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REMOVAL OF RADON FROM RESIDENTIAL WATER SUPPLIES BY A UNIQUE AERATION METHOD

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ABSTRACT

North East Environmental Products, Inc. has conducted extensive field research into the treatment of residential water supplies using aeration techniques. The paper describes the results of our research conducted in New Hampshire. The paper includes the basic design of the aeration process used in the research, a discussion of the parameters studied, and a summary of the critical performance results. As with other aeration applications, iron, manganese and calcium can cause fouling. A discussion of these operational considerations will be presented along with methods for turning these problems into beneficial treatment opportunities. An approximate cost comparison of the available treatment alternatives is also given.

Application of this technology to radon removal from small community water supplies is also viable. Appropriate design parameters are presented.

Radioactive radon gas has received a great deal of public attention in the last couple of years. Numerous articles in the popular and scientific press and television documentaries have attempted to make the public aware of the health risks posed by high radon levels in homes. Only recently has much attention been focused in the press on water supplies as a possible source of radon contamination. While it is very important to educate people to the potential dangers of radon in water supplies, the next logical step has been generally missing. That is, very little has been written concerning what to do about the problem once it has been identified. This article will describe what treatment alternatives are available for radon in residential water supplies and presents a case study of a residential water supply that has been successfully treated.

THE PROBLEM

Radon is a colorless, odorless gas that is created by the natural radioactive decay of uranium. Uranium and all other radioactive elements decay because they are not energetically stable. They release various particles (alpha and beta) and forms of energy (gamma rays) in the process of slowly coming to a stable form of matter. The decay sequence of uranium is quite complex, however, one of the decay products, called a daughter product, of uranium is radium. It is radium that decays into radon. Radon is the only gas in the decay series of radium, all of the other daughters are solids. It is the fact that radon is a mobile gas, that can move through fractures in the rock, through the pore spacers in the soil and dissolve in ground water, that allows it to come into contact with humans.

According to health experts, it is the alpha particles that cause the most severe health threat. Alpha particles are relatively large and will only travel a short distance before striking other matter and giving up their high energy. Alpha particles will only travel a few centimeters in air and only, at most, a few millimeters in the human body. Therefore, when a person inhales air containing a high concentration of radon, the most likely organ to be affected by the alpha particles is the lungs. In addition, three of the decay products of radon are also alpha emitters. Polonium-218, lead-214, bismuth-214 and polonium-214 are all daughters of radon. When radon decays, these elements are formed one after another. Since these elements are solids they attach themselves to dust particles in the air and are carried into the lungs with each breath of air where they decay and give off harmful alpha particles.

Ingestion of water containing radon is much less of a problem than inhalation. Because alpha particles cannot even pass through a piece of paper, it is very unlikely that when radon, or one of its daughters, decays while located in the stomach or intestine, the alpha particle will travel to and strike the lining of the digestive tract. It will more likely be absorbed by the fluids in the digestive tract and dissipate its energy harmlessly. Of course, at extremely high radon concentrations the risk of ingestion damage may become significant.

It has been estimated that of the approximately 120,000 lung cancer deaths each year between 5,000 and 20,000 of those cancers were caused by radon gas exposure. This is the second leading cause of lung cancer. The leading cause is, of course, cigarette smoking. Of the lung cancers caused by radon, the EPA Office of Drinking Water has stated that between 100 and 1,500 of these cases can be attributed to radon entering homes through their water supplies (1). This range of cancer deaths is greater than the cancer risk from all the other water supply contaminants combined (2). Radon contamination of water supplies is certainly a large and serious problem.

HOW DOES RADON GET INTO THE HOME

Because radon is a natural decay product of uranium, it is found in areas that have deposits of uranium. Although uranium deposits of high enough concentration to justify mining are quite rare, lower level concentrations of uranium are very common. Two of the most common geologic formations that frequently contain uranium are granite bedrock and phosphate deposits. Granite bedrock is very common throughout the United States and the world, so the occurance of radon is a rather common world-wide problem. As of this writing, the EPA is expected to promulgate a radon in water standard by the end of September. All indications are that the Maximum Contaminant Level (MCL) standard will be set at some level lower than 1000 pc/l. At this level, based on there being approximately 10 million private bedrock wells in this country and about 10% of them have radon levels over 1000 pc/l, there are about 1 million radon contaminated wells (3).

This standard will be established for public drinking water supplies only since the EPA and other federal agencies do not have clear mandates to regulate environmental matters in private homes. However, it is obvious that if a standard is set for public water supplies it is prudent for individual home owners to follow the same standards for their own protection. It is also possible that state Public Health Departments may, once a federal standard is set, establish their own water supply standards similar to those for bacterial contamination of private wells.

Radon can enter a home along with the water from a bedrock well. Because radon is a volatile gas, it is quite easily removed from the water when it is used for typical household activities such as bathing and washing dishes. Some estimates based on assumptions about water use patterns and house construction details predict that each 10,000 pc/l concentration of radon in the water supply will translate into an indoor air concentration of 1 pc/l (4). EPA studies have apparently confirmed that this approximation is reasonably accurate for an "average home". If a house has a relatively low air exchange rate, this concentration will be higher.

AVAILABLE TREATMENT ALTERNATIVES

Water supplies can be treated through the use of aeration or carbon adsorption techniques. Aeration techniques simply allow the radon to volatilize from the water and exhaust it outdoors where it can disperse harmlessly. Adsorption methods collect the radon on activiated carbon and allow it to decay in place.

Aeration devices are relatively simple in that through various methods they contact the water with enough air to evaporate the radon. The treated water then can be pumped into the home water system.

There are basically four types of aeration processes that can be used for residential water treatment; spray aeration, packed columns, diffused aeration and a new process called horizontally extended shallow aeration.

In spray aeration, shown in Figure 1, untreated water from the well is sprayed into a tank through a fine mist spray nozzle. The spray nozzle

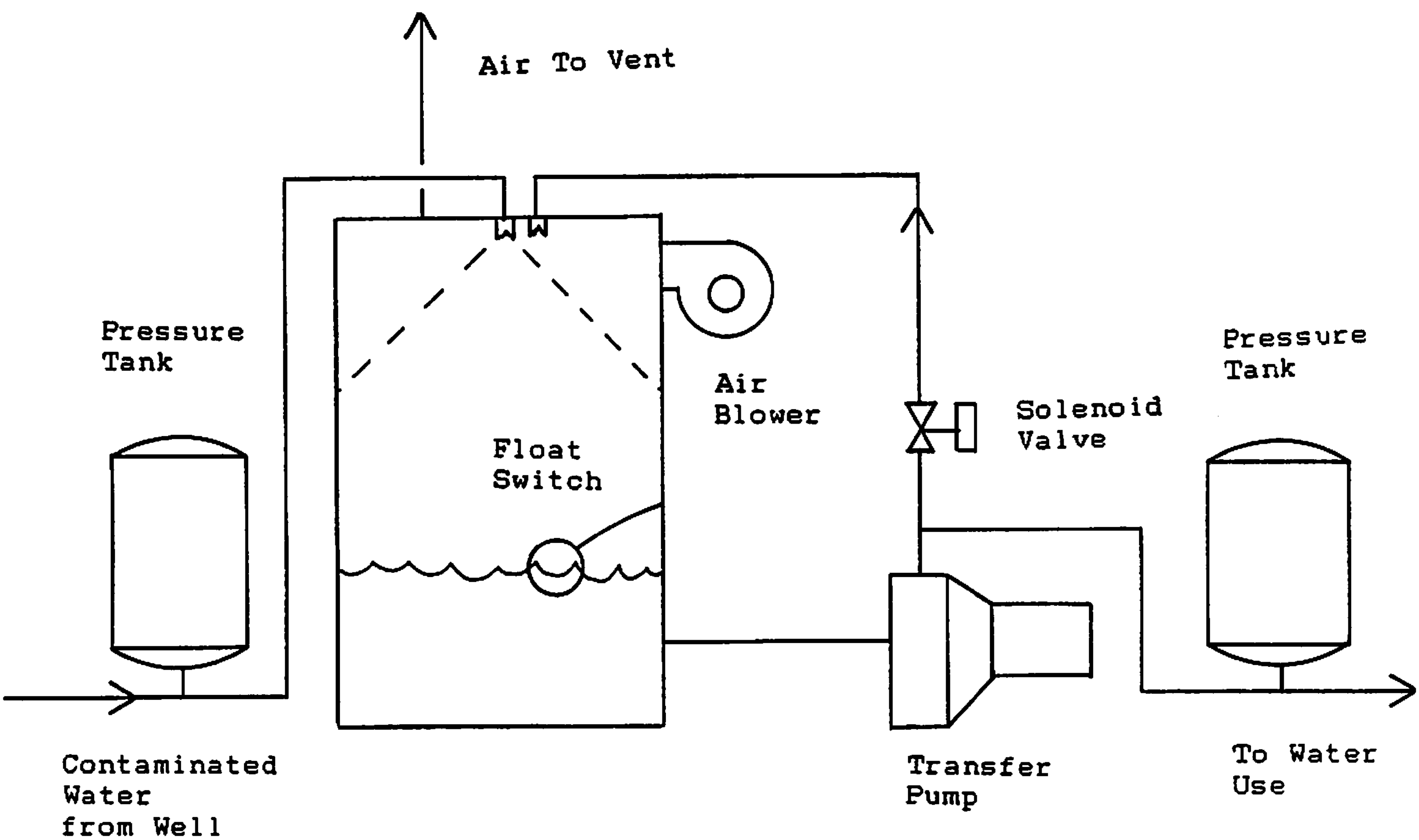

Figure 1. Spray Aeration

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. In order to achieve higher removal efficiencies, the water must be resprayed and retreated several times. Essentially any treatment efficiency desired can be achieved with this system. The disadvantage of this process is that the water must be repumped several times (four to five times usually), and that in order to have a ready supply of treated water the holding tank must be quite large (about 100 gallons). Equipment using this process is available under the trade name No-Rad (patented).

Packed columns have been extensively used for removing volatile organic chemicals from contaminated ground water supplies. These systems can be scaled down for use in a residential setting for removal of very volatile radon gas. Figure 2 shows a residential scale system in which the well water is sprayed into the top of a small air stripping column (available under the trade name Clearadon, patent pending). The column is filled with about five feet of a common inert dumped 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 air 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 principle limiting factor in packed column aeration of radon is the height available for the air stripping column. Maximum practical packing depth in most residential setting is six feet which produces a removal efficiency of about 95%. For relatively low levels of radon contamination (i.e. up to 20,000 pc/l), this is entirely adequate. Above this level the packed column system becomes impractical; that is, at a radon MCL of 1000 pc/l.

A third aeration method is diffused aeration. Figure 3 shows this type of process. One supplier manufactures this product (patented) under the trade name of The Stripper. The contaminated well water is sprayed into the first of two or more aeration tanks. Air is forced into the bottom of these holding tanks through the fine bubble diffusers located at the bottom of each tank by a relatively high pressure air blower. As the air bubbles rise up 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 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 (make the tank bigger), by increasing the number of bubbles (increase the air flow rate and the size of the diffuser), or by baffling the tank so that it performs like a plug flow reactor rather than like a completely mixed reactor. The disadvantages of this system are that a relatively high pressure air blower is required (25 to 35 inches of water column) and that the air holes in the diffuser may foul up easily because they are very small, about 0.025 inches.

Figure 4 shows the fourth type of aeration device, the CLEARADON II radon

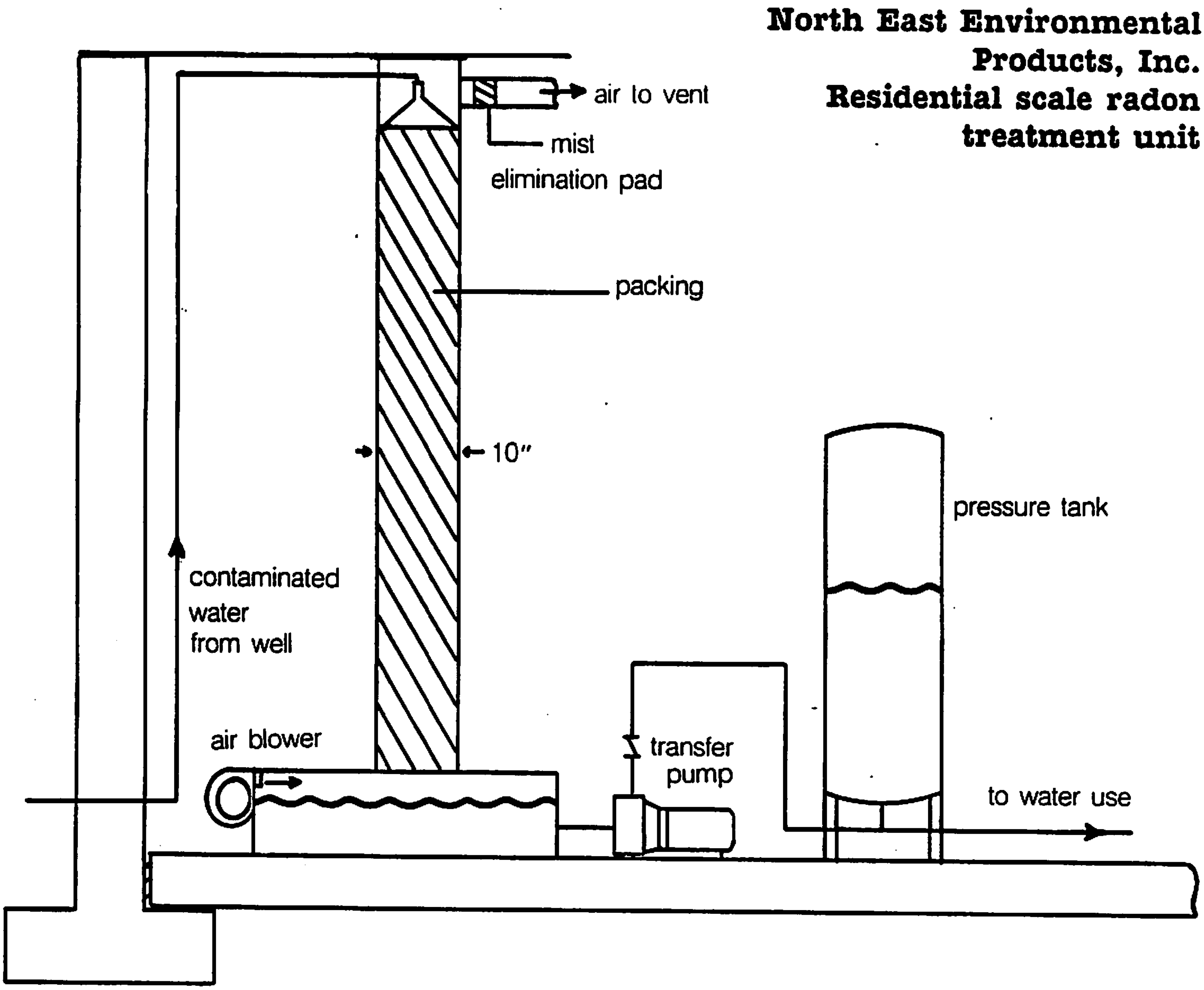

Figure 2. Air Stripper

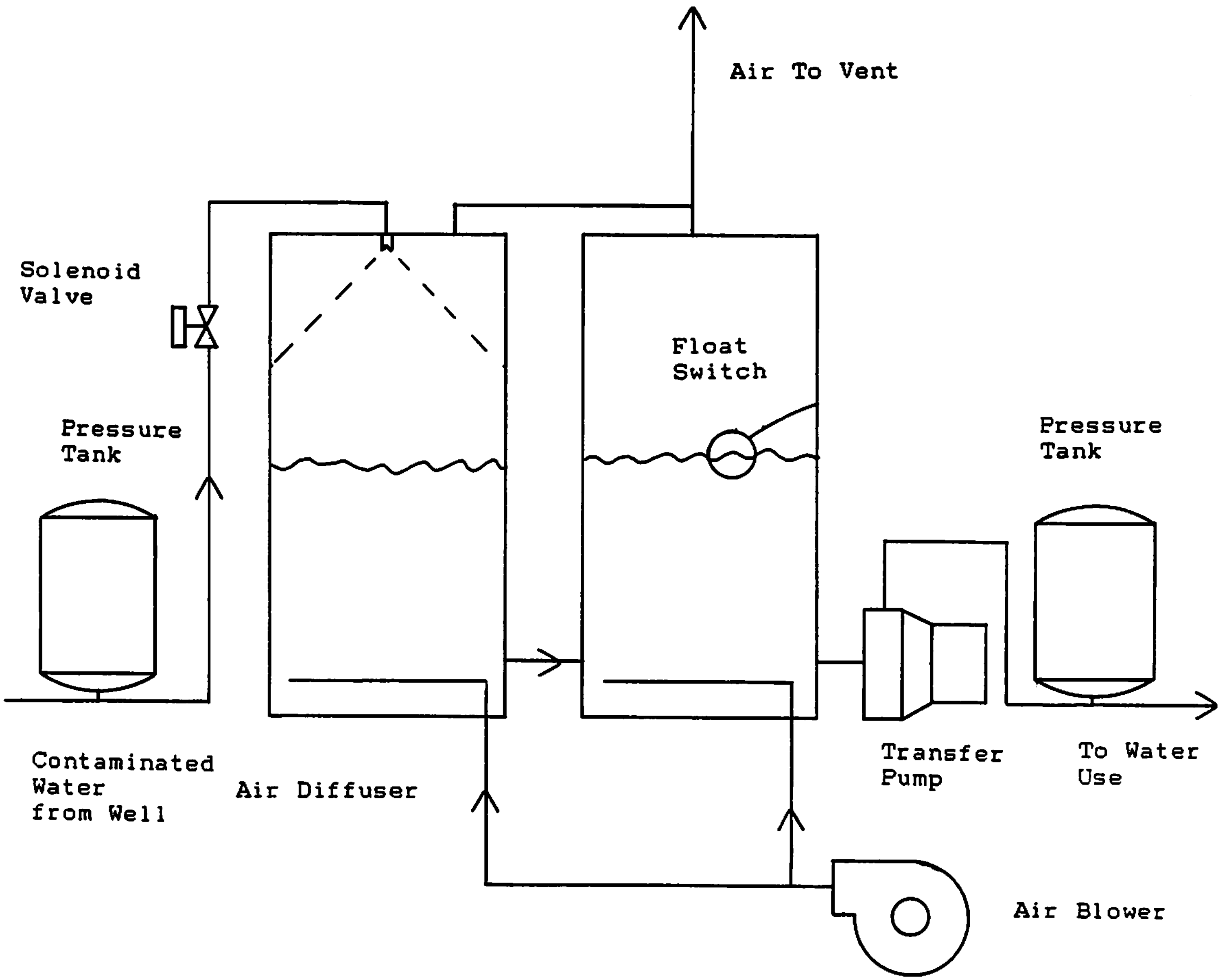

Figure 3. Diffused Aeration

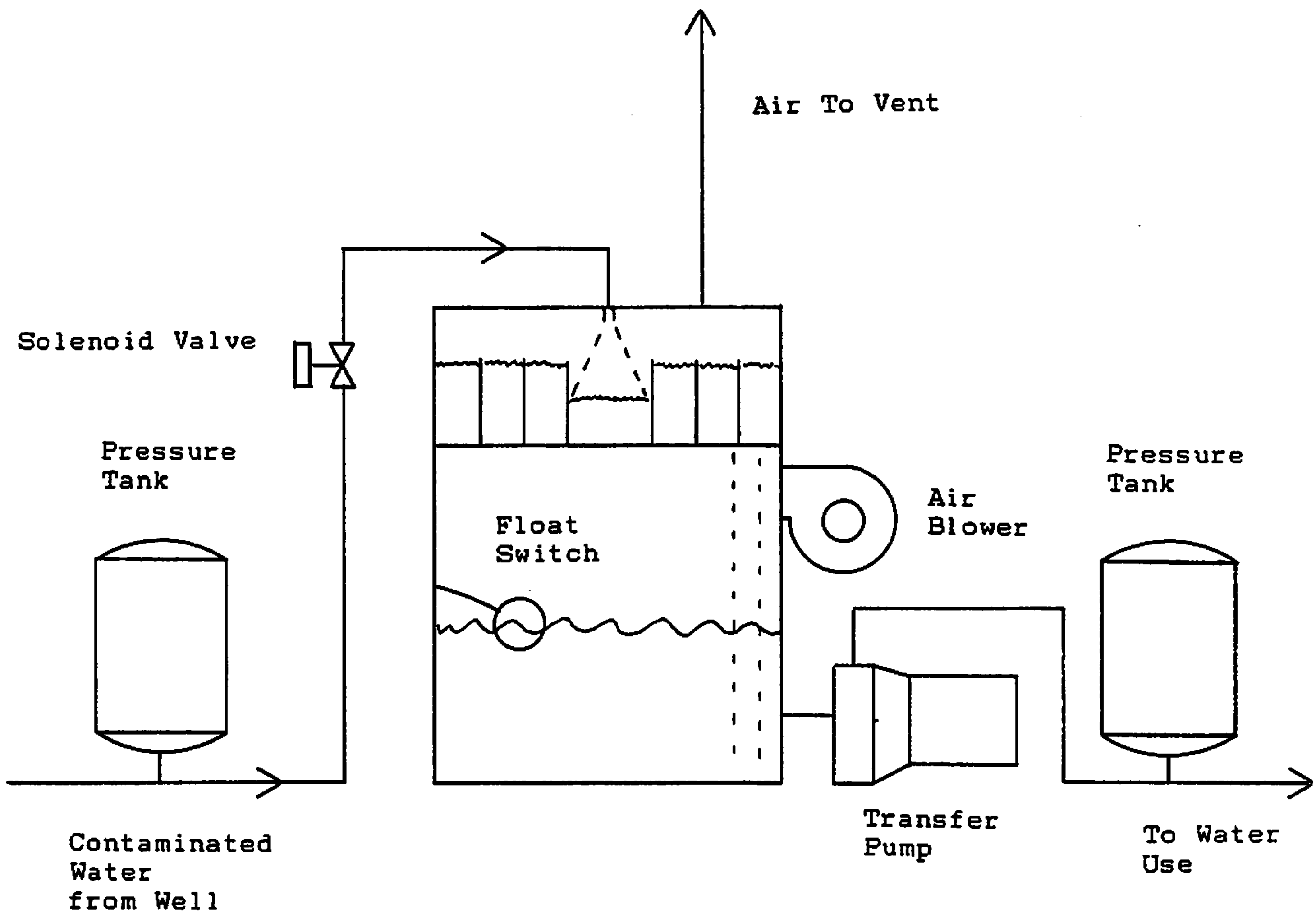

Figure 4. Horizontally Extended Shallow Aeration

removal system (patent pending), which uses a horizontally extended shallow aeration tray design to contact the water and air. Water from the drilled well is piped to the aeration unit where it is sprayed into the aeration tray. The water flows across the tray between the 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 for volatilization of the radon from the water. The air evaporates up to 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 and requires very little maintenance. The shallow aeration system has three principal advantages over the other systems. First, the aeration tray is smaller than 2 feet in diameter and only 10 inches high. The complete system can, therefore, be smaller and shorter than the other designs. Second, the air pressure required for operation is only 3 to 4 inches of water column so a much less expensive type of blower can be used. And third, 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. The main disadvantage of this system is that is uses approximately 100 cfm of air whereas the previous systems use between 10 and 50 cfm. In some homes an outside air source may be necessary to prevent basement depressuriztion.

In general, aeration devices have several advantages and beneficial side effects. Aeration devices do not accumulate radioactive elements and, therefore, do not present a radiation exposure problem and they do need to be licensed as low level radiation sources. Aeration devices can also remove hydrogen sulfide from the water and can assist in the removal of iron and manganese. With the addition of a filter following the aeration device, the system could be expected to remove radon, hydrogen sulfide, iron and manganese from most water supplies. Aeration devices can also be used to remove volatile organic chemicals such as gasoline components from water supplies.

Adsorption devices remove radon by adsorbing the radon onto the surface of a specially prepared "activated carbon". Once adsorbed onto the carbon the radon continues to decay and give off radiation. However, the equipment is usually not located in the immediate living area of the home. After two to three weeks, the amount of radon being adsorbed on the carbon equals the decay rate of the radon already adsorbed, and the system reaches a steady state. The radiation given off by the unit, therefore, levels off at some point dependent on the radon level in the ground water.

The advantage of this type of system is that it has very few moving parts and should have quite a long, useful life. The disadvantages are the radioactive build-up on the carbon, which may or may not be a problem depending on the specific situation, and the possibility of fouling of the carbon bed. Contaminants in the water such as iron, manganese, and calcium will be filtered out by the carbon and will eventually plug it. The systems can be cleaned by back washing but this is not 100% effective.

PRODUCT DEVELOPMENT/CASE HISTORY

In the spring of this year, it became obvious that the EPA was very likely going to promulgate a radon in water standard of less than 1000 pc/l. In response to this major change (prior to this spring, it was generally believed that the standard would be established at approximately 10,000 pc/l), my company began work to invent a new aeration process that would meet the following objectives:

1. Achieve greater than 99% removal efficiency.
2. Be small enough to eliminate space restriction problems.
3. Avoid fouling problems.
4. Not require a high pressure blower (less than 10 inch wc).
5. Be as simple as possible to minimize both cost and mechanical problems.
6. Not infringe on existing patented processes.

The system developed was described previously as the horizontally extended shallow aeration system. This process accomplishes in a horizontal space the same removal efficiencies that are obtained in a 10 to 12 foot tall packed or sieve tray type air stripping column. As shown in Figure 4, untreated water is sprayed into the center of a shallow baffled sieve tray. It then flows in a spiral pattern between the baffles to a downcomer at the outside of the sieve tray.

As the water is flowing through the sieve tray, air is blown up through the 3/16 inch diameter holes. The air emanating from the holes forms a froth of large air bubbles to a depth of five to six inches. This froth provides the mass transfer area for the radon to volatilize from the water into the air. The purpose of the baffles is to prevent mixing of the water on the sieve tray. The baffles are only spaced about 3 inches apart and are more than 6 inches high. Since the water flow rate along the baffled channels is approximately 8 feet per minute (at a water flow rate of 6 gpm), there is very little chance of treated water near the downcomer mixing upstream with the highly contaminated water entering the tray. This arrangement is comparable to a large number of small completely mixed reactors operating in series.

An initial prototype system was constructed and set up at a private residence in New Hampshire which had a water flow rate of 4.5 gpm. Test results were as follows:

TABLE 1. INITIAL PROTOTYPE TEST RESULTS

Untreated Water Radon conc. pc/l	Treated Water Radon conc. pc/l	% Removal	Air Flow Rate*
106,046	20,040	99.8	High
119,369	2506	98.0	Medium
164,244	20,040	87.8	Low

* A defective instrument prevented accurate measurement of air flow rate.

Based on the preliminary results obtained, a more complete prototype system was fabricated and was operated at two private residences served by drilled wells. Both wells were approximately 400 feet deep and yielded continuous water flow rates of 6 gallons per minute. The first site (Site A) had an average radon concentration of 600,000 pc/l while the second site (Site B) had an average radon concentration of 120,000 pc/l. Test results are as follows:

TABLE 2. PROTOTYPE TEST RESULTS

Site A

Test Number	1	2	3	4	5
Tray Size, in.	24 x 24	24 x 24	24 x 24	24 x 24	24 x 24
No. of holes in tray	280	280	380	480	480
Weir height, in.	none	none	none	none	none
Spray Nozzle Mist Type	coarse	coarse	coarse	coarse	none
Water flow rate, gpm	6	6	6	6	6
Air flow rate, cfm	61	47	50.7	105	135
Inlet Radon Conc. pc/l	587,712	613,081	569,727	595,477	628,581
Outlet Radon Conc. pc/l	1,782	3,196	1391	2023	10,104
% reduction	99.70	99.48	99.76	99.66	98.39

Site B

Test Number	6	7	8	9	10
Tray Size, in.	16 x 24	16 x 24	16 x 24	16 x 24	16 x 24
No. of holes in tray	325	325	325	325	325
Weir height, in.	none	none	2	2	0.785
Water flow rate, gpm	6	6	5	5	6
Air flow rate, cfm	90*	110*	90*	110*	110*
Inlet Radon Conc. pc/l	120,000	130,000	108,900	132,127	150,000
Outlet Radon Conc. pc/l	3,800	3,900	465	381	3,200
% reduction	96.83	97.00	99.57	99.71	97.87

Test Number	11
Tray Size, in.	24 x 24
No. of holes in tray	420
Weir height, in.	1.5
Water flow rate, gpm	6
Air flow rate, cfm	110*
Inlet Radon Conc. pc/l	120,000
Outlet Radon Conc. pc/l	320
% reduction	99.73

* Approximate air flow rate.

These test results showed that the principal factor effecting the removal of radon from water is the amount of surface area generated for mass transfer. The principal variable, of course, is the air flow rate. A certain minimum volumn of air must be blown through the water as it flows across the aeration tray in order to cause the water to become a violently agitated froth. This minimum air volumn is dependent on six dependent and independent variables including water depth on the aeration tray, water flow rate, weir height, weir length, length of flow path and width of flow path. In the arrangements tested, an air to water ratio of from 60 to 160 cu ft/cu ft was necessary to achieve removal efficiencies above 99.5%. Work is continuing on optimization of these variables. The intent is to minimize both the air flow rate and the equipment size while maintaining the efficiency of the system over a broad range of possible operating conditions.

Water depth on the aeration tray is principally controlled by the height of the weir placed at the outlet end of the aeration tray. Our experiments confirmed information contained in standard distillation texts that a minimum water depth on the aeration tray of two inches is required for good froth generation. When the water depth is less than two inches, the maximum froth depth obtainable at any air flow rate is about 4 inches. At a water depth of two inches, 6 inches of froth was easily generated. A deeper froth and, therefore, more mass transfer surface area can be generated by making the water depth greater. This is done, however, at the expense of a higher pressure drop requirement on the blower.

It is very desirable to maintain the total system pressure drop at less than 4 inches of water column. There are very few applications for blowers that have capacities of about 100 cfm and more than 3 inches of water column pressure. Therefore, in order to maintain the objective of developing an operational system at the lowest possible selling cost it is necessary to design the system for less than 4 inches of water column pressure drop. Higher pressure blowers could be designed but they would be relatively expensive.

SMALL COMMUNITY WATER SYSTEMS

For small community water systems, the horizontally extended shallow aeration (HESA) systems may offer significant advantages over the packed tower designs currently envisioned. Principally, the HESA systems can in all cases be less than three feet tall. This eliminates the need for a large, tall stack extending above the treatment building. It also eliminates any concerns about freezing problems in northern climates. A HESA system for a small community system would follow the same design parameters as the residential scale systems, i.e. an air to water ratio in the range from 60/1 up to 110/1, a liquid depth on the aeration tray of 2 to 3 inches, and water linear velocity of 8 feet per minute.

SUMMARY

Research has been conducted to develop an aeration system that meets the very stringent radon water standard expected to be promulgated soon by the EPA. The basic research on this system has been completed, and the fundamental design parameters have been identified and quantified. Product development work based on this research is essentially complete, and a consumer product is expected to be available to meet the need that will be generated by the expected EPA standard.

REFERENCES

1. Deland, M.R. Indoor Radon: A New England Perspective. Environmental Education Report & Newsletter, Vol. 15, no. 2, pp. 8-10.

2. Cothern, C.R. Development of Regulations for Radionuclides in Drinking Water. Keynote address, NWWA Conference, Radon, Radium and Other Radioactivity in Ground Water: Hydrogeologic Impact and Application to Indoor Airborne Contamination. April 7-9, 1987.

3. Logtin, J.P. Occurance of Radon, Radium and Uranium in Ground Water. Jour. AWWA, July, 1988.

4. Radon Reduction Techniques for Detached Houses: Technical Guidance. EPA/625/5-86/019. U.S. Environmental Protection Agency, Office of Research and Development. June, 1986.