

# Radon Levels with and without Remediation at McNenny State Fish Hatchery, Spearfish, South Dakota, USA

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## Abstract

Radon gas liberated during the aeration of groundwater is an occupational health concern for hatchery workers. This study surveyed radon levels at three locations (fish rearing tankroom, conference room, and office area) within the main hatchery building at McNenny State Fish Hatchery, Lawrence County, South Dakota, USA. Levels were recorded with and without the operation of an exhaust fan in the tankroom. Radon levels from all locations throughout the study ranged from 0.74 Bq/m<sup>3</sup> (0.02 pCi/L) to 1446.7 Bq/m<sup>3</sup> (39.10 pCi/L). Without the exhaust fan running, the conference room had the lowest mean  $\pm$  SE radon level of 353.72  $\pm$  34.41 Bq/m<sup>3</sup> (9.56  $\pm$  0.93 pCi/L) and the tankroom had the highest level at 939.8  $\pm$  126.17 Bq/m<sup>3</sup> (25.40  $\pm$  3.41 pCi/L). With the exhaust fan running, the office had the lowest mean value of 28.86  $\pm$  5.92 Bq/m<sup>3</sup> (0.78  $\pm$  0.16 pCi/L), and the tankroom again had the highest level of 192.4  $\pm$  16.65 Bq/m<sup>3</sup> (5.20  $\pm$  0.45 pCi/L). Radon levels in all three locations were significantly correlated with the number of tanks with water running for fish production. Radon levels without remediation were well-above the United States Environmental Protection Agency's actionable level of 4.0 pCi/L, within the enclosed hatchery building. The use of an exhaust fan significantly decreased radon levels in all locations, with radon reduced to safe levels in the office and conference room.

## Keywords

Radon, Fish Hatchery, Rearing

## 1. Introduction

Radon gas (<sup>222</sup>Rn) is a radioactive by-product of naturally-occurring uranium decay in soil and bedrock [1]-[3]. It is also found in groundwater, particularly in

areas with high uranium concentrations [4] [5]. Radon has a low solubility in water and is easily liberated from water during aeration [4] [6] [7]. When fish hatcheries aerate water to increase dissolved oxygen or degas excessive nitrogen, radon gas can also be released [2] [6]-[8]. This can be an issue in fish hatcheries using large quantities of groundwater, particularly if aeration occurs in the same building as offices, laboratories, or other workspaces for hatchery employees [2] [9].

Long-term exposure to radon has well-documented negative impacts on human health [1] [4] [6] [10]. Radon is the leading cause of lung cancer in non-smokers worldwide and the second leading cause of lung cancer after smoking in the United States [11] [12]. Radon and smoking are also synergistic risk factors for developing lung cancer [13]-[15]. Radon-induced lung cancer was estimated to have caused over 225,000 deaths worldwide in 2012 [16].

Official recommendations and regulations addressing human health concerns and radon levels are based on exposure durations [17] [18]. A maximum radon reference level of 8.1 picocuries/liter (pCi/L) or 300 Bq/m<sup>3</sup> for European member states was set by the 2013/59/Euratom Directive [19]. While the United States currently does not regulate radon exposure, federal guidelines recommend maximum airborne radon levels of 4 pCi/L or 148 Bq/m<sup>3</sup> (37 Bq/m<sup>3</sup> = 1 pCi/L) [12] [14] [20].

Radon can be problematic in fish hatcheries, particularly those that use large quantities of groundwater [2]. Aeration of radon-containing water or fish rearing inside a closed building can create a human health concern, which is greatly amplified if that same building contains offices, laboratories, shops, or other workspaces for hatchery employees [2] [9]. Despite the worldwide growth of aquaculture and a large number of fish hatcheries [21], there are few studies examining radon levels in hatchery buildings. Dwyer and Orr [1] documented airborne radon levels of 200 - 250 pCi/L in a building at a governmental fish hatchery. Kitto *et al.* [2] reported airborne radon levels of 81 pCi/L at a commercial fish hatchery. Twenty-five percent of the hatcheries surveyed in the state of Pennsylvania, USA, required radon remediation, with levels ranging from 17.2 pCi/L to 40 pCi/L [8]. Lastly, Gerber *et al.* [9] reported radon levels in three hatchery buildings in the state of South Dakota, USA and noted a positive correlation between the number of fish rearing tanks receiving water and airborne radon levels.

McNenny State Fish Hatchery in Lawrence County, South Dakota, USA, is a government-owned-and-operated facility producing fish for recreational angling. Egg incubation and initial fish rearing occur in the same building as the hatchery offices, conference area, and laboratory. The tankroom used for fish rearing has passive ventilation as well as an exhaust fan that, until recently, was rarely used. This study was undertaken because hatchery radon levels were unknown, along with the possible need for remediation and its possible effectiveness.

## 2. Methods

This study was conducted at McNenny State Fish Hatchery, Lawrence County, South Dakota, USA (Figure 1). Production water for the hatchery building comes

from three open-bore artesian wells approximately 90-m deep. To remove super-saturated nitrogen gas and increase dissolved oxygen levels, the water, under its own pressure, is directed to the top of an open-air degassing/aeration tower outside of the hatchery tankroom (**Figure 2**). This tower also acts as a water tower providing gravity-flow water to the hatchery tankroom.



**Figure 1.** Aerial view of McNenny State Fish Hatchery with the location of the main hatchery building and aeration tower noted.



**Figure 2.** Aeration/degassing tower at McNenny State Fish Hatchery.

The hatchery tankroom contains 35, 1.8-m diameter circular tanks and occupies approximately one-half of the floor space of the main hatchery building (**Figure 3**). The remainder of the building houses offices, a conference area, mechanical rooms, and storage areas (**Figure 4**). The side of the building containing fish rearing has four small, screened vents and an exhaust fan for ventilation. The tankroom is typically only passively heated via the 11°C fish production water flowing through the hatchery tanks. Doors from the tankroom to the rest of the hatchery are closed when not in use. The remainder of the building is heated and cooled by forced air from a water-based heat pump. Most of the doors within this remainder of the building typically remain open.



**Figure 3.** Photograph of the main hatchery building at McNenny State Fish Hatchery.

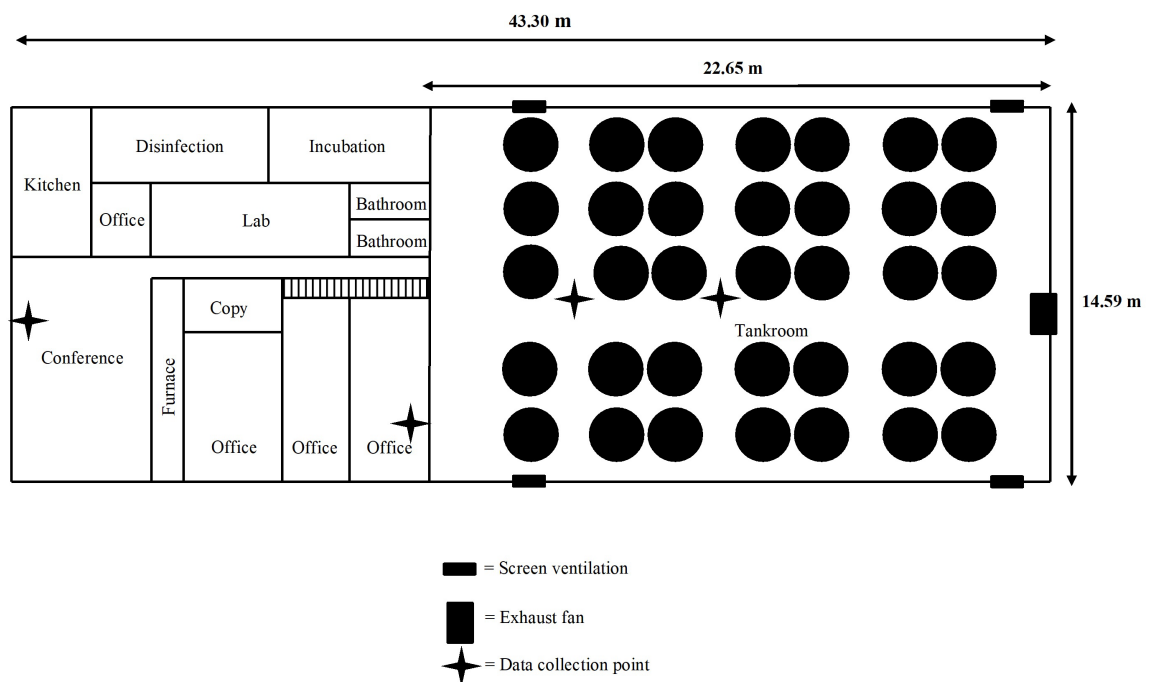


**Figure 4.** Photograph of inside the tankroom in the main hatchery building at McNenny State Fish Hatchery.

Radon levels were measured using radon meters (Corentium Home, Airthings Norway) with an accuracy/precision of 5.4 pCi/L/2000 Bq/m<sup>3</sup> [22] and recorded

daily. Meters were placed in the tankroom, conference room, and one office (**Figure 5**). Radon levels were recorded daily from 8 August 2020 to 20 September 2021. In addition to recording daily radon levels, the number of fish rearing tanks in use (receiving water) was also recorded. Because this study was done while actual fish production was occurring and production loadings changed throughout the year, the number of tanks being used changed as well. To determine the impacts of exhaust fan use on radon levels in the hatchery building, it was turned on approximately one-half of the days of the study, with the timing of use ensuring it was both on and off an adequate number of days in relation to different tank numbers in use.

Data were analyzed using the SPSS statistical program (24.0, IBM, Armonk, NY, USA). In addition to descriptive statistics, regression and correlation analysis were used to examine any possible relationships between radon levels and the number of rearing tanks being used. Significance was pre-determined at  $P < 0.05$ .



**Figure 5.** Schematic of the main hatchery building at McNenny State Fish Hatchery, Spearfish, South Dakota, USA. Screen ventilation is marked by horizontal rectangles, the exhaust fan is marked by a vertical rectangle, and radon meters are marked by four-point stars.

### 3. Results

Among all three locations within the main hatchery building, radon levels ranged from 0.02 pCi/L to 39.10 pCi/L (**Table 1**). Without the exhaust fan in operation, the conference room had the lowest mean (SE) radon level of 9.56 (0.93) pCi/L, and the highest was in the tankroom at 25.40 (3.41) pCi/L (**Figures 6-8**). With the exhaust fan operating, the office had the lowest mean (SE) radon level of 0.78 (0.16) pCi/L, while the highest was in the tankroom at 5.20 (0.45) pCi/L.

**Table 1.** The number of tanks receiving water, number of daily readings (N), and mean ( $\pm$ SE) radon levels (pCi/L) with and without the presence of an exhaust fan in the main hatchery building at McNenny State Fish Hatchery.

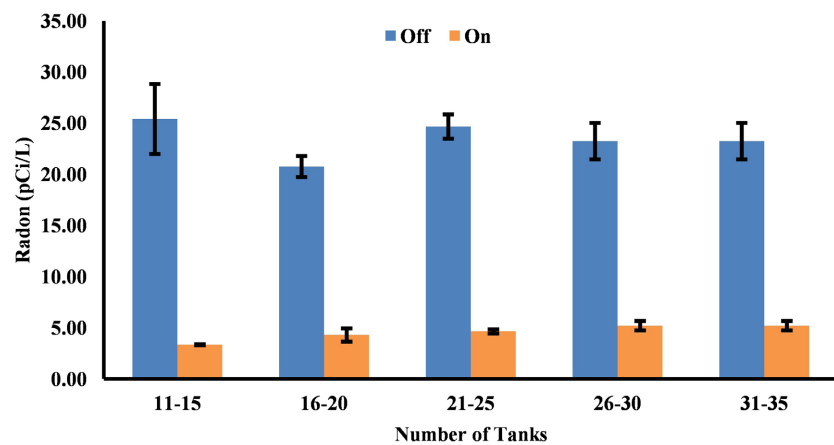
Number of Tanks	Fan	Tankroom		Conference Room			Office			N
12	On	3.24		0.89			0.83			1
	Off	19.38		7.50			8.02			1
15	On	3.41	$\pm$ 0.05	1.02	$\pm$ 2.27	0.75	$\pm$ 0.25			2
	Off	14.58	$\pm$ 0.76	7.99	$\pm$ 0.28	7.92	$\pm$ 0.70			3
17	On	5.30	$\pm$ 1.15	1.73	$\pm$ 1.45	1.50	$\pm$ 1.36			11
	Off	13.96	$\pm$ 1.02	6.11	$\pm$ 0.93	6.04	$\pm$ 0.84			14
18	On	3.21	$\pm$ 0.34	0.71	$\pm$ 0.60	0.61	$\pm$ 0.50			10
21	On	4.87	$\pm$ 0.32	1.50	$\pm$ 1.37	1.44	$\pm$ 0.77			12
	Off	12.95	$\pm$ 1.15	6.81	$\pm$ 0.78	7.17	$\pm$ 0.96			8
23	On	3.87	$\pm$ 1.05	2.20	$\pm$ 0.17	0.76	$\pm$ 1.69			2
	Off	12.80	$\pm$ 0.49	9.26	$\pm$ 1.04	11.01	$\pm$ 1.30			2
25	On	4.60	$\pm$ 0.29	0.81	$\pm$ 0.78	0.83	$\pm$ 0.47			16
	Off	13.30	$\pm$ 2.04	4.84	$\pm$ 1.22	7.97	$\pm$ 1.57			12
26	On	6.59	$\pm$ 1.79	2.46	$\pm$ 2.31	2.56	$\pm$ 3.01			7
	Off	11.40	$\pm$ 1.85	6.25	$\pm$ 0.85	6.16	$\pm$ 1.28			7
27	On	4.88	$\pm$ 0.27	1.16	$\pm$ 1.19	0.88	$\pm$ 0.59			21
	Off	11.48	$\pm$ 1.85	5.69	$\pm$ 2.11	6.79	$\pm$ 2.38			10
29	On	4.45	$\pm$ 1.06	1.12	$\pm$ 1.20	0.93	$\pm$ 1.03			4
	Off	16.55	$\pm$ 3.83	5.28	$\pm$ 1.00	6.49	$\pm$ 0.60			3
31	On	7.26	$\pm$ 0.42	5.95	$\pm$ 1.89	2.01	$\pm$ 1.11			29
	Off	11.60	$\pm$ 2.80	9.31	$\pm$ 3.07	7.43	$\pm$ 3.51			12
32	On	5.75	$\pm$ 0.28	1.02	$\pm$ 1.46	0.75	$\pm$ 0.32			33
	Off	16.83	$\pm$ 1.28	8.81	$\pm$ 1.57	9.32	$\pm$ 1.72			26
34	On	5.88	$\pm$ 0.26	2.13	$\pm$ 3.58	1.25	$\pm$ 1.02			49
	Off	11.92	$\pm$ 2.02	7.83	$\pm$ 1.72	7.75	$\pm$ 1.77			26
35	On	4.72	$\pm$ 0.34	1.49	$\pm$ 2.45	1.20	$\pm$ 0.88			36
	Off	15.66	$\pm$ 1.29	7.93	$\pm$ 0.83	9.06	$\pm$ 1.15			27

Radon levels were significantly correlated to the number of tanks in use (with water running) in all three locations: the tankroom ( $R^2 = 0.063$ ,  $p = 0.002$ ; **Figure 9**), conference room ( $R^2 = 0.129$ ,  $p = 0.001$ ; **Figure 10**), and office ( $R^2 = 0.136$ ,  $p = 0.001$ ; **Figure 11**).

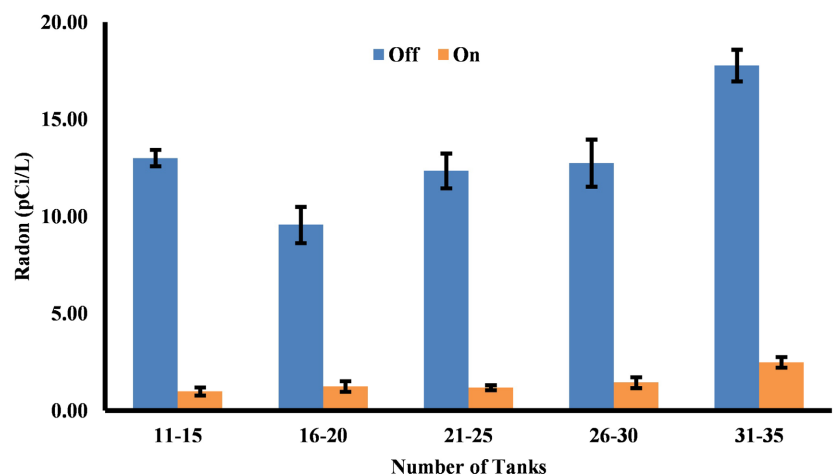
#### 4. Discussion

The results of this study indicate that without the presence of an exhaust fan, airborne radon levels throughout the hatchery building are high enough to require remediation. Without the exhaust fan running, radon levels in the tankroom, con-

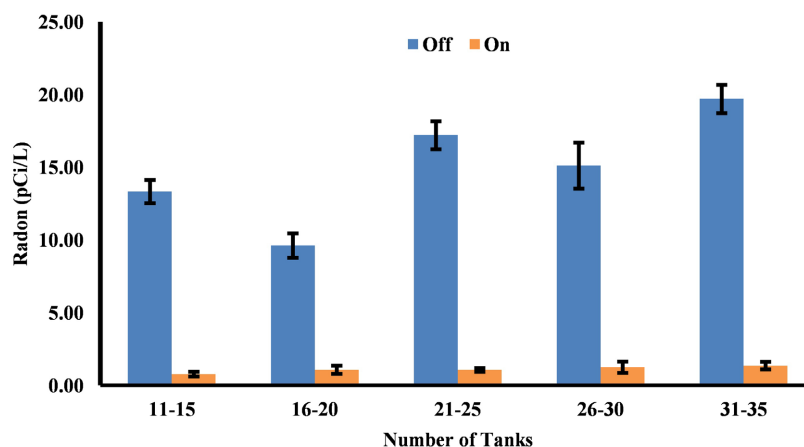
ference room and office all exceed the recommended maximum radon levels of 4 pCi/L and 8.1 pCi/L set by the USA and European Union [12] [19] [20]. Even with the exhaust fan running, radon levels in the tankroom area in the hatchery building still exceed the USA recommended maximum levels for long-term exposure. However, hatchery employees spend limited amounts of time within the tankroom, thereby lowering the need for mitigation. Hatchery employees usually spend less than an hour within the tankroom each day to feed and clean the tanks of fish. The conference room and office experienced lower radon levels compared to the tankroom. This is likely explained by the walls and closed doors separating those areas from the tankroom, the heating and cooling system servicing only that area of the main hatchery building, and the location of the open screened panels and exhaust fan in the tankroom [23]-[27].



**Figure 6.** Mean radon readings (pCi/L) with the exhaust fan off and on in relation to the number of tanks in use (with flowing water) in the tankroom at McNenny State Fish Hatchery.

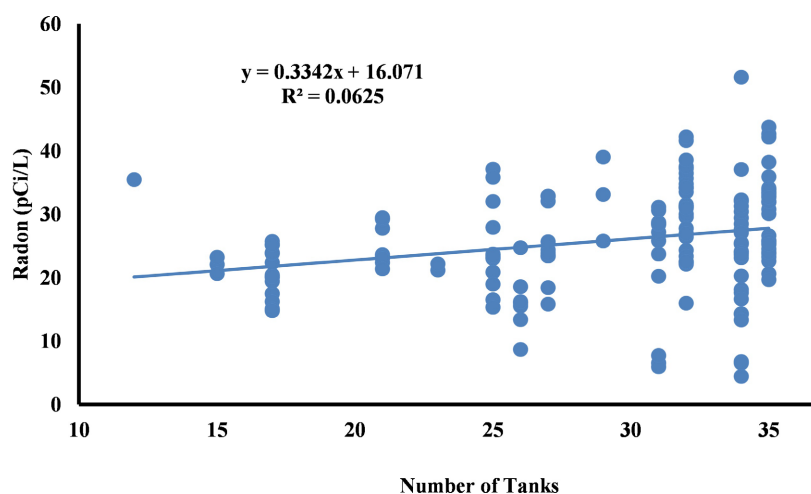


**Figure 7.** Mean radon readings (pCi/L) with the exhaust fan off and on in relation to the number of tanks in use (with flowing water) in the conference room at McNenny State Fish Hatchery.

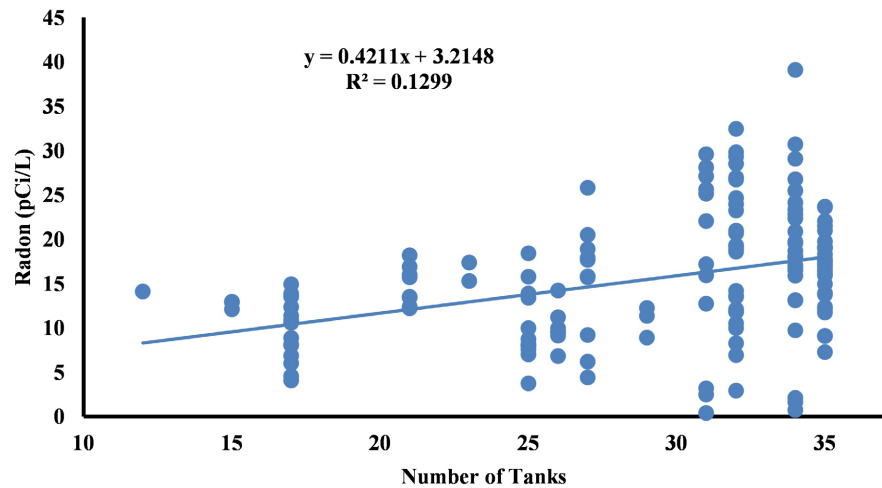


**Figure 8.** Mean radon readings (pCi/L) with the exhaust fan off and on in relation to the number of tanks in use (with flowing water) in the office at McNenny State Fish Hatchery.

Radon levels at McNenny State Fish Hatchery were lower than those reported at other fish hatcheries. Dywer and Orr [1] documented radon levels in hatchery rearing buildings at 200-to-250 pCi/l. A fish hatchery in the USA state of New York reported indoor levels as high as 600 pCi/L [2]. Gerber *et al.* [9] reported radon levels as high as 62 pCi/L at another hatchery in South Dakota. In contrast, three Pennsylvania fish hatcheries reported radon levels above 4 pCi/L [8]. Differences in hatchery building ventilation, building construction, aeration methods and locations, and uranium concentrations within the soil may all contribute to the differences in radon levels between fish hatcheries [28]-[30]. For example, Cleg-horn Springs hatchery aeration occurs in sealed columns in conjunction with oxygen injection, preventing any radon liberation [9]. This likely explains the higher readings at that hatchery compared to those observed with an open aeration column at McNenny Hatchery. In addition, McNenny Hatchery is located in an area with uranium-rich soil with variable, but typically high radon levels [31] [32]

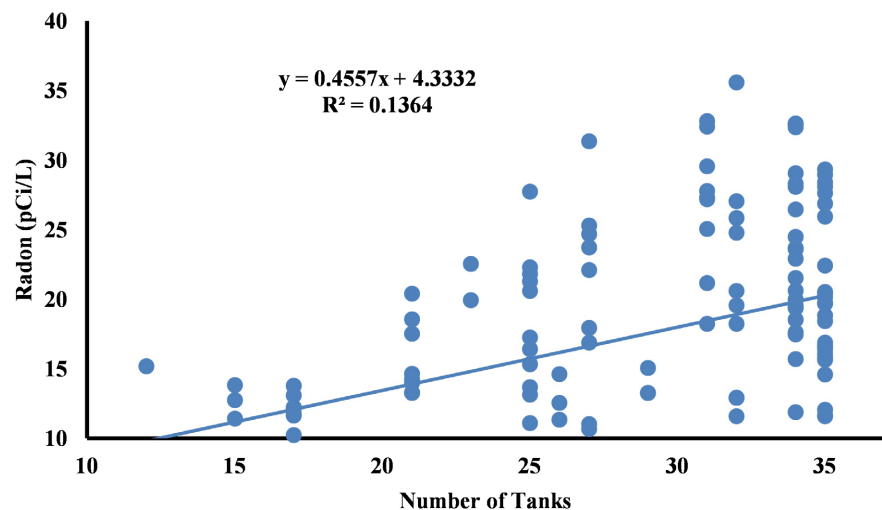


**Figure 9.** Radon readings (pCi/L) in relation to the number of tanks in use (with flowing water) in the tankroom at McNenny State Fish Hatchery.



**Figure 10.** Radon readings (pCi/L) in relation to the number of tanks in use (with flowing water) in the conference room at McNenny State Fish Hatchery.

Radon levels were significantly correlated with the number of tanks in use (with water flowing). This clearly indicates that the groundwater is the source of the radon and that radon gas liberation occurs via aeration [7] [9] [33]. The aeration tower for McNenny State Fish Hatchery is located outdoors, external to all hatchery buildings. Even though this initial aeration removes some radon, residual radon still remains so that when water is dispensed through the tank spray bars, further aeration occurs, and additional radon is liberated [7] [9] [34] [35]. Similarly, Lewis [8] observed large increases in indoor airborne radon levels with increased water flows in a hatchery rearing building.



**Figure 11.** Radon readings (pCi/L) in relation to the number of tanks in use (with flowing water) in the office at McNenny State Fish Hatchery.

The results of this study indicate that within the main hatchery building at McNenny State Fish Hatchery, the presence of ventilation and an exhaust fan

greatly decreases indoor radon levels and reduces the need for further mitigation. However, given the relatively high radon levels in the tankroom even after mitigation, hatchery staff should limit their time in the tankroom to only when necessary [1] [3] [4] [6] [10] [36]-[38].

## 5. Conclusion

This is the first study to examine radon levels at McNenny State Fish Hatchery and the second to be conducted in a fish hatchery in South Dakota, USA [9]. During fish production, radon gas levels in the tankroom, conference room and office at McNenny State Fish Hatchery were over the recommended maximum of 4 picocuries/liter (pCi/L) unless an exhaust fan in the tankroom was in operation. While staff currently spend limited time in the tankroom, should that change in the future, additional forced ventilation or other remediation strategies may be needed. Limiting staff exposure time in the tankroom and operating the exhaust fan in the main hatchery building at McNenny State Fish Hatchery are recommended.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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