Report of Working Group 30 on *Assessment of Marine Environmental Quality of Radiation around the North Pacific*

The 2016 business meeting of Working Group on *Assessment of Marine Environmental Quality of Radiation around the North Pacific* (WG 30/WG-AMR) was held in San Diego, USA, from 09:00 to 18:00 on November 4, 2016. Co-Chairs Profs. Yusheng Zhang (China) and Kathryn A. Higley (USA) welcomed the members and observers and made the opening address. Eighteen participants, including seven WG members from five member countries (except Russia) attended the meeting (***WG 30 Endnote 1***). The agenda for the WG30 2016 business meeting was discussed and adopted without revision by the WG members (***WG 30 Endnote 2***).

Participants of the WG 30 2016 annual meeting. Left photo, front row from the left: Wu Men, Suk Hyun Kim, Kathryn A. Higley (Co-Chair), Kyung Tae Jung, John N. Smith, Tomowo Watanabe, Yusheng Zhang (Co-Chair), Núria Casacuberta; back row from the left: Chuanlin Huo (MEQ Chair), Daisuke Ambe, Hideki Kaeriyama, Delvan Neville, Allen H. Andrews, Takami Morita, Shizuho Miki, Jung Hyup Lee, Jinqiu Du. Right photo, the participants at the WG 30 business meeting.

AGENDA ITEM 2
Overview and update of WG 30

After adopting the meeting agenda, Prof. Yusheng Zhang made a presentation on an overview and update of the WG since its third meeting held during the PICES 2015 Annual Meeting in Tsingdao, China to summarize the progress of the WG for the past year.

AGENDA ITEM 3
Country reports

Each member country of the WG 30 provided an overview of the research that they had conducted in the past year following the WG work plan. All of member country report summaries are listed in ***WG 30 Endnote 3***.

AGENDA ITEM 4
Term extension

The members discussed the life term of the WG 30 and agreed to prolong it one-year to the end of 2017 in order to collect more data on radioactivity to support the conclusions on the risk assessment of the radionuclides from the FDNPP accident in the North Pacific for the final report of WG 30 and to complete the final report, one more scholar scientific paper and the brochure of WG 30. WG 30 will bring the request for an extension to MEQ (***WG 30 Endnote 4***).

AGENDA ITEM 5
Outline and assignment of the WG 30 final report and time schedule

A draft outline and assignment of the WG 30 Final Report provided by Co-Chair, Prof. Yusheng Zhang was discussed and revised in detail by the members. Moreover, the members discussed and formatted a time schedule to complete the outline of WG 30 final report (***WG 30 Endnote 5***)

AGENDA ITEM 6
WG 30 brochure

The contents for the brochure of WG 30 were discussed during the meeting. The members preferred to produce a brochure introducing terms of references, on-going projects and major achievements obtained so far by the WG on monitoring and assessment of marine environmental quality of radiation around the North Pacific rather than a popular science booklet about radioactivity in (marine) environment. All of the member countries for the meeting agree to provide 2 achievement figures for the brochure before the end of November 2016.

AGENDA ITEM 7
Work Plan for 2017

The components for the work plan of WG 30 in 2017 were discussed during the meeting. The group reached consensus that the work plan and main goals of the WG in 2017 are to:

(1) Complete the WG 30 Final Report
(2) Compile a brochure of the WG 30
(3) Fulfil a new paper about lessons learned from Fukushima release as it applies to the next unplanned ocean release, etc.
(4) Collaborate with SCOR RiO5 in August 2017
(5) Hold a 2-day WG business meeting during the PICES 2017 Annual Meeting
(6) Encourage the member countries to make a proposal for further developing a new working group on radioactivity under parent committee MEQ.

WG 30 Endnote 1

WG 30 participation list

<u>Members</u>

Kathryn A. Higley (USA, Co-Chair)
Kyung Tae Jung (Korea)
Suk Hyun Kim (Korea)
Takami Morita (Japan)
John N. Smith (Canada)
Tomowo Watanabe (Japan)
Yusheng Zhang (China, Co-Chair)

<u>Members unable to attend</u>

China: Hongzhi Li, Wu Men, Wen Yu
Korea: In-Seong Han, Young-Il Kim
Russia: Vladimir Goryachev

<u>Observers</u>

Daisuke Ambe (Japan)
Allen H. Andrews (USA)
Núria Casacuberta (SCOR)
Jinqiu Du (China)
Jianhua He (China)
Chuanlin Huo (MEQ Chair)
Hideki Kaeriyama (Japan)
Jung Hyup Lee (Korea)
Wu Men (China)
Shizuho Miki (Japan)
Delvan Neville (USA)

WG 30 Endnote 2

WG 30 meeting agenda

1. Adoption of the meeting agenda
2. Overview and update of WG 30
3. Country reports
4. Term extension of the WG 30
5. Outline and assignment of the WG 30 final report and time schedule
6. WG 30 brochure
7. Work Plan for 2017

WG 30 Endnote 3

WG30 member country report summaries

Canada

Report on Canadian Monitoring of Fukushima Radioactivity on Line P

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Dartmouth, NS, Canada

1. Introduction

An earthquake-triggered tsunami on March 11, 2011 caused extensive damage to the nuclear power facilities in Fukushima, Japan, resulting in the discharge of large quantities of ^{137}Cs and other radionuclides directly into the western North Pacific Ocean during the month following the accident (Fig. 1). The radioactivity plume was immediately transported northeastward towards North America under the influence of the strong Kuroshio Current and was expected to approach the Canadian coastline within a few years. This plume of radioactivity becomes very much diluted by the time it arrives off the North American coastline, but the eventual magnitude of the signal is difficult to predict owing to uncertainties in the quantity of material initially discharged from Fukushima, the trajectory of the plume and the degree of mixing that will occur with uncontaminated water. Model projections for the eventual concentrations of radioactivity in Canadian continual shelf waters off Victoria, British Columbia, differ by as much as an order of magnitude, but the models do agree that some of the highest levels of radioactivity from Fukushima will be observed in Canadian waters.

The Fukushima radioactivity can be identified by the presence of ^{134}Cs which has a half-life of about 2 y. Owing to its relatively short half-life (compared to that of 30 y for ^{137}Cs) virtually all of the ^{134}Cs from fallout from atmospheric nuclear weapons tests in the 1950s and 1960s has been eliminated by radioactive decay. As a result, the detection of any ^{134}Cs is a certain indicator of the presence of Fukushima radioactivity. Further, since the ratio of ^{134}Cs/^{137}Cs was about 1 for material discharged during the accident, the contribution of Fukushima to the ^{137}Cs inventory in the ocean can be simply estimated from the measured ratios, knowing the time between sample analysis and the accident itself. This provides the fundamental rationale for a Fukushima monitoring program.

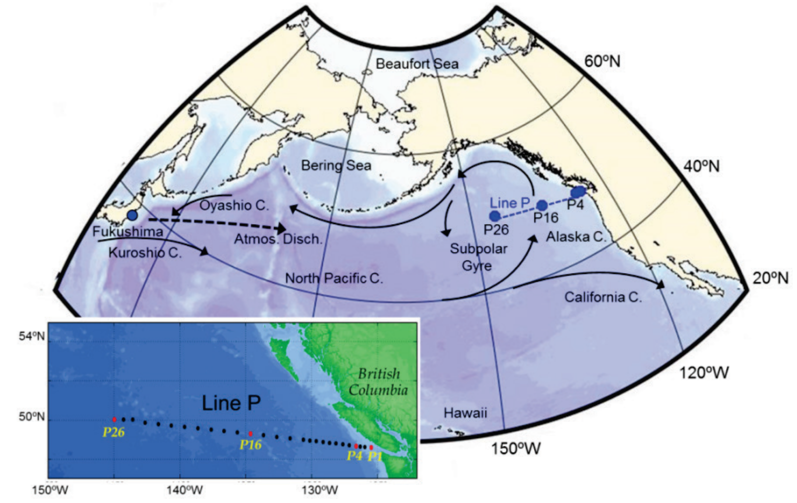

Fig. 1 Location of the site of the Fukushima Daiichi Nuclear Power Plant accident in Japan. Current (C.) systems transported direct oceanic discharges of Fukushima radioactivity eastward across the Pacific and then northward across Line P at the eastern edge of the subpolar gyre. Dashed line shows general northeastward direction for the transport of atmospheric discharges.

2. Monitoring program

The Fisheries and Oceans Canada (DFO) monitoring program for the sampling and analysis of seawater for the radio-isotopes, ^{134}Cs and ^{137}Cs, was initiated shortly after the accident in June, 2011. The purpose of this program was to: (1) evaluate the potential exposure of Canadian marine resources to Fukushima radioactivity and (2) determine the accuracy and future reliability of global circulation models in their predictions of radioactivity transport from Fukushima through the eastern North Pacific. Seven sampling operations were conducted in June of 2011, 2012 and 2013 and February and August of 2014, 2015 and 2016, respectively, on the CCGS *John P. Tully* on Line P, which extends westward from Victoria (Fig. 1). Large volume water samples were collected at multiple water depths to a maximum of 1000 m at Sta. P4 on the Canadian continental shelf and at Sta. P26, approximately 1500 km offshore. Forty to 60 litres of seawater were collected at each sampling depth and the water was pumped through a cartridge containing KCFC resin which selectively adsorbs Cs ions from seawater. The resin cartridges were shipped to the radioanalytical laboratory at Bedford Institute of Oceanography where they were analysed on a liquid nitrogen cooled Ge gamma ray detector for Cs isotopes.

3. Major achievements

The 2011 results reveal the presence of fallout ^{137}Cs at levels of less than 2 Bq/m^3 in seawater while levels of ^{134}Cs were below the detection limit. These data supplied an important baseline against which subsequent measurements of Fukushima radioactivity can be evaluated. The 2012 results showed the presence of ^{134}Cs at Sta. P26 but not at Sta. P4, indicating that the Fukushima signal was approaching the Canadian continental shelf but had not yet arrived by June, 2012. The 2013 results revealed the presence of ^{134}Cs in the upper 100 m along the entire length of Line P indicating that the Fukushima signal had fully arrived in Canadian waters. Levels of ^{137}Cs from Fukushima were estimated to be about 1 Bq/m^3 in June, 2013 which is equivalent to the previous background levels of ^{137}Cs from atmospheric fallout. These levels had increased to values of about 2–4 Bq/m^3 by February and August, 2014 and then to levels of 5–6 Bq/m^3 by February, 2015 at Sta. P26 as a result of the arrival of the Fukushima plume. ^{137}Cs levels continued to increase at the inshore shelf station, Sta. P4, in 2015–2016 to 4 Bq/m^3 and at Sta. 16 to 7 Bq/m^3 by February, 2016. However, the ^{137}Cs signal began to decline at the ocean interior station, Sta. P26, and by February, 2016 had returned to a value of 4 Bq/m^3. These levels of Fukushima ^{137}Cs are now equal to or higher than those in the western North Pacific with the exception of waters proximal to Fukushima itself. These results show that the main inventory of Fukushima radioactivity has shifted from the western to eastern North Pacific on a time scale of 4–5 years as predicted by ocean circulation models. The present levels of Fukushima ^{137}Cs off Canada are significant, but are still several orders of magnitude below those that would be considered to be a threat to the environment or human health.

4. Conclusions

The present monitoring results show that Fukushima inputs during 2012–2016 resulted in a factor of 5 increase in the fallout background for ^{137}Cs in seawater on Line P off the Canadian coastline. This increase in seawater concentrations would likely result in an increase in ^{137}Cs throughout the various components of the ecosystem. Models predict that ^{137}Cs levels will begin to level off on Line P in 2016 at concentrations of 5–7 Bq/m^3 and begin to decline in 2017–2018. Despite the dramatic rise in ^{137}Cs concentrations since 2013, this will only return eastern North Pacific waters to fallout ^{137}Cs concentrations that prevailed in the 1970s–1980s. DFO monitoring on Line P is currently planned for missions in February and August 2017 in order to observe the continued increase and subsequent leveling off in the Fukushima signal. The present results will be used to plan the frequency of future monitoring activities in 2018–2019. Currently, the DFO monitoring program for seawater is the only continuous monitoring program for Fukushima radioactivity in the Eastern North Pacific.

China

Report on Chinese Monitoring of Fukushima Radioactivity in Northwest Pacific

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1. Introduction

To better understand the distribution and impact of radionuclides released from the Fukushima nuclear accident (FNA), WG 30 members of China, following the WG Work Plan, have conducted the three major works since the 2015 PICES Annual Meeting: (1) Two cruises of marine radioactivity monitoring in the northwestern Pacific; (2) Study on the assessment method of marine radioactive environmental quality and the corresponding software development; (3) Radiological research on marine organisms in China.

2. Monitoring program

In order to understand the fate of radioactive contaminants after the Fukushima nuclear accident and to assess the relevant effect and radiological risk on the open ocean in the northwest Pacific, two cruises were implemented by the Third Institute of Oceanography, State Oceanic Administration (SOA) of China in September–October 2015 and May–June 2016 (Fig.1). During the two cruises, more than 200 seawater samples were sampled at 80 stations, and squid samples were collected at different stations. The seawater and squid samples were analyzed for artificial radionuclides ^{134}Cs, ^{137}Cs, ^{90}Sr, ^{110m}Ag, *etc*.

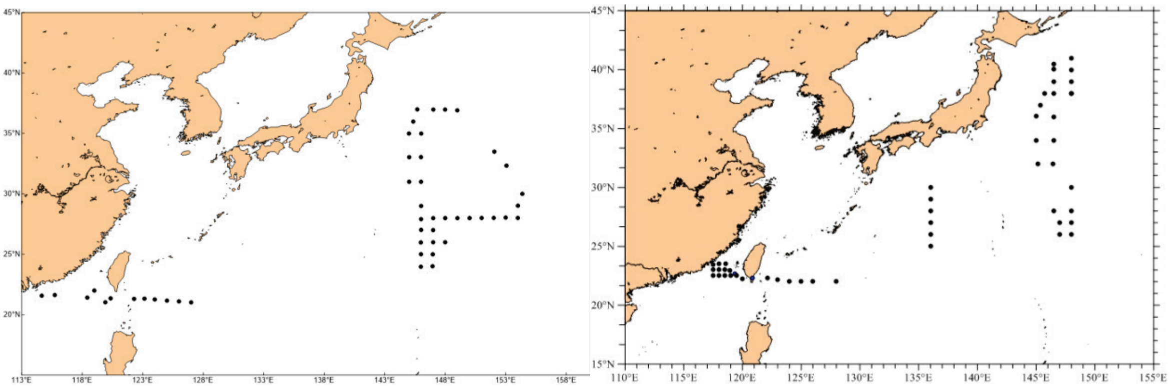

Fig. 1 The map of sampling areas (Left: cruise in September–October 2015; Right: cruise in May–June 2016).

3. Major achievements

3.1 Monitoring results of marine environment radioactivity in the northwestern Pacific

The radioactivity levels of artificial radionuclides (^{134}Cs, ^{137}Cs, ^{90}Sr, *etc*.) in seawater and marine biota samples were obtained, and the results showed that (a) ^{134}Cs still existed in the seawater of the North Pacific (Fig. 2); (b) Activities of ^{137}Cs and ^{90}Sr decreased to the range of background levels (Figs. 3 and 4); and (c) Radioactivity levels of ^{134}Cs and ^{110m}Ag were under the detection limit in the marine biota samples.

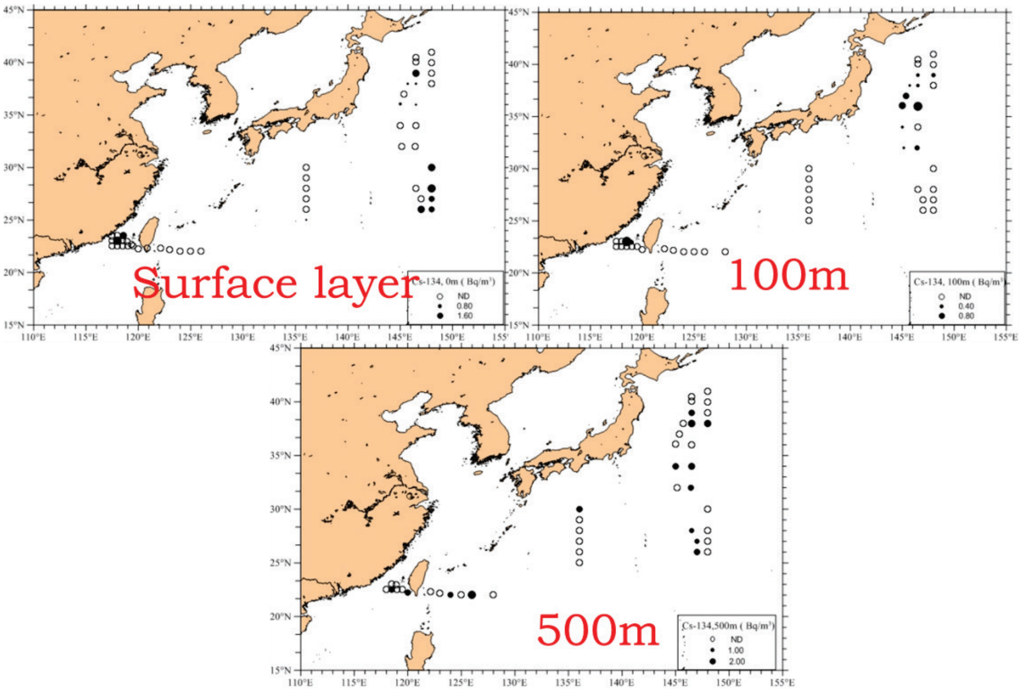

Fig. 2 Radioactivity of ^{134}Cs in different depths of seawater.

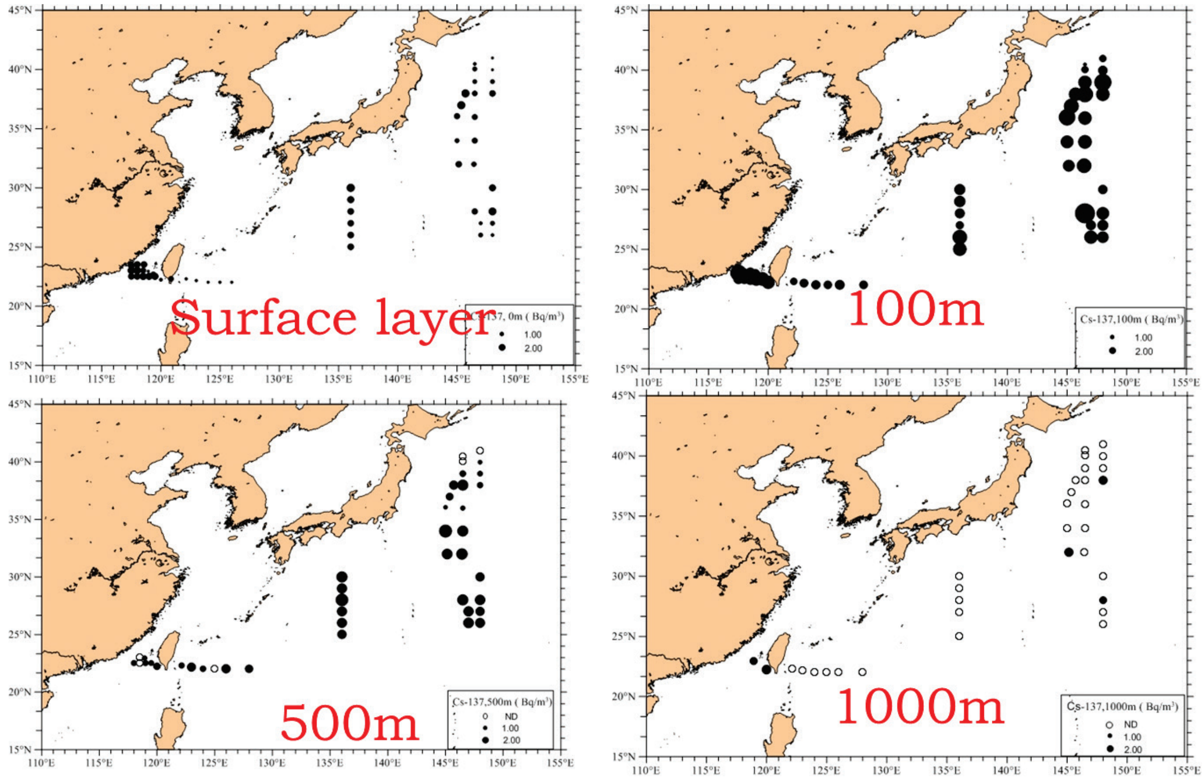

Fig. 3 Radioactivity of ^{137}Cs in different depths of seawater.

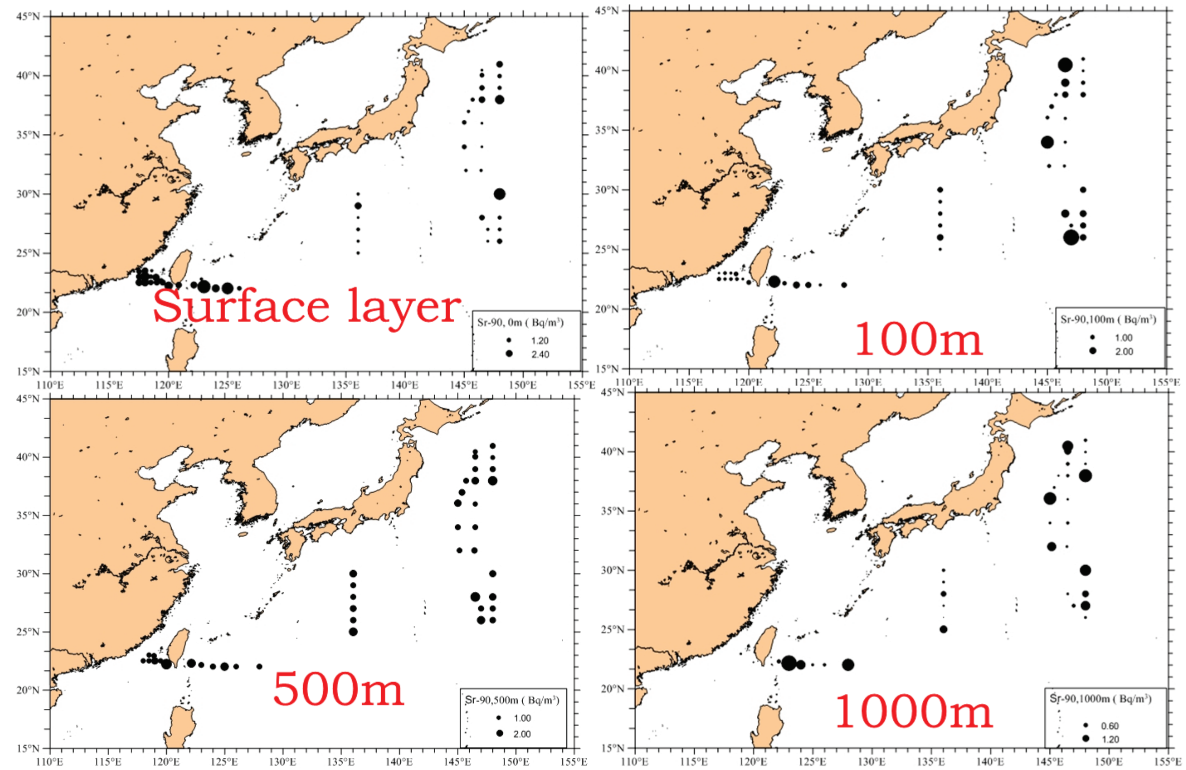

Fig. 4 Radioactivity of ^{90}Sr in different depths of seawater.

3.2 Assessment method of marine radioactive environmental quality

Nowadays there is increasing concern about radioactive pollution, especially from the Fukushima nuclear accident. All countries owning nuclear power plants are making every possible effort to prevent the environment from radioactive pollution by drawing up an effective management strategy. During a period of two years starting 2010, Chinese marine scientists investigated an integrated approach to the scientific, managerial and societal issues surrounding the environmental effects of contaminants emitting ionizing radiation, with an emphasis on marine biota and ecosystems, which is similar to ERICA of Europe and GRADED of USA. ^{110m}Ag, ^{58}Co, ^{60}Co, ^{134}Cs, ^{137}Cs, ^{3}H, ^{131}I, ^{40}K, ^{54}Mn, ^{226}Ra, ^{90}Sr, ^{232}Th, ^{238}U and ^{65}Zn are chosen as assessing radionuclides. Thirteen types of marine organisms are selected as reference organisms. This method contains three assessment functions. The first function is marine radioactive environmental quality grading, which includes four grades indicating safe to dangerous. The screening threshold between the first and the second grades is based on the corresponding radioactive background level. The screening threshold between the second and the third grades is based on the deduced safe activities of radionuclides for human beings. The screening threshold between the third and the fourth grades is based on the deduced safe activities of radionuclides for non-human organisms. The second function is radiation effort assessment of marine organisms, which adopts the ERICA ecosystem screening benchmark of 400 μGy/h. The third function is the risk of long-time discharge of low-level radioactive wastes. In order to simplify the related assessments, MREQAC v1.0 software has been drawn up (Fig. 5). MREQAC can be used in any Windows System, without installation. There are three models in the software and each of them corresponds to one function mentioned above, which are independent of each other and can be used simultaneously. The user just needs to start MREQAC and input the corresponding parameters, such as the activities of the environmental mediums, and the software can output the assessment results and save them as Excel documents automatically. It is powerful and easy to operate, and can meet the needs of the marine radioactive environmental quality assessments.

Fig. 5 Assessment software MREQAC for marine radioactive environmental quality.

3.3 Radiological research on marine organisms

The Laboratory of Marine Isotopic Technology and Environmental Risk Assessment, Third Institute of Oceanography, SOA, is focusing on radioecology and is currently performing a study on the effects of acute external exposure on the growth of marine organisms, such as the marine medaka *Oryzias melastigma* and cultured shellfish abalone, using an indoor culture system. In order to understand the half lethal dose of irradiation of marine organisms and its effect on growth and propagation, this study investigated the effects of acute radiation exposure of ^{137}Cs source of doses 1, 5, 10, 30, and 60 Gy on *O. melastigma* and of ^{60}Co source of 10, 30, 60, 150, and 400 Gy to an economically valuable shellfish abalone, respectively. The preliminary results showed that half lethal dose of abalone was 13.2 Gy under the ^{60}Co acute external irradiation and the feeding status of abalone at the high dose of γ irradiation was significantly reduced after a few days of incubation. For *O. melastigma*, its half lethal dose of ^{137}Cs irradiation was 26.5 Gy and the feeding status seemed to be not significantly different among the diverse treatments.

4. Conclusions

In the past year, China has implemented two cruises of marine radioactivity monitoring in the northwestern Pacific, set up an assessment method of marine radioactive environmental quality and corresponding software, and performed some radiological experiments on marine organisms. By the end of May–June 2016, ^{134}Cs still existed in the seawater of North Pacific; activities of ^{90}Sr and ^{137}Cs decreased to the range of background levels. Radioactivity levels of ^{134}Cs and ^{110m} Ag were under the detection limit in marine biota samples. The marine radioactive environmental quality software of China has proven to be powerful and easy to operate, and can meet the needs of the marine radioactive environmental quality assessments. Radiological research on marine organisms has produced some initial results in the past year.

Japan

Report on Japanese Research of Marine Radioactivity

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1. Introduction

After the Fukushima Dai-ichi Nuclear Power Plant (FDNPP) accident in March, 2011, detailed monitoring of radioactive materials is being continued in Japan. The monitoring is carried out mainly for radiocesium which is the most important nuclide in the FDNPP accident. The spatial and temporal changes of the contamination of marine environment are described in detail by the monitoring data. We can also get lots of information about the behaviors of radiocesium in the marine environment by analyzing the monitoring data. We briefly report on the situation of radioactivity contamination of the marine environment in the waters of East Japan and the progress of studies on environmental radioactivity in Japan.

2. Monitoring activities for marine environmental radioactivity

Many radioactivity monitoring projects related to the FDNPP accident are being conducted under the coordination of the Nuclear Regulation Authority (NRA) and Japan Fisheries Agency (JFA). Intensive radioactivity research on sea water, sea sediment and marine organisms in the waters off Fukushima Prefecture and the neighboring regions is being continued. A large amount of data obtained by these investigations is published on semi-real time via the internet. Most of the data for environmental radioactivity are available from the NRA's web site, http://radioactivity.nsr.go.jp/en/. Radioactivity data for marine organisms are also published on the JFA's web site, http://www.jfa.maff.go.jp/e/inspection/. The data set for the marine organisms includes more than 84,200 inspection results up to the end of October, 2016. Basic long-term radioactivity monitoring for environmental and dietary materials in Japan is also maintained by NRA. The data reports of the long-term radioactivity monitoring are available from the NRA-operated English website, http://www.kankyo-hoshano.go.jp/en/. The database includes monitoring data in the 15 areas around Nuclear Power Plants in Japan.

3. Status of the FDNPP accident to marine environment in the area near FDNPP

The status of radioactive materials in the fisheries products off the coast of Fukushima Prefecture and the neighboring regions leaked by the FDNPP accident were summarized in the report "Report on the Monitoring of Radionuclides in Fishery Products" published by JFA at http://www.jfa.maff.go.jp/e/inspection/. High radiocesium concentration of more than 1×10^4 Bq/kg was detected temporarily in sea water of the surrounding waters of FDNPP in early April, 2011 after which the radiocesium concentration decreased quickly after the direct leakage of highly contaminated water stopped. Although the level of radiocesium concentrations in sea water is slightly high in comparison with the level in the period before the accident, the decreasing trend is observed clearly. The level of radiocesium concentrations in sediment of the surrounding waters of FDNPP is in the range of 10 to several thousand Bq/kg in a dry state and concentrations still remain higher than those before the accident. Although the changing trends of the radiocesium concentration of sediment are different among sites, slow decreasing trends are observed at most of the monitoring sites. The inspection results of radiocesium concentrations for pelagic fishes show a rapid decrease in 2011, and most of the results are included in the range below 25 Bq/kg-wet after 2012 and in the range below 10 Bq/kg-wet in 2016. For the demersal fishes, slow but steady decreasing trends of radiocesium concentration are observed. In the period after April, 2015, inspection results exceeding the Japanese limit of 100 Bq/kg-wet have not been detected in marine organisms, and over 99% of inspection results for demersal fish was below 25 B/kg-wet in 2016.

4. Research in marine environmental radioactivity related to the FDNPP accident in Japan

The status of radioactive materials leaked by FDNPP accident into the marine environment has been investigated at many institutes. Modelling and simulation studies of the transport of radiocesium in the ocean have been performed at CRIEPI (Central Research Institute of Electric Power Industry) and JAEA (Japan Atomic Energy Agency). Tsumune *et al*. (2012, 2013) and Kawamura *et al*. (2014) investigated the transport process of radiocesium in the North Pacific by using a general circulation model and Tsumune *et al*. (2013) estimated the total amount of leaked radiocesium from the results of simulation. The survey data of radiocesium concentration in the marine environment (sea water, sea sediment) have been analyzed by IER (Institute of Environmental Radioactivity, Fukushima Univ.), JAMSTEC (Japan Agency for Marine-Earth Science and Technology), JAEA, MERI (Marine Ecology Research Institute) and FRA (*cf*. Kaeriyama, 2016). Kumamoto *et al*. (2014) and Kaeriyama *et al*. (2014, 2016) detected the southward transport of radiocesium by the North Pacific Subtropical Mode Water. Aoyama *et al*. (2015) showed the pathways of radiocesium in the upper layer of the North Pacific Ocean. Ambe *et al*. (2014) showed a detailed map of radiocesium concentration in the sea sediment off the coast of Fukushima Prefecture and adjacent area. Ono *et al*. (2015) investigated radiocesium bonded to the organic fraction of sediments. Kakehi *et al*. (2016) described the rapid diffusion process of radiocesium contained in river water at the river mouth. The radiocesium monitoring data for marine organisms have been investigated by Fukushima Prefectural Fisheries Experimental Station (FPFES) and FRA (2015). Wada *et al*. (2013), Sohtome *et al*. (2014) and Kaeriyama *et al*. (2015) showed the decreasing trends of the radiocesium concentration in fisheries products, benthic organisms and zooplankton, respectively. Wada *et al*. (2016) analyzed the radiocesium concentration data of marine organisms off Fukushima for the period 2011–2015 and showed the improving progress of radiocesium contamination. Shigenobu *et al*. (2014) performed a statistical evaluation of the extraordinarily-high value of radiocesium concentration of the fat greenling caught in the summer of 2012 and revealed that it was an extremely rare case. Recently, the detailed statistical evaluations of monitoring data have done by Okamura *et al*. (2016). Fujimoto *et al*. (2015) analyzed the radioactivity of the otoliths of fishes caught in the port of FDNPP. Tateda *et al*. (2013) and Tateda *et al*. (2015) investigated the contamination process of marine organisms off Fukushima Prefecture by using bio-kinetic models. Miki *et al*. (2016) summarized the results of strontium-90 measurements in marine fishes after the accident and confirmed that the strontium-90 contamination of marine fishes has remained at a lower level compared to radiocesium.

5. Dissemination of accurate knowledge about radioactivity contamination

The mitigation of the damage caused by non-scientific reports about radioactivity contamination is an important issue for society. Risk-communications with the public on marine food safety related to radioactivity are being conducted by JFA, the Fukushima Prefectural government, *etc*. For one of these activities, FRA published an easy-to-read pamphlet explaining the basic knowledge and status of the contamination for public (https://www.fra.affrc.go.jp/bulletin/radioactivity_pamphlet2015/cover_index.html, in Japanese). FPFES and FRA present monitoring and research results about radioactivity contamination in the waters off Fukushima Prefecture at meetings of the Fukushima Prefectural Federation of Fisheries Co-operative Association every month to help fishermen understand the information on restarting the fishery.

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Korea

Report of Republic of Korea for 2016 marine radioactivity-related activities

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[2]KoreaNational Institute of Fisheries Science, Busan, Republic of Korea

1. Introduction

Marine radioactivity-related activities in Republic of Korea include monitoring in Korean waters and modeling. Monitoring of radionuclides has continued on a regular basis since 1994. In particular, the Korea Institute of Nuclear Safety (KINS) and National Institute of Fisheries Science (NIFS), formerly National Fisheries Development Research Institute (NFDRI), have carried out the Marine Environmental Radioactivity Survey (MERS) in the sea regions off the coast of Korea based on the Korean Atomic Safety Law 105 through their collaboration. Since the 2011, enhanced monitoring activities have been carried out arising from the Fukushima nuclear accident. Prior to 2011, the sampling of MERS had been done biannually, but the survey frequency and area were extended after the Fukushima accident. KIOST (Korea Institute of Ocean Science and Technology) was involved on a limited scale in monitoring the distribution of artificial radionuclides in the seawater of the northwestern Pacific Ocean over the period of 2012 to 2014. Since 2011 KIOST has carried out research on biological concentration factors affecting the major marine organisms in Korean waters.

In addition to monitoring, considerable use of modeling has been made in Korea. In 2015 KIOST focused on the development of the Northwestern Pacific marine biota model which takes into account both the pelagic and benthic food webs. Further extension of the model was made in 2016. Brief summary of modeling activities are described in this report along with monitoring activities.

2. Marine radioactivity-related research activities

2.1 Monitoring-related activities

Figure 1 shows MERS monitoring stations in 2015. After the Fukushima accident, regular samplings were carried out seasonally at a total of 27 stations, and monthly or bimonthly samplings were additionally carried out at a total of 6 stations.

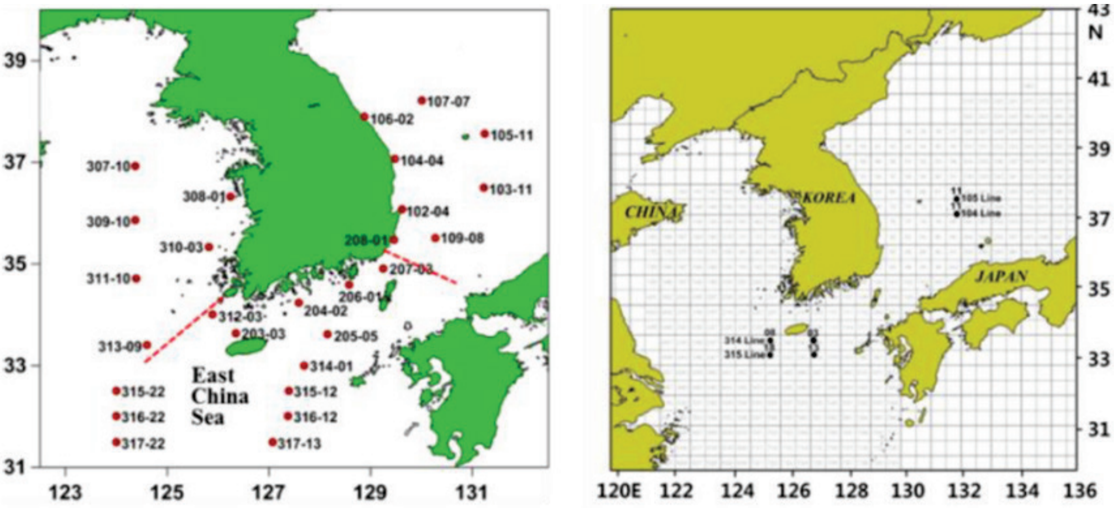


Fig. 1 Monitoring stations in Korean waters: (left) locations of 27 sampling stations, (right) locations of 6 intense sampling stations.

NIFS analyzed long-term variation in major radionuclides (^{137}Cs, ^{3}H, $^{239+240}$Pu and ^{90}Sr) in Korean waters over the period of 1994 to 2015. There are fluctuations in the concentration values but an overall decreasing tendency is evident (Fig. 2). It is noted that ^{3}H has values significantly higher than the other three radionuclides.

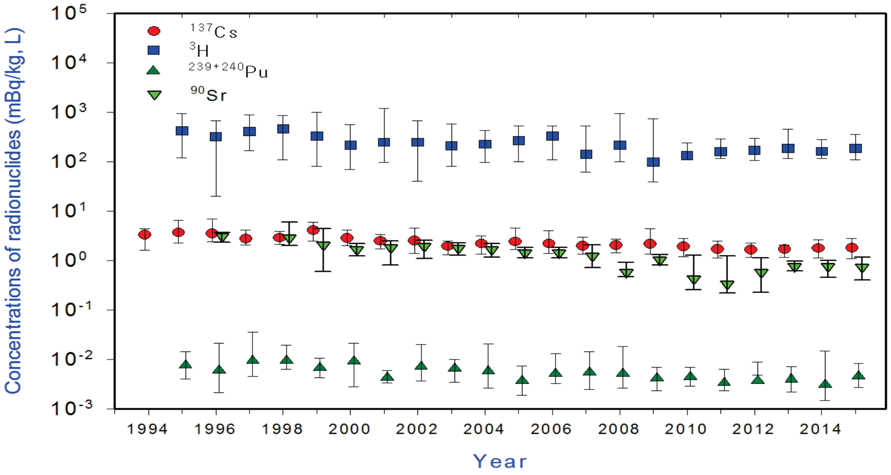


Fig. 2 Long-term variation in radionuclides (^{137}Cs, ^{3}H, $^{239+240}$Pu and ^{90}Sr) in Korean waters from 1994 to 2015.

Over the period of 2015 to 2016, the Marine Radionuclide Research Group of KIOST collected samples of major marine organisms caught from the sea around Korean Peninsula (Fig. 3) to understand the distributions of radionuclides in biota. Lab experiments have been carried to investigate the concentration factors for individual marine organisms. Estimated values for ^{137}Cs and $^{239+240}$Pu are shown in Figure 4.

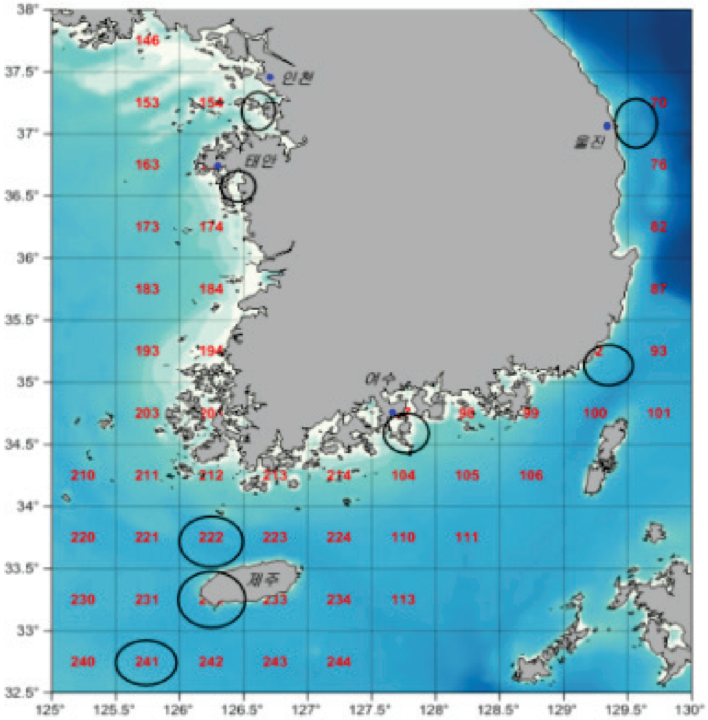


Fig. 3 Locations where samples of marine organisms were collected by KIOST from 2015 to 2016 to estimate biological concentration factors.

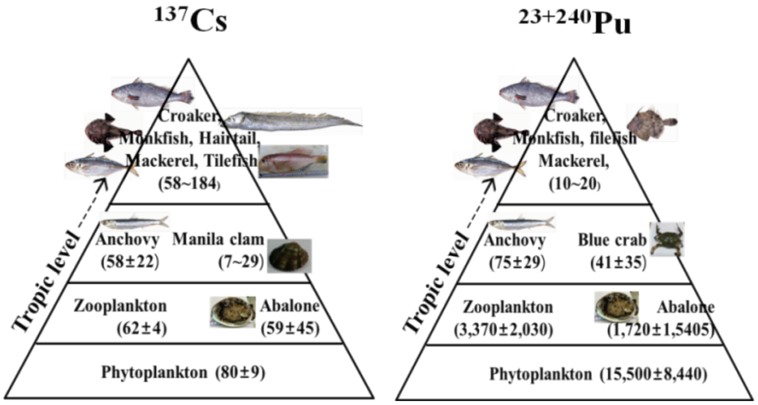


Fig. 4 Change in concentration factors of ^{137}Cs and $^{239+240}$Pu according to trophic levels estimated from laboratory experiments.

2.2 Modeling-related activities

Most of the marine radioactivity modeling activities in Korea have been carried out in cooperation with China, Korea and Ukraine. Since December 2011, KIOST has been carrying out joint research with FIO the First Institute of Oceanography, State Oceanic Administration (SOA) of China for the development of marine radioactivity transport and fate models. The first stage in cooperative research was finished at the end of 2014 and the second stage in cooperation started in December 2014. Research includes teamwork in modeling of circulation, waves, suspended sediment and radioactivity transport. FIO/KIOST developed a global model to predict the long-term dispersion of radionuclides released from the Fukushima Dai-ichi Nuclear Power Plant. In 2015 and 2016 the transport of radionuclides ^{137}Cs and ^{134}Cs was simulated with North Pacific-scale atmospheric input along with the previously considered direct release to the ocean. Figure 5 shows part of simulated results compared with Canadian observations in the northeastern Pacific. Details on Korea–China cooperative research can be found at http://www.mrcor.org.

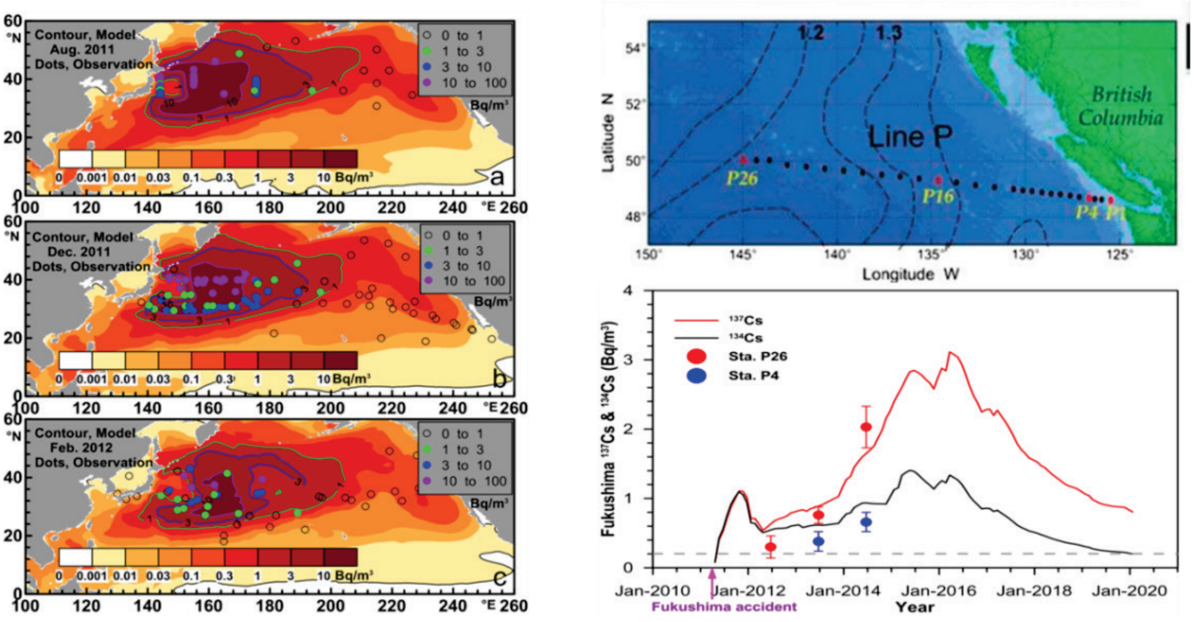


Fig. 5 Simulated results of ^{134}Cs and ^{137}Cs transport in the North Pacific using a global model with atmospheric and direct release inputs (left panels). Model validation results through the comparison with Canadian observations at stations along Line P (right panels).

Considerable effort has been put into the modeling of artificial radionuclides. Since 2012 researchers from IMMSP (Institute of Mathematical Machine and System Problems, Ukraine) have been a part of the joint research Korea-China team, attending the Korea-China workshop held at Qingdao and preparing joint research papers on biota modeling. Two biota-related papers which are concerned with the influence of the global fallout and Fukushima-induced radionuclide releases of ^{137}Cs and ^{90}Sr on marine organisms through the pelagic marine food web around the Fukushima Dai-ichi and adjacent seas in NW Pacific were jointly published in 2014. The model equipped with a pelagic marine food web is called BURN-POSEIDON. In 2015 and 2016 the benthic food web was added to take into account the influence of radioactivity-contaminated bottom sediments on the marine organisms. Application of the so called Extended-BURN-POSEIDON model was made for Fukushima-derived ^{137}Cs and a related paper was jointly published in 2016. In the course of applying ^{90}Sr, the need for a model extension was raised. Close examination revealed that use of the single target tissue approach in BURN- and Extended-BURN-POSEIDON caused underestimation of ^{90}Sr concentration in fishes. The model was thereafter extended to a multi-target tissue approach and is called the Multi-BURN-POSEIDON model. In practice, three target tissues such as flesh, bone and organs were considered for fishes. Figure 6 shows the marine food webs for Extended-BURN-POSEIDON and Multi-BURN-POSEIDON.

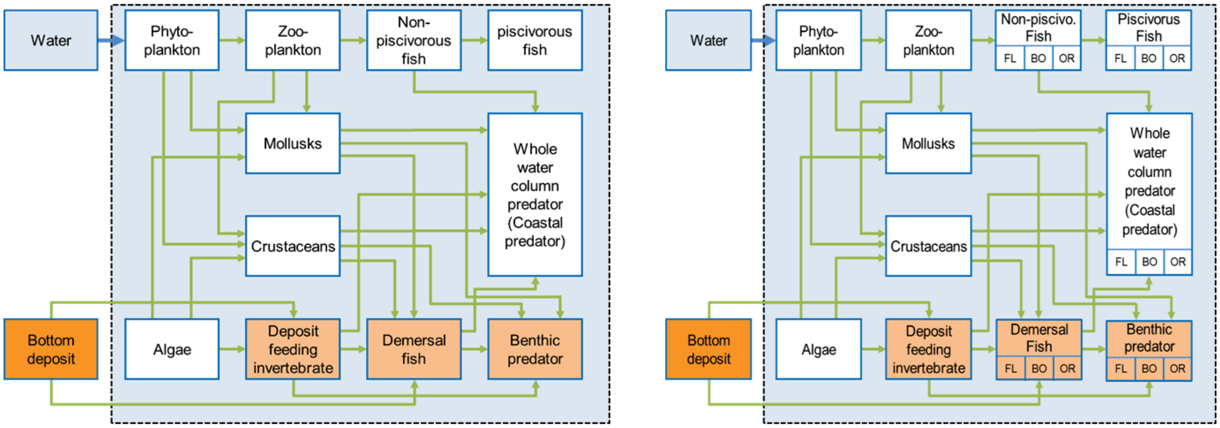
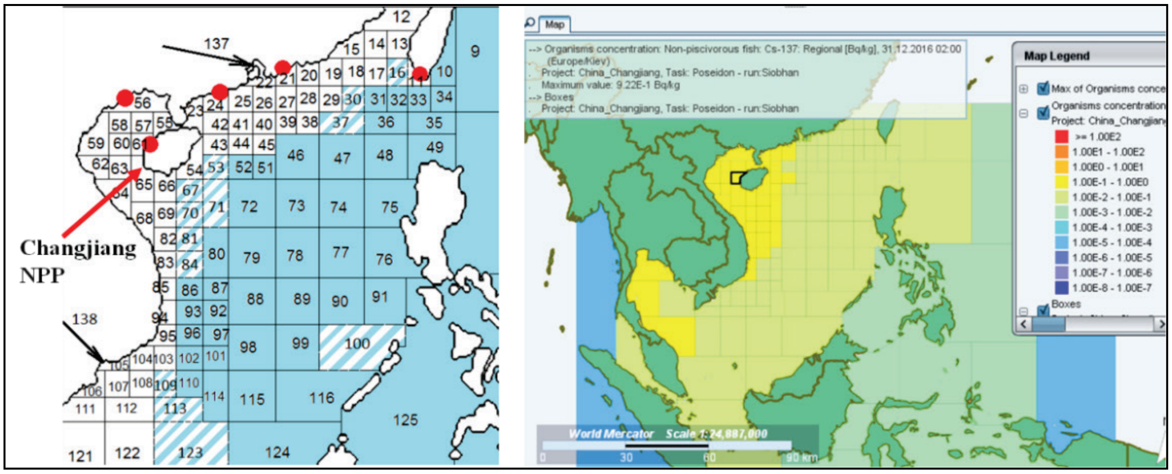


Fig. 6 Marine food webs considered in (left) Extended-BURN-POSEIDON; (right) Multi-BURN-POSEIDON models.

As one of the cooperative activities between China–Korea–Ukraine, the BURN-POSEIDON model has been implemented for the South China Sea. Figure 7 shows the horizontal box configuration and a simulation example according to a hypothetical release from the Changjing Nuclear Power Plant (NPP).



--> Organisms concentration: Non-piscivorous fish: Cs-137: Regional [Bq/kg], 31.12.2016 02:00 (Europe/Kiev)
. Project: China_Changjiang, Task: Poseidon - run:Siobhan
. Maximum value: 9.22E-1 Bq/kg
--> Boxes
. Project: China_Changjiang, Task: Poseidon - run:Siobhan

Fig. 7 BURN-POSEIDON model for the South China Sea: (left) horizontal box configuration, (right) simulated concentration of ^{137}Cs in non-piscivorous fish after 1 year following a hypothetical release from the Chanjiang NPP.

3. Major achievements

Monitoring in Korean waters shows that radioactivity concentration remains at the background level, indicating that up to now there is little impact of the Fukushima-derived radionuclides on Korean waters. Analysis of marine organism samples in Korean waters from 2012 to 2015 also indicates that levels of ^{137}Cs concentration also remain at the background level. Calculation of biological concentrations factors has revealed considerable discrepancies with recommended values in 2004 by IAEA.

International cooperation in the development of transport and biota models has been carried out. The fact that FIO/KIOST simulation of the transport of ^{134}Cs and ^{137}Cs in the North Pacific produced results which are in reasonable agreement with observations may be one of the achievements in the modeling field. Cooperation in biota modeling may be considered as the most meaningful achievement. Long-term applications of the Extended-BURN-POSEIDON model to Fukushima-derived ^{137}Cs were made taking into account the global fallout from 1945 and the Fukushima-derived atmospheric and direct oceanic releases. In 2016, a paper published in *Biogeosciences* described how and why the concentration of ^{137}Cs in benthic fishes remains at a relatively high level, when comparing pelagic fishes. Introduction of a multi-target tissue model which has solved the problem of underestimating ^{90}Sr in previous single target tissue model may be one of the most important achievements in radioactivity biota modeling.

4. Conclusions

Marine radioactivity monitoring activities by Republic of Korea have been carried out on a limited scale in Korean waters. International cooperative research may be required to get the more comprehensive data sets. Considerable discrepancies have been found in the biological concentration factors between the values analyzed by KIOST and those recommended by IAEA. Further investigation is obviously needed on this matter, possibly through the internal cooperation, for example, between the Third Institute of Oceanography, China, and KIOST.

In addition to the development of Extended-BURN-POSEIDON equipped with pelagic and benthic food webs, preliminary results from the further refined model, Multi-BURN-POSEIDON, are very encouraging. The model might be an essential component of the decision supporting system for future accidents in the Northwestern Pacific region. Along with the biota model, an advanced modeling system for predicting marine radioactivity transport for the Yellow and East China seas is underway. A report on more detailed results can be expected in 2017.

USA

Report on Marine Radioactivity Work 2016

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1. Introduction

Over the last year, Oregon State University has engaged in: (1) Public outreach via posters, flyers and a display stand, (2) Further measurements of ^{134}Cs and ^{137}Cs in North Pacific albacore tuna (*Thunnus alalunga*), (3) Bystander effect modelling from first-principles, (4) Laying groundwork for future work with polygonal mesh models. Measurements and public outreach have also been conducted in the U.S. by the Our Radioactive Ocean project.

2. Public outreach

In the years since the original large-scale release at Fukushima Daiichi Nuclear Power Plant (FDNPP), the rate of inquiry and concern from members of the general public has declined significantly. Reports of ^{134}Cs detection on the U.S. West Coast through the Our Radioactive Ocean project sparked new interest from members of the public and news organizations, but overall there does not seem to be a large outstanding concern public body at this time. The citizen-science program of Our Radioactive Ocean provided concerned members of the public the opportunity to engage in answering their own apprehensions first hand. In Oregon, joint work between Oregon State University, Oregon Sea Grant and NOAA allowed for the development of an easy-to-understand flyer regarding the highest observed levels of FDNPP-derived radioactivity in U.S. foodstuffs, including a display pictured in Figure 1.

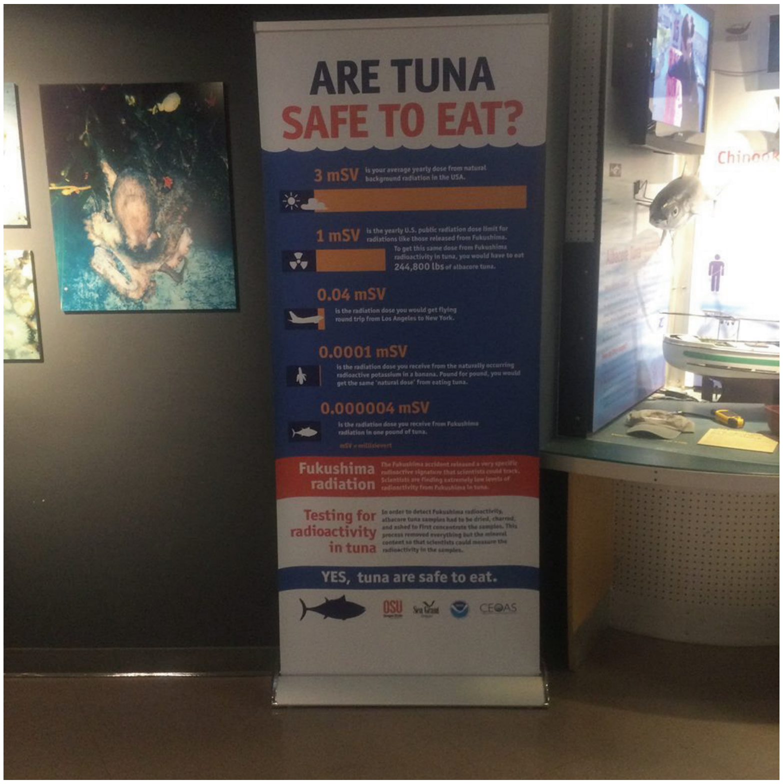

Fig. 1 Display stand at Hatfield Marine Science Center, Newport, Oregon.

3. Measurements

Research continues at Oregon State University to measure the concentrations of ^{134}Cs and ^{137}Cs in *Thunnus alalonga* found along the U.S. West Coast. In the last few years, the albacore fishery in southern California has not been as active as it was historically, which has drastically limited the number of samples that could be collected from the southern California region. Nonetheless, approximately 200 albacore carcasses were collected and continue to be processed and analyzed for radiocesium concentrations. These figures inform human health concerns and dose calculations to the albacore, both of which peaked in 2012 and never reached levels that would require intervention for human or ecological safety. Besides some water sampling done by Oregon State University in partnership with NOAA, ^{134}Cs and ^{137}Cs concentrations have been measured substantially through the Our Radioactive Ocean project (Fig. 2).

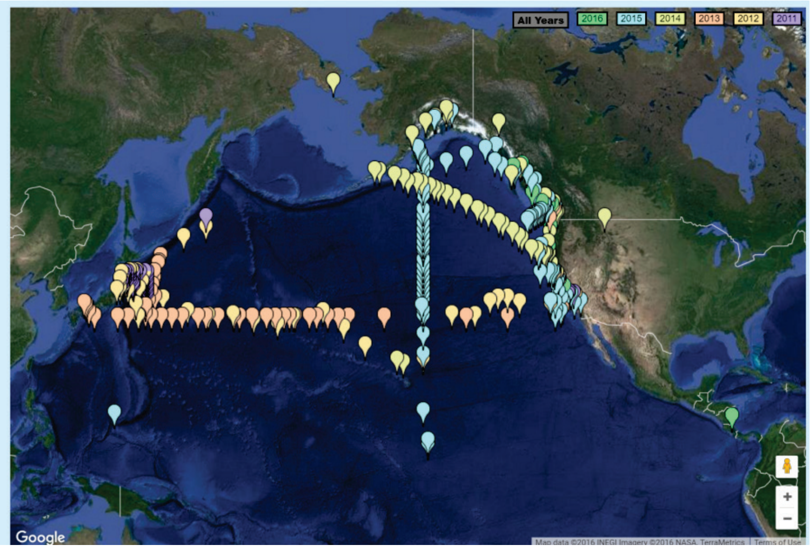

Fig. 2 Our Radioactive Ocean http://www.ourradioactiveocean.org/results.html provides members of the public with concentrations of radiocesium both at sea and on the shoreline, largely through a crowd-funded citizen-scientist program.

Work continues at Oregon State University to measure the tissue densities and elemental compositions in select species. Both play a significant role in rates of photon and electron interactions and ultimately, differences in dose conversion coefficients for both internal and external radiation sources.

4. Bystander effect via First Principles

Ongoing research at Oregon State University is modelling the mechanism for radiation-induced effects in biota by coupling models operating on different time scales. This should allow for the prediction of radiation sickness as well as tumor outcomes in a manner that include the so-called bystander effect, wherein cells that did not receive a dose will die due to neighboring cells receiving a dose.

5. Groundwork for 2017 work

In the 2017 groundwork, a series of 26 high-resolution diffusible iodine contrast enhanced micro-CTs have been made of numerous marine organisms, including forage fish, mollusks, krill, and shrimp (Fig. 3). These images will be used as part of the development of a new protocol for the creation of 3D dosimetric models of biota. By developing the new protocol using exclusively open-source software, the opportunity will be present to collaborate with scientists abroad in producing and refining the models. Further, the models will be built using polygonal surface meshes rather than voxels, allowing for more realistic curvature and fine-scale structures without forcing exceedingly high computational requirements for larger, more homogenous portions of a given model.

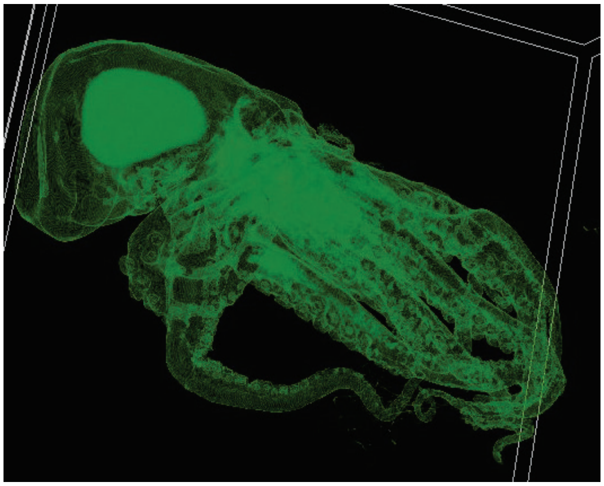

Fig. 3 Prototype surface rendering of a juvenile octopus.

WG 30 Endnote 4

Proposal for a 1-year extension of WG 30

1. Achievements to date

1.1 Working group meetings in the PICES annual meetings
- The 1st Working Group meeting during PICES-2013 in Nanaimo, Canada;
- The 2nd Working Group meeting during PICES-2014 in Yeosu, Korea;
- The 3rd Working Group meeting during PICES-2015 in Qingdao, China;
- The 4th Working Group meeting during PICES-2016 in San Diego, USA.

1.2 Paper Sessions and workshops at PICES Annual Meetings
- Submitted to MEQ Paper Session at PICES-2013;
- Submitted to MEQ Paper Session at PICES-2014;
- Convened the first workshop (W5) on "*Monitoring and assessment of environmental radioactivity in the North Pacific*" at PICES-2015;
- Convened the second Workshop (W10) on "*Distribution and risk analysis of radionuclides in the North Pacific*" at PICES-2016.

1.3 Presentations and posters
- 40 oral presentations including 4 invited presentations;
- 6 posters.

2. The reasons for extension
- To collect more data on radioactivity to support the conclusion on the risk assessment of the radionuclides from the FNA in the North Pacific for the final report, as the Fukushima-associated release continues to evolve across the North Pacific;
- To improve the numerical simulation method for modeling the transportation of radioactive material in the Northwest Pacific;
- To complete dosimetry solutions to biota in ecosystems of the North Pacific;
- To complete a scholarly publication on monitoring and assessment of the radioactivity in the Northwest Pacific, and a short brochure summarizing the results to come out of WG 30;
- To collaborate with SCOR Rio 5 in August 2017 [tentative];
- To complete the final report of WG-30.

3. New plan (November 2016–December 2017)
    - Now–March 15: Finish and submit member country part report;
    - March 15–April 24: Finish the first version of manuscript and the brochure of the WG 30;
    - April 25–May 15: Finish the first circulation and revise the manuscript;
    - May 16–June 15: Finish the second version of manuscript;
    - June 16–July 15: Finish the second circulation and revise the manuscript;
    - July 16–August 15: Finish the third version of manuscript and submit ideas, framework, texts and figures about the new paper;
    - August 15–before the PICES-2017 annual meeting: Discuss and draft the new paper;
    - 2-day WG 30 business meeting at PICES-2017: All the members review and complete the final report and new paper manuscript at PICES-2017.
    - December: Submit the final report and the new paper manuscript to the PICES.

WG 30 Endnote 5

Outline and assignment of the WG 30 final report and time schedule

Final Report of Working Group 30 on *Assessment of Marine Environmental Quality of Radiation around the North Pacific*

Acknowledgements (China and USA)
Executive Summary (All member countries)
1 Background (All member countries)
2 Level and Trend of Marine Radioactivity in North Pacific
  2.1 Coastal Waters of Japan (Japan)
    2.1.1 Seawater
    2.1.2 Biota
    2.1.3 Sediment
    2.1.4 Summary
  2.2 Northwest Pacific (China, Japan, Korea)
    2.2.1 Seawater
    2.2.2 Biota
    2.2.3 Sediment
    2.2.4 Summary
  2.3 Off-shore Waters of North America (Canada, USA)
    2.3.1 Seawater
    2.3.2 Biota
    2.3.3 Sediment
    2.3.4 Summary
  2.4. Coastal Waters of China (China)
    2.4.1 Seawater
    2.4.2 Biota
    2.4.3 Sediment
    2.4.4 Summary
  2.5. Coastal Waters of Korea (Korea)
    2.5.1 Seawater
    2.5.2 Biota
    2.5.3 Sediment
    2.5.4 Summary

3 Potential Radiological Impact on Marine Species (USA, China)
  3.1 Assessment Method
  3.2 Assessment Result
  3.3 Summary
4 Technical Progress in Marine Radioactivity Monitoring, Prediction and Radiological Risk Assessment
  4.1 Modeling and Prediction (Korea)
  4.2 Innovation of Monitoring Devices (China)
  4.3 Voxel Model etc. for Radiological Dose Assessment (USA, China)
  4.4 Radiological Risk Assessment Tools (China, USA)
  4.5 Summary (Korea, China, USA)
5 Inventory of Expertise and Programs Related to Marine Radioactivity in PICES Member Countries
  5.1 Marine Radioactivity Expert Database (All member countries)
  5.2 National Research and Monitoring Programs and Collaboration Initiatives (All member countries)
6 Collaboration between PICES WG 30 and Other Scientific Organization and between Member Countries (All member countries)
7 Summaries and Recommendations (All member countries)

Appendices
Appendix 1 WG 30 Terms of Reference (China and USA)
Appendix 2 WG 30 Membership (China and USA)
Appendix 3 Other Products of WG30 (All member countries)
Appendix 4 Meeting Reports and Workshop Summaries from the Previous PICES Annual Meetings Related to the WG 30 (USA and China)

II. Time schedule (Nov 2016-Dec 2017)

(1) Now–March 15: Finish and submit different part reports of the WG 30 Final Report by all member countries to Kathy and Yusheng.
(2) March 15–April 24: Compile the first version of manuscript (M1 of the WG 30 Final Report).
(3) April 25–May 15: Revise the manuscript (M1) and finish the 1st circulation by all member countries.
(4) May 16–June 15: Finish the second version of manuscript (M2).
(5) June 16–July 15: Revise the manuscript (M2) and finish the 2nd circulation by all member countries.
(6) July 16–August 15: Finish the 3rd version of manuscript (M3); and submit ideas, framework, texts and figures about the new paper by all member countries.
(7) August 15 – before PICES-2017: Discuss and draft the new paper.
(8) 2 days of the WG 30 business meeting during PICES-2017: All the WG 30 members review and revise the M3 and new paper manuscript.
(9) October–November: Complete the final report and new paper manuscript.
(10) December: Submit the WG30 Final Report and the new paper manuscript to PICES Secretariat.