PEER REVIEW HISTORY

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ARTICLE DETAILS

TITLE (PROVISIONAL)	Estimated association between dwelling soil contamination and internal radiation contamination levels after the 2011 Fukushima Daiichi nuclear accident in Japan
AUTHORS	Tsubokura, Masaharu; Nomura, Shuhei; Sakaihara, Kikugoro; Kato, Shigeaki; Leppold, Claire; Furutani, Tomoyuki; Morita, Tomohiro; Oikawa, Tomoyoshi; Kanazawa, Yukio

VERSION 1 - REVIEW

REVIEWER	Noboru Takamura Atomic Bomb Disease Institute, Nagasaki University, Japan
REVIEW RETURNED	24-Jan-2016

GENERAL COMMENTS	Tsubokura et al. evaluated the relationship between internal and soil Cs-137 concentration using data on internal contamination level in residents of Fukushima. They found that soil contamination level did not contribute to the internal contamination of residents in Fukushima, and emphasized the importance of individual measurements in residents after nuclear disaster. This is very important study to clarify the different mechanism of internal exposure between Chernobyl and Fukushima accidents. Major points 1. In the results of logistic regression analysis, authors showed that season of examination was independently associated with internal radiation exposure. This result should be discussed in the “Discussion” section. Is it due to the different food style in summer season compared with other seasons (for example, less consumption of mushrooms)? 2. Also, age was independently was independently associated with internal radiation exposure. Authors also should describe possible mechanism of the different levels of internal exposure between generations. Minor points 1. Page 14, lines 7-8: Some references should be included which include the information on the radiation inspection certificates. 2. Page 15, lines 38-39: In the end of last sentence of the paragraph, add “in Fukushima”.

REVIEWER	Ohtsura Niwa Radiation Effects Research Foundation
REVIEW RETURNED	28-Jan-2016

GENERAL COMMENTS	This manuscript should cite the paper by one of the authors which

	discuss the lack of relationship between the soil radioactivity levels and the WBC measurement levels in Fukushima.

REVIEWER	Christopher L. Rääf Medical Radiation Physics Department of Translational Medicine Skåne University Hospital Lund university SE-205 02 Malmö
REVIEW RETURNED	22-Feb-2016

GENERAL COMMENTS	The fundemental approach of relating the radionuclide deposition or ground contamination to that in the residents of the area has been adressed by Scandinavian and Russian studies in the 1990s and 2000s. I wished that the authors in this competent report would have considered more of the findings in their results, as I believe that the findings here, would not have come as a surspirise, that is, the difficulty in finding a predicitable relationship between ground cntamination and that in man. The reviewer also provided a marked copy with additional comments. Please contact the publisher for full details.

REVIEWER	Elena A. Shishkina Urals Research Center for Radiation Medicine, Russia
REVIEW RETURNED	24-Feb-2016

GENERAL COMMENTS	A limited number of radiation situations makes their study extremely important. Investigation of correlation between 134,137Cs whole-body content and Cs soil contamination is an interesing topic in terms of radiological protection. Negative result reported in the manuscript is the result supporting previous research in Chernobyl region. As it was reported in Zvonova et al (1995), "No correlation between Cs whole-body content and Cs soil contamination was found; Cs accumulation in a body depends greatly on natural factors such as type of soil, on social factors such as food habits including consumption of forest products, and on countermeasures to reduce internal exposure." Based on the Chernobyl studies, the approaches to evaluation of 137,134Cs body burden were elaborated based on (1) individual WBC measurements (Lebedev, 1993) or (2) radioecological modeling (ICRP, 1993; Shutov, 1993). The second includes : - initial level of superficial lands pollution - soil-specific soil-to- plant transfer factors for different type of plants - plant –to-milk and plant-to-meat transfer factors - structure of human ration and its age modification A lot of papers were focused on dosimetrical comparison of radiological modeling results and results based on WBC measurements of 137,134Cs. The good agreement allow to formulate the national standards and methods for radiation protection accepted in different countries arownd the world. The paper under review is ignored the state-of-art of the problem and a well-developed methodology of radioecological studies. On the other hand the authors use methods of population-based epidemiological studies. The methodology transfer from one

	discipline to another is usually interesting and it could be fruitful potentially. Key comments on the text of the article can be classified as follows: 1. The lack of justification the research design with predictable negative result 2. Indepentent variable was represented by very uncertain data on soil surface dencity of Cs isotopes activity based on airborne monitoring a few years befor WBC measurements. Therefore, the soil contamination approximated for a specific household require in uncertainty evaluation to confirm its sutability for individual comparison with WBC data. It seems that the variable is measured at the group level, that is typical for ecological studies. The lack of uncertainty description for independent variable results in the impression, that the model 1 is used improperly and it is excessive manipulation with the data comparing noise with noise (the WBC data are mostly very uncertain). Particular notes Keywords: incert 137,134Cs and delete "dose reconstruction" Page 3, Results section: delete "(but not clinical)" Page 8, first sentence in section 'Home soil contamination levels': incert reference linked to the website with dath (MEXT) Page 8, 2nd sentence of 2nd paragraph in section 'Home soil contamination levels': explain what is "a time extrapolation method"? Does this account only a half-life or takes also into account the migration of radionuclides in the environment? Table 1: introduce the acronym BMI Table 3: Bq instead of bq; Relative risk is an epidemiological term. You have to introduce the term and its application in the context of the cross-sectional ecological studies. There is no mention of the risk in the paper body. References Zvonova I.A., Jesko T.V., Balonov M.I., Danilova I.O., Wallström E., Alpsten M., Thornberg C., Mattsson S. 134Cs and 137Cs Whole-Body Measurements and Internal Dosimetry of the Population Living in Areas Contaminated by Radioactivity After the Chernobyl Accident. Radiat Prot Dosimetry (1995) 62 (4): 213-221. ICRP. Age-dependet doses to members of the public from intake of radionuclides: Part 2. Ingestion dose coefficients. Ann. ICRP 23 (3/4) Publication 67. – Oxford: Pergamon, 1993. Shutov, V.N. Caesium and strontcium radionuclide migration in the agricultural ecosystems and estimation of internal doses to the population / V.N. Shutov [et al.]; ed. by S. Mervin and M. Balonov // The Chernobyl Papers. Doses to the Soviet Population and Early Health Effects Studies. Research Enterprises. – 1993. – V. 1 – P. 167–218.

VERSION 1 – AUTHOR RESPONSE

RESPONSE TO REVIEWERS

Thank you for your detailed review of the content of this manuscript. Responses to reviewers are set out in order. My response is indented and italicized for ease of reference. We have finished revising our manuscript according to your administrative requirements.

Response to Reviewer #1

1. In the results of logistic regression analysis, authors showed that season of examination was

independently associated with internal radiation exposure. This result should be discussed in the "Discussion" section. Is it due to the different food style in summer season compared with other seasons (for example, less consumption of mushrooms)? Also, age was independently associated with internal radiation exposure. Authors also should describe possible mechanism of the different levels of internal exposure between generations.

Thank you for addressing this. We agree with the reviewer, and have added the sentences in Discussion section as follows.

"While the older aged group showed significantly higher levels of internal Cs-137 than the younger aged group, this finding is presumably because the rates of Cs metabolism in body and renal Cs excretion show decrease with age. The seasonal changes in the levels of internal Cs-137 were assumed to be due to the changes in consumption of contaminated locally grown produce such as mushroom and mountain vegetables during harvesting as was shown in previous studies in Chernobyl." (line 5, page 16)

2. Page 14, lines 7-8: Some references should be included which include the information on the radiation inspection certificates.

Thank you for addressing this issue. The numbers (93.9 - 99.9%) in the manuscript are the results of the present study, and these finding are comparable to our previous study. We have changed sentences and added the reference as follows.

"The present study showed that the proportions of residents consuming produce in supermarkets or locally grown produce with radiation inspection certificates were overwhelmingly large (93.9 - 99.9%, depending on produce type, which is comparable to our previous study). 1" (line 23, page 14)

3. Page 15, lines 38-39: In the end of last sentence of the paragraph, add "in Fukushima".
We have added the words in the manuscript. (line 7, page 17)

Response to Reviewer #2:
1. This manuscript should cite the paper by one of the authors which discuss the lack of relationship between the soil radioactivity levels and the WBC measurement levels in Fukushima.

Thank you for reviewing our manuscript. We have added the references in the Discussion section.

"With successful food control, the soil contamination levels in the areas in which the residents are living may not affect their internal contamination levels. 2,3" (line 24, page 16)

Response to Reviewer #3:
1. The fundamental approach of relating the radionuclide deposition or ground contamination to that in the residents of the area has been addressed by Scandinavian and Russian studies in the 1990s and 2000s. I wished that the authors in this competent report would have considered more of the findings in their results, as I believe that the findings here, would not have come as a surprise, that is, the difficulty in finding a predictable relationship between ground contamination and that in man.

Thank you for your kind suggestions. We have changed the title, edited the text and added some references to the Scandinavian and Russian studies in Introduction and Discussion sections as follows.

"Several researches post-Chernobyl disaster addressed the relationship of radionuclide soil contamination to the human's internal contamination, and showed the difficulty in assuming a

predictable relationship between them.4-8 However, there has been no study that evaluates if this soil contamination-based estimation method for internal contamination levels is appropriate approach in the context of the Fukushima disaster." (line 7, page 6)

Some previous studies in the context of the Chernobyl disaster demonstrated the difficulty in estimating the levels of internal contamination based on radionuclide deposition or soil contamination.5,7,8 This present study support their findings in case of the Fukushima Daiichi nuclear power plant accident. (line 8, page 14)

"Third, there is a geographical, social and cultural difference such as food habits including consumption of forest products between Japan and the Chernobyl disaster-stricken inland areas in Europe." (line 20, page 15)

Response to Reviewer #4:
1. The lack of justification the research design with predictable negative result.

We applied Tobit regression in the present study because a large number of the WBC participants had exposure levels lower than the detection limits of the WBC. The Tobit regression model can determine risk factors for the overall levels of internal contaminations by adjusting for the left-censoring effect of the detection limit.

To make it clearer, we have edited the text as follows:

"We used Tobit regression analysis to evaluate the relationship between internal and soil contamination after adjusting for potential covariates. Because WBC measurement has a limited detection capability, the levels of internal contamination in large number of screening participants fell below the detection threshold, resulting in zero measurement values. Tobit regression is an appropriate analysis method that adjusts standard linear regression models for left-censoring effects such as those observed with WBCs. Justification for the use of Tobit regression analysis in the context of WBC measurements post-Fukushima disaster can be found elsewhere. 9,10" (line 2, page 10)

2. Indepentent variable was represented by very uncertain data on soil surface density of Cs isotopes activity based on airborne monitoring a few years before WBC measurements. Therefore, the soil contamination approximated for a specific household require in uncertainty evaluation to confirm its sustability for individual comparison with WBC data. It seems that the variable is measured at the group level, that is typical for ecological studies. The lack of uncertainty description for independent variable results in the impression, that the model 1 is used improperly and it is excessive manipulation with the data comparing noise with noise (the WBC data are mostly very uncertain).

We totally agree with your concerns about uncertainty in the soil contamination data, and therefore, we conducted sensitivity analyses by constructing regression models where the levels of soil contamination were classified in either equal intervals (Model 2) and quantiles form (Model 3). As the variable for soil contamination and other covariates showed similar results in Model 1 to 3, we believe the uncertainty in the soil contamination data does not substantially affect our findings and conclusions. In addition, given the small confidence intervals (or standard error) of each variable for the regression estimates, the uncertainty in the WBC data used in this study might be marginal.

To make it clearer we added the following sentences in the text.

"Because some uncertainty might exist regarding the soil contamination levels, we conducted sensitivity analyses by constructing regression models where the levels of soil contamination were

analysed in two types of categorical forms—equal intervals and quantiles; that is, we made the three regression models as described below: Model 1: soil contamination in continuous form Model 2: soil contamination in categorical forms with equal intervals Model 3: soil contamination in categorical forms with quantiles". (line 11, page 11)

"Because Model 1 to 3 showed similar results for the regression estimates on the soil contamination, the uncertainty in the soil contamination data might be marginal" (line 16, page 13)

"Given the small confidence intervals (or standard error) of each covariate for the regression estimates, the uncertainty in the WBC data used in this study might be small." (line 3, page 14)

3. Keywords: insert 137,134Cs and delete "dose reconstruction"

We have changed the words in the Keywords section.

4. Page 3, Results section: delete "(but not clinical)"

We have deleted the words in the manuscript.

5. Page 8, first sentence in section 'Home soil contamination levels': insert reference linked to the website with dath (MEXT)

We have inserted the reference.

6. Page 8, 2nd sentence of 2nd paragraph in section 'Home soil contamination levels': explain what is "a time extrapolation method"? Does this account only a half-life or takes also into account the migration of radionuclides in the environment?

Extrapolation means creating a line between the two given points and extending it to a point of interest. In this study, we know soil contamination levels at two time points, 28 June 2012 (5th MEXT monitoring) and 28 December 2012 (6th MEXT monitoring). So, the soil contamination level, St,i for those who participated in the WBC screening at time t and were living at location i, was estimated using the following equation:

$$S_{(t,i)}=S_{(1,i)} + ((S_{(2,i)} - S_{(1,i)}))/((T_2 - T_1))(t - T_1)$$

where T1 is 28 June 2012; T2 is 28 December 2012; S1,i is soil contamination level at location i as of 28 June 2012; and S2,i is soil contamination level at location i as of 28 December 2012.

We did not consider either half-life of radionuclides or their migration in the environment, which might impose constraints on the study. However, it must be noted that principle radionuclides released from the Fukushima nuclear power plant are Iodine-131 (500 PBq), Cesium-134 (10 PBq) and Cesium-137 (10 PBq), and their radioactive half-life are one week, two years, and 30 year, respectively. Then, given that soil contamination attributed to Iodine-131 and Cesium-134 were negligible or modest, respectively, at the time of the 5th and 6th MEXT monitoring due to their short half-life, the influence of this constraint might not be very serious. In addition, because Cesium-137 has such a long-year half-life, the radioactive decay was marginal in the short period between dates of the WBC screening and MEXT monitoring.

7. Table 1: introduce the acronym BMI
We have added the words in Table1.

8. Table 3: Bq instead of bq; Relative risk is an epidemiological term. You have to introduce the term and its application in the context of the cross-sectional ecological studies. There is no mention of the risk in the paper body.

Relative risk indicates the multiplicative change in Cs-137 contamination levels for a per-unit increase in the variables.
We appreciate the reviewer's suggestion and revised the text in the method section as follows:

"...we therefore used the exponentiated forms of the coefficients in the regression results to indicate the multiplicative change in Cs-137 contamination levels for a per-unit increase in the variables, which is presented as 'relative risk' in the resulting table." (line 14, page 10)

Reference lists

1. Tsubokura M, Kato S, Nomura S, et al. Absence of internal radiation contamination by radioactive cesium among children affected by the Fukushima Daiichi nuclear power plant disaster. Health Phys 2015; 108(1): 39-43.
2. Tsubokura M, Kato S, Nihei M, et al. Limited internal radiation exposure associated with resettlements to a radiation-contaminated homeland after the Fukushima Daiichi nuclear disaster. PLoS One 2013; 8(12): e81909.
3. Kim E, Kurihara O, Tani K, et al. Intake ratio of 131I to 137Cs derived from thyroid and whole-body doses to Fukushima residents. Radiation Protection Dosimetry 2016; 168(3): 408-18.
4. UNSCEAR. Annex C: Radioactive contamination due to nuclear explosions. UNSCEAR 1977 report: sources and effects of ionizing radiation. New York: United Nations; 1977.
5. Aarkrog A. Concept of seasonality in the light of the Chernobyl accident. Analyst 1992; 117(3): 497-9.
6. ICRP. ICRP Publication 67 : Age-dependent Doses to Members of the Public from Intake of Radionuclides - Part 2 Ingestion Dose Coefficients. New York: International Commission on Radiological Protection; 1992.
7. Zvonova IA, Jesko TV, Balonov MI, et al. 134Cs and 137Cs Whole-Body Measurements and Internal Dosimetry of the Population Living in Areas Contaminated by Radioactivity After the Chernobyl Accident. Radiation Protection Dosimetry 1995; 62(4): 213-21.
8. Raaf CL, Hubbard L, Falk R, Agren G, Vesanen R. Transfer of 137Cs from Chernobyl debris and nuclear weapons fallout to different Swedish population groups. Sci Total Environ 2006; 367(1): 324-40.
9. Sugimoto A, Gilmour S, Tsubokura M, et al. Assessment of the risk of medium-term internal contamination in Minamisoma City, Fukushima, Japan, after the Fukushima Dai-ichi nuclear accident. Environ Health Perspect 2014; 122(6): 587-93.
10. Nomura S, Tsubokura M, Gilmour S, et al. An evaluation of early countermeasures to reduce the risk of internal radiation exposure after the Fukushima nuclear incident in Japan. Health Policy Plan 2015.

VERSION 2 – REVIEW

REVIEWER	Noboru Takamura Nagasaki University, Japan
REVIEW RETURNED	22-Apr-2016

GENERAL COMMENTS	Authors adequately revised the manuscript according to the suggestion of this reviewer, and answered correctly. I think that now the manuscript should be accepted.

REVIEWER	Christopher L. Rääf Medical Physics Dept of Translational Medicine Lund university SE-205 02 Malmö Sweden
REVIEW RETURNED	23-Apr-2016

GENERAL COMMENTS	I am reviewer #3, and although the import inssue in clearing out that these findings somewhat deviate from observations made in Scandinavia and Russia have been made, it appears, however, that some of my questions presented as “bubbles” in the pdf-document containing the original document were lost. I appreciate that they have carried out several of my suggested changes but I still have some important questions that still are unanswered. I suggest that the editor demand that these be answered or cleared before publication. It will not then be necessary to have me re-reviewing it. Q1: P11; rows 48-50 (original paper): Of these investigated, how many exhibited contents BELOW the detection levels (c. 250 Bq)? Have these been omitted in the presented mean values? Q2: P11; rows 52-54 (original paper): It may be explained later, but how did You average over the surveyed time? Did single individuals undergo WBC repeated times? Would it not be more preferable to use average individual "time accumulated body concentrations" to match with the soil contamination?

VERSION 2 – AUTHOR RESPONSE

Response to Reviewer #1

1. P11; rows 48-50 (original paper): Of these investigated, how many exhibited contents BELOW the detection levels (c. 250 Bq)? Have these been omitted in the presented mean values?

Of 7,987 participants who underwent internal radiation screening, 145 people showed detectable levels of Cs-137. We have omitted undetected participants in calculation of mean values. To clarify this, we added the words as follows.

“Internal contamination was detected in 145 participants (1.8%). Among these participants with detectable levels of Cs-137, the mean body burden and concentrations were 558.6 Bq/body (range: 252 – 16,810 Bq/body) and 9.0 Bq/kg (range: 3.0 - 247.2 Bq/kg), respectively.” (line 4, page 12)

2. P11; rows 52-54 (original paper): It may be explained later, but how did you average over the surveyed time? Did single individuals undergo WBC repeated times? Would it not be more preferable to use average individual "time accumulated body concentrations" to match with the soil contamination?

I agree with the reviewer that to use average individual "time accumulated body concentrations" would be more preferable for the analysis, if individuals underwent repeated WBC measurements. However, each individual underwent WBC screening only once over the surveyed time. The mean body burden of Cs-137 was simple arithmetic average of all WBC results with detectable levels of Cs-137. To clarify this, we have added the sentence as follows.

“Each individual underwent WBC screening only once over the surveyed time.” (line 1, page 12)

VERSION 3 – REVIEW

REVIEWER	Takamura, Noboru Nagasaki University, Japan
REVIEW RETURNED	09-May-2016

GENERAL COMMENTS	Once again, I feel that authors adequately answered to points raised by this reviewer, and now the manuscript should be accepted.

REVIEWER	Christopher L. Rääf Medical Physics Department of Translational Medicine Lund university SE-205 02 Malmö Sweden
REVIEW RETURNED	21-May-2016

GENERAL COMMENTS	I am now satisfied with the answers given by the authors in the detailed sheet regarding the frequency of WBC measuremnt and how the cases with WBC-öevels below detection levels were treated. I therefore have no more objections regarding publishing this work.