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A COMPARISON OF RADON-IN-WATER MITIGATION SYSTEMS

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ABSTRACT

The results of a one to four year comparison study are presented for different design types of radon-in-water mitigation systems: diffused bubble aerator with and without water softener, shallow tray aerator with water softener, and spray and diffused aerator tank with charcoal tank. The four wells which supply these mitigation systems vary in radon content from an arithmetic mean of 43,894 pCi/L to 457,807 pCi/L. The diffused bubble aerator with water softener provided the most successful mitigation with 99.9% radon removal efficiency, while the spray and diffused aerator tank with charcoal filter tank produced the least successful radon removal efficiency at 77.7%. Various problems observed of these radon-in-water mitigation systems are documented. The implications of these findings are discussed, as well as mitigation effects upon naturally occurring radium and uranium.

INTRODUCTION

A recent large data set of private well water samples for radon indicate that Connecticut wells have the third highest geometric mean (2,822 pCi/L) and second highest arithmetic mean* (10,786 pCi/L) out of 42 states (Vitz, 1990). The existence of this significant source of carcinogenic risk is of concern, especially since a maximum contaminant level (MCL) of 300 pCi/L for public drinking water is being considered by the U.S. EPA (Helms and Rydell, 1992). This proposal, coupled with advice from our agency, has led to an increased use of technologies designed for reducing radon in well water.

Three types of radon-in-water reduction systems have been placed in Connecticut homes in the recent past: shallow tray aerators (shallow tray), diffused bubble aerators (diffused), and a spray and diffused aeration tank with charcoal filter tank (S & D + CT). These devices are often installed upon the basis of a single water test for radon. Testing for ancillary radionuclides (radium and uranium) is rarely performed, although these radon precursors are often present in Connecticut well water.

This study examined the three types of aeration systems in place in four Connecticut homes for varying length of times (one to four years). Waterborne radionuclides measured included radon, radium-226, radium-228, and uranium-238. Indoor air and system exhaust stacks were also measured for radon.

MATERIALS AND METHODS

Water samples for radon were collected following EPA guidelines (EPA, 1978). Duplicates were taken for all samples analyzed. Additionally, the well sample source faucet was permitted to run from 5-10 minutes to assure a deep well sample which reflects actual radon concentrations (McHone, et al, 1993). All radon, radium-226, and uranium-238 samples were analyzed by the Department of Public Health and Addiction Services Laboratory. Passive radon in air measurements were conducted using charcoal packets, charcoal liquid scintillation, and alpha track detectors according to the manufacturer's directions. Radon grab samples were taken and measured using a Pylon®

* All means reported in this paper are arithmetic means unless otherwise noted.

model AB-5 radiation monitor. Gamma radiation was determined with a Ludlum® model 19 radiation detector and an Eberline® model RO2 radiation detector.

Three types of radon in water mitigation systems were evaluated: diffused bubble aerator both with and without an attached water softener, shallow tray aerator with water softener, and a spray and diffused aerator tank with charcoal tank. All four devices examined were located in the basement of each house. The diffused bubble aerator consists of a 32" x 17.5" x 43.5" three stage diffused bubble aerator tank; one of the systems studied is connected to a water softener (WS). The shallow tray aerator uses forced draft countercurrent air stripping through baffled aeration in a 28" x 36" tank. The spray and diffused aerator tank consists of a 62" x 33" fiberglass tank into which water passes through a combination of spray and diffused aeration. There is a charcoal filter tank (CT) attached to the spray and diffused aerator tank.

Each type of device, and period of time studied, is seen in Table 1 below, along with the number of samples collected.

RESULTS

The data in Table 1 presents the relationship between the well number, mitigation system installed, the range of sampling dates and the number of samples collected throughout this study. Samples were taken over a period of from one to four years, dependent upon the time of recruitment of the homeowner into the study. Efforts was made to collect samples upon a monthly basis.

Table 1. Outline of well study sampling parameters.

WELL#	TYPE†	SAMPLING DATES	# OF SAMPLES COLLECTED
1	Diffused	2/92-1/93	9
2	Diffused + WS	4/90-6/93	26
3	Shallow Tray + WS	6/89-6/93	44
4	S & D + CT	11/91-6/93	25

The well sampling data both describes and limits knowledge of the well's inherent radionuclide fluctuations. The four mitigation systems examined were installed in order to mitigate radionuclides in water. Each well has inherently different levels of radionuclides which fluctuated about a mean value. These arithmetic mean values for the various radionuclides examined are depicted in Table 2 below.

Table 2. Mean levels of pre-mitigation well radionuclides (pCi/L).

WELL#‡	Rn-222§	Ra-226	U-238
1	43.9	4.5	1.0
2	457.8	17.7	7.4
3	317.8	21.4	7.6
4	142.8	15.0	0.4

The data in Table 2 shows that all of the wells have radon present in amounts which may warrant mitigation. Associated with the radon levels in all of these wells are measurable amounts of the antecedent radionuclides uranium and radium. Measurable radium-228 has not been exhibited in these wells. The two highest wells also have uranium in excess of 7 pCi/L.

In Table 2, well #2 is seen to demonstrate the highest mean value for radon out of the four wells studied, and the second highest values for radium and uranium. Well #1 had the lowest values for radon and radium. Well #3

† Type of mitigation system installed with the well.

‡ Each well is mitigated by a different system as described in Table 1.

§ Radon values are x 10^3.

which has the second highest mean for radon, and the highest mean for radium and uranium, while well #4 had the second lowest radon and radium mean value, and lowest uranium value.

Table 3. Pre-mitigation well radionuclide ranges (pCi/L).

WELL#[‡]	Rn-222[§]	Ratio[‖]	Ra-226	U-238
1	28.2-55.0	1:2.0	3.1-6.4	ND[¶]-2
2	346.4-546.8	1:1.6	0.3-32.2	ND-41
3	34.2-661.2	1:19.3	1.1-67.0	ND-50
4	33.7-252.5	1:7.5	ND-39.4	ND-3

Table 3 characterizes the intrinsic well radionuclide ranges prior to mitigation system effects. Large fluctuations in radionuclide levels are present in most of these wells, as is seen by their ranges and variance values in Table 4.

Table 4. Variance of pre-mitigation well radionuclides (pCi/L).

WELL#[‡]	Rn-222[§]	Ra-226	U-238
1	16.8	1.5	0.8
2	45.5	7.5	10.5
3	208.2	17.6	14.2
4	74.5	9.6	1.0

Tables 5 and 6 show the effects of the various mitigation systems upon the radionuclides present in the wells studied.

Table 5. Mean levels of post-mitigation well radionuclides (pCi/L).

TYPE	Rn-222	Ra-226	U-238
Diffused	1,664	5.8	0.8
Diffused + WS	247	0.6	ND
Shallow Tray + WS	1,963	0.2	ND
S & D + CT	31,801	16.6	0.3

Table 6. Efficiency of mitigation (%).

TYPE	Rn-222	Ra-226	U-238
Diffused	96.2	0	20.0
Diffused + WS	99.9	96.6	100.0
Shallow Tray + WS	99.4	99.1	100.0
S & D + CT	77.7	0	25.0

Table 7 presents the results of radon air sampling at the discharge pipe for the aeration system, and compares these results to radon water values at the approximate time of sampling.

[‖] Ratio of lower limit of the range to the upper limit.

[¶] Not detected.

Table 7. Stack sampling at discharge pipe of aeration system (pCi/L)[#]

TYPE	Water Rn-222 (pCi/L)**	Stack Rn-222 (pCi/L)	Location
Diffused	48.9	3,440	Ground Level
Diffused + WS	400.8	8,000	Rooftop
Shallow Tray + WS	513.6	1,540	Ground Level
S & D + CT	243.4	6,450	Rooftop

DISCUSSION

As seen in Table 2, three of the four wells studied, with the exception of the well #2, have radium-226 in excess of current public drinking water regulations (Dupuy, et al, 1992). Should the a homeowner desire to use the EPA Safe Drinking Water Act (SDWA) as guidance for radionuclide acceptability, and the lowest radium maximum contaminant level (MCL) under consideration by EPA be enacted (2 pCi/L), all of the wells would require remediation for this radionuclide (Dupuy, et al, 1992). At present, the lowest MCL for uranium being considered by the EPA under SDWA is 5 pCi/l (Dupuy, et al, 1992). The two highest wells in this study have uranium levels in excess of this proposed MCL.

Figure 1 below depicts a comparison of radon levels before and after the effects of each mitigation system. It is derived from the data in Tables 2 and 5. The most significant radon reduction was achieved by the diffused bubble aerator + WS system, followed closely by the shallow tray aerator + WS and diffused bubble aerator systems. The spray and diffused aerator tank + CT system removed the least amount of radon; all of these removal efficiencies are seen in Table 6 above.

Figure 1.

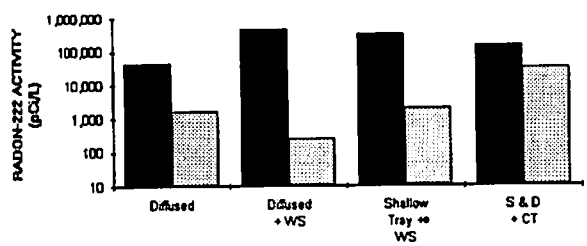

FIGURE 1. PRE- AND POST-MITIGATION MEAN RADON-222 LEVELS

Figure 2 below depicts a comparison of radium levels before and after the effects of each mitigation system, as derived from the data presented in Tables 2 and 5. The two systems having water softeners, the diffused bubble aerator + WS and the shallow tray aerator + WS, were able to remove most of the radium-226 present. The systems without water softeners, the diffused bubble aerator and the spray and diffused aerator tank + CT, did not mitigate the radium-226 present in the water supply. The post-mitigation increase in radium-226 may be an artifact of laboratory analysis.

[#] Results of the average of 10 one minute grab samples during the apex of radon emissions from the top of the stack.

** Pre-mitigation water sample taken at about the same time and date of the air sample. These radon in water values are x 10^3.

Figure 2.

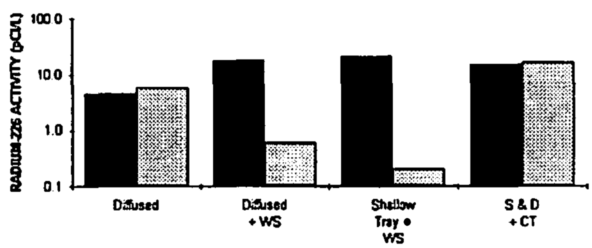

FIGURE 2. PRE-AND POST-MITIGATION MEAN RADIUM-226 LEVELS

Figure 3 below demonstrates the results of each mitigation system upon uranium levels in each well, as taken from the data presented in Tables 2 and 5. Similar to their effects upon radium, the two of the systems which had water softeners connected to them (the diffused bubble aerator and the shallow tray aerator systems) were able to remove all of the uranium-238 present. As expected, the systems without water softeners, a diffused bubble aerator and the spray and diffused aerator tank + CT, had little effect upon the uranium-238 present in the water supply. It is possible that the removal efficiency of this radionuclide in the diffused bubble aerator and the spray and diffused aerator tank + CT systems is an artifact of the small levels measured, which are near the limit of detection as attained in the laboratory.

Figure 3.

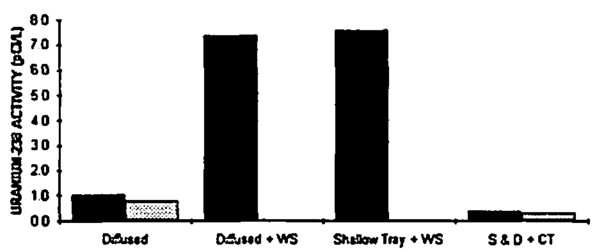

FIGURE 3. PRE-AND POST-MITIGATION MEAN URANIUM-238 LEVELS

As implied by Table 3 and Figures 1 through 3, the mitigation systems are tasked to address radionuclide fluctuations which are not apparent to the homeowner after a single round of sampling. A single sample of any of these wells does not address the significant variations about a mean value which can occur. We have previously documented the inadequacy of a single water sample to assess radon levels in well water (Siniscalchi, et al, 1993).

The least radon variance observed (16,800 pCi/L) was in well #1, to which is attached the diffused bubble aerator system, while the spray and diffused aerator + WS system was tasked to mitigate a well (#3) with a radon variance of 208,200 pCi/L. The ratio of the lower to upper limit of the range of radon value also demonstrates a much greater ratio in wells #3 (1:19.3) and #4 (1:7.5) than that of wells #1 (1:2.0) and #2 (1:1.6). The well exhibiting the most stable radon values had the highest overall mean radon value (#2) and was mitigated with the diffused bubble aerator + WS system.

A homeowner receiving a sample value for radon at the lower end of the radionuclide ranges shown in Table 3 may be surprised by sampling data demonstrating the higher end of values. A mitigation system choice can be made based upon the lower end of sampling data which would not appropriately mitigate higher radon levels or radium or uranium in the well water.

An examination of Tables 5 and 6 reveals that the most effective system in this study with respect to radon removal is the diffused bubble aerator + WS, which brought the well having the greatest overall mean radon level to less than 250 pCi/L, a reduction of almost 100%. Both the diffused bubble aerator + WS and the shallow tray aerator + WS achieved removal of virtually all radium and uranium from their respective wells. The spray and diffused aerator tank + CT achieved the least removal of all radionuclides among the systems studied.

The data in Table 7 illustrate the importance of proper ventilation of water mitigation radon ventilation stacks. Fortunately, all systems were ventilated to prevent reentry of radon plumes into the home. The ground level stacks were ventilated at the crest of small hilltops away from the homes.

Table 8. Efficiency of radon mitigation as applied to hypothetical wells.

TYPE	Rn-222(%)	Efficiency #1 (pCi/L)	Efficiency #2 (pCi/L)
Diffused	96.2	107	7,900
Diffused + WS	99.9	3	300,000
Shallow Tray + WS	99.4	17	50,000
S & D + CT	77.7	629	1,345

Table 8 demonstrates what the results would be of applying each of the mitigation systems studied to hypothetical wells. Efficiency #1 demonstrates the results of applying each mitigation system to an average Connecticut well of 2,822 pCi/L. Efficiency #2 shows the highest radon value which could be present in a well and successfully mitigated with each mitigation system to 300 pCi/L. In the event of an EPA SDWA national public drinking water standard for radon of 300 pCi/L, the four mitigation systems studied would have varying success in achieving this standard. Assuming an average radon level in Connecticut of 2,822 pCi/L, three of the four systems studied (diffused bubble aerator with and without water softener, shallow tray aerator with water softener) would reduce the radon to less than 300 pCi/L. The spray and diffused aeration tank with CT system would be unable to achieve this level of mitigation. As demonstrated by the efficiency #2 values, the spray and diffused aeration tank with CT is the single mitigation system which cannot successfully mitigate the average Connecticut well.

PROBLEMS ENCOUNTERED WITH MITIGATION SYSTEMS

Diffused Bubble Aerator

As expected, the diffused bubble aerator does not appear to greatly affect radium or uranium levels. The 20% reduction of uranium seen in Table 6 and Figure 3 may be an artifact of measurement of this low concentration. Air radon readings taken throughout the first floor and basement of the home throughout the sampling period with activated charcoal detectors and charcoal liquid scintillation radon detectors, and radon grab samples using the Pylon® at no time exceeded the EPA guideline of 4.0 pCi/L.

Diffused Bubble Aerator With Water Softener

When combined with a water softener, the diffused bubble aerator did significantly reduce radium and uranium levels. However, when a radon mitigation system is connected to a well having high levels of other radionuclides, problems may develop.

During January and February of 1992, periodic radon measurements using 4 day charcoal liquid scintillation radon detectors revealed that radon levels in the basement of the home in which this mitigation system was placed were elevated (7.5-10.2 pCi/L). Radon air measurements in the first floor of the house radon indicated levels of 1.3-3.3 pCi/L. Radon levels in previous months were below 4.0 pCi/L. Radon grab samples in the basement initially did not exceed 4.0 pCi/L. However, upon investigation it was determined that the source of the elevated radon air readings was from a flexible plastic tubing which discharged wash liquid from the water softener tank into a vertical pipe which accepted wash water discharge. The liquid released from this tank was measured for radionuclides and was found to contain 513,200 pCi/L radon, 33.1 pCi/L radium-226, and 20 pCi/L uranium.

The plastic tubing discharge was subsequently sealed air-tight to the pipe using plastic sheeting material and duct tape. This sealing of the plastic tubing discharge from the water softener tank has stopped the leak of radon into the basement.

Also during 1992, the water flow rate into household taps slowed considerably, and the homeowners shut off the diffused bubble aerator with WS system for various time periods. In March, radon in air levels (using 4 day charcoal liquid scintillation detectors) reached a high of 90.3 pCi/L in the first floor bathroom and 23.0 pCi/L in the basement during the time that the water mitigation system was turned off. It was determined that the prefilter to the mitigation system had not been changed for the last two years, and had become saturated with particulate matter and become obstructed. The prefilter was changed, and the liquid from this filter contained 393,000 pCi/L radon, 481 pCi/L radium, 52 pCi/L uranium, and 38 pCi/L thorium.

Gamma radiation readings taken in March of 1993 indicated that the water softener tank was emitting 1.5 mR/hr (closed window, background radiation = 10 μR/hr). Therefore, the water softener tank had become a source of radiation. It is reasonable to assume that prior to replacement, the prefilter had also been a source of radiation.

Shallow Tray Aerator With Water Softener

Radon air sampling data for the past three years has resulted in levels below 4.0 pCi/L. No problems have been encountered with the use of this system.

Spray And Diffused Aerator Tank With Charcoal Filter Tank

Radon air sampling with passive detectors have resulted in levels below 4.0 pCi/L. However, radon grab sampling with the Pylon® radiation monitor detected levels exceeding EPA guidelines both in the small basement room where the spray and diffused aerator tank with CT is located (4.2 pCi/L), and directly on top of the bubble aeration tank (10.0 pCi/L). Grab sampling readings taken throughout the rest of the basement and the house on four separate occasions throughout a one month winter period did not reveal radon readings in excess of EPA guidelines.

Gamma radiation measurement taken during March of 1993 indicated that the charcoal tank was emitting 2.8 mR/hr (closed window, background radiation = 8 μR/hr). Therefore, the charcoal filter tank had become a source of radiation.

CONCLUSIONS

Although limited by the fact that only four wells and one or two examples were examined for each type of mitigation system, certain conclusions are warranted[††].

The well sampling data emphasize the need to conduct multiple samples prior to a mitigation system selection. Substantial variances were observed for the radionuclides studied (especially for radon) in the four wells sampled. We have observed up to a nineteen-fold difference in the lower and upper range limits for well water radon.

All systems studied accomplished radon removal of 77% or greater. Both the diffused bubble aerator and shallow tray aerator systems were most effective (>96%) in removing radon from well water. Out of the systems studied, the diffused bubble aerator with and without water softener units, and the shallow tray aerator with water softener unit would achieve the proposed EPA SDWA public drinking water standard using the average well water in Connecticut. The spray and diffused aerator tank with charcoal filter tank did not attain the level of performance of the other systems, and may not mitigate the average Connecticut well successfully if held to the same standard.

As expected, aeration systems appear not to be able to affect radium or uranium levels in water. When combined with a water softener, a diffused bubble aerator or shallow tray aerator may effectively remove all radionuclides present in well water. The spray and diffused aerator with charcoal tank system did not effectively remove radium or uranium from the well water.

[††] It is the intent of the Radon Program to continue to study the wells and mitigation systems presented here along with additional examples.

Gamma emissions may occur from system components, such as prefilters, water softener tanks, and carbon tanks. System maintenance including regular changing of filters should be performed. Aeration tanks having household system discharge points should be carefully measured for leaks which may increase radon levels in the home.

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REFERENCES

EPA. EPA/EERF-Manual-78-1. Radon in water sampling program. 1978.

Dupuy, C.J., Healy, D., Thomas, M.A., Brown, D.R., Siniscalchi, A.J., Dembek, Z.F. A survey of naturally occuring radionuclides in groundwater in selected bedrock aquifers in Connecticut and implications for public health policy. In: Regulating drinking water quality. Lewis Publishers, 1992.

Helms, G., Rydell, S. Regulation of radon in drinking water. In: Regulating drinking water quality. Lewis Publishers, 1992.

Longtin, J. Occurrence of radionuclides in drinking water, a national study. In: Cothern, C.R; Rebers, P.A., eds. Radon, radium and uranium in well water. Lewis Publishers, 1989.

McHone, N.W.; Thomas, M.A.; Siniscalchi, A. Temporal variations in bedrock well water radon and radium and water radon's effect on indoor air radon. The 1992 international symposium on radon and radon reduction technology. In print. 1993.

Siniscalchi, A.J.; Dembek, Z.F.; Brown, D.R.; Dupuy, C.J.; Thomas, M.A.; McHone, N.W.; Weiss, B.S.; van der Werff, M.C. Risk assessment implications of temporal variation of radon and radium well water concentrations. The 1992 international symposium on radon and radon reduction technology. In print. 1993.

Vitz, E. Preliminary results of a nationwide waterborne radon survey. The 1989 international symposium on radon and radon reduction technology. 1990.