J. Int. Environmental Application & Science, Vol. 3 (3): 142-146 (2008)

Comparison of natural radioactivity removal methods for drinking water supplies: A review*

E. Esmeray, M. E. Aydin

Selcuk University Environmental Engineering Department, Konya–Turkey
e-mail: eesmeray@selcuk.edu.tr

Received March 10, 2008; Accepted April 14, 2008

Abstract: In this study, natural radioactivity removal methods have been compared for present drinking water supplies (privately owned wells or small water works) which have radioactivity values higher than determined standards (WHO & EPA standards). There are several methods known to remove radioactivity from water such as aeration to remove "Rn^{222}", adsorption by granular activated carbon (GAC) to remove "Uranium", ion exchange methods (IX) to remove "Ra^{266} and Ra^{288}", reverse osmosis (RO) to remove "Gross alpha and Gross Beta, Uranium" and various adsorption methods to remove other radionuclides. Main factor of preferring a removal method depends on radioactive material's physical and chemical features. However, the methods have to be tested for different types of water qualities. In this aspect method's designation, setup, cost, advantage/disadvantage, yield ratio, waste, equipment, source water quality has been considered.

Keywords: Natural radioactivity, Removal methods, Drinking water, GAC, RO, IX

Introduction

The activity concentrations of natural radioactivity in groundwater are connected to the activity concentrations of uranium (^{238}U and ^{235}U) and thorium(^{232}T) and their decay products in the ground and bedrock. This is due to groundwater reacting with ground and bedrock and releasing quantities of dissolved components that depend on mineralogical and geochemical composition of the soil and rock, chemical composition of the water, the degree of weathering of the rock, redox conditions and residence time of groundwater in the soil and bedrock (Vesterbacka, 2007).

Radiation of natural origin at the Earth's surface consists of two components namely cosmic rays and radiation from the radioactive nuclides in the earth's crust. The latter component, the terrestrial radiation, mainly originates from the so-called primordial radioactive nuclides that were made in the early stage of the formation of the solar system. Uranium, thorium and potassium are, however, the main elements contributing to natural terrestrial radioactivity (UNSCEAR, 1993).

All nuclear reactions are not spontaneous. Some reactions occur when stable isotopes are bombarded with particles such as neutrons. This method of inducing a nuclear reaction to proceed is termed artificial radioactivity. Since about 1940, a set of new elements with atomic numbers over 92 (the atomic number of the heaviest naturally occurring element, Uranium) have been artificially made. They are called the transuranium elements. Natural and artificial radioactivity rate in the earth is given in Figure1.

In several European countries, the ground water may contain high amounts of natural radionuclides, derived mainly from the ^{238}U-series. Elevated levels of natural radionuclides in ground waters are mainly associated with uranium and thorium bearing soil and rock minerals, or with uranium, thorium and radium deposits. Countrywide surveys of natural radioactivity in drinking water have been conducted in several European countries. The surveys made in the Nordic countries especially indicate that high concentrations of radon and other radionuclides

Presented at the VIth International Conference of Modern Management of Mine Producing, Geology and Environmental Protection, (SGEM 2007),Albena-Varna, Bulgaria, 11 –15 June 2007

usually occur in water extracted from wells, which have been drilled in bedrock. In surface waters the concentrations are usually low as in ground waters occurring in soil deposits. In most European countries ground water is widely used as a raw water source for water works. There is also an increasing tendency to replace surface water with ground water. However, this involves an increased risk of natural radionuclides in water. (IDS-WATER, 2007)

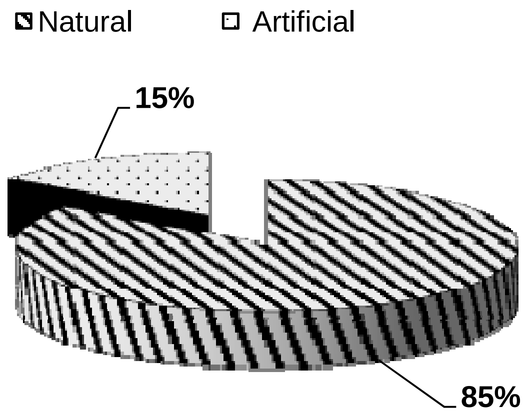

Fig 1. Natural and artificial radioactivity rate in the earth

Removal methods of natural radioactivity

High levels of natural radionuclides in drinking water are accompanied with potential health risks for the population by increasing the radiation dose. Therefore, water should be purified before using it. Various processes based on different principles can be applied to remove the radioactivity from water.

Some of them are aeration, the granular activated carbon (GAC) filtration, Ion exchangers (IX), Reverse Osmosis (RO) or the nanofiltration (NF). In addition that some equipment originally designed for removing iron (Fe) and manganese (Mn) are capable of removing also natural radionuclides. Aeration is a method that is usually applied to remove radon (^{222}Rn) from drinking water. Aeration must be used if the concentration of radon is high, however the granular activated carbon (GAC) filtration can be used when the radon concentration of water is moderately low. Different natural radionuclides can also be removed using various types of adsorptive filters. If our drinking water supplies are contains uranium (^{238}U, ^{234}U) and radium (^{226}Ra), ion exchangers should be used. Ion exchangers can also used to remove lead (^{210}Pb) and polonium (^{210}Po) but these needs to be studied in more detail. Membrane techniques are capable of removing uranium, ^{226}Ra, ^{210}Pb and ^{210}Po concurrently.

These techniques are Reverse Osmosis (RO) or the nanofiltration (NF). The removal of uranium, ^{226}Ra, ^{210}Pb and ^{210}Po from drinking water depends on their speciation. In order to find effective removal methods for these nuclides the knowledge on their speciation in ground water should be known. When selecting methods for removal of ^{210}Pb and ^{210}Po from ground waters it must be taken into consideration that these radionuclides exist mainly bound in particles in water. Installing a new treatment technology requires an investment of both time and money. There are several alternative compliance options that may be more appropriate for some systems. Each option has its own considerations that should be weighed against a system's particular circumstances. Some natural radionuclides, their removal methods and removal efficiency are given below (Tables 1-7).

Table 1. Radon removal techniques and efficiency (EPA, 2006)

Removal Techniques	Efficiency
Aeration (BAT) (example tech. given below)	70-99 %
Packed Tower	90-99 %
Diffused buble	70-99 %
Tray	80-90 %
Spray	80-90 %
Mechanical Surface	>90 %
GAC (POU-POE) Very Small Systems	80 - 99 %
➢ High EBCT requirements	
➢ Potential radiation exposure problem	
➢ Potential waste disposal problems	

*BAT: Best available treatment technology, EBCT: Empty-bed contact time, POU: Point of use, POE: Point of entry

Table 2. Radium removal techniques and efficiency (EPA, 2006)

Removal Techniques	Efficiency
Coagulation/Filtration (Selectivity sequence given below)	65 - 95 %
$Ra^{+2} > Ba^{+2} > Ca^{+2} > Mg^{+2} > Na^{+2} > H^{+2}$	
Lime softening	80 - 95 %
Membrane processes	90 - 99 %
Selective Complexers	97 + %

Table 3. Uranium removal techniques and efficiency (EPA, 2006)

Removal Techniques	Efficiency
Coagulation/Filtration	80 - 95 %
Lime softening	85 - 99 %
Anion Exchange	90 - 99 %
Activated Alumina	90 - 99 %
Membrane processes	90 - 99 %

Table 4. Gross alpha, beta particle & photon emitters removal techniques (EPA, 2006)

Natural Radionuclides	Removal Techniques
Gross alpha	Reverse osmosis (RO)
Beta particle & Photon Emitters	Ion Exchange (IX), Reverse osmosis (RO)

Table 5. Summary of Natural radionuclides' removal techniques

Natural Radionuclides	Removal Techniques
Radium-226 Radium-228	Cation exchange, lime softening, reverse osmosis
Gross Alpha (Excluding Radon and Uranium)	Reverse osmosis
Uranium	Anion exchange, lime softening, reverse osmosis, enhanced coagulation
Beta Particle and Photon	Ion exchange, reverse osmosis

Comparison of Removal Methods

Table 6. Treatment Options Summary (Texaswater.tamu.edu, 2006)

Technology	Contaminants*	Initial Cost±	Limitations
Ion Exchange	arsenic (As),perchlorate (P), nitrate (N), radium (R), uranium (U), gross beta emitters (β)	\$400- \$1500	Competing contaminants
Reverse Osmosis	As, P, N, U, R, β, adjusted alpha emitters (α)	\$300-\$1000	Poor water recovery
Distillation	As, N, R, U	\$300-\$1200	Energy requirement
Aeration	Radon	\$3000-	Off-gas
GAC	Radon	\$300-800	aeration is a better choice

* Does not imply co-treatment capabilities for all contaminants listed.
± Only estimate of unit cost– does not include installation or O & M costs.

Table 7. Applicability of best available technologies and small system compliance technologies (EPA, 2000)

Treatment Technology	Designation: BAT and/or &SSCT?	Customer Served (SSCTs only)	Treatment Capabilities: Radium (Ra)	Uranium (U)	Gross Alpha (G)	Beta/p Boton (B)	Source Water Consideration	Operator Skill Required
IX	BAT&SSCT	25-10,000	✓	✓		✓	All ground water	Intermediate
Point of Use (POU) IX	SSCT	25-10,000	✓	✓		✓	All ground water	Basic
Reverse Osmosis (RO)	BAT&SSCT	25-10,000 (Ra,G,B) 25-501,000 (U)	✓	✓	✓	✓	Surface waters usually requiring pre-filtration	Advanced
POU RO	SSCT	25-10,000	✓	✓	✓	✓	Surface waters usually requiring pre-filtration	Basic
Lime Softening	BAT&SSCT	25-10,000 (Ra) 25-501,000 (U)	✓	✓			All waters	Advanced
Green Sand Filtration	SSCT	25-10,000	✓				Typically ground water	Basic
Co-precipitation with Barium Sulfate	SSCT	25-10,000	✓				Ground water with suitable water quality	Intermediate to Advanced
Electrdialysis/ Electrdialysis Reversal	SSCT	25-10,000	✓				All ground water	Basic to Intermediate
Pre-formed Hydrous Manganese oxide filtration	SSCT	25-10,000	✓				All ground water	Intermediate
AA	SSCT	25-10,000		✓			All ground water	Advanced
Coagulation/ filtration	BAT&SSCT	25-10,000		✓			Wide range of water qualities	Advanced

Results and Discussion

Aeration and GAC are effective treatment technologies for radon. Of the two technologies, only aeration will be listed as a BAT and likely be the technology of choice in almost all cases. GAC will likely be considered for only very small systems and for POU/POE. Removal efficiencies of more than 98% can be achieved, for example, with diffused bubble and packed tower aerators. Most aeration facilities can be constructed to achieve radon removal efficiencies of more than 95% or even more than 99%. All technologies effective for hardness removal are generally effective for radium removal. Cation exchange, lime softening and reverse osmosis are the technologies currently being applied for radium removal. Most conventional technologies have some capability for uranium removal. Anion exchange has been successfully applied for uranium removal from small ground water systems.

Suggestions

Selecting a water treatment device takes a lot of consideration. The first thing that we want to do before purchasing a system is get your water tested by a certified third-party lab that will test for all constituents. We may run across free water tests being offered by treatment unit distributors.These tests often only test for superficial things in the water such as salt and hardness, and don't include many potential contaminants that pose health effects. We want our results to come from an unbiased lab that is giving us the information that we really want and need, not from someone who is trying to sell us a unit. Once we know what is in our water, we must select a treatment unit or combination of units that will remove those contaminants. If we have multiple contaminants of concern, then we need to look at the system's ability to remove all of them. We mentioned the ion exchange process earlier as a system that you must be cautious using if more than one chemical is present. For most systems, prefilters help remove pollutants such as solids that may disrupt the removal process in the main treatment unit. Upon investigating potential treatment options, we will want to compare the initial cost of the unit and other operation and maintenance costs. We'll want to consider the operation and maintenance requirements to keep the system running as it should and also how long the system is expected to last (life expectancy) if properly maintained. Look at how well the system is going to be able to remove the contaminant. Also consider the reputation of the manufacturer/seller as well as the warranties that they offer. Finally, it is important that we understand the wastes associated with the unit and ensure we have a means for disposal. We don't want to spend money on a system, run it for a while, and then find out that all you have done is generate waste without a way to properly dispose of it. (EPA, 2006)

Acknowledgement: *This authors wish to acknowledge the financial assistance given by the BAP of Selcuk University without whom this project would not have been possible.*

References

Anonim., 2006, Onsite Drinking Water Treatment, http://texaswater.tamu.edu/Resources/drinkg water_factsheets/OnsiteDrinkingWaterTreatment033106.ppt

EPA (Environmental Protection Agency), 2006,. A Regulators' Guide to the Management of Radioactive Residuals from Drinking Water Treatment Technologies, http://www.epa.gov/radiation/docs/tenorm/816-r-05-004.pdf

EPA., 2000. "National Primary Drinking Water Regulations; Radionuclides, Final Rule. December 7, 2000" Federal Register. Vol. 65, No. 236.

IDS-WATER, 2007, http://www.idswater.com

ITS, 1997, Institution of Turkish Standards. Annual Progress Report.

UNSCEAR, 1993, United Nation Scientific Committee on the Effect of Atomic Radiation. Report, United Nations, New York

VESTERBACKA, 2007, Natural radioactivity in drinking water in Finland, Boreal Environmental research 12:11-16 ISSN: 1239-6095, February 2007

WHO, 1993, Guidelines for Drinking Water Quality. Recommendations, Vol. 1, 2nd edition. World Health Organization, Geneva.