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IAEA-RML-2014-02 Proficiency Test for Determination of Radionuclides in Sea Water

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IAEA-RML-2014-02 PROFICIENCY TEST FOR DETERMINATION OF RADIONUCLIDES IN SEA WATER

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IAEA-RML-2014-02 PROFICIENCY TEST FOR DETERMINATION OF RADIONUCLIDES IN SEA WATER

INTERNATIONAL ATOMIC ENERGY AGENCY
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FOREWORD

The Radiometrics Laboratory of the IAEA Environment Laboratories (NAEL) has been providing quality support products and services for the past 50 years. These include the organization of proficiency tests and laboratory comparisons, and the production of certified reference materials, including a wide range of marine sample matrices and radionuclide levels.

As part of these activities, a third proficiency test was organized in the framework of the technical cooperation project entitled Marine Benchmark Study on the Possible Impact of the Fukushima Radioactive Releases in the Asia-Pacific Region, to test the performance of participating laboratories in an analysis of radionuclides in a seawater sample. This exercise was initiated to support Member States in seawater analyses of tritium, strontium-90 and caesium isotopes in relation to the accident at the Fukushima Daiichi nuclear power station, in March 2011, and subsequent contamination of the marine environment.

The IAEA wishes to thank all the participants and laboratories who took part in this proficiency test. The IAEA is also grateful to the Government of Monaco for its support.

The IAEA officers responsible for this publication were A.V. Harms and I. Osvath of the IAEA Environment Laboratories.

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CONTENTS

1. INTRODUCTION

The IAEA Environment Laboratories (IAEA-EL) in Monaco and Seibersdorf regularly organize proficiency tests (PT) for radionuclides in environmental samples to support laboratories in IAEA Member States. The organization and the results of a third PT organised in the frame of the IAEA Technical Cooperation project RAS/7/021 Marine Benchmark Study on the Possible Impact of the Fukushima Radioactive Releases in the Asia-Pacific Region are described in this report.

2. MATERIAL AND METHODS

2.1. PROFICIENCY TEST OBJECTIVES

This proficiency test was organized in the frame of the IAEA Technical Cooperation project RAS/7/021 Marine Benchmark Study on the Possible Impact of the Fukushima Radioactive Releases in the Asia-Pacific Region. This third exercise was initiated to support Member States in seawater analyses of tritium, strontium-90 and caesium isotopes, in relation to the Fukushima Daiichi nuclear power station accident in Japan (March 2011) and subsequent contamination to the marine environment. The results of this exercise allowed the participating laboratories to evaluate their performance in the analysis of the radionuclides for this sample type.

2.2. PARTICIPANTS

A total of 14 laboratories from 11 countries participated in the exercise. In addition to the 10 laboratories taking part in the IAEA Technical Cooperation project RAS/7/021 (from Australia, China, India, Indonesia, Malaysia, New Zealand, Philippines, Sri Lanka, Thailand and Viet Nam), 4 other laboratories from Oman, Thailand and Viet Nam also took part in the exercise. The ten laboratories associated with the RAS/7/021 project are indicated with the symbol * following their participation code (i.e. Participants 1*, 2*, 3*, 4*, 5*, 6*, 7*, 8*, 9* and 10*). The full list of participants is given on pages 27–29.

2.3. MATERIAL DISTRIBUTION AND REPORTING REQUIREMENTS

A sample containing 5 L of filtered and acidified Mediterranean seawater spiked by the IAEA with the radionuclides ^{3}H, ^{90}Sr, ^{134}Cs and ^{137}Cs was distributed to the participants, with the massic activities only known to the IAEA. The massic activities were traceable to a standard provided by Czech Metrology Institute ČMI. The combined massic activities in the exercise samples were lower than the natural activity level of ^{40}K in seawater (which is approximately 12 Bq kg^{-1}). The ^{3}H, ^{90}Sr, ^{134}Cs and ^{137}Cs massic activities for the samples were approximately 2.8, 0.35, 0.12 and 0.31 Bq kg^{-1}, respectively. The sample also contained a non-active Cs-carrier at 10 mg kg^{-1} in order to stabilise the solution and to avoid adsorption of Cs to the container walls. No Sr was added to the sample as non-active Sr present naturally in seawater will act as a carrier for ^{90}Sr.

The participants were required to report to the IAEA the ^{3}H, ^{90}Sr, ^{134}Cs and ^{137}Cs massic activities (in Bq kg^{-1}) of the proficiency test sample combined with the associated uncertainties (also in Bq kg^{-1}). Additionally, the participants were asked to submit the following:

- A short description of the analytical method used for the sample analysis. The Information Sheet sent to the participants suggested for ^{3}H distillation followed by liquid scintillation counting. For ^{90}Sr precipitation from seawater as mixed Ca/Sr oxalate or carbonate follow by a standard ^{90}Sr procedure (e.g. a radiochemical procedure such as precipitation with fuming nitric acid, liquid-liquid extraction or extraction chromatography followed by a measurement technique such as gas-flow proportional counting or liquid scintillation counting). For ^{134}Cs and ^{137}Cs three methods were suggested: (i) direct gamma spectrometry, (ii) adsorption on AMP (ammonium molybdophosphate, $(NH_4)_3PO_4Mo_{12}O_{36}$) and subsequent gamma spectrometry or (iii) adsorption on copper hexacyanoferrate ($Cu_2[Fe(CN)_6]$) and subsequent gamma spectrometry;
- Type of calibration and software used for gamma ray spectrometry;

– Nuclear data used;
– An uncertainty budget for the measurement results.

The reference date for reporting massic activities was set at 1 August 2014. At this date, the ranges for the traceable massic activities in the proficiency test exercise samples sent to the participants were 2.69–2.83 Bq kg^{-1} ^{3}H, 0.3326–0.3515 Bq kg^{-1} ^{90}Sr, 0.1112–0.1175 Bq kg^{-1} ^{134}Cs and 0.2951–0.3118 Bq kg^{-1} ^{137}Cs, respectively (see Table 1).

TABLE 1. IAEA ASSIGNED VALUES

Participant	^{3}H massic activity (Bq kg^{-1})	^{90}Sr massic activity (Bq kg^{-1})	^{134}Cs massic activity (Bq kg^{-1})	^{137}Cs massic activity (Bq kg^{-1})
1*	2.80 ± 0.06	0.3485 ± 0.0021	0.1165 ± 0.0005	0.3092 ± 0.0019
2*	2.82 ± 0.06	0.3500 ± 0.0021	0.1170 ± 0.0005	0.3105 ± 0.0019
3*	2.79 ± 0.06	0.3470 ± 0.0021	0.1160 ± 0.0005	0.3079 ± 0.0019
4*	2.77 ± 0.06	0.3437 ± 0.0021	0.1149 ± 0.0005	0.3049 ± 0.0019
5*	2.69 ± 0.06	0.3326 ± 0.0020	0.1112 ± 0.0004	0.2951 ± 0.0018
6*	2.82 ± 0.06	0.3509 ± 0.0021	0.1173 ± 0.0005	0.3113 ± 0.0019
7*	2.80 ± 0.06	0.3481 ± 0.0021	0.1164 ± 0.0005	0.3088 ± 0.0019
8*	2.76 ± 0.06	0.3421 ± 0.0021	0.1144 ± 0.0005	0.3035 ± 0.0019
9*	2.81 ± 0.06	0.3495 ± 0.0021	0.1169 ± 0.0005	0.3101 ± 0.0019
10*	2.83 ± 0.06	0.3515 ± 0.0021	0.1175 ± 0.0005	0.3118 ± 0.0019
11	2.79 ± 0.06	0.3463 ± 0.0021	0.1158 ± 0.0005	0.3073 ± 0.0019
12	2.80 ± 0.06	0.3483 ± 0.0021	0.1164 ± 0.0005	0.3090 ± 0.0019
13	2.81 ± 0.06	0.3492 ± 0.0021	0.1168 ± 0.0005	0.3098 ± 0.0019
14	2.79 ± 0.06	0.3464 ± 0.0021	0.1158 ± 0.0005	0.3074 ± 0.0019

3. PERFORMANCE CRITERIA

The methodology adopted for this exercise was slightly updated from the existing IAEA methodology. The scoring system took into account the accuracy, precision and trueness of the reported data and included in the evaluation both the combined standard uncertainty of the target value and the combined standard uncertainty reported by the participating laboratories. The IAEA values, which were used for the data evaluation, were the certified values of radionuclides at the reference date. A result must pass three tests to be assigned the status "Accepted", otherwise it was assigned the status "Warning" or "Not accepted".

3.1. ACCURACY

The first step in producing a score for a result $Value_{Analyst}$ was the estimation of the bias. The relative bias between the Analyst's value and the IAEA target value was calculated as follows and expressed as a percentage:

$$Bias_{relative} = \frac{Value_{Analyst} - Value_{IAEA}}{Value_{IAEA}} \times 100\% \quad (1)$$

The absolute value of the relative bias was compared to the Maximal Accepted Relative Bias (MARB). Participants' results were scored as "Pass" for accuracy when:

$$|Bias_{relative}| \leq \text{MARB} \quad (2)$$

The MARB values used in this evaluation were 20% for both ^{134}Cs and ^{137}Cs and 25% for both ^{3}H and ^{90}Sr.

3.2. PRECISION AND TRUENESS

The precision *P* for each result was calculated according to the following equation:

$$P = \sqrt{\left(\frac{unc_{IAEA}}{Value_{IAEA}}\right)^2 + \left(\frac{unc_{Analyst}}{Value_{Analyst}}\right)^2} \times 100\% \quad (3)$$

The precision *P* was compared to the Limit of Accepted Precision (LAP). The participants' results were scored as "Pass" for precision when:

$$P \leq \text{LAP} \quad (4)$$

The Limit of Accepted Precision (LAP) values used in this evaluation were 20% for both ^{134}Cs and ^{137}Cs and 25% for both ^{3}H and ^{90}Sr.

The participants' results for trueness were scored as "Pass" when:

$$|Bias_{relative}| \leq \frac{Value_{Analyst}}{Value_{IAEA}} 2.58\, P \quad (5)$$

3.3. FINAL EVALUATION

For the final evaluation, all three scores were combined (see Table 2). The result was considered as "Accepted" if it passed all three tests. If the accuracy test was failed, the result was considered as "Not accepted". If the accuracy test was passed but one of the other two tests was failed, the result was assigned the "Warning" status. The "Warning" status will reflect cases in which the reported result was close enough to the assigned property value, but its associated uncertainty was deemed to be either too small or too large.

TABLE 2. PERFORMANCE EVALUATION CRITERIA

Accuracy	Precision	Trueness	Final evaluation
Pass	Pass	Pass	Accepted
Pass	Fail	Pass	Warning
Pass	Pass	Fail	Warning
Fail	Pass/Fail	Pass/Fail	Not accepted

The evaluation criteria can also be illustrated by plotting the relative bias against the relative uncertainty of the participants' result (see Figure 1). In the illustrated case, a relative uncertainty of 1% for the IAEA target value is assumed with MARB and LAP limits of 20%.

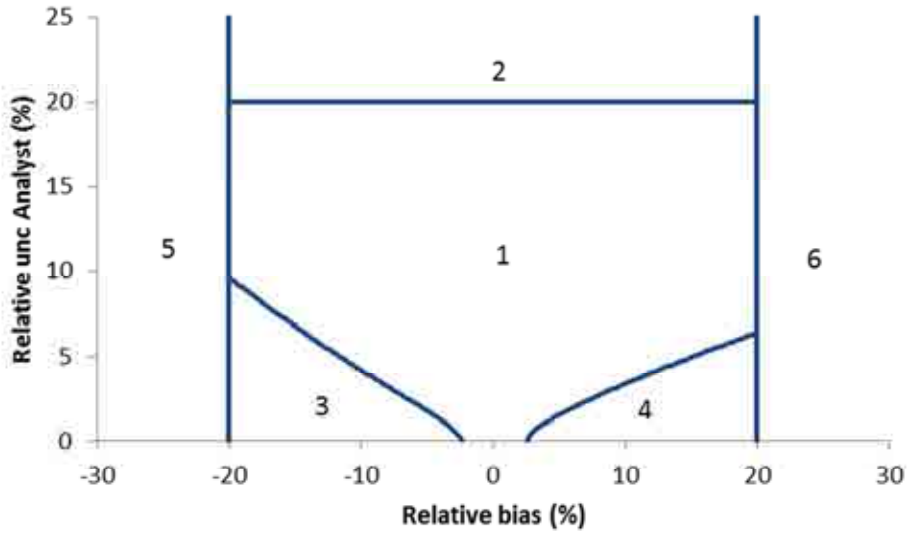

FIG. 1. Visualisation of performance evaluation criteria.

The plot consists of six zones (Zone 1 "Accepted"; Zones 2, 3 and 4 "Warning"; Zones 5 and 6 "Not accepted"), whose areas are defined by the three tests used above to evaluate the data. The areas of Zones 1, 3 and 4 are finite, while the areas of Zones 2, 5 and 6 are infinite. A result located in Zone 1 passes all three tests (evaluation "Accepted"). A result located in Zone 2 fails only the precision test as its associated uncertainty is deemed to be too large (evaluation: "Warning"). A result located in Zones 3 and 4 fails only the trueness test as its associated uncertainty is deemed to be too small (evaluation: "Warning"). A result located in Zones 5 and 6 fails (at least) the accuracy test as its relative bias is larger than the MARB (evaluation: "Not accepted").

3.4. COMPARISON OF PARTICIPANTS' VALUES WITH THE IAEA VALUES

The means and the uncertainties for the combined participants' results were calculated according to a method developed by Cox (i.e. the weighted mean of the largest consistent subset containing *p* results)[1] and subsequently compared with the IAEA values. The mean of the combined participants' results, $Value_{Combined}$, was tested against the IAEA value, $Value_{IAEA}$, using this equation:

$$t = \frac{Value_{Combined} - Value_{IAEA}}{\sqrt{(unc_{Combined})^2 + (unc_{IAEA})^2}} \quad (6)$$

[1] Cox, M.G., 2007. The evaluation of key comparison data: determining the largest consistent subset. Metrologia 44 187-200

The effective degrees of freedom ν_{eff} were determined with the Welch-Satterthwaite equation. The effective degrees of freedom ν_{eff} were rounded and the critical value t_{crit} for this value was identified. The criterion for passing the t test was:

$$|t| < t_{crit} \quad (7)$$

If the absolute value of t was greater than the critical value t_{crit}, this indicates there was a significant difference between the combined participants' results and the IAEA value.

4. RESULTS AND DISCUSSION

In total 37 measurement results were reported by 14 laboratories from 11 countries for ^{3}H, ^{90}Sr, ^{134}Cs and ^{137}Cs. The overall evaluation of these results showed that 43% of all reported measurement results fulfilled the PT criteria of acceptability, while 43% of the individual measurement results were not accepted with the remaining 14% having the warning status. The performance evaluation for ^{3}H, ^{90}Sr, ^{134}Cs and ^{137}Cs is summarised in Table 3. For the subset of subset of RCA RAS/7/021 results, the values were: 36% 'Accepted', 53% 'Not accepted' and 11% 'Warning'.

TABLE 3. SUMMARY EVALUATION OF THE RADIONUCLIDES REPORTED

Radionuclide	Number of submitted results	Accepted	Warning	Not accepted
^{3}H	4 (3)	2 (1)	0	2 (2)
^{90}Sr	7 (7)	4 (4)	0	3 (3)
^{134}Cs	13 (9)	5 (3)	3 (1)	5 (5)
^{137}Cs	13 (9)	5 (2)	2 (2)	6 (5)

NOTE: The numbers in brackets represent the subset of RCA RAS/7/021 results

There was no significant negative bias of the combined participants' results for ^{3}H (–6.9%), ^{90}Sr (6.0%) ^{134}Cs (1.3%), and a significant positive bias for ^{137}Cs (12%) (see Table 4). However, this significant bias is probably a result of a statistical anomaly as the complete ^{137}Cs data set is inconsistent with a relatively small LCS (62%).

TABLE 4. COMPARISON OF THE COMBINED PARTICIPANTS' RESULTS WITH THE IAEA VALUE

Radio-nuclide	Combined participants' result (Bq kg^{-1})	IAEA value (Bq kg^{-1})	Size of the LCS* (%)	t-value	Critical t-value	Bias (%)
^{3}H	2.6 ± 0.3	2.80 ± 0.05	4 (100%)	–1.34	3.18	–6.9
^{90}Sr	0.365 ± 0.022	0.344 ± 0.012	5 (71%)	1.63	2.57	6.0
^{134}Cs	0.118 ± 0.006	0.1163 ± 0.018	10 (77%)	0.44	2.23	1.3
^{137}Cs	0.344 ± 0.022	0.309 ± 0.005	8 (62%)	3.15	2.36	12

*Size of the LCS (largest consistent subset) denotes the percentage of the returned results contributing to combined participants' results

Table 5 summarises the data evaluation sorted by laboratory code.

TABLE 5. SUMMARY EVALUATION

Participant ID	^{3}H	^{90}Sr	^{134}Cs	^{137}Cs
1*		NA	A	W
2*	NA	NA	NA	NA
3*	A	NA	NA	NA
4*	NA	A	A	A
5*		A		
6*			W	W
7*		A	A	NA
8*		A	NA	A
9*			NA	NA
10*			NA	NA
11			A	A
12			W	NA
13			W	A
14	A		A	A

* RCA RAS/7/021 participant

The performance evaluation sorted by radionuclide and the bias plots are presented in Appendix I (see Tables 6–9 and Figures 2–9). In the bias plots, the 'Accepted' results are represented by dark blue points. 'Warning' and 'Not accepted' results are represented by the yellow and red points, respectively. The error bars represent the standard uncertainties of the bias (with a coverage factor of $k = 1$). The dotted lines represent a relative bias of ± 25% or ± 20% (Maximum Accepted Bias for $^{3}H/^{90}Sr$ and $^{134}Cs/^{137}Cs$, respectively). The performance evaluation sorted by laboratory code is presented in Appendix II. All laboratories reported their values with standard uncertainties ($k = 1$). However, a spread in the submitted uncertainties was observed with relative uncertainties (at $k = 1$) ranging from 7.7% to 20% for ^{3}H, from 4.7% to 12% for ^{90}Sr, from 4.2% to 48% for ^{134}Cs and from 2.6% to 26% for ^{137}Cs. However, most reported relative uncertainties were in the range of 4% – 15% for both ^{134}Cs and ^{137}Cs.

For ^{3}H, all four participants performed a distillation of the seawater samples, followed by liquid scintillation counting (LSC). For ^{90}Sr, all participants used gas-flow proportional counting (GPC) as the analysis technique, except Participants 5* and 8* who used LSC. Chemical separation techniques used included precipitations of Sr-carbonate, fuming nitric acid precipitations, cation-exchange chromatography, Sr-extraction chromatography and liquid-liquid extraction of ^{90}Y with HDEHP. No significant difference between the performances of the chemical separation techniques is apparent. For ^{134}Cs and ^{137}Cs, a majority of the participants measured the seawater samples directly with gamma spectrometry, while a minority of laboratories either used a pre-concentration technique (e.g. adsorption on either ammonium molybdophosphate or copper hexacyanoferrates) to separate the caesium radionuclides from the seawater matrix followed by gamma spectrometry (Participants 1*, 2*, 4* and 9*) or they used a combination of the two techniques (Participant 14). No significant difference in the performance between the two techniques is apparent.

APPENDIX I. PERFORMANCE EVALUATION TABLES SORTED BY RADIONUCLIDE

TABLE 6. EVALUATION RESULTS FOR ^{3}H

Lab Code	Lab Value (Bq kg^{-1})	Lab uncert. (Bq kg^{-1})	IAEA Value (Bq kg^{-1})	IAEA uncert. (Bq kg^{-1})	Relative bias (%)	P (%)	Trueness limit (%)	Accuracy	Precision	Trueness	Final Score
1*	–	–	2.80	0.06	–	–	–	–	–	–	Not reported
2*	1.98	0.40	2.80	0.06	–29	20	37	Fail	Pass	Pass	Not accepted
3*	2.45	0.25	2.79	0.06	–12	10	24	Pass	Pass	Pass	Accepted
4*	3.47	0.49	2.77	0.06	25	14	46	Fail	Pass	Pass	Not accepted
5*	–	–	2.69	0.06	–	–	–	–	–	–	Not reported
6*	–	–	2.82	0.06	–	–	–	–	–	–	Not reported
7*	–	–	2.80	0.06	–	–	–	–	–	–	Not reported
8*	< 2.4	–	2.76	0.06	–	–	–	–	–	–	Not evaluated
9*	–	–	2.81	0.06	–	–	–	–	–	–	Not reported
10*	–	–	2.79	0.06	–	–	–	–	–	–	Not reported
11	–	–	2.79	0.06	–	–	–	–	–	–	Not reported
12	–	–	2.82	0.06	–	–	–	–	–	–	Not reported
13	–	–	2.81	0.06	–	–	–	–	–	–	Not reported
14	2.73	0.21	2.83	0.06	–3.4	8.0	20	Pass	Pass	Pass	Accepted

* RCA RAS/7/021 participant

TABLE 7. EVALUATION RESULTS FOR ^{90}Sr

Lab Code	Lab Value (Bq kg^{-1})	Lab uncert. (Bq kg^{-1})	IAEA Value (Bq kg^{-1})	IAEA uncert. (Bq kg^{-1})	Relative bias (%)	P (%)	Trueness limit (%)	Accuracy	Precision	Trueness	Final Score
1*	0.725	0.057	0.3485	0.0021	108	7.9	42	Fail	Pass	Fail	Not accepted
2*	0.107	0.011	0.3483	0.0021	–69	11	8.5	Fail	Pass	Fail	Not accepted
3*	0.435	0.028	0.3470	0.0021	25	6.5	21	Fail	Pass	Fail	Not accepted
4*	0.361	0.017	0.3437	0.0021	5.0	4.7	13	Pass	Pass	Pass	Accepted
5*	0.354	0.033	0.3326	0.0020	6.4	9.3	26	Pass	Pass	Pass	Accepted
6*	–	–	0.3509	0.0021	–	–	–	–	–	–	Not reported
7*	0.349	0.042	0.3481	0.0021	0.3	12	31	Pass	Pass	Pass	Accepted
8*	0.332	0.024	0.3421	0.0021	–3.0	7.3	18	Pass	Pass	Pass	Accepted
9*	–	–	0.3492	0.0021	–	–	–	–	–	–	Not reported
10*	–	–	0.3464	0.0021	–	–	–	–	–	–	Not reported
11	–	–	0.3463	0.0021	–	–	–	–	–	–	Not reported
12	–	–	0.3500	0.0021	–	–	–	–	–	–	Not reported
13	–	–	0.3495	0.0021	–	–	–	–	–	–	Not reported
14	–	–	0.3515	0.0021	–	–	–	–	–	–	Not reported

* RCA RAS/7/021 participant

TABLE 8. EVALUATION RESULTS FOR ^{134}Cs

Lab Code	Lab Value (Bq kg^{-1})	Lab uncert. (Bq kg^{-1})	IAEA Value (Bq kg^{-1})	IAEA uncert. (Bq kg^{-1})	Relative bias (%)	P (%)	Trueness limit (%)	Accuracy	Precision	Trueness	Final Score
1*	0.122	0.007	0.1165	0.0005	4.4	5.5	15	Pass	Pass	Pass	Accepted
2*	0.0158	0.0015	0.1164	0.0005	–86	9.6	3.5	Fail	Pass	Fail	Not accepted
3*	0.18	0.01	0.1160	0.0005	55	5.6	22	Fail	Pass	Fail	Not accepted
4*	0.108	0.013	0.1149	0.0005	–6.0	12	29	Pass	Pass	Pass	Accepted
5*	–	–	0.1112	0.0004	–	–	–	–	–	–	Not reported
6*	0.120	0.057	0.1173	0.0005	2.3	48	125	Pass	Fail	Pass	Warning
7*	0.125	0.016	0.1164	0.0005	7.4	13	35	Pass	Pass	Pass	Accepted
8*	0.082	0.015	0.1144	0.0005	–28	18	34	Fail	Pass	Pass	Not accepted
9*	0.20	0.03	0.1168	0.0005	71	15	66	Fail	Pass	Fail	Not accepted
10*	0.067	0.010	0.1158	0.0005	–42	15	22	Fail	Pass	Fail	Not accepted
11	0.120	0.005	0.1158	0.0005	3.6	4.2	11	Pass	Pass	Pass	Accepted
12	0.122	0.033	0.1170	0.0005	4.2	27	73	Pass	Fail	Pass	Warning
13	0.117	0.026	0.1169	0.0005	0.1	22	57	Pass	Fail	Pass	Warning
14	0.109	0.011	0.1175	0.0005	–7.7	10	24	Pass	Pass	Pass	Accepted

* RCA RAS/7/021 participant

TABLE 9. EVALUATION RESULTS FOR ^{137}Cs

Lab Code	Lab Value (Bq kg^{-1})	Lab uncert. (Bq kg^{-1})	IAEA Value (Bq kg^{-1})	IAEA uncert. (Bq kg^{-1})	Relative bias (%)	P (%)	Trueness limit (%)	Accuracy	Precision	Trueness	Final Score
1*	0.256	0.010	0.3092	0.0019	–17	3.9	8.3	Pass	Pass	Fail	Warning
2*	0.0664	0.0022	0.3090	0.0019	–79	3.4	2.4	Fail	Pass	Fail	Not accepted
3*	0.37	0.02	0.3079	0.0019	20	5.4	17	Fail	Pass	Fail	Not accepted
4*	0.313	0.021	0.3049	0.0019	2.6	6.7	18	Pass	Pass	Pass	Accepted
5*	–	–	0.2951	0.0019	–	–	–	–	–	–	Not reported
6*	0.265	0.057	0.3113	0.0019	–15	22	47	Pass	Fail	Pass	Warning
7*	0.376	0.035	0.3088	0.0019	22	9.3	29	Fail	Pass	Pass	Not accepted
8*	0.258	0.021	0.3035	0.0019	–15	8.2	18	Pass	Pass	Pass	Accepted
9*	0.39	0.10	0.3098	0.0019	26	26	83	Fail	Fail	Pass	Not accepted
10*	0.41	0.04	0.3074	0.0019	32	10	34	Fail	Pass	Pass	Not accepted
11	0.307	0.008	0.3073	0.0019	–0.1	2.7	6.9	Pass	Pass	Pass	Accepted
12	0.230	0.033	0.3105	0.0019	–26	14	27	Fail	Pass	Pass	Not accepted
13	0.338	0.049	0.3101	0.0019	8.8	15	41	Pass	Pass	Pass	Accepted
14	0.311	0.031	0.3118	0.0019	–0.2	10	26	Pass	Pass	Pass	Accepted

* RCA RAS/7/021 participant

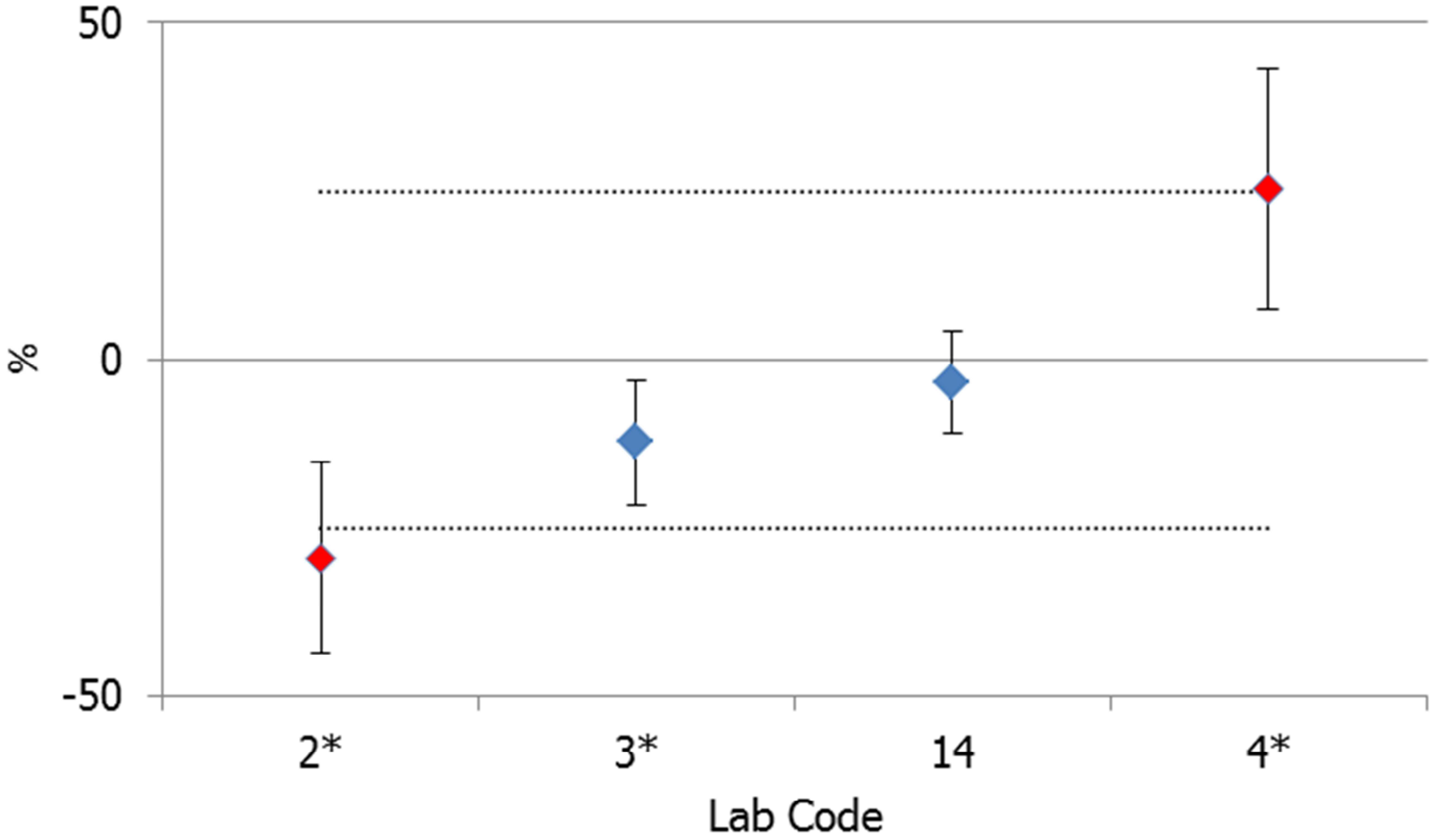

FIG. 2. H-3 bias all participants.

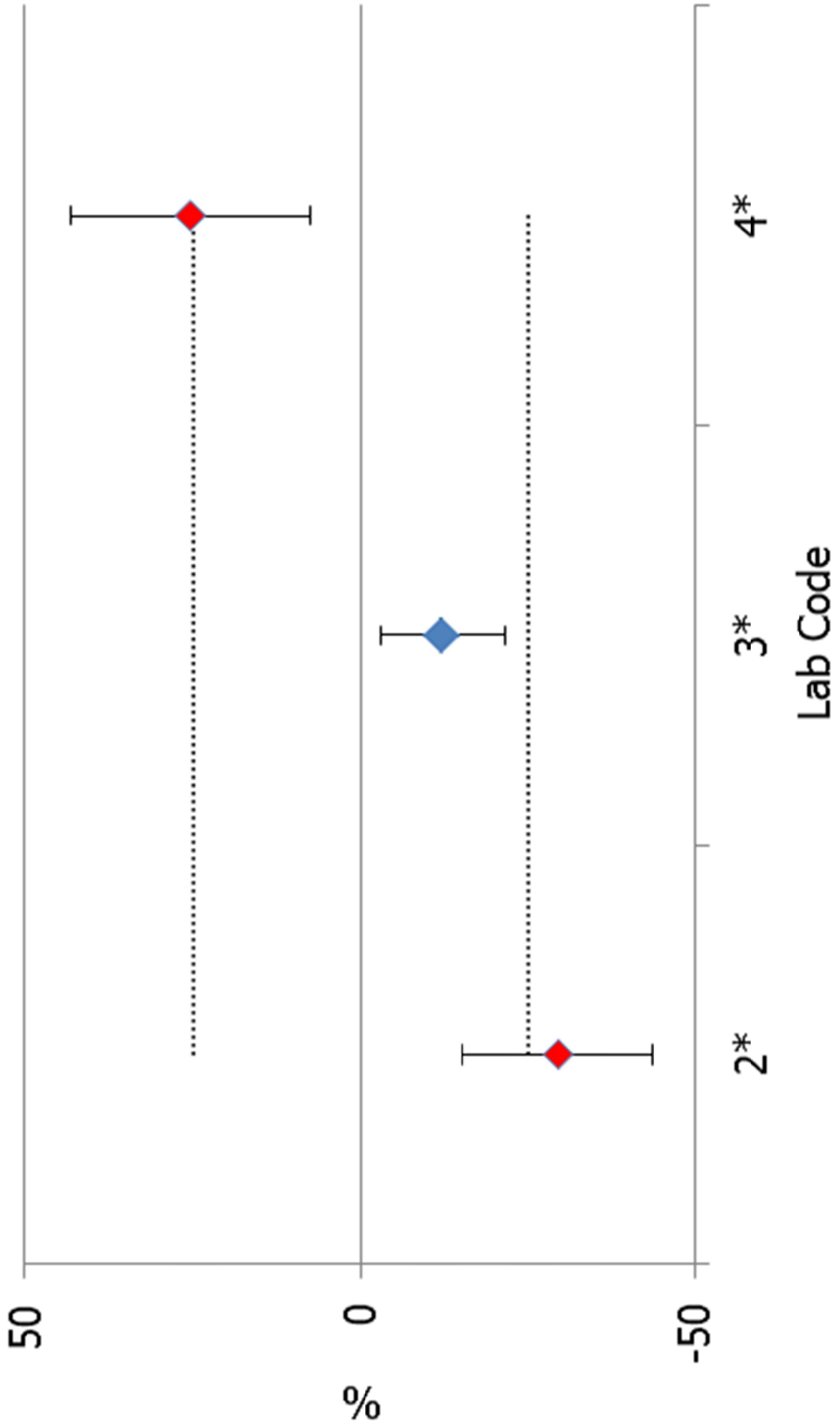

FIG. 3. H-3 bias RCA RAS/7/021 participants.

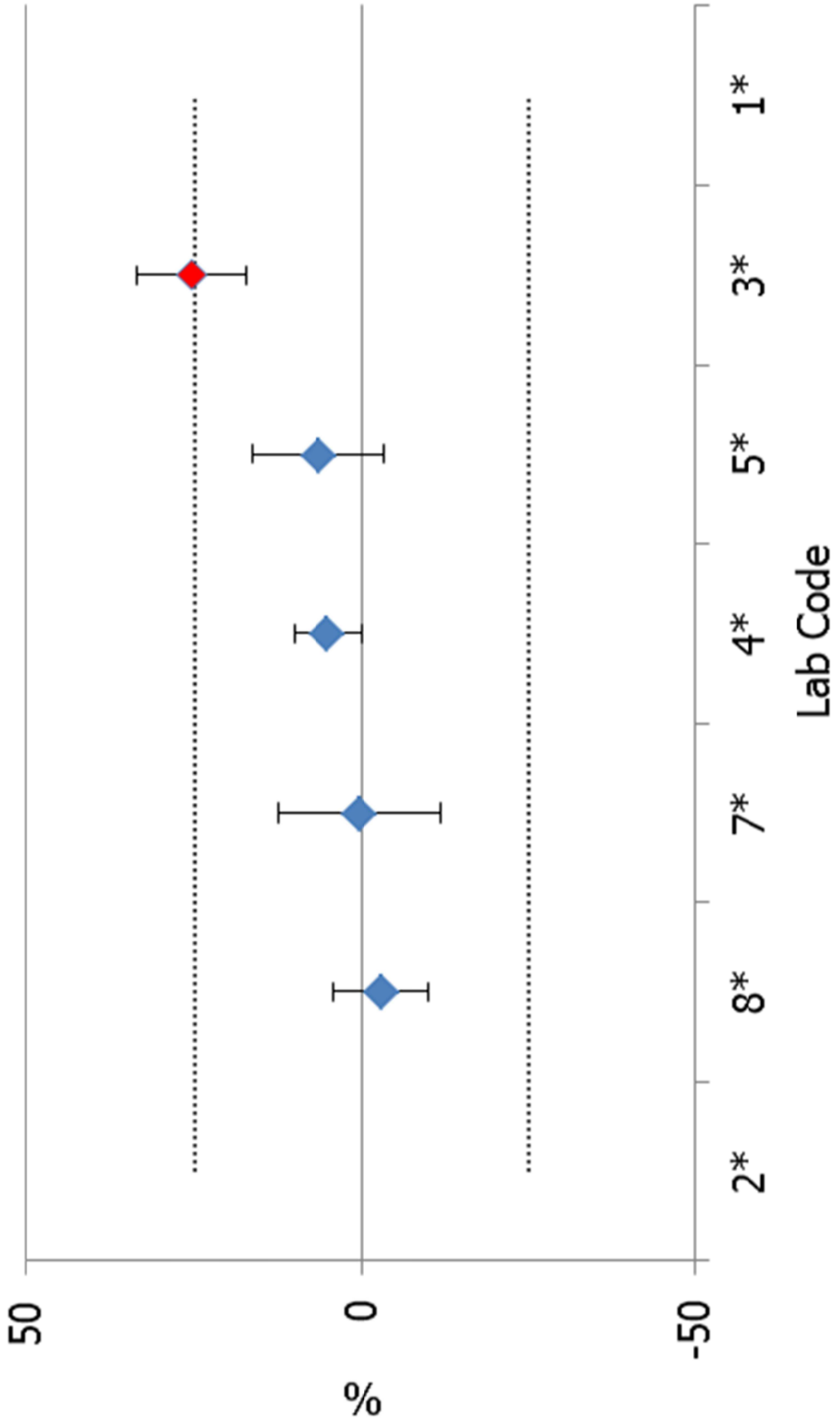

FIG. 4. Sr-90 bias all participants.

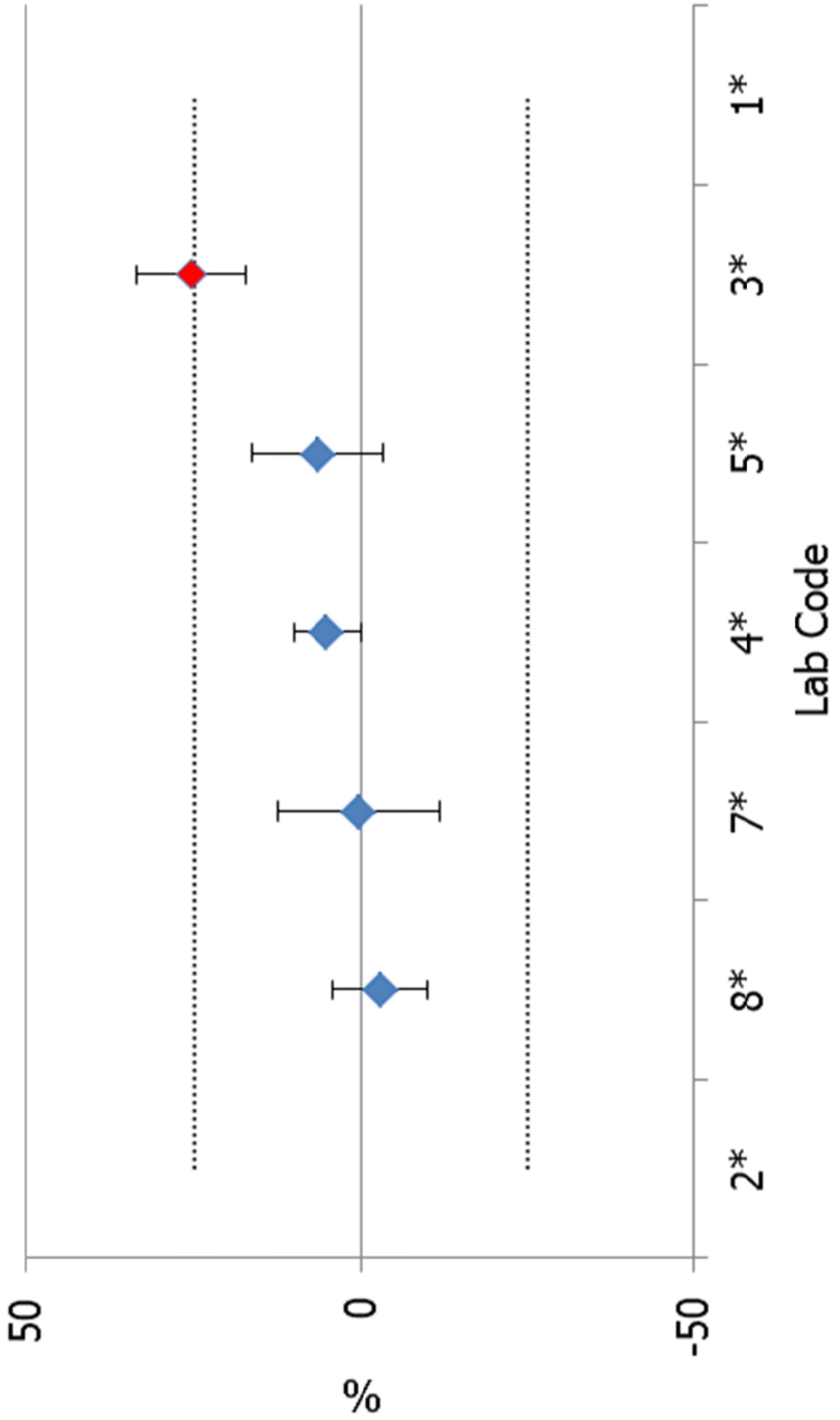

FIG. 5. Sr-90 bias RCA RAS/7/021 participants.

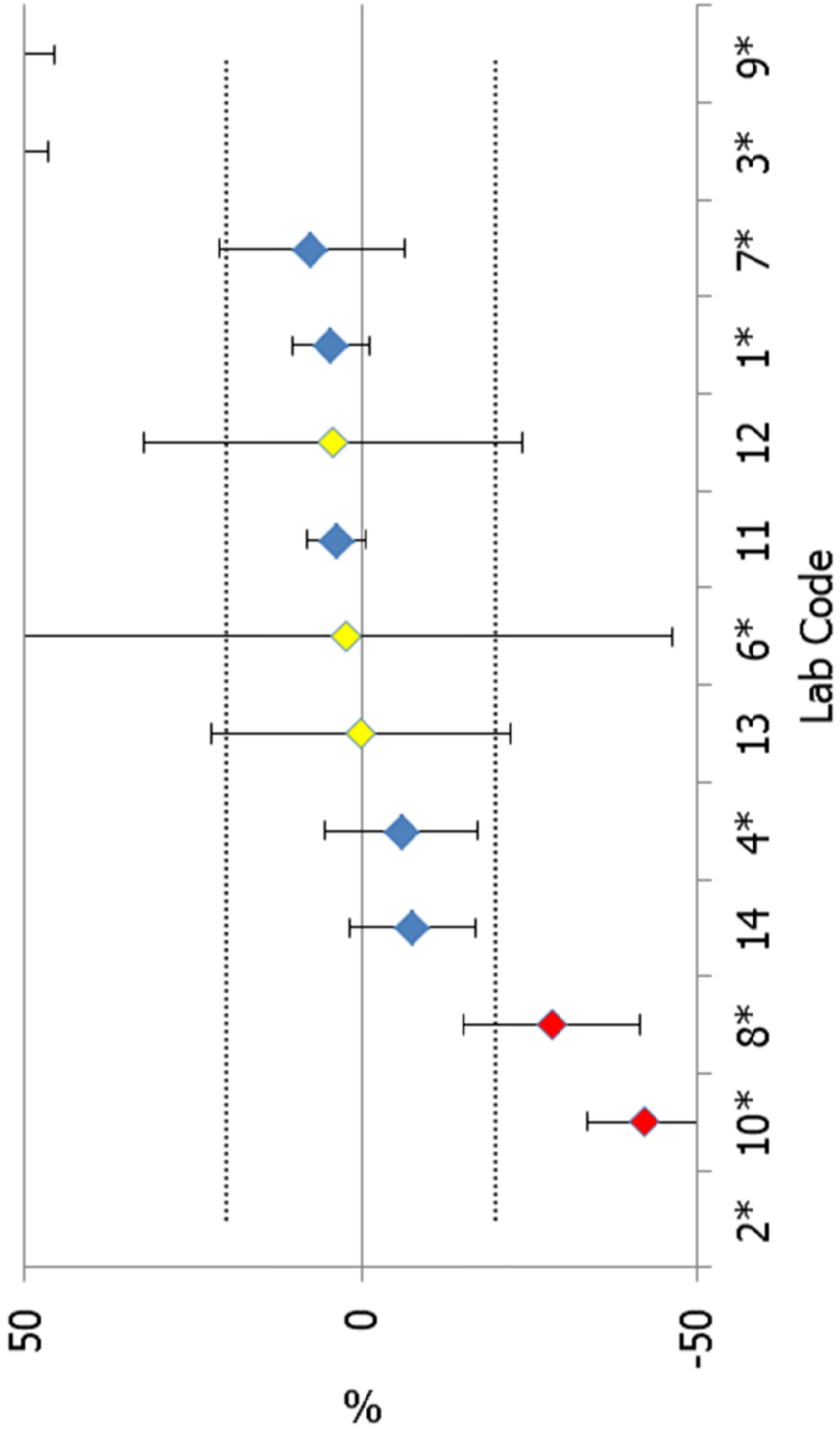

FIG. 6. Cs-134 bias all participants.

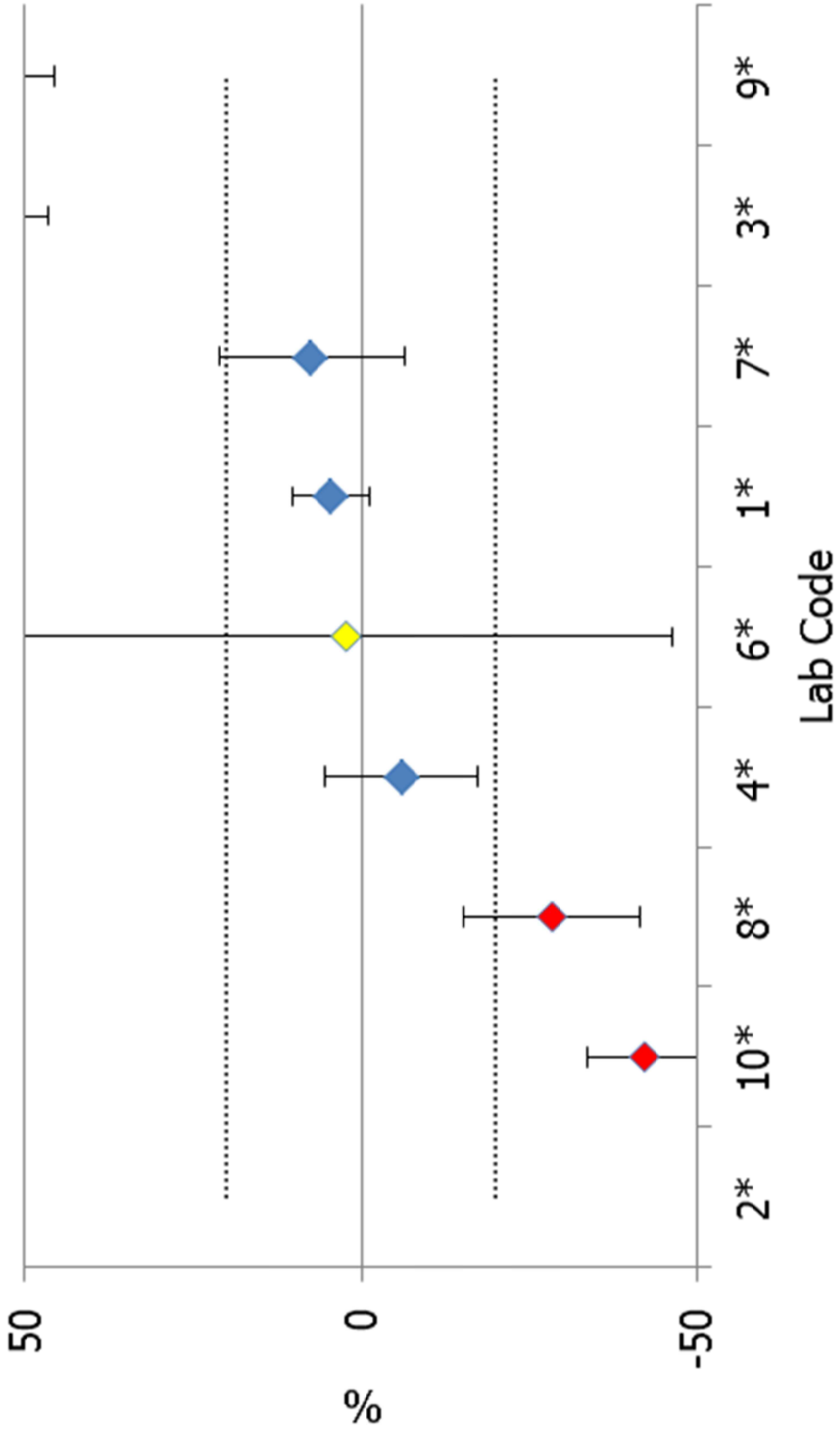

FIG. 7. Cs-134 bias RCA RAS/7/021 participants.

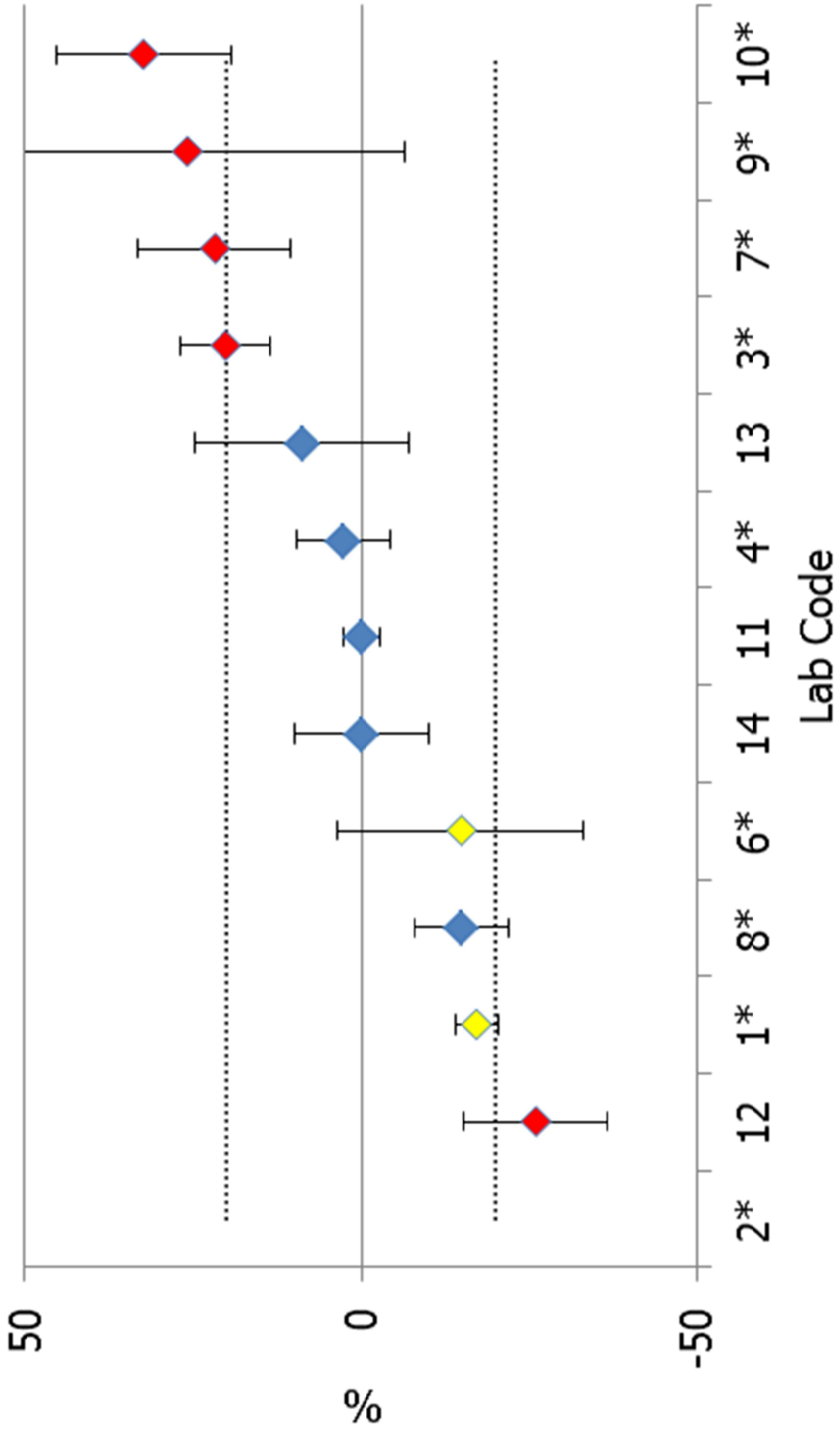

FIG. 8. Cs-137 bias all participants.

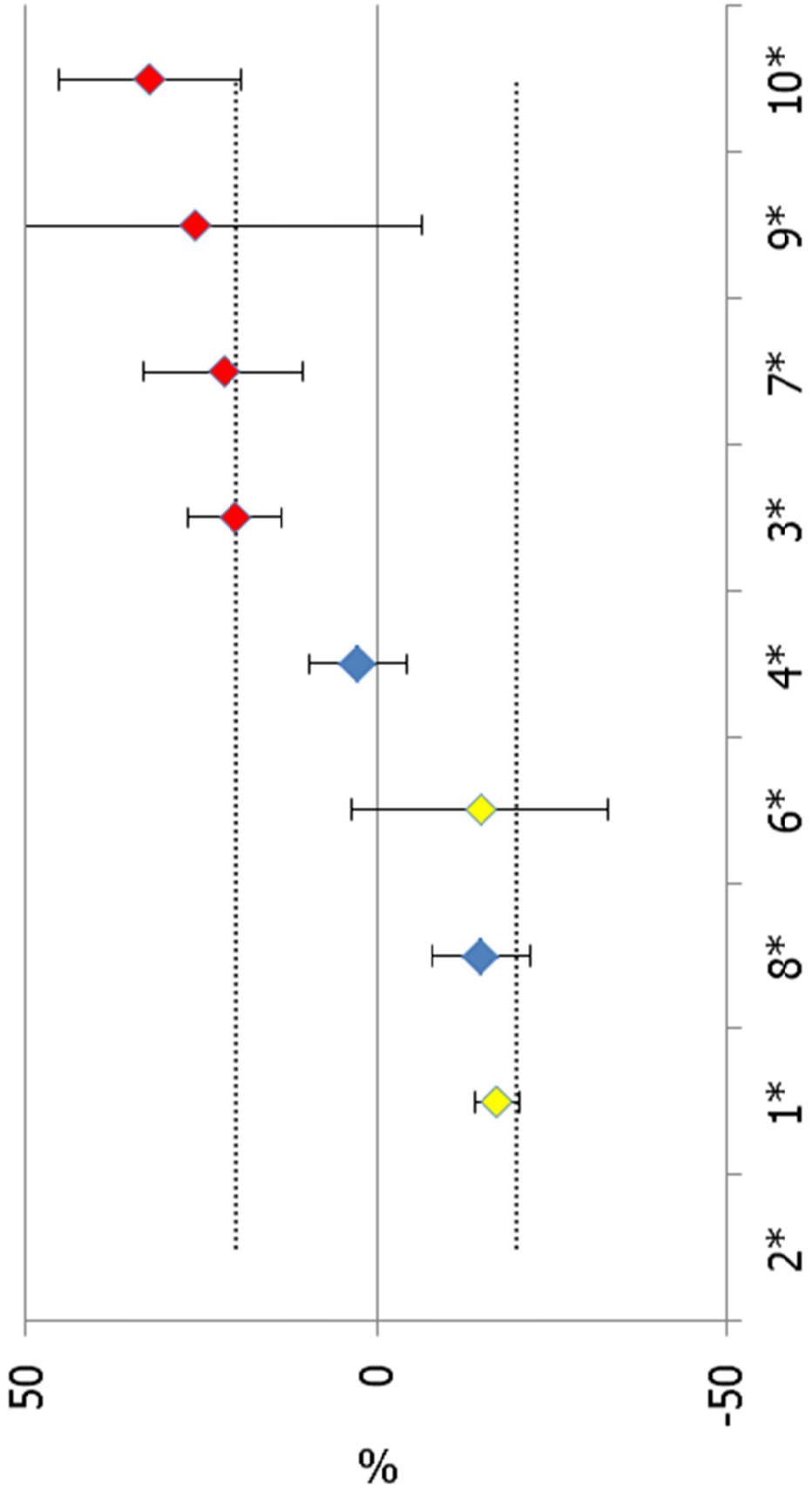

FIGURE 9. Cs-137 bias RCA RAS/7/021 participants.

APPENDIX II. PERFORMANCE EVALUATION TABLES SORTED BY LABORATORY CODE

LABORATORY CODE 1*.

Radio-nuclide	Lab Value (Bq kg^{-1})	Lab uncert. (Bq kg^{-1})	IAEA Value (Bq kg^{-1})	IAEA uncert. (Bq kg^{-1})	Relative bias (%)	P (%)	Trueness limit (%)	Accuracy	Precision	Trueness	Final Score
^{3}H	–	–	2.80	0.06	–	–	–	–	–	–	Not reported
^{90}Sr	0.725	0.057	0.3485	0.0021	108	7.9	42	Fail	Pass	Fail	Not accepted
^{134}Cs	0.122	0.007	0.1165	0.0005	4.4	5.5	15	Pass	Pass	Pass	Accepted
^{137}Cs	0.256	0.010	0.3092	0.0019	–17	3.9	8.3	Pass	Pass	Fail	Warning

* RCA RAS/7/021 participant

LABORATORY CODE 2*.

Radio-nuclide	Lab Value (Bq kg^{-1})	Lab uncert. (Bq kg^{-1})	IAEA Value (Bq kg^{-1})	IAEA uncert. (Bq kg^{-1})	Relative bias (%)	P (%)	Trueness limit (%)	Accuracy	Precision	Trueness	Final Score
^{3}H	1.98	0.40	2.80	0.06	–29	20	37	Fail	Pass	Pass	Not accepted
^{90}Sr	0.107	0.011	0.3483	0.0021	–69	11	8.5	Fail	Pass	Fail	Not accepted
^{134}Cs	0.0158	0.0015	0.1164	0.0005	–86	9.6	3.5	Fail	Pass	Fail	Not accepted
^{137}Cs	0.0664	0.0022	0.3090	0.0019	–79	3.4	2.4	Fail	Pass	Fail	Not accepted

* RCA RAS/7/021 participant

LABORATORY CODE 3*.

Radio-nuclide	Lab Value (Bq kg^{-1})	Lab uncert. (Bq kg^{-1})	IAEA Value (Bq kg^{-1})	IAEA uncert. (Bq kg^{-1})	Relative bias (%)	P (%)	Trueness limit (%)	Accuracy	Precision	Trueness	Final Score
^{3}H	2.45	0.25	2.79	0.06	–12	10	24	Pass	Pass	Pass	Accepted
^{90}Sr	0.435	0.028	0.3470	0.0021	25	6.5	21	Fail	Pass	Fail	Not accepted
^{134}Cs	0.18	0.01	0.1160	0.0005	55	5.6	22	Fail	Pass	Fail	Not accepted
^{137}Cs	0.37	0.02	0.3079	0.0019	20	5.4	17	Fail	Pass	Fail	Not accepted

* RCA RAS/7/021 participant

LABORATORY CODE 4*.

Radio-nuclide	Lab Value (Bq kg^{-1})	Lab uncert. (Bq kg^{-1})	IAEA Value (Bq kg^{-1})	IAEA uncert. (Bq kg^{-1})	Relative bias (%)	P (%)	Trueness limit (%)	Accuracy	Precision	Trueness	Final Score
^{3}H	3.47	0.49	2.77	0.06	25	14	46	Fail	Pass	Pass	Not accepted
^{90}Sr	0.361	0.017	0.3437	0.0021	5.0	4.7	13	Pass	Pass	Pass	Accepted
^{134}Cs	0.108	0.013	0.1149	0.0005	–6.0	12	29	Pass	Pass	Pass	Accepted
^{137}Cs	0.313	0.021	0.3049	0.0019	2.6	6.7	18	Pass	Pass	Pass	Accepted

* RCA RAS/7/021 participant

LABORATORY CODE 5*.

Radio-nuclide	Lab Value (Bq kg^{-1})	Lab uncert. (Bq kg^{-1})	IAEA Value (Bq kg^{-1})	IAEA uncert. (Bq kg^{-1})	Relative bias (%)	P (%)	Trueness limit (%)	Accuracy	Precision	Trueness	Final Score
^{3}H	–	–	2.69	0.06	–	–	–	–	–	–	Not reported
^{90}Sr	0.354	0.033	0.3326	0.0020	6.4	9.3	26	Pass	Pass	Pass	Accepted
^{134}Cs	–	–	0.1112	0.0004	–	–	–	–	–	–	Not reported
^{137}Cs	–	–	0.2951	0.0019	–	–	–	–	–	–	Not reported

* RCA RAS/7/021 participant

LABORATORY CODE 6*.

Radio-nuclide	Lab Value (Bq kg^{-1})	Lab uncert. (Bq kg^{-1})	IAEA Value (Bq kg^{-1})	IAEA uncert. (Bq kg^{-1})	Relative bias (%)	P (%)	Trueness limit (%)	Accuracy	Precision	Trueness	Final Score
^{3}H	–	–	2.82	0.06	–	–	–	–	–	–	Not reported
^{90}Sr	–	–	0.3509	0.0021	–	–	–	–	–	–	Not reported
^{134}Cs	0.120	0.057	0.1173	0.0005	2.3	48	125	Pass	Fail	Pass	Warning
^{137}Cs	0.265	0.057	0.3113	0.0019	–15	22	47	Pass	Fail	Pass	Warning

* RCA RAS/7/021 participant

LABORATORY CODE 7*.

Radio-nuclide	Lab Value (Bq kg^{-1})	Lab uncert. (Bq kg^{-1})	IAEA Value (Bq kg^{-1})	IAEA uncert. (Bq kg^{-1})	Relative bias (%)	P (%)	Trueness limit (%)	Accuracy	Precision	Trueness	Final Score
^{3}H	–	–	2.80	0.06	–	–	–	–	–	–	Not reported
^{90}Sr	0.349	0.042	0.3481	0.0021	0.3	12	31	Pass	Pass	Pass	Accepted
^{134}Cs	0.125	0.016	0.1164	0.0005	7.4	13	35	Pass	Pass	Pass	Accepted
^{137}Cs	0.376	0.035	0.3088	0.0019	22	9.3	29	Fail	Pass	Pass	Not accepted

* RCA RAS/7/021 participant

LABORATORY CODE 8*.

Radio-nuclide	Lab Value (Bq kg^{-1})	Lab uncert. (Bq kg^{-1})	IAEA Value (Bq kg^{-1})	IAEA uncert. (Bq kg^{-1})	Relative bias (%)	P (%)	Trueness limit (%)	Accuracy	Precision	Trueness	Final Score
^{3}H	< 2.4	–	2.76	0.06	–	–	–	–	–	–	Not evaluated
^{90}Sr	0.332	0.024	0.3421	0.0021	–3.0	7.3	18	Pass	Pass	Pass	Accepted
^{134}Cs	0.082	0.015	0.1144	0.0005	–28	18	34	Fail	Pass	Pass	Not accepted
^{137}Cs	0.258	0.021	0.3035	0.0019	–15	8.2	18	Pass	Pass	Pass	Accepted

* RCA RAS/7/021 participant

LABORATORY CODE 9*.

Radio-nuclide	Lab Value (Bq kg^{-1})	Lab uncert. (Bq kg^{-1})	IAEA Value (Bq kg^{-1})	IAEA uncert. (Bq kg^{-1})	Relative bias (%)	P (%)	Trueness limit (%)	Accuracy	Precision	Trueness	Final Score
^{3}H	–	–	2.81	0.06	–	–	–	–	–	–	Not reported
^{90}Sr	–	–	0.3492	0.0021	–	–	–	–	–	–	Not reported
^{134}Cs	0.20	0.03	0.1168	0.0005	71	15	66	Fail	Pass	Fail	Not accepted
^{137}Cs	0.39	0.10	0.3098	0.0019	26	26	83	Fail	Fail	Pass	Not accepted

* RCA RAS/7/021 participant

LABORATORY CODE 10*.

Radio-nuclide	Lab Value (Bq kg^{-1})	Lab uncert. (Bq kg^{-1})	IAEA Value (Bq kg^{-1})	IAEA uncert. (Bq kg^{-1})	Relative bias (%)	P (%)	Trueness limit (%)	Accuracy	Precision	Trueness	Final Score
^{3}H	–	–	2.79	0.06	–	–	–	–	–	–	Not reported
^{90}Sr	–	–	0.3464	0.0021	–	–	–	–	–	–	Not reported
^{134}Cs	0.067	0.010	0.1158	0.0005	–42	15	22	Fail	Pass	Fail	Not accepted
^{137}Cs	0.41	0.04	0.3074	0.0019	32	10	34	Fail	Pass	Pass	Not accepted

* RCA RAS/7/021 participant

LABORATORY CODE 11.

Radio-nuclide	Lab Value (Bq kg^{-1})	Lab uncert. (Bq kg^{-1})	IAEA Value (Bq kg^{-1})	IAEA uncert. (Bq kg^{-1})	Relative bias (%)	P (%)	Trueness limit (%)	Accuracy	Precision	Trueness	Final Score
^{3}H	–	–	2.79	0.06	–	–	–	–	–	–	Not reported
^{90}Sr	–	–	0.3463	0.0021	–	–	–	–	–	–	Not reported
^{134}Cs	0.120	0.005	0.1158	0.0005	3.6	4.2	11	Pass	Pass	Pass	Accepted
^{137}Cs	0.307	0.008	0.3073	0.0019	–0.1	2.7	6.9	Pass	Pass	Pass	Accepted

LABORATORY CODE 12.

Radio-nuclide	Lab Value (Bq kg^{-1})	Lab uncert. (Bq kg^{-1})	IAEA Value (Bq kg^{-1})	IAEA uncert. (Bq kg^{-1})	Relative bias (%)	P (%)	Trueness limit (%)	Accuracy	Precision	Trueness	Final Score
^{3}H	–	–	2.82	0.06	–	–	–	–	–	–	Not reported
^{90}Sr	–	–	0.3500	0.0021	–	–	–	–	–	–	Not reported
^{134}Cs	0.122	0.033	0.1170	0.0005	4.2	27	73	Pass	Fail	Pass	Warning
^{137}Cs	0.230	0.033	0.3105	0.0019	–26	14	27	Fail	Pass	Pass	Not accepted

LABORATORY CODE 13.

Radio-nuclide	Lab Value (Bq kg^{-1})	Lab uncert. (Bq kg^{-1})	IAEA Value (Bq kg^{-1})	IAEA uncert. (Bq kg^{-1})	Relative bias (%)	P (%)	Trueness limit (%)	Accuracy	Precision	Trueness	Final Score
^{3}H	–	–	2.81	0.06	–	–	–	–	–	–	Not reported
^{90}Sr	–	–	0.3495	0.0021	–	–	–	–	–	–	Not reported
^{134}Cs	0.117	0.026	0.1169	0.0005	0.1	22	57	Pass	Fail	Pass	Warning
^{137}Cs	0.338	0.049	0.3101	0.0019	8.8	15	41	Pass	Pass	Pass	Accepted

LABORATORY CODE 14.

Radio-nuclide	Lab Value (Bq kg^{-1})	Lab uncert. (Bq kg^{-1})	IAEA Value (Bq kg^{-1})	IAEA uncert. (Bq kg^{-1})	Relative bias (%)	P (%)	Trueness limit (%)	Accuracy	Precision	Trueness	Final Score
^{3}H	2.73	0.21	2.83	0.06	–3.4	8.0	20	Pass	Pass	Pass	Accepted
^{90}Sr	–	–	0.3515	0.0021	–	–	–	–	–	–	Not reported
^{134}Cs	0.109	0.011	0.1175	0.0005	–7.7	10	24	Pass	Pass	Pass	Accepted
^{137}Cs	0.311	0.031	0.3118	0.0019	–0.2	10	26	Pass	Pass	Pass	Accepted

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