RADIOACTIVE CONTAMINATION DETECTION IN WATER USING WIRELESS SENSOR NETWORK

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ABSTRACT

Radioactive contamination is the result of regular operation of nuclear power plants, leakage or accident during the production, or use of radionuclides (radioisotopes). They occur throughout the nuclear fuel cycle and continue to give off harmful radioactive particles and rays for very protracted periods. Radioactive elements can contaminate water adversely affecting human health as well as aquatic lives. It is difficult to manually collect water samples and test the presence of radioactive contamination in those samples. This also limits the area of collection. This paper reviews various methods of detecting radioactive contamination in water resources, their advantages, shortcomings and challenges during implementation. The authors have found self-maintaining, scalable, low cost Zigbee based Wireless Sensor Network (WSN) supporting web technology for detecting and monitoring nuclear radiation technique developed by Li Wu et al. (2014) the most appropriate.

Keywords: *Radioactive contamination, Wireless sensor network (WSN)*

1. INTRODUCTION

Nuclear Power plants plays an important role in power supply in most of the countries. Radioactive contamination occurs as a result of regular operation of nuclear power plants, leakage or accident during the production, or use of radionuclides (radioisotopes) [6]. Radiation generally occurs throughout the nuclear fuel cycle and continues to discharge treacherous radioactive particles and rays for extensive periods. Nuclear plants are usually built near to the sea as sea water can be used to cool the reactor. The water used to cool the reactor can be contaminated with radioactive elements. A serious threat occurs due to accident of the power plants during earthquake or terrorist attack. The chain reaction of uranium in nuclear power plant is regulated by the use of control rods but when exposed to the environment can result in uncontrolled chain of reactions thus contaminating the water resource to a greater extent. Moreover, water distribution systems are susceptible to intentional as well as accidental or unintentional radioactive contamination [1]. Thus it is necessary to build reliable and nuclear radiation monitoring system. Traditionally, the cable system employing CAN, RS-485 and RS-232 were widely used in industrial applications. However, due to complexity of wiring system, difficult maintenance and less reliability during disasters such as hurricane and earthquake, WSN has become very popular for detecting and monitoring radiation in industrial areas.
Gurkan Tuna et al. (2012) have presented a self-deploying wireless sensor network (WSN) which prevents rescue team/ person from direct exposure to radiation during radiation levels measurement as well as energy harvesting techniques to increase network lifetime [13].The use of multiple robots could reduce the overall duration of operation. Amira A.A.ELmagid et al. (2012) introduced different approaches of sensor network deployment combining Genetic Algorithm and Fuzzy Logic. Similarly, to prolong network lifetime, Yoshinori Matsumoto et al. (2013) developed low power radiation monitoring system employing a sensor network and one board-type radiation module compatible with Grove System. They facilitated environment monitoring with new network module operating at 920 MHz and further designed a software “NEW VIEWER” for the radiation time-series log file [4]

Most of the techniques use sleep modes for the sensor nodes to reduce power usage to prolong network lifetime. This introduces delay and also only the end devices can go to sleep mode while the routers and the coordinators must be awake all the time. Li Wu et al. (2014) developed a self-maintaining, scalable, low cost Zigbee based WSN supporting web technology for detecting and monitoring nuclear radiation and also designed an Uninterruptible Power Supply (UPS) to prevent nodes from going to sleep mode [6].

Radioactive elements can contaminate water adversely affecting human health as well as aquatic lives. Although in most of the regulated water reservoirs, there is regular monitoring of water quality, potential threat of intended contamination to water resources and tragic events which occurred in Chernobyl and Fukushima substantiate the requirement to improve the real-time monitoring systems that can alert public or the authorities if the radiation in water reservoir exceeds permissible level [1]. Although, radiation from the radioactive material makes it possible to track down and determine their quantity even in very minor amounts, Radio waves propagation in water is weak .Thus, it is difficult to precisely determine radioactivity taking place under water with the sensors placed outside water resource. Therefore, there is a need of underwater sensor network to track radioactivity under water.

The remaining of the paper is organized as follows. Section 2 briefly describes the wireless sensor network. Section 3 discusses the need for detection of radioactive contamination in water. Section 4 presents case study, Section 5 discusses current techniques for radioactive contamination detection in water. Section 6 discusses the challenges of using WSN to track and detect radioactivity in water. And finally in Section 7, we present the conclusion.

2. WIRELESS SENSOR NETWORK

Recent advancement in digital electronics, Wireless communications and Micro Electro Mechanical Systems (MEMS) has made Wireless Sensor Networks (WSNs) more popular. WSNs comprises of small sensor nodes deployed over a study area capable of communicating within shorter distance. WSNs sense, collect and measure information from the deployed area and finally via internet pass required information to the users. The information is sensed, measured and collected from the environment by the smart sensor node and finally through internet and passed to the user. Among various application areas of WSNs like military, remote automation etc. detection and monitoring of radioactive radiation is among them. They are trustworthy to handle emergency before uncontrollable condition.

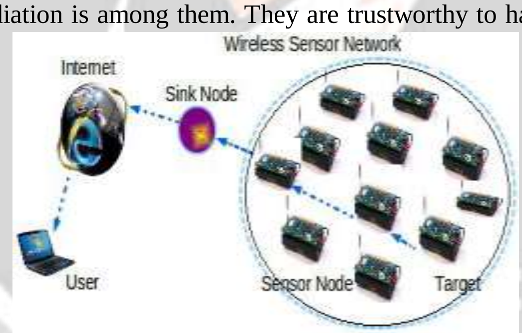

Fig. 1 Wireless Sensor Networks

WSN composed of radiation detectors are deployed at different locations over the area of interest. Detection and location have been proposed on the basis of physical law that radiation received by a sensor is composed of background plus a signal and signal rate decreases as the distance increases. Signal detection via sensor networks can be classified as decision fusion and value fusion and among them value fusion is more appropriate for radiation detection. Further passive detection where signals can be detected by measuring neutrons or gamma rays that had been emitted from radioactive material is preferred.

Deployment of most reliable sensors on the basis of energy, reliability, communication and sensing range over a wide area (large scale) can be better done through the use of optimization techniques like Genetic Algorithm and Fuzzy Logic.

3. NEED FOR DETECTION OF RADIOACTIVITY IN WATER

All the things are made of atoms. Generally atoms do not transform to other atom all by themselves i.e. they are stable. Radioactive atoms transform to other atoms impulsively due to instability. Once a radioactive atom undergoes such a transition, it transforms to a stable atom. The process is called "decay" or "disintegration". When radioactive material decays into stable material it also results in the release of ionizing radiation. These radiations have enormous energy. When they interact with other materials, they eliminate electrons from the atoms of the material and this phenomenon pose hazard to health.

More than 100 different isotopes only yielded in reactors and atomic bombs, including Iodine-131, Cesium-137, Strontium-89 and Strontium-90 are responsible for radioactivity. Radioactive elements like Iodine-131 can escape from damaged nuclear plants as a gas, and captured in atmospheric water, sometimes can create a huge radioactive cloud and pollute the existing water supplies and produce contaminated rain. Similarly, groundwater flowing over parent rock can pick up Radon and convey it to local water supplies.

Exposure of the body to radiation raises the probability of impairment to DNA, cells, tissues, chromosomes and other crucial moecules. Each radioactive decay occurs at variable rates. Example; iodine-131 can stay in the body only for some weeks since it has a half-life of only eight days. But, Strontium-90 has a half-life of 28.7 years, and as a consequence persists in teeth and bone for numerous years. Long term exposure can cause genetic mutations, death of cell, cancer, birth defects, and harm to reproductive and endocrine system. Sickness due to radiation can result in nausea, vomiting, diarrhea, skin burns, hair loss, general weakness and possibly death. Units

4. CASE STUDY

The explosion of a nuclear generator in Chernobyl (Ukraine) in 1986 formed a huge radioactive cloud that resulted in pollution of the prevailing water supplies and caused contaminated rain in neighboring countries.

The steam generator tube at Indian Point-2 shattered in February 15, 2000. During this event 20,000 gallons of radioactive coolant was discharged into the plant. This incident occurred due to the poor maintenance of the plant. The accident triggered a radioactive release to the atmosphere. One week later, 200 gallons of radioactive water was discharged into the Hudson River accidentally [1].

Radioactive toxins such as strontium-90 and tritium have been seeping from at least two of the spent fuel pools located at Indian Point into the Hudson River and groundwater since August 2005. In January 2007, strontium-90 was detected in four out of twelve fishes tested in the Hudson River [1].

In the days following earthquake that occurred in 2011 and nuclear plant explosions, water in the sea which was used to cool the nuclear power plants conveyed radioactive materials back to the Pacific Ocean. One of the major radioactive elements that spilled into sea was Plutonium.

5. CURRENT METHODS FOR MONITORING RADIOACTIVITY IN WATER

5.1. Traditional Methods

Standardization organization such as ISO has proposed various radiometric techniques such as Gamma ray spectrometry, Liquid scintillation, thin source method or thick source method. However, Gamma ray spectrometry does not provide sufficient sensitivity when applied to untreated water sample [1]. And, also practical problems arise while sampling and concentration process is time consuming. Radiochemical separation methods have to be employed for most radionuclides of interest especially if large quantities of samples (e.g., above 50 L) are required. Gross alpha and beta activity is usually measured by counting the dry residue of a water sample. The availability of low-background liquid scintillation counters equipped with alpha–beta discrimination device provides an alternative for gross alpha and beta determination. Liquid scintillation has several advantages over other traditional methods. This analytical method uses liquid chemical which is capable of converting the kinetic energy of nuclear emission into light energy. Advanced Liquid Scintillation Analysis (LSA) systems provide discrimination between alpha and beta radiations, and reliable passive and active background reduction systems. LSA variations are also currently used for U and Ra isotopes and 3H measurements. Due to the optimal detection power of the LSC technique, overall performance is usually satisfactory but spectral resolution is poor. Uranium can be measured using non-radiometric techniques (spectrophotometry, fluorimetry, atomic adsorption and atomic emission). However, these techniques, while allowing the determination of the total concentration of uranium, do not supply any information about its isotopic composition. Inductively coupled plasma mass spectrometry can be used for the determination of many radioisotopes including 99Tc, 226Ra, 235,236,238U, 232Th, and 239,240Pu, based on their masses instead of their radioactive properties.

5.2. Mass Spectrometry

Depending upon the type of ion sources mass spectrometry based on non-radiometric techniques for the quantitative determination of radionuclides is available. Among them ICO-MS based on atomization, conversion and separation of ions based on mass/charge ratio is one. Several advantages like sample matrix interferences freedom, reduced sample preparation, precise detection limits, very large dynamic range, multi-elemental screening capability and scalability have made it more popular nowadays. It reduces the use of radioactive isotopes by allowing differentiation among stable isotopes. It further allows to measure isotopes ratio. But high initial cost, daily maintenance cost and oxides and hydroxides generated interferences effecting harshly on analytical accuracy are limitations of this technique. At the same time adoption of Dynamic Reaction Cell (DRC) or Collision Cell (CC) has greatly benefitted ICP-MS. At Fukushima ICP-DRC-MS was remarkably used to screening of Strontium and Plutonium [1].

5.3. NaI Based Detection

C. Tsabaris et al. (2004) developed real time underwater sensor based on NaI scintillator to use in marine environment to measure background radiation of 137Cs. Authors have presented an idea of monitoring the radioactive levels in sea environment by developing low cost floating network. The developed system could also be used as an alarm system for water pollution and gamma ray detection [8]. Similarly, the Environmental Network Monitoring System (ENMS), which is based on NaI detector probe, has two entities namely Central station (CS) and Detection Station (DS). A number of DSs has been developed by The National Institute for Radioelements for water radiological monitoring in environmental, for example, ENMS-WGS D5b and ENMS-WGS D1b [1]. Radiation level is continuously measured by the DSs and compared to the threshold alarm level determined by the user. These systems are immersed in water and the power supply is provided through battery or solar energy.

5.4. Wireless Sensor Network

Andres Gomez et al. (2015) has presented environment monitoring self-sustainable radioactive sensor node. Radio transceiver and ultra-low power WUR were combined to transmit back the sensed data in order to periodically update a precise map of level of radioactivity in the affected area. Designed node woks in collaboration with an unmanned vehicle to continuously update and produce an accurate level of radioactivity in affected area. Proposed solution provides accurate time resolution with a low latency but at the mean time this requires aggressive duty-cycle and coarse time resolution due to polling [3]. Similarly, Li Wu et al. (2014) presented the implementation of WSNs based on Zigbee. They further designed monitoring platform in which real time data supplied by the WSN could be processed and displayed. Large amount of sensors deployed on the nuclear power plant monitor environmental conditions. These data are transmitted relayed to the Zigbee coordinators via Zigbee router when required. Then, the data is transmitted to the server via GPRS gateway. This information would be updated at the web monitoring platform. Further they have built an alarm system to indicate abnormality of the collected data. Location with abnormal data would be marked via web. But the designed system works on web not on android phone [6].

Gurkan Tuna et al (2012) deploy WSNs using mobile robots for the detection of possible radiation leakage. Their self- deploying WSN prevents rescue team/ person from direct exposure to radiation during radiation levels measurement. Mobile robots are used to deploy WSN in either autonomous or tele-operated manner in remote zone so as to measure radiation leakage in disaster zone. They have used various energy harvesting techniques like solar energy harvesting, air flow energy harvesting and modulated backscattering to increase life time of deployed WSN. Multiple robots can be used for deployment purpose. However, these systems are appropriate for terrestrial monitoring rather than under water since radio wave propagation in water are weak [13].

Methods	**Description**	**Remarks**
Traditional (Gamma ray spectrometry, Liquid scintillation etc)	Gamma ray spectrometry is based on counting the number of photons. Liquid scintillation, an analytical method uses liquid chemical which is capable of converting the kinetic energy of nuclear emission into light energy.	Gamma ray spectrometry-no sensitivity when applied to untreated water sample. Also, sampling and concentration process are time consuming. LSC –satisfactory overall performance but poor spectral resolution.

Mass Spectrometry (e.g.: ICO-MS)	Non-radiometric techniques for the quantitative determination of radionuclides Based on atomization, conversion and separation of ions based on mass/charge.	Sample matrix interferences freedom, reduced sample preparation, precise detection limits, very large dynamic range, multi-elemental screening capability and scalability. High initial cost, daily maintenance cost and oxides and hydroxides generated interferences effecting harshly on analytical accuracy
NaI based Detection (e.g.: ENMS-WGS D5b and ENMS-WGS D1b)	Real time underwater sensor based on NaI scintillator to measure background radiation of 137Cs.	Radiation level continuously measured but low sensitivity to radiation under water due to weak radio propagation in water.
Wireless Sensor Network	Deployment of environment monitoring self-sustainable radioactive sensor node which can transmit back the sensed data in order to periodically update a precise map of level of radioactivity in the affected area.	Can use alarm system. Prevents rescue team/ person from direct exposure to radiation during radiation levels measurement. Suitable for terrestrial monitoring.

TABLE 1. COMPARISON OF VARIOUS RADIOACTIVE DETECTION TECHNIQUES

6. CHALLENGES

In the natural world, there is always radiation emitted from radionuclides as they decay. Although background radiation poses little threat, they can confuse the measurement. It is difficult to differentiate between background radiation and the radiation which emanates from contamination. Determining the threshold background radiation can be a challenge.

Radio waves propagation in water is weak. Thus, it is difficult to precisely determine radioactivity taking place under water with the sensors placed outside water resource.

Being expensive, deployment of large number of high precision sensor nodes would be infeasible.

Choosing an appropriate network topology and understanding the design tradeoffs between sensor networks parameters and performance is also challenging.

Maintaining connectivity can be a challenge in case of underwater sensor network. Network connectivity may alter due to small-scale movement or surface waves, water currents or other similar effects change.

Similarly, for underwater sensor networks, maintenance is another challenging part. In a harsh underwater environment, some nodes can be misplaced and finally lost over time. Some of the possible risks include failure of waterproofing, underwater life or fishing trawlers. Therefore some redundant sensor nodes also must be deployed so that loss of a single node will not have broader effect.

In Wireless Sensor Networks energy and power consumption are another limitations. It is essential that all modules of the system operate at as low a duty cycle as possible. This problem can be solved to some extent using optimization techniques like genetic algorithm and fuzzy logic.

7. CONCLUSION

Radioactive elements can contaminate water and adversely affect human health as well as aquatic lives. Since it is difficult to manually collect water samples and test the presence of radioactive contamination in those samples, it creates the need of wireless sensor network (WSN) for radioactive contamination detection in water. This paper reviews various methods of detecting radioactive contamination in water resources using WSN, their advantages, shortcomings and challenges during implementation. There are various challenges while deploying WSN for this purpose which need to be overcome. Optimization techniques such as Genetic algorithm and Fuzzy logic can be used for the deployment of most reliable sensors on the basis of energy, reliability, communication and sensing range over a wide area (large scale).

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