Gallagher, Carol

Subject: FW: Comments on Interim Staff Guidance FSME_ISG-01 Evaluations Of Uranium Recovery Facility Surveys Of Radon And Radon Progeny In Air And Demonstrations Of Compliance With 10 CFR 20.1301

Attachments: C Bladey_27MAY14_Comments Rn Guidance.pdf

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2

-----Original Message-----
From: sbrown@senesusa.com [mailto:sbrown@senesusa.com]
Sent: Tuesday, May 27, 2014 4:55 PM
To: Gallagher, Carol
Cc: Schmidt, Duane
Subject: Comments on Interim Staff Guidance FSME_ISG-01 Evaluations Of Uranium Recovery Facility Surveys Of Radon And Radon Progeny In Air And Demonstrations Of Compliance With 10 CFR 20.1301

Ms. Gallagher

Please find attached our comments on the subject NRC interim draft guidance. We would be most appreciative if receipt could be acknowldeged via "reply" to this email. thank you very much

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May 27, 2014

Cindy Bladey
Chief, Rules, Announcements, and Directives Branch (RADB)
Office of Administration,
Mail Stop: 3WFN-06-44M
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: Comments on *Interim Staff Guidance FSME_ISG-01 Evaluations Of Uranium Recovery Facility Surveys Of Radon And Radon Progeny In Air And Demonstrations Of Compliance With 10 CFR 20.1301 Revised Draft Report for Comment*– Federal Register Volume 79, Number 59 (Thursday, March 27, 2014) - Notices - Pages 17194-17195

Dear Ms. Bladey:

We are pleased for the opportunity to submit the following comments on the subject draft interim NRC staff guidance.

General Comments.

NRC is to be commended for the improvements made relevant to the previous version of this draft and for the diligence in which previous comments have been considered and responses documented. Nonetheless, several basic overarching requirements that seem to underpin the detail presented in the guidance remain challenging to accomplish. These are:

- Although NRC recognizes that under some circumstances calculations alone have been an acceptable way to demonstrate compliance with public dose limits in the past, the guidance appears to state that field measurements must be made to validate any calculations that have been used and is the fundamental method to demonstrate compliance with the public dose limits at 20.1301.

- The default annual average radon concentration in unrestricted areas that must be used per 10CFR20, Appendix B is 0.1 pCi per liter which assumes 100% equilibrium with radon progeny (EF =1) vs. the 10 pCi per liter value in 10CFR20, Appendix B which assumes no progeny present, (EF = 0). The guidance is not clear if historical references from the literature presented in the document would be acceptable to the staff to demonstrate compliance in the absence of site specific measurements of progeny equilibrium at numerous locations of interest (points of compliance).

The draft guidance provides comprehensive identification of the many factors which affect the ability to measure radon and progeny in the environment at these very low levels, of the variable environmental conditions that affect radon / progeny concentrations at any given time as well as providing many relevant references from the technical literature including from other NRC documents. Nonetheless, the guidance to staff remains unclear regards to whether or not a licensee can demonstrate compliance without definitive measurements at such low levels relative to natural background of radon, recognizing its inherent temporal variability (time of day, season of year) and potential variability over relatively short distances due to local mineralization, surface features, etc.

First Principles:

It is believed helpful to initially recognize previously stated regulatory positions and/or guidance by NRC on acceptable methods to demonstrate compliance with the fundamental dose limits of 10 CFR 20.1301, as specifically related to the issue of "by measurement vs. calculation". Examples follow:

1. From 10 CFR 20.1302 *Compliance with dose limits for individual members of the public.*

(b) A licensee shall show compliance with the annual dose limit in § 20.1301 by…

(1) Demonstrating by measurement or calculation that the total effective dose equivalent to the individual likely to receive the highest dose from the licensed operation does not exceed the annual dose limit;………

Author Note: 10 CFR 20.1302 clearly states that calculational methods, without reference to "verification by measurement" can be acceptable methods for demonstrating compliance to the fundamental public dose limits in 10CFR20.1301

2. NUREG 1156 – *Consolidated Guidance about Materials Licenses* (2001), Vol. 11, Appendix Q – *Methodology for Determining Public Dose*

The licensee may show compliance with the annual dose limit for individual members of the public by:

Demonstrating by measurement or calculation *that the TEDE to the individual likely to receive the highest dose at the boundary of the unrestricted area does not exceed **I** mSv (100 mrem).*

Demonstrating that the annual average concentration of radioactive material released in gaseous and liquid effluents at the boundary of the unrestricted area does not exceed *the values specified in Table 2 of Appendix B to Part 20.*

In order to perform a dose assessment, the licensee should identify all potential sources of external and internal radiation exposure to members of the public. The licensee must then take radiation measurements or perform calculations to demonstrate compliance.

Author Note: Following this introduction, the document then provides detailed guidance for acceptable methods to demonstrate compliance via both "by measurement" and "by calculation"

3. NUREG-1501 (1994), *Background as a Residual Radioactivity Criterion for Decommissioning* states the following:

In areas where background is both high and widely variable, the ability to assess facility–related radionuclides becomes increasingly difficult. Even with the application of state-of-the-art measurement techniques and the collection of large amounts of radiological data, radiological dose limits for some radionuclides cannot be measured with sufficient certainty using current survey techniques.

Authors Note: This document was an Appendix to the *Generic Environmental Impact Statement in Support of Rulemaking on Radiological Criteria for Decommissioning of NRC-Licensed Nuclear Facilities.* The associated discussion recognized that in some circumstances, e.g., those involving residual contamination from naturally occurring radioactive materials, the ability to "measure" very low levels of residual contamination relative to the natural background of these radionuclides, which can be several times higher, is not technically feasible and calculational methods must be used.

Summary of "First Principles": These existing NRC regulations and previously published NRC guidance that appear to be quite relevant should be acknowledged in the radon guidance document.

Overview of Key Issues

Some important difficulties associated with demonstration of compliance by measurement of radon in unrestricted areas, applying the annual average concentration associated with the 50 mrem per year limit (from which the 10CFR20, Appendix B, Table 2 values have been derived) can be summarized as follows:

1. Measurement of 0.1 pCi/l (or even a few tenths pCi/l) radon in air relative to a variable natural background which can be upwards of 5 – 10 times greater than this.
2. Establishing an appropriate progeny equilibrium factor a relatively short time and distance from its emission point considering that when the radon is initially released from its source ("fresh radon") from water or tailings impoundments, well heads, header houses, ISR plant IX systems, etc., the radon is essentially absent of progeny

(EF close to 0).It is the progeny, not the radon gas itself, that delivers the majority of dose to the exposed individual.

3. Adequacy of the precision and accuracy at these very low radon concentrations of the current "state of the art" of technologies currently being used for measurements of environmental radon (primarily via passive alpha – track detectors)

The remainder of this general comment section provides some thoughts and hopefully some insights regards to items 1 and 2 above. For the circumstances and recently identified issues relating to the precision and accuracy of the radon alpha track detectors being used today and potential improvements to be made, these subjects have been addressed in detail by Dr. Mark Salasky's presentation (Landauer) at the NRC's public meeting radon workshop in Bethesda on 2 April 2014 entitled "Radtrak Landauer Radon Manufacture, Calibration and Detection Limits", as well as in detailed comments provided by others on this draft guidance (e.g., see comments of the Wyoming Mining Association).

Regards to item 1 above, the circumstance of the variable natural radon background, the presentation at the NRC's public meeting radon workshop in Bethesda on 2 April 2014 by Dr. Douglas Chamber's addressed these challenges in detail (*Comments on Measuring Long-Term Average Radon Levels)* and is provided here as Attachment A. The objective of Dr. Chamber's presentation was to provide a short commentary on natural levels of ambient radon, and selected comments on challenges of measuring small incremental (above background) levels of Rn-222

Dr. Chambers's summary and observations on this subject included the following:

- Background levels of ambient Rn-222 are quite variable
- Variation in background levels of Rn-222 are > 0.1 pCi/L
- The detection level of track etch detectors is > 0.1 pCi/L
- Challenging, and <u>perhaps not possible</u>, to measure such small increments with any precision
- A bright-line approach doomed to failure
- Consider combination of modelling (MILDOS) with "appropriate" confirmation by measurement (but must acknowledge limitations and use of statistical test)

Difficulty # 2 above, relates to the establishment of an appropriate equilibrium factor which is critical since the progeny concentration associated with the radon is what essentially determines the resultant dose. The difference between the two extremes, i.e., EF = 1 (100% progeny equilibrium) and EF = 0 (w/o progeny) results in the differences in the 10CFR20, App. B annual average concentration limits respectively of 0.1 pCi/l vs.10 pCi/l.

Section 4.9.3.1 of the Draft Radon Guidance, *Outdoor equilibrium factor by travel time,* recognizes and describes some of the basic principles of the physics associated with ingrowth of radon progeny from a fresh source (per Evans 1969) and how travel time as a function of wind speed and distance could be used to estimate the progeny EF at a point of compliance at near to site unrestricted areas. However, the Draft Guide appears to dismiss the acceptability of method since *wind speeds are characterized by a distribution of wind speeds that is generally not close to a uniform distribution…use of an average wind speed may not provide a reasonable* *basis for an estimate of travel time and determination of average equilibrium factor.*

It must be noted that the unrestricted area concentrations presented in 10CFR20, App B, Table 2 are annual average concentrations, i.e., if the individual were exposed to this average concentration continuously for one year, they would receive a dose of 50 mrem. These concentrations are not "ceiling values' for which an instantaneous exceedance would constitute a non compliance. Accordingly, we suggest that use of average annual meteorological conditions, i.e., the annual wind rose (speeds, directions, frequencies) is appropriate for this purpose. A detailed discussion involving use of the physics described in Evans 1969 involving several representative combinations of distance and wind speed is presented in Appendix B, This analysis suggests that at typical distances of interest from the licensed areas (e.g., 1-2 km) and at several example annual average wind speeds representative of the environs of uranium recovery facilities in the Western US, progeny equilibrium factors are expected in the range of 0.1 - 0.3.

Specific Comments

Page 7, Flowchart:

This figure indicates in the upper box that the default equilibrium factor (EF) = 0.5 but nonetheless, the flowchart uses the 10CFR20, Appendix B value of 0.1 pCi/l (with daughters present) as the critical value in the decision box " Is net radon value less than or greater than App B value (0.1pCi/l)" which is based on an EF = 1. For an EF = 0.5, the annual average radon concentration limit would be 0.2 pCi/l. This appears to be a conflict in the flowchart and should be corrected.

Page 10, Section 4.1: Defines surveys as measurements or calculations of levels of radiation or concentrations of radioactive material.

Note that this is consistent with the requirements in 10CFR20.1302 that:

(a) *The licensee shall make or cause to be made, as appropriate, surveys of radiation levels in unrestricted and controlled areas and radioactive materials in effluents released to unrestricted and controlled areas to demonstrate compliance with the dose limits for individual members of the public in § 20.1301.*

(b) *A licensee shall show compliance with the annual dose limit in § 20.1301 by...*

(2) *Demonstrating by measurement or calculation that the total effective dose equivalent to the individual likely to receive the highest dose from the licensed operation does not exceed the annual dose limit*

Accordingly, in lieu of the ability to make meaningful measurements, as can be the case with low levels of naturally occurring radioactive materials in the environment, NRC states that calculations are an acceptable method for demonstrating compliance with the public exposure criteria of 10CFR20.1301. The guidance document should so state this and reference the applicable NRC regulations at 10CFR20.1302 and other relevant NRC guidance, e.g., NUREG 1156 and 1501 as discussed previously in these comments.

Page 11, Section 4.2: Reference to NUREG 0859 as a basis for requiring environmental monitoring during operations to demonstrate compliance with public dose limits.

NUREG 0869 is entitled *Compliance Determination Procedures for Environmental Radiation Protection Standards for Uranium Recovery Facilities 40 CFR Part 190* (1982). This report describes the procedures used within NRC's Uranium Recovery Licensing Branch for evaluating compliance with EPA regulations at 40 CFR 190 for uranium milling operations. The report contains descriptions of these procedures, dose factors for evaluating environmental measurement data, and guidance to the NRC staff reviewer. However, since 40 CFR 190.10 explicitly excludes radon and progeny from its stated public dose limits, this reference is not relevant since it is not applicable to measurement of radon and/or progeny in the environment.

Page 13, Section 4.2.2: Suggests the need for measurement of operational process parameters to calculate radon releases

This is a good suggestion but can be quite challenging due to the difficulties associated with accurate measurements of radon in solutions and process flow rates at multiple locations, temperature and pressure conditions at points of releases, etc. However, the literature indicates this was attempted a few times some years ago. Perhaps it appropriate to reference the following:

> Marple L and Dziuk T, 1982. *Radon Source Terms at In Situ Uranium Extraction Facilities in Texas*. In: Proceedings of the Sixth Annual Uranium Seminar. South Texas Minerals Section AIME. Corpus Christi, Texas. September 11-14, 1982.
>
> Brown S and Smith R, 1980. *A Model for Developing the Radon Loss (Source) Term for a Commercial In Situ Leach Uranium Facility*. In: M Gomez (Editor), Radiation Hazards in Uranium Mining – Control, Measurement and Medical Aspects, Soc. Min. Eng., pp 794-800

Page 13, Section 4.3: Discussion that "unlicensed material" should not be considered as part of natural background.

Several places in 10CFR20 are clear that the purpose of the regulations is to establish standards for licensed material and that "background" does not include it:

> 10 CFR Part 20 defines background as follows:
>
> *Background radiation means radiation from cosmic sources; naturally occurring radioactive material, including radon (except as a decay product of source or special nuclear material); "Background radiation" does not include radiation from source, byproduct, or special nuclear materials regulated by the Commission.*
>
> 10 CFR § 20.1001 Purpose states:

(a) The regulations in this part establish standards for protection against ionizing radiation resulting from activities conducted under licenses issued by the Nuclear Regulatory Commission.

(b) It is the purpose of the regulations in this part to control the receipt, possession, use, transfer, and disposal of licensed material by any licensee in such a manner that the total dose to an individual (including doses resulting from licensed and unlicensed radioactive material and from radiation sources other than background radiation) does not exceed the standards for protection against radiation prescribed in the regulations in this part

10 CFR § 20.1301 Dose limits for individual members of the public states:

(a) Each licensee shall conduct operations so that -

(1) The total effective dose equivalent to individual members of the public from the licensed operation (bold added) does not exceed 0.1 rem (1 mSv) in a year,

Accordingly, it appears that the limitation to licensed operations in 10 CFR Part 20.1301 is restrictive and essentially confines doses from radon to such operations.

Page 14, Section 4.3: References NUREG -1501 for discussion of variability of background

On this issue NUREG-1501 states the following:

"*In areas where background is both high and widely variable, the ability to assess facility–related radionuclides becomes increasingly difficult. Even with the application of state-of-the-art measurement techniques and the collection of large amounts of radiological data, radiological dose limits for some radionuclides cannot be measured with sufficient certainty using current survey techniques.*"

Accordingly, as discussed previously in these comments, NRC has recognized that for some circumstances, e.g., low levels of naturally occurring radioactive materials in the environment, it may not be possible to be measured and therefore, by implication, calculations are necessary to demonstrate compliance to the dose limits.

Page 16, Section 4.5: Reference to NRC Health Physics Position 223 (HPPOS -223)

This position statement primarily addresses uncertainties associated with analytical or instrumentation measurements i.e., the variability and uncertainty of measurement techniques regarding a physical parameter which is itself in fact a constant. An important aspect of the "uncertainty" related to measurement of relatively low levels of radon in the environment is a result of the variability of the parameter itself that is being measured as a function of time (diurnal and seasonal variation, e.g.). The "uncertainty" being discussed by HPPOS-223 is not directly relevant to the circumstances of the variability of radon concentrations due to the variability of the physical parameter itself (i.e. background concentration as function of time of day, time of year, etc.). Accordingly, this distinction should be clarified regarding the applicability of the reference to HPPOS –223.

Page 17, Section 4.6: Discussion on sensitivity of the Kusnetz method for environmental measurements.

As NRC suggests in the guidance document, the use of the Kusnetz method for environmental measurements may not achieve the desired sensitivity and accuracy. Regulatory Guide 8.30 - *Health Physics Surveys In Uranium Recovery Facilities* (Section 2.3) provides direct methods for determination of Lower Limits of Detection (LLDs) for the modified Kusnetz Method. It is suggested that this information be included in the radon guidance document.

Note that at a radon concentration of 0.1 pCi/l at 100% equilibrium and since 100 pCi/l of radon in equilibrium with its alpha emitting progeny by definition equals 1 WL; 0.1pCi/l = 0.001 WL which is below the practical lower limit of 0.03 working level suggested in Regulatory Guide 8.30 and below the 0.025 WL calculated in the example presented in Appendix B to the guide. This suggests that progeny concentrations at the very low environmental levels of interest here using the Kusnetz (or similar) methods cannot be directly measured.

It is also of note that the MILDOS code does calculate progeny concentrations at user designated compliance points of interest and uses this to estimate dose at that location. The general implication in other portions of the guidance document that licensees have been ignoring public dose contributions from radon progeny does not appear to be correct

Page 21, Section 4.9.2: Discussion on NCRP guidance on equilibrium factors (EF)

The values suggested as "default" by NCRP are from 0.5 – 0.7 and therefore it follows that the assumption of EF = 1 is probably not reasonable. Accordingly, the 10CFR20, Appendix B annual average concentration limit of 0.1 pCi/l (assuming EF = 1) should be greater if NCRP recommended values are used. NRC states that they do not have a technical basis for endorsing an EF value lower than upper range of NCRP recommendation, i.e., EF = 0.7. Then this value could be used as a default in the absence of other site-specific data. The guide should state this.

As previously discussed herein, Appendix B to these comments provides a detailed discussion of an approach to estimate site specific EFs involving use of the physics described in Evans 1969 by using several example representative combinations of distance and wind speed. This analysis suggests that at typical distances of interest from the licensed areas (e.g., 1-2 km) and at several example annual average wind speeds representative of the environs of uranium recovery facilities in the Western US, progeny equilibrium factors are expected in the range of 0.1 - 0.3. This approach could be used as "site specific data" in lieu of the NCRP defaults discussed above. See the previous discussion on this herein.

Page 30, Section 4.13

The example used that suggests, "radon measurements are made each time the vendor visits the site" is probably not realistic. Numerous vendors can visit a uranium recovery site in the course of a week and expecting the health physics staff to follow them around taking measurements during each visit is not practical or reasonable. Rather, a few representative locations relevant for typical vendor visits could be modeled or measured.

We appreciate the opportunity to have provided the above comments. We would of course be most willing to answer any questions or provide clarifications on our comments at a subsequent time if it is of interest to NRC.

Regards

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Attachment A

Comments on Measuring Long-Term Average Radon Levels

Presented To:

NRC Workshop on Evaluation of Radon and Radon Progeny in Air and Compliance with 10CFR20.1301 and (2)

Presented By:

Douglas B. Chambers, Ph.D.

April 2, 2014

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Objective

- Not a detailed critique of interim Guidance, rather

  a short commentary on natural levels of ambient radon, and selected comments on challenges of measuring small incremental (above background) levels of Rn-222

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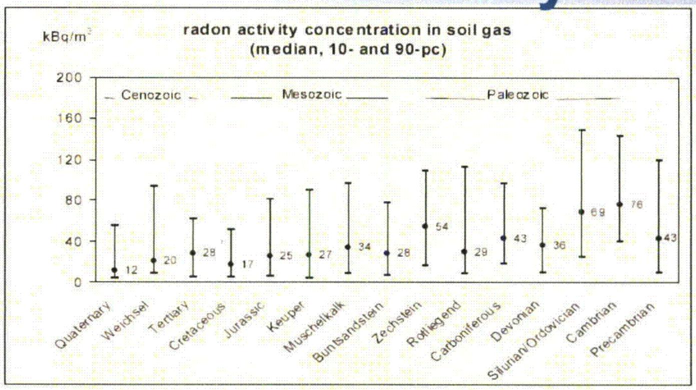
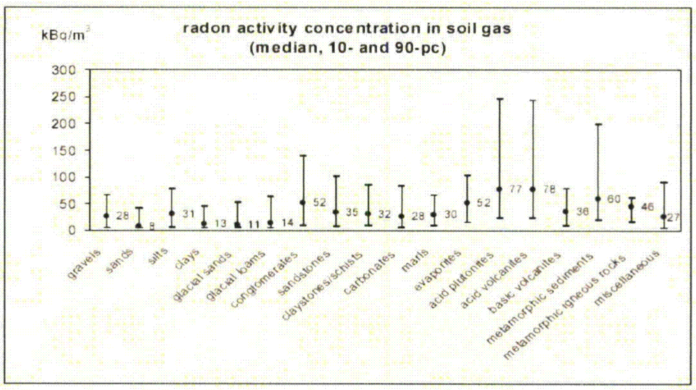
Outdoor Radon

- **Radon released from Ra-226 in soils is the single largest source of Rn-222 in the atmosphere**
- **Radon levels in outdoor air are affected by the regional geology**
- **Studies of outdoor air in Nevada indicate a median statewide concentration of 0.4 pCi/L with outdoor concentrations of up to 1.4 pCi/L (Price 1994)**
- **Radon levels change diurnally and by season**
  - radon concentrations typically reach their maximum in the summer to early winter, whereas from late winter to spring, concentrations are usually at a minimum as a result of meteorological changes and soil moisture conditions (NAS 1999).

Radon Concentration in Soil gas of Sedimentary Rocks

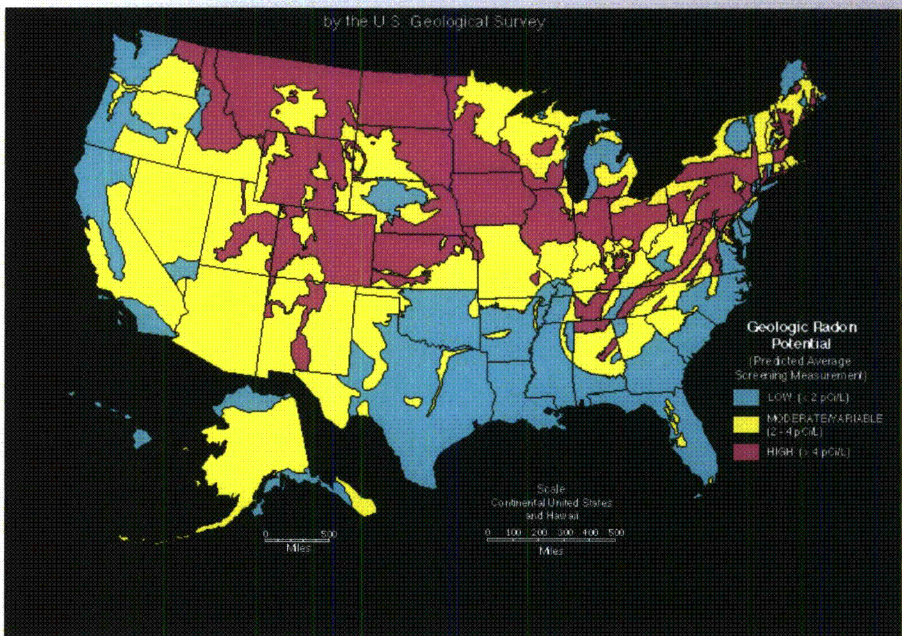


- according to geological age



- according to rock type

Generalized Geologic Radon Potential of the United States



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Outdoor Radon cont'd

- According to NAS 1999, measurements taken over the continental US, Alaska and Hawaii show the highest concentrations are found in the Colorado Plateau where measurements ranged from 0.5 to 0.75 pCi/L of air (18.5–30 Bq/m^3)
- The NAS 1999 also report average outdoor radon levels ranging from 0.12 to 0.3 pCi/L

NRC Interim Staff Guidance

- **Intended for NRC staff when reviewing uranium recovery licensee surveys for radon**
- **Suggests can demonstrate compliance by measurement or calculation**
  - 0.1 pCi/L with daughters
  - 10 pCi/L without daughters
- **"net", i.e., above background**
- **Challenging (perhaps not possible) to measure annual increments of order of 0.1 pCi/L given natural variation and measurement limitations**

Types of Radon Monitoring (1)

- **Short Term**
  - 2 days up to 3 months
  - ***Use results with caution***
  - Radon concentrations vary over time long-up with long term measurement
  - Devices for Short Term Monitoring include
    - Activated Charcoal Adsorption - Electret Ion Chamber
    - Charcoal Liquid Scintillation - Continuous Radon Monitoring
    - Continuous Working Level Monitor - Alpha Track
  - Long-term data most relevant for assessing effects

Types of Radon Monitoring (2)

- **Long Term Monitoring**
  - 3 to 12 months in duration
  - Recommended Devices for Long Term Monitoring
    - Alpha track detector
    - Electret Ion Chamber
    - Digital Detector
  - Long term measurement provides better indication of annual average radon concentration than short term measurement (diurnal and seasonal effects already accounted for)

Recent Experience from Indoor Radon Monitoring in Port Hope (1)

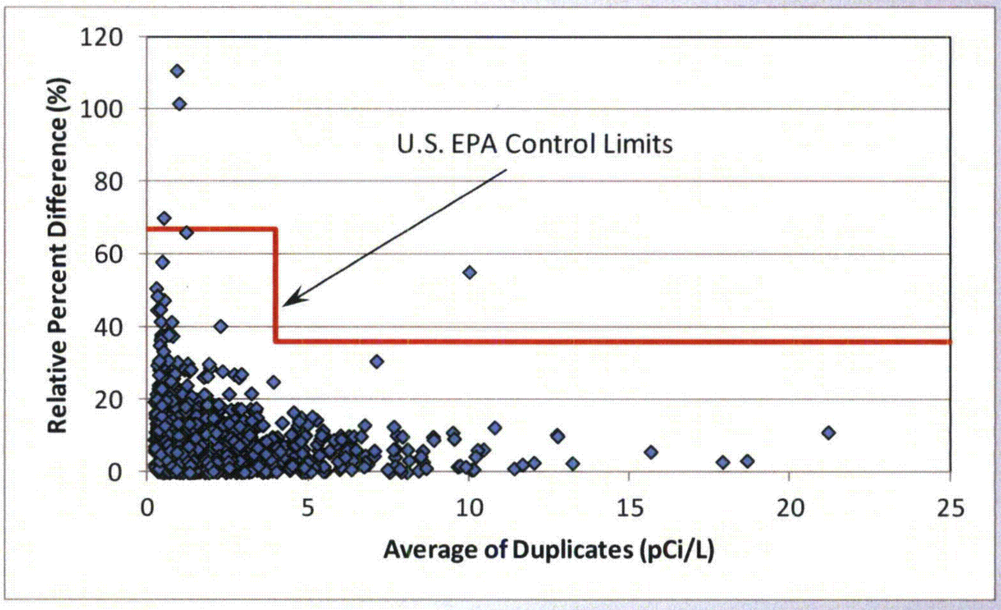
- SENES retained to complete indoor radon monitoring for approximately 1350 properties
- Client decided that monitors would be alpha-track radon monitors supplied by RSSI (CR-39)

- Long-term measurements (5-6 months)
- An example to illustrate challenges in measuring radon at low concentrations

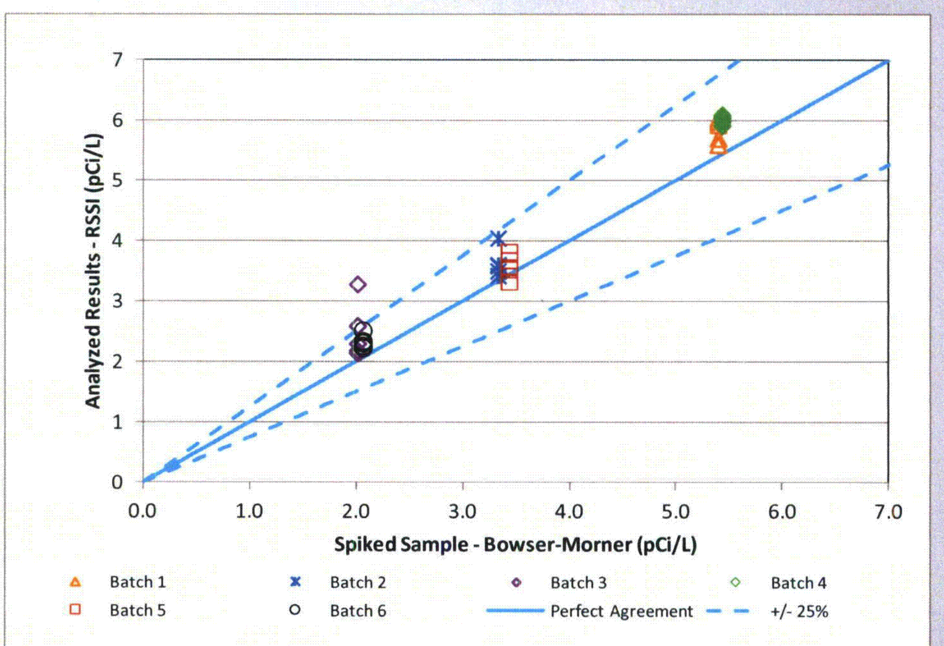
Quality Assurance/Quality Control (Port Hope)

- **Duplicates (at about 10 % of locations)**
- **Additional radon monitors were deployed for QA/QC**
  - Blind spike samples
    - 30 blind spikes sent to Bowser-Morner
  - Travel blanks
    - Travel blank monitor sent with each shipment
  - Blanks
    - Unexposed radon monitors, sent in sealed bags that were never opened

Duplicate Pairs



Blind Spike Samples – RSSI vs. Bowser-Morner



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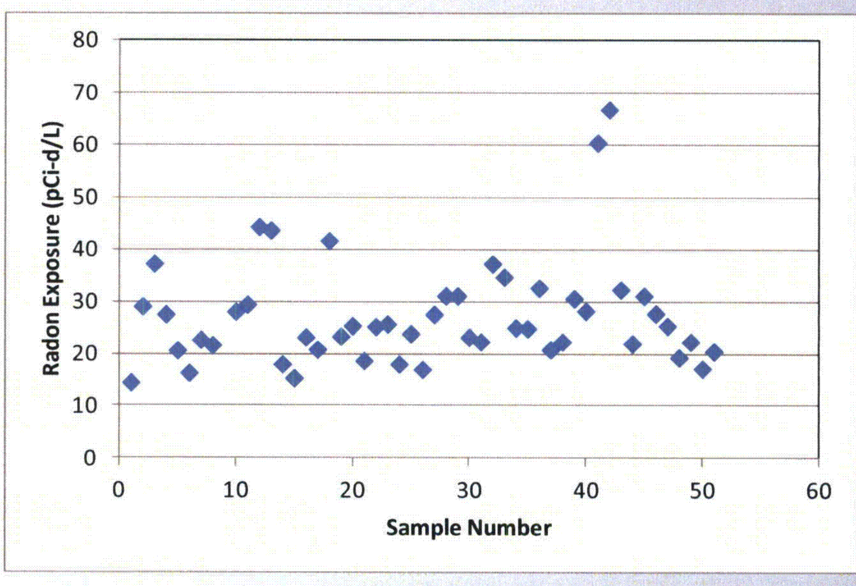
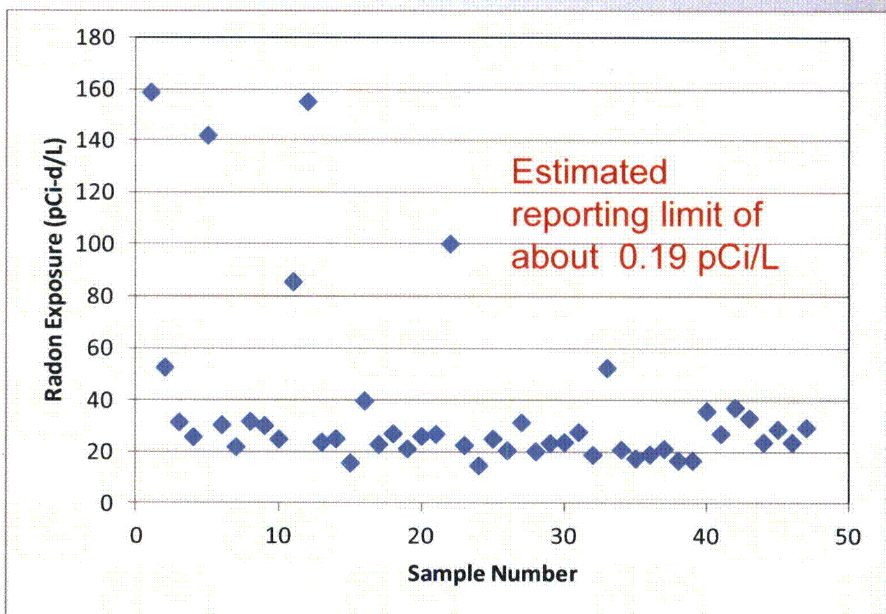
Radon Exposure in Travel Blanks



Radon Exposure in Blanks



Main Observations

- Background levels of ambient Rn-222 are quite variable
- Variation in background levels of Rn-222> 0.1 pCi/L
- The detection level of track etch detectors > 0.1 pCi/L
- Challenging, perhaps not possible, to measure such small increments with any precision
- A bright-line approach doomed to failure
- Consider combination of modelling (MILDOS) with "appropriate" confirmation by measurement (acknowledging limitations and use of statistical test)

Attachment B

The Effect Of Equilibrium Factor on the Radon Concentration Associated with Compliance to 10 CFR20, Appendix B Annual Average Concentration Limits (Public Dose of 50 mrem/year)

David W. Adams
Steven H. Brown, CHP
SENES Consultants
February 2014

In 2011, the United States Nuclear Regulatory Commission (USNRC) issued draft regulatory guidance for comment entitled "Evaluations of Uranium Recovery Facility Surveys of Radon and Radon Progeny in Air and Demonstrations of Compliance with 10 CFR 20.1301" (USNRC, 2011). In this document, the NRC proposes that uranium recovery facilities must demonstrate that effluents result in a radon concentration in air at the site boundary (or any unrestricted area where the maximally exposed member of public could be) of less than or equal to 0.1 pCi/L for radon with daughters present, implying that there is 100% equilibrium relative to radon and the activities of its decay products (and 10 pCi/l without progeny). The draft guidance states that surveys of radon in air for compliance with 10 CFR 1301/1302 must include measurements of radon in air at the boundary location, or nearest resident. The "conservative" assumption that the progeny are in equilibrium with the radon is not scientifically valid, as this paper will discuss. In fact, aged global radon is assumed to have an average equilibrium factor (EF) of 0.6 outdoors, with a range from 0.2 to 1, while 0.5 to 0.7 being most common (UNSCEAR, 2000).

The 0.1 pCi/L annual average concentration of radon 222 in air in an unrestricted area at 100 % equilibrium (as well as 10 pCi/l without daughters present) is derived by the USNRC to be the concentration at which a member of the public would receive 50 millirem (mrem) total effective dose equivalent (TEDE) per year of exposure. Radon 222 produces very little inhalation dose in humans as radon, an alpha emitter, does not deposit internally in the lungs because it is an inert noble gas. However, its progeny, such as polonium 218, lead 214, and polonium 214, are particulate metallic or semi-metallic elements and therefore deposit onto lung tissue where they will decay, releasing energy and delivering dose. The alpha decay of polonium 218 and polonium 214 emits highly energetic charged particles (helium nuclei) which, at high concentrations, can damage lung tissue and are attributed as a cause of increased occurrence of lung cancer in exposed populations.

For radon progeny to be present, some time must pass from the generation of "pure" radon (e.g. from uranium ISR solutions) for ingrowth of the progeny. The percentage of equilibrium is referred to as the equilibrium factor (EF), which ranges from 0 to 1, or from "pure" radon without any progeny present (i.e. at the time of generation from its source) to 100 % equilibrium with progeny fully ingrown. Radon exiting from an array of wells or header houses or the Central Processing Plant (CPP) at a typical in situ uranium recovery (ISR) site, or from evaporation ponds or tailings impoundments at a conventional uranium mill, initially emit essentially pure radon (Time = 0) which therefore has an equilibrium factor close to 0. Equation 1 defines the relationship between NRC's 10CFR20, Appendix B annual average concentration limit (based on an annual public dose limit of 50 mrem) and the equilibrium factor. Figure 1 depicts the ingrowth of radon progeny from "pure radon" as a function of time (after Evans, 1969).

$$\frac{0.1\ pCi/L}{Equilibrium\ Factor} = Effluent\ Concentration\ Which\ Results\ in\ 50\ mrem\ TEDE$$

Equation 1

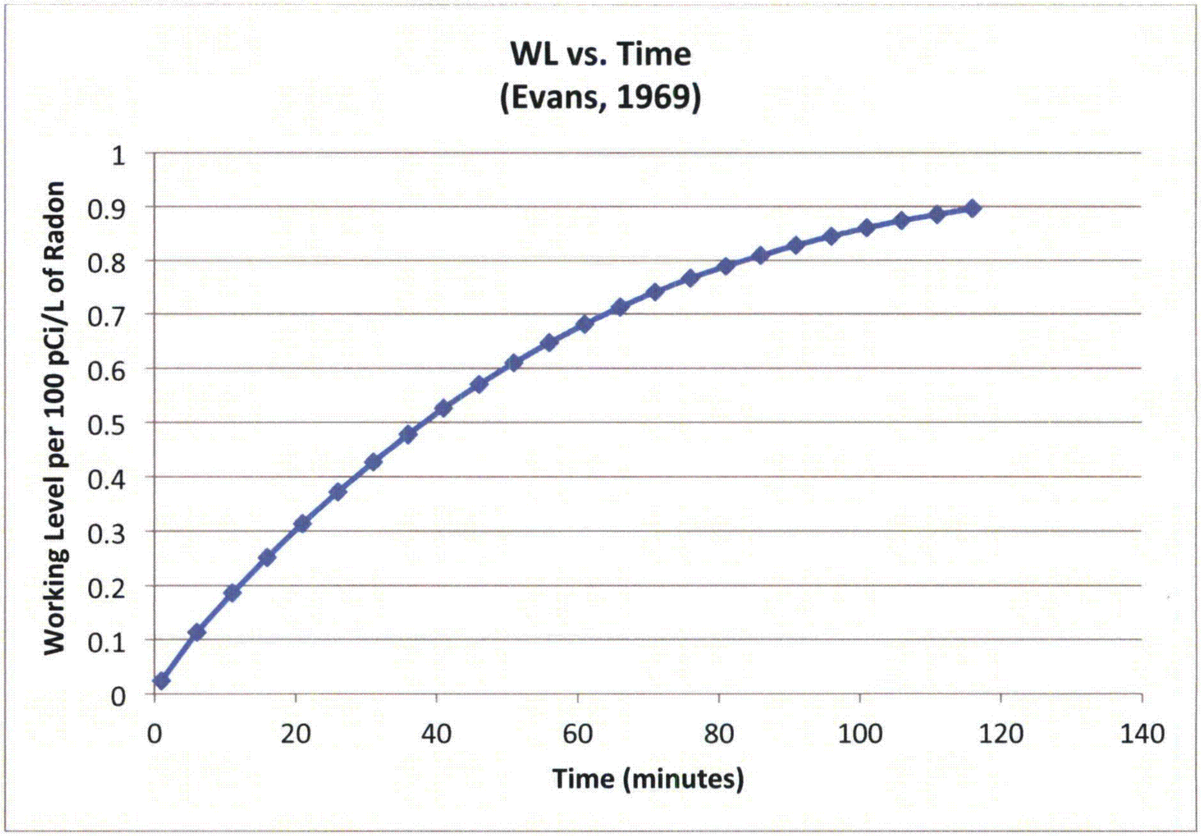


Figure 1

Working level and Equilibrium Factors associated with 100 pCi/l of pure radon as function of time

The percent equilibrium drives dose as the greater the progeny concentration, the higher dose from the same radon concentration. Consider the moment as radon exits a wellhead or impoundment; no time has passed for the radon to decay (T=0), so the equilibrium factor is essentially 0. Using Evan's model (Figure 1), approximately 120 minutes must pass for the radon to reach 90% equilibrium with its progeny. Our interest here is outdoors (ISR well fields, effluents from CPP, surface impoundments, etc.), such that the radon is susceptible to the environmental conditions into which they are released. However, the wind is always "blowing" to some degree. Average wind speeds in the United States range from below 4 meters per second (9 miles per hour) to greater than 10 meters per second (22 miles per hour) as is shown in Figure 2. The radon gas will move away from the source with the wind. As radon decays over time, the progeny will "grow in" and the equilibrium factor will increase. The radon will disperse and decay as it travels in the direction of the prevailing wind at that time. This process is illustrated in Figure 3 for several wind speeds, chosen arbitrarily to demonstrate the concept. Note that the equilibrium factor is a variable at identical distances as a function of the wind speed, i.e., the time it took for the radon to get there. It is also of interest to note that some of the highest average wind speeds in the US occur in the great basins of Wyoming where many uranium ISR operations are currently located.

Using Figure 3, and assuming that the boundary location where a member of the public may reside or be present is 500 m (0.5 km) from the CPP, at the wind speeds used as examples, the equilibrium factor ranges from 0.04 (4.47 m/s or 10 mph wind) to 0.14 (1.34 m/s or 3 mph wind). At this distance, the concentration associated with these EFs that would result in 50 mrem /yr TEDE (criteria of 10CFR20, Appendix B), would be 0.71 pCi/L or 2 pCi/L, respectively (Equation 1). Since the annual limit of 50 mrem would be received over the course of the year, and the 10CFR20, Appendix B unrestricted area concentration limits are in fact "annual averages", average wind speeds (using wind rose data for the specific site of interest) should be used, not the worst case scenario of little or no wind, in estimating the equilibrium factor at a specific distance and location. Although the equilibrium factor will increase as a function of distance (time), the radon concentration decreases rapidly due to dispersion and would be expected to be indistinguishable from background beyond one or two kilometers.

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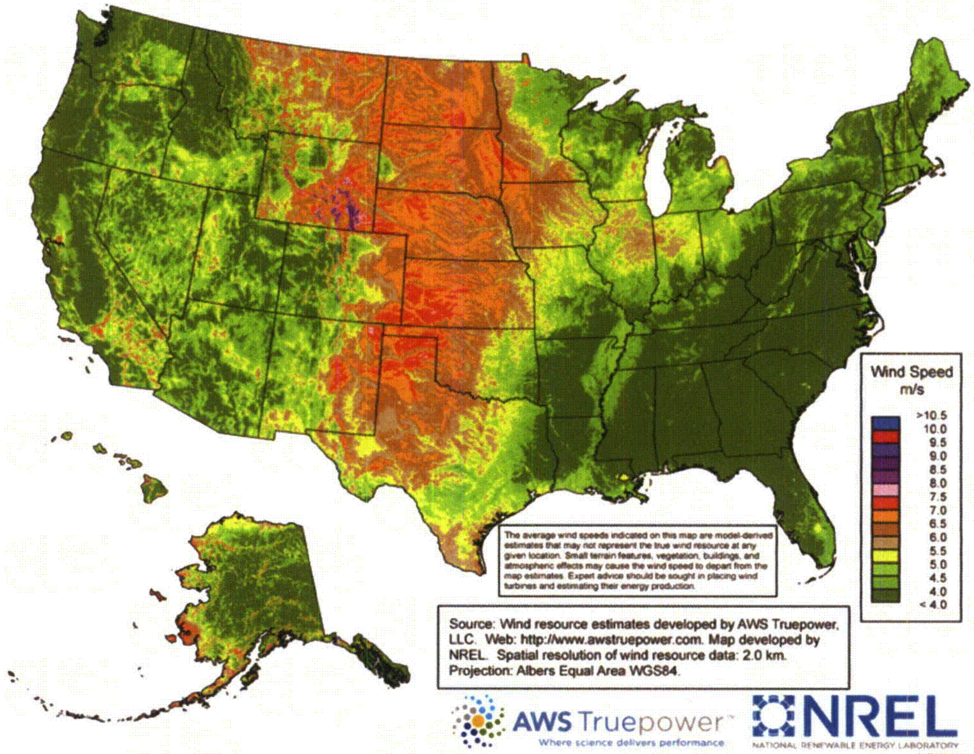

Figure 2

Average wind speeds in the United States (NREL; based on 30 meter meteorological tower measurements)

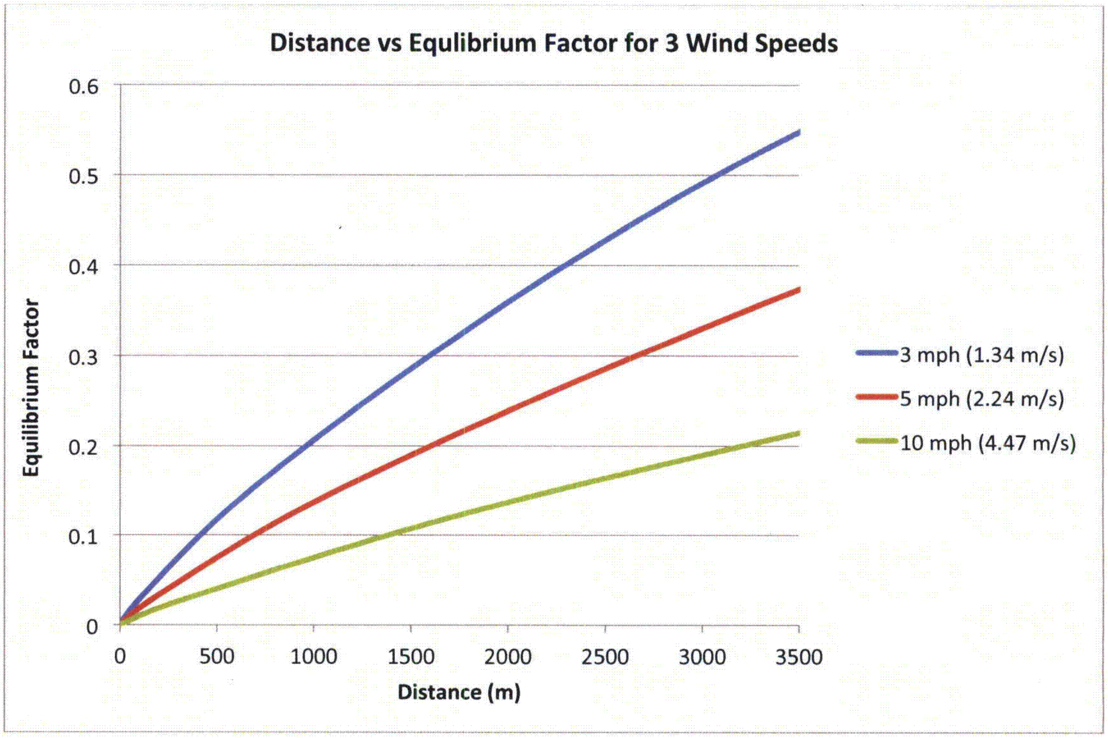

Figure 3

Radon equilibrium factor vs. distance (and time) for 3 wind speeds