# Cost Per Life-Year Saved in the Regulation of Radioactive Food Contamination Due to the Fukushima I Nuclear Accident

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## 1 Foodstuff Regulation

Just after the Fukushima I nuclear accident (11 March 2011), radioactive contamination was detected in vegetables and milk in the area up to 250km far from the plant. Ministry of Health, Labor and Welfare set provisional regulation values (Table 1) for radioactive iodines and caesiums, and began to prohibit the distribution of milk and vegetables produced in the area where the concentrations over the regulation values were found since 21 March.

Table 1: Provisional regulation values

(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<br>Crops<br>Meat, egg and fishes | 500 |

In July 2011, beef contamination of radioactive caesiums was found and the distribution of all the beef from Fukushima Prefecture was stopped for about 1 month. In October, kaki (Japanese persimmon) was found to include radioactive caesium. Although the contamination was under the regulation value, radioactive caesium was supposed to be concentrated when kaki is dried. Date region of Fukushima Prefecture is famous for producing anpo-gaki (a kind of dried kaki). Fukushima Prefectural Government requested the producers not to produce anpo-gaki. In November, rice contamination was detected, and the rice that had grown in the area of about 7000ha, where rice with the concentration above 100 Bq/kg was found, was excluded from food delivery.

New standard values for foodstuffs contaminated with radioactive caesium were set in March 2012, which were to be applied since April (Table2).

Table 2: New standard values for radioactive caesium for foodstuffs

(Bq/kg)

| | |
|---|---|
| Drinking water | 10 |
| Milk and dairy products | 50 |
| Other foods | 100 |

In this study I have estimated the magnitudes of risk-reduction and the costs brought about by the foodstuff-regulation concerning vegetables from March to May, beef from July to August, anpo-gaki in the autumn and rice produced in 2011. Risk-reduction is measured in terms of loss of life-expectancy (LLE) due to additional deaths from cancer caused by internal radiation exposure, and I have estimated the values for cost per life-year saved of the regulation of the above mentioned foodstuffes.

## 2 Coefficients for calculating LLE

Table 3: Coefficients for LLE due to radiation exposure

| Age | LLE due to the exposure to radiation[1) ] (day/mSv) | Internal dose coefficient for radiocaesiums[2)] (mSv/Bq) | LLE due to the intake of radiocaesiums (day/Bq) |
|---|---|---|---|
| 0-9 | 1.5 | $1.1 \times 10^{-5}$ | $1.7 \times 10^{-5}$ |
| 10-19 | 0.99 | $1.6 \times 10^{-5}$ | $1.6 \times 10^{-5}$ |
| 20-34 | 0.59 | $1.6 \times 10^{-5}$ | $9.5 \times 10^{-6}$ |
| 35-49 | 0.31 | $1.6 \times 10^{-5}$ | $4.9 \times 10^{-6}$ |
| 50 | 0.066 | $1.6 \times 10^{-5}$ | $1.1 \times 10^{-6}$ |
| All | 0.42 | | $6.1 \times 10^{-6}$ |

1) These values were obtained by applying the model presented by Preston et al (2003), which gives $ERR = 0.35d\exp[-0.038(x-30) - 0.7\log(y/70)]$ for male and $ERR = 0.59d\exp[-0.038(x-30) - 0.7\log(y/70)]$ for female, where $ERR$ represents excess relative risk, $d$ dose [Sv], $x$ the age at the time of exposure, and $y$ the attained age, to the mortalities due to cancer and other causes for Japanese population and the distribution of the population by age and by sex in 2009.

2) ICRP(1996), Publication 72, *Annals of the ICRP*, 26(1). Radioactivities of Cs-134 and Cs-137 are assuemed to be equal.

## 3 Cost per life-year saved in the Regulation of foodstuffs

### 3.1 Vegetables

Cost [yen] = Reduction in delivery due to the prohibition [kg]
× Price in 2010 [yen/kg]

Reduction in LLE [year] = Radiocaesium concentration [Bq/kg]
× Reduction in delivery due to the prohibition [kg]
× LLE Coefficient [year/Bq]

$$\text{CPLYS} = \frac{\text{Cost [yen]}}{\text{Reduction in LLE [year]}}$$

Table 4: Cost estimates due to the regulation of vegetables

| | March | | April | | May | |
|---|---|---|---|---|---|---|
| | Reduction in delibery (t) | Cost (million yen) | Reduction in delibery (t) | Cost (million yen) | Reduction in delibery (t) | Cost (million yen) |
| Shiitake mushroom | - | - | 21 | 20 | 0 | 0 |
| Crown daisy | - | - | 92 | 57 | 28 | 14 |
| Leek | 157 | 68 | 112 | 52 | 20 | 6 |
| Spring onion | 335 | 111 | 0 | 0 | 0 | 0 |
| Broccoli | 0 | 0 | 5 | 2 | 0 | 0 |
| Spinach | 208 | 76 | 145 | 91 | 145 | 63 |
| Mizuna | 22 | 10 | 15 | 8 | 7 | 3 |
| Others | 147 | 102 | 286 | 244 | 260 | 121 |
| Total | 869 | 370 | 674 | 470 | 433 | 190 |

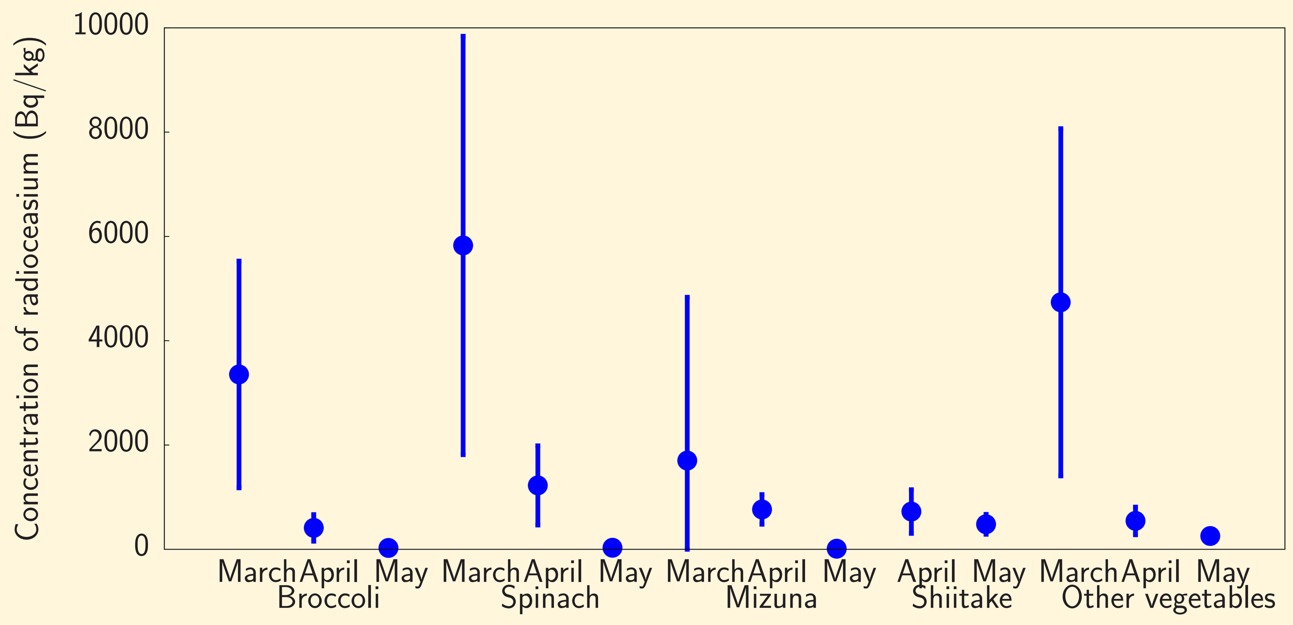


Figure 1: Concentration of radiocaesium in vegetables in Fukushima in 2011

Table 5: CPLYS for the regulation of vegetables

| | March | April | May |
|---|---|---|---|
| Cost (million yen) | 370 | 470 | 190 |
| Life-year saved (year) | 33 (19-46)* | 6.1 (4.3-8.0) | 1.2 (0.95-1.4) |
| CPLYS (million yen) | 11 (8.0-19) | 77 (59-110) | 160 (140-200) |
| CPLYS (1000 USD)** | 0.14 (0.10-0.23) | 0.97 (0.74-1.4) | 2.1 (1.7-2.5) |

* ( ): 90% confidence interval.

** 80 yen = 1 USD.

### 3.2 Beef

In July 2011 beef containing more than 500 Bq/kg of radiocaesiums was detected and shipment of all the cattles raised in Fukushima Prefecture was banned from 19 July. The cause of the contamination was identified as feeding of contaminated rice straw, and the ban was lifted on the condition that all the beef cattle being shipped be checked on radioactive caesiums.

The number of beef cattle shipped from Fukushima Prefecture dropped to zero in August, recovered afterwards and the total shipment from July 2011 to Februrary 2012 was kept not less than that one year before (Fig. 2).

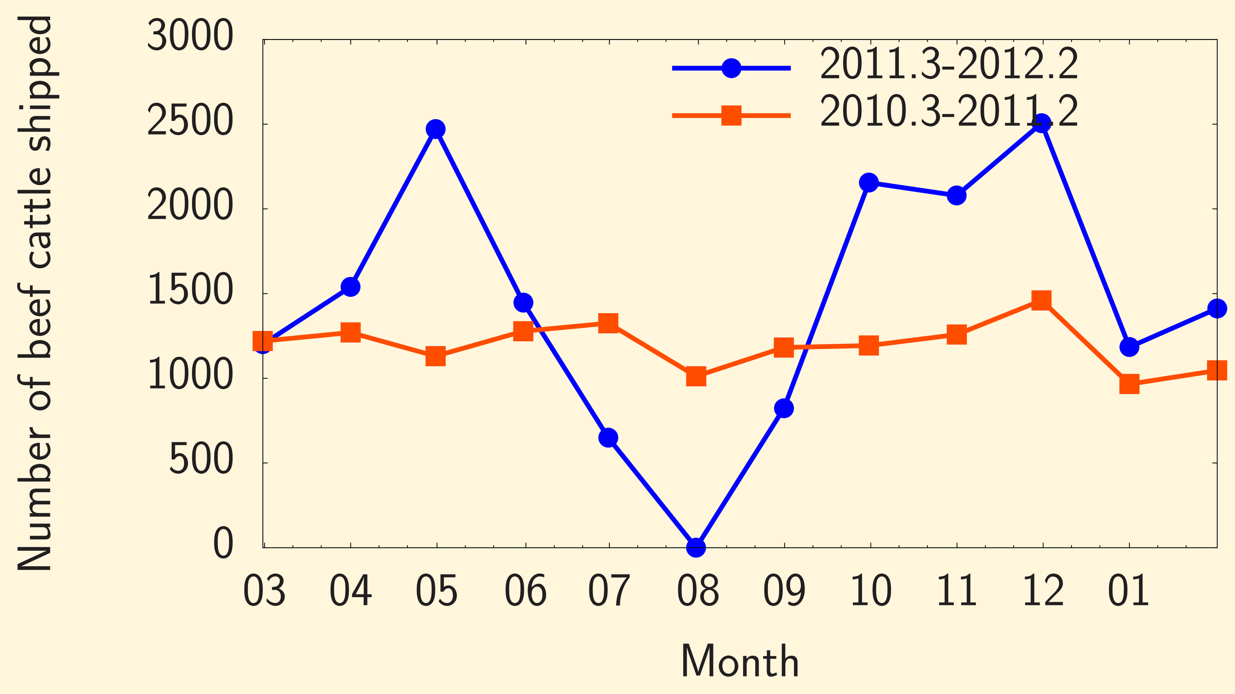


Figure 2: The number of beef cattle shipped from Fukushima Prefecture to Tokyo market

The costs due to the regulation of beef shipment consist of:
1. Extra production cost due to the delay of shippment,
2. Deterioration in quality of beef.

Table 6: Cost per life-year saved of the regulation of beef distribution

| Cost (yen/kg) | | | Radiocaesium (Bq/kg) | | |
|---|---|---|---|---|---|
| Delay | Deterio-ration | Total | w/o regulation | with regulation | reduction |
| 117 | 15 | 132 | 61 | 40 | 21 (15-28) |
| LLE reduction (year) | | | CPLYS(million yen/year) | | |
| $3.5 \times 10^{-7}$ (2.5-4.6 $\times 10^{-7}$) | | | 370 (290-520) | | |

### 3.3 Rice

Radioactive caesium exceeding the provisional regulation value, 500 Bq/kg, was detected in the rice produced in Onami district in Fukushima city in November 2011. Survey by the prefectural government found out rice whose radiocaesium exceeds the provisional regulation value in other seven districts.

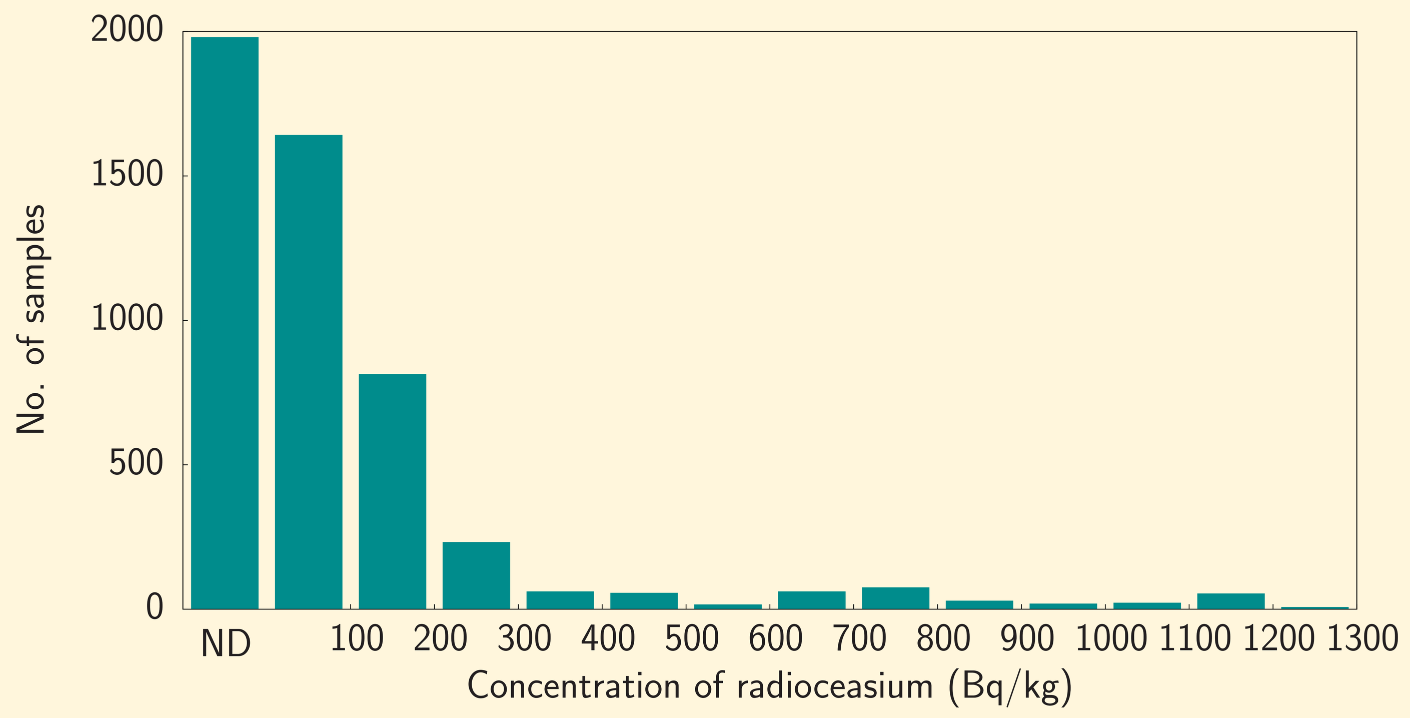


Figure 3: Distribution of the concentration of radiocaesium in rice produced in Onami district

Distribution of the concentration in rice produced in Onami district is as shown in Fig. 3. Concentration values for the other districts which produced rice with contamination exceeding the provisional regulation value is distributed as shown in Table 7.

Table 7: Distribution of concentration values for the seven districts in Fukushima, Date, and Nihonmatsu cities other than Onami

| Concentration of radiocaesium (Bq/kg) | ND | 0-100 | 100-500 | 500- |
|---|---|---|---|---|
| Number of samples | 1226 | 474 | 178 | 22 |

In total, 4600 tonnes of rice with the estimated average concentration of 58 Bq/kg (with a 90% confidence interval of 54-61 Bq/kg), which is equivalent to 26 (24-27) Bq/kg in polished rice, was withdrawn from food delivery, which reduced the intake of radiocaesium by 110 million Bq. LLE reduction brought about by this regulation is 1.8 (1.7-1.9) years. The lost value of the rice is 1.1 billion yen. As a result, CPLYS is 620 (590-660) million yen (7.8 million USD).

The survey by the prefectural government also identified several districts which did not produce rice with radiocaesium exceeding 500 Bq/kg, but produced rice with radiocaesium exceeding 100 Bq/kg. The distribution of the concentration values is as shown in Table 8.

Table 8: Concentration values for the district produced rice with 100-500 Bq/kg of radiocaesium

| Concentration of radiocaesium (Bq/kg) | ND | 0-100 | 100-500 |
|---|---|---|---|
| Number of samples | 6730 | 1632 | 313 |

Average concentration value is estimated to be 36 Bq/kg, which means 16 Bq/kg in polished rice. On the average, 32,000 tonnes of rice with the concentration of 16 Bq/kg was withdrawn from food delivery, which reduced the intake of radiocaesium by 460 million Bq. This caused LLE reduction by 7.8 years, whereas the lost value of the rice is 7.8 billion yen; CPLYS is 1.0 billion yen (13 million USD).

### 3.4 Anpo-gaki (dried persimmon)

The average concentration of radiocaesium in the samples of anpo-gaki produced in Date region was 250 Bq/kg, three of the samples having the values exceeding 500 Bq/kg. The prefectural government requested to stop the production.

The damage cost due to the stop of the production was estimated to be 2.2 billion yen. It is estimated that 1900 tonnes of ampo-gaki was not produced, which has reduced the intake of radiocaesium by 490 MBq (350-630 MBq), which would have reduced the LLE by 8.2 (5.8-11) years. The CPLYS is estimated to be 280 (220-390) million yen (3.5 million USD).

### 3.5 Summary of CPLYS of the foodstuff regulations

The values for cost per life-year saved of the regulation of foodstuffs are summarized in Table 9. These values are comparable with the values for CPLYS of several past regulations of toxic chemicals in Japan (Table 10).

Table 9: CPLYS of the regulations of foodstuffs

| | | CPLYS (million yen) | |
|---|---|---|---|
| Vegetables | March | 11 | (8.0-19) |
| | April | 77 | (59-110) |
| | May | 160 | (140-200) |
| Beef | | 370 | (290-520) |
| Rice | 500Bq/kg- | 620 | (590-660) |
| | 100-500Bq/kg | 1000 | (1000-1000) |
| Anpo-gaki | | 280 | (220-390) |

Table 10: CPLYS of past regulations of toxic chemicals in Japan

| Regulation | CPLYS (million yen) |
|---|---|
| Prohibition of chlordane | 45 |
| Mercury regulation in the caustic soda production | 570 |
| Mercyry removal from dry batteries | 22 |
| Regulation of benzene in gasoline | 230 |
| Dioxin control (emergency countermeasures) | 7.9 |
| Dioxin control (long-term countermeasures) | 150 |

## 4 Value of a life-year and efficient standards for foodstuffs

WTP-based value of a statistical life (VSL) ranges from 200 to 2000 million yen for Japanese people, with the average of 800 million yen. The value of a life-year derived from the VSL of 800 million yen is 20 million yen. Compared with the value of a life-year, the values for CPLYS are much higher, except for the regulation of vegetables.

The standard values for foods which would keep the CPLYS not to exceed the value of a life-year is given as:

$$q = \frac{p}{vc} \quad [\text{Bq/kg}],$$

where $q$ is the standard value (Bq/kg), $p$ is the cost (yen/kg), $v$ is the value of a life-year (yen/year) and $c$ is the LLE due to the intake of radiocaesium (year/Bq). The values for $q$ for several categories of food are shown in Table 11.

Table 11: Efficient standard values for foods

| | Cost (yen/kg) | Standard value (Bq/kg) |
|---|---|---|
| Vegetables | 250 | 750 (300-3000) |
| Beef | 1400 | 4200 (1700-17000) |
| Rice | 240 | 720 (290-2900) |
| Anpo-gaki | 910 | 2900 (1100-11000) |

## 5 Countermeasures to reduce radiocaesium

In the first year, regulations are, in many cases, accompanied by disposal of agricultural products. That may be a reson for the high costs of regulation. During this period, however, countermeasures in the production processes have been applied, such as:

- Cleaning of the bark of fruit trees,
- Application of potassium fertilizer and zeolite to rice fields, and
- Prohibition of feeding cattles on grass containing radiocaesium of more than 100Bq/kg.

These countermeasures may be cheaper than disposing of the products. For example, cleaning of the bark of Japanese persimmon trees was done in winter 2011-2012. As a result, the radiocaesium contamination in anpo-gaki was reduced from 250 Bq/kg to 130 Bq/kg on the average (Fig. 4), which would have reduced the intake of radiocaesium by 940 (190-1700)MBq for the next 10 years, that means the reduction of LLE by 16 (3.1-28) years. The cost for the cleaning was 700 million yen, implying CPLYS of 44 (25-220) million yen.

But the production of anpo-gaki was stopped again in 2012 because the concentration values exceeded the present standard of 100 Bq/kg. This regulation incurred cost of 2.3 billion yen, and would prevent the intake of 260 (210-300) MBq of radiocaesium, which would reduce LLE by 4.3 (3.5-5.1) years, implying CPLYS of 530 (450-660) million yen.

This example shows that the prohibition of the distribution of foods is much less cost-effective than a countermeasure in production.

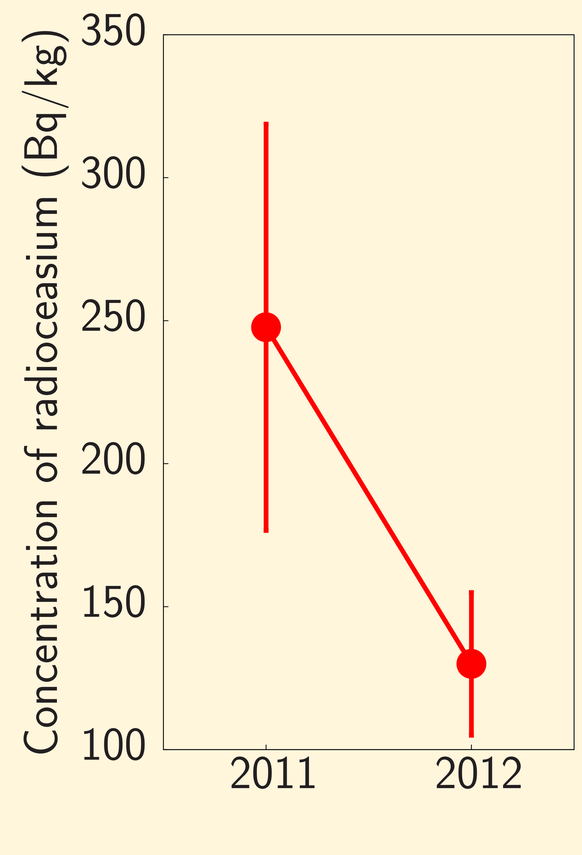


Figure 4: Radiocaesium contamination in anpo-gaki