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PART VI: Radionuclides

Chapter 13

RADON REMOVAL FROM POTABLE WATER SUPPLIED BY MUNICIPAL AND SINGLE HOME WATER WELLS

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ABSTRACT

Activated charcoal can remove contaminants such as radionuclides from potable water. In northern Virginia, a community water well normally producing about 17 million gallons of water per year plus many small homesite water wells were used to study the monthly and seasonal variation in waterborne radon concentration, These wells were also used to study the ability of activated charcoal to capture the dissolved radon before it reaches the home occupants. It was found that the percentage of radon removal was related to the volume of treated water, the type of activated charcoal, and the length of time that the charcoal was used. In brief, if sufficient activated charcoal was placed in the water treatment tank, the removal of waterborne radon could reach 90 percent. While the intensity of radiation that escaped through the walls of the capture tank was easily detected, estimates indicate that the health risk was minimal while the capture tanks were in operation, and during the replacement of the used and radioactive charcoal.

Keywords: radon, water, remediation

1. INTRODUCTION

Naturally occurring radionuclides are trace elements when found in rocks, soils, and water. There are 2,000 known radionuclides, which are species of atoms that

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emit radiation as they undergo radioactive decay through emission of alpha, beta, and gamma rays. The radioactive isotopes that carry the most health risk are alpha-particle emitters. Most of the radon in nature is Rn-222, which is an alpha-emitter, and is part of a decay series that includes other alpha-emitters including radium (Ra-226) and plutonium (Po-218, Po-214, and Po-210), which can cause cancer.

Radon is in groundwater that travels through cracks in bedrock. Water from wells normally has a much higher concentration of radon than the surface water in rivers, lakes and streams. The radon in groundwater as it is pumped out of a well remains in the water until the water escapes from a water outlet in the home.

Since it easily transfers from water to air, radon is rarely found in surface waters. Radon levels can vary greatly from one region to the next, because of differences in the local geology. Radon in well water also varies due to local, site specific factors such as well depth, distance from the radon source, pumpage patterns and the characteristics of the radon source.

The USEPA has concluded that the ingestion of radon and its decay products (mainly in well water) poses significant cancer risks other than lung cancer. The USEPA has noted that the cancer risks from radon in water (soft tissue cancer) are high. The cancer risk from radon in water is higher than the cancer risk nationally estimated to result from any other drinking water contaminant. Hess et al (1983, 1985) showed a correlation between radon in potable water and the incidence of cancer of many types. Under some circumstances, it seems likely that ingested radon could give a significant radiation dose to the stomach, which can lead to a significant risk of stomach cancer (Hursh et al., 1965). Radon decay products may also give a substantial dose to skin, since ingested radon escapes by in part through the skin (Harvey, 1971).

In 1992, Congress directed the USEPA to report on the risks from exposure to radon, the costs to control this exposure, and the risks from treating to remove radon. Drinking water that is contaminated with radon in excess of the USEPA's proposed MCL of 300 pCi/L is used by over 19 million people according to available USEPA data and poses significant, but avoidable health risks (USEPA, 1995). As required by the 1996 amendments to the Safe Drinking Water Act (SDWA), the USEPA should have established an enforceable standard for radon in tap water by the year 2000. Almost 2 of every 10,000 individuals exposed to 300 pCi/L of radon in water would develop a fatal case of cancer as a result of exposure to radon at this level.

In north-central Virginia and south-central Maryland, municipal water supplies obtained from reservoirs provide radon-free potable water. However, the average waterborne radon concentration in private and municipal water wells in

north-centralVirginia and south-central Maryland is much more than the USEPA's MCL for radon (Mose et al., 2001).

Most of the wells examined in most of the following study are in several different types of rock in northern Virginia and southern Maryland. The geological units in the northern Virginia and southern Maryland Appalachians are found over vast areas. Each unit can be traced over most of the terrain. The oldest unit in the study area is a quartzite, which was deposited as beach sand almost 600 million years ago. The deposition of this sand marks the beginning of a 200 million year interval, during which an increasing deep sea covered what is now the Piedmont Province of eastern Virginia and Maryland. Many additional layers of sedimentary and volcanic strata were deposited in this ancient pre-Atlantic ocean basin until about 400 million years ago. During the interval between approximately 400 and 300 million years ago, these ancient sedimentary and interlayered volcanic strata were deeply buried, to depths of about 5 miles. The sand was recrystallized into the metamorphic rock called quartzite. Clay rich strata formed mica-rich and feldspar-rich (felsic) metamorphic rocks. In some areas, high temperatures produced chambers of molten material which subsequently cooled to form the granites of the Appalachian Mountain system.

About 10% of the homes in northern Virginia use well water. The water from some of these wells exceed 4,000 pCi/L of radon, the average is about 2,000 pCi/L, and few homes have waterborne radon as low as 300 pCi/L . In the study area, water wells in the quartz rich sedimentary rocks yield well water that averages about 1,000 pCi/L. Wells in the felsic metamorphic rocks average about 2,000 pCi/L, and wells in the granite rocks average about 5,000 pCi/L.

Although it is known that radon and its decay products in well water can cause cancer, inexpensive methods of removing these radionuclides. The following report was based on measurements designed to determine the variability through time of radon concentrations in well water, well-to-home decreases in waterborne radon, and the effectiveness of radon removal from well water by using tanks of activated charcoal in large systems and small home systems.

2. DETERMINATION OF THE VARIABILITY THROUGH TIME OF RADON CONCENTRATIONS IN WATER WELLS, USING SHORT TIME INTERVALS (HOURS AND DAYS)

In most homes with wells, water is used repeatedly over short time intervals. Sometimes a much larger volume is used over a few days, as for example when watering a lawn or garden. More commonly, water is frequently used in smaller volumes, for operating showers, dishwashers and cloths washers. In all the cases,

most of the well water comes from the cracks in the local bedrock in the vicinity of the well.

As a pump runs, it lowers the level of water in the well and agitates water in the well. It was anticipated that waterborne radon would decrease during repeated and prolonged use of a water well, when some radon is lost by coming out of the water in the well and escaping out of the top of the well. However, no known experiments have been performed to test this possibility. It equally might be true that as water is removed from the well by the pump, water with more radon might enter the well. Data from several experiments are given in Table 1.

Table 1. Daily and Hourly Tests of Waterborne Radon

Experiment 1. Well in Fairfax, VA

Date	Time	Well Water Radon (pCi/)
4/02/06	1000	3820
4/18/07	900	2400
6/02/07	1100	2600
6/03/07	1100	2700
6/04/07	1000	2320
6/05/07	1200	2240
6/06/07	1300	2450
6/07/07	900	2250
6/10/07	1300	3650
6/10/07	1330	3020
6/10/07	1430	2620
6/10/07	1530	2380
6/10/07	1630	2160
6/10/07	1930	2100
6/10/07	2200	1820
6/10/07	900	3650
6/12/07	1100	2980

Experiment 2. Well number 1 in Culpeper, VA

Date	Time	Well Water Radon(pCi/)
2/20/06	1000	240
4/13/07	1230	520
4/13/07	1330	<100
4/13/07	1430	<100
4/20/07	1300	150
4/20/07	1330	100
4/20/07	1400	600
4/20/07	1430	210

Experiment 3. Well number 2 in Culpeper, VA

Date	Time	Well Water Radon(pCi/)
2/15/06	1800	570
2/20/07	1000	300
4/22/07	0800	700
4/22/07	0900	600
4/22/07	1100	540
4/22/07	1200	480
4/22/07	1300	470

2.1 Results

As shown in Table 1, waterborne radon did not show a steady increase or decrease when tested once a day, over several days. However, when waterborne radon was tested once an hour, over several hours, the waterborne radon concentration decreased. The pattern of change reveals the probable explanation.

The Experiment 1 well, VA well, when tested hourly on 6/10/07, showed a steady decrease in waterborne radon. The Experiment 2 well, when tested hourly on 4/22/07, also showed a steady decrease in waterborne radon. The Experiment 2 well is only about 300 meters from the Experiment 3 well, and because of similar geology, should have similar waterborne radon. However, the Experiment 2 well provides considerably less water, because there are fewer cracks in the bedrock in the vicinity at this well site compared to the Experiment 3 well. It was observed, as shown on Table 1, that the radon in the Experiment 1 well was initially similar (a few 100 pCi/L) to that in the Experiment 3 well. However, after about I hour the amount of water coming out of the Experiment 2 well decreased greatly, to about 1/10 of its original productivity. At the same time, the amount of waterborne radon decreased greatly.

It seems likely that when the level of water in the Experiment 2 well is lowered, the water pump is “churning” the water, which happens when the water level is so low that the top of the water pump is exposed. In this condition, radon dissolved in the water would be driven out of the water around the pump, and would escape up the nearly empty well pipe. The water that does get pushed out of the well by the pump should then have considerably less radon. As shown in Table 1, in all three experiments, the waterborne radon hour-to-hour decrease is a mechanical phenomenon relate to water agitation caused by the well water pump.

3. THE WELL-TO-HOME DECREASE IN WATERBORNE RADON

The concentration of radon in drinking water decreases in the distribution system when it travels from the treatment plant to customers. Measurements were made of potable water radon at Prince William well sites and at homes served by these wells. The water collections were made using the kitchen water faucet, after running the water for a few minutes until it seemed not to get any colder. Then the water faucet was turned to slow non-turbulent flow. The non-turbulent method of collection is the best, because it reduces loss of radon during the moment of sample collection.

Water was also collected as it flowed out of the wellhead collection tank, to determine the level of radioactivity that was being sent to the homes. Well number WO-6 was selected for the well-to-home study (Table 2).

3.1 Results

In this study of well-to-home loss of radioactivity, the well-to-home loss of radioactivity was about 30%. This seems large, because in this community as in most large systems, normally less than one day occurs between the times that well water is pumped from storage tanks to the time it reaches the surrounding homes (Mose, 2007). The half-life for radon-222 is 3.8 days, so one might expect that a loss of radioactivity of less than 30% (perhaps 20%) would occur between when water is taken out of the wells and when the water arrives at the homes.

Perhaps the well-to-home time interval is actually more than one day. Perhaps some radon gas escapes from the pipes and tanks (radon can escape through holes smaller than holes through which water can escape). In fact, another factor may play a role in affecting the well-to-home change. It is known that metals such as radium (which decays to radon) can accumulate on the interior walls of water pipes. Pipes that are older might be expected to have more accumulation of radium and other uranium-chain radionuclides on the interior of the pipes, which should serve to increase waterborne radon concentrations after the water leaves the water well, and thereby reduce the well-to-home decrease.

In any event, the well-to-home loss of radioactivity, at 30%, is still too small to make the water safe. That is, while water provided by the Prince William Service Authority (PWCSA) well WO-6 is always in excess of 2,000 pCi/L, the well-to-home decrease does not ever cause the waterborne radon in the home to fall below the USEPA's MCL of 300 pCi/L.

4. THE DETERMINATION OF THE EFFECTIVENESS OF RADON REMOVAL FROM WELL WATER BY USING TANKS OF ACTIVATED CHARCOAL.

There are two technologies most commonly used for removal of radon from well water. They are Aeration and Granulated Activated Charcoal (GAC). GAC in the United States has long been used for the control of synthetic organic chemicals and taste and odor problems. Since the detection of high levels of radon in drinking water supplies, a number of research studies have been undertaken to evaluate the effectiveness of GAC for controlling radon. As the water moves through a bed of activated carbon, the radon is adsorbed onto the carbon until all the available GAC surface area is taken up.

Table 2. Decrease of waterborne radon between the Algonquin Hills System Well Number WO 6 and a home on Running Dear Road in Prince William County, Virginia

Date	Well (pCi/)	Home(pCi/)	Decrease
02/05/91	2540	1750	31 %
02/11/91	N/A	1080	N/A
02/12/91	3510	2140	39
02/15/91	2010	940	53
03/28/91	2610	1990	24
04/02/91	2640	1830	31
06/06/91	2430	1780	27
06/07/91	2150	1780	17
06/24/91	2460	N/A	N/A
07/10/91	3260	2680	18
07/25/91	2630	1830	30
11/19/91	2230	1320	41
12/16/91	2130	1730	19
Avg = 30	Avg = 2558	Avg = 1797	

The adsorption process occurs when the radon molecules diffuse through the water to the surface of the GAC. Radon sorbs at the interface between the water and the carbon. Therefore, the higher the surface area of the GAC, the more effective is the adsorption process. The outer surface of the carbon provides some area for adsorption, but most of the surface area is in the pores within the carbon particles.

Contaminant removals are a function of the available interfacial area between water and GAC, and the rate at which the water flows through the GAC. The success of a GAC system also depends on competitive adsorption from natural organic matter in the water, which can compete with radon for adsorption sites. Also, adsorption can be greatly limited by suspended solids in the water, which coat the outer surface of the GAC. These solids are often oxides and carbonates of Fe, Mn and Pb. Consequently, GAC systems may require some kind of pretreatment to minimize the organic loading of the carbon, and eventually clogging of the carbon bed. Filtration ahead of the GAC system is the most common solution to prevent clogging of the GAC bed.

In theory, waterborne radon is retained in the GAC, and the water leaves the charcoal tank relatively free of radon and radon decay products. GAC systems have been shown to be effective at lowering waterborne radon levels, but more needs to be known about the length of the complete removal interval, and about the radioactivity that builds up in the filter bed.

Gamma radiation exposure from GAC tanks and waste disposal issues of used GAC related to the accumulation of radioactivity on the media are two concerns associated with using GAC for radon removal in homes. The decay of radon within the GAC bed results in the growth of radon progeny. Beta, gamma and alpha emissions come from the decay of Po-218, Pb-214, Bi-214 and Po-214, which have short half-lives. In addition to these radioactive decay products, there is also a buildup of radioactive Pb-210 on the GAC bed, and Pb-210 has a long half-life (22 years). In short, the accumulation of radon and other radionuclides on the activated charcoal poses a potential health risk to home occupants.

Fortunately, only gamma radiation can pass through the walls of a GAC tank. The level of gamma radiation surrounding the bed depends on the influent radon level, radon effluent level, the distance from the bed. The exposure rate is significantly lower a few feet from the GAC bed, compared to the maximum exposure rate found at the surface of the GAC vessel.

All types of GAC have a finite adsorption capacity that is determined by the characteristics of the targeted contaminant. When the contaminant begins to appear in the effluent, breakthrough is said to have occurred. In the radon adsorption process, an adsorbed radon atom decays, reducing the interfacial

concentrations of radon and restoring some adsorption capacity to allow new radon atoms to become adsorbed. Once the breakthrough concentration reaches an excessive level, the carbon must be regenerated or replaced.

4.1 Results

4.1.1. Measurements Using a Large Water Treatment System

One of the study wells in Prince William County (well WG-7) delivers about 17,000,000 gallons of VOC-free potable water each year to Prince William County residents. For many years GAC has been used to remove Volatile Organic Carbon (VOC) present in well WG-7. The water is rendered VOC-free by passing it through two 2,000 cubic foot tanks containing GAC. Well WG-7 was selected for a radon study, because in theory VOC removal and radon removal might be similar (Table 3).

At well WG-7, the GAC in each of the two tanks is changed in alternating years. That is, once a year the older charcoal in one of the tanks is replaced. The tank with the older charcoal is filled with new charcoal (the old charcoal goes to a landfill), and the water pathway is changed so as to have the water pass through the tank of one-year-old charcoal, and then through the tank of just-replaced charcoal.

Table 3. Radon from Prince William County well WG-7.

Tank Well Water	Month	Radon Concentration(pCi/L)	% Reduction
Well water	03	1800	-
After first tank		1880	0%
After second tank		730	59%
Well water	06	1640	-
After first tank		1290	0%
After second tank		800	38%
Well water	07	2330	-
After first tank		2040	12%
After second tank		750	68%
Well water	02	2190	-
After first tank		830	62%
After second tank		90	96%
Well water	02	No measurement	-
After first tank		1250	
After second tank		310	
Well water	03	1680	-
After first tank		1280	24%
After second tank		350	79%
Well water	03	1760	-
After first tank		1250	29%

Table 3. Continued

Tank Well Water	Month	Radon Concentration(pCi/L)	% Reduction
After second tank		430	76%
Well water	04	1990	-
After first tank		1080	46%
After second tank		460	77%
Well water	05	2150	-
After first tank		1720	20%
After second tank		570	73%
Well water	06	2160	-
After first tank		1650	24%
After second tank		560	74%
Well water	08	2090	-
After first tank		1540	26%
After second tank		620	70%
Well water	09	1650	-
After first tank		1440	13%
After second tank		690	58%
Well water	11	1950	-
After first tank		1260	35%
After second tank		580	70%
Well water	12	2160	-
After first tank		1780	18%
After second tank		740	66%
Well water	01	2110	-
After first tank		1690	20%
After second tank		240	89%
Well water	03	1830	-
After first tank		1820	0.5%
After second tank		810	56%

Currently there are no Federal regulations governing the disposal of radioactive waste generated by water treatment facilities. The US Nuclear Regulatory Commission's does not regulate naturally occurring radioactive material. The USEPA notes that most States deal with the disposal of radioactive water treatment residuals on a case-by-case basis. The States have no specific regulations or guidelines for these radioactive residuals, but instead apply existing solid waste or hazardous waste disposal requirements. Since a GAC system in a home creates such a small volume of radioactive charcoal, GAC from homes are normally disposed as normal trash.

Tests using a field radiation meter first were conducted on the outside of the two charcoal-containing tanks at well WG-7 to make sure that it was safe to work around the tanks. The measurements showed that while the charcoal does retain radionuclides, the intensity of gamma-radiation from radon decay product Bi-214

(a short-lived, but strong gamma emitter) outside the tanks is not a significant health risk, even assuming long-term exposure. That is, a person whose office is inside the building containing the tanks would not be exposed to a significant gamma-dose assuming 40 hours/week in the office. Other forms of radiation, such as beta and alpha radiation, cannot escape the metal tanks as long as the charcoal remains in the tanks.

The investigation conducted to determine the radon-removal effectiveness of GAC to remove waterborne radon at well WG-7 in Prince William County showed that well water from well WG-7 exceeds 2,000 pCi/L, but after the water passes through the two GAC tanks, the waterborne radon is less than 800 pCi/L.

After flowing through one large tank of GAC, the waterborne radon from well WG-7 decreased by an average of 22 % from the untreated well water. It decreased by 70% after a second large tank of GAC. Although the radon in the water leaving the charcoal treatment at well WG-7 is not reduced to less than the USEPA's MCL of 300 pCi/L, most of the radon was removed. This is important, considering that this is a high volume well, sending thousands of gallons each day to homes in Prince William County. The reduction in health risk is significant

4.1.2 Measurements Using Small Water Treatment Systems

The National Inorganics and Radionuclides Survey (NIRS) conducted by EPA indicated that the concentration of radon in United States groundwater supplies ranged up to about 25,000 pCi/L (Longtin, 1988). Levels of radon in groundwater supplies had range of 100 to 1000 pCi/L for 61.5% of the 978 sites sampled in the NIRS. The highest levels of radon observed in the NIRS were in small system supplies serving fewer than 500 people. About 83% of groundwater systems have a radon concentration of less than 500 pCi/L and that about 10% of ground water systems have a radon concentration between 500 and 1000 pCi/L.

Point of entry GAC units consist of a metal or a fiberglass pressure vessel containing one or more cubic feet of activated carbon. The two basic configurations for homesite operation is the down flow fixed bed and the up flow fixed bed. The system is operated by gravity or under pressure. Downward flow systems are also used when the unit is used to filter out suspended solids. Two or more fixed beds operated in parallel typically are used when a high flow rate would require a vessel diameter too large to be economical or feasible. Down flow fixed bed systems are the simplest configuration for radon removal of groundwater at the point where it enters a home.

In most homes, GAC systems operate in an up flow mode where the contaminated water is introduced under pressure at the bottom of the carbon bed,

and flows up through the bed to the top. The radon moves with the water up through the GAC bed until there is available area for adsorption to take place.

After some experimentation, it had been determined that GAC made from cocoanut provided the best radon removal among the many types of GAC available to water treatment companies. In Table 4, the results of using GAC made from coconut shells are reported for several homes in northern Virginia over the past 15 years.

Experiments conducted prior to the results presented here determined that GAC volumes less than 2 cubic feet were not effective for long-term (more than one year) removal of waterborne radon in significant amounts (Mose, 2007). The systems installed in the homes summarized in table 10 all were 2 to 2 1/4 cubic

Table 4. Reduction of Waterborne Radon in Northern Virginia Homes

Home	Pre-Remediation(pCi/)	Post-Remediation(pCi/)	% Decrease	Location
1	1990--------- 3070	NA	-	Great Falls, VA
	12/27/90----3690	12/27/90----150	96%	
	01/20/92----3130	01/20/92----580	81%	
	09/19/92----1990	09/19/92----740	63%	
2	02/11/91--- -3890	NA	-	
	10/09/91----3590	10/9/91-------850	76%	Annandale, VA
3	01/31/91----4490	NA	-	
	04/08/91----3890	04/08/91--------150	96%	
	05/14/91----4710	05/14/91--------350	93%	
	08/28/92----3890	08/28/92------2370	39%	
	09/16/92----4350	09/16/92-------2830	35%	
4	1990--------11,380	NA	-	Clifton, VA
	01/18/91-----9290	01/18/91------1590	83%	
	03/31/91---10,330	03/31/91------1780	83%	
	06/05/91-----6620	06/05/91------1110	83%	
	06/11/91---12,190	06/11/91------1610	87%	
	09/03/91-----8880	09/03/91------3910	56%	
	04/11/92-----6800	04/11/92--------450	93%	
	08/28/92-----9900	08/28/92------2770	72%	
	04/30/97----10750	04/30/97-------400	96%*	
	06/12/98-----8640	06/12/98--------800	91%	
5	01/19/91-----3180	NA	-	Great Falls, VA
	08/02/91-----2990	08/02/91-------450	84%	
	01/20/92-----3360	01/20/92-------970	71%	
	09/19/92-----3040	09/19/92------1080	64%	
	05/13/93-----2390	05/13/93------<100	96%	
6	03/12/91------4620	NA	-	
	09/03/91------2960	09/03/91------475	84%	Clifton, VA
7	01/15/91-------1630	NA	-	
	04/06/91-------2340	04/06/91------150	94%	Dale City, VA
	01/18/92------1780	01/18/92------180	90%	
	NA	04/26/97------400	-	

Table 4. Continued

Home	Pre-Remediation(pCi/)	Post-Remediation(pCi/)	% Decrease	Location
8	03/24/92------4550	NA	-	
	08/18/92------4890	08/18/92---------250	95%	Oakton, VA
	05/13/93------4840	05/13/93--------2460	49%	
9	08/18/92------8390	NA	-	
	04/08/97------7490	04/08/97-------1960	73%	Clifton, VA
10	1990---- -----5650	NA	-	McLean, VA
	11/10/90-- --6530	11/30/90-------1750	73%	
	10/30/90--- -4190	10/30/90--------650	85%	
11	10/05/92------3320	NA	-	Clifton, VA
12	03/25/93------4500	NA	-	
	04/30/97-----6270	04/30/97-----2120	66%	Clifton, VA
13	12/18/90-----7320	NA	-	Great Falls, VA
	04/24/93------7700	04/24/97------310	96%	
14	12/18/90-----7060	NA	-	Great Falls, VA
	04/6/91------7180	04/06/91-----460		
15	04/17/91----4340	04/17/91------560	87%	Clifton, VA
	06/21/91----4090	06/21/90------140	96%	
	08/22/92----5200	08/22/92----<100	98%	
16	04/28/92-----7190	NA	-	Clifton, VA
	12/18/99-----9740	12/18/99---<100	99%	
17	11/1/90-----5020	NA	0	McLean, VA
	11/10/90---4360	11/10/90-----1440	67%	
	01/18/91----5570	01/18/91------110	98%	
	02/18/92----4200	02/18/92------240	94%	
18	1990---------4360	NA	-	Clifton, VA
	03/30/91----4570	03/30/91-----250	94%	
	08/28/92----4370	08/28/92-----290	93%	
19	1990--------5000	NA	-	Oakton, VA
	03/30/91---4120	03/30/91------280		
20	04/02/06 3820	540	86%	Fairfax, VA
	04/18/07 2400	570	76%	
	06/02/07 2600	810	69%	
	06/03/07 2700	880	67%	
	06/04/07 2320	630	72%	
	06/05/07 2240	630	72%	
	06/06/07 2450	810	67%	
	06/07/07 2250	630	72%	
	06/10/07 3650	850	82%	
Time for 06/10/07 date				
	1300 3650	850	77%	
	1330 3020	830	73%	
	1430 2620	640	76%	
	1530 2380	630	73%	
	1630 2160	640	70%	
	1930 2100	600	71%	
	2200 1820	570	69%	
	06/12/07 2980	660	78%	

Table 4. Continued

Home	Pre-Remediation(pCi/)		Post-Remediation(pCi/)	% Decrease	Location
21	09/92	3130	580	81%	Great Falls, VA
22	10/14/05	1050	<100	90%	Woodbridge, VA
	01/13/06	1870	<50	90%	
23	10/01/89	5260	820	84%	Clifton, VA
	1990	NA	930	-	
	1990	4990	<50	90%	
24	01/13/06	2000	<100	90%	Woodbridge, VA
	01/13/06	3580	680	81%	
25	01/14/06	3400	NA	-	Great Falls, VA
	12/14/06	3500	320	91%	
26	07/25/05	2340	<100	90%	Woodbridge, VA
	01/13/06	NA	<100		
27	03/07	1700	NA	-	Aldie, VA
	07/09/07	1350	190	86%	

feet of coconut GAC in one tank, and used an upward flow of well water through beds of the charcoal.

The experiments reported here, with 2 to 2 ½ cubic feet of GAC made from cocoanut shells, removed between 70% and 90% the waterborne radon. The percent removal did not show a steady increase or decrease through time. Changes did occur through time, in that the % decrease rose or fell in an apparent random fashion.

In one experiment (see home 20, data for 6/10/07), pre-GAC and post-GAC were obtained hourly as water continuously flowed into a sink. The pre-GAC measurement of waterborne radon decreased, but the post-GAC measurement showed an almost constant % decrease of about 70%.

5. CONCLUSION

The month-to-month variations of water radioactivity cannot be related to the chemistry of the rocks holding the groundwater, because the uranium content of the rock reservoir from which ground water obtains radon does not change. It seems more likely that rainfall changes might cause seasonal radioactivity changes in well water. The monthly amount of new downward moving water derived from rainfall does change. During late spring to early summer, when more rainfall normally occurs, the radioactivity of groundwater increases.

Waterborne radon did not show a steady increase or decrease when tested once a day, over several days. However, when waterborne radon was tested once an hour, over several hours, the waterborne radon concentration decreased. It seems likely that when the level of water in a well lowers due to frequent

pumping, the water pump is "churning" the water. Dissolved radon in the water is driven out of the water around the pump, and escapes up the empty well pipe. Consequently, the water that does get pushed out of the well by the pump has less and less dissolved radon. In the study of well-to-home loss of radioactivity, the well-to-home loss of radioactivity was about 30%. This seems to be large, because in this community as in most large systems, normally less than one day passes between the times that well water is pumped from storage tanks to the time it reaches the surrounding homes. The half-life for radon-222 is 3.8 days, so one might expect that a loss of radioactivity of less than 30% between when water is taken out of a well and when the water arrives at a home. Perhaps the well-to-home time interval is actually more than one day. Perhaps some radon gas escapes from the pipes and tanks. In any event, the well-to-home loss of radioactivity, at 30%, is too small to make the water safe. For example, water provided by the Prince William Service Authority (PWCSA) well WO-6 is always in excess of 2,000 pCi/L, the well-to-home decrease does not ever cause the waterborne radon in the home to fall below the USEPA's MCL of 300 pCi/L.

An investigation conducted to determine the effectiveness of GAC to remove waterborne radon from large-productivity water systems showed that in a case where radioactivity exceeds 2,000 pCi/L, after the water passed through two GAC tanks, the waterborne radon was less than 800 pCi/L. Although the radon in the water leaving the charcoal treatment was not reduced to less than 300 pCi/L, most of the radon was removed. This is a high volume well, sending thousands of gallons each day to homes, so the reduction in health risk is significant.

In a study of approximately 25 homes with wells, two or more cubic feet of activated charcoal made from cocoanut shells removed, on average, about 70% of the waterborne radon. The effectiveness of the GAC systems in the homes sometimes showed considerable variation through time, but the data do not show a steady increase or decrease in radon removal.

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