Interlaboratory comparison 2024 Determination of radionuclides in seawater, sediment and fish

Marine Monitoring: Confidence Building and Data Quality Assurance

IAEA Project Report

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SUMMARY REPORT

The IAEA Marine Environment Laboratories in Monaco are assisting the Government of Japan in ensuring that its regularly updated Comprehensive Radiation Monitoring Plan (CRMP) is comprehensive, credible and transparent through the project "Marine Monitoring: Confidence Building and Data Quality Assurance". During the period 2014 – 2023, 13 interlaboratory comparisons (ILCs) and 10 proficiency tests (PTs) were organised within this project to test the sampling and analytical performance of Japanese laboratories monitoring radionuclides in seawater, sediment and fish under this plan.

This report focuses on the ILC organised in 2024. As for previous ILCs in this project, a joint sampling campaign to collect seawater, sediment and fish samples was undertaken. In this case, sampling was conducted in October 2024 with observers from the IAEA and Japanese authorities involved in the CRMP. Additionally, experts from three laboratories in China, the Republic of Korea and Switzerland, all from member laboratories of the IAEA ALMERA network (Analytical Laboratories for the Measurement of Environmental Radioactivity), participated. Seawater and sediment samples were collected at offshore locations close to TEPCO's Fukushima Daiichi Nuclear Power Station. Several species of fish were sampled from a market in Fukushima Prefecture. The samples were then homogenised, split and sent to each participating laboratory for analysis. The results of the analyses of each participating laboratory – ten from Japan (participating on behalf of the Japanese authorities); the IAEA Marine Environment Laboratories; and the three ALMERA laboratories from China, the Republic of Korea and Switzerland – were subsequently collected and evaluated by the IAEA.

Comparisons of the results received for each sample and radionuclide demonstrate that the overwhelming majority are not significantly different from each other. A statistical analysis of the results shows that almost 95% of the statistical tests applied passed with a high level of confidence (99%).

It can therefore be concluded with confidence that participating laboratories reported reliable and comparable results for the tested radionuclides in seawater, sediment, and fish samples, prepared and analysed according to each laboratory's regularly used methods (although levels of ^{134}Cs and ^{238}Pu are close to detection limits in all sample types and thus difficult to intercompare).

On the basis of the results of ILC 2024, the IAEA can report that Japan's sample collection procedures continue to adhere to the appropriate methodological standards required to obtain representative samples. As in other ILCs and PTs in this project, Japanese laboratories involved in the analyses of radionuclides in marine samples as part of the CRMP have reported accurate results that demonstrate a high degree of proficiency.

1. INTRODUCTION

The IAEA Marine Environment Laboratories are assisting the Government of Japan in ensuring that its regularly updated Comprehensive Radiation Monitoring Plan (CRMP) [1] is comprehensive, credible and transparent through the project "Marine Monitoring: Confidence Building and Data Quality Assurance". During the period 2014 – 2023, 13 interlaboratory comparisons (ILCs) and 10 proficiency tests (PTs) have been organised within this project to test the sampling and analytical performance of Japanese laboratories monitoring radionuclides in seawater, sediment and fish as part of the CRMP.

PTs and ILCs are standard methods for participating laboratories to assess the quality of their measurement results in comparison with those of other participating laboratories, and to identify any potentially needed improvements. PTs involve evaluation of performance against pre-established criteria whereas ILCs involve organization, performance and evaluation of measurements on the same or similar items by two or more laboratories in accordance with predetermined conditions [2]. The PT and ILC results from this project published so far can be accessed on the IAEA web pages[1].

This report focuses on the ILC which was organised in 2024. It describes the joint sampling campaign undertaken in October 2024 to collect seawater, sediment and fish samples, the measurement results and the statistical evaluation of the results.

In total, 14 laboratories participated in the ILC: ten from Japan (participating on behalf of the Japanese authorities); the IAEA Marine Environment Laboratories in Monaco; and three laboratories from China, the Republic of Korea and Switzerland, all member laboratories of the IAEA ALMERA network (Analytical Laboratories for the Measurement of Environmental Radioactivity)[2]. The participating laboratories are presented in Table 1 and the samples provided to each laboratory for planned analyses in Table 2.

[1] Published ILC and PT reports are accessible at: https://www.iaea.org/topics/coastal-and-marine/coastal-pollution-trends/marine-monitoring-confidence-building-and-data-quality-assurance

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

TABLE 1. LABORATORIES PARTICIPATING IN ILC 2024

Identifier	Participant
IAEA	IAEA Marine Environment Laboratories, Monaco
FP	Fukushima Prefectural Centre for Environmental Creation, Fukushima, Japan
JAEA	Japan Atomic Energy Agency, Ibaraki, Japan
JCAC	Japan Chemical Analysis Center, Chiba, Japan
KAKEN	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
MERI	Marine Ecology Research Institute, Chiba, Japan
SEIKAN	SEIKAN KENSA CENTER Inc., Shizuoka, Japan
SPIEZ	Spiez Laboratory (Labor Spiez), Switzerland
TIO	Third Institute of Oceanography, Ministry of Natural Resources, Xiamen, China
TPT	Tokyo Power Technology Ltd., Fukushima, Japan
TRK	Tohoku Ryokka Kankyohozen Co. Ltd., Miyagi, Japan

TABLE 2. OVERVIEW OF ILC 2024

Sample type	Nuclide	IAEA	FP	JAEA	JCAC	KAKEN	KANSO	KEEA	KINS	MERI	SEIKAN	SPIEZ	TIO	TPT	TRK
Seawater	^{3}H	✓	✓	×	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	×
	^{90}Sr	✓	✓	×	✓	×	✓	✓	✓	×	×	✓	✓	✓	×
	^{134}Cs	✓	✓	×	✓	×	✓	✓	✓	✓	×	✓	✓	✓	✓
	^{137}Cs	✓	✓	×	✓	×	✓	✓	✓	✓	×	✓	✓	✓	✓
Sediment	^{134}Cs	✓	✓	×	✓	×	×	×	✓	×	×	✓	✓	✓	✓
	^{137}Cs	✓	✓	×	✓	×	×	×	✓	×	×	✓	✓	✓	✓
	^{238}Pu	✓	✓	✓	✓	×	×	×	✓	×	×	✓	✓	×	×
	^{239,240}Pu	✓	✓	✓	✓	×	×	×	✓	×	×	✓	✓	×	×
Fish	^{134}Cs	✓	×	×	×	×	×	×	✓	✓	✓	✓	✓	×	✓
	^{137}Cs	✓	×	×	×	×	×	×	✓	✓	✓	✓	✓	×	✓

Notes:

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

2. SEAWATER, SEDIMENT AND FISH SAMPLING AND PREPARATION

2.1. SEAWATER AND SEDIMENT SAMPLING LOCATIONS

Surface seawater samples were collected at five sampling locations (M-101, M-102, M-103, M-104, and T-D1) and sediment samples at three locations (F-P04, T-S3, and T-S8) offshore TEPCO's Fukushima Daiichi Nuclear Power Station. The sampling locations are shown in Figure 1 and their coordinates are provided in Table 3.

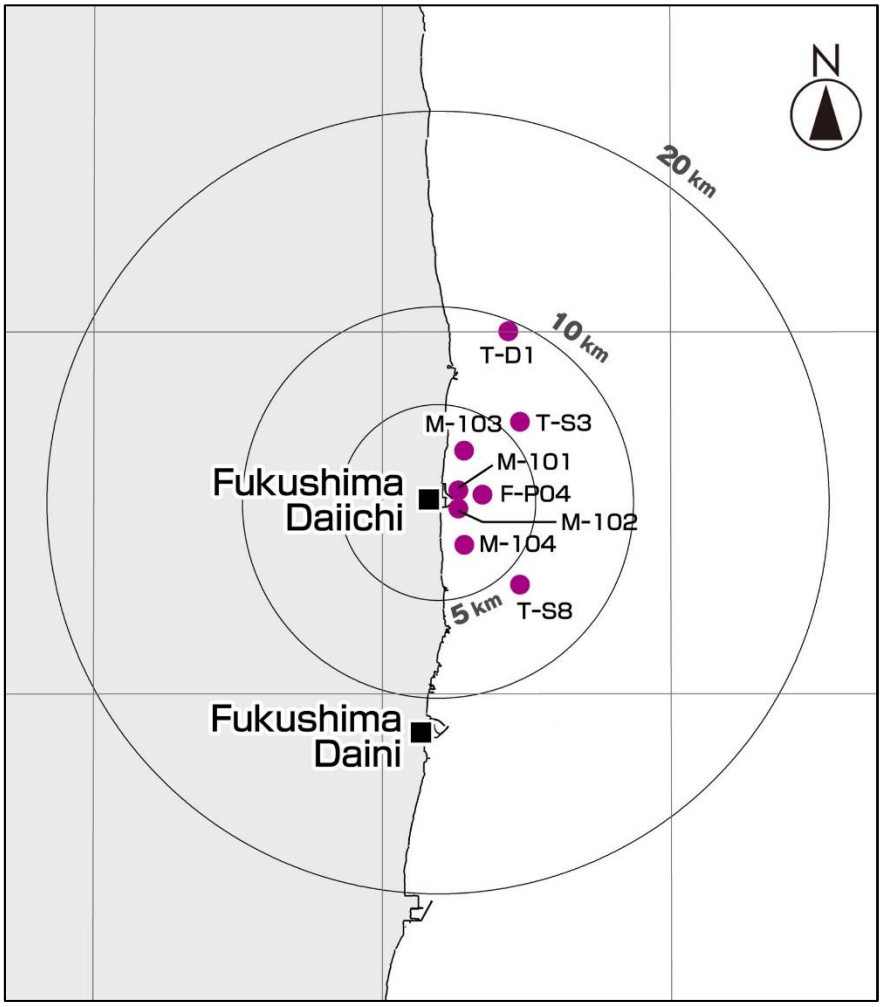

FIG. 1. Surface seawater and sediment sampling locations offshore TEPCO's Fukushima Daiichi Nuclear Power Station.

TABLE 3. COORDINATES OF THE SURFACE SEAWATER AND SEDIMENT SAMPLING LOCATIONS

Sampling location	Latitude (N)	Longitude (E)
M-101 (seawater)	37°25′36″	141°02′36″
M-102 (seawater)	37°25′06″	141°02′36″
M-103 (seawater)	37°26′42″	141°02′48″
M-104 (seawater)	37°24′06″	141°02′48″
T-D1 (seawater)	37°30′00″	141°04′20″
F-P04 (sediment)	37°25′27″	141°03′26″
T-S3 (sediment)	37°27′30″	141°04′44″
T-S8 (sediment)	37°23′00″	141°04′44″

2.2. SEAWATER

Seawater samples were collected between 7 and 11 October 2024 from sampling locations M-101, M-102, M-103, M-104 and T-D1 for subsequent analysis for ^{90}Sr, ^{134}Cs and ^{137}Cs and, separately, for ^{3}H.

For each radionuclide and sampling location, eight laboratories planned to participate in the analyses. In addition, an archive sample was collected from each location.

For ^{90}Sr, ^{134}Cs and ^{137}Cs, the sample collection and distribution methods at each sampling location were:

- A 400 L plastic container with four valves was first filled with seawater.
- Separate 20 L collapsible liquid containers were filled simultaneously from each of the four valves until all required samples had been taken. The 400 L plastic container was refilled as necessary for facilitating provision of the required sample volume to all participants.
- Each sample was acidified to pH 1–2 with concentrated HCl.
- Three 20 L samples from each sampling location were provided to each laboratory planning to participate in analyses for radiocaesium (^{134}Cs and ^{137}Cs) or ^{90}Sr.

For ^{3}H, the sample collection and distribution method were:

- From the same 400 L plastic container from which the samples to be analysed for ^{90}Sr, ^{134}Cs and ^{137}Cs were taken, separate 2 L containers were filled, two at a time, from the four valves.
- One 2 L sample was provided without any pretreatment 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.

2.3. SEDIMENT

Sediment samples were collected using a grab sampler between 7 and 9 October 2024 offshore from TEPCO's Fukushima Daiichi Nuclear Power Station at sampling locations F-P04, T-S3 and T-S8 (Figure 1 and Table 3).

The samples were subsequently oven-dried at 105°C on large fibre Reinforced Plastic (FRP), crushed using stainless-steel spatulas, and sieved through a 2 mm mesh sieve at the JCAC laboratory. No grinding was required prior to sieving due to the sandy nature of the sediments. 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 mass 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. Approximately 300 g of homogeneous dried sediment from each sampling location was then shipped to each participating laboratory analysing for all radionuclides of interest (^{134}Cs, ^{137}Cs, ^{238}Pu and ^{239,240}Pu). For those analysing only for either Cs or Pu isotopes, approximately 150 g was provided.

2.4. FISH

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 30 September 2024. These fish species were caught by pole and line fishing or bottom trawling on the same date in the vicinity of TEPCO's Fukushima Daiichi Nuclear Power Station at depths between 37 and 122 m.

Each batch of fish was prepared by fileting, homogenising the muscle tissue and then splitting into separate samples at MERI (Chiba) on 10 October 2024. One set of samples, each containing a mass of approximately 2.4 kg of each species of fish, were analysed in turn by the three participating Japanese laboratories. Additional sets of samples, each containing masses of approximately 1.2 kg of each fish species, were frozen and shipped to the IAEA Marine Environment Laboratories in Monaco and three ALMERA laboratories, KINS, SPIEZ and TIO for analysis.

The fish samples were analysed for ^{134}Cs and ^{137}Cs by gamma-ray spectrometry in each participating laboratory. Two sets of measurement results for the fish samples were requested. The first were for measurement times per sample of 1 hour. Such measurements comply with procedures set out in a testing manual for radioactive substances in food for emergencies published by the Ministry of Health, Labour and Welfare and are thus consistent with those routinely conducted by Japanese laboratories participating in the Comprehensive Radiation Monitoring Plan.

The second set of measurement results requested were for measurement times per sample of 24 hours. These were intended to facilitate effective intercomparison of the results from each laboratory by reducing detection limits and counting uncertainties, particularly for ^{134}Cs.

3. METHODOLOGY OF RADIONUCLIDE DETERMINATION

3.1. SEAWATER

Radionuclides of interest in seawater were determined by 12 laboratories participating in ILC 2024: FP, JCAC, KAKEN, KANSO, KEEA, MERI, TPT and TRK, all participating on behalf of the Nuclear Regulation Authority, Japan; IAEA; and KINS, SPIEZ and TIO, member laboratories of the IAEA ALMERA network (see Tables 1 and 2).

3.1.1. IAEA methodology for seawater

3.1.1.1. ^{3}H analysis

The samples were measured by liquid scintillation counting after double vacuum distillation (at 35°C) and electrolytic enrichment followed by a second vacuum distillation. 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.

3.1.1.2. ^{90}Sr analysis

Liquid-liquid extraction with di-(2-ethylhexyl) phosphoric acid (HDEHP) was used for the separation of yttrium from seawater samples, while caesium was precipitated from the same sample by using ammonium molybdophosphate (AMP). The ^{90}Sr activity concentration was calculated based on the measurement of ^{90}Y (yttrium oxalate source) β activity using a proportional counter with an efficiency of up to 44%.

3.1.1.3. ^{134}Cs and ^{137}Cs analysis

Caesium was separated with AMP, followed by gamma-ray spectrometry using a HPGe detector.

3.1.2. FP methodology for seawater

3.1.2.1. ^{3}H analysis

Approximately 1 kg of the sample material was purified by vacuum distillation and enriched to a final mass of 120 g by alkaline electrolysis. Electrolytes were removed from the enriched sample by vacuum distillation. 50 g of enriched water sample was mixed with 50 mL of scintillator (Ultima Gold LLT) and measured with a liquid scintillation counter (500 min/sample). The tritium activity was determined using a tritium spike method.

3.1.2.2. ^{90}Sr analysis

A cation exchange resin column was used for pre-concentration of strontium from each seawater sample, followed by precipitation of carbonates and an additional cation exchange resin column for separation of calcium. ^{90}Y was removed by scavenging and, following sufficient ingrowth , ^{90}Y was co-precipitated with iron hydroxide and then measured using a low background β counter calibrated with a standard ^{90}Y source.

3.1.2.3. ^{134}Cs and ^{137}Cs analysis

Chemical separation of caesium by AMP and manganese dioxide (MnO_2), followed by analysis by gamma-ray spectrometry using a HPGe detector.

3.1.3. JCAC methodology for seawater

3.1.3.1. ^{3}H analysis

The seawater samples were distilled, followed by electrolytic enrichment. 50 mL of the purified sample was mixed with 50 mL of scintillation cocktail and measured with a liquid scintillation counter.

3.1.3.2. ^{90}Sr analysis

A cation exchange resin column was used for pre-concentration of strontium from each 40 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 and, following sufficient ingrowth, ^{90}Y was co-precipitated with iron hydroxide and then was measured using a low background β counter.

3.1.3.3. ^{134}Cs and ^{137}Cs analysis

Chemical separation of radiocaesium was undertaken using AMP and followed by gamma-ray spectrometry using a HPGe detector.

3.1.4. KAKEN methodology for seawater

3.1.4.1. ^{3}H analysis

Each seawater sample was analysed according to the "Tritium Analysis Method" (Radiation Measurement Method Series 9 published by the Japanese Ministry of Education, Culture, Sports, Science and Technology). Distilled samples of mass 65 g were counted using a liquid scintillation counter.

3.1.5. KANSO methodology for seawater

3.1.5.1. ^{3}H analysis

The samples were purified by distillation using glassware selected to ensure that the concentration of tritium in water was maintained. Next, 1 L of the distilled sample was electrolytically concentrated using a solid polymer electrolytic film. Then, 50mL of the sample was mixed with 50mL of scintillation cocktail (Ultima Gold LLT) in a PTFE (polytetrafluoroethylene) bottle and counted on a low background liquid scintillation counter for 500 minutes.

3.1.5.2. ^{90}Sr analysis

An ion exchange resin was used for pre-concentration of strontium in each seawater sample, followed by precipitation of carbonates and barium chromate. After sufficient ingrowth , ^{90}Y was separated using a ferric hydroxide co-precipitation technique and measured by a gas-flow counter.

3.1.5.3. ^{134}Cs and ^{137}Cs analysis

Chemical separation of radiocaesium was undertaken using AMP and followed by gamma-ray spectrometry with a HPGe detector.

3.1.6. KEEA methodology for seawater

3.1.6.1. ^{3}H analysis

Each seawater sample was distilled and electrically enriched by approximately 40 times the starting concentration. The enriched sample was neutralised and distilled. 10 g of the enriched sample was mixed with 10 g of scintillation cocktail in a 20 mL low diffusion polyethylene vial and counted for 800 min using a low background liquid scintillation counter.

3.1.6.2. ^{90}Sr analysis

Strontium pre-concentration of 40 L seawater samples was carried out using a cation exchange resin, followed by separation of carbonate precipitation and oxalate precipitation. Strontium-calcium separation was carried out using a cation exchange resin. Barium was separated from strontium as the insoluble barium chromate precipitate. The strontium-yttrium separation was carried out by co-precipitation of yttrium with ferric hydroxide. The strontium chemical recovery was determined by ICP-AES. After allowing two weeks for ^{90}Y ingrowth, ^{90}Y was measured immediately after separation from ^{90}Sr by proportional counting.

3.1.6.3. ^{134}Cs and ^{137}Cs analysis

Chemical separation of radiocaesium was undertaken by co-precipitation using AMP and followed by gamma-ray spectrometry with a HPGe detector.

3.1.7. KINS methodology for seawater

3.1.7.1. ^{3}H analysis

Tritium was measured using electrolysis and liquid scintillation counting. 1 L of seawater was distilled, and 800 mL of the distillate was concentrated to 40 mL via alkaline electrolytic enrichment, followed by a second distillation. For measurement, 10 mL of the distilled sample was mixed with 10 mL of scintillation cocktail (Ultima Gold LLT) in a PTFE (polytetrafluoroethylene) vial. The samples were stabilized in the liquid scintillation counter before measurement, and each sample was measured for 500 minutes. Calibration was performed using a custom quenching set prepared by spiking a certified reference material (CRM, NIST 4927g) in vials with the same geometry as the samples.

3.1.7.2. ^{90}Sr analysis

Strontium pre-concentration of 30 kg seawater samples 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 after allowing two weeks for ^{90}Y ingrowth. The chemical yield was determined by ICP-OES (Inductively Coupled Plasma Optical Emission Spectroscopy).

3.1.7.3. ^{134}Cs and ^{137}Cs analysis

Chemical separation of radiocaesium was undertaken using AMP and followed by gamma-ray spectrometry with a HPGe detector.

3.1.8. MERI methodology for seawater

3.1.8.1. ^{3}H analysis

Each seawater sample was first purified by distillation. Then, ^{3}H was concentrated by electrolysis (a sample volume of 500 mL was reduced to 50 mL). This enriched sample was further purified by distillation. 50 mL of the distillate was mixed with 50 mL of Ultima Gold uLLT scintillation cocktail to prepare a sample for measurement, then measured using a low background liquid scintillation counter.

3.1.8.2. ^{134}Cs and ^{137}Cs analysis

Chemical separation of radiocaesium was undertaken using AMP and followed by gamma-ray spectrometry using a HPGe detector.

3.1.9. SPIEZ methodology for seawater

3.1.9.1. ^{3}H analysis

Tritium analyses were carried out, on behalf of SPIEZ, at EAWAG, the Swiss Federal Institute of Aquatic Science and Technology. A low-level mass spectrometry method was used, whereby the activity concentration of ^{3}H in each sample was determined through the ingrowth of a decay product ^{3}He under controlled conditions. 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 [3].

3.1.9.2. ^{90}Sr analysis

Calcium oxalate was precipitated from each sample. The precipitate was dissolved in 3M HNO_3 and passed through a preconditioned Sr-resin column. The Sr fraction was eluted with 0.005 M HNO_3.

$SrCO_3$ sources were prepared and counted by low level gas proportional counting. The radiochemical yield was determined by ICP-OES, using a known amount of strontium carriers.

3.1.9.3. ^{134}Cs and ^{137}Cs analysis

The caesium radioisotopes were extracted from about 16 L seawater via adsorption onto an AMP-PAN resin and then counted by gamma ray spectrometry using a HPGe detector. The chemical yield was determined using stable caesium as tracer and ICP-MS measurement.

3.1.10. TIO methodology for seawater

3.1.10.1. ^{3}H analysis

Tritium was determined by liquid scintillation counting following distillation and electrolytic enrichment.

3.1.10.2. ^{90}Sr analysis

Strontium pre-concentration of 35 L seawater samples was undertaken by carbonate co-precipitation. Liquid-liquid extraction with di-(2-ethylhexyl) phosphoric acid (HDEHP) was used for the separation of yttrium from seawater samples. The ^{90}Sr activity concentration was calculated based on the measurement of ^{90}Y (yttrium oxalate source) β activity using a gas α/β counter.

3.1.10.3. ^{134}Cs and ^{137}Cs analysis

Caesium was precipitated using AMP from 20 L of each seawater sample and counted by gamma-ray spectrometry using a HPGe detector.

3.1.11. TPT methodology for seawater

3.1.11.1. ^{3}H analysis

Each seawater sample was first purified by vacuum distillation in a rotary evaporator with sodium peroxide and potassium permanganate, followed by electrolytic enrichment (500 mL reduced to 60 mL). The enriched sample was further purified by vacuum distillation, mixed with a scintillation cocktail and measured using a low background liquid scintillation counter.

3.1.11.2. ^{134}Cs and ^{137}Cs analysis

Caesium was separated with AMP, followed by gamma-ray spectrometry using a HPGe detector.

3.1.12. TRK methodology for seawater

3.1.12.1. ^{134}Cs and ^{137}Cs analysis

Caesium was separated with AMP, followed by gamma-ray spectrometry using a HPGe detector.

3.2. SEDIMENT

Radionuclides of interest in sediment samples were determined by nine laboratories participating in ILC 2024: FP, JAEA, JCAC, TPT and TRK, participating on behalf of the Nuclear Regulation Authority, Japan; IAEA; and KINS, SPIEZ and TIO, member laboratories of the IAEA ALMERA network (see Tables 1 and 2).

3.2.1. IAEA methodology for sediment

3.2.1.1. ^{134}Cs and ^{137}Cs analysis

Gamma-ray spectrometry using a p Broad Energy HPGe detector.

3.2.1.2. ^{238}Pu and $^{239,240}Pu$ analysis

Classical digestion followed by ion exchange, electrodeposition and counting by alpha spectrometry. An aliquot of 5 g of sediment sample was ashed and spiked with a ^{242}Pu tracer. The sample was totally dissolved by using concentrated acids. After $Fe(OH)_3$ precipitation and plutonium oxidation state adjustment, double ion exchange (DOWEX 1×4) was used for Pu purification. Plutonium was electrodeposited from Na_2SO_4/H_2SO_4 electrolyte solution on stainless-steel discs and counted by alpha spectrometry.

3.2.2. FP methodology for sediment

3.2.2.1. ^{134}Cs and ^{137}Cs analysis

Gamma-ray spectrometry using a HPGe detector.

3.2.2.2. ^{238}Pu and $^{239,240}Pu$ analysis

Alpha spectrometry with a Si detector after leaching, radiochemical separation and purification of plutonium by using an anion exchange resin column followed by electrodeposition from the purified solution.

3.2.3. JAEA methodology for sediment

3.2.3.1. ^{238}Pu and $^{239,240}Pu$ analysis

For the sample from T-S8 the sediment was first heated to 450°C. The sample was spiked with a ^{242}Pu tracer, then immersed in a HNO_3 solution and heated for leaching. Plutonium ions were extracted from the filtered leaching solution by an ion-exchange method, electrodeposited onto stainless steel plates and counted by alpha spectrometry.

3.2.4. JCAC methodology for sediment

3.2.4.1. ^{134}Cs and ^{137}Cs analysis

Direct counting gamma-ray spectrometry using a HPGe detector.

3.2.4.2. ^{238}Pu and $^{239,240}Pu$ analysis

Plutonium isotopes were measured with a Si semiconductor detector after leaching, radiochemical separation and purification of plutonium by using an anion exchange resin column followed by electrodeposition from the purified solution.

3.2.5. KINS methodology for sediment

3.2.5.1. ^{134}Cs and ^{137}Cs analysis

Direct counting on a p-type coaxial HPGe detector with relative efficiency 30%.

3.2.5.2. ^{238}Pu and $^{239,240}Pu$ analysis

A ^{242}Pu tracer was added to 20 g of dried sample and digested with 8M HNO_3. The oxidation state of dissolved plutonium was adjusted to Pu(IV) with ascorbic acid in a 5 M HNO_3 solution and purified

using extraction chromatography resins TEVA. Plutonium fractions were then electroplated and measured by alpha spectrometry for 300,000 s.

3.2.6. SPIEZ methodology for sediment

3.2.6.1. ^{134}Cs and ^{137}Cs analysis

Direct counting on a HPGe detector for between 215 and 305 hours. The sample volume was 79 cm^3.

3.2.6.2. ^{238}Pu and $^{239,240}Pu$ analysis

The samples were counted by alpha spectrometry (^{238}Pu) and sf-ICP-MS (^{239}Pu and ^{239}Pu) after total dissolution by melting with lithium borate, and pre-concentration with extraction-chromatography (TEVA resin). The eluted Pu was measured directly by ICP-MS. For alpha spectrometry, the samples were prepared for alpha spectrometry by electrodeposition on stainless steel discs.

3.2.7. TIO methodology for sediment

3.2.7.1. ^{134}Cs and ^{137}Cs analysis

Gamma-ray spectrometry using a HPGe detector.

3.2.8. TPT methodology for sediment

3.2.8.1. ^{134}Cs and ^{137}Cs analysis

Gamma-ray spectrometry using a p-type coaxial HPGe detector.

3.2.9. TRK methodology for sediment

3.2.9.1. ^{134}Cs and ^{137}Cs analysis

Gamma-ray spectrometry using a p-type coaxial HPGe detector.

3.3. FISH

Radionuclides of interest in fish samples were determined by seven laboratories participating in ILC 2024: MERI, SEIKAN and TRK, all participating on behalf of the Japan Fisheries Agency; IAEA; and KINS, SPIEZ and TIO, member laboratories of the IAEA ALMERA network (see Tables 1 and 2).

3.3.1. IAEA methodology for fish

3.3.1.1. ^{134}Cs and ^{137}Cs analysis

Direct counting on a p-type coaxial HPGe detector of relative efficiency 70%. The samples were prepared in 1 L Marinelli beakers.

3.3.2. KINS methodology for fish

3.3.2.1. ^{134}Cs and ^{137}Cs analysis

Direct counting on a p-type coaxial HPGe detector of relative efficiency 30%. The samples were prepared in 1 L Marinelli beakers.

3.3.3. MERI methodology for fish

3.3.3.1. ^{134}Cs and ^{137}Cs analysis

Direct counting by a p-type coaxial HPGe detector of relative efficiency 47%. The samples were prepared in 2 L Marinelli beakers.

3.3.4. SEIKAN methodology for fish

3.3.4.1. ^{134}Cs and ^{137}Cs analysis

Direct counting on a p-type coaxial HPGe detector of relative efficiency 46%. The samples were prepared in 2 L Marinelli beakers.

3.3.5. SPIEZ methodology for fish

3.3.5.1. ^{134}Cs and ^{137}Cs analysis

Direct counting on a HPGe detector for between 161 and 239 hours. The samples were prepared in 0.5 L containers.

3.3.6. TIO methodology for fish

3.3.6.1. ^{134}Cs and ^{137}Cs analysis

Direct counting on a p-type coaxial HPGe detector of relative efficiency 65%. The samples were prepared in 2 L Marinelli beakers.

3.3.7. TRK methodology for fish

3.3.7.1. ^{134}Cs and ^{137}Cs analysis

Direct counting by a HPGe detector. The samples were prepared in 2 L Marinelli beakers.

4. 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 [4] was performed, comparing the two results. 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 [5], 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 [5]:

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

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 [4], 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.

5. RESULTS

5.1. GENERAL

The results are presented in Tables 4 – 9 and Figures 2 – 10.

5.1.1. 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.

5.1.2. Reference time

All activity concentrations and massic activities for seawater, sediment and fish were reported at a reference time of 16 October 2024 12:00 UTC.

5.2. SEAWATER

Table 4 contains the results reported by the participating laboratories (IAEA, FP, JCAC, KAKEN, KANSO, KEEA, KINS, MERI, SPIEZ, TIO, TPT, and TRK) for the activity concentrations of ^{3}H, ^{90}Sr, ^{134}Cs and ^{137}Cs in the seawater samples. Figures 2 to 4 show the activity concentrations of these radionuclides in the seawater samples.

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

Nuclide	Sample	IAEA	FP	JCAC	KAKEN	KANSO	KEEA	KINS	MERI	SPIEZ	TIO	TPT	TRK	Reference value
^{3}H	M-101	381 ± 21	423 ± 34	461 ± 26	404 ± 47	–	–	409 ± 52	460 ± 25	470 ± 10	520 ± 60	–	–	440 ± 15
	M-102	83 ± 14	74 ± 19	118 ± 15	–	140 ± 10	–	109 ± 31	110 ± 12	NM	430 ± 50	–	–	148 ± 46
	M-103	93 ± 15	88 ± 19	127 ± 15	–	140 ± 10	–	115 ± 35	120 ± 12	140 ± 10	290 ± 30	–	–	120.4 ± 8.1[1]
	M-104	1045 ± 46	1270 ± 83	1245 ± 56	–	–	1300 ± 50	1331 ± 85	1200 ± 50	1130 ± 20	1470 ± 160	–	–	1223 ± 42
	T-D1	70 ± 14	–	91 ± 15	65 ± 15	–	–	151 ± 32	110 ± 12	90 ± 10	190 ± 20	47 ± 13	–	99 ± 17
^{90}Sr	M-101	1.031 ± 0.032	0.75 ± 0.19	0.97 ± 0.15	–	1.1 ± 0.2	0.99 ± 0.16	0.74 ± 0.11	–	1.11 ± 0.38	1.43 ± 0.11	–	–	1.014 ± 0.083
	M-102	0.960 ± 0.026	0.55 ± 0.18	0.56 ± 0.12	–	1.1 ± 0.2	0.66 ± 0.14	0.61 ± 0.11	–	1.33 ± 0.36	0.60 ± 0.08	–	–	0.750 ± 0.089
	M-103	1.291 ± 0.039	1.29 ± 0.24	1.20 ± 0.18	–	1.3 ± 0.2	1.21 ± 0.17	1.007 ± 0.093	–	1.07 ± 0.40	1.37 ± 0.09	–	–	1.239 ± 0.047
	M-104	1.023 ± 0.027	0.66 ± 0.19	0.73 ± 0.14	–	1.2 ± 0.2	0.87 ± 0.16	0.770 ± 0.090	–	0.71 ± 0.27	0.91 ± 0.09	–	–	0.882 ± 0.058
	T-D1	1.104 ± 0.035	–	1.02 ± 0.15	–	0.98 ± 0.17	0.86 ± 0.15	0.62 ± 0.11	–	1.51 ± 0.34	0.83 ± 0.09	1.78 ± 0.19	–	1.05 ± 0.14

Note:

NM: Not measured; no value reported.

[1] TIO's result for ^{3}H was identified as an outlier and excluded from the calculation of the reference value.

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

Nuclide	Sample	IAEA	FP	JCAC	KAKEN	KANSO	KEEA	KINS	MERI	SPIEZ	TIO	TPT	TRK	Reference value
^{134}Cs	M-101	<0.72	<2.0	<0.66	–	–	–	<0.42	<0.71	<1.7	<1.1	–	<0.94	NC†
	M-102	<0.72	<1.8	<0.77	–	<0.80	–	<0.43	<0.88	<1.4	<1.1	–	–	NC†
	M-103	0.40 ± 0.13	<1.8	<0.72	–	–	<0.77	0.466 ± 0.086	<0.85	<1.4	<1.1	–	–	NC‡
	M-104	<0.75	<2.1	<0.71	–	–	<0.75	<0.43	<0.79	<0.95	<1.1	–	–	NC†
	T-D1	<0.45	–	<0.70	–	–	–	<0.42	<0.87	<1.5	<1.1	<0.55	<0.89	NC†
^{137}Cs	M-101	6.18 ± 0.57	7.34 ± 0.80	6.17 ± 0.40	–	–	–	6.44 ± 0.29	8.20 ± 0.73	6.11 ± 0.68	7.4 ± 0.4	–	6.0 ± 1.3	6.71 ± 0.27
	M-102	6.18 ± 0.56	6.83 ± 0.74	6.39 ± 0.42	–	5.9 ± 0.29	–	6.21 ± 0.31	6.80 ± 0.62	6.14 ± 0.61	8.5 ± 0.4	–	–	6.61 ± 0.31
	M-103	34.9 ± 3.0	22.4 ± 1.8	24.3 ± 1.5	–	–	24.3 ± 1.0	37.1 ± 1.0	26.0 ± 2.2	25.1 ± 2.4	29.1 ± 1	–	–	27.9 ± 2.0
	M-104	6.42 ± 0.64	7.96 ± 0.89	7.71 ± 0.49	–	–	7.58 ± 0.41	6.70 ± 0.38	7.40 ± 0.66	7.99 ± 0.84	9.3 ± 0.5	–	–	7.61 ± 0.33
	T-D1	7.15 ± 0.65	–	7.15 ± 0.46	–	–	–	8.34 ± 0.41	7.90 ± 0.70	7.56 ± 0.78	9.1 ± 0.5	7.37 ± 0.29	6.6 ± 1.4	7.75 ± 0.27

Notes:

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

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

Table 5 contains the zeta scores for the activity concentrations of ^{3}H, ^{90}Sr, ^{134}Cs and ^{137}Cs in the seawater samples.

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

Nuclide	Sample	IAEA	FP	JCAC	KAKEN	KANSO	KEEA	KINS	MERI	SPIEZ	TIO	TPT	TRK
^{3}H	M-101	-2.63	-0.54	0.78	-0.80	–	–	-0.62	0.77	1.79	1.37	–	–
	M-102	-1.38	-1.54	-0.63	–	-0.17	–	-0.74	-0.81	NM	**4.52**	–	–
	M-103	-1.83	-1.81	0.44	–	1.74	–	-0.16	-0.03	1.74	**5.46**	–	–
	M-104	**-3.13**	0.56	0.34	–	–	1.29	1.25	-0.39	-2.08	1.58	–	–
	T-D1	-1.43	–	-0.41	-1.67	–	–	1.56	0.55	-0.50	**3.78**	-2.64	–
^{90}Sr	M-101	0.19	-1.40	-0.31	–	0.44	-0.17	-2.29	–	0.26	**3.37**	–	–
	M-102	2.31	-1.08	-1.39	–	1.75	-0.63	-1.11	–	1.65	-1.35	–	–
	M-103	1.03	0.22	-0.22	–	0.32	-0.19	-2.63	–	-0.43	1.53	–	–
	M-104	2.32	-1.24	-1.13	–	1.64	-0.11	-1.20	–	-0.68	0.30	–	–
	T-D1	0.37	–	-0.19	–	-0.38	-1.11	-2.77	–	1.38	-1.49	**3.45**	–
^{134}Cs	M-101	DL	DL	DL	–	–	–	DL	DL	DL	DL	–	DL
	M-102	DL	DL	DL	–	DL	–	DL	DL	DL	DL	–	–
	M-103	Note 1	DL	DL	–	–	DL	Note 1	DL	DL	DL	–	–
	M-104	DL	DL	DL	–	–	–	DL	DL	DL	DL	–	–
	T-D1	DL	–	DL	–	–	–	DL	DL	DL	DL	DL	DL
^{137}Cs	M-101	-0.95	0.82	-1.30	–	–	–	-0.78	2.10	-0.91	1.63	–	-0.63
	M-102	-0.75	0.30	-0.49	–	-1.82	–	-1.00	0.30	-0.76	**4.11**	–	–
	M-103	2.17	-2.22	-1.59	–	–	-1.70	**4.43**	-0.69	-0.97	0.60	–	–
	M-104	-1.85	0.40	0.19	–	–	-0.07	-2.02	-0.32	0.46	**3.16**	–	–
	T-D1	-0.96	–	-1.30	–	–	–	1.37	0.22	-0.25	2.69	-1.10	-0.85

Notes:

NM: Not measured; no value reported.

DL: As a value less than the detection limit was submitted, no evaluation was performed.

Note 1: Value of -0.41 for $\zeta_{1,7}$.

$\zeta_{i,j}$ indexes: number 1 refers to IAEA, number 2 to FP, number 3 to JCAC, number 4 to KAKEN, number 5 to KANSO, number 6 to KEEA, number 7 to KINS, number 8 to MERI, number 9 to SPIEZ, number 10 to TIO, number 11 to TPT and number 12 to TRK.

5.3. SEDIMENT

Table 6 contains the results reported by the participating laboratories (IAEA, FP, JAEA, JCAC, KINS, SPIEZ, TIO, TPT and TRK) for the massic activities of radionuclides in the sediment samples. Figures 5 to 8 show the massic activities of ^{134}Cs, ^{137}Cs and ^{239,240}Pu in the sediment samples.

TABLE 6. MASSIC ACTIVITIES (Bq kg^{-1} dry weight) OF RADIONUCLIDES IN SEDIMENT SAMPLES

Nuclide	Sample	IAEA	FP	JAEA	JCAC	KINS	SPIEZ	TIO	TPT	TRK	Reference value
^{134}Cs	F-P04	0.556 ± 0.087	<0.95	–	<0.69	0.64 ± 0.12	0.874 ± 0.059	0.69 ± 0.08	<0.98	<0.76	0.697 ± 0.072
	T-S3	<0.51	<0.74	–	<0.55	<0.58	<0.15	<0.15	<0.74	<0.66	NC†
	T-S8	0.42 ± 0.11	–	–	<0.58	0.63 ± 0.11	0.657 ± 0.044	0.72 ± 0.09	<0.87	0.85 ± 0.20	0.639 ± 0.061
^{137}Cs	F-P04	40.3 ± 2.7	50.3 ± 2.9	–	45.6 ± 2.6	46.2 ± 1.5	58.1 ± 3.5	47.3 ± 2.5	46.3 ± 1.5	45 ± 1.3	47.0 ± 1.7
	T-S3	8.19 ± 0.56	8.42 ± 0.55	–	15.48 ± 0.90	8.39 ± 0.35	7.41 ± 0.45	6.97 ± 0.37	8.77 ± 0.40	10.56 ± 0.42	9.22 ± 0.95
	T-S8	36.1 ± 2.5	–	–	44.2 ± 2.5	45.9 ± 1.5	44.9 ± 2.7	45.8 ± 2.4	40.3 ± 1.3	49.5 ± 1.4	43.9 ± 1.7
^{238}Pu	F-P04	<0.012	<0.012	–	0.0046 ± 0.0011	0.0056 ± 0.0014	<0.030	NM	–	–	NC‡
	T-S3	<0.011	<0.018	–	0.0053 ± 0.0012	0.0086 ± 0.0016	<0.030	NM	–	–	NC‡
	T-S8	<0.013	–	0.0083 ± 0.0028	0.0066 ± 0.0017	0.0068 ± 0.0015	<0.030	NM	–	–	NC‡
^{239,240}Pu	F-P04	0.366 ± 0.019	0.353 ± 0.030	–	0.338 ± 0.011	0.358 ± 0.016	0.3755 ± 0.0075	NM	–	–	0.3595 ± 0.0078
	T-S3	0.342 ± 0.018	0.387 ± 0.034	–	0.348 ± 0.012	0.332 ± 0.014	0.3540 ± 0.0064	NM	–	–	0.3495 ± 0.0063
	T-S8	0.552 ± 0.023	–	0.5180 ± 0.0021	0.528 ± 0.017	0.555 ± 0.022	0.596 ± 0.013	NM	–	–	0.549 ± 0.015

Notes:

NM: Not measured; no value reported.

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

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

Table 7 contains the zeta scores for the massic activities of ^{134}Cs, ^{137}Cs, ^{238}Pu and ^{239,240}Pu in the sediment samples.

TABLE 7. ZETA SCORES FOR MASSIC ACTIVITIES OF RADIONUCLIDES IN SEDIMENT SAMPLES

Nuclide	Sample	IAEA	FP	JAEA	JCAC	KINS	SPIEZ	TIO	TPT	TRK
^{134}Cs	F-P04	-1.51	DL	–	DL	-0.55	2.18	-0.08	DL	DL
	T-S3	DL	DL	–	DL	DL	DL	DL	DL	DL
	T-S8	-2.11	–	–	DL	-0.11	0.27	0.89	DL	1.10
^{137}Cs	F-P04	-2.36	1.07	–	-0.52	-0.40	**3.11**	0.09	-0.36	-1.04
	T-S3	-0.97	-0.76	–	**5.10**	-0.84	-1.78	-2.26	-0.45	1.33
	T-S8	-2.95	–	–	0.10	0.97	0.35	0.73	-1.83	2.80
^{238}Pu	F-P04	DL	DL	–	Note 1	Note 1	DL	NM	–	–
	T-S3	DL	DL	–	Note 2	Note 2	DL	NM	–	–
	T-S8	DL	–	Note 3	Note 3	Note 3	DL	NM	–	–
^{239,240}Pu	F-P04	0.41	-0.23	–	-1.97	-0.12	1.81	NM	–	–
	T-S3	-0.43	1.14	–	-0.13	-1.31	0.71	NM	–	–
	T-S8	0.11	–	-2.13	-1.08	0.25	2.76	NM	–	–

Notes:

Note 1: Value of -0.64 for $\zeta_{4,5}$.

Note 2: Value of -1.70 for $\zeta_{4,5}$.

Note 3: Values of 0.52, 0.49 and -0.07 for $\zeta_{3,4}$, $\zeta_{3,5}$ and $\zeta_{4,5}$, respectively.

DL: As a value less than the detection limit was submitted, no evaluation was performed.

NM: Not measured; no value reported.

$\zeta_{i,j}$ indexes: number 1 refers to IAEA, number 2 FP, number 3 JAEA, number 4 JCAC, number 5 KINS, number 6 SPIEZ, number 7 TIO, number 8 TPT, and number 9 TRK.

5.4. FISH

Table 8 contains the results reported by the participating laboratories (IAEA, KINS, MERI, SEIKAN, SPIEZ, TIO and TRK) for the massic activities of ^{134}Cs and ^{137}Cs in the fish samples. Figures 9 and 10 show the massic activities of ^{137}Cs in the fish samples.

TABLE 8. MASSIC ACTIVITIES of ^{134}Cs (Bq kg^{-1} fresh weight) IN FISH SAMPLES

Nuclide	Sample: Species	IAEA	KINS	MERI	SEIKAN	SPIEZ	TIO	TRK	Reference value
^{134}Cs (1h)	24FA0001: Redwing searobin	<0.53	<0.65	<0.3	<0.41	NM	NM	<0.39	NC†
	24FA0002: Finespotted flounder	<0.49	<0.78	<0.24	<0.38	NM	NM	<0.42	NC†
	24FA0003: Pufferfish	<0.58	<0.7	<0.33	<0.41	NM	NM	<0.42	NC†
	24FA0004: Crimson sea bream	<0.57	<0.78	<0.37	<0.38	NM	NM	<0.42	NC†
	24FA0005: Olive flounder	<0.6	<0.71	<0.3	<0.41	NM	NM	<0.34	NC†
	24FA0006: Japanese jack mackerel	<0.64	<0.73	<0.3	<0.35	NM	NM	<0.38	NC†
^{134}Cs (24h)	24FA0001: Redwing searobin	<0.094	<0.12	<0.045	<0.061	<0.14	<0.18	<0.058	NC†
	24FA0002: Finespotted flounder	<0.097	<0.14	<0.051	<0.065	<0.085	<0.18	<0.064	NC†
	24FA0003: Pufferfish	<0.094	<0.13	<0.049	<0.069	<0.086	<0.18	<0.061	NC†
	24FA0004: Crimson sea bream	<0.089	<0.14	<0.049	<0.073	<0.084	<0.18	<0.061	NC†
	24FA0005: Olive flounder	<0.097	<0.15	<0.051	<0.071	<0.1	<0.18	<0.063	NC†
	24FA0006: Japanese jack mackerel	<0.093	<0.14	<0.051	<0.069	<0.13	<0.18	<0.060	NC†

Notes:

NM: Not measured; no value reported.

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

TABLE 8. MASSIC ACTIVITIES of ^{137}Cs (Bq kg^{-1} fresh weight) IN FISH SAMPLES (CONTINUED)

Nuclide	Sample: Species	IAEA	KINS	MERI	SEIKAN	SPIEZ	TIO	TRK	Reference value
^{137}Cs (1h)	24FA0001: Redwing searobin	<0.60	<0.49	0.386 ± 0.087	<0.41	NM	NM	<0.35	NC‡
	24FA0002: Finespotted flounder	<0.53	<0.92	0.346 ± 0.097	0.49 ± 0.11	NM	NM	<0.39	NC‡
	24FA0003: Pufferfish	<0.58	<0.42	0.396 ± 0.085	<0.41	NM	NM	<0.42	NC‡
	24FA0004: Crimson sea bream	<0.45	<0.38	<0.31	<0.45	NM	NM	<0.37	NC†
	24FA0005: Olive flounder	<0.51	<0.45	0.402 ± 0.090	<0.37	NM	NM	<0.42	NC‡
	24FA0006: Japanese jack mackerel	<0.50	<0.76	<0.31	<0.34	NM	NM	<0.42	NC†
^{137}Cs (24h)	24FA0001: Redwing searobin	0.410 ± 0.036	0.369 ± 0.039	0.381 ± 0.032	0.45 ± 0.022	0.388 ± 0.047	0.486 ± 0.057	0.405 ± 0.028	0.413 ± 0.015
	24FA0002: Finespotted flounder	0.341 ± 0.030	0.308 ± 0.029	0.291 ± 0.026	0.313 ± 0.020	0.244 ± 0.027	0.525 ± 0.046	0.344 ± 0.027	0.334 ± 0.033
	24FA0003: Pufferfish	0.419 ± 0.034	0.389 ± 0.033	0.362 ± 0.031	0.362 ± 0.020	0.353 ± 0.031	0.414 ± 0.040	0.368 ± 0.027	0.376 ± 0.011
	24FA0004: Crimson sea bream	0.300 ± 0.031	0.281 ± 0.027	0.311 ± 0.028	0.308 ± 0.020	0.269 ± 0.029	0.334 ± 0.035	0.307 ± 0.026	0.301 ± 0.011
	24FA0005: Olive flounder	0.289 ± 0.030	0.295 ± 0.030	0.288 ± 0.026	0.279 ± 0.019	0.286 ± 0.033	0.380 ± 0.038	0.279 ± 0.025	0.293 ± 0.012
	24FA0006: Japanese jack mackerel	0.153 ± 0.023	0.185 ± 0.027	0.171 ± 0.020	0.179 ± 0.017	0.159 ± 0.040	0.205 ± 0.027	0.173 ± 0.023	0.1752 ± 0.0087

Notes:

NM: Not measured; no value reported.

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

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

Table 9 contains the zeta scores for the massic activities of ^{137}Cs in the fish samples. Note that as values less than detection limits were submitted in all cases for the massic activities of ^{134}Cs in the fish samples, no evaluation was performed for this radionuclide.

TABLE 9. ZETA SCORES FOR THE MASSIC ACTIVITIES OF ^{137}Cs IN FISH SAMPLES

Nuclide	Sample: Species	IAEA	KINS	MERI	SEIKAN	SPIEZ	TIO	TRK
^{137}Cs (1h)	24FA0001: Redwing searobin	DL	DL	Note 1	DL	NM	NM	DL
	24FA0002: Finespotted flounder	DL	DL	Note 2	Note 2	NM	NM	DL
	24FA0003: Pufferfish	DL	DL	Note 1	DL	NM	NM	DL
	24FA0004: Crimson sea bream	DL	DL	DL	DL	NM	NM	DL
	24FA0005: Olive flounder	DL	DL	Note 1	DL	NM	NM	DL
	24FA0006: Japanese jack mackerel	DL	DL	DL	DL	NM	NM	DL
^{137}Cs (24h)	24FA0001: Redwing searobin	-0.08	-1.19	-1.08	1.78	-0.55	1.33	-0.29
	24FA0002: Finespotted flounder	0.17	-0.65	-1.12	-0.59	-2.29	**3.73**	0.25
	24FA0003: Pufferfish	1.34	0.42	-0.48	-0.79	-0.79	1.00	-0.31
	24FA0004: Crimson sea bream	-0.04	-0.80	0.39	0.40	-1.18	0.99	0.24
	24FA0005: Olive flounder	-0.14	0.07	-0.20	-0.79	-0.22	2.40	-0.63
	24FA0006: Japanese jack mackerel	-1.06	0.39	-0.23	0.26	-0.42	1.18	-0.10

Notes:

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

Note 2: Value of -1.03 for $\zeta_{3,4}$.

DL: As a value less than the detection limit was submitted, no evaluation was performed.

$\zeta_{i,j}$ indexes: number 1 refers to IAEA, number 2 KINS, number 3 MERI, number 4 SEIKAN, number 5 SPIEZ, number 6 TIO and number 7 TRK.

6. CONCLUSION

A detailed data analysis was performed on the activity concentrations reported for ^{3}H, ^{90}Sr, ^{134}Cs and ^{137}Cs in five seawater samples, the massic activities reported for ^{134}Cs, ^{137}Cs and $^{239,240}Pu$ in three sediment samples and the massic activities reported for ^{134}Cs and ^{137}Cs in six fish samples. All samples were collected offshore TEPCO's Fukushima Daiichi Nuclear Power Station in October 2024. The samples were shared between 14 laboratories: 10 from Japan (FP, JAEA, JCAC, KAKEN, KANSO, KEEA, MERI, TPT, SEIKAN and TRK); the IAEA Marine Environment Laboratories in Monaco; and 3 laboratories from the IAEA ALMERA network (SPIEZ, Switzerland; KINS, Republic of Korea and TIO, China).

Of the 215 statistical tests applied to the dataset, just 12 results (5%) were evaluated as not agreeing at the 99.7% confidence level. The cases shown in Table 10 had zeta scores greater than 3 or less than -3 when compared with the reference value, indicating disagreement at the 99.7% confidence level.

TABLE 10. RESULTS SHOWING DISAGREEMENT AT THE 99.7% CONFIDENCE LEVEL

Sample Type	Radionuclide	Sample	Laboratory	Zeta Score
Seawater	^{3}H	M-102	TIO	4.52
		M-103	TIO	5.46
		M-104	IAEA	-3.13
		T-D1	TIO	3.78
	^{90}Sr	M-101	TIO	3.37
		T-D1	TPT	3.45
	^{137}Cs	M-102	TIO	4.11
		M-103	KINS	4.43
		M-104	TIO	3.16
Sediment	^{137}Cs	F-P04	SPIEZ	3.11
		T-S3	JCAC	5.10
Fish	^{137}Cs	24FA0002	TIO	3.73

The overwhelming majority of results – 203 of 215 evaluated (95%) – showed agreement at the 99.7% confidence level, demonstrating that participating laboratories are reporting reliable and comparable results for the tested radionuclides in seawater, sediment and fish samples, analysed according to each laboratory's regularly used methods. Notably, only two of the twelve non-agreeing results were reported by Japanese laboratories.

Following this sampling mission, the IAEA can state with confidence that Japan's sample collection procedures continue to follow the appropriate methodological standards required to obtain representative samples. The accurate results obtained in ILC 2024 and in previous IAEA ILCs demonstrate a consistently high degree of proficiency on the part of the Japanese laboratories involved in the analyses of radionuclides in marine samples for the Comprehensive Radiation Monitoring Plan (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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[5] POMMÉ, S. and KEIGHTLEY, J.D. 2015. Determination of a reference value and its uncertainty through a power-moderated mean. Metrologia **52**, S200-S212.

APPENDIX: FIGURES

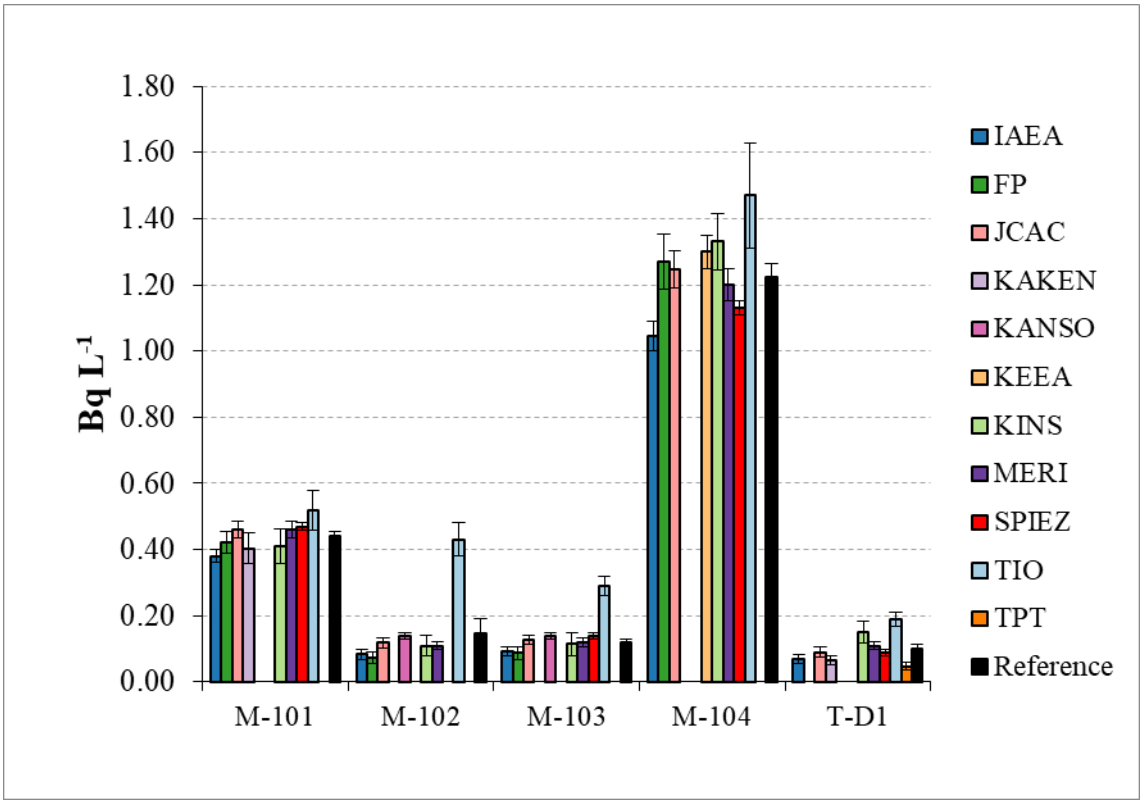

FIG. 2. Activity concentrations of ^{3}H in seawater samples.

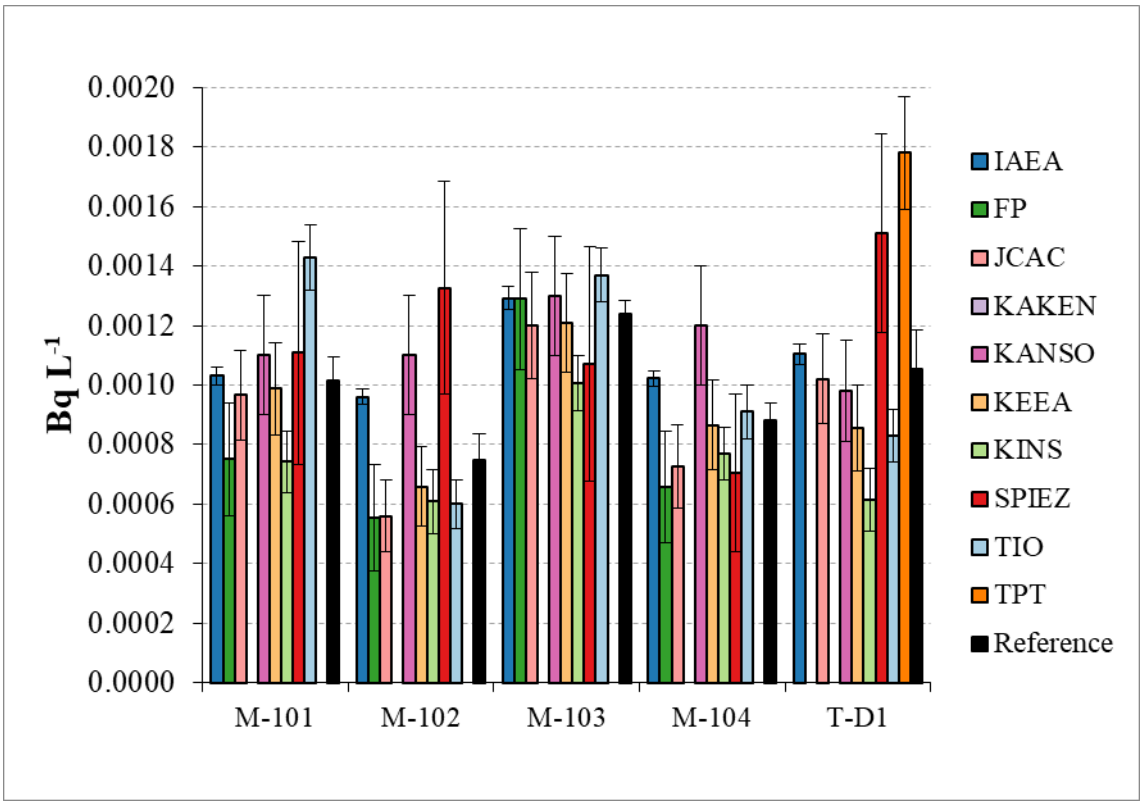

FIG. 3. Activity concentrations of ^{90}Sr in seawater samples.

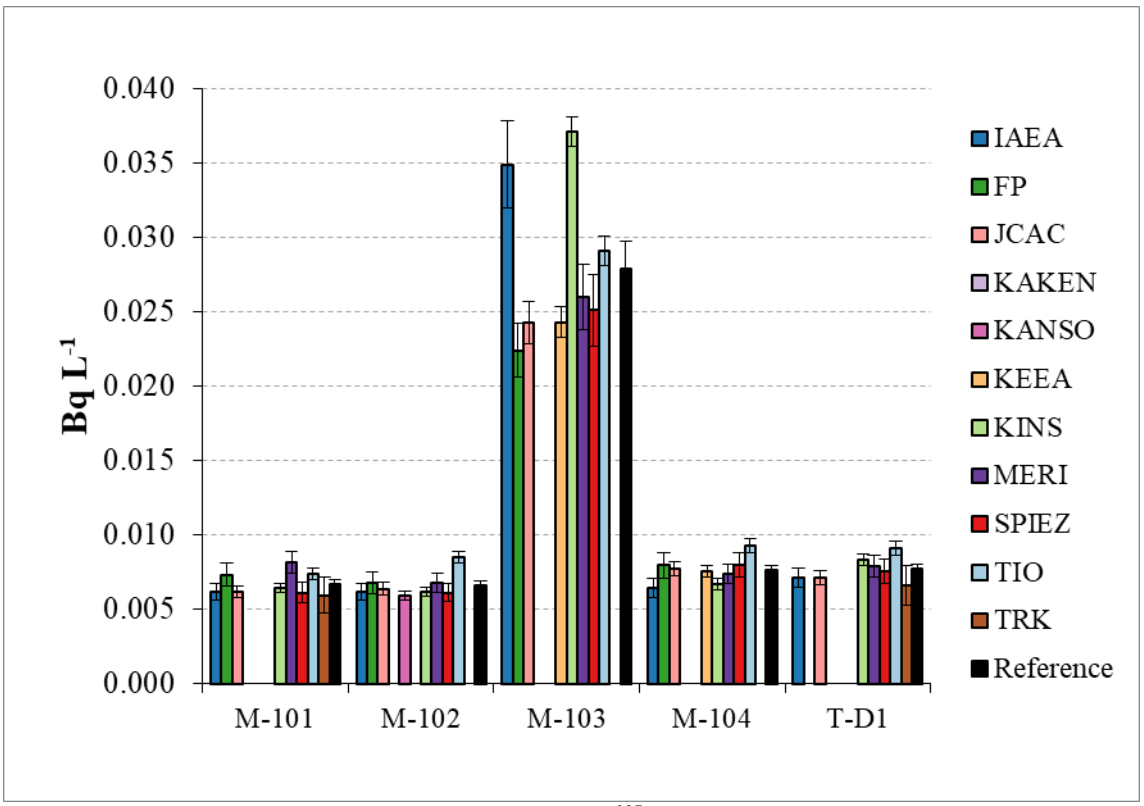

FIG. 4 Activity concentrations of ^{137}Cs in seawater samples.

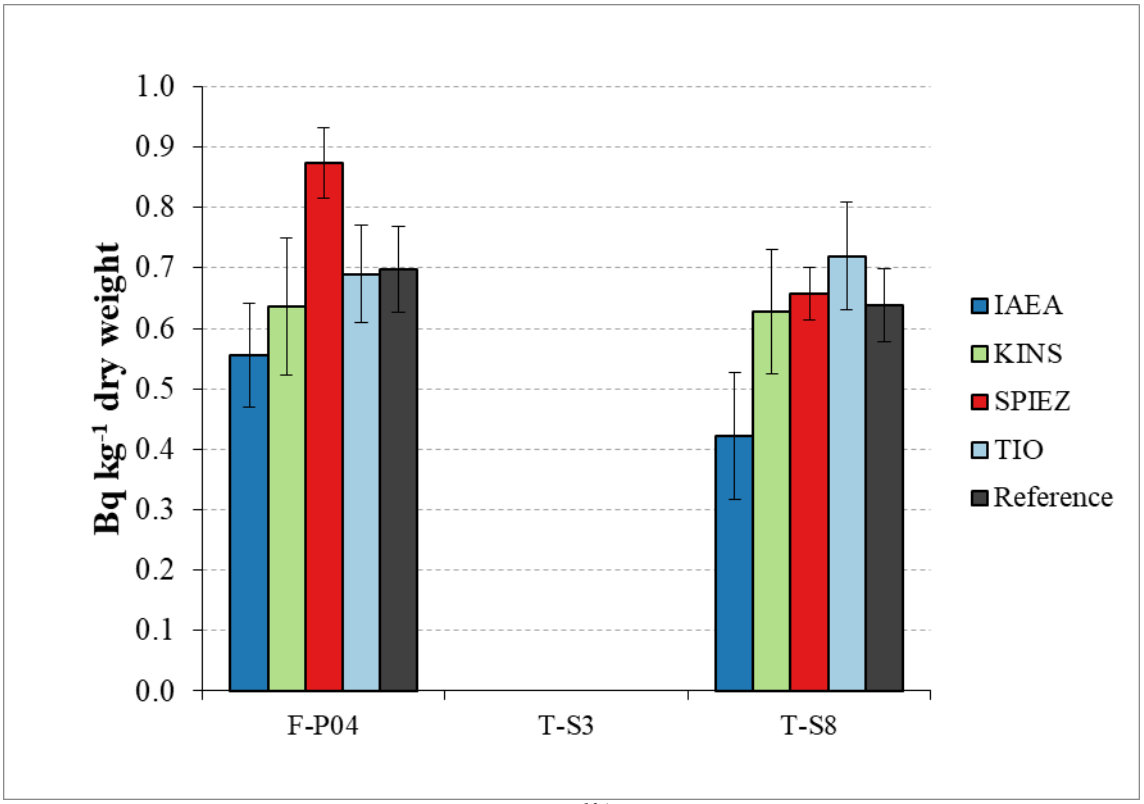

FIG. 5. Massic activities of ^{134}Cs in sediment samples.

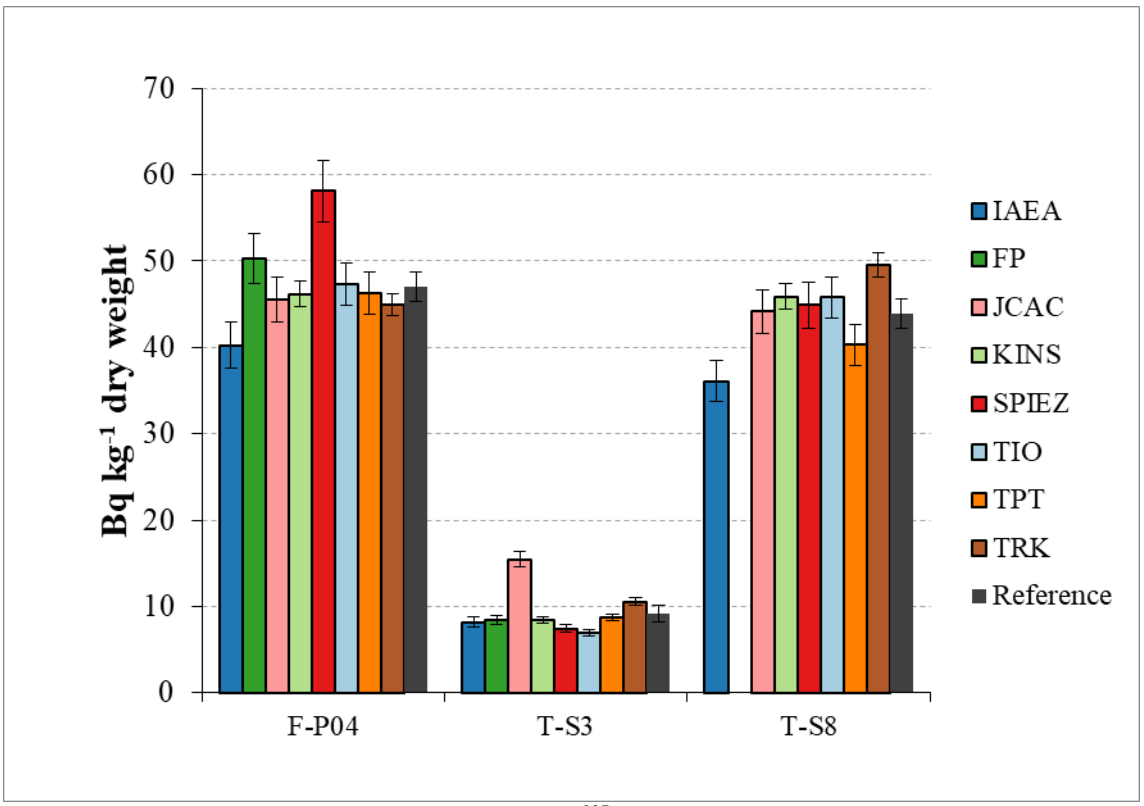

FIG. 6. Massic activities of ^{137}Cs in sediment samples.

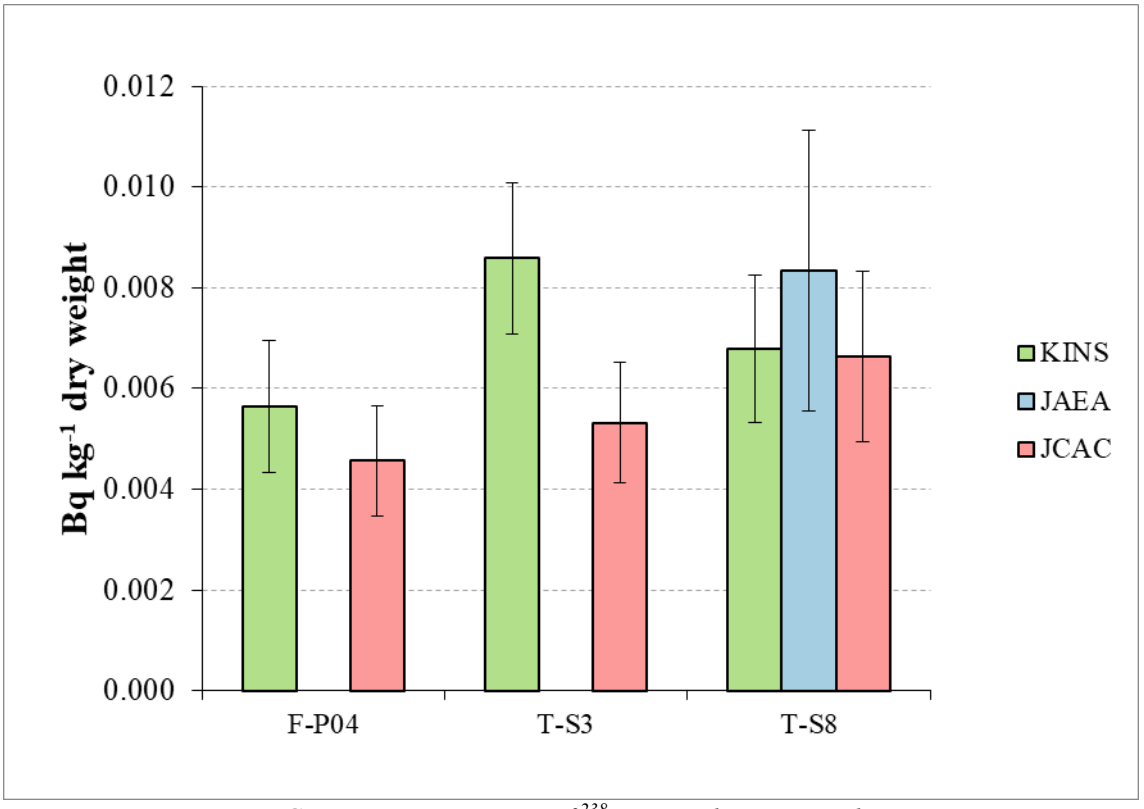

FIG. 7. Massic activities of ^{238}Pu in sediment samples.

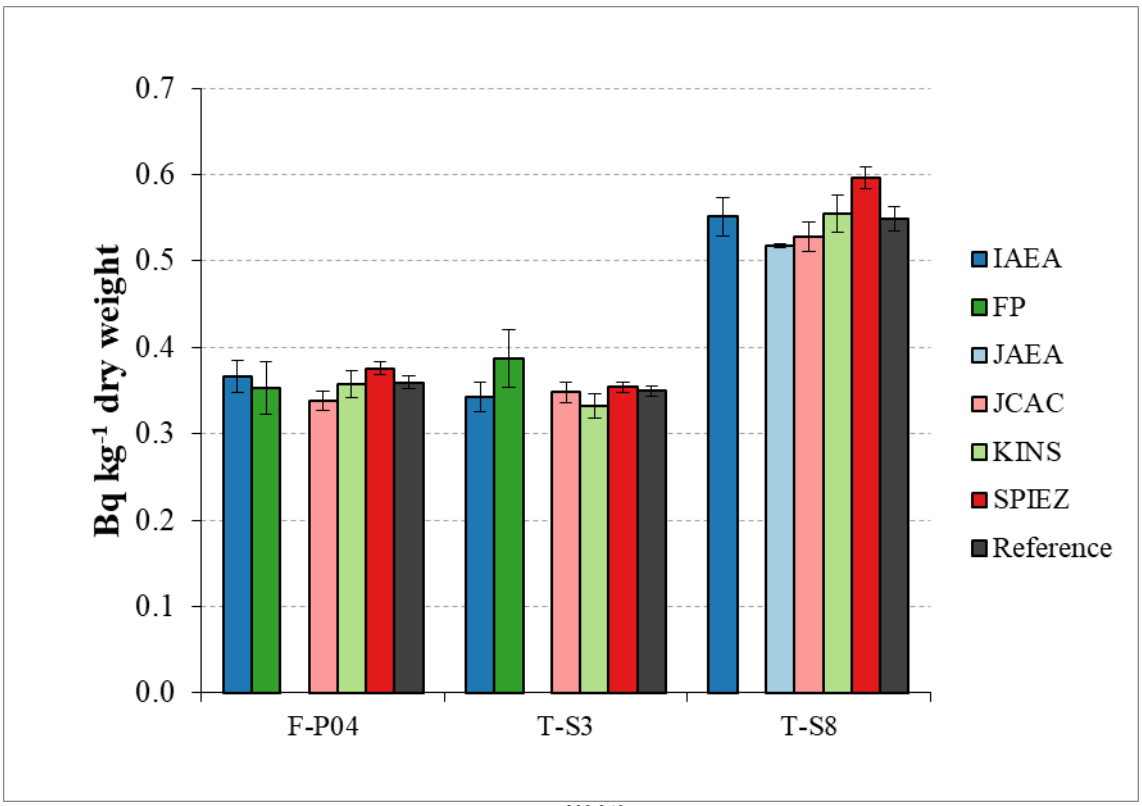

FIG. 8. Massic activities of ^{239,240}Pu in sediment samples.

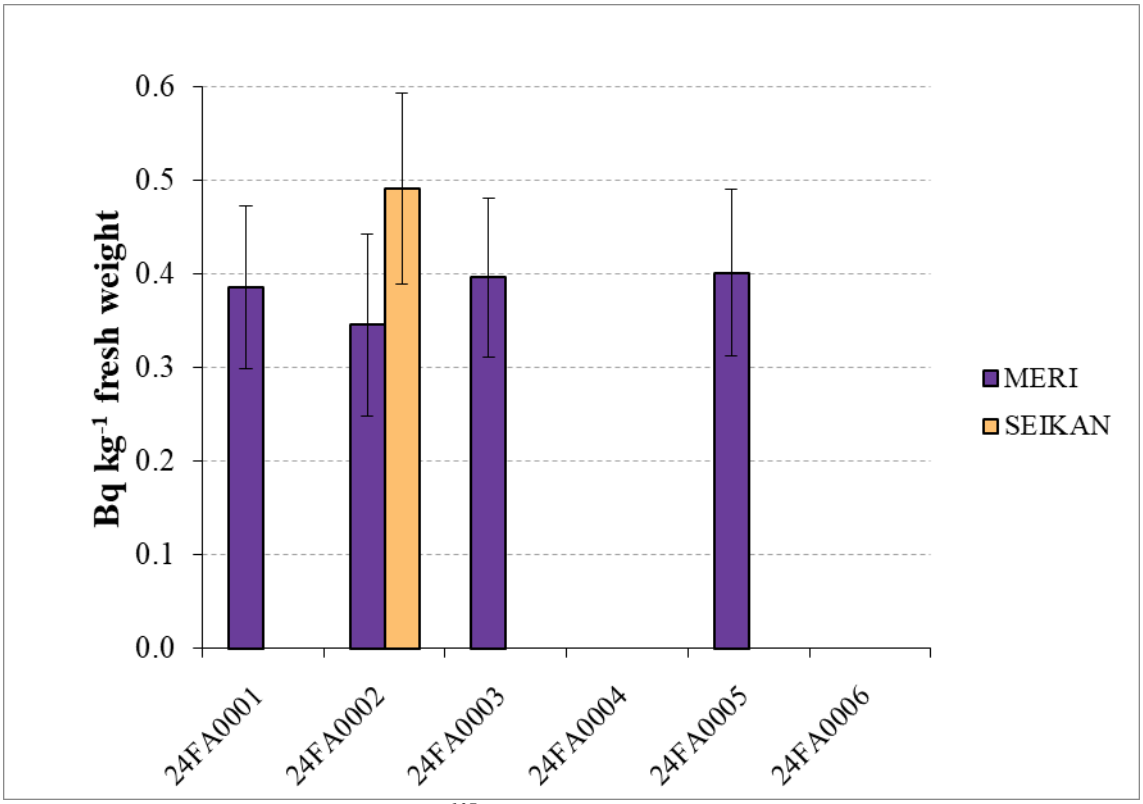

FIG. 9. Massic activities of ^{137}Cs in fish samples (1 hour measurement time).

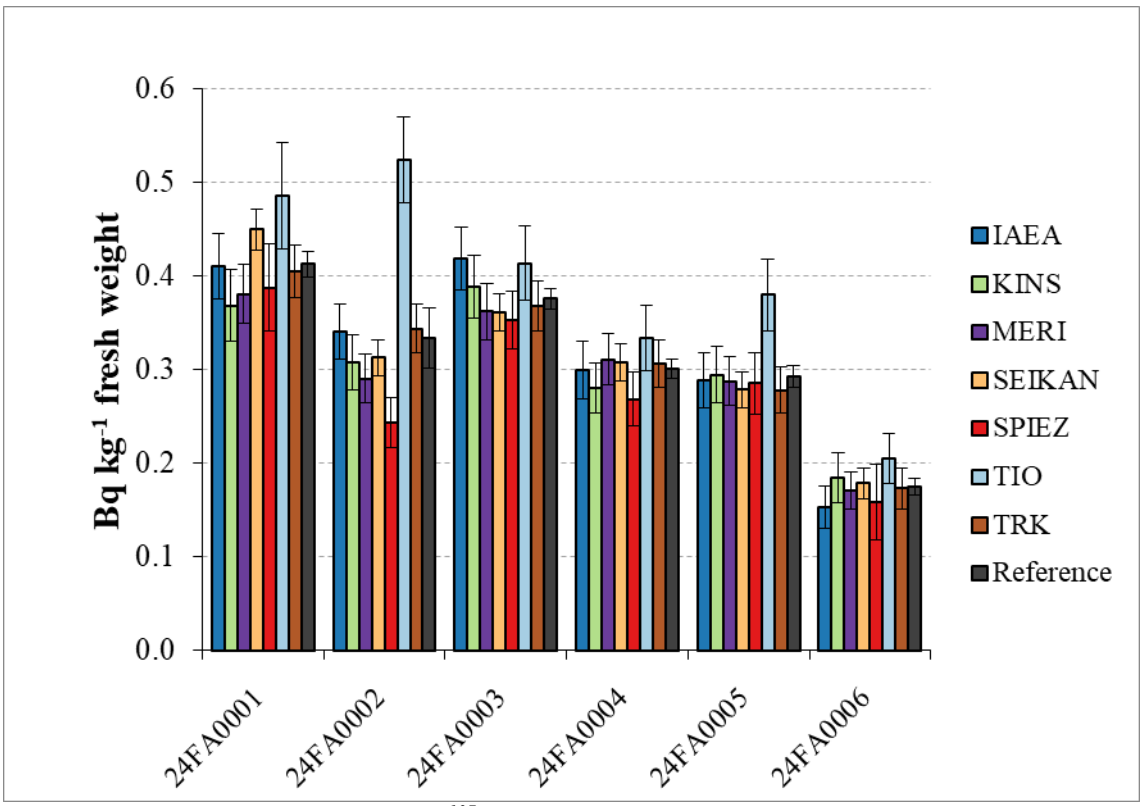

FIG. 10. Massic activities of ^{137}Cs in fish samples (24-hour measurement time).