# Cost-Benefit Analysis of the Countermeasures for Agricultural Products against Contamination with Radioactive Substances in the Cases of Japanese Persimmon and Rice

OKA Tosihiro
(Fukui Prefectural University, Japan, Tel: +81 776 61 6000. E-mail: oka@fpu.ac.jp.)

Annual Meeting of Society for Risk Analysis
Denver, December 8, 2014

## 1 Introduction

After the Fukushima Daiichi nuclear accident in March 2011, the Japanese government determined provisional regulation values for radioactive substances and began to prohibit the distribution of contaminated agricultural products. In Table 1 the values are presented for cost per life-year saved (CPLYS) of this regulation with respect to vegetables and rice in 2011.

Table 1: 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 | Oonami District | Areas 500Bq/kg< | Areas 100-500Bq/kg |
| Cost (billion 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 (million yen) | 8.0 | 51 | 100 | 310 | 660 | 1000 |

Oka 2014.

'Costs' here represent the market values of the agricultural products that were not sold because of the regulation. A value for the 'benefit' per life-year saved, which should be set against the CPLYS, has been estimated to be 20 million yen (Oka 2014). Except for the vegetables in early days since the accident, the CPLYS are much greater than the benefit.

A new standard for radioactive caesium, 100 Bq/kg for general foods, has been applied since April 2012. In order to prevent products from containing radiocaesium exceeding this standard, the following countermeasures have been carried out:

1) Bark washing of fruit trees
2) Fertilization of potassium and zeolite and deep cultivation in rice fields
3) Total inspection of rice.

If these measures have been more cost-effective in reducing the exposure to radiation due to the intake of contaminated food than the simple prohibition of the deliveration of products, the regulation with the new standard may have been efficient. Was that the case?

## 2 Bark washing of fruit trees

The caesium concentrations in peach, pear, apple and Japanese persimmon produced in Fukushima Prefecture (Date area is the major source) did not exceed the then provisional regulation value, 500 Bq/kg, but many samples of dried persimmon (anpo-gaki) were found to contain radiocaesium exceeding 500 Bq/kg. The government of Fukushima Prefecture requested the farmers not to process persimmon. Farmers conducted bark washing of fruit trees in winter 2011-12 aiming to ensure fresh fruits in the next year never contain radiocaesium greater than the new standard, and that they be able to resume the production of anpo-gaki.

Table 2: Average concentration of radiocaesium in anpo-gaki processed on trial

(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.

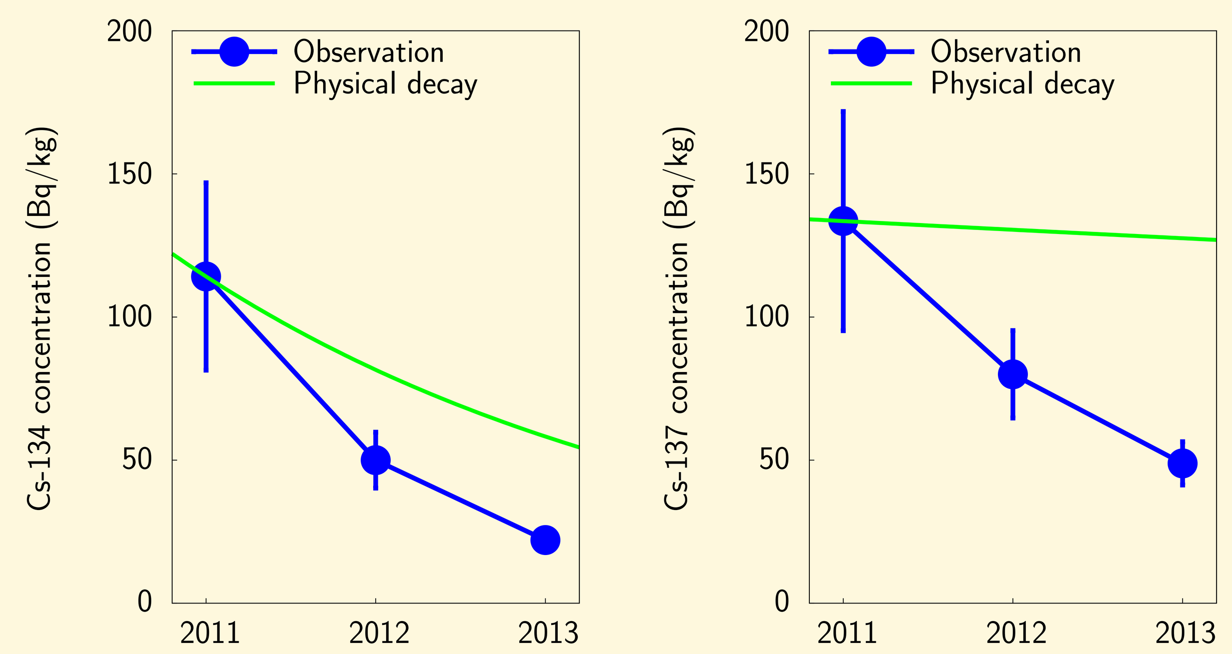


Figure 1: Cs concentration in anpo-gaki on test processing (Date area). Data from Fukushima prefecture. The error bars represent 90% CI for the mean of the population.

The results of the processing test of anpo-gaki is shown in Table 2 and in Fig. 1. The reduction here must have included the reduction caused by:

1) physical decay,
2) biological elimination, and
3) bark washing.

Provided that radiocaesium declines exponentially, decay constants excluding physical decay are estimated as shown in Table 3.

Table 3: Decay constant excluding physical decay in anpo-gaki

| | Cs-134 | Cs-137 | Total |
|---|---|---|---|
| 2011-2012 | - | - | 0.489 |
| 2012-2013 | 0.480 | 0.470 | 0.473 |

By and large they are constant. Since bark washing was carried out once in winter 2011-12, if its effect remained only until the next harvest, the fact that the decay constant in 2012-13 is as large as that in 2011-12 means the washing was not effective in reducing radiocaesium in fruits.

Sato (2014) reported that bark washing carried out in December 2011 had reduced radiocaesium concentration in fruits of Japanese persimmon not only in 2012 but also in 2013. Sato et al. (2014) presented a model:

$$y = K \exp(-Dx),$$

where $y$ represents the concentration of Cs-137, $x$ the number of years since the nuclear accident, and $D$ the decay constant, which was estimated at:

$$\begin{cases} D = 1.19 \quad (95\%\text{CI} : 1.10, 1.28) & \text{for the case of washing} \\ D = 0.846 \quad (95\%\text{CI} : 0.772, 0.920) & \text{for the case of nonwashing,} \end{cases}$$

indicating the bark washing raises the decay constant by 0.344 (95%CI: 0.229, 0.459).

On the basis of this finding, assuming that the decay constant excluding physical decay will be lower by 0.344 in the hypthetical case where the bark were not washed than the actual case, the long-term effect of bark washing on the caesium concentration in anpo-gaki will be as presented in Fig. 2.

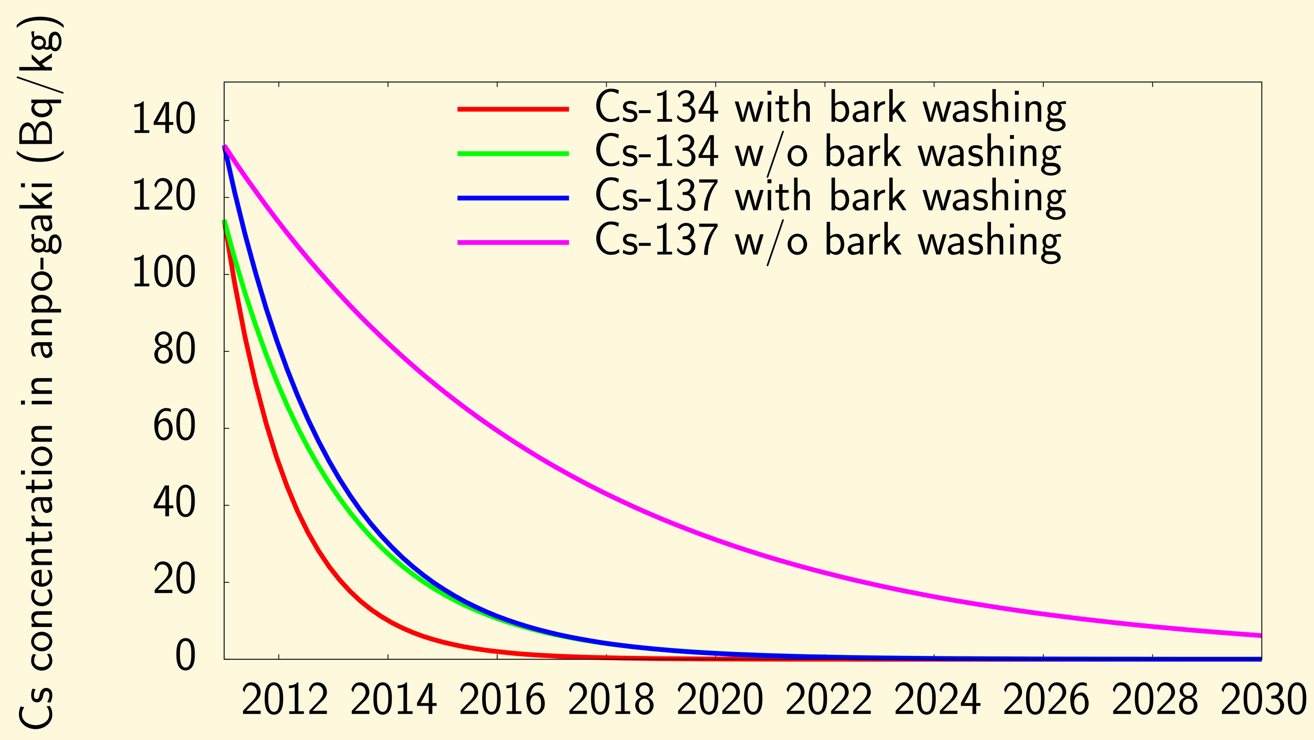


Figure 2: Difference in Cs concentration in anpo-gaki with and without bark washing

Multiplying these differences by the annual production of anpo-gaki, 1737 tonne, will produce the reductions in intake of radiocaesium when people eat anpo-gaki. Applying the loss of life-expectancy (LLE) coefficients of radiocaesium ingestion in Table 4 to these intake reductions will give us values for life-year saved due to the bark washing.

Table 4: Loss of life-expectancy coefficient of radiocaesium ingestion

| | Cs-134 | Cs-137 |
|---|---|---|
| Dose coefficient for Cs ingestion (mSv/Bq)[1] | $1.9 \times 10^{-5}$ | $1.3 \times 10^{-5}$ |
| LLE coefficient of dose (year/mSv)[2] | $1.1 \times 10^{-3}$ | |
| LLe coefficient of Cs ingestion (year/Bq) | $2.0 \times 10^{-8}$ | $1.4 \times 10^{-8}$ |

1) ICRP(1996), 2) Oka(2014)

Accumulated life-years saved by the bark washing is shown in Fig. 3.

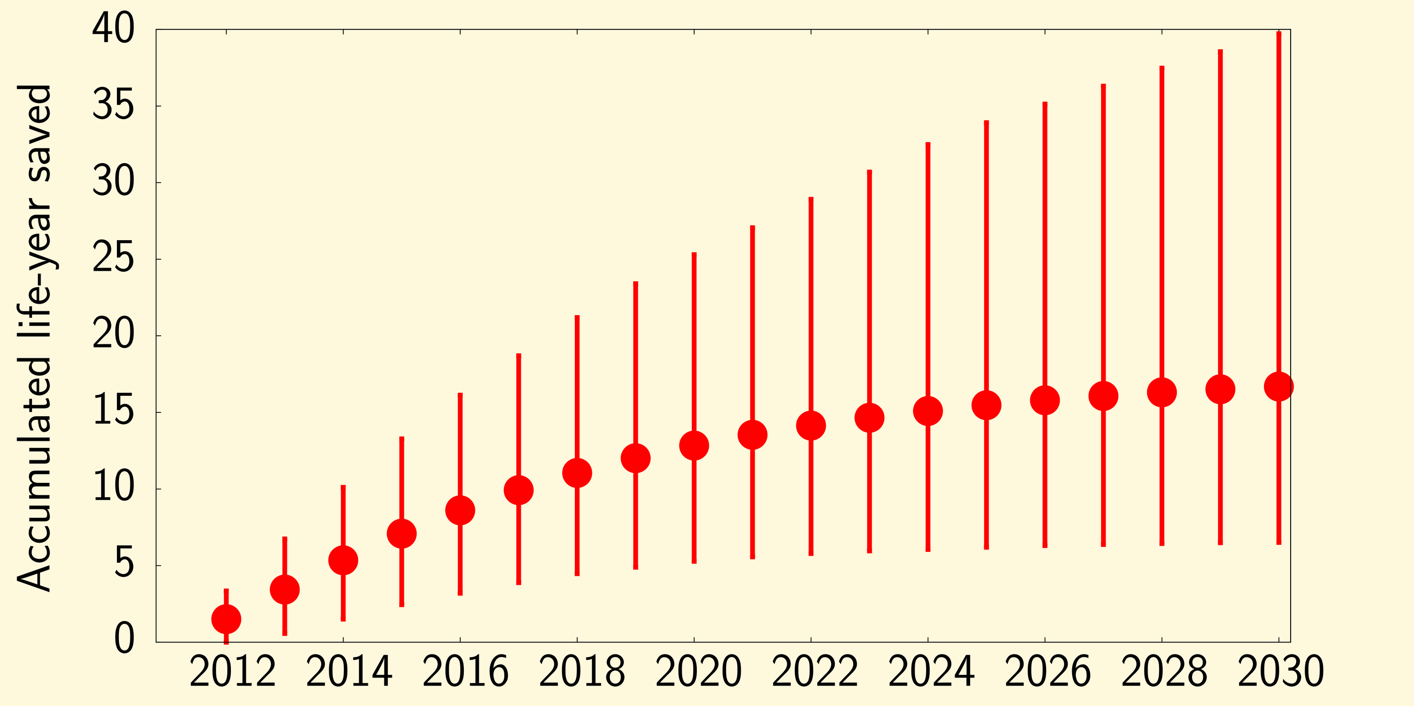


Figure 3: Accumulated life-years saved by the bark washing of Japanese persimmon. The error bars represent 90% CI reflecting the standard errors of the radiocaesium concentration and of the decay constant.

The total cost of the bark washing for Japanese persimmon was estimated to be 699 million yen, from which values for CPLYS can be calculated. Taking the effects of washing for the first two years, 2012 and 2013, into account, CPLYS is 230 million yen, while taking the effects for the first 5 years into account, CPLYS is 81 million yen, taking the effects for the first 10 years into account, CPLYS is 52 million yen, and taking the effects for the first 19 years into account, CPLYS is 42 millione yen (Fig. 4).

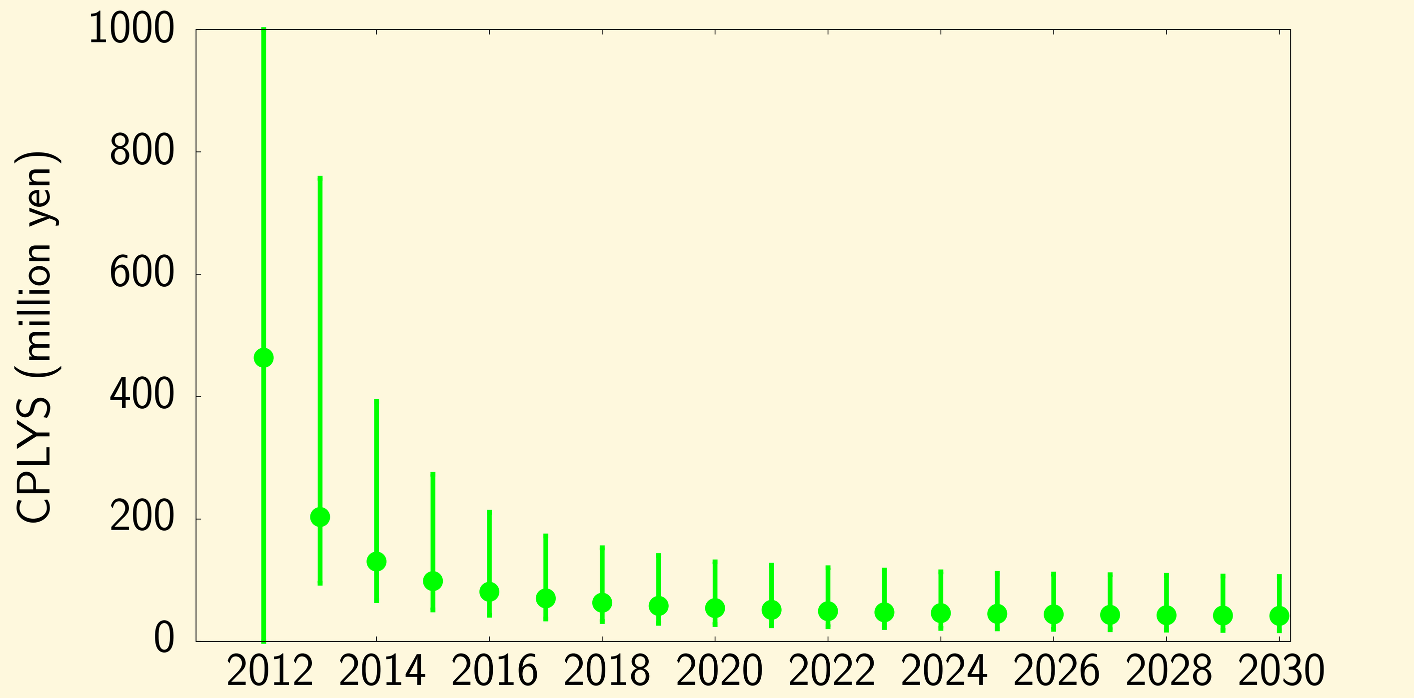


Figure 4: CPLYS for bark washing of Japanese persimmon. What the error bars represent is the same as Fig.3.

## 3 Measures to prevent rice from absorbing radiocaesium

In Date city, where rice with radiocaesium above 100 Bq/kg had been produced from 14 districts (from six of which rice with radiocaesium above 500 Bq/kg had been produced) in 2011, fertilization with potassium and zeolite, and deep cultivation were carried out to prevent rice from absorbing caesium in 2012. All the rice bags (containing 30kg of rice) were inspected (in total 161,632 bags in Date city), none of which turned out to have radiocaesium concentration above 100 Bq/kg (Table 5).

Table 5: Results of the total inspection of rice in 2012 (Date city)

| Radiocaesium concentration (Bq/kg) | ND | 25-50 | 51-75 | 76-100 |
|---|---|---|---|---|
| Percentage | 99.707% | 0.255% | 0.037% | 0.001% |

In 2011, 4.495% of the 2603 farmers within the 14 districts had produced rice with radiocaesium above 100 Bq/kg, 18.440% of them had produced rice with radiocaesium under 100 Bq/kg, and 77.065% of them had produced rice in which radiocaesium had not been detected. This distribution of caesium concentration should have been transformed into the distribution presented in Table 5.

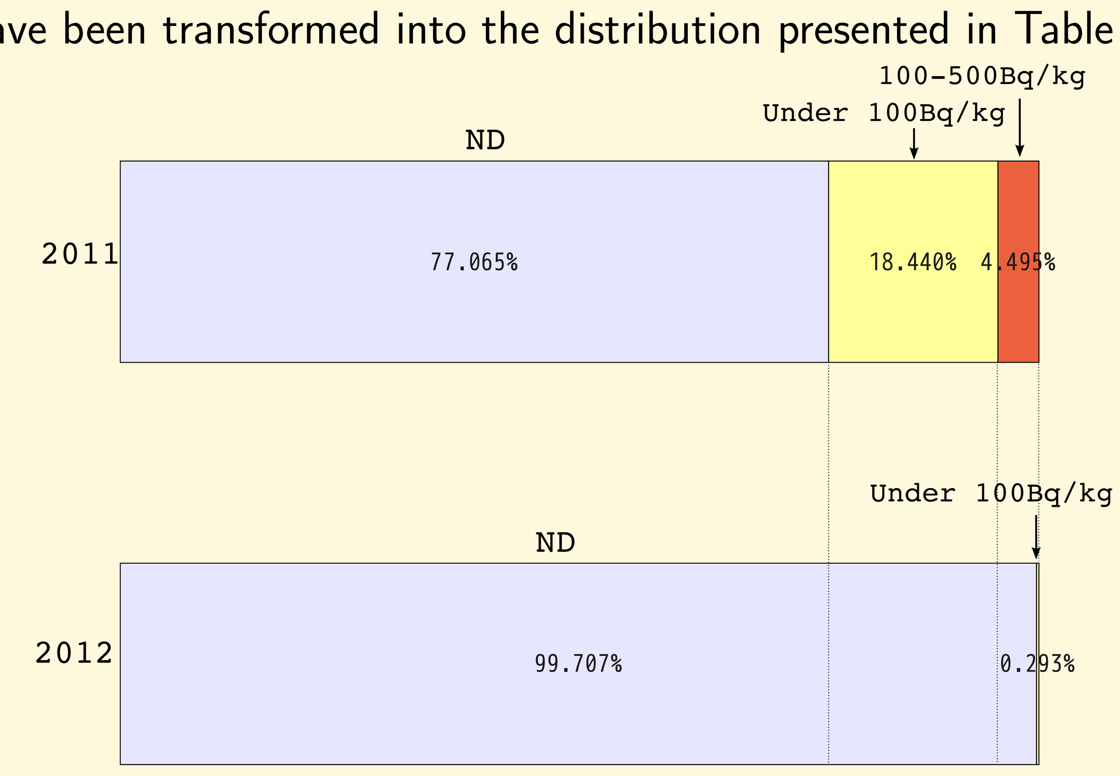


Figure 5: Distribution of radiocaesium concentration in rice produced in Date city: 2011 and 2012

Of the 4.495% of the rice, which had had caesium exceeding 100 Bq/kg in 2011, 0.293% may have fallen into the group of 25 to 100 Bq/kg in 2012, and the residual 4.202% may have fallen into the group of ND. The latter 4.202% should be the category which represents the largest reduction in caesium concentration. The estimated reduction is 173 Bq/kg.

Table 6: Effects and costs of the measures to prevent rice from absorbing radiocaesium in Date city

| Radiocaesium in 2011 | | | <100Bq/kg | 100-500Bq/kg | |
|---|---|---|---|---|---|
| Percentage | | | 18.440% | 4.202% | 0.293% |
| Average concentration | 2011 | (Bq/kg) | 69 | 186 | 186 |
| | 2012 | (Bq/kg) | 13 | 13 | 38 |
| Reduction | | (Bq/kg) | 57 | 173 | 148 |
| Natural decline | | (Bq/kg) | 23 | 61 | 61 |
| Physical decay | | (Bq/kg) | 8.3 | 22 | 22 |
| Reduction by countermeasure | brown rice | (Bq/kg) | 26 | 90 | 65 |
| | white rice | (Bq/kg) | 11 | 40 | 29 |
| Cost | | (yen/ha) | 870,000 | | |
| Production | | (tonne/ha) | 4.4 | | |
| Unit cost | | (yen/kg) | 197 | | |
| | | (yen/Bq) | 17 | 5.0 | 6.9 |
| LLE | | (year/Bq) | $1.6 \times 10^{-8}$ | | |
| CPLYS | | (billion yen) | 1.1 | 0.30 | 0.42 |

But this includes physical decay as well as other natural reduction. Niizuma and Fujimura (2014) reported that the natural decay constant including physical decay was 0.424. On the basis of this estimate, the reduction due to the countermeasure on rice field is inferred to be 90 Bq/kg, which corresponds to 40 Bq/kg for white rice.

The cost of the countermeasure was estimated at 870,000 yen/ha, which implies 197 yen/kg-rice, provided the average rice product is 4.4 tonne/ha. This is equivalent to 5.0 yen/Bq for the category of rice with reduction of 40 Bq/kg in white rice, which implies 300 million yen per life-year saved, using the LLE coefficient of $1.6 \times 10^{-8}$ year/Bq.

## 4 Conclusion

The bark washing of Japanese persimmon was a countermeasure that could have saved a life-year at the cost of tens of millions yen. The cost is in the same order as the benefit, even if it cannot be said as lower than the benefit, if Japanese persimmon had been processed to anpo-gaki. Actually the processing was not resumed in 2012 because some samples of anpo-gaki had the concentration exceeding the new standard, 100 Bq/kg. This gave rise to a loss of about 2 billion yen, which implies a cost above 500 million yen per life-year saved.

In 2013, some areas were designated as the model areas for resuming anpo-gaki production, but the production was yet one tenth of the amount before the nuclear accident.

The countermeasures on rice field is the one that would have saved a life-year at the cost of 300 million yen even for the category of the most heavily contaminated rice, which represents only 4 to 5% of the rice grown in the area where the countermeasure is carried out. Furthermore, total inspection was implemented, which detected 71 bags of rice with concentration above 100 Bq/kg in 2012 at a cost of 6 billion yen per year. The detection excluded those bags of rice from distribution, and saved 0.0020 years of life. The resulting CPLYS is greater than 2 trillion yen.

These countermeasures have been implemented in order to ensure that agricultural products not contain radiocaesium above 100 Bq/kg, and thereby recover market acceptance of Fukushima's agricultural products. That is a rational reaction to the regulation by the government and the bad reputation amoung cunsumers, but the regulation that caused the reaction should be evaluated from the viewpoint of efficiency. If the new standard value were not universally 100 Bq/kg, some of the countermeasures might not have been necessary and processing of anpo-gaki might have been started again earlier.

## Acknowledgement

This work was supported by JSPS KAKENHI Grant Number 25340144.

## References

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