Concentrations of Radiocaesium, ^{90}Sr and ^{129}I in Agricultural Crops Collected from Fukushima Prefecture and Reference Areas

Institute of Environmental Radioactivity
Fukushima University

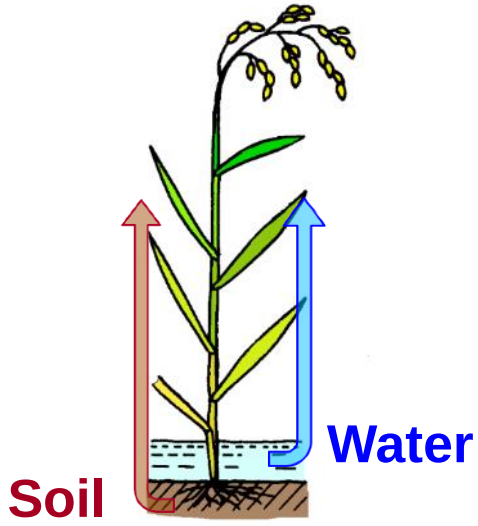
Hirofumi Tsukada

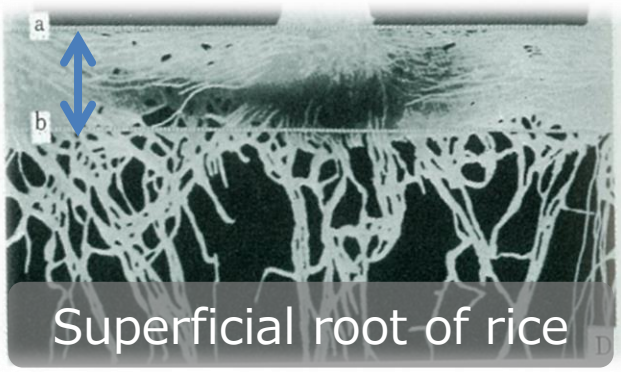
Contents

- ✓ Soil･Irrigation water
- ✓ Agricultural crops
- ✓ Internal radiation dose

Comparison of radiocaesium transfer between water-to-rice and soil-to-rice

Transfer ratio of water-to-rice is approximately 10,000 times higher than that of soil-to-rice.





Transfer of water-to-rice (dissolved fraction)

$$\frac{\text{Radiocaesium activity concentration in brown rice (Bq/kg)}}{\text{Radiocaesium activity concentration in water (Bq/L)}}$$

～10 （Estimate from pot experiments）

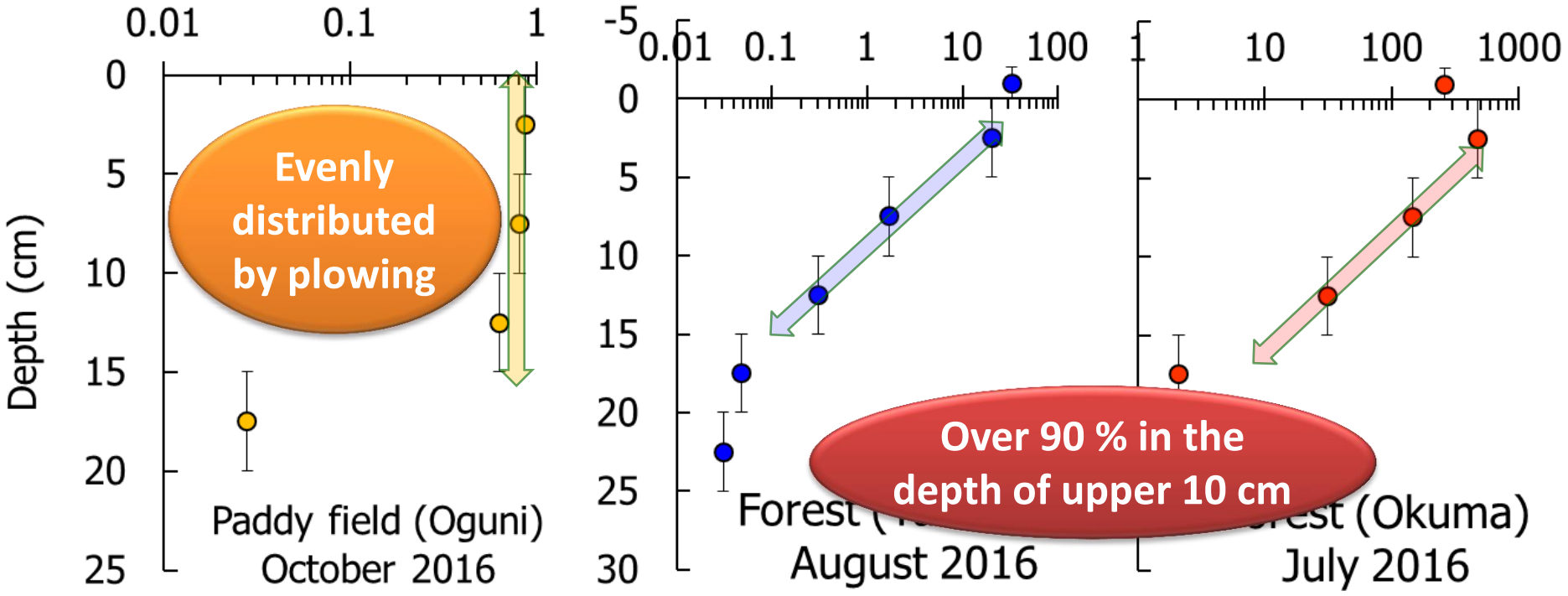
Transfer of soil-to-rice

$$\frac{\text{Radiocaesium activity concentration in brown rice (Bq/kg)}}{\text{Radiocaesium activity concentration in soil (Bq/kg)}}$$

～0.001 （Data in Oguni）

Vertical profile of ^{137}Cs in agricultural field and uncultivated field in Fukushima after 5 years from the accident

^{137}Cs activity concentration in soil (Bq/g)



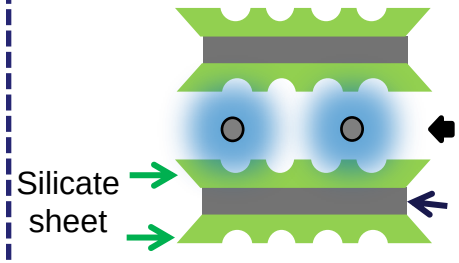
55 km north-west from FDNPS

35 km north-west from FDNPS

1.1 km south-west from FDNPS

Fractions of radiocaesium in soil

2:1 aluminosilicate clay minerals

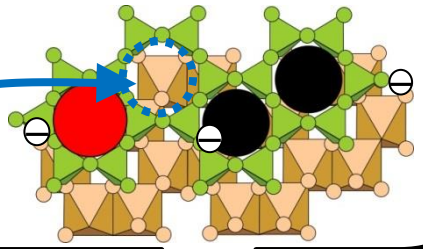


Each aluminosilicate sheet has negative charges

Image of opening site from the view of plane

Frayed Edge Site (FES)

Cavity size is relatively similar to the diameters of K^+ and Cs^+



Negative charge

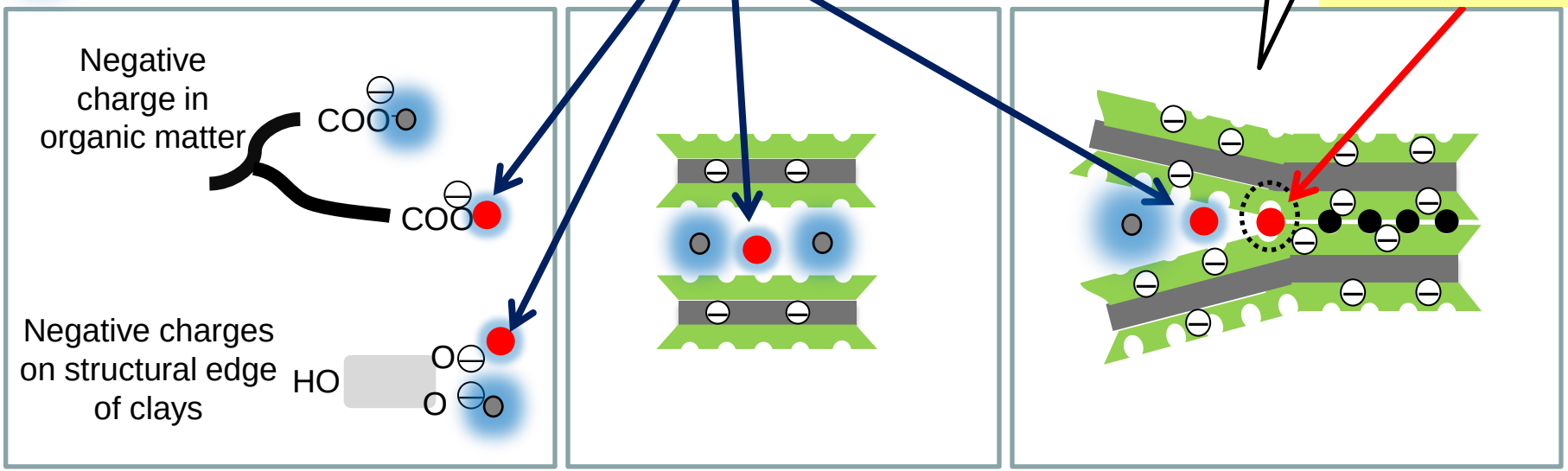
Cs^+ K^+

Cation ions (ca. Ca^{2+}, Mg^{2+}, etc.)

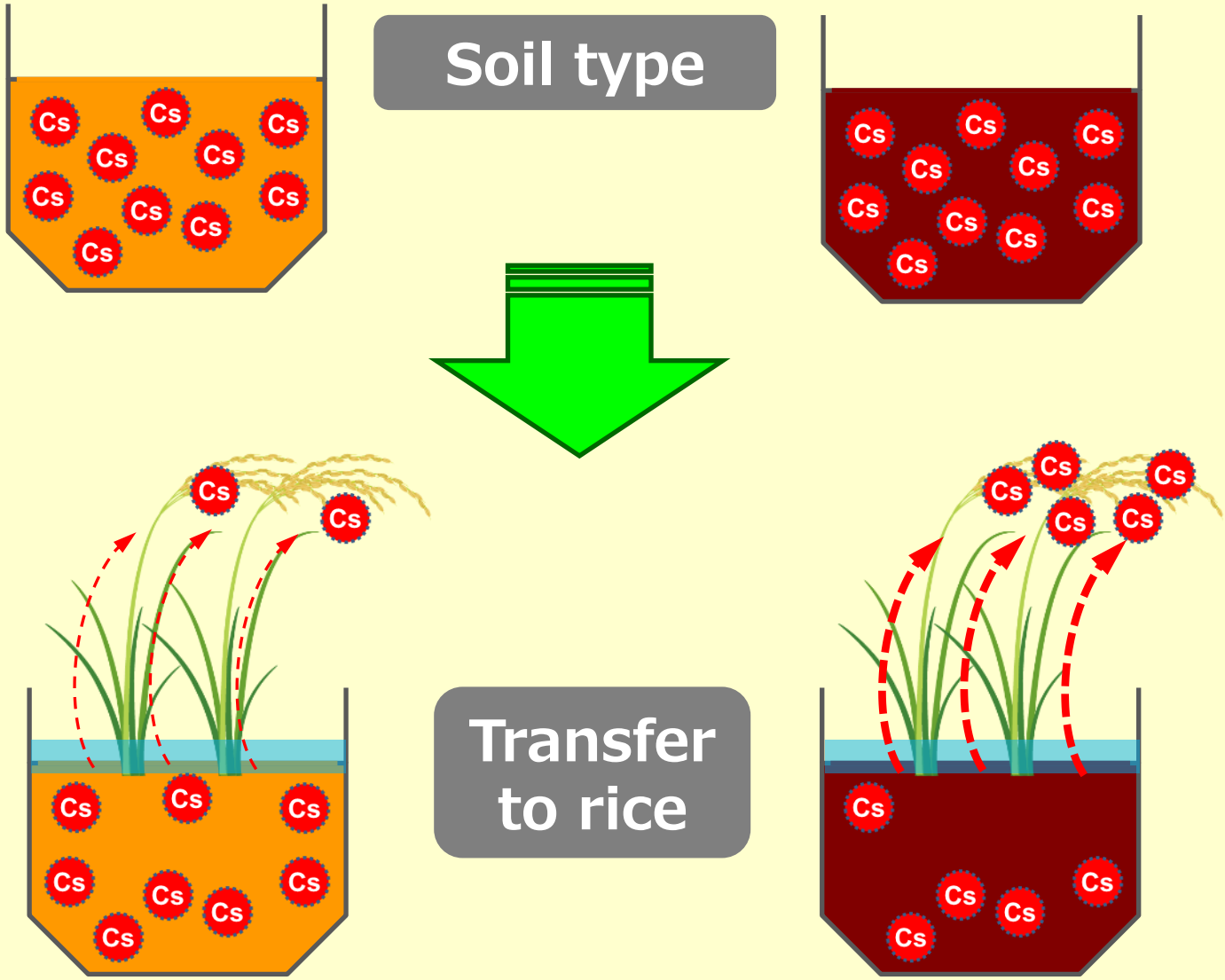
Hydrated water

Exchangeable fraction

Strongly bound fraction



Phytoavailability and immobilization of radiocaesium depended on soil properties



Radiocaesium Interception Potential, RIP
(RIP: Indicator of Cs adsorption capacity in soil)

$$RIP\,(mmol/kg) = K_c^{EFS}(Cs\text{-}K) \times [FES]$$

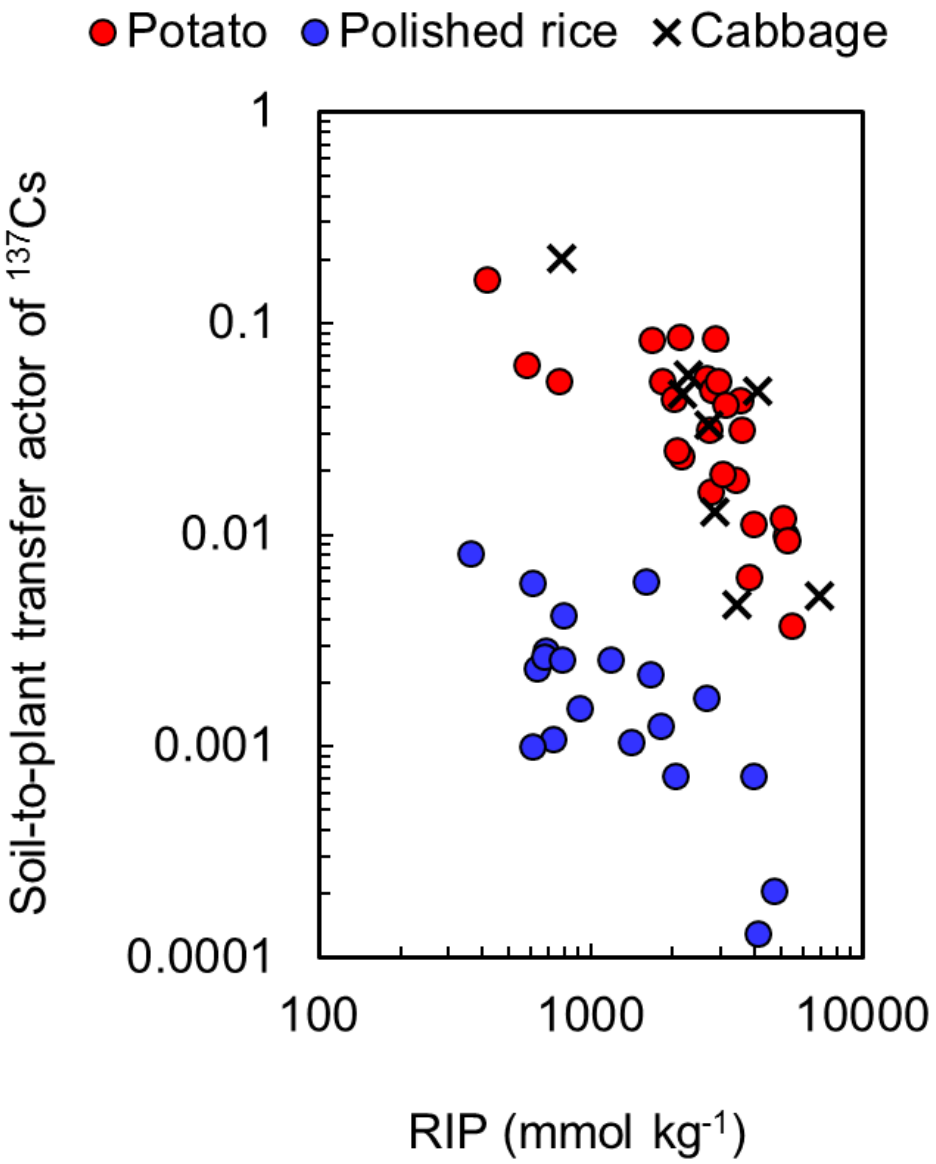
- $K_c^{EFS}(Cs\text{-}K)$: Selectivity coefficient of trace Cs to K of the FES
- [FES]: Amount of FES

Analysis of RIP with dialysis tube

RIP: Lower → Higher
Bioavailability: Higher → Lower

(Cremers et al., 1988; Wauters et al., 1996)

Relationship between RIP and Transfer Factor of ^{137}Cs



Higher RIP value

Lower transfer factor

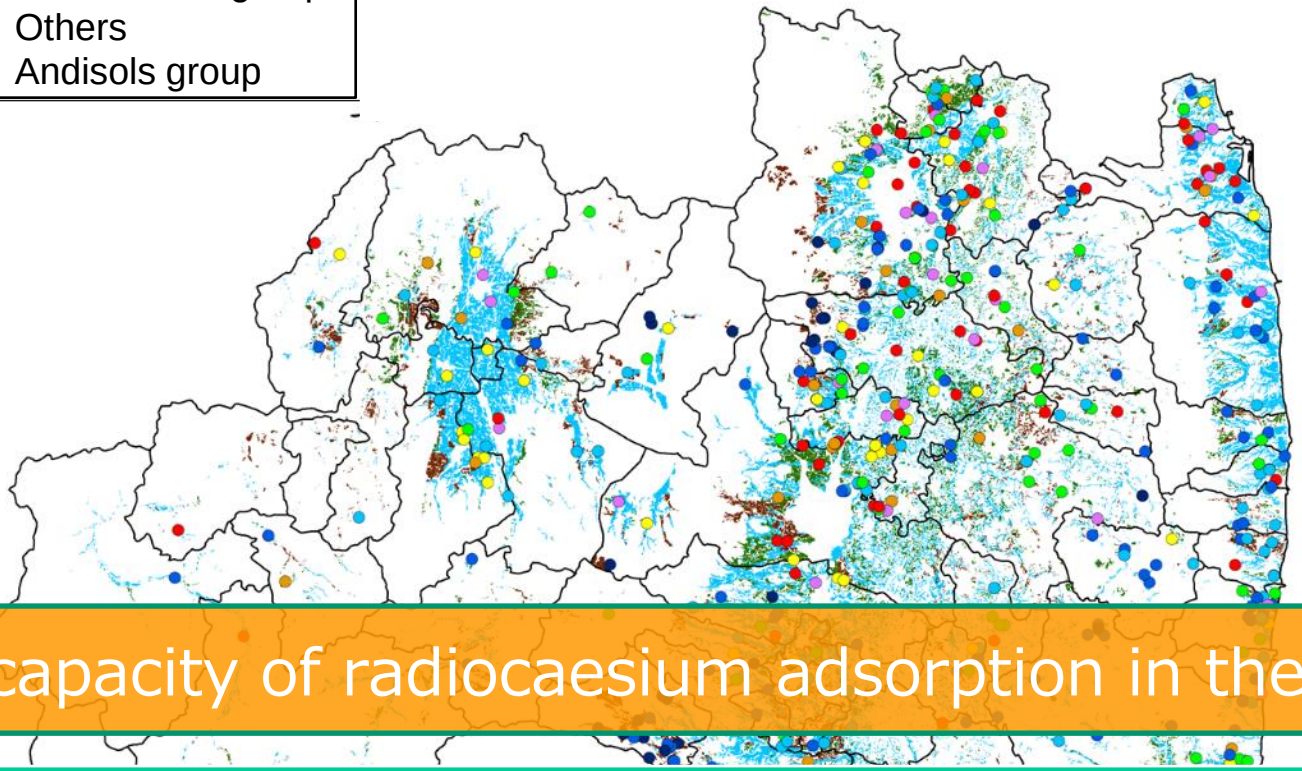
Lower concentration in plant

Distribution of RIP values in Fukushima Prefecture

RIP (mmol kg^{-1})
- 500以下
- 500 - 1000
- 1000 - 1500
- 1500 - 2000
- 2000 - 2500
- 2500 - 3000
- 3000 - 3500
- 3500以上

Soil type
- Lowland soil group
- Others
- Andisols group

1900 ± 1600 (74 – 13000, n=539) mmol kg^{-1}

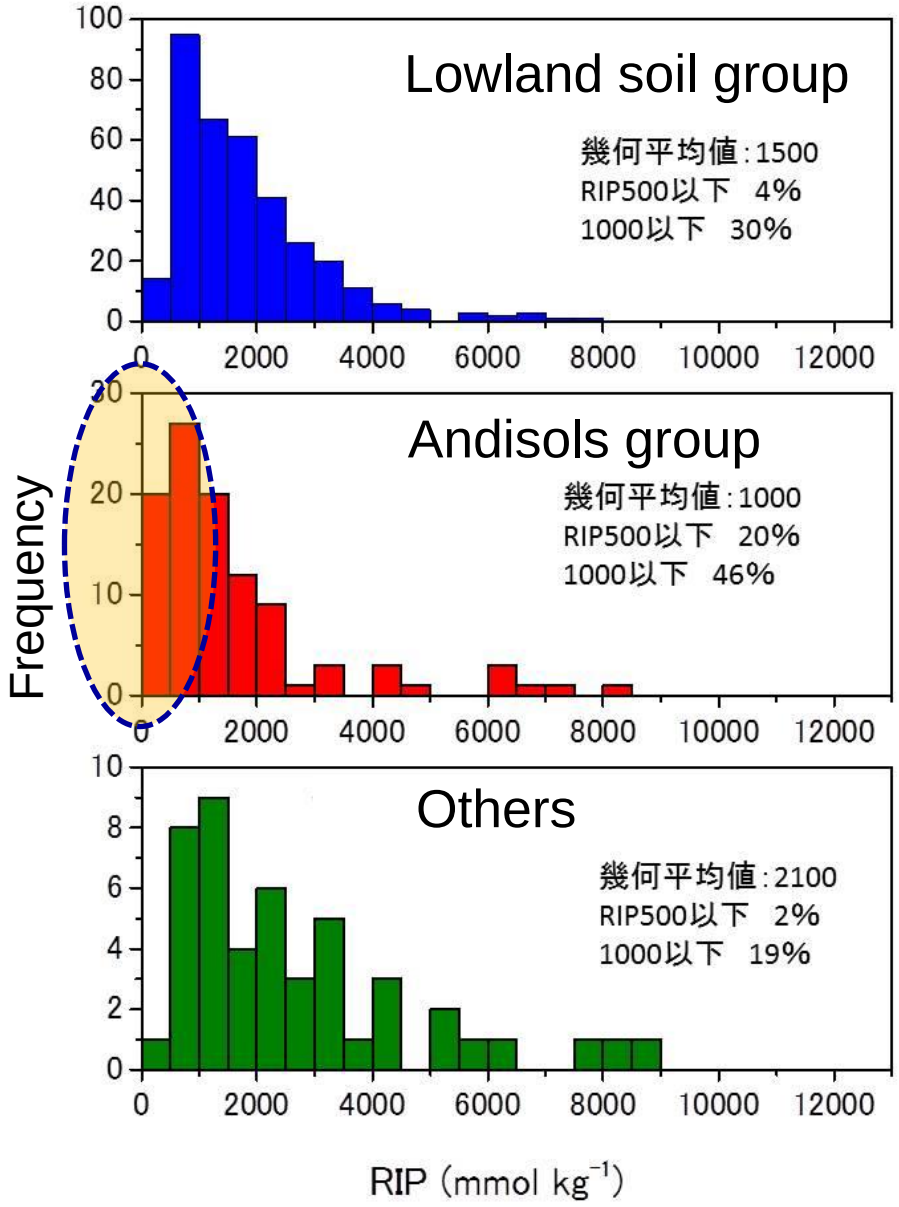


Sufficient capacity of radiocaesium adsorption in the soils

RIP values around FDNPS（mmol/kg）

	Minami-soma	Tomioka	Okuma	Futaba	Namie	Katsurao	Iidate
Mean	1,390	1,790	984	1,640	873	1,600	1,560
Number	57	7	6	6	6	6	5

Distribution of RIP value in soil type collected throughout Fukushima Prefecture



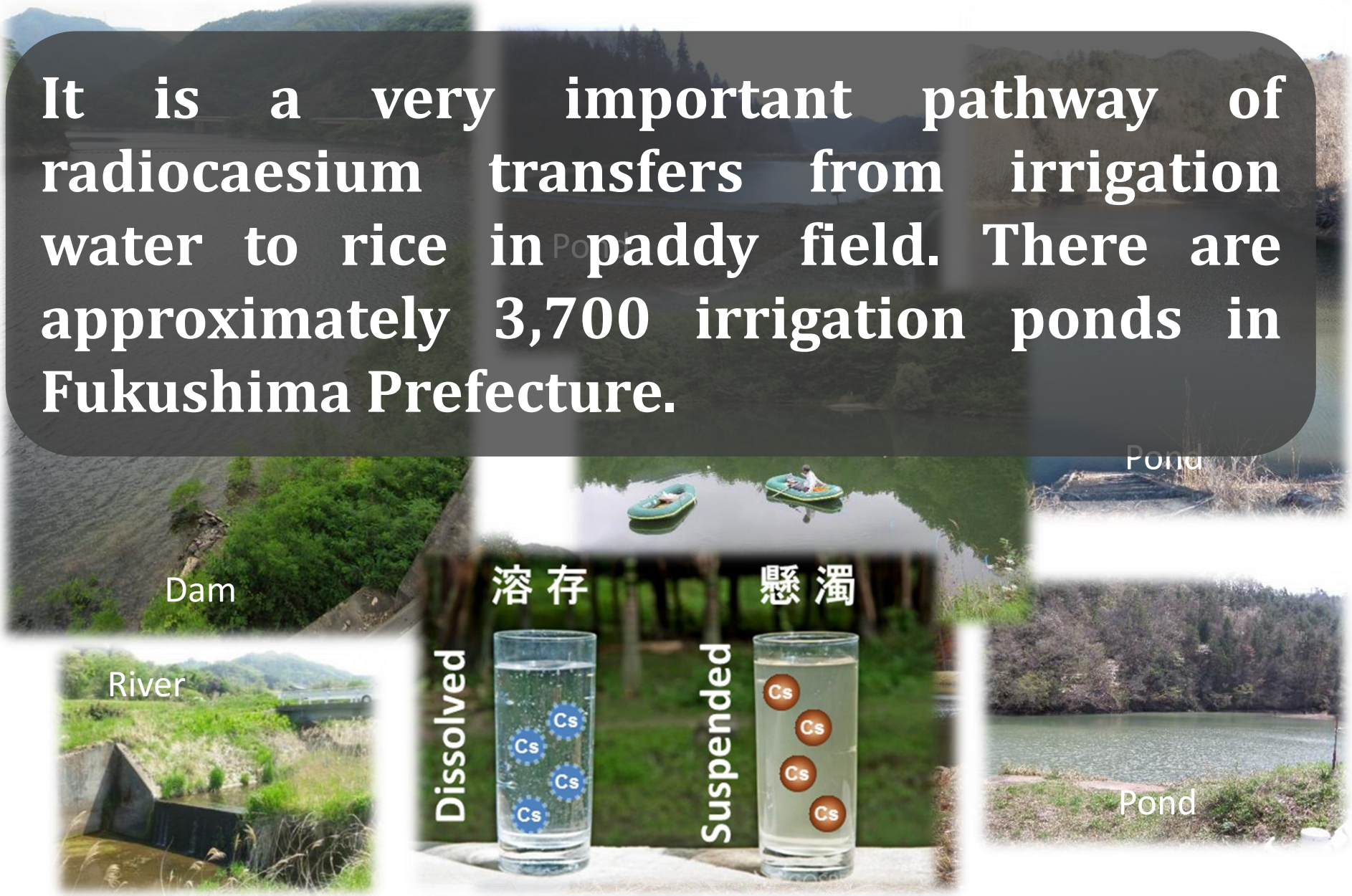
Soil type	RIP（mmol kg^{-1}）
Lowland soil	1,900±1,500 (n=358)
Andisols	1,600±1,600 (n=102)
Others	2,800±2,300 (n=48)

The RIP value under 500 mmol kg^{-1} in the Andisols group was 20%, which was the highest frequency among the groups.

It will be required to apply amendments for continuing farming reliably.

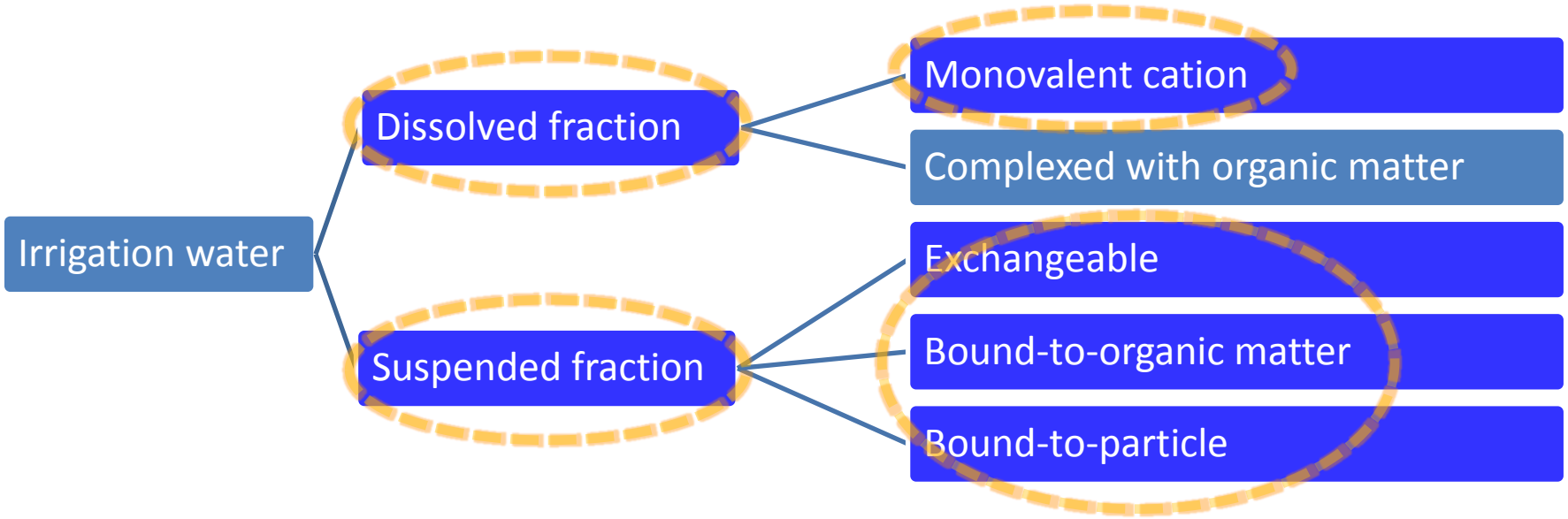
Irrigation dam, ponds and rivers in Fukushima

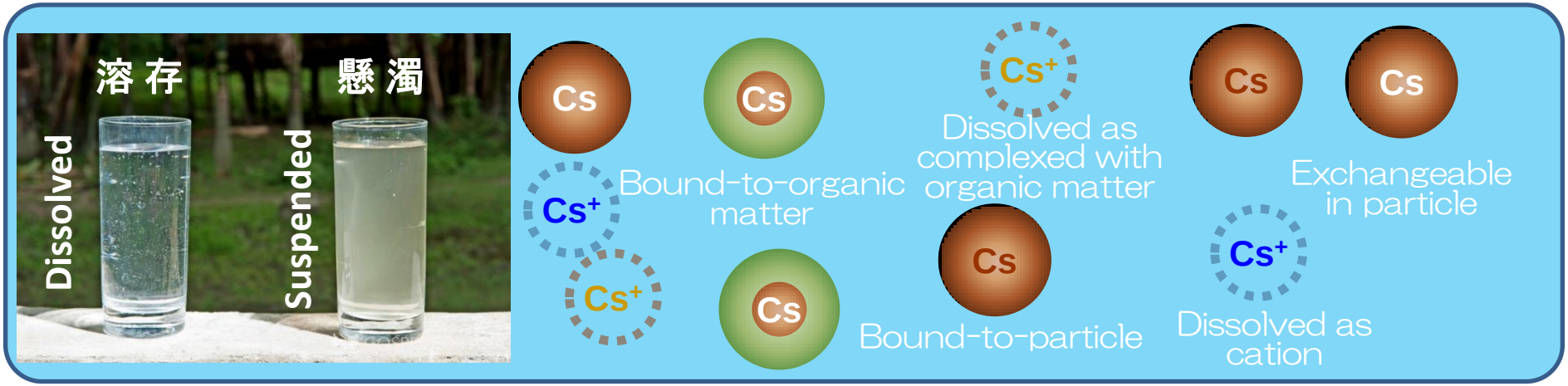
It is a very important pathway of radiocaesium transfers from irrigation water to rice in paddy field. There are approximately 3,700 irrigation ponds in Fukushima Prefecture.



Physicochemical fractions of radiocaesium in irrigation water

Bioavailability of radiocaesium is different with its physicochemical fractions:





Location of sampling area in Oguni, Date

Concentration of radiocesium in soil in 2014: 3000 Bq/kg

Concentration of radiocesium in brown rice harvested in 2011 was over 500 Bq/kg, and then that in 2014 was 2-30 Bq/kg.

Irrigation water

Paddy field

Sampling of suspended matter with continuously centrifugal method

Suspended substances are collected with continuous high-speed centrifugation method

Collecting time: 4-6 h (5000 rpm)

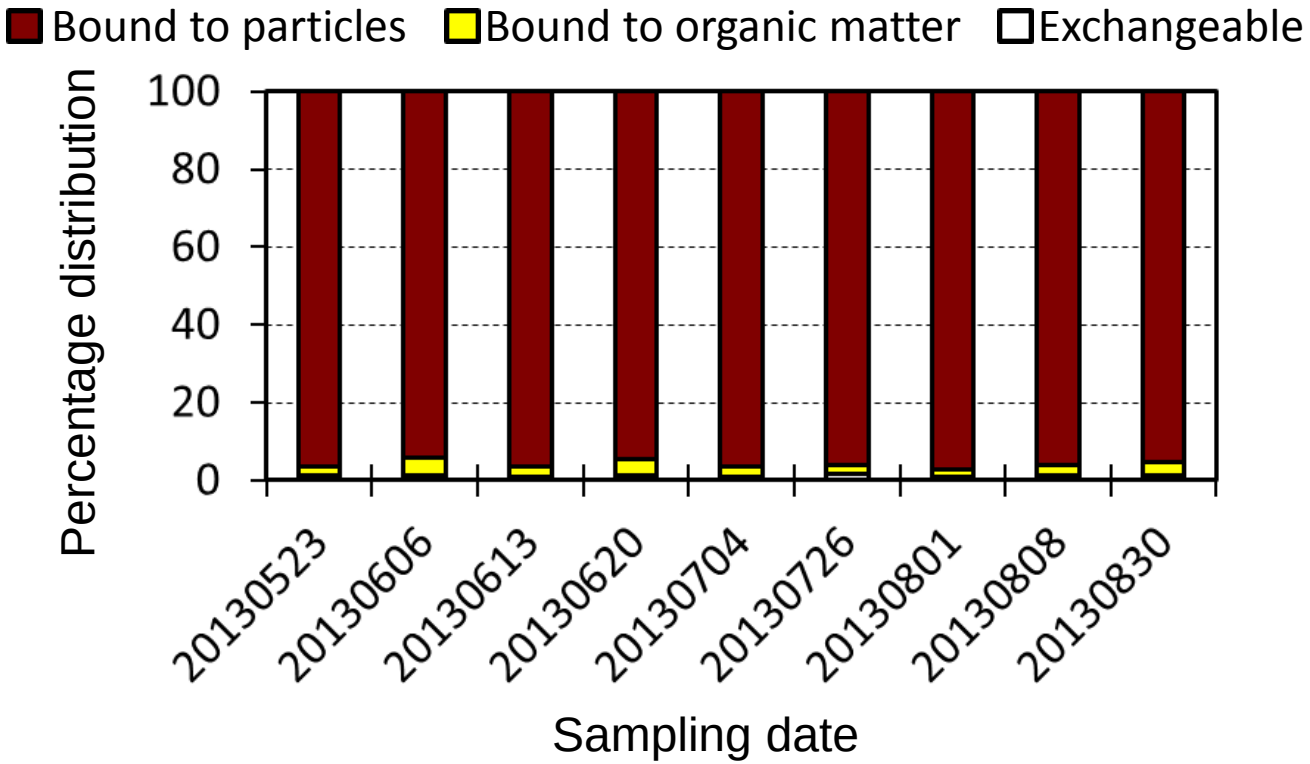
Flow rate: 12.5 L/min

Total flow amount: 2000-4000 L

Collected suspended matter: >2 g

Suspended matter collected in inside wall of rotor

Physicochemical fractions of ^{137}Cs in suspended matter collected in Oguni river, Date



Percentage distribution	Average	Min		Max
Exchangeable	1.2	0.90	—	1.5
Bound to organic matter	2.9	1.8	—	4.5
Bound to particles	96	94	—	97

Difficult to dissolve in water and to transfer to plant

Sampling points of irrigation water collected within 80 km zone (n=54)

Sampling point

Sampling location

Minamisoma (16), Iidate (13), Tomioka (5), Manie (5), Futaba (5), Okuma (4), Koriyama, Soma, Date, Nihonmatsu, kawauchi, Naraha

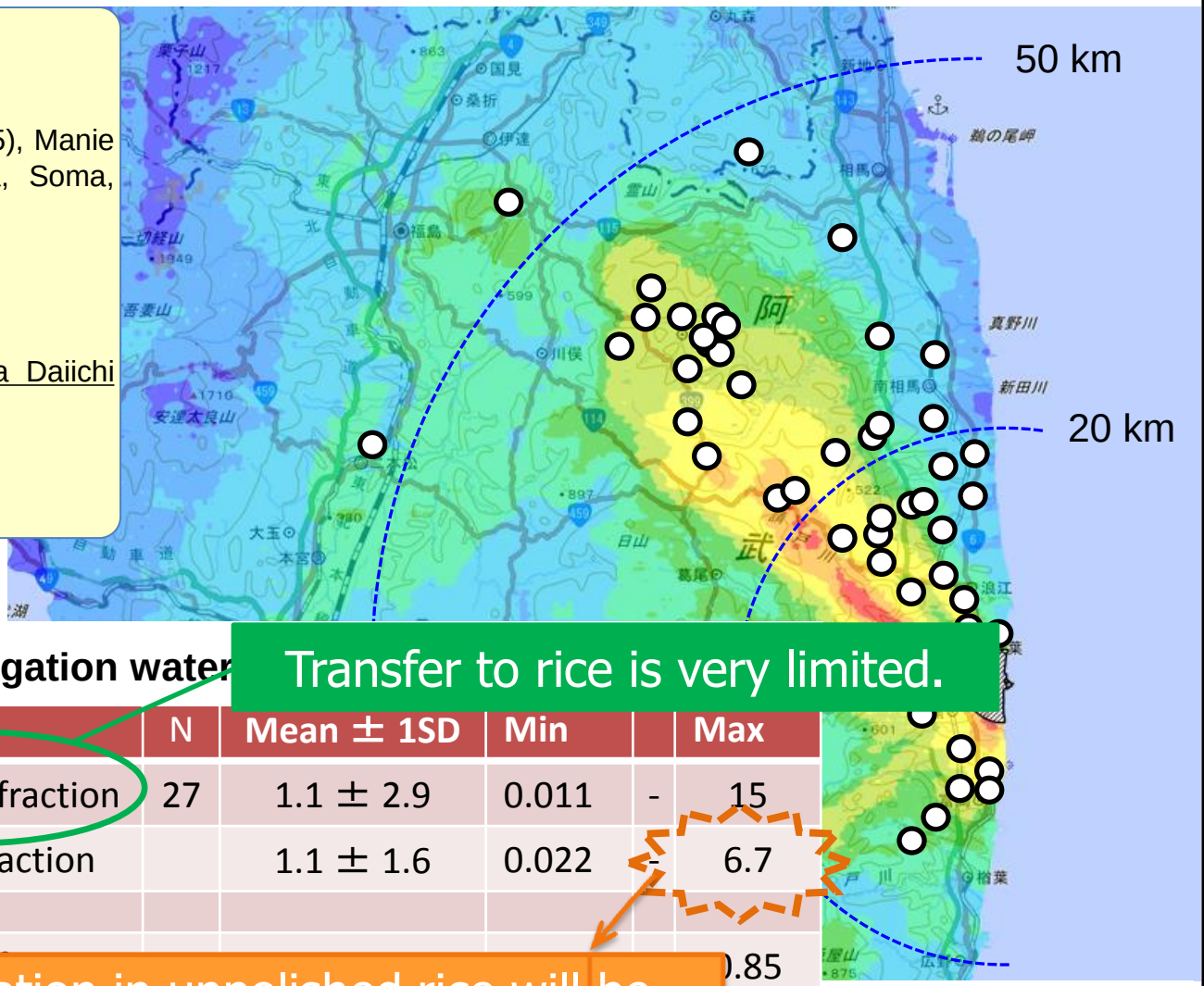
Type of utilization

Pond (42), Dam (2), River (10)

Distance from the TEPCO's Fukushima Daiichi Nuclear Power Station

Within 50 km, 51; Within 20 km, 27

Sapling period:2014/4/7～2014/10/16



Concentration of ^{137}Cs in irrigation water

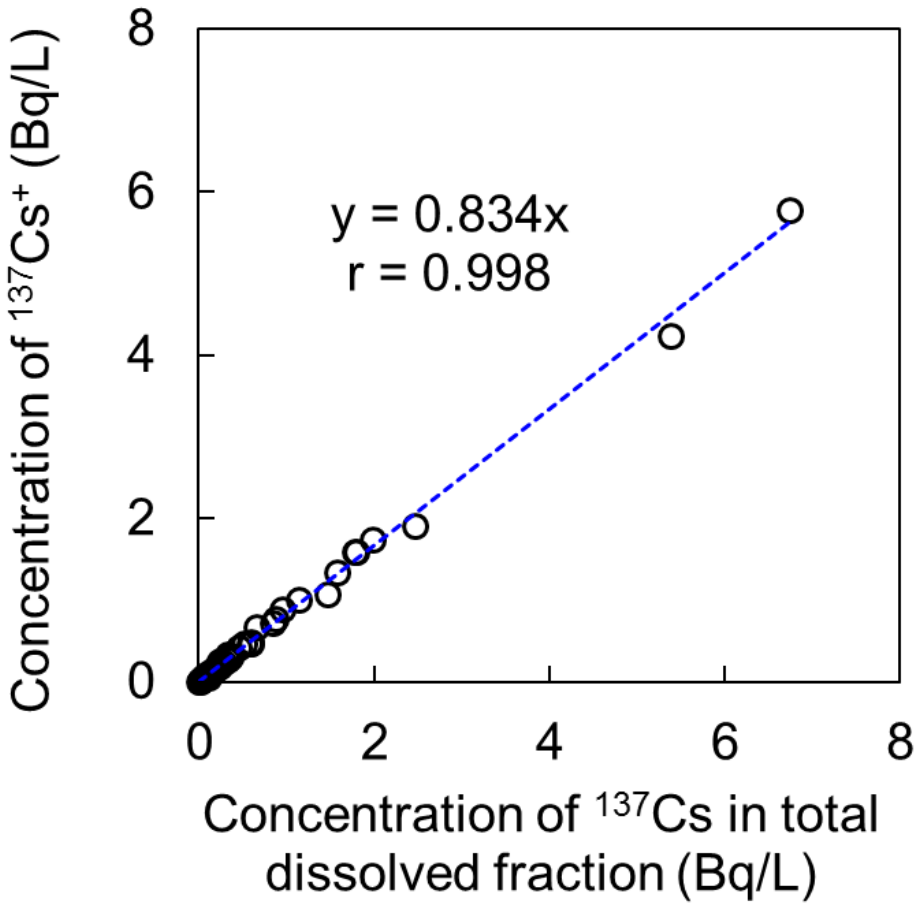
Sampling area	Fraction	N	Mean ± 1SD	Min		Max
Within 20 km zone	Suspended fraction	27	1.1 ± 2.9	0.011	-	15
	Dissolved fraction		1.1 ± 1.6	0.022	-	6.7
						0.85
						1.1

Transfer to rice is very limited.

^{137}Cs activity concentration in unpolished rice will be expected several ten Bq/kg.

年11月19日現在）

Relationship between concentration of ^{137}Cs in total dissolved fraction and concentration of monovalent $^{137}Cs^{+}$ collected within 80 km zone from FDNPS



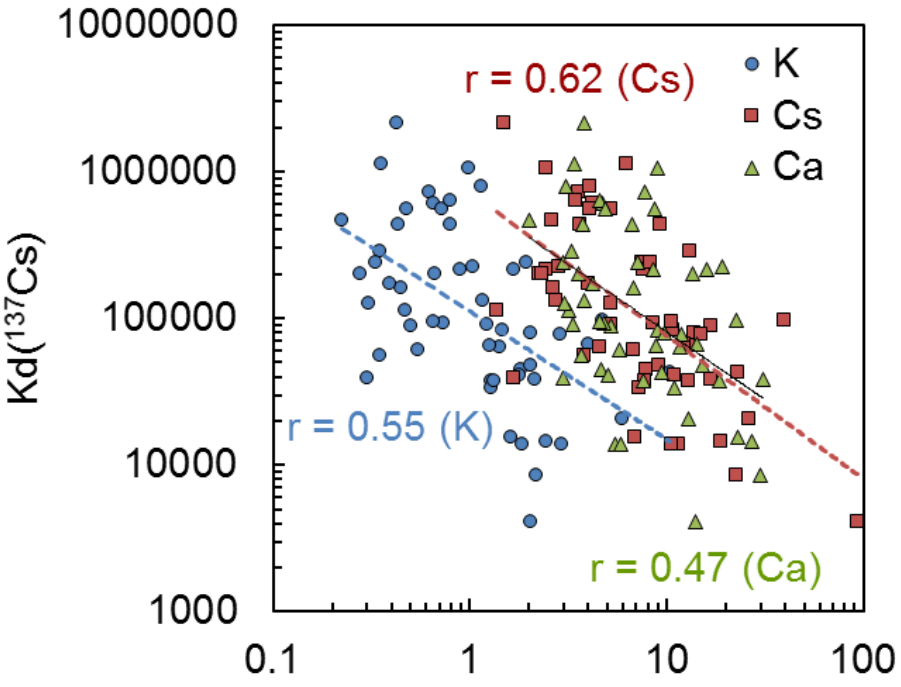
Concentration ratio of $^{137}Cs^{+}$ to ^{137}Cs in total dissolved fraction: 0.88 ± 0.15

Concentration of ^{137}Cs in suspended and dissolved fractions, and Kd(^{137}Cs) in agricultural waters collected within 80 km zone of Fukushima Prefecture and IAEA reported values of Kd

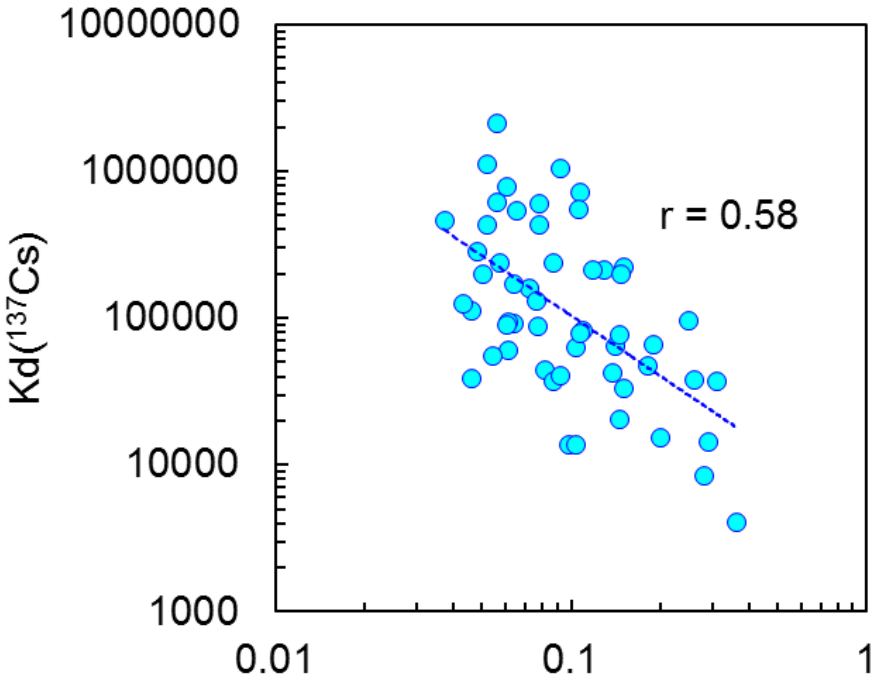
$$\text{Distribution coefficient (Kd)} = \frac{^{137}\text{Cs in suspended fraction (Bq/kg)}}{^{137}\text{Cs in dissolved fraction (Bq/L)}}$$

	Institution	Arithmetic mean	Geometric mean	Median	Min		Max	Remarks
Suspended matter	This work	48	25	27	2	-	303	Bq/g
Dissolved	This work	0.663	0.229	0.238	0.007	-	6.75	Bq/L
Kd (n=54)	This work	250,000	110,000	93,500	4,100	-	2,130,000	Suspended matter
Kd (n=2)	Ueda et al. (2013)	-	-	-	230,000	-	520,000	Suspended matter
Kd (n=26)	Yoshimura et al. (2015)	-	-	-	19,000	-	2,200,000	Suspended matter
Kd (n=219)	IAEA	-	29,000	-	1,600	-	520,000	Suspended matter

Relationship between Concentrations of major cations or electric conductivity and Kd-value



Concentrations of K (mg/L), Cs (ng/L) and Ca (mg/L) in dissolved fraction



Electric conductivity (mS/cm) in dissolved fraction

Inspection of radionuclides in agricultural plants in Fukushima Prefecture

Rice

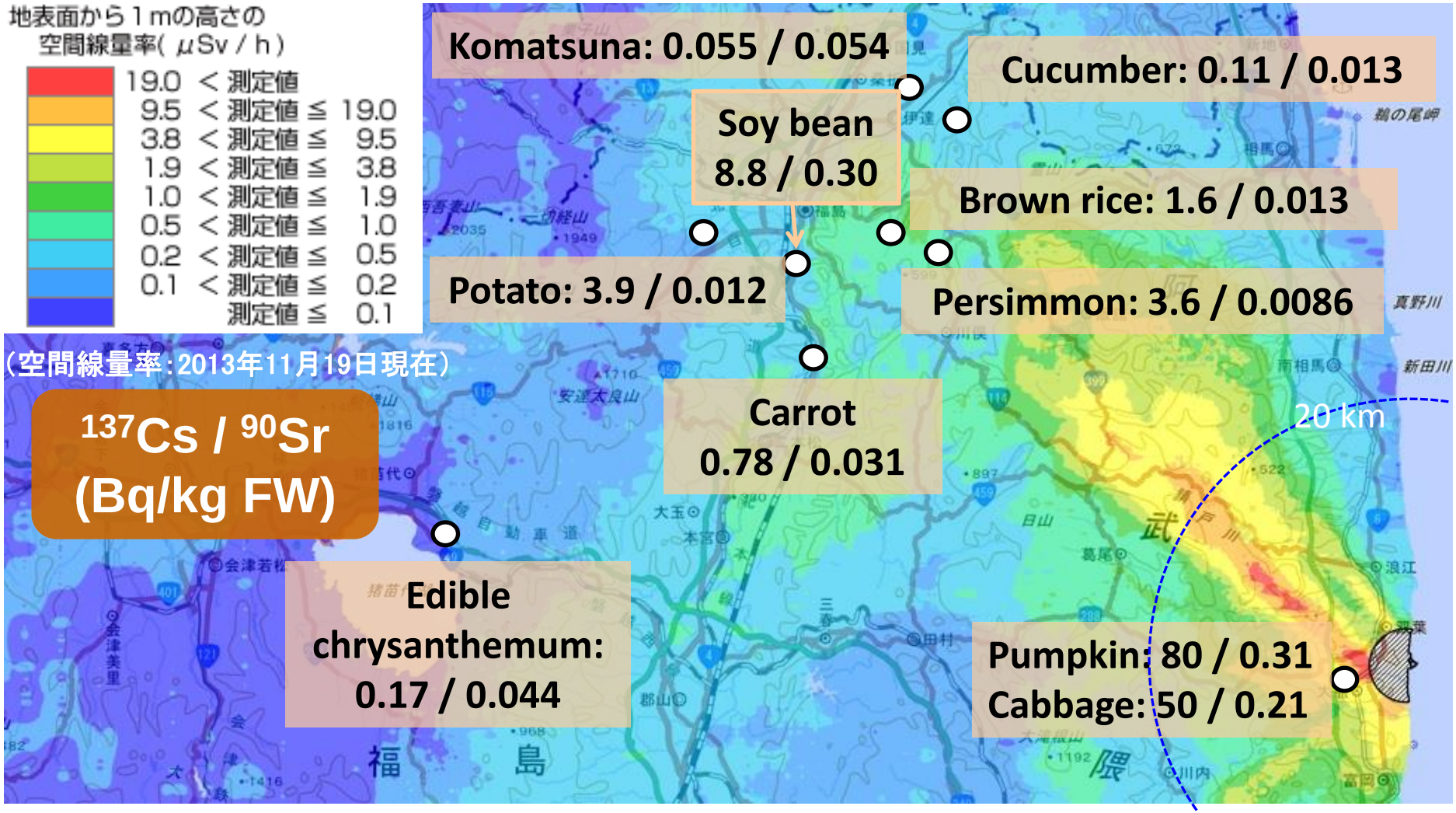
Dried persimmon

Number of inspection of radiocaesium in rice from 2012 to 2018 in Fukushima Prefecture

(Bq/kg 生)	<25	25～50	51～75	76～100	≥100
2012	10,344,579	40	295	317	71
2013	11,005,234	6	269	322	28
2014	11,014,936	0	1	1	2
2015	10,498,573	2	4	0	0
2016	10,265,957	0	0	0	0
2017	9,976,124	35	0	0	0
2018	9,068,403	8	0	0	0

Approximately 10 million of rice bags (30 kg each) were inspected every year and there is no bags over the Standard Limits from 2015.

Activity concentrations of ^{137}Cs and ^{90}Sr in agricultural plants collected from Fukushima in 2013 (before decontamination)



^{137}Cs and ^{90}Sr activity concentrations throughout Japan (excluding Fukushima):
^{137}Cs, ND～10 Bq/kg fresh weight; ^{90}Sr, ND～0.91 Bq/kg fresh weight

Concentrations of radiocaesium and ^{90}Sr in agricultural crops collected from experimental fields in difficult-to-return zones

$^{134}Cs+^{137}Cs$ Bq/kg FW	Iitate	Namie	Kawamata
2015	0.12～0.55 (cucumber, pumpkin, eggplant, tomato)	0.11～1.6 (leek, carrot, brown rice)	0.26～0.65 (brown rice, potato, taro potato)
2016	–	0.37～1.3 (brown rice, potato, pumpkin, sweet potato)	–

^{90}Sr Bq/kg FW	Iitate	Namie	Kawamata
2015	0.0065～0.030	0.0087～0.10	0.0036～0.034
2016	–	0.0077～0.099	–

Derived from global fallout in 1950s-1060s

Activity concentrations of radiocaesium and ^{90}Sr in agricultural crops (Bq/kg FW) collected from central and coastal areas in Fukushima

Year	Area	Number	Radiocaesium Mean (Min–Max)	^{40}K (Mean)
2012*	Central area	36	7.2 (<0.2 – 40)	130
2013*	Central area	42	2.0 (<0.1 – 14)	110
2015**	Central and coastal areas	25	1.3 (0.11 – 7.3)	102
2016**	Coastal area	31	2.2 (0.03 – 22)	97
2017**	Coastal area	33	0.68 (0.03 – 6.6)	95

Year	Area	Number	^{90}Sr Mean (Min–Max)
2015**	Central and coastal areas	15	0.021 (0.002 – 0.10)
2016**	Coastal area	15	0.065 (0.008 – 0.45)
2017**	Coastal area	16	0.029 (0.005 – 0.11)

* Before decontamination, ** After decontamination

Radiation dose of Human in Fukushima

Pathway of radiation exposure

External exposure

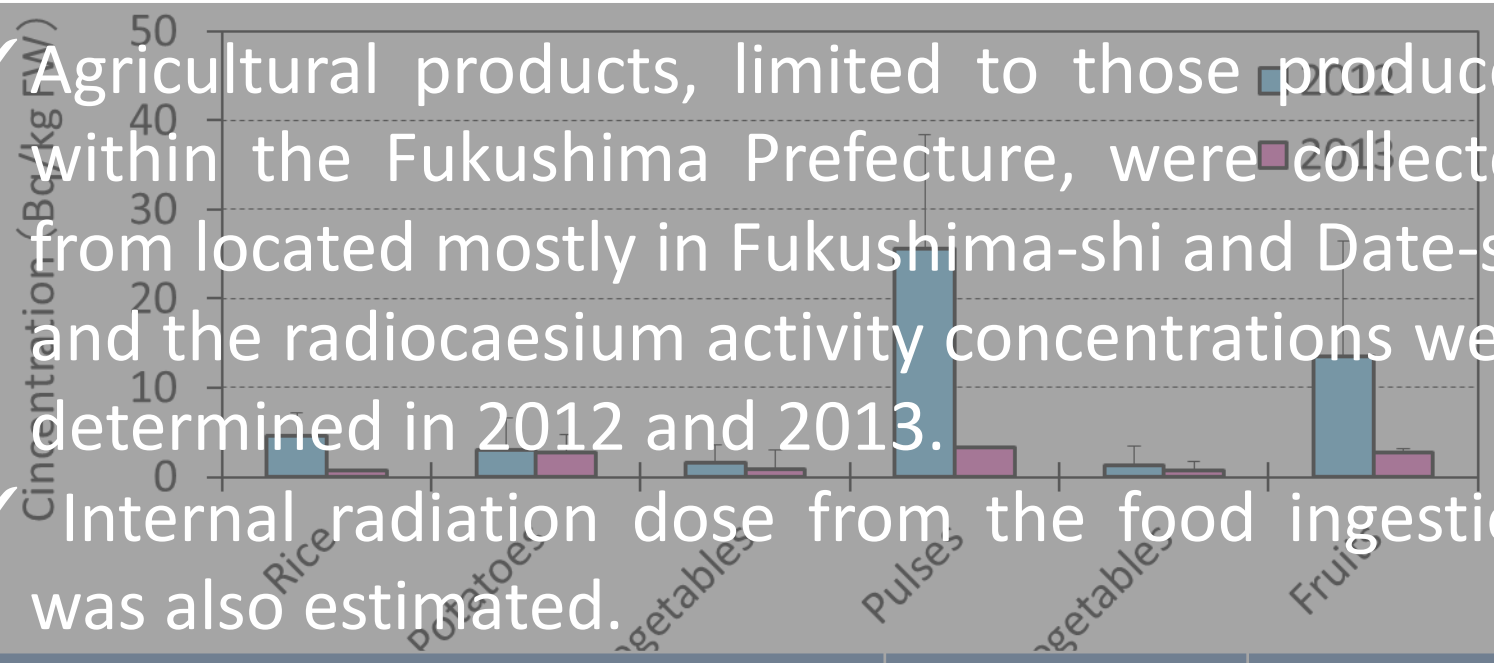
Radiation exposure from outside the human body

Internal exposure

Radiation exposure from radioactive substances incorporated inside the human body

- Intake of food
- Inhalation

Radiocaesium activity concentration in agricultural products limited to production within the Fukushima Prefecture



✓Agricultural products, limited to those produced within the Fukushima Prefecture, were collected from located mostly in Fukushima-shi and Date-shi, and the radiocaesium activity concentrations were determined in 2012 and 2013.

✓Internal radiation dose from the food ingestion was also estimated.

Internal radiation dose（mSv）	2012	2013
male（over 19）	0.069	0.016
female（over 19）	0.054	0.012

Year	Number	$^{134+137}$Cs (Average, Bq/kg FW))	Min—Max	^{40}K（Average, Bq/kg FW）
2012	36	7.2	＜0.2 — 40	130
2013	42	2.0	＜0.1 — 14	110

1/4

Internal and external radiation doses in Fukushima-shi during 2013-2014

Radiation Dose (mSv / y)				
	INTERNAL		EXTERNAL	EXT / INT
Adult (male)	0.016		0.44	27
	Inhalation	Intake of foods		
	0.000035	0.016		

Internal radiation dose is much smaller than external radiation dose in Fukushima

ご清聴ありがとうございました
Thank you very much for your attention!