TESTING, MAPPING, PUBLIC EDUCATION AND MITIGATION OF URANIUM AND RADON IN HOUSEHOLD WATERS IN GEORGIA[1]

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Abstract

The Agricultural and Environmental Services Laboratories (AESL) and The College of Family and Consumer Sciences of the University of Georgia launched a new Radon in Household Water Testing and Education program from August, 2015. Various methods of sampling, sample preparation, and counting assays on a liquid scintillation counter are practiced by different laboratories testing radon in water across the United States. This paper discusses the results of our study comparing a selected set of those variables on the recovery of radon from two "radon in water standard" samples and a household well water from Georgia. We also shed lights on the potential areas and associated geology that merits testing of uranium and radon in the household wells in Georgia. Furthermore, our current and past (since 2010) monitoring, mapping, public education, and mitigation programs for uranium and radon in household well waters are included.

Introduction

Radiation exposure from naturally occurring radionuclides in drinking water sources may result in various public health concerns. In this regard, alpha radiation emitted by uranium, radium, and their progenies, including radon are particularly important. The World Health Organization (WHO) suggests that when the radioactivity in drinking water exceeds the recommended level of 0.5 Bq/L (or 13.5 pCi/L) for gross-alpha (α) or 1 Bq/L (or 27 pCi/L) for gross-beta (β) activities, radionuclide-specific concentrations should be brought into compliance with WHO guidance levels: 0.1 Bq/L for ^{228}Ra; 1 Bq/L each for $^{223–226}$Ra, ^{234}U, and ^{235}U; 10 Bq/L for ^{238}U; 100 Bq/L for ^{222}Rn, and 15 μg/L for total uranium (WHO 2004). According to International Commission on Radiological Protection (2007), once ingested radionuclides can be absorbed into the blood

[1]*This study was partially funded by The University of Georgia Radon Education Program which is supported by Georgia Department of Community Affairs through funding from State Indoor Radon Grants (SIRG) program of The United States Environmental Protection Agency, Region-4.*

stream, accumulate in specific tissues and organs that they may damage or can be excreted out of the body. For example, 66% of absorbed uranium is rapidly eliminated via urine, while the rest is distributed and stored in the kidney (12–25%), bone (10–15%), and soft tissues (Wrenn et al., 1985). Radium accumulates primarily in the bone (Wrenn et al., 1985). Ingested uranium primarily causes chemical toxicity, especially nephrotoxicity (Zamora et al., 1998; Zamora et al., 2009); whereas ingested radium and radon are known to induce radiotoxicity and could lead to cancer (Wrenn et al., 1985). Once ingested, radon gas diffuses into the stomach wall and irradiates the stomach wall tissues and can cause stomach cancer (Hopke et al., 2000). Inhaled radon from indoor air is known to cause lung cancer (Darby et al., 2005). Radon in household water supply poses both inhalation and ingestion risks. Most risk from radon in water comes from radon released into the air when water is used for showering, laundering, and other household purposes. According to USEPA (2012), the risk of lung cancer from inhaled radon from air is much larger than the risk of stomach cancer from ingesting water with radon in it. A *very rough rule of thumb* for estimating the contribution of radon in household water to indoor air radon is that water with 10,000 pCi/L of radon contributes about 1 pCi/L to the level of radon in the indoor air. Based on a National Academy of Sciences report (NAS, 1999) on radon in drinking water, EPA estimates that radon in drinking water causes about 168 cancer deaths per year, 89% from lung cancer caused by breathing in radon released from water, and 11% percent from stomach cancer caused by ingesting drinking radon-containing water.

Radionuclides from three naturally occurring decay series (headed by ^{238}U, ^{230}Th, & ^{235}U), have long been known to be present in ground water and surface water in Georgia (Cline et al., 1983; Hess et al., 1985; Zapecza and Szabo, 1988; Coker and Olive, 1989). In a previous study, Albertson (2003) found elevated gross alpha particle activity, elevated radium-226, and elevated combined radium-226 and radium-228 activity in some community water systems in the Piedmont, Blue Ridge, and parts of the Coastal Plain physiographic provinces of Georgia. Elevated uranium concentrations were detected in drinking water in the Piedmont and Blue Ridge physiographic provinces (Albertson, 2003). Coker and Olive (1989) tested 90 wells in Georgia for radon and other radionuclides and concluded that groundwater from the granite and gneiss aquifers in the Piedmont contained the highest average concentrations of naturally occurring radionuclides. Stone et al. (2002) found elevated levels of radium in drinking water in the "piedmont and coastal plain sandhills" and elevated uranium in water in the "piedmont (and Blue Ridge) region" of South Carolina.

In 2010, routine water testing of some private drinking water wells at AESL revealed high levels of uranium with concentrations above EPA's maximum contaminant levels (MCLs) of 30 parts per billion (ppb). These wells were located in specific areas of the state. Our data showed that high level of uranium in well water was often associated with a high level of radon gas measured in air by the homeowner (Lynch et al., 2016). Uranium and radon in deep wells originate from naturally occurring granitic bedrock located primarily in the Piedmont and Blue-Ridge (PBR) regions of Georgia (Albertson, 2003). Although there has not been any report directly linking these contaminants and illnesses, numerous health problems, including cancer, kidney problems, autoimmune disorders, gastrointestinal symptoms, and neuropathy have been reported to various agencies from counties that were found to have high uranium and radon in well water. Conversations with residents and county officials established a need for more public education, testing, and informational resources. From 2010 to 2013, the University of Georgia Cooperative

Extension conducted a public education program along with a half-price water testing service to encourage well owners to test their waters. The intent was to expand the database to better understand the nature and extent of the problem, and increase public awareness in this regard.

In 2015, the AESL and The College of Family and Consumer Sciences of the University of Georgia launched a new Radon in Household Water Testing and Education program. Liquid scintillation (LS) counting is the analytical method recommended by the Environmental Protection Agency (EPA) for measurement of radon in water (Whittaker et al., 1989) and approved for use in New York State by the Environmental Laboratory Approval Program (Kitto et al., 2008, NYSDOH, 2007). However, laboratories testing radon in drinking water across the United States follow different methods of sampling, sample preparation, and counting assays by liquid scintillation counting. The advantages and disadvantages of these methods are yet to be evaluated. This paper reports the following outcomes of the testing and education programs on uranium and radon in Georgia household well waters:

1. Results of a study comparing various methods of sampling, sample preparation, and liquid scintillation counting assays on the recovery of radon from two standard samples and a selected household well water sample from Georgia with a view to selecting the best method.
2. Mapping uranium concentration in private drinking water wells based on voluntary submission of samples by the well owners.
3. Impact of public education programs on a) peoples' consideration of water testing for uranium and radon, b) enhancement public awareness about these contaminants, and c) the engagement of community advocates in protecting public health.

Methodology

Optimization of Sampling and Analytical Methods for Radon in Well Waters

We used two radon (^{222}Rn) in water standard samples designated as "Standard-15" and "Standard-17" obtained from the co-author Kitto and numerous samples from a well in Monroe County, Georgia. A prior analysis at University of Georgia Agricultural and Environmental Services Laboratories showed the well water contained 629 ppb uranium. Additional water tests carried out at Air Chek, Inc. (Mills River, NC) reported 3.8 pCi/L radium (^{226}Ra + ^{228}Ra) and 79,000 pCi/L radon (^{222}Rn). The "Standard-15" and "Standard-17" are reusable radon-in-water standards as they were prepared using a ^{226}Ra-loaded filter sandwiched in polyethylene sheeting (Kitto et al., 2010). At full ingrowth, the ^{222}Rn produced by the sandwiched ^{226}Ra sources in both "Standard-15" and "Standard-17" should be 4375 pCi/L at 100% emanation, but due to retardation by the polyethylene, produces only 3762 pCi/L at 86% emanation. Using these two standard water samples and the well water samples, we compared the following five variables to optimize sampling and analytical methods for testing radon in well waters:

1. *Methods of sampling***:** We compared "Submerged Bottle" versus "Direct Fill" methods of sample collection. Two samples were collected for each method.

   For the "Submerged Bottle" method (Figure (1)), water was collected into a bowl by

gently flowing down one side with minimal disturbance. Then the entire sample bottle and lid were submerged under water in the bowl, opened, and filled. The water-filled bottle was capped while still under water and turned it upside down. If air bubbles were present, the bottle was emptied and refilled again until air bubbles were no longer observed. The procedure was repeated with the second bottle.

For the "Direct Fill" method (Figure (2)), gently flowing water was collected directly into the top opening of the sample bottle, carefully avoiding turbulence. The bottle was allowed to gently overflow, forming a slight dome of water at the opening. The bottle was promptly capped and checked for air bubbles by inverting bottle and tapping gently. If air bubbles were present, the bottle was emptied and the filling procedure repeated until air bubbles were no longer observed in the water sample. The procedure was repeated with the second bottle.

Figure (1): Submerged bottle method of sampling.

Figure (2): Direct-fill method of sampling.

2. *Type of scintillation fluids***:** We compared the efficacy of two different scintillation fluids namely, "Opti-Fluor" and "High Efficiency Mineral Oil Scintillator" (PerkinElmer, Waltham , MA), as both are recommended and used for analyzing radon in water. "Opti-Fluor" used in this study is a biodegradable benzene-based mixture of high flash point and low volatility organic solvents that produced a background count rate of 15 cpm and 71% quench parameter, it is biodegradable. The "High Efficiency Mineral Oil Scintillator" used in this study contains primarily white mineral oil (60-80%) and 1,2,4-trimethylbenzene (20-40%), is not biodegradable, with a background of 15 cpm and 107.5% counting efficiency.

3. *Volume of sample and scintillation fluid***:** Recovery of radon was compared for two different preparations: "8 mL sample + 8 mL scintillation fluid" versus "10 mL sample + 10 mL scintillation fluid".

4. *Methods of mixing the sample and scintillation fluid***:** We compared two different methods of mixing sample and scintillation fluid on the recovery of radon. For the first method, called "Separate Drawing" (Figure (3)), the scintillation fluid (8 or 10 mL) was pipetted into the scintillation vial, and then the sample (8 mL or 10 mL) was pipetted and buried underneath the scintillation fluid. The second method, called "Simultaneous Drawing" (Figure (4)), had the scintillation fluid (8 mL or 10 mL) drawn into a pipette, then the sample (8 mL or 10 mL) was drawn into the same pipette underneath the

scintillation fluid and finally both sample and scintillation fluid was dispensed into the scintillation vial. The vials were capped immediately in both methods and shaken to expedite transfer of radon into the scintillation fluid.

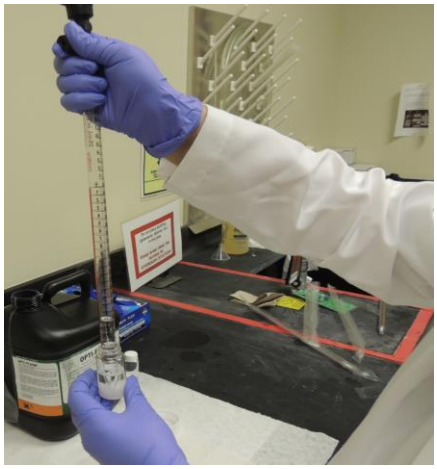

Figure (3): "Separate Drawing" method.

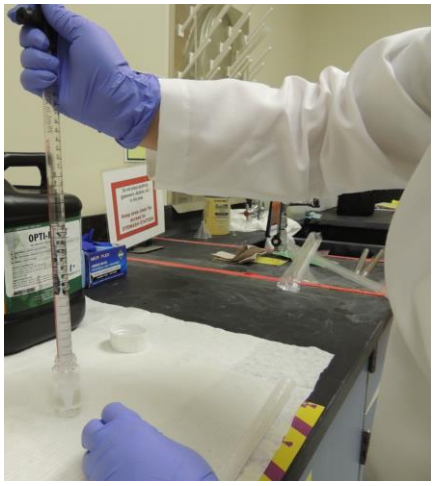

Figure (4): "Simultaneous Drawing" method.

5. *Liquid scintillation counting (LSC) assays***:** We compared radon recovery from two different liquid scintillation counting assays as presented in Table 1 below.

Table (1): The two different LSC assays compared in this study.

Regions	**Assay-1**		**Assay-2**	
	Lower Limit (keV)	Upper Limit (keV)	Lower Limit (keV)	Upper Limit (keV)
A	0	2000	130	700
B	0	2000	150	1800
C	0	2000	0	2000

The "Assay-1" is a full spectrum assay covering the whole range of energy with the region of interest (ROI) from 0 to 2000 keV. In contrast, the "Assay-2" is limited within the ROI for ^{222}Rn from 130 to 700 keV, excluding the counts below 130 keV (which is indeed from "Bremsstrahlung" radiation). Cutting out the low-energy (below 130 keV) betas also reduces the quenching and background there. The efficiency (cpm/dpm) in Assay-2 is 3.0 to 3.1 (or about 66% absolute efficiency for each emission).

Procedure for Testing Uranium in Well Waters

Well water samples, from the homeowners received at the laboratory by voluntary submission as well as that from the well used for radon method development study, were preserved by addition of HNO_3 to pH < 2.0 upon receipt and filtered prior to analysis when suspended solids appear excessive for passage through the ICP nebulizer. Uranium in the acidified-filtered samples was carried following the EPA method 200.5 on an "ICP-AVOES" instrument, model "ARCOS FHE" (SPECTRO Analytical Instruments GmbH, Germany). In this method, analysis of

samples begins with introduction of the sample into the nebulizer/spray chamber where uniform droplets are swept via an argon gas stream into a high temperature plasma torch. The power delivered by a radio frequency field is absorbed by atomic species in the sample inducing an electronic transition to higher orbital. Upon passage through this high energy field, the electrons 'relax' into more stable orbits releasing the previously absorbed energy. Much of this released energy is measurable as light in the ultraviolet to visible range of the electromagnetic spectrum. The wavelength of the light emitted corresponds to a specific analyte, and it is 385.958 nm for uranium. The intensity of the light emitted by uranium is positively correlated to concentration in the original sample, and thus the intensity is calibrated to indicate the concentration. It is worth mentioning here that this method is appropriate for the simultaneous analysis of any and all analytes specified in EPA method 200.7.

Testing and Education Programs on Uranium and Radon

From 2010 to 2013, the University of Georgia Cooperative Extension conducted a public education program that included half-price water testing service to encourage well owners to test their waters. The intent was to expand the database to better understand the nature and extent of the problem. The public educational program, implemented in a few selected counties to increase public awareness and engage other stakeholders in protecting public health from the harmful effects of these drinking water contaminants.

Results and Discussion

A. Studies on the Well Water Sample

Sampling method: Direct-Fill Method versus Submerged Bottle Method

Duplicate water samples were collected from the private well by both "Direct Fill" and "Submerged Bottle" methods. They were prepared in the laboratory by "Simultaneous Drawing" of 10 mL Opti-Fluor fluid and 10 mL sample, and then counted by both "Assay-1 (0-2000 keV)" and "Assay-2 (130-700 keV)". As depicted in Figure (5), measured radon in "Direct Fill" sampling was significantly lower than that in "Submerged Bottle" sampling in both "Assay-1 (0-2000 keV)" and "Assay-2 (130-700 keV)". Such results suggest that the "Direct Fill" method of sampling is prone to a substantial loss of radon as compared to "Submerged Bottle" method. It is also worth mentioning here that it is very difficult to collect a sample by "Direct Fill" without air bubble. Generally, it required several attempts to collect a bubble free sample. So this method of sampling was dropped from our laboratory's recommendation.

The "Assay-2" gave significantly higher radon results than "Assay-1" regardless of sampling method (Figure (5)). Thus, it is clear that exclusion of the low-energy portion (prior to 130 keV) with higher background and Bremsstrahlung radiation is a better way to analyze radon in water.

Sample preparation: onsite versus laboratory

Duplicate samples, collected by the "Submerged Bottle" method, were prepared onsite using 8 or

10 mL mineral oil and Opti-Fluor by "Separate Drawing" (2 × 2 × 2 = 8 samples in total). Another set of 8 samples collected by the same method were brought to the laboratory and prepared in the same away using 8 or 10 mL of mineral oil or Opti-Fluor fluid. All of these 16

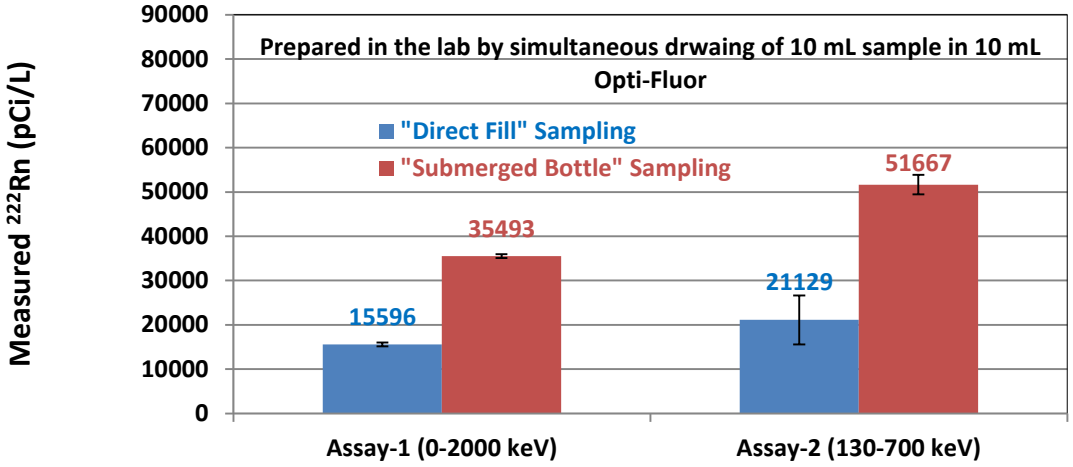

Figure (5): Measured radon in a well water as affected by two different methods of sampling.

samples were counted on LSC by both "Assay-1 (0-2000 keV)" and "Assay-2 (130-700 keV). The results revealed that radon concentration in the samples prepared onsite were significantly higher than obtained for the samples prepared in the laboratory (Figure (6)) in both "Assay-1 (0-2000 keV)" and "Assay-2 (130-700 keV)". Here also, the "Assay-2" gave significantly higher radon results than "Assay-1" regardless of whether the samples were prepared onsite or in the laboratory (Figure (6)). Our results suggest that radon is better retained in the scintillation fluids

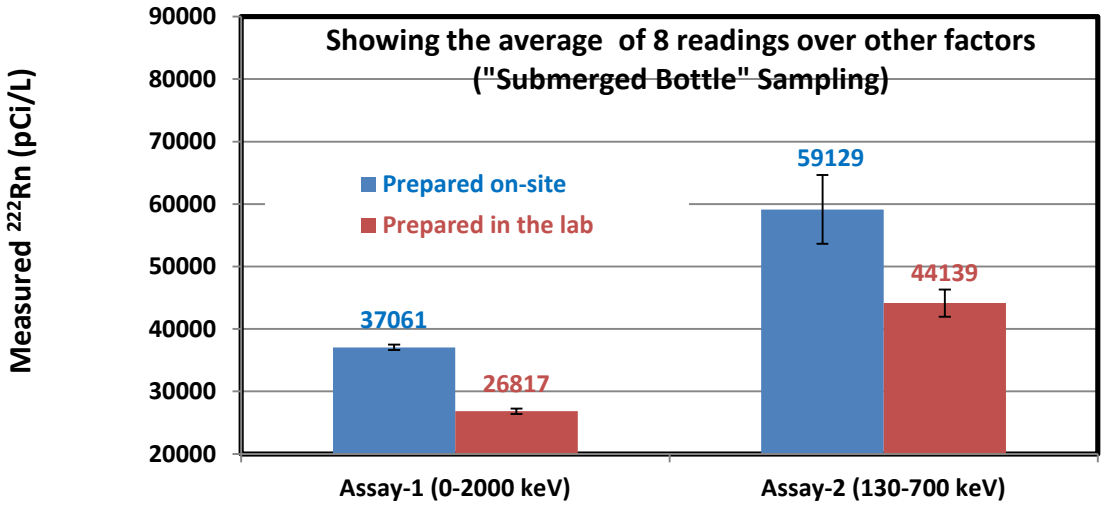

Figure (6): Measured radon in a well water collected by "Submerged Bottle Method" when prepared onsite versus in the laboratory and counted by two different LSC assays.

if the samples are buried under the scintillation fluid onsite soon after their collection. However, ordinary homeowners would most likely be unable to do it correctly by themselves and it would expose them to the scintillation fluid.

Effects of scintillation fluid type, volume of scintillation fluid and sample, and methods of mixing

As depicted in Figure (7), use of mineral oil as the scintillation fluid resulted in significantly higher radon count rates than Opti-Fluor, regardless of the volume ratios of scintillation fluid : sample (8mL : 8mL or 10 mL : 10 mL) and the mixing methods ("Simultaneous Drawing" or "Separate Drawing").

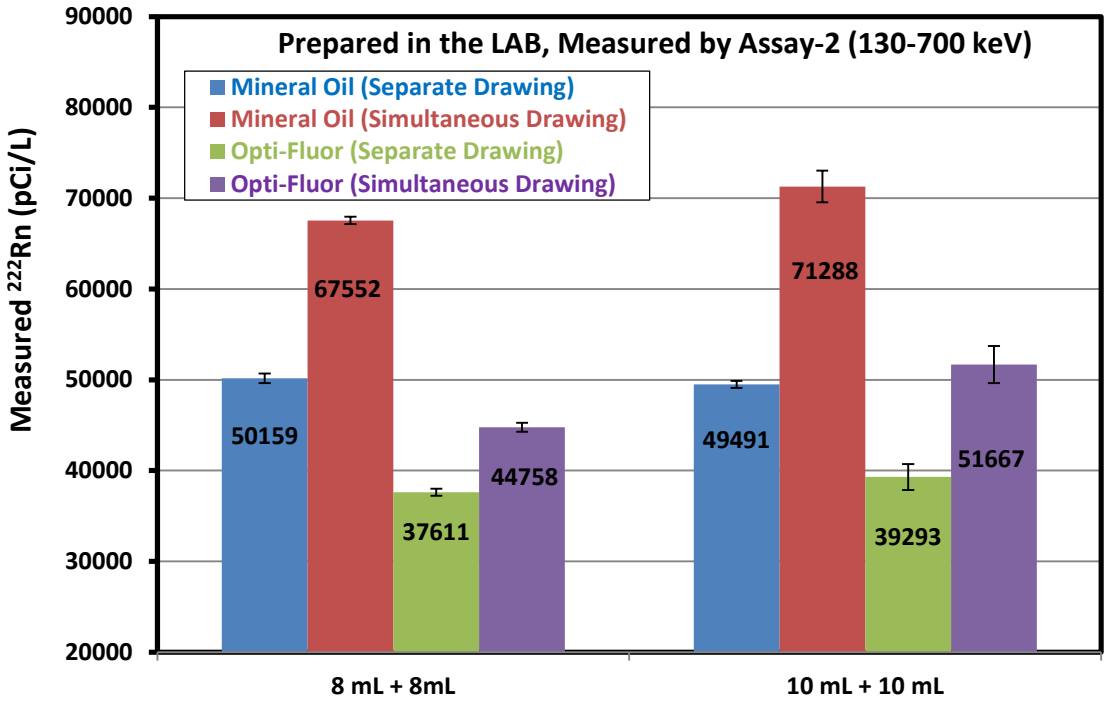

Figure (7): Measured radon levels in a well water collected by the "Submerged Bottle Method" and prepared in the laboratory to compare:

- Two different scintillation fluids: Mineral Oil *versus* Opti-Fluor.
- Two different preparation methods: Separate Drawing *versus* Simultaneous Drawing.
- Two different volume ratios of Sample : Scintillation Fluid, 8 mL : 8 mL *versus* 10 mL : 10 mL.

The extraction of radon from water relies on the fact that radon is more soluble in organic solvents than in water. When added to water, the scintillation fluid (emulsifying) initially forms a white emulsion, which should separate into two clear layers before counting to avoid the disruption of extraction and recovery of the radon and interference of water soluble radionuclides, such as radium, with radon counting. Mineral oil is more effective to bring about such desired separation into two distinct layers faster (Figure (8)).

Figure (8a): Sample + Fluid (Opti-Fluor and mineral oil) at 3 hours after mixing.

Figure (8b): Sample + Fluid (Opti-Fluor and mineral oil) at 5 hours after mixing.

Figure (8c): Sample + Fluid (Opti-Fluor and mineral) at 68 hours after mixing.

Use of 10 mL sample in 10 mL scintillation fluid gave higher count rates than 8 mL sample in 8 mL scintillation fluid in all cases except possibly separate drawing of mineral oil and sample. Similarly, "Simultaneous Drawing" of scintillation fluid and sample resulted in higher radon count rates than "Separate Drawing", suggesting that some radon escaped in case of "Separate Drawing".

B. Studies on the Standard Samples

The expected radon concentrations in both "Standard-15" and "Standard-17" are 3762 pCi/L at 86% emanation and 4375 pCi/L at 100% emanation (Kitto et al, 2008). After 90 day ingrowth, the Assay-1(0-2000 keV) gave unacceptably lower radon counts (2545 and 2666 pCi/L) than that (4976 and 4296 pCi/L) given byAssay-2 (130-700 keV) for both standard-15 and standard-17 regardless of the scintillation fluid used (Figure (9)). A further study after 60 day ingrowth was carried out to compare the performance of "Mineral Oil" versus "Opti-Fluor" and "Simultaneous Drawing" versus "Separate Drawing" by using Assay-2 (130-700 keV) only. The results show that use of "Mineral Oil" gave higher radon activity than "Opti-Fluor" and "Simultaneous Drawing" gave higher radon activity than "Separate Drawing" (Figure (10)), just as we observed with the well water. However, in both studies (Figure (9) and (10)), the "Mineral Oil" overestimated the radon activity more than the predicted or assigned value.

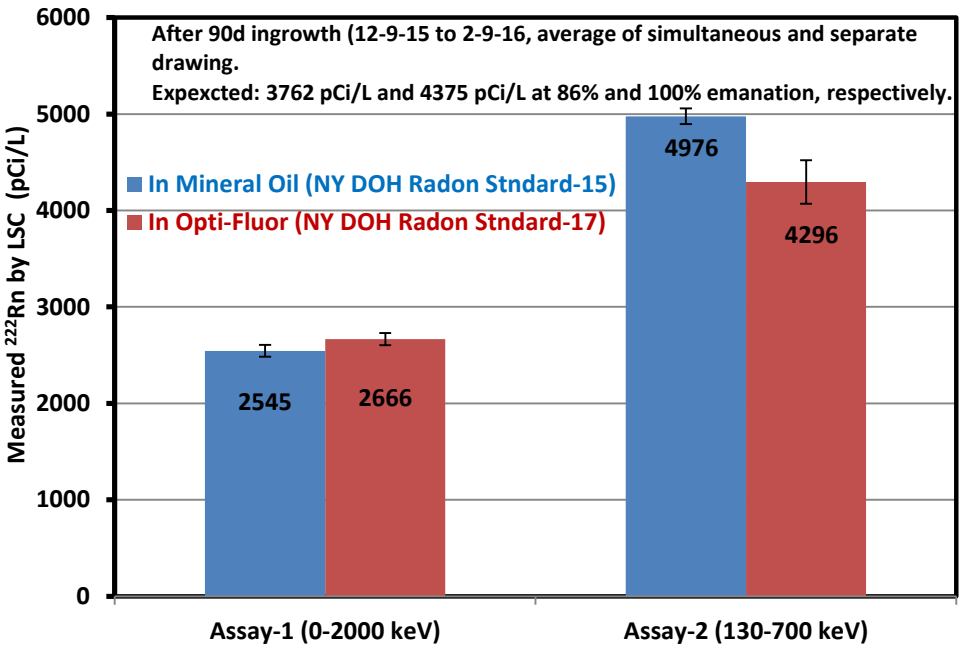

Figure (9): Measured radon in two standard samples when 8 mL sample prepared in 8 mL mineral oil versus Opti-Fluor and counted by two different LSC assays.

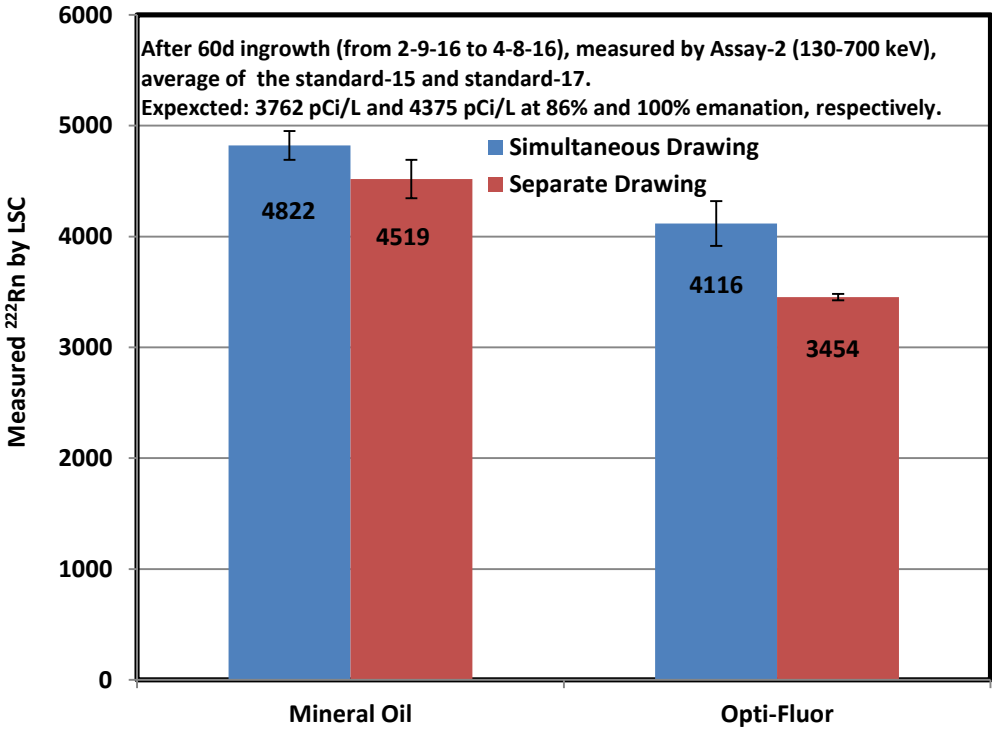

Figure (10): Measured radon in the two standard samples when 8 mL sample prepared in 8 mL mineral oil versus Opti-Fluor by simultaneous and separate drawing.

Monitoring, Mapping, Public education, and Mitigation Programs for Uranium and Radon in Georgia Well Waters

From 2010 to 2013, the University of Georgia Cooperative Extension conducted a public education program along with a half-price water testing service to encourage well owners to test their waters. The intent was to expand the database to better understand the nature and extent of the problem.

The half-price testing service resulted in a substantial increase in voluntary submission of water samples for testing these contaminants, which in turn, enhanced our understanding about the nature and extent of the problems in the state. The testing program has been still continuing, but at a list price. The laboratory developed a mapping program and made it available online for public at http://aesl.ces.uga.edu/water/map/. As of June 13, 2016, the total number of water samples tested for uranium was 1170. Of these, 133 had detectable amounts of uranium (above 10 ppb) with 56 being above the 30 ppb MCL. One of the wells tested as high as 6297 ppb, which is more than 200 times greater than EPA's MCL for uranium for public water supplies. All of these 56 samples were from the Piedmont Blue Ridge Regions above the "Fall Line" (Figures (11) and (12)). The testing program for radon in water at AESL began on August 26, 2015. As of June 13, 2016, 29 well waters were tested for radon. Out of these 27 had detectable level of radon (100 pCi/L) with 9 exceeding the proposed MCL (300 pCi/L) and 3 exceeding the AMCL (4000 pCi/L). All of these 9 well water samples were from the areas above "Fall Line" (Figures (13) and (14)).

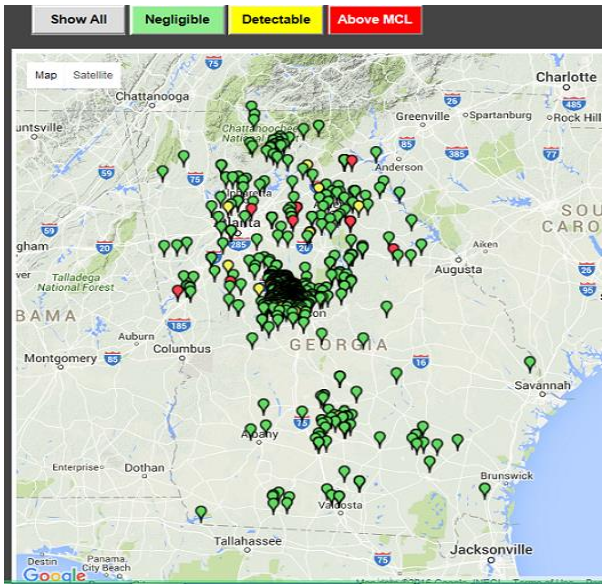

Figure (11): Distribution of well water samples tested for uranium at Agricultural and Environmental Services Laboratories (AESL), University of Georgia (UGA) from 03-20-2008 to 06-13-2016.

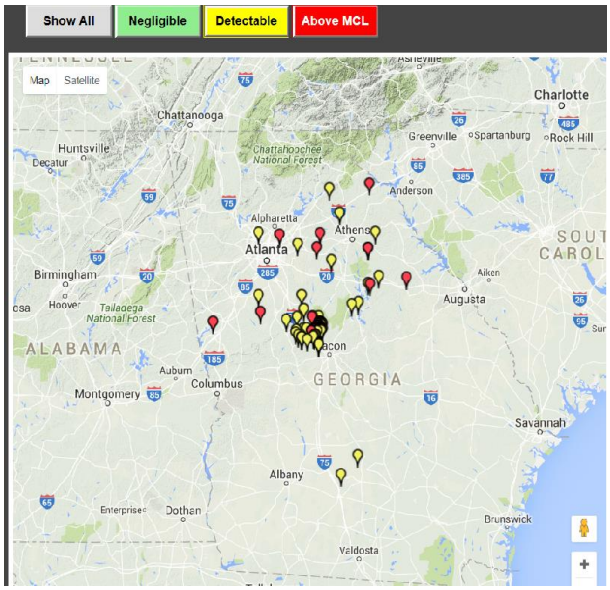

Figure (12): Distribution of well water samples with uranium levels that are detectable (10 ppb) or above EPA's MCL (30 ppb) for drinking water (based on the test performed during 03-20-2008 to 06-13-2016 at AESL, UGA).

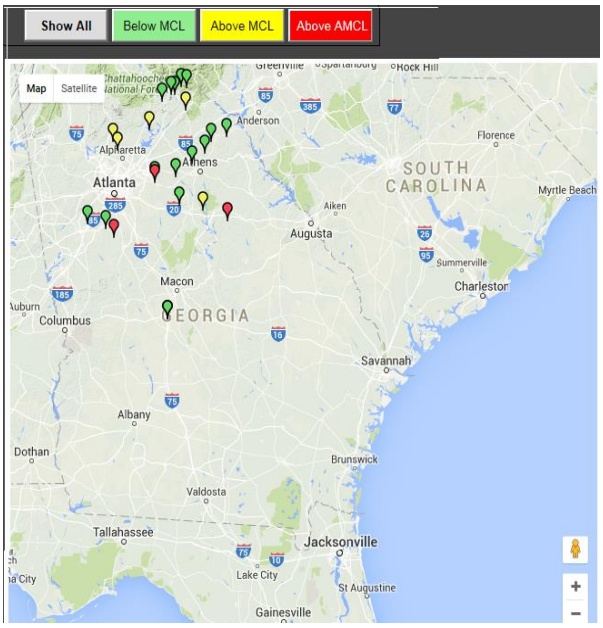

Figure (13): Distribution of well water samples tested for radon at Agricultural and Environmental Services Laboratories (AESL), University of Georgia (UGA) from 08-26-2015 to 06-08-2016.

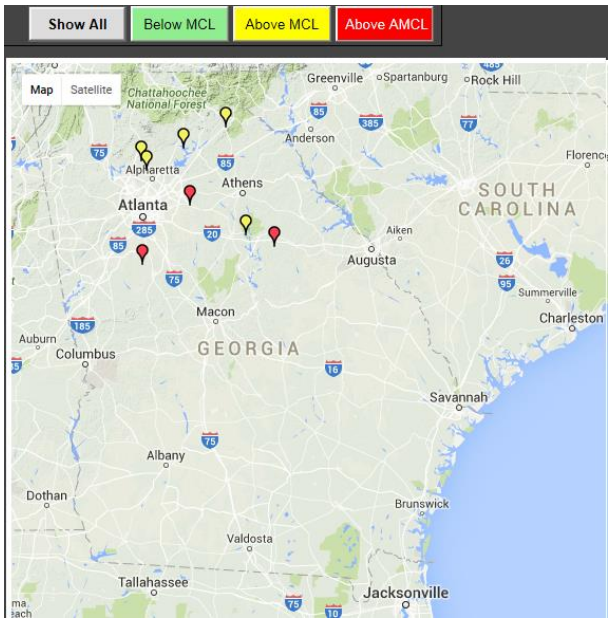

Figure (14): Distribution of well water samples with radon levels that are above MCL (300 pCi/L) or above AMCL (4000 pCi/L) for drinking water (based on the test performed during 08-26-2015 to 06-08-2016 at AESL, UGA).

The public educational program, implemented in a few selected counties, resulted in an increased public awareness, engaged other stakeholders, and contributed to protecting public health. Several public education workshops were conducted and attended by hundreds of county residents. The objectives of the workshops were: (1) Educate consumers about uranium and radon, (2) Promote testing water for uranium and radon in air; and (3) Provide information on treatment systems to remove these contaminants. More than 90% of the workshop attendees responded positively to questions about their knowledge gained and their ability to handle their well water problems after participating in a workshop.

Radon in air sampling kits were also made available in the workshop and from the county extension offices. Homeowners with high levels of radon in their air were encouraged to test for radon in the water. In the homes with high level of radon in water, indoor air radon level was continuously measured for 7-10 days using a "Radstar RS800 Continuous Radon Monitor Instrument" (AccuStar, Medway, MA). In some instances, a high level of radon in the water resulted in high levels in the air especially when the shower and/or washing machine were in use (Figure (15)).

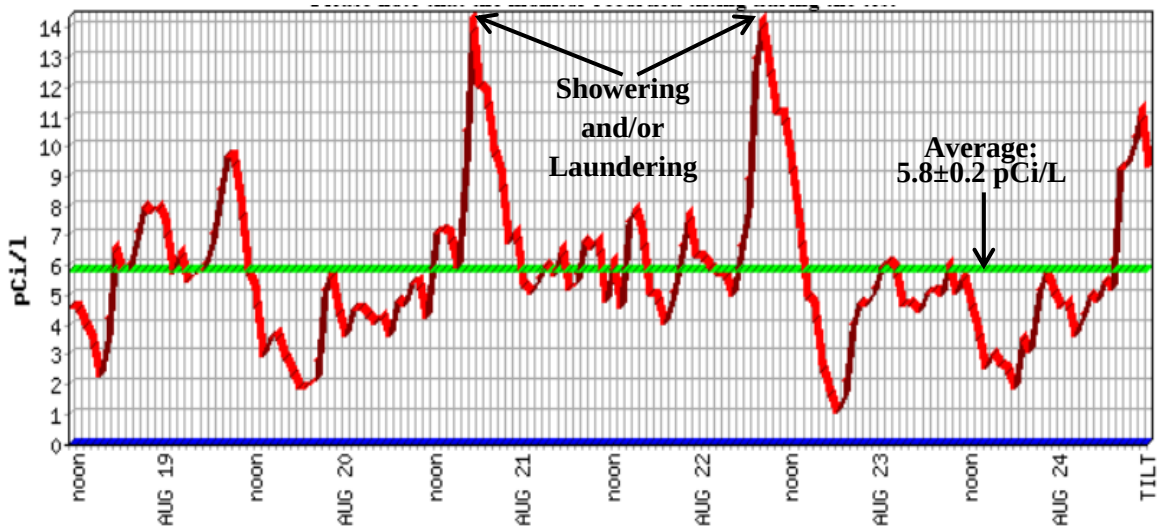

Figure (15): Continuous radon monitoring results in the indoor air in a GA home. The household well water of this home had 629 ppb uranium, 3.8 pCi/L radium (^{226}Ra + ^{228}Ra), and 79,012 pCi/L radon (^{222}Rn).

Extension responded at the county and state levels to numerous telephone enquiries, questions, concerns from well owners, extension agents, social workers, health department workers, journalists, and representatives from federal, state, county, and city governments. There were areas with very high levels of uranium and radon exceeding the removal ability of the common household water treatment systems. The only viable option for those affected is to obtain their water supply from the public water system. However, extending county water distribution lines to areas with high uranium and radon required a multimillion-dollar investment. Our program laid out the evidence-based groundwork that led to increased collaboration with state health and environment agencies, EPA, and community advocates that resulted in the county securing the required financing and extend water lines to the areas of the county impacted by contaminated well water. Another positive outcome was the ability to secure funds for Extension to purchase a liquid scintillator to test for radon in water. This provides service to the residents of the state and a new revenue stream. The program has enhanced our understanding about the nature and extent of uranium and radon problems in the state and how by engaging with community advocates we can make a big impact.

Conclusions

Regarding sampling and analysis of radon in water, this study arrived following important conclusions:

- "Direct-fill" method of sampling is susceptible to significant loss of radon gas, so "submerged bottle" method is better.

- Radon is better retained for LSC if the samples are buried under the scintillation fluid onsite soon after their collection. However, ordinary homeowners would most likely be unable to do it correctly by themselves.

- "Mineral oil" generally gives higher radon counts than "opti-fluor". But the results of PT or standard samples showed that "mineral oil" over estimates the actual radon concentration whereas "opti-fluor" always gave the results close to the assigned value.

- "Simultaneous Drawing" of water sample under the scintillation fluid in the same pipette gave higher radon counts than "Separate Drawing".

- The Assay-2 (130-700 keV) based on the region of interest (ROI) for radon is better than the full spectrum assay (0-2000 keV).

The public education program encouraged Georgia homeowners to test their waters for uranium and radon. In some instances, test data showed that high level of radon (and uranium) in water was associated with high radon in air especially when the shower and/or washing machine were in use. In some cases, the uranium and radon levels in water were too high to be removed by a common household water treatment system. The best option would have been to obtain water from the public water system but extending county water distribution lines to areas with high uranium and radon that required a multimillion-dollar investment. Our program laid out the evidence-based groundwork that led to increased collaboration with state health and environment agencies, EPA, and community advocates that resulted in the county securing financing to extend water lines to the areas of the county impacted by contaminated well water. Another positive outcome was the ability to secure grant funds for Extension to purchase a liquid scintillator to test for radon in water. The program has enhanced our understanding about the nature and extent of uranium and radon problems in the state and how we can make an even greater impact by engaging with community advocates and various stakeholders. The program has also made a significant impact by educating homeowners and improve their knowledge on determining appropriate mitigation strategies, thereby creating a healthier environment and improve their quality of living.

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