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Measurement of Activity concentration of Thorium in Environmental samples by Alpha Spectrometry system

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Abstract

Background: As a part of environmental radioactivity monitoring program, it is necessary to determine the activities of alpha emitting radionuclides in the environmental samples. Identification and quantification of particle alpha emitting radionuclides such as thorium, plutonium, uranium etc. with long half-life plays a key role in environmental characterization and radiation protection. However, studies on alpha emitting radionuclide, thorium present in environmental samples are rare and deserve a systematic and extensive research work. In order to do so several environmental samples such as soil, water have been collected from the Rooppur Nuclear Power Plant area, a sunflower plant from the Curzon Hall, Dhaka university area along with a borehole water sample from Beximco Pharmaceuticals Ltd. **Method:** The measurement of the concentration of alpha emitting radionuclide, thorium, comprises of chemical dissolution of samples, chemical separation using ion-exchange method, preparation of counting source by electrodeposition and need to count by an alpha spectrometry system. Dry ashing method has been used for preparing soil and plant samples. On the other hand co-precipitation method has been used for preparing water samples. An essential requirement for the measurement of alpha emitter is the exact identification of photo peaks present in a spectrum produced by the silicon surface barrier detector system which is calibrated by the standard sources of ^{230}Th and $^{239+240}$Pu. A single photo peak observed in alpha spectrum within the energy range 4.64-4.72 MeV. This indicates the presence of ^{230}Th in soil, water and plant samples. **Results:** The measured activity concentrations of 230Th in different environmental samples were found to be in the range of 3.86 to 8.13 Bq/kg in soil; 0.32 to 0.44 Bq/L in water; 2.5 to 5.4 Bq/kg in different parts of a matured sunflower plant. **Conclusion:** Our studied will be helpful for the radiological impact on the environment after commissioning of the nuclear power plant and any other nuclear fallout could be assessed by using this baseline data. In addition, these data will be useful in the assessment of internal doses partly and the trend of public radiation exposure.

Keywords: Environmental Samples, Alpha Spectrometry System, Alpha emitting radionuclide, and Rooppur Nuclear Power Plant area.

Introduction

Thorium is widely distributed in the earth’s crust. It is about three times more abundant than uranium. Most compounds of thorium have very low solubility in water and thus have a very large residence time in the lungs following inhalations. Thorium that does become systematically incorporated translocates principally to the radiosensitive bone surfaces with an estimated half life of 8000 days [1]. The International Commissions on Radiological Protections (ICRP) has set a limit for intake by inhalation of ^{232}Th lower than ^{238}Pu because of its high specificity for the bone , long biological half life , and dose associated with subsequent progeny [2]. The liner energy transfer (LET) for alpha particle is so high and this particle is hazardous for health when internally deposited in human body. Information on the transfer of thorium into human and environment bears a considerable interest and could be useful in evaluating potential health hazard. And also study of alpha radiation in environment is necessary for radiological studies of the element in the environment. The most common ores of thorium are thorite $(Th,U)SiO_4$ and monazite $(Ce,La,Nd,Th)PO_4$. Monazite is a relatively common form of beach sand. This sand may contain up to 10 percent thorium. It can be found, among other places, on the beaches of Florida, Kerala state in India and Cox's Bazar and off-shore islands in Bangladesh. Different isotopes of thorium behave identically chemically, but do have slightly differing physical properties: for example, the densities of ^{228}Th, ^{229}Th, ^{230}Th, and ^{232}Th in g cm^{-3} are respectively expected to be 11.524, 11.575, 11.626, and 11.727. The isotope ^{229}Th is expected to be fissionable with a bare critical mass of 2839 kg, although with steel reflectors this value could drop to 994 kg [3]. However, in deep seawaters the isotope ^{230}Th becomes significant enough that IUPAC reclassified thorium as a binuclidic element in 2013. In fact, uranium ores with low thorium concentrations can be purified to produce gram-sized thorium a sample of which over a quarter is the ^{230}Th isotope [4].

Bangladesh is going to establish a nuclear reactor. So first of all we should think about the protection of public health. It is needless to say that we have the possibility to absorb alpha emitter or other radionuclide from different environmental entities such as soil and water. For this reason we need to know the radioactivity of different environmental samples as well as potential redistribution of progeny of different radionuclide in earth's crust that can assist us to take necessary steps if the radioactivity exceeds its minimum limit. So, considering these factor it is necessary to determine the activity of thorium in environmental samples for understanding its dosimetric consequence along with monitoring radioactivity of thorium in Bangladesh.

Materials and Methods

Sample Location and Sample Collection

In order to measure the radioactivity of thorium in different environmental entities such as soil and water samples were collected randomly from the Nuclear power plant site (NPP) of Rooppur. The Rooppur nuclear power plant will be built at, 200 km north-west of Dhaka, in the Ishwardi subdistrict of Pabna District, in the northwest of the country. The geographic coordinate of Rooppur for latitude and longitude are 24°03'36" N and 89°02'24" E. The location for sample collection is given below by showing a geographical map Fig 1 & 2.

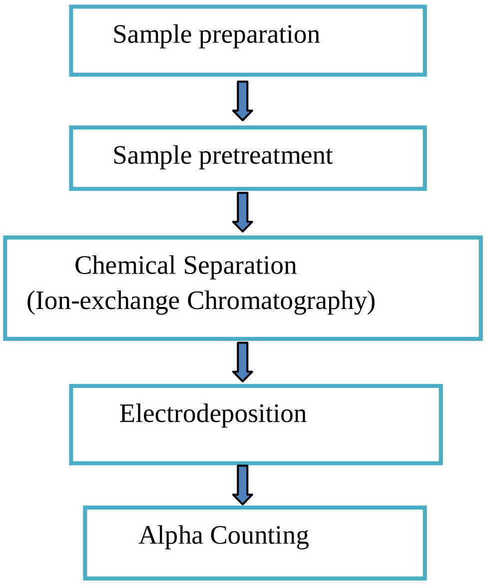
The choice of sampling was based on the regular monitoring of radiation background in and around the nuclear power plant site. The soil samples were collected fom 0-2" depth of the earth surface in the respective collection area. The water sample were collected from deep tube well, tap and river situated around the RNNP site. The samples were kept into the previously cleaned cylindrical plastic-container using manual procedure. Along with these samples a bore hole water was collected from the Baximco pharma Ltd and a matured sunflower plant was collected from the Curzon Hall area of Dhaka University.

Sample Preparation

After screening and cleaning, the soil and plant samples were sun dried. Then the plant sample was grinded into the powdered form. The dried soil and grinded plant samples were ashed in a muffle furnace by gradually increasing temperature from 450-550^{o}C to destroy organic matters, if any, to obtain a uniform ash [5]. In case of plant samples, the sample was burned for longer time in the furnace to ensure it is free from carbon. The soil sample was burned until the brick red appearance of the sample was not produced and the plant sample was burned until the white ash was not appeared. The water sample was used to radiochemical separation without any sample preparation or pretreatment.

Radiochemical Separation Procedures

A general outline of the radio-analytical procedures for the determination of Thorium in environmental samples is below. It consists of chemical dissolution of samples, chemical separation of Thorium by ion-exchange method, preparation of counting source by electrodeposition method and measurement of Thorium by Alpha spectroscopy method [6].



A flow chart showing general outline of experimental procedure

Ion-exchange Method for Soil and Plant Sample

A known amount of the sample was digested in Teflon beaker. For this purpose 10 mL conc. HNO_3, 12 mL conc. HF acid and 2 mL conc. $HClO_4$ was added to the sample. In case of plant sample H_2O_2 was used instead of HF. HF was used to remove the sand portion form the soil sample. On the other hand conc. HNO_3 acid and conc. $HClO_4$ was used to remove the oxidizing and the organic material from the soil and plant sample. The sample solution was heated at least 5 hour on the hot plate at temperature 150^oC. After evaporating the sample solution near to dryness, 100 mL 8M HNO_3 and 1 mL conc. HF was added to the sample. Further 1 mL conc. HF was added to ensure removal of sand from the soil sample. Then the sample solution was boiled at least 30 minute and then cooled at room temperature. The cooled sample solution was filtrated. The filtrate was passed into the anion exchange resin column and the residue was discarded. In this method an ion-exchange column was prepared with a glass column and a glass –wool plug. The column was filled with dowex 1x8 anion exchange resin (Cl^- form) of 50-100 mesh, conditioned with 8M HNO_3. The solution was passed through the column at the rate of 1 mL per minute. 50 mL of 8M HCl was passed through the column and the effluent was collected for thorium and evaporated at slow heat to dryness. Further 10 mL concentrated HNO_3 and 1 mL concentrated $HClO_4$ acid was added to ensure the complete removal of organic material and then the solution was evaporated to dryness. In the mean time 10 mL 0.9 M H_2SO_4 was added to dissolve the residue.

Co-precipitation Method for Water Sample

Thorium in water sample was separated by co-precipitation method. For this purpose 50.0 mL water sample was taken in a pyrex beaker. The water sample was acidified by adding 15 mL of concentrated H_3PO_4 acid. Then, 2 g $CaCl_2$ was dissolved to the water sample. The pH of the solution was changed to ~9 by addition of the ammonia solution. After changing the pH, white precipitate of $CaHPO_4$ was formed and thorium was co-precipitaed as $[Th(PO_4)_2]^{2-}$ along with $CaHPO_4$. The precipitated was centrifuged and the aliquot solution was discarded. Then, the precipitated was dissolved by adding concentrated HNO_3. Few drops of H_2O_2 was added to destroy the organic material if it is present in the sample solution. The solution was boiled at least 30 minute and after natural cooling it was passed in to the anion exchange resin column.

Electrodeposition Technique

Before electrodeposition of thorium the pH of the thorium solution was adjusted to ~1.5-2. For this purpose, 3 drops of freshly prepared thymol blue indicator was added to the solution. This was change the color of solution pink (Magenta pink). Then 2-3 mL of NH_4OH solution was added to the thorium solution and the color of the solution were changed pink to light yellow. Further few drops of 0.9 M H_2SO_4 was added which was turned yellow color to pink (Salmon pink). For electrodeposition, an improved and modified set up was designed and developed which is shown in above figure. An electrodeposition cell consists of a hollow cylinder made of polystyrene of 2 cm in internal diameter and 10 cm in length. Stainless steel planchet (2.5 cm diameter) was used as the cathode for electrodeposition and the centrally suspended platinum rod constituted the anode and also acted as a stirrer. The current and voltage of the regular power supply were measured by voltmeter 0-30 V and ammeter 0-1 A. The volume of eluted thorium solution was reduced to 25 mL by slow heating. After cooling, 2 ml of methanol was added to enhance the viscosity of the thorium solution. The current and voltages used were 60 mA and 25 volts respectively. The distance between the electrodes and the time of electrodeposition selected were 1 cm and 2 hours respectively. After electrodeposition the electrodeposited planchtte was backed 5 minutes under the IR lamp. It is mentioned that sometimes Fe^{3+} eluted from anion exchange column along with Th^{4+}. The reduction potential value of Fe^{3+}/ Fe couple is -0.04 V and Th^{4+}/Th is - 1.78 V. Due to lower reduction potential value of Th^{4+}, it reduces more readily and the Fe^{3+} remains in the solution.

Measurement of Alpha Activity

The electrodeposited planchet was placed 1cm below from a silicon surface barrier detector fitted in a standard vacuum chamber coupled with a multichannel analyser and associated electronics for alpha counting. A block diagram of Alpha spectrometry system is shown in Fig 3.The detector was operated at a bias voltage 50 volt as specified by the manufacturer and verified in our laboratory for best counting. The activity of thorium in different environmental sample such as soil, water and plant were determined from the counts obtained from computed areas of the respective alpha spectrum obtained in the multichannel analyser (MCA). The counting time was selected 10000 sec for each of the sample. The activity (A) in Bq/kg of the sample is obtained using the following relation:

$$A = {}^{N}/_{Ewt} \quad \text{--}(1)$$

Where N is the net count per sec (cps) due to selected alpha spectral area, E is the counting efficiency of the detector, W is the fresh weight of the sample (kg)) taken for analysis and t is the counting time in sec.

The efficiency and resolution of of the surface barrier detector were measured experimentally using the two standard electrodeposited alpha sources (^{230}Th and ^{239}Pu). A typical alpha spectrum of standard ^{230}Th and ^{239}Pu sources is shown in Fig.4. the counting effeiciency is found to be 15% and the resolution at full width at half maximum (FWHM) of the detector was found to be 93.24 keV.

Results and Discussion

Activity Concentration of Different Environmental Sample

The radioactivity of thorium (^{230}Th) in different soil samples and water collected from in and around the Rooppur Nuclear Power Plant (RNPP) area and different parts of Sunflower plant collected from Dhaka university campus is given in the table 1. The values of radioactivity are calculated on the basis of fresh weight. The error activity is calculated to obtain the precise value of radioactivity.

The alpha particle emission probability form a radionuclide is denoted by P_α. The alpha emission probability P_α was reported 76.3 % for ^{230}Th and 21.7 % for ^{232}Th in certain energy of alpha particle. So once again we can say that in terms of alpha activity ^{230}Th is higher than ^{232}Th, but while considering mass, ^{232}Th would be 1.5×10^5 times more than ^{230}Th. In our alpha spectrum obtained from different environmental sample we got a single photo peak with maximum count at energy about 4.68 MeV, which is the consistence to the energy of ^{230}Th (4.62 to 4.68). No peak was obtained to the corresponding ^{232}Th energy range (3.95 to 4.01 MeV). Due to high suction of sample source chamber the daughter radionuclides of ^{230}Th do not get chance to interfere in the alpha spectrum.

The typical concentration range of thorium in soil is 2-12 μg/g (ppm), with an average value of 6μg/g [9]. The thorium content of soil normally increases with an increase in clay content of soil. In most soil, thorium will remain strongly sorbs onto soil and the mobility will be very slow. The presence of ions an ligands (CO_3^{2-}, humic matter) that can form soluble complexes with thorium should increase its mobility in soil. Chelating agents produced by certain microorganisms (*Pseudomonas aeruginosa*) present in soils may enhance the dissolution of thorium in soils. The solubilisation of ^{230}Th is higher than the ^{232}Th due to small size of ^{230}Th. That's why the deposition of ^{230}Th is not at rest. So the distribution of ^{230}Th in soil sample widely varied from soil to soil. In our experiment the calculated alpha activity value of ^{230}Th in ten RNPP soil samples vary widely between 3.86 to 8.13 Bq/kg. The alpha activity of ^{230}Th ranged from 4.44 to 16.30 Bq/kg in soil sample collected from in and around the Dhaka city was reported [5-6]. Another alpha activity value of ^{230}Th in the analysed soil samples was reported to be the range of 32.5-60.5 Bq/kg [7]. Both of this reported maximum activity value exceeds our measured value. The radioactivities of environmental sample (soil, water) randomly changed due to excavating of land and enhance mobility of radioisotopes in soil and water surface. So it is not possible to get consistence result of radioactivity in environmental sample. To compare the activity concentration of ^{230}Th in different soil sample collected from in and around the Roop pur Nuclear Power Plant site (RNPP) a bar graph is shown in Fig.5. It is observed that the activity concentration level of ^{230}Th in ten soil sample collected from different location possesses no potential variation. That means the distribution of alpha emitting radionuclide, ^{230}Th in soil sample around the Roop pur Power Plant site (RNPP) is more or less same. In spite of this soil sample, the highest alpha activity, 8.13 Bq/kg and soil sample the lowest alpha activity, 3.86 Bq/kg. From the sample collection geographical map given in sample collection section, it is noticed that soil sample 5 collected from Ishwardi and soil sample 2 collected from Pakshi. Soil sample 4 and soil sample 6 also collected form Ishwardi containing alpha activity 6.40 Bq/kg and 7.06 Bq/kg. So we can assume that the surface soil of Ishwardi abundant with natural radionuclide ^{230}Th compare than other sample collected area. As ^{230}Th comes from ^{238}U decay series, in another word we can say that the activity of ^{238}U in surface soil of Ishwardi is higher than the other collected area. Sample 1 was collected from the RNNP site it also possesses a significant amount of ^{230}Th alpha activity, 7.60 Bq/kg.

Compared to uranium, relatively less information was located on the levels of thorium in natural waters. The concentrations of dissolved thorium in water with high pH (more than 8) are expected to be very low, and the concentration may increase with the decrease of pH. For example the concentration of dissolve thorium in an alkaline lake was up to 8.1×10^{-5} Bq/L (2.21pCi/L). The dissolve thorium concentration can increase by the formation of soluble complexes. The anions or ligands likely to form complexes with thorium in natural water are CO_3^{2-} and humic materials; although some of the thorium-citrate complexes may be stable at pH above 5 [8]. It was reported that the activity concentration of ^{232}Th rarely exceed 0.1

pCi/L (3.7 x 10^{-6} Bq/L) in natural water, but the activity concentration of ^{230}Th, a progeny of ^{238}U, may be as high as 0.4 pCi/ L (1.4 x 10^{-5} Bq/L). In natural surface water in Austria, the concentration of thorium (isotope undefined) was reported to be 1.24-2.90 μg/L. The activity concentration of ^{230}Th in water under low pH condition which may occur from the leaching of uranium tailings may be as high as 38 mg/L [9]. The activity concentration of ^{230}Th in a lake (Mono Lake) of California had been reported to be as high 1.41 pCi/ L (5.2 x 10^{-5} Bq/ L) [10]. Thorium also been detected in ground waters. In groundwater in Austria, concentrations ranged from 0.5-2.90 μg/L. In a California well, thorium-230 was detected at a concentration as high as 1.3 pCi/L (4.8 x 10^{-5} Bq/L). The average concentrations of ^{232}Th and ^{230}Th in United States community water supplies derived from both surface water and groundwater are less than 0.01 pCi/L and less than 0.04 pCi/L, respectively [8]. Another reported value for the activity concentration of ^{230}Th in water sample was 0.0008-0.0258 mBq/L [11]. In present study the activity concentration of ^{230}Th in pond surface water varied from 0.32 to 0.44 Bq/L. The activity concentration of river surface water varied from 0.26 to 0.38 Bq/L. The activity concentration of ground water such as tube well water, tap water and bore hole water vaired from 0.40 to 0.21 Bq/L. All of reported value do not possesses so much consistency with our studied activity concentration value of ^{230}Th. Again radioactivity is not fixed value it changes with time and the change is monitored by ongoing studies. To compare the activity concentration of ^{230}Th in different water sample collected from in and around the Roop pur Nuclear Power Plant site (RNPP) a bar graph is shown in Fig.6. From the graph we can observe that pond water 2 contains highest value of radioactivity, 0.44 Bq/L among all of water sample. Pond water 2 was collected from north side of Pakshi paper mill. Pond water 1, 3 and 4 which was collected from different location of pakshi contain ^{230}Th activity concentration 0.32 Bq/L, 0.34 Bq/L and 0.36 Bq/L respectively. The average activity concentration is calculated as 0.36 Bq/L. River water 2, collected from Pakshi contains highest extent of ^{230}Th activity concentration than other two river water. ^{230}Th activity concentration in river water are 0.26 Bq/L, 0.38 Bq/L and 0.28 Bq/L respectively. The average activity concentration is calculated as 0.30 Bq/L. Among all of ground water sample tube well water 2, collected from Ishwardi possesses highest value of ^{230}Th activity concentration. The observed value of ^{230}Th activity concentration in tap water, tube well water 1 and tube well 2 is 0.29 Bq/L, 0.36 Bq/L, and 0.40 Bq/L respectively. The average activity concentration value of all ground water is 0.35 Bq/L. Another bar graph based on the average activity of different type of water sample is shown in Fig.7. It is observed that pond water contains high extent of ^{230}Th activity concentration rather than ground and river water.

In a sense we can say that ground water contains highest value of radioactivity due to presence of natural occurring radionuclide in the earth crust. But this sense is not always true sometimes surface water contain higher value of radioactivity than ground water. This is because the radionuclides present in the ground water are more mobile rather than radionuclides present in surface water. In ground water, radionuclide can come to contact with anions, ligands and humic materials easily. Most of the radionuclide form soluble complexes with this material and displace from their depositing place. This is one of the reasons for varying of activity concentration of natural occurring radionuclides from one place to another in a certain region.

If we compare activity concentration of ^{230}Th between pond and river water, river water contain less ^{230}Th activity concentration rather than pond water. As if both are surface water but their activity concentrations vary widely. In this case we can assume that pond water in confined in a certain space whereas river water is not confined and it is widely flowed. That’s why mobility of radionuclides in river water is more enhanced than pond water. So activity concentration varied widely between pond and river surface water. Another ground water named as bore hole water collected from Beximco Pharmaceuticals Ltd. contains ^{230}Th activity concentration 0.21 Bq/L. This water is used for Pharmaceuticals purpose so it is refined ground water. For this reason this water contains least ^{230}Th activity concentration among of all water samples.

The plant/soil transfer ratio for thorium is less than 0.01, indicating that it wills not bio-concentrate in plants from soil. However, plants grown at the edge of the impoundments of uranium tailings containing elevated levels of thorium had a plant/soil concentration ratio of about 3. This indicates that most of the thorium accumulated in plant system comes as a progeny of uranium decay series. Vegetation concentration ratios for thorium-232 (a concentration ratio of about 0.1) and thorium-228 (a maximum concentration ratio of about 0.4) were lower than that of thorium-230. The root systems of grasses and weeds adsorb thorium from the soil but the transport of thorium from the root to the aboveground parts of the plant is not very extensive, as indicated by l00-fold higher concentrations of all three isotopes (thorium-228, thorium-230, and thorium-232) in the root than in the aboveground parts of the plant [12]. Sunflower (*Helianthus annuus*) is of the most promising environmental crops that is being used in diverse situations for environmental clean-up. It is the most promising terrestrial candidate for metal and radionuclide removal from water and soil. Terrestrial plants are thought to be more suitable for rhizofiltration because they produce longer more substantial, often fibrous root systems with large surface areas for metal sorption. In our experiment the activity concentration of ^{230}Th in different parts of a matured sunflower plant was found 2.5± 0.005 Bq/kg to 5.4 ± 0.008 Bq/kg. Generally sunflower absorbs uranium vigorously than thorium due to lower solubility of thorium. In our experiment we do not found any ^{232}Th in sunflower plant but we found ^{230}Th. It indicates that sunflower mainly absorbs uranium and we get ^{230}Th in different parts of sunflower plant as a progeny of uranium decay series. The activity concentration of ^{230}Th in agricultural samples, such as fresh vegetables, root vegetables was reported in our country having a range of 0.05 to 0.34 Bq/kg [6], which are less than our observed value found in different parts of the sunflower plant. It is one of the indications that sunflower plant is highly radionuclide accumulator. To compare the activity concentration of ^{230}Th in different parts of the sunflower plant a bar graph is shown in Fig.8. From this bar graph we can see that the amount of activity concentration ^{230}Th in different parts of sunflower plant, such as root, stem, leaf and flower are gradually decreases. The highest activity concentration of ^{230}Th was found in roots, 5.4 Bq/kg and lowest activity concentration of ^{230}Th was found in flower 2.5 Bq/ kg. It is strong evidence that transport of thorium from the root to the aboveground parts of the plant is not very extensive.

Measurement of radioactivity of ^{230}Th after radiochemical separation has been accomplished by alpha spectrometry method followed by electrodeposition of sample solution. The radioactivity of ^{230}Th in soil and water samples collected from in and around the under constructed Rooppur Nuclear Power plant (RNPP) site must be useful as baseline data for the purpose of detecting any changes in radioactivity in future. Rooppur Nuclear Power plant will be operated by using uranium fuel. Our studied radionuclide ^{230}Th only comes from as a progeny of uranium decay series. So, radiological impact on the environment after commissioning of the nuclear power plant and any other nuclear fallout could be assessed by using this baseline data. In addition, these data will be useful in the assessment of internal doses partly and the trend of public radiation exposure. The distribution of ^{230}Th in different parts of the sunflower plant has been investigated. The activity concentration of ^{230}Th in different parts of sunflower plant is higher than that of some reported value of agricultural sample. So, sunflower plant acts as highly radionuclides accumulator. This accumulation process is known as rhizofiltration. Rhizofiltration has been employed using sunflower in a U.S. Department of Energy (DOE) pilot project with uranium waste at Ashtabula, Ohio, and on water from a pond near the Chernobyl nuclear plant in the Ukraine. In future, if our country starts the project of phytoremadiation technologies to clean up contaminated radionuclides from soil and water then the measured activity concentration of ^{230}Th in sunflower plant will be base line data. The sun flower plant was collected from Curzon hall area, University of Dhaka. In addition, the activity concentration of ^{230}Th will give partial information about the radioactivity level around the Curzon hall. The activity concentration of ^{230}Th in pharmaceutical refined borehole ground water has been investigated. This activity concentration data of ^{230}Th will be helpful to mitigate the contamination of natural occurring radionuclide in to the pharmaceuticals products.

Acknowledgement

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Figures and Tables

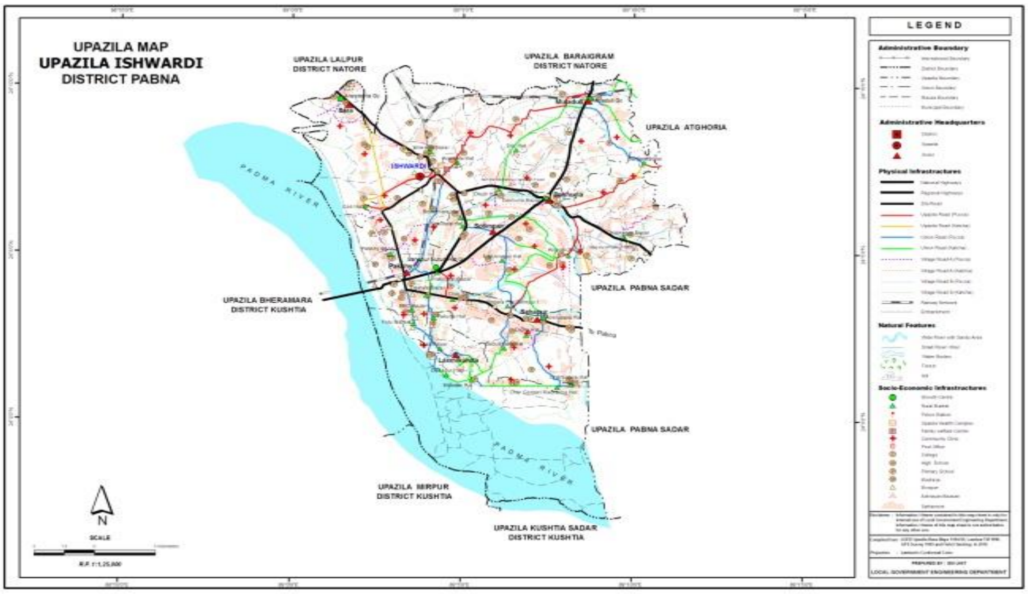

Fig. 1. Map of Ishwardi sub district

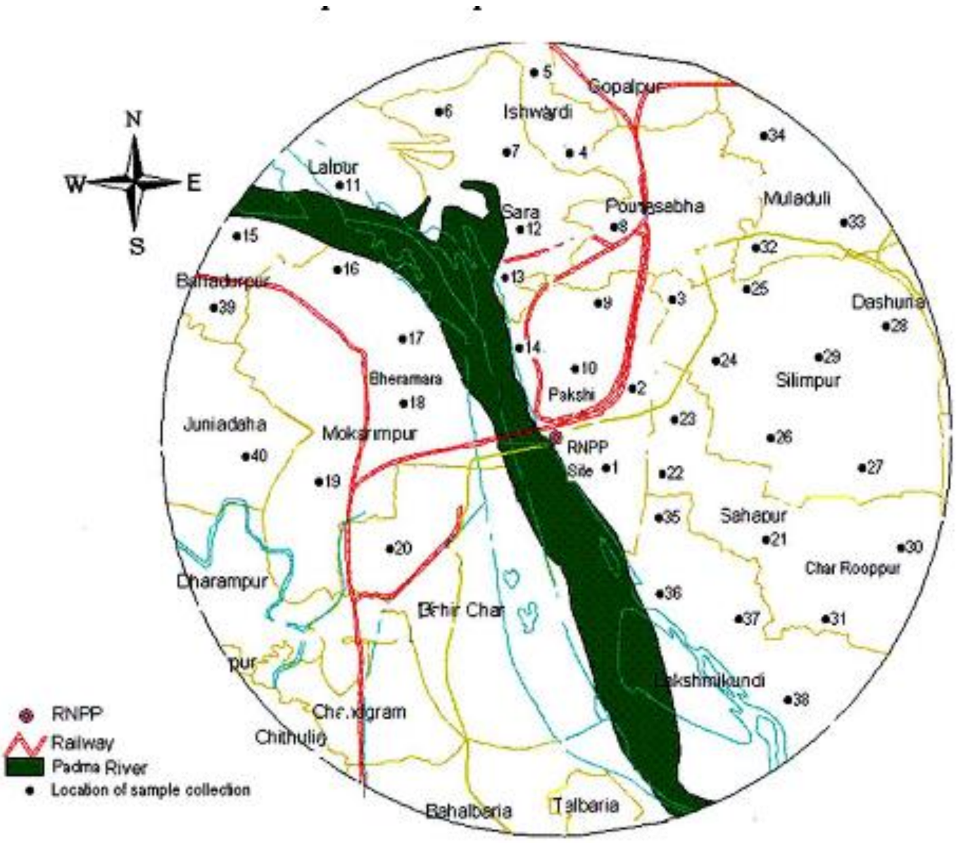

Fig. 2. Geographical map of sample collection area

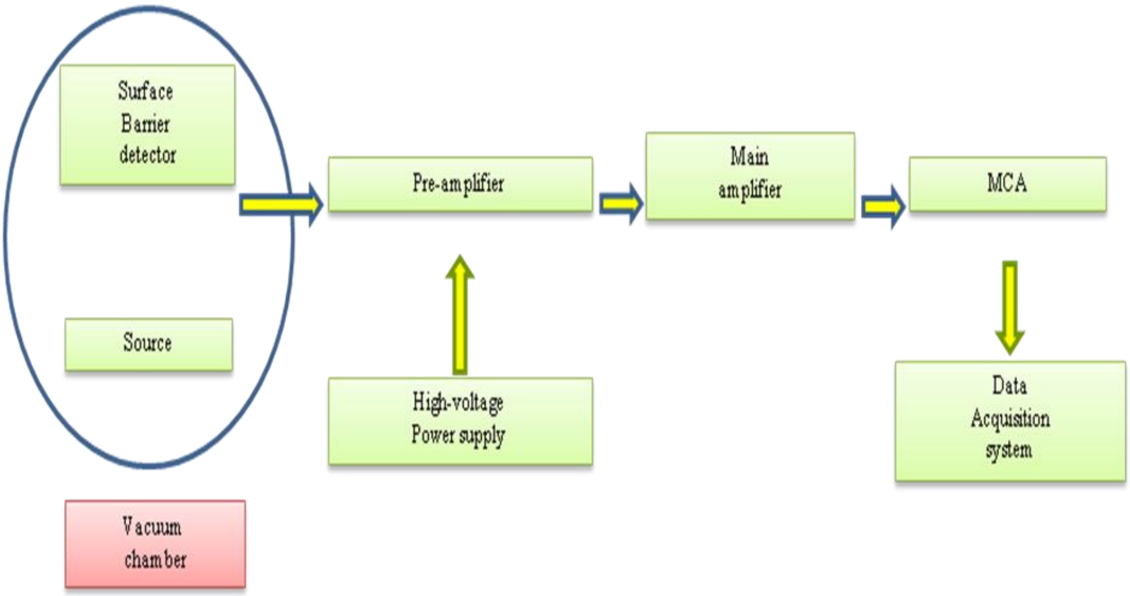

Fig. 3. A block Diagram of Alpha spectrometry system

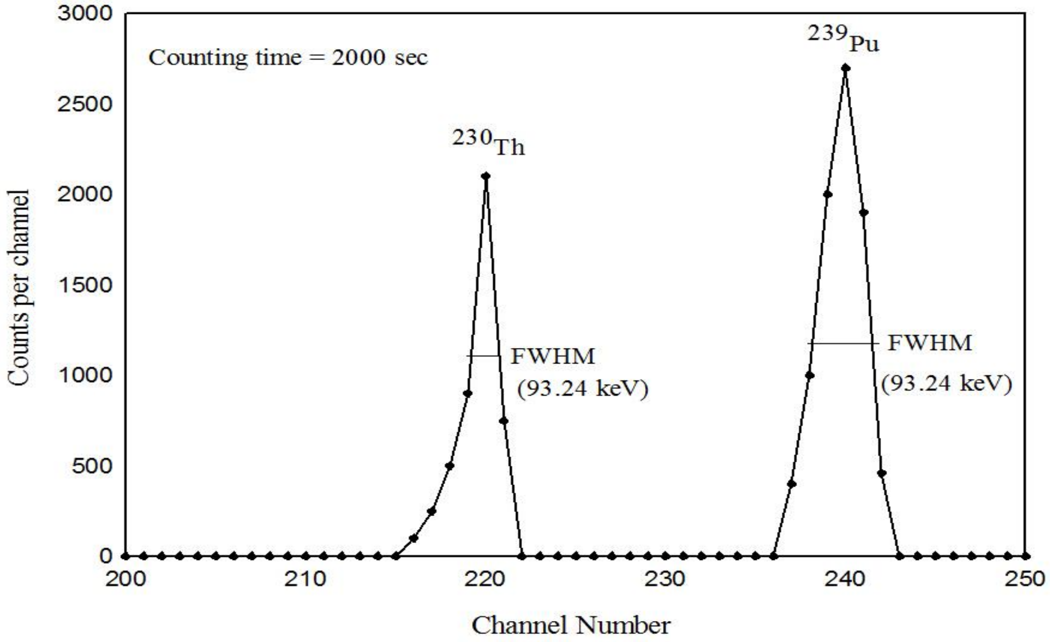

Fig. 4. A typical alpha spectrum of 230Th and 239Pu obtained by a high resolution silicon surface barrier detector

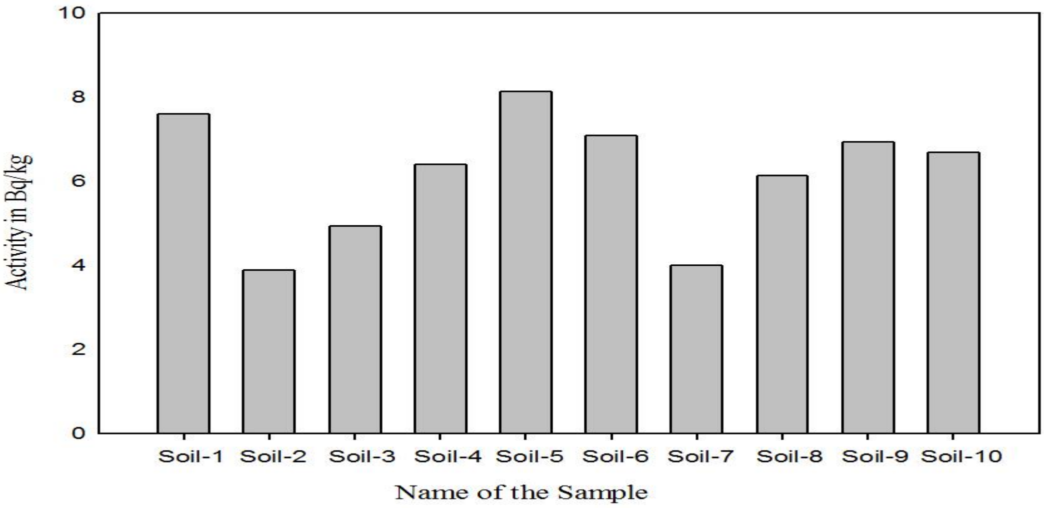

Fig. 5. Comparison of activity concentration among different soil samples collected from in and around the RNPP site

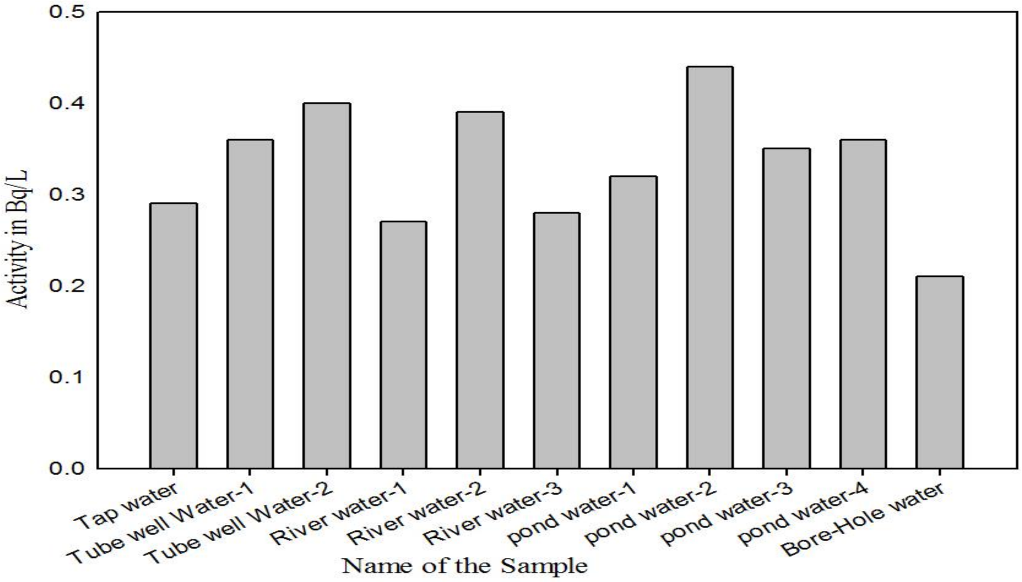

Fig. 6. Comparison of activity concentration among different water samples collected from in and around the RNPP site

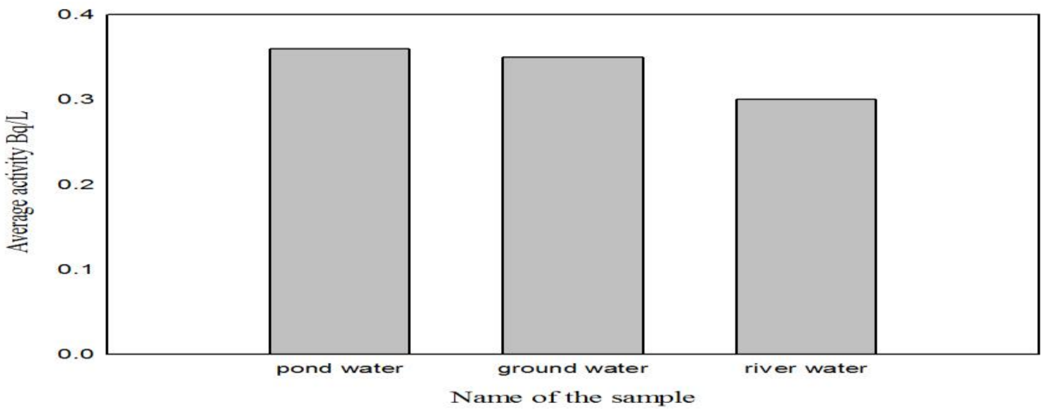

Fig.7. Comparison of average activity concentration among different types of water sample

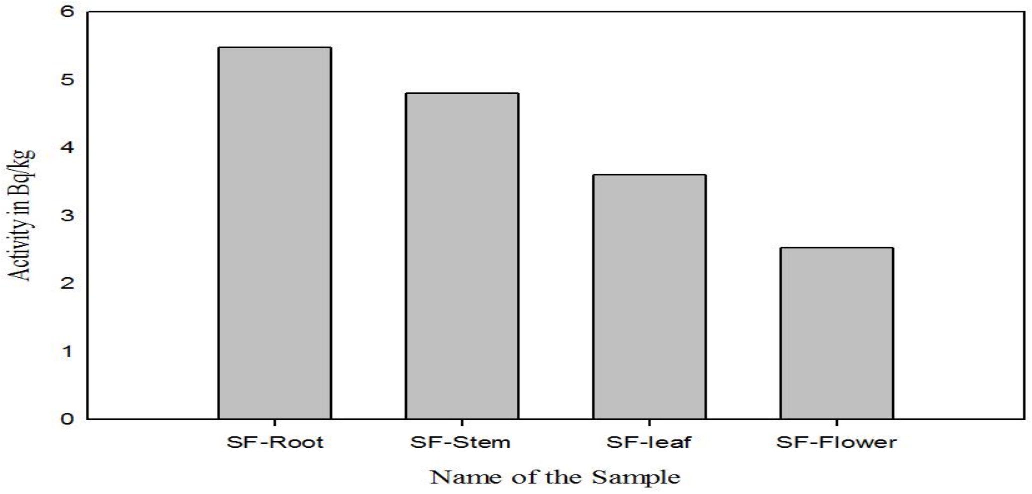

Fig. 8. Comparison of activity concentration among different parts of sunflower plant sample

Table-1. Radioactivity of thorium (^{230}Th) in different RNPP soil samples

Type of sample	Name of sample	Activity in Bq/kg or Bq/L
Surface Soil of RNPP site	Soil 1	7.60
	Soil 2	3.86
	Soil 3	4.93
	Soil 4	6.40
	Soil 5	8.13
	Soil 6	7.06
	Soil 7	4.00
	Soil 8	6.13
	Soil 9	6.93
	Soil 10	6.66
Different type of water sample from RNPP site	Tap water	0.29
	Tube well water 1	0.36
	Tube well water 2	0.40
	River water 1	0.26
	River water 2	0.38
	River water 3	0.28
	Pond water 1	0.32
	Pond water 2	0.44
	Pond water 3	0.34
	Pond water 4	0.36
	Borehole ground water	0.21
Different parts of Sunflower plant	Root	5.4
	Stem	4.8
	Leaf	3.6
	Flower	2.5

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