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Intercomparison of Radioactivity Analysis in Environmental Samples based on the 2017 Cooperation Program between JCAC and RMC

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2019

RADIATION MONITORING CENTER ATOMIC ENERGY COUNCIL
EXECUTIVE YUAN

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Appendix

This report summarizes the achievements made in the 2017 cooperation program within the framework of the memorandum for the Technical Exchange between the Radiation Monitoring Center Atomic Energy Council, Executive Yuan, Taiwan R. O. C. (hereafter referred to as RMC) and the Japan Chemical Analysis Center (hereafter referred to as JCAC).

The 2017 cooperation program was carried out from November 16, 2017 to October 1, 2019 based on the Minutes of the 30th Annual Meeting held at JCAC on November 15-16, 2017.

The program consists of:

(1) Intercomparison of radioactivity measurements using environmental samples collected by RMC and JCAC

(2) Intercomparison of radiation dose measurements using thermoluminescence dosimeters

(3) Technical information exchange

(4) Technical support

1. Intercomparison of radioactivity measurements

1.1 Samples

The samples used for intercomparison between RMC and JCAC were fresh water, seawater, tea leaves ash and soil. Details of sampling and the analytical methods are shown in Table 1.

Seawater (Japan) sample was collected by JCAC. All other samples were collected by RMC. Fresh water, seawater and tea leaves ash samples were divided into halves without any pretreatment, one half was analyzed by RMC and the other was sent to JCAC for analysis. Soil sample was also divided into halves after pretreatment at RMC, one half was analyzed by RMC and the other was sent to JCAC for analysis.

Table 1 List of intercomparison samples

Sample	Sampling location	Sampling date	Sample condition	Amount of sample	γ	^{90}Sr	^{137}Cs	^{137}Cs ^{134}Cs	U	^{3}H	β	^{239}Pu ^{240}Pu
Fresh water	Long-Tan	Jan. 1, 2019	Liquid	1 L	—	—	—	—	—	○	—	—
				5 L	—	—	—	—	—	—	○	—
Seawater	Kaohsiung			5 L	—	—	—	—	○	—	○	—
Tea leaves	Shin-Ban-San		Ash	100 g	○	○	○	—	—	—	○	—
Soil	(Long-Tan 1)		Dry	1 kg	○	—	○	—	○	—	○	—
Soil	(Long-Tan 2)		Ash	1 kg	—	○	—	—	—	—	—	—
Soil	San-Zhi		Ash	0.5 kg	—	—	—	—	—	—	—	○
Seawater	Japan	Nov.8, 2017	Liquid	20 L	—	—	—	○	—	—	—	—

γ:Determination of γ-ray emitting nuclides with Ge semiconductor detector

^{90}Sr:Determination of ^{90}Sr by radiochemical analysis

^{137}Cs:Determination of ^{137}Cs by radiochemical analysis

^{137}Cs, ^{134} Cs:Determination of γ-ray emitting nuclides with Ge semiconductor detector

U:Determination of α-ray of uranium with Si semiconductor detector

^{3}H:Determination of ^{3}H with liquid scintillation counter

β:Measurement of gross β activity with low-background gas-flow counter

^{239}Pu, ^{240}Pu: Determination of ^{239}Pu, ^{240}Pu and ^{240}Pu/^{239}Pu atom ratio with HR-ICP-MS

1.2 Analytical methods

1.2.1 γ-ray spectrometry

(1) Pretreatment

1) Tea leaves: (See Fig. 1)

At RMC, the tea leaves ash sample was homogenized and divided into three portions. An aliquot of the one portion of the sample was put in a plastic container (6 cmφ × 4.5 cm height), and used for γ-ray spectrometry. The remaining two portions were used for radiochemical analysis of ^{90}Sr and ^{137}Cs, and for gross β activity measurement, respectively.

At JCAC, the tea leaves ash sample was homogenized and divided into three portions. An aliquot of the sample was put in a plastic container (U-8: 5 cmφ × 6 cm height), and used for γ-ray spectrometry. The remaining two portions were used for radiochemical analysis of ^{90}Sr and ^{137}Cs, and for gross β activity measurement, respectively.

2) Soil (Long-Tan 1): (See Fig. 2)

At RMC, after the soil sample was dried at 110℃ and sifted through a 10 mesh sieve, an aliquot of 1 kg of the sample was sent to JCAC. The sieved sample was homogenized and divided into three portions. An aliquot of the one portion of sample was put in a plastic container (6 cmφ × 4.5 cm height) and used for γ-ray spectrometry. The remaining two portions were used for radiochemical analysis of ^{137}Cs and U, and for gross β activity measurement, respectively.

At JCAC, the soil sample was dried at 105℃, homogenized and divided into three portions. An aliquot of the one portion of sample was put in a plastic container (U-8: 5 cmφ × 6 cm height) for γ-ray spectrometry. The remaining two portions were used for radiochemical analysis of ^{137}Cs, U, and gross β activity measurement, respectively.

3) Seawater (Japan) : (See Fig. 3)

At RMC, AMP (ammonium phosphomolybdate) was added into the seawater and stirred. AMP was separated, dissolved and transferred into a plastic container (6 cmφ × 4.5 cm height) for γ-ray spectrometry.

At JCAC, AMP (ammonium phosphomolybdate) was added into the seawater and stirred. AMP was separated, filtered and transferred into a plastic container (U-9: 5 cmφ × 3 cm height) for γ-ray spectrometry.

(2) Measurement

γ-ray spectrometry was carried out by using Ge semiconductor detectors at RMC and JCAC, respectively. The instruments and operating conditions are shown in Table 2.

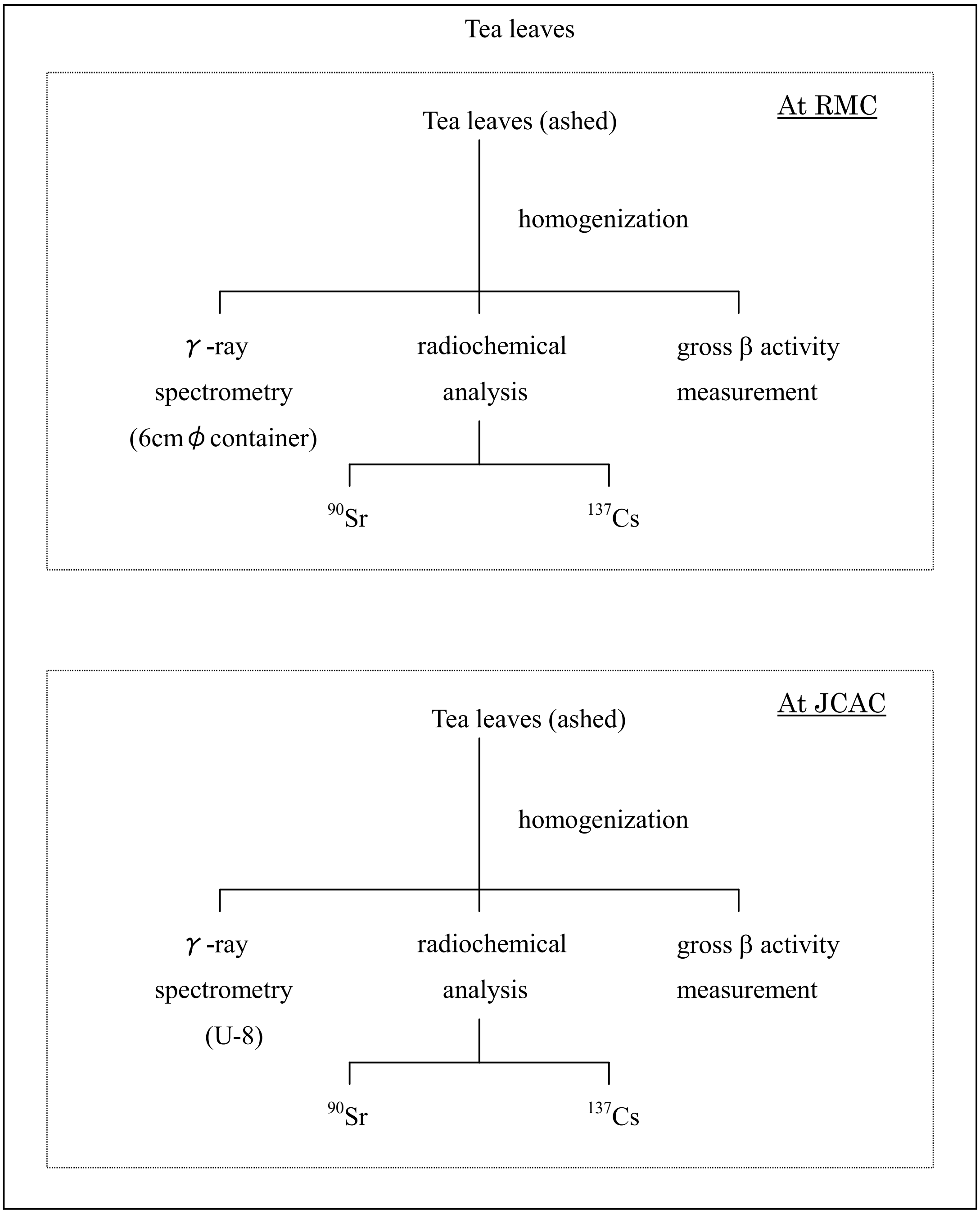


Fig. 1 Pretreatment method for tea leaves sample

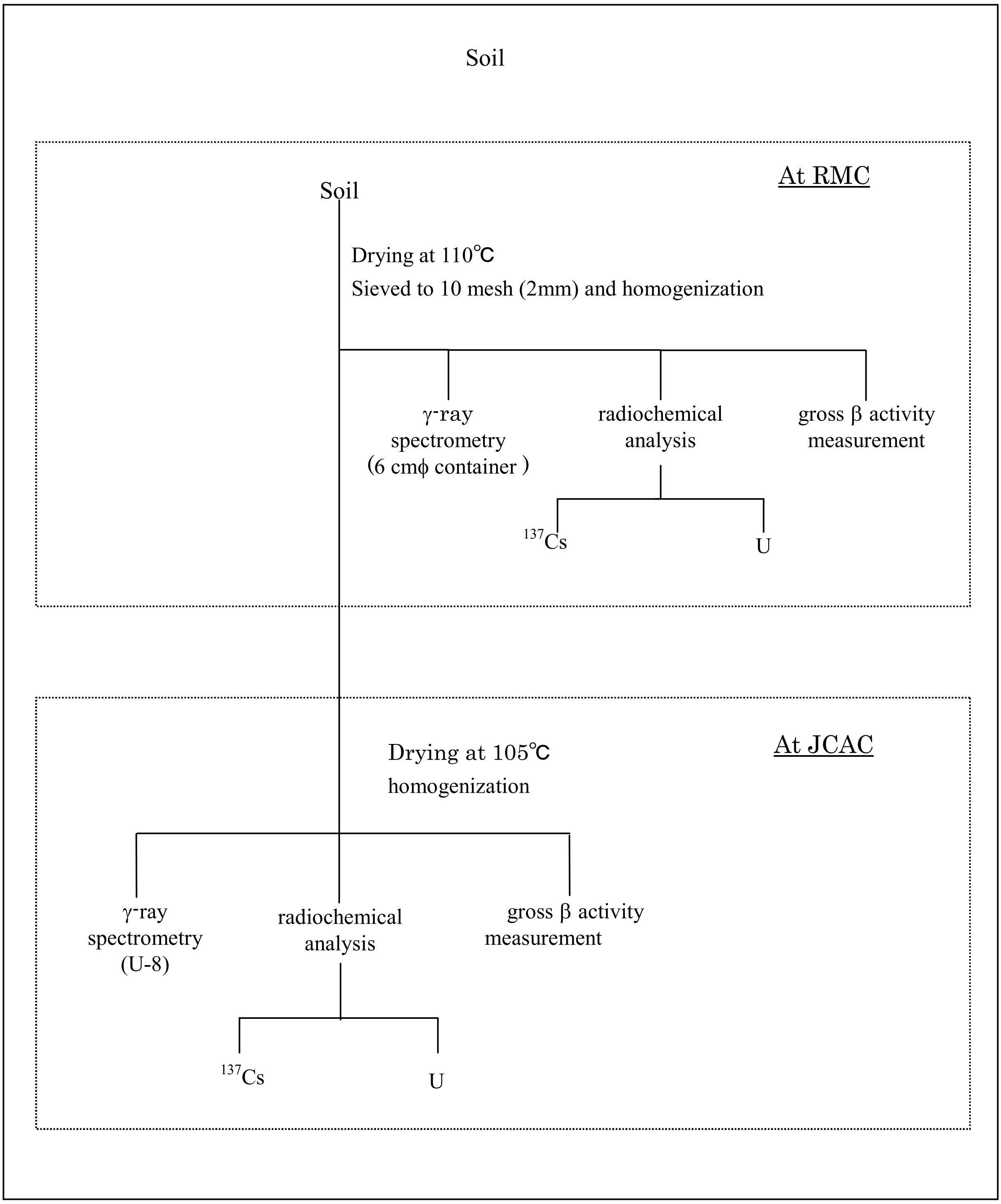


Fig. 2 Pretreatment method for soil samples

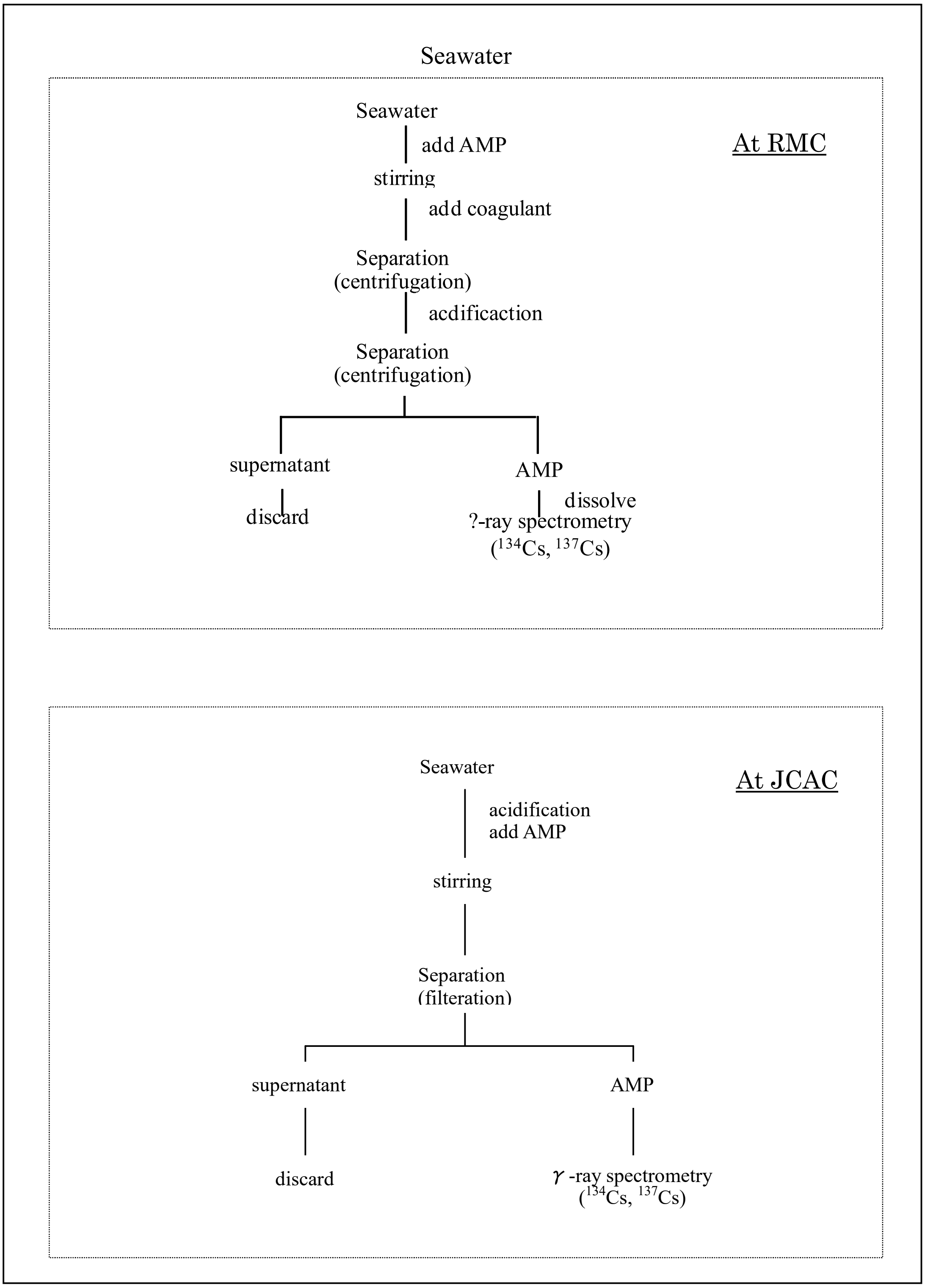


Fig. 3 Pretreatment method for seawater sample

Table 2 Instruments and operating conditions for γ-ray spectrometry

	RMC			JCAC		
Sample	Tea leaves	Soil	Seawater	Tea leaves	Soil	Seawater
Detector	DET 07 CANBERRA GC4020			No.50 ORTEC GEM-40190		
Pulse height Analyzer	CANBERRA Genie 2000XP			SEIKO EG&G		
Energy resolution (FWHM for 1332keV)	1.86 keV			1.7 keV		
Relative efficiency to 3 inch ϕ × 3inch NaI(Tl) detector	40 %			45 %		
Calibration standard	Multigamma Standard Calibrate Sample (Agar)			JRIA mixed point source and ^{137}Cs volume sources with different thickness		
Container	Tea leaves and Soil 6cmϕ ×4.5cm height Sea water 6cmφ × 2cm height			Tea leaves and Soil 5cmϕ ×6cm height Sea water 5cmϕ ×3cm height		
Counting time	30,000 ～ 80,000 s			70,000 ～ 80,000 s		
Computer	Personal Computer			Personal Computer		

1.2.2 Determination of ^{90}Sr and ^{137}Cs

(1) Pretreatment

1) Tea leaves

At RMC, no additional pretreatment was applied, because the sample was taken from that which had already been pretreated in paragraph 1.2.1(1).

At JCAC, no additional pretreatment was applied, because of the same reason mentioned above.

2) Soil (Long-Tan 1) for the determination of ^{137}Cs:

At RMC, no additional pretreatment was applied, because the portion of the dried sample was pretreated in paragraph 1.2.1 (1).

At JCAC, no additional pretreatment was applied, because of the same reason mentioned above.

3) Soil (Long-Tan 2) for the determination of ^{90}Sr:

At RMC, the soil sample was mixed thoroughly and used for the determination of ^{90}Sr.

At JCAC, the soil sample was also mixed thoroughly and used for the determination of ^{90}Sr.

(2) Chemical separation (See Fig. 4)

1) Tea leaves

At RMC, small quantity of nitric acid was added to the ashed tea leaves sample after adding given quantity of carrier solution containing Sr^{2+} and Cs^{+}. Then Sr and Cs were chemically separated as shown in Fig. 4. Finally, the precipitate of the ^{90}Y fraction was filtered using filter paper. The precipitate on the filter paper was dried and used directly for measurement of β-ray activity.

The coprecipitate of Cs was formed by adding AMP (ammonium phosphomolybdate). The coprecipitate in a plastic container was dried and used directly for measurement of γ-ray activity.

At JCAC, the chemical separation procedure of Sr was basically the same as that of RMC. And following processes were added.

The samples were decomposed with aqua regia and nitric acid. Sr was purified using a cation exchange resin column.

Cs was precipitated as cesium chloroplatinate with hexachloroplatinum acid. The precipitate was filtered on filter paper for preparation of β-ray measurement samples.

2) Soil

At RMC, 100 g of the dried soil (Long-Tan 1) was heated at 450℃ for 10 hours to decompose organic matter, Cs were then chemically separated as shown in Fig. 4. For Sr analysis, 100 g of the ashed soil (Long-Tan 2) was used for the Sr purification. The preparation of filter papers for β and γ-ray activity measurement methods was basically the same as those for ashed sample.

At JCAC, 100 g of the dried soil (Long-Tan 1) was heated at 450℃ for 12 hours to decompose organic matter. For Sr analysis, 100 g of the ashed soil (Long-Tan 2) was used for Sr analysis, and the chemical separation procedure of Sr was basically the same as that of RMC, and following processes were added. In order to avoid the reduction in chemical yield, Sr was precipitated with oxalic acid to remove iron. Sr was purified using a cation exchange resin column.

Cs was precipitated as cesium chloroplatinate with hexachloroplatinum acid. The precipitate was filtered on filter paper for preparation of β-ray measurement samples.

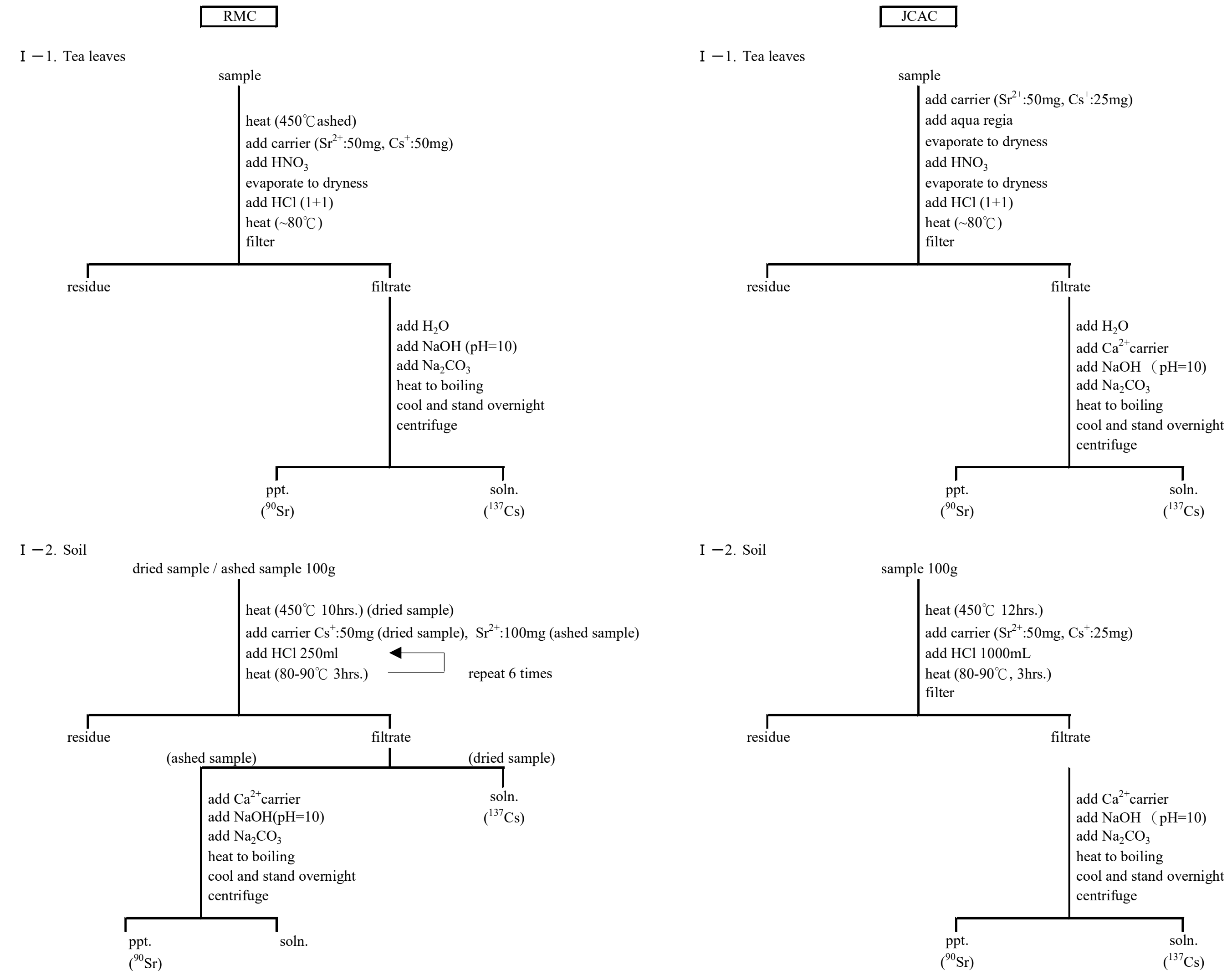
(3) Measurement

The measurements of β-ray activity from ^{90}Sr were carried out using low background gas-flow counter, while the measurement of γ-ray activity from ^{137}Cs was carried out using Ge semiconductor detector at RMC.

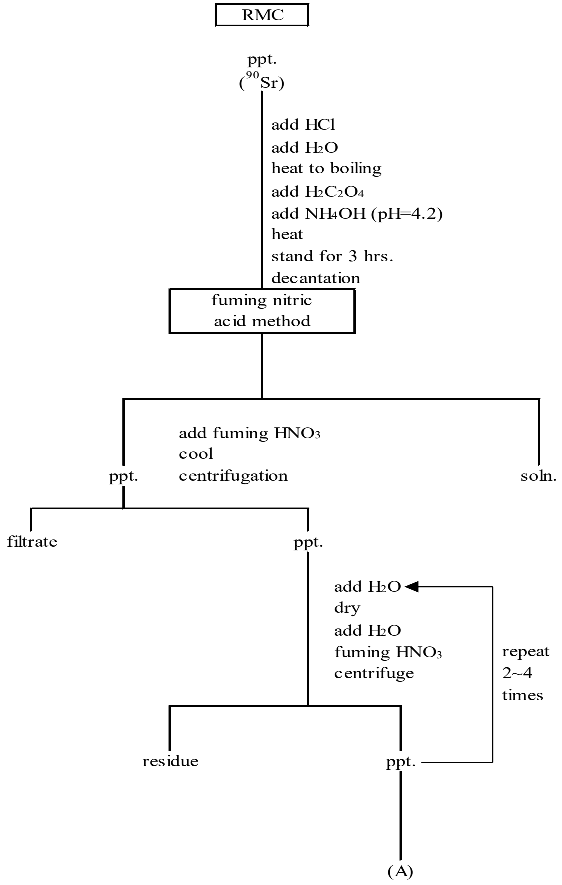
The ^{90}Sr and ^{137}Cs activity were determined by using low background GM counter at JCAC. The instruments and operating conditions are shown in Table 3.

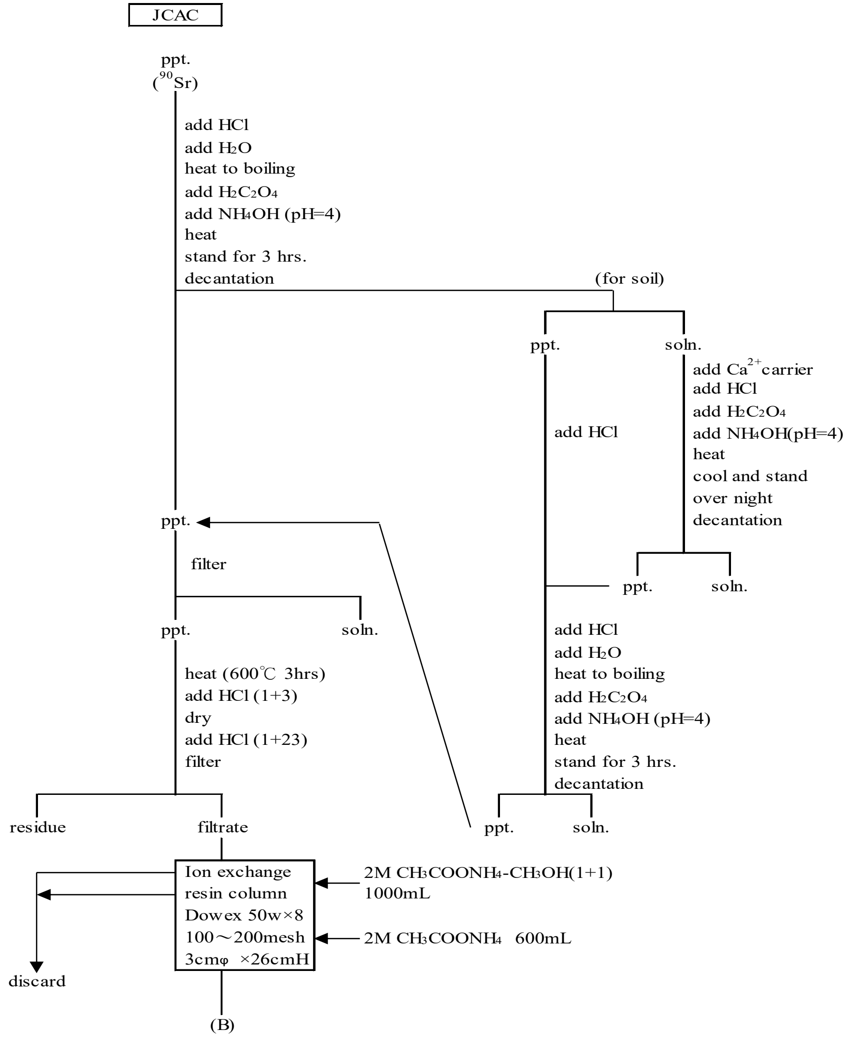
Fig.4 Flowchart for chemical separation of ^{90}Sr and ^{137}Cs

Ⅰ. Pre-separation

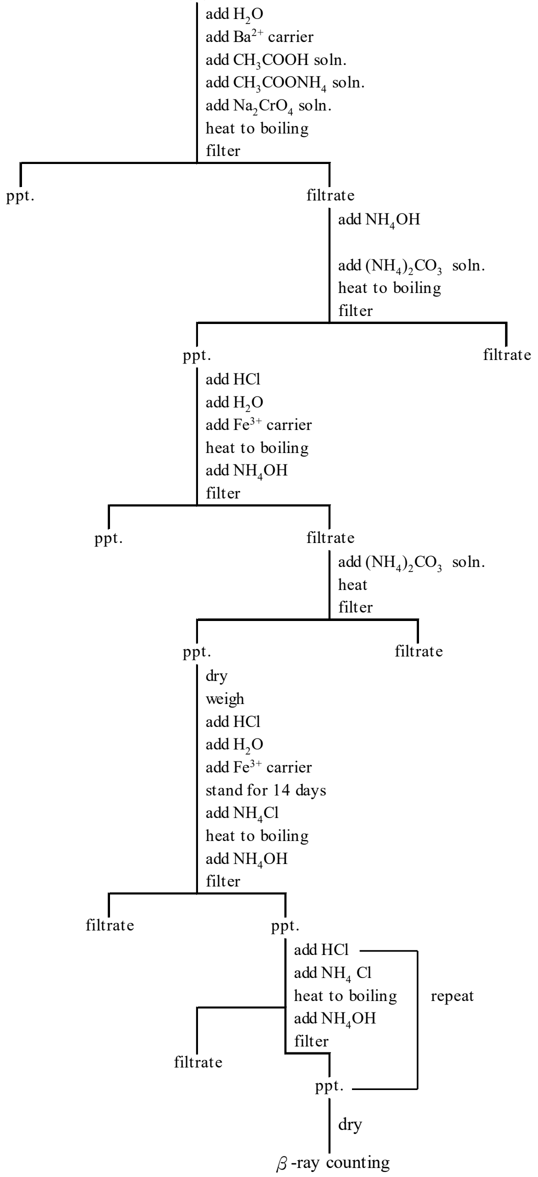


Ⅱ. Chemical separation of ^{90}Sr

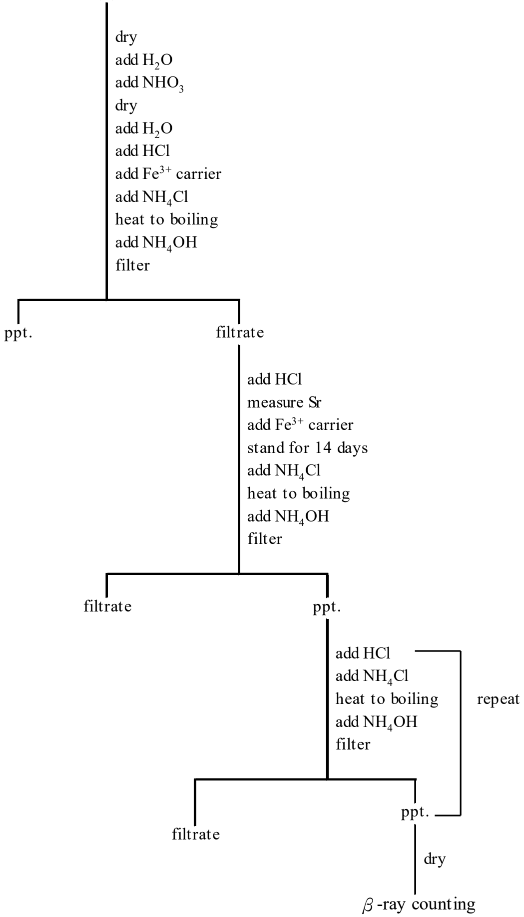




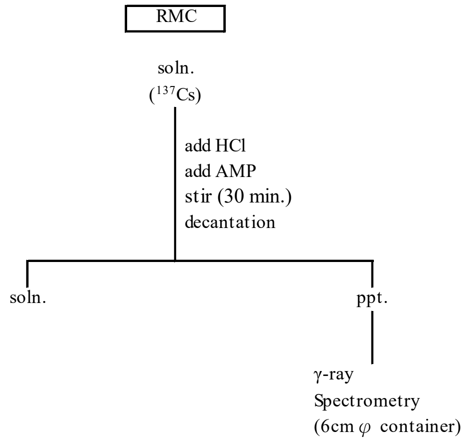
(A)


add H_2O
add Ba^{2+} carrier
add CH_3COOH soln.
add CH_3COONH_4 soln.
add Na_2CrO_4 soln.
heat to boiling
filter
ppt.
filtrate
add NH_4OH
add $(NH_4)_2CO_3$ soln.
heat to boiling
filter
ppt.
filtrate
add HCl
add H_2O
add Fe^{3+} carrier
heat to boiling
add NH_4OH
filter
ppt.
filtrate
add $(NH_4)_2CO_3$ soln.
heat
filter
ppt.
filtrate
dry
weigh
add HCl
add H_2O
add Fe^{3+} carrier
stand for 14 days
add NH_4Cl
heat to boiling
add NH_4OH
filter
filtrate
ppt.
add HCl
add NH_4 Cl
heat to boiling
add NH_4OH
filter
repeat
filtrate
ppt.
dry
β-ray counting

(B)


dry
add H_2O
add NHO_3
dry
add H_2O
add HCl
add Fe^{3+} carrier
add NH_4Cl
heat to boiling
add NH_4OH
filter
ppt.
filtrate
add HCl
measure Sr
add Fe^{3+} carrier
stand for 14 days
add NH_4Cl
heat to boiling
add NH_4OH
filter
filtrate
ppt.
add HCl
add NH_4Cl
heat to boiling
add NH_4OH
filter
repeat
filtrate
ppt.
dry
β-ray counting

Ⅲ. Chemical separation of ^{137}Cs



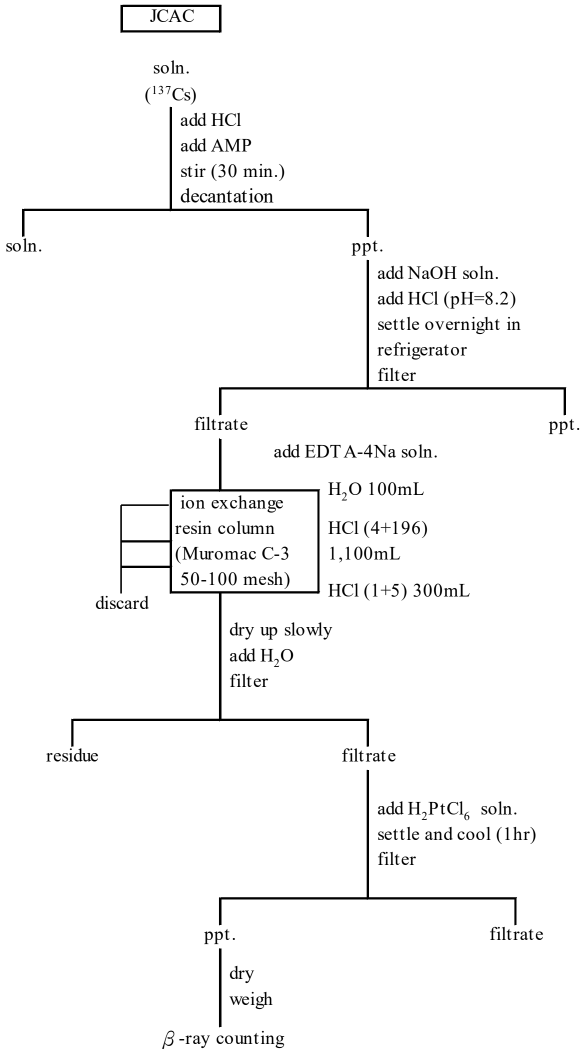


Table 3 Instruments and operating conditions for radiochemical analysis of ^{90}Sr, ^{137}Cs and gross β activity

Organization		RMC		JCAC		
Nuclide		^{90}Sr	Gross β	^{90}Sr	^{137}Cs	Gross β
Counting system		Tennelec Series 5		(Hitachi) Aloka LBC-471Q		
Detector	Type	2 π gas-flow type proportional counter(with window)		2 π gas-flow type GM counter (with window)		
	Diameter	2 inch ϕ		1 inch ϕ		
	Counting gas	P-10 gas [*1]		Q gas [*2]		
	Background	0.69 cpm	fresh water, ash and soil: 0.68 cpm seawater: 2.33 cpm (include glass fiber)	0.1 ～ 0.3cpm		
	Efficiency	43.2 %	34.5 ~ 46.8 %	26 %	25～26%	fresh water, ash and soil:20-26% seawater:30 %
Calibration standard		^{90}Y $Fe(OH)_3$	KCl	^{90}Y $Fe(OH)_3$	^{137}Cs Cs_2PtCl_6	fresh water, ash, soil: KCl seawater: U_3O_8
Counting dish		2 inch ϕ	2 inch ϕ	1 inch ϕ		
Counting time		100 min.	50 min.	60~180min.	90 min.	60min.

[*1] P-10 gas : Ar (90%) , methane (10%)

[*2] Q gas : He (99%) , isobutane (1%)

1.2.3 Determination of Uranium

(1) Pretreatment

1) Seawater (Kaohsiung)

At RMC, the seawater sample was used directly for chemical separation.

At JCAC, the seawater sample was used directly for chemical separation.

2) Soil (Long-Tan 1)

At RMC, no additional chemical pretreatment was applied, because the dried soil sample was prepared as written in paragraph 1.2.1(1).

At JCAC, no additional chemical pretreatment was applied, because of the same reason mentioned above.

(2) Chemical separation (See Fig. 5)

1) Seawater

At RMC, 1L of the seawater sample was used for uranium analysis. Uranium was chemically separated by using solvent extraction (TBP-xylene) and electrodeposited on a stainless steel disk as shown in Fig. 5. The disk was used for α-ray spectrometry.

At JCAC, 2L of the seawater sample was used for uranium analysis. Uranium was chemically separated using solvent extraction (TBP-xylene) and electrodeposited on a stainless steel disk as shown in Fig. 5. The disk was used for α-ray spectrometry.

2) Soil

At RMC, 5 g of the dried soil sample was used for uranium analysis. Uranium was chemically separated by using solvent extraction (TBP-xylene) and electrodeposited on a stainless steel disk as shown in Fig. 5. The disk was used for α-ray spectrometry.

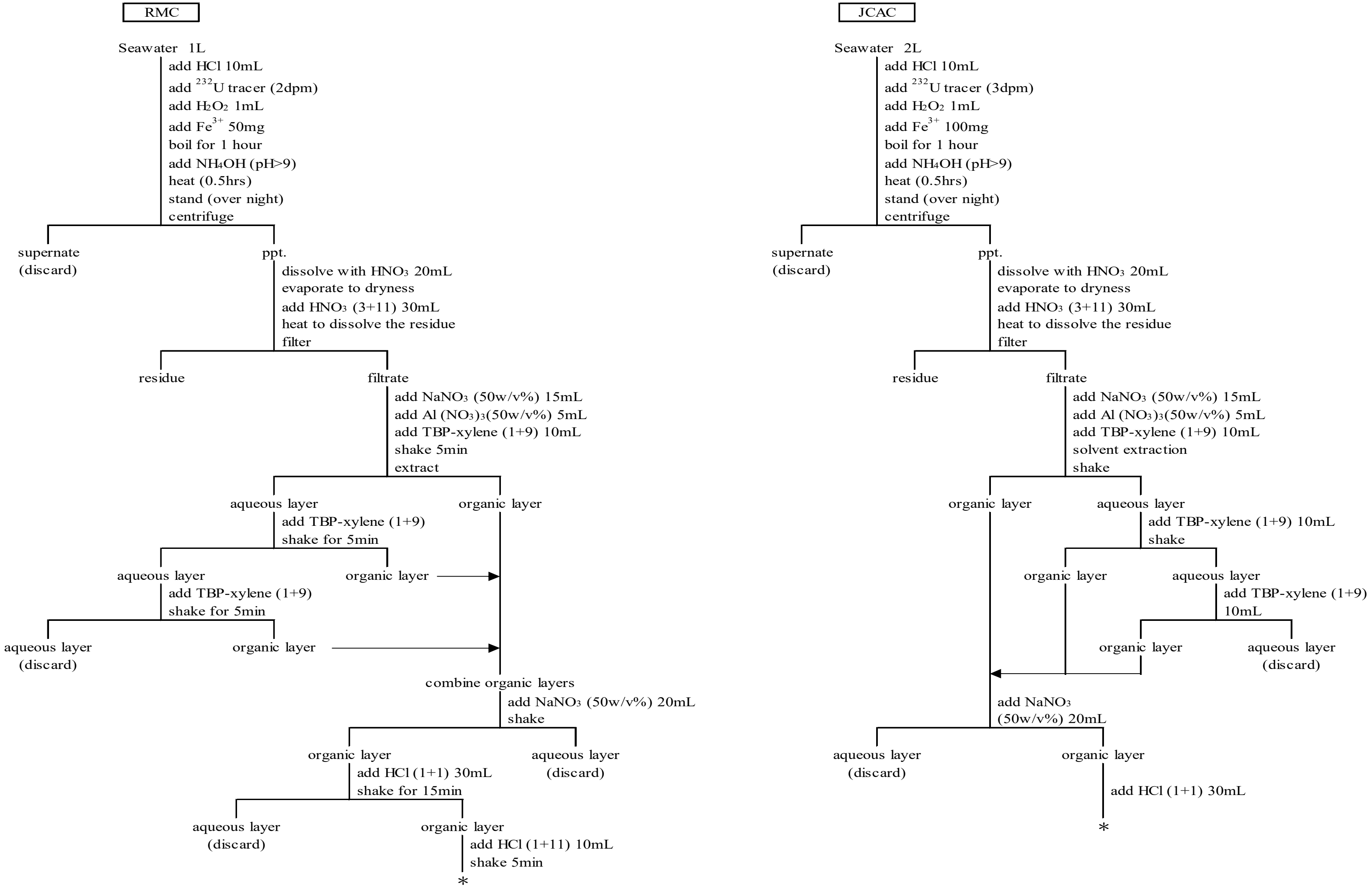
At JCAC, 5 g of the dried soil sample was used for uranium analysis. Uranium was chemically separated by using solvent extraction (TBP-xylene) and electrodeposited on a stainless steel disk as shown in Fig. 5. The disk was used for α-ray spectrometry.

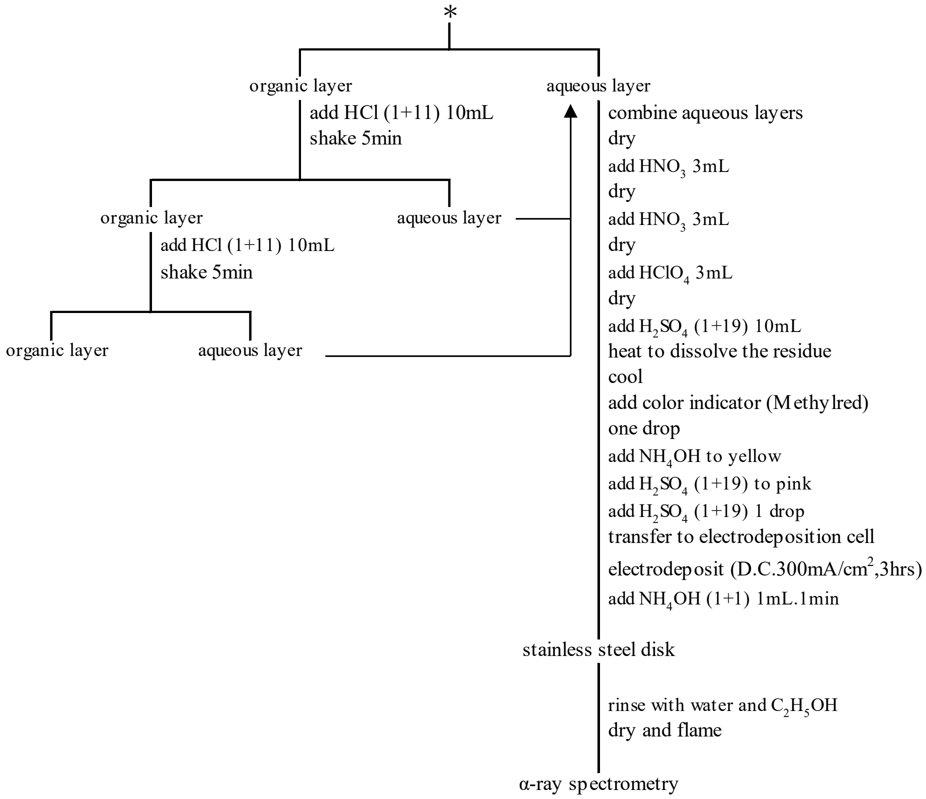
(3) Measurement

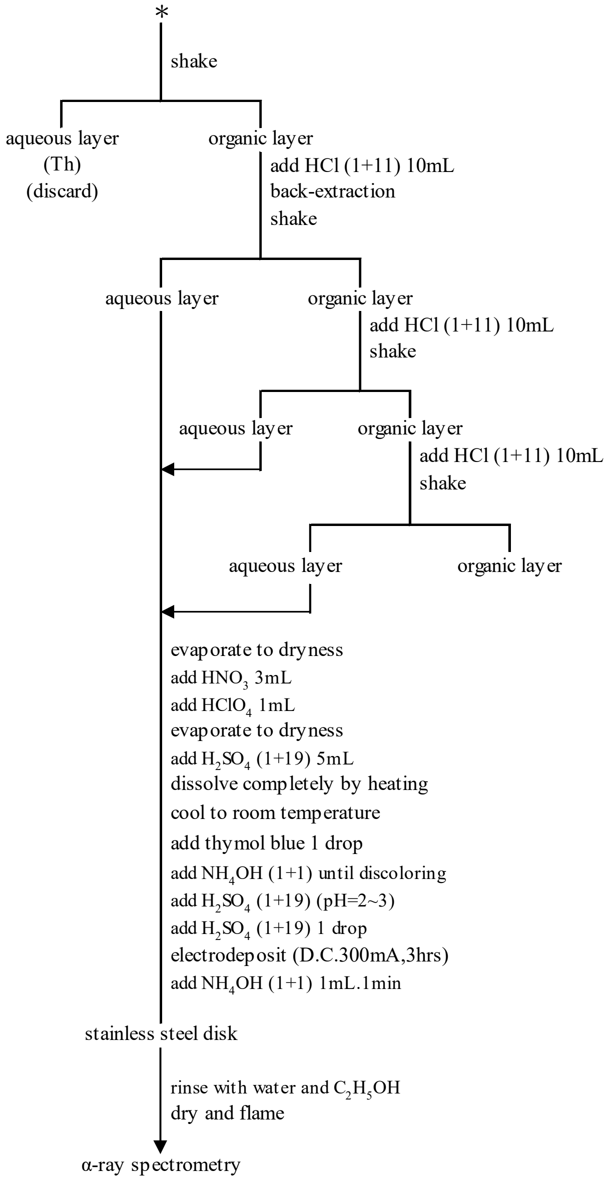
RMC and JCAC carried out α-ray spectrometry using silicon semiconductor detectors, respectively. The instruments and operating conditions are shown in Table 4.

Fig.5 Flowchart for chemical separation of uranium

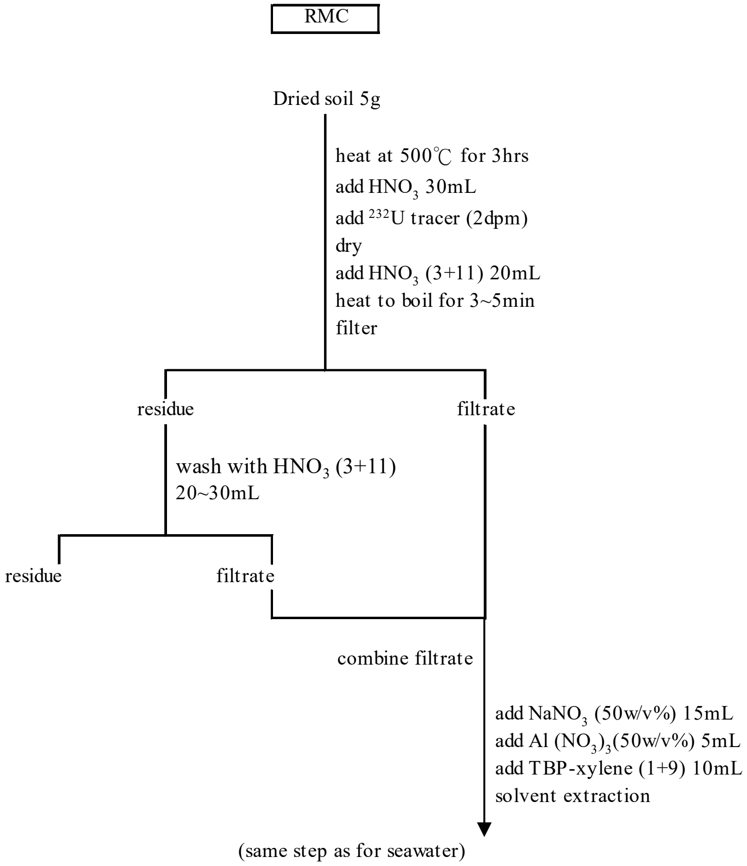
Ⅰ. Seawater



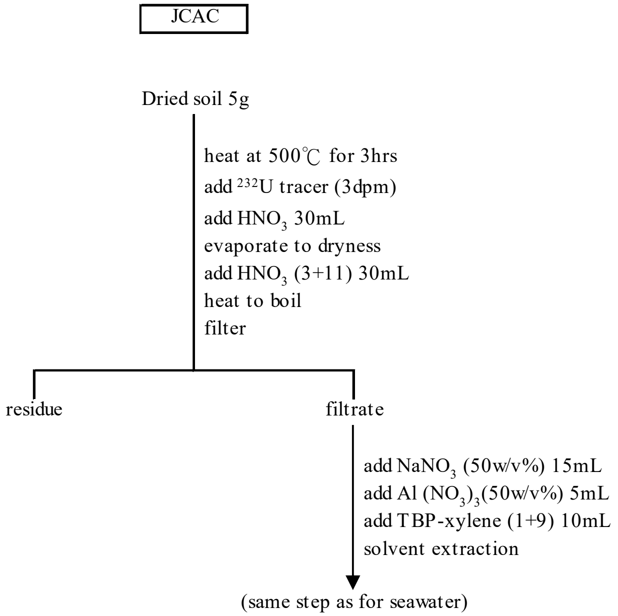

*
organic layer
aqueous layer
add HCl (1+11) 10mL
shake 5min
organic layer
aqueous layer
add HCl (1+11) 10mL
shake 5min
organic layer
aqueous layer
combine aqueous layers
dry
add HNO_3 3mL
dry
add HNO_3 3mL
dry
add $HClO_4$ 3mL
dry
add H_2SO_4 (1+19) 10mL
heat to dissolve the residue
cool
add color indicator (Methylred)
one drop
add NH_4OH to yellow
add H_2SO_4 (1+19) to pink
add H_2SO_4 (1+19) 1 drop
transfer to electrodeposition cell
electrodeposit (D.C.300mA/cm^2,3hrs)
add NH_4OH (1+1) 1mL.1min
stainless steel disk
rinse with water and C_2H_5OH
dry and flame
α-ray spectrometry


*
shake
aqueous layer
(Th)
(discard)
organic layer
add HCl (1+11) 10mL
back-extraction
shake
aqueous layer
organic layer
add HCl (1+11) 10mL
shake
aqueous layer
organic layer
add HCl (1+11) 10mL
shake
aqueous layer
organic layer
evaporate to dryness
add HNO_3 3mL
add $HClO_4$ 1mL
evaporate to dryness
add H_2SO_4 (1+19) 5mL
dissolve completely by heating
cool to room temperature
add thymol blue 1 drop
add NH_4OH (1+1) until discoloring
add H_2SO_4 (1+19) (pH=2~3)
add H_2SO_4 (1+19) 1 drop
electrodeposit (D.C.300mA,3hrs)
add NH_4OH (1+1) 1mL.1min
stainless steel disk
rinse with water and C_2H_5OH
dry and flame
α-ray spectrometry

Ⅱ. Soil



RMC
Dried soil 5g
heat at 500℃ for 3hrs
add HNO_3 30mL
add ^{232}U tracer (2dpm)
dry
add HNO_3 (3+11) 20mL
heat to boil for 3~5min
filter
residue
filtrate
wash with HNO_3 (3+11)
20~30mL
residue
filtrate
combine filtrate
add $NaNO_3$ (50w/v%) 15mL
add Al $(NO_3)_3$(50w/v%) 5mL
add TBP-xylene (1+9) 10mL
solvent extraction
(same step as for seawater)



JCAC
Dried soil 5g
heat at 500℃ for 3hrs
add ^{232}U tracer (3dpm)
add HNO_3 30mL
evaporate to dryness
add HNO_3 (3+11) 30mL
heat to boil
filter
residue
filtrate
add $NaNO_3$ (50w/v%) 15mL
add Al $(NO_3)_3$(50w/v%) 5mL
add TBP-xylene (1+9) 10mL
solvent extraction
(same step as for seawater)

Table 4　Instruments and operating conditions for uranium analysis

		RMC		JCAC	
Sample		Seawater	Soil	Seawater	Soil
Detector	Model	ORTEC 576A Silicon Semiconductor Detector		ORTEC 576A Silicon Semiconductor Detector	ORTEC Octete plus Silicon Semiconductor Detector
	Active area	24 mm ϕ		24 mm ϕ	
	Resolution (FWHM)	20 keV		21 keV, 47 keV	
	Efficiency	19 % , 27 %		24 %, 28%	
Background		0 cpm		0 cpm	
Calibration standard		^{241}Am		U_3O_8, ^{241}Am	
Counting time		80,000 seconds		80,000 seconds	

1.2.4 Determination of Tritium

(1) Pretreatment

Fresh water

At RMC, 100 mL of the fresh water sample was distilled after adding approximately 0.1 g of potassium permanganate and 0.1 g of sodium peroxide. 10 mL of liquid scintillator (Ultima Gold LLT) was added to 10 mL of distilled sample in a plastic vial, mixed thoroughly and cooled before β-ray activity measurement.

At JCAC, 100 mL of the fresh water sample was distilled after adding approximately 0.1 g of potassium permanganate and 0.1 g of sodium peroxide. 50 mL of liquid scintillator (Ultima Gold LLT) was added to 50 mL of distilled sample in a teflon vial, mixed thoroughly and cooled before β-ray activity measurement.

(2) Measurement

β-ray activity measurement was carried out by using liquid scintillation counter at RMC and JCAC, respectively. The instruments and operating conditions are shown in Table 5.

Table 5 Instruments and operating conditions for tritium analysis

	RMC	JCAC
Counter	(Hitachi) Aloka LSC-LB7	(Hitachi) Aloka LSC-LB5
Counting vial	Plastic vial 20 mL	Teflon vial 100 mL
Liquid scintillator	Ultima Gold LLT 10 mL	Ultima Gold LLT 50 mL
Distilled sample volume	10 mL	50 mL
Efficiency	20.62 %	30.97 %
Calibration standard	Special Index of the Transformed external standard spectrum	External standard channel ratio method
Counting time	50 min. × 10 times	50 min. × 10 times
Background	1.26 cpm	3.12 cpm
FOM ($EV/\sqrt{B}$)	183.7	876.7

1.2.5 Measurement of gross β activity

(1) Pretreatment

1) Fresh water

At RMC, 1 L of the fresh water sample was evaporated to near dryness. All the residue was put in a dish of 2 inches in diameter, with dilute nitric acid used for washing the beaker. After drying, flame to convert the nitrate salt to oxides, the dish was used for gross β activity measurement.

At JCAC, 1 L of the fresh water sample was evaporated to dryness. The residue was dissolved with nitric acid and the sample was evaporated to near dryness. All the residue was put in a dish of 1 inch in diameter, with dilute nitric acid used for washing the beaker, and completely evaporated by using an infrared lamp. The dish was used for gross β activity measurement.

The pretreatment procedure used for fresh water sample is shown in Fig. 6.

2) Seawater

At RMC, 1L of the seawater sample was boiled after adding given quantity of Co^{2+} carrier solution. After adjusting pH to 9.0～9.5 with aqueous ammonia, 1.2 g of thioacetamide powder was added. The solution was boiled for 2 hours. The solution was then cooled and allowed to stand until the precipitate settled at the bottom of the beaker. The precipitate was filtered using filter paper. The precipitate was transferred together with the filter paper to a dish of 2 inches in diameter, then dried in an oven and used for gross β activity measurement.

At JCAC, the chemical separation procedure was the same as that of RMC. After making precipitate, it was filtered using filter paper of 1 inch in diameter. The precipitate was transferred together with the filter paper to a dish of 1 inch in diameter, dried by infrared lamp, a few drop of collodion was added, dried again and used for gross β activity measurement.

The pretreatment procedure for seawater is also shown in Fig. 6.

3) Tea leaves and soil

Each portion of the ashed tea leaves and dried soil samples in the pretreatment procedure for γ-ray spectrometry or radiochemical analysis was also used for the measurement of gross β activity.

At RMC, 0.5 g of the ashed tea leaves and the dried soil were taken and placed separately in dishes of 2 inches in diameter. A small quantity of alcohol was poured into the samples and the surface of each sample was flattened while it was wet. After drying, each dish was used for gross β activity measurement.

At JCAC, 0.5 g of the ashed tea leaves and the dried soil were taken and placed separately in dishes of 1 inch in diameter. A small quantity of alcohol was poured into the samples and the surface of each sample was flattened while it was wet. After each sample was dried by an infrared lamp, a few drop of collodion was added. After drying, each dish was used for gross β activity measurement.

The pretreatment procedures for the tea leaves and soil samples are shown in Fig. 7.

(2) Measurement

Gross β activity measurement was carried out using low background gas-flow type proportional counter at RMC and low background gas-flow type GM counter at JCAC, respectively. The instruments and operating conditions are shown in Table 3.

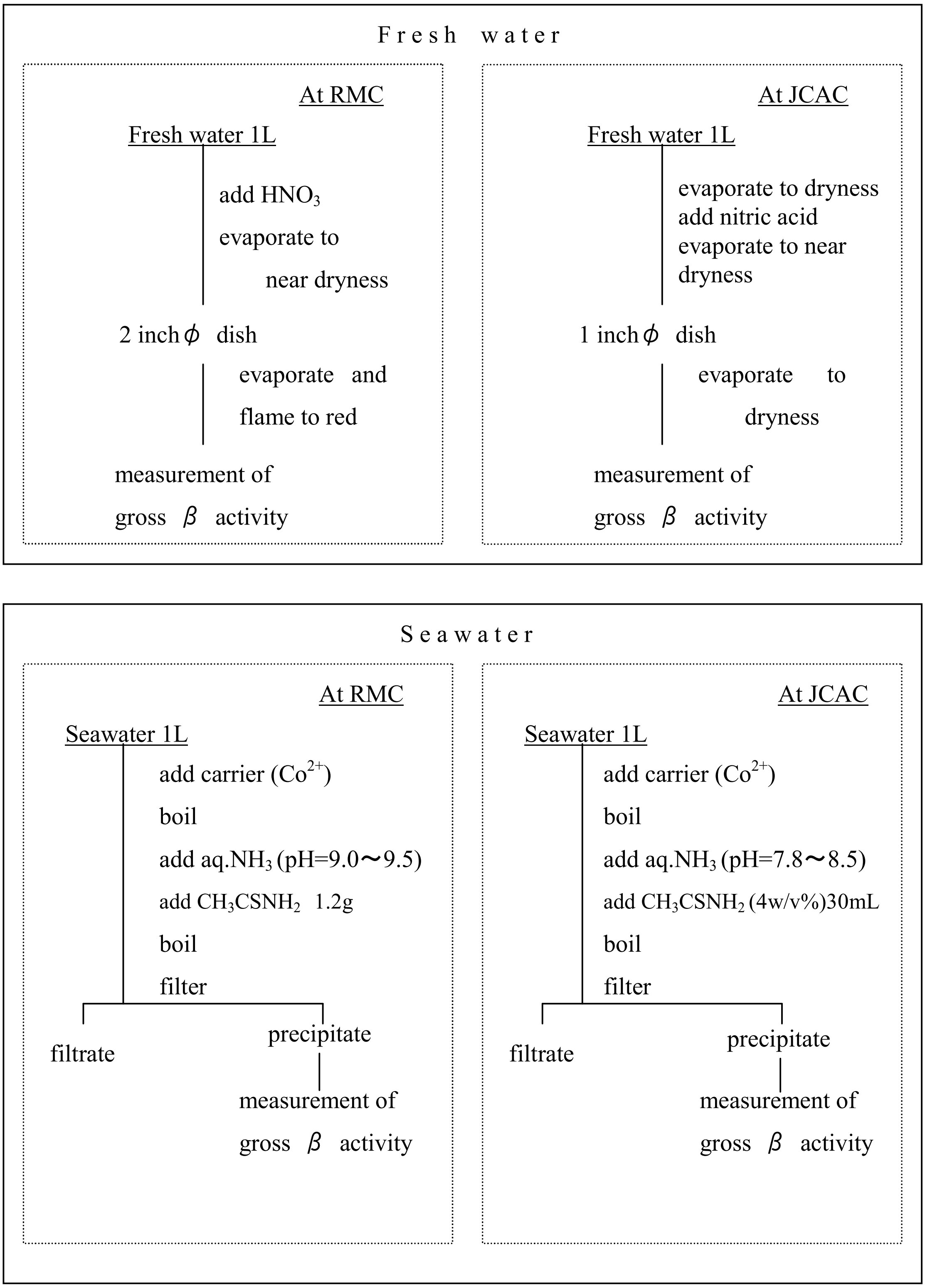


Fig. 6 Pretreatment method for gross β activity measurement

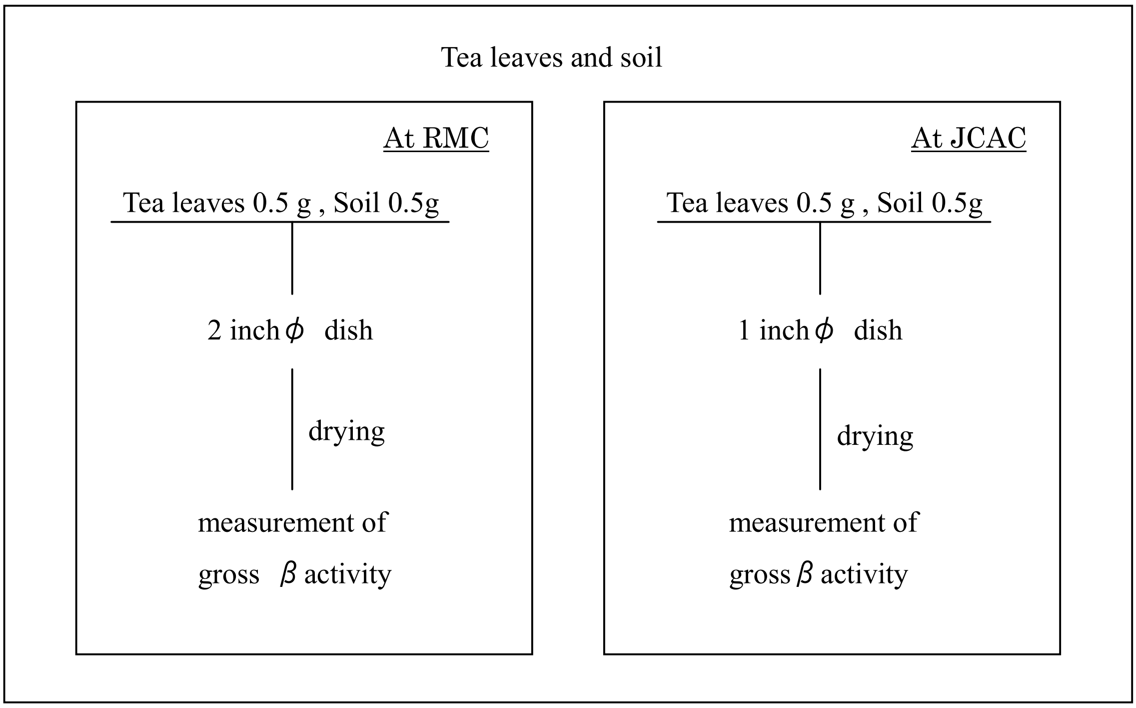


Fig. 7 Pretreatment method for gross β activity measurement

1.2.6 Determination of Plutonium

(1) Pretreatment

Soil (San-Zhi)

At RMC, 5 g of ashed soil was taken for analysis. The sample was spiked with ^{242}Pu tracer and leached with 40 mL of hot 3:2 HNO_3 for 2 hours. During the leaching step, the soil was boiled and stirred under a reflux condenser. The mixture was then filtered and then 0.5 mL of 30% H_2O_2 and 0.2 g of $NaNO_2$ were used for the valence adjustment of Pu.

After the adjustment of the oxidation state of Pu to Pu(IV), the solution was added into a column with 3 mL preconditioned anion exchange column (Dowex 1×8, 100–200 mesh). The column was washed with 50 mL of 8 M HNO_3 and 50 mL of 9 M HCl to remove the interfering elements and Pu was eluted from the column by reduction with 15 mL of freshly prepared 9 M HCl–0.1M NH_4I. The eluted solution was heated to dryness, and then dissolved in 2% HNO_3 for plutonium analysis.

At JCAC, about 5 g of ashed soil was sampled and heated at 500°C for 12 hours. The sample was spiked with ^{242}Pu tracer and leached with 100 mL of 3:2 HNO_3 for 3h on a hot plate. The sample was filtered and then added 10 mL of 20% $NaNO_2$ for the valence adjustment of Pu. After the adjustment of the oxidation state of Pu (Pu(IV)), the solution was added into a column with 6 mL preconditioned anion exchange resin (Dowex 1 × 8, 100-200 mesh). The column was washed with 120 mL of 8 M HNO_3 and 200 mL of 10 M HCl to remove the interfering elements and Pu was eluted from the column by reduction with 100 mL of freshly prepared 10 M HCl-0.1 M NH_4I. The eluted solution was heated to dryness, and 10 mL of 4 M-CH_3COOH was added and dissolved by heating. This solution was passed through the column to remove U. The column was washed twice with 10 mL of 4 M CH_3COOH to recover remained Pu in the column. The solution was heated to dryness, and then dissolved in 1 M HNO_3 for plutonium measurement.

The pretreatment procedure used for soil sample is shown in Fig. 8.

(2) Measurement

The determination for the activities of ^{239}Pu and ^{240}Pu was carried out by using HR-ICP-MS at RMC and JCAC, respectively. The instruments and operating conditions are shown in Table 6.

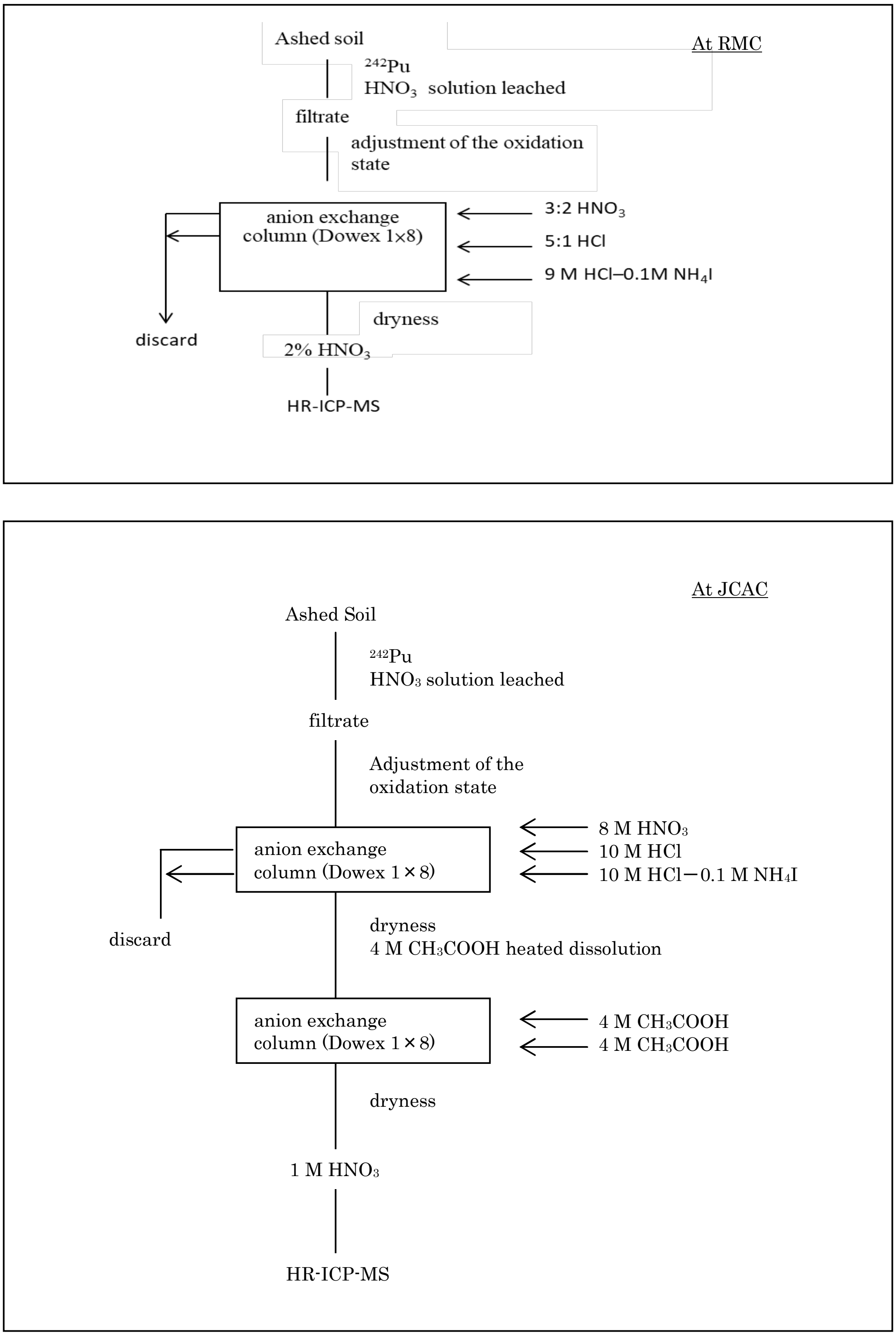


Fig. 8 Pretreatment method for plutonium activity measurement

Table 6 Instruments and operating conditions for plutonium analysis

	RMC	JCAC
instrument	Element XR	Element 2
RF power	1200 W	1300W
Mass resolution	Low	Low
Nebulizer	Apex-HF desolvating nebulizer	Glass concentric nebulizer
Sampling and skimmer cones	Nickel	Nickel

1.3 Criteria for evaluation of results

In this report, E_n score applied to evaluate for each laboratory results.

The value of the E_n was calculated according to the following equation:

$$En = \frac{Value_{RMC} - Value_{JCAC}}{\sqrt{u^2_{RMC} + u^2_{JCAC}}}$$

where

$Value_{RMC}$: RMC result

$Value_{JCAC}$: JCAC result

U_{RMC}: expanded uncertainty (k=2) of RMC

U_{JCAC}: expanded uncertainty (k=2) of JCAC

The result was assigned “acceptable” score if: $En \leqq 1$

The result was assigned “not acceptable” score if: $En > 1$

1.4 Results

The sampling and pretreatment data are shown in Table 7. The analytical results are shown in Table 8.The E_n score are shown in Table 9.The results of ^{240}Pu /^{239}Pu atom ratio are shown in Table10.

The intercomparison samples and measured radionuclides are as follows.

1) γ-ray spectrometry

Tea leaves (^{40}K and ^{137}Cs)

Soil (^{40}K, ^{137}Cs, ^{208}Tl and ^{228}Ac)

Seawater (^{134}Cs and ^{137}Cs)

The E_n score are within 1.0 except for ^{40}K and ^{137}Cs in soil.

2) Radiochemical analysis

Fresh water (^{3}H and gross β)

Seawater (Uranium and gross β)

Tea leaves (^{90}Sr, ^{137}Cs and gross β)

Soil (^{90}Sr, ^{137}Cs, ^{239}Pu, ^{240}Pu, ^{240}Pu /^{239}Pu atom ratio, Uranium and gross β)

The E_n score are within 1.0 except for gross β in fresh water.

1.5 Remarks

The E_n score for ^{40}K(Soil), ^{137}Cs(Soil) and gross β(Fresh water) were greater than 1. RMC and JCAC conducted the following examination.

1) γ-ray spectrometry for soil

- Re-evaluation of soil sample

A

(1) Soil sample (packed in a container for gamma-ray measurement by JCAC) was sent back from JCAC to RMC

(2) RMC opened the sample container, took the soil sample and filled it into another container. RMC measured the sample and the results were compared with the results measured in JCAC.

(3) The values in ^{137}Cs in RMC and JCAC were 21.6 ± 2.0 and 23.5 ± 2.7 Bq/kg, respectively. The En score is <1.

(4) The values in ^{40}K of RMC and JCAC were 469.3 ± 45 and 493 ± 56 Bq/kg, respectively. The En score is <1.

B

(1) Soil sample (packed in a container for gamma-ray measurement by RMC) was sent back from RMC to JCAC

(2) JCAC opened the sample container, took the soil sample and filled it into another container. JCAC measured the sample and the results were compared with the results measured in RMC.

(3) The values in ^{137}Cs in RMC and JCAC were 19.8 ± 1.9 and 23.1 ± 2.5 Bq/kg, respectively. The En score is <1.

(4) The values in ^{40}K of RMC and JCAC were 408.4 ± 37.9 and 466 ± 49 Bq/kg, respectively. The En score is <1.

- The inhomogeneity is suspected to be the reason. RMC have re-checked the homogeneity of soil sample. The value in ^{137}Cs ranges from 19.8 to 21.9 and the uncertainty contributed from inhomogeneity is 7.27%, higher than that of 2.05% in previous. RMC will put more effort to assure the uncertainty from inhomogeneity lower than 5%.

2) Grossβ for fresh water

(1) Evaluation of sample preparation methods: the results were in good agreement

- Grossβ sample prepared in RMC and measured in JCAC, the values is 1.26

± 0.08. Comparing to that prepared and measured in JCAC, the value is 1.18 ± 0.077（expanded uncertainty k=2）. The En score is <1.

- Grossβ sample prepared in JCAC and measured in RMC, the values is 1.43 ± 0.08, Comparing to that prepared and measured in RMC, the values is 1.45 ± 0.08（expanded uncertainty k=2）.The En score is <1.
- Fresh water samples were analyzed according to each preparation method and then were measured in JCAC : The values of JCAC and RMC were 1.22 ± 0.075, RMC 1.13 ± 0.07（expanded uncertainty k=2）, respectively. The En score is <1.

(2) Evaluation of the calibration curves:

- When the sample weight >100 mg, KCl was used for the calibration curve for JCAC and RMC : Although the dpm values of KCl were different (JCAC 849; RMC 880 dpm/g), the En score for the gross beta activities of tea and soil were <1.
- When the sample weight <100 mg, U_3O_8 and KCl were used for the calibration curve for JCAC and RMC, respectively. JCAC has shown the activities calculated from U_3O_8 and KCl calibration source are very similar. RMC has tested the activities of various weights (40 to 300 mg) with different amounts of sample or by adding stable strontium carrier salt, the differences of activity were only within 3%.
- The reason for the difference of the unstable area of calibration curve between JCAC and RMC is not clear. Both parties agreed to analyze the fresh water and calculated from the more stable area of calibration curve by controlling the residual weight >200 mg next program, if possible.

.

Table 7　Sampling and pretreatment data

Upper line: RMC Lower line: JCAC

Sample	Sampling date	Sampling location	Sampling method and amount	Nuclides	Pretreatment Method	Amount for analysis	Measurement sample mass
Fresh water	Jan. 1, 2019	Long-Tan	Underground water, sampling with plastic bucket, 40L, filtered. For JCAC, 5L added 5mL conc.HCl and 1L not acidified for ^3H.	^3H	distilled with $KMnO_4$ and Na_2O_2	—	10mL
				^3H	distilled with $KMnO_4$ and Na_2O_2	—	50mL
				Gross β	dry for Gross β	1.0L	83.3mg
				Gross β	dry for Gross β	1.0L	128.2mg
Seawater		Kaohsiung	Sampling with plastic bucket, 100L, filtered. For JCAC, 5L added 5mL conc.HCl.	U Gross β	— cobalt sulfide co-precipitation	1.0L 1.0L	— 36.6mg
				U Gross β	— cobalt sulfide co-precipitation	2.0L 1.0L	— 21.8mg
Seawater	Nov. 8, 2017	Japan	Provided by Fukushima prefecture	γ	adsorption onto AMP and dissolve with ammonia.	20.0L	55.34 g
				γ	adsorption onto AMP	20.0L	8.41g
Tea leaves ash	Jan. 1, 2019	Shin-Ban-San	Sampling from a farm. Grind, mix and ash at 450℃.	γ, ^{90}Sr, ^{137}Cs, Gross β	— —	— , 10g/ash 10g/ash, —	47.8g/ash , — — , 0.50g/ash
				γ, ^{90}Sr, ^{137}Cs, Gross β	— —	— ,15.00g/ash, 15.00g/ash, —	44.00g/ash, — — , 0.50g/ash
Soil		Long-Tan 1	Sampling with spade.	^{137}Cs, U, Gross β	dry(110℃) grind, mix.	100g, 5.0g, —	— , — 0.50g
				^{137}Cs, U, Gross β	dry(105℃) and homogenize	100.1g, 5.0g, —	— , — 0.50g
				γ	dry(110℃) grind, mix.	—	167.2g
				γ	dry(105℃) and homogenize	—	102.51g
		Long-Tan 2	Grind, mix and ash at 450℃.	^{90}Sr	—	100g	—
				^{90}Sr	—	50.0g	—
		San-Zhi	Grind, mix and ash at 450℃.	^{239}Pu, ^{240}Pu	—	5.0g	—

				^{239}Pu, ^{240}Pu	—	5.04g	—

Table 8 Analytical results Upper line: RMC Lower line: JCAC

Sample (Sampling	Sampling date	γ-ray spectrometry					Radiochemical analysis							Unit
		^{40}K	^{134}Cs	^{137}Cs	^{208}Tl	^{228}Ac	^{90}Sr	^{137}Cs	Total U	^{3}H	Gross β	^{239}Pu	^{240}Pu	
Fresh water	Jan. 1, 2019	—	—	—	—	—	—	—	—	45.1 ± 2.5 (1.3)	—	—	—	Bq/L
		—	—	—	—	—	—	—	—	47.0 ± 4.6 (0.34)	—	—	—	
		—	—	—	—	—	—	—	—	—	1.45 ± 0.08 (0.03)	—	—	
		—	—	—	—	—	—	—	—	—	1.18 ± 0.077 (0.036)	—	—	
Seawater (Kaohsiung)		—	—	—	—	—	—	—	0.087±0.018 (0.004)	—	0.044 ± 0.025 (0.012)	—	—	Bq/L
		—	—	—	—	—	—	—	0.0874±0.0060 (0.0028)	—	0.0340 ± 0.013 (0.0064)	—	—	
Seawater (Japan)	Nov. 8, 2017	—	3.3 ± 0.8 (0.36)	30.5 ± 2.6 (0.78)	—	—	—	—	—	—	—	—	—	mBq/L
		—	4.1 ± 1.8 (0.87)	33.3 ± 5.2 (0.85)	—	—	—	—	—	—	—	—	—	
Tea leaves ash (Shin-Ban -San)	Jan. 1, 2019	5540± 514.1 (122)	—	22.1 ± 3.5 (1.5)	—	—	90.6± 10.7 (2.8)	21.7 ± 5.8 (2.7)	—	—	9184.0± 718.2 (123.3)	—	—	Bq/kg dry ash.
		5910 ± 800 (40)	—	22.9 ± 3.5 (0.85)	—	—	91.0 ± 12 (2.9)	21.3 ± 2.6 (1.1)	—	—	8940 ± 610 (160)	—	—	
Soil (Long-Tan 1)		408.4 ± 37.9 (12.1)	—	19.8 ± 1.9 (0.6)	11.4 ± 1.3 (0.5)	37.7 ± 3.5 (1.1)		18.0 ± 1.9 (0.5)	12.7 ± 2.0 (0.6)	—	633.2 ± 79.8 (34.9)	—	—	Bq/kg dry wt.
		493 ± 56 (7.7)	—	23.5 ± 2.7 (0.47)	12.7 ± 1.6 (0.37)	41.1 ± 5.2 (1.3)		18.5 ± 2.1 (0.39)	13.4 ± 1.2 (0.56)	—	581 ± 100 (42)	—	—	
Soil (Long-Tan 2)		—	—	—	—	—	37.2 ± 4.0 (0.4)	—	—	—	—	—	—	Bq/kg dry ash.
		—	—	—	—	—	43.0 ± 6.2 (0.65)	—	—	—	—	—	—	
Soil (San-Zhi)		—	—	—	—	—	—	—	—	—	—	1.65 ±0.11 (0.03)	1.02 ±0.07 (0.03)	Bq/kg dry ash.
		—	—	—	—	—	—	—	—	—	—	1.76 ±0.11 (0.01)	1.10 ±0.07 (0.02)	

Measured results are shown in the form of " measured results ± expanded uncertainties "(k=2) for nuclides respectively.
（counting error 1σ）
The results are decay-corrected to sampling date (except gross β).

Table 9 The values of the E_n score

Sample (Sampling location)	γ-ray spectrometry					Radiochemical analysis						
	^{40}K	^{134}Cs	^{137}Cs	^{208}Tl	^{228}Ac	^{90}Sr	^{137}Cs	Total U	^{3}H	Gross β	^{239}Pu	^{240}Pu
Fresh water (Long-Tan)	—	—	—	—	—	—	—	—	-0.4	—	—	—
Fresh water (Long-Tan)	—	—	—	—	—	—	—	—	—	2.4	—	—
Seawater (Kaohsiung)	—	—	—	—	—	—	—	0.0	—	0.4	—	—
Seawater (Japan)	—	-0.4	-0.5	—	—	—	—	—	—	—	—	—
Tea leaves ash (Shin-Ban -San)	-0.4	—	-0.2	—	—	0.0	0.1	—	—	0.3	—	—
Soil (Long-Tan 1)	-1.2	—	-1.1	-0.6	-0.5	—	-0.2	0.3	—	0.4	—	—
Soil (Long-Tan2)	—	—	—	—	—	-0.8	—	—	—	—	—	—
Soil (San-Zhi)	—	—	—	—	—	—	—	—	—	—	-0.7	-0.7

Table 10 Evaluation results of intercomparison for ^{240}Pu/^{239}Pu atom ratio

Measure	Sample	Nuclides	Unit	Lab	Data	Evaluation criteria	Evaluation value 1)	Difference 2)	Judgment 3)
ICP-MS	Soil	^{240}Pu /^{239}Pu	atom ratio	RMC	0.170 ± 0.0035	≦7 %	0.0119	0.000	Good
				JCAC	0.170 ± 0.0027				

1) Evaluation value: The value is calculated by 7% of the higher value between RMC and JCAC.
2) Difference: Difference between the analytical values obtained by RMC and JCAC.
3) Judgment: If the difference is higher than an evaluation value, "discuss" is expressed, otherwise, "Good".

2. Intercomparison of radiation dose measurements

2.1 Instruments

Thermoluminescence dosimeters (hereafter referred to as TLDs) were used for radiation dose measurements. The instruments and operating conditions are shown in Table 11.

2.2 Method of the radiation dose measurements

The program of the radiation dose measurements consists of three kinds of tests. These are (1) a field-exposure test at RMC’s monitoring points, (2) a standard irradiation test with RMC's irradiation equipment and (3) a standard irradiation test with JCAC's irradiation equipment.

An outline of each test is shown in Table 12.

(1) Field-exposure test at RMC's three monitoring points.

1) The five sets of JCAC's TLDs, each set consists of 5 TLDs (10 elements: One TLD has 2 elements), were annealed at 400℃ for 5 minutes by JCAC.
2) After JCAC's TLDs were sent from JCAC to RMC, the first three sets were field-exposed by RMC at three monitoring points for 92 days. The fourth set was kept in a case of 5 cm thick lead for the control.
3) All JCAC's TLDs were sent back to JCAC in a container made of 2 mm thick lead, and measured by JCAC.
4) RMC independently carried out the same test using RMC's TLDs.
5) The net doses were calculated by subtracting the control dose from the total doses. [The total dose includes field-exposed dose, self dose and a round-trip transit-dose. The control dose includes self dose and a round-trip transit-dose.] Each dose is shown as an average of 10 data.

(2) Standard irradiation test using RMC's irradiation equipment.

1) The three sets of TLDs, each set consists of 5 TLDs (10 elements), were annealed at 400℃ for 5 minutes by JCAC.
2) After JCAC’s TLDs were sent from JCAC to RMC, the two sets were exposed to 263 μGy and 526 μGy, respectively, using a ^{137}Cs γ-ray source at RMC.
3) The remaining set was used to evaluate the transit-dose between RMC

and JCAC.

4) All TLDs were sent back to JCAC in a container made of 2 mm thick lead.

5) After arriving at JCAC, all TLDs were measured by JCAC immediately.

6) Net doses were calculated by subtracting the transit-dose from the total doses (The total dose includes the irradiation dose and the transit-dose). Each dose is shown as an average of 10 data.

(3) Standard irradiation test using JCAC's irradiation equipment

1) The three sets of TLDs, each set includes 5 TLDs (10 elements), were annealed at 250℃ by RMC.

2) After RMC’s TLDs were sent from RMC to JCAC, the two sets were exposed to 173 μGy and 242 μGy, respectively, using a ^{137}Cs γ-ray source at JCAC.

3) The remaining set was used for evaluating the transit-dose between JCAC and RMC.

4) All TLDs were sent back to RMC in a container made of 2 mm thick lead.

5) All TLDs were measured by RMC shortly after arriving at RMC.

6) Net doses were calculated by subtracting the transit-dose from the total doses (The total dose includes the irradiation dose and the transit-dose). Each dose is shown as an average of 10 data.

Table 11 Instruments and operating conditions for TLD dosimetry

	RMC	JCAC
TLD reader Read temperature	UD-716AGL Panasonic Apporox.250℃ Fixed	UD-512P Panasonic Apporox.300℃ (heater:420℃)
TLD TLD material Number of TLD for each measurement	UD-814AS1 Panasonic $CaSO_4$:Tm 5 pieces (10 elements)	UD-200S Panasonic $CaSO_4$:Tm 5 pieces (10 elements)
TLD annealing oven	UD-716AGL Panasonic 250℃ 2min.	UD-605C Panasonic 400℃ 5min.
Method of calibration	Standard irradiation by the batch	Standard irradiation to each element at each measurement
Irradiation dose level for calibration	Field-1(RMC):149 μGy Field-2(RMC):202 μGy Field-3(RMC):263 μGy Control(RMC): 35.0 μGy High: 526 μGy Low: 263 μGy	Field-1(RMC): 177 μGy Field-2(RMC): 234 μGy Field-3(RMC): 303 μGy Control(RMC): 74.3 μGy High: 564 μGy Low: 293 μGy
Irradiation dose	High: 526 μGy Low: 263 μGy	High: 242 μGy Low: 173 μGy
Determination of irradiation dose	Ionization chamber (800mL) EXRADIN A6 Standard Imaging Co.	Ionization chamber (4000mL) AE-132a OYOGIKEN Co.
γ-ray source	^{137}Cs (370 GBq)	^{137}Cs (18.5 GBq)

Table 12 Outline of TLD field-exposure test and standard irradiation tests

(1) Field-exposure test at RMC's monitoring points

1)RMC

Number of TLD	Monitoring point	Date of annealing	Term of environmental irradiation	Date of reading
5	RMC field-1	April 08, 2019	April 08, 2019～July 08, 2019	July 10, 2019
5	RMC field-2	April 08, 2019	April 08, 2019～July 08, 2019	July 10, 2019
5	RMC field-3	April 08, 2019	April 08, 2019～July 08, 2019	July 10, 2019
5	Control	April 08, 2019	April 08, 2019～July 08, 2019	July 10, 2019

2)JCAC

Number of TLD	Monitoring point	Date of annealing	Term of environmental irradiation	Date of reading
5	RMC field-1	March 19, 2019	April 08, 2019～July 08, 2019	August 02, 2019
5	RMC field-2	March 19, 2019	April 08, 2019～July 08, 2019	August 02, 2019
5	RMC field-3	March 19, 2019	April 08, 2019～July 08, 2019	August 02, 2019
5	Control	March 19, 2019	April 08, 2019～July 08, 2019	August 02, 2019
5	For transit dose （from JCAC to RMC）	March 19, 2019	――	――

(2) Standard irradiation test using RMC's irradiation equipment

1) Annealing at JCAC

March 19, 2019 (15 TLDs)

2) Irradiation at RMC

April 02, 2019 (High dose 5 TLDs)

April 01, 2019 (Low dose 5 TLDs)

3) Reading at JCAC

April 08, 2019 (15 TLDs)

(3) Standard irradiation test using JCAC's irradiation equipment

1) Annealing at RMC

March 06, 2019 (15 TLDs)

2) Irradiation at JCAC (High and Low dose)

March 19, 2019 (10 TLDs)

3) Reading at RMC

March 28, 2019 (15 TLDs)

2.3 Criteria for evaluation of results

In this report, E_n score applied to evaluate for each laboratory results.

The value of the E_n was calculated according to the following equation:

$$En = \frac{Value_{RMC} - Value_{JCAC}}{\sqrt{u^2_{RMC} + u^2_{JCAC}}}$$

where

$Value_{RMC}$: RMC result

$Value_{JCAC}$: JCAC result

U_{RMC}: expanded uncertainty (k=2) of RMC

U_{JCAC}: expanded uncertainty (k=2) of JCAC

The result was assigned “acceptable” score if: $En \leqq 1$

The result was assigned “not acceptable” score if: $En > 1$

2.4 Results

The results are shown in Table13. The E_n score are shown in Table 14. The E_n score are within 1.

2.5 Remarks

There is nothing to be discussed and improved.

Table 13 Results of TLD field-exposure test and standard irradiation tests

(1)Field-exposure test at RMC’s monitoring points　April 08, 2019～July 08, 2019　　Unit: μ Gy

Item / Organization	Total dose			Control（BKG）	Transit-dose (reference)	Net dose		
	Field-1	Field-2	Field-3			Field-1	Field-2	Field-3
RMC	144±3	203±4	293±6	44±1	——	100±3	159±4	249±6
JCAC	177±3	235±2	313±5	74±1	——	103±3	161±2	239±5

＊：These data include a round-trip transit-dose.　　Net dose= Total dose－Control

(2)Standard irradiation tests using RMC’s irradiation equipment　　Unit: μ Gy

Item / Organization	Total dose＊		Transit-dose (to JCAC)	Net dose		Irradiation dose	
	Low	High		Low	High	Low	High
RMC	——	——	——	——	——	263	526
JCAC	282±7	551±16	24±1	258±7	527±16	——	——

＊：These data include a round-trip transit-dose.　Net dose= Total dose－Transit dose

(3)Standard irradiation tests using JCAC’s irradiation equipment　　Unit: μ Gy

Item / Organization	Total dose＊		Transit-dose (to RMC)	Net dose		Irradiation dose	
	Low	High		Low	High	Low	High
RMC	196±4	264±5	23±0.4	173±4	241±5	——	——
JCAC	——	——	——	——	——	173	242

＊：These data include a round-trip transit-dose.　　Net dose= Total dose－Transit dose

Measured results are shown in the form of “average ± standard deviation of 10 data”.

RMC’s expanded uncertainties (k=2) are 6.1% for measurement and 3.0% for irradiation respectively.

JCAC’s expanded uncertainties (k=2) are 6.4 % for measurement and 1.9 % for irradiation respectively.

Table14 The values of the E_n score

(1)Field-exposure test at RMC’s monitoring points

Field-1	-0.2
Field -2	-0.1
Field -3	0.4

(2)Standard irradiation tests using RMC’s irradiation equipment

Low	0.3
High	0.0

(3)Standard irradiation tests using JCAC’s irradiation equipment

Low	0.0
High	-0.1

3. Technical information exchange

(1) Both parties discussed following items.

1) Re-evaluation of ^{40}K and ^{137}Cs for soil sample.

2) Re-evaluation of gross β for fresh water sample.

(2) JCAC appreciated to have gotten the following information.

Annual report of environmental radiation surveillance for nuclear facilities of Taiwan on 2017 & 2018

4. Technical support

JCAC provided the training courses to RMC as follow.

Date	Place	Item
Jul.29～Aug.3, 2018	RMC	1.Gamma-ray spectrometry
Sep.10～Sep.14, 2018	JCAC	1.Tritium analysis 2. Sampling, sample preparation
Oct.7～Oct.15, 2019	JCAC	1. Radium analysis 2. ^{210}Po analysis

Appendix 1

Minutes of the 30th Annual Meeting

Minutes of the 30th Annual Meeting on the Memorandum for Technical Cooperation between Radiation Monitoring Center(RMC) and Japan Chemical Analysis Center(JCAC)

Date : November 15-16, 2017

Place: Japan Chemical Analysis Center (JCAC)
295-3, Sanno-cho, Inage-ku, Chiba-shi, Chiba, Japan

Attendants:

From RMC

Mr. Ming-Te Hsu
Mr. Pei-Huo Lin
Dr. Wen-Hsien Tsai

From JCAC

Dr. Takao Morimoto
Mr. Kenji Kaneko
Mr. Shigeru Bamba
Mr. Hirofumi Shinohara
Ms. Marumi Hayano
Mr. Keisuke Isogai
Mr. Takeshi Maeyama
Mr. Wataru Nitta
Ms. Tomoko Ohta

Agenda

1. Opening addresses by representatives of both parties
2. Discussion on the results of the 2015 cooperation program
   (1) Intercomparison study program
   (2) Technical information exchange program
   (3) Technical support program
3. Discussion on the 2017 cooperation program
   (1) Intercomparison study program
   (2) Technical information exchange program
   (3) Technical support program
   (4) Annual meeting in 2019
4. Presentations

SUMMARY

1. Opening addresses by representatives of both parties

RMC: Mr. Ming-Te Hsu

JCAC: Dr. Takao Morimoto

2. Discussion on the results of the 2015 cooperation program

(1) Intercomparison study program (Report 28E02)

RMC and JCAC confirmed the description of the analytical methods for γ-ray spectrometry, radiochemical analysis (^{90}Sr, ^{137}Cs, Uranium and ^{3}H) , gross β activity and radiation dose measurement in accordance with the report.

1) γ-ray spectrometry

All analytical results are in good agreement between RMC and JCAC.

2) Radiochemical analysis

All analytical results are in good agreement between RMC and JCAC.

3) Radiation dose measurement

Both parties agreed that the values determined by the parties for the field-exposure tests and standard irradiation tests were in good agreement.

(2) Technical information exchange

1) Both parties discussed following item.

RMC developed a new pretreatment method for gross β activity of fresh water. Both parties validated the analytical method.

2) JCAC appreciated to have gotten the following information.

Annual report of environmental radiation surveillance for nuclear facilities of Taiwan on 2015 & 2016.

(3) Technical support program

JCAC provided a training course on rapid determination of radiostrontium to RMC in May 2017.

3. Discussion on the 2017 cooperation program

(1) Intercomparison study program (Appendix I)

1) Radioactivity analysis for environmental samples

The intercomparison program of 2017 will essentially follow the same program as that of 2015. Soil sample for ^{239}Pu, ^{240}Pu and ^{240}Pu/^{239}Pu atom ratio will be added.

The samples and items of analysis are listed in Appendix I.

RMC will send the samples to JCAC before the end of March 2019.

The analytical results obtained by JCAC will be sent to RMC by the end of August 2019.

2) Radiation dose measurement

The intercomparison program of 2017 will essentially follow the same program as that of 2015.

The items of tests are also listed in Appendix I.

Field-exposure test in RMC will be carried out from April to June 2019.

Standard irradiation test at RMC will be carried out in May 2019.

Standard irradiation test at JCAC will be carried out in May 2019.

The results measured by JCAC will be sent to RMC by the end of August 2019.

3) Evaluation method

Analytical results will be evaluated with E_n-number based on uncertainties.

(2) Technical information exchange program

Both parties will exchange technical information such as monitoring program, analytical methods.

(3) Technical support program

Both parties will conduct analytical support, if RMC or JCAC need.

(4) Annual meeting in 2019

The 31th annual meeting is scheduled to take place at RMC in

November 2019.

4. Presentations

(1) Cesium-137 activity in environmental samples from the Taiwan coast (RMC/ Dr. Wen-Hsien Tsai)

(2) Radioactivity monitoring in Tokyo Bay - temporal variations of ^{134}Cs and ^{137}Cs in sea sediment and seawater - (JCAC/ Mr. Keisuke Isogai)

(3) Development and standardization of pretreatment method for monitoring low level radio Cs in fresh water and sea water (AIST/ Dr. Yasutaka)

Signatures

For RMC	For JCAC
徐明德	磯貝啓介
Mr. Ming-Te Hsu	Mr. Keisuke isogai
Title: Director	Title: Executive Director
Date: November 16, 2017	Date: November 16, 2017

Appendix I

List of intercomparative subjects and samples (2017 Cooperation Program)

1. Radioactivity analysis

Sample	γ	^{90}Sr	^{137}Cs	U	^{3}H	β	Pu
Fresh water	—	—	—	—	○	○	—
Seawater	—	—	—	○	—	○	—
Tea leaves	○	○	○	—	—	○	—
Soil	○	○	○	○	—	○	○

γ : Determination of γ-ray emitting nuclides with Ge semiconductor detector

^{90}Sr : Determination of ^{90}Sr by radiochemical analysis

^{137}Cs : Determination of ^{137}Cs by radiochemical analysis

U : Determination of α-ray of uranium with Si semiconductor detector

^{3}H : Determination of ^{3}H with liquid scintillation counter

β : Measurement of gross β activity with low-background gas-flow counter

Pu : Determination of ^{239}Pu, ^{240}Pu and ^{240}Pu/^{239}Pu atom ratio with HR-ICP-MS

(1) All samples will be collected by RMC.

(2) Pretreatment

1) Fresh water and seawater will be sent to JCAC without any pretreatment.

2) Tea leaves will be dried, ashed and homogenized then sent to JCAC.

3) Soil will be dried and homogenized then sent to JCAC.

2. Dosimetry

(1) Field-exposure test at RMC's monitoring points

1) Tests using RMC's TLDs

Number of TLD	Monitoring point
5	RMC -1
5	RMC -2
5	RMC -3
5	For self dose

2) Tests using JCAC's TLDs

Number of TLD	Monitoring point
5	RMC -1
5	RMC -2
5	RMC -3
5	For self dose
5	For transit dose (between JCAC to RMC)

(2) Reference irradiation test at RMC (use 15 TLDs each)

1) Irradiation at RMC

2) Reading at JCAC

(3) Reference irradiation test at JCAC (use 15 TLDs each)

1) Irradiation at JCAC

2) Reading at RMC

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