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An Article on Study of the Methods to Remove Natural Radioactivity from Water body: Safety Measures and caution to prevent Radioactive Pollution

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Abstract—*Naturally occurring radioactive substances are frequently found in ground water. Certain rock types naturally contain radioactive elements referred to as NORM (Naturally Occurring Radioactive Materials). When a source of drinking water comes in contact with NORM-bearing rocks, radionuclides may accumulate in the water to levels of concern. The predominant radionuclides found in water include. As water is treated to remove impurities, radionuclides may collect and eventually build up in filters, tanks, and pipes at treatment plants. The small amounts of NORM present in the source water may concentrate in sediment or sludges. Because the NORM is concentrated due to human activity, it is classified as TENORM (Technologically Enhanced Radioactive Material). Most of this waste is disposed in landfills and lagoons, or is applied to agricultural fields. Most drinking water treatment sludges are thought to contain radium (Ra-226) levels comparable to typical concentrations in soils. However, some water supply systems, primarily those relying on groundwater sources, may generate sludge with much higher Ra-226 levels. Furthermore, some water treatment systems are more effective than others in removing naturally-occurring radionuclides from the water.*

1. INTRODUCTION

The small amounts of NORM (Naturally Occurring Radioactive Materials) present in the source water may concentrate in sediment or sludges. Because the NORM is concentrated due to human activity, it is classified as TENORM (Technologically Enhanced Radioactive Material). Most of this waste is disposed in landfills and lagoons, or is applied to agricultural fields. Most drinking water treatment sludges are thought to contain radium (Ra-226) levels comparable to typical concentrations in soils. However, some water supply systems, primarily those relying on groundwater sources, may generate sludge with much higher Ra-226 levels. Furthermore, some water treatment systems are more effective than others in removing naturally-occurring radionuclides from the water [1-3].

Radioactive substances are those that are unstable in nature. Naturally occurring uranium, thorium, radium, and radon emit radiation to reach a more stable condition. This process is called radioactive decay. By measuring the type of radiation emitted, the specific energy level or levels of radiation and the rate of decay, scientists are able to identify a radioactive substance and determine how much of it is present. Radioactivity is usually measured in curies in the United States. The unit typically used to describe the concentration of radioactivity present in drinking water is the picocurie per liter (pCi/L) – one trillionth of a curie. Uranium is also expressed as micrograms per liter (ug/L), a mass per unit volume measurement. A microgram is one millionth of a gram. About 99 percent of uranium ingested in food or water will leave a person's body in the feces, and the remainder will enter the blood. Most of this uranium will be removed by the kidneys and excreted in the urine within a few days. A small amount of the uranium in the bloodstream will be deposited in a person's bones, where it is likely to remain for several years.

1.1 Effects of Radioactive Pollution

The effects of radioactive pollutants depend upon half-life, energy releasing capacity, rate of diffusion and rate of deposition of the contaminant. The effects may be *somatic* (affecting individual) or *genetic* (affecting future generations). Some of the effects are cancer, shortening of life span and genetic effects of mutations. The other effects of radioactive pollution include:

- Radiations may break chemical bonds, such as DNA in cells; this affects the genetic make-up and control mechanisms.

- Fatigue, nausea, vomiting and loss of hair (exposure at low doses of radiations, i.e. 100-250 rads).

- The bone marrow is affected, blood cells are reduced, decreased in body immunity, blood fails to clot, and the irradiated person soon dies of infection and bleeding (exposure at low doses, i.e. 400-500 rads).

- Higher irradiation doses (10,000 rads) cause damage to the tissues of heart, brain, etc.

2. TOXIC EFFECTS

In addition to the risk of cancer posed by uranium and all other radionuclides discussed below, uranium is associated with non-cancer effects. The organ of concern, the "target organ", of uranium's chemical toxicity is the kidney. Uranium interferes with re-absorption of proteins. Miners and millers who were exposed to high doses of uranium showed effects which were usually mild and reversible. The EPA set a Maximum Contaminant Level for uranium of 30 micrograms per liter based on the chemical toxicity of uranium. Nuclear energy is a clean, safe, reliable and competitive energy source. It is the only source of energy that can replace a significant part of the fossil fuels (coal, oil and gas) which massively pollute the atmosphere and contribute to the greenhouse effect. If we want to be serious about climate change and the end of oil, we must promote the more efficient use of energy, we must use renewable energies – wind and solar – wherever possible, and adopt a more sustainable life style [4]. This will not be nearly enough to slow the accumulation of atmospheric CO_2, and satisfy the needs of our industrial civilization and the aspirations of the developing nations. Nuclear power should be deployed rapidly to replace coal, oil and gas in the industrial countries, and eventually in developing countries An intelligent combination of energy conservation, and renewable energies for local low-intensity applications, and nuclear energy for base-load electricity production, is the only viable way for the future. Tomorrow's nuclear electric power plants will also provide power for electric vehicles for cleaner transportation. With the new high temperature reactors we will be able to recover fresh water from the sea and support hydrogen production. We believe that the opposition of some environmental organizations to civilian applications of nuclear energy will soon be revealed to have been among the greatest mistakes of our times [5].

3. PRESENT SCENARIO

Our industrial civilization runs on energy and 85% of the world's energy is provided by the fossil fuels, coal, oil and gas. Coal began to be used extensively in Britain when its forests were no longer able to satisfy the energy requirements of embryo industrialization. Coal is found almost everywhere and reserves should last several centuries. Petroleum began by replacing whale oil at the end of the 19th century, and its use has grown ever since. Discoveries of new deposits are not keeping up with consumption and production of oil is about to peak. At the present rate of consumption, reserves are estimated to last a few decades, but consumption is growing rapidly. More than half the world's oil production today is located in the fragile and politically unstable area of the Persian Gulf, as is an even greater fraction of our future reserves; Gas was at first a byproduct of oil extraction and it was thrown away. It has since been mastered to become a major source of energy. Reserves are similarly limited and estimated to last for a few decades. These fossil fuels were laid down over geological times and it seems likely they will have been totally exploited over the few centuries from about 1850 to 2100. The World Health Organisation (WHO) has issued recommendations for natural and man-made radionuclides in drinking water. The limits for drinking water are:

1 Gross alpha activity (without radon) 0.1Bq/L

2 Gross beta activity (without tritium) 1Bq/L.

If either gross alpha or gross beta activity exceeds the limit, an individual radionuclide concentration has to be determined and a total annual dose has to be calculated. In the case this dose exceeds a value of 0.1mSv, remedial actions should be taken.[6]

4. NATURAL RADIOACTIVITY

The main primordial natural radionuclides as sources of human exposure to radiation are uranium (238U), thorium (232Th) and potassium (40K). The heavy nuclides 238U and 232Th decay through long decay-chains which include several radioactive elements and end in the stable isotopes of lead. Uranium and thorium and nuclides of their decay-chains are present in the ground in all rocks and soils, the amount depending on the rock type. In the decaychain of 238U are radon (222Rn) and its short-lived and long-lived daughter products. The long-lived daughter products of radon are 210Po and 210Pb. Table I sets out all the nuclides present in the uranium decay chain. Nuclide 40K will not be further discussed because variation in the amount of 40K in the water has no substantial effect on the dose.

5. OCCURRENCE OF NATURAL RADIOACTIVITY IN DRINKING WATER

Water The distribution of accumulations of natural radionuclides in Europe can be estimated—as a first approximation—on the basis of the occurrence of the main European uraniferous deposits. Most of the deposits are related to the Moldanubian zone of the Herzynian (Variscan) orogen or to the directly adjacent zone. The Moldanubian Zone is the inner zone of the Herzynian Orogen, corresponding to the area of maximum orogenic, metamorphic and plutonic activity. It extends from the north-western part of the Iberian peninsula, through Brittany, central France, and southern Germany to former Czechoslovakia. Moldanubian outcrops mainly form the crystalline complexes of the Central Iberian Zone, the Vendée of the Armorican Massif (Brittany), the French Central Massif, the Vosges and the Black Forest (western France / southern Germany) and the western Bohemian Massif including the Erzgebirge (former Czechoslovakia and the southern part of eastern Germany).

6. METHODS FOR REMOVING NATURAL RADIOACTIVITY FROM DRINKING WATER:

6.1 Aeration

Aeration is based on the mass transfer of radon from the aqueous phase to the gaseous phase. The transfer can be accomplished based upon different principles. Most commercial aerators combine these principles in order to achieve the best performance.

1. Spray aeration. Radon-laden water is forced into a ventilated tank through a spray nozzle. The water is transformed into small droplets and radon is released from the interfacial surface into the surrounding air. The radon-rich air is exhausted into the open air through a ventilation channel by a fan. The aerated water is fed into the household water line.

2. Diffused bubble aeration. Radon-laden water is fed into a tank where it is brought into contact with small air bubbles. The bubbles can be created with an air compressor and a plate diffuser fixed to the bottom of the tank, or by circulating the water through an ejector, which mixes clean air into the water. The bubbles rise to the surface of the water where they are exhausted into the open air through a ventilation channel.

3. Packed tower aeration. Water is directed into the top of a vertically positioned tower. The tower is filled with an inert packing material (e.g. nets or plastic balls). As the water passes through the packing material, a large surface area between the air and the water is created from which radon can be released. A small blower fan forces air up through the packing, which carries the radon gas out of the unit. [7-8]

4. Bubble plate or shallow tray aeration. These techniques are similar to the diffused bubble aeration but the air bubbles are larger and more air is usually compressed through the water.

Aeration is capable of removing only radon, which is directly funneled into the open air. Therefore, no accumulation of radioactivity occurs in the aeration process. The concentration of radon in the exhaust air depends on the radon concentration in raw water and the air-to-water (A/W) ratio. Mostly, A/W ratio of about 10 is sufficient to remove 95% of radon, though much higher ratios are often applied. Table II sets out the concentrations and volumes of radon-rich exhaust air produced by systems with different radon concentrations in raw water and different rates of water use

6.2 Granular activated carbon filtration

Granular activated carbon (GAC) filters are 20–100 L filters that are installed at the water line right after the pressure tank in such a way that they treat all water used by a household (point-of-entry). The removal efficiency for radon depends on the bed size of the GAC filter and can be close to 100%. GAC filtration can best be employed in a single household where the radon concentration of water does not exceed 5,000 Bq/L because GAC filters emit gamma radiation when they are in service. The higher the radon concentration and the larger the water use, the more intense the dose rate around the filter becomes. Furthermore, GAC filters accumulate 210Pb that is formed by the radioactive decay of radon inside the filter. The rate of accumulation of 210Pb also depends on the rate of daily water use and the radon concentration in the influent. Radon is retained on GAC by physical adsorption. Although the adsorption process is reversible, the GAC beds are capable of retaining most of the radon long enough to allow its radioactive decay inside the filter. [9-11] After three weeks in service the adsorption rate of radon equals the rate of its radioactive decay; thus there is a constant number of radon atoms (and its short-lived daughter products) adsorbed on the GAC bed. This state is called the adsorption-decay steady state and results from the relatively short half-life of radon. The short-lived decay products, 218Po, 214Pb, 214Bi and 214Po, and the longlived 210Pb generated by radon are retained on the carbon bed. 214Pb and 214Bi cause most of the gamma rays but are negligible in the waste due to their short half-life. The long-lived 210Pb, however, is accumulated during the whole time the GAC filter is in service. Depending on the water consumption and radon concentration in the influent, high levels of activitySTUK-A175 25 of 210Pb may be found in spent GAC beds. 210Pb attains secular equilibrium with its progeny, 210Bi and 210Po; thus the total activity of the bed is three times higher than for 210 Pb alone.

6.3 Fe- and Mn- removal techniques

There are three main principles on which the commercial Fe- and Mnremoval equipment is based. All of these removal units are installed to treat all household water (point-of-entry) and are regenerated or backwashed atSTUK-A175 27 certain intervals depending on the quality of the effluent and the daily water use. Table III sets out the removal efficiencies for different radionuclides, by the operation principle.

1. Aeration-filtration technique. The first step is to treat water with air or oxygen in order to oxidise iron form +II state (ferrous) to +III state (ferric). Ferric ions are readily hydrolysed and precipitate as ferric hydroxide, $Fe(OH)_3$. Manganese is oxidised from +II state to +III or +IV state to achieve a subsequent precipitation of $MnCO_3$, MnS, $Mn(OH)_2$, MnOOH, MnO_2 or Mn_3O_4. These metal precipitates may adsorb radionuclides such as uranium, radium, lead and polonium. In the second step, the precipitates are removed from water by filtration. Backwashing is applied to remove the precipitates from the filter and to drain the wastes into the sewer.

2. Manganese greensand filtration. In this technique, the oxidisation and filtration steps are carried out applying one fixed bed, manganese greensand. Before commissioning, the greensand bed is conditioned with manganese to form MnO_2 sites on the greensand granules. These sites exhibit oxidising power that enables oxidisation and subsequent precipitation of soluble species of iron and manganese. Therefore, radionuclides may also be retained. The bed is backwashed and regenerated with dilute $KMnO_4$ solution to restore the oxidising power at certain intervals.

3. Ion exchange technology. Strong acid cation exchangers can be applied to remove soluble species of iron and manganese as well as hardness from household water. The method is based on ion exchange between the soluble cations in water and the sodium ions located in the functional groups of the resin. Radionuclides occurring as cations or cationic compounds may be exchanged and thus removed by cation exchange. Regeneration is carried out with saturated sea-salt solution at certain intervals.

6.4 Ion exchange techniques

Ion exchangers are applied to the removal of uranium (238U, 234U) and radium (226Ra). Lead (210Pb) and polonium (210Po) may sometimes be removed (depends on water quality) by ion exchange technology as well. Generally speaking, uranium (and polonium) is removed with an anion exchanger while radium (and lead) are removed with a cation exchanger. These exchangers can also be combined in one unit to enable simultaneous removal. Different operation principles and exchange materials can be utilised. Organic ion exchangers (resins) can usually be regenerated, which means that the substances retained in the resin can be removed and the exchange properties restored. The properties of many inorganic exchangers (mineral based) cannot be restored by regeneration and therefore they must be discarded after exhaustion (see Chapter 4.6). The operation principles of ion exchange units are:

1. Point-of-entry (POE) exchangers with automatic regeneration. These units are the largest (bed volumes approx. 40 litres) and often make useof both anion and cation exchangers in one bed (mixed bed). They areSTUK-A17529installed in the household water line in such a way that all householdwater is treated. An automatic feature starts the regeneration at regularintervals (time- or volume-related). Regeneration is mostly carried outwith saturated sea salt solution.

Point-of-entry (POE) exchangers without automatic regeneration. The bed volumes of these units are usually 20–40 litres and they are mounted in the incoming water line of a household. An additional purpose of this installation is to remove uranium and humus before a GAC unit in order to prevent the GAC filter from fouling. After the estimated exhaustion, the filters are sent to a commercial company for regeneration or to be filled with a new batch of resin.

1. Point-of-use (POU) exchangers. These units are smaller; the bed volumesare mostly 5–20 litres. Since uranium, radium, lead and polonium are harmful only when ingested, only the drinking water needs to be treated. These units can be mounted in the kitchen sink cabinet or at the beginning of the cold water line to the kitchen because drinking water ismostly taken from the kitchen tap. When the capacity of the unit is near exhaustion, it is sent to a commercial company that regenerates there sin or replaces the resin with a fresh batch.

2. Tap-mounted filters. These units are attached directly to the kitchen tapand the installation needs no professional plumbing. The size of thesefilters is usually approx. one litre. Because the filters are relativelyinexpensive, they are mostly discarded after a certain period of time and replaced with a new one. The resin can, however, be regenerated eitherby sending it to a commercial company or by performing it in a bucketfilled with sea salt solution.

3. Pour-through filters. The bed volumes of these filters are very small; the volume of the resin is often 0.1–0.2 litres. The unit consists of two containers. The lower container (reservoir) is filled by pouring water into the upper basin and allowing the water to pass through the resin by exerting gravitational pressure (e.g. BritaÔ can). The resin is discardedafter a certain period (time- or volume-related) and replaced.

Strong basic anion exchangers (SBA resins) exhibit an extremely high affinity for uranium, that normally occurs as a negatively-charged carbonate complex in groundwater. After the exhaustion of the resin, substances that are more weakly bound in the resin are replaced by *uranium and the removal of uranium remains undisturbed* [14-16]

6.5 Membrane techniques

Membrane techniques are mostly applied to simultaneous POE or POU removal of uranium, radium, lead and polonium. In principle, the feed water is forced into a membrane unit exerting relatively high pressure (5–50 bar). Inside the membrane unit there is a semi-permeable membrane. The pore radii of the membranes determine which ions are allowed to push through into the permeate (purified water) and which are rejected (concentrate). Radionuclide removal on either domestic or waterworks scale can best be carried out by reverse osmosis or nanofiltration:

1. Reverse osmosis (RO). The yield of RO filtration is usually low, only 10– 30%. This means that for every cubic metre of water there is 700–900 litres of concentrate. Therefore, these units are mostly applied as POU removal systems. Reverse osmosis removes most dissolved ions, thus the permeate is de-mineralized. The permeate, therefore, is corrosive and cannot usually be fed into the plumbing system without re-hardening [17].

7. SAFETY MEASURES TO PREVENT NUCLEAR POLLUTION

On one hand, the peaceful uses of radioactive materials are so wide and effective that modern civilization cannot go without them, and on the other hand, there is no cure for radiation damage. However, the only option against nuclear hazards is to check and prevent radioactive pollution by taking the following measures and precautions.

1. safety measures should be enforced strictly;
2. leakages from nuclear reactors, careless handling, transport and use of radioactive fuels, fission products and radioactive isotopes have to be totally stopped;
3. there should be regular monitoring and quantitative analysis through frequent sampling in the risk areas;
4. waste disposal must be careful, efficient and effective;
5. appropriate steps should be taken against occupational exposure;
6. safety measures should be strengthened against nuclear accidents; and
7. Preventive measures should be followed so that background radiation levels do not exceed the permissible limits.

7.1 Radioactive Waste Management

Part of the reason that radioactive pollution is a problem is that radiation can remain for up to a million years if levels of certain isotopes are high enough. For this reason radioactive waste management is very important and plans stretch up to around 100 years in the future, with ongoing evaluations and research into these to make sure radioactive pollution affects us as little as possible. There are four main techniques used for radioactive waste management:

- ***Geological disposal*** – this is, effectively, the burying of radioactive material. Large geologic formations are located and tunnels as deep as 1000m underground are drilled. Rooms are then excavated at the bottom of these and radioactive material is stored here until it has decayed enough to not be dangerous any more. Radioactive waste has also previously been dumped into the world's oceans but following the sixteenth meeting of the LDC (London Dumping Convention) in 1993, the dumping of radioactive waste into the sea is banned, permanently.
- ***Transmutation***–transmutation of radioactive waste is the process of consuming this radioactive waste and turning it into less harmful waste. This is currently not used very often due to high costs, however, research is being done to make the process more efficient and more economically viable. This currently is our most environmentally friendly radioactive waste management technique and, as such, when perfected will effectively solve the problem of radioactive waste.
- ***Re-use of radioactive waste*** – some radioactive isotopes, such as strontium-90 and caesium-137 are able to be extracted for use in other industries such as food irradiation. The re-use of radioactive waste means that the quantity of waste produced is reduced, so this

serves as another good environmentally friendly management scheme.

- ***Space disposal*** – space disposal is not currently used to reduce radioactive pollution, due to the potential problems which could occur when attempting to carry out the procedure. If, for example, a rocket used to launch the waste fails (and bear in mind that many rockets would have to be used due to the large amount of radioactive waste) then huge amounts of radioactive material would be released into the atmosphere, causing significant health risks to people within thousands of miles of the launch. Sometime in the future this may be possible, however, for now, it is best for us to avoid space disposal.

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