UNSCEAR United Nations Scientific Committee on the Effects of Atomic Radiation

DEVELOPMENTS SINCE THE 2013 UNSCEAR REPORT ON THE LEVELS AND EFFECTS OF RADIATION EXPOSURE DUE TO THE NUCLEAR ACCIDENT FOLLOWING THE GREAT EAST-JAPAN EARTHQUAKE AND TSUNAMI

A 2016 white paper to guide the Scientific Committee's future programme of work

EVALUATING RADIATION SCIENCE FOR INFORMED DECISION-MAKING

UNITED NATIONS

DEVELOPMENTS SINCE THE 2013 UNSCEAR REPORT ON THE LEVELS AND EFFECTS OF RADIATION EXPOSURE DUE TO THE NUCLEAR ACCIDENT FOLLOWING THE GREAT EAST-JAPAN EARTHQUAKE AND TSUNAMI

A 2016 white paper
to guide the Scientific Committee's
future programme of work

UNITED NATIONS
New York, 2016

This document is available on the UNSCEAR website at www.unscear.org.
Any inquiries regarding this document should be sent to the UNSCEAR secretariat (unscear@unscear.org).

CONTENTS

The attachment cited in this white paper is electronically available for download from http://www.unscear.org/unscear/en/publications/Fukushima_WP2016.html

EXECUTIVE SUMMARY

This summary is extracted from the report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the seventy-first session of the United Nations General Assembly.[1]

[…]

9. The Committee recalled its assessment of the exposures and effects due to the nuclear accident after the 2011 great east-Japan earthquake and tsunami, as presented in its report to the sixty-eighth General Assembly in 2013 (A/68/46) and the supporting detailed scientific annex.[2] It had concluded in that report that, in general, doses were low and that therefore associated risks were also likely to be low. Cancer rates were expected to remain stable. Nevertheless, in the report the Committee had noted a possibility that the risk of thyroid cancer among those children most exposed to radiation could increase. However, it also noted that the likelihood of a large number of radiation-induced thyroid cancers in Fukushima Prefecture—such as after the Chernobyl accident—could be discounted because absorbed doses to the thyroid after the Fukushima accident were substantially lower. It had concluded that no discernible changes in the incidence of birth defects and hereditary disease were expected, and that the effects on terrestrial and marine ecosystems would be transient and localized. Cancer rates for workers were expected to remain stable.

10. Following its assessment, the Committee put in place arrangements for follow-up activities to enable it to remain abreast of additional relevant information as it was published. The Committee's report of its sixty-second session to the seventieth General Assembly included the findings from the follow-up activities it had conducted up to that time.

11. The Committee continued to identify further information that had become available up to the end of 2015, and systematically appraised relevant new publications to assess their implications for its 2013 report. A notable publication was the report by the International Atomic Energy Agency (IAEA) on the accident at the Fukushima Daiichi nuclear power station.[3] It describes the accident and its causes, evolution and consequences based on an evaluation of data and information from a large number of sources available at the time it was written. That report and a large proportion of the new publications again confirmed the main assumptions and findings in the Committee's 2013 report. None of the publications materially affected the main findings in the 2013 report or challenged its major assumptions. Several publications were identified for which further analysis or more conclusive evidence from additional research was needed. On the basis of the material reviewed, the Committee saw no need, at the current time, to make any change to its overarching conclusions. However, several of the research needs identified by the Committee had yet to be addressed fully by the scientific community.

12. The Committee plans to continue to identify and systematically appraise new information on the accident, and evaluate the outcomes periodically at its annual sessions. It also plans to actively engage with those responsible for formulating, implementing and advising on major research programmes in Japan, in order to rapidly assimilate emerging

[1] *Official Records of the General Assembly, Seventy-first session, Supplement No. 46* (A/71/46).
[2] United Nations publication, Sales No. E.14.IX.1.
[3] International Atomic Energy Agency, *The Fukushima Daiichi Accident: Report by the Director General* (GC(59)/14), accompanied by technical volumes 1-5.

issues, and highlight questions needing further research. At an appropriate time, dependent on the outcomes, the Committee expects to consider the need to update its 2013 report.

13. The Committee requested the secretariat, subject to available resources, to publish the findings of its systematic review of new scientific literature as a non-sales publication in English and also to foster its publication in Japanese.

I. INTRODUCTION

1. The Committee had assessed radiation exposures of the public, workers and non-human biota that resulted from the 11 March 2011 accident at the Fukushima Daiichi nuclear power station (FDNPS), considered the health implications, and presented its findings in its annual report to the United Nations General Assembly in August 2013.[4] The United Nations subsequently published the Committee's findings and the detailed scientific annexes underpinning them on 2 April 2014 [U3]. The publication (referred to hereafter as the "2013 report") was well received by the General Assembly, governments, the scientific community and the media/public in Japan.

2. The Committee's assessment had, in general, been based on information disclosed or published before the end of October 2012. Subsequently, much additional relevant information has been published or become available and this activity is likely to continue for the foreseeable future. The Committee intends to remain abreast of such developments because they may have implications for the results of its assessment (for example in corroborating, challenging or refining its findings and/or contributing to addressing identified research needs); doing so will enable the Committee to take informed and timely decisions on the need to refine or update its previous findings. The Committee expects that providing sound scientific appraisal of new material will also help *(a)* those affected by the accident to better understand the situation and *(b)* inform decision-making.

3. Accordingly, at its sixty-first session (21–25 July 2014), the Committee had requested the secretariat to "submit for consideration at its sixty-second session (1–5 June 2015) preliminary plans […] for follow up activities to update and consolidate some of the findings and conclusions of the Committee's assessment of the radiological consequences of the Fukushima Daiichi accident". It also asked the secretariat to "promptly develop a standing mechanism to stay aware of new scientific developments in the follow-up to the accident. That mechanism should be based on the ad hoc arrangements that had been developed for conducting its recent assessment of the accident. The Committee also asked the secretariat to report annually on the implications for the Committee's programme of work".

4. In response, the secretariat developed a project plan of follow-up activities, which has since been endorsed by the Committee and is being implemented. The project comprises two phases: Phase I, a systematic and ongoing review of new information; and Phase II, an update of the 2013 report at an appropriate time. The overall aim of Phase I (up to at least 2016 and beyond) is to "keep the Committee regularly apprised of the implications of new publications and research activities related to the accident with a view to initiating a formal update of the 2013 report (i.e. Phase II) at an appropriate time". The more specific objectives of Phase I include:

(a) To systematically keep the overall radiological situation on the FDNPS accident under review by collecting and appraising published information;

(b) To collect and evaluate progress made in, and plans for, major research projects and programmes related to pending questions;

---

[4] *Official Records of the General Assembly, Sixty-eighth session, Supplement No. 46* and corrigendum (A/68/46 and Corr.1).

(c) To promptly identify inconsistencies between information issued after October 2012 and the 2013 report;

(d) To conduct ad hoc analyses to help clarify the situation and which could be used subsequently in any update of the 2013 report;

(e) To respond to questions and critiques of the 2013 report;

(f) To report annually to the Committee at its regular sessions on the outcomes of the above.

5. At its sixty-second session, the Committee agreed to the publication of a white paper[5] setting out: *(a)* an assessment of the implications of new scientific developments (up till the end of 2014) for the findings of the 2013 report; and *(b)* a commentary on general themes raised in the few critiques made of the 2013 report. In addition, two electronic attachments were made available providing additional technical information that supplemented the 2013 report. This first white paper was published in October 2015 [U4].

6. This second white paper sets out a further assessment of the implications of new scientific developments (since the first white paper and up to the end of 2015)[6] for the findings of the 2013 report. It provides a summary of the main outcomes of the follow-up activities that underpin the findings reported by the Committee to the General Assembly.

II. EVALUATION OF NEW INFORMATION

7. The scope of new information analysed by the Committee in its first white paper was, in general, restricted to publications in English in peer-reviewed journals which had not been included or referenced in the 2013 report (i.e. published after October 2012, the cut-off date that had been generally adopted for information analysed in the report), but which had become available or published before the end of 2014. This second white paper covers information not previously considered that has become available or published before the end of 2015. In principle, the scope of the second white paper was extended to include not only publications in peer-reviewed journals, but also peer-reviewed conference papers, reports issued by regional/national institutes/organizations, government departments/ministries, learned societies, utilities, and similar bodies,[7] reports issued by intergovernmental organizations, and major compilations[8] (and/or analyses) of data from official and other sources. In practice, only one publication was identified for review from these additional categories: the report on the Fukushima accident published by the International Atomic Energy Agency (IAEA) [I2].

8. The approach the Committee used to identify, screen and appraise new information was as described in the first white paper, with the exception of the introduction of a new topical area, that of transfer through the terrestrial and freshwater environments. Introducing this

[5] White papers are documents developed for the Committee to guide its future programme of work and that the Committee has decided to share with the wider community.

[6] Publications considered for this white paper comprised those which had not been reviewed in the previous white paper and which had become available up to the end of 2015, including publications which had been made available online. This white paper therefore includes some publications with an earlier publication date than 2015 and some with a final publication date in 2016.

[7] In exceptional cases, the scope was extended to scientific reports issued by non-governmental organizations.

[8] Large volumes of data continue to be generated and published at relatively frequent intervals by various Japanese organizations, and it would not be practicable to include all of these for review within this project. Consideration has, therefore, been limited to more substantive compilations of data that have the potential to be useful in the context of any future reassessment or in extending the scope of any such reassessment.

additional topical area enabled the Committee to explicitly consider the implications of the increasing number of publications in this field. In screening potentially relevant publications and selecting those which should be subject to more detailed appraisal, particular consideration was given to whether the publication had the potential to:

- Challenge[9] the assumptions in the 2013 report;
- Materially affect the conclusions of the 2013 report; or
- Address research needs either identified in the 2013 report or in topical areas where a wide consensus was emerging.

As a result, this white paper has a greater focus on new information that may potentially challenge the assumptions and conclusions of the 2013 report, rather than on new information which confirms these assumptions and conclusions. It also highlights some of the more relevant information which has become available that would be valuable to any future assessment of the impacts of the accident at FDNPS. However it is not intended to provide a comprehensive overview of all new information relating to the FDNPS accident.

9. The following chapters describe the main outcomes of the screening and appraisal of new sources of information for each topical area in turn. In each case, a brief recapitulation is provided of the findings of the 2013 report, because these provide the context for the review, as well as of the conclusions of the previous white paper. This is followed by a summary of the outcomes of the appraisals, and conclusions about the implications both for the 2013 report and any follow-up activities. Finally, chapter X sets out overall conclusions from this second white paper and includes a tabular summary of those sources of new information deemed to make a significant contribution to addressing identified research needs.

III. UPDATES ON RADIONUCLIDE RELEASES TO ATMOSPHERE, DISPERSION AND DEPOSITION

A. Recapitulation of the 2013 report

10. The Committee had reviewed estimates of total releases to the atmosphere of ^{131}I and ^{137}Cs (the two most significant radionuclides from the perspective of exposures of people and the environment). These estimates had ranged generally from 100 to 500 petabecquerels (PBq) for ^{131}I and from 6 to 20 PBq for ^{137}Cs. The averages of the published estimates were about 10% and 20%, respectively, of the corresponding releases to the atmosphere estimated for the Chernobyl accident. Much of the released material was dispersed over the Pacific Ocean, but, depending on the meteorological conditions, a fraction was dispersed over eastern mainland Japan, and radioactive material was deposited on the ground by means of *(a)* dry deposition, and *(b)* wet deposition with rain and snow. The main deposition on land occurred to the north-west of the FDNPS site, but significant deposition also occurred to the north, south and west of the FDNPS site.

[9] A publication would be considered to challenge an assumption in the 2013 report or materially affect its conclusions if its implications were sufficient to warrant the Committee considering issuing an addendum to the 2013 report.

11. In general, the Committee had relied on measurements of the deposition densities of radionuclides as the basis for its estimates of doses to the public from external exposure and from inhalation. However, where measurement data were unavailable for the periods when exposures occurred (e.g. for evacuees) and could no longer be obtained, the Committee had needed to use an estimate of the source term (including the temporal patterns of release rates), together with appropriate atmospheric transport, dispersion and deposition modelling (ATDM), to estimate levels in the environment and resulting doses to people. The Committee had chosen a published source term for this purpose [T12]. The releases of the radiologically dominant radionuclides ^{131}I and ^{137}Cs in this source term were 120 and 8.8 PBq, respectively. While at the lower end of the range of published estimates, and possibly an underestimate of the total release, the Committee had considered this source term as the most appropriate for estimating doses incurred as a result of dispersion over the land mass of Japan (see paragraphs B15–B16 in [U3]).

B. Findings of review of new publications

12. The first white paper concluded that no publications had been identified in this area that materially affected the main findings or challenged the major assumptions of the 2013 report; several publications confirmed the assumptions in whole or part. One publication was identified that provided a refinement of the source term estimate used in the 2013 report [K3], and the Committee recommended the use of this refinement in preference in any subsequent studies, although it did not expect that its use would alter significantly the doses estimated in the 2013 report.

13. Of the publications considered in this second white paper, 12 peer-reviewed journal papers and the IAEA report [I2] have been reviewed in detail. Many confirmed the assumptions and findings of the 2013 report in whole or in part. The main implications of the findings of these publications are summarized below.

14. The IAEA report [I2] included reviews of numerous peer-reviewed papers and other relevant data sources published up to the first quarter of 2015. It provided estimates of the total amount and characteristics of releases to the atmosphere. It did not provide any further detailed information on the releases as a function of time beyond what was available for the Committee's assessment in the 2013 report. Excluding the very early estimates made in March/April 2011 on the basis of limited information, the IAEA report estimated the ranges of releases of ^{133}Xe, ^{137}Cs and ^{131}I to atmosphere to be 6,000–12,000 PBq, 7–20 PBq and 100-400 PBq, respectively. These ranges agree well with those set out in the Committee's 2013 report of about 7,000 PBq for ^{133}Xe, 6–20 PBq for ^{137}Cs and 100–500 PBq for ^{131}I. Most of the radioactive material released to the atmosphere was blown eastward by the prevailing winds, depositing onto and dispersing within the northern Pacific Ocean. Uncertainties in estimations of the amount and composition of the radioactive substances released were difficult to resolve for reasons that included the lack of monitoring data on the deposition of the atmospheric releases on the ocean [I2].

15. Lebel et al. [L2] analysed available measurements of the forms in which iodine was released from FDNPS and how these forms changed during dispersion in, and deposition from, the atmosphere. They estimated that, overall, about one half of the iodine had been released in a volatile or gaseous form, with the other half released as a particulate. They analysed the variation in the ratio of measured levels of airborne iodine and caesium with distance from FDNPS, and concluded that iodine released in a volatile or gaseous form comprised both elemental and organic forms, although the relative amounts released of each remained

uncertain. This is contrary to the assumption in the 2013 report that one half of the iodine was released in an elemental form with the other half as a particulate (i.e. release of iodine in an organic form was not assessed).

16. In light of the conclusions of Lebel et al. [L2], explicit account should be taken, for completeness and additional rigour, of releases of iodine in organic forms in any future update of the 2013 report. For plausible assumptions as to the fraction of iodine released in organic forms, the thyroid doses estimated in the 2013 report for those evacuated would decrease by a small amount (i.e. perhaps about ten to twenty per cent). For those not evacuated, the estimated doses would increase by a factor depending on distance from FDNPS. At short distances, where doses were highest, any underestimation would be unlikely to exceed several tens of per cent. At larger distances, the potential underestimation would be larger but the estimated levels of dose at such distances were very small. Katata et al. [K3], in updating the source term [T12] used in the 2013 report, have provided an indication of the amount of iodine that may have been released in organic forms, based on experimental and other evidence.

17. Leadbetter et al. [L1] investigated the impact of different meteorological datasets and different wet scavenging coefficients on the model predictions of radionuclide deposits following the accident at FDNPS. Saito et al. [S1] described improvements in macro-scale atmospheric transport models that included new approaches to modelling deposition, e.g. newly implemented algorithms for simulating dry deposition, wet scavenging, and gravitational settling of radionuclide aerosol particles. With this work both groups of authors addressed the need for further improvement in modelling wet deposition in atmospheric transport models, which had been highlighted in the 2013 report.

18. Christoudias and Lelieveld [C1] and Evangeliou et al. [E1] confirmed that winds transported a large portion of the atmospheric releases over the Pacific Ocean, as noted in the 2013 report. Evangeliou et al. estimated that around 23% of the released ^{137}Cs was deposited over Japan and 76% over the oceans (North Pacific and North Atlantic); Christoudias and Lelieveld estimated that about 80% of the radioactive material released from FDNPS was deposited on to the Pacific Ocean. The data presented on the deposition of radionuclides in various countries and regions of the world may be useful for subsequent assessments.

19. Hirayama et al. [H8] assessed the time distribution of ^{131}I concentration in air from measurements made at several monitoring posts in Fukushima Prefecture in March 2011 using peak count rates and the calculated response of NaI(Tl) detectors. The data provide a new source of information on ^{131}I concentrations in air during the first days of the accident and thus have the potential to improve knowledge about radioiodine concentrations in air, for which very few direct measurements have previously been published. Hirayama et al. have compared the concentrations of ^{131}I in air integrated over time derived from these monitoring data with information set out in the 2013 report (table B10) based on ATDM predictions for particular locations and times. No firm conclusions could, however, be drawn from this comparison because of differences between the locations of the monitoring posts and the few locations for which relevant ATDM predictions had been presented in the 2013 report.

20. The Committee has carried out a more rigorous comparison of the measurements of Hirayama et al. with its own estimates of ^{131}I concentrations in air at nearby locations; the latter had been used to underpin the 2013 report. An electronic attachment has been developed to provide the detailed comparison. For some of the monitoring posts (i.e. those at Okuma and Futaba), the time series of measurements presented by Hirayama et al. were incomplete, with

no measurements[10] over time periods when the ATDM analysis indicated high levels of ^{131}I concentration in air; thus, no valid comparisons could be made for these locations (other than for more limited time periods when ^{131}I concentrations in air based on measurements were low). For three other monitoring posts (Shoukan/Naraha, Futatunuma/Hirono, and Momijiyama/Fukushima City), the time-integrated ^{131}I concentrations in air that had been estimated using ATDM ranged from a factor of about 2 times higher to about 8 times lower than the corresponding measurements presented by Hirayama et al. Such differences are not surprising given the uncertainties in ATDM predictions, uncertainties in the methods used (and acknowledged) by Hirayama et al., and differences between the exact location of the monitoring posts and where ATDM estimates had been made. For two of these locations, time-integrated ^{131}I concentrations in air (and doses via inhalation) in the 2013 report had been estimated, not from ATDM alone, but by using ATDM estimates to scale measurements of deposition densities. For these two locations, the time-integrated ^{131}I concentrations in air estimated in this way were only a few tens of per cent lower than those estimated by Hirayama et al. The good agreement between the measured levels and those predicted using ATDM in combination with measured deposition levels—albeit for only a few locations—provides added confidence in the robustness of the methodological approach used in the 2013 report to estimate radionuclide concentrations in air and doses via inhalation.

21. The data presented by Hirayama et al. also provide support for the estimates made in the 2013 report of ^{131}I concentrations in air (and subsequently doses via inhalation) to which evacuees were exposed prior to their evacuation from Futaba and Okuma. These evacuations were completed before 12 March 2011 and the ATDM estimates indicated that there would have been no exposures prior to this time. The measurements at Futaba and Okuma show the arrival of air masses with elevated concentrations of ^{131}I at varying times during the day of 12 March (i.e. after the evacuation had been completed) and, as such, confirm the dose estimates in the 2013 report.

22. Muramatsu et al. [M16] confirmed the understanding summarized in the 2013 report that the plume containing higher $^{131}I/^{137}Cs$ ratios moved in a southerly direction. Furthermore, they concluded that there was good agreement between the ^{131}I deposition map as constructed from the direct measurements of ^{131}I [S2] and that reconstructed from later measurements of ^{129}I. The newly reconstructed data for ^{131}I deposition (based on measurements of ^{129}I in soil samples) has the potential to further improve estimations of the ^{131}I source term and also to improve assessments of doses to inhabitants and evacuees from inhalation. Analysis of the remaining soil samples from the very large soil sampling campaign has the potential to provide valuable additional data in the future about the initial deposition of ^{129}I and ^{131}I.

23. Oura et al. [O7] presented a comprehensive new dataset of hourly concentrations of ^{134}Cs and ^{137}Cs in air, derived from samples automatically collected on filter tapes at 99 air quality monitoring stations from 12 to 23 March, 2011, in eastern Japan. This dataset provides a new and unique source of information about radiocaesium concentrations in air at a large number of monitoring stations and with a high resolution in time. The dataset could enable improved source term estimates, an improved assessment of the levels of radionuclides in air, and an improved assessment of inhalation doses which could potentially challenge the findings of the 2013 report. This can only be judged by a more detailed comparison with the assumptions and data used in the 2013 report. The authors stated that they are in the process of

[10] The reasons for the absence of measured levels during these periods are not fully clear (an additional publication by Hirayama et al. [H7] stated that data for these monitoring posts after 14 March 20:00 JST “could not be analysed because of a drastic increase or a lack of data”), but may have resulted from failure of the equipment or saturation due to the passage of air masses with highly elevated concentrations of radionuclides.

carrying out similar analysis of the remainder of the approximately 400 air quality monitoring stations and providing information about concentrations in air for many more locations, and for other radionuclides in the future.

24. Steinhauser et al. [S10] reported the results of an analysis of weekly air filter measurements, which revealed sporadic releases of radionuclides long after FDNPS was stabilized. This article indicated that secondary releases of radioactive materials were possible—even years after the accident—because of decommissioning and dismantling activities on the FDNPS site. The estimated size of these secondary releases was small in comparison with the releases in the immediate aftermath of the accident, and their impact for assessed doses (both in the past and in the future) is therefore negligible.

25. Akimoto [A3] reported on measurements of radiocaesium concentration in the air and deposited on the ground in Fukushima City during the period from June 2011 until July 2013. These measurements showed that resuspension of deposited radiocaesium led to only very low concentrations in air, confirming the assumption made in the 2013 report that the contribution of resuspension to doses was negligible.

C. Potential implication of new publications

26. The Committee has noted the new data that are becoming available on concentrations in air of ^{131}I, ^{134}Cs and ^{137}Cs as a function of time, on ^{131}I deposition based on measurements of ^{129}I in soil samples, and on the chemical form of the iodine released. These data have the potential to significantly improve source term estimates, and estimates of the levels of radionuclides in the air and deposited on the ground. Similar analyses of other existing samples are expected to yield further data in the near future. A detailed comparison of these new data with those used in the 2013 report would be needed to fully understand their implications.

27. The Committee has identified that research in the following specific areas would have the greatest potential to contribute to addressing the needs identified in the 2013 report:

(a) Continuing to investigate the modelling of wet deposition in atmospheric transport and dispersion models;

(b) Continuing to improve inverse and reverse modelling to estimate the source term;

(c) Improving current estimates of the source term making use of all available measurement data, in particular the new data on ^{131}I deposition reconstructed from measurements of ^{129}I deposition, on ^{131}I concentrations in air and on ^{134}Cs and ^{137}Cs concentrations in air;

(d) Extending the reconstruction of ^{131}I deposition based on ^{129}I measurements to the remaining soil samples;

(e) Extending the measurements of radionuclide concentrations on filter tapes from air quality monitoring stations to the remaining filter samples;

(f) Analysing and comparing the new data on ^{131}I, ^{134}Cs and ^{137}Cs concentrations in air against previous monitoring and modelling results;

(g) Analysing emerging data on aerosol particle size and speciation measurements for ^{137}Cs to better determine inhalation characteristics for the purposes of estimating doses.

IV. UPDATES ON RADIONUCLIDE RELEASES TO WATER, DISPERSION AND DEPOSITION

A. Recapitulation of the 2013 report

28. The Committee had concluded that the direct discharges and releases from FDNPS to the ocean mainly occurred during the first month following the accident, and that the continuing releases were unlikely to affect the Committee's assessment of doses to the public significantly. The Committee had concluded that these direct releases were about 10–20 PBq for ^{131}I and 3–6 PBq for ^{137}Cs, mainly on the basis of estimates derived using three-dimensional modelling. In addition, the Committee had concluded that the release to the ocean from deposition from the atmosphere was about 60–100 PBq for ^{131}I and 5−8 PBq for ^{137}Cs, with only a small percentage of this occurring within a radius of 80 km from FDNPS. The Committee had concluded that measured levels of ^{137}Cs in seawater near the FDNPS site declined rapidly from a peak of 68,000 Bq/L (6.8×10^7 Bq/m^3) on 7 April 2011 and were generally below 200 Bq/L (2×10^5 Bq/m^3) by the end of April, after which the rate of decrease was much smaller. Concentrations decreased rapidly with distance from the coast: at 15 km and 30 km offshore from the FDNPS site, they were about 100 times and 1,000 times lower, respectively, than near the FDNPS site. The measured levels of ^{137}Cs in sediment generally lay between 10 and 1,000 Bq/kg of dry sediment, except in the port of FDNPS, where measured levels were much higher.

29. At the time the 2013 report was finalized, radioactive water had still been leaking on the site, and groundwater had been transporting radionuclides into the aquatic environment. The Committee had also noted the appearance of significant amounts of fission and activation products in stagnant water in the basements of the reactor and turbine buildings. The Committee had identified that key priorities for scientific research were to improve the characterization of the leaks and releases to the aquatic environment, and forecasting and quantifying the long-term transport and mixing of these releases.

B. Findings of review of new publications

30. The Committee concluded in the first white paper that its findings in this area of the 2013 report remained valid and were largely unaffected by new information that had since been published.

31. Of the publications considered in this second white paper, 14 peer-reviewed journal articles and the IAEA report [I2] were reviewed in detail. None contradicted the findings of the 2013 report, and several confirmed the assumption of a general decreasing trend of the direct discharge to the ocean. Several publications addressed identified research needs. Their contributions are summarized in the following paragraphs.

32. The IAEA report noted that there was considerable variation between different estimates of the direct discharge to the ocean published between 2011 and 2013. This variability was considered to be due to the large uncertainties in the different oceanic circulation and radionuclide dispersion models and in the different modelling approaches used by each study, and the lack of spatially distributed observations in the surrounding region. The report noted that the direct discharges and releases of ^{137}Cs were generally estimated to be in the range 1–6 PBq, but that there were assessments that had reported estimates up to 26.9 PBq. Estimates of this magnitude had also been noted in the 2013 report, but the Committee had

considered them to be less reliable because they had generally been derived with extrapolation methods assuming constant dispersion rates.

33. Aoyama et al. [A7] derived estimates of the total release to the atmosphere and then to the ocean by deposition. The authors estimated the inventory of ^{137}Cs in the ocean from measurements of concentrations of ^{134}Cs and ^{137}Cs in surface water made across the North Pacific Ocean in April and May 2011. They then compared this estimate of the inventory with one derived using atmospheric dispersion and deposition models and a particular source term for the release to the atmosphere [T12], as well as the estimate of the direct release to the ocean derived by Tsumune et al. [T18]. The authors reported that the comparison suggested that the deposition of ^{137}Cs released to the atmosphere on to the ocean surface was in the range of 11.7-14.8 PBq, somewhat higher than the estimate of 5–8 PBq given in the 2013 report. However, the range quoted by Aoyama et al. does not appear to take account of the uncertainty associated with the assumptions made about the vertical profile of radiocaesium with water depth, or the uncertainty in the estimate of the direct release to the ocean. Including these uncertainties would give a much wider range of estimates for deposition on to the ocean surface, which would encompass the range given in the 2013 report. In addition, as had been noted in the 2013 report and in the first white paper, the Terada et al. source term was derived from measurements of radionuclide deposition levels on land and would not be the most reliable source term to use to assess deposition on to the ocean. More recently, Katata et al. [K3] and Kobayashi et al. [K9] have made use of a wider range of measurements on land and in the ocean, and used coupled models to make better estimates of both total releases to the atmosphere and releases as a function of time, although they did not estimate deposition on to the ocean (see [U4]).

34. The contribution of inputs from rivers to the discharge of radiocaesium into the Pacific Ocean has been studied in several papers. The annual discharge of ^{137}Cs from rivers has been estimated to be between 5 and 10 TBq [A1, K8], representing of the order of 1 to 2% of the initial deposition on to the catchment area of the rivers most affected by the FDNPS accident. These catchments would be expected to be a continuing source of radiocaesium to the Pacific Ocean. Takata et al. [T7] estimated the fraction of ^{137}Cs bound to particles in different rivers that became desorbed in the presence of cations (especially K^+) in estuaries. This is of interest because radiocaesium in the dissolved phase is more easily taken up by marine biota. Takata et al. found that this fraction ranged from a few per cent to more than 50% under conditions of high river discharge (e.g. floods).

35. The general decrease of the direct releases to the ocean has been confirmed by the continuous monitoring at the outlets of FDNPS. However, this monitoring has also shown sporadic increases of ^{137}Cs levels as a result of exchanges of water between the harbour and the ocean [H9]. Most of these sporadic increases correspond to heavy rainfall events. Hirose has concluded that there are two main pathways by which radionuclides are continuing to be discharged into the ocean. One is a continuous release due to exchange of waters between the harbour and the open ocean, and the other is a sporadic discharge of contaminated water via drainage because of rainfall.

36. Several publications have reported the decrease of concentration of radiocaesium in surface seawater at different distances from FDNPS. These studies have found the following results:

(a) In 2014, the ^{137}Cs concentration in the north canal of Units 5 and 6 and at the northern outlet of FDNPS was around 1,000 Bq/m^3 [A6, H9];

(b) Within the 20 km zone, ^{137}Cs concentrations in 2014 were between 10 and 100 Bq/m^3, one to two orders of magnitude higher than background levels [H9];

(c) In a series of three cruises from June 2011 to June 2012 in the northwest Pacific (hundreds to thousands of kilometres from FDNPS) there was about a 40-fold decrease in the average ^{137}Cs concentration during this one-year period, with average concentrations of ^{137}Cs of 3.4 Bq/m^3 in June 2012 [M8];

(d) During winter 2012, the average ^{137}Cs inventory between 42°N and 4°S along the 149°E meridian (region extending between 400 and 4,000 km from FDNPS) was estimated to be about 1.3 times the residual inventory from nuclear weapons testing [K16].

37. Several publications have documented the transport of ^{134}Cs and ^{137}Cs in the Pacific Ocean, and some of these have discussed the physical processes responsible for this transport. These studies have found the following results:

(a) Lateral inputs of ^{137}Cs transported via suspended particulate matter have been observed on the continental shelf break, 115 km south-east of FDNPS [B7]. Buesseler et al. have suggested that these particles, originating from shallower regions and possibly resuspended during typhoons, transported only small amounts of ^{137}Cs relative to the inventory buried nearshore, and therefore that this transport process did not significantly reduce the levels of ^{137}Cs in the coastal sediment;

(b) Mesoscale oceanic eddies (approximately 200 km diameter), which develop in the subarctic frontal zone of the northwest Pacific (on the northern side of the Kuroshio Extension), accumulated and transported radiocaesium downward to a depth of 500 m [B6];

(c) Radiocaesium was also transported into deeper water (water depth: 100–400 m) in the ocean during winter by the action of wind [A6].

38. The long-distance eastward transport of radiocaesium by oceanic currents has been monitored in the Pacific as far as the North American coast. Radiocaesium released from the FDNPS accident was first detected in June 2012 at 1,500 km from the British Columbia coast at a concentration of 0.3 Bq/m^3. Subsequent observations at the same point in February 2014 revealed an increase to 2 Bq/m^3 throughout the upper 150 m of the water column. In June 2013, ^{137}Cs attributable to the FDNPS accident was detected on the Canadian continental shelf at a concentration of 0.5 Bq/m^3 [S8]. These concentrations are similar to concentrations of ^{137}Cs of 1 Bq/m^3 found prior to the accident, which were due to fallout from weapons testing.

39. Concerning the westward transport of radiocaesium, observations south of Java, Indonesia in September 2012 [S12] did not detect any increase in radiocaesium concentrations that could be attributed to the accident, nor did regular monitoring around Sri Lanka between September 2011 and April 2013 [W5].

C. Potential implication of new publications

40. The Committee has concluded that its findings in this area of the 2013 report remain valid and are largely unaffected by new information that has since been published. The Committee has noted several publications that will contribute to an improved understanding of the release and subsequent dispersion of radionuclides in the marine environment.

V. UPDATES ON TRANSFER OF RADIONUCLIDES IN TERRESTRIAL AND FRESHWATER ENVIRONMENTS

A. Recapitulation of the 2013 report

41. In the 2013 report, the Committee had modelled transfers through terrestrial and freshwater environments to estimate doses to members of the public from ingestion of foodstuffs for the second year after the FDNPS accident onwards. The Committee had estimated these doses using the FARMLAND model [B5]. This model was used to predict the migration of deposited radionuclides into the soil and their subsequent uptake into food products. Some modifications had been made to the model to account for East-Asian agricultural conditions (especially for rice, vegetables and fruit), but many radiological and agricultural parameter values based on Northern European data had been retained.

42. In the 2013 report, the food categories with the highest per capita intake by weight for adults, included in the assessment of doses from ingestion for the second year onwards, had been rice, “other vegetables” (assumed to be in the leafy green vegetables category), wheat and wheat products (assumed to be in the cereals category), fruit and milk. The aim had been to make realistic estimates of doses and the focus had been on assessing average doses to representative groups in the population, therefore consumption of wild food products, such as game animals or mushrooms, had not been considered.

43. On the basis of these assumptions, and that food restrictions remained in place, the Committee had estimated doses from ingestion for periods after the first year that were one to two orders of magnitude lower than those from external exposure to deposited radionuclides. Several subsequent studies, in which the internal exposure of people has been measured directly, have confirmed the dominance of the external exposure pathway, and have indicated that doses from ingestion estimated using the FARMLAND model were more likely overestimates than underestimates (see section VI below).

44. The Committee had identified the need to better characterize the distributions of doses to the public and to better quantify the uncertainties in the dose estimation as priorities for future research. In this context, notwithstanding the minor contribution ingestion of foodstuffs had made to estimated doses, better information on the transfer of radionuclides to foodstuffs, and specifically regional and national parameters for models would be useful for future assessments of the consequences of the FDNPS accident. In addition, such information would be helpful to improve understanding of the potential impact of environmental remediation programmes.

B. Findings of review of new publications

45. The Committee did not explicitly consider new publications on transfers through the terrestrial and freshwater environments in the first white paper. For this second white paper the Committee gave priority to the transfer pathways of radiocaesium (which had made the dominant contribution to ingestion doses after the first year) to food products and to information published in 2015.

46. Of the publications considered in this second white paper, 25 have been reviewed in detail. The main implications of the findings of these publications are summarized below.

1. Radiocaesium fixation and migration in soil

47. In the 2013 report, migration of radiocaesium into deeper layers of well-mixed soil used for crop production had been assumed to be slow, with, for example, only about 7% migrating below the top 30 cm of well-mixed soils after 10 years (based on a migration rate constant of 1.9×10^{-5} per day). No data have been identified (in publications reviewed in this white paper) which show radiocaesium attributable to the FDNPS accident at soil depths below 30 cm.

48. Rates of radiocaesium migration were measured in soils from locations excluding forests and residential areas by Lepage et al. [L3] and in an extensive survey by Matsuda et al. [M5]. In both studies, most radiocaesium remained in the upper 5 cm, despite high cumulative rainfall, some of which was associated with typhoons.

49. Uematsu et al. [U1] and Nakao et al. [N5] measured the ability of soils to bind radiocaesium and the influence of different soil characteristics. Both studies found that the amounts of micaceous clay minerals and organic matter present were key factors influencing the extent of binding of radiocaesium in soil. There was some evidence that the binding of the radiocaesium in soils developed from volcanic ash may be lower (and, therefore, that the uptake of radiocaesium by plants and its migration rate down the soil profile may be higher) than that of other soil types.

2. Radiocaesium transfer from soil to crops

50. Seven of the reviewed papers [F1, F2, I4, K4, K11, O2, S3] have reported values of concentration ratio (the ratio of the concentration of a radionuclide in the food product to its concentration in soil) for the transfer of radiocaesium from soil to brown rice, derived from both pot and field experiments conducted between 2011 and 2013. These publications suggest that the concentration ratio for brown rice may have been higher (by up to around an order of magnitude) in the first one or two years than assumed in the 2013 report, but declined between 2011 and 2012 at a similar rate to that predicted in the 2013 report.

51. Sato et al. [S5] reported concentration ratios for the transfer of radiocaesium from soil to six different types of fruit in 2011. The values reported were all higher (by between 1.6 and 16 times) than that assumed in the 2013 report, with the highest values for Japanese cherry. Two studies by Kusaba et al. [K17, K18] on blueberries and chestnuts suggested that radiocaesium adhered to bark surfaces was an important source of radiocaesium for the fruit in the first three years after deposition, rather than radiocaesium in soil. The reductions in radiocaesium concentration in chestnuts and blueberries reported in the two studies [K17, K18] were faster than those predicted using the FARMLAND model. In contrast, Tagami and Uchida [T2] found that the rate of decline in the concentration of ^{137}Cs in persimmon at a specific site in Chiba was similar to that which would be predicted by the FARMLAND model, whereas for persimmon collected in Fukushima Prefecture it was slower.

52. For leafy green vegetables, Aung et al. [A9, A10] reported concentration ratios for ^{137}Cs which were consistent with that used in the 2013 report, with some values up to two times lower and others two or three times higher. Ohse et al. [O2] also reported higher radiocaesium concentration ratios (by up to a factor of 20) for a range of crops, including eggplant, pumpkin, soybean and cabbage, grown in soil with high radiocaesium concentrations in Okuma town in 2012. Tagami and Uchida [T1] reported a reduction in the concentration of ^{137}Cs in giant butterbur, which occurred at a faster rate than would be predicted for leafy green vegetables using the assumptions of the 2013 report.

53. Kubo et al. [K12] reported mean concentration ratios for radiocaesium in buckwheat, and Hoshino et al. [H13] reported concentration ratios for rye. The concentration ratios initially (in 2011 and 2012) were around an order of magnitude higher than that assumed for cereal and pasture in the 2013 report but had declined by 2013 to a similar value. Sunaga et al. [S11] reported limited data showing concentration ratios ranging from 20% lower to 40% higher than that assumed in the 2013 report for cereal and pasture.

54. The Committee identified no papers published in 2015 on the transfer of radiocaesium to wheat crops or agricultural animal products.

3. Radiocaesium transfer to food products not considered in the 2013 report

55. Hiraide et al. [H6] and Nakai et al. [N4] showed that the transfer of radiocaesium to forest mushrooms in Japan was as high as that reported in other countries (e.g. [I1]).

56. Tsuboi et al. [T13] reported a correlation between the radiocaesium concentration in Ayu fish internal organs (which are often eaten by Japanese people), and that in soils of the catchment, for five rivers in 2012–2013. Matsuda et al. [M3] measured the radiocaesium concentration in 11 freshwater fish species from three lakes with different radiocaesium levels. The radiocaesium concentrations in lake water, sediments and fish were correlated with that of surface soil near the lakes.

57. The Committee identified no papers published in 2015 on the transfer of radiocaesium to wild animals.

C. Potential implication of new publications

58. The Committee has concluded from this preliminary review that its assumptions and findings in this area of the 2013 report remain broadly valid. New information that is specific to Japanese conditions has become available on transfers of radioactive material in soils and into foods. This information would be more appropriate for any future assessment of the FDNPS accident than parameter values based on European conditions, which had been used in the 2013 report in the absence of more relevant alternatives. Use of this information may lead to detailed changes in the time-dependence of the doses from ingestion of foods predicted for the second year after the accident onwards and in the relative importance of different foodstuffs. However, the Committee expects that the overall effect on predicted ingestion doses for the second year onwards would be minor, mainly because of the continued application of food restrictions. In addition, measurements on people (see section VI below) have confirmed that internal exposure was very small compared with external exposure, and suggested that the doses from ingestion of foods predicted using the FARMLAND model were likely to be overestimates.

59. The following areas of research would be particularly beneficial in providing better regional and national parameters on the transfer of radionuclides to foodstuffs for future assessments and in improving understanding of the potential impact of environmental remediation programmes:

(a) Identification and quantification of the long-term impact of fixation mechanisms for radiocaesium in Japanese soils and demonstrate the effect of fixation in different soils on plant uptake;

(b) Continued study of the migration of radiocaesium in agricultural and forest environments and their transfer into various agricultural and wild foods (especially in the categories of rice and "other vegetables", wild boar, wild plants and mushrooms);

(c) Development of a spatial and temporal model of environmental transfer processes specific to the diversity of food produced and consumed in Japan to support prediction of long-term ingestion doses, addressing, in particular:

– Variation in radiocaesium uptake from different soil types and the mechanistic basis for the differences;

– Feeding and management regimes of key domestic agricultural animals and wild animals;

– The potential long-term contribution of transfer of radiocaesium in rivers and lakes to food products;

(d) Measurement of long-term changes with time in radiocaesium concentrations in various agricultural and wild foods;

(e) Continued study of the effectiveness of remediation measures in reducing radiocaesium transfer from soil to agricultural products.

VI. UPDATES ON EVALUATION OF DOSES FOR THE PUBLIC

A. Recapitulation of the 2013 report

60. The Committee's aim had been to make realistic estimates of doses to defined groups of individuals considered representative of the different subsets of the Japanese population. For the assessment of doses from external exposure, the Committee had used models with parameter values mostly derived from European studies after the Chernobyl accident, and validated with numerous individual thermoluminescent dosimeter measurements conducted in the affected Bryansk region of Russia. The Committee had used these models in its 2013 report in combination with population-averaged deposition densities of radionuclides for Japanese districts or prefectures, derived by combining measurements of radionuclide deposition densities with the density of population. Data on population densities as well as on age compositions and occupancy factors for different groups of the Japanese population had been based on the 2010 Japanese census.

61. For the assessment of doses to the public from internal exposure, the Committee had considered two exposure pathways, inhalation and ingestion. Exposure from inhalation had been assessed only from radionuclides in the passing radioactive plume, with subsequent inhalation of resuspended radionuclides considered insignificant. Exposure from inhalation of radionuclides in the passing plume had been estimated from measurements of deposition density using ratios of the concentrations of radionuclides in air to deposition density levels derived using the assumed source term and ATDM.

62. Intakes of radionuclides in food and drinking water in the first year following the accident had been assessed using the database of food and drinking water measurements carried out in Fukushima Prefecture and other prefectures of Japan. This database included many measurements made for food inspection purposes and therefore had some bias associated

with the sampling: samples with potentially elevated activity concentrations were more likely to have been selected. However, at the time of preparation of the 2013 report, no other food measurements had been available.

63. For subsequent years, a modified form of the FARMLAND model [B5] had been applied for estimating the transfer of radionuclides through terrestrial food chains, with some transfer coefficients adjusted for the conditions and agricultural practices of contemporary Japan. The model had been used in combination with input data on population-averaged deposition densities of radionuclides for Japanese districts or prefectures.

64. For residents of evacuated communities, where it had not been possible to use measurements of radionuclide concentrations in the environment, the Committee had estimated time-varying concentrations of radionuclides in the environment using the assumed source term for releases to the atmosphere and ATDM. Doses from external exposure and from inhalation had then been estimated for the periods before, during and after evacuation using scenarios representing the movements of residents derived from the results of a survey using questionnaires.

65. Measurements of radionuclides in people, such as whole-body-counter (WBC) and thyroid measurements, provide a direct source of information on internal exposure. However, at the time of preparation of the 2013 report, the number of thyroid measurements had been limited (about 1,100 persons) and these data could only be used to corroborate modelled doses to the thyroid in a few settlements. In addition, data from WBC measurements had only become available to the Committee at a late stage of the 2013 report preparation, and comprehensive data analysis had not been possible. Nevertheless, some assessment of doses from internal exposure based on human measurements had been carried out by the Committee and were presented in the 2013 report (see paragraphs 116–118 of [U3]). These had indicated that estimates of dose from internal exposure based on whole-body measurements were substantially lower than those based on modelling.

B. Findings of review of new publications

66. In the first white paper, the Committee concluded that its findings in this area remained valid and were largely unaffected by new information that had been published subsequently. By far the majority of the new publications broadly supported or confirmed the main assumptions made in, and the findings of, the 2013 report. Further whole body measurements had given added weight to the statement made in the 2013 report that effective doses from ingestion of radionuclides in foodstuffs may, in practice, have been much lower than those estimated theoretically.

67. Of the publications considered in this second white paper, 16 peer-reviewed journal papers and the IAEA report [I2] have been reviewed in detail. None materially affected the main findings of the 2013 report, while nine of them provided confirmation of the main assumptions in whole or part. The main implications of the outcome of this review are summarized below.

68. The IAEA report [I2] included reviews of numerous peer-reviewed papers and other relevant data sources published up to the first quarter of 2015. The contributors to the IAEA report undertook in-depth analysis of the available data, including stochastic analysis of public dose distributions and comparison of available dose parameters with those from the 2013

report [U3]. In all cases they came to conclusions that the available information did not contradict the findings of the 2013 report.

1. External exposure

69. The Fukushima Health Management Survey (FHMS),[11] including the Basic Survey for dose estimation from external exposure, was launched after the FDNPS accident. Information was collected from questionnaires completed by more than 500,000 individuals (representing 26% of all residents of Fukushima Prefecture in 2011) on the behaviour of residents during the first four months after the accident [I7]. In combination with information on space- and time-dependent dose rates,[12] these data enabled the assessment of individual effective doses from external exposure over the four-month period. Ishikawa et al. presented the distribution of doses over the first four months for 421,394 individuals from all of Fukushima Prefecture, by seven areas, several particular districts, and by age and gender.

70. The full dataset of dose estimates for the first four months had a distribution as follows: 62% received less than 1 mSv; 94% less than 2 mSv; and 99% less than 3 mSv. The arithmetic mean and maximum value of all the individual doses from external exposure were 0.8 and 25 mSv, respectively. The larger mean doses were assessed as being received by residents of areas located to the north and west of FDNPS, namely Kempoku (1.4 mSv), Kenchu (1.0 mSv) and Soso (0.8 mSv). Among the districts, the largest mean dose (more than 4 mSv) was assessed as being received by residents of Iitate Village. Somewhat larger doses were assessed as being received by senior people (50–79 y) compared to other adults (20–49 y) and especially to children and adolescents (0–19 y). This is in contrast with the 2013 report [U3], where doses to infants and children were assessed to be larger than doses to adults. Doses to men were assessed as generally slightly larger than doses to women.

71. Although some comparisons can be made of the FHMS dose estimates with the doses estimated in the 2013 report (on the basis that the doses from external exposure in the first year for people not leaving the area would be about double those in the first four months), more detailed comparisons would require special analysis. The 2013 report presented doses for particular social groups and towns, whereas the FHMS has reported doses for larger areas and populations. However, both studies concluded that estimated doses from external exposure were generally low [I7, U3].

72. Naito et al. [N3] compared the individual doses from external exposure of 26 residents of various affected areas of Fukushima Prefecture measured by means of personal electronic dosimeters (D-shuttle) between 20 September and 7 November 2013. Doses were assessed from ambient dose rate measurements with account taken of daily activity patterns, quantified by means of geographic information system detectors worn by each volunteer. The results have shown that, on average, effective doses to the individuals were 29% of the ambient equivalent dose rate, integrated over time, as the volunteers moved around. This is in reasonable agreement with the assessments in the 2013 report [U3].

[11] The Fukushima Health Management Survey is a large programme of health questionnaires and health screening conducted by Fukushima Medical University with Japanese government funding. The screening has two primary components: thyroid disease screening among those exposed at ages 0–18 years, and screening of women who were pregnant or breast-feeding at the time of the FDNPS accident and their offspring.

[12] In this and subsequent paragraphs, the terminology used by the authors of the reviewed publication has been followed, while recognizing that it can be imprecise.

73. Nomura et al. [N6] demonstrated a statistically significant correlation between *(a)* individual doses from external exposure measured during a three-month period in 2012 by 520 school children in Minamisoma City and *(b)* dose rates measured outside their homes. In contrast, no statistically significant correlation was found between individual dose and age or gender, or behaviour during outdoor activities at school. This can be partially explained by the fact that dose rates outside homes (0.19–1.38 μSv/h) were generally higher than dose rates in the school grounds (0.06–0.22 μSv/h).

74. In Minamisoma City, 881 school children took part in a screening programme aimed at determining individual doses from internal and external exposure in 2012–2013 [T14]. All the children wore individual glass dosimeters over three months during various seasons and each of them had the content of radiocaesium in the body measured by WBC. The total annual effective doses ranged from 0.025 to 3.5 mSv with a median of 0.7 mSv. Caesium radionuclides were detected (at levels above 220 Bq for ^{134}Cs and 250 Bq for ^{137}Cs) in only three children out of the 881, and it was estimated that 90.3% of the total dose was the result of external radiation exposure. This finding is consistent with the 2013 report [U3]. The study also showed that annual effective doses among children in Minamisoma City during the second year after the FDNPS accident were low.

75. Mikami et al. [M9] constructed maps of the air dose rates around FDNPS using the results of measurements obtained from approximately 6,500 locations for three different time periods. Temporal changes in the air dose rates were examined. The reduction of the air dose rate in the 18-month period from June 2011 to December 2012 was found to be 10% greater than that resulting solely from radioactive decay of radiocaesium during that interval, in reasonable agreement with the modelling of radiocaesium migration into soil carried out for the 2013 report [U3]. The trend in the reduction of the air dose rate was observed to be independent of land use.

76. Yoshida-Ohuchi et al. [Y7] measured dose rates indoors in 69 detached wooden houses and outside in an open field in the evacuated village of Iitate and in the Odaka district of Minamisoma City. From 522 survey results, they calculated the ratio of the indoor dose rate to the outdoor dose rate, i.e. the dose reduction factor (DRF). The median DRF value found was 0.43 with an interquartile range of (0.34–0.53). This is in agreement with parameters used by the Committee for public dose assessment in its 2013 report [U3]. The authors found no difference in the DRF for the first and second floors. However, the location of the room within the house, the area topography, and the use of cement roof tiles did influence the DRF. The median DRF for living rooms (usually located on the front side of the house) was 0.38 (0.31–0.47), and that for the rooms facing the backyard was 0.49 (0.41–0.62).

77. Satoh et al. [S6] calculated the age-dependent dose conversion coefficients for external exposure to deposited radiocaesium using Monte Carlo simulation to estimate the dose received by babies, children and adults. The work extended previous studies and the results were consistent with those studies. Although the effective dose rates for younger people were estimated to be higher than those for adults, they were numerically less than the ambient dose equivalent rate that is continuously monitored around FDNPS. The authors also proposed a method to derive the dose conversion coefficients for a volumetric source by using the conversion coefficients for planar sources. They used this method to estimate the dose received from radiocaesium distributed with an assumed depth profile in the soil. They also derived the conversion coefficients for the effective dose accumulated over the first and second months, the first year, and over a lifetime (assumed to be 50 years) following the deposition of the radiocaesium. These data are helpful to estimate doses received by people remaining in areas

with enhanced levels of radioactive material as a result of the accident or for those returning and staying in remediated areas.

2. Internal exposure

78. Orita et al. [O5] reported on WBC screening of 2,839 residents of Iwaki City in 2012 and of 2,092 residents in 2013. The results showed that 99% of subjects registered below 300 Bq of radiocaesium in their bodies in the first screening, and all subjects registered below 300 Bq in the second screening. The corresponding ranges of the estimated committed effective dose from internal exposure were 0.01–0.06 mSv for the first screening and 0.01-0.02 mSv for the second screening. Long-term follow-up studies will be useful to confirm these very low chronic internal exposure levels and “to reduce anxiety among the residents by communicating radiation health risks”. The results are in line with the estimates of the 2013 report [U3].

79. Tsubokura et al. [T15] presented further evidence of the small contribution of internal exposure to the effective dose of children living in Minamisoma City in 2013. Of 3,299 elementary and middle school students in the city, 3,255 individuals (98%) were screened by WBC measurements during school health check-ups. Not a single student was detected with levels of radioactive caesium above the detection limit of 220 Bq of ^{134}Cs or 250 Bq of ^{137}Cs. The detection limits correspond to annual effective doses from internal exposure to ^{134}Cs and ^{137}Cs together of 66, 40, and 25 µSv for those aged 6, 10, and 15 y, respectively, assuming a constant daily intake of radiocaesium. The children included those who consumed foodstuffs from outside Fukushima Prefecture, those who consumed foodstuffs produced in unspecified areas, and those who consumed locally produced foodstuffs (including foodstuffs not tested for possible radionuclide content).

80. Further evidence of low-level internal exposure of the public in 2013–2015 has been provided by Hayano et al. [H2]. Three WBCs (Babyscan), suitable for scanning infants and children less than 130 cm tall, operated between December 2013 and March 2015 in three hospitals located to the north, west and south of FDNPS. During that period, 2,707 children between one and twelve years of age from Fukushima, Miyagi and Ibaraki prefectures were measured. The body content of radiocaesium in all children was less than the minimum detection level of 3 Bq/kg. The minimum detection level corresponded to a radiocaesium intake rate of less than 1–2 Bq/day (depending on age) and an annual dose due to internal exposure from radiocaesium of 8–16 µSv, assuming a constant daily intake. This is consistent with the assessment in the 2013 report which estimated doses from internal exposure after the first year to be very low.

81. The parents of the infants and children scanned were asked to complete a questionnaire regarding the family’s dietary habits. The percentage of families which avoided drinking any local water and consuming any rice or vegetables produced in Fukushima Prefecture varied between 1% and 4% in Daigo Town and Miharu Town, and between 57% and 65% in Minamisoma City and Soma Town. These differences were attributed to different perceptions of radiation risk, but did not reflect differences in documented local radiation levels, which were similar in Miharu Town, Minamisoma City and Soma Town [H2].

82. In order to reveal the possible radiological role of ^{90}Sr as a potential source of longer-term post-accident public exposure, Nabeshi et al. [N1] carried out an analysis of 53 samples of vegetable and animal foods collected from all over Japan between 2011 and 2013. They detected ^{90}Sr in 25 out of 40 samples in which radiocaesium had been previously detected, and

also in 8 out of 13 samples in which radiocaesium had not been detected. The ^{90}Sr concentrations in sea fish, freshwater fish, rice, grains, beans, beef, and other foods did not significantly exceed concentrations reported before the FDNPS accident. There was also no difference between the ^{90}Sr concentrations in the samples in which radiocaesium was detected and those in the samples in which it was not. Thus, ^{90}Sr concentrations in food samples were concluded to be indistinguishable from the background ^{90}Sr concentrations arising from global fallout from nuclear weapons testing, suggesting that no marked increase of ^{90}Sr concentrations (nor exposures resulting from them) has occurred as a result of the FDNPS accident. The authors intend to continue to analyse the ^{90}Sr in various food samples, including samples harvested from neighbouring areas to FDNPS in order to collect more data for future reference.

3. Remediation

83. Decontamination of settlements in the evacuated Special Decontamination Area (SDA) and inhabited Intensive Contaminated Survey Area (ISCA) has been in progress since 2012. In some of the remediated towns in the SDA, evacuation orders were lifted in 2014, and the return of residents began. Dose rate measurements have been carried out on a regular basis before and after remediation, but are yet to be published in the peer-reviewed literature. It is important that the effectiveness of decontamination is assessed in terms of the reduction not only in dose rate but also in the annual effective dose of residents, both individual and collective. The latter can be assessed either by estimating the dose from external exposure from dose rate measurements or by measuring the personal dose of residents before and after decontamination.

84. Following remediation, the method of estimating doses from external exposure from radionuclide ground depositions, as used in the 2013 report, may be less valid, and prospective doses would be better assessed from outdoor and indoor dose rate measurements. Yajima et al. [Y1] measured ambient dose rates at many residential and occupational sites throughout a number of study areas in Fukushima Prefecture and also individual doses with personal dosimeters. The measurement results indicated that the ratio of individual dose based on a personal dosimeter to the weighted ambient dose rate from external exposure was 0.7. The paper also presented some national human occupancy parameters and building shielding parameters that can be compared with those used in the 2013 report [U3]. For all areas investigated, the estimated effective dose to outdoor workers was substantially higher than that to indoor workers.

85. Martin et al. [M2] developed a low-altitude unmanned aerial vehicle equipped with a lightweight gamma-spectrometer and height normalization system and tested it at three sites within Fukushima Prefecture. The aim was to produce high spatial resolution (of less than 1 m) maps of deposition levels of radioactive material. The system provides a valuable method to rapidly examine both areas with enhanced deposition levels and those which have been remediated, whilst greatly reducing the dose received by the operator. The availability of such equipment will be important for accurate characterization with high spatial resolution of the deposition levels of radioactive material, verification that areas have been remediated, and assessment of the effectiveness of remediation.

C. Potential implication of new publications

86. The Committee has concluded that its findings in this area of the 2013 report remain valid and are largely unaffected by new information that has since become available. The

majority of the new publications broadly support or confirm the main assumptions made in, and the findings of, the 2013 report, in particular:

(a) Radiation doses to the general public in Japan continue to decline in line with the findings of the 2013 report;

(b) Doses to the general public in Japan from external exposure, determined by personal dose measurements or dose rate measurements combined with national shielding factors for buildings and exposure scenarios, are in general agreement with the findings of the 2013 report;

(c) Doses to the general public in Japan from ingestion of radiocaesium in foods as determined by WBC measurements are small and do not contradict the findings of the 2013 report for 2012 and subsequent years;

(d) Progress has been made in clarifying the radiological role of radionuclides other than caesium and iodine, e.g. ^{90}Sr, the contribution of which to dose from internal exposure seems to be insignificant.

87. The Committee has identified research in the following specific areas as having the greatest potential to contribute to addressing the research needs identified in the 2013 report:

(a) Continue to measure the dose rates due to external exposure to deposited material in various environments, forecast and track changes over time;

(b) Determine regional and national values necessary for refinement of dosimetric models, such as the following parameter values:

- Shielding parameters of buildings;
- Time spent outdoors and indoors in various building types in different seasons, and as a function of age and social group;
- Parameters related to the system of food distribution, and consumption habits of cultivated and wild foods);

(c) Measure individual doses from external exposure to residents of towns with elevated deposition of radionuclides in order to validate dosimetric models and obtain an experimental basis for uncertainty analysis;

(d) Further conduct in vivo measurements of radiocaesium in people with different food habits to support refinement in the estimation of doses and their distribution;

(e) Clarify the role of soil-to-plant transfer, the food distribution system of Japan, national food consumption habits, and the system of inspecting foods in Japan for radioactive material, in influencing the levels of exposure from ingestion of radionuclides in food;

(f) Measure radiocaesium concentrations in various foods (agricultural and wild) as a function of time after the FDNPS accident;

(g) Quantify the impact of environmental remediation programmes (decontamination, agricultural measures and others) both in terms of reduction of environmental radiation indicators (such as dose rate and activity concentrations) and their impact on averted dose from external and internal exposure of residents;

(h) Better characterize the distributions of modelled doses to the public, expressing variability between individuals, using probabilistic approaches, and compare them with human measurements.

VII. UPDATES ON EVALUATION OF DOSES FOR WORKERS

A. Recapitulation of the 2013 report

88. The main aim of the Committee's work had been to judge the extent to which the individual doses reported in Japan provided a true and reliable measure of the doses actually incurred by workers, and therefore the extent to which the reported doses could support a reliable commentary on the implications for health. By the end of October 2012, the Tokyo Electric Power Company (TEPCO) had reported statistics on doses to about 25,000 workers at the FDNPS site, most of whom were employed by contractors. According to TEPCO's reports, the average effective dose to FDNPS workers over the first 19 months after the accident had been about 10 mSv. About 34% of the workforce had received effective doses over this period above 10 mSv, while 0.7% of the workforce (corresponding to 173 individuals) had received effective doses more than 100 mSv. The highest reported effective dose was 679 mSv for the TEPCO worker who had also received the highest reported committed effective dose due to internal exposure (590 mSv). Dose statistics had been reported separately for a few hundred emergency services workers.

89. The Committee's independent assessments of the doses due to internal exposure for 12 workers (out of a total of 13) who had committed effective doses due to internal exposure higher than 100 mSv had confirmed that they had received absorbed doses to the thyroid due to inhalation of ^{131}I in the range of 2 to 12 Gy.

90. The reliability of the internal exposure assessments for the much larger number of workers with lower assessed internal exposures had been evaluated by performing independent assessments for randomly selected samples of workers.

91. The Committee had confirmed the reliability of the assessments reported by TEPCO for those of its workers where ^{131}I in the body had been detected. However, for most of the workers, in vivo monitoring of ^{131}I in the thyroid had not started until mid- to late-May 2011, and in many cases this delay had meant that ^{131}I could no longer be detected. For the same reason, the contribution to internal exposure from intakes of shorter-lived radionuclides such as ^{132}Te and ^{133}I could not be reliably assessed. The Committee had been unable to confirm the reliability of the assessments reported by TEPCO for those of its workers for whom ^{131}I had not been detected in the body, nor the reliability of the internal exposure assessments reported by contractors for their workers.

92. The Committee had judged that the major factor potentially affecting the reliability of external exposure assessments had been the sharing of electronic personal dosimeters during March 2011 (because the majority of the dosimeters had been lost in the tsunami flood), with only one worker in a team wearing a dosimeter for many missions.

93. The Committee had had insufficient information on beta irradiation to make an informed assessment of doses to the eye lens of workers (paragraph 143 in [U3]).

B. Findings of review of new publications

94. The Committee concluded in the first white paper that, while significant changes had been made to doses estimated for some workers since the 2013 report, the Committee did not expect that these would materially affect its main findings. However, this would need to be confirmed by a fuller analysis of the data and methodologies adopted in the re-evaluations.

95. Of the publications considered in this second white paper, six peer-reviewed journal articles and the IAEA report [I2] have been reviewed in detail. One publication [Y6] provides information on improved monitoring procedures, and a second [K10] provides data and analyses. Both publications might be relevant to any follow-up assessment to the Committee’s 2013 report. None of the publications confirm or challenge major assumptions of the 2013 report, nor do they materially affect its main findings.

96. The IAEA report [I2] presented a statistical analysis of doses to workers which took account of the reassessments of doses to TEPCO workers and contractors, which became available after the publication of the 2013 report. The personal dose equivalent values for both TEPCO workers and contractor workers were statistically analysed to derive probability density distributions and cumulative probability distributions of personal dose equivalent for workers for 2011. The estimates of the occupational exposures of these on-site workers are consistent with the findings of the 2013 report.

97. Yasui [Y6] presented lessons learned from a fact-finding study conducted by the Japanese Ministry of Health, Labour and Welfare (MHLW). This study was carried out in response to cases where personal alarm dosimeter readings at FDNPS had been deliberately manipulated, by the use of lead shielding placed over the dosimeter, to give lower values for doses arising from external exposure. The fact-finding study was conducted “to identify similar cases and determine measures to prevent a recurrence of this incident” using methods specified by MHLW [Y6]. If it were to be found that such cases were widespread, this could affect the Committee’s evaluation of the reliability of doses from external exposure reported in Japan. MHLW has stated that its study found no further cases with intentionally tampered data. The focus of Yasui was on lessons learned that could improve radiation protection of FDNPS workers by making improvements to practical external exposure monitoring procedures, rather than the issue of deliberate manipulation of readings. However, Yasui comments that, because of the mutual interest of workers and employers in concealing the manipulation of exposure data, “… The MHLW did not expect to discover additional incidents of dosimeter manipulation through its screening and interviews, but, rather, intended to use them to gather information to construct systems to detect future manipulation of dosimeter data and minimize worker motivation to participate in the manipulative behaviour.” Given these comments, there remain some questions about the robustness of the findings of the survey relating to the extent of deliberate manipulation. Considering the evidence that it had access to, the Committee judges that, if any further deliberate manipulation did occur, it was probably not widespread, and that the findings of the 2013 Fukushima assessment would remain valid.

98. There have been few peer-reviewed publications reporting dose assessments for health-care workers who were involved in the treatment of casualties during the emergency phase of the accident. Kodama et al. [K10] reported the results of in vivo monitoring conducted for 101 hospital employees at Minamisoma Municipal General Hospital (25 km north of FDNPS) in July and August 2011. The measurements were part of a broader study to investigate the impact of a nuclear power plant accident on nearby medical centres. The monitored health-care workers had provided care to outpatients and hospitalized patients during the period 11-20 March 2011, after which all hospitalized patients had been evacuated. The health-care

workers could potentially have been exposed to patients with external and/or internal radionuclide contamination. On 14 March, working employees took stable iodine and were instructed to wear chemical protective clothing. Measurements were made of radionuclides in the whole body for the health-care workers, and estimates were made of committed effective dose. Caesium-134 was detected in 24 of the 101 employees, and committed effective doses from intakes of ^{134}Cs were reported as less than 1 mSv in all cases. It is unclear why results are reported for ^{134}Cs in the body, but not for ^{137}Cs, since ^{137}Cs in detectable amounts would be expected to accompany ^{134}Cs. These relatively low doses are consistent with findings for other off-site workers reported in the 2013 report. This appears to be only the second peer-reviewed publication in English that reports committed effective doses assessed from in vivo monitoring measurements for health-care workers (Results for five members of a Radiation Emergency Medical Assistance Team (REMAT) from Nagasaki University were reported in Matsuda et al. [M4]. Committed effective doses from intakes of ^{131}I, ^{137}Cs and ^{134}Cs were reported as less than 0.1 mSv for all five members of the REMAT). Further peer-reviewed publications relating to health-care workers at different locations are available in Japanese.

C. Potential implication of new publications

99. The Committee has concluded that its findings in this area of the 2013 report remain valid and are largely unaffected by new information that has been published so far.

100. The Committee did not find any new information that would enable it to reach informed judgments on the exposure of the lens of the eye or on improving the quality of its dose estimates in the various areas identified in the 2013 report. Further research in these areas would be particularly valuable.

VIII. UPDATES ON HEALTH IMPLICATIONS FOR WORKERS AND PUBLIC

A. Recapitulation of the 2013 report

101. The Committee had found that health risks resulting from the FDNPS accident were expected to be far lower than those for the Chernobyl accident, owing to the substantially lower doses received by the public and workers. No deterministic effects from radiation exposure had been observed among the public and none had been expected. No increase in spontaneous abortions, miscarriages, perinatal mortality, birth defects or cognitive impairment had been expected from exposures during pregnancy. Nor had a “discernible increase in heritable disease among the descendants of those exposed from the accident” (paragraph 224 of [U3]) been expected. No discernible radiation-related increases in rates of leukaemia or breast cancer (two of the most radiogenic cancer types), nor in other types of solid cancer besides possibly thyroid cancer, had been expected. A large excess of thyroid cancer due to radiation exposure, such as occurred after the Chernobyl accident, could be discounted, because the estimated thyroid doses due to the FDNPS accident were substantially lower than those sustained around Chernobyl. However, the sensitive ultrasound-based thyroid screening of those under 18 years old at the time of the accident had been expected to detect a large number of thyroid cysts and solid nodules, including a number of thyroid cancers “that would not normally have been detected without such intensive screening” (paragraph 225 of [U3]). However, similar even slightly higher rates of cysts and nodules had been found in the prefectures of Aomori, Yamanashi and Nagasaki that had not received significant radionuclide deposition from the

accident. The substantial numbers that had already been observed in the FHMS had been considered likely to be due to the sensitivity of the screening and not to radiation effects.

102. Among FDNPS emergency workers, deterministic effects had been considered unlikely, but the Committee had been unable to preclude the possibility of hypothyroidism, or to assess the risk of cataracts because of insufficient information on doses to the lens of the eye from beta irradiation. Although 2−3 excess cancers could be inferred over the lifetime among the 173 workers with doses greater than 100 mSv (mainly from external exposure), the Committee had considered it unlikely that such increased incidence of cancer due to irradiation would be discernible. The Committee had judged the magnitude of any inferred risk of thyroid cancer among workers to be such that any increase in incidence due to radiation exposure would likely not be discernible.

103. The Committee had noted that the major health impacts that had been observed among the general public and among workers were mental health problems and impaired social well-being [U3]. The Committee did not assess health effects unrelated to radiation exposure: estimation of the occurrence and the severity of such health effects was outside of the Committee’s mandate.

B. Findings of review of new publications

104. The Committee concluded in the first white paper that its findings in this area of the 2013 report remained valid and were largely unaffected by new information that had since been published.

105. Of the publications considered in this second white paper, 11 peer-reviewed journal articles and the IAEA report [I2] have been reviewed in detail. Only one report, discussed below, appeared to challenge the assumptions or findings of the 2013 report; the others served to strengthen or complement the report findings. Three publications provided information on thyroid cancer screening among those who were young at the time of examination, including information on the detection rates of thyroid cysts, nodules and cancers in groups exposed or not exposed to radiation in order to provide a perspective on the rates found in the FHMS. Two more provided insights from radiation biology that were pertinent to interpreting the childhood thyroid cancers detected by screening. The remaining publications provided information on heart and other non-cancer diseases or on the health of workers.

106. The IAEA report [I2] described health surveys initiated in Japan following the accident at FDNPS, including both the FHMS of the general population and the monitoring of the health of workers involved in remediation. The report concluded that, at the time of its publication, there were no health effects among workers or members of the public that could be diagnosed by a physician and confirmed by pathology and that could be attributed to exposure to radiation arising from the accident at FDNPS.

107. The IAEA report compared estimates of the Lifetime Attributable Risk Fraction (LARF) (the fraction of the incidence of cancer that is estimated to be attributable to radiation exposure) associated with the reported doses to FDNPS workers for the period March 2011–August 2014 for various forms of malignancy. LARFs were derived using both the ICRP risk model and the WHO risk model [W4]. The IAEA report determined that the inferred LARFs for solid cancer, leukaemia and all cancer were all less than 1%. The LARF for thyroid cancer varied among workers according to the thyroid dose received, but the LARF for the entire worker population for whom thyroid doses were available was of the order of 3% or less with either risk model.

108. The IAEA report also provided LARF estimates for the public at a range of locations and for various populations, including children, in the areas where higher doses were received. These groups received lower doses than emergency workers, so the values of LARF were lower, at 0.1 to 1%. The LARF for thyroid cancer in young children was of the order of 1% or less for all of the areas for which thyroid dose information was available.

109. The IAEA report provided a preliminary update of thyroid screening results in the FHMS, including 121,997 children/adolescents from Fukushima Prefecture who had received a second round of thyroid screening. Of these, 1,043 were referred for confirmatory testing because of detected thyroid solid nodules or cysts. Five children had new diagnoses of papillary thyroid cancer, with a mean age of 13.1 y (range 6–18 y) at the time of the accident. However, 10 more children were awaiting fine needle aspiration biopsy or surgery, so an accurate estimate of cancer incidence/prevalence was not yet available.[13] The IAEA report observed that similar results were obtained when the same screening was carried out on children living far away from the areas affected by the accident, and that the proportion of suspicious or malignant cases was almost the same among regions in Fukushima Prefecture. In many cases, thyroid cancers were found in children in the late teenage years, but no cases were found in the most vulnerable group of children who were aged under five years at the time of the accident. The IAEA report concluded that the thyroid abnormalities detected in the survey were unlikely to be associated with radiation exposure due to the accident.

110. In three areas of Japan with negligible radiation exposure as a result of the accident, investigators conducted a 2–15 month follow-up examination of 31 children who had been diagnosed as having a thyroid nodule or cyst at initial thyroid ultrasound screening [H4]. They found that a third of the cases had a diagnosis of “normal” upon re-examination, while one was diagnosed with thyroid cancer and the others with various benign lesions. A similar analysis in the FHMS screening programme of initially diagnosed thyroid nodules and cysts would be of interest for comparison.

111. One paper [T17] (and a subsequently published response to criticisms [T16]) claimed to demonstrate that there had been a radiation-induced increase in thyroid cancer incidence: the authors reported a 50-fold (95% CI: 25, 90) excess in Fukushima Prefecture. However, the study design and methods were too susceptible to bias [J2] to warrant this interpretation. Tsuda et al. [T17] did not adequately account for the impact of the sensitive ultrasound screening of the thyroid upon the observed rate of thyroid cancer. Their conclusions were based on a comparison of the rate of thyroid cancer among those people screened by FHMS with the rates found elsewhere in Japan where few children had undergone thyroid screening. Studies of other populations screened in childhood, particularly those who underwent ultrasound screening in three unexposed Japanese prefectures [H3], as well as other screening studies of young people in Japan [T6], found baseline rates of thyroid cancer in the absence of radiation exposure that were similar to the FHMS rates. Similarly, the Republic of Korea experienced an apparent large increase in thyroid cancer rates once they instituted universal screening [A2]. It is also likely that some of the cancers detected by screening may have existed before the radiation exposure [T5].

112. Wakeford et al. [W2] carried out an analysis of the data in the Tsuda et al. paper by comparing the thyroid cancer prevalence among children studied by FHMS who were residing

[13] The first white paper indicated that 51 thyroid cancers had been found by FHMS screening up to that time, as stated in a published paper [N2]. This figure appears to have been an error (the correct figure was 50 cancers plus one benign tumour), as indicated elsewhere in the same paper.

in localities with relatively low, medium, and high exposures as a result of the accident, as defined by Tsuda et al. The analysis by Wakeford et al. did not show any dose–response trend. In fact, the ratio of thyroid cancer prevalence between the localities with the highest and lowest exposures was only 1.08 (95% CI: 0.60, 1.96) [W2]. Other inconsistencies between Tsuda et al. and the substantial body of data on radiation-induced thyroid cancer in childhood include: *(a)* the Tsuda et al. paper reported excesses within 1–2 years after radiation exposure, whereas studies after the Chernobyl accident and other studies with much larger doses to the thyroid did not show excesses within 3–4 years; *(b)* all the thyroid cancers in the FHMS occurred among those 6–18 years old at radiation exposure, while other studies show the greatest incidence of thyroid cancer induction was among those with early childhood exposure (before age 5); and *(c)* the measured doses to the thyroid were much too low to be consistent with the high prevalence they reported [T6, W2]. Because of these weaknesses and inconsistencies, the Committee does not consider that the study by Tsuda et al. presents a serious challenge to the findings of the 2013 report.

113. Williams [W6] presented a biological theory of the development of clinical thyroid cancer which implies that only a small percentage of thyroid cancers identified in tissue samples taken in childhood would be likely to develop into clinically significant cancer (i.e. associated with the uncontrolled growth of cancer cell clones) in years ahead if left untreated. Thyroid follicular cells divide much more rapidly in early childhood than in adolescence or adulthood, and this could increase the opportunity for cancer development due to radiation-induced mutations primarily in those exposed in early childhood. The anticipated chain of events would include the mutations that lead initially to a clone of cells that is identifiable microscopically as a thyroid cancer in a tissue sample, followed by mutations at subsequent cell divisions that lead to uncontrolled growth of the cancer cell clone, resulting in a clinical cancer. However, cancers associated with exposure in early childhood were not found in the FHMS. On the contrary, all the cancers occurred among those exposed at ages six years or above (mean age 13.1 years), suggesting that the thyroid tumours may not be radiogenic. Research is ongoing to find new biomarkers that identify mutations or gene expression patterns that differentiate radiogenic from sporadic thyroid cancers (e.g. [D1, S7]), with the goal of improving estimations of the risk of radiation-induced thyroid cancer and the ability to attribute cases to their cause. Progress is being made, but much yet needs to be done before viable biomarkers are likely to be established. Given its potential implications, research in this area should be actively pursued.

114. Regarding other health parameters, Ishii et al. [I6] performed a range of clinical examinations and laboratory tests on a population whose residences were in areas with some of the highest radiation exposures but that had not been evacuated. They concluded there were no substantial adverse effects upon basic physiological and metabolic parameters for those with radiation exposure. However, because the number of children under the age of 16 years was small, and their results were not broken down by age, the effects in children were not well addressed. The IAEA report [I2] summarized a study suggesting an increase in body mass index, glycated haemoglobin (HbA1c), elevated blood pressure and abnormal liver function among residents of Fukushima Prefecture, and another study indicating increases in obesity, hypertension and hyperlipidaemia in Iitate Village. However, the IAEA report concluded that these changes were attributable to stress and changes in lifestyle. Similarly, the triple disaster and perceptions of hazards have led to stresses with consequent psychological effects [G2, O3], but such psychological stresses are common to most disasters and are not due to radiation exposure [O4], so have not been considered further by the Committee.

115. White blood cell, neutrophil and lymphocyte counts were compared in various localities of Fukushima Prefecture within a year of the accident; the counts for persons in the localities with the highest levels of radiation exposure did not differ from those in localities with lower exposure [S4].

116. There were few published data on the health of FDNPS workers. The IAEA report [I2] indicated that MHLW had sponsored ultrasound examinations of the thyroid for 627 emergency workers whose equivalent dose to the thyroid was more than 100 mSv in 2011, along with 1,437 who had lower exposures. There were no significant differences in thyroid findings between the two groups, which is consistent with expectations, given *(a)* the relatively low exposures, *(b)* that those exposed were adults, and *(c)* the short time interval after exposure.

117. In 1976, under the Industrial Accident Compensation Insurance scheme provided by the then Ministry of Labour (now the MHLW), the Japanese government had established the basis for the award of compensation to occupationally exposed workers. Under this established scheme, leukaemia may be deemed eligible for medical compensation by a medical review panel if the dose was at least 5 mSv times the number of years between exposure and diagnosis of the malignancy. A similar scheme applies for certain other lympho-haematopoietic malignancies with modification based on their comparative radiosensitivity. One person who worked at FDNPS in 2012 and 2013 and developed leukaemia was granted compensation under this scheme during 2015. The granting of this compensation claim is the result of the application of the pre-existing policy on the granting of compensation claims. It does not imply a scientifically proven cause–effect relationship between radiation exposure and the health effect (see annex A [U5]).

118. An expert group was convened by the International Agency for Research on Cancer (IARC) and Fukushima Medical University to consider future health risks in Fukushima Prefecture and plan strategies to address them [I5]. Their recommendations generally paralleled those in the 2013 report, but with added emphasis on collaborations and data-sharing to enhance the scientific and public health value of the studies.

C. Potential implication of new publications

119. The Committee has concluded that its findings in this area of the 2013 report remain valid and are largely unaffected by new information that has since been published. A study which appeared to challenge the Committee’s findings regarding radiogenic thyroid cancer risk was found to be seriously flawed.

120. The Committee has noted, and will remain abreast of, ongoing research and investigations into the health implications of the accident and, in particular, the health survey being carried out in Fukushima Prefecture. It has identified the following specific areas where further data or information would have the greatest potential to contribute to addressing the research needs identified in the 2013 report:

(a) In order to properly understand the findings of the thyroid screening programme in Fukushima Prefecture it is highly desirable to be able to place these findings in the context of the results from an adequately-sized study of an equivalent Japanese population that was unaffected by the releases from the FDNPS accident. Such a study would provide definitive evidence to evaluate the current assessment that the Fukushima Prefecture findings are a reflection of the fundamental nature of thyroid disease in this age range, rather than any

effect of exposure to radiation, although the study would clearly require appropriate ethical approval;

(b) More detailed publication of the numbers of people screened by FHMS, and of thyroid nodules and thyroid cancers broken down by age and sex, because this would permit more accurate comparisons with the existing data from people screened but unexposed;

(c) Completion of dose estimation for the young people in the FHMS screening study; this would permit a dose-related analysis which could provide a stronger basis for inference than comparisons with other populations who may differ from the FHMS study in age, sex, screening protocols, and other factors;

(d) Well-standardized outcome information, including mortality and incidence of cancer and non-cancer diseases and birth defects, together with clinical and laboratory findings with good quality control. Provision should be made to link these with radiation exposure and harmonized information on lifestyle to permit the most informed assessment of health experience and risk, in order, in time, to address important questions that both scientists and the public may have;

(e) Systematic collection and analysis of data pertaining to the health of FDNPS emergency workers, especially among those who received higher doses.

IX. UPDATES ON EVALUATION OF DOSES AND EFFECTS FOR NON-HUMAN BIOTA

A. Recapitulation of the 2013 report

121. The Committee had estimated radiation doses due to the accident to non-human biota by applying suitable models. The corresponding estimates of effects due to the radiation exposure had then been inferred by synthesizing the Committee’s generic evaluations of dose–effects relationships. Exposures of both marine and terrestrial non-human biota following the accident had been, in general, too low for acute effects to be observed, although some exceptions had been considered possible because of local variability. The Committee had concluded that, in general, population-relevant effects on non-human biota in the marine environment would have been confined to areas close to where highly radioactive water was discharged and released into the ocean. Although the Committee had been unable to exclude a risk of effects to individuals of certain terrestrial species, in particular mammals, it had considered observable effects at the population level to be unlikely. It had concluded that any radiation effects would have been constrained to a limited area where the deposition density of radioactive material was greatest, and that, beyond this area, the potential for effects on biota was insignificant.

122. The Committee had made reference to studies in which effects in various terrestrial biota had been observed in areas with enhanced levels of radioactive material as a result of the FDNPS accident [H10, M12, M13]. It had noted that the substantial impacts reported for populations of wild organisms from these studies were inconsistent with the main findings of the Committee’s theoretical assessment. The Committee had expressed reservations about these observations, noting that uncertainties with regard to dosimetry and possible confounding factors made it difficult to substantiate firm conclusions from the cited field studies.

B. Findings of review of new publications

123. The Committee concluded in the first white paper that its findings in this area of the 2013 report remained broadly supported by the available evidence. However, it recognized potential limitations in its approach owing to reliance largely on laboratory-based rather than field studies. It identified a need for multidisciplinary field studies tailored to analyse the impacts of ionizing radiation on populations of wild organisms interacting under the conditions prevalent within ecosystems in areas with enhanced levels of radioactive material.

124. Of the publications considered in this second white paper, 52 peer-reviewed journal articles and the IAEA report [I2] have been reviewed in detail. The main implications of the findings of these publications are summarized below.

125. The IAEA report [I2] included an impact assessment for all ecosystems. The IAEA assessment used a somewhat different methodology to that adopted by the Committee in the 2013 report (which incorporated dynamic transfer models, enabling the estimation of maximum dose rates occurring over shorter time periods). The overall results were largely consistent, although the IAEA was more definite on whether population-level effects observed in field studies may be linked to radiation exposure, concluding that no impacts on populations and the ecosystems (both terrestrial and marine environments) were expected. Furthermore, the IAEA concluded that long-term effects were not expected, given that the estimated short-term doses were generally well below levels at which highly detrimental acute effects might be observed, and dose rates declined relatively rapidly after the accident.

126. Several papers reported concentrations of radionuclides in, and their transfer to, non-human biota [A8, B1, H1, H5, K5, K13, M3, T9, T10, T11, T13, W1]. The results presented were generally consistent with the input datasets used for the environmental impact assessment carried out for the 2013 report, having, in some cases, been drawn from the same or related information sources. Data have also been presented for a number of new organism groups or life stages that had not been considered by the Committee [A11, A12, K1, S9, T8, Y3, Y8] but for which a broad comparison of radionuclide concentrations could be made (e.g. values can be compared for species falling under generic categories such as invertebrates). The radionuclide levels reported in these publications also appear to be consistent with those used in the 2013 report. All of the above-mentioned, and other publications [B2, M6, Y4] of less direct relevance, may facilitate a refinement of the models applied in the 2013 report. Where exposures to terrestrial organisms have been derived [F4] and, in some exemplary studies, where these have been supported by experimental determinations in the field [F5, K14], dose rates generally correspond well with those presented in the 2013 report.

127. Several papers [B3, K19, M10, O6, Y2] appeared to support the finding of the 2013 report that the contribution of radionuclides in marine sediment to exposures of marine biota in the initial period of the accident were negligible compared to other sources, whereas others (e.g. [K7]) do not. Some studies [I3, K2, M1] suggest that steady state transfer models (as assumed in the 2013 report) may not be appropriate for a few components of some ecosystems (e.g. fish in rivers and trees in forests), even several months after the accident.

128. Sublethal effects on biota in the Fukushima area have been observed in some studies. Chromosomal aberrations increased in wild mice inhabiting areas with elevated radionuclide concentrations in Fukushima Prefecture, and were correlated with the estimated doses [K15]. In a study on wild carp, Suzuki [S13] observed deleterious impacts on various blood parameters for fish taken from areas with elevated radionuclide concentrations, although it was not possible to demonstrate negative impacts on fish health due to the radiation. Fujita et al.

[F3] observed that earthworms from a “high-dose” region (defined in the study as one with ambient dose equivalent rates of around 3 μSv/h — notably using units not appropriate for wildlife) had a significantly greater extent of DNA damage than those from the “low-dose” region (defined in the study as those with dose rates around 0.3 μSv/h), whereas differences were not apparent for wild boar. This study is not consistent with the expectation (as inferred in the 2013 report) that mammals would be more at risk of harm than invertebrates because of the greater radiosensitivity of the former. Nonetheless, as noted elsewhere [F3, U2], DNA damage does not necessarily correspond to impairment of biological functions, and ultimately fitness, of wildlife. Similarly, Ochiai et al. [O1] observed low blood cell counts in monkeys from Fukushima City, and speculated that, because the animal’s immune system had been compromised to some extent, individual animals and the entire troop were potentially susceptible to infectious disease.

129. Matsushima et al. [M7] observed no clear abnormalities in the gonadal tissues of frogs, collected from sites with elevated levels of radionuclide concentrations. In contrast, Watanabe et al. [W3] showed that Japanese fir tree populations near FDNPS exhibit a significantly increased number of morphological defects, compared to a control population far from FDNPS. The frequency of the defects corresponded to the deposition densities of radioactive material at the study sites, although numerous other confounding factors (e.g. accidental damage or environmental stress, such as frost) could account for the observation of morphological changes. Accumulated doses to vegetation in areas with relatively high deposition densities were estimated for the 2013 report. The estimated doses for trees were similar to those at which disturbances in growth, reproduction and morphology of conifers had been observed following the Chernobyl accident (albeit that this inference was not made explicitly in the 2013 report).

130. Murase et al. [M17] observed that the reproductive performance of a top avian predator, a goshawk, had declined markedly following the FDNPS accident and deteriorated progressively for three study years after the accident. The authors concluded that impacts were primarily caused by an increase in the ambient dose equivalent rate, as measured under goshawk nests, as a result of the nuclear accident, rather than by other factors. Whilst the reported change to reproductive performance appears to be a sound observation, given the length of time the goshawk had been studied (owing to its protected status), the study area was 100–120 km south-west of FDNPS in North Kanto, an area not significantly affected by releases from the accident. Murase et al. [M17] noted dramatic impacts on reproduction at ambient dose equivalent rates not greatly elevated above natural background levels, and certainly substantially below any of the thresholds generally considered to be detrimental at the individual level.

131. The studies of Hiyama et al. [H12] and Taira et al. [T4] have built upon earlier work by the same group [H11, T3] studying the pale grass blue butterfly, as reported in the 2013 report and the first white paper. The authors found stronger correlations of abnormality rates with distance from FDNPS than with radiation dose (for the offspring generation), but argued that this reflected (unsubstantiated) elevated irradiation of study sites south of FDNPS by short-lived radionuclides in the early phase. Hiyama et al. [H12] contended that butterfly populations were severely disturbed as a result of radiation exposure, although abnormality rates had returned to levels existing before the accident by 2013. Taira et al. [T4] examined the geographical, temporal and temperature-dependent changes of the forewing size of butterflies. After accounting for all factors, the authors maintained their conclusion that the size reduction, observed only in Fukushima Prefecture in 2011, was caused by radiation exposures. Perturbations to specific biological end points such as wing-size may be caused by many environmental factors and complex interactions between them, as illustrated by this paper.

Akimoto [A4] noted that abnormalities and mortality of aphids were significantly higher in the region affected by the accident compared to controls shortly after the accident, but that the viability and healthiness of the insects were significantly improved by 2013. Confounding factors, including the removal of human management activities, can have substantial negative impacts on populations of some insect species such as bees [Y9], and need to be accounted for in assessments of stressor impacts.

132. Møller et al. [M14] provided an analysis of bird abundance data, based on census methods in regions around Fukushima and Chernobyl, which appeared, at least in part, to be based on information published earlier. The study demonstrated a negative impact of exposure to ionizing radiation on abundance and on a number of ecological characteristics in birds, whilst accounting for potentially confounding variables (such as coverage by vegetation and agricultural habitat). For the period 2011–2014, Møller et al. [M15] found that the abundance of birds in regions of Fukushima Prefecture decreased with increasing levels of background radiation (as reported in their earlier publications [U4]), with significant variation between species. The authors argued that their findings were consistent with the hypothesis that the negative effects of radiation exposure on abundance and species richness accumulate over time. The work is supported by the dose reconstruction presented by Garnier-Laplace et al. [G1], drawing on the same census datasets. Reconstructed dose rates were commensurate with a level considered by Garnier-Laplace et al. to induce physiological disturbances in birds. The authors also reproduced the result that overall bird abundance in Fukushima Prefecture decreased with increasing total doses, albeit that no dose rates exceeded the benchmark of 100 µGy/h used in the 2013 report. Even though there are improvements in dose reconstruction of this type, some weaknesses remain in the approaches applied. In a related study by Bonisoli-Alquati et al. [B4] on barn swallows, exposure to radiation was observed not to correlate with higher genetic damage in nestlings, although, at higher levels of radiation exposure, numbers of birds declined and the fraction of juveniles decreased. The above studies suggest that the traditional view, that the absence of cytogenetic damage would rule out elevated risk at the population level, may be too simplistic, and that environmental disturbances induced by stressors might not be entirely understandable from knowledge of the stressor's effects on individual organisms [U4].

133. Full environmental impact assessments have been reported by some authors for the marine environment in proximity to FDNPS [J1, K6, K7] and at more distant locations [Y5, Y10]. These assessments confirm the finding of the 2013 report that marine biota populations were not at significant risk of severe impact from radiation exposure. In contrast, Aliyu et al. [A5] concluded that the exposure models and dose/dose-rate benchmarks applied in the 2013 report were inappropriate for inferring possible impacts on population integrity.

C. Potential implication of new publications

134. The Committee has concluded that its findings in this area of the 2013 report remain valid and are broadly supported by much of the new information that has since been published. In particular, several publications confirm the validity of the dose rates for non-human biota derived in the 2013 report. More questions may arise in relation to how these dose-rates are then interpreted, and, in particular, whether it is sufficient to focus on endpoints that do not take full account of the complexity of ecosystem interactions. As noted in the first white paper, a large proportion of available dose–response data pertain to exposures of small groups of individuals, maintained in isolation and under controlled laboratory conditions. From these data, and a much more limited set of field observations, dose rates at which populations are considered to be at risk can be derived. However, under real conditions, exposure to stressors might potentially trigger non-linear changes in ecosystem function and structure that cannot be

predicted from effects on individual organisms. There remains a clear requirement for follow-up studies investigating the dose response at high levels of biological organization (e.g. population) that take due account of biota interactions within ecosystems. A multidisciplinary approach would be essential to achieve this.

X. CONCLUSIONS

135. Of the new sources of information appraised for this second white paper, a large proportion confirmed one or other of the major assumptions in the 2013 report. None materially affected the main findings in, or challenged the major assumptions of, the 2013 report. Those that had the potential to do so, albeit subject to further analysis or confirmation from studies of better quality, are summarized briefly below.

A. Potential challenges to 2013 report

136. New data [H8, M16, O7] are becoming available on measured concentrations in air of ^{131}I, ^{134}Cs and ^{137}Cs as a function of time, and on ^{131}I deposition from ^{129}I measurements in soil samples. These data have the potential to significantly improve estimates of the source term and of the levels of radionuclides in the air and deposited on the ground. Similar analyses of other existing samples should yield further data in the near future. There is also more, albeit limited, information [L2] emerging on the chemical form in which iodine was released and transported in the atmosphere. A detailed comparison of these new data with the data used in the 2013 report would be needed to fully understand their implications.

137. The latest in a series of estimates of the source term for releases to atmosphere developed by a group of researchers at the Japan Atomic Energy Agency [K3] was highlighted in the first white paper. In addition to providing improved estimates of the temporal pattern of the release, this source term estimate also takes account of the release of iodine in three different physico-chemical forms (elemental, organic and particulate). This further strengthens the Committee’s view that use of this latest estimate would be preferable to that used in the 2013 report, where only two forms (elemental and particulate) were considered. As made clear in the first white paper, the use of this source term would not, in general, be expected to alter significantly the doses estimated in the 2013 report, with the possible exception of estimated doses to evacuees. Estimated doses to the thyroid may also increase when account is taken of the release of iodine in organic forms, but any significant increases would be confined to large distances from FDNPS where doses are small. The possible implications for the estimated doses to evacuees and for estimated doses to the thyroid at larger distances would need more detailed analysis.

138. One publication [T17] claimed to demonstrate that there had been a radiation-induced increase in thyroid cancer rates. This study was found to be seriously flawed. The weaknesses and inconsistencies of this study were confirmed by a considerable body of evidence.

139. Further publications [B4, H12, M14, M15, T4] have been identified, in addition to those reviewed in the first white paper, reporting population-level effects on non-human biota that would not be expected from the Committee’s assessment. In the Committee’s view, the results from these studies remain inconclusive, and the findings in this area of the 2013 report remain broadly supported by the bulk of the available evidence. Further, multidisciplinary research is still needed to resolve these apparent differences.

B. Contributions to research needs

140. Table 1 summarizes those publications that have been judged to have made a significant contribution to addressing the research needs identified in the 2013 report. However, several of those research needs have yet to be addressed fully by the scientific community (at least in peer-reviewed publications).

Table 1. Publications considered to make a significant contribution to one or other identified research need

Research need	*Publications making a high contribution to research need*	*Publications making a medium contribution to research need*
RELEASES TO ATMOSPHERE, DISPERSION AND DEPOSITION		
Improve estimates of amount and characteristics of releases to atmosphere as a function of time	[M16, O7]	[L2, S1, S10]
RELEASES TO WATER, DISPERSION AND DEPOSITION		
Measure and improve characterization of leaks of radioactive water and releases to aquatic environment over time	[A1, H9, K8, K16]	
Forecast and quantify long-term transport and mixing of releases and consequent exposures through aquatic pathways	[A6, M8, S8]	[B6, B7]
TRANSFER THROUGH TERRESTRIAL AND FRESHWATER ENVIRONMENTS		
Collate relevant information on transfer parameter values for food chain pathways	[K11, N5, O2, U1]	[A9, F1, F2, H6, H13, K4, K12, L3, M3, N4, S3, S5, S11, T1, T2, T13]
DOSES TO THE PUBLIC		
Measure dose rates due to external exposure to deposited material in various environments, forecast and track changes over time and quantify impact of environmental remediation programmes	[Y7]	[I7, M2, M5, M9, N3, S6, T14, Y1]
Conduct in vivo measurements of radionuclides in people to support refinement in the estimation of doses and their distribution and to estimate current and future levels of exposure		[I2, O5, T14, T15]
Quantify possible contribution to dose from internal exposure of radionuclides other than iodine and caesium		[N1]
HEALTH IMPLICATIONS		
Continue the ongoing health survey in Fukushima Prefecture		[I2, S4]
Analyse and quantify the impact of ultrasonographic surveys on the apparent incidence of thyroid cancer in Fukushima Prefecture	[H4]	[M11, W6]
Consider the feasibility of establishing a cohort for epidemiological study with members whose individual doses could be adequately assessed		[I5]
DOSES AND EFFECTS FOR NON-HUMAN BIOTA		
Measure and assess the environmental exposures typical for certain species of non-human biota, and further analyse whether radiation exposure was an important factor in causing environmental effects reported in field studies but which were inconsistent with the Committee's assessment	[B4, F3, F5, G1, H12, J1, K2, K13, K14, M1, M7, T4, W3, Y9]	[A11, A12, B2, B3, F4, H5, I3, K7, K19, M3, M6, M10, M14, M15, M17, O1, O6, S9, S13, T11, T13, W1, Y3, Y8]

Acknowledgements

In approving this white paper for publication, the Committee wishes to acknowledge with gratitude the help of the experts directly involved in undertaking follow-up activities relating to levels and effects of radiation exposure due to the nuclear accident after the 2011 great East-Japan earthquake and tsunami.

Senior technical advisers

W. Weiss (Germany) and K. Kodama (Japan)

Expert group

M. Balonov (Russian Federation), C. Estournel (France), G. Etherington (United Kingdom), F. Gering (Germany), B. Howard (United Kingdom), R. Shore (United States), S. Solomon (Australia), P. Strand (Norway)

Japanese working group

T. Aono (Japan), K. Ozasa (Japan), S. Saigusa (Japan), T. Takahashi (Japan), H. Yasuda (Japan)

Critical reviewers

J. Chen (Canada), N. Harley (United States), G. Hirth (Australia), J.-R. Jourdain (France), F. Mettler (United States), B.I. Min (Republic of Korea), S. Shinkarev (Russian Federation), J. Simmonds (United Kingdom), K.S. Suh (Republic of Korea), H. Vandenhove (Belgium)

Project manager

G.N. Kelly (United Kingdom)

References

A1 Adhiraga Pratama, M., M. Yoneda, Y. Shimada et al. Future projection of radiocesium flux to the ocean from the largest river impacted by Fukushima Daiichi Nuclear Power Plant. Sci Rep 5: 8408 (2015).

A2 Ahn, H.S., H.J. Kim and H.G. Welch. Korea's thyroid-cancer “epidemic”--screening and overdiagnosis. N Engl J Med 371(19): 1765-1767 (2014).

A3 Akimoto, K. Annual and weekly cycles of radioactivity concentration observed in Fukushima City. Health Phys 108(1): 32-38 (2015).

A4 Akimoto, S. Morphological abnormalities in gall-forming aphids in a radiation-contaminated area near Fukushima Daiichi: selective impact of fallout? Ecol Evol 4(4): 355-369 (2014).

A5 Aliyu, A.S., A.T. Ramli, N.N. Garba et al. Fukushima nuclear accident: preliminary assessment of the risks to non-human biota. Radiat Prot Dosim 163(2): 238-250 (2015).

A6 Aoyama, M., Y. Hamajima, M. Hult et al. ^{134}Cs and ^{137}Cs in the North Pacific Ocean derived from the March 2011 TEPCO Fukushima Dai-ichi Nuclear Power Plant accident, Japan. Part one: surface pathway and vertical distributions. J Oceanogr 72(1): 53-65 (2015).

A7 Aoyama, M., M. Kajino, T.Y. Tanaka et al. ^{134}Cs and ^{137}Cs in the North Pacific Ocean derived from the March 2011 TEPCO Fukushima Dai-ichi Nuclear Power Plant accident, Japan. Part two: estimation of ^{134}Cs and ^{137}Cs inventories in the North Pacific Ocean. J Oceanogr 72(1): 67-76 (2015).

A8 Arai, T. Radioactive cesium accumulation in freshwater fishes after the Fukushima nuclear accident. Springerplus 3: 479 (2014).

A9 Aung, H.P., Y.S. Aye, A.D. Mensah et al. Relations of fine-root morphology on ^{137}Cs uptake by fourteen Brassica species. J Environ Radioact 150: 203-212 (2015).

A10 Aung, H.P., S. Djedidi, A.Z. Oo et al. Growth and ^{137}Cs uptake of four Brassica species influenced by inoculation with a plant growth-promoting rhizobacterium Bacillus pumilus in three contaminated farmlands in Fukushima prefecture, Japan. Sci Total Environ 521-522: 261-269 (2015).

A11 Ayabe, Y., T. Kanasashi, N. Hijii et al. Radiocesium contamination of the web spider Nephila clavata (Nephilidae: Arachnida) 1.5 years after the Fukushima Dai-ichi Nuclear Power Plant accident. J Environ Radioact 127: 105-110 (2014).

A12 Ayabe, Y., T. Kanasashi, N. Hijii et al. Relationship between radiocesium contamination and the contents of various elements in the web spider Nephila clavata (Nephilidae: Arachnida). J Environ Radioact 150: 228-235 (2015).

B1 Baumann, Z., N. Casacuberta, H. Baumann et al. Natural and Fukushima-derived radioactivity in macroalgae and mussels along the Japanese shoreline. Biogeosciences 10(6): 3809-3815 (2013).

B2 Baumann, Z., N.S. Fisher, C.J. Gobler et al. Fukushima ^{137}Cs at the base of planktonic food webs off Japan. Deep-Sea Res Part I 106: 9-16 (2015).

B3 Black, E.E. and K.O. Buesseler. Spatial variability and the fate of cesium in coastal sediments near Fukushima, Japan. Biogeosciences 11(18): 5123-5137 (2014).

B4 Bonisoli-Alquati, A., K. Koyama, D.J. Tedeschi et al. Abundance and genetic damage of barn swallows from Fukushima. Sci Rep 5: 9432 (2015).

B5 Brown, J. and J.R. Simmonds. FARMLAND a dynamic model for the transfer of radionuclides through terrestrial foodchains. NRPB-R273. National Radiological Protection Board, Chilton, 1995.

B6 Budyansky, M.V., V.A. Goryachev, D.D. Kaplunenko et al. Role of mesoscale eddies in transport of Fukushima-derived cesium isotopes in the ocean. Deep-Sea Res Part I 96: 15-27 (2015).

B7 Buesseler, K.O., C.R. German, M.C. Honda et al. Tracking the fate of particle associated Fukushima Daiichi cesium in the ocean off Japan. Environ Sci Technol 49(16): 9807-9816 (2015).

C1 Christoudias, T. and J. Lelieveld. Modelling the global atmospheric transport and deposition of radionuclides from the Fukushima Dai-ichi nuclear accident. Atmos Chem Phys 13(3): 1425-1438 (2013).

D1 Dom, G., M. Tarabichi, K. Unger et al. A gene expression signature distinguishes normal tissues of sporadic and radiation-induced papillary thyroid carcinomas. Br J Cancer 107(6): 994-1000 (2012).

E1 Evangeliou, N., Y. Balkanski, H. Florou et al. Global deposition and transport efficiencies of radioactive species with respect to modelling credibility after Fukushima (Japan, 2011). J Environ Radioact 149: 164-175 (2015).

F1 Fujimura, S., Y. Muramatsu, T. Ohno et al. Accumulation of ^{137}Cs by rice grown in four types of soil contaminated by the Fukushima Dai-ichi Nuclear Power Plant accident in 2011 and 2012. J Environ Radioact 140: 59-64 (2015).

F2 Fujimura, S., Y. Sakuma, M. Sato et al. Difference in Cs-137 concentration of brown rice between the years of 2011 and 2012 in Fukushima Prefecture. J Radioanal Nucl Chem 303(2): 1147-1150 (2015).

F3 Fujita, Y., Y. Yoshihara, I. Sato et al. Environmental radioactivity damages the DNA of earthworms of Fukushima Prefecture, Japan. Eur J Wildl Res 60(1): 145-148 (2014).

F4 Fujiwara, K., T. Takahashi, P. Nguyen et al. Uptake and retention of radio-caesium in earthworms cultured in soil contaminated by the Fukushima nuclear power plant accident. J Environ Radioact 139: 135-139 (2015).

F5 Fuma, S., S. Ihara, I. Kawaguchi et al. Dose rate estimation of the Tohoku hynobiid salamander, Hynobius lichenatus, in Fukushima. J Environ Radioact 143: 123-134 (2015).

G1 Garnier-Laplace, J., K. Beaugelin-Seiller, C. Della-Vedova et al. Radiological dose reconstruction for birds reconciles outcomes of Fukushima with knowledge of dose-effect relationships. Sci Rep 5: 16594 (2015).

G2 Goto, A., E.J. Bromet, K. Fujimori et al. Immediate effects of the Fukushima nuclear power plant disaster on depressive symptoms among mothers with infants: a prefectural-wide cross-sectional study from the Fukushima Health Management Survey. BMC Psychiatry 15: 59 (2015).

H1 Hasegawa, M., S. Kaneko, S. Ikeda et al. Changes in radiocesium concentrations in epigeic earthworms in relation to the organic layer 2.5 years after the 2011 Fukushima Dai-ichi Nuclear Power Plant accident. J Environ Radioact 145: 95-101 (2015).

H2 Hayano, R.S., M. Tsubokura, M. Miyazaki et al. Whole-body counter surveys of over 2700 babies and small children in and around Fukushima Prefecture 33 to 49 months after the Fukushima Daiichi NPP accident. Proceedings of the Japan Academy 91(8): 440-446 (2015).

H3 Hayashida, N., M. Imaizumi, H. Shimura et al. Thyroid ultrasound findings in children from three Japanese prefectures: Aomori, Yamanashi and Nagasaki. PLoS One 8(12): e83220 (2013).

H4 Hayashida, N., M. Imaizumi, H. Shimura et al. Thyroid ultrasound findings in a follow-up survey of children from three Japanese prefectures: Aomori, Yamanashi, and Nagasaki. Sci Rep 5: 9046 (2015).

H5 Higaki, T., S. Higaki, M. Hirota et al. Radiocesium distribution in bamboo shoots after the Fukushima nuclear accident. PLoS One 9(5): e97659 (2014).

H6 Hiraide, M., M. Sunagawa, H. Neda et al. Reducing radioactive cesium transfer from sawdust media to Pleurotus ostreatus fruiting bodies. J Wood Sci 61(4): 420-430 (2015).

H7 Hirayama, H., H. Matsumura, Y. Namito et al. Method to separate plume- and accumurated surrounding-contributions to peak count rate using pulse height distribution time histories at monitoring post. KEK Internal 2014-7. High Energy Accelerator Research Organization (KEK), Japan, 2015.

H8 Hirayama, H., H. Matsumura, Y. Namito et al. Estimation of time history of I-131 concentration in air using NaI(Tl) detector pulse height distribution at monitoring posts in Fukushima prefecture. Trans At Energy Soc Japan 14(1): 1-11 (2015). (Japanese).

H9 Hirose, K. Current trends of ^{137}Cs concentrations in coastal waters near the Fukushima Daiichi NPP. J Radioanal Nucl Chem 307(3): 1699-1702 (2015).

H10 Hiyama, A., C. Nohara, S. Kinjo et al. The biological impacts of the Fukushima nuclear accident on the pale grass blue butterfly. Sci Rep 2: 570 (2012).

H11 Hiyama, A., C. Nohara, W. Taira et al. The Fukushima nuclear accident and the pale grass blue butterfly: evaluating biological effects of long-term low-dose exposures. BMC Evol Biol 13: 168 (2013).

H12 Hiyama, A., W. Taira, C. Nohara et al. Spatiotemporal abnormality dynamics of the pale grass blue butterfly: three years of monitoring (2011-2013) after the Fukushima nuclear accident. BMC Evol Biol 15: 15 (2015).

H13 Hoshino, Y., T. Higashi, T. Ito et al. Tillage can reduce the radiocesium contamination of soybean after the

Fukushima Dai-ichi nuclear power plant accident. Soil Tillage Res 153: 76-85 (2015).

I1 IAEA. Handbook of parameter values for the prediction of radionuclide transfer in terrestrial and freshwater environments. Technical Reports Series 472. International Atomic Energy Agency, Vienna, 2010.

I2 IAEA. The Fukushima Daiichi Accident. International Atomic Energy Agency. Vienna, 2015.

I3 Iguchi, K., K. Fujimoto, H. Kaeriyama et al. Cesium-137 discharge into the freshwater fishery ground of grazing fish, ayu Plecoglossus altivelis after the March 2011 Fukushima nuclear accident. Fish Sci 79(6): 983-988 (2013).

I4 Ii, I., K. Tanoi, Y. Uno et al. Radioactive caesium concentration of lowland rice grown in the decontaminated paddy fields in Iitate-Village in Fukushima. Radio-isotopes 64: 299-310 (2015). (Japanese).

I5 Inamasu, T., S.J. Schonfeld, M. Abe et al. Meeting report: suggestions for studies on future health risks following the Fukushima accident. Environ Health 14: 26 (2015).

I6 Ishii, T., M. Tsubokura, S. Ochi et al. Living in contaminated radioactive areas is not an acute risk factor for non-communicable disease development: a retrospective observational study. Disaster Med Public Health Prep 10(1): 34-37 (2016).

I7 Ishikawa, T., S. Yasumura, K. Ozasa et al. The Fukushima Health Management Survey: estimation of external doses to residents in Fukushima Prefecture. Sci Rep 5: 12712 (2015).

J1 Johansen, M.P., E. Ruedig, K. Tagami et al. Radiological dose rates to marine fish from the Fukushima Daiichi accident: the first three years across the North Pacific. Environ Sci Technol 49(3): 1277-1285 (2015).

J2 Jorgensen, T.J. Re: Thyroid cancer among young people in Fukushima. Epidemiology 27(3): e17 (2016).

K1 Kaeriyama, H., K. Fujimoto, D. Ambe et al. Fukushima-derived radionuclides ^{134}Cs and ^{137}Cs in zooplankton and seawater samples collected off the Joban-Sanriku coast, in Sendai Bay, and in the Oyashio region. Fish Sci 81(1): 139-153 (2015).

K2 Kanasashi, T., Y. Sugiura, C. Takenaka et al. Radiocesium distribution in sugi (Cryptomeria japonica) in eastern Japan: translocation from needles to pollen. J Environ Radioact 139: 398-406 (2015).

K3 Katata, G., M. Chino, T. Kobayashi et al. Detailed source term estimation of the atmospheric release for the Fukushima Daiichi Nuclear Power Station accident by coupling simulations of an atmospheric dispersion model with an improved deposition scheme and oceanic dispersion model. Atmos Chem Phys 15(2): 1029-1070 (2015).

K4 Kato, N., N. Kihou, S. Fujimura et al. Potassium fertilizer and other materials as countermeasures to reduce radiocesium levels in rice: Results of urgent experiments in 2011 responding to the Fukushima Daiichi Nuclear Power Plant accident. Soil Sci Plant Nutr 61(2): 179-190 (2015).

K5 Kawai, H., A. Kitamura, M. Mimura et al. Radioactive cesium accumulation in seaweeds by the Fukushima 1 Nuclear Power Plant accident-two years' monitoring at Iwaki and its vicinity. J Plant Res 127(1): 23-42 (2014).

K6 Keum, D.K., B.H. Kim, K.M. Lim et al. Radiation exposure to marine biota around the Fukushima Daiichi NPP. Environ Monit Assess 186(5): 2949-2956 (2014).

K7 Keum, D.K., I. Jun, B.H. Kim et al. A dynamic model to estimate the activity concentration and whole body dose rate of marine biota as consequences of a nuclear accident. J Environ Radioact 140: 84-94 (2015).

K8 Kinouchi, T., K. Yoshimura and T. Omata. Modeling radiocesium transport from a river catchment based on a physically-based distributed hydrological and sediment erosion model. J Environ Radioact 139: 407-415 (2015).

K9 Kobayashi, T., H. Nagai, M. Chino et al. Source term estimation of atmospheric release due to the Fukushima Dai-ichi Nuclear Power Plant accident by atmospheric and oceanic dispersion simulations. J Nucl Sci Technol 50(3): 255-264 (2013).

K10 Kodama, Y., T. Oikawa, K. Hayashi et al. Impact of natural disaster combined with nuclear power plant accidents on local medical services: a case study of Minamisoma Municipal General Hospital after the Great East Japan Earthquake. Disaster Med Public Health Prep 8(6): 471-476 (2014).

K11 Kondo, M., H. Maeda, A. Goto et al. Exchangeable Cs/K ratio in soil is an index to estimate accumulation of radioactive and stable Cs in rice plant. Soil Sci Plant Nutr 61(1): 133-143 (2015).

K12 Kubo, K., K. Nemoto, H. Kobayashi et al. Analyses and countermeasures for decreasing radioactive cesium in buckwheat in areas affected by the nuclear accident in 2011. Field Crops Res 170: 40-46 (2015).

K13 Kubota, T., Y. Shibahara, S. Fukutani et al. Cherenkov counting of ^{90}Sr and ^{90}Y in bark and leaf samples collected around Fukushima Daiichi Nuclear Power Plant. J Radioanal Nucl Chem 303(1): 39-46 (2015).

K14 Kubota, Y., H. Takahashi, Y. Watanabe et al. Estimation of absorbed radiation dose rates in wild rodents inhabiting a site severely contaminated by the Fukushima Dai-ichi nuclear power plant accident. J Environ Radioact 142: 124-131 (2015).

K15 Kubota, Y., H. Tsuji, T. Kawagoshi et al. Chromosomal aberrations in wild mice captured in areas differentially contaminated by the Fukushima Dai-ichi Nuclear Power Plant accident. Environ Sci Technol 49(16): 10074-10083 (2015).

K16 Kumamoto, Y., M. Aoyama, Y. Hamajima et al. Impact of Fukushima-derived radio-cesium in the western North Pacific Ocean about ten months after the Fukushima Dai-ichi nuclear power plant accident. J Environ Radioact 140: 114-122 (2015).

K17 Kusaba, S., K. Matsuoka, K. Abe et al. Changes in radiocesium concentration in a blueberry (Vaccinium virgatumAiton) orchard resulting from radioactive fallout. Soil Sci Plant Nutr 61(1): 169-173 (2015).

K18 Kusaba, S., K. Matsuoka, T. Saito et al. Changes in radiocesium concentration in a Japanese chestnut (Castanea crenataSieold & Zucc.) orchard following radioactive fallout. Soil Sci Plant Nutr 61(1): 165-168 (2015).

K19 Kusakabe, M., S. Oikawa, H. Takata et al. Spatiotemporal distributions of Fukushima-derived radionuclides in nearby marine surface sediments. Biogeosciences 10(7): 5019-5030 (2013).

L1 Leadbetter, S.J., M.C. Hort, A.R. Jones et al. Sensitivity of the modelled deposition of Caesium-137 from the Fukushima Dai-ichi nuclear power plant to the wet deposition parameterisation in NAME. J Environ Radioact 139: 200-211 (2015).

L2 Lebel, L.S., R.S. Dickson and G.A. Glowa. Radioiodine in the atmosphere after the Fukushima Dai-ichi nuclear accident. J Environ Radioact 151 Pt 1: 82-93 (2016).

L3 Lepage, H., O. Evrard, Y. Onda et al. Depth distribution of cesium-137 in paddy fields across the Fukushima pollution plume in 2013. J Environ Radioact 147: 157-164 (2015).

M1 Mahara, Y., T. Ohta, H. Ogawa et al. Atmospheric direct uptake and long-term fate of radiocesium in trees after the Fukushima nuclear accident. Sci Rep 4: 7121 (2014).

M2 Martin, P.G., O.D. Payton, J.S. Fardoulis et al. Low altitude unmanned aerial vehicle for characterising remediation effectiveness following the FDNPP accident. J Environ Radioact 151 Pt 1: 58-63 (2016).

M3 Matsuda, K., K. Takagi, A. Tomiya et al. Comparison of radioactive cesium contamination of lake water, bottom sediment, plankton, and freshwater fish among lakes of Fukushima Prefecture, Japan after the Fukushima fallout. Fish Sci 81(4): 737-747 (2015).

M4 Matsuda, N., K. Yoshida, K. Nakashima et al. Initial activities of a radiation emergency medical assistance team to Fukushima from Nagasaki. Radiat Meas 55: 22-25 (2013).

M5 Matsuda, N., S. Mikami, S. Shimoura et al. Depth profiles of radioactive cesium in soil using a scraper plate over a wide area surrounding the Fukushima Dai-ichi Nuclear Power Plant, Japan. J Environ Radioact 139: 427-434 (2015).

M6 Matsui, S., S. Kasahara, G. Morimoto et al. Radioactive contamination of nest materials of the Eurasian Tree Sparrow Passer montanus due to the Fukushima nuclear accident: The significance in the first year. Environ Pollut 206: 159-162 (2015).

M7 Matsushima, N., S. Ihara, M. Takase et al. Assessment of radiocesium contamination in frogs 18 months after the Fukushima Daiichi nuclear disaster. Sci Rep 5: 9712 (2015).

M8 Men, W., J. He, F. Wang et al. Radioactive status of seawater in the northwest Pacific more than one year after the Fukushima nuclear accident. Sci Rep 5: 7757 (2015).

M9 Mikami, S., T. Maeyama, Y. Hoshide et al. The air dose rate around the Fukushima Dai-ichi Nuclear Power Plant: its spatial characteristics and temporal changes until December 2012. J Environ Radioact 139: 250-259 (2015).

M10 Misumi, K., D. Tsumune, T. Tsubono et al. Factors controlling the spatiotemporal variation of ^{137}Cs in seabed sediment off the Fukushima coast: implications from numerical simulations. J Environ Radioact 136: 218-228 (2014).

M11 Mitsutake, N., T. Fukushima, M. Matsuse et al. BRAF(V600E) mutation is highly prevalent in thyroid carcinomas in the young population in Fukushima: a different oncogenic profile from Chernobyl. Sci Rep 5: 16976 (2015).

M12 Møller, A.P., A. Hagiwara, S. Matsui et al. Abundance of birds in Fukushima as judged from Chernobyl. Environ Pollut 164: 36-39 (2012).

M13 Møller, A.P., I. Nishiumi, H. Suzuki et al. Differences in effects of radiation on abundance of animals in Fukushima and Chernobyl. Ecol Indic 24: 75-81 (2013).

M14 Møller, A.P., T.A. Mousseau, I. Nishiumi et al. Ecological differences in response of bird species to radioactivity from Chernobyl and Fukushima. J Ornithol 156(S1): 287-296 (2015).

M15 Møller, A.P., I. Nishiumi and T.A. Mousseau. Cumulative effects of radioactivity from Fukushima on the abundance and biodiversity of birds. J Ornithol 156(S1): 297-305 (2015).

M16 Muramatsu, Y., H. Matsuzaki, C. Toyama et al. Analysis of 129I in the soils of Fukushima Prefecture: preliminary reconstruction of ^{131}I deposition related to the accident at Fukushima Daiichi Nuclear Power Plant (FDNPP). J Environ Radioact 139: 344-350 (2015).

M17 Murase, K., J. Murase, R. Horie et al. Effects of the Fukushima Daiichi nuclear accident on goshawk reproduction. Sci Rep 5: 9405 (2015).

N1 Nabeshi, H., T. Tsutsumi, Y. Uekusa et al. Surveillance of strontium-90 in foods after the Fukushima Daiichi Nuclear Power Plant Accident. Shokuhin Eiseigaku Zasshi 56(4): 133-143 (2015).

N2 Nagataki, S. and N. Takamura. A review of the Fukushima nuclear reactor accident: radiation effects on the thyroid and strategies for prevention. Curr Opin Endocrinol Diabetes Obes 21(5): 384-393 (2014).

N3 Naito, W., M. Uesaka, C. Yamada et al. Evaluation of dose from external irradiation for individuals living in areas affected by the Fukushima Daiichi Nuclear Plant accident. Radiat Prot Dosim 163(3): 353-361 (2015).

N4 Nakai, W., N. Okada, S. Ohashi et al. Evaluation of ^{137}Cs accumulation by mushrooms and trees based on the aggregated transfer factor. J Radioanal Nucl Chem 303(3): 2379-2389 (2015).

N5 Nakao, A., A. Takeda, S. Ogasawara et al. Relationships between paddy soil radiocesium interception potentials and physicochemical properties in Fukushima, Japan. J Environ Qual 44(3): 780-788 (2015).

N6 Nomura, S., M. Tsubokura, T. Furutani et al. Dependence of radiation dose on the behavioral patterns among school children: a retrospective analysis 18 to 20 months following the 2011 Fukushima nuclear incident in Japan. J Radiat Res 57(1): 1-8 (2016).

O1 Ochiai, K., S. Hayama, S. Nakiri et al. Low blood cell counts in wild Japanese monkeys after the Fukushima Daiichi nuclear disaster. Sci Rep 4: 5793 (2014).

O2 Ohse, K., K. Kitayama, S. Suenaga et al. Concentration of radiocesium in rice, vegetables, and fruits cultivated in the evacuation area in Okuma Town, Fukushima. J Radioanal Nucl Chem 303(2): 1533-1537 (2015).

O3 Ohto, H., M. Maeda, H. Yabe et al. Suicide rates in the aftermath of the 2011 earthquake in Japan. Lancet 385(9979): 1727 (2015).

O4 Ohtsuru, A., K. Tanigawa, A. Kumagai et al. Nuclear disasters and health: lessons learned, challenges, and proposals. Lancet 386(9992): 489-497 (2015).

O5 Orita, M., N. Hayashida, H. Nukui et al. Internal radiation exposure dose in Iwaki city, Fukushima prefecture after the accident at Fukushima Dai-ichi Nuclear Power Plant. PLoS One 9(12): e114407 (2014).

O6 Otosaka, S. and Y. Kato. Radiocesium derived from the Fukushima Daiichi Nuclear Power Plant accident in seabed sediments: initial deposition and inventories. Environ Sci Process Impacts 16(5): 978-990 (2014).

O7 Oura, Y., M. Ebihara, H. Tsuruta et al. A database of hourly atmospheric concentrations of radiocesium (^{134}Cs and ^{137}Cs) in suspended particulate matter collected in March 2011 at 99 air pollution monitoring stations in eastern Japan. J Nucl Radiochem Sci 15: 2 (2015).

S1 Saito, K., T. Shimbori and R. Draxler. JMA's regional atmospheric transport model calculations for the WMO technical task team on meteorological analyses for Fukushima Daiichi Nuclear Power Plant accident. J Environ Radioact 139: 185-199 (2015).

S2 Saito, K., I. Tanihata, M. Fujiwara et al. Detailed deposition density maps constructed by large-scale soil sampling for gamma-ray emitting radioactive nuclides from the Fukushima Dai-ichi Nuclear

Power Plant accident. J Environ Radioact 139: 308-319 (2015).
S3 Saito, T., K. Takahashi, T. Makino et al. Effect of application timing of potassium fertilizer on root uptake of ^{137}Cs in brown rice. J Radioanal Nucl Chem 303(2): 1585-1587 (2015).
S4 Sakai, A., T. Ohira, M. Hosoya et al. White blood cell, neutrophil, and lymphocyte counts in individuals in the evacuation zone designated by the government after the Fukushima Daiichi Nuclear Power Plant accident: the Fukushima Health Management Survey. J Epidemiol 25(1): 80-87 (2015).
S5 Sato, M., D. Takata, K. Tanoi et al. Radiocesium transfer into the fruit of deciduous fruit trees contaminated during dormancy. Soil Sci Plant Nutr 61(1): 156-164 (2015).
S6 Satoh, D., T. Furuta, F. Takahashi et al. Age-dependent dose conversion coefficients for external exposure to radioactive cesium in soil. J Nucl Sci Technol 53(1): 69-81 (2015).
S7 Selmansberger, M., J.C. Kaiser, J. Hess et al. Dose-dependent expression of CLIP2 in post-Chernobyl papillary thyroid carcinomas. Carcinogenesis 36(7): 748-756 (2015).
S8 Smith, J.N., R.M. Brown, W.J. Williams et al. Arrival of the Fukushima radioactivity plume in North American continental waters. Proc Natl Acad Sci USA 112(5): 1310-1315 (2015).
S9 Sohtome, T., T. Wada, T. Mizuno et al. Radiological impact of TEPCO's Fukushima Dai-ichi Nuclear Power Plant accident on invertebrates in the coastal benthic food web. J Environ Radioact 138: 106-115 (2014).
S10 Steinhauser, G., T. Niisoe, K.H. Harada et al. Post-accident sporadic releases of airborne radionuclides from the Fukushima Daiichi Nuclear Power Plant site. Environ Sci Technol 49(24): 14028-14035 (2015).
S11 Sunaga, Y., H. Harada and T. Kawachi. Weathering half-life of radioactive cesium for winter rye (Secale cerealeL.) and Italian ryegrass (Lolium multiflorumLam.) directly contaminated by the 2011 Fukushima Daiichi Nuclear Power Station accident. Soil Sci Plant Nutr 61(2): 200-211 (2015).
S12 Suseno, H., I.B. Wahono and Muslim. Radiocesium monitoring in Indonesian waters of the Indian Ocean after the Fukushima nuclear accident. Mar Pollut Bull 97(1-2): 539-543 (2015).
S13 Suzuki, Y. Influences of radiation on carp from farm ponds in Fukushima. J Radiat Res 56 Suppl 1: i19-i23 (2015).
T1 Tagami, K. and S. Uchida. Effective half-lives of ^{137}Cs in giant butterbur and field horsetail, and the distribution differences of potassium and ^{137}Cs in aboveground tissue parts. J Environ Radioact 141: 138-145 (2015).
T2 Tagami, K. and S. Uchida. Effective half-lives of ^{137}Cs from persimmon tree tissue parts in Japan after Fukushima Dai-ichi Nuclear Power Plant accident. J Environ Radioact 141: 8-13 (2015).
T3 Taira, W., C. Nohara, A. Hiyama et al. Fukushima's biological impacts: the case of the pale grass blue butterfly. J Hered 105(5): 710-722 (2014).
T4 Taira, W., M. Iwasaki and J.M. Otaki. Body size distributions of the pale grass blue butterfly in Japan: Size rules and the status of the Fukushima population. Sci Rep 5: 12351 (2015).
T5 Takahashi, H., T. Ohira, S. Yasumura et al. Re: Thyroid cancer among young people in Fukushima. Epidemiology 27(3): e21 (2016).
T6 Takamura, N. Re: Thyroid cancer among young people in Fukushima. Epidemiology 27(3): e18 (2016).
T7 Takata, H., K. Hasegawa, S. Oikawa et al. Remobilization of radiocesium on riverine particles in seawater: The contribution of desorption to the export flux to the marine environment. Mar Chem 176: 51-63 (2015).
T8 Takata, H., M. Kusakabe and S. Oikawa. Radiocesiums (^{134}Cs, ^{137}Cs) in zooplankton in the waters of Miyagi, Fukushima and Ibaraki Prefectures. J Radioanal Nucl Chem 303(2): 1265-1271 (2015).
T9 Tanoi, K., K. Uchida, C. Doi et al. Investigation of radiocesium distribution in organs of wild boar grown in Iitate, Fukushima after the Fukushima Daiichi nuclear power plant accident. J Radioanal Nucl Chem 307(1): 741-746 (2016).
T10 Tateda, Y., D. Tsumune and T. Tsubono. Simulation of radioactive cesium transfer in the southern Fukushima coastal biota using a dynamic food chain transfer model. J Environ Radioact 124: 1-12 (2013).
T11 Tateda, Y., D. Tsumune, T. Tsubono et al. Radiocesium biokinetics in olive flounder inhabiting the Fukushima accident-affected Pacific coastal waters of eastern Japan. J Environ Radioact 147: 130-141 (2015).
T12 Terada, H., G. Katata, M. Chino et al. Atmospheric discharge and dispersion of

radionuclides during the Fukushima Dai-ichi Nuclear Power Plant accident. Part II: verification of the source term and analysis of regional-scale atmospheric dispersion. J Environ Radioact 112: 141-154 (2012).

T13 Tsuboi, J., S. Abe, K. Fujimoto et al. Exposure of a herbivorous fish to ^{134}Cs and ^{137}Cs from the riverbed following the Fukushima disaster. J Environ Radioact 141: 32-37 (2015).

T14 Tsubokura, M., S. Kato, T. Morita et al. Assessment of the annual additional effective doses amongst Minamisoma children during the second year after the Fukushima Daiichi Nuclear Power Plant disaster. PLoS One 10(6): e0129114 (2015).

T15 Tsubokura, M., S. Kato, S. Nomura et al. Absence of internal radiation contamination by radioactive cesium among children affected by the Fukushima Daiichi nuclear power plant disaster. Health Phys 108(1): 39-43 (2015).

T16 Tsuda, T., A. Tokinobu, E. Yamamoto et al. Response to the Commentary by Professor Davis and the Seven Letters. - a well-known fact should be disseminated to remedy the problems. Epidemiology 27(3): e21-23 (2016).

T17 Tsuda, T., A. Tokinobu, E. Yamamoto et al. Thyroid cancer detection by ultrasound among residents ages 18 years and younger in Fukushima, Japan: 2011 to 2014. Epidemiology 27(3): 316-322 (2016).

T18 Tsumune, D., T. Tsubono, M. Aoyama et al. Distribution of oceanic ^{137}Cs from the Fukushima Dai-ichi Nuclear Power Plant simulated numerically by a regional ocean model. J Environ Radioact 111: 100-108 (2012).

U1 Uematsu, S., E. Smolders, L. Sweeck et al. Predicting radiocaesium sorption characteristics with soil chemical properties for Japanese soils. Sci Total Environ 524-525: 148-156 (2015).

U2 UNSCEAR. Sources and Effects of Ionizing Radiation. Volume II: Effects. Scientific Annexes C, D and E. UNSCEAR 2008 Report. United Nations Scientific Committee on the Effects of Atomic Radiation. United Nations sales publication E.11.IX.3. United Nations, New York, 2011.

U3 UNSCEAR. Sources, Effects and Risks of Ionizing Radiation. Volume I: Report to the Genera Assembly and Scientific Annex A. UNSCEAR 2013 Report. United Nations Scientific Committee on the Effects of Atomic Radiation. United Nations sales publication E.14.IX.1. United Nations, New York, 2014.

U4 UNSCEAR. Developments since the 2013 UNSCEAR Report on the Levels and Effects of Radiation Exposure due to the Nuclear Accident following the Great East-Japan Earthquake and Tsunami. A 2015 white paper to guide the Scientific Committee's future programme of work. United Nations Scientific Committee on the Effects of Atomic Radiation. United Nations, New York, 2015.

U5 UNSCEAR. Sources, Effects and Risks of Ionizing Radiation. Report to the General Assembly and Scientific Annexes A and B. UNSCEAR 2012 Report. United Nations Scientific Committee on the Effects of Atomic Radiation. United Nations sales publication E.16.IX.1. United Nations, New York, 2015.

W1 Wada, T., Y. Nemoto, S. Shimamura et al. Effects of the nuclear disaster on marine products in Fukushima. J Environ Radioact 124: 246-254 (2013).

W2 Wakeford, R., A. Auvinen, R.N. Gent et al. Re: Thyroid cancer among young people in Fukushima. Epidemiology 27(3): e20-21 (2016).

W3 Watanabe, Y., S. Ichikawa, M. Kubota et al. Morphological defects in native Japanese fir trees around the Fukushima Daiichi Nuclear Power Plant. Sci Rep 5: 13232 (2015).

W4 WHO. Health risk assessment from the nuclear accident after the 2011 Great East Japan earthquake and tsunami, based on a preliminary dose estimation. World Health Organization, Geneva, 2013.

W5 Wickramasooriya, P.L., V.A. Waduge, T.N. Attanayake et al. Radioactive caesium evidence for the absence of contamination of Sri Lanka sea water by the Fukushima accident. Environ Chem Lett 13(4): 487-493 (2015).

W6 Williams, D. Thyroid growth and cancer. Eur Thyroid J 4(3): 164-173 (2015).

Y1 Yajima, K., O. Kurihara, Y. Ohmachi et al. Estimating annual individual doses for evacuees returning home to areas affected by the Fukushima nuclear accident. Health Phys 109(2): 122-133 (2015).

Y2 Yamamoto, K., K. Tagami, S. Uchida et al. Model estimation of ^{137}Cs concentration change with time in seawater and sediment around the Fukushima Daiichi Nuclear Power Plant site considering fast and slow reactions in the seawater-sediment systems. J Radioanal Nucl Chem 304(2): 867-881 (2015).

Y3 Yamamoto, S., T. Yokoduka, K. Fujimoto et al. Radiocaesium concentrations in the muscle and eggs of salmonids from Lake Chuzenji, Japan, after the Fukushima fallout. J Fish Biol 84(5): 1607-1613 (2014).

Y4 Yamashita, J., T. Enomoto, M. Yamada et al. Estimation of soil-to-plant transfer factors of radiocesium in 99 wild plant species grown in arable lands 1 year after the Fukushima 1 Nuclear Power Plant accident. J Plant Res 127(1): 11-22 (2014).

Y5 Yang, B., Y. Ha and J. Jin. Assessment of radiological risk for marine biota and human consumers of seafood in the coast of Qingdao, China. Chemosphere 135: 363-369 (2015).

Y6 Yasui, S. Fact-finding survey in response to the manipulation of personal alarm dosimeter collection efficiency: lessons learned about post-emergency radiation protection from the TEPCO Fukushima Daiichi APP accident. J Occup Environ Hyg 12(6): D96-102 (2015).

Y7 Yoshida-Ohuchi, H., M. Hosoda, T. Kanagami et al. Reduction factors for wooden houses due to external gamma-radiation based on in situ measurements after the Fukushima nuclear accident. Sci Rep 4: 7541 (2014).

Y8 Yoshimura, M. and A. Akama. Radioactive contamination of aquatic insects in a stream impacted by the Fukushima nuclear power plant accident. Hydrobiologia 722(1): 19-30 (2014).

Y9 Yoshioka, A., Y. Mishima and K. Fukasawa. Pollinators and Other Flying Insects inside and outside the Fukushima Evacuation Zone. PLoS One 10(11): e0140957 (2015).

Y10 Yu, W., J. He, W. Lin et al. Distribution and risk assessment of radionuclides released by Fukushima nuclear accident at the northwest Pacific. J Environ Radioact 142: 54-61 (2015).

unscear.org

In 1955 the United Nations General Assembly established the Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in response to concerns about the effects of ionizing radiation on human health and the environment. At that time fallout from atmospheric nuclear weapons tests was reaching people through air, water and food. UNSCEAR was to collect and evaluate information on the levels and effects of ionizing radiation. Its first reports laid the scientific grounds on which the Partial Test Ban Treaty prohibiting atmospheric nuclear weapons testing was negotiated in 1963.

Over the decades, UNSCEAR has evolved to become the world authority on the global level and effects of atomic radiation. UNSCEAR's independent and objective evaluation of the science are to provide for—but not address—informed policymaking and decision-making related to radiation risks and protection.

V.16-08753