Interlaboratory comparison 2022
Determination of radionuclides in seawater, sediment and fish

Marine Monitoring: Confidence Building and Data Quality Assurance

IAEA Project Interim Report

IAEA
International Atomic Energy Agency

SUMMARY REPORT

The IAEA Marine Environment Laboratories in Monaco are assisting the Government of Japan in ensuring that its regularly updated Sea Area Monitoring Plan is comprehensive, credible and transparent through the project “Marine Monitoring: Confidence Building and Data Quality Assurance”. During the period 2014 – 2021, 11 interlaboratory comparisons (ILCs) and 8 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 as part of the Sea Area Monitoring Plan.

This report focuses on the ILC which was organised in 2022. 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 November 2022 with observers from the IAEA and Japanese authorities involved in the Sea Area Monitoring Plan. Additionally, two experts from laboratories in Finland and the Republic of Korea, both 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 – 11 from Japan (participating on behalf of the Japanese authorities); the IAEA Marine Environment Laboratories; and the two ALMERA laboratories from Finland and the Republic of Korea – 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 over 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 2022, the IAEA can report that Japan's sample collection procedures continue to adhere to the appropriate methodological standards required to obtain representative samples. The results, as for those from other ILCs and PTs in this project, demonstrate a continued high level of accuracy and competence on the part of the Japanese laboratories involved in the analyses of radionuclides in marine samples as part of the Sea Area Monitoring Plan.

1. INTRODUCTION

The IAEA Marine Environment Laboratories are assisting the Government of Japan in ensuring that its regularly updated Sea Area Monitoring Plan is comprehensive, credible and transparent through the project "Marine Monitoring: Confidence Building and Data Quality Assurance". During the period 2014 – 2021, 11 interlaboratory comparisons (ILCs) and 8 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 Sea Area Monitoring Plan.

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 [1]. 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 2022. It describes the joint sampling campaign undertaken in November 2022 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: 11 from Japan (participating on behalf of the Japanese authorities); the IAEA Marine Environment Laboratories in Monaco; and two laboratories from Finland and the Republic of Korea, both 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 participation of each in specific analyses in Table 2.

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[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://nucleus.iaea.org/sites/ReferenceMaterials/Pages/ALMERA.aspx

TABLE 1. LABORATORIES PARTICIPATING IN ILC 2022

Identifier	Participant
IAEA	IAEA Marine Environment Laboratories, Monaco
ENS	Eurofins Nihon Soken K.K., Fukushima, Japan
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, Onjuku, Japan
STUK	Radiation and Nuclear Safety Authority, Finland
SWRI	SOUGOUMIZU Institute, Ltd., Osaka, Japan
TPT	Tokyo Power Technology Ltd., Fukushima, Japan
TRK	Tohoku Ryokka Kankyohozen Co. Ltd., Miyagi, Japan

TABLE 2. OVERVIEW OF ILC 2022

Sample type	Nuclide	IAEA	ENS	FP	JAEA	JCAC	KAKEN	KANSO	KEEA	KINS	MERI	STUK	SWRI	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	✓	✓	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	✗	✗

Note: 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.

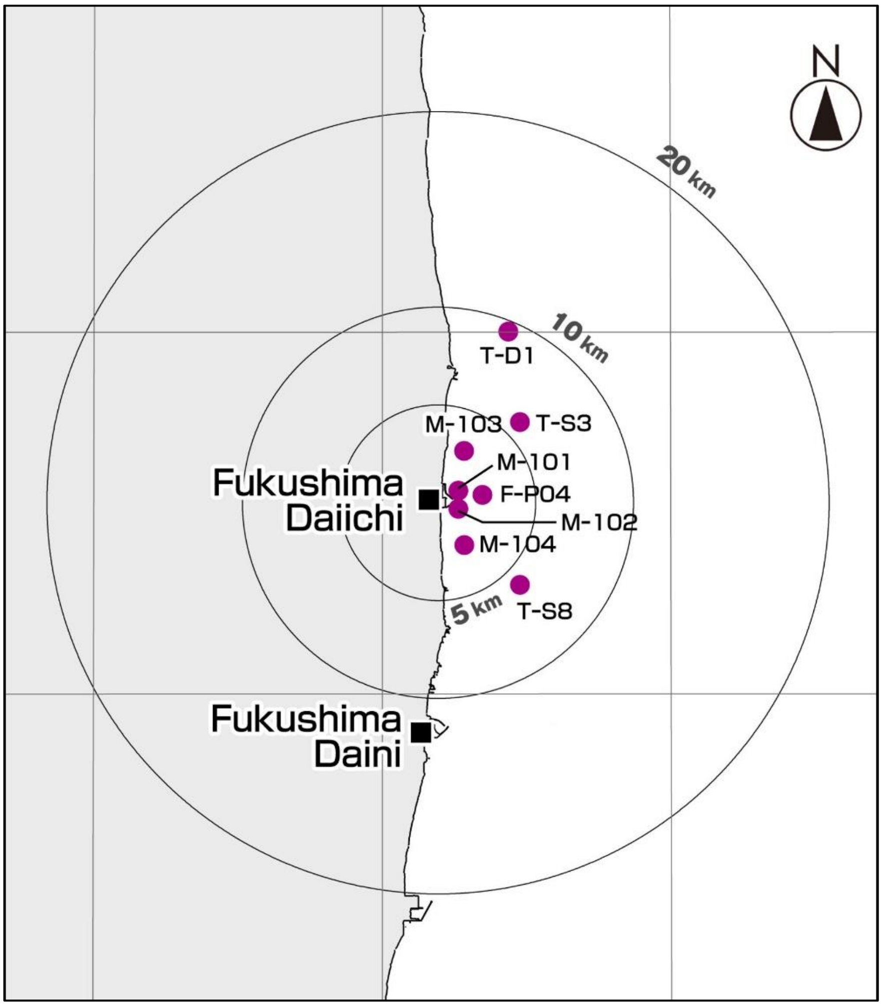

FIG. 1. Surface seawater and sediment sampling locations offshore TEPCO's Fukushima Daiichi Nuclear Power Station.

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 10 November 2022 from each sampling location for subsequent analysis for ^{90}Sr, ^{134}Cs and ^{137}Cs and, separately, for ^{3}H.

Seven laboratories planned to participate in the analyses for ^{90}Sr, ^{134}Cs and ^{137}Cs, or all three radionuclides from sampling locations M-101, M-102, M-103, M-104 and T-D1. The collection and distribution methods at each sampling location were:

- A 400 L plastic container with four valves was first filled with seawater. As this container cannot be filled to full capacity, two separate fills were required to facilitate provision of the required sample volume to all participants.
- Separate 20 L cubitainers were filled simultaneously from each of the four valves. Six cubitainers were filled from each valve, resulting in a total of 24 20 L samples from each sampling location.
- 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.

The seawater sampling procedure and distribution matrix, meant to ensure the homogenisation of the samples, are shown in Table 4.

TABLE 4. SAMPLE DISTRIBUTION BETWEEN SEVEN LABORATORIES (^{90}Sr, ^{134}Cs AND ^{137}Cs)

Valve number	1		2		3		4	
Seawater sample codes	1-1-3		1-2-3		1-3-3		1-4-3	
	1-1-4		1-2-4		1-3-4		1-4-4	
	2-1-1		2-2-1		2-3-1		2-4-1	
	2-1-2		2-2-2		2-3-2		2-4-2	
	3-1-1		3-2-1		3-3-1		3-4-1	
	3-1-2		3-2-2		3-3-2		3-4-2	
Distribution pattern of the participating laboratories coded A, B, C, D, E, F, G and H	A	B	C	D	E	F	G	H
	1-1-3	1-2-3	1-3-3	1-4-3	1-1-4	1-2-4	1-3-4	1-4-4
	2-1-1	2-2-1	2-3-1	2-4-1	2-1-2	2-2-2	2-3-2	2-4-2
	3-1-1	3-2-1	3-3-1	3-4-1	3-1-2	3-2-2	3-3-2	3-4-2

Note:

The sample for laboratory D was retained as a spare.

For ^{3}H, seven laboratories planned to participate in the analyses of samples from each sampling location. The sample collection and distribution methods 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, resulting in a total of eight 2 L samples from each sampling location.
- One 2 L sample was provided to each laboratory.

The seawater sampling procedure and the distribution matrix for ^{3}H are shown in Table 5.

TABLE 5. SAMPLE DISTRIBUTION BETWEEN SEVEN LABORATORIES (^{3}H)

Valve number	1		2		3		4	
Seawater sample codes	1-1-1		1-2-1		1-3-1		1-4-1	
	1-1-2		1-2-2		1-3-2		1-4-2	
Distribution pattern of the participating laboratories coded A, B, C, D, E, F, G and H	A	B	C	D	E	F	G	H
	1-1-1	1-2-1	1-3-1	1-4-1	1-1-2	1-2-2	1-3-2	1-4-2

Note:

The sample for laboratory D was retained as a spare.

2.3. SEDIMENT

Sediment samples were collected using a grab sampler on 7 November 2022 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 stainless-steel trays, crushed using stainless-steel spatulae, 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 division 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 350 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 170 g was provided.

2.4. FISH

Six batches of frozen fish, one each of olive flounder (*Paralichthys olivaceus*), whitespotted conger (*Conger myriaster*), crimson sea bream (*Evynnis tumifrons*), redwing searobin (*Lepidotrigla microptera*), shotted halibut (*Eopsetta grigorjewi*) and willowy flounder (*Tanakius kitaharai*), were collected from the fish market at Hisanohama Port on 7 November 2022. The 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 40 and 130 m.

Each batch of fish was prepared by fileting, homogenising the muscle tissue and then splitting into separate samples at MERI (Onjuku) on 11 November 2022. One set of samples, each containing a mass of approximately 2.5 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 the two ALMERA laboratories, KINS and STUK, 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 Sea Area 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 11 laboratories participating in ILC 2022: FP, JCAC, KAKEN, KANSO, KEEA, MERI, TPT and TRK, all participating on behalf of the Nuclear Regulation Authority, Japan; IAEA; and KINS and STUK, 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 1,200 g of the sample material was purified by vacuum distillation. 1,000 g of the purified sample was enriched to a final mass of 15 g by alkaline electrolysis. The enriched sample was neutralized by CO_2 gas bubbling and the electrolyte was removed by vacuum distillation. 10 g of enriched water sample was mixed with 10 mL of scintillator (Ultima Gold uLLT) 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, once the sample reached secular equilibrium, ^{90}Y was co-precipitated with iron hydroxide and then measured using a low background β counter.

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

Chemical separation of caesium by ammonium molybdophosphate (AMP) and manganese dioxide (MnO_2), followed by gamma-ray spectrometry with 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 (500 mL reduced to 55 mL). 50 mL of the purified sample was mixed with 50 mL of liquid scintillation fluid 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 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, once the sample reached secular equilibrium, ^{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 Teflon bottle and counted on a low background liquid scintillation counter for 1000 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 secular equilibrium was attained, ^{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 the sample to reach secular equilibrium, ^{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 determined by liquid scintillation counting following distillation, electrolytic enrichment and second distillation. The distilled water was mixed with a scintillation cocktail (Ultima Gold LLT) in a Teflon vial.

3.1.7.2. ^{90}Sr analysis

Strontium pre-concentration of 40 L 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 the sample to reach secular equilibrium. The chemical yield was determined by ICP-OES.

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. STUK methodology for seawater

3.1.9.1. ^{3}H analysis

Each seawater ample was distilled twice. For the first distillation, 0.1 mg of AgNO3 was added to the sample. After both distillations, 8 ml of the distilled sample and 12 ml of UltimaGold uLLT scintillation cocktail were added to a plastic LSC-bottle and counted on a Quantulus liquid scintillation counter for 600 minutes. Three background samples (1000 minutes) and H-3 standards (30 minutes) were also counted. The sample, H-3 standards and backgrounds were stabilized for three days prior to counting to prevent chemiluminescence in the counter.

3.1.9.2. ^{90}Sr analysis

Sr was precipitated from each seawater sample as mixed Ca/Sr-carbonate, followed by extraction chromatography with a Sr-resin (Triskem). Sr-90 activity concentrations were then determined by low background liquid scintillation counting.

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

Approximately 12 L of each seawater sample was evaporated and measured in a 535 ml Marinelli beaker by HPGe gamma-ray spectrometry.

3.1.10. TRK methodology for seawater

3.1.10.1. ^{134}Cs and ^{137}Cs analysis

Caesium was separated with AMP, followed 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 distillation. The distilled seawater was then mixed with a scintillation cocktail to prepare a sample for measurement 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.

3.2. SEDIMENT

Radionuclides of interest in sediment samples were determined by eight laboratories participating in ILC 2022: FP, JAEA, JCAC, TPT and TRK, participating on behalf of the Nuclear Regulation Authority, Japan; IAEA; and KINS and STUK, 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-type coaxial 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 samples 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*

Dried samples were spiked with a ^{242}Pu tracer and digested with 8M HNO3. The dissolved plutonium was adjusted to Pu(IV) with ascorbic acid in a 5 M HNO3 solution and purified using ion-chromatography resins TEVA. Plutonium fractions were then electroplated and measured by alpha spectrometry.

3.2.6. STUK methodology for sediment

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

About 125 g of each sample was measured by HPGe gamma-ray spectrometry in a cylindrical geometry for about 72 hours.

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

For each sample, an aliquot of dry sediment was digested using MARS, followed by separation by DOWEX 1x4 and Cerium co-precipitation at the end of the analysis. The samples were counted by alpha spectrometry for 8000 minutes.

3.2.7. TRK methodology for sediment

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

Gamma-ray spectrometry using a p-type coaxial 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.

3.3. FISH

Radionuclides of interest in fish samples were determined by six laboratories participating in ILC 2022: ENS, MERI, and SWRI, all participating on behalf of the Japan Fisheries Agency; IAEA; and KINS and STUK, 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 an n-type coaxial HPGe detector of relative efficiency 48%. The samples were prepared in 1 L Marinelli beakers.

3.3.2. ENS methodology for fish

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

The samples were prepared in 2L Marinelli beakers and counted by gamma-ray spectrometry using a p-type coaxial HPGe detector.

3.3.3. KINS methodology for fish

3.3.3.1. ^{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.

3.3.4. MERI methodology for fish

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

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

3.3.5. STUK methodology for fish

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

The samples were prepared in 0.535 ml Marinelli beakers and counted by gamma-ray spectrometry using a p-type coaxial HPGe detector.

3.3.6. SWRI methodology for fish

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

The samples were prepared in 2L Marinelli beakers and counted by gamma-ray spectrometry using a p-type coaxial HPGe detector.

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 or three measurement results above the detection limit were received, then one or three zeta tests [2] were performed. The zeta $\zeta_{i,j}$ test is defined as:

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

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 value of the zeta test exceeded 2.58, the results were evaluated as being significantly different (at a 99% confidence level).

If the data set contained four or more results, the statistical evaluation consisted of a method for calculating a comparison reference value as a power-moderated mean of the combined results [3], which is currently being used by the Consultative Committee for Ionizing Radiation, Section II: Measurement of radionuclides, CCRI(II). After calculating a reference value, a relative degree of equivalence (DoE) was calculated for each submitted result and if this relative DoE was significantly different from zero, the corresponding result was evaluated as being discrepant. The relative DoE (%) was calculated according to:

$$\text{DoE (\%)} = \frac{x_{\text{lab}} - X_{\text{ref}}}{X_{\text{ref}}} . 100 \tag{2}$$

where:

x_{lab} is the individual laboratory result; and
x_{ref} is the reference value calculated as the power-moderated mean of the combined results.

The standard uncertainty of the relative DoE, u_{DoE}, was calculated according to reference [2]. If the absolute value of the relative DoE exceeded 2.58 times u_{DoE}, the corresponding result was evaluated as being discrepant (at a 99% confidence level), as the relative DoE in this case would be significantly different from zero.

5. RESULTS

5.1. GENERAL

The results are presented in Tables 6 – 11 and Figures 2 – 12.

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 and not a confidence interval, unless otherwise indicated (i.e. in Tables 7, 9 and 11).

5.1.2. Reference time

All activity concentrations and massic activities for seawater, sediment and fish were reported at a reference time of 7 November 2022 12:00 UTC.

5.2. SEAWATER

Table 6 contains the results reported by the participating laboratories (IAEA, FP, JCAC, KAKEN, KANSO, KEEA, KINS, MERI, STUK, TPT, and TRK) for the activity concentrations of ^{3}H, ^{90}Sr, ^{134}Cs and ^{137}Cs in the seawater samples. Figures 2 to 5 show the activity concentrations of these radionuclides in the seawater samples.

TABLE 6. ACTIVITY CONCENTRATIONS (mBq L^{-1}) IN SEAWATER SAMPLES

Nuclide	Sample	IAEA	FP	JCAC	KAKEN	KANSO	KEEA	KINS	MERI	STUK	TPT	TRK	Reference value
^{3}H	M-101	119.5 ± 9.4	129 ± 18	156 ± 19	134 ± 26	–	–	137 ± 31	170 ± 24	<1110	–	–	135.6 ± 7.9
	M-102	40.4 ± 9.1	<38	86 ± 17	–	73 ± 9	–	<90	100 ± 21	<1110	–	–	72 ± 13
	M-103	30.6 ± 9.1	32 ± 11	47 ± 12	–	79 ± 9	–	<90	93 ± 20	<1110	–	–	55 ± 13
	M-104	30.1 ± 8.9	48 ± 12	90 ± 17	–	–	57 ± 9	<87	64 ± 19	<1110	–	–	55.6 ± 9.8
	T-D1	37 ± 9	–	76 ± 16	<76	–	–	<88	72 ± 20	<1110	<94	–	–
^{90}Sr	M-101	1.75 ± 0.21	1.7 ± 0.2	1.06 ± 0.15	–	1.3 ± 0.2	1.11 ± 0.17	0.52 ± 0.13	–	0.94 ± 0.23	–	–	1.19 ± 0.17
	M-102	1.21 ± 0.16	0.8 ± 0.1	0.773 ± 0.14	–	0.85 ± 0.19	0.75 ± 0.15	0.61 ± 0.11	–	0.88 ± 0.21	–	–	0.822 ± 0.070
	M-103	1.03 ± 0.14	1.0 ± 0.1	0.726 ± 0.13	–	0.77 ± 0.18	0.79 ± 0.15	0.53 ± 0.12	–	<0.64	–	–	0.810 ± 0.080
	M-104	0.761 ± 0.090	0.9 ± 0.1	0.699 ± 0.13	–	1.1 ± 0.2	0.57 ± 0.14	0.48 ± 0.12	–	1.48 ± 0.27	–	–	0.82 ± 0.12
	T-D1	1.00 ± 0.13	–	0.787 ± 0.13	–	0.88 ± 0.18	0.70 ± 0.17	0.51 ± 0.15	–	0.84 ± 0.26	1.10 ± 0.22	–	0.819 ± 0.075

TABLE 6. ACTIVITY CONCENTRATIONS (mBq L^{-1}) IN SEAWATER SAMPLES (CONTINUED)

Nuclide	Sample	IAEA	FP	JCAC	KAKEN	KANSO	KEEA	KINS	MERI	STUK	TPT	TRK	Reference value
^{134}Cs	M-101	0.969 ± 0.089	<3.3	1.11 ± 0.3	–	–	–	<1.5	<0.94	<1.3	–	<0.98	–
	M-102	<0.42	<3.4	<0.87	–	<0.8	–	<1.3	<0.78	1.2 ± 0.11	–	–	–
	M-103	<0.38	<3.4	<0.93	–	–	<0.73	<1.5	<0.91	<2.3	–	–	–
	M-104	<0.18	<3.3	<1.1	–	–	<0.77	<1.4	<0.78	<1.2	–	–	–
	T-D1	0.158 ± 0.042	–	<0.86	–	–	–	<1.3	<0.99	<1.2	<0.94	<0.90	–
^{137}Cs	M-101	28.9 ± 1.5	41.5 ± 2.9	44.8 ± 2.3	–	–	–	36.7 ± 1.8	42 ± 3.1	30.9 ± 0.84	–	38.3 ± 0.74	37.3 ± 2.3
	M-102	11.65 ± 0.57	11.5 ± 1.2	24 ± 1.3	–	10.5 ± 0.4	–	10.4 ± 0.6	10 ± 0.79	9.38 ± 0.49	–	–	12.4 ± 2.0
	M-103	8.69 ± 0.46	9.8 ± 1.1	9.93 ± 0.58	–	–	9.03 ± 0.45	9.06 ± 0.47	8.4 ± 0.66	10.4 ± 0.72	–	–	9.23 ± 0.26
	M-104	6.14 ± 0.32	6.47 ± 0.84	7.97 ± 0.48	–	–	6.80 ± 0.38	6.44 ± 0.43	6.6 ± 0.53	5.99 ± 0.38	–	–	6.61 ± 0.25
	T-D1	8.09 ± 0.44	–	9.28 ± 0.54	–	–	–	8.11 ± 0.43	8.6 ± 0.68	7.32 ± 0.43	9.00 ± 0.45	7.88 ± 0.30	8.27 ± 0.27

Table 7 contains the degrees of relative equivalence for the activity concentrations of ^{3}H, ^{90}Sr, ^{134}Cs and ^{137}Cs in the seawater samples.

TABLE 7. DEGREES OF EQUIVALENCE (%) IN SEAWATER SAMPLES

Nuclide	Sample	IAEA	FP	JCAC	KAKEN	KANSO	KEEA	KINS	MERI	STUK	TPT	TRK
^{3}H	M-101	-12 ± 18	-5 ± 32	15 ± 34	-1 ± 47	–	–	1 ± 56	25 ± 43	DL	–	–
	M-102	-44 ± 51	DL	18 ± 64	–	1 ± 51	–	DL	39 ± 74	DL	–	–
	M-103	-44 ± 67	-42 ± 71	-15 ± 73	–	44 ± 67	–	DL	70 ± 97	DL	–	–
	M-104	-46 ± 55	-14 ± 62	62 ± 79	–	–	2 ± 55	DL	15 ± 86	DL	–	–
	T-D1	Note 1	–	Note 1	DL	–	–	DL	Note 1	DL	DL	–
^{90}Sr	M-101	47 ± 52	43 ± 52	-11 ± 45	–	9 ± 52	-7 ± 48	**-56 ± 43**	–	-21 ± 55	–	-
	M-102	47 ± 49	-3 ± 33	-6 ± 43	–	3 ± 58	-9 ± 46	-26 ± 36	–	7 ± 61	–	-
	M-103	27 ± 44	24 ± 36	-10 ± 43	–	-5 ± 56	-2 ± 48	-35 ± 40	–	–	–	-
	M-104	-7 ± 45	10 ± 46	-15 ± 51	–	34 ± 67	-30 ± 53	-41 ± 49	–	81 ± 84	–	-
	T-D1	23 ± 39	–	-4 ± 41	–	7 ± 55	-15 ± 52	-37 ± 44	–	2 ± 76	34 ± 67	-
^{134}Cs	M-101	Note 2	DL	Note 2	–	–	–	DL	DL	DL	–	DL
	M-102	DL	DL	DL	–	DL	–	DL	DL	Note 3	–	–
	M-103	DL	DL	DL	–	–	DL	DL	DL	DL	–	–
	M-104	DL	DL	DL	–	–	DL	DL	DL	DL	–	–
	T-D1	Note 3	–	DL	–	–	–	DL	DL	DL	DL	DL
^{137}Cs	M-101	**-23 ± 18**	11 ± 23	20 ± 21	–	–	–	-2 ± 19	13 ± 25	**-17 ± 17**	–	3 ± 17
	M-102	-6 ± 42	-7 ± 45	**93 ± 46**	–	-16 ± 41	–	-16 ± 42	-20 ± 43	-25 ± 41	–	–
	M-103	-6 ± 13	6 ± 28	8 ± 16	–	–	-2 ± 13	-2 ± 13	-9 ± 18	13 ± 20	–	–
	M-104	-7 ± 14	-2 ± 32	**21 ± 19**	–	–	3 ± 16	-3 ± 18	0 ± 21	-9 ± 16	–	–
	T-D1	-2 ± 14	–	12 ± 17	–	–	-	-2 ± 14	4 ± 21	-11 ± 14	9 ± 15	-5 ± 11

Notes:

The numerical results in this table are stated in the format xx ± yy, where the number following the symbol ± is the 99% confidence interval.

Note 1: Values of -2.12, -1.60 and 0.15 for $\zeta_{1,3}$, $\zeta_{1,8}$ and $\zeta_{3,8}$, respectively.

Note 2: Value of -0.45 for $\zeta_{1,3}$.

Note 3: No evaluation was possible as only one value above the detection limit was submitted.

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 refers to FP, number 3 refers to JCAC, number 4 refers to KAKEN, number 5 refers to KANSO, number 6 refers to KEEA, number 7 refers to KINS, number 8 refers to MERI, number 9 refers to STUK, number 10 refers to TPT and number 11 refers to TRK.

5.3. SEDIMENT

Table 8 contains the results reported by the participating laboratories (IAEA, FP, JAEA, JCAC, KINS, STUK, TPT and TRK) for the massic activities of radionuclides in the sediment samples. Figures 6 to 9 show the massic activities of ^{134}Cs, ^{137}Cs and ^{239,240}Pu in the sediment samples.

TABLE 8. MASSIC ACTIVITIES (Bq kg^{-1}-dry) IN SEDIMENT SAMPLES

Nuclide	Sample	IAEA	FP	JAEA	JCAC	KINS	STUK	TPT	TRK	Reference value
^{134}Cs	F-P04	0.645 ± 0.088	<1.3	–	1.32 ± 0.30	1.09 ± 0.27	1.010 ± 0.063	1.11 ± 0.32	1.32 ± 0.27	1.01 ± 0.11
	T-S3	4.60 ± 0.25	6.24 ± 0.69	–	4.28 ± 0.40	4.74 ± 0.37	4.68 ± 0.20	4.32 ± 0.34	5.38 ± 0.59	4.75 ± 0.22
	T-S8	0.369 ± 0.073	–	–	<0.71	<0.85	0.487 ± 0.042	<0.9	<0.97	–
^{137}Cs	F-P04	31.6 ± 1.3	36.6 ± 2.3	–	33.5 ± 1.7	34.7 ± 1.2	37.6 ± 1.2	40.1 ± 1.3	34.4 ± 1.1	35.5 ± 1.1
	T-S3	174.7 ± 6.9	185 ± 12	–	187 ± 9.4	181.0 ± 6.0	181 ± 5.5	182.0 ± 5.2	202.0 ± 5.6	184.8 ± 3.5
	T-S8	16.72 ± 0.68	–	–	17.2 ± 0.91	15.6 ± 0.6	17.10 ± 0.59	16.20 ± 0.60	15.98 ± 0.72	16.42 ± 0.27
^{238}Pu	F-P04	0.0107 ± 0.0053	0.0050 ± 0.0016	–	0.0067 ± 0.0013	<0.0078	<0.052	–	–	–
	T-S3	0.0172 ± 0.0073	–	–	0.0081 ± 0.0014	<0.0075	<0.027	–	–	–
	T-S8	0.0199 ± 0.0067	–	<0.0077	0.0075 ± 0.0017	<0.0080	<0.028	–	–	–
^{239,240}Pu	F-P04	0.397 ± 0.021	0.427 ± 0.019	–	0.397 ± 0.012	0.419 ± 0.028	0.228 ± 0.031	–	–	0.4071 ± 0.0089
	T-S3	0.486 ± 0.026	0.420 ± 0.025	–	0.436 ± 0.013	0.466 ± 0.021	0.397 ± 0.030	–	–	0.451 ± 0.015
	T-S8	0.496 ± 0.026	–	0.509 ± 0.036	0.497 ± 0.014	0.520 ± 0.024	0.418 ± 0.034	–	–	0.503 ± 0.011

Table 9 contains the degrees of relative equivalence for the massic activities of ^{134}Cs, ^{137}Cs, ^{238}Pu and ^{239,240}Pu in the sediment samples.

TABLE 9. DEGREES OF EQUIVALENCE (%) IN SEDIMENT SAMPLES

Nuclide	Sample	IAEA	FP	JAEA	JCAC	KINS	STUK	TPT	TRK
^{134}Cs	F-P04	**-36 ± 33**	DL	–	30 ± 73	8 ± 66	0 ± 31	10 ± 78	30 ± 65
	T-S3	-3 ± 16	31 ± 37	–	-10 ± 22	0 ± 21	-1 ± 15	-9 ± 20	13 ± 32
	T-S8	Note 1	–	–	DL	DL	Note 1	DL	DL
^{137}Cs	F-P04	-11 ± 12	3 ± 17	–	-6 ± 14	-2 ± 11	6 ± 11	**13 ± 11**	-3 ± 11
	T-S3	-5 ± 10	0 ± 15	–	1 ± 13	-2 ± 9	-2 ± 8	-1 ± 8	**9 ± 8**
	T-S8	2 ± 10	–	–	5 ± 14	-5 ± 9	4 ± 9	-1 ± 9	-3 ± 11
^{238}Pu	F-P04	Note 2	Note 2	–	Note 2	DL	DL	–	–
	T-S3	Note 3	–	–	Note 3	DL	DL	–	–
	T-S8	Note 4	–	DL	Note 4	DL	DL	–	–
^{239,240}Pu	F-P04	6 ± 28	14 ± 27	-	6 ± 26	12 ± 30	**-39 ± 30**	–	–
	T-S3	10 ± 15	-5 ± 15	-	-1 ± 11	5 ± 13	-10 ± 17	–	–
	T-S8	1 ± 14	-	4 ± 19	1 ± 11	6 ± 13	-15 ± 18	–	–

Notes:

The numerical results in this table are stated in the format xx ± yy, where the number following the symbol ± is the 99% confidence interval.

Note 1: Value of -1.40 for $\zeta_{1,6}$.

Note 2: Values of 1.04, 0.74 and -0.83 for $\zeta_{1,2}$, $\zeta_{1,4}$ and $\zeta_{2,4}$, respectively.

Note 3: Value of 1.24 for $\zeta_{1,4}$.

Note 4: Value of 1.80 for $\zeta_{1,4}$.

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 refers to FP, number 3 refers to JAEA, number 4 refers to JCAC, number 5 refers to KINS, number 6 refers to STUK, number 7 refers to TPT, and number 8 refers to TRK.

5.4. FISH

Table 10a and 10b contain the results reported by the participating laboratories (IAEA, ENS, KINS, MERI, STUK and SWRI) for the massic activities of ^{134}Cs and ^{137}Cs in the fish samples. Figures 10 to 12 show the massic activities of ^{134}Cs and ^{137}Cs in the fish samples.

TABLE 10A. MASSIC ACTIVITIES of ^{134}Cs (Bq kg^{-1}-wet) IN FISH SAMPLES

Nuclide	Sample number: Species	IAEA	ENS	KINS	MERI	STUK	SWRI	Reference value
^{134}Cs (1h)	22FA0001: Olive flounder	<0.81	<0.57	<0.82	<0.30	–	<0.53	–
	22FA0002: Whitespotted conger	<0.86	<0.58	<0.74	<0.26	–	<0.47	–
	22FA0003: Crimson sea bream	<0.84	<0.61	<0.71	<0.31	–	<0.54	–
	22FA0004: Redwing searobin	<0.82	<0.62	<0.71	<0.30	–	<0.52	–
	22FA0005: Shotted halibut	<0.93	<0.45	<0.66	<0.31	–	<0.5	–
	22FA0006: Willowy flounder	<0.85	<0.57	<0.7	<0.30	–	<0.48	–
^{134}Cs (24h[1])	22FA0001: Olive flounder	<0.086	<0.088	<0.16	<0.051	<0.019	<0.081	–
	22FA0002: Whitespotted conger	<0.15	<0.094	<0.13	<0.046	<0.027	<0.069	–
	22FA0003: Crimson sea bream	<0.16	<0.084	<0.14	<0.052	0.0310 ± 0.0059	<0.079	–
	22FA0004: Redwing searobin	<0.16	<0.092	<0.13	<0.044	<0.023	<0.084	–
	22FA0005: Shotted halibut	<0.13	<0.076	<0.13	<0.053	<0.044	<0.077	–
	22FA0006: Willowy flounder	<0.15	<0.091	<0.13	<0.044	<0.036	<0.077	–

Note:

[1] The samples were counted by STUK for at least 48 hours.

TABLE 10B. MASSIC ACTIVITIES of ^{137}Cs (Bq kg^{-1}-wet) IN FISH SAMPLES

Nuclide	Sample number: Species	IAEA	ENS	KINS	MERI	STUK	SWRI	Reference value
^{137}Cs (1h)	22FA0001: Olive flounder	0.64 ± 0.11	<0.57	<0.52	0.36 ± 0.12	–	0.55 ± 0.15	–
	22FA0002: Whitespotted conger	0.32 ± 0.14	<0.55	<0.82	<0.30	–	<0.54	–
	22FA0003: Crimson sea bream	0.60 ± 0.18	<0.62	0.66 ± 0.16	0.50 ± 0.10	–	<0.58	–
	22FA0004: Redwing searobin	0.86 ± 0.17	0.96 ± 0.22	0.65 ± 0.18	0.60 ± 0.11	–	0.66 ± 0.18	0.714 ± 0.070
	22FA0005: Shotted halibut	0.81 ± 0.17	<0.59	<0.70	0.67 ± 0.12	–	0.69 ± 0.19	–
	22FA0006: Willowy flounder	0.65 ± 0.17	<0.60	<0.55	0.36 ± 0.12	–	<0.49	–
^{137}Cs (24h[1])	22FA0001: Olive flounder	0.514 ± 0.033	0.471 ± 0.035	0.529 ± 0.038	0.483 ± 0.025	0.405 ± 0.021	0.495 ± 0.041	0.478 ± 0.019
	22FA0002: Whitespotted conger	0.230 ± 0.014	0.262 ± 0.032	0.229 ± 0.027	0.255 ± 0.018	0.234 ± 0.015	0.226 ± 0.035	0.238 ± 0.008
	22FA0003: Crimson sea bream	0.539 ± 0.049	0.566 ± 0.037	0.574 ± 0.046	0.571 ± 0.028	0.508 ± 0.024	0.569 ± 0.032	0.550 ± 0.014
	22FA0004: Redwing searobin	0.592 ± 0.047	0.494 ± 0.036	0.599 ± 0.041	0.571 ± 0.027	0.523 ± 0.029	0.591 ± 0.033	0.559 ± 0.018
	22FA0005: Shotted halibut	0.709 ± 0.047	0.606 ± 0.037	0.659 ± 0.040	0.609 ± 0.029	0.635 ± 0.034	0.613 ± 0.043	0.633 ± 0.016
	22FA0006: Willowy flounder	0.409 ± 0.043	0.425 ± 0.034	0.373 ± 0.03	0.419 ± 0.023	0.360 ± 0.023	0.409 ± 0.040	0.396 ± 0.013

Note:

[1] The samples were counted by STUK for at least 48 hours.

Tables 11a and 11b contain the degrees of relative equivalence for the activity concentrations of ^{134}Cs and ^{137}Cs, respectively, in the fish samples.

TABLE 11A. DEGREES OF EQUIVALENCE (%) FOR THE ACTIVITY CONCENTRATIONS OF ^{134}Cs IN FISH SAMPLES

Nuclide	Sample: Species	IAEA	ENS	KINS	MERI	STUK	SWRI
^{134}Cs (1h)	22FA0001: Olive flounder	DL	DL	DL	DL	–	DL
	22FA0002: Whitespotted conger	DL	DL	DL	DL	–	DL
	22FA0003: Crimson sea bream	DL	DL	DL	DL	–	DL
	22FA0004: Redwing searobin	DL	DL	DL	DL	–	DL
	22FA0005: Shotted halibut	DL	DL	DL	DL	–	DL
	22FA0006: Willowy flounder	DL	DL	DL	DL	–	DL
^{134}Cs (24h)	22FA0001: Olive flounder	DL	DL	DL	DL	DL	DL
	22FA0002: Whitespotted conger	DL	DL	DL	DL	DL	DL
	22FA0003: Crimson sea bream	DL	DL	DL	DL	Note 1	DL
	22FA0004: Redwing searobin	DL	DL	DL	DL	DL	DL
	22FA0005: Shotted halibut	DL	DL	DL	DL	DL	DL
	22FA0006: Willowy flounder	DL	DL	DL	DL	DL	Note 1

Notes:

The numerical results in this table are stated in the format xx ± yy, where the number following the symbol ± is the 99% confidence interval.

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

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

TABLE 11B. DEGREES OF EQUIVALENCE (%) FOR THE ACTIVITY CONCENTRATIONS OF ^{137}Cs IN FISH SAMPLES

Nuclide	Sample: Species	IAEA	ENS	KINS	MERI	STUK	SWRI
^{137}Cs (1h)	22FA0001: Olive flounder	Note 1	DL	DL	Note 1	DL	Note 1
	22FA0002: Whitespotted conger	DL	DL	DL	DL	DL	DL
	22FA0003: Crimson sea bream	Note 2	DL	Note 2	Note 2	DL	DL
	22FA0004: Redwing searobin	20 ± 54	35 ± 71	-9 ± 59	-16 ± 34	DL	-7 ± 58
	22FA0005: Shotted halibut	Note 3	DL	DL	Note 3	DL	Note 3
	22FA0006: Willowy flounder	Note 4	DL	DL	Note 4	DL	DL
^{137}Cs (24h)	22FA0001: Olive flounder	7 ± 18	-2 ± 19	11 ± 21	1 ± 15	-15 ± 14	3 ± 22
	22FA0002: Whitespotted conger	-3 ± 13	10 ± 33	-4 ± 28	7 ± 18	-2 ± 15	-5 ± 36
	22FA0003: Crimson sea bream	-2 ± 22	3 ± 16	4 ± 21	4 ± 12	-8 ± 10	3 ± 14
	22FA0004: Redwing searobin	6 ± 21	-12 ± 16	7 ± 18	2 ± 13	-6 ± 14	6 ± 15
	22FA0005: Shotted halibut	12 ± 18	-4 ± 14	4 ± 16	-4 ± 11	0 ± 13	-3 ± 17
	22FA0006: Willowy flounder	3 ± 26	7 ± 21	-6 ± 18	6 ± 13	-9 ± 14	3 ± 25

Notes:

The numerical results in this table are stated in the format xx ± yy, where the number following the symbol ± is the 99% confidence interval.

Note 1: Values of 1.76, 0.52 and -1.02 for $\zeta_{1,4}$, $\zeta_{1,6}$ and $\zeta_{4,6}$, respectively.

Note 2: Values of -0.28, 0.48 and 0.89 for $\zeta_{1,3}$, $\zeta_{1,4}$ and $\zeta_{3,4}$, respectively.

Note 3: Values of 0.67, 0.46 and -0.10 for $\zeta_{1,4}$, $\zeta_{1,6}$ and $\zeta_{4,6}$, respectively.

Note 4: Value of 1.45 for $\zeta_{1,4}$.

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 refers to ENS, number 3 refers to KINS, number 4 refers to MERI, number 5 refers to STUK, and number 6 refers to SWRI.

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 November 2022. The samples were shared between 14 laboratories: 11 from Japan (ENS, FP, JAEA. JCAC, KAKEN, KANSO, KEEA, MERI, SWRI, TPT and TRK); the IAEA Marine Environment Laboratories in Monaco; and 2 laboratories from the IAEA ALMERA network (KINS, Republic of Korea; and STUK, Finland).

From this analysis it can be concluded that the overwhelming majority of results are not significantly different from each other. A global analysis of the whole data set demonstrated just 9 discrepant values from the 192 statistical tests applied to the data, i.e. more than 95 % were passed with a high level of confidence (99%). The exceptions were the following cases where the relative DoE was significantly different from zero:

- DoE (%) = -56 ± 43 for the ^{90}Sr activity concentration in the seawater sample from M-101 submitted by KINS.
- DoE (%) = -23 ± 18 for the ^{137}Cs activity concentration in the seawater sample from M-101 submitted by IAEA.
- DoE (%) = -17 ± 17 (after rounding) for the ^{137}Cs activity concentration in the seawater sample from M-101 submitted by STUK.
- DoE (%) = 93 ± 46 for the ^{137}Cs activity concentration in the seawater sample from M-102 submitted by JCAC.
- DoE (%) = 21 ± 19 for the ^{137}Cs activity concentration in the seawater sample from M-104 submitted by JCAC.
- DoE (%) = -36 ± 33 for the ^{134}Cs activity concentration in the sediment sample from F-P04 submitted by IAEA.
- DoE (%) = 13 ± 11 for the ^{137}Cs activity concentration in the sediment sample from F-P04 submitted by TPT.
- DoE (%) = 9 ± 8 for the ^{137}Cs activity concentration in the sediment sample from T-S8 submitted by TRK.
- DoE (%) = -39 ± 30 for the ^{239,240}Pu activity concentration in the sediment sample from F-P04 submitted by STUK.

Despite these departures, it can be said with confidence that the laboratories are reporting 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.

Following this sampling mission, the IAEA can confidently report that Japan's sample collection procedures continue to follow the appropriate methodological standards required to obtain representative samples. The results obtained in ILC 2022 demonstrate a continued high level of accuracy and competence on the part of the Japanese laboratories involved in the analyses of radionuclides in marine samples for the Sea Area Monitoring programme.

REFERENCES

[1] INTERNATIONAL ORGANISATION FOR STANDARDISATION, Conformity assessment — General requirements for proficiency testing. ISO/IEC 17043:2023, Geneva (2023).

[2] INTERNATIONAL ORGANISATION FOR STANDARDISATION, Statistical methods for use in proficiency testing by interlaboratory comparisons, ISO 13528:2022, Geneva (2022).

[3] 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

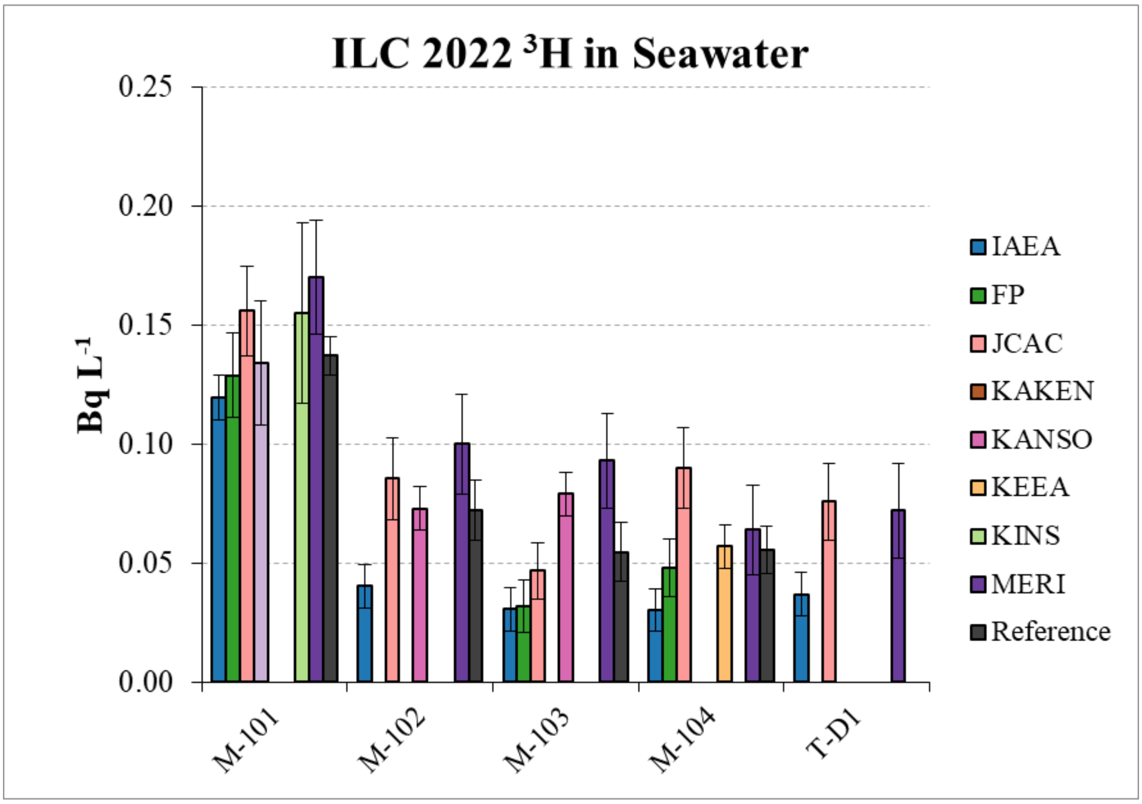

FIG. 2. Activity concentrations of ^{3}H in seawater samples.

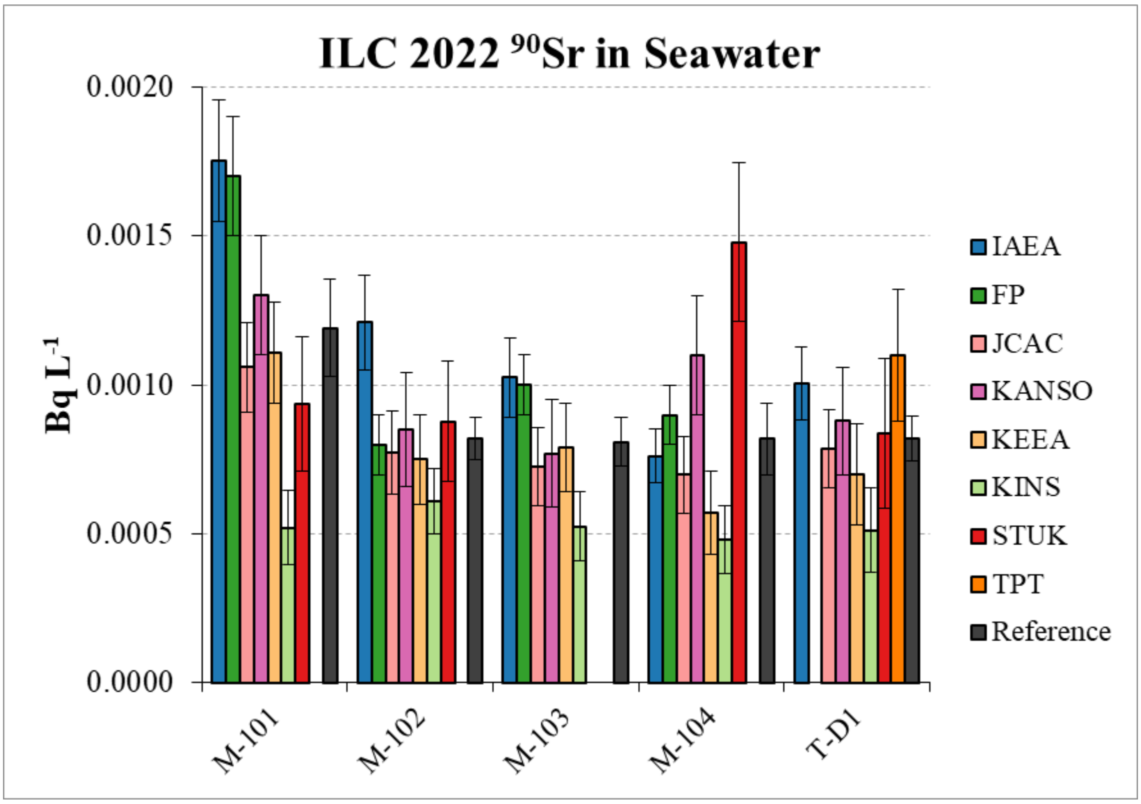

FIG. 3. Activity concentrations of ^{90}Sr in seawater samples.

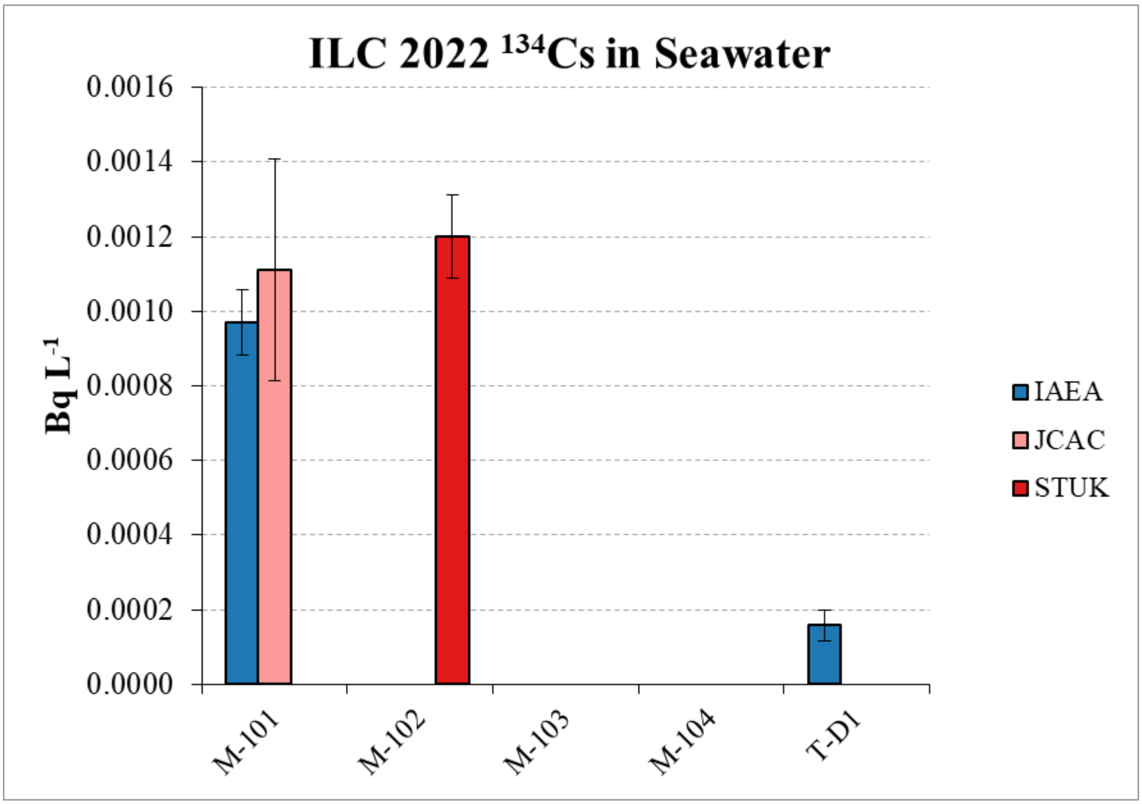

FIG. 4. Activity concentrations of ^{134}Cs in seawater samples.

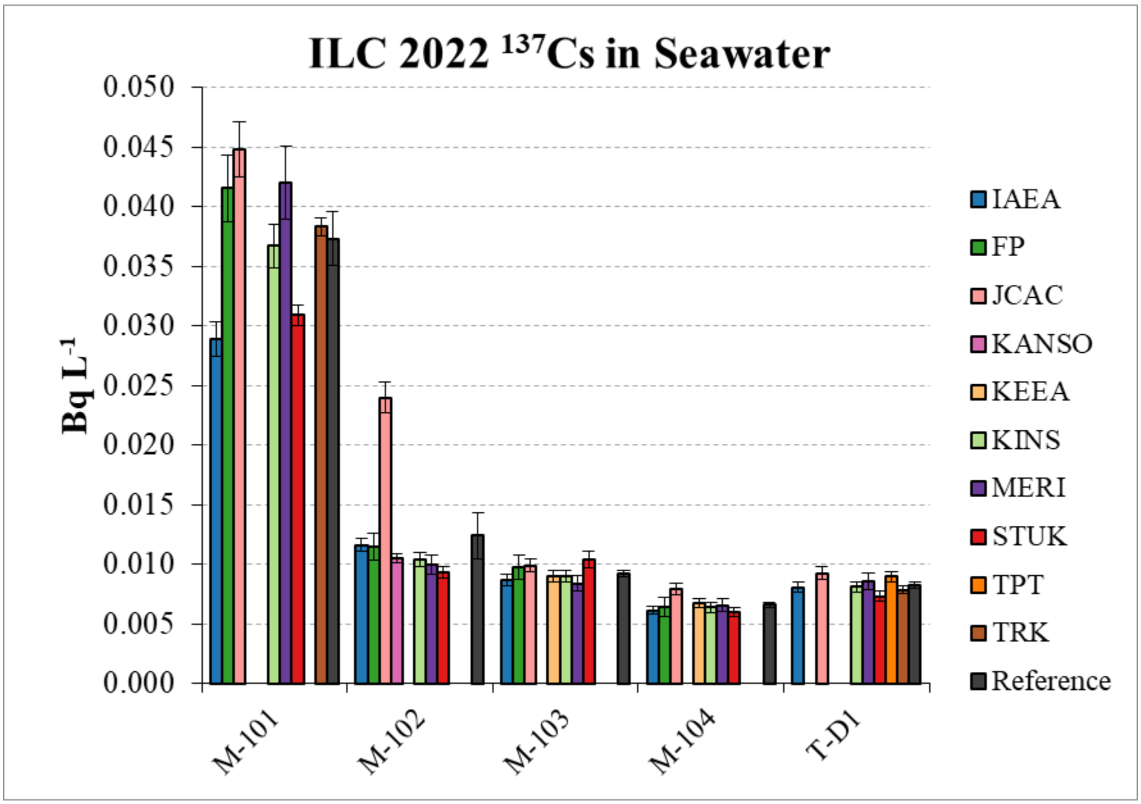

FIG. 5 Activity concentrations of ^{137}Cs in seawater samples.

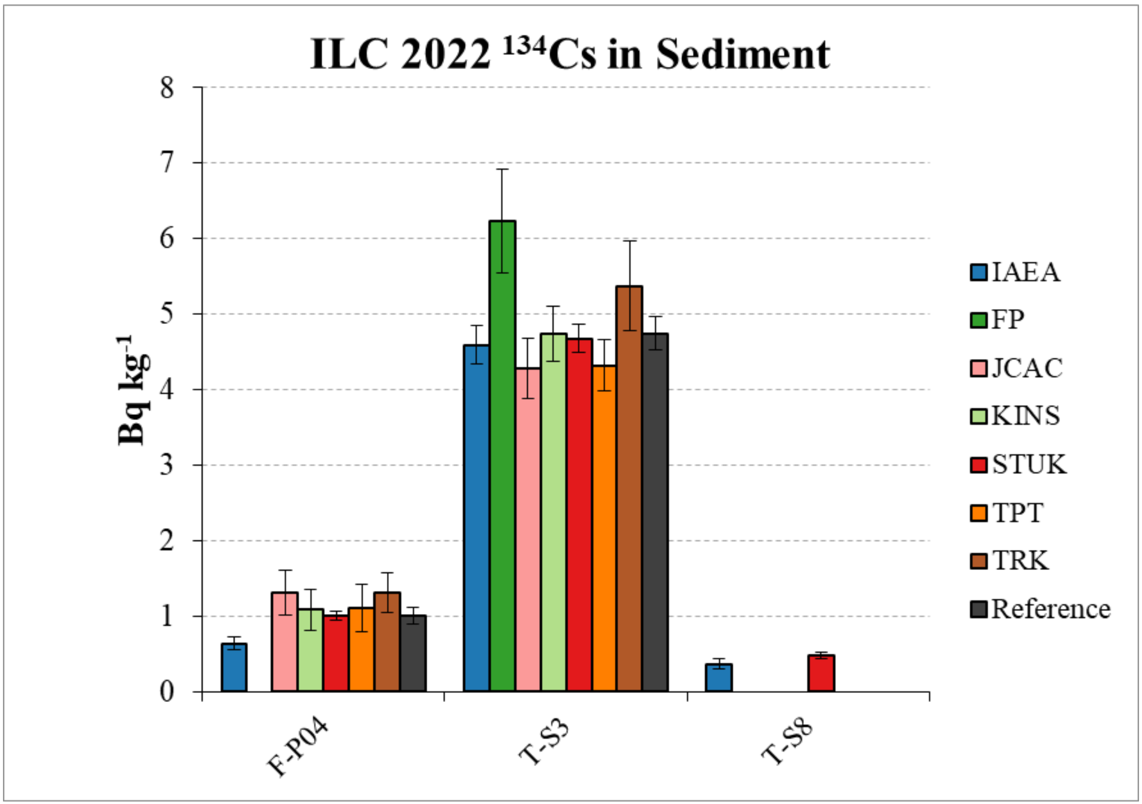

FIG. 6. Massic activities of ^{134}Cs in sediment samples.

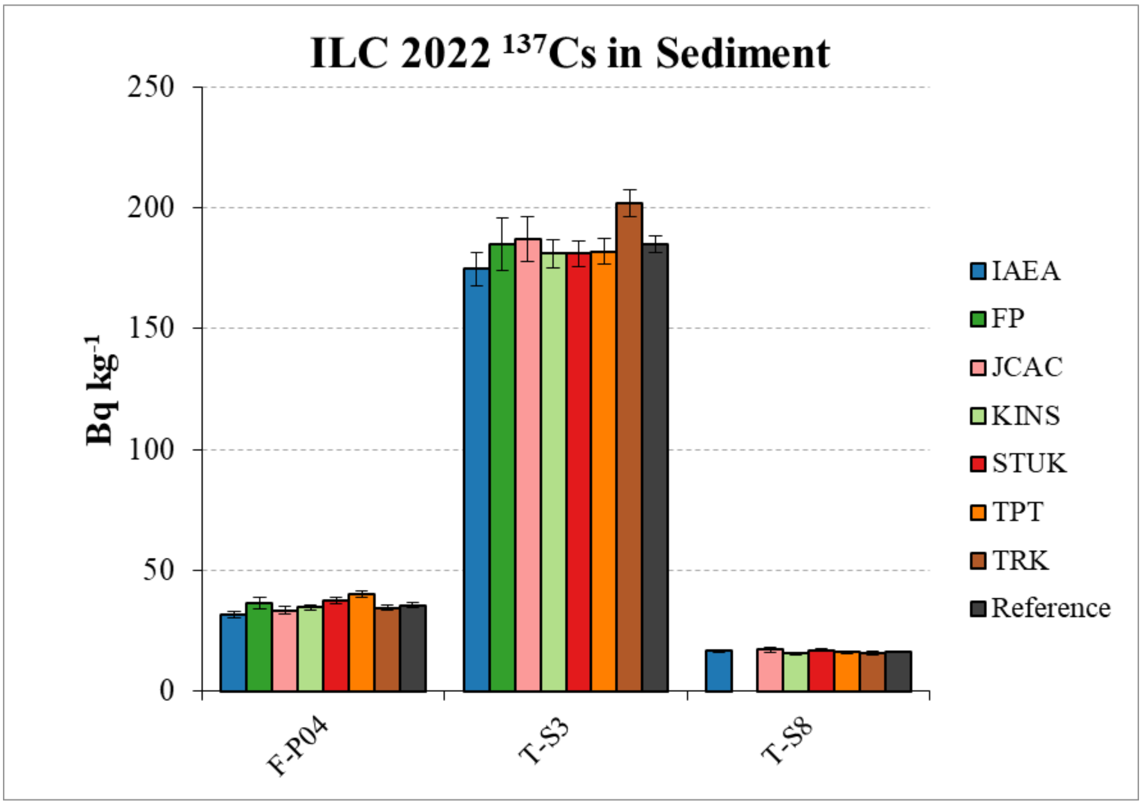

FIG. 7. Massic activities of ^{137}Cs in sediment samples.

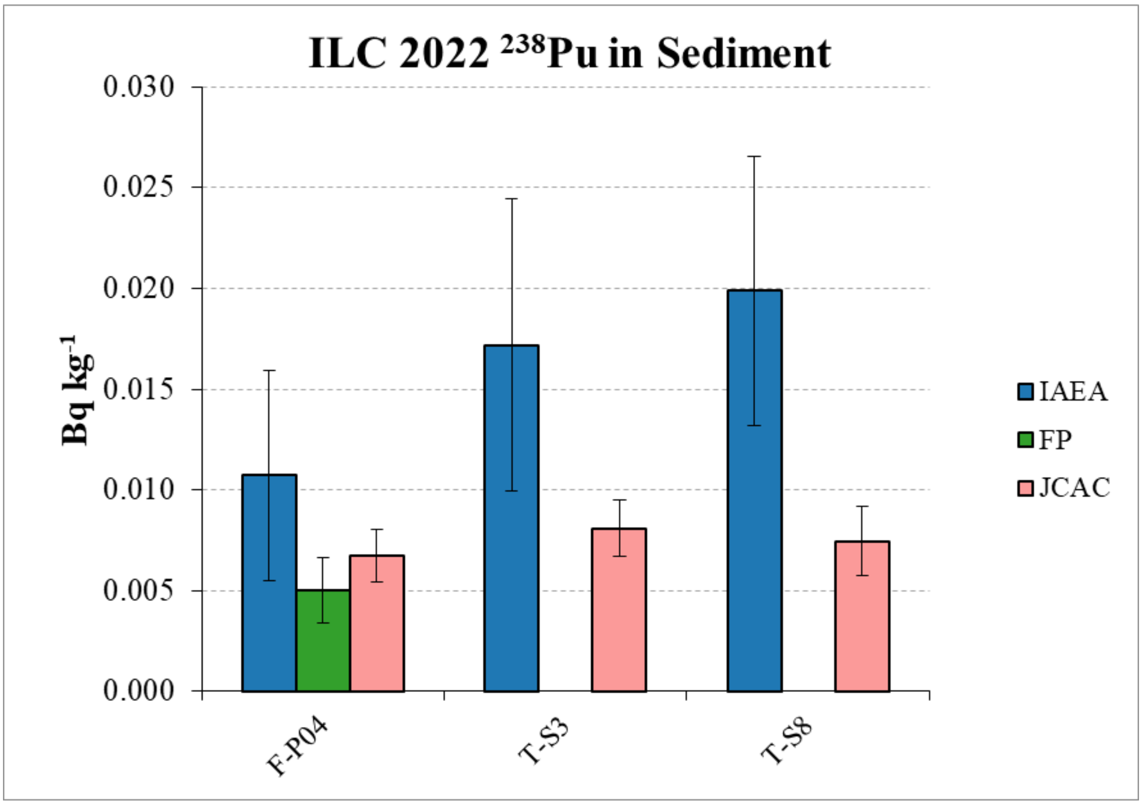

FIG. 8. Massic activities of ^{238}Pu in sediment samples.

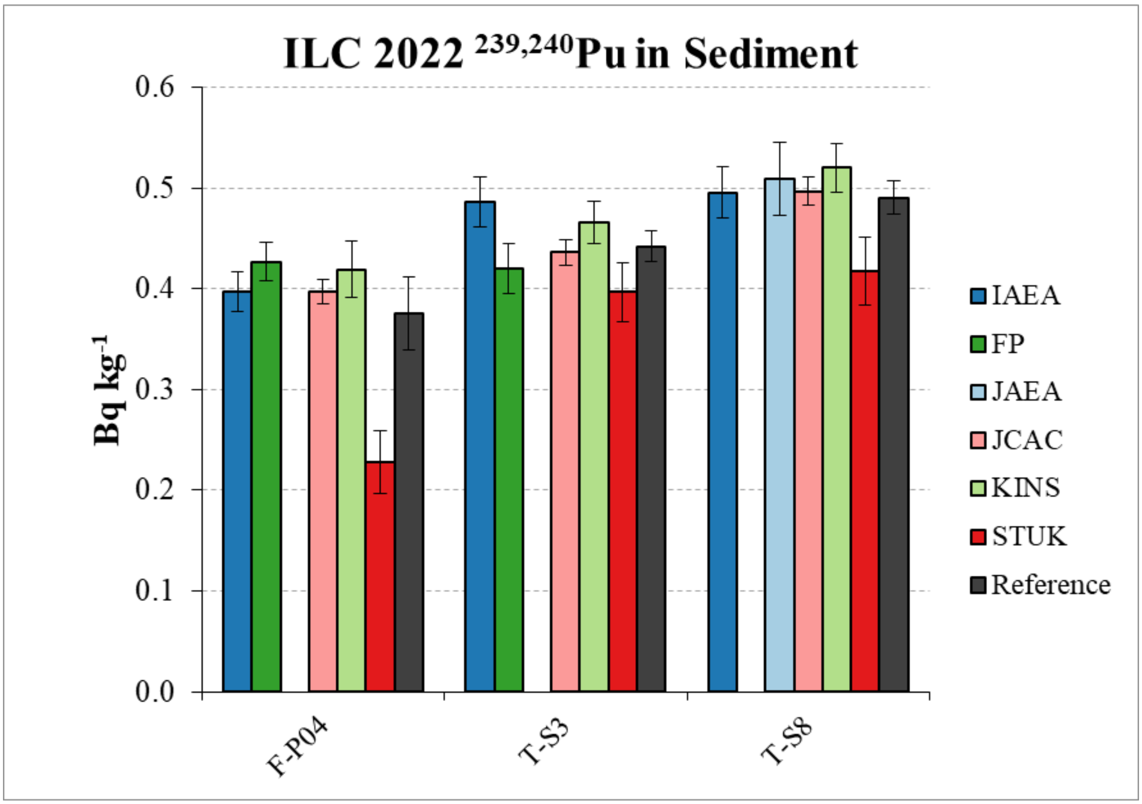

FIG. 9. Massic activities of ^{239,240}Pu in sediment samples.

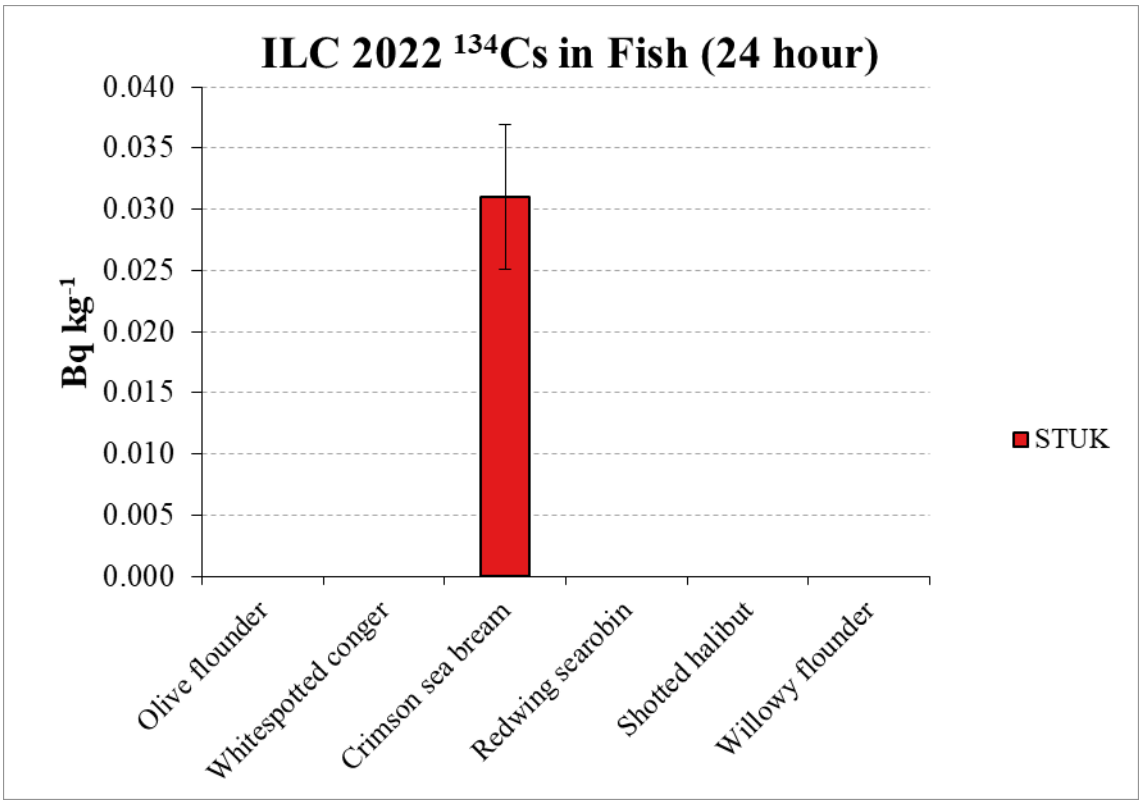

FIG. 10. Massic activities of ^{134}Cs in fish samples (24-hour measurement time).

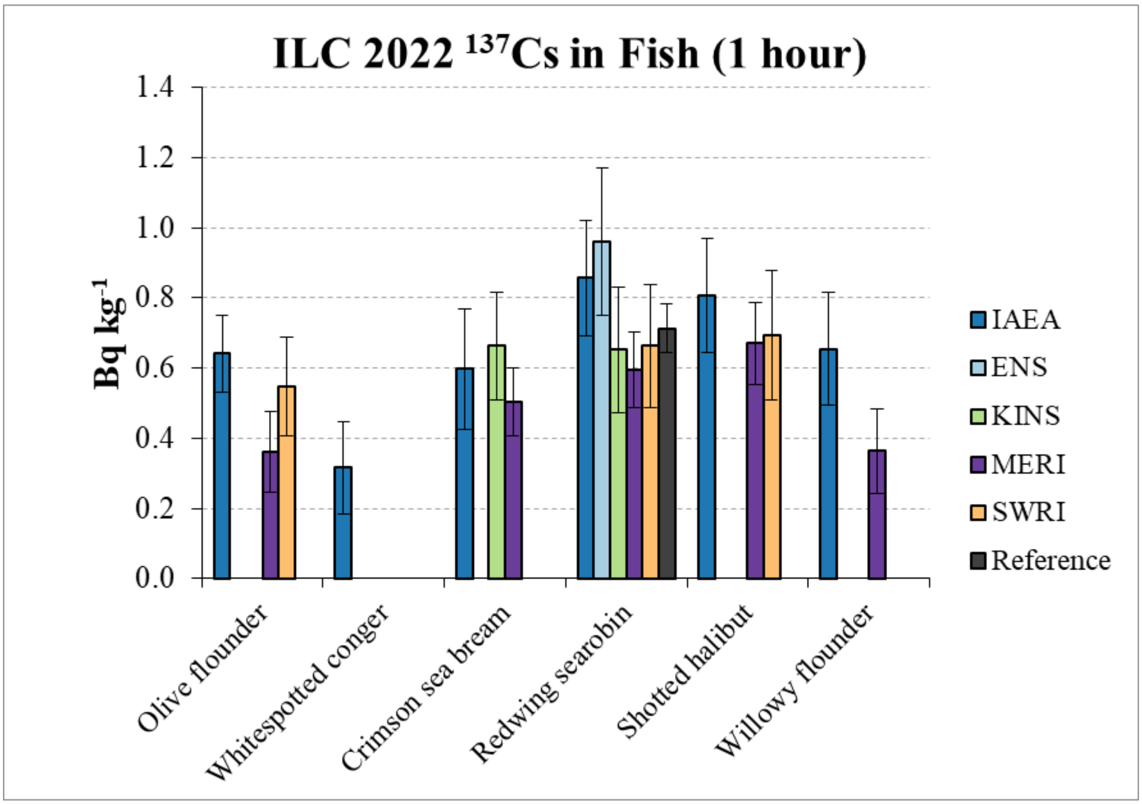

FIG. 11. Massic activities of ^{137}Cs in fish samples (1 hour measurement time).

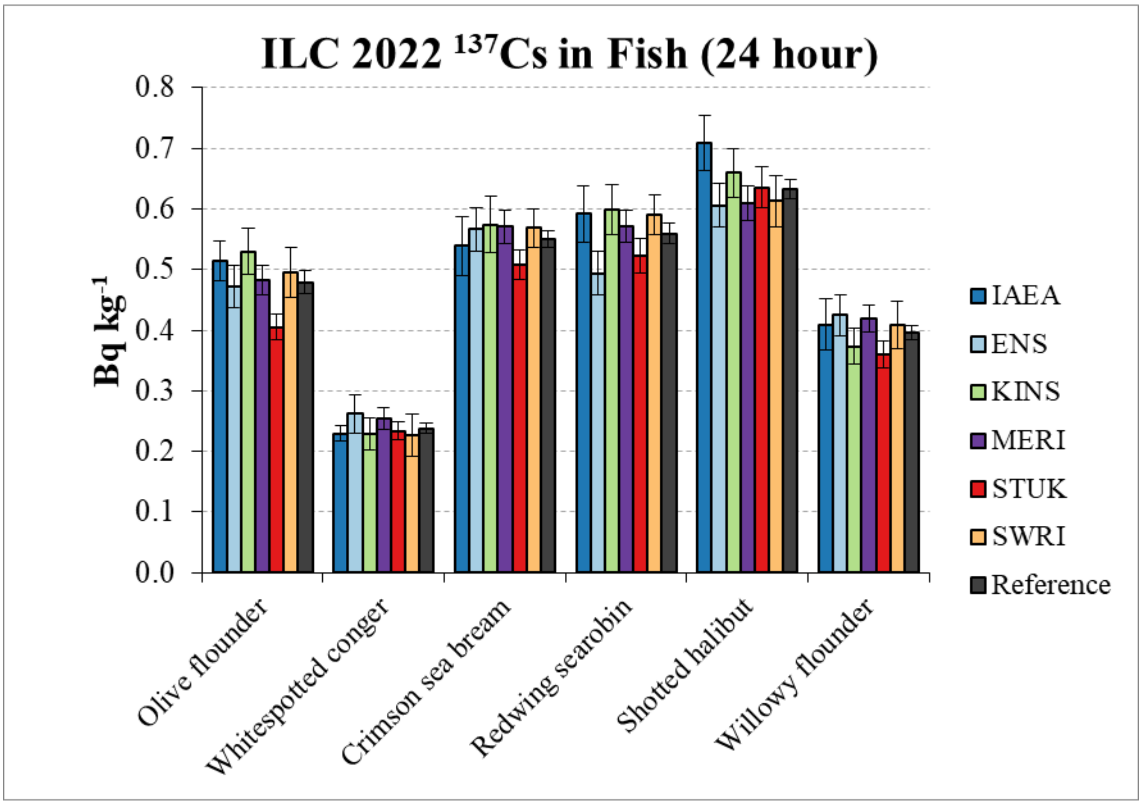

FIG. 12. Massic activities of ^{137}*Cs in fish samples (24-hour measurement time).*