1995_30

RADON MITIGATION OF GROUNDWATER AT A COMMERCIAL FISH HATCHERY

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ABSTRACT

Groundwater radon levels of 83 Bq/L (2240 pCi/L) generated indoor radon levels >3300 Bq/m^3 (89 pCi/L) at a commercial fish hatchery. Passive and active mitigation strategies to reduce the waterborne radon levels included a packed column, a waterfall through perforated grates, surface aeration, and bottom bubblers. Though waterborne concentrations were reduced up to 83% using a combination of mitigation procedures, a comparable reduction in indoor radon concentrations was not observed. Measurements by two continuous radon detectors agreed with those from grab flasks. A diurnal cycle showed that indoor radon levels peaked in early afternoon, probably as a result of warmer air being dissolved in the water during mitigation. Reduction of indoor radon levels below 148 Bq/m^3 (4 pCi/L) was achieved by direct air ventilation at high flow rates.

INTRODUCTION

Efforts to diminish the risk of cancer from inhalation of radon, a gaseous decay product of naturally-occurring radium (^{226}Ra), has focused primarily on reducing radon infiltration into homes from the surrounding soil. Radon is also present in all groundwater due to ^{226}Ra in adjacent rock and soil. While use of water containing high concentrations of dissolved radon may temporarily increase indoor radon levels in homes, facilities which utilize large quantities of groundwater indoors are subject to continuous elevated levels of indoor radon. One such operation occurs at the Catskill Fish Hatchery (CFH), where groundwater flows through indoor troughs containing developing fish. Previous mitigation of a fish hatchery was accomplished by venting air from hooded tanks (Harris and Craig 1991).

MATERIALS AND METHODS

The CFH, operated by the New York State Department of Environmental Conservation, provides brown trout for annual stream stocking. During hatchery operation (fall through spring), water flows through troughs in the CFH supplying oxygen as eggs are incubated and the fish grown to ~20 cm. Two wells provided groundwater containing 83-86 Bq/L (2240-2320 pCi/L) of radon to open pits outside the hatchery. These radon levels are typical for the area and agree with concentrations from the well supplying the manager's residence. Water, pumped into the bottom of a 1.8-m deep pit (3.6 m^3 water), overflows through a passive aerator into a larger pit (5.2 m^3 water) of 0.6-m depth. Well 3 (940 L/min), and occasionally well 4 (410 L/min), operated during sample collection. Four layers of perforated grates, expanding the entire pit width, have permanently replaced the original single packed column. The purpose of the passive aerator is to remove nitrogen and increase the oxygen content of the water. The passive systems operate continuously. Water from the pits is combined in a manhole and dispersed into up to 40 troughs inside the hatchery. During winter months windows are closed to conserve heat and employees occupy the trough room up to 8 h/day. During the summer water is diverted to outside pools. Testing was conducted during routine hatchery operation.

Active mitigation techniques included a commercial surface aerator in the deep pit and two bottom bubblers, assembled from 3.8-cm diam PVC to each pits' dimensions, submerged into the deep and shallow pits. Holes of 3-mm diam were drilled 2 cm apart along the bottom of the bubblers. Air flow through the bubblers was varied from 0.3 to 2.6 m^3/min.

Radon in water was measured using the EPA-recommended (Whittaker et al. 1987) methods of liquid scintillation (LS) counting or Lucas cell (LC) analysis. With LS, 10 mL of water was extracted using a plastic transfer pipet and injected beneath 10 mL of high-efficiency mineral oil. For LC analysis, radon was transferred from a 10-mL water aliquot by bubbling air into an evacuated scintillation cell. Pylon scintillation cells (PC) were used for field measurements using the same transfer protocol as LCs.

LC analyses were conducted using a 100-min count on a Randam SC-5 alpha-scintillation counter with cell backgrounds of 0.2 to 1.5 cpm, an absolute efficiency (ϵ) of 79% for radon and its alpha-emitting progeny. LS analyses involved 50-min counts on a Packard 1900CA LS spectrometer with a background of 3.7 counts per minute (cpm) and ϵ of 68% for radon and its four short-lived progeny. PC analyses were conducted using a Pylon AB-5 alpha-scintillation counter with an ϵ of 72%, typical counting times of 5 or 10 min, and cell backgrounds of 0.3 to 2.0 cpm. For all three analyses triplicate counting of each sample was typically conducted over one week to monitor radon's decay. Lower limits of detection under typical conditions and a 2-d decay are approximately 0.3, 0.6, and 1.1 Bq/L (8, 16, and 30 pCi/L) for LC, LS, and PC determinations, respectively.

Continuous indoor-air radon measurements were conducted using a Pylon passive radon detector (PRD) and a commercial radon monitor installed in the CFH trough room. Grab samples were collected in glass flasks and transferred to LCs for analysis. A fan capable of directly ventilating 260 m^3/min or ~5 ACH was installed in the trough room.

RESULTS AND DISCUSSION

Water

Waterborne radon levels in the deep pits averaged 83 Bq/L (2240 pCi/L), as the water was primarily from well 3. As show in Table 1, radon levels in water passed through the packed column decreased 34%, while the perforated grates achieved a 52% reduction. Both systems achieved approximately equal (58%) radon reduction in the trough water. A previous study (Harris and Craig 1991) reported a 60% reduction by a packed column.

Table 1. Groundwater radon concentrations (Bq/L; pCi/L in parentheses) at a commercial fish hatchery following various mitigations.

Mitigation Strategy	Deep Pit	Shallow Pit	Indoor Trough
Packed Column	83 (2240)	55 (1490)	36 (970)
Perforated Grates	83 (2240)	39 (1050)	34 (920)
Surface Aeration of Deep Pit	51 (1380)	26 (700)	24 (650)
Bubbling of Deep Pit (2.6 m^3/min)	48 (1300)	26 (700)	24 (650)
Bubbling of Shallow Pit (1.9 m^3/min)	83 (2240)	28 (760)	25 (670)
Aeration + Shallow Bubbler	51 (1380)	14 (380)	14 (380)

The surface aerator placed in the deep pit decreased radon levels 36%. The perforated grates reduced the radon an additional 31%, and levels had decreased 72% in trough samples relative to the wellhead. As with the passive-only system, the grates remove about half of the radon in the entering water.

The small bubbler was submerged into the deep pit and attached to a high-volume pump. Waterborne radon concentrations at several air flows are shown in Fig. 1. Though radon concentrations consistently decreased at increasing air flows, the reduction is not proportional. At 2600 L/min of air flow, radon levels decreased to 15 Bq/L (405 pCi/L), a 56% reduction in trough radon levels over the perforated grate system and a 82% reduction from wellhead levels. The bubbler removed slightly more waterborne radon than the surface aerator, though reductions became equivalent in the trough samples. As above, the grates remove about half of the radon remaining in the water.

The large bubbler was submerged in the shallow pit and attached to a medium-volume pump. At 960 L/min of air flow through the bubbler, radon concentrations in the troughs decreased 30% over the perforated grates. A 43% reduction was achieved with twice the air flow. The combination of the bubbler at 1.9 m^3/min air flow and the surface aerator reduced radon levels 58% greater than the perforated grates alone and 83% from the wellhead concentrations. While only 14 Bq/L (380 pCi/L) of waterborne radon remained following the combined mitigation (day 291), indoor radon levels decreased 30-50% (1200-1500 Bq/m^3; 32-41 pCi/L). Thus a proportional decrease in indoor concentrations was not observed.

<u>Air</u>

Airborne radon concentrations in the basements of the hatchery and manager's residence ranged from 140-185 Bq/m^3 (5 pCi/L), indicating that soil-gas is a minor contributor to levels observed in the trough room. Concentrations from grab samples taken on the hatchery's second floor ranged from 440-630 Bq/m^3 (12-17 pCi/L). Using only passive mitigation (day 290), daytime indoor concentrations exceeded 3300 Bq/m^3 (89 pCi/L). Figure 2 shows a comparison of radon concentrations determined by the PRD, the radon monitor, and grab flasks. In most cases the agreement is excellent considering the time lag inherent in the continuous measurements. The decrease during day 286 resulted from accidental starting of the direct-ventilation fan. Mitigation changes followed each radon monitor recording (diamonds in Fig. 2). These daily changes in mitigation hinder the observation of a strong diurnal cycle, which is somewhat evident on days 288-290 and 295-299. Continuous measurements for seven weeks (Fig. 3) shows that the daily cycle maximizes in concentration about 2^{pm}, though opened windows and fan ventilation sometimes suppressed the effect. The observed cycle is opposite that typically found for indoor radon levels in homes. This cycle maximizes indoor radon concentrations during working hours. As most parameters (e.g., groundwater temperature, flow rate, radon concentration) remained constant, we postulate that the increase in indoor radon during early afternoon results from warmer air (relative to nighttime) being bubbled through the water as a result of surface aeration and the perforated grates. As the water is nearly saturated with air, a small increase in water temperature will cause an increase in dissolved air evolving from the water. The increased emanation of air transports additional radon from the water. Measurements of water temperature were not made. The higher surface-to-volume ratio of the troughs, relative to the pit, enhances the emanation. In addition to explaining the diurnal cycle, we speculate that the emanation of air from the trough water increases as more air is bubbled through the water, increasing the dissolved air content of the water. Therefore, as more air is bubbled through the water to remove radon, more air is released from the water in the troughs, causing an increase in the radon released from the water into the room air. This would explain the disproportionate decrease in waterborne radon (83%) when compared with the decrease in indoor concentrations (30-50%).

All combinations of waterborne radon mitigations were insufficient to reduce indoor concentrations below the EPA-proposed maximum contaminant level. Beginning on day 292 the direct-ventilation fan was cycled through three flow rates. In combination with the surface aerator and shallow-pit bubbler, the fan reduced radon concentrations to 600, 400, and 200 Bq/m^3 (16, 11 and 5 pCi/L) at low, medium and high ventilation rates (days 292-295). With cessation of the active water mitigation, indoor radon levels increased and resumed a diurnal cycle. Levels to 200 Bq/m^3 (5.4 pCi/L) were achieved with high ventilation rates, with lower levels attained only by opening hatchery windows.

CONCLUSIONS

Passive and active mitigation strategies were applied to reduce the waterborne radon levels at a commercial fish hatchery. Equivalent radon reductions (58%) were achieved with a packed column and perforated grates. Surface aeration and bottom bubblers reduced levels by 71%. Though waterborne concentrations were reduced up to 85% using a combination of strategies, a comparable reduction in indoor concentrations was not observed. A diurnal cycle showed that indoor radon levels peaked in early afternoon as a result of warmer water temperatures. Reduction of indoor radon levels below 148 Bq/m^3 (4 pCi/L) could only be achieved by direct air ventilation at high flow rates.

ACKNOWLEDGEMENTS

Although the work described in this paper was partially funded by the U.S. Environmental Protection Agency as part of the State Indoor Radon Grants (SIRG) Program, the contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

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Figure 1. Radon concentrations in water mitigated using a bubbler in the deep pit and various air flows.

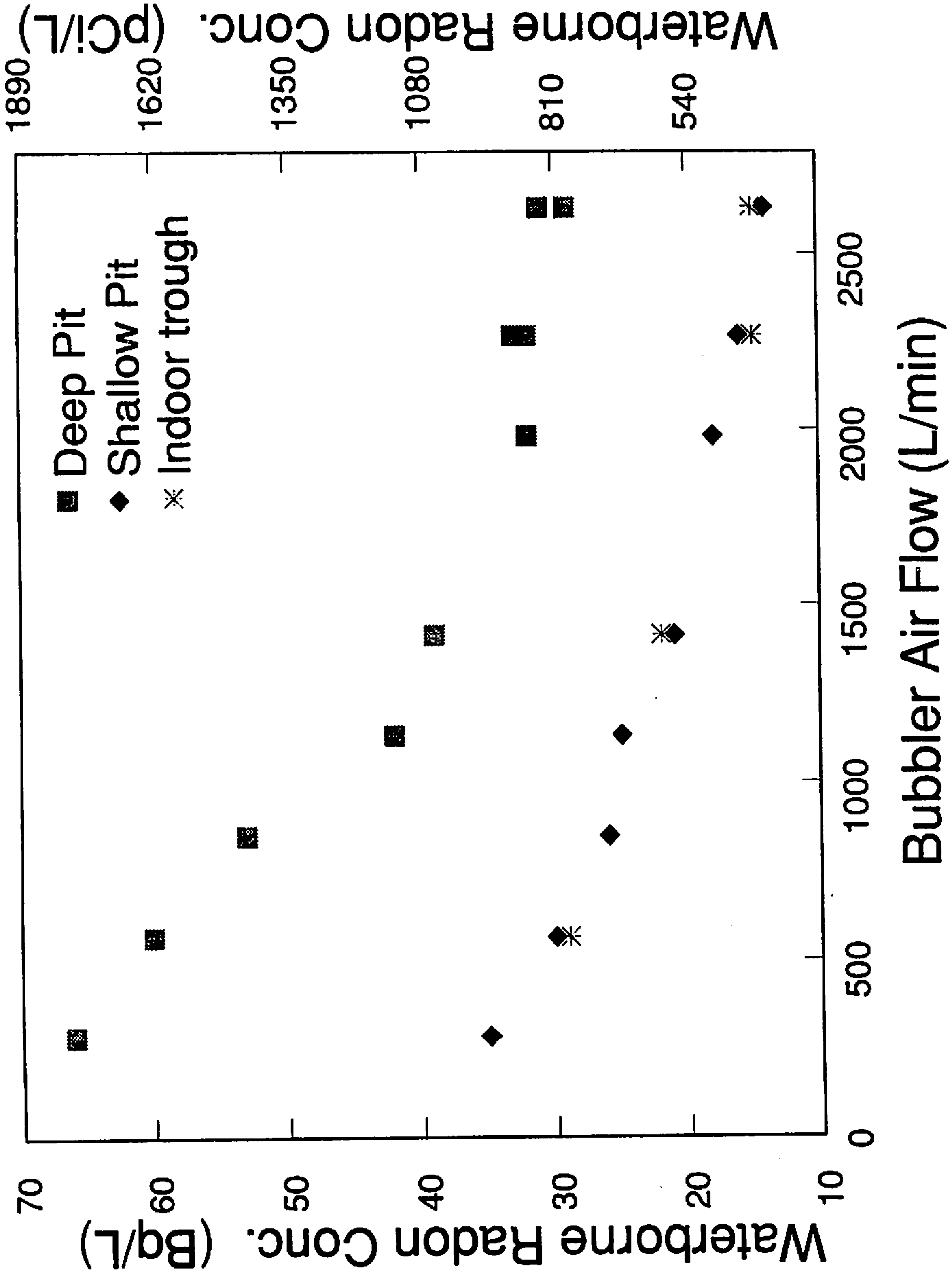

Figure 2. Comparison of radon concentrations determined during water and air mitigations.

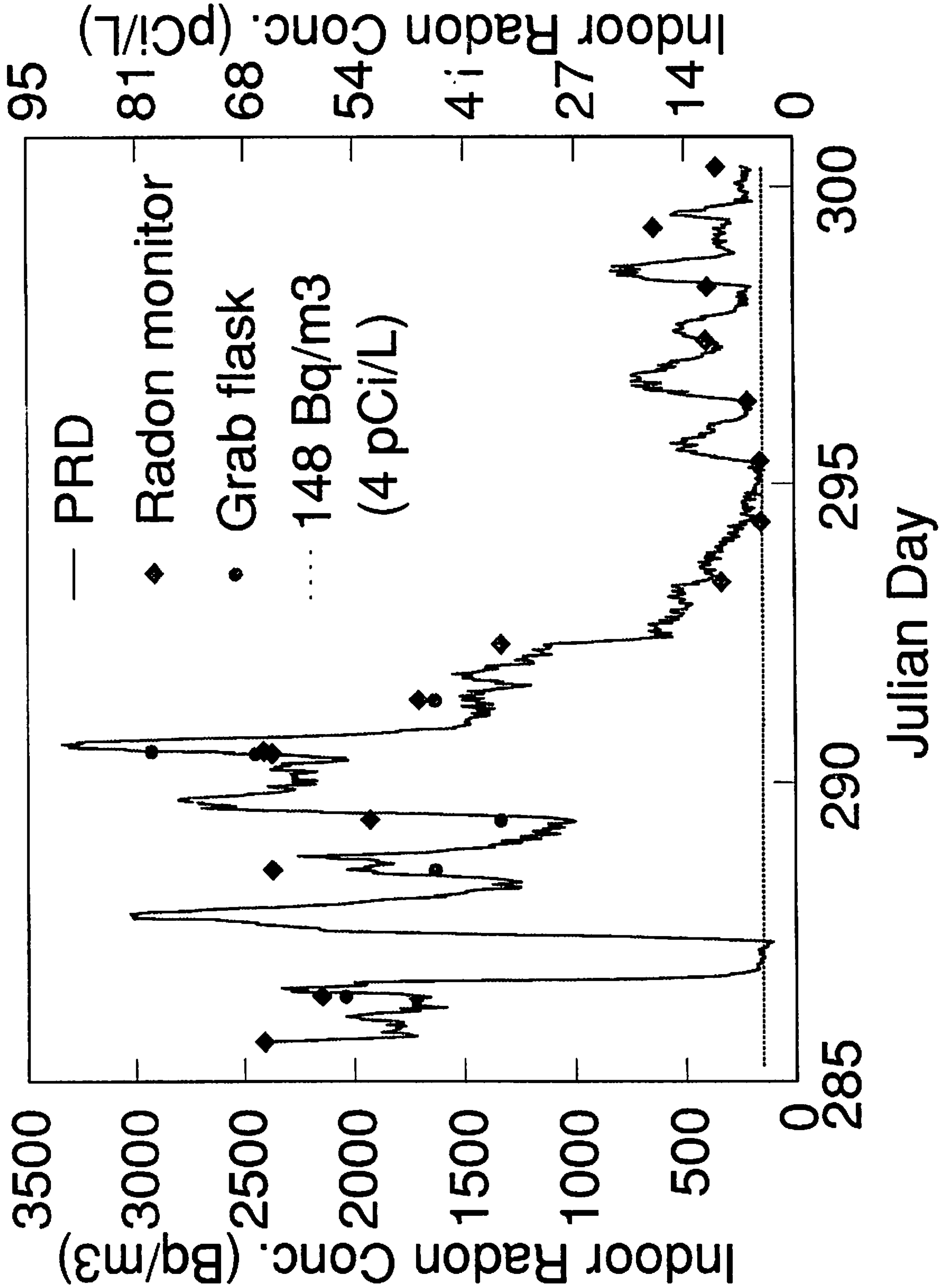

Figure 3. Continuous radon concentrations show that maximum concentrations occurred about 2pm.