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Research paper

AN Overview of Radioisotopels Study in Water Pollution

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Abstract

Radioisotopes can be defined as the radioactive isotopes of an element. They refer to the atoms that contain an unstable combination of neutrons and protons. The combination can occur naturally or by altering the atoms. Nowadays, radioactive materials have become major contributing pollutants for a lot of cases of disability and mortality in all over the world. They have become a serious fear of the human, environment, and aquatic organism, although they are exposed to low levels of exposure. Therefore, to overcome these problems, the effective and easier prevention strategies should be taken and encouraged by all related parties such as industries, residents, and government. Radioisotope becomes as an essential part in medical, radiography and other fields of research including the environmental study. One of the applications is they can be used as the indicators in order to identify the pollutant sources. This method can be applied in surface water around industrial area and non-industrial area. As the example, the standard limit concentration of Uranium is 10ppb while for Thorium is 0.50 ppb. The study regarding radioisotope usually uses analytical instruments, for example, Inductively Coupled-Plasma Mass Spectrometry (ICP-MS) and X-Ray Fluorescence (XRF). Basically, this paper will give ideas on overview of radioisotope study and reference for acquiring a better quality of surface water in the present and future by using the environmental forensic study application.

Keywords: *Radioactive Materials; Radioisotope Tracing; Pollutant Sources.*

1. Introduction

The decrease in water quality status and availability of water quantity gave various of problems and affected the lives of millions of people. This problem occurred due to the rapid development and industries activities in the country. The rapid growth of population gave severe stress of the available freshwater resources (Deodhar et al., 2014). The presence of elements indicates the pollution level over the region (Dhara et al., 2011). Among the sources of the pollutants that can pollute the water resources, radioactive materials are one of them. They have become major contributing pollutants for a lot of cases of disability and mortality in all over the world.

Water in its natural state contains environmental isotopes. The isotopes that commonly use in the investigation of hydrology are the stable isotopes of a water molecule and the radioactive isotopes. The examples of stable isotopes are deuterium and oxygen-18 while for radioactive isotopes, tritium and carbon-14 is one of the examples (Deodhar et al., 2014). Stable isotopes are excellent indicators of water circulation, while radioactive isotopes are of special value in detecting the time of residence, assuming no contamination of water has occurred (Deodhar et al., 2014). The commonly used isotopes for various applications in hydrology studies and their universally accepted standards are listed in tables 1, table 2 and table 3 (Deodhar et al., 2014). In hydrology field, an environmental stable isotope that is used for tracing the origin of pollutant is ^{15}N, ^{37}Cl and ^{11}B. ^{15}N has 0.366 percent of natural abundance, ^{37}Cl has 24.23 percent of natural abundance and ^{11}B has 80.1 percent of natural abundance. Besides, environmental radioisotope usually uses for groundwater and sediment dating. For example, Tritium, Carbon, Chlorine-36, and Cesium-137. The example for artificially radioisotopes is Tritium, Cobalt-60, Bromine-82, and Gold-198 which has 12.43 years, 5.3 years, 36 hours and 2.7 days of half-life respectively.

Table 1: Environmental Stable Isotopes (Source: Deodhar et al., 2014)

Isotope	Ratio	Percent natural abundance	Reference (ppm)	Commonly measured phases	Application in hydrology
^{2}H	$^{2}H/^{1}H$	0.015	VSMOW (155)	H_2O, CH_4	Origin of water
^{13}C	$^{13}C/^{12}C$	1.11	VPDB	CO_2, Carbonates	Carbonates source, Groundwater dating
^{15}N	$^{15}N/^{14}N$	0.366	Air N2 (3677)	N_2, NH_4NO_3	Source of pollution
^{18}O	$^{18}O/^{16}O$	0.204	VSMOW (2005)	H_2O, CO_2, SO_4^{-2}, NO_3^-	Origin of water
^{34}S	$^{34}S/^{32}S$	4.21	CDT	SO_4^{-2}, Sulphides, H_2S	Origin of salinity, Redox condition of aquifer
^{37}Cl	$^{37}Cl/^{35}Cl$	24.23	SMOC (0.324)	Saline waters	Source of pollution
^{87}Sr	$^{87}Sr/^{86}Sr$	07.00	USGS Tridacna	Solution	Provenance of water
^{11}B	$^{11}B/^{10}B$	80.1	NISTRM 951-(Sodium Borate)	Solution	Source of pollution

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Table2: Environmental Radioisotopes (Source: Deodhar et al., 2014)

Isotope	Half-life (years)	Type	Energy (MeV)	Applications in hydrology
Tritium	12.3	Beta	0.019	Young groundwater dating
Carbon	5730	Beta	0.156	Old groundwater dating
Chlorine-36	3.1 X 10^5	Beta	0.714	Very old groundwater dating
*Cesium-137	30	Gamma	0.661	Sediment dating

Table 3: Artificial Radioisotopes (Source: Deodhar et al., 2014)

Isotope	Half-life (years)	Chemical form	Applications in hydrology
Tritium	12.43 y	HTO	Groundwater recharge rate and flow direction
Cobalt-60	5.3 y	$K_3[Co(CN)_6]$	Groundwater recharge rate
Bromine-82	36 h	NH_4Br	Groundwater velocity, effluent dispersion
Gold-198	2.7 d	$HauCl_3$	Seepage entry and exit points in dams

This paper gives ideas on overview of isotope study, especially for radioactive isotope. This information may be beneficial as the reference for acquiring a better quality of water resources in the present and future. Figure 1 gives the flow chart of the overview that will be discussed in this paper.

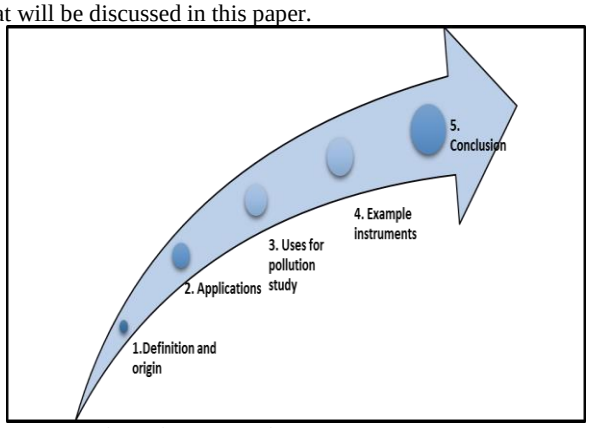


Fig. 1: The flow of overview of radioisotope study in water pollution

2. Definition and Origin of Radioisotope

Radioisotopes refer to elements that have radioactive isotopes. They have an unstable combination of neutrons and protons. Their combination can occur naturally or artificially by altering the atoms. To produce radioisotopes, the atoms can be altering by using a nuclear reactor, cyclotron, particles accelerators or radionuclide generators. In other word, radioisotopes refer to different isotopes of the same element have the same protons number in their atomic nuclei but different numbers of neutrons. They also have same chemical properties. This atom has excess nuclear energy that making it unstable.

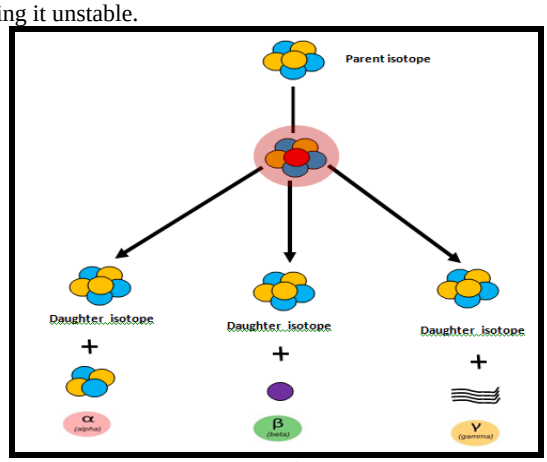


Fig. 2: The occurrence of radioactive isotopes

The excess energy can be either emitted as gamma radiation, emitted from the nucleus of a new particle such as alpha particle and beta particle of conversion electron (Calkins, 1952). Atoms containing this unstable combination regain their stability by shedding of its excess radioactive energy. This process is called as radioactive decay (please refer figure 2). Their existence can be measured with a time period called a 'half-life'. This term means the how long it takes for half of the isotope to disappear. Some of the radioisotopes only live for only minutes.

3. Applications of Radioactive Isotopes

Radioactive isotopes are not only a source of human exposure, but it has many applications, too (Dolhanczuk, 2015). It can be used in many fields of study such as for medication, the study of research and industries purposes. For example, the radioactive isotope is used for generation of electricity, testing materials, diagnosis and treating of people (Dolhanczuk, 2015). Some of the example applications of radioactive isotopes for medication, research, and industries field are summarized as shown in table 4, table 5, and table 6. In medicine field, radioisotopes are an essential part of radiopharmaceuticals. Radioisotopes such as Cobalt-60 are used in the treatment of cancer. Gamma-emitting isotopes are attached to some kind of suitable carrier in the body such as monoclonal antibody, which targets particular site of cancer cells. Then, gamma-ray destroys the cells of cancer with minimal damage to the surrounding of tissues.

Table 4: Applications of radioactive isotope in medication

Radioactive Isotope	Applications in Medication
Cobalt-60	Radiation therapy to prevent cancer
Iodine-131	Locate brain tumors, monitor cardiac, liver and thyroid activity
Carbon-14	Study metabolism changes for patients with diabetes, gout, and anemia
Carbon-11	Tagged onto glucose to monitor organs during a PET scan
Sodium-24	Blood circulation study
Thallium-201	Determination of damage in tissue of heart and for detection of tumors
Technetium-99m	To locate the brain tumors and the damage of heart cells, radiotracer in medical diagnostics, imaging of organs and blood flow studies

The most frequently used radioisotope in medicine field is technetium-99m. This radioisotope has the half-life of 6 hours. It is useful for medical diagnostics of organs and the flow of blood. Nuclear medicine uses small amounts of radiation to provide information about the body of a person and functioning of specific organs, ongoing biological processes in the body and also the diseases state of an illness. This radioisotope allows for the exploration of various parts of the body and emits only gamma rays whose energy of 140 keV is well adapted to gamma camera detectors (Ihsanullah, 1992).

Table 5: Applications of radioactive isotope in industries

Radioactive Isotope	Applications in Industries
Americium-241	For making uniform thickness when rolling steel and paper, for determine the location of oil wells
Sodium-24	For oil well studies and to locate leaks in pipelines
Iridium-192	Test integrity of boilers and aircraft parts
Uranium-235	Nuclear power plant and naval propulsion systems fuel, production of fluorescent glassware and colored wall tiles
Californium-252	For determination of moisture content of soil, important for road construction and building industries

Table 6: Applications of radioactive isotope in research study

Radioactive Isotope	Applications in Research
Carbon-14	Archeology application such as for carbon dating of organisms and substances, research study to determine steps involved in plant photosynthesis

Phosphorus-32 Phosphorus-33	Used in research involving biology and genetics
Selenium-75	Protein studies in life science
Strontium-85	Metabolism and bone formation studies
Hydrogen-3 or Tritium	Use for study life science and drug metabolism

Other than the applications in medication, radioactive isotope also widely used for industries. For example, Uranium-235 is used for nuclear power plant and naval propulsion systems fuel, production of fluorescent glassware and colored wall tiles. While radioactive isotopes also useful for scientific research. Basically, the amount of time radioactive isotopes takes for half of the quantity of original isotopes to decay is constant, neglect the quantity of the presence of it at the beginning. Based on the principle, the age of geologic events can be measured by using selected radioactive isotope (Patrut et al., 2011; Kolar et al., 2011; Zazzo et al., 2011; Clauer et al., 2013). For instance, the parent-daughter system is used to determine the age of the earth is a Uranium-Lead system. The Uranium decay to Lead in the samples of earth, the moon, and meteorites indicate that all planets in solar systems formed 4.5 billion years ago(Clauer et al., 2013). In archeology study, if an object contains carbon and unsure of its age, the radioisotope of Carbon-14 is used to determine its age. This process is called as radiocarbon dating (Terry et al., 2006; Richter et al., 2009; Joris et al., 2008).

3. Uses of Radioactive Isotopes for Environmental Field (Pollution Study)

Radioactive isotopes are also used in the environmental study (Medich et al., 2006; Lecroart et al., 2010; Dolhanczuk et al., 2015; Wahab et al., 2016). For example, K-40, P-32, O-15, and Fe-59 are used to study the dynamics and mechanisms processes that occurred in plant and soil while C-14, U-238, U-235, and Th-232 are used to determine the age of minerals, rocks, soil, and sediments. To identify the mechanism and dynamics of trace metal bonding in port sediments, Cd-109, Co-60, Cr-51, Fe-59, Mn-54, and Zn-65 are used (Lecroart et al., 2010; Medich et al., 2006). Besides, K-40, Sr-90, Cs-137, Ca-45, P-32, and I-131 is used in the study of the circulation of elements and radioisotopes study in the food chain (Dolhanczuk et al., 2015). In the monitoring studies, natural isotopes such as K-40, Pb-210, U-238, Ra-226 and Po-210 are used. Other than that, the artificial isotopes also used for the monitoring. For example, Fe-59, P-32, Co-60, Cs-137, Te-99 and I-131 (Dolhanczuk et al., 2015). These studies include the assessment of the activity of cesium isotopes in soil surface (Dolhanczuk et al., 2006; Kubica et al., 2010; Szabo et al., 2012; Kubica et al., 2014).

In water pollution studies, the isotope of Ra-226 is used for determination of underground water zones. It is possible to estimate the amount of outflowing underground water and its change in time, and later estimate the extent of carrying pollutants to coastal water (Kelly et al., 2002). Ra-226 also may be used to determine the inflow of underground water from various reservoirs to surface water and also to identify the mixing zone of the components (Kelly et al., 2002). Radon isotope, which is Rn-222, also can be used similarly as Ra-226. This isotope is useful as a marker for inflow of surface water into karst systems and the zones of inflow of underground water into surface water (Kelly et al., 2002).

In monitoring studies of water pollution, Mola et al. (2013) found that relatively high Uranium and Radium were obtained in algae collected from the plant, compared to results taken from the unimpacted Riba-Roja Reservoir. In another research done by Paschoa et al. (1979), the highest values have been found in waters close to Uranium mining and milling. While for tracing the source of pollution in sediments, Yusoff et al. (2015) found that high ratio of >1.5 of 23OTh/232Th in sediment samples from Kota Kinabalu Port may be getting recharged from the anthropogenic input of 230Th. Monitoring and accurate determination of the trace elements are very important because some of the elements which are nutrients can act as a toxin, too if they are in high concentration and above the limit (Dhara et al., 2011). For example, the standard limit concentration of Uranium is 10ppb while for Thorium is 0.50 ppb (Wahab et al., 2016).

4. Examples of Instruments Use for Tracing Radioisotope

There is a lot of instruments and equipment that are suitable for tracing the radioisotope. Most common examples of instruments used are Inductively Coupled-Plasma Mass Spectrometry (ICP-MS), X-Ray Fluorescence Spectrometry (XRF), Neutron Activation Analysis (NAA), Alpha Spectrometry and Gamma Spectrometry (Akyuz et al., 2001; Yuan et al., 2004; Gunathilaka et al., 2011; Mola et al., 2013; Dolhanczuk, 2015; Yusoff et al., 2015; Wahab et al., 2016) . Figure 3,4,5 and 6 showed the photograph of instruments used for tracing of the radioisotope. The most suitable one is alpha spectrometry and gamma spectrometry.

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is a versatile technique that can achieve the level of detection many orders of magnitude lower than X-Ray Fluorescence Spectrometry (XRF). ICP-MS is able to determine many elements as quickly and more liquid form samples. For example, soil pollutants like ^{99}Tc that pose the high risk for human are quantified and their behavior is analyzed using the Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Uchinda and Tagami, 2003).

Meanwhile, X-Ray Fluorescence Spectrometry (XRF) is a rapid, versatile technique which lends itself to a wide variety of samples from powders to liquids. XRF has high limits of detection and possibility of matrix effects to occur is higher. Current research aimed at improving the X-Ray Fluorescent (XRF) analyses for geological and ecological samples. The focus is on methods for correcting the matrix effects, in which major components absorb some of X-rays emitted from trace components (Revenko 2002). Neutron Activation Analysis (NAA) use thermal neutron in order to activate isotopes of trace elements in samples. This instruments can determine for multi-element and it has the ppb-level limit of detection.



Fig. 3: Inductively Coupled Plasma Mass Spectrometry (Source: http://science.sckcen.be/en/Services/Testing/Radiochemical)



Fig. 4: X-Ray Fluorescence Spectrometry
(Source: http://centrallab.ump.edu.my/index.php/en/)

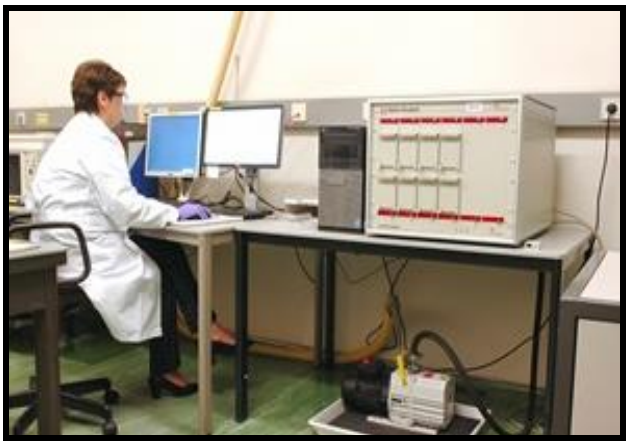


Fig. 5: Alpha Spectrometry
(Source:http://science.sckcen.be/en/Services/Testing/Radiochemical)



Fig. 6: Gamma Spectrometry
(Source:http://science.sckcen.be/en/Services/Testing/Radiochemical)

5. Conclusion

Radioisotopes play a significant role in many fields of study, medicine, industries and research, especially for environmental pollution. A number of studies investigated about radioisotope tracing and monitoring, but there is limited research that focusing on surface water has been done by the researchers. Most of the study mostly focusing on the sediment, air, groundwater and aquatic organism only (Akyuz et al., 2001; Jacqueline et al., 2014). Therefore, the study regarding radioactive isotopes in surface water pollution should be encouraged for the better quality of water supply. For acquiring the better quality of water, continuation and extension of hydrological research are needed (Deodhar et al., 2014). It is highly recommended that environmental forensic application is used in order to trace the origin of pollutants in the water resources. The radioisotopes techniques have proved to be effective tools for solving many critical hydrological and water pollution problems. The application of radioactive isotopes techniques for water resources and water pollutions is expected to be developed enormously in the present and future. The use of latest operate equipment such as Inductively Coupled-Plasma Mass Spectrometry (ICP-MS), X-Ray Fluorescence Spectrometry (XRF), Neutron Activation Analysis (NAA), Alpha Spectrometry and Gamma Spectrometry will be useful for tracing radioactive isotopes in water resources and water pollutions studies. However, the most suitable equipment to be used in tracing the radioactive isotopes is Alpha Spectrometry and Gamma Spectrometry. The radioactive isotopes techniques are a better way because this technique is faster, effective, and efficient. This technique is also environmental friendly as it will not too much disturb and affect the nature.

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