deposited mainly in the skin should not be interpreted in the same way as exposure to penetrating radiation to the whole body. The other error has to do with making granite surface measurements for estimating risks. Even when a person is in contact with the granite, the center of their body is typically 30 cm or one foot away. Thus, a better measurement for safety decisions should be made at a distance of one foot.

Scintillation Detectors. These detectors commonly use a crystal of sodium iodide (NaI) which converts gamma or x-ray energy into light photons. These photons are converted to an electrical signal through a photomultiplier tube and the signal is processed as a count rate for activity measurements. They are much more sensitive to gamma and x-rays than any other detector because of high density. High density means more electrons per unit volume and the corresponding higher probability that an incoming gamma ray will strike an electron and produce a signal. These detectors are also very fast. The major limitation of scintillation detectors is that their response is highly dependent on the energy of the signal. Since all exposure reading instruments are calibrated in reference to the signal from cesium-137 (662 keV gamma), then all instruments (ion chambers, GM, or scintillation) should give the same reading for a cesium signal. However, for a signal with lower energy (which will always occur for x-rays), the scintillation detector could over respond by as much as a factor of 10 to 100. Conversely, at higher energies this detector could respond too low.

Calibration and Energy Dependence. Most people do not understand that exposure reading instruments are primarily only calibrated for a cesium signal. A radiation signal from any other source could give a very different response depending on how the instrument responds to different energies. Thus, if you do not know how your instrument responds to different energies and you do not know anything about the energy of the source, great errors could occur. Your instrument manufacturer should be able to tell you how your instrument will respond at different energies. It would be helpful to compare your instrument response with the anticipated energies which you wish to measure, so you can determine if your instrument is reading too high or too low. To account for energy differences for activity measurements the best option is to calibrate your instrument with the same source which you wish to measure.

Geometry. This has to do with the orientation of the detector to the signal. Since all radiation measurements are made by comparison, the best results are achieved by using the instrument in the same way it was calibrated. For example, a pancake GM probe is usually calibrated for activity measurements with a source positioned by a jig which holds the source at about ¼ inch from the face of the detector. Thus, all readings with this detector should be taken at a distance of ¼ inch. According to the inverse square law for point source of gamma radiation (doubling the distance reduces the signal by a factor of four), a reading taken at ½ inch is in error by 400%.

Verifying Instrument Response. When asked whether an instrument is responding properly, people often say when the instrument is on it clicks, or the calibration sticker shows that it was recently calibrated. Neither of these answers verify that the instrument is responding the same way it did at the time of calibration. The best way to verify response is to take a reading from a check source (ideally a source that will remain constant over a period of years) at the time of calibration. This check source reading should be recorded on the instrument calibration sticker. The normal steps to take before using a radiation instrument are: 1) check visually for any signs of damage to the detector, cables, or meter housing, 2) verify the battery condition, and lastly 3) take a check source reading. The normal practice is to accept readings within 20% of the original reading.

Interpretation of Measurements. Assuming that you have chosen the proper instrument, verified that it is working properly and that you are using it the same what it was calibrated, and your understand the limitations of your instrument, you may now acquire measurement data. When interpreting these measurements, it may be helpful to know there are no absolute measurements for radiation. Since radiation is random in time and direction, repeated measurements will always differ and all radiation measurements are only “best estimates.” For evaluating the quality of radiation data, you have to consider, “What quality is needed for the particular decision to be made?” The standard practice assumes that portable radiation instruments should be accurate within 20% of the true value. If this seems high, consider the discussion above which describes several factors that could cause your instrument to be in error by several hundred percent. The basic rules before making an expensive decision based on portable radiation instruments are to ask lots of questions about how the measurements were made and as a minimum confirm the measurement by repeating (ideally with a different instrument or different people). This last caution can be problematic in an emergency where the first tendency is to take quick action for protecting people.

Conclusion. We conclude this article with two questions. Is your radiation instrument telling you what you think it is and is the measurement defensible as the basis for an expensive safety decision?

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Outline for this Presentation

- Steps for defensible measurements
- Interpretation may be more about attitudes and risk perceptions, than about technology
- Two axioms on interpreting measurements
- A few anecdotes about interpretations
- Interpretation as a response to fears
- Caution leads to "precautionary principle"
- Dealing with uncertainty
- Many factors can cause measurements to be misleading

Steps for Defensible Measurements

- 1. Deciding what to measure ?
  - Exposure or contamination ?
- 2. Choosing the proper instrument
- 3. Verifying instrument performance
- 4. Using the instrument properly
  - According to calibration ?
- If you have been careful with above steps,
  - There are still countless pitfalls
  - You now have measurements to interpret

Two Axioms on Measurements

1) "Measurement results have no meaning until interpreted for a particular purpose"

They are just numbers

2) "Measurements only have a meaning in terms of how they are interpreted"

The meaning is whatever people believe

Psychology of Radiation Measurements

- Interpretation may have as much to do with attitudes and perceptions as it does with technology
- Same measurements may have different meanings for others
- Examples:
  - Technician at nuclear plant, "We got a hot one here!"
  - Industrial worker saw GM meter go off scale
  - Granite counter tops
  - Firemen observing twice background
  - Screaming GM meter

Common Aspect of Scenarios

- If its measureable, it must be bad!
- Interpretation of measurements is often a matter of responding to fears
- One person's answer for defending conservative decision, "Why take chances?"
- Common mindset
  Measurement = "Deadly Radiation"
- Risks of NOT taking action
  - Fears, criticism, responsibilities
  - Making a mistake

Questions for Interpretation ?

- What do the numbers mean ?
- Are the measurements defensible ?
- What decision do you want to make ?
- How much resources are you willing to commit on the basis of these measurements ?
- What is the risk of making a mistake ?
  - What if you act or do not act ?
  - How will you be held accountable ?
  - Possible litigation ?
  - Upset workers ? Union ? Management ?

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Making Good Decisions

- How to avoid decisions that may not be warranted by the data, false positives
  - Be skeptical, ask lots of questions before decisions
- Repeat measurements for confirmation, with other people and other instruments ideally
- Typical when finding actionable levels
  - Most want to take immediate action
- No one wants to be criticized
  - For not taking action

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Dealing with Uncertainty

- Most people do not want to deal with uncertainty, they want absolute values
- They typically do not ask questions to evaluate the data or to determine if the data are defensible
- Tendency is to assume all data are of high quality and suitable for making decisions
  - When the number is written down , it becomes reliable

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Defending Results

- Ask lots of questions
- How do you know if the data are any good ?
- Right instrument, working properly, used properly, calibration, energy dependence, geometry ?
- Report results with estimates of all sources of uncertainty,
  - Be careful of significant figures
- Always repeat for confirmation,
  - Before reporting or making expensive decisions

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Summary

- Common assumptions
  - If its measurable - it must be bad
  - Written data are always good
  - Must take immediate action
- Common to make decisions (cry wolf)
  - Without verifying the measurement
- Stay calm
- As minimum – repeat at least once
  - For confirmation, ideally with other instruments and people, if possible

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Summary

- What do the numbers mean ?
- Measurements only have meaning in terms of interpretation
- Data interpretation may be driven by fears
  - Of radiation
  - Of consequences, health risks, liabilities
  - Of making a mistake
- Is your interpretation defensible ?
- What are you willing to commit ?

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Questions ?
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