IAEA Review of Safety Related Aspects of Handling ALPS Treated Water at TEPCO's Fukushima Daiichi Nuclear Power Station

Third Interlaboratory Comparison on the Determination of Radionuclides in the Marine Environment

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EXECUTIVE SUMMARY

In 2021, the IAEA started its review of safety related aspects of handling ALPS (Advanced Liquid Processing System) treated water at TEPCO's Fukushima Daiichi Nuclear Power Station (FDNPS). Consistent with the request from the Government of Japan, the IAEA statutory functions and the mandate of the Task Force, the scope of the IAEA review is tailored to assessing safety related aspects of the implementation of Japan's *Basic Policy on Handling of ALPS Treated Water at the Tokyo Electric Power Company's Holdings' Fukushima Daiichi Nuclear Power Station* against the IAEA's Safety Standards. The approach outlined in the Basic Policy is to conduct a series of controlled discharges of ALPS treated water into the sea ('batch discharges') over a period of decades.

Consistent with the relevant IAEA's Safety Standards, TEPCO is required to determine the characteristics and activity of the ALPS treated water (e.g., through the radiological environmental impact assessment) to be discharged into the sea, and to establish and implement monitoring programmes to ensure that public exposure due to the discharges is adequately assessed and that the assessment is sufficient to verify and demonstrate compliance with the authorization granted by the Nuclear Regulation Authority (NRA).

To conduct its safety review, the IAEA has organized the work of the Task Force into three main components, the assessment of protection and safety; regulatory activities and processes; and sampling, independent analysis and data corroboration. The latter activities include three elements:

- Sampling, analysis and interlaboratory comparison for ALPS treated water from the FDNPS.
- Sampling, analysis and interlaboratory comparison for environmental samples (e.g., seawater, fish) from the surrounding environment of FDNPS.
- Assessment of the capabilities of dosimetry service providers involved in the monitoring of internal and external radiation exposure of workers at FDNPS.

The IAEA's sampling, independent analysis and data corroboration activities also include a review of sampling and analytical methods used by TEPCO and any other relevant technical institutions.

The corroboration of source and environmental monitoring conducted by TEPCO and relevant Japanese authorities is based on interlaboratory comparisons (ILCs). ILCs, along with proficiency tests (PTs), are standard methods for laboratories to assess the quality of their measurement results in comparison with those of other participating laboratories, and to identify any potential improvements. PTs involve the evaluation of performance against pre-established criteria whereas ILCs involve the organization, performance, and evaluation of measurements on the same or similar items by two or more laboratories in accordance with predetermined conditions.

For this third ILC to corroborate the results of environmental monitoring under the IAEA's ALPS safety review, samples of seawater, sediment, fish and seaweed were taken in October 2024 from offshore locations and a fish market close to FDNPS.

Extensive monitoring of the marine environment around the FDNPS is conducted according to the Comprehensive Radiation Monitoring Plan (CRMP). TEPCO and other relevant Japanese authorities including the NRA, the Ministry of the Environment (MOE), and the Japan Fisheries Agency (FAJ), have responsibilities under the CRMP. Enhancements to the CRMP to specifically address the discharge of ALPS treated water were introduced in March 2022. This ILC constitutes the second corroboration by the IAEA of the results of this monitoring since the discharges started in August 2023.

This publication reports the results of the third ILC. It describes the joint sampling mission undertaken to collect seawater, sediment, fish and seaweed samples with observation from experts from the IAEA

and participating third-party member laboratories of the IAEA ALMERA network (Analytical Laboratories for the Measurement of Environmental Radioactivity)[1]; the analytical techniques used by participating laboratories – from Japan (participating on behalf of the Japanese authorities); the IAEA and the participating ALMERA network laboratories; the measurement results and the statistical evaluation of the results.

In total, ten laboratories undertook analyses and reported results for the ILC. Analyses were undertaken by Japanese laboratories participating in marine monitoring relevant to the ALPS treated water discharges within the CRMP and by the following two IAEA Nuclear Sciences and Applications Laboratories:

- IAEA Marine Environment Laboratories, Radiometrics Laboratory (RML), Monaco;
- Isotope Hydrology Laboratory (IHL), Vienna, Austria.

Under the coordination of the IAEA, selected third-party laboratories – Third Institute of Oceanography, Ministry of Natural Resources, China; the Korea Institute of Nuclear Safety (KINS), Republic of Korea; and the Spiez Laboratory, Switzerland – all members of the ALMERA network with demonstrable competence in the methods required, also conducted analyses of samples as ILC participants.

The results of the analyses undertaken at each laboratory were reported to the IAEA. For results that could be intercompared (i.e. for radionuclides for which activity concentrations above detection limits were reported by at least two laboratories) a statistical evaluation to assess agreement was carried out by the IAEA. The results are presented in tables and charts in this report.

Although some discrepancies were found, their small number is notable given that the analytical methods are often complex (e.g. for OBT, TFWT and ^{14}C in fish) and that higher uncertainties are usually associated with complex analyses of low, and close to detection limit, levels. There were no order of magnitude variations, and no systematic deviations identified between the results reported by Japanese laboratories and those reported by the IAEA and the ALMERA member laboratories. Therefore, despite the discrepancies, the key findings of this ILC are:

- Sample collection procedures followed the appropriate methodological standards required to obtain representative samples.
- Japanese laboratories have reported accurate results that demonstrate a high degree of proficiency.

The IAEA notes that these findings provide confidence in Japan's capability for conducting reliable and high-quality monitoring related to the discharge of ALPS treated water.

Additional ILCs will be conducted in the future for ALPS treated water and environmental samples, as well as occupational radiation protection. Future ILCs will continue to allow for an assessment of Japan's capability to evaluate any changes in the levels of relevant radionuclides in the marine environment, relative to the baseline.

Furthermore, the corroboration of environmental monitoring complements a separate project – NA3/38 Marine Monitoring: Confidence Building and Data Quality Assurance – addressing the quality of data from marine monitoring undertaken in Japan following the accident at FDNPS. Through project NA3/38, which has been implemented since 2014, the IAEA is assisting the Government of Japan in ensuring that sea area monitoring carried out under the regularly updated CRMP is comprehensive, credible and transparent and is helping to build confidence of the stakeholders in the accuracy and

[1] More information on the ALMERA network is available from the following website: https://analytical-reference-materials.iaea.org/almera.

quality of the marine monitoring data. Within project NA3/38, the IAEA has organized a series of ILCs and PTs to test the sampling and analytical performance of the Japanese laboratories for the analysis of radionuclides in seawater, sediment and fish samples. Data from this project are available online[2].

[2] https://www.iaea.org/about/organizational-structure/department-of-nuclear-sciences-and-applications/division-of-iaea-marine-environment-laboratories/marine-monitoring-confidence-building-and-data-quality-assurance

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1. INTRODUCTION

1.1. BACKGROUND

The corroboration of a representative subset of the radioactivity measurement results reported by TEPCO and relevant Japanese authorities during both the pre-operational and the operational phases of discharge of ALPS treated water to the sea at TEPCO's Fukushima Daiichi Nuclear Power Station (FDNPS), and a review of the methods for related sampling and analysis used by TEPCO and relevant Japanese authorities is being undertaken by the IAEA. This corroboration provides an independent check of the accuracy of the radiological data resulting from source and environmental monitoring programmes related to the ALPS treated water discharges upon which the safety related aspects of the discharge of ALPS treated water are being evaluated. A primary objective is to promote transparency and provide sound information to enable interested parties to evaluate the radiological data used by Japan as the basis for planning and implementing the discharge of ALPS treated water into the sea.

The corroboration of source and environmental monitoring is based on interlaboratory comparisons (ILCs). ILCs, along with proficiency tests (PTs), are standard methods for laboratories to assess the quality of their measurement results in comparison with those of other participating laboratories, and to identify any potential improvements. PTs involve the evaluation of performance against pre-established criteria whereas ILCs involve the organization, performance and evaluation of measurements on the same or similar items by two or more laboratories in accordance with predetermined conditions [1].

This publication reports the results of the third ILC to corroborate environmental monitoring. It describes the joint sampling mission undertaken to collect seawater, sediment, fish and seaweed samples with observation from experts from the IAEA and third-party member laboratories of the IAEA ALMERA network (Analytical Laboratories for the Measurement of Environmental Radioactivity) [2]; the analytical techniques used by participating laboratories – from Japan (participating on behalf of the Japanese authorities); the IAEA and the participating ALMERA network laboratories; the measurement results and the statistical evaluation of the results.

Extensive monitoring of the marine environment around the FDNPS is conducted according to the Comprehensive Radiation Monitoring Plan (CRMP) [3]. TEPCO and other relevant Japanese authorities have responsibilities under the CRMP. This plan defines sampling locations, frequency of sampling, target detection limits and responsibilities of the organizations involved. The monitoring comprises sampling and analysis of seawater to different depths, sediment, fish and seaweed. The aim of this plan includes ensuring a comprehensive overview of the radiological situation in the marine environment and providing an adequate basis for assessments of radiation exposures from marine pathways. In practice, sampling and analysis are often carried out by contracted laboratories but TEPCO and the other relevant Japanese authorities, as defined in the CRMP, have responsibility for reporting the results of the monitoring with which they have been tasked.

Enhancements to the CRMP to specifically address the discharge of ALPS treated water were introduced in March 2022. These included the monitoring of ^{3}H in seawater at increased frequencies plus monitoring quarterly for 'seven major radionuclides', namely ^{60}Co, ^{90}Sr, ^{106}Ru, ^{125}Sb, ^{129}I, ^{134}Cs and ^{137}Cs. Monitoring of organically bound tritium (OBT), tissue free-water tritium (TFWT) and ^{14}C in fish and ^{129}I in seaweed is also being undertaken.

This monitoring started more than one year before the first discharges of ALPS treated water. The results provide a baseline of activity concentrations in the marine environment against which any consequences of the discharges can be assessed. This ILC is based on samples collected in October 2024 and

constitutes the second corroboration of the results of this monitoring by the IAEA since the discharges started in August 2023.

The samples were taken at sampling locations defined in the CRMP, with observation by experts from the IAEA and third-party member laboratories of the IAEA ALMERA network, using the same techniques used for routine monitoring. Similarly, the radionuclides analysed for each sample are defined in the CRMP and the analyses were carried out by the participating Japanese laboratories using the same methods as those used for routine monitoring.

The IAEA wishes to thank all laboratories that participated in this ILC and the Japanese organisations that provided logistical support. The IAEA is also grateful to the Government of Monaco for its support.

1.2. OBJECTIVE

This publication reports the results of the third ILC to corroborate environmental monitoring related to the discharges of ALPS treated water at FDNPS.

1.3. SCOPE

This publication reports all aspects of the third ILC to corroborate environmental monitoring related to the discharge of ALPS treated water at FDNPS including: the ILC design; participating laboratories; the methods employed for sampling and for distribution of the samples between participating laboratories; the analytical methods used by each participating laboratory to determine activity concentrations of radionuclides in the samples; the methodology employed for the statistical evaluation of the results; and the results and conclusions.

1.4. STRUCTURE

This publication describes the participating laboratories (Section 2); the methods employed for the sample collection and pre-treatment, and for the distribution of the samples between participating laboratories (Section 3), and the analytical methods used by each participating laboratory to determine activity concentrations of radionuclides in the samples (Section 4). The methodology employed for the statistical evaluation of the results is described in Section 5. The results of the ILCs are presented in Section 6 and conclusions in Section 7. The results of the ILCs are also presented in charts in Appendix I.

2. PARTICIPATING LABORATORIES

In total, ten laboratories participated in the ILC: Six from Japan, participating on behalf of TEPCO and other relevant Japanese authorities having responsibilities under the Comprehensive Radiation Monitoring Plan (CRMP); the IAEA; and selected third-party laboratories – Third Institute of Oceanography (TIO), Ministry of Natural Resources, China; the Korea Institute of Nuclear Safety (KINS), Republic of Korea; and Spiez Laboratory, Switzerland – all members of the IAEA ALMERA network [2].

ALMERA is a network comprising more than 200 member laboratories globally. It provides a platform for maintaining and developing capabilities for the determination of radionuclides in air, water, soil, sediment and vegetation that can be used for both routine and environmental emergency monitoring in the IAEA Member States.

IAEA analyses were undertaken at two participating IAEA Nuclear Sciences and Applications Laboratories:

- IAEA Marine Environment Laboratories, Radiometrics Laboratory (RML), Monaco;
- Isotope Hydrology Laboratory (IHL), Vienna, Austria.

The participating laboratories are presented in Table 1 and the samples provided to each laboratory for planned analyses in Table 2.

TABLE 1. LABORATORIES PARTICIPATING IN ILC 2024

Identifier	Participant
IAEA	IAEA Laboratories, Austria and Monaco
JCAC	Japan Chemical Analysis Center, Chiba, Japan
KAKEN[1]	KAKEN Co. Ltd., Ibaraki, Japan
KANSO	KANSO TECHNOS Co. Ltd., Osaka, Japan
KEEA	Kyushu Environmental Evaluation Association, Fukuoka, Japan
KINS	Korea Institute of Nuclear Safety, Daejeon, Republic of Korea
SPIEZ	Spiez Laboratory (Labor Spiez), Switzerland
MERI	Marine Ecology Research Institute, Chiba, Japan
TIO	Third Institute of Oceanography, Ministry of Natural Resources, Xiamen, China
TPT[1]	Tokyo Power Technology Ltd., Fukushima, Japan

Note:

[1] Laboratories conducting analysis under contract from TEPCO.

TABLE 2. OVERVIEW OF ILC 2024

Sample type	Nuclide	IAEA	JCAC	KAKEN	KANSO	KEEA	KINS	MERI	SPIEZ	TIO	TPT
Seawater	^{3}H	✓	✓	✓	✓	✓	✓	×	✓	✓	×
	^{60}Co	✓	✓	×	×	×	✓	×	✓	✓	×
	^{90}Sr	✓	✓	×	×	×	✓	×	✓	✓	×
	^{106}Ru	✓	✓	×	×	×	✓	×	✓	✓	×
	^{125}Sb	✓	✓	×	×	×	✓	×	✓	✓	×
	^{129}I	✓	✓	×	×	×	✓	×	✓	✓	×
	^{134}Cs	✓	✓	×	×	×	✓	×	✓	✓	×
	^{137}Cs	✓	✓	×	×	×	✓	×	✓	✓	×
Sediment	^{134}Cs	✓	✓	×	×	×	✓	×	✓	✓	✓
	^{137}Cs	✓	✓	×	×	×	✓	×	✓	✓	✓
Fish (market)	^{3}H (OBT)	✓	×	×	✓	✓	✓	×	✓	✓	×
	^{3}H (TFWT)	✓	×	×	✓	✓	✓	✓	✓	✓	×
	^{14}C	✓	✓	×	×	×	✓	×	✓	✓	×
Fish (fixed net)	^{3}H (OBT)	✓	✓	✓	×	×	✓	×	✓	✓	✓
	^{3}H (TFWT)	✓	✓	✓	×	×	✓	×	✓	✓	✓
	^{14}C	✓	✓	×	×	×	✓	×	✓	✓	×
Seaweed	^{129}I	✓	✓	×	×	×	✓	×	✓	✓	✓

Notes:

The symbol ✓ indicates that the laboratory participated in the specific analysis (sample type and radionuclide), the symbol × indicates that it did not participate.

3. SAMPLE COLLECTION, PRETREATMENT AND DISTRIBUTION

Samples of seawater, sediment, fish and seaweed were collected in October 2024 from offshore locations and a fish market close to FDNPS. A selection of sample collection and pre-processing activities were observed by experts from the IAEA and third-party member laboratories of the IAEA ALMERA network. The sampling locations are shown in Figure 1. The coordinates of these sampling locations are provided in Table 3.

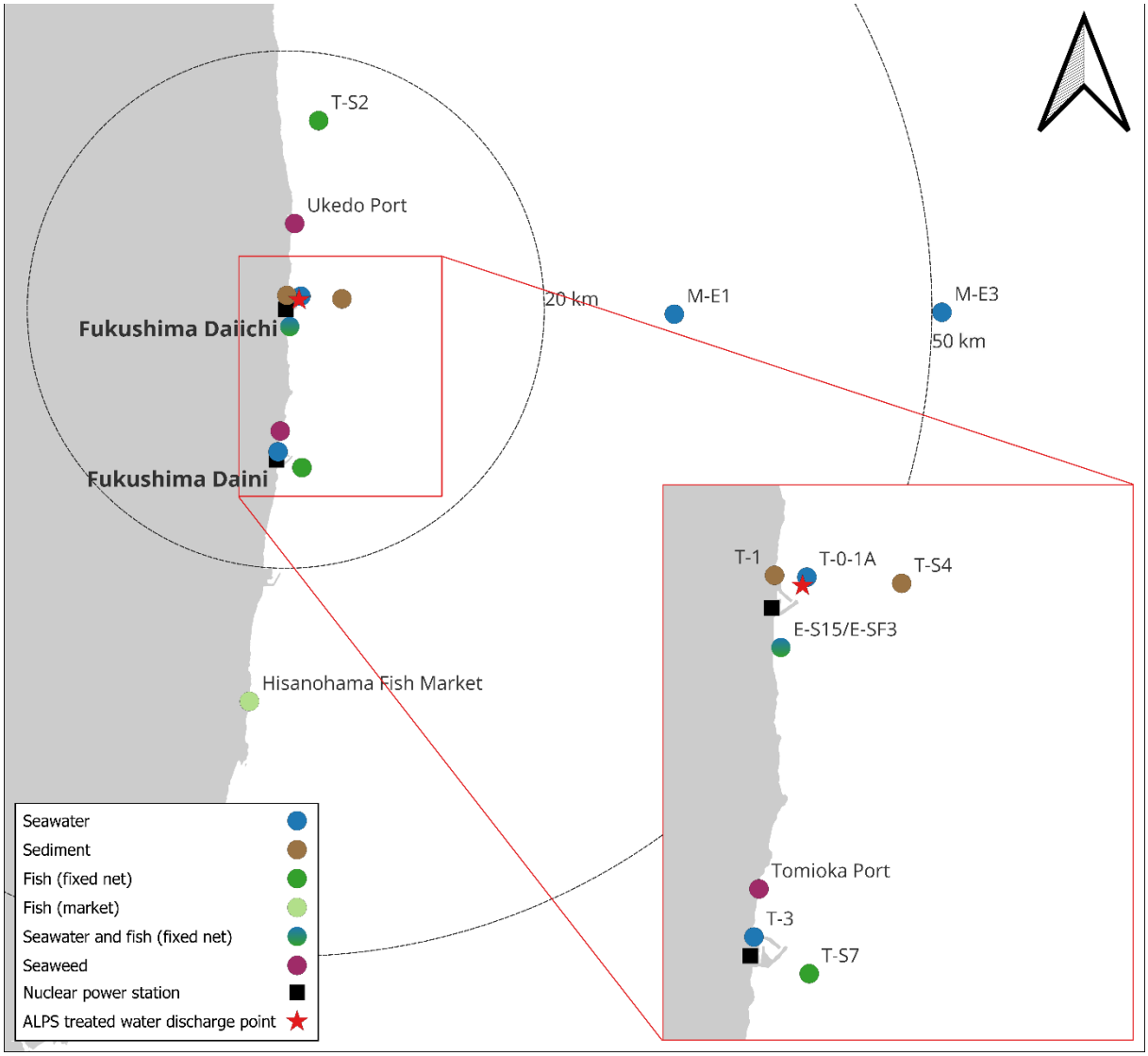


FIG. 1. Sampling locations close to FDNPS.

TABLE 3. COORDINATES OF SAMPLING LOCATIONS

Sampling location	Latitude (N)	Longitude (E)	Samples
E-S15/E-SF3[1]	37.4094	141.0368	Seawater and fish (fixed net)
T-0-1A	37.4306	141.0467	Seawater
T-3	37.3222	141.0264	Seawater
M-E1	37.4170	141.3730	Seawater
M-E3	37.4170	141.6070	Seawater
T-1	37.4311	141.0344	Sediment
T-S4	37.4286	141.0825	Sediment
T-S2	37.5528	141.0625	Fish (fixed net)
T-S7	37.3111	141.0472	Fish (fixed net)
Hisanohama Fish Market	37.1484	141.0010	Fish (market)
Ukedo Port	37.4811	141.0413	Seaweed
Tomioka Port	37.3367	141.0283	Seaweed

Note:

[1] Both correspond to the same location. However, for seawater (E-S15) it is a point while for fish (E-SF3) the sampling extends along the length of the fixed net.

3.1. SEAWATER

Surface seawater samples were collected at five sampling locations (E-S15, T-0-1A, T-3, M-E1 and M-E3) offshore FDNPS (Figure 1 and Table 3). The samples from E-S15, T-0-1A and T-3 were collected on 7 and 8 October 2024. Due to bad weather during this period, sampling from M-E1 and M-E3, located at 30 and 50 km from shore respectively, was postponed and eventually carried out on 17 December 2024 without IAEA observation. Samples from all sampling locations were to be analysed for ^{3}H and, from E-S15, for 'seven major radionuclides', namely ^{60}Co, ^{90}Sr, ^{106}Ru, ^{125}Sb, ^{129}I, ^{134}Cs and ^{137}Cs. Separate samples from E-S15 were provided to participating laboratories for ^{3}H; ^{129}I; radiocaesium (^{134}Cs and ^{137}Cs); ^{90}Sr; and for other gamma-emitting radionuclides (^{60}Co, ^{106}Ru, ^{125}Sb).

For ^{3}H, six laboratories planned to participate in the analyses of samples from all sampling locations, except for E-S15 for which there were five laboratories.

For T-0-1A, T-3, M-E1 and M-E3, the sample collection and distribution methods were:

- A 30 L plastic container was first filled with seawater using a pump. The seawater was then dispensed from the 30 L container into 2 L containers. A total of seven 2 L samples were collected (one for archive).
- One 2 L sample was provided to each laboratory.

For E-S15, the sample collection and distribution methods for ^{3}H were:

- A 400 L plastic container with four valves was first filled with seawater.
- Separate 2 L containers were filled, two at a time, from the four valves, resulting in a total of six 2 L samples from this sampling location (one for archive).
- One 2 L sample was provided to each laboratory.

Five laboratories planned to participate in the analyses for ^{90}Sr; ^{134}Cs and ^{137}Cs; other gamma-emitting radionuclides (^{60}Co, ^{106}Ru, ^{125}Sb); and ^{129}I for sampling location E-S15. The collection and distribution methods were:

- Samples for analysis for ^{129}I were taken using the same method described above for ^{3}H for the E-S15 location. One 2 L sample was provided to each laboratory.
- From the same 400 L plastic container used for ^{3}H sampling, separate collapsible liquid containers were filled simultaneously from each of the four valves: 20 L containers for ^{90}Sr, ^{134}Cs and ^{137}Cs analyses, and 10 L containers for ^{60}Co, ^{106}Ru and ^{125}Sb analyses. A total of eighteen 20 L samples and six 10 L samples were taken (including one set for archive). Two separate fills of the 400 L container were required to provide sufficient sample volume to all participants. Each sample was acidified to pH 1–2 with concentrated HCl. Three 20 L samples and one 10 L sample from E-S15 were provided to each laboratory.

For all seawater samples, the fill sequence, valve numbers and recipient laboratories were recorded, as appropriate, facilitating traceability of each sample container.

3.2. SEDIMENT

Sediment samples were collected using two methods: a grab sampler offshore at location T-S4, and by hand at the shore within the FDNPS site at location T-1. (Figure 1 and Table 3).

The samples were subsequently oven-dried at 105°C on large fibre reinforced polymer (FRP) trays, crushed using stainless-steel spatulas, and sieved through a 2-mm mesh sieve at the JCAC laboratory in Chiba. The sandy nature of the sediments eliminated the need for grinding prior to sieving. The fraction with grain size <2 mm was sieved to ≤250 μm, then placed in a plastic bag and mixed thoroughly to ensure homogeneity.

An incremental subsampling method was used for the provision of samples to participating laboratories. Each sample was divided into two aliquots using a splitter; one aliquot was archived and the second one was further divided until the required sample weight for each laboratory was attained. The sequence of division of each sample depended on the total mass of the sieved material. The samples were then bottled in 500 mL plastic bottles and shipped to the IAEA Marine Environment Laboratories in Monaco where their ^{137}Cs homogeneity was checked using gamma-ray spectrometry with High Purity Germanium (HPGe) detectors. Depending on sampling location, between approximately 100 to 220 g of homogeneous dried sediment was then shipped to each participating laboratory for analysis for ^{134}Cs and ^{137}Cs.

3.3. FISH (MARKET)

Six batches of frozen fish, one each of redwing searobin (*Lepidotrigla microptera*), finespotted flounder (*Pleuronichthys japonicus*), pufferfish (*Takifugu snyderi*), crimson sea bream (*Evynnis tumifrons*), olive flounder (*Paralichthys olivaceus*) and Japanese jack mackerel (*Trachurus japonicus*), were collected from the fish market at Hisanohama Port on 9 October 2024 soon after being landed. The fish were caught by pole-and-line fishing or bottom trawling in the vicinity of FDNPS at depths between 45 and 135 m. To ensure sufficient sample material for all participating laboratories, preliminary sampling of the same species was conducted at Hisanohama Port on 30 September 2024 and for two species – finespotted flounder (*Pleuronichthys japonicus*) and olive flounder (*Paralichthys olivaceus*) – additional sampling was required on 18 October 2024. These fish were caught using the same methods at depths between 22 and 135 m

Each batch of fish was divided into two sub-batches: one for provision of samples to be analysed for ^{3}H – organically bound tritium (OBT) and tissue free water tritium (TFWT) – and one for ^{14}C. Special care was taken to ensure that the fish to be analysed for tritium were isolated from ice used for cooling during shipment and, subsequently, from tap water during pre-treatment.

Each sub-batch of fish of each species was prepared separately by fileting, homogenising the muscle tissue and then dividing into separate samples at the MERI laboratory in Chiba starting on 11 October 2024. These were frozen and shipped to the participating laboratories. Each laboratory received approximately 1.2 kg of each species of fish for analysis for ^{3}H (0.3 kg for MERI who planned to analyse for TFWT only) and 0.5 kg for analysis for ^{14}C.

3.4. FISH (FIXED NET)

Fish samples were collected at three sampling locations (E-SF3, T-S2 and T-S7) offshore TEPCO's Fukushima Daiichi Nuclear Power Station (Figure 1 and Table 3). The fish were caught using fixed gill nets at each location. Nets were installed on selected dates in October and November 2024 at each location and hauled in the following morning. One batch of olive flounder (*Paralichthys olivaceus*) was collected at each location.

Each batch of fish of each species was prepared separately by fileting, homogenising the muscle tissue and then dividing into separate samples. The samples from T-S2 and T-S7 were processed at TEPCO's laboratory in Fukushima and the samples from E-SF3 at the JCAC laboratory in Chiba. These were frozen and shipped to the participating laboratories. Each laboratory received approximately 1 kg of each species of fish for analysis for ^{3}H and, for E-SF3, additionally for analysis for ^{14}C.

3.5. SEAWEED

Seaweed samples were collected at Ukedo Port and Tomioka Port offshore TEPCO's Fukushima Daiichi Nuclear Power Station (Figure 1 and Table 3). At Tomioka Port (Ministry of the Environment sampling location E-SW2), a sample of arame (*Eisenia bicyclis*) was collected by divers. The seaweed was prepared by first removing the leaves and discarding the stems, homogenising and then dividing into separate samples at the JCAC laboratory in Chiba. These were frozen and shipped to the participating laboratories. Each laboratory received approximately 1 kg for analysis for ^{129}I.

At Ukedo Port and Tomioka Port (sampling locations of TEPCO) one sample each of Besa suringar (*Besa paradoxa*) and arame (*Eisenia bicyclis*), respectively, were collected by divers. The seaweed was prepared as above at TEPCO's laboratory in Fukushima. Each laboratory received approximately 1 kg of each species of seaweed, frozen, for analysis for ^{129}I.

4. ANALYTICAL METHODS

4.1. SEAWATER

Radionuclides in seawater were analysed by eight laboratories participating in this ILC: JCAC, KAKEN, KANSO and KEEA (Japan); IAEA; and KINS, SPIEZ and TIO (see Tables 1 and 2).

4.1.1. ^{3}H analysis

The IAEA used two methods of analysis for ^{3}H in seawater: a low-level mass spectrometry method whereby the activity concentration of ^{3}H in a sample is determined through the ingrowth of a decay product ^{3}He under controlled conditions; and liquid scintillation counting (LSC) following purification and electrolytic enrichment of the seawater samples. The ^{3}He ingrowth method was carried out at the IHL. The second method was performed at both IHL and MEL. The results reported were determined using the first method as the detection limit achievable was lower, typically of the order of 10 mBq/L.

For the ^{3}He ingrowth method, a 100 mL aliquot of each seawater sample was added to an all-metal container and degassed for one to two hours using a dedicated degassing unit to remove all preexisting ^{3}He. The degassed samples were stored for a period of five to six weeks to allow sufficient ^{3}He-ingrowth and then counted on a Thermo Fisher Helix SFT split flight tube noble gas mass spectrometer. To ensure accurate measurements, gas samples with known ^{3}He content and water samples with known ^{3}H content [4] were used to calibrate the mass spectrometer's sensitivity, temporal drift, and linearity. The background of the mass spectrometer system was also determined.

Tritium analyses were carried out, on behalf of SPIEZ, at EAWAG, the Swiss Federal Institute of Aquatic Science and Technology. A similar low-level mass spectrometry method was used. For each sample, an aliquot of 1 L of seawater was transferred to a custom-made enrichment cell, a fully metallic stainless-steel bottle with a copper neck tube. After degassing, the copper bottleneck was tightly closed using a clamp and stored. After approximately 6 months, the ^{3}He produced by the decay of ^{3}H was measured in a 90° magnetic sector mass spectrometer equipped with a Baur-Signer source [5].

In the second method used by the IAEA, the samples were measured by liquid scintillation counting after purification by distillation and electrolytic enrichment. An ultra-low level liquid scintillation counter was used for the counting of an aliquot of the enriched and distilled sample mixed with a scintillation cocktail.

All other participating laboratories analysed the seawater samples in a similar manner: purification by distillation followed by electrolytic enrichment, mixing with scintillation cocktail and measurement by LSC. Enrichment factors were typically 5 to 50 times the initial ^{3}H activity concentration in the seawater. For the Japanese laboratories – JCAC, KAKEN, KANSO and KEEA – the specifics of the methods implemented complied with the “Tritium Analysis Method (Radiation Measurement Method Series 9)” published by the Secretariat of the Nuclear Regulation Authority [6]. SPIEZ analysed the samples by LSC following purification by distillation but without enrichment.

4.1.2. ^{90}Sr analysis

The IAEA and TIO both used liquid-liquid extraction with di-(2-ethylhexyl)phosphoric acid (HDEHP) for the separation of yttrium from the seawater sample. The ^{90}Sr activity concentration was determined through the measurement of ^{90}Y (yttrium oxalate source) β activity using a proportional counter.

JCAC employed a cation-exchange resin column to pre-concentrate strontium from the 50 L seawater sample, followed by precipitation of carbonates and an additional cation exchange resin column for

separation of calcium. ^{90}Y was removed by scavenging. Following a two-week ingrowth period, ^{90}Y was co-precipitated with iron hydroxide and then was measured using a low background β counter.

SPIEZ precipitated calcium oxalate, which was subsequently dissolved in 3M HNO_3 and passed through a preconditioned Sr-Resin column. The strontium fraction was eluted with 0.005 M HNO_3. $SrCO_3$ sources were prepared for low level gas proportional counting (LB-770). The detection system was calibrated using freshly prepared ^{90}Sr, ^{90}Y and ^{89}Sr sources. The radiochemical yield was determined gravimetrically, using a known amount of strontium carriers.

At KINS strontium pre-concentration of the 40 L seawater sample was carried out using a cation exchange resin. Eluted strontium was then recovered using strontium carbonate precipitation and then strontium was purified again using fuming nitric acid. ^{90}Y and ^{90}Sr were determined by liquid scintillation counting in Cerenkov mode following sufficient ^{90}Y ingrowth. The chemical yield was determined by ICP-OES (Inductively Coupled Plasma Optical Emission Spectroscopy).

4.1.3. ^{134}Cs and ^{137}Cs analysis

At IAEA, JCAC, KINS and TIO ammonium molybdophosphate (AMP) was used for purification of the seawater samples and the chemical separation of caesium from the seawater. This was followed by analysis by gamma-ray spectrometry using HPGe (High Purity Germanium) detectors. The retention of stable Cs in the AMP was determined by ICP-MS.

At SPIEZ, ammonium molybdophosphate-Polyacrylonitrile (AMP-PAN) was used to remove Cs isotopes from seawater. Cs isotopes were then eluted from AMP-PAN using a solution of sodium hydroxide. An aliquot of the eluate was taken for yield determination by measuring stable Cs by ICP-MS. The eluate was then analysed by gamma-ray spectrometry using a HPGe detector. The detector was calibrated using LabSOCS mathematical efficiency calibration software and physical calibration sources.

4.1.4. Other gamma-emitting radionuclides (^{60}Co, ^{106}Ru and ^{125}Sb) analysis

At TIO, ^{60}Co, ^{106}Ru and ^{125}Sb was precipitated using $Co(OH)_2$, NiS and MnO_2, respectively, followed by counting by gamma-ray spectrometry.

In all other participating laboratories, the sample was prepared in large containers (1 L Marinelli beakers for the IAEA, KINS and SPIEZ; 2 L Marinelli beakers for JCAC) and analysed without further treatment by gamma-ray spectrometry using HPGe detectors.

^{106}Ru was determined by gamma-ray spectrometry via decay of its progeny ^{106}Rh.

4.1.5. ^{129}I analysis

The IAEA and SPIEZ analysed ^{129}I in the seawater sample using gamma-ray spectrometry. The methods are as described in the previous section for ^{60}Co, ^{106}Ru and ^{125}Sb.

At JCAC the seawater sample was filtered, aliquoted and diluted for measurement of ^{129}I by ICP-MS (Inductively Coupled Plasma Mass Spectrometry). Rhenium was employed as an internal standard.

At KINS, after oxidation and reduction processes, the seawater sample was chemically separated using anion exchange resin. The elute was precipitated as PdI_2 using $PdCl_2$ solution, and the PdI_2 precipitate was filtered. Dried PdI_2 mounted on a PTFE (polytetrafluoroethylene) planchette was measured by X-ray spectrometry for the determination of ^{129}I.

4.2. SEDIMENT

Radionuclides of interest in sediment samples were analysed by six laboratories participating in this ILC: from Japan, JCAC and TPT; IAEA; and KINS, SPIEZ and TIO (see Tables 1 and 2).

4.2.1. ^{134}Cs and ^{137}Cs analysis

All participating laboratories measured ^{134}Cs and ^{137}Cs in sediment by gamma-ray spectrometry using HPGe detectors, following preparation of the samples in cylindrical containers.

4.3. FISH

Radionuclides of interest in fish samples collected from the fish market were analysed by eight laboratories participating in this ILC: from Japan, JCAC, KANSO, KEEA and MERI; IAEA; and KINS, SPIEZ and TIO (see Tables 1 and 2).

For the fish sampled at sea using fixed nets, radionuclides of interest were analysed by five laboratories: JCAC, KAKEN and TPT (Japan); IAEA; and KINS. SPIEZ and TIO were provided with fish samples collected by fixed next but did not analyse them.

4.3.1. ^{3}H (OBT and TFWT) analysis

The samples were vacuum freeze-dried at all laboratories. The tissue free water and dry materials were recovered, weighed and the drying rate (%) calculated.

At IAEA, the tissue free water was analysed for ^{3}H using the ^{3}He ingrowth method as described in section 4.1.1 for seawater.

At KINS, KANSO, KEEA, MERI and TIO the tissue free water recovered from the samples by vacuum freeze-drying was purified by reflux decomposition and distillation, mixed with scintillation cocktail, and counted by LSC to determine the ^{3}H activity concentration.

JCAC, KAKEN and TPT implemented the same method but with additional steps: following distillation the ^{3}H was concentrated by electrolytic enrichment and the samples were distilled again prior to counting by LSC. This method complied with the "Analysis Method of Tritium (Radiation Measurement Method Series 9)" [6].

For OBT, the dried fish material was first ground using a food processor at IAEA. It was then analysed for OBT using two separate analytical methods: the ^{3}He ingrowth method and high-pressure combustion followed by LSC.

For each sample analysed using the ^{3}He ingrowth method, approximately 90 g of dry material was placed in an all-metal sample container (diameter 13 cm x 21 cm) and degassed using a Turbo Molecular Pump. It was then stored for ^{3}He ingrowth for a period of 7 to 9 weeks. At the end of this time, the sample container was connected to the ultra-high vacuum helium purification line attached to a Thermo Fisher Helix SFT split flight tube noble gas mass spectrometer to measure the ^{3}He produced from the OBT over the ingrowth period.

For the second method, approximately 10 g of dry material was combusted in a Parr high pressure oxygen combustion vessel and a cold trap in the vacuum line was used to recover the combustion water. The process was repeated three times to collect approximately 15 mL of combustion water in total. The combustion water was distilled, mixed with a scintillation cocktail and counted using by LSC.

KINS and TPT used the same high pressure combustion method as IAEA for OBT.

At JCAC, KANSO, KAKEN, KEEA and TIO combustion water was obtained from the dry material using a quartz tube furnace. Each dried sample was inserted into a quartz tube and combusted at 650–750°C in an electric furnace. The combustion water was collected in a cold trap. Copper oxide was used as a combustion catalyst. Organic matter present in the combustion water was decomposed with refluxing. The sample was then distilled, mixed with scintillator cocktail and counted by LSC to determine the ^{3}H activity concentration. At all laboratories, conversion from Bq/L to Bq/kg fresh weight for OBT measurements was based on the dry matter content determined during vacuum freeze-drying and the hydrogen content obtained by elemental analysis of the dried sample.

4.3.2. ^{14}C analysis

At KINS, each freeze-dried sample was combusted to CO_2 which was then collected by bubbling into ammonium water (1:1). Calcium chloride was added to the solution and the precipitate $CaCO_3$ (calcium carbonate) retrieved. $CaCO_3$ (6 g) was reacted with hydrochloric acid water (1:1) on nitrogen purging to generate CO_2. The CO_2 was absorbed using Carbo-Sorb E, mixed with a scintillation cocktail (PermaFluor E+) in a Teflon vial and CO_2 counted by LSC.

The IAEA's samples were analysed using a similar technique by the Low-Level Radioactivity Measurements (LRM) Laboratory of the Belgian Nuclear Research Centre (SCK CEN), under contract.

A distinction was that the scintillation cocktail was Pico-Fluor Plus. This method is accredited to ISO/IEC 17025 at SCK-CEN (accreditation number 015-TEST under the Belgian National Accreditation Body, BELAC).

JCAC used different methods for the fish sampled from market and for fish caught by fixed nets. For fish collected from the market, fish muscle was freeze-dried, ground to a powder and homogenised. Then, 5–10 g was thermally decomposed with pure oxygen in a combustion apparatus at 1000°C. CO_2 was collected by bubbling into ammonium water (1:1). Calcium chloride was added to the solution and the precipitate $CaCO_3$ (calcium carbonate) retrieved. $CaCO_3$ (25-27 mg) was reacted with pure phosphoric acid (4 mL) on a vacuum line to generate CO_2. Subsequently, a graphite target (>2 mg) was retrieved by flowing pure hydrogen into the CO_2 and loaded with a pre-purified Fe catalyst at 600°C for 6 hours. After removal of the Fe, pure graphite was measured by AMS for calculation of the ^{14}C specific activity (Bq/g carbon) in the sample.

For fish caught by fixed nets, at JCAC a dried sample was burned under high oxygen pressure in a combustion device. The generated carbon dioxide was synthesized into benzene using a vacuum line. Then, 2 mL of the synthesized benzene was mixed with 0.5 mL of scintillation cocktail and counted by LSC.

SPIEZ freeze-dried, ground, and homogenized two aliquots of each sample, determining the dry matter content during this process. Each aliquot was divided into two subsamples (four subsamples per sample total), which were burned separately in an elemental analyser to quantify total carbon content and convert the material to graphite. The graphite subsamples were analysed for ^{14}C using accelerator mass spectrometry at the Laboratory for the Analysis of Radiocarbon with AMS at the University of Bern (Switzerland). The mean activity of the four separate analyses for each sample was the reported result.

At TIO, the same freeze-dried sample material was used for both ^{14}C and OBT analysis. The CO_2 produced from combustion of each sample was collected in a sodium hydroxide solution; calcium chloride was then added to precipitate calcium carbonate. The dried calcium carbonate precipitate was precisely weighed, mixed with scintillation cocktail and counted by LSC to determine the ^{14}C activity concentration.

4.4. SEAWEED

Radionuclides of interest in seaweed samples were analysed by five laboratories participating in this ILC: from Japan, JCAC and TPT; IAEA; and KINS and SPIEZ (see Tables 1 and 2). TIO was provided with seaweed samples but did not analyse them.

4.4.1. ^{129}I analysis

IAEA and KINS analysed the freeze-dried seaweed samples by gamma spectrometry using HPGe detectors.

At SPIEZ, the seaweed samples were dried at 40°C for two weeks and then analysed by gamma spectrometry using HPGe detectors.

At JCAC, the sample was freeze-dried, ground to a powder and homogenised. Then 0.5-1 g was added to a ceramic boat and mixed with V_2O_5 (Vanadium Oxide). Then the sample was placed in a quartz tube and heated at 1000ºC under a flow of oxygen gas. The iodine released by heating was collected with a trap solution containing TMAH (tetramethyl ammonium hydroxide) and Na_2SO_3 (sodium sulfite). The trap solution was diluted for measurement of ^{129}I by ICP-MS. Rhenium was employed as an internal standard.

TPT freeze-dried each seaweed sample after washing with seawater. It was then crushed and dissolved in 25% TMAH solution. The TMAH solution was centrifuged and the resulting supernatant water filtered. This was weighed and the ^{127}I concentration measured to determine the total iodine content of the wet seaweed sample.

The TMAH solution was exchanged to 1M HNO_3 using an anion-exchanging resin. The $^{129}I/^{127}I$ isotopic ratio was then measured by triple quadrupole ICP-MS (ICP-QQQ) and multiplied by the total iodine content of the wet seaweed sample.

5. STATISTICAL EVALUATION OF THE RESULTS

The IAEA collected and evaluated the results reported by all ILC participants. The method used for the statistical evaluation depended on the number of results received for each sampling location, sample type and radionuclide.

If two measurement results above the detection limit were received, one zeta test [7] was performed. If three results were received, three zeta tests were performed. The zeta $\zeta_{i,j}$ test is defined as:

$$\zeta_{i,j} = \frac{x_i - x_j}{\sqrt{u_i^2 + u_j^2}} \quad (1)$$

where:

x_i is the value of laboratory i (Bq $unit^{-1}$);
x_j is the value of laboratory j (Bq $unit^{-1}$);
u_i is the standard uncertainty for the value of laboratory i (Bq $unit^{-1}$);
u_j is the standard uncertainty for the value of laboratory j (Bq $unit^{-1}$); and
$unit$ is the unit of volume or mass, L or kg, as appropriate for the particular sample type.

If two results were received, $\zeta_{1,2}$ was calculated, while for three received results $\zeta_{1,2}$, $\zeta_{1,3}$ and $\zeta_{2,3}$ were calculated.

If the data set contained four or more results above the detection limit, the statistical evaluation consisted of a method for calculating a comparison reference value as a power-moderated mean of the combined results [7], which is currently being used by the Consultative Committee for Ionizing Radiation, Section II: Measurement of radionuclides, CCRI(II). For each sample and radionuclide combination, a comparison reference value x_{ref} was determined as a power-moderated mean of the combined results [8]:

$$x_{ref} = \sum_{i=1}^{N} w_i x_i$$

where x_i is the value reported by the laboratory i, N is the number of results reported and w_i is a normalized weighting factor.

A ζ (zeta) score was then calculated for each laboratory as follows.

$$\zeta = \frac{d_i}{u(d_i)}$$

where $d_i = x_i - x_{ref}$, the difference between the value reported by the laboratory x_i and the reference value x_{ref}, and $u(d_i)$ is the standard uncertainty associated with d_i, taking the correlation between individual results and the reference value into account.

Following the current ISO standard for statistical methods for use in proficiency testing [7], for zeta scores between -3 and 3, the corresponding result was evaluated as agreeing with the reference value at a 99.7% confidence level and for zeta scores greater than 3 or less than -3 the reported result was evaluated as not agreeing at a 99.7% confidence level.

6. RESULTS

6.1. GENERAL

The results are presented in Tables 4 – 14 and Figures 2 – 11.

6.1.1. Uncertainties

Uncertainties quoted in this report are combined standard uncertainties, i.e. with a coverage factor of $k = 1$. The numerical result of a measurement is stated in the format xxx ± yyy, where the number following the symbol ± is the numerical value of the combined standard uncertainty.

6.1.2. Reference time

All activity concentrations of radionuclides in seawater, sediment, fish and seaweed samples were reported for a common reference time of 7 October 2024 12:00 UTC.

6.2. SEAWATER

Table 4 contains the results reported by laboratories (IAEA, JCAC, KAKEN, KANSO, KEEA, KINS, SPIEZ and TIO) for activity concentrations of ^{3}H, ^{60}Co, ^{90}Sr, ^{106}Ru, ^{125}Sb, ^{129}I, ^{134}Cs and ^{137}Cs in the seawater samples. Figures 2 – 3 present these results visually.

TABLE 4. ACTIVITY CONCENTRATIONS (mBq L^{-1}) IN SEAWATER SAMPLES

Nuclide	Sample	IAEA	JCAC	KAKEN	KANSO	KEEA	KINS	SPIEZ	TIO	Reference value
^{3}H	E-S15	1509 ± 34	1438 ± 64	–	–	–	1480 ± 70	1630 ± 40	1553 ± 170	1525 ± 37
	T-0-1A	285 ± 15	325 ± 21	296 ± 37	–	–	322 ± 52	350 ± 10	609 ± 66	357 ± 47
	T-3	373 ± 12	417 ± 24	378 ± 46	–	–	426 ± 52	430 ± 10	607 ± 66	429 ± 32
	M-E1	41.2 ± 4.5	46 ± 13	–	70 ± 12	–	<88	NM	<150	NC‡
	M-E3	32.0 ± 4.5	40 ± 13	–	–	49 ± 10	<88	NM	162 ± 18	70 ± 31
^{60}Co	E-S15	<20	<83	–	–	–	<90	<28	<1	NC
^{90}Sr		1.347 ± 0.039	1.08 ± 0.13	–	–	–	0.77 ± 0.18	1.3 ± 0.2	0.69 ± 0.07	1.04 ± 0.14
^{106}Ru		<310	<620	–	–	–	<840	<230	<16	NC†
^{125}Sb		<78	<200	–	–	–	<260	<70	<10	NC†
^{129}I		<660	<2.0	–	–	–	<37	<29	NM	NC†
^{134}Cs		<0.41	<0.73	–	–	–	<0.51	<1.0	<1.1	NC†
^{137}Cs		17.9 ± 1.6	18.3 ± 1.2	–	–	–	19.0 ± 1.0	21.3 ± 2.0	27 ± 1	20.7 ± 1.8

Notes:

NM: Not measured; no value reported.

NC‡: Not calculated, as fewer than four results above the detection limit were reported.

NC†: Not calculated, as all reported results were below the detection limit.

Table 5 contains the zeta scores for the activity concentrations of ^{3}H, ^{60}Co, ^{90}Sr, ^{106}Ru, ^{125}Sb, ^{129}I, ^{134}Cs and ^{137}Cs in the seawater samples.

TABLE 5. ZETA SCORES FOR ACTIVITY CONCENTRATIONS OF RADIONUCLIDES IN SEAWATER SAMPLES

Nuclide	Sample	IAEA	JCAC	KAKEN	KANSO	KEEA	KINS	SPIEZ	TIO
^{3}H	E-S15	-0.38	-1.42	–	–	–	-0.68	2.32	0.17
	T-0-1A	-1.50	-0.65	-1.10	–	–	-0.56	-0.16	**3.45**
	T-3	-1.72	-0.33	-1.02	–	–	-0.05	0.04	2.72
	M-E1	Note 1	Note 1	–	Note 1	–	DL	NM	DL
	M-E3	-1.24	-0.94	–	–	-0.67	DL	NM	2.80
^{60}Co	E-S15	DL	DL	–	–	–	DL	DL	DL
^{90}Sr		2.23	0.26	–	–	–	-1.36	1.25	-2.37
^{106}Ru		DL	DL	–	–	–	DL	DL	DL
^{125}Sb		DL	DL	–	–	–	DL	DL	DL
^{129}I		DL	DL	–	–	–	DL	DL	NM
^{134}Cs		DL	DL	–	–	–	DL	DL	DL
^{137}Cs		-1.35	-1.26	–	–	–	-0.91	0.25	**3.33**

Notes:

DL: No evaluation was performed when values below the detection limit were submitted.

Note 1: Values of -0.38, -2.25 and -1.34 for $\zeta_{1,2}$, $\zeta_{1,4}$ and $\zeta_{2,4}$, respectively.

NM: Not measured; no value reported.

$\zeta_{i,j}$ indexes: number 1 refers to IAEA, number 2 to JCAC, number 3 to KAKEN, number 4 to KANSO, number 5 to KEEA, number 6 to KINS, number 7 to SPIEZ and number 8 to TIO.

6.3. SEDIMENT

Table 6 contains the results reported by laboratories (IAEA, JCAC, KINS, SPIEZ, TIO and TPT) for activity concentrations of ^{134}Cs and ^{137}Cs in the sediment samples. Figures 4 and 5 present these results visually.

TABLE 6. ACTIVITY CONCENTRATIONS OF ^{134}Cs AND ^{137}Cs (Bq kg^{-1} dry weight) IN SEDIMENT SAMPLES

Nuclide	Sample	IAEA	JCAC	KINS	SPIEZ	TIO	TPT	Reference value
^{134}Cs	T-1	1.51 ± 0.16	1.39 ± 0.20	1.66 ± 0.18	1.65 ± 0.08	1.37 ± 0.17	1.41 ± 0.33	1.55 ± 0.06
	T-S4	<0.47	<0.51	<0.61	<0.19	<0.36	<0.79	NC†
^{137}Cs	T-1	107.2 ± 7.1	108.4 ± 6.2	109 ± 4	119 ± 7	142.3 ± 7.2	99.8 ± 3.4	113.8 ± 6.1
	T-S4	5.95 ± 0.42	8.17 ± 0.50	8.47 ± 0.35	8.5 ± 0.5	11.28 ± 0.6	7.28 ± 0.35	8.25 ± 0.72

Note:

NC†: Not calculated, as all reported results were below the detection limit.

Table 7 contains the zeta scores for the activity concentrations of ^{134}Cs and ^{137}Cs in the sediment samples.

TABLE 7. ZETA SCORES FOR ACTIVITY CONCENTRATIONS OF ^{134}Cs AND ^{137}Cs IN SEDIMENT SAMPLES

Nuclide	Sample	IAEA	JCAC	KINS	SPIEZ	TIO	TPT
^{134}Cs	T-1	-0.25	-0.91	0.66	1.47	-1.15	-0.44
	T-S4	DL	DL	DL	DL	DL	DL
^{137}Cs	T-1	-0.78	-0.69	-0.70	0.62	**3.36**	-2.11
	T-S4	-2.91	-0.10	0.29	0.30	**3.49**	-1.27

Note:

DL: No evaluation was performed when values below the detection limit were submitted.

6.4. FISH

Table 8 contains the results reported by laboratories (IAEA, KANSO, KEEA, KINS, MERI and TIO) for activity concentrations of ^{3}H – organically bound tritium (OBT) and tissue free water tritium (TFWT) – in the fish samples collected from the fish market. Figures 6 and 7 present these results visually.

TABLE 8. ACTIVITY CONCENTRATIONS OF ^{3}H (OBT, TFWT) IN FISH SAMPLES (MARKET)

Nuclide	Sample number: Species	IAEA	KANSO	KEEA	KINS	MERI	TIO
^{3}H (OBT, Bq kg^{-1} f.w.)	T24FA0001: Redwing searobin	<0.010	<0.045	<0.041	<0.30	–	<0.16
	T24FA0002: Finespotted flounder	0.0149 ± 0.0025	<0.046	<0.043	<0.32	–	<0.18
	T24FA0003: Pufferfish	0.0222 ± 0.0034	<0.044	<0.039	<0.28	–	<0.16
	T24FA0004: Crimson sea bream	0.0202 ± 0.0029	<0.045	<0.042	<0.32	–	<0.19
	T24FA0005: Olive flounder	0.0193 ± 0.0029	<0.046	<0.041	<0.262	–	<0.18
	T24FA0006: Japanese jack mackerel	0.0189 ± 0.0028	<0.05	<0.044	<0.42	–	<0.19
^{3}H (TFWT, Bq L^{-1})	T24FA0001: Redwing searobin	0.072 ± 0.014	<0.32	<0.24	<2.2	<0.32	<0.10
	T24FA0002: Finespotted flounder	0.062 ± 0.011	<0.32	<0.23	<2.2	<0.32	0.13 ± 0.05
	T24FA0003: Pufferfish	0.065 ± 0.013	<0.32	<0.24	<2.2	<0.32	0.19 ± 0.05
	T24FA0004: Crimson sea bream	0.0532 ± 0.0081	<0.31	<0.24	<2.2	<0.35	<0.10
	T24FA0005: Olive flounder	0.106 ± 0.016	<0.32	<0.24	<2.2	<0.35	<0.10
	T24FA0006: Japanese jack mackerel	0.074 ± 0.013	<0.32	<0.24	<2.1	<0.35	<0.10

Table 9 contains the zeta scores for the activity concentrations of OBT and TFWT fish samples collected from the fish market.

TABLE 9. ZETA SCORES FOR ACTIVITY CONCENTRATIONS OF ^{3}H (OBT, TFWT) IN FISH SAMPLES (MARKET)

Nuclide	Sample number: Species	IAEA	KANSO	KEEA	KINS	MERI	TIO
^{3}H (OBT, Bq kg^{-1} f.w.)	T24FA0001: Redwing searobin	DL	DL	DL	DL	–	DL
	T24FA0002: Finespotted flounder	Note 1	DL	DL	DL	–	DL
	T24FA0003: Pufferfish	Note 1	DL	DL	DL	–	DL
	T24FA0004: Crimson sea bream	Note 1	DL	DL	DL	–	DL
	T24FA0005: Olive flounder	Note 1	DL	DL	DL	–	DL
	T24FA0006: Japanese jack mackerel	Note 1	DL	DL	DL	–	DL
^{3}H (TFWT, Bq L^{-1})	T24FA0001: Redwing searobin	Note 1	DL	DL	DL	DL	DL
	T24FA0002: Finespotted flounder	Note 2	DL	DL	DL	DL	Note 2
	T24FA0003: Pufferfish	Note 3	DL	DL	DL	DL	Note 3
	T24FA0004: Crimson sea bream	Note 1	DL	DL	DL	DL	DL
	T24FA0005: Olive flounder	Note 1	DL	DL	DL	DL	DL
	T24FA0006: Japanese jack mackerel	Note 1	DL	DL	DL	DL	DL

Notes:

DL: No evaluation was performed when values below the detection limit were submitted.

Note 1: No evaluation was possible as only one value above the detection limit was submitted.

Note 2: Value of -1.32 for $\zeta_{1,6}$.

Note 3: Value of -2.42 for $\zeta_{1,6}$.

$\zeta_{i,j}$ indexes: number 1 refers to IAEA, number 2 to KANSO, number 3 to KEEA, number 4 to KINS, number 5 to MERI and number 6 to TIO.

Table 10 contains the results reported by laboratories (IAEA, JCAC, KINS, SPIEZ and TIO) for activity concentrations of ^{14}C in the fish samples collected from the fish market. Figure 8 presents these results visually.

TABLE 10. ACTIVITY CONCENTRATIONS OF ^{14}C (Bq kg^{-1} fresh weight) IN FISH SAMPLES[1]

Nuclide	Sample number: Species	IAEA	JCAC	KINS	SPIEZ	TIO	Reference value
^{14}C	24FA0001: Redwing searobin	28.4 ± 3.4	24.11 ± 0.21	22.9 ± 1.1	23.2 ± 1.0	20 ± 1.2	23.2 ± 1.2
	24FA0002: Finespotted flounder	29.9 ± 3.6	25.77 ± 0.19	23.8 ± 1.5	25.3 ± 1.1	23.7 ± 1.4	25.26 ± 0.72
	24FA0003: Pufferfish	32.4 ± 4.3	21.76 ± 0.17	20.7 ± 2.1	21.7 ± 1	22.7 ± 1.3	23.0 ± 1.8
	24FA0004: Crimson sea bream	27.9 ± 3.5	25.25 ± 0.19	22 ± 1.2	25.6 ± 0.6	24.7 ± 1.4	24.77 ± 0.81
	24FA0005: Olive flounder	20.8 ± 2.5	24.59 ± 0.19	20.3 ± 1.7	24.9 ± 1.1	19.9 ± 1.2	22.4 ± 1.2
	24FA0006: Japanese jack mackerel	31.3 ± 4.1	28.34 ± 0.21	24.5 ± 2.0	28.7 ± 1.3	27.2 ± 1.6	27.89 ± 0.79

Table 11 contains the zeta scores for the activity concentrations of ^{14}C in the fish samples collected from the fish market.

TABLE 11. ZETA SCORES FOR ACTIVITY CONCENTRATIONS OF ^{14}C IN FISH SAMPLES

Nuclide	Sample number: Species	IAEA	JCAC	KINS	SPIEZ	TIO
^{14}C	24FA0001: Redwing searobin	1.62	0.78	-0.24	-0.02	-2.21
	24FA0002: Finespotted flounder	1.37	0.71	-1.05	0.04	-1.14
	24FA0003: Pufferfish	2.32	-0.71	-0.97	-0.69	-0.15
	24FA0004: Crimson sea bream	0.95	0.59	-2.35	0.91	-0.05
	24FA0005: Olive flounder	-0.66	1.97	-1.20	1.81	-1.69
	24FA0006: Japanese jack mackerel	0.88	0.57	-1.83	0.63	-0.45

Table 12 contains the results reported by laboratories (IAEA, JCAC, KAKEN, KINS and TPT) for activity concentrations of ^{3}H – OBT and TFWT – and ^{14}C in the fish samples caught by fixed nets. Figures 9 – 11 present these results visually.

TABLE 12. ACTIVITY CONCENTRATIONS OF ^{3}H (OBT, TFWT) AND ^{14}C IN FISH SAMPLES

Nuclide	Sample	IAEA	JCAC	KAKEN	KINS	TPT
^{3}H (OBT, Bq kg^{-1} f.w.)	E-SF3: Olive flounder	0.0472 ± 0.0057	<0.045	–	<0.27	–
	T-S2: Olive flounder	0.0453 ± 0.0032	–	<0.034	<0.26	–
	T-S7: Olive flounder	0.0276 ± 0.0035	–	–	<0.29	<0.034
^{3}H (TFWT, Bq L^{-1})	E-SF3: Olive flounder	0.675 ± 0.035	0.745 ± 0.037	–	<2.1	–
	T-S2: Olive flounder	0.166 ± 0.020	–	0.156 ± 0.032	<2.1	–
	T-S7: Olive flounder	0.103 ± 0.014	–	–	<2.2	0.075 ± 0.025
^{14}C (Bq kg^{-1} f.w)	E-SF3: Olive flounder	32.3 ± 4.2	25.1 ± 0.43	–	20.00 ± 0.91	–

Table 13 contains the zeta scores for the activity concentrations of ^{14}C in the fish samples in fish samples caught by fixed nets.

TABLE 13. ZETA SCORES FOR ACTIVITY CONCENTRATIONS OF ^{3}H (OBT, TFWT) AND ^{14}C IN FISH SAMPLES

Nuclide	Sample	IAEA	JCAC	KAKEN	KINS	TPT
^{3}H (OBT, Bq kg^{-1} f.w.)	E-SF3: Olive flounder	Note 1	DL	–	DL	–
	T-S2: Olive flounder	Note 1	–	DL	DL	–
	T-S7: Olive flounder	Note 1	–	–	DL	DL
^{3}H (TFWT, Bq L^{-1})	E-SF3: Olive flounder	Note 2	Note 2	–	DL	–
	T-S2: Olive flounder	Note 3	–	Note 3	DL	–
	T-S7: Olive flounder	Note 4	–	–	DL	Note 4
^{14}C (Bq kg^{-1} f.w)	E-SF3: Olive flounder	Note 5	Note 5	–	Note 5	–

Notes:

DL: No evaluation was performed when values below the detection limit were submitted.

Note 1: No evaluation was possible as only one value above the detection limit was submitted.

Note 2: Value -1.38 for $\zeta_{1,2}$.

Note 3: Value 0.26 for $\zeta_{1,3}$.

Note 4: Value 0.99 for $\zeta_{1,5}$.

Note 5: Values of 1.71, 2.87 and **5.07** for $\zeta_{1,2}$, $\zeta_{1,4}$ and $\zeta_{2,4}$, respectively.

$\zeta_{i,j}$ indexes: number 1 refers to IAEA, number 2 to JCAC, number 3 to KAKEN, number 4 to KINS and number 5 to TPT.

6.5. SEAWEED

Table 14 contains the results reported by laboratories (IAEA, JCAC, KINS, SPIEZ and TPT) for activity concentrations of ^{129}I in the seaweed samples.

TABLE 14. ACTIVITY CONCENTRATIONS OF ^{129}I (Bq kg^{-1} f.w.) IN SEAWEED SAMPLES

Nuclide	Sample	IAEA	JCAC	KINS	SPIEZ	TPT
^{129}I	E-SW2 Tomioka Port (*Eisenia bicyclis*)	<0.20	<0.06	<0.093	<0.52	–
	T-K2 Ukedo Port (*Besa paradoxa*)	<0.33	–	<0.085	<0.51	<0.02
	T-K3Tomioka Port (*Eisenia bicyclis*)	<0.24	–	0.137 ± 0.033	<0.58	<0.02

No evaluation of the results has been performed as only one value above the detection limit was submitted.

7. CONCLUSION

A detailed data analysis was performed on the activity concentrations reported for ^{3}H, ^{60}Co, ^{90}Sr, ^{106}Ru, ^{125}Sb, ^{129}I, ^{134}Cs and ^{137}Cs in seawater samples; for ^{134}Cs and ^{137}Cs in sediment samples; for organically bound tritium (OBT), tissue free water tritium (TFWT) and ^{14}C in fish samples; and ^{129}I in seaweed samples. All samples were collected offshore TEPCO's FDNPS in the period from September to November 2024. The samples were shared between ten laboratories: six from Japan (JCAC, KAKEN, KANSO, KEEA, MERI and TPT); IAEA; three ALMERA network member laboratories (KINS, SPIEZ and TIO).

IAEA analyses were undertaken at two participating IAEA Nuclear Sciences and Applications Laboratories:

- IAEA Marine Environment Laboratories, Radiometrics Laboratory (RML), Monaco; and
- Isotope Hydrology Laboratory (IHL), Vienna, Austria.

From this analysis it can be concluded that the majority of results were in agreement. Of the 90 statistical tests applied to the data set, results from five cases were evaluated as not agreeing at the 99.7% confidence level, meaning that almost 95% of tests demonstrated agreement. The following cases had zeta scores greater than 3 or less than -3 when compared with the reference value, indicating disagreement at the 99.7% confidence level:

- $\zeta = 3.45$ for the ^{3}H activity concentration in the seawater sample from T-0-1A submitted by TIO.
- $\zeta = 3.33$ for the ^{137}Cs activity concentration in the seawater sample from E-S15 submitted by TIO.
- $\zeta = 3.36$ for the ^{137}Cs activity concentration in the sediment sample from T-1 submitted by TIO.
- $\zeta = 3.49$ for the ^{137}Cs activity concentration in the sediment sample from T-S4 submitted by TIO.

The following case had a zeta score greater than 3 when results from two laboratories were compared directly, also indicating disagreement at the 99.7% confidence level:

- $\zeta = 5.07$ for ^{14}C in fish sample E-SF3: Olive flounder between JCAC and KINS.

The low number of discrepant results in this ILC is notable given that the analytical methods are often complex (e.g. for OBT, TFWT and ^{14}C in fish) and that higher uncertainties are usually associated with complex analyses of low, and close to detection limit, levels. There were no order of magnitude variations, and no systematic deviations identified between the results reported by Japanese laboratories and those reported by the IAEA and the ALMERA member laboratory. Therefore, despite these discrepancies, the laboratories demonstrated the ability to report fit-for-purpose, reliable, and comparable results for the tested radionuclides in seawater, sediment, fish and seaweed samples prepared and analysed according to each laboratory's regularly used methods. Many reported results were below detection limits and therefore could not be quantitatively intercompared. However, reported values adhered to the target detection limits for each sample and radionuclide as defined in the Comprehensive Radiation Monitoring Plan (CRMP). The IAEA recommends the organisation of such ILCs annually to maintain and improve the quality of the data reported by the participating laboratories.

Therefore, based on its evaluation, the IAEA can confirm that Japan's sample collection procedures followed the appropriate methodological standards required to obtain representative samples. The accurate results obtained in this ILC and in previous IAEA ILCs demonstrate a high degree of proficiency on the part of the Japanese laboratories involved in the analyses of radionuclides in marine samples for environmental monitoring related to the discharges of ALPS treated water as part of the CRMP.

By extension, the accurate and consistent results reported by Japanese laboratories in successive ILCs provide a high degree of confidence in the routine monitoring results produced under the CRMP. The activity concentrations measured in the ILCs are consistent with those reported through routine monitoring, which show that radionuclide concentrations in the marine environment around Fukushima Daiichi Nuclear Power Station remain relatively low and stable.

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APPENDIX I

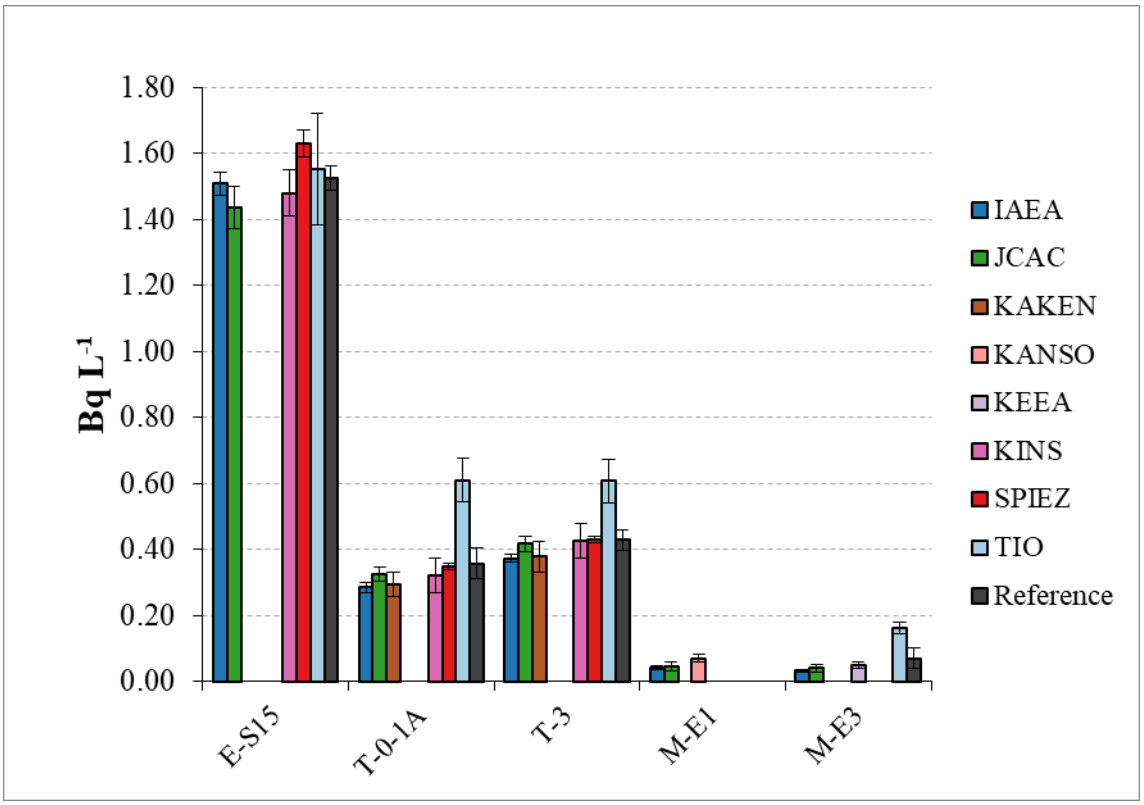


FIG. 2. Activity concentrations of ^{3}H in seawater samples.

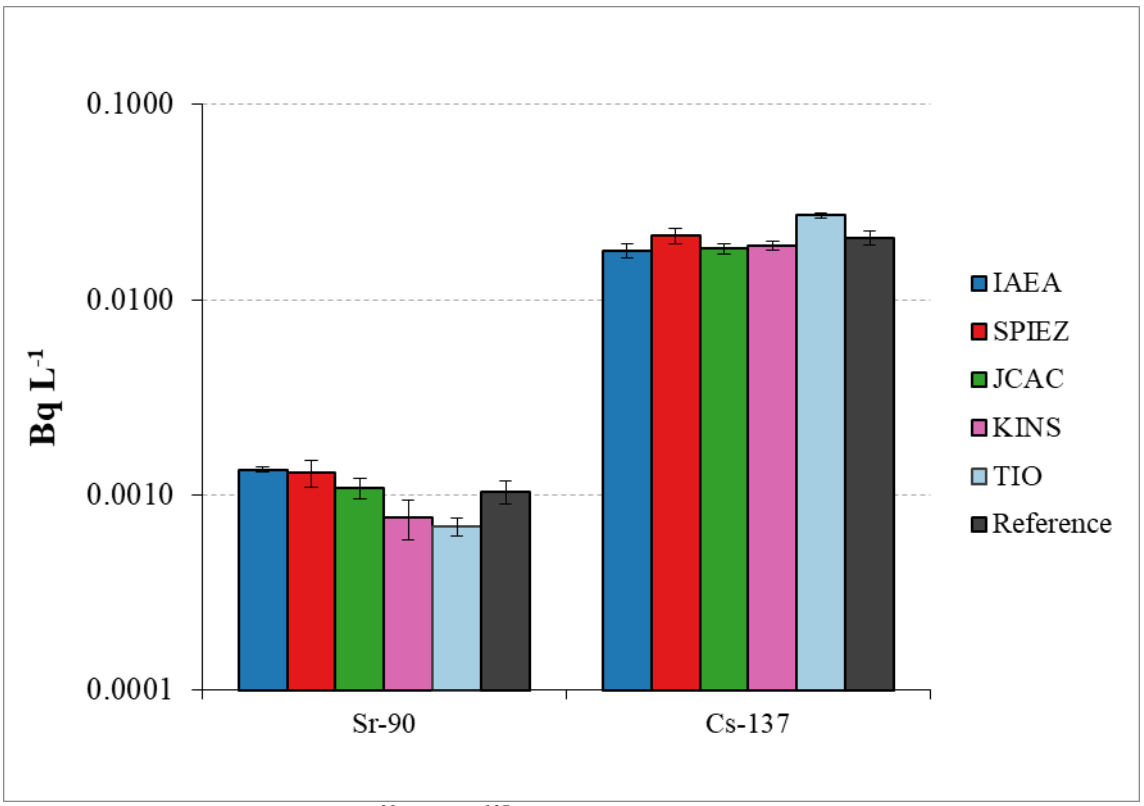


FIG. 3. Activity concentrations of ^{90}Sr and ^{137}Cs in the seawater sample from E-S15 (note logarithmic scale).

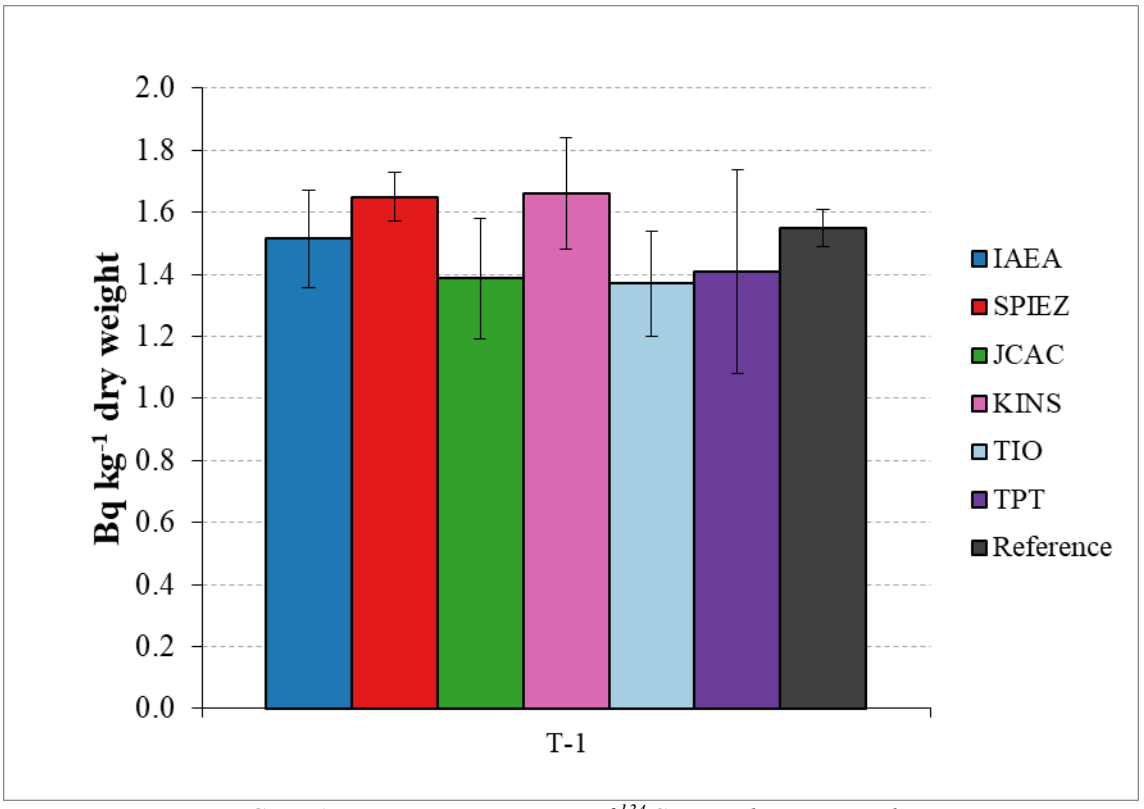


FIG. 4. Activity concentrations of ^{134}Cs in sediment samples.

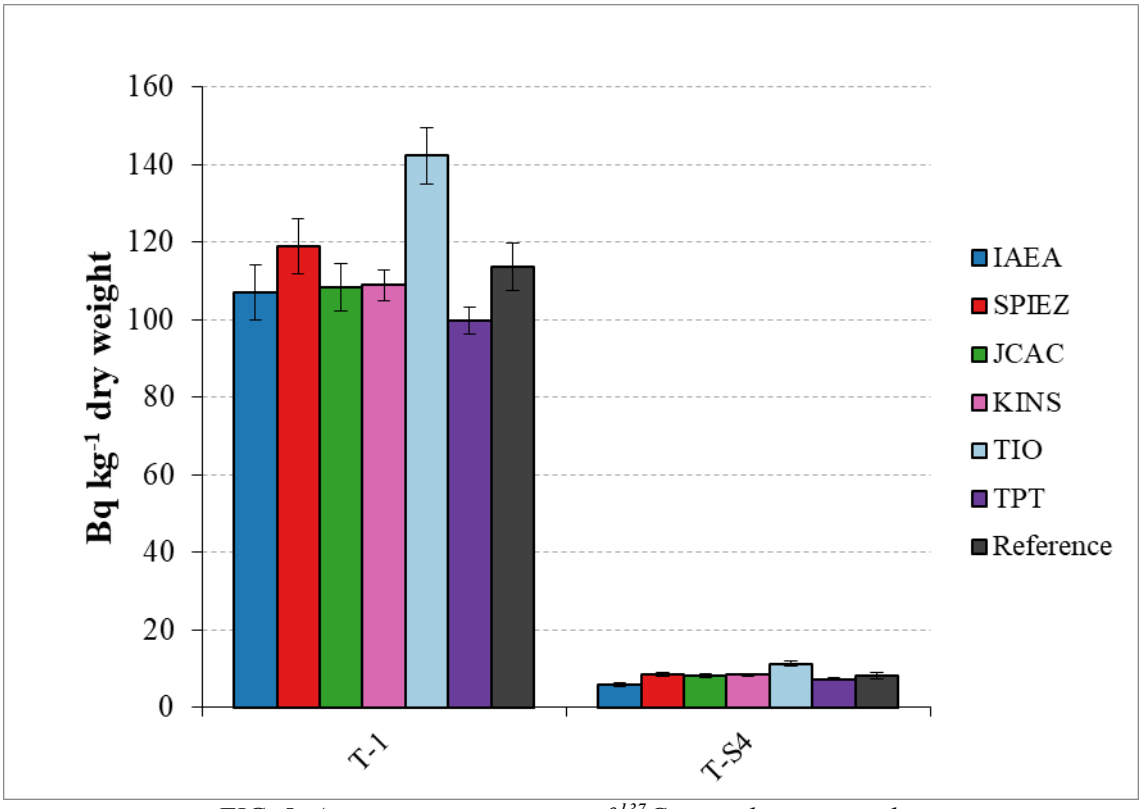


FIG. 5. Activity concentrations of ^{137}Cs in sediment samples.

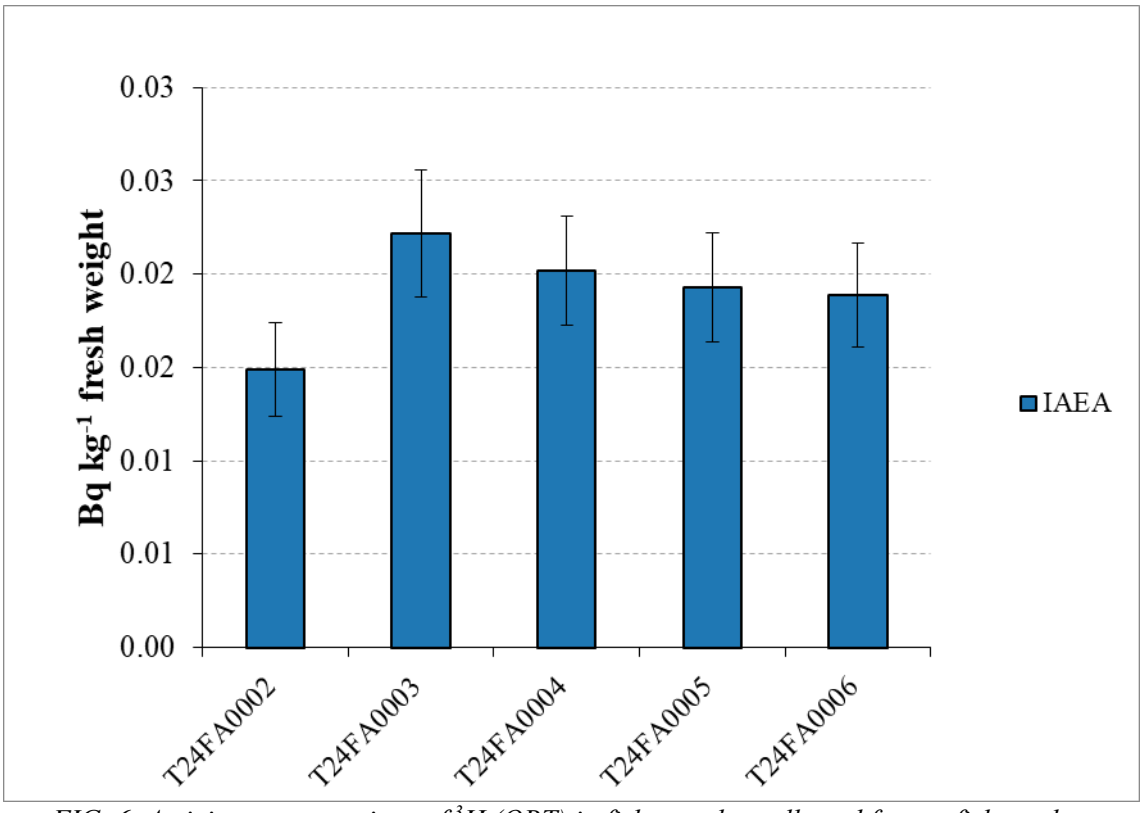


FIG. 6. Activity concentrations of ^{3}H (OBT) in fish samples collected from a fish market.

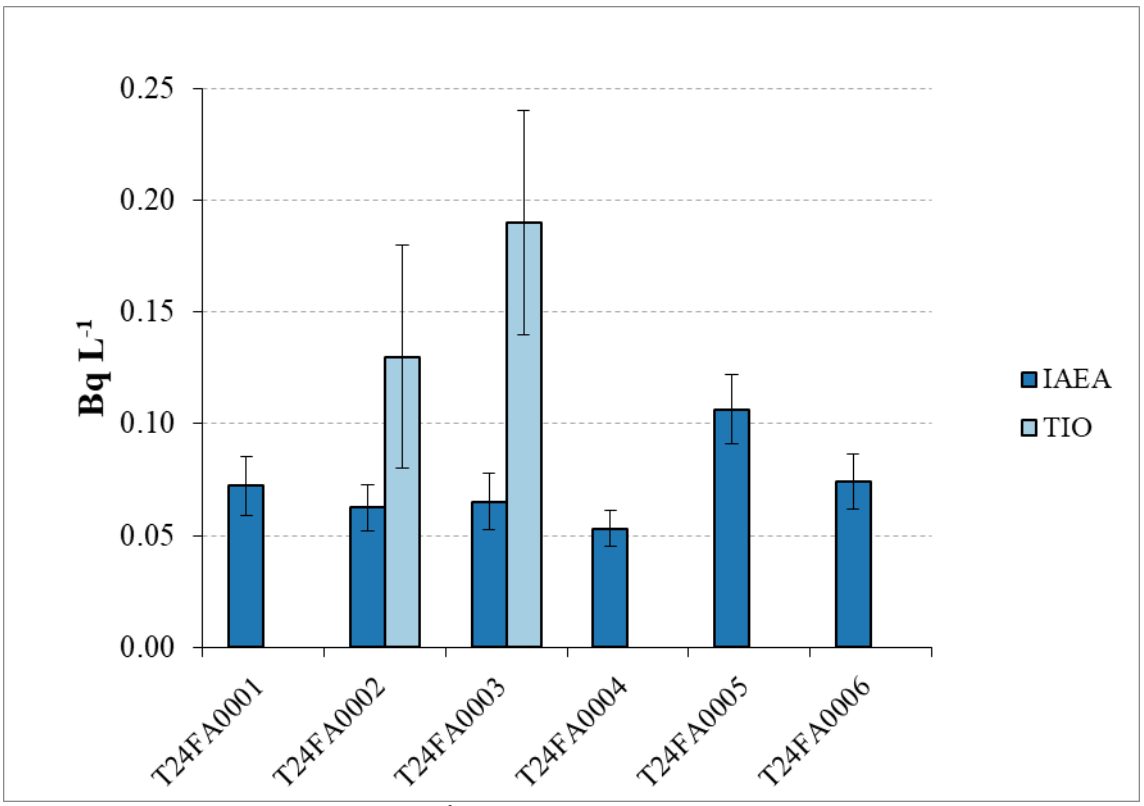


FIG. 7. Activity concentrations of ^{3}H (TFWT) in fish samples collected from a fish market.

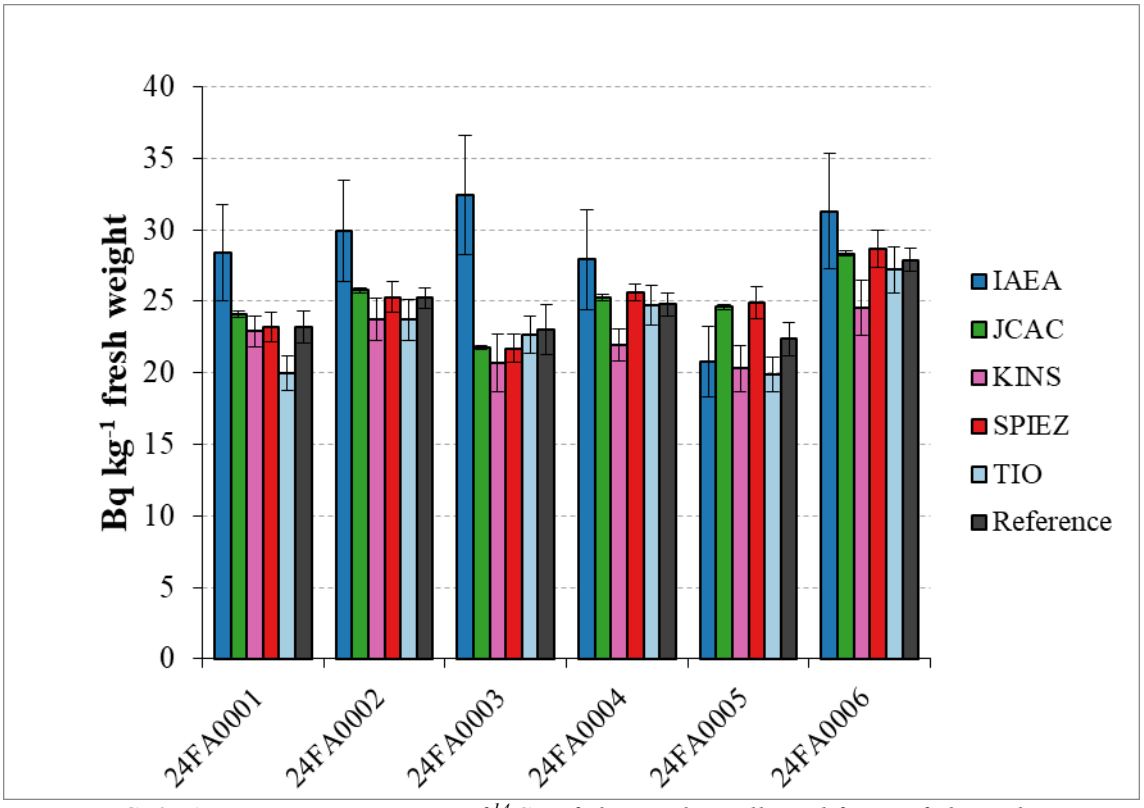


FIG. 8. Activity concentrations of ^{14}C in fish samples collected from a fish market.

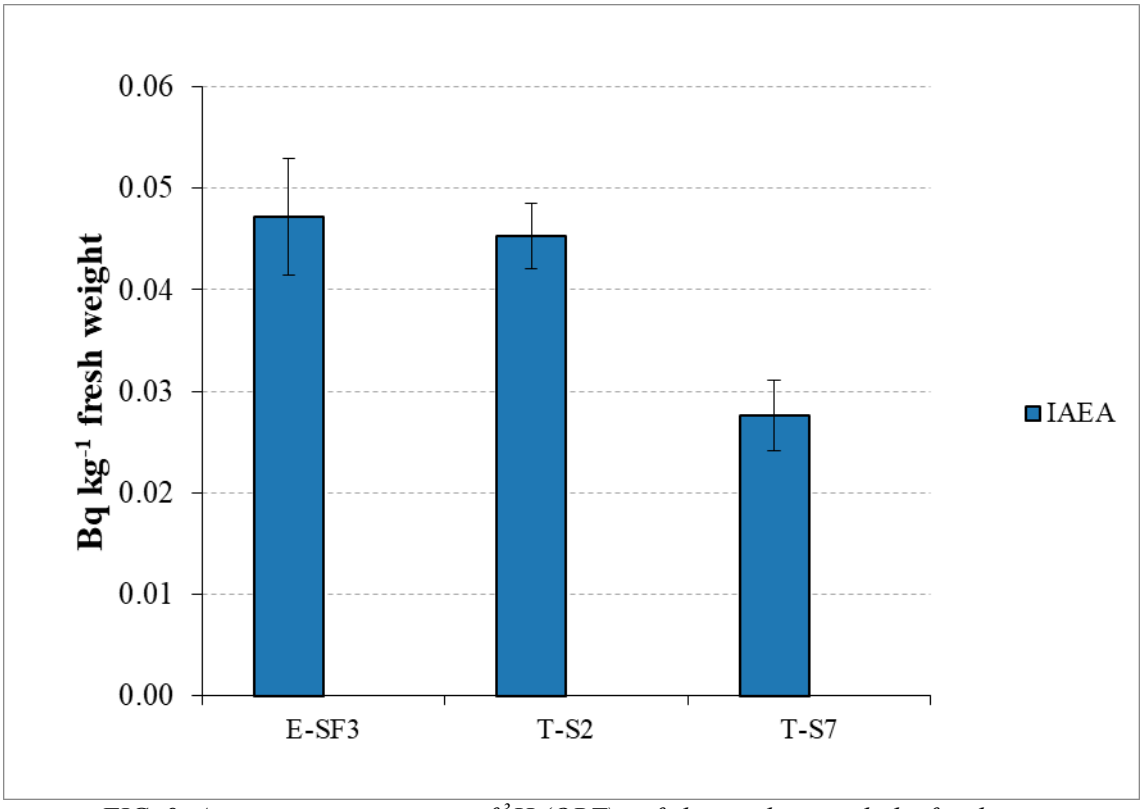


FIG. 9. Activity concentrations of ^{3}H (OBT) in fish samples caught by fixed nets.

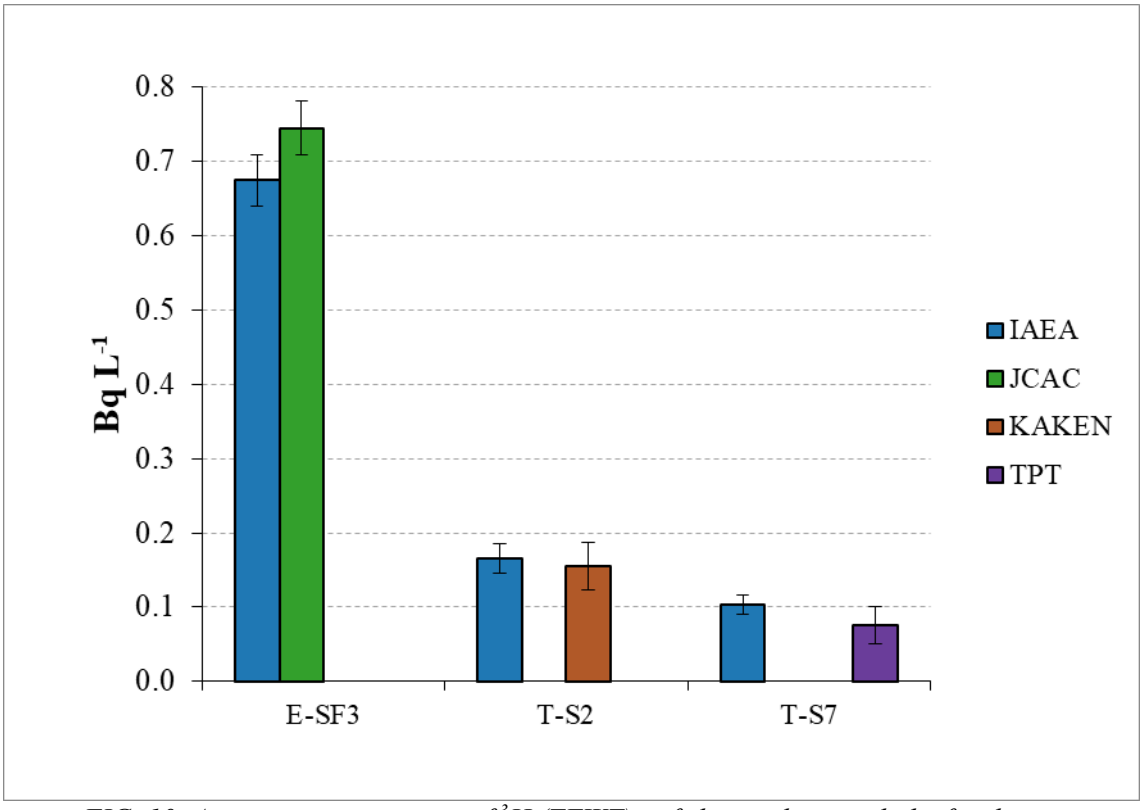


FIG. 10. Activity concentrations of ^{3}H (TFWT) in fish samples caught by fixed nets.

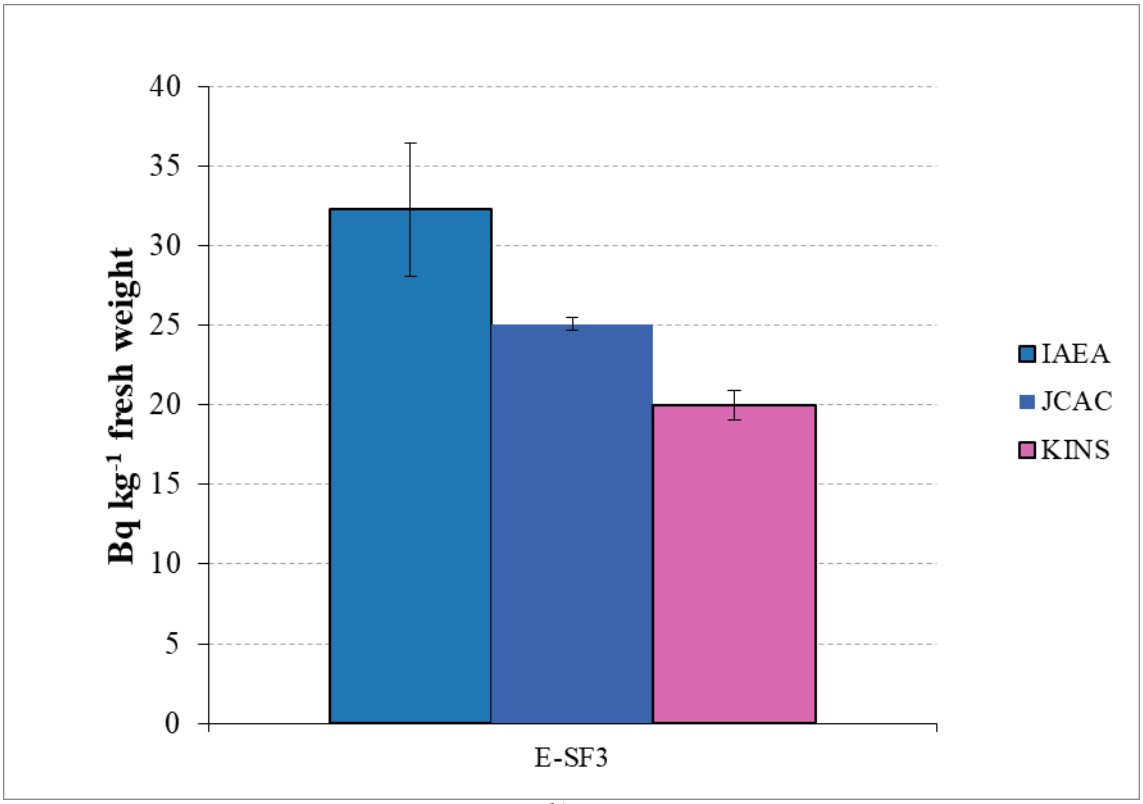


FIG. 11. Activity concentrations of ^{14}C in fish samples caught by fixed nets.

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