

# Separation Cum Pre-Concentration Technique for Determination of Uranium in Sea, Brine and Ground Water at Nano to Sub nanogram Levels

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## ABSTRACT

Investigations were carried out for separation/pre concentration of uranium from aqueous solutions of different TDS using Powdered Activated Carbon (PAC). Parameters like amount of PAC, contact time, pH, volume of solutions and reagents for desorption were optimized. The sorption of uranium is more than 95% at pH 4-5 using 0.5 gram PAC with a contact time of 10 minutes. The sorbed uranium on PAC is recovered using 0.8N HNO<sub>3</sub> and determined by LED Fluorimetry. Method was successfully applied to ground water, sea water and brine water. Methodology is simple, selective, cost effective with minimal skills. RSD of the method varies  $\pm$  6-14 %.

**Keywords :** Uranium, PAC, Separation, Pre Concentration, Ground Water, Sea Water, Brine Water

## I. INTRODUCTION

Uranium (U) gets leached in to ground water or surface waters through rocks, soils, agricultural inputs etc. Similar to many other heavy metals, uranium is also toxic to humans and animals. The most toxicological end point is damage to the kidney through chemical interactions [1]. Various geochemical surveys are in vogue in order to find out economically viable uranium deposits. Hydro-geochemical survey is one of the most widely used exploration techniques, to locate buried uranium deposits in soil-covered areas. It also helps in narrowing down the target areas and to delineate anomalous zones favorable for uranium. Due to the limitation of the techniques available for quantifying uranium below 1 ng/mL, some of the areas go uninterpreted which may be the promising areas for the uranium exploration program. Hence, ground-water samples require to be analyzed down to 0.01 ng/mL for a meaningful interpretation of the data

which demands pre-concentration prior to analysis. In this study, the authors developed a simple separation and pre-concentration method based on the sorption of uranium using powdered activated carbon (PAC), resulting in enrichment factor of 200 for below 1 ng/mL uranium values in ground-water samples. Uranium separated prior to determination in high Total Dissolved Solids (TDS), sea and brine water samples.

The concentration of uranium (U) in ground, sea, and brine water is at ppb levels. There are several techniques available for the determination of uranium at trace levels [2-6] but they are not sufficiently sensitive at sub ppm and ppb levels and could not be employed as field techniques. Even though, inductively coupled plasma quadrupole mass spectrometry (ICP-QMS) is capable of uranium determination at ppb level, it is sensitive to the sample matrix. Samples like sea, brine, and high TDS ground-water samples cannot be feed to the ICP-MS

directly. Hence it requires a separation step [7] prior to uranium determination and thus is limited for use in field applications. Robbins et al. [8] reported a field procedure for the determination of uranium in natural water by laser-induced fluorimetry. The method is rapid, does not involve separation, and can be directly applied as a field technique. Though this technique is capable of determining uranium at ppb levels it suffers interference from dissolved organic matter, manganese, iron, and high TDS. The phosphate salts used as fluorescence enhancing reagents cannot tolerate high concentrations of calcium, magnesium and background electrolytes which form insoluble phosphates and leads to erroneous values. Sea water and brine water contains high concentrations of chloride, which acts as a strong quencher, reduces uranium fluorescence intensity, and even the standard additions method is also not feasible for direct determination. In addition to chloride, high TDS also limits direct determination of uranium due to physical interference of calcium and magnesium which forms insoluble phosphates with fluorescence enhancing buffer, hence, it needs to be separated from the matrix. In this context, the authors developed a simple rapid simultaneous separation and pre-concentration method for the determination of traces of uranium in high TDS natural waters, sea, and brine water. Uranium is commonly separated and pre-concentrated by precipitation methods [9–11], ion exchange and chromatographic methods [12–15], extraction methods [16–19], and sorption methods [20–22]. Each of these methods has merits and limitations in their application. Of these methods, the adsorption methods are front runners for the separation and pre-concentration of uranium in natural ground, sea, and brine waters to determine at nano to sub nano gram levels because of their simplicity and selectivity. Various adsorbents such as olivine rock [23], coir pith [24], kaolinite [25], bio mass [26], goethite [27], modified rice stem [28], and activated carbon [29-30]

are used by many researchers for either removal or separation of uranium. Activated carbon is the most effective and economic material because of its stability, simplicity, selectivity, easy availability, re-generation, and re-use. Mellah et al [29] used granular activated carbon for removal of uranium at pH 3 with a contact time of 240 minutes. Karadeniz et al [30] carried out investigations on the adsorption of uranium using activated carbon, and the optimum parameters were pH 3 with a shaking time of 3 hours. In both of these cases, the pH is acidic and requires a higher contact time which limits their application to an exploration program where a large number of ground-water samples used for exploration studies. Hence, these authors tried to apply powdered activated carbon, for the simultaneous separation and pre-concentration of uranium at a near to neutral pH with less contact time. Earlier, some authors used the powdered activated carbon (PAC) extensively for the pre-concentration of transition metals, rare earth elements and platinum group elements (PGE), and the PAC is further extended for pre-concentration of uranium and removal of uranium [31], [32]. The most common salts of uranium in natural waters are carbonates, chlorides, sulfates, phosphates, nitrates, etc. Uranium forms complexes with chlorides and sulfates which are predominant anions in ground, brine, sea-waters, and gets sorbed on powdered activated carbon. In carbonate-bearing water and sea-water, uranium forms a strong complex with carbonate and the predominant species is  $UO_2(CO_3)_3^{4-}$  [33]. At pH 4 – 5, most of the carbonate presents in sea and ground water is destroyed and uranyl ions set free to form complexes with other ions and get sorbed on PAC to give quantitative sorption within 10 minutes. After sorption on PAC, maximum uranium recovery was obtained by leaching with 0.8N nitric acid. These investigations are presented in this paper.

## II. METHODS AND MATERIAL

### A. Instrumentation

1. LED (Light Emitting Diode), Fluorimeter, LF-2 supplied by Quantalase Enterprises Private Limited, India was used for uranium measurements at ppb levels by the present preconcentration method. The instrumental specifications are given in Table 1.

2. Pellet Fluorimeter (ECIL make, India) was used for the measurement of uranium in sufficiently pre-concentrated water samples by treating with aluminum nitrate and solvent extraction with ethyl acetate. A suitable aliquot was evaporated to dryness in platinum blanks, fused with flux, and fluorescence measurements are taken.

### B. Reagents

1. Powdered Activated Carbon (PAC), Sd-Fine chemicals, commercially available was used. PAC was purified by boiling with 1.6 M HNO<sub>3</sub> to remove impurities. Details of PAC are given in Table 2.

2. Tetra Sodium Pyrophosphate deca hydrate, Emparta, ACS (Merck Specialties Private Limited) was used.

3. Nitric acid (Assay: 70%, ExcelsaR, Qualigens, Fisher Scientific) was used.

4. Ortho Phosphoric acid (Assay: 88%, ExcelsaR, Qualigens, Fisher Scientific) was used for pH adjustment.

5. Deionized water was used throughout this work.

6. Tetra Sodium Pyrophosphate buffer: 5 gm of Tetra Sodium Pyrophosphate was dissolved in 100 mL distilled water and the pH adjusted to 7 to 7.5 using dilute phosphoric acid. This solution is referred as buffer in the text and acts as a fluorescence enhancing reagent.

### C. Standard Solutions

1. Standard stock solution of uranium (VI) of 1 mg/mL was prepared by dissolving an appropriate quantity of U<sub>3</sub>O<sub>8</sub> (Uranyl nitrate UO<sub>2</sub>(NO<sub>3</sub>)<sub>2</sub>·6H<sub>2</sub>O;

Assay: 98-102%, GR Grade (Loba Chemie) was ignited to 850°C in a furnace to form U<sub>3</sub>O<sub>8</sub> in a minimum amount of nitric acid, and then further diluted to 1 litre with quartz distilled water.

2. Working standard solutions of U<sub>3</sub>O<sub>8</sub>, 1 mL=100 µg, 1mL=10µg, 1mL=1µg, were prepared fresh by appropriately diluting the standard stock solution.

3. Calibration standards of U<sub>3</sub>O<sub>8</sub>, 1 ng/mL, 2 ng/mL, 10 ng/mL, 20 ng/mL, 50 ng/mL and 100 ng/mL were prepared in 50 mL volumetric flasks by adding 4 mL of Tetra Sodium Pyro phosphate buffer.

### D. Collection of Ground-water and Sea-water samples

From various parts of Andhra Pradesh, ground water from bore wells, brine and sea water samples were collected in polythene bottles after washing with deionized water followed by drying before collection. These samples were filtered through 0.45 micron Whatman filter paper and finally acidified with nitric acid to a pH at approximately 2.

### E. Pre concentration Procedure

Two liters of sea water or brine water or ground water was taken and the pH adjusted to 4-5 with dilute HCl. Then 0.5 g PAC was added and left standing for 10 minutes with occasional stirring, and the solution filtered using a 540 Whatman filter paper. Uranium sorbed on PAC is recovered by leaching with 0.8N nitric acid. The ground-water samples were filtered through Whatman 540 filter paper, washed with 0.8N HNO<sub>3</sub>, the solution dried on a water bath to evaporate the acid and then made up to 10 mL volume by adding 1 mL buffer. Uranium was determined by the LED fluorimetric technique. In case of sea water, the volume was made up to 10 mL after evaporation of the acid on a water bath. It was then further diluted 10 times prior to uranium determination by LED fluorimetry after addition of 1 mL buffer.

### III. RESULTS AND DISCUSSION

To keep blank values very low, PAC (purified by boiling with 1.6M HNO<sub>3</sub>), acids and water were purified as the uranium concentration is at nano gram levels in water. In the present investigations, the sorption of uranium from the aqueous solutions on PAC was carried out at 10 nano gram level. Various experimental parameters, such as like effect of pH, quantity of PAC, time of contact, effect of volume, were studied using ground-water spiked with 10 ng/mL uranium and the optimized parameters were applied to sea-water and brine-water samples.

#### A. Effect of pH

Studies were carried out from pH 1 to 10, to optimize the pH for the quantitative sorption of uranium on 0.5 g of PAC for one liter of natural ground-water doped with 10 µg uranium with contact time of 2 hours. Uranium from the aqueous solutions is sorbed quantitatively (>95%) on PAC at pH 4 to 5. At pH 3 and pH 6, uranium sorption was 81% and 85%, respectively; at pH 2 and pH 7 uranium sorption was 50%; at pH 1 and pH 9, sorption was coming down to 20% and 16%, respectively. At pH 10 it is further comes down to 10%. The results are shown in Figure 1. The percent sorption of uranium decreased drastically above pH 6 is due to the presence of carbonate and bicarbonate ions which affect the uranium sorption.

#### B. Effect of Quantity of PAC

To optimize the quantity of PAC for quantitative sorption of uranium, at pH 4 to 5 with 1 litre of natural ground water doped with 10 µg uranium which corresponds to 10 ng/mL, with a contact time of 2 hours, studies were carried out with 0.1 to 2.0 g of PAC. The sorption of uranium gets increased from 0.1 to 0.5 g of PAC, and remains almost constant even up to 2.0 g. The results are shown in Table 3. When 0.1 g of PAC was used, the recovery of uranium was

around 88%. This indicates that PAC may be insufficient for complete sorption of uranium. Hence, keeping in view the maximum concentration of uranium at 5000 ppb in ground-water and 3 ppb in sea-water, the PAC quantity was fixed at 0.5 g for 1 liter volume. For calcium-rich and magnesium-rich ground-water samples containing very low concentrations of uranium, it may be necessary to start with a large volume of sample solution to achieve a high enrichment factor. In such cases, the quantity of PAC may be increased accordingly.

#### C. Effect of Contact Time

The quantitative sorption (>95%) of uranium from the aqueous phase onto a solid phase, i.e. PAC, depends on the contact time of the two phases. Studies were carried out at pH 4 to 5 with one liter of natural ground-water doped with 10 µg of uranium using 0.5 g of PAC up to 2 hours right from instantaneous filtration. The results listed in Table 4 indicate that sorption of uranium is > 95% within the first 10 minutes of contact time of the two phases. At contact time of 10 minutes and above, it was found experimentally that highly reproducible results were obtained (see Table 4).

#### D. Effect of Volume

Samples having high concentrations of chloride and TDS with an uranium concentration <1 ppb requires simultaneous separation and pre concentration of uranium from the rest of the matrix. The pre concentration factor should be high enough to raise the uranium concentration several times above the detection limits of the LED fluorimeter in order to have highly reliable and reproducible values. Also, with the high enrichment factor, the effect of procedural blank is negligible. Thus, in order to see the effect of volume, studies were carried out with varying volumes of natural ground water from 100 mL to 2000 mL at pH 4 to 5 with 0.5 g of PAC and a contact time of 10 minutes. The results obtained are

given in Table 5. Recoveries were found to be quantitative, indicating that the sample volume can be increased up to 2 liters with the optimized parameters.

#### E. Desorption Studies

Either dry ashing of carbon or leaching with mineral acids can be used for desorption of uranium from PAC. Since dry ashing is a time-consuming procedure, the authors studied the desorption using mineral acids. The most common mineral acids used are hydrochloric acid, nitric acid, sulfuric acid and phosphoric acid. Phosphoric acid and sulfuric acid are unsuitable as desorbing agents for uranium as their boiling point is very high and hence, the complete removal of acids by evaporation before determination of uranium by LED fluorimetry is a tedious process. As chlorides of HCl act as quencher during fluorescence measurement of uranium, nitric acid was preferred for desorption of uranium from PAC and the recovery was more than 95%. In order to optimize the concentration of nitric acid, studies were carried out with various concentrations of HNO<sub>3</sub> from 0.2 to 0.8N HNO<sub>3</sub>. With 0.8N nitric acid (5%), uranium recovery was more than 95%, hence 0.8N nitric acid was fixed as the optimum parameter for desorption of uranium from PAC. The results are given in Table 6.

#### F. Effect of Other Ions

The effect of various anions and cations on uranium sorption was also carried out in ground water samples of varying TDS. The results in Table 7 show that the effect of anions and cations on uranium sorption is negligible.

#### G. Repeatability of the Method

Experiments were conducted to test the repeatability of the method by taking 2 liters of four ground water samples and one sea water sample in quadruplicate. The procedure followed for the pre-concentration

was same as the described earlier and the RSD of the method varied from 6 to 14%.

#### H. Accuracy of the Method

Due to non-availability of standard sea-water, brine-water and ground-water samples in our laboratory, the accuracy of the present method was checked by spiking one liter of natural and synthetic ground-water and sea-water after treating them with 0.5 g of fresh PAC at pH 4 to 5 to remove more than 99% of uranium present in the samples. Synthetic ground-water and sea-water samples were prepared by dissolving appropriate concentrations of Na, K, Ca, Mg, Cl<sup>-</sup>, HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, etc, in ultra pure deionized water. These natural and synthetic ground-water and sea-water samples were spiked with 10 ng, 100 ng, 1000 ng, and 10,000 ng of uranium corresponding to 0.01 ng, 0.1 ng, 1 ng and 10 ng of uranium, respectively. The percent recovery was more than 95% and the results are given in Table 8. This indicates that the method is accurate, reliable, and independent of matrix effect on the sorption of uranium.

#### J. Application to Sea-water, Brine-water and Ground-water Containing U <1 ppb

Sea-water contains high concentrations of chloride, sodium, calcium, sulphate, and magnesium ions along with uranium at the ppb level. Uranium determination cannot be carried out directly by LED fluorimetry, and requires separation from the matrix to eliminate the chloride interference and the effect of high concentration of calcium and magnesium salts which form insoluble phosphates. By the present method, uranium can be easily determined by LED fluorimetry after its separation, unlike Pellet fluorimetry which involves use of salting out agent, corrosive solvent, flux, platinum blanks, furnace, and lengthy procedures.

Two litres of sea-water and brine-water samples were processed by the procedure described above, and the

uranium was determined by LED fluorimetry. The values obtained by LED fluorimetric technique are comparable with the pellet fluorimetric technique and the results are given in Table 9.

In some of the areas where uranium in ground water is less than 1 ppb (one nano gram per milliliter) goes undetected due to the non-availability of quantifiable uranium values. But the ground water samples require to be analyzed down to 0.01 ppb for meaningful interpretation of data of the specific areas, which demands pre-concentration prior to analysis. Even the determination of uranium at very low levels, requires a separation of the precipitating elements such as Ca, Mg, and the quenching elements such as Fe, Mn, Cl-. As the PAC is non-selective to alkali and alkaline earth salts, the majority of calcium and magnesium salts are left behind in the solution and uranium gets sorbed selectively onto PAC. Hence, the present preconcentration method is applied to some of the ground water samples having uranium concentrations of <1ppb and with varying TDS. By this method, the uranium values obtained by LED fluorimetry are compared with Pellet fluorimetric values and the results are comparable with each other as seen in Table 7.

The high TDS water samples containing 0.01 ng/mL of uranium are pre concentrated to 10mL from two liter volume (enrichment factor of 200) would contain 20 ng/mL in the final volume of 10 mL, which corresponds to 2 ng/mL. The 2 ng/mL can be easily determined by LED fluorimetry, and the total procedural blank solution corresponds to 10% of the uranium present in the two liters of ground-water samples. Hence, samples containing 0.01 ng/mL of uranium can easily be analyzed by the present method with an enrichment factor of 200.

#### **K. Sorption Mechanism of Uranium on PAC**

The sorption of uranium can be attributed to physisorption/chemisorption. The -OH, -COOH groups on PAC were chemically bonded with uranyl ion. The mechanism of sorption of uranium on PAC may be from both ion exchange and electron donating acceptor complexation reactions at the edge sites. At pH 4 to 5, PAC has a positive surface charge where the uranium removal from the solution takes its maximum value. The maximum loading of uranium ions (load factor) on PAC is 10 milligram per gram. The manuscript covers the application of PAC for removal of uranium from ground-water and sea-water, and at the same time preconcentrates and estimates low concentrations of uranium in water. The detailed systematic studies for the sorption mechanism of surface analysis, etc., will be part of a separate research paper and will be submitted later.

#### **IV. CONCLUSION**

The present method of separation and pre-concentration of uranium from sea-water, brine-water, and ground-water containing high calcium, sodium, magnesium, chloride, and other major cations and anions, is simple. The method involves only the addition of powdered activated carbon (PAC) which has a high adsorption capacity of 10 milligram of uranium per gram of PAC, at pH 4 to 5, and filtering PAC containing uranium after 10 minutes. The uranium from PAC is recovered with 0.8N nitric acid and determined by the LED fluorimetric technique. The method could be applied to water samples containing uranium at concentrations of <1 ppb, and the quantitative data obtained are useful in delineating anomalous zones favorable to the presence of uranium. In the absence of such data, areas containing uranium, go uninterpreted and hence these data are meaningful and helps in identifying the concealed deposits. The determination of uranium using the proposed method

is possible in the presence of high calcium and hence no special chemistry is needed to separate calcium and other matrix elements. Since the reported fluorescence enhancing reagents have limitations with respect to high calcium, magnesium, chloride, and other TDS in the samples, the method is highly useful for these types of samples. The RSD of the method varied from  $\pm 6\%$  to  $14\%$ . The method is accurate, reliable and the values are in close agreement with reported pre-concentration methods (pellet fluorimetric method). The method can be applied in field laboratory studies as well as for the removal of uranium from potable water and industrial waste discharges of the nuclear industry.

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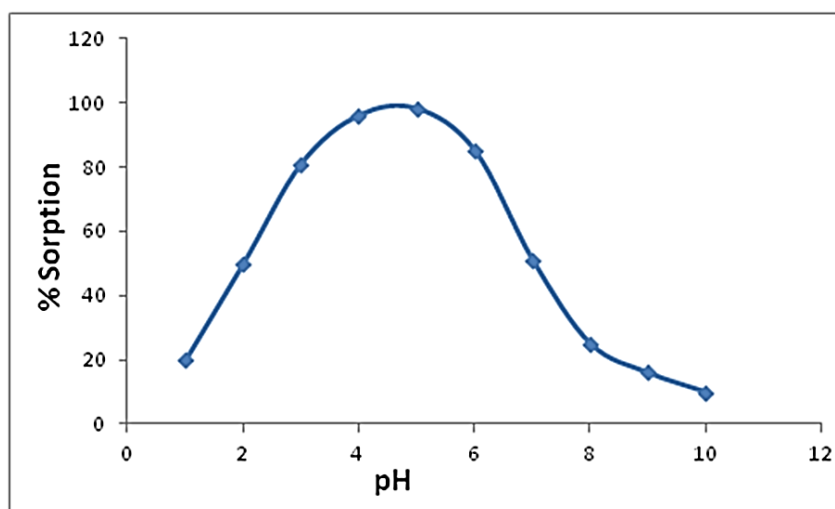
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**Figure 1 : Effect of pH on Uranium Sorption**

Sample Volume: 1 liter; U added: 10 µg, PAC: 0.5 G, Contact time: 2 hours



**Table 1** : Specifications of LED (Light Emitting Diode), Fluorimeter, LF-2

Analytical Technique	Fluorescence of Uranium
Element analysed	Uranium in aqueous medium
Excitation source	LED ( Light Emitting Diodes)
Detector	Photo Multiplier Tube
Minimum concentration	0.2 microgram uranium/ liter i.e. 0.2 ppb
Dynamic range	0.2 to 500 ppb
Accuracy	5% or 0.05 ppb whichever is larger
Reproducibility	Better than 5%

**Table 2** : Details of PAC

Particle size	300 mesh
pH	6 to 7.5
LOD(105° C for 2 hours)	3%
Ash	2%
Acid soluble	0.5%
Phosphate	Negligible
Chloride (Cl)	0.01%
Sulphate (SO <sub>4</sub> )	0.01%
Iron (Fe)	0.01%
Zinc(Zn)	0.001%

**Table 3** : Effect of Quantity of PAC

Quantity of PAC(g)	%Recovery of Uranium
0.1	88
0.2	91
0.5	95
1.0	96
2.0	96

Sample Volume: 1 liter; U added: 10 µg, pH: 4-5, Contact time: 2 hours

**Table 4** : Effect of contact time

Contact time	%Recovery of Uranium
Instantly	85
10mts	95
30mts	96
1hr	96
2hr	96

Sample Volume: 1 liter; U added: 10 µg, PAC: 0.5 G, pH: 4-5

**Table 5 : Effect of Volume**

Volume (mL)	% Recovery of Uranium
100	98
200	97
500	98
1000	95
2000	95

U added: 10 µg, PAC: 0.5 G, Contact time: 10 minutes, pH: 4-5

**Table 6 : Desorption of U from PAC**

Conc. of HNO <sub>3</sub>	% Desorption
pH - 2	10
0.2N HNO <sub>3</sub>	80
0.3NHNO <sub>3</sub>	82
0.5NHNO <sub>3</sub>	84
0.8NHNO <sub>3</sub>	99

Sample Volume: 1 liter, U added: 10 µg, PAC: 0.5 G, Contact time: 10 minutes, pH: 4-5

**Table 7 : Application to Ground-water, Sea-water and Brine-water samples**

S. No	Sample No.	TDS mg/L	HCO <sub>3</sub> <sup>-</sup> mg/L	Cl <sup>-</sup> mg/L	SO <sub>4</sub> <sup>-2</sup> mg/L	Na <sup>+</sup> mg/L	K <sup>+</sup> mg/L	Ca <sup>+2</sup> mg/L	Mg <sup>+2</sup> mg/L	U(ppb) by Present Method	U(ppb) By Pellet Fluorimetry
										Enrichment factor is 200	
1	AMD-1	540	426	99	73	80	10	88	27	0.01±0.001	<1
2	AMD-2	620	335	103	50	104	7	60	37	0.03±0.003	<1
3	AMD-3	970	405	174	37	104	2	40	67	0.05±0.004	<1
4	AMD-4	1100	148	298	104	53	3	90	79	0.02±0.002	<1
5	AMD-5	1250	527	249	68	243	1	40	63	0.05±0.006	<1
6	AMD-6	1450	313	241	130	150	19	60	67	0.1±0.006	<1
7	AMD-7	1550	299	383	170	251	18	70	71	0.1±0.008	<1
8	AMD-8	1740	412	423	163	216	81	80	97	0.04±0.005	<1
9	AMD-9	2100	750	491	236	364	155	120	79	0.5±0.03	<1
10	AMD-10	2800	663	790	370	650	2	135	49	0.5±0.04	<1
11	AMD-SW-1	34000	136	18250	2569	10200	265	355	1250	3.1±0.2	3
12	AMD-SW-2	35000	145	19353	2701	10752	390	416	1295	2.9±0.2	2
13	AMD-BW-1	85000	532	44380	6000	17950	6300	700	38300	5.0±0.3	4
14	AMD-BW-2	101000	391	55030	8000	24660	7100	900	46800	2±0.2	2

Sample Volume: 2 liter, U added: 10 µg, PAC: 0.5 G, Contact time: 10 minutes, pH: 4-5, SW- Sea-water, BW – Brine-water

**Table 8 :** Evaluation of accuracy of the present method

Water Type	U ( in ng) present in sample	U added ( in ng) in 1000mL sample	U found ( in ng) in 10mL sample	% Recovery of U
QDW	<0.5	10000	9650	96
		1000	972	97
		100	96	96
		10	9.2	92
NGW-2	<0.5	10000	9745	97
		1000	965	96
		100	94	94
		10	9.4	94
NGW-4	1	10000	9820	98
		1000	954	95
		100	93	92
		10	10	91
SGW	<0.5	10000	9625	96
		1000	945	94
		100	93	93
		10	9	90
NSW	3	5000	4750	95
		1000	953	95
SSW	3	3000	2920	97
		1000	964	96

QDW: Quartz Distilled Water

NGW-2: Natural Ground water with high TDS

NGW-4: Natural Ground water with high Ca ,Mg, Cl and SO<sub>4</sub>

SGW: Synthetic Ground water with high Ca , Mg, Cl and SO<sub>4</sub>

NSW: Natural sea water

SSW: Synthetic sea water

**Table 9 :** Application to sea water and brine samples of high TDS

S. No	Sample No.	U(ppb) by Present Method Enrichment factor is 200	U(ppb) By Pellet Fluorimetry
1	AMD(SW)	3.1±0.2	3
2	AMD(SW)	3.2±0.3	2
3	AMD(SW)	2.9±0.2	2
4	AMD-(BW)	5.0±0.3	4
5	AMD-(BW)	0.5±0.03	<1
6	AMD-(BW)	2±0.2	2

SW- Sea-water, BW – Brine-water