An Investigation of Radon Occurrence in Pennsylvania Fish and Boat Commission Fish Culture Stations

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Introduction

The Pennsylvania Fish and Boat Commission operate 14 fish culture stations throughout the Commonwealth. The exclusive purpose of this operation is to provide stocked fish in Commonwealth lakes and streams for licensed anglers. Both warm water and cold water species are raised and stocked. Warm water species raised include muskellunge and bass. Cold water species include rainbow, brook, brown, and lake trout. The majority of the fish culture stations use ground water, either spring or well, for their daily operations.

With the awareness of radon in water and the potential impact this could have on the indoor environment, it became apparent that attention should be given to such facilities as water treatment plants and fish hatcheries, where large quantities of groundwater are often used. Some of the fish hatcheries in this study used greater than 500,000 gallons of groundwater daily.

A number of previous studies have looked at both water treatment plants and fish hatcheries regarding indoor radon concentrations arising from groundwater releases. Fisher et al. 1996, found indoor radon concentrations in Iowa water treatment plants as high as 133 pCi/L arising from radon-222 groundwater concentrations of 815 pCi/L. Dwyer and Orr 1992, found indoor radon concentrations in the Ennis (Montana) National Fish Hatchery of 200-250 pCi/L. The groundwater radon concentration was not published for this study. Post-mitigation radon concentrations ranged from 25-40 pCi/L. Kitto et al. 1998, found indoor radon concentrations of 89 pCi/L arising from groundwater concentrations of 2243 pCi/L in a New York State Hatchery. Post-mitigation efforts managed to reduce indoor radon concentrations to 5.4 pCi/L. Harris and Craig 1991, investigated another national fish hatchery in Neosho, Missouri. They found indoor radon concentrations of 100-300 pCi/L arising from radon in groundwater concentrations of 400-600 pCi/L. No post-mitigation values were reported.

As of this writing the US Environmental Protection Agency has yet to publish a final standard for Radon-222 in public drinking water. The current proposed maximum contaminate level (MCL) is 300 pCi/L; with an alternate maximum contaminate level (AMCL) of 4000 pCi/L. Due to Radon's High Henry's Constant of 2200 atmospheres it does not want to remain in solution and when brought into the home or building environment it readily volatilizes into air. How much radon is released into the air depends on several factors; the flow rate and the type of aerating mechanism, such as kitchen spigot, washing machine, shower head, or in the case of fish hatcheries, degassing columns inside the hatch house and the extent of water drop from spigot to water surface. The latest National Academy of Sciences report (1999) continues to support a transfer coefficient of 10,000 pCi/L of radon in water contributing 1 pCi/L to indoor air for the typical home environment.

Materials and Methods

Radon in air measurements were performed using Pylon AB-5 Passive Radon Detectors and short and long-term Electret Ion Chambers. When applicable, long-term Electret Ion Chambers and Landauer Alpha Track Detectors (Radtrak) were deployed for yearlong tests.

The Pennsylvania Department of Environmental Protection, Bureau of Laboratories, performed all radiological analysis. Radon in water samples were collected in 20-milliliter (ml) glass scintillation vials containing 10 ml of mineral oil. A 12 ml plastic syringe was used to draw the sample and immerse it below the mineral oil. The vial was then quickly capped. Duplicate samples were collected. A Packard 2250 Liquid Scintillation Counter was used to perform 100-minute counts of each vial. A 20-30 pCi/L lower limit of detection was typical for counting conditions encountered.

For all other radiological analysis a one-gallon plastic container was used to collect source water from the well or spring, or both. Natural Uranium was analyzed by laser fluorescence using the Scintrex UA3 Uranium Analyzer. Radium-228, Gross Alpha, and Gross Beta was analyzed on the Gamma Products G5400-Auto-Quad Gas-Flow Proportional counter, using 100-minute counting time. Radium-226 was analyzed via the de-emanation method, with samples transferred to scintillation cells and counted on the Ludlum Model 2000 Scaler and Model 182 Photomultiplier Tube, also using 100-minute counting times.

Results and Discussion

Radon in water and radon in air measurements were performed in 12 state operated fish hatcheries located throughout the Commonwealth. Gross Alpha and Gross Beta measurements were also made from one-gallon water samples. Site topography ranged from rolling farmlands to flat planes, to mountainous valleys. Geology varied from site to site, however, the predominant geology was shale, siltstone, sandstone, limestone, and dolomite. The water supply for the hatcheries ranged from groundwater wells and springs, to surface water lakes and streams. Most of the facilities had some combination of the above water supplies.

From a comparison point of view one of the most problematic areas of study is the great variability from one hatchery to another. The hatcheries vary in building design, building volume, and building tightness. The source water varies from one hatchery to another and also varies at each individual site. At one moment a hatchery may be using 200-gallons per minute (GPM) from Well Number 1 and 100 GPM from a particular spring, a week later they may be using all spring water. Additionally, the volume of water used in the hatch house varies throughout the year, from zero flow when no fish are being raised, to some maximum flow when the hatch house is in full operation, to values in between. Different fish species being *raised also* add to the variability from one hatchery to another. Another source of variability is the type and extent of water treatment. Some water, depending on its dissolved nitrogen content, goes through degassing units. These degassing units can be large or small and they can also be inside or outside of the hatch house. Sometimes oxygen injection is employed along with degassing. Sometimes well water must be heated and this usually occurs inside the hatch house. Some water goes through filter banks to remove small sediments. These filters could be sand filters or

25-micron membrane filters. Inside the hatch house the water from the spigots flowing into the troughs can have a drop of 12-18 inches to the water surface and it may or may not go through additional packing material causing degassing. Sometimes there is no drop of water at all and the water is injected directly under the surface of the trough water. This causes less splashing and less off gassing. A final source of variability and outside the control of the hatchery is the temporal variation of radon in groundwater.

A US Geological Survey study (Senior, 1998) of Radon-222 variability in Southeastern Pennsylvania showed one well that ranged from 7900 pCi/L to 2800 pCi/L over a four-year period, which is a 95% difference. Dilution by recharge changes in contributing areas to the aquifer, and seasonal fluctuations in the water table were given as reasons for the variation over time. A study of groundwater radon variability over a 2-year period in Raleigh and Chapel Hill, North Carolina by Drane et al 1997, found variations in individual wells from as little as 39% difference (1890 pCi/L to 2808 pCi/L) to as high as 103% difference (12,100 pCi/L to 37,900 pCi/L).

In this study groundwater radon variability was measured at the Benner Spring Fish Culture Station. Four duplicate samples were taken from Benner Spring from 11/99 to 8/00 and five duplicate samples were taken from Well No. 2 from 11/99 to 8/00. See Table 1 for individual results.

Table 1 - *Benner Spring*

Sample Date	Dup. Sample Rslts.	Coeff. Of Variation	Average (pCi/L)
11/01/1999	457/502 pCi/L	6.6%	480 pCi/L
01/13/2000	515/500 pCi/L	2.1%	508 pCi/L
06/22/2000	552/498 pCi/L	7.2%	525 pCi/L
08/30/2000	459/479 pCi/L	3.0%	469 pCi/L

Table 1 - *Well No. 2*

Sample Date	Dup. Sample Rslts.	Coeff. Of Variation	Average (pCi/L)
11/01/1999	335/271 pCi/L	15%	303 pCi/L
11/15/1999	282/273 pCi/L	2.3%	278 pCi/L
01/13/2000	312/351 pCi/L	8.3%	332 pCi/L
06/22/2000	344/393 pCi/L	9.4%	369 pCi/L
08/30/2000	327/349 pCi/L	4.6%	338 pCi/L

Benner Spring shows an 11% difference from high to low concentration over a ten-month period and Well No. 2 shows a 28% difference from high to low over the same time period. These fairly uniform results over time may be due to the large volume of water being extracted from both well (700-1000 GPM) and spring (4500-6000 GPM) and from the almost constant use of each. Additionally, the larger percent difference in Well No. 2 may in part be due to sampling error. Due to the plumbing it was difficult to get a slow, steady stream of water. The larger coefficient of variation for Well No. 2 also supports this conclusion.

Various values have been quoted for average Radon-222 groundwater concentrations in Pennsylvania. The US Environmental Protection Agency (EPA 520/5-85-008) did a survey for radioactivity in public groundwater supplies and found an average of 756 +/- 832 pCi/L (n=89). A survey by the Pennsylvania Department of Environmental Protection (PADEP) (Ruppert, 1993) of Pennsylvania community groundwater systems found a population-weighted mean of 1229 pCi/L (n=493). Dixon and Lee (1988) reported a mean radon concentration of 1570 pCi/L for Pennsylvania groundwater systems.

Radon In Water

Groundwater samples from this study included wells, springs, and one lake sample and in general were lower than the above quoted values for Pennsylvania groundwater. The average for 29 wells and springs sampled was 463 +/- 430 pCi/L. The Lake was 12 pCi/L and excluded from the average. A distribution of values can be seen in Table 2.

Table 2 - *Groundwater Radon Conc.*

Hatchery Site	Water Source	Rn. Conc +/- 2 Sigma
Bellefonte	Spring	343 +/- 25 pCi/L
	Well No. 1	425 +/- 34 pCi/L
Benner Spring	Benner Spring	480 +/- 29 pCi/L
	Well No. 2	303 +/- 24 pCi/L
Big Spring	Big Spring	132 +/- 23 pCi/L
Corry	Well No. 3&4	839 +/- 41 pCi/L
	Annex Springs	530 +/- 35 pCi/L
	Foster Springs	269 +/- 26 pCi/L
	Well No. 12	230 +/- 25 pCi/L
Huntsdale	Spring No. 1	595 +/- 43 pCi/L
	Spring No. 2	864 +/- 50 pCi/L
	Spring No. 3	118 +/- 25 pCi/L
	Spring No. 4	107 +/- 25 pCi/L
	Spring No. 6	109 +/- 25 pCi/L
	Boucher Spring	133 +/- 26 pCi/L
	Deep Aquifer	116 +/- 25 pCi/L
	McNanna Spring	352 +/- 36 pCi/L
Linesville	Well No. 2	169 +/- 24 pCi/L
	Well No. 5	127 +/- 23 pCi/L
	Lake	12 +/- 18 pCi/L
Oswayo	Lower Spring	727 +/- 35 pCi/L
	Upper Spring	539 +/- 32 pCi/L
Pleasant Gap	Shugurt Spring	600 +/- 40 pCi/L
	Blue Spring	124 +/- 23 pCi/L
Pleasant Mount	Well No. 2	2156 +/- 56 pCi/L
	Spring	1210 +/- 42 pCi/L
Reynoldsdale	Spring	716 +/- 32 pCi/L
Tionesta	Well No. 1	544 +/- 33 pCi/L

	Well No. 2	417 +/- 31 pCi/L
Tylersville	Ruhl Seven Spring	139 +/- 22 pCi/L

The range of values for the above groundwater sites runs from 107 to 2156 pCi/L, this however, is for sites located throughout the entire Commonwealth. Interestingly, there can be a fair difference even at the same site. Two different sites with multiple groundwater sources showed a range of values from 107 to 864 pCi/L (Huntsdale) and 124 to 600 pCi/L (Pleasant Gap). However, other sites showed very uniform concentrations among different groundwater sources (Corry, Benner Spring, Bellefonte). At these three sites the maximum difference was only around 80 pCi/L.

Looking at the groundwater radon concentrations from Table 2, most radon professionals who deal with the general public and residential dwellings would not get too excited about these types of numbers. In fact the average for the 28 groundwater sources in Table 2 was 465 pCi/L. If one uses the 10,000 to 1 rule, whereby 10,000 pCi/L of radon in water will contribute approximately 1 pCi/L to the home environment, this 465 pCi/L would only contribute 0.04 pCi/L to the indoor environment, an insignificant contribution. However, we must consider the differences between the residential home environment and the hatchery, and two major differences come to mind; the hatcheries have not made major efforts to reduce the building air exchange rate, whereas the residential home environment has an air exchange rate of approximately 0.5 to 1.0 air changes per hour, and the typical residential home environment, consisting of 2.5 people uses about 710 liters of water per day. During this study water use in the hatch house's ranged from 326,880 to 3,163,680 liters per day. Here in lies the problem! Even relatively low radon in water concentrations can contribute significantly to indoor air concentrations when very large volumes of water are in use, particularly when a moderate amount of aeration is taking place of this water in the enclosed environment.

A large amount of aeration/degassing of groundwater takes place at the hatcheries, some of this is intentional and some unintentional. The primary purpose of the intentional aeration/degassing process is to remove gaseous nitrogen from the water and to increase the oxygen content. This aeration/degassing usually takes place outside of the hatch house in specially designed structures. The groundwater is pumped into the top of the structure and then falls by gravity through wooden slats or plastic packing material to the bottom chamber for supply into the hatch house. During this study eight outdoor aeration/degassing units were encountered. They ranged from 55-gallon plastic drums filled with packing material to large wooden enclosures 20 feet high lined with wooden slats. The percent reduction in radon in water from pre to post-degassing ranged from 83% to 12%, with an average reduction for all eight of 41%. In some of the hatcheries this aeration/degassing takes place inside the hatch house. One hatchery had a moderate sized degasser attached to the wall inside the hatch house, and a number of the hatcheries have PVC tubing filled with packing material to deliver the water to the troughs. Both of these designs provide ample opportunity for radon off-gassing inside the hatch house. The unintentional degassing can occur when the water drops about 12-15 inches from the spigot to the trough water surface, this same drop occurs when the water empties from the bottom of the trough into the in floor discharge. There is some degassing from the water in the trough itself, and finally some degassing occurs when the water is heated. Some of the hatcheries must heat the water in order to moderate 39° Fahrenheit well water, too cold for trout production. The percent radon in water reduction for these unintentional designs ranged from 55% to 7%, with an average of 29%.

During the initial phases of this study, one-gallon samples of groundwater were taken at each site, often from different sources. These samples were analyzed by the PADEP Bureau of Laboratories for gross alpha, gross beta, Ra-226, Ra-228, and Natural Uranium. After six of these comprehensive analyses it was observed that Ra-226, Ra-228, and Natural Uranium were all very low, we therefore discontinued these tests. We continued to use gross alpha and gross beta as screening tools. If the gross alpha were greater than or equal to 5 pCi/L, Ra-226 and Natural Uranium would be analyzed. If the gross beta were greater than 15 pCi/L, Ra-228 would be analyzed. No gross alpha or gross beta exceeded our cutoff. For 19 samples the gross alpha ranged from -0.36 to 3.8 pCi/L, and the gross beta ranged from -6.9 to 2.4 pCi/L. For seven samples the Ra-226 ranged from 0.009 to 0.24 pCi/L, Ra-228 ranged from -0.05 to 0.35 pCi/L, and Natural Uranium ranged from 0.2 to 0.33 pCi/L. Table 3 below compares the average values from hatchery samples with the US EPA Maximum Contaminant Levels (MCL) for public drinking waters, and the average values as stated in the EPA Nationwide Survey of Radioactivity in Public Water Supplies (EPA 520/5-85-008).

Table 3 - *Radioactivity In Groundwater*

	Hatchery (Avg. pCi/L)	**EPA Values for PA (pCi/L)**	**EPA MCL**
Gross Alpha	1.2 +/-1, n=19	1.5 +/- 3.4, n=90	15 pCi/l
Gross Beta	0.8 +/- 2, n=19	2.0 +/- 1.5, n=90	50 pCi/L
Ra-226	0.14 +/- .01, n=7	0.6 +/- 0.6, n=10	5 pCi/L
Ra-228	0.25 +/- .2, n=7	No Value	5 pCi/L
Nat. Uranium	0.24 +/- 0.4, n=7	7.5 +/- 4.9, n=10	30 pCi/L

The 5 pCi/L for Radium is for a combined Ra-226/Ra-228.

The groundwater radiological analysis at hatchery sites shows values all well below current EPA MCL's, as well as below the most recent (1985) EPA survey data for Pennsylvania.

Radon in Air

A radon in air measurement was made at each hatchery during our initial visit using either a continuous monitor or the EIC's or a combination of both. All measurements were made for a period of one week, one in the hatch house and one in the manager's office. It is difficult to compare indoor radon concentrations across all hatcheries due to the variability that arose from sampling at various seasons, and the great variation in water use from one hatchery to another. Table 4 shows indoor radon concentrations in the various hatch houses.

Table 4 - *Hatch House Indoor Air Concentrations*

Hatchery	Month Tested	Indoor Air Radon Conc.
Bellefonte	May	27.7 pCi/L
Benner Spring	September	17.2 pCi/L
Big Spring	March	7.7 pCi/L
Corry	February April	20 pCi/L* 40 pCi/L**
Huntsdale	January	3.2 pCi/L 7.3 pCi/L
Linesville	February	1.3 pCi/L
Oswayo	February	5.6 pCi/L
Pleasant Gap	April	7.3 pCi/L
Pleasant Mount	April	8.2 pCi/L 7.8 pCi/L
Reynoldsdale	October	13.2 pCi/L
Tionesta	February	4.2 pCi/L
Tylersville	January	5.6 pCi/L

Note: Two of the above facilities have two separate hatch houses on site (Huntsdale & Pleasant Mount).
* 60 GPM, ** 275 GPM

Based on our screening measurements we felt that there were three facilities that need remedial measures taken, Bellefonte, Benner Spring, and Corry. For the remainder of the facilities we have long-term alpha track testing ongoing, shortly to be started, or complete. Table 5 shows the results of the completed long-term testing.

Table 5 - *Yearlong ATD Results*

Hatchery	Month of Scrn Msmt	Screening Msmt	Yearlong Result
Benner Spring	September	17.2 pCi/L (HH)	17.3 pCi/L
Benner Spring	September	11.7 pCi/L (lab)	13.7 pCi/L
Benner Spring	------------	None	2.0 pCi/L (office)
Big Spring	March	7.7 pCi/L (HH)	3.8 pCi/L
Big Spring	March	4.3 pCi/L (office)	2.1 pCi/L
Huntsdale	January	3.2 pCi/L (HH1)	3.4 pCi/L
Huntsdale	January	7.3 pCi/L (HH2)	4.2 pCi/L
Huntsdale	---------	None	1.3 pCi/L (office)
Huntsdale	---------	None	3.3 pCi/L (office)
Huntsdale	---------	None	1.3 pCi/L (office)
Pleasant Gap	April	7.3 pCi/L (HH)	5.7 pCi/L
Pleasant Gap	------	None	2.4 pCi/L (office)

Screening measurements and yearlong measurements agree quite closely at several sites, at others sites the year-long result is roughly one-half of the screening measurement, and at two sites the year-long result is higher than the initial screening measurement. This limited long-term data shows that only Benner Spring is in need of remedial measures.

An attempt was made to calculate the hatch house indoor radon concentration arising from the radon in water liberated into the hatch house air. For this calculation one assumption and three derived values are needed. It was assumed that the hatch house had an air exchange rate of 1 air change per hour (ACH). The dimensions of the building were obtained at the initial visit and from this was calculated volume (l). The flow rate of water coming into the hatch house was also noted during initial measurements, and finally we needed the amount of radon liberated from the water into the hatch house air. For this we used two measured values, the radon in water concentration as the water enters the hatch house and the radon in water concentration as the water is discharged into the in-floor discharge system. The difference between these two values is the radon that is liberated into the air. A simple division is then carried out whereby the numerator is flow rate into the hatch house (l/day) times the radon in water liberated (pCi/L), to give units of pCi/day and in the denominator is the building volume (l) adjusted for 1 ACH for a 24-hour day, to give units of l/day. Thus we have pCi/day divided by l/day to give an answer in pCi/L. Table 6 shows the results of these calculations and comparison of these calculated values with the actual measured screening measurements in the hatch house.

Table 6 - *Calculated Results*

Hatchery	**Measured Air Conc. (pCi/L)**	**Calc. Air Conc. (pCi/L)**	**Source H2O Conc. (pCi/L)**	**Rn Liberated to Air (pCi/min)**
Benner Spring	17.2	5.9	392	52,450
Bellefonte	27.7	5	384	132,575
Big Spring	7.7	6.6	132	149,393
Corry	20	4.1	758	58,409
Corry	40	18.9	758	267,708
Huntsdale	3.2	2	109	33,750
Huntsdale	7.3	0.8	133	28,935
Linesville	1.3	0.04	148	3500
Oswayo	5.6	3.5	633	35,909
Pleasant Gap	7.3	2.1	Unknown	35,984
Pleasant Mt	8.2	3.5	1683	35,208
Pleasant Mt	7.8	4.5	Unknown	66,666
Reynoldsdale	13.2	1.1	716	51,431
Tionesta	4.2	0.8	480	21,079
Tylersville	5.6	0.5	139	11,592

Soil radon gas was not taken into account in the above calculation, in fact, indoor radon arising from the soil was only determined in the Bellefonte Hatchery. Soil gas values taken into consideration would lower the measured radon gas value, since currently this value is a combination of both soil gas and radon off-gassing. As can be seen from the above table, all calculated values underestimate the actual measured air concentration. The reason for this underestimation is unknown, however, it could be due to the quoted daily water use being too low, the radon liberated value may also be too low, or the assumed air change rate of 1 ACH may be too high, but this seems highly unlikely. A refinement of all values would be expected to produce closer agreement.

A Special Case

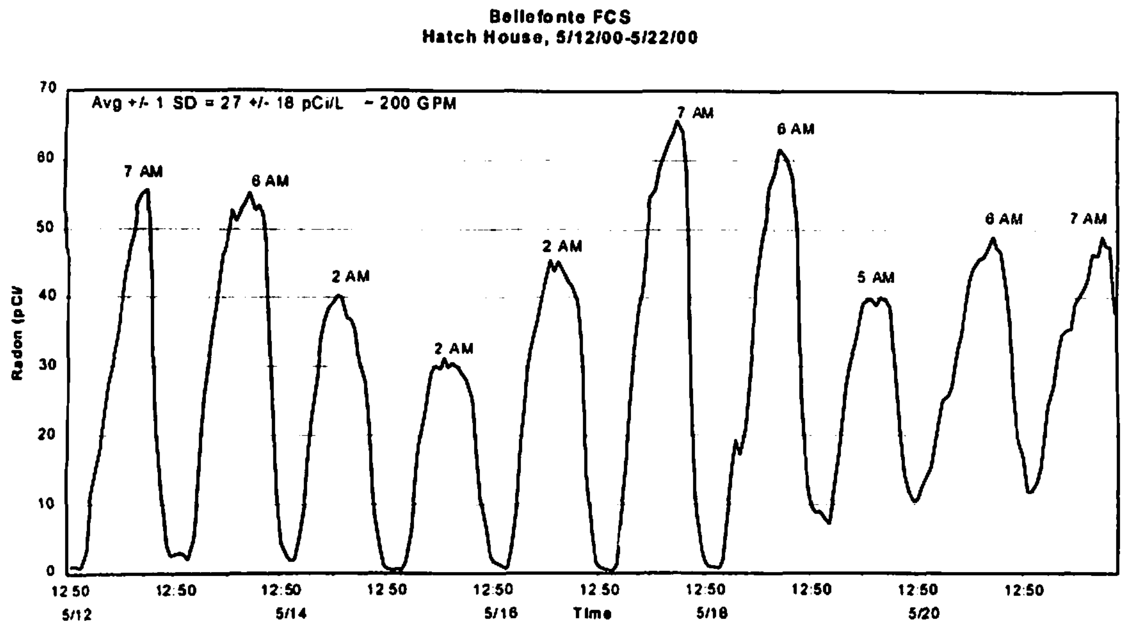
The Bellefonte Fish Culture Station is located in Central Pennsylvania approximately 5-10 miles northeast of State College, PA. It is next to Fisherman's Paradise on Spring Creek. This hatchery consists of two separate hatch house's, the lower hatch house at the far end of the complex consisting only of a hatch house, and the upper hatch house consisting of a hatch house, office space, lunch room, garage and visitor center all in the same building. The following discussion concern's the upper hatch house.

The upper hatch house is 43'x 48' with 12' ceilings. It is heated by gas, hot water, ceiling mounted units. There are two ceiling mounted exhaust fans in this hatch house and one in the incubation room. The hatch house has two garage doors on opposite sides of the building. Adjoining the hatch house is a garage for vehicle maintenance and storage. This part of the building also has a garage door.

The facility is served by one spring and two wells. See Table 2 for groundwater radon concentrations. Well No. 2 was not in service during our initial sampling. Often the hatch house will use a mix of the three groundwater sources to supply the hatch house fish production. As the water enters the building it is pumped to a small room above the garage where it goes through a 4'x 3'deep round drum packed with plastic packing material. There is no counter current air exchange on this column nor is there a distributor tray at the top of the column. This room is vented to the outside via a ceiling fan. After this degassing column the water is then pumped into the hatch house to one of the 17 troughs and three round drums for fish production. The water can also be pumped to the eggs in the incubation room. As the water travels through the eight-inch header pipe above the troughs it drops down through a spigot and then into a 24 inch long by 3-inch wide PVC pipe filled with packing material. From the bottom of this pipe the water drops about 12-15 inches to the water surface in the trough. It appears that most of the radon off gassing occurs through this 24-inch pipe. The water discharges from the troughs into an open channel in the floor and then goes to a sediment and/or clarifier pond for final discharge into the stream.

Initial radon in air measurements were made in May 2000 in the upper hatch house, see Graph 1. During this time the hatch house was using about 200 GPM, consisting of a mix of Well No. 1 and 2. Due to the ongoing operation of this facility it was not possible to maintain this building under closed-building conditions. This in part may explain the large fluctuations evident on the graph.

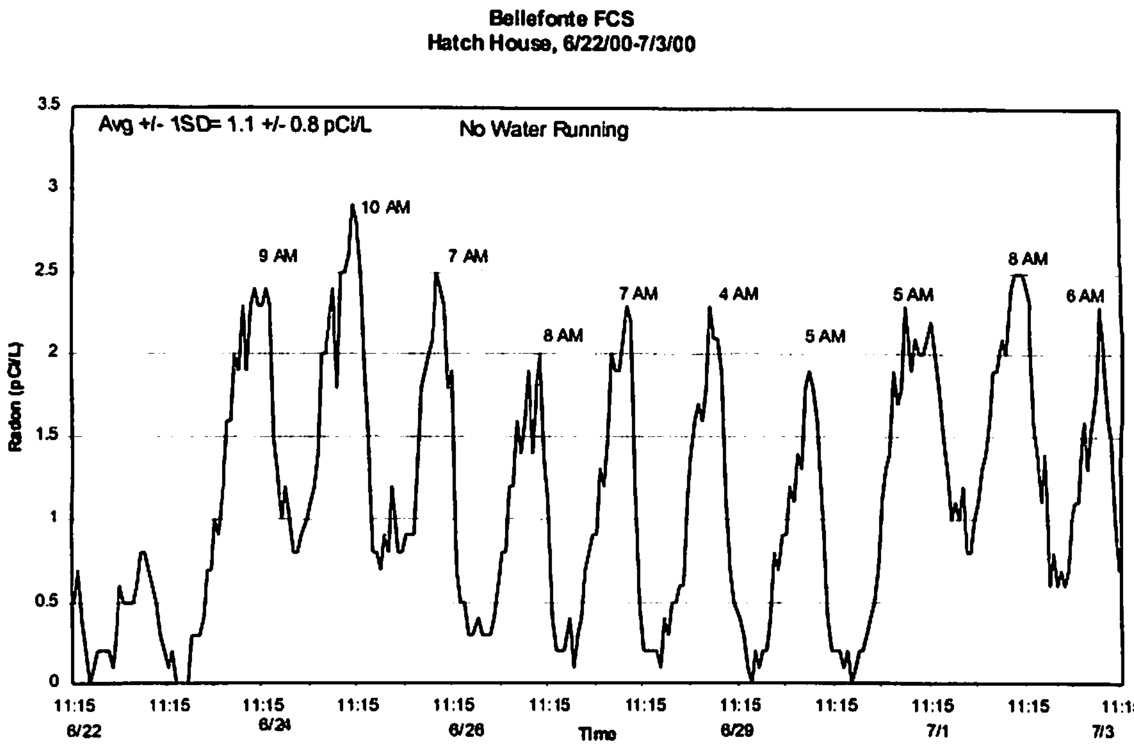
Graph 1 - Radon in Air Results



The average for the 10-day exposure was 27 pCi/L, with a minimum of 0.5 and a maximum of 65.8 pCi/L. The maximum radon concentrations show consistent peaks in the early morning (2 a.m. to 7 a.m.) hours. This tends to be consistent with the general trend in single-family homes where the maximum tends to occur during nighttime or early morning hours and the minimum occurs during daytime hours (Hans, et al. 1985). Work in a Missouri hatchery by Harris and Craig 1991, showed a similar trend where radon values peaked at 3:00 a.m. and fell dramatically by 8:00 a.m. This data is in stark contrast to the work of Kitto et al. in a New York State hatchery where they plotted the radon concentration over a 50-day period and found the maximum during early afternoon hours. They postulated that this maximum may be due to warmer air being used to aerate the water. Their testing occurred in September and October. The initial testing in this study occurred in May and the hatch house received ample outdoor ventilation *during* work time hours probably explaining the low concentration from around 10 a.m. to 5 p.m., fortunately for the workers.

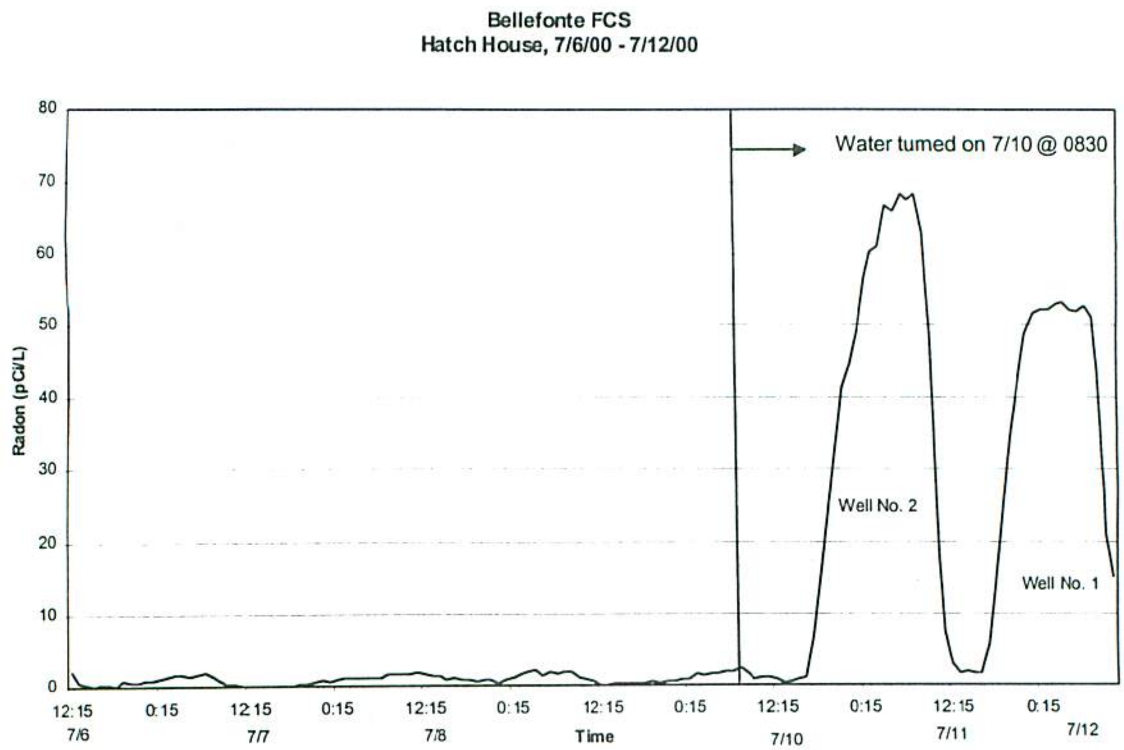
By June all fish had been placed in outside holding pens and we could test the hatch house with no water running. Graph 2 shows hatch house radon concentrations under this condition.

Graph 2 - Radon In Air measurements



This radon data still shows the early morning peaks, however in four of the days there has been a shift of several hours, toward the 8 a.m. to10 a.m. time frame. As can be seen from the 11 days of data the average is very low. This low average may again be due partly to workers leaving doors open and/or the lack of air tightness of the hatch house. An adjoining office to the hatch house, which was kept under better closed-building conditions, showed 8.1 pCi/L with no water running in the hatch house. This would tend to suggest that there is a marginal soil-gas problem. The extent of the radon in water off gassing to hatch house indoor radon concentrations can be seen from the following graph (Graph 3). This continuous monitor data shows the hatch house with no water running from July 6 to July 10. On July 10 at 8:30 a.m. the water was turned on from Well No. 2 at about 40 GPM. The one garage door was left open from July 10 at 8:30 a.m. to 3:00 p.m. This explains the delay of about eight hours before the graphed radon concentrations start to rise. The building was then maintained under closed-building conditions until the end of the experiment on July 12 at 10:30 a.m. On July 11 Well No. 2 was shut down and Well No. 1 was brought on line at the same flow rate.

Graph 3 - Hatch House Water Off/On

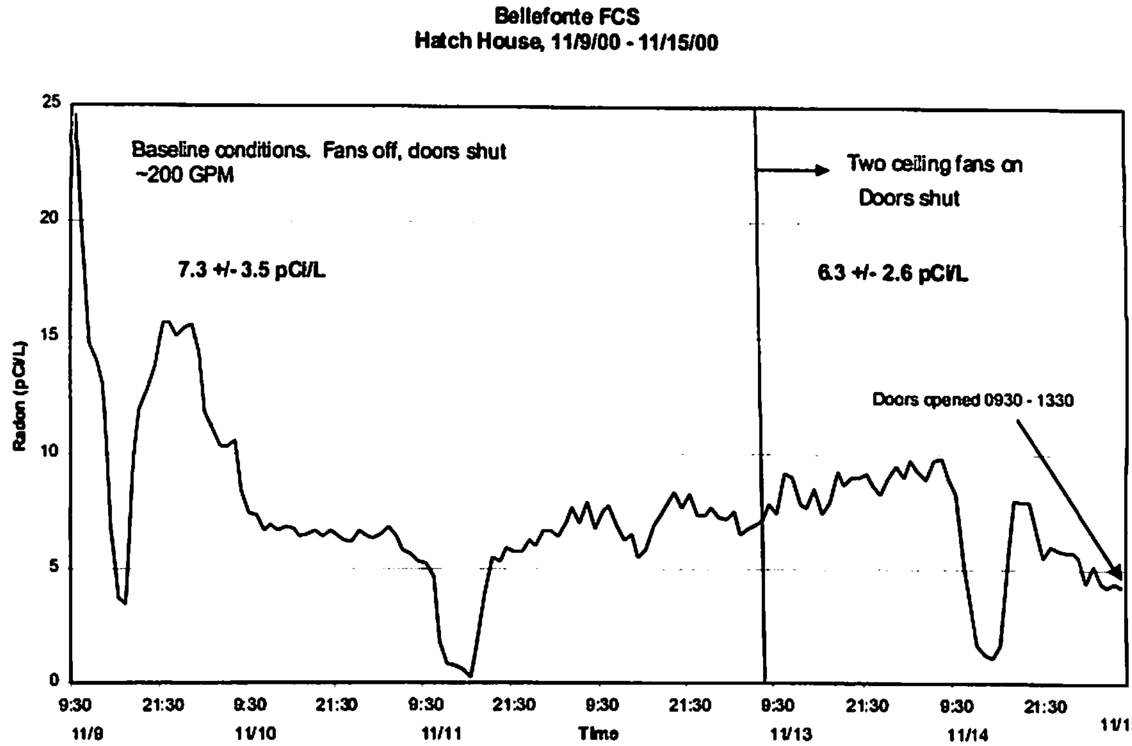


There seems to be no question that waterborne off gassing is the main contributor to hatch house radon. This graph with only two days of data still shows the early morning peaks at around 7:15 a.m. for Well No. 2 and 3:15 a.m. for Well No. 1.

Remedial Measures

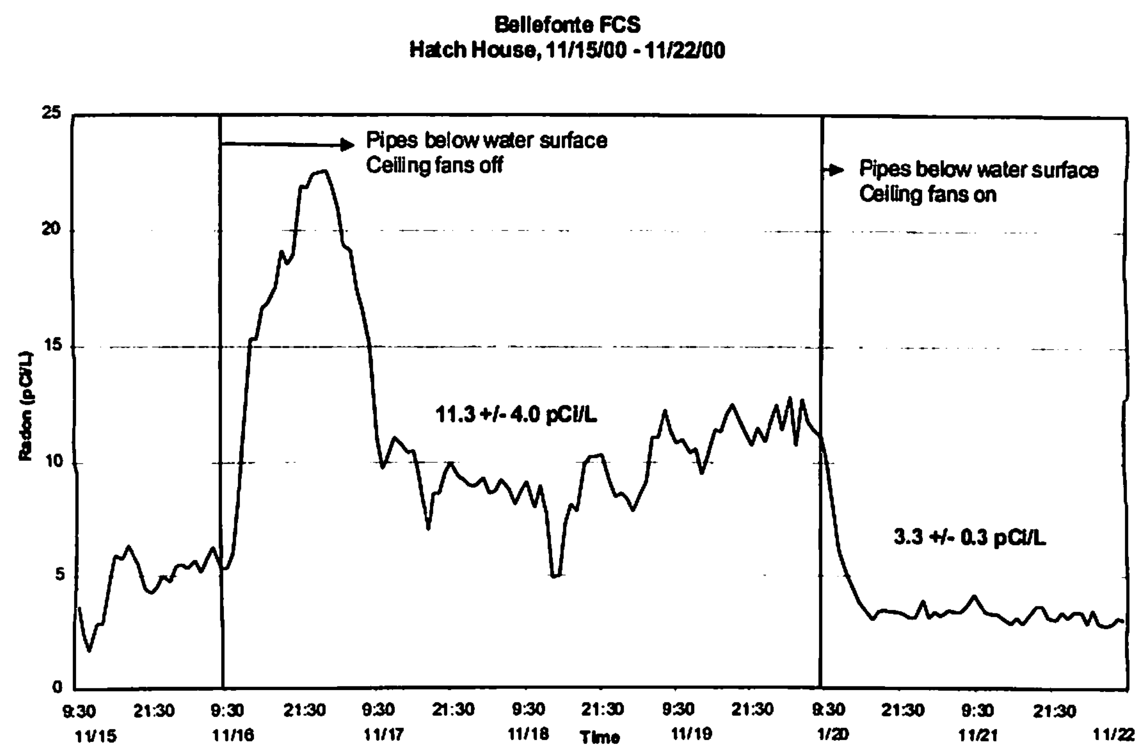
To date remedial measures have only been undertaken at the Bellefonte facility. Work also needs to be done at the Corry and Benner Spring facilities. Graph 4 shows the progress of various hatch house changes. Two graphs are presented, Graph 4a and Graph 4b in order to spread out the data and make visual inspection easier. Graph 4a shows the first six days of data, with days November 9 through 13 showing baseline conditions with about 200 GPM of hatch house water use and closed-building conditions. November 13 through 15 shows the effect of two hatch house ceiling fans being turned on, still under closed-building conditions. Closed-building conditions were lost on the 15th from 9:30 a.m. to 1:30 p.m.

Graph 4a



Graph 4b shows the effects of delivering the water to the troughs below the surface of the water, and finally the last part of Graph 4b shows a combination of below water delivery and ceiling exhaust fans running.

Graph 4b



Baseline radon concentrations (7.3 pCi/L) in Graph 4a are well below the baseline concentrations observed in Graph 1 (27 pCi/L) under similar conditions except for one item. An adjoining room used for incubation was in operation and a ceiling fan was running. Due to the fact that the hatch house is very leaky and at ground level I suspect that the incubation room ceiling fan was ventilating the hatch house with outdoor air. At 9:00 a.m. on the 13th two ceiling fans in the hatch house were turned on and hatch house radon concentrations did not appreciably change from baseline. Possibly, the incubation room fan was already providing a maximum ventilation and additional ventilation did not make much difference. On the 16th at 9:00 a.m. (Graph 4b) the pipes delivering water to the troughs were introduced below the surface of the trough water and the packing material in the pipes was removed. The ceiling fans were turned off, and the average concentration during this time period was 11.3 pCi/L. It is not clear why this time period has a higher average than the baseline condition time period, it is possible that a significant amount off-gassing was still taking place as the water exited the trough into the in-floor discharge. Both time periods had hatch house ceiling fans off and the baseline conditions had small packed columns for degassing directly above the troughs in operation, whereby starting on the 16th these packed columns were removed and the water was injected below the water surface. The final scenario consisted of pipes under water surface and hatch house ceiling fans on. Under this condition the most radon control was achieved with a two-day average of 3.3 pCi/L. Whereas this last scenario provided the best radon reduction it also made the hatch house uncomfortably cold to work in, due to the increased ventilation, at least during the cold weather months. Interestingly, the work on the New York State hatchery found a similar conclusion. With only water mitigation hatch house radon was 41 pCi/L, with only direct vent fans on, hatch house radon was 14 pCi/L, but with a combination of both measures hatch house radon was 5.4 pCi/L.

There was one other means of radon control already built into the hatch house and that was the packed column in the attic of the building, previously described. This packed column received water containing 425 pCi/L and after the column the radon in water had been reduced to 182 pCi/L, for a reduction of 57%. A number of improvements could be made to this column to provide additional radon reduction. Space permitting, the height of the column could be increased, add a counter-current air exchange, and use a distributor tray at the top of the column. These three items act to increase the efficiency of the column for gas exchange. It would be very interesting to see what effect they would have on post-degasser radon in water concentrations.

Care must be exercised when designing a packed column for hatchery operations. Water temperature is one very critical parameter that must be tightly controlled. Ideal water temperature for trout production is 52° with an acceptable range of 48° to 55° Fahrenheit (Personal Communication, James Harvey). One hatchery in Northern Pennsylvania measured well water temperature of 50° Fahrenheit in summer and 47° Fahrenheit in winter. With a packed column located outside and using outside air for stripping there could be a 5-7 degree change in water temperature depending on the time of year. A five-degree drop in water temperature was viewed as problematic for this facility (Personal Communication, Dr. Harold Kincaid). Were it not for the above problems increasing water temperature would be another useful remedial measure. A temperature difference of 10° Centigrade can affect Henry's constant by a factor of two or three. Temperature is one of the most important operating parameters in the removal of volatile compounds in water treatment aeration systems (Faust, et al. 1998).

Other researchers (Kitto et al. 1998; Harris and Craig 1991; Dwyer and Orr 1992) have tried to capture the off-gassing radon inside the hatch house using plastic hoods and fans, venting the off-gassed radon to outdoors.

For a number of the hatcheries in this study one very logical remedial measure would be to eliminate as much agitation and degassing of water inside the hatch house. A number of the hatcheries had the small column degassers directly above the troughs and one hatchery had a large wall mounted degasser inside the hatch house. Either eliminating or moving these degassers to the outside would be one step in the right direction.

Conclusions

Radon measurements were conducted in fish hatcheries located throughout the state in order to assess the potential radon exposure that hatchery personnel may be receiving. Almost all of these hatcheries use some source of groundwater for fish production in their hatch houses. Groundwater radon concentrations ranged from about 100 to 2000 pCi/L, with an average of 463 pCi/L. It has been demonstrated that even low radon in groundwater concentrations can lead to elevated indoor air radon problems. These indoor radon problems arise primarily from the very large volumes of water used in the hatch house and the degree of agitation of the water. At least at one facility it was conclusively shown that radon in water off gassing was the source of the indoor radon. Radiological analysis of groundwater sources for Natural Uranium, Radium-226, Radium-228, Gross Alpha, and Gross Beta activity all showed very low values, well below EPA Maximum Contaminant Levels.

Radon in air measurements at the hatcheries showed values ranging from 1.3 to 40 pCi/L. These values are highly dependent upon the status of operation of the hatchery at the time of measurement. There can be great variability in hatch house operation from one month to the next, as well as from one hatchery to another. Yearlong testing has been completed at four hatcheries, and is on-going at six others. Three other hatcheries are in need of remedial measures.

Some remedial work has been attempted at the Bellefonte Hatchery. This work consisted of decreasing the amount of off gassing in the hatch house and increasing the building ventilation. The combination of these two measures brought radon reductions to approximately 4 pCi/L, however, at the expense of personnel comfort. Increased ventilation during November made the hatch house unreasonably cold. Work will be ongoing at this site.

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