Cost-Effectiveness of the Policy Measures to Reduce Human Health Risks from Radioactive Contamination due to the Fukushima Daiichi Nuclear Accident

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Introduction (1)

- The accident of the Fukushima Daiichi NPP of TEPCO occurred in March 2011.
- The policy measures at the early stages:
  - Evacuation from areas located within a radius of 20 km from the power plant, and from those where the annual cumulative dose of radiological exposure could exceed 20 mSv
  - Regulation of contaminated agricultural products
- Later policy actions:
  - Decontamination of the evacuation area
  - Strengthened food monitoring
  - Stricter food standards
  - Contermeasures in agriculture to reduce food contamination

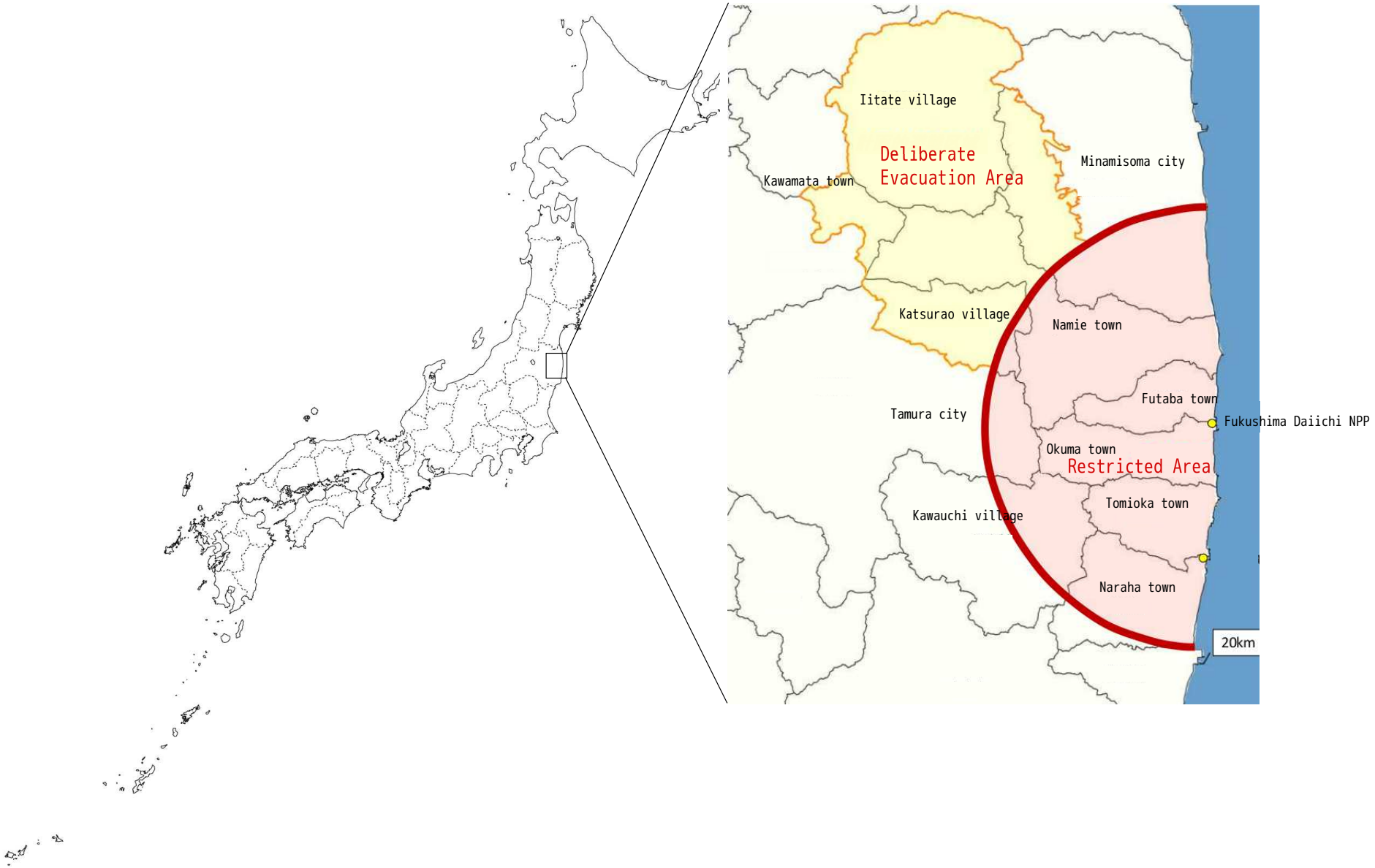
Introduction (2)

- Health effects of radiation esposure
  - Deterministic effects
    - ★ There are thresholds
    - ★ Not observed in Fukushima
  - Stochastic effects—cancer
    - ★ No thresholds
    - ★ There is a point at which the society ceases to devote further resources to reduce the risk.
- The aim of this study:
  - To identify the points for various policy measures taken by the Japanese government
    - ★ Restriction of the distribution of foods, countermeasures in agriculture, decontamination
  - The risk reduction in term of loss of life expectancy (LLE)
  - Cost per life-year saved (CPLYS)
  - Compare with the Chernobyl case
  - Cost-benefit analysis

Orders of evacuation and relocation

- Evacuation order
  - Within 3 km, 21:23 11 March 2011
  - Within 10 km, 5.44 12 March 2011
  - Within 20 km, 18:25 12 March 2011
- Order to go to shelter for 20-30 km, 15 March 2011
  Recommendation for voluntary evacuation for 20-30 km, 25 March 2011
- Within 20 km $\longrightarrow$ 'Restricted area', 22 April 2011
  Area with 20 mSv/y and more $\longrightarrow$ 'Deliberate evacuation area'

Restricted area and deliberate evacuation area



Foodstuff regulation

- Provisional regulation values (since 21 March 2011)

(Bq/kg)

Iodine		Caesium	
Drinking water	300	Drinking water	200
Milk and dairy products	300	Milk and dairy products	200
Vegetables (excluding roots and potetoes)	2000	Vegetables	500
		Crops	
		Meat, egg and fishes	

- New standard values (since April 2012)

(Bq/kg)

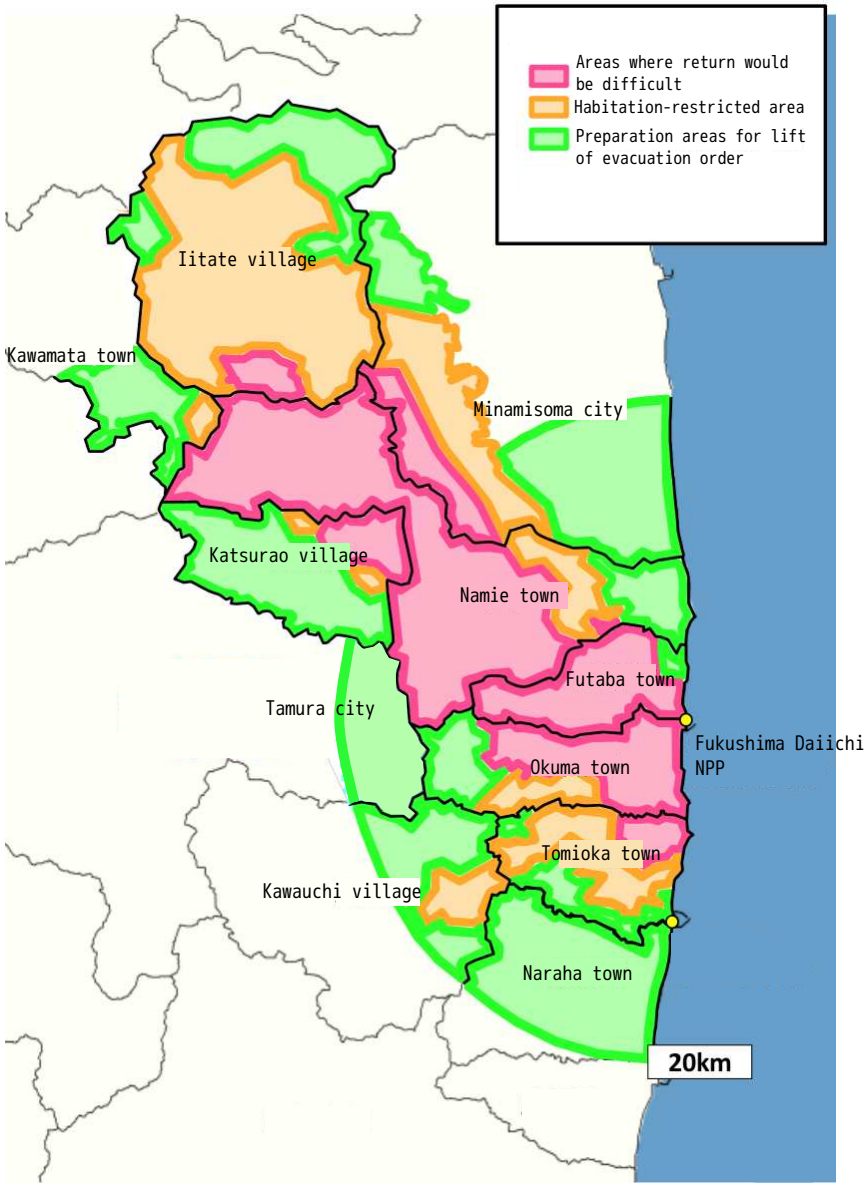
Drinking water	10
Milk and dairy products	50
Other foods	100

Countermeasures in agriculture

- Rice
  - Supplying sufficient amount of potassium and zeolite
  - Deep cultivation
  - Total inspection of rice bags
- Fruits trees
  - Bark washing of fruits trees
  - Total inspection of anpo-gaki (dried japanese persimmon)

Decontamination area

- Special decotamination area
  - Area 1: preparation areas for lift of evacuation order (1-20 mSv/y)
  - Area 2: habitation-restricted areas (20-50 mSv/y)
  - Area 3: areas where return would be difficult (50 mSv/y and more)
- Intensive contamination survey area
  - Outside the Special Decontamination Area, where annual individual dose for the first year had been predicted to be between 1 and 20 mSv



Loss of life expectancy (LLE)

- Cancer risk models

$$\begin{cases} R = \alpha d e^{-0.34(x-30)} \left(\frac{a}{70}\right)^{-0.86} & \text{(for solid cancer)} \\ R = (1.55d + 0.83d^2) e^{-1.06x' - 0.20x't + 0.02x't^2 - 0.0003x't^3 + 0.0007x't'} & \text{(for leu} \end{cases}$$

- LLE by age at exposure

(year/mSv)

Age at exposure	Male	Female	Average
0-9	2.7×10^{-3}	4.4×10^{-3}	3.5×10^{-3}
10-19	1.7×10^{-3}	2.9×10^{-3}	2.1×10^{-3}
20-34	1.1×10^{-3}	1.8×10^{-3}	1.5×10^{-3}
35-49	7.3×10^{-4}	1.1×10^{-3}	9.0×10^{-4}
50-	2.6×10^{-4}	3.0×10^{-4}	2.8×10^{-4}
All ages	8.8×10^{-4}	1.3×10^{-3}	1.1×10^{-3}

- Dose coefficients for oral intake of radiocaesium

(10^{-5}mSv/Bq)

Age	0	1	5	10	15	Adult
Cs-134	2.6	1.6	1.3	1.4	1.9	1.9
Cs-137	2.1	1.2	0.96	1.0	1.3	1.3

ICRP(1996).

Costs and effects of the prohibition of the distribution of contaminated vegetables and rice produced in Fukushima Prefecture in 2011

	Vegetables 2011			Rice		
	March	April	May	Onami District	Areas 500Bq/kg-	Areas 100-500Bq/kg
Ave. conc. (Bq/kg)	4000	720	180	52	24	16
Quantity (t)	740	520	350	175	4000	32,000
Cost (bil. yen)	1.9	2.2	0.94	0.045	1.0	7.6
Life-year saved	21	4.3	0.87	0.14	1.5	7.3
CPLYS (mil. yen)	8.0	51	100	310	660	1000

Oka (2014).

Bark washing of fruit trees

- 549,516 fruit trees were washed (of which 257,517 were persimmon) with high pressure washer in Date city in 2011 winter.
- Decrease in the Cs concentration in anpo-gaki (dried persimmon).

(Bq/kg)

	Cs-134	Cs-137	Total
2011	-	-	247.7 (SD: 197.9)
2012	50.0 (SD: 34.1)	80.0 (SD: 53.4)	130.0 (SD: 87.1)
2013	22.1 (SD: 13.7)	48.9 (SD: 28.8)	71.0 (SD: 42.0)

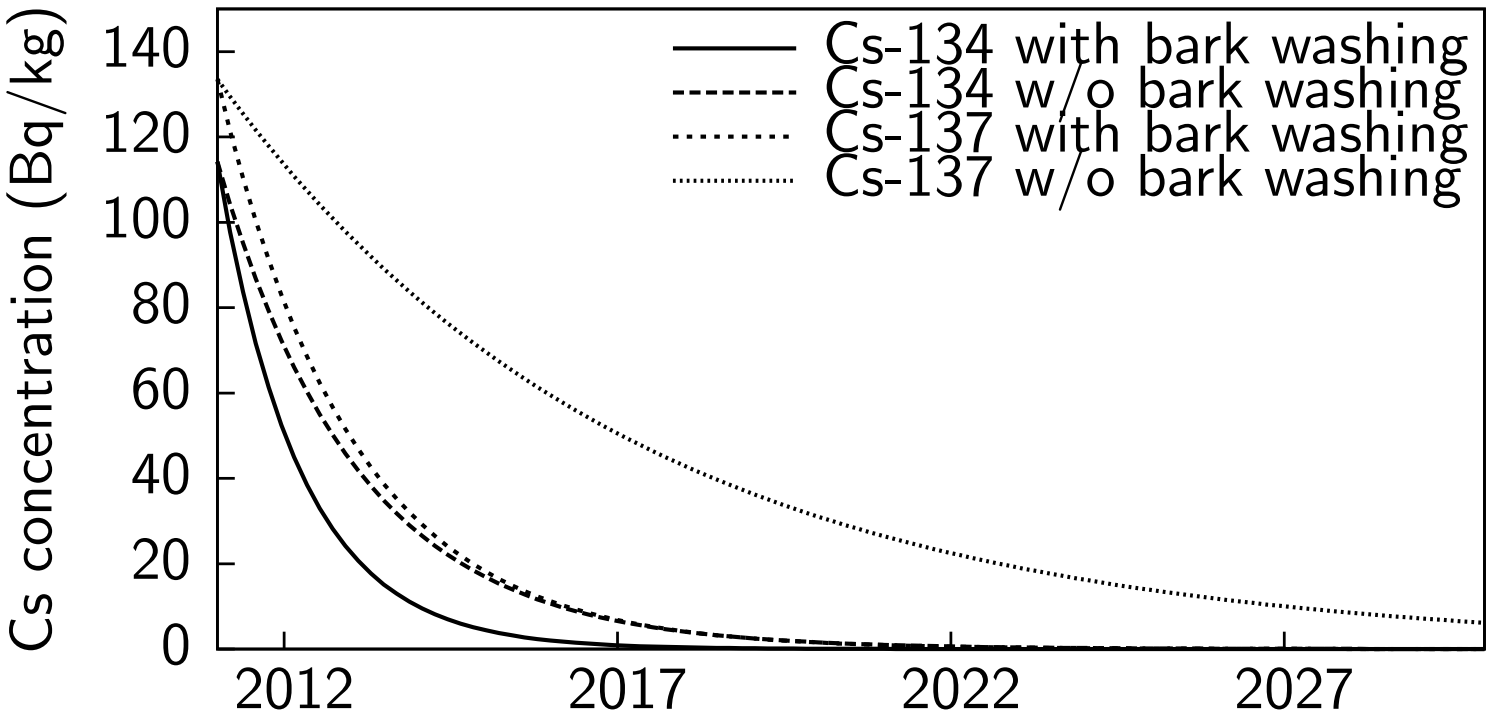
Data from Fukushima Prefecture.

- These decreases were due to
  - bark washing,
  - physical decay,
  - natural biological elimination.
- According to Sato's (2014) findings:
  - bark washing had effects for several years,
  - decay constant is different between fruits of washed trees and those of unwashed trees by 0.344,

effects of bark washing were identified.

Effect of bark washing and CPLYS

- Prospected effecs in Cs concentration in anpo-gaki by bark washing

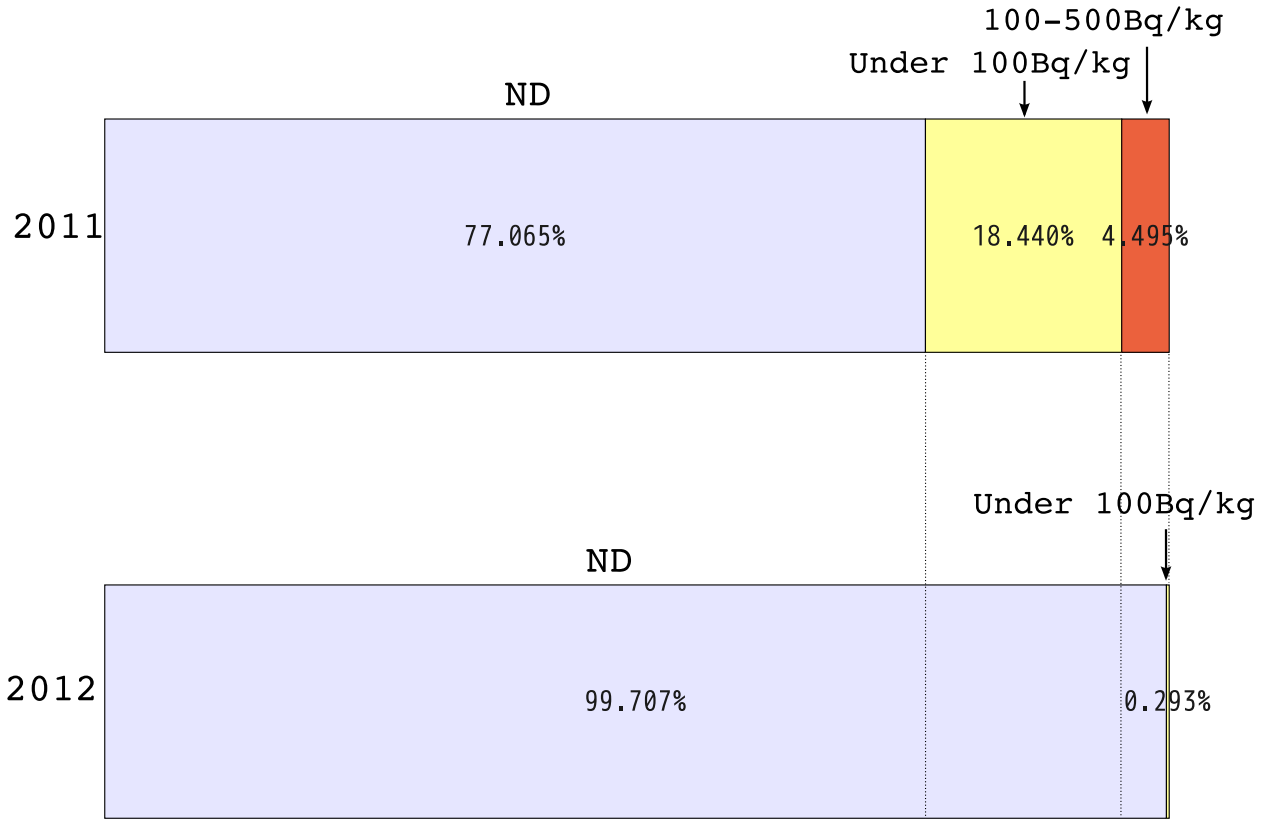


- The cost of bark washing of persimmon trees was 622 million yen.
- The anual production of anpo-gaki is 1737 tonnes.

Period (year)	2	5	19
LLe reduction (year)	3.4	8.6	17
CPLYS (million yen)	180	72	37

Result of the total inspection of rice in 2012

- Reduction in Cs concentration of rice produced in Date city



161,632 bags were inspected.

CPLYS of the measures to prevent radiocaesium intake in rice

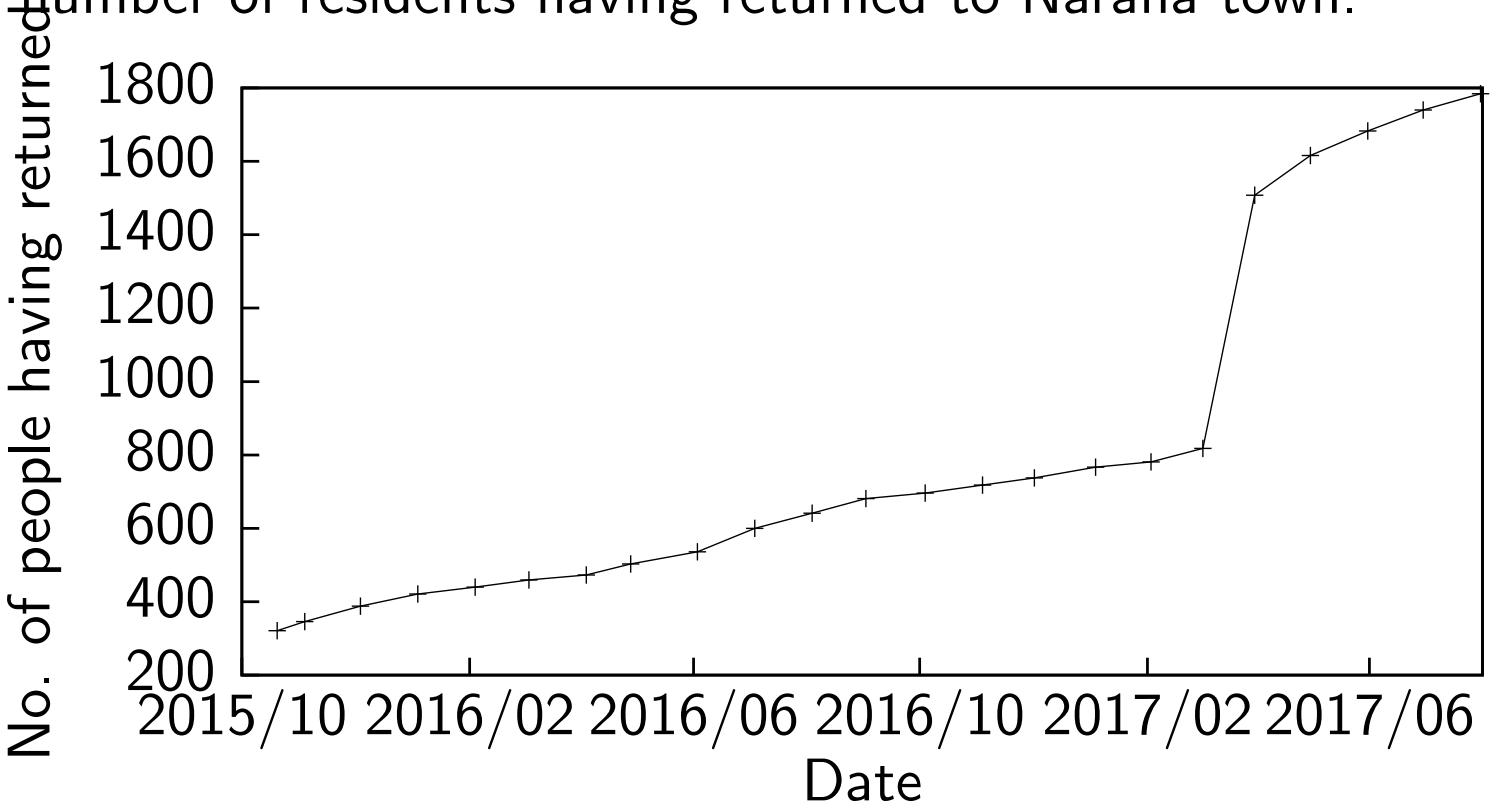
- These reductions are due to:
  - Application of potassium and zeolite and deep cultivation,
  - Physical decay, and
  - Natural biological reduction.
- A value for natural decay constant excluding physical decay is proposed as 0.424.
- Given this value, the maximum reduction by the countermeasures would be 48 Bq/kg for polished rice.
- The cost of the countermeasures is 866,000 yen/ha, or 195 yen/kg-rice. $\longrightarrow$4.1 yen/Bq (1.6×10^{-8} year-LLE/Bq)
- CPLYS is 250 million yen. (only for 4.202% of rice to which countermeasures applied)

Decontamination work

- Naraha is the first town where the whole region had been designated as Restricted Area and the evacuation order was lifted (on 5 September 2015).
- 20.1 km^2 has been decontaminated. Removed soil and waste amounted to 594,000 bags, each containing 1 m^3.
- 77,911 pairs of air dose rate before and after the decontamination, from 8 November 2012 to 25 December 2013.
- The average reduction in the air dose rate at the time of the lift of evacuation order, 5 September 2015, is 0.250 μSv/h, which is equivalent to 0.922 (99%CI: 0.913, 0.931) mSv/y as the effective dose.

Residents' Return to Naraha town

- The number of residents having returned to Naraha town.



- The LLE reduction enjoyed by the residents who will return to Naraha town with regard to the exposure to radiation for 30 years since the return was calculated, totally amounting to 55 person-years.
- The cost was 57.24 billion yen.
- CPLYS was 1.0 billion yen.

Summary of the results

	CPLYS (million yen/year-LLE)
Restriction of food distribution	
Vegetables in early stages in 2011	8.0-100
Rice in 2011	300-1000
Countermeasures in agriculture	
Bark washing of persimmon trees	37-180
Measures to prevent rice from intaking caesium	250-∞
Decontamination of the evacuation area	1000

620,000 to 7,700,000 Euro/year-LLE under 1 Euro=130 yen.

Reports on cost-effectiveness of the measures to reduce radiological exposure in the Chernobyl case (1)

Decontamination

- 1986-90 The millitary, civil defence troops, and special brigades
  - 4000-12,000 roubles (3200-9600 Euro) per manSv (Bryansk region) (Antsipov et al. 2000)
  - 6700-28,000 Euro per manSv (Ukraine) (*ibid.*)
- 1991-
  - 14,000 Euro per manSv at a Kindergarten and school of the village of Dzerzhinsk (Gomel region)
    It is said:
    Because countermeasures to reduce radiocaesium in foodstuffs had already done, decontamination is justified, but with very high costs (e.g. 1-2 times higher than GNP per capita), one should take into account the social and psychological significance of such work (*ibid.*).

Reports on cost-effectiveness of the measures to reduce radiological exposure in the Chernobyl case (2)

Internal exposure is much more important in Chernobyl than in Fukushima. In general, countermeasures to reduce internal dose are regarded as more cost-effective than decontamination to reduce external dose.

- Annual doses from internal exposure can be reduced to below 1 mSv with the cost up to 70,000 Euro/person-Sv. (Jacob et al. 2000)
- When the cost exceeds 100,000 Euro/person-Sv, decontamination becomes an option. (*ibid.*)
- Considerable collective dose can be averted by quite cost-effective remediation strategies, with the costs of 20,000 or 40,000 Euro/person-Sv. (Jacob et al. 2009)

Comparison of Fukushima and Chernobyl cases

- 1 person-Sv causes about 1.1 years of LLE.
  $\longrightarrow$ 1 billion yen/year-LLE or 7,700,000 Euro/year-LLE is equivalent to 7,000,000 Euro/person-Sv.
  —70 times larger than 100,000 Euro/person-Sv.
  —240 times larger than GDP per capita of Japan.
- The maximum benefit per life-year saved in Japan is estimated to be 20 million yen.
  $\longrightarrow$ The measures except for the regulation of vegetables in the early stages have the costs that are greater than the benefits.

Efficiency and equity

- ICRP framework
  - Planned exposure situations—the dose limit=1 mSv/y (for the public)
  - Emergency exposure situations—the reference level should be set between 20 mSv/y and 100 mSv/y.
  - Existing exposure situations—the reference level should be set between 1 mSv/y and 20 mSv/y.
- The dose exceeding the upper limit of the range recommended by ICRP for the reference level is regarded as inequitable, and within the range a reference value should be chosen according to the principle of optimization, which include efficiency as an important criterion.
- The Japanese government did not explicitly take optimization into account, but simply chose the lower limits of the recommended ranges as criteria or targets.

Food standards

The new standard values were said to be based on the intervention exemption level of 1 mSv/y, which appeared in Codex Standard.

- Provisional regulation value (before April 2012)
  —500 Bq/kg for most foods
- The new standard value (since April 2012)
  —100 Bq/kg for general foods
- The government stated food safety was sufficient under the provisional regulation value.
  - Median internal exposure was 0.051 mSv/y, and the dose would not exceed 1 mSv/y with the probability of 99.95% under the provisional regulation values.
  - Median internal exposure would be 0.043 mSv/y, and the probability of not exceeding 1 mSv/y would increase to 99.99% and more under the new standard value.
- Strengthning the standard to 100 Bq/kg caused additional wasting of agricultural produce and required countermeasures in agricultre, which generated additional costs.

Food regulation and trade

- Before the Fukushima disaster, Japan had a standard for radiocaesium in imported foods affected by the Chernobyl disaster—370 Bq/kg.
- Since April 2012, the new standard, 100 Bq/kg, came to be applied also to imported foods.
  $\longrightarrow$ The cases of breach increased since then.
- The present standard value is not unfair in the sence that it is applied equally to imported and domestic products, conforming to the GATT principle of non-discriminatory treatment.
- Codex standards were, however, made to eliminate regulation that comply with the GATT principle, but do not have sufficient scientific basis, and as a result impede fair trade.
- China, Korea, Taiwan, and Russia now prohibit import of all kinds of foods or all aquatic products from several regions of the east part of Japan. The Japanese government accuses the prohibition as not scientific. But, is the Japanese standard of 100 Bq/kg not unfair?

Conclusion

- We estimated the values of CPLYS for the policy measures to reduce health risks from the radiation exposure from radiocaesium released from the Fukushima Daiichi NPP.
- We found the values are much greater than the comparable estimates from the Chernobyl case, and that the values are in most cases greater than the benefit per life-year saved.
- We discussed the observations from the perspective of efficiency and equity.