Rapid and Simultaneous Determination of Np and Pu in Environmental Samples Using Sequential Injection Anion Exchange Chromatography and ICP-MS

PhD student: Jixin Qiao

Supervisor: Xiaolin Hou
Co-supervisor: Per Roos, Manuel Miró

Risø-DTU, Technical University of Denmark

NKS-B Workshop on Radioanalytical chemistry for Radioecology and Waste Management, 16-20th Nov. 2009

BACKGROUND

Plutonium isotopes (^{238,239,240,241}Pu) and Neptunium (^{237}Np) are highly hazardous radioactive pollutants in the environment due to:

1) long radioactive half-lives;

2) high radiological toxicities;

3) long-term persistence in environment.

Table 1. Nuclear Properties of Important Plutonium Isotopes

Isotope	Half-life	Specific activity (Bg/g)	Principal decay mode	Decay energy (MeV)
^{238}Pu	87.7yr	6.338×10^{11}	α	α 5.499 (70.9%)
^{239}Pu	2.411×10^{4}yr	2.296×10^{9}	α	α 5.157 (70.77%)
^{240}Pu	6.561×10^{3}yr	8.401×10^{9}	α	α 5.168 (72.8%)
^{241}Pu	14.35yr	3.825×10^{12}	β^- >99.99%	α 4.896 (83.2%)
^{237}Np	2.411×10^{6}yr	2.603×10^{7}	α	α 4.788 (51%)

BACKGROUND

The determination of plutonium isotopes and Neptunium in the environment is important for:

1) environmental risk **assessment** and **monitoring** of sites around nuclear facilities;

2) emergency **preparedness**;

3) **surveys** for the contaminated area resulting from nuclear weapon tests, nuclear accidents, and the discharge of nuclear waste.

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BACKGROUND

1) The **levels of plutonium** isotopes and **neptunium** in the environment are very **low** and depending of the location.

2) **Plutonium** and **neptunium** often coexist with **matrix elements** (Ca, Mg, Al, V…) and **other radionuclides** (Th, U, Am, Cm…).

Table 2. Environmental level of ^{238}Pu and ^{239,240}Pu

Sample	^{238}Pu	^{239,240}Pu
Soil, Bq/kg	0.07	0.1-7
Herbaceous plants ,Bq/kg	4.5×10^{-4}	0.3-2
Lichen, Bq/kg	-	4-10
Grain, vegetables, Bq/kg	$(0.2\text{-}14)\times10^{-4}$	$(4\text{-}89)\times10^{-4}$
Lake water ,Bq/L	-	$(0.1\text{-}29)\times10^{-6}$
Sea water, Bq/L	-	$(0.7\text{-}52)\times10^{-6}$

BACKGROUND

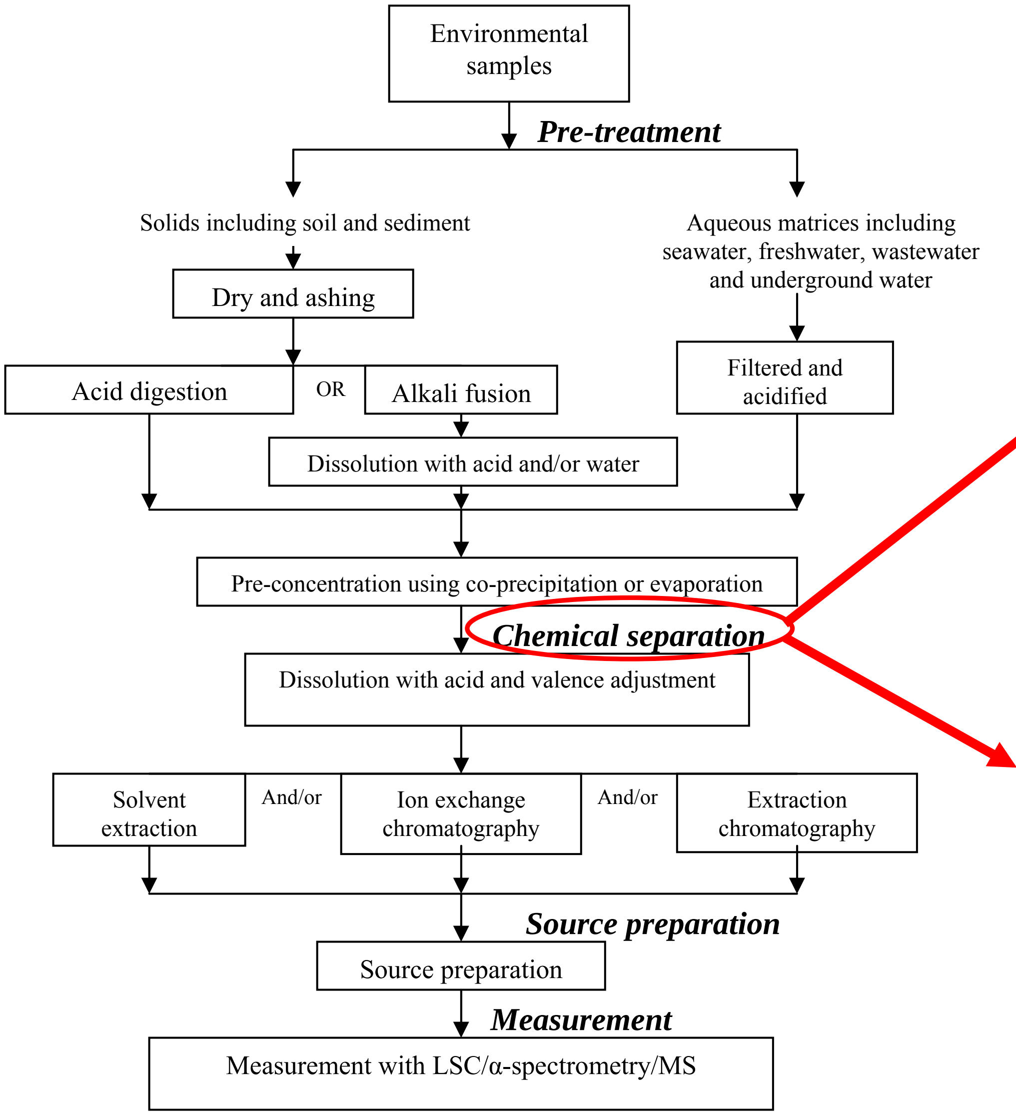

Fig. 1 Analytical procedure for the determination of Pu and Np in environmental samples

Advantages

- sensitive;
- precise;
- accurate.

Disadvantages

- time-consuming;
- labour intensive;
- generate hazardous liquid and solid waste.

OBJECTIVE

Objective:

To develop a new analytical method for determination of plutonium isotopes and neptunium in environmental samples.

Main Points: 1)Automatic

2)Rapid

3)Simultaneous

MAIN CHALLENGES

- **Small column size**
- **Same behavior of Pu and Np on the column**
- **Valence adjustment**
- **High chemical yields**
- **Good decontamonation factors (U, Th, Pb)**

STRATEGY

Ion-exchange Chromatography + **Sequential Injection (SI)** → **ICP-MS**

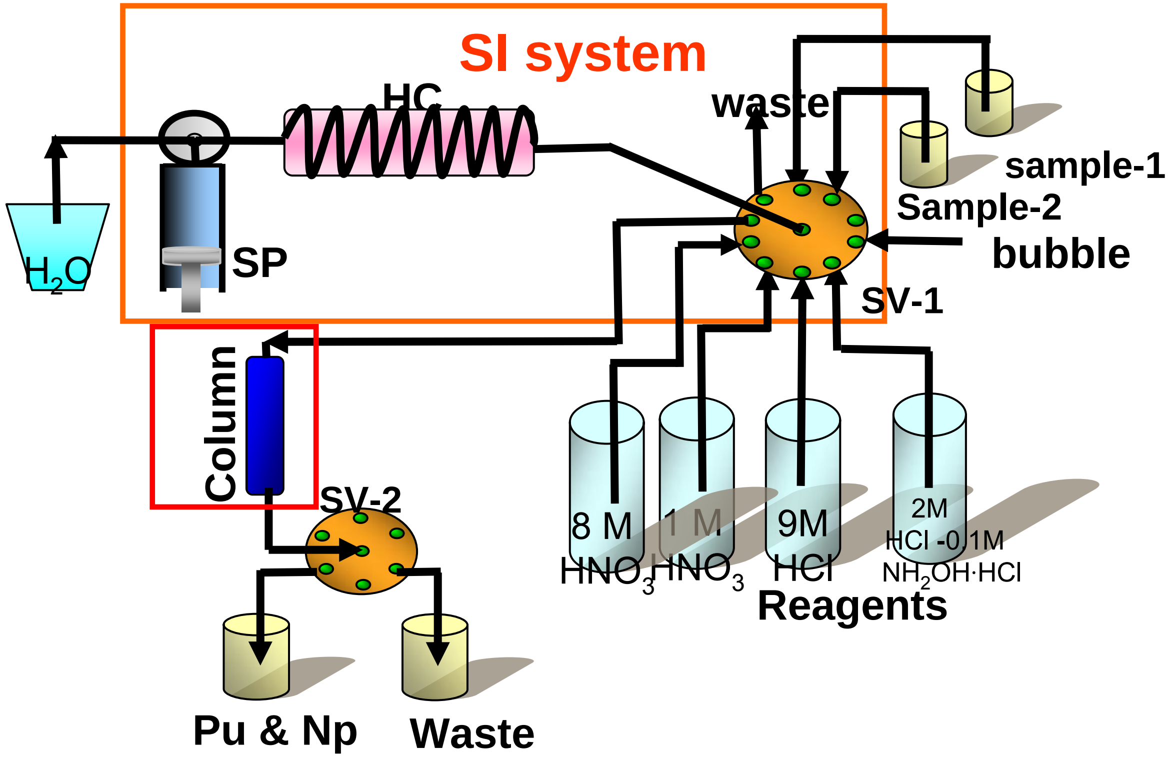

Fig. 2 Scheme of a SI system

EXPERIMENT AND RESULTS

Samples

Soil: Danish soil, reference material from a laboratory round-robin intercomparison. The reference values of ^{239}Pu and ^{240}Pu are 0.140 ± 0.008 and 0.098 ± 0.006 Bg/kg.

Sediment, plants, seawater…

Anion exchange chromatographic column

Column size: 16mL (1.0 x 20 cm)
8mL (0.7 x 20 cm)
4mL (0.7 x 10 cm)
2mL (0.5 x 10 cm)
2mL (0.7 x 5.0 cm)

Resin: AG 1x2 (50-100mesh), AG 1x4 (50-100mesh), AG 1x4(100-200mesh), AG 1x8(50-100mesh).

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Instrumentation

1)FIAlab system 3500

- ♣ Syringe/peristaltic pump
- ♣ 10-port selection valve

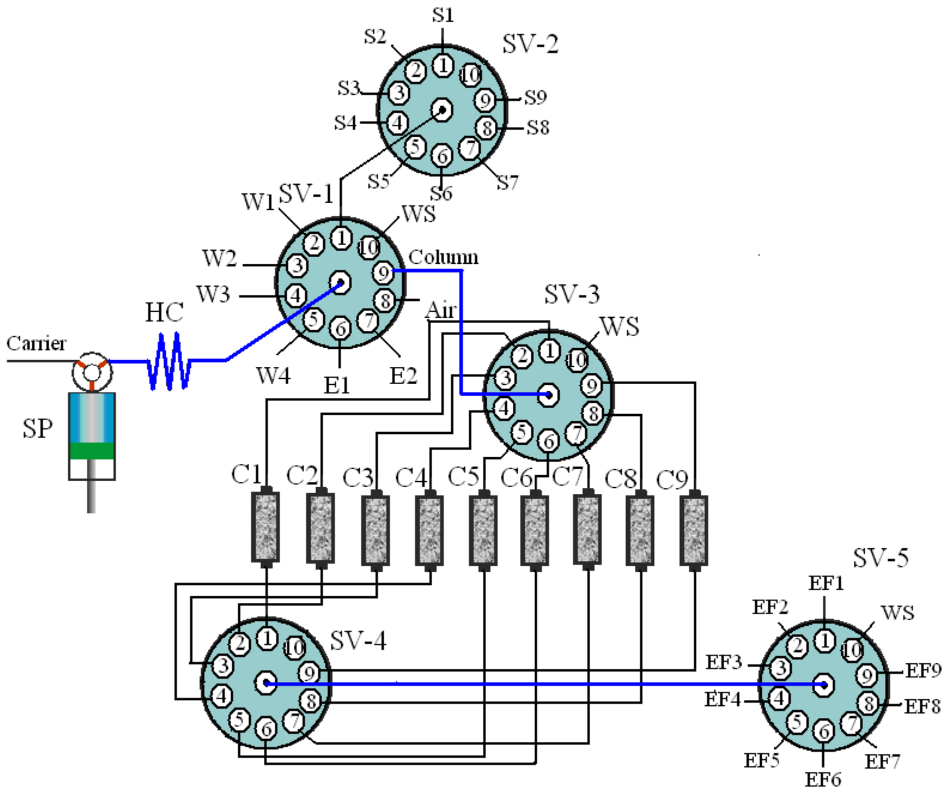
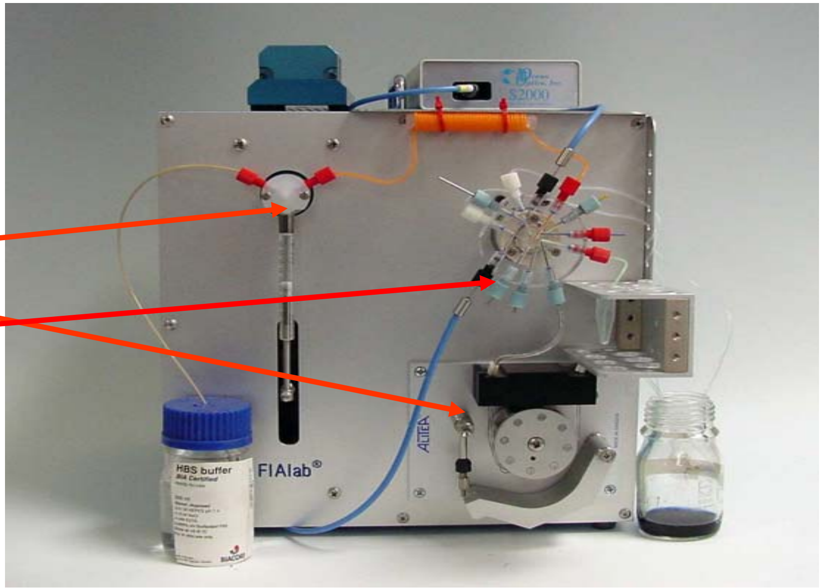
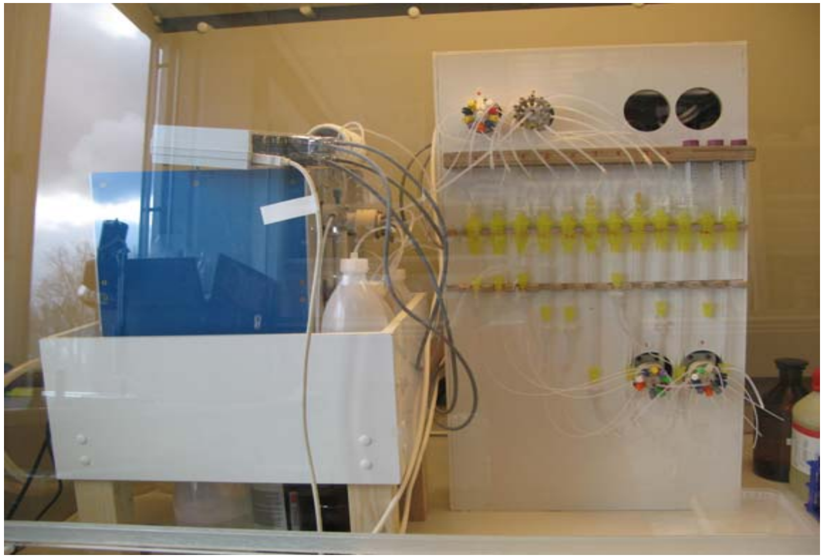


Fig.3. Scheme of the experimental setup





Instrumentation

2)ICP-MS

Thermo X-series inductively coupled plasma mass spectrometry (ICP-MS)

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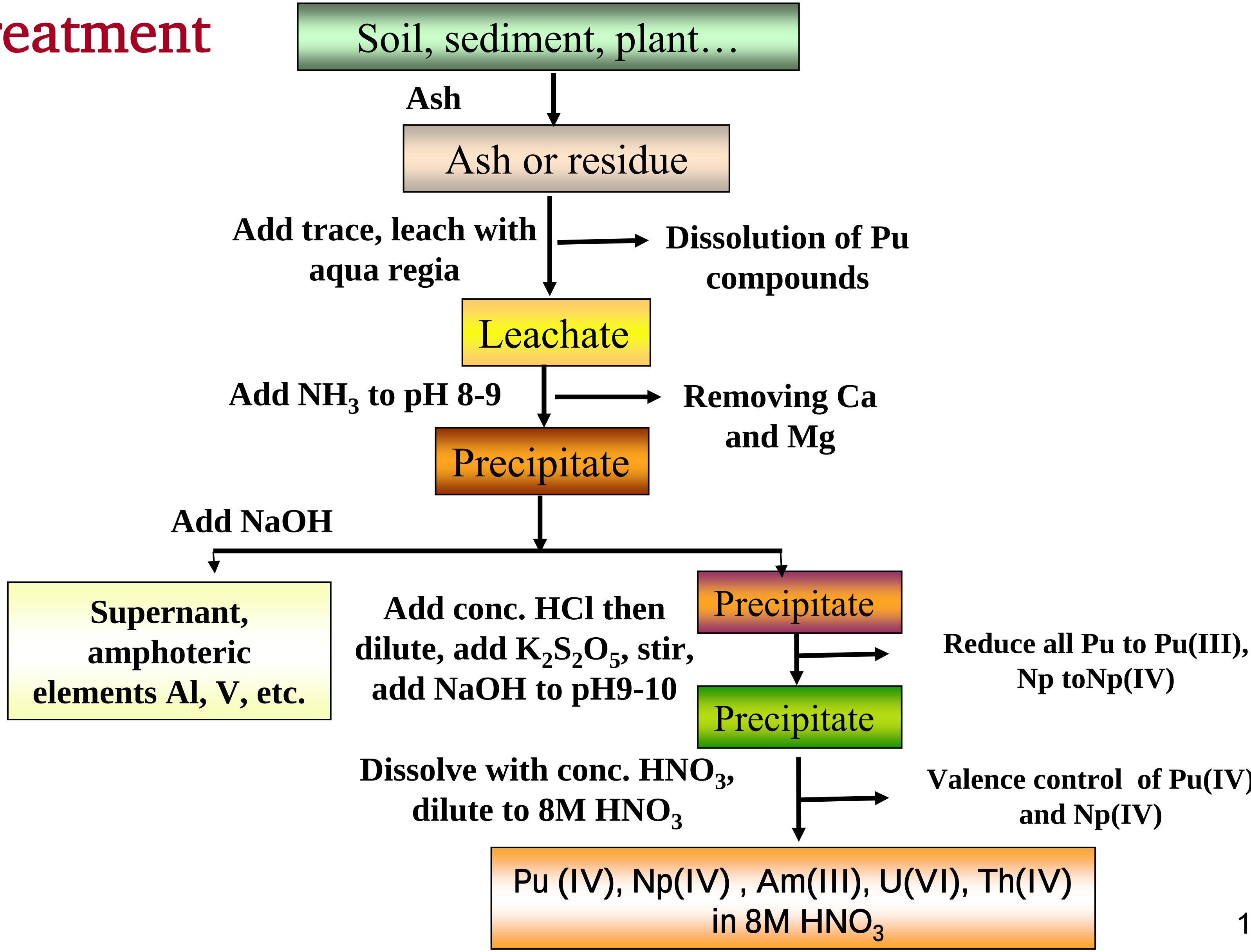
Pre-treatment



Separation & detection

Pu (IV), Np(IV) , Am(III),U(VI), Th(IV) in 8 M HNO_3

↓

Sample loading on anion exchange column

Wash with 8M HNO_3 → **Remove most matrix elements, Am(III), U(VI)…**

Wash with 9M HCl → **Remove Th(IV)**

↓

Pu (IV) and Np(IV) on the column

Elute with 0.1M $NH_2OH{\cdot}HCl$ -2M HCl or 0.5M HCl ↓

Pu and Np

↓

ICP-MS

Experimental paramaters for comparison

- **Column size**
- **Resin type**
- **Washing solution (1.0-8.0 mol/L HNO_3)**
- **Elution soultion (NH_2OHHCl-HCl, 0.1-1.0mol/L HCl)**
- **Flow rate (1.0-5.0 mL/min)**

Key factors for evalution of experimental results

- **Chemical yields of Pu and Np**

  ☺>85% ☹<85%

- **Ratio between the chemical yield of ^{237}Np and ^{242}Pu**

  ☺0.9-1.1 ☹otherwise

- **Mearured values of ^{239}Pu and ^{240}Pu**

  ☺agree well with the reference values

  ☹otherwise

- **Deconatmination factors for U, Th and Pb**

  ☺>10^3 ☹<10^3

EXPERIMENT AND RESULTS

Table 3. comparison of different experimental conditions for the separation of Pu and Np (1)

Column size	Resin	Separation condition#	Chemical yield of ^{242}Pu, Y_{Pu} (%)	Chemical yield of ^{237}Np, Y_{Np} (%)	Ration of Y_{Np}/Y_{Pu}	^{239}Pu measured (Bq/kg) *	^{240}Pu measured (Bq/kg) *	Decontamination factor **		
								^{238}U	^{232}Th	Pb
16mL (1.0 × 20cm)	AG1 × 2	W-1, 2.5 E-1, 1.0	102.3 ± 5.1	95.8 ± 4.8	0.9	0.14 ± 0.0	0.10 ± 0.01	3.3×10^3	1.9×10^4	1.4×10^4
	AG1 × 4		99.9 ± 5.0	94.8 ± 4.7	0.9	0.23 ± 0.02	0.08 ± 0.01	3.0×10^2	2.9×10^3	5.6×10^3
	AG1 × 8		96.4 ± 4.8	90.9 ± 4.5	0.9	1.39 ± 0.14	0.11 ± 0.01	4.2×10^1	3.8×10^2	1.2×10^4
8mL (0.7 × 20cm)	AG1 × 2	W-1, 2.5 E- 2, 1.0	71.5 ± 3.6	67.4 ± 3.4	0.9	0.17 ± 0.02	0.12 ± 0.01	1.1×10^3	5.2×10^3	3.1×10^4
	AG1 × 4		100.0 ± 5.4	100.0 ± 5.3	1.0	0.16 ± 0.02	0.10 ± 0.01	1.6×10^3	6.4×10^3	3.9×10^3
	AG1 × 8		94.2 ± 4.7	87.9 ± 4.4	0.9	0.16 ± 0.02	0.10 ± 0.01	3.2×10^2	7.8×10^2	8.1×10^3
	AG1 × 8	W-1, 5.0 E-2, 2.5	91.9 ± 4.6	80.1 ± 4.0	0.9	0.18 ± 0.02	0.12 ± 0.01	1.1×10^2	9.1×10^1	8.8×10^3
4mL (0.7 × 10cm)	AG1 × 2	W-1, 2.5 E-2, 1.0	71.2 ± 3.6	48.4 ± 2.4	0.7	0.12 ± 0.01	0.06 ± 0.01	2.1×10^3	4.4×10^3	1.1×10^4
	AG1 × 4		100.0 ± 5.0	98.2 ± 4.9	1.0	0.12 ± 0.01	0.10 ± 0.01	1.3×10^3	2.4×10^3	2.2×10^4
	AG1 × 8		98.7 ± 4.9	97.2 ± 4.9	1.0	0.16 ± 0.02	0.10 ± 0.01	1.0×10^3	8.9×10^2	8.6×10^3
	AG1 × 8	W-1, 5.0 E-2, 2.5	92.6 ± 4.6	86.3 ± 4.3	0.9	0.17 ± 0.02	0.12 ± 0.01	2.2×10^2	9.8×10^1	2.7×10^3

EXPERIMENT AND RESULTS

Table 3. comparison of different experimental conditions for the separation of Pu and Np (2)

Column size	Resin	Separation condition#	Chemical yield of ^{242}Pu, Y_{Pu} (%)	Chemical yield of ^{237}Np, Y_{Np} (%)	Ration of Y_{Np}/Y_{Pu}	^{239}Pu measured (Bq/kg) *	^{240}Pu measured (Bq/kg) *	Decontamination factor **		
								^{238}U	^{232}Th	Pb
2mL (0.5 × 10cm)	AG1 × 2	W-2, 2.5 E-2, 2.5	75.0 ± 3.8	19.0 ± 1.0	0.3	0.26 ± 0.03	0.08 ± 0.01	3.2×10^2	2.0×10^2	2.6×10^3
		W-2, 5.0 E-2, 2.5	48.6 ± 2.4	35.7 ± 1.8	0.7	0.15 ± 0.02	0.10 ± 0.01	8.9×10^2	6.8×10^2	9.3×10^3
	AG1 × 4	W-2, 2.5 E-2, 2.5	103.0 ± 5.2	106.0 ± 5.3	1.0	0.14 ± 0.01	0.09 ± 0.01	3.9×10^3	2.4×10^4	2.7×10^4
		W-2, 5.0 E- 2, 2.5	94.0 ± 4.7	89.7 ± 4.5	1.0	0.25 ± 0.03	0.09 ± 0.01	3.9×10^2	6.7×10^3	1.6×10^4
	AG1 × 8	W-2, 2.5 E-2, 2.5	90.5 ± 5.0	88.7 ± 4.9	1.0	0.25 ± 0.03	0.09 ± 0.01	3.4×10^2	2.7×10^2	9.0×10^5
		W-2, 5.0 E-2, 2.5	100.5 ± 5.0	98.7 ± 4.9	1.0	0.29 ± 0.03	0.07 ± 0.01	4.8×10^1	2.1×10^2	2.9×10^5
	AG1 × 4	W-2, 2.5 E-4, 2.5	72.9 ± 3.6	64.1 ± 3.2	0.9	0.18 ± 0.02	0.12 ± 0.01	1.6×10^3	1.7×10^4	6.1×10^3
		W-3, 2.5 E-4, 2.5	81.8 ± 4.1	69.2 ± 4.1	0.8	0.38 ± 0.04	0.10 ± 0.01	2.1×10^3	1.3×10^4	7.5×10^3
		W-4, 2.5 E-4, 2.5	80.2 ± 4.0	63.8 ± 4.1	0.8	0.19 ± 0.02	0.09 ± 0.01	2.4×10^3	1.4×10^4	1.5×10^4
		W-5, 2.5 E-4, 2.5	39.6 ± 2.0	20.6 ± 4.1	0.5	0.20 ± 0.02	0.15 ± 0.02	2.6×10^3	1.1×10^4	9.4×10^3
		W-6, 2.5 E-4, 2.5	31.0 ± 1.6	11.7 ± 4.1	0.4	0.19 ± 0.02	0.20 ± 0.02	3.1×10^3	5.0×10^4	1.2×10^5

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Table 3. comparison of different experimental conditions for the separation of Pu and Np (3)

Column size	Resin	Separation condition #	Chemical yield of ^{242}Pu, Y_{Pu} (%)	Chemical yield of ^{237}Np, Y_{Np} (%)	Ration of Y_{Np}/Y_{Pu}	^{239}Pu measured (Bq/kg) *	^{240}Pu measured (Bq/kg) *	Decontamination factor **		
								^{238}U	^{232}Th	Pb
2mL (0.5 × 10cm)	AG1 × 4, 100-200 mesh	W-2, 2.5 § E-3, 2.5	61.0 ± 3.1	64.9 ± 3.2	1.1	0.18 ± 0.02	0.12 ± 0.01	3.1×10^3	2.8×10^4	1.2×10^4
		W-2, 2.5 E-4, 2.5	91.6 ± 4.6	91.0 ± 4.6	1.0	0.14 ± 0.01	0.10 ± 0.01	6.9×10^3	1.7×10^4	1.0×10^3
		W-2, 2.5 E- 5, 2.5	66.8 ± 3.3	74.6 ± 3.7	1.1	0.14 ± 0.01	0.09 ± 0.01	8.6×10^3	1.2×10^4	1.0×10^3
		W-2, 2.5 E-6, 2.5	78.5 ± 3.9	81.6 ± 4.1	1.0	0.14 ± 0.01	0.07 ± 0.01	6.3×10^3	1.9×10^4	1.5×10^3
		W-3, 2.5 E-4, 2.5	35.9 ± 1.8	61.2 ± 3.1	1.7	0.22 ± 0.02	0.19 ± 0.02	3.4×10^3	3.1×10^4	2.9×10^3
		W-4, 2.5 E-4, 2.5	82.3 ± 4.1	80.9 ± 4.0	1.0	0.21 ± 0.02	0.12 ± 0.01	3.8×10^3	1.4×10^4	4.3×10^4
		W-5, 2.5 E-4, 2.5	63.6 ± 3.2	30.1 ± 1.5	0.5	0.19 ± 0.02	0.10 ± 0.01	4.5×10^3	3.1×10^4	1.8×10^4
2mL (0.7 × 5cm)	AG1 × 4, 100-200 mesh	W-2, 2.5 E-4, 2.5	40.4 ± 2.0	37.1 ± 1.9	0.9	0.18 ± 0.02	0.07 ± 0.01	1.1×10^4	1.6×10^3	7.2×10^3
1mL (0.5 × 5cm)	AG1 × 4, 100-200 mesh	W-2, 2.5 E-4, 2.5	50.7 ± 2.5	44.8 ± 2.2	0.9	0.14 ± 0.02	0.10 ± 0.01	4.1×10^3	4.0×10^3	1.5×10^4

The reference values of ^{239}Pu and ^{240}Pu concentration in the Danish soil were reported to be 0.140 ± 0.008 Bq/kg and 0.098 ± 0.006 Bq/kg.* Experimental results are given as the average of three replicates ± standard deviation. ** The relative standard deviations were in all instances better than 10%. § flow rate, mL/min.# W-1: washing sequence 200mL of 8 mol/L HNO_3 + 100mL of 9 mol/L HCl; W-2: 100mL of 8 mol/L HNO_3 + 100mL of 9 mol/L HCl; W-3: 100mL of 6 mol/L HNO_3 + 100mL of 9 mol/L HCl;W-4: 100mL of 4 mol/L HNO_3 + 100mL of 9 mol/L HCl; W-5: 100mL of 2 mol/L HNO_3 + 100mL of 9 mol/L HCl; W-6: 100mL of 1 mol/L HNO_3 + 100mL of 9 mol/L HCl; Pu eluting solution: E-1:Pu elution solution 200mL of 0.1 mol/L NH_2OH·HCl-2 mol/L HCl; E-2: 100mL of 0.1 mol/L NH_2OH·HCl-2 mol/L HCl; E-3: 40mL of 0.1 mol/L NH_2OH·HCl-2 mol/L HCl; E-4: 40mL of 0.5 mol/L HCl; E-5: 40mL of 0.1 mol/L HCl; E-6: 40mL of 1.0 mol/L HCl.

EXPERIMENT AND RESULTS

Table 3. Comparison of different experimental conditions for the separation of Pu and Np (1)

Column size	Resin	Separation condition#	Chemical yield of ^{242}Pu, Y_{Pu} (%)	Chemical yield of ^{237}Np, Y_{Np} (%)	Ration of Y_{Np}/Y_{Pu}	^{239}Pu measured (Bq/kg) *	^{240}Pu measured (Bq/kg) *	Decontamination factor **		
								^{238}U	^{232}Th	Pb
16mL (1.0 × 20cm)	AG1 × 2	W-1, 2.5 E-1, 1.0	☺	☺	☺	☺	☺	☺	☺	☺
	AG1 × 4		☺	☺	☺	☹	☹	☹	☺	☺
	AG1 × 8		☺	☺	☺	☹	☺	☹	☹	☺
8mL (0.7 × 20cm)	AG1 × 2	W-1, 2.5 E- 2, 1.0	☹	☹	☺	☺	☺	☺	☺	☺
	AG1 × 4		☺	☺	☺	☺	☺	☺	☺	☺
	AG1 × 8		☺ (blue)	☺ (blue)	☺ (blue)	☺	☺	☹	☹	☺
	AG1 × 8	W-1, 5.0 E-2, 2.5	☺	☹	☺	☹	☹	☹	☹	☺
4mL (0.7 × 10cm)	AG1 × 2	W-1, 2.5 E-2, 1.0	☹	☹	☹	☺	☹	☺	☺	☺
	AG1 × 4		☺	☺	☺	☺	☺	☺	☺	☺
	AG1 × 8		☺	☺	☺	☹	☺	☺	☹	☺
	AG1 × 8	W-1, 5.0 E-2, 2.5	☺	☺	☺	☹	☹	☹	☹	☺

EXPERIMENT AND RESULTS

Table 3. Comparison of different experimental conditions for the separation of Pu and Np (2)

Column size	Resin	Separation condition#	Chemical yield of ^{242}Pu, Y_{Pu} (%)	Chemical yield of ^{237}Np, Y_{Np} (%)	Ration of Y_{Np}/Y_{Pu}	^{239}Pu measured (Bq/kg) *	^{240}Pu measured (Bq/kg) *	Decontamination factor **		
								^{238}U	^{232}Th	Pb
2mL (0.5 × 10cm)	AG1 × 2	W-2, 2.5 E-3, 2.5	☹	☹	☹	☹	☹	☹	☹	☺
		W-2, 5.0 E-3, 2.5	☹	☹	☹	☺	☺	☹	☹	☺
	AG1 × 4	W-2, 2.5 E-3, 2.5	☺	☺	☺	☺	☺	☺	☺	☺
		W-2, 5.0 E- 3, 2.5	☺	☺	☺	☹	☺	☹	☺	☺
	AG1 × 8	W-2, 2.5 E-3, 2.5	☺	☺	☺	☹	☺	☹	☹	☺
		W-2, 5.0 E-3, 2.5	☺	☺	☺	☹	☹	☹	☹	☺
	AG1 × 4	W-2, 2.5 E-4, 2.5	☹	☹	☺	☹	☹	☺	☺	☺
		W-3, 2.5 E-4, 2.5	☹	☹	☹	☹	☺	☺	☺	☺
		W-4, 2.5 E-4, 2.5	☹	☹	☹	☹	☺	☺	☺	☺
		W-5, 2.5 E-4, 2.5	☹	☹	☹	☹	☹	☺	☺	☺
		W-6, 2.5 E-4, 2.5	☹	☹	☹	☹	☹	☺	☺	☺

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Table 3. Comparison of different experimental conditions for the separation of Pu and Np (3)

Column size	Resin	Separation condition #	Chemical yield of ^{242}Pu, Y_{Pu} (%)	Chemical yield of ^{237}Np, Y_{Np} (%)	Ration of Y_{Np}/Y_{Pu}	^{239}Pu measured (Bq/kg) *	^{240}Pu measured (Bq/kg) *	Decontamination factor **		
								^{238}U	^{232}Th	Pb
2mL (0.5 × 10cm)	AG1 × 4, 100-200 mesh	W-2, 2.5 § E-3, 2.5	☹	☹	☺	☹	☹	☺	☺	☺
		W-2, 2.5 E-4, 2.5	☺	☺	☺	☺	☺	☺	☺	☺
		W-2, 2.5 E- 5, 2.5	☹	☹	☺	☺	☺	☺	☺	☺
		W-2, 2.5 E-6, 2.5	☹	☹	☺	☺	☹	☺	☺	☺
		W-3, 2.5 E-4, 2.5	☹	☹	☹	☹	☹	☺	☺	☺
		W-4, 2.5 E-4, 2.5	☹	☹	☺	☹	☹	☺	☺	☺
		W-5, 2.5 E-4, 2.5	☹	☹	☹	☹	☺	☺	☺	☺
2mL (0.7 × 5cm)	AG1 × 4, 100-200 mesh	W-2, 2.5 E-4, 2.5	☹	☹	☺	☹	☹	☺	☺	☺
1mL (0.5 × 5cm)	AG1 × 4, 100-200 mesh	W-2, 2.5 E-4, 2.5	☹	☹	☺	☺	☺	☺	☺	☺

The reference values of ^{239}Pu and ^{240}Pu concentration in the Danish soil were reported to be 0.140 ± 0.008 Bq/kg and 0.098 ± 0.006 Bq/kg.* Experimental results are given as the average of three replicates ± standard deviation. ** The relative standard deviations were in all instances better than 10%. § flow rate, mL/min.# W-1: washing sequence 200mL of 8 mol/L HNO_3 + 100mL of 9 mol/L HCl; W-2: 100mL of 8 mol/L HNO_3 + 100mL of 9 mol/L HCl; W-3: 100mL of 6 mol/L HNO_3 + 100mL of 9 mol/L HCl;W-4: 100mL of 4 mol/L HNO_3 + 100mL of 9 mol/L HCl; W-5: 100mL of 2 mol/L HNO_3 + 100mL of 9 mol/L HCl; W-6: 100mL of 1 mol/L HNO_3 + 100mL of 9 mol/L HCl; Pu eluting solution: E-1:Pu elution solution 200mL of 0.1 mol/L $NH_2OH{\cdot}HCl$-2 mol/L HCl; E-2: 100mL of 0.1 mol/L $NH_2OH{\cdot}HCl$-2 mol/L HCl; E-3: 40mL of 0.1 mol/L $NH_2OH{\cdot}HCl$-2 mol/L HCl; E-4: 40mL of 0.5 mol/L HCl; E-5: 40mL of 0.1 mol/L HCl; E-6: 40mL of 1.0 mol/L HCl.

Main Results

1) ^{242}Pu performs well as a tracer for both Pu isotope and ^{237}Np.
2) Cross-link of the resins has significant effluence on the separation efficiency. Finally, AG 1x4 resin was chosen as the optimum.
3) Small-sized column packed with 2mL resin suffices up to 10g of soil.

Table 4. Selected results from the experiment (10g of soil)

Column size	Resin	Chemical yield of ^{242}Pu, Y_{Pu} (%)	Chemical yield of ^{237}Np, Y_{Np} (%)	Ration of Y_{Np}/Y_{Pu}	^{239}Pu measured (Bq/kg) *	^{240}Pu measured (Bg/kg)**	Decontamination factor ***		
							^{238}U	^{232}Th	^{208}Pb
2mL (0.5 × 10cm)	AG1 × 4, 50-100 mesh	103.0 ± 5.2	106.0 ± 5.3	1.0	0.14 ± 0.01	0.09 ± 0.01	3.9 × 10^3	2.4 × 10^4	2.7 × 10^4
	AG1 × 4, 100-200 mesh	91.6 ± 4.6	91.0 ± 4.6	1.0	0.14 ± 0.01	0.10 ± 0.01	6.9 × 10^3	1.7 × 10^4	1.0 × 10^3

*The reference value is 0.140 ± 0.008 Bg/kg. **The reference value is 0.098 ± 0.006 Bg/kg.
** The relative standard deviations were in all instances better than 10%.

EXPERIMENT AND RESULT

RISØ

Main Results

4) The total time of on-line separation for a single sample is ~ 2.5h.

For comparation: 2-3days is need for off-line separation.

5) Chemical yields of Pu and Np equally range from 90% to 100%.

6) Decontamination factor for ^{238}U, ^{232}Th and ^{208}Pb are in the range of 10^3 to 10^4.

Table 4. Selected results from the experiment (10g of soil)

Column size	Resin	Chemical yield of ^{242}Pu, Y_{Pu} (%)	Chemical yield of ^{237}Np, Y_{Np} (%)	Ration of Y_{Np}/Y_{Pu}	^{239}Pu measured (Bq/kg) *	^{240}Pu measured (Bg/kg)**	Decontamination factor ***		
							^{238}U	^{232}Th	^{208}Pb
2mL (0.5 × 10cm)	AG1 × 4, 50-100 mesh	103.0 ± 5.2	106.0 ± 5.3	1.0	0.14 ± 0.01	0.09 ± 0.01	3.9×10^3	2.4×10^4	2.7×10^4
	AG1 × 4, 100-200 mesh	91.6 ± 4.6	91.0 ± 4.6	1.0	0.14 ± 0.01	0.10 ± 0.01	6.9×10^3	1.7×10^4	1.0×10^3

*The reference value is 0.140 ± 0.008 Bg/kg. **The reference value is 0.098 ± 0.006 Bg/kg.

*** The relative standard deviations were in all instances better than 10%.

And so?

1) Innovation: Automatic
Rapid
Simultaneous
Low consumption of resins
Low generation of wastes

2) Nexp step: Stability of Np(IV) and Pu(IV)
Capacity of the SI system
Reusability of the resin

ACKNOWLEDGEMENT

- **Xiaolin Hou**
- **Per Roos**
- **Manuel Miró**
- **Radioecology and Tracers Programme (headed by Sven P. Nielsen), Radiation Research Divison, Risø-DTU, Denmark.**

THANK YOU !

Personal e-mail: qiaojixin2004@gmail.com