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# There is a direct correlation between the amount of cesium in the blood and the amount of radioactivity in skeletal muscle: Cattle studies in the radiation-free zone around the Fukushima Daiichi nuclear power plant

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## ABSTRACT

Many radioactive substances were released into the air after the accident at the Fukushima Daiichi Nuclear Power Plant (FNPP). Beef contamination with radioactive cesium in 2011 also surpassed the 500 Bq/kg limit. Japanese consumers still worry about ingesting radioactive materials. Previous research showed a linear relationship between 500 and 2500 Bq/kg for radioactive cesium (<sup>137</sup>Cs) activity in cow blood and muscle. The radioactive concentrations around the current safety threshold of 100 Bq/kg were unknown, but the correlation still held. The blood <sup>137</sup>Cs levels of 17 animals in the FNPP evacuation zone were determined to be less than 10 Bq/kg. The results showed a linear connection between cesium radioactivity in muscle and blood radioactivity ( $Y = 28.0X$ ,  $R^2 = 0.590$ ) at low radioactivity concentrations. By spotting potentially harmful cattle before they reach the market, this strategy will help reduce the occurrence of food-borne illnesses.

**Key words:** food safety, Fukushima Daiichi Nuclear Power Plant, radioactive cesium, radioactive substances.

## INTRODUCTION

A large amount of artificial radioactive chemicals have been released into the environment after the Fukushima Daiichi Nuclear Power Plant (FNPP) disaster (Bowyer et al. 2011; Kinoshita et al. 2011; Sinclair et al. 2011; Yasunari et al. 2011). In particular, the leak of radioactive cesium (<sup>137</sup>Cs and <sup>134</sup>Cs) is reason for concern (Calabrese, 2011). We recently observed (Fukuda et al., 2013) that <sup>137</sup>Cs radioactivity in several organs of cattle corresponded with <sup>137</sup>Cs radioactivity in whole peripheral blood. We anticipated that these findings supported the use of blood radioactivity as a

surrogate for assessing cesium in muscle as a measure of food safety. The importance of this connection, however, was established in Only high-radioactive cattle, with levels between 500 and 2500 Bq/kg of skeletal muscle, have had this connection evaluated (Fukuda et al., 2013), but the details are sketchy. In April 2012 (Okada et al., 2013), the Japanese government reduced the radioactive cesium safety level from 500 Bq/kg to 100 Bq/kg. The revised standard of 100 Bq/kg emphasizes the need of studying the potential relationship between blood Cs and organ Cs radioactivity.

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T. FUKUDA *et al.***Table 1** The details of the analyzed cattle

Date of sampling	Sampling location	Sex	Date of birth	Strain
2011.8.31	Fukushima, Minami-Soma city	Heifer	2010.08.04	Japanese Black
2011.8.31	Fukushima, Minami-Soma city	Heifer	2011.01.18	Japanese Black
2011.9.6	Fukushima, Kawauchii village	Heifer	1994.12.05	Japanese Black
2011.10.20	Fukushima, Kawauchii village	Heifer	NA	Japanese Black
2011.11.15.	Fukushima, Kawauchii village	Heifer	2005.09.18	Holstein
2011.12.27.	Fukushima, Naraha town	Heifer	2005.09.18	Holstein
2011.12.27.	Fukushima, Naraha town	Heifer	2006.02.23	Holstein
2011.12.27.	Fukushima, Naraha town	Heifer	2007.02.05	Holstein
2011.3.8	Fukushima, Naraha town	Heifer	2000.12.12	Japanese Black
2011.3.8	Fukushima, Naraha town	NA	NA	Japanese Black
2012.3.14.	Fukushima, Naraha town	Heifer	2005.12.15	Holstein
2012.3.15.	Iwate, Ichinoseki city	Steer	2009.04.10	Japanese Black
2012.3.15.	Iwate, Ichinoseki city	Steer	2009.03.20	Japanese Black
2012.3.15.	Iwate, Ichinoseki city	Steer	2009.03.03	Japanese Black
2012.3.15.	Iwate, Ichinoseki city	Steer	2009.05.20	Japanese Black
2013.1.17.	Tochigi, Nasu-shiobara city†	Heifer	2006.01.23	Japanese Black
2013.1.17.	Tochigi, Nasu-shiobara city†	Heifer	2008.11.25	Japanese Black

†Samples were obtained from the radiocontamination feeding test. NA, not available.

With the aim of measuring muscle cesium radioactivity from peripheral blood, this research examined the

## METHODS AND SUPPLIES

### Sampling and Radiation Activity Analysis

Between August 29, 2011, and September 12, 2012, we took samples of peripheral blood and muscle from 223 cattle in the FNPP evacuation zone. Muscle tissue was collected from three different areas of the body to serve as stand-ins: the Longissimus dorsi, the Bicep femoris, and the Masseter. High-purity Germanium (HPGe) detectors (Ortec Co., Oak Ridge, TN, USA) were used to measure the radioactivity of the samples, as detailed elsewhere (Fukuda *et al.*, 2013). Decay corrections were applied to all measurements as of the date of the most recent major release, March 15, 2011. Seventeen cattle were chosen for additional testing because their blood cesium activity was below 10 Bq/kg. Eleven of the total 17 animals were found abandoned in the designated evacuation area. Nasu-shiobara city also investigated blood and muscle samples taken from four steers in Iwate

### Ethics

This research was funded by the Japanese government via the Ministry of Education, Culture, Sports, Science, and Technology as part of a series of nationwide studies related to the 2011 Great East Japan Earthquake. Previous research (Fukuda *et al.*, 2013) describes the technique and animal care in great detail. In short,

## RESULTS

We investigated the radioactivities of muscle samples in order to better understand the connection between the levels of radioactive cesium in the blood and those in the muscle.

relationship between blood and skeletal muscle cesium radioactivity.

prefecture and two cattle in Tochigi prefecture that had been fed radioactively contaminated feed. Below is a description of the testing regime's feeding conditions. Free access to the contaminated grass (approximately 3000 Bq/kg) was provided to the cattle from March through October of 2011. The cattle were then housed in barns from November 2011 to March 2012, during which time they were fed radioactively tainted food (about 2000 Bq/kg). Cattle were fed a diet with zero Bq/kg of radioactive material from April through June of 2012. Additionally, throughout the months of August through October of 2012, cattle were allowed unrestricted access to the contaminated grass (approximately 2000 Bq/kg). Cattle were housed in barns and fed tainted food (about 100 Bq/kg) from November 2012 to January 2013 before being slaughtered.

veterinarians from the Fukushima prefecture's Livestock Hygiene Service Center (LHSC) gathered organs and blood from dead animals. We previously published (Fukuda *et al.*, 2013) a protocol for the humane sacrifice of cattle by veterinarians.

The blood <sup>137</sup>Cs content in the abandoned animals was found to be less than 10 Bq/kg. In order to test the correlation, data from 17 animals was examined. Table 1 provides a summary of the data we have about the



livestock. Control animals were kept in Hokkaido prefecture, which is located in northern Japan, 630 km from the FNPP (Fukuda et al., 2013). We found that no photopeaks of <sup>134</sup>Cs and <sup>137</sup>Cs were visible in these animals. We determined that every cow with a radioactive level in the meat over 100 Bq/kg originated in the restricted area. Seventeen blood samples and thirty-four muscle samples were tested from the seventeen animals. As can be seen in Figure 1, a total of 34 data points were used to create the graph. Radioactive cesium in the blood sample averaged 0.48 Bq/kg (<sup>137</sup>Cs). The measurement uncertainty is lowest when the

sample size and measurement context are both large. Because of this, we determined the lowest detectable sample size to be 70 g and calculated the detection and determination limits for this amount. Background measurements showed that the detection limit for radioactive cesium was between 0.023 and 0.037 Bq/kg, as seen in supplementary Figure 1. In addition, we estimated that the detection threshold was between 0.257 and 0.411 Bq/kg. All of the <sup>137</sup>Cs and <sup>134</sup>Cs samples discovered here exceeded the detection threshold. Our detecting condition was adequate for obtaining quantitative findings based on this data.

BLOOD AND MUSCLE CESIUM LEVELS IN CATTLE 3

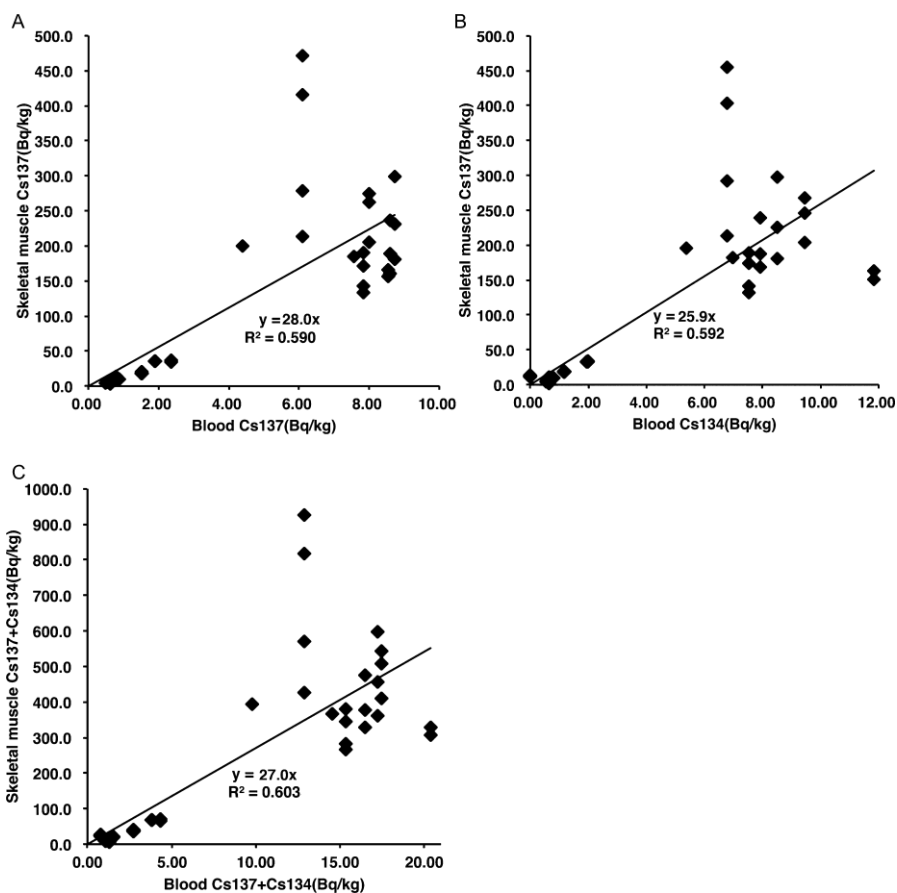


Figure 1 Cesium radioactivity in skeletal muscle and blood samples from cattle in the Fukushima Daiichi evacuation zone. A positive correlation was observed between blood and muscle radioactivity of <sup>137</sup>Cs (A), <sup>134</sup>Cs (B) and total radioactive cesium (<sup>137</sup>Cs + <sup>134</sup>Cs) (C).



At low radioactivity, as illustrated in Figure 1A, there is a linear association between blood and muscle  $^{137}\text{Cs}$  activity ( $Y = 28.0X$ ,  $R^2 = 0.590$ ). Total radioactive cesium ( $^{137}\text{Cs}$  and  $^{134}\text{Cs}$ ; Fig. 1C) and  $^{134}\text{Cs}$  activity (Fig. 1B) in the matched animals

## DISCUSSION

In May 2011, radioactive cesium contamination was discovered in vegetables, fruit, milk, and tea leaves; in July 2011, it was found in meat; and in September 2011, it was found in rice. The Japanese Ministry of Agriculture, Forestry, and Fisheries failed to warn farmers in a timely manner about the dangers of feeding dry rice straw to cattle, which led to the contamination of the country's beef supply. Concerns about the safety of beef on the market have arisen due to the accumulation of radioactive cesium in the meat. Several varieties of meat have been found to contain radioactive cesium (Isogai et al., 2013), and experts have called for an assessment of the danger of chronic exposure to radioactive cesium (Calabrese, 2011). In light of these worries, we looked into the connection between cesium radioactivity in the blood and in the muscles.

Radioactive cesium is more concentrated in skeletal muscle, according to a prior regression investigation of numerous organs in cattle (Fukuda et al., 2013). There was a significant link found between blood

it was unknown if this association was maintained at lower skeletal muscle radioactivity levels, such as 100 Bq/kg, until this research was conducted. and organ cesium radiation about 500-2500 Bq/kg in skeletal muscle. Our results demonstrate that cesium radio-concentration in blood may be used to estimate cesium concentration in skeletal muscle, even at low cesium concentrations. Total cesium radioactivity in skeletal muscle was found to be 27.0 times greater than in blood, as determined by the regression analysis. The current study suggests that a blood concentration of about 4 Bq/kg corresponds to a safe controlled level in muscle. The slope of the regression line is greater than it was in our earlier work, which

showed a similar relationship. Figure 2 also displays the relationship between the mean and standard deviation. Compared to using all measurement points ( $R^2 = 0.742$  in  $^{137}\text{Cs}$ ), using only the average and standard deviation yields a greater  $R^2$  value.

Even within the same area, the radioconcentration of cesium differed depending on the animals. In summary, compared to previous sampling days, December 27th, 2011 Holstein cattle exhibited considerably lower radioconcentrations in blood and muscle. The cattle's feeding history would account for the December 27 figure being lower. Owner-provided information suggests that after only two days in the assessment zone, the cows were let out into the pasture to graze on the radioactive grass. Background information collected from the landowner indicated that for the remaining time frame, radioactive contamination did not exist in the grass. Cattle's background and length of time in the evacuation zone may account for observed variations in radioactive cesium concentrations.

found that the concentration of radioactive cesium in skeletal muscle was 21.3 times higher ( $^{137}\text{Cs}$ ) than that in blood. Measuring or sampling error might be to blame for this discrepancy. In a region with minimal radioactivity, the readings rely more heavily on correcting these mistakes. A shorter amount of time is needed to complete the measurements in the high radioactivity region. However, a reading of 2-3 Bq/kg takes around 24 hours to complete. Greater accuracy in measuring radioactivity might help mitigate this problem.

Our findings suggest that this method may be effective for screening high-risk animals above and above the radioactivity restriction for meat (100 Bq/kg), therefore helping to stop the spread of contaminated meat. We want to extend the existing findings by creating a program that extrapolates the radioactive cesium concentration in muscle from the concentration in blood.

Concerns regarding the safety of animal products from Fukushima remain among Japanese consumers. Therefore, the recovery of Fukushima's livestock output may benefit from the introduction of more



sensitive technologies for measuring radioactive cesium at lower radio-concentration levels, such as 50 Bq/kg. Increasing the sample size and refining detection methods are crucial for more precise

estimate. The results of this study have the potential to improve the food safety of meat and aid in the cattle industry's recovery in areas hit hard by the Great East Japan Earthquake.

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were summarized into average and standard deviation for each cattle. A positive correlation was observed between blood and muscle radioactivity of <sup>137</sup>Cs (A), <sup>134</sup>Cs (B) and total radioactive cesium (<sup>137</sup>Cs + <sup>134</sup>Cs) (C).

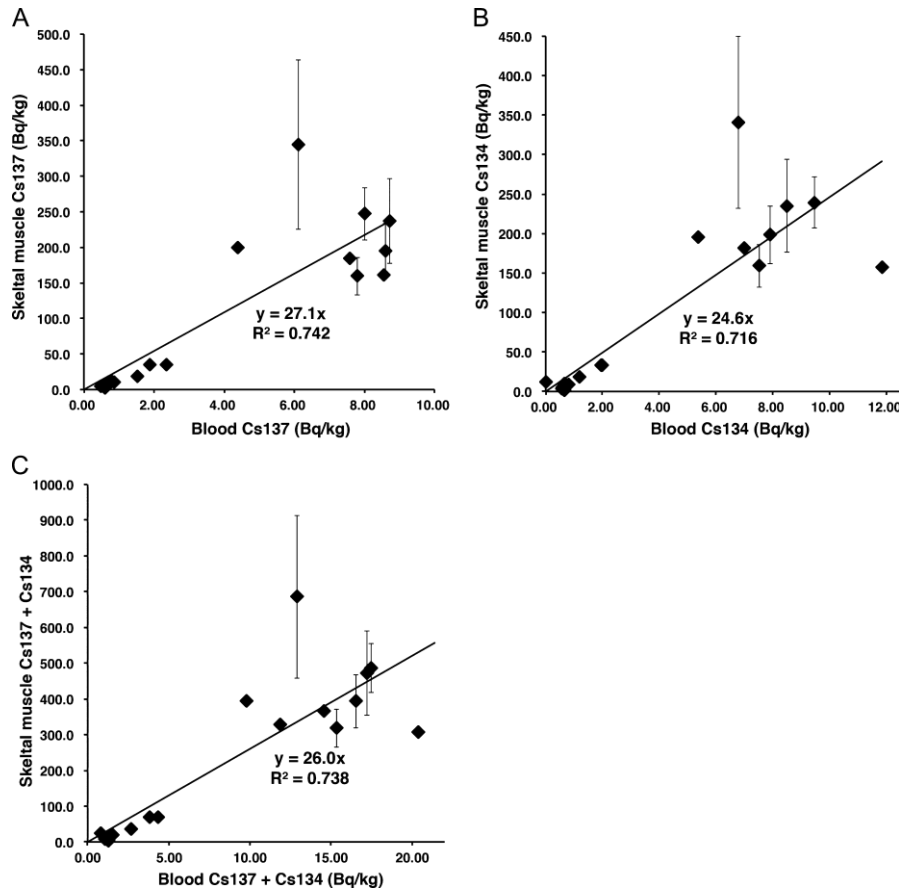


Figure 2 Cesium radioactivity in skeletal muscle and blood samples from cattle. The measuring points



## BLOOD AND MUSCLE CESIUM LEVELS IN CATTLE 5

**Conclusion**

Even in low-radioactivity regions, the amount of radioactive cesium in the blood may be used as a proxy for

the amount in the muscle. Livestock productivity might benefit from the monitoring of radioactive cesium in blood.

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