# How to Avoid Errors of Measurements and Interpretation for NORM

## (Naturally Occurring Radioactive Materials)

**Round Table 230**

**Radiation Safety in the Oil and Gas Industry**

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

**Consultant, Dade Moeller Training Academy**
Ray.johnson@moellerinc.com

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Workers at facilities handling materials coming from the ground may not know that these materials could contain NORM (Naturally Occurring Radioactive Material). Consequently, these workers may not be trained to make measurements for dealing with radiation from NORM. To assess radiation exposures, a Geiger-Mueller (GM) detector may be used without understanding the errors that can occur with count rate or exposure rate measurements. To answer questions about NORM safety, workers need to know how radiation measurements fit into eight steps for evaluating safety. These eight steps include characterizing the radiation source, measurements of exposure at locations actually occupied by workers, and knowing the duration of their exposures. Defensible measurements begin by deciding what to measure, choosing the proper meter, verifying its performance, determining where to take measurements, and using the meter properly. Common measurement mistakes for NORM include, using the wrong instrument or probe, reading the wrong scale, improper calibrations, taking readings in the wrong locations, and not considering occupancy time for assessing worker exposures. Other factors affecting NORM measurement quality include errors due to energy dependence, mistaking mR/hr vs μR/hr, including a beta signal for exposure measurements, geometry, and operator factors.

Errors of data interpretation also abound. Interpretation of measurements may have as much to do with fears of radiation as it does with technology. The bottom line is that the meaning of a measurement is whatever people believe. The big question is whether the radiation meter is telling you what you think it is? The answer will very often be "NO." There are over 20 factors that can cause a radiation measurement to be misleading. Before making expensive decisions for safety, workers are cautioned to confirm the initial measurements by repeating, ideally with different instruments and people. The best answer for concerned workers is to have them do the measurements themselves. There are two guidelines for evaluation of NORM measurements: 50 microR/hour or less for recycling decisions and 2,000 microR/hour or more for judging worker or public safety.

# Raymond H. Johnson, MS, PSE, PE, FHPS, CHP

Director, Radiation Safety Counseling Institute 301-370-8573

- 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)
- 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, 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 analysis 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 | 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. |

### *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) and Radiation Instruments School (2014). PEP, CEL and Journal Reviewer. AAHP Instructor; Treasurer, AAHP (2008 – 2011). 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 (1983-1991), 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.), Studied H.P. communication styles and presented Myers-Briggs seminars to over 3500 H.P.s since 1984. Over 35 professional society awards. Licensed 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- 2013.

Contact at: 301-990-6006, ray@radiationcounseling.org. 301-370-8573, www.radiationcounseling.org

# Oilfield Worker NORM Safety – A Few Observations

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

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**Concerns for NORM Worker Safety**

Employers of oilfield workers have a duty, according to OSHA regulations, to provide reasonable protection to workers from all hazards that may occur in oilfield operations. One of the potential hazards for oilfield workers is exposure to **Naturally Occurring Radioactive Materials (NORM).** Such exposures have become a special concern to oilfield workers who are not trained for radiation safety. Since oilfield management and workers have not received training on radiation, their natural tendency is to be very conservative on the side of safety. Because the media has continuously referred to radiation as "Deadly Radiation," since the advent of nuclear weapons and nuclear power, most everyone is now conditioned to believe all radiation is deadly and to be avoided at all costs. Most people do not understand that potential harm is related to the extent of their radiation dose. While people have died from extreme exposures to radiation, we are actually very resistant to harmful effects of radiation. Medical doctors know this from the enormous amounts of radiation needed to kill cancer cells (cancer treatment with radiation is based on the fact that cancers cells are more susceptible to damage by radiation than normal cells).

**Fears of Radiation and Radiation Mythology[1, 2]**

Because most people have only heard of radiation as "bad news," special precautions for NORM safety seem warranted. What workers do not realize is that most everything they have heard and come to believe about radiation is mythology (what is commonly believed, but not technically true). Radiation myths perpetuated by the media have come to be accepted as facts and have resulted in a universal fear of radiation. Everyone who has ever heard of radiation now

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1. **Johnson, R.H, Psychological and Mental Health Aspects of Ionizing Radiation Exposure**. Encyclopedia of Environmental Health, Elsevier Publications. October 2010. 18 pages.
2. **Johnson, R.H., Communication Issues about NORM/TENORM for Workers, the Public, and the Media** (Chapter 11, 34 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).

has an instinctive fear of radiation similar to natural fears of heights, snakes, spiders, immersion, etc. These fears are also fueled by imagination of terrible consequences anticipated as a result of radiation exposures. Some of the most popular myths include:

1. **Deadly Radiation -** This is a myth because radiation is only deadly under extreme circumstances (such as a catastrophic accident which is exceedingly unlikely to ever happen). Since ordinary aspirin can also be deadly, the analogy would be to say, "I have a headache, so I am going to take a dose of "deadly aspirin."
2. **No Safe Level of Radiation -** This is false because we are all exposed to substantial amounts of radiation all the time, without evidence of effects (we average over 300 mrem in a year (a millirem is a quantify of radiation energy deposited in our body) from natural background radiation in the US and over 20,000 mrem a year in other countries).
3. **Radiation Will Kill You –** True, but only under extreme conditions. Only 29 people have died from documented radiation exposures in the US since 1945.
4. **Radon and CT Scans are OK –** This is false. Radon is the largest source of all natural radiation exposures (much greater than NORM or any other radiation workers will likely ever receive on the job) primarily in our homes averaging over 200 mrem in a year in the US at an average radon level of 1.3 pCi/L. CT scans can result in 1,000 to 2,000 mrem or more per scan. Many people seem to believe that radiation which is naturally occurring or doctor prescribed does not count.
5. **Radiation Will Make You Glow –** This is false and the origin of this myth is unclear.

Such myths are popular because they explain the mysteries of radiation in simple terms that do not require any technical understanding. These myths are also generally accepted because they are aligned with what everyone has heard repeatedly through the media for decades.

**The Power of Images Behind Radiation Fears**

Psychologists know that all fears can be tracked back to underlying images. The person fearful of radiation does not know that their fear is related to any particular image, they just know and feel that their fear is prudent and justified. Most everyone can recall horrible pictures of persons injured in Hiroshima or Nagasaki. It is interesting to note, however, that most people do not recall such images in relation to radon exposures or CT scans. Since terrifying images are related to feelings and fears for survival. Unfortunately, better technical information may not change people's views. Thus, even when people appear to understand the technical basis for radiation safety, when suddenly confronted with a need to make a safety decision, they may automatically revert to their images of consequences and what they have heard for their lifetimes (mostly mythology).

**Industry Guidelines for NORM Safety**

There are no federal or national regulations for NORM and only a few states have developed their own regulations, mainly related to the oil and gas industry. In many states, such as California, the oil industry has had to set its own guidelines for safety. For example, the American Petroleum Institute issued guidelines in 2006[3]. Unfortunately, while this bulletin contains much good information, it also perpetuates common mythology. For example, in Section 1- General - it states, *"If body tissues or organs are exposed to excessive radiation, biological damage can occur in the individuals exposed or in their descendants, increasing their risk of cancer and birth defects."* The first part of this quote is true, although it gives no indication on what "excessive" means and for many people that is any radiation above zero. The second part about "birth defects" is false. No birth defects on descendants have ever been identified[4.] API Bulletin E2 goes on to define NORM impacted equipment as any equipment for which the external radiation levels exceed direct radiation levels specified by the State. This leaves the definition ambiguous when the State does not have regulatory limits for NORM.

In lieu of specific State guidance, Suggested State Regulations for Radiation Control may be useful[5.] These regulations only apply to licensed sources of NORM. However, two guidelines may be considered,, namely; 1) the limit of 100 mrem in a year (100,000 microRoentgen - μR) for NORM exposures to the public (a member of the public is anyone not trained for radiation safety), and 2) to release metal for recycling the exposure level on any accessible surface should be less than 50 μR /hr including background radiation. Some recycling facilities have more restrictive limits, such as 25 μR /hr. While that limit may assure the facility does not incorporate NORM into its recycling process, that recycling limit should NOT be used to designate limits for worker safety for many reasons. First of all the recycling limit is to assure that recyclers can sell their product without public fears of contamination with radioactive material. Secondly, even at a surface exposure rate of 50 μR /hr a worker would have to be in continuous contact with the metal surface for a working year of 2,000 hours to reach the annual public limit of 100 mrem. For short exposure times the USNRC specifies a public limit of 2,000 μR in an hour. Depending on the length of time handling a particular piece of NORM contaminated equipment, the limits could be 4,000 μR /hr for 30 minutes, or 8,000 μR /hr for 15 minutes, and so on.

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3. **Bulletin on Management of Naturally Occurring Radioactive Materials (NORM) in Oil and Gas Production**. API Bulletin E2, Second Edition, April 2006.
4. **US. Nuclear Regulatory Commission. Regulatory guide 8.29. Instruction Concerning Health Risks From Occupational Radiation Exposure.** USNRC, Office of Nuclear Regulatory Research, Washington, DC. February 1996.
5. **Regulation and Licensing of Technologically Enhanced Naturally Occurring Radioactive Material (TENORM).** Part N, Suggested State Radiation Control Regulations, SSRCR Volume 1, 2004, Available from the Conference of Radiation Control Program Directors at CRCPD.org.

**Measurements of NORM**

Many errors can cause measurements of NORM to be very misleading. Some of these errors include;

1 In many cases measurements are made with the wrong detector for a particular safety decision
2 The instrument is not calibrated for NORM
3 The instrument is not used as it was calibrated.
4 Mistaking beta particle measurements as gamma radiation
5 The measurements are made in the wrong location.

Some facilities use Geiger Mueller (GM) detectors for measuring count rates when they should be using an exposure measuring instrument to determine worker safety. Also ideally, NORM measurement instruments should be calibrated with a NORM source, such as radium-226. Instruments normally calibrated with cesium-137 could give readings too high or too low by factors of two or more. Some instruments, such as a pancake GM, also respond to a beta particle signal which cannot be measured in units of μR/hr. Since all NORM emits beta particles, exposure readings on a GM detector could be too high by a factor of 20 due to beta particle interference. To obtain a true measure of exposure in μR /hr, the beta signal has to be blocked by a piece of plastic for shielding. Another common error is to make surface exposure readings without considering the location of workers and whether they actually have any significant time in contact with the NORM surface.

**Interpretation of NORM Measurements[6]**

Some of the common errors in the interpretation of NORM measurements include;

1. Attempting to assess worker health risks on the basis of count rate measurements. Such measurements may be used to determine whether one reading is higher or lower than another, but they cannot be used to assess health risks. Also, such readings may be mainly due to short lived decay products of radon (lead- 214 and bismuth-214), which will decay away in four hours (if not continuously replenished from radon).
2. The second most common error is to assign radiation doses tor workers based on exposure readings taken on a metal surface (such as a pipe) without considering the location of workers or the occupancy time in connection with the surface reading. API Bulletin E2 recommends measurements at one foot and one meter away from a NORM contaminated item (without regard to where workers are located). However, to assess actual radiation dose to workers, it is important to take measurements at occupied locations and also take into account the occupancy time.
3. As noted above, mistaking a beta signal for a gamma signal can result in readings that are too high by a factor of 20.

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6. **Johnson, R.H, and Kenoyer, J. Is Your Radiation Instrument Telling you What you Think it is?** Technical article for the American Industrial Hygiene Association monthly magazine, *The Synergist*, March 2012. 3 pages.

## Practical Considerations for NORM Safety

When NORM is encountered at facilities where radiation is not expected and no one has training for radiation safety, the tendency is to drastically over protect. Many facilities treat NORM as if any radiation exposure is "deadly." Getting NORM on your skin or clothing is NOT necessarily dangerous. Since all soil contains NORM, getting dirt on your hands or clothing should be handled in the same way that workers would protects themselves on any dirty job by wearing coveralls and gloves. Such NORM can be removed by washing.

Inhalation of NORM may also not be a hazard by itself. If the air is so dusty that respiratory protection is needed, then that protection will also minimize inhalation exposures to NORM. In most cases a throwaway P95, N95 or R95 particulate mask will be adequate. Actions to protect workers should be commensurate with the amount of actual NORM exposures. No special precautions are needed for exposures less than 2,000 μR in an hour (unless these exposures would add to 100,000 μR in a year). Decisions for safety should be based upon actual measurements of worker exposure (with appropriate instruments) taking into account worker locations and actual contact time with NORM. Measurements at one foot or one meter from a NORM contaminated object have no meaning unless that location is occupied a significant amount of time. Workers who handle NORM should also know that our hands are very resistant to harm by radiation.

## Summary and Conclusions

Management and workers without training for radiation safety and encountering NORM for the first time are typically very fearful of potential radiation exposures. Fears of radiation have been fostered for decades by radiation mythology propagated by the media. These fears may lead to extremely conservative practices for radiation safety that may actually increase worker risks (excessive protective clothing can cause heat stress). Fears may also be compounded by radiation measurements with inappropriate instruments or taking readings on surfaces or other locations without consideration of worker locations or occupancy time. Radiation instruments are also not usually calibrated for NORM sources and consequently the measured values may not be true measures of NORM.

State and industry guidelines for radiation safety are lacking, ambiguous, or misunderstood. The greatest misinterpretation of guidelines is the use of recycling limits as an indication of hazard to NORM workers. The very low limits for recycling (such as 25 μR /hr) are based on fears that the recycled product will not be saleable if people believe it is consummated with NORM or any radioactive material. The recycling limit was never intended to be a limit for protection of workers. Trained NORM workers are allowed 5,000,000 μR in a year or 2,500 μR /hr for continuous exposure. (a 4 – 5 hour class on NORM Safety would qualify workers as trained radiation workers). Untrained workers are allowed 2,000 μR in an hour or 100,000 μR in a year. Normal coveralls may also provide adequate protection from contamination with NORM and throwaway P95, N95, or R95 dust masks may be adequate for inhalation protection.

Ray Johnson, MS, PSE, PE, FHPS, CHP, is a 50 year career specialist in radiation safety. He currently directs the Radiation Safety Counseling Institute where he provides consulting, training, and counseling on issues involving radiation safety. He has been a Certified Health Physicist for 33 years and specializes in radiation instruments, nuclear gauges, industrial x-ray, NORM, and radiation risk communication. He has trained over 3,500 radiation safety officers since 1985. He is a past president of the Health Physics Society and the American Academy of Health Physics and has over 600 publications and presentations on radiation safety.

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## How to Avoid Errors of Measurements and Interpretation for NORM

Ray Johnson, MS, PE, PSE, FHPS, CHP, Director
Radiation Safety Counseling Institute
ray@radiationcounseling.org
301-370-8573

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## Situation

- Workers handling materials from the ground may not know that everything coming from the ground contains NORM
- Workers may become alarmed when learning they have NORM in their workplace
- They are Not hired or trained to deal with radiation
- Easy to obtain a GM or NaI radiation meter and begin measurements without understanding the limitations of such meters

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## NORM Fears - Examples

- Paper Mill
  - Industrial worker saw GM meter go off scale
- Oil Field Workers
  - Classifying pipe as "radioactive"
- Granite counter tops
  - Misunderstanding measurements
- Screaming GM meter
  - Hard to ignore

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## Situation

- Our five senses do not tell us of radiation
- From lack of understanding, workers may react with alarm and make poor decisions for safety
- Interpretation of measurements is often a matter of responding to fears
- Hearing a Geiger counter may lead to the conclusion, ***"If its measurable, it must be bad"***

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## Is It Safe?

- To answer this question workers may obtain a GM meter and make measurements without knowing how the meter responds to NORM
- Radiation Instruments are often misused
- Measurements are often misunderstood
- Decisions are made on count rates or exposures measured in the wrong places

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## How to Answer "Is it Safe"

1. What are properties of radiation
   - $\alpha$, $\beta$, $\gamma$, x-ray ?
   - Form and quantity ?
2. Where is it located - Inverse square law ?
3. How is it contained - Shielding ?
4. How will it move in the environment ?
5. What are the exposure conditions – mR / hr ?
6. What is the duration of the exposure – hr ?
7. How much energy is deposited in our body - mrem ?
8. How does this compare with limits or guidelines?

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## Good Decisions for Radiation Safety

- We rely upon good measurements to tell us the type and amount of radiation
- Big questions ?
  - Why are you making measurements ?
  - Is your radiation instrument telling you what you think it is ?
  - What can go wrong ?
  - How good do the data need to be ?

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## Steps for Defensible Measurements

1. Deciding what to measure ?
   Exposure (mR / hr) or activity (cpm) ?
2. Choosing the proper meter
3. Verifying meter performance
4. Deciding where to take measurements
4. Using the meter properly
   According to calibration ?
5. If you have been careful with the above steps,
   - You now have measurements to interpret
   - There are still countless pitfalls

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## Choosing the Right Meter ?

- What is your need for data?
- Exposure or activity measurements?
- What decisions do you want to make?
- May have to rely on an available meter
- Could be marginal or totally inadequate

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## Verifying Meter Operation

- How do you know if your meter is working properly ?
- Battery check ?
- Check source response ?
  - Appropriate source ?
- Possible probe or cable failure ?
- Current calibration ?

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## Proper Instrument Usage

- Calibration conditions
  - Reproduce calibration conditions for defensible measurements
- Geometry conditions (Positioning)
  - How was meter calibrated ?
- Speed of probe movement

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## Where to Take Measurements ?

- Common to take measurements in contact with a pipe surface
- OK for recycling decisions
- Not useful for determining worker exposures – mR / hr
- Better to measure exposure at locations actually occupied by workers
- Take into account occupancy time

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## Interpretation of Radiation Measurements

- What do the measurements mean ?
- Interpretation may have as much to do with attitudes and perceptions as it does with technology
- Is interpretation based on fears ?
- Same measurements may have different meanings for others
- What decisions are warranted by the measurements ?



## 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



## Questions for Interpretation ?

- What decision do you want to make ?
- How good do the measurements need to be ?
- What do the numbers mean ?
- Are the measurements defensible ?
- 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 ?



## Questions for Interpreting Radiation Measurements

- Radiation is a random event
  - Random in time and direction
- What does this mean for measurements ?
  - All measurements are "best estimates"
- How do we determine the quality or uncertainty of a measurement ?
- How good does the measurement have to be for a defensible decision ?
- How much money are we willing to spend ?



## Quality of Portable Instruments

- NIST standard may be within + / - 5 %
- Calibrations may be within + / - 10 %
- Rule-of-thumb, + / - 20 %
- Allowance for uncertainty affected by:
  - Choosing right instrument
  - Is it working properly ?
  - Is it calibrated properly ?
  - Is it used properly ?
  - How does instrument respond to different energies ?



## 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

## 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, ideally with other people and other instruments
- 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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## 9 Factors Affecting Quality

1. Wrong detector or wrong probe
2. Calibration conditions – Cs-137 for mR / hr
3. Energy dependence - most NORM is lower energy
4. Misreading decade multiplier or full scale
5. Misreading mR / hr vs μR / hr
6. Including beta in mR / hr measurements
7. Geometry
8. Operator fatigue and judgments
9. Backscatter and self absorption

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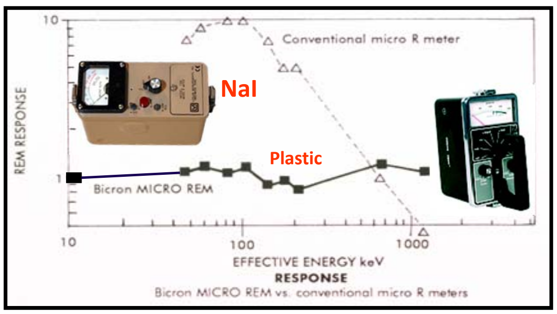
## NaI and Plastic Scintillator Energy Response

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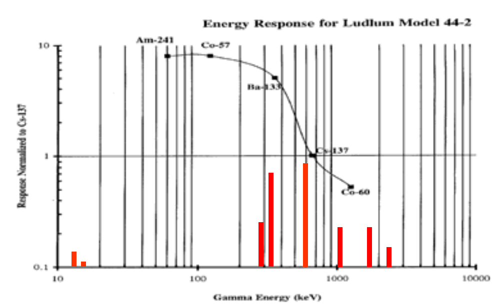
## NaI Energy Response

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## Effect of Energy Response

- NaI could read too high by factor of 1.5 to 2
- Thus, readings are conservative for safety
  - Would you want a meter that reads too high or too low ?
- The regulatory guideline is 2 mR in an hour
  - If your meter reads 1 mR / hr, then you are definitely below 2 mR / hr

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## Operator Factors

- Operator Judgments
  - Choice of detector ? (what do you need to measure)?
  - How fast to move the probe?
  - How thorough to scan?
  - How close to the surface (geometry) ?
- Operator fatigue
  - What happens to judgments and quality of readings when operator becomes tired?

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## Factors Affecting Uncertainty in Radiation Measurements

1. Radiation is random
2. Variation in standards
3. Sensitivity of instruments
4. Counting time
5. Amount of radiation
6. Background and variations

1. Geometry
2. Uniformity of samples
3. Sample location
4. Sample selection bias
5. Sample preparation
6. Volume and weight errors

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## Evaluation of Data ?

- Ask lots of questions
- How do you know if the data are any good ?
- Right instrument, working properly, used properly, calibration, energy dependence, geometry, operator factors ?
- Always repeat for confirmation,
  - Before reporting or making expensive decisions
- Compare with guidelines
  - 50 microR / hr or less for recycling
  - 2,000 microR / hr for public (or worker) exposures

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## Have Workers Do Measurements

- Best answer to, “Is it Safe”
  - Have workers do their own measurements
  - Compare with background – 10 microR / hr
  - Compare with radioactive antiques
  - Compare with regulations
    - 2 mrem in an hour
    - 100 mrem in a year
- Best to enable workers to answer their own questions

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## Summary

- Workers may react with alarm when hearing a Geiger counter
- Interpretation of measurements is as much about fears as technology
- Measurement is only one piece of information
  - Eight steps to answer, “Is it safe”
  - Most important – exposure rate & duration
- Encourage workers to make their own measurements

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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, 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
  - Making a mistake
- Is your interpretation defensible ?
- What are you willing to commit ?

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## Summary

- **We rely on instruments to tell us of radiation**
  - **Choice of instrument, working properly,**
  - **Using it properly (according to calibration)**
- **Is our radiation meter telling us what we think it is ?**
  - **At least 20 sources of errors in readings**
- **Measurements are only numbers until interpreted – meaning is what is believed**

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## Questions ?

ray@radiationcounseling.org
**301-370-8573**

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