Unit 6. Domestic Water: Radon Measurement and Control

Contents

Objectives

06.01 Describe the relationship between radon in water and radon in air for the average home and the health effects due to radon in water.

06.02 Identify the conditions under which testing for radon in water is indicated.

06.03 [1]***Describe the various techniques for collecting water samples for analyses and the factors affecting the accuracy of measurement results in the sample collection procedure.
****Describe mitigation techniques for radon in water and considerations for installation and long-term operation.

1 *These objectives are only for radon measurement specialists.

**These objectives are only for radon mitigation specialists.

***These objectives are only for measurement applicants.

****These objectives are only for mitigation applicants.

I. Objective

This chapter familiarizes the Florida certified mitigator with the issue of radon in water. Its scope, however, does not provide sufficient detail for the typical mitigator to install radon in water reduction systems. Additional skills relating to water quality and plumbing practices are not included in this manual. What is discussed are issues relating to radon in water sampling, as well as an overview of mitigation techniques. The goal of this chapter is to make the mitigator conscious of water as an additional radon source. In this way, the mitigator can recognize that in some cases a dual approach to radon in soil gas as well as radon in water may be necessary to achieve the reduction desired.

It is envisioned that if a radon in water problem is encountered, the mitigator will be able to sample the water and seek additional expertise in the design and installation of a radon in water reduction system.

II. Overview

For homes in which the well water contains high levels of radon, radon transfer to the indoor air through water use can be a significant source of the airborne radon. This unit explains:

- The importance of waterborne radon.
- How to collect a water sample.
- How to interpret the results of a water analysis.
- The water treatment technologies available for radon removal.
- The economics of radon removal from household water supplies.
- How to locate qualified suppliers/installers of treatment units.

III. Importance Of Radon In Water

There are three possible sources of airborne radon in households:

- Soil gas.
- Water supply.
- Building/construction materials.

Although soil gas is generally recognized as the largest natural source of radon in homes, the water supply can contribute a significant fraction. In fact, in certain homes the water supply bas been shown to be responsible for essentially 100 percent of the elevated levels of airborne radon. Additionally, the localized concentration of radon released from water during showering or similar activities can be extremely high.

To assess potential public exposure to radon in drinking water on a nationwide basis, the EPA conducted a national survey of radon in finished drinking water from 1,000 sites throughout the United States. This survey was part of a national survey on inorganics and radionuclides, called the National Inorganics and Radionuclides Survey (NIRS). Sampling was carried out between July 1, 1984 and October 31, 1986, and 990 samples were actually sampled out of the 1,000 sites targeted. Survey results showed that 72.5 percent of the sites bad radon concentrations greater than 100 pCi/L (the minimum reporting level) and a maximum activity level of 25,700 pCi/L (Ref. 10).

To date, elevated levels of radon in individual wells have been found in many states, but especially in Maine, New Hampshire, and Colorado. Preliminary results from a nationwide survey of radon levels in private groundwater supplies indicate that private wells usually have several times the radon concentration of municipal supplies. Levels exceeding 20,000 pCi/L were found in 13 states. Findings also suggested that radon levels in individual wells are determined more by "micro-geological factors operating within a few feet of the well" (such as disruption close to the well caused by the digging of a well) than by area wide geology (Ref. 20).

In July 1992, the EPA proposed a maximum contaminant level (MCL) of 300 pCi/L in public drinking supplies. This proposed standard was based upon the risk primarily associated with the out-gassing of radon from these water supplies as a contribution of breathable radon and associated decay products in the air.

At the proposed MCL of 300 pCi/L. radon could easily become one of the most treated for contaminants in drinking water. As of 1980 there were 60,000 public water supplies in the United States that would be affected by this regulation. Eighty percent or 48,000 of these use groundwater as all or part of their water supply, where radon concern could be pronounced (Ref. 5). The average radon concentration in groundwater ranges between approximately 300 and 800 pCi/L, depending upon system size (well yield). For private home supplies, it is estimated that the mean radon level is approximately 750 pCi/L. For public groundwater supplies in the United States, small and large systems average approximately 300 pCi/L and 600 pCi/L, respectively. For wells containing only 20,000 pCi/L, removal must be greater than 98 percent to meet an MCL of 300 pCi/L.

A. Water vs Air Radon Concentration

Waterborne radon concentrations are generally much higher than those found in air. The unit picoCuries" per liter (pCi/L) is used to express an amount of radon per liter of air (or per liter of water in this instance). Until recent years, the levels at which these concentrations became a cause for concern were thought to be very different for the two media. Ingestion of radon through drinking water was not considered to pose a significant health threat until the levels reached several hundred thousand pCi/L. Recent experimental work, however, suggests the number of fatal cancers from radon ingestion in drinking water may be significant (Ref. 17, 3). Although the uncertainty of this work is large, it has raised the possibility that radon ingestion may represent a major pathway for risk when stomach cancer is included in the risk analysis.

It takes relatively high levels of waterborne radon to result in significantly elevated levels of airborne radon. This is due to the partial transfer of radon from water to air and more importantly, the relatively small volume of water used as compared to the large volume of diluting air inside a home. Some researchers have determined that, on average, 1 pCi/L of airborne radon will result from the normal use of a water supply containing 10,000 pCi/L. Whereas this number is only an average and is subject to extreme variation, it does illustrate the large difference in the significance of water and air radon concentrations (see Figure 6-1). It is important to explain this consideration to the homeowner, as it is sometimes difficult to convince a person to be concerned about 10 pCi/L in the air when the water supply contains 10,000 pCi/L.

B. Water to Air Radon Transfer

The amount of radon transferred from water to air is a function of:

- The waterborne radon level.
- The amount of water used.
- The type of water use activity, e.g., shower (high transfer) vs. running water
- in a sink (low transfer).
- The water and air temperatures.

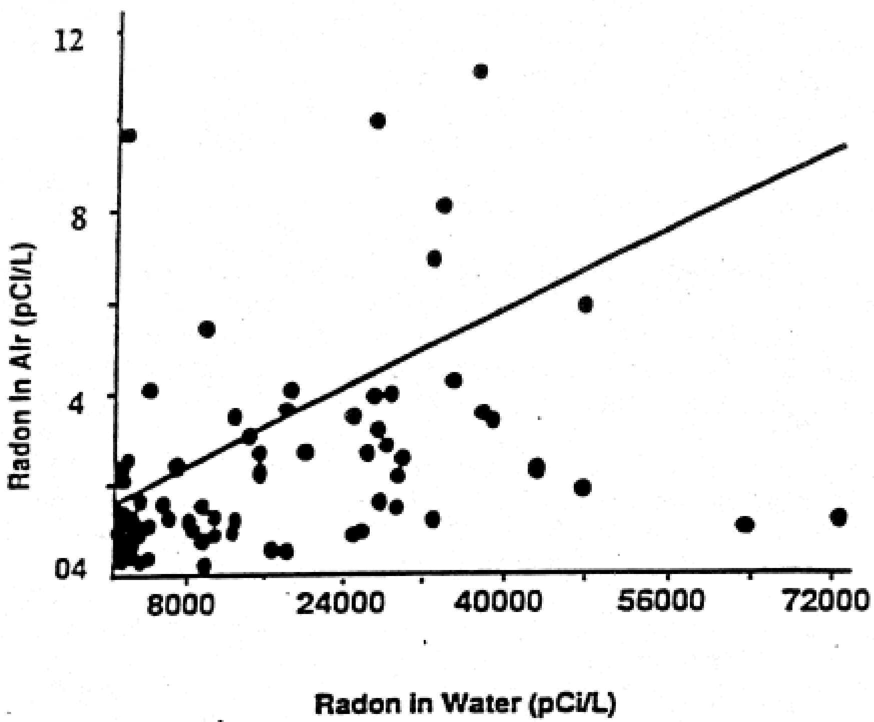

Figure 6-1 Radon in Air vs. Radon in Water, Source: Hess

Levels of radon observed in household well water supplies range from near 0 to over 1 million pCi/L. Using the assumption that 10,000 pCi/L in the water will add 1.0 pCi/L to the overall accumulation of airborne radon in the home, it takes a waterborne radon level of 40,000 pCi/L to result in the EPA guideline level of 4 pCi/L in the air.

However:

- The 10,000:1 ratio is not valid in all cases.
- Water is rarely the only contributor to the airborne radon level.
- The conditions at a specific household may dictate concern about levels significantly lower than 40,000 pCi/L of radon in its water supply.

- Levels far greater than the whole house average can be found in areas of hot water use, such as showers, laundry rooms etc.

EPA does not currently have a maximum containment level (MCL) for radon in drinking water. In July 1992, however, as pan of its proposed revised regulations (Ref. 4) on radionuclides for community drinking water supplies, EPA proposed an MCL of 300 pCi/L. This low level was proposed, because radon removal treatment is considered to be affordable and technologically feasible for public water supplies. Using the air-to-water rule of thumb ratio of 1 to 10,000, radon at this level contributes about 0.03 pCi/L of radon in the air. This corresponds to an estimated lifetime cancer risk of 2 x 10'4 (2 in 10,000) and is consistent with EPA's risk guidelines for regulating other drinking water contaminants.

The drinking water MCL is only directly applicable to public water supplies. The current guidelines used by individual states for radon in private household water supplies typically range between 10,000 and 20,000 pCi/L. This is expected to change now that EPA has formally proposed a lower MCL of 300 pCi/L, and it is likely that home purchasers will use this lower value for decisions associated with contingencies in real estate transactions. Radon mitigators, therefore, may find an increasing emphasis placed on water radon in the near future, even though the contribution is in most cases smaller than EPA air guidelines of 4 pCi/L.

IV. Sample Collection

Identifying the significance of a well water supply to the airborne radon levels in a home begins with a water analysis. The basic sampling/analysis process should minimize the loss of radon during collection and transport; a range of 4-6 hours between collection and counting is typical. Counting should be performed by a reputable laboratory employing control blanks and radon standards. (Many states are able to provide names of suitable laboratories.) It should be noted that EPA currently does not include water analysis as part of its RMP program.

A. Sampling Methods

In the absence of an EPA-approved standard method for sample collection, the following two basic methods are used in the field.

- The direct syringe method (on-site, direct set-up for subsequent counting by liquid scintillation inthe lab).
- Collection of a volume of water with subsequent set up and counting by liquid scintillation in the lab. For the most representative results, the water should be run until any holding tank (or pressure tank) has been completely purged of "old" water and replaced with water directly from the well.

1. Direct Syringe Method

The direct syringe method involves collecting a water sample by means of a ten cubic centimeter syringe and injecting it into a sample vial of mineral oil (see Figure 6- 2). Radon is preferentially soluble in mineral oil, therefore, the radon from the water sample will migrate from the water to the mineral oil. This allows for the sample bottle containing the water and oil to be shipped to the laboratory without significant out-gassing of the radon. The laboratory will add a scintillant fluid to the sample which will fluoresce proportionally to the amount of radon and RDPs in the sample. This fluorescence can be detected by a scintillation counter, which allows the laboratory to calculate the radon in the original water sample.

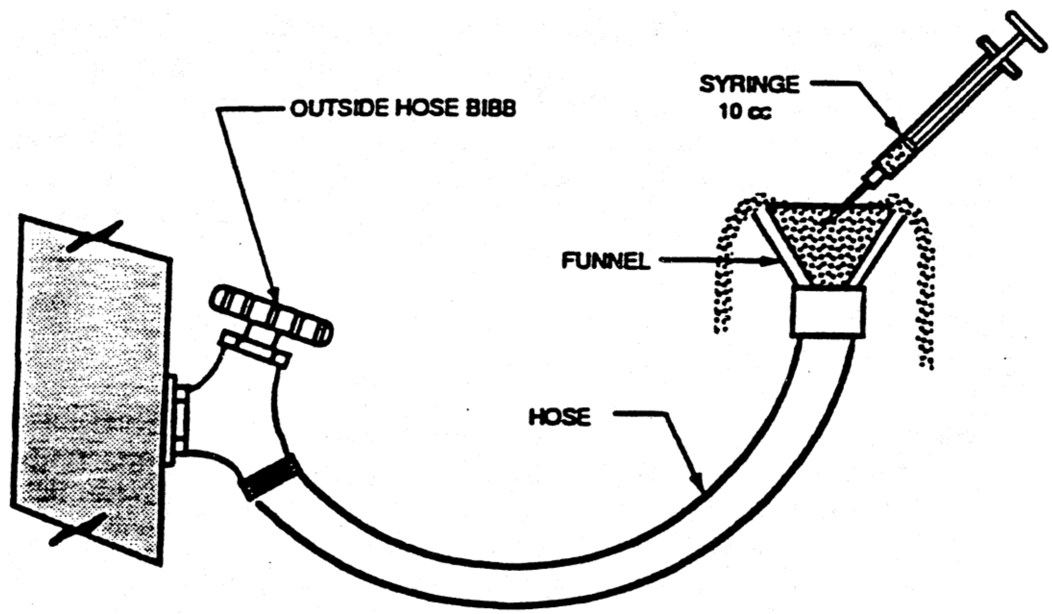

Figure 6-2. Direct Syringe Method, Source: Burkhart

More specifically the steps of this method are as follows:

- Select a sample point in the home where the water does not pass through the hot water beater. An outside hose connection would be a convenient location. Run water from the faucet for a sufficient period of time to insure that the water to be sampled is from the well rather than water which has settled in the pipes or the pressure tank.
- Connect a female hose connector to the faucet that is attached to a short length of hose and a funnel. With the funnel held vertically, open the faucet allowing water to slowly fill the hose and overflow the funnel.
- Insert the syringe below the level of the water in the funnel and slowly withdraw a ten cc sample into the syringe (some labs may require different quantities of water sample).
- Remove the syringe from the water and insert the needle of the syringe into the sample vial pre-filled with mineral oil that was obtained from the laboratory. Put the needle below the surface of the mineral oil and insert the water sample into the sample vial.
- Record the date and time the sample was taken, as well as the volume of sample that was taken with the syringe and ship to the lab.

Note that some laboratories supply sample vials that are pre-filled with mineral oil, while some supply the vial pre-filled with the scintillant solution. Scintillant solutions are often toluene-based and are therefore flammable. Whereas flammable liquids cannot be sent to the laboratory via mail, the vials tilled with mineral oil can be mailed at the present time (the analyst should verify US Mail regulations prior to shipment or ship via ground carrier).

2. Water Sample Collection Method

An alternate method is to take a water sample without adding it to a solution and therefore reduce shipping concerns. This adds some additional errors, however, due to radon out-gassing during the shipment of the sample (Ref. 1). The procedure for this method is as follows:

- If a faucet aerator is present, remove it from the tap.
- For the most representative results, the water should be run until any holding tank or pressure tank has been completely purged of "old" water and replaced with water directly from the well.

- Fill a 40-mL glass vial slowly to avoid the formation of bubbles, allowing the vial to overflow a few seconds (see Figure 6-3). Alternatively, the vial can be filled by submerging it (and its cap) in a bowl into which the water is running. (Inthe alternate method, the bowl is held sufficiently close to the tap so the water level in the bowl is actually above the faucet outlet. The excess water continuously spills out of the bowl into the sink below (see Figure 6-4).

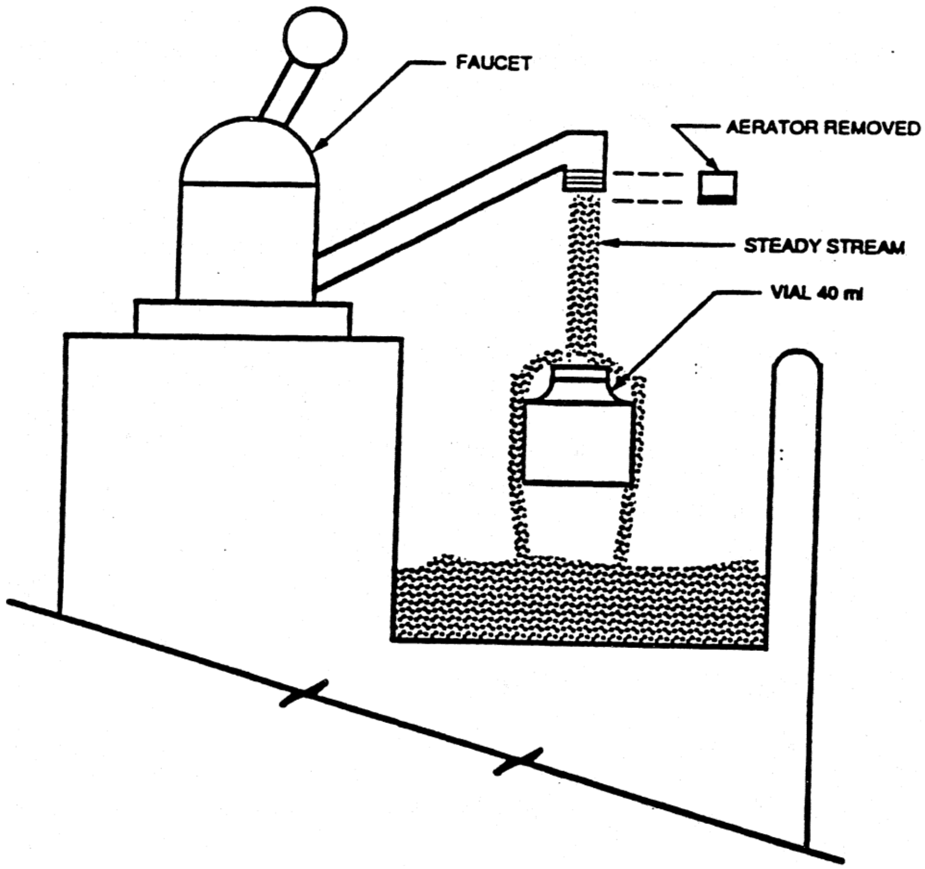

Figure 6-3. Direct Water Sample from Faucet, Source: Burkhart

- Immediately cap the vial, being careful to avoid trapping an air bubble. The vial should have a screw cap, with a Teflon or aluminum-faced seal.

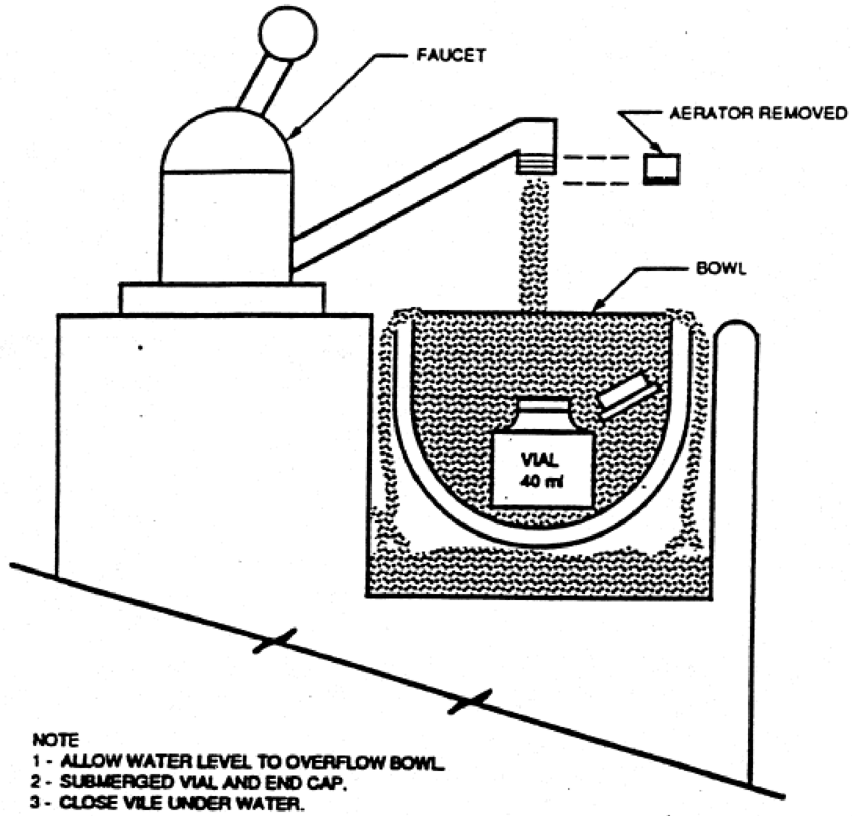

Figure 6-4. Water Sample from Overflowing Bowl, Source: Burkhart

- Invert the vial and check for air bubbles. If air bubbles are present, redo the sample.
- Record the date and time that the sample was taken and, identify the location.
- Pack the bottle carefully to avoid breakage.
- Mail the sample to the laboratory for counting on the same day as collection. Transit time should be less than 3 days; preferably, use overnight delivery. This minimizes decay and the associated counting error. The sample should be counted the same day it is received at the laboratory.

B. Analysis and Quality Control

The two methods of analyzing collected water samples, acceptable in terms of sensitivity and accuracy, are liquid scintillation counting and gamma counting. Liquid scintillation counting analysis, the basis for which is discussed by Pritchard and Gesell (Ref. 18), is the most commonly used method.

Radon analysis precision is a function of the level of radon present, the counting time, and the elapsed time between sampling and counting. Figure 6-5 presents typical levels of uncertainty (2-sigma) for samples that are promptly mailed to the laboratory.

As with airborne radon, waterborne radon varies tremendously from house to house in a given locality. In an actual case in Maine, two houses, 50 yards apart, measured on a given day had waterborne radon levels of 16,000 pCi/L and 1,600,000 pCi/L, respectively.

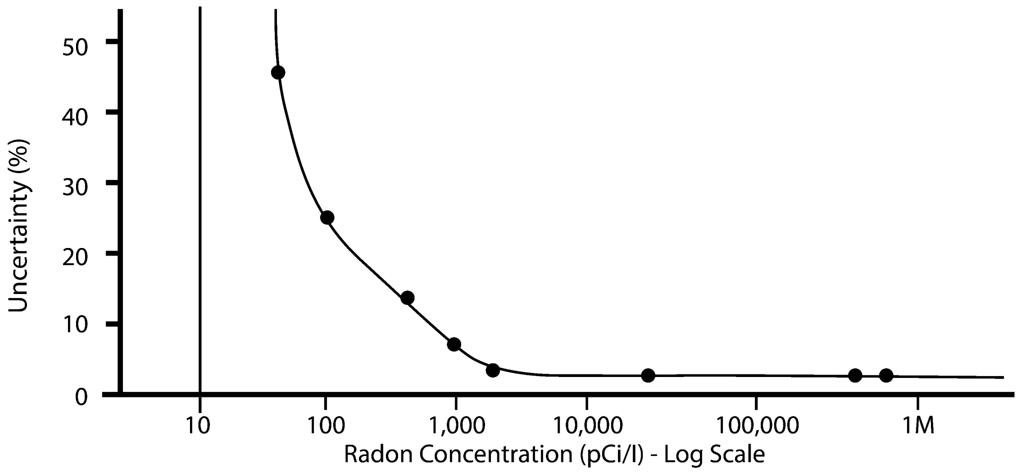

Figure 6-5. Typical Levels of Uncertainty (Counting) for Promptly Mailed Samples, Source: Lowry

Radon in water for a given well can also vary substantially over a relatively short time; levels can change by a factor of two or three on a daily basis. This makes water radon measurement by a single grab sample potentially inaccurate, although many times this is the only information upon which a decision is based. In cases where a single sample has indicated a level of concern two additional grab samples, each taken on a different day, should give a reasonable idea of the average radon level in the water supply. Typical costs for a single water radon analysis range between $20 and $50.

In a recent Maine study, 10 sites were tested randomly over a three-week period to determine the typical variation of radon in granitic bedrock wells (Ref. 15). Table 6-1 is a summary of the variation found in those 10 sites. The wide variations between minimum, maximum, and average radon levels clearly demonstrate the limitations of taking only one radon in water sample at a given site. For example, if Site 5 were tested on a given day and found to have only 18,900 pCi/L, it would fall beneath the Maine action guideline of 20,000 pCi/L. In reality, it has an average radon level of 53,695 pCi/L, and may require mitigation.

In addition to a radon analysis or multiple radon analyses for higher levels, it is advisable to have the water tested for its gross alpha concentration. This measure will give an indication of the possible presence of radium-226 and uranium-238/234, and, in very rare cases, polonium-210. The current drinking water MCL for gross alpha in public water supplies is 15 pCi/L, while for radium-226 it is 5 pCi/L. The revised regulations of July 1991 propose to raise the radium-226 MCL to 20 pCi/L and define MCL for Radium-226 at the level of 15 pCi/L This proposed regulation also plans a separate radium-228 MCL at 20 pCi/L.

Radon Levels in pCi/L

Site #	Maximum Pci/L	Minimum Pci/L	Average Pci/L	Coefficient of Variation %
1	3,090	1,420	2,619	16.41
2	21,200	12,400	16,539	14.05
3	43,600	24,900	34,595	12.7
4	99,200	10,900	40,781	54.24
5	66,400	18,900	53,695	20.55
6	125,000	34,200	95,549	24.33
7	128,000	74,500	107,196	13.67
8	164,000	21,100	125,603	30.39
9	1,080,000	273,000	758,760	27.66
10	85,000	51,400	69,238	16.65

Table 6-1. Summary of Radon Sampling Program at 10 Sites over a 3-Week Period (Ref. 5)

While there is no current MCL for uranium, the regulations announced a proposed MCL of 20 µg/l of total uranium. Both uranium and radium have been shown to be significant health problems in themselves. Since uranium-238/234 and radium-226 are in the decay series above radon, it is common to find them also at elevated concentrations in waters with high radon. The same Maine study cited previously (Ref. 15) documented the occurrence of gross alpha, uranium, and radon in a number of wells containing various levels of radon. Table 6-2 is a summary of those findings. Note that gross alpha is a measure of the long-lived, alpha-emitting radionuclides in water and does not include radon. Gross alpha tests are essentially screening tests and relatively imprecise. It is important to note that 8 out of 10 wells had one or more radiological parameters (in addition to radon) that exceeded acceptable standards for drinking water. The data strongly suggest that at least a gross alpha analysis should be done for wells containing elevated radon. The cost of a typical gross alpha analysis is $20 to $30. Specific analysis for uranium or radium-226 will typically cost $50 to $100.

Site #	Radon Level in Well pCi/L	Gross Alpha pCi/L	Uranium ug/l	Radium pCi/l
1	2,619	1.2	0.6	0.04
2	16,540	12.3	25.0	0.10
3	34,600	46.0	152.0	0.06
4	40,780	112.3	170.0	0.82
5	53,700	6.8	12.4	0.88
6	69,330	361.5	655.0	1.46
7	95,550	772.1	1320.0	6.59
8	107,200	32.2	±0.1	3.84
9	125,600	43.1	19.0	3.94
10	758,800	266.1	990.0	5.44

Table 6-2. Gross Alpha, Uranium and Radium Levels in High Radon Wells (Ref. 5)

V. Interpretation of Results

Virtually all homes with a private well have airborne radon contributed by the water supply. This is due to the natural equilibrium established for radon between water and air. Almost all groundwater contains radon at levels greater than the equilibrium value that exists between the atmosphere (extremely low radon) and water. The distribution ratio of a gas between air and water is known as Henry's Constant; radon is easily transferred because its Henry's Constant is relatively high. Exposing groundwater to the atmosphere (air) will result in this equilibration process and the transfer (stripping) of waterborne radon into the air.

If the water to air radon ratio in the living area is greater than the rough ratio of 10,000:1, water can be a large contributor to the airborne radon. In one of the few documented cases where sufficient water and air radon data were taken in a home with high waterborne radon, the ratio of water to air radon was found to be about 30,000:1 in the kitchen area. In the bathroom area, the ratio was highly variable but averaged about 50,000:1: this was largely due to the extreme airborne level caused entirely by the water.

The movement of radon from within the water to the air increases as a function of:

- Concentration of radon in the water (the higher the concentration the more radon can migrate to the surface of the water and escape).

- The amount of surface area between the water and the air. A glass of water will have a water to air contact area of a couple of square inches on the surface of the water. However if the same glass of water were tossed into the air (where it would turn into droplets) its new surface area would be hundreds of square inches. This occurs when water is sprayed from a shower or inside a dishwasher.
- The temperature of the water. Henry's constant increases dramatically as the water temperature is increased. That is, as the temperature of the water increases, more radon will leave the water. This is why more radon de-gassing occurs from hot-water use, such as a shower, than from cold- water use (like drawing cooking water). This phenomenon is the same as when water is heated on a stove. As the water heats the bottom of the pan. air comes out of solution and can be seen rising from the bottom of the pan.

Another indication that water is a significant contributor to airborne radon is the response of continuously monitored airborne radon to water-use events. In homes where airborne radon is caused primarily by water use, the air radon exhibits sharp peaks after water-use events and falls to relatively low levels during long periods without water use. Figure 6-6 presents data taken in the living area of a home where waterborne radon (18,000 pCi/L) contributed significantly to the airborne level. These continuous readings show rapid peaks in airborne radon levels after water use in the home, followed by a slow decline in concentration during periods of non-usage. These peaks would be significantly higher if measured in the bathroom or laundry. In homes where water and soil gas might be approximately equal in their contribution, a similar pattern - although somewhat reduced in its overall variation - would be seen. The soil gas contribution would be based upon which radon would increase due to water use; however, given the inherent variability in both water and air radon levels the case where a combination of sources exists is more difficult to interpret.

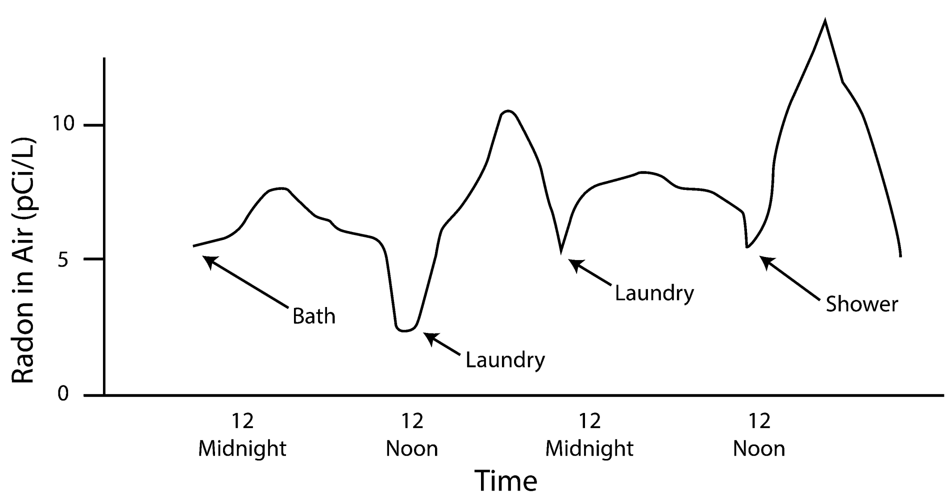

Figure 6-6. Radon Concentration in Air Related to Water Use, Source: Hess

Continuously monitoring radon while having the occupants note their type of water use can provide a good indicator of the contribution of radon in water. Another qualitative method can be to take a radon grab sample in the bathroom, then turn on the hot-water of the shower and close the door. After 15 minutes repeat the grab sample in the bathroom and determine if a large change in radon concentration has occurred. This method cannot tell you how much radon is in the water, but it can tell you if a water sample should be taken.

The professional mitigator should be keenly aware of investigating for radon in water in a home that was vacant during the time period that the short-term and follow- up measurements occurred. Without occupants, the potential contribution of radon from water may not have been detected due to the lack of water usage. Attempting to mitigate a home that has a 10 pCi/L contribution from soil gas and a 5 pCi/L contribution from water to less than 4 pCi/L would be impossible with ASD approaches alone.

When both water and soil gas are major contributors in a given home, a limited number of grab air samples may not facilitate meaningful interpretation. Integrated measurements will not show the variability of air radon with water use. In these cases, sufficient continuous air radon monitoring is needed to estimate accurately the relative contribution by water. Such monitoring can be expensive. Alternatively, using the 10,000:1 rule of thumb, it is usually safe to assume that an effective treatment system (90% + removal efficiency) should be able to reduce indoor levels by 1pCi/L for each 10,000 pCi/L in the water entering the system. In some cases, it may be more cost effective to apply this rule to determine whether the desired target level can be achieved through water mitigation than to perform extensive continuous monitoring to get definitive data.

Although some indication of the potential benefit of water treatment can be made by comparing water and air radon levels, the only way to document accurately the benefit of water treatment is to monitor the air radon level before and after water radon is removed, both for the house as a whole and for specific problem areas such as bathrooms. As data become available from sites where this has been done, more meaningful guidelines for mitigation can be recommended.

VI. Radon Removal Methods

Radon removal water treatment methods for individual households should be point-of-entry devices that treat the entire water supply, rather than point-of-use devices that treat only the drinking water. This is because the water used for non-drinking purposes contributes the most radon to the air.

There are three basic water treatment methods that could be used to remove radon from water supplies:

- Decay storage.
- Aeration.
- Granular activated carbon (GAC) adsorption/decay.

Decay storage is technically a good method but is impractical for both space and cost reasons. GAC generally is very effective at removing radon from water, but it suffers from gamma emission problems and eventual disposal problems related to accumulation of RDPs. Aeration is also an effective approach, but generally more mechanically complex and requires more maintenance than GAC.

The following sections present a basic description of each of the treatment methods and give the advantages and disadvantages of each.

A. Decay Storage

One approach to reducing radon levels in water would be to hold water in a storage reservoir, and allow radon to decay prior to use. This actually occurs to a varying extent in public water supply storage reservoirs. Since radon has a half-life of 3.8 days, after 27 days, 99% of the radon originally present would have decayed. On the average, a person uses approximately 60-100 gallons of water per day in the home. For a typical family of four, that amounts to 240-400 gallons per day, or 6,400-10,800 gallons for 27 days. A tank this large is normally considered impractical and extremely expensive for 99% removal. If low levels of removal are needed (50-70%) storage may be practical.

B. Overview of Aeration

In the same way as radon can easily de-gas from water sprayed during the use of a shower, spraying water into an enclosed tank with air blowing through can affect a controlled separation of radon from water. This process occurs inside of a tank at atmospheric pressure. Therefore, a pump is required to increase the water pressure; such that the water can be delivered throughout the house. Basically, the four types of aeration systems involve methods of contacting air and water. The four approaches are:

- **Spray:** Where water is sprayed into a tank with air blown upwards and out to a vent and discharged to the atmosphere.
- **Diffused Bubble:** Where a reservoir of water is held and air is injected below the water and bubbles up through the water. The air leaving the surface of the water is then discharged to the outside.
- **Packed Column:** Where water trickles down through a large pipe or "column" that contains loosely filled material (packing). The water forms a falling film on the packing which increases the surface area for de-gassing. Simultaneously, air is blown into the bottom of the column so it can rise through the column and sweep the de-gassed radon away.
- **Shallow Aeration:** Where water is allowed to pass over a plate or tray inside of a tank. The tray has perforations in it that allow for air to be blown up through the water on the tray, thus affecting the air/water contact.

1. Performance

Spray Aeration

As illustrated in Figure 6-7, in spray aeration, untreated water from the well is sprayed into a tank through a fine mist spray nozzle. The spray nozzle generates a large amount of water surface area from which radon volatilizes. Usually a small air blower is used to pass a small amount of air through the equipment, to carry the radon out of the tank, and to vent it outside of the home. Typically, a simple spray nozzle will remove approximately 50% of the radon from the untreated water. To achieve higher removal efficiencies, the water must be resprayed (retreated) several times. Eventually any treatment efficiency desired can be achieved with this system, provided that sufficient air to water contact time exists. The disadvantage of this process is that the water must be re-pumped (usually four to five times). In addition, as with all aeration systems, the holding tank must be quite large (about 100 gallons) in order to have a ready supply of treated water.

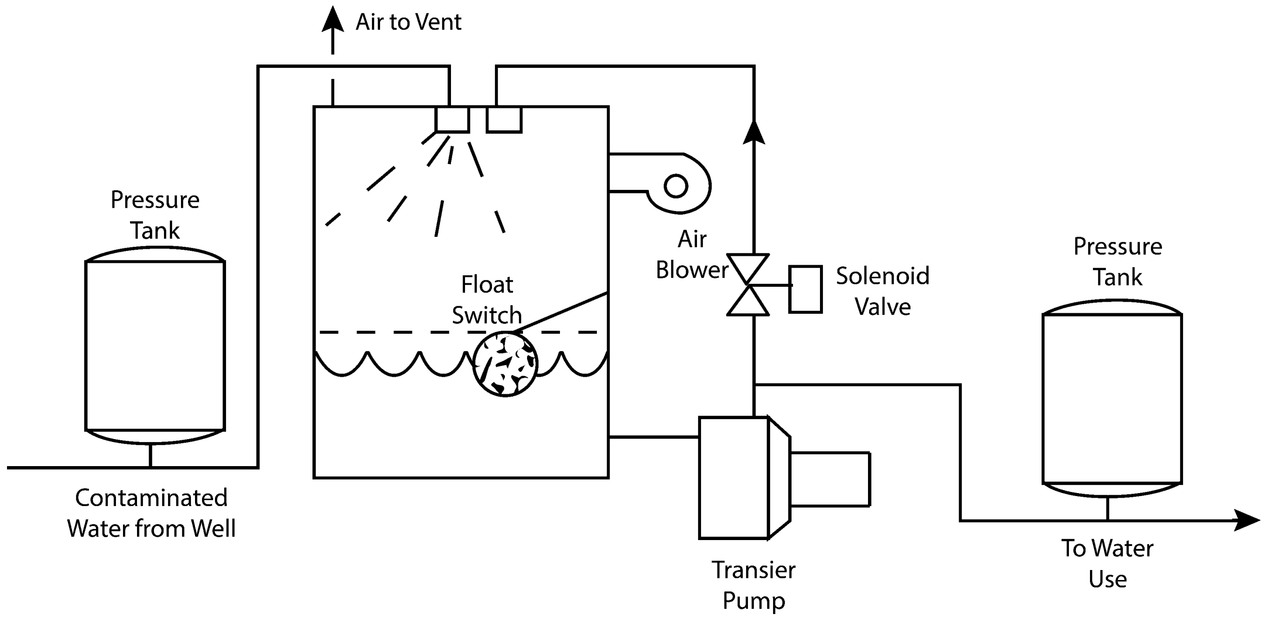

Figure (6-7). Spray Aeration, Source; NYSEO

Diffused Bubble

A second aeration method is diffused bubble aeration, illustrated in Figure 6-8. Well water is sprayed into the first of two or more aeration tanks. A relatively high pressure blower forces air into the bottom of these holding tanks through fine bubble diffusers located at the bottom of each tank. As the air bubbles rise through the water, the radon volatilizes into the air bubbles. In this case, the mass transfer area for the volatilization of radon from water is generated by the small air bubbles as they rise through the water. Since each tank is essentially completely mixed, very high removal efficiencies cannot be achieved in a single tank. Usually from two to six tanks in series are required to achieve better than 99% efficiency. The efficiency of an aeration tank can be improved by:

- Increasing the residence time of the water in the tank (making the tank bigger).
- Increasing the number of bubbles (increasing the air flow rate and the size of the diffuser).
- Baffling the tank such that the incoming untreated water does not immediately go out the discharge side of the tank.

The disadvantages of this system are that a relatively high pressure blower is required (25 to 35 inches of water column) and that the air holes in the diffuser may foul easily because they are very small (about 0.025 inches.) In addition, as with other aeration techniques, the treated water must be re-pressurized for household use.

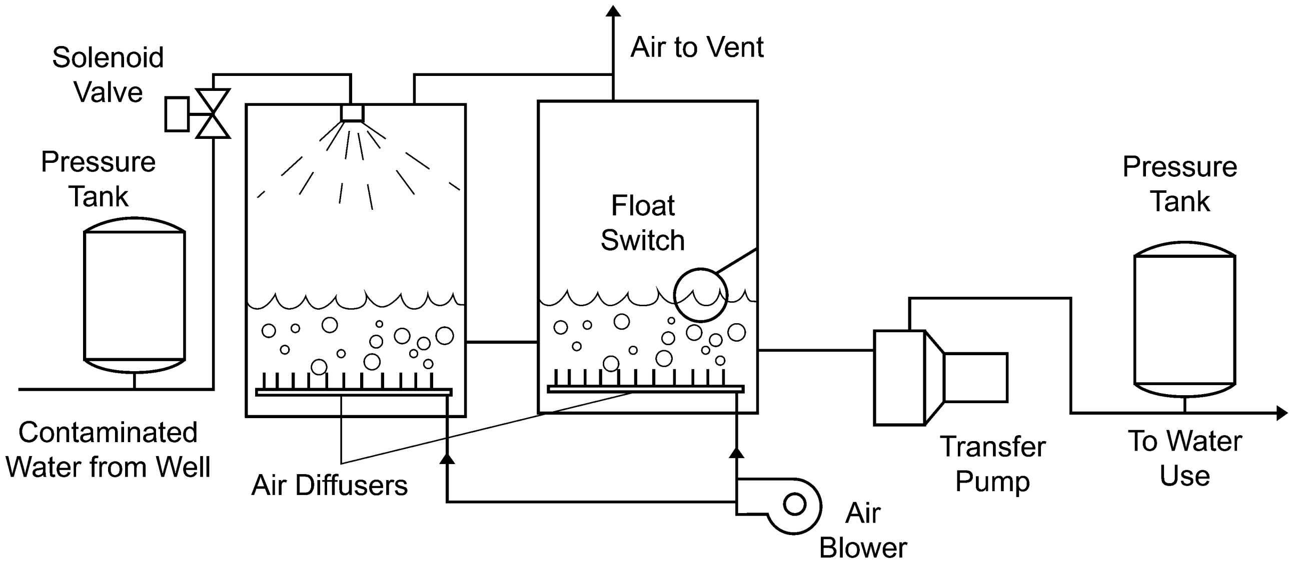

Figure 6-8. Diffused Bubble Aeration, Source; NYSEO

Packed Columns

Packed columns have been used extensively for removing volatile organic chemicals from contaminated groundwater supplies. These systems can be scaled down for use in a residential setting for removal of very volatile radon gas. Figure 6-9 presents a residential-scale system in which the well water is sprayed into the top of a small air- stripping column. The column is filled with about five feet of an inert packing material. As the water falls down through the packing, a large amount of surface area is generated from which the radon can volatilize. A small blower forces air up through the packing, which carries the radon gas out of the column to an outdoor vent. The efficiency of these systems has been shown to be approximately 90 to 95%. The principal limiting factor in packed column aeration of radon is the height available for the air stripping column. The maximum practical packing depth in most residential settings is six feet, which produces a removal efficiency of about 92-95%. For relatively low levels of radon contamination (i.e., up to 20,000 pCi/L), this is entirely adequate. Above this level the packed column systems become impractical.

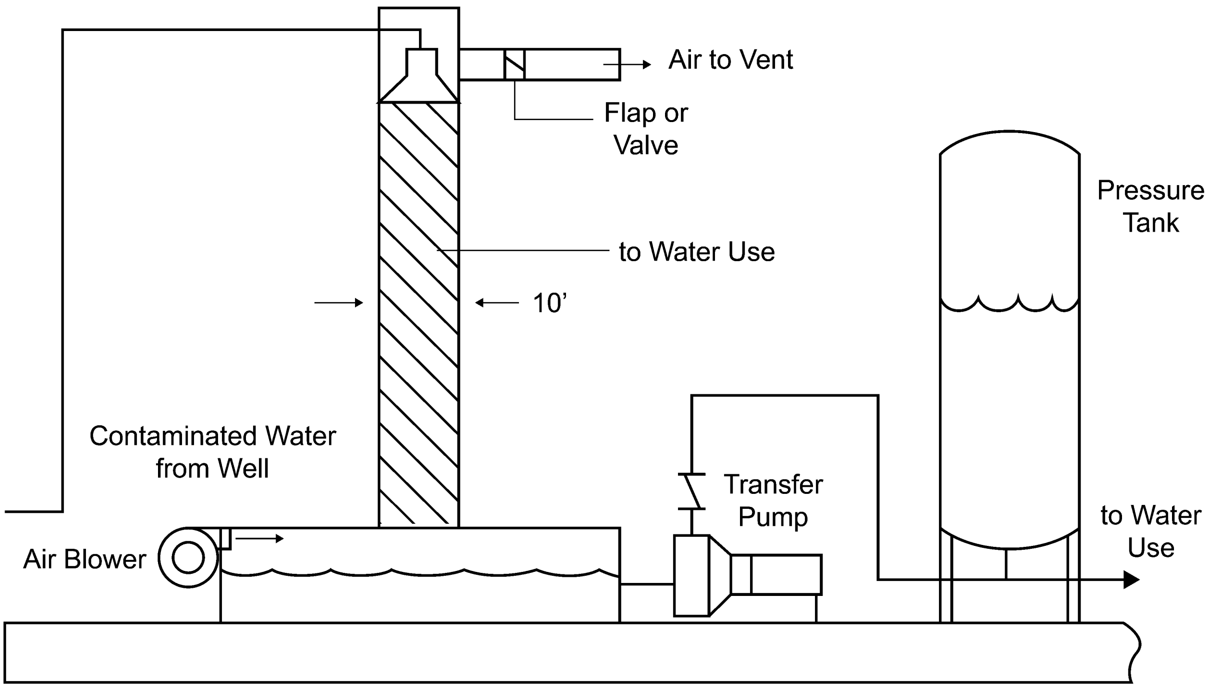

Figure 6-9. Packed Column

Shallow Aeration

Figure 6-10 describes the fourth type of aeration device, which uses a horizontally extended shallow aeration tray design. Water is supplied to the aeration unit where it is sprayed into the aeration tray. The water flows across the tray between baffles, as air is blown up through holes in the tray. The air forms a froth of water on the tray, creating a very large area in which radon from the water can be volatilized. The air strips as much as 99.5% of the radon, which is vented outside the home. The cleaned water then collects in the bottom of the radon removal unit and is pumped into the water pressure tank. This system, as with the previous systems, is completely automatic.

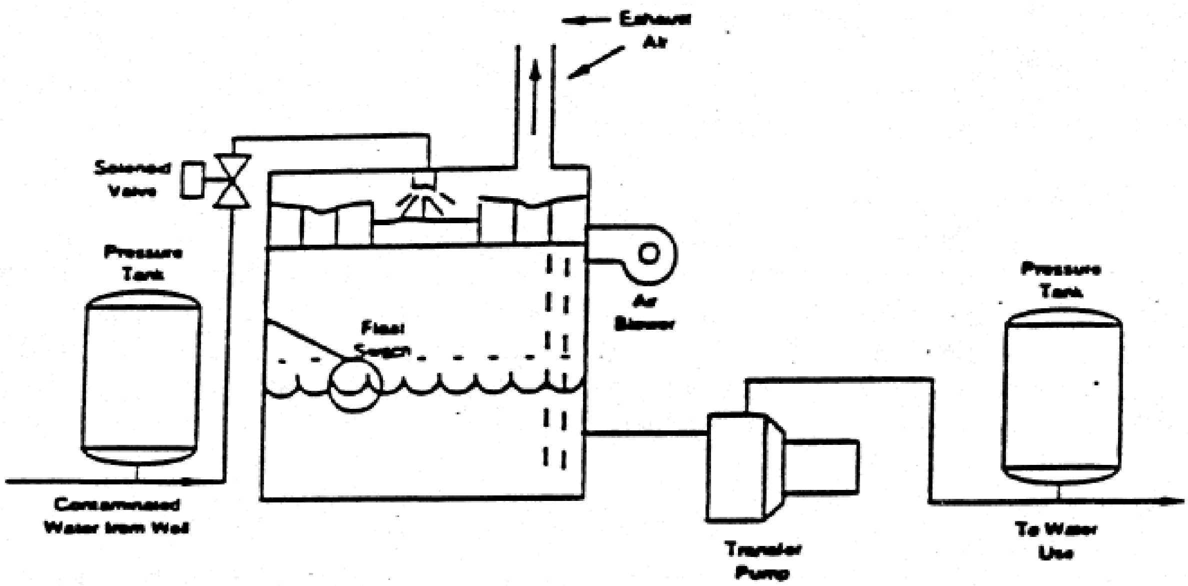

Figure 6-10. Shallow Aeration, Source: NYSEO

The shallow aeration system has three principal advantages over the other systems:

- The aeration tray for residential systems is smaller than 2 feet in diameter and only 10 inches high; the complete system is therefore smaller and shorter than the other designs.
- The air pressure required for operation is only 3 to 4 inches of water column. facilitating use of a much less expensive type of blower.
- The air holes in the aeration tray are much larger than those used in the diffused aeration design (3/16 of an inch) and, therefore, fouling problems are virtually eliminated.

A potential disadvantage of this system is that it uses approximately 100 cfm of air, whereas the previous system uses between 10 and 50 cfm.

2. Installation Considerations For Aeration Systems

Air Supply

All aeration systems must have a source of air. Some packaged units have the blowers mounted next to the aeration tank or column. Although this is convenient, it means that the blower or compressor will draw air from the room in which the unit is placed. This can cause the room to be depressurized, which could lead to increased radon entry or a potential back-draft concern for nearby combustion compliances.

In addition to these systems being efficient in removing radon from the water they are equally efficient in scrubbing the air which passes through them. This process causes whatever contaminants that may be in the air stream to enter the household drinking water. If the air is brought in from the outside and the inlet to the pipe is near where a car may idle, the water can pick up nauseating odors and fumes. Also, the inlet should not be near where fertilizers and pesticides might be used. Great care should be taken in protecting the quality of the incoming air.

Discharge Points

One should carefully plan the location of the discharge point of the aeration system. At present the discharge point should comply with all location and separation distances specified in EPA's Interim Radon Mitigation Standards to avoid re-entrainment into the home.

Discharge Piping

The air that leaves the aeration units will be at 100% humidity. This means that discharge piping that leaves the house to the cold outside will have condensation of moisture occurring inside the piping. Traps are to be avoided in the piping, and insulation to reduce the potential of freezing should be placed around the piping.

Microbiological Growth and Contamination

Domestic wells are not treated for microbiological growth in the same way as public water supplies. Typically, well water is well filtered by the ground around the well casing. The act of blowing air into the drinking water can introduce airborne bacteria.

During periods of frequent water use this may not cause a problem. However, during periods of no water use (such as when the occupants go on vacation), the water in the aeration tank can become stagnant and allow the bacteria to multiply. It is for this reason that some type of post-treatment may be prudent on these systems. Homeowner maintenance regarding this concern should be clearly stated.

Hardness Fouling

As air passes through aeration systems, some of the water will evaporate and leave with the exhausted air stream. As this occurs, dissolved solids in the water can drop out in the tank or packing. Calcium and magnesium salts that typically cause "hardness" problems in hot water heaters etc. can also adhere to the internal surfaces of these systems. Routine maintenance and cleaning may be required to ·prevent build up on spray nozzles and packing surfaces.

Reduction Efficiencies

Figure 6-11 summarizes performance data for diffused bubble aeration systems at 21 sites. Figure 6-12 presents comparable data for shallow aeration systems at 32 test sites, where pretreatment water radon levels ranged from 19,000 to 26 million pCi/L Both systems are capable of over 99% radon-removal. Packed towers can also achieve this level of efficiency, although not within the 6-foot height limitation of most homes. However, packed towers are probably the most efficient process for small community watersupplies.

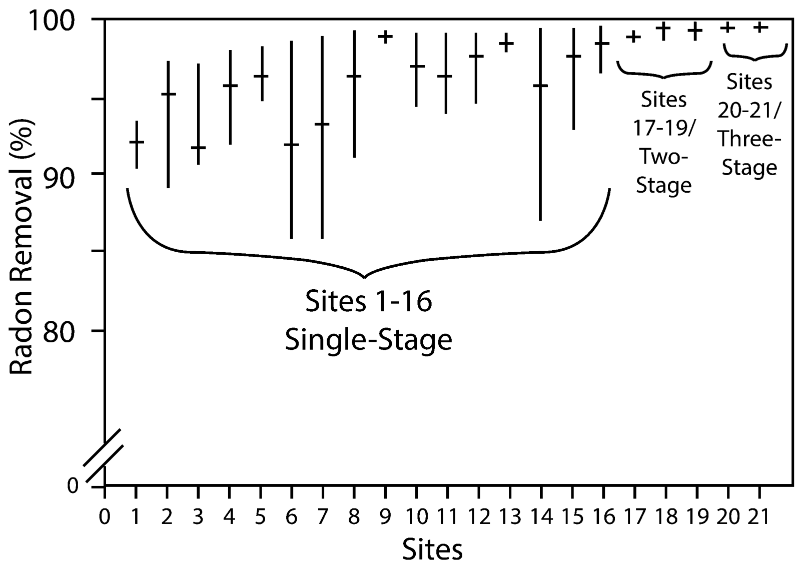

Figure 6-11. Performance of Single-Stage, Two-Stage and Three-Stage Diffused Bubble Aeration Systems, Source: Lowry

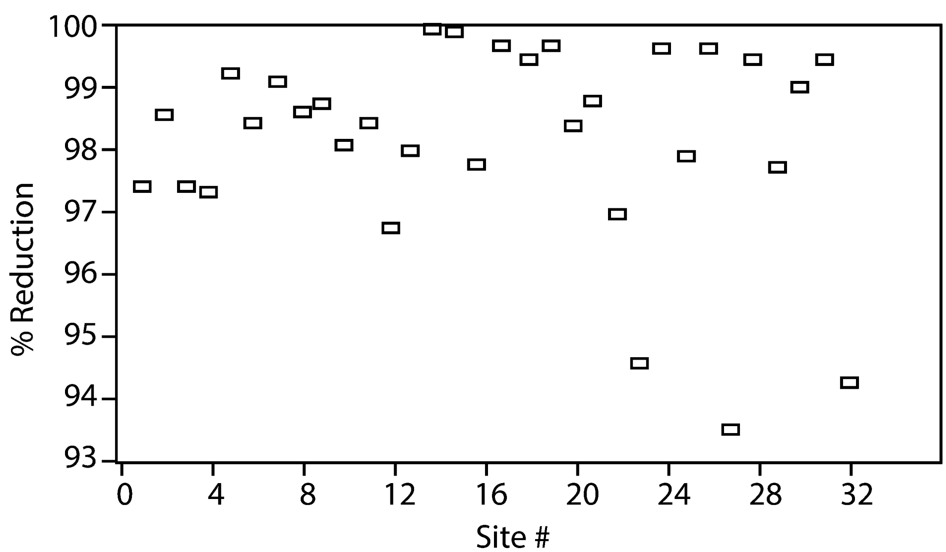

Figure 6-12. Performance of Shallow Aeration Systems, Source: Lamarre

C. Granular Activated Carbon (GAC)

Unit Three described how activated carbon canisters can be used to determine the radon in the air by virtue of the fact that radon can be adsorbed onto and held in the pores of activated charcoal. Similarly, when water containing high concentrations of radon is passed through a bed of activated carbon the radon is adsorbed onto the carbon, thereby affecting a separation of radon from water.

Once the radon has been collected onto the carbon, it is held there long enough for the radon to continue through its normal decay chain. In essence, the radon is trapped in the carbon bed and its decay products are also firmly held in place. Carbon style filters, when used for removal of other organic contaminants, exhibit what is referred to as "breakthrough" (when the bed becomes fully loaded with the contaminant and it can no longer be removed). Because the radon on the bed is constantly breaking down this loading or breakthrough does not occur. This allows carbon units to operate until they become plugged with contaminants, rather than becoming saturated with radon.

A significant advantage of this technique is that the carbon beds are within pressure tanks that allow for easy insertion into the water supply to the house, without the need for a pump or pressure tank to deliver the water to the point of use. The major disadvantage is the amount of gamma radiation that emanates from the tank due to the RDPs that have been trapped in the bed from the decaying radon.

1. *Performance*

The key to the effectiveness of GAC treatment is the adsorption/decay steady state that occurs for radon and its short-lived RDPs (Ref. 13 and 11). The net result of this unique operation, brought about by the short half-lives of these radioactive atoms and the extremely small mass accumulation it represents, is that a GAC bed has the potential to last for decades with respect to radon and its RDPs.

The GAC unit is installed in the main water supply line after the hydro-pneumatic (pressure) tank (Figure 6-13 shows a typical installation). The GAC unit should be protected from sediment by providing a simple, small, replaceable sediment cartridge, which is available for about $50. The cartridge is installed upstream of the GAC unit and avoids any need to routinely backwash the GAC bed. Automatic backwashing with untreated water is detrimental to the performance of any GAC unit and is to be avoided. Field experience shows that it is unnecessary to backwash more than once a year. However, the sediment trap may serve as a repository of radioactive waste (see below). Additionally, depending on the concentration, iron, manganese, and hardness may also be removed from the water supply upstream from the GAC unit. This hardness may also be removed from the water supply upstream from the GAC unit. This may cost $1700 or more.

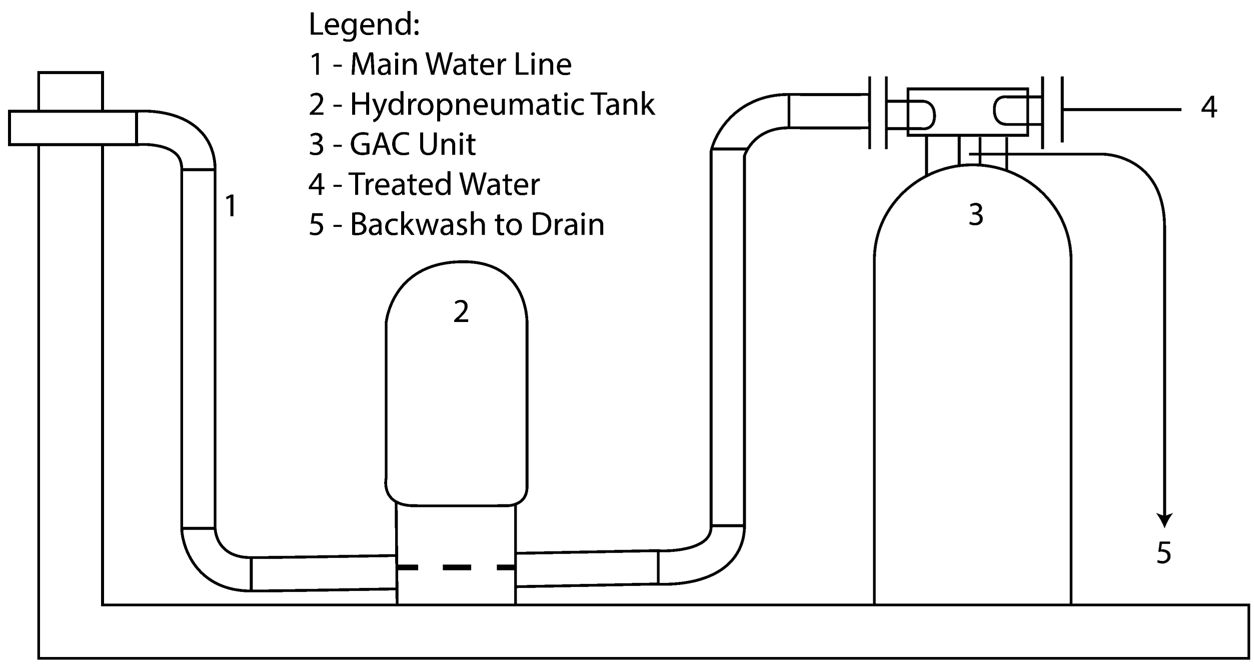

Figure 6-13. Typical GAC Installation, Source: NYSEO

Modeling studies and field performance (Ref. 7, 16) have shown that the type of GAC selected is significant. The mathematical model for sizing a given GAC unit is in the Glossary. For all practical applications, a GAC unit of 1.5 to 3.0 cubic feet (ft^3) will significantly reduce any household radon level that has been discovered to date. Depending upon the type of GAC selected, removals will be between 75 and 99 percent for a typical household. As with aeration systems, if uranium and/or radium are present in significant quantities, the appropriate ion exchange resin treatment units should be used as pretreatment prior to installing the GAC unit.

Some GAC units have been found to achieve far less removal than anticipated. A large fraction of the GAC units placed on sites in New Jersey, for example, have performed poorly. Over a 6-month period, these GAC systems deteriorated in their performance to levels of 50 to 75 percent removal. The reason for this is unknown at the present time, but it is suspected to be related to natural water chemistry of these water supplies. Approximately 5 percent of current installations are estimated to exhibit this behavior.

2. Accumulation of Radioactivity on the GAC

A significant issue in GAC treatment is the buildup of low-level radiation on the GAC bed caused by accumulated RDPs. While this has not been studied as extensively as radon removal, it is known that for a given household's water use, the buildup of the first four, short-lived RDPs reaches a steady state level in proportion to the radon removal This takes about 22 days, after which time lead-210 (21-year half-life), bismuth-210 (5-day half-life), and polonium-210 (138-day half-life) are the only RDPs accumulating.

It is the gamma activity of the second and third RDPs, lead-214 and bismuth-214, that is detectable on and near the surface of the fiberglass tank housing the GAC bed. Since these RDPs do not increase after 22 days, the gamma level reaches a steady state and does not increase unless the long-term radon level increases. The maximum gamma level at steady state is a function of radon concentration in the water. A practical relationship has been developed to predict this level at 1mR/hr at the tank surface for every 10,360 pCi/L in the well water (Ref. 15).

The maximum gamma activity of a GAC unit is located at the tank surface, at a height corresponding to the top of the bed. The gamma reading falls off significantly with distance, but even at several feet, the levels are significantly greater than background for wells containing more than 20,000 pCi/L of radon. For GAC units treating very high levels of radon it is not uncommon to be able to detect gamma levels greater than background in living areas above the installation.

A recent research study on the potential for increased gamma exposure due to GAC radon removal has provided useful data (Ref. 15). That study produced the following recommendations, based upon the international guidelines for increased radiation exposure to the general population:

- When a GAC unit is located in an area not routinely occupied (such as a cellar), the vessel should not require shielding until the radon level in the raw water supply is greater than 100,000 pCi/L
- When a GAC unit is located in a living area and occupants will be within 3 feet of it for more than 8 hours per day, shielding should be used if the radon in the raw water supply is greater than 21,000 pCi/L
- If the raw water radon is greater than 20,000 pCi/L, a source restriction at the vessel of 20 mR/hr would require that any GAC vessel be shielded.
- Shielding with an encapsulating water vessel is very effective; virtually any household application of GAC can be effectively shielded if the unit is located in a non-living area. Water shielding is more effective and economical than other forms of shielding, including lead. Any high density material, however, would provide some degree of shielding.
- Shielding by placing the tank outside the home in a buried concrete vault is also an effective approach for using high levels of radon in water.

Figure 6-14 is a summary of the relationship of allowable distance to meet two scenarios associated with international guidelines for radiation exposure. Scenarios A and B are for the public and the general population, respectively. Scenario B allows for an increased gamma exposure rate (8 hours/day) of 58 µR/hr over an assumed 15 µR/hr background.

It is presently up to individual homeowners to decide if increased radiation over background is acceptable. Whereas the data indicate that only a small percentage of all wells have high enough levels to be a cause for technical concern, many homeowners will not accept any increase in gamma exposure. Therefore, they must be alerted to this phenomenon associated with GAC. Every GAC installation should be made with this aspect fully disclosed and explained.

Another aspect of GAC use in radon removal is the buildup of the long-lived lead-210 and its two decay products, bismuth-210 and polonium-210. Recently (Ref. 15), its retainment has been documented with the following conclusions:

- A GAC (85L) bed treating approximately 1.1x 10^6 pCi/L radon for 22 months at an average water usage rate of 886 L/day accumulated a measured quantity of lead-210 of over 300 µCi.

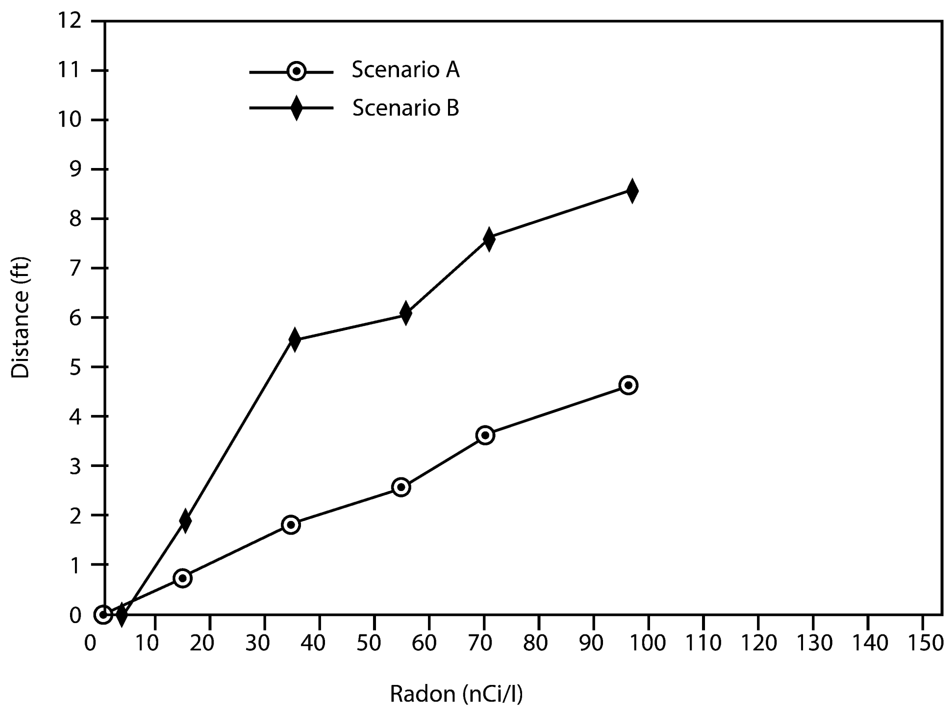

Figure 6-14. Distance Required to Meet International Guidelines for Radiation Exposure-Public (A) and General Population (B), Source: Hess

- Since the lead-210 produced by the adsorption/decay steady state of radon appears to be totally retained, it is believed that bismuth-210, polonium-2 10, and lead-206 (stable) are also retained. Each of these isotopes have been shown to be retained in their heavier isotopic forms as short-lived RDPs; therefore, it can be assumed from a chemical perspective, that the longer-lived isotopes will be equally retained.
- The measured and calculated levels of accumulated polonium-210 are very significant in GAC beds treating high concentrations of radon. Using exempt quantities as a guide for determining the classification of low-level radioactive waste, it can be shown that the majority of GAC units treating ground-waters with even low radon levels will fall into that category. In fact, using stringent criteria that exist in some States it can be shown that most GAC units treating groundwater supplies can be classified as low-level waste after only a relatively short period of operation.
- More research is needed to study the effects of variable pH and GAC regeneration on the retainment of lead-210, bismuth-210, and polonium-210.

Note that the accumulation of lead-210 and its RDPs does not appear to pose an external exposure hazard in the same way that gamma does. Rather, these longer-lived isotopes are largely alpha and beta emitters and must be ingested or inhaled to be hazardous in this application. The issue, consequently, is that of proper disposal, which is a policy question. It is unlikely that any restrictions could be enforced on domestic disposal of such materials. Some State regulators, however, have begun to indicate a strong concern regarding this aspect of GAC use for radon removal, and it is uncertain what the future status of GAC bed disposal will be.

An additional disposal question has been raised as a result of research showing that radium and uranium are adsorbed by GAC. GAC units intended to remove radon will also be able to remove uranium. If the GAC unit also accumulates uranium, this may constitute an additional reason to restrict its ultimate disposal. Again, it will be up to individual States to regulate this aspect of GAC use and disposal.

D. GAC Versus Aeration

GAC and aeration are normally compared according to cost and performance; however, in radon removal applications, other factors must also be considered. These factors are shielding requirements for GAC, possible licensing and/or disposal requirements for spent GAC, filtering of incoming air, and venting of radon removed by aeration.

GAC and several types of aeration systems are capable of excellent radon removal. However, aeration is expected to become the preferred alternative in both private and public water supply removal of radon. The capability of several types of aeration systems to remove radon to desired levels, without the gamma-emission and disposal disadvantages of GAC, makes aeration the most effective alternative for the removal of radon from public water supplies. However, the radon removed by aeration must be vented outdoors to the atmosphere and care must be taken in locating the exhaust vent (see Unit Five, Fan and Exhaust location).

Aeration systems have several disadvantages. Because aeration is performed at atmospheric pressure, aeration systems require re-pressurization of the water supply, which adds to the complexity and cost of the system. Outside air introduced into the water may result in bacterial and algae growth contamination of the water supply and aeration unit. Thus, the microbiological condition of the water supply needs to be periodically examined and disinfection of the water practiced if necessary.

Aeration has the beneficial side effects of removing hydrogen sulfide and assisting in the removal of iron and manganese from water. Oxidation of iron and manganese, however, can cause fouling of the aeration system or introduce an iron and manganese problem if the finished drinking water is not properly handled with a filtration system.

Several factors may be expected to affect the viability of GAC as an alternative in the future. Large or multiple GAC vessels used in series may be needed to meet low radon concentration requirements. The need to shield units to reduce gamma emissions is also a drawback. In addition, disposal issues and licensing must be considered. Consequently, the principal application of GAC may be in treating water supplies with low levels of radon (less than 5000 pCi/L), where the issues of efficiency, gamma emissions and GAC disposal are not as significant.

Table 6-3 provides a summary of key advantages and disadvantages of these systems. Note that iron and manganese removal may be needed at sites which have experienced problems with these materials. Precipitated iron and manganese, if not taken care of with pretreatment, can cause problems with GAC effectiveness; they can also increase the maintenance requirements of aeration systems. Should iron removal be needed its cost is comparable to that of single unit GAC treatment. Other organic materials, bacteria, and particulates may also require regular removal.

Advantages	Disadvantages
Aeration:	**Aeration**
Removes radon before water is distributed through out the	Mechanically complex
No radioactive accumulation	Requires maintenance
No spent waste to dispose of	Quality of air must be protected
No gamma emission concern	Requires re-pressurization of water
	Discharge air must be properly vented
	Microbiological growth can occur
	Hardness may build up
GAC:	**GAC:**
If installed at pump or where water supply enters house, removes	Can become fouled with water contaminants unless pre-filtered
radon before distribution throughout house	No approved means for final disposal
Can improve taste and color of water	Gamma emissions can be significant and shielding can be expensive
Less costly that aeration if shielding not required	
Simple to install and maintain	
Does not require re-pressurization of water for distribution	

Table 6-3. A Comparison of Aeration vs GAC

VII. Economics And Sources of Treatment Units

A. Economics

In evaluating the economic advantages of GAC vs. aeration, it is important to consider not only capital and operation and maintenance costs, but also such factors as the need for pretreatment, discharge of radon to the immediate atmosphere, the buildup of radon and RDPs in the GAC bed and water quality parameters.

A single GAC unit, including a sediment filter, costs approximately $800 to $1,200 installed and has minimal operation and maintenance costs. Assuming that adequate space is available for installation, an aeration system can cost approximately $3,000 or more if pre- and post-water treatment are necessary. With no operating parts, a GAC unit is mechanically simple, and treatment occurs under pressure. For wells containing less than 5,000 pCi/l of radon, this may be the most cost-effective alternative, assuming that:

- The homeowner is willing to accept the slight increase in gamma exposure rate in the immediate vicinity of the unit.
- The unit is exempt from disposal requirements that may be imposed in the future.
- The specific water supply does not cause premature fouling of the GAC.

For wells containing in excess of 5,000 pCi/L, two units in series will cost approximately $1,600 to $2,000, installed. Approximately $200 more will be needed for a water shield, bringing the total to about $1,800-2,200. If lower removal and an unshielded vessel are acceptable, then the cost of $800-1,200 is still valid for higher radon wells.

Aeration systems capable of removing essentially all of the radon, such as multi-staged diffused bubble aeration or shallow tray aeration, will cost approximately $2,200-$3,000. The associated operating and maintenance cost will be minimal (approximately $4 per month), reflecting the cost of an extra water pump and an air blower. If the water source has a significant level of iron or manganese, system and maintenance costs will be higher by 5-10 percent or more, depending on conditions.

B. Sources

GAC treatment units are commercially available for a variety of waterborne impurities. Removals of 99 percent and greater are possible with a properly designed unit. Automatic backwash is unnecessary and should be disconnected if it is provided. Sediment removal should be provided before the GAC unit is installed. Finally, treatment units should be monitored to ensure that the unit is functioning as expected.

Few water treatment experts who deal directly with homeowners are qualified to provide the technology for removing health-related contaminants This is especially true in the area of radon removal. Evaluate GAC system suppliers/installers based on their knowledge of radon and the implications of using GAC in its removal. Suppliers should be fully informed of the potential for increased gamma exposure by the ·occupants of the home, as well as the disposal and handling issues associated with GAC. GAC installers should use a gamma/beta survey meter to demonstrate the gamma radiation coming off the unit to the homeowner.

State and/or Regional EPA offices should have a listing of qualified water treatment experts/suppliers to provide proper GAC units. Because radon removal from water is new, relatively few of these people have sufficient experience with or understanding of the problem. Although this will change with time, currently the State-level water/radon regulatory authority is probably the best source of information about treatment units.

Activity

Identifying Water as A Significant Source of Air Radon

Purpose: To provide an opportunity to demonstrate an understanding of the importance of radon in the water supply and its relation to the radon in the indoor air.

Directions: For the following cases, estimate the relative possible contributions of water radon vs. soil gas radon, and state whether you would recommend mitigation by water treatment.

Case 1:

Water radon	=	22,000 pCi/L	
Air radon	=	50 pCi/L	(average kitchen)
	=	30 pCi/L	(minimum kitchen)
	=	65 pCi/L	(maximum kitchen)

Case 2:

Water radon	=	120,000 pCi/L	
Air radon	=	6 pCi/L	(average kitchen)
	=	15 pCi/L	(maximum kitchen)
	=	0.5pCi/L	(minimum kitchen)
	=	25 pCi/L	(maximum bath)

Case 3:

Water radon	=	50,000 pCi/L	
Air radon	=	10 pCi/L	(average living area)
	=	50 pCi/L	(average basement)
	=	5 pCi/L	(maximum bath)

Case 4:

Water radon	=	100,000 pCi/L	
Air radon	=	500 pCi/L	(average living area)

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Review Questions, Unit 6, Dec 2003, Form A

1. If the concentration of radon in water supplied to a house is 30,000 pCi/l, how much radon might the water contribute to the household air?

    A. 3 pCi/l

    B. 300 pCi/l

    C. l,500 pCi/l

    D. 3,000 pCi/l

2. Which measurement techniques are routinely used when analyzing a water sample for radon content?

    A. The water sample is counted directly with a Geiger counter in the field

    B. The water sample is drawn directly into an evacuated scintillation cell and counted in the field

    C. The water sample is poured into a charcoal canister and counted in the laboratory

    D. The water sample is placed in a liquid scintillator and counted in the laboratory

Radon in water, pCi/l

Site#	Range			Average
1	66,400	-	18,900	53,695
2	1,080,000	-	273,000	758,760
3	21,200	-	12,400	16,539
4	125,000	-	34,200	95,549
5	164,000	-	21,100	125,603

Figure 601

3. Figure 601 shows water test results for five different water systems. Several samples were taken on different days. The range and average results are shown. Based on this data, what level of

variation in radon concentration is most likely to occur between water samples taken for radon measurements?

A. 1.1 to 1

B. 1.5 to 1

C. 2.0 to 1

D. 4.0 to 1

4. Which of the following suggests that water is the major source of radon in a house with average airborne radon levels of 5 pCi/L in the living area

   A. charcoal canisters placed in the living area measures average waterborne radon levels

   B. continuous radon monitor results show concentration peaks after dishwashing and bathing times

   C. grab samples collected in the unfinished basement show 10 pCi/L radon in air measurements

   D. grab samples collected in the well show an airborne Concentration of 30 pCi/L

5. All of the following are disadvantages of aeration methods for removing radon from water EXCEPT

   A. requiring maintenance to prevent hard water fouling

   B. producing elevated gamma exposure levels

   C. requiring a blower vented to the outside

   D. requiring re-pressurization of the water supply

Answers to Review Questions, Unit 6

Review Question	Answer	Student Manual, Unit 06, Page Number
06.1 [2]***/****	A	3-5
06.2***	D	5-9
06.3***	D	9-11
06.4****	B	2-4
06.5****	B	15-22

2 * These questions are only for radon measurement specialists.

** These questions are only for radon mitigation specialists.

** These questions are only for measurement applicants.

**** These questions are only for mitigation applicants.