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Short communication

Assessment of the effectiveness of the post-Fukushima food monitoring campaign in the first year after the nuclear accident: A hypothesis

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ABSTRACT

The purpose of this study was to assess whether or not the food monitoring campaign after the Fukushima nuclear accident has been successful in reducing the number of above-limit-food from reaching the consumers. The hypothesis of this study is that the fraction of "post-market" food can be used for this purpose, when the post-market fraction in the above-limit (p′) items is compared to the post-market fraction in the entity of food items (p) that have been screened for radionuclides (^{134}Cs and ^{137}Cs). Indeed the post-market fraction in most vegetarian produce decreased significantly in the above-limit food items ($p'/p < 1$), indicating a high efficiency of the monitoring campaign. For tea, however, the analysis reveals a low efficiency of the campaign ($p'/p \approx 1$). For beef, the fraction of post-market-foods within the above-limit samples was much higher than the respective fraction in the entity of measured samples ($p'/p > 1$), indicating a much lower effectiveness of the monitoring action for beef. The author speculates that, by following the governmental monitoring manual (which gives "meat" only second priority), the sudden exceedances caught the monitoring agencies unprepared and triggered a much higher density monitoring of beef with the delay of several weeks. Even then, many above limit items reached the market (mainly because the monitoring during this period had focused on the post-market). Therefore, it is likely that some above-limit beef has been consumed by the public. For other meat products, the fraction of post-market samples was very low, which does not allow for the validation of the effectiveness of the monitoring campaign. Overall, the monitoring seemed to have been more effective for vegetarian produce than for meat.

1. Introduction

Internal exposure caused by intake of contaminated foods is a major threat to human health after nuclear accidents (Hamada and Ogino, 2012; Travnikova et al., 2001). Depending on the type of food, the effective half-lives of ^{137}Cs can be in the range of several years (Merz et al., 2015a) and, therefore, will be health relevant for many years to come after an accident. Consequently, monitoring of food has been treated with high priority by the Japanese authorities in the aftermath of the Fukushima nuclear accident (March 11, 2011). They ordered the radioanalysis of hundreds of thousands of food items to secure food safety. In our previous publication, we briefly outlined the main characteristics of the food monitoring program and some radioecological aspects of the enormous data set that has been compiled by the Japanese government (Merz et al., 2015b) and potential problems from underestimating ^{90}Sr concentrations in food which is one of the understudied radionuclides after Fukushima (Steinhauser, 2014). We concluded that it seems very unlikely that more than very few members of the public in Japan exceeded the maximum permissible additional internal exposure of 1 mSv/year. However, in a discussion of that article, *Science* rightfully stated that "a significant quantity of the vegetable foods initially exceeded the limits" (Normile, 2015). *Science* also mentioned that "nongovernmental watchdog groups have reported finding items on grocery store shelves that exceed the limit" (Normile, 2015). These findings fuel the public concern in Japan about food safety and makes (at least some) people wonder how

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effective the food monitoring campaign has been, if above-limit food items still make it onto the shelves of grocery stores.

The intrinsic nature of random sampling, of course, can only employ statistical methods to quantify probabilities (Seto and Uriu, 2015), but never prevent singular above-limit food items from reaching the shelves. It is very difficult, however, to communicate the associated risks to the public. Only when the entity of a food product is measured prior to reaching the markets, absolute safety can be reached. This level of safety has been impressively accomplished in the monitoring of rice in Japan following the Fukushima accident (Nihei et al., 2015). Such comprehensive monitoring campaigns, however, cannot be employed for more perishable food, such as meat or vegetables. Instead, Japanese scholars have used food duplicate studies to assess the true exposure by analyzing the duplicates of foods that have been collected by selected participants of these studies (Harada et al., 2012), or purchased by researchers (Koizumi et al., 2012). In these duplicate studies, participants have prepared one identical extra meal of everything they ate over the duration of the survey. This duplicate has been measured to assess the participant's internal exposure. Finally, whole-body measurements have been performed on large numbers of citizens of Fukushima Prefecture, reflecting the uptake of radiocesium (^{134}Cs and ^{137}Cs) (Hayano et al., 2013). All the studies mentioned found relatively low exposure to radionuclides through intake of contaminated foods. In this study, we attempt the first assessment of the effectiveness of the monitoring campaign in terms of reducing the number of above-limit foods from being consumed by members of the public. For this objective, the information contained in the governmental monitoring data set (Merz et al., 2015b; Ministry of Health Labour and Welfare (MHLW), 2014) was harnessed. The general approach was to use the data that are already at hand rather than launching another measurement campaign, which naturally would have been a major logistical and financial endeavor.

2. Materials and methods

In the immense data set compiled by the MHLW (Merz et al., 2015b; Ministry of Health Labour and Welfare (MHLW), 2014), the analyzed food items were categorized in three “market-categories”: namely “pre-market”, “post-market” or “not specified”. Pre-market items were obtained directly at the producers, farmers etc., whereas post-market items were bought in grocer's shops, supermarkets or the like. “Not specified” could be any of the other two market categories or anything in between the main two market categories. The radiocesium data set used in this study ranges from March 11, 2011 to Mach 31, 2012 and covers all Japanese prefectures.

The key hypothesis of this study was that the ratios of post-market items to the entity of samples measured can be used to assess the effectiveness of the Fukushima food monitoring campaign.

Let N be the number of all samples of one food category, and p the fraction of post-market samples, so that the number of post-market items equals pN. Let N′ be the number of samples which exceed the limit, and p′ the fraction of post market samples exceeding the regulatory limits, consequently p′N′ being the number of post-market samples exceeding the limit. If the fraction of post-market food items amongst above-limit foods (p′) was lower than the fraction of post-market foods in the total number of samples of the respective food category (p), so that the following condition is fulfilled: $p'/p < 1$, the monitoring campaign has effectively removed above-limit foods from the market and thus protected the consumer. The same scenario could also be described as follows: The probability, within all samples, that a sample exceeds the limit, is prob(C > limit; all) = N′/N. For post market samples, this probability is prob(C > limit; post-market)=(p′N′)/(pN). If the latter probability is lower than the former, monitoring has been successful. The ratio of these probabilities equals

$$\frac{(p'N'/pN)}{(N'/N)} = \frac{p'}{p}$$

and thus is identical to the aforementioned ratio.

If the fraction of post-market foods amongst above-limit food remains unchanged when compared with the fraction of post-market items in the total number of samples of a certain food category ($p'/p \approx 1$), it may indicate that the food monitoring program has lacked effectiveness to a certain degree and failed to prevent above-limit foods from reaching the shelves of the market (Scenario 1 in Fig. 1). In case $p'/p < 1$, as described above, the food monitoring campaign has effectively worked and reduced the number of above-limit foods reaching the grocery stores (Scenario 2 in Fig. 1). In case the increase of the fraction of post-market items that are above the regulatory limit is observed compared with the post-market fraction in all monitored items ($p'/p > 1$) (Scenario 3 in Fig. 1), this may indicate some other mechanisms that require further investigation. It can be assumed that food inspectors purchase post-market samples in competition with regular consumers. They therefore reflect the fraction of foods in the monitoring campaign that has reached the market and represent food that has been consumed by members of the public. The distribution of radiocesium measured in post-market food samples hence can be assumed the same as the one in food which has actually been consumed.

In this study, focus has been on radiocesium (^{134}Cs and ^{137}Cs) contaminations in the main food categories vegetables (including algae), mushrooms, fruits and berries, beef, wild boar meat, tea leaves and tea products, as well as other animal products (including chicken meat, eggs, and game). The half-lives of ^{134}Cs and ^{137}Cs are 2.07 y and 30.08 y, respectively.

2.1. Choice of the metric

The metric of p′/p has been chosen because customers, for obvious reasons, will focus on post-market foods only, as they appear within reach of the customer's consumption. It probably provides little relief to the customer knowing that hundreds or thousands of samples have been “caught” in the pre-market, exceeding the limits. The only thing concerned customers will be interested in, is how many effectively made it into the shelves. This is why the author believes that p′/p is a more intuitive metric than others, as is compares the fractions of food samples sampled in the grocery stores to those exceeding the limits in the grocery stores. For example, it will provide a certain degree of relief, if customers realize that for a certain type of food, 20% of this type of food have been sampled in stores, but only 0.5% of samples of this food type exceeding the limits were found in the shelves. However, there are also other potentially useful metrics, such as a direct comparison between the fraction of above-limit contaminated items in the pre-market (pre′) and the post-market (p′/pre′), which will be briefly discussed as well.

3. Results and discussion

Prior to studying the market fractions, the nature and characteristics of above-limit foods need to be identified. For an overview, Fig. 2 summarizes the average activity concentration (a) and number (b) of above-limit food items in the main food categories that have been targeted for this study. The regulatory limit for these