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IAEA Analytical Quality in Nuclear Applications Series No. 42

# IAEA-RML-2013-01 Proficiency Test for Determination of Radionuclides in Sea Water

IAEA
International Atomic Energy Agency

# IAEA-RML-2013-01 PROFICIENCY TEST FOR DETERMINATION OF RADIONUCLIDES IN SEA WATER

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# IAEA-RML-2013-01 PROFICIENCY TEST FOR DETERMINATION OF RADIONUCLIDES IN SEA WATER

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2015

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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 second 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 strontium-90 and caesium isotopes in relation to the accident at the Fukushima Daiichi nuclear power plant, 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, and to G. Bilancia for providing technical assistance.

The IAEA officers responsible for this publication were A.V. Harms, M.K. Pham and H. Nies of the IAEA Environment Laboratories.

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# 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 second PT organised in the frame of the IAEA Technical Cooperation project RAS/7/021 entitled 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. This second exercise was initiated to support Member States in seawater analyses of 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 31 laboratories from 24 countries participated in the exercise. In addition to the 11 laboratories taking part in the IAEA Technical Cooperation project RAS/7/021 (from Australia, Bangladesh, China, Indonesia, Malaysia, New Zealand, Pakistan, Philippines, Sri Lanka, Thailand and Viet Nam), 20 other laboratories from Thailand, USA, Viet Nam and OSPAR and HELCOM contracting parties also took part in the exercise. The 11 laboratories associated with the RAS/7/021 project are indicated with the symbol * following their participation code (i.e. Participants 1*, 4*, 5*, 10*, 11*, 13*, 16*, 19*, 20*, 22* and 26*). The full list of participants is given on pages 33–37.

## 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 $^{90}$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 $^{90}$Sr, $^{134}$Cs and $^{137}$Cs massic activities for the samples were approximately 0.17, 0.33 and 0.42 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 $^{90}$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 $^{90}$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 July 2013. At this date, the ranges for the traceable massic activities in the proficiency test exercise samples sent to the participants were 0.1721–0.1788 Bq $kg^{-1}$ $^{90}Sr$, 0.3303–0.3433 Bq $kg^{-1}$ $^{134}Cs$ and 0.416–0.432 Bq $kg^{-1}$ $^{137}Cs$, respectively (see Table 1).

TABLE 1. IAEA ASSIGNED VALUES

| Participant | $^{90}Sr$ massic activity (Bq $kg^{-1}$) | $^{134}Cs$ massic activity (Bq $kg^{-1}$) | $^{137}Cs$ massic activity (Bq $kg^{-1}$) |
|---|---|---|---|
| 1* | 0.1788 ± 0.0011 | 0.3433 ± 0.0014 | 0.432 ± 0.003 |
| 2 | 0.1740 ± 0.0011 | 0.3339 ± 0.0013 | 0.421 ± 0.003 |
| 3 | 0.1768 ± 0.0011 | 0.3393 ± 0.0014 | 0.428 ± 0.003 |
| 4* | 0.1743 ± 0.0011 | 0.3344 ± 0.0013 | 0.421 ± 0.003 |
| 5* | 0.1759 ± 0.0011 | 0.3375 ± 0.0014 | 0.425 ± 0.003 |
| 6 | 0.1724 ± 0.0010 | 0.3308 ± 0.0013 | 0.417 ± 0.003 |
| 7 | 0.1766 ± 0.0011 | 0.3389 ± 0.0014 | 0.427 ± 0.003 |
| 8 | 0.1767 ± 0.0011 | 0.3391 ± 0.0014 | 0.427 ± 0.003 |
| 9 | 0.1758 ± 0.0011 | 0.3373 ± 0.0014 | 0.425 ± 0.003 |
| 10* | 0.1753 ± 0.0011 | 0.3365 ± 0.0014 | 0.424 ± 0.003 |
| 11* | 0.1770 ± 0.0011 | 0.3397 ± 0.0014 | 0.428 ± 0.003 |
| 12 | 0.1782 ± 0.0011 | 0.3420 ± 0.0014 | 0.431 ± 0.003 |
| 13* | 0.1767 ± 0.0011 | 0.3391 ± 0.0014 | 0.427 ± 0.003 |
| 14 | 0.1752 ± 0.0011 | 0.3362 ± 0.0014 | 0.424 ± 0.003 |
| 15 | 0.1780 ± 0.0011 | 0.3416 ± 0.0014 | 0.430 ± 0.003 |
| 16* | 0.1737 ± 0.0011 | 0.3333 ± 0.0013 | 0.420 ± 0.003 |
| 17 | 0.1721 ± 0.0010 | 0.3303 ± 0.0013 | 0.416 ± 0.003 |
| 18 | 0.1725 ± 0.0011 | 0.3311 ± 0.0013 | 0.417 ± 0.003 |
| 19* | 0.1729 ± 0.0011 | 0.3318 ± 0.0013 | 0.418 ± 0.003 |
| 20* | 0.1745 ± 0.0011 | 0.3348 ± 0.0013 | 0.422 ± 0.003 |
| 21 | 0.1761 ± 0.0011 | 0.3379 ± 0.0014 | 0.426 ± 0.003 |
| 22* | 0.1757 ± 0.0011 | 0.3372 ± 0.0014 | 0.425 ± 0.003 |
| 23 | 0.1786 ± 0.0011 | 0.3427 ± 0.0014 | 0.432 ± 0.003 |
| 24 | 0.1748 ± 0.0011 | 0.3355 ± 0.0013 | 0.423 ± 0.003 |
| 25 | 0.1788 ± 0.0011 | 0.3431 ± 0.0014 | 0.432 ± 0.003 |
| 26* | 0.1733 ± 0.0011 | 0.3326 ± 0.0013 | 0.419 ± 0.003 |
| 27 | 0.1744 ± 0.0011 | 0.3346 ± 0.0013 | 0.422 ± 0.003 |
| 28 | 0.1737 ± 0.0011 | 0.3334 ± 0.0013 | 0.420 ± 0.003 |
| 29 | 0.1754 ± 0.0011 | 0.3366 ± 0.0014 | 0.424 ± 0.003 |
| 30 | 0.1770 ± 0.0011 | 0.3397 ± 0.0014 | 0.428 ± 0.003 |
| 31 | 0.1776 ± 0.0011 | 0.3408 ± 0.0014 | 0.429 ± 0.003 |
| 32 | 0.1761 ± 0.0011 | 0.3379 ± 0.0014 | 0.426 ± 0.003 |

## 3. PERFORMANCE CRITERIA

The methodology adopted for this exercise was slightly updated from the existing IAEA methodology. The scoring system takes into account the accuracy, precision and trueness of the reported data and includes in the evaluation both the combined standard uncertainty of the target value and the combined standard uncertainty reported by the participating laboratories. The IAEA target values, which will be used for 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 will assigned the status "Warning" or "Not accepted".

### 3.1. ACCURACY

The first step in producing a score for a result $Value_{Analyst}$ is the estimation of the bias. The relative bias between the Analyst's value and the IAEA target value is 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 are scored as "Pass" for accuracy when:

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

The MARB values used in this evaluation were 15% for both $^{134}$Cs and $^{137}$Cs and 25% for $^{90}$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 are scored as "Pass" for precision when:

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

The Limit of Accepted Precision (LAP) values used in this evaluation were 15% for both $^{134}$Cs and $^{137}$Cs and 25% for $^{90}$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 is close enough to the assigned property value, but its associated uncertainty is 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 15%.

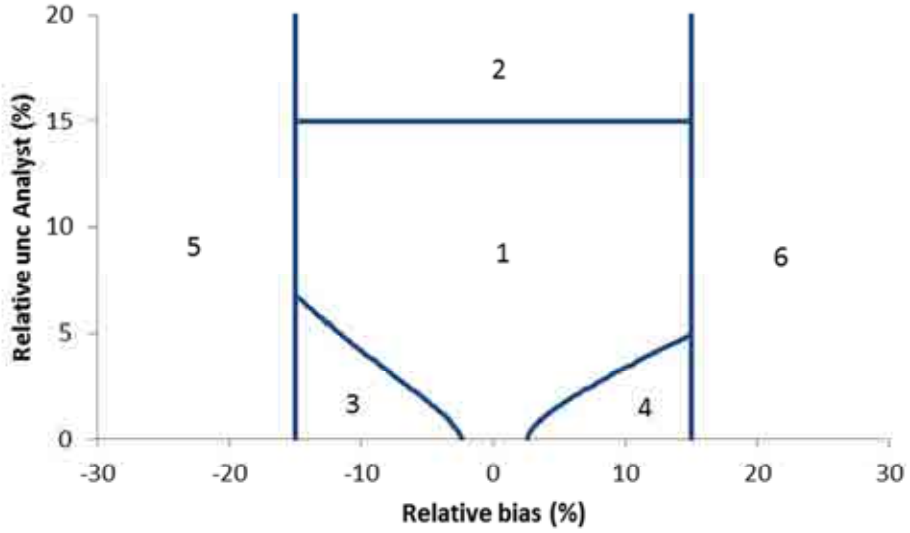


*FIG. 1. Visualisation of performance evaluation criteria.*

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 $\nu_{eff}$ were determined with the Welch-Satterthwaite equation. The effective degrees of freedom $v_{eff}$ 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

Measurement results were reported by 32 laboratories from 24 countries for $^{90}$Sr, $^{134}$Cs and $^{137}$Cs. The overall evaluation of these results showed that 69% of all reported measurement results fulfilled the PT criteria of acceptability, while 20% of the individual measurement results were not accepted with the remaining 11% having the warning status. The performance evaluation for $^{90}$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: 52% 'Accepted', 32% 'Not accepted' and 16% 'Warning'.

TABLE 3. SUMMARY EVALUATION OF THE RADIONUCLIDES REPORTED

| Radionuclide | Number of submitted results | Accepted | Warning | Not accepted |
|---|---|---|---|---|
| $^{90}$Sr | 13 (5) | 8 (1) | 1 (0) | 4 (4) |
| $^{134}$Cs | 31 (10) | 21 (6) | 3 (2) | 7 (2) |
| $^{137}$Cs | 30 (10) | 22 (6) | 4 (2) | 4 (2) |

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

For $^{134}$Cs there was a significant negative bias of the combined participants' results (–3.8%), while there was no significant bias for both $^{90}$Sr (–0.5%) and $^{137}$Cs (–2.0%) (see Table 4). For $^{90}$Sr and $^{137}$Cs about half of the participants' results showed a negative bias (62% and 46% of the results, respectively), while for $^{134}$Cs the majority of participants' results (81% of the results) showed a negative bias. Coincidence summing is a problem for $^{134}$Cs as it leads to signal loss and hence underestimation of the activity levels for this radionuclide. It is clear from the results that some participants did not make a sufficient correction for coincidence summing.

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

| Nuclide | Combined participants' result (Bq kg$^{-1}$) | IAEA value (Bq kg$^{-1}$) | Size of the LCS$^{\$}$ (%) | t-value | Critical t-value | Bias (%) |
|---|---|---|---|---|---|---|
| $^{90}$Sr | 0.174 ± 0.006 | 0.175 ± 0.004 | 9 (69%) | –0.24 | 2.16 | –0.5 |
| $^{134}$Cs | 0.321 ± 0.005 | 0.337 ± 0.007 | 26 (84%) | –3.78 | 2.03 | –4.9 |
| $^{137}$Cs | 0.416 ± 0.006 | 0.425 ± 0.009 | 25 (83%) | –1.51 | 2.02 | –2.0 |

$^{\$}$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. Six laboratories (Participants 2, 6, 8, 11*, 17 and 30) scored 'Accepted' ratings for all three radionuclides. Eleven laboratories (Participants 1*, 7, 13*, 14, 15, 16*, 18, 21, 27, 28 and 29) scored two 'Accepted' ratings (when no $^{90}$Sr results were submitted). A full overview of all ratings is given in Table 6.

TABLE 5. SUMMARY EVALUATION

| Lab code | $^{90}Sr$ | $^{134}Cs$ | $^{137}Cs$ |
|---|---|---|---|
| 1* | | A | A |
| 2 | A | A | A |
| 3 | W | W | W |
| 4* | NA | W | NA |
| 5* | NA | NA | A |
| 6 | A | A | A |
| 7 | | A | A |
| 8 | A | A | A |
| 9 | A | A | W |
| 10* | NA | A | A |
| 11* | A | A | A |
| 12 | | NA | NA |
| 13* | | A | A |
| 14 | | A | A |
| 15 | | A | A |
| 16* | | A | A |
| 17 | A | A | A |
| 18 | | A | A |
| 19* | NA | NA | NA |
| 20* | | W | W |
| 21 | | A | A |
| 22* | | A | W |
| 23 | | NA | A |
| 24 | | NA | |
| 25 | | NA | A |
| 26* | | | |
| 27 | | A | A |
| 28 | | A | A |
| 29 | | A | A |
| 30 | A | A | A |
| 31 | A | A | NA |
| 32 | | NA | A |

TABLE 6. OVERVIEW OF PERFORMANCE

| Rating | Number of participants | Lab code |
|---|---|---|
| 3 A | 6 | 2, 6, 8, 11*, 17 and 30 |
| 2 A | 11 | 1*, 7, 13*, 14, 15, 16*, 18, 21, 27, 28 and 29 |
| 2 A and 1 W | 1 | 9 |
| 2 A and 1 NA | 2 | 10* and 31 |
| 1 A and 1 W | 1 | 22* |
| 1 A and 1 NA | 3 | 23, 25 and 32 |
| 1 A and 2 NA | 1 | 5* |
| 2 W | 1 | 20* |
| 3 W | 1 | 3 |
| 1 NA | 1 | 24 |
| 2 NA | 1 | 12 |
| 1 W and 2 NA | 1 | 4* |
| 3 NA | 1 | 19* |

The performance evaluation sorted by radionuclide and the bias plots are presented in Appendix I (see Tables 7–9 and Figures 2–7). 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 ± 15% (Maximum Accepted Bias for $^{90}$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 expanded uncertainties ($k = 2$). However, a large spread in the submitted uncertainties was observed with relative uncertainties (at $k = 2$) ranging from 3.4% to 37% for $^{90}$Sr, from 1.1% to 25% for $^{134}$Cs and from 4.0% to 34% for $^{137}$Cs. However, most reported relative uncertainties were in the range 7% to 24% for $^{90}$Sr and 4% to 14% for both $^{134}$Cs and $^{137}$Cs.

For Sr-90, the majority of the participants used gas-flow proportional counting (GPC) as the analysis technique, while three laboratories (Participants 8, 11* and 30) used liquid scintillation counting (LSC), in all cases after chemical separation of Sr from the seawater matrix. Chemical separation techniques used included precipitations of Sr-oxalate or Sr-carbonate, cation-exchange chromatography, Sr-extraction chromatography and direct liquid-liquid extraction of Y-90. The results based on GPC show a larger variability (the range of the relative bias was between –37% and 81%, although two GPC results [Participants 17 and 31, who both used direct liquid-liquid extraction of Y-90] had a relative bias of less than ± 1.5%) than the three results based on LSC (these three results all had a relative bias of less than –4%).

For $^{134}$Cs and $^{137}$Cs, the 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 hexacyanoferrates containing either copper, nickel or cobalt) to separate the caesium radionuclides from the seawater matrix followed by gamma spectrometry (Participants 4*, 10*, 18, 20*, 28, 29 and 31) or they used a combination of the two techniques (Participants 3, 11* and 13*). No significant difference in the performance between the two techniques is apparent although in general the reported relative uncertainties (at $k = 2$) for the direct measurements were somewhat larger, typically around 12% for the direct measurements and around 9% for the pre-concentration methods.

## APPENDIX I. PERFORMANCE EVALUATION TABLES SORTED BY RADIONUCLIDE

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* | – | – | 0.1788 | 0.0011 | – | – | – | – | – | – | Not reported |
| 2 | 0.18 | 0.02 | 0.1740 | 0.0011 | 3.5 | 11 | 30 | Pass | Pass | Pass | Accepted |
| 3 | 0.208 | 0.008 | 0.1768 | 0.0011 | 18 | 3.7 | 11 | Pass | Pass | Fail | Warning |
| 4* | 0.130 | 0.024 | 0.1743 | 0.0011 | –25 | 18 | 36 | Fail | Pass | Pass | Not accepted |
| 5* | 0.110 | 0.005 | 0.1759 | 0.0011 | –37 | 4.6 | 7.5 | Fail | Pass | Fail | Not accepted |
| 6 | 0.162 | 0.020 | 0.1724 | 0.0010 | –6.0 | 12 | 29 | Pass | Pass | Pass | Accepted |
| 7 | – | – | 0.1766 | 0.0011 | – | – | – | – | – | – | Not reported |
| 8 | 0.17 | 0.02 | 0.1767 | 0.0011 | –3.8 | 12 | 29 | Pass | Pass | Pass | Accepted |
| 9 | 0.205 | 0.016 | 0.1758 | 0.0011 | 17 | 7.8 | 23 | Pass | Pass | Pass | Accepted |
| 10* | 0.317 | 0.016 | 0.1753 | 0.0011 | 81 | 4.9 | 23 | Fail | Pass | Fail | Not accepted |
| 11* | 0.174 | 0.010 | 0.1770 | 0.0011 | –1.7 | 5.8 | 15 | Pass | Pass | Pass | Accepted |
| 12 | – | – | 0.1782 | 0.0011 | – | – | – | – | – | – | Not reported |
| 13* | – | – | 0.1767 | 0.0011 | – | – | – | – | – | – | Not reported |
| 14 | – | – | 0.1752 | 0.0011 | – | – | – | – | – | – | Not reported |
| 15 | – | – | 0.1780 | 0.0011 | – | – | – | – | – | – | Not reported |
| 16* | – | – | 0.1737 | 0.0011 | – | – | – | – | – | – | Not reported |

continues

| continued | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |
| 17 | 0.174 | 0.003 | 0.1721 | 0.0010 | 1.1 | 1.8 | 4.8 | Pass | Pass | Pass | Accepted |
| 18 | – | – | 0.1725 | 0.0011 | – | – | – | – | – | – | Not reported |
| 19* | 0.129 | 0.015 | 0.1729 | 0.0011 | –25 | 11 | 22 | Fail | Pass | Fail | Not accepted |
| 20* | – | – | 0.1745 | 0.0011 | – | – | – | – | – | – | Not reported |
| 21 | – | – | 0.1761 | 0.0011 | – | – | – | – | – | – | Not reported |
| 22* | – | – | 0.1757 | 0.0011 | – | – | – | – | – | – | Not reported |
| 23 | – | – | 0.1786 | 0.0011 | – | – | – | – | – | – | Not reported |
| 24 | – | – | 0.1748 | 0.0011 | – | – | – | – | – | – | Not reported |
| 25 | – | – | 0.1788 | 0.0011 | – | – | – | – | – | – | Not reported |
| 26* | – | – | 0.1733 | 0.0011 | – | – | – | – | – | – | Not reported |
| 27 | – | – | 0.1744 | 0.0011 | – | – | – | – | – | – | Not reported |
| 28 | – | – | 0.1737 | 0.0011 | – | – | – | – | – | – | Not reported |
| 29 | – | – | 0.1754 | 0.0011 | – | – | – | – | – | – | Not reported |
| 30 | 0.174 | 0.010 | 0.1770 | 0.0011 | –1.7 | 5.5 | 14 | Pass | Pass | Pass | Accepted |
| 31 | 0.175 | 0.006 | 0.1776 | 0.0011 | –1.4 | 3.6 | 9.0 | Pass | Pass | Pass | Accepted |
| 32 | – | – | 0.1761 | 0.0011 | – | – | – | – | – | – | 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* | 0.342 | 0.024 | 0.3433 | 0.0014 | –0.4 | 6.9 | 18 | Pass | Pass | Pass | Accepted |
| 2 | 0.332 | 0.027 | 0.3339 | 0.0013 | –0.6 | 8.1 | 21 | Pass | Pass | Pass | Accepted |
| 3 | 0.304 | 0.007 | 0.3393 | 0.0014 | –10 | 2.2 | 5.0 | Pass | Pass | Fail | Warning |
| 4* | 0.314 | 0.006 | 0.3344 | 0.0013 | –6.2 | 1.9 | 4.6 | Pass | Pass | Fail | Warning |
| 5* | 0.28 | 0.02 | 0.3375 | 0.0014 | –17 | 7.2 | 15 | Fail | Pass | Fail | Not accepted |
| 6 | 0.330 | 0.013 | 0.3308 | 0.0013 | –0.2 | 3.8 | 9.8 | Pass | Pass | Pass | Accepted |
| 7 | 0.335 | 0.019 | 0.3389 | 0.0014 | –1.2 | 5.5 | 14 | Pass | Pass | Pass | Accepted |
| 8 | 0.320 | 0.025 | 0.3391 | 0.0014 | –5.6 | 7.8 | 19 | Pass | Pass | Pass | Accepted |
| 9 | 0.32 | 0.02 | 0.3373 | 0.0014 | –5.1 | 6.3 | 15 | Pass | Pass | Pass | Accepted |
| 10* | 0.304 | 0.014 | 0.3365 | 0.0014 | –9.7 | 4.5 | 10 | Pass | Pass | Pass | Accepted |
| 11* | 0.333 | 0.022 | 0.3397 | 0.0014 | –2.0 | 6.5 | 16 | Pass | Pass | Pass | Accepted |
| 12 | 0.285 | 0.015 | 0.3420 | 0.0014 | –17 | 5.1 | 11 | Fail | Pass | Fail | Not accepted |
| 13* | 0.32 | 0.02 | 0.3391 | 0.0014 | –5.6 | 6.3 | 15 | Pass | Pass | Pass | Accepted |
| 14 | 0.33 | 0.01 | 0.3362 | 0.0014 | –1.9 | 3.1 | 7.7 | Pass | Pass | Pass | Accepted |
| 15 | 0.324 | 0.011 | 0.3416 | 0.0014 | –5.2 | 3.3 | 8.0 | Pass | Pass | Pass | Accepted |
| 16* | 0.327 | 0.021 | 0.3333 | 0.0013 | –1.9 | 6.4 | 16 | Pass | Pass | Pass | Accepted |
| 17 | 0.331 | 0.007 | 0.3303 | 0.0013 | 0.2 | 2.2 | 5.6 | Pass | Pass | Pass | Accepted |
| 18 | 0.320 | 0.015 | 0.3311 | 0.0013 | –3.4 | 4.7 | 12 | Pass | Pass | Pass | Accepted |

continues

| continued | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |
| 19* | 0.242 | 0.016 | 0.3318 | 0.0013 | –27 | 6.6 | 12 | Fail | Pass | Fail | Not accepted |
| 20* | 0.286 | 0.012 | 0.3348 | 0.0013 | –15 | 4.2 | 9.3 | Pass | Pass | Fail | Warning |
| 21 | 0.331 | 0.022 | 0.3379 | 0.0014 | –2.0 | 6.5 | 16 | Pass | Pass | Pass | Accepted |
| 22* | 0.310 | 0.031 | 0.3372 | 0.0014 | –8.1 | 9.8 | 23 | Pass | Pass | Pass | Accepted |
| 23 | 0.56 | 0.03 | 0.3427 | 0.0014 | 63 | 5.4 | 23 | Fail | Pass | Fail | Not accepted |
| 24 | 0.450 | 0.003 | 0.3355 | 0.0013 | 34 | 0.7 | 2.2 | Fail | Pass | Fail | Not accepted |
| 25 | 0.41 | 0.03 | 0.3431 | 0.0014 | 19 | 7.3 | 23 | Fail | Pass | Pass | Not accepted |
| 26* | < 1.6 | – | 0.3326 | 0.0013 | – | – | – | – | – | – | Not evaluated |
| 27 | 0.358 | 0.022 | 0.3346 | 0.0013 | 6.9 | 6.1 | 17 | Pass | Pass | Pass | Accepted |
| 28 | 0.324 | 0.007 | 0.3334 | 0.0013 | –2.8 | 2.1 | 5.4 | Pass | Pass | Pass | Accepted |
| 29 | 0.330 | 0.007 | 0.3366 | 0.0014 | –2.0 | 2.1 | 5.4 | Pass | Pass | Pass | Accepted |
| 30 | 0.370 | 0.025 | 0.3397 | 0.0014 | 8.9 | 6.8 | 19 | Pass | Pass | Pass | Accepted |
| 31 | 0.332 | 0.020 | 0.3408 | 0.0014 | –2.6 | 6.0 | 15 | Pass | Pass | Pass | Accepted |
| 32 | 0.280 | 0.035 | 0.3379 | 0.0014 | –17 | 13 | 27 | Fail | Pass | Pass | Not 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* | 0.403 | 0.022 | 0.432 | 0.003 | –6.8 | 5.4 | 13 | Pass | Pass | Pass | Accepted |
| 2 | 0.385 | 0.031 | 0.421 | 0.003 | –8.5 | 8.1 | 19 | Pass | Pass | Pass | Accepted |
| 3 | 0.400 | 0.008 | 0.428 | 0.003 | –6.4 | 2.1 | 5.1 | Pass | Pass | Fail | Warning |
| 4* | 0.491 | 0.010 | 0.421 | 0.003 | 17 | 2.2 | 6.4 | Fail | Pass | Fail | Not accepted |
| 5* | 0.42 | 0.03 | 0.425 | 0.003 | –1.2 | 7.2 | 18 | Pass | Pass | Pass | Accepted |
| 6 | 0.417 | 0.019 | 0.417 | 0.003 | 0.1 | 4.6 | 12 | Pass | Pass | Pass | Accepted |
| 7 | 0.409 | 0.024 | 0.427 | 0.003 | –4.2 | 5.9 | 15 | Pass | Pass | Pass | Accepted |
| 8 | 0.430 | 0.025 | 0.427 | 0.003 | 0.6 | 5.8 | 15 | Pass | Pass | Pass | Accepted |
| 9 | 0.41 | 0.07 | 0.425 | 0.003 | –3.5 | 17 | 42 | Pass | Fail | Pass | Warning |
| 10* | 0.407 | 0.012 | 0.424 | 0.003 | –4.0 | 3.0 | 7.5 | Pass | Pass | Pass | Accepted |
| 11* | 0.433 | 0.026 | 0.428 | 0.003 | 1.2 | 6.0 | 16 | Pass | Pass | Pass | Accepted |
| 12 | 0.349 | 0.016 | 0.431 | 0.003 | –19 | 4.6 | 9.7 | Fail | Pass | Fail | Not accepted |
| 13* | 0.380 | 0.035 | 0.427 | 0.003 | –11 | 9.2 | 21 | Pass | Pass | Pass | Accepted |
| 14 | 0.44 | 0.02 | 0.424 | 0.003 | 3.9 | 4.6 | 12 | Pass | Pass | Pass | Accepted |
| 15 | 0.44 | 0.04 | 0.430 | 0.003 | 1.5 | 9.2 | 24 | Pass | Pass | Pass | Accepted |
| 16* | 0.424 | 0.020 | 0.420 | 0.003 | 1.0 | 4.8 | 12 | Pass | Pass | Pass | Accepted |
| 17 | 0.428 | 0.010 | 0.416 | 0.003 | 2.8 | 2.4 | 6.4 | Pass | Pass | Pass | Accepted |
| 18 | 0.40 | 0.02 | 0.417 | 0.003 | –4.1 | 5.0 | 12 | Pass | Pass | Pass | Accepted |

continues

continued

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 19* | 0.352 | 0.018 | 0.418 | 0.003 | –16 | 5.0 | 11 | Fail | Pass | Fail | Not accepted |
| 20* | 0.479 | 0.018 | 0.422 | 0.003 | 14 | 3.8 | 11 | Pass | Pass | Fail | Warning |
| 21 | 0.433 | 0.030 | 0.426 | 0.003 | 1.7 | 7.0 | 18 | Pass | Pass | Pass | Accepted |
| 22* | 0.392 | 0.009 | 0.425 | 0.003 | –7.7 | 2.3 | 5.4 | Pass | Pass | Fail | Warning |
| 23 | 0.41 | 0.02 | 0.432 | 0.003 | –5.0 | 4.9 | 12 | Pass | Pass | Pass | Accepted |
| 24 | – | – | 0.423 | 0.003 | – | – | – | – | – | – | Not reported |
| 25 | 0.370 | 0.045 | 0.432 | 0.003 | –14 | 12 | 27 | Pass | Pass | Pass | Accepted |
| 26* | < 1.3 | – | 0.419 | 0.003 | – | – | – | – | – | – | Not evaluated |
| 27 | 0.437 | 0.024 | 0.422 | 0.003 | 3.6 | 5.6 | 15 | Pass | Pass | Pass | Accepted |
| 28 | 0.430 | 0.009 | 0.420 | 0.003 | 2.4 | 2.2 | 5.8 | Pass | Pass | Pass | Accepted |
| 29 | 0.440 | 0.009 | 0.424 | 0.003 | 3.8 | 2.2 | 5.8 | Pass | Pass | Pass | Accepted |
| 30 | 0.450 | 0.045 | 0.428 | 0.003 | 5.1 | 10 | 27 | Pass | Pass | Pass | Accepted |
| 31 | 0.561 | 0.034 | 0.429 | 0.003 | 31 | 6.0 | 20 | Fail | Pass | Fail | Not accepted |
| 32 | 0.44 | 0.02 | 0.426 | 0.003 | 3.3 | 4.6 | 12 | Pass | Pass | Pass | Accepted |

* RCA RAS/7/021 participant

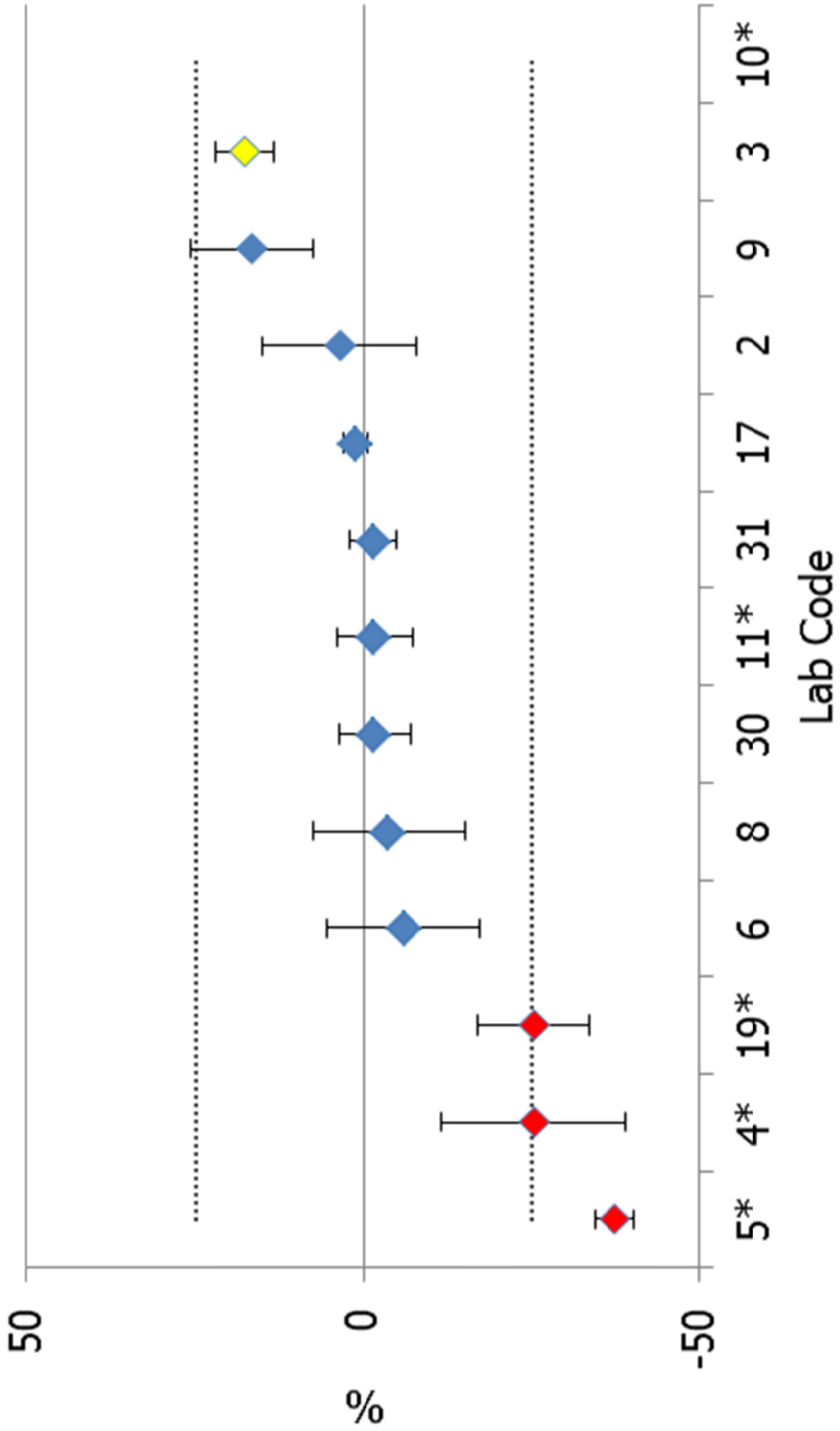


*FIG. 2. Sr-90 bias.*

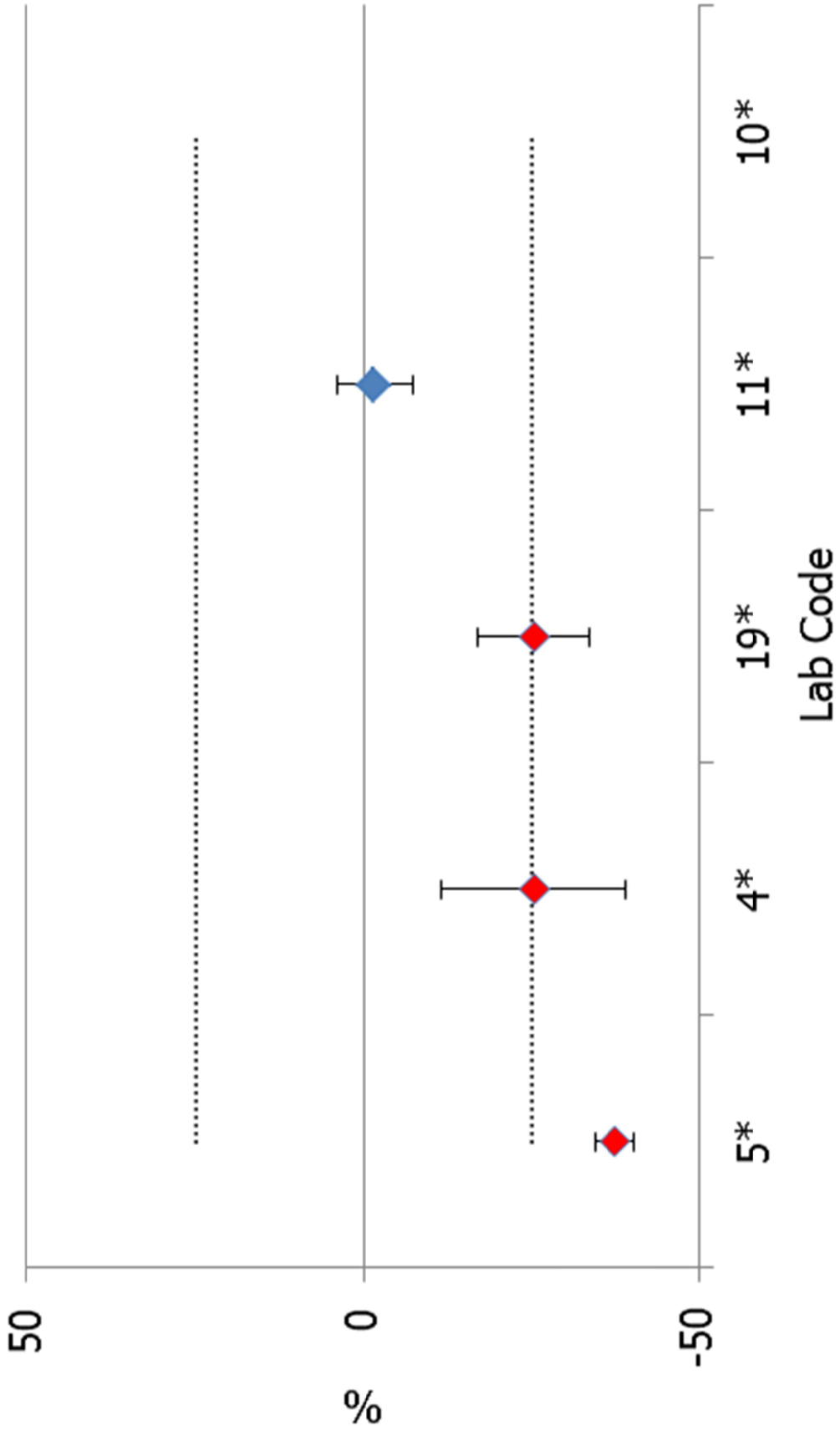


*FIG. 3. Sr-90 bias RCA RAS/07/021 participants.*

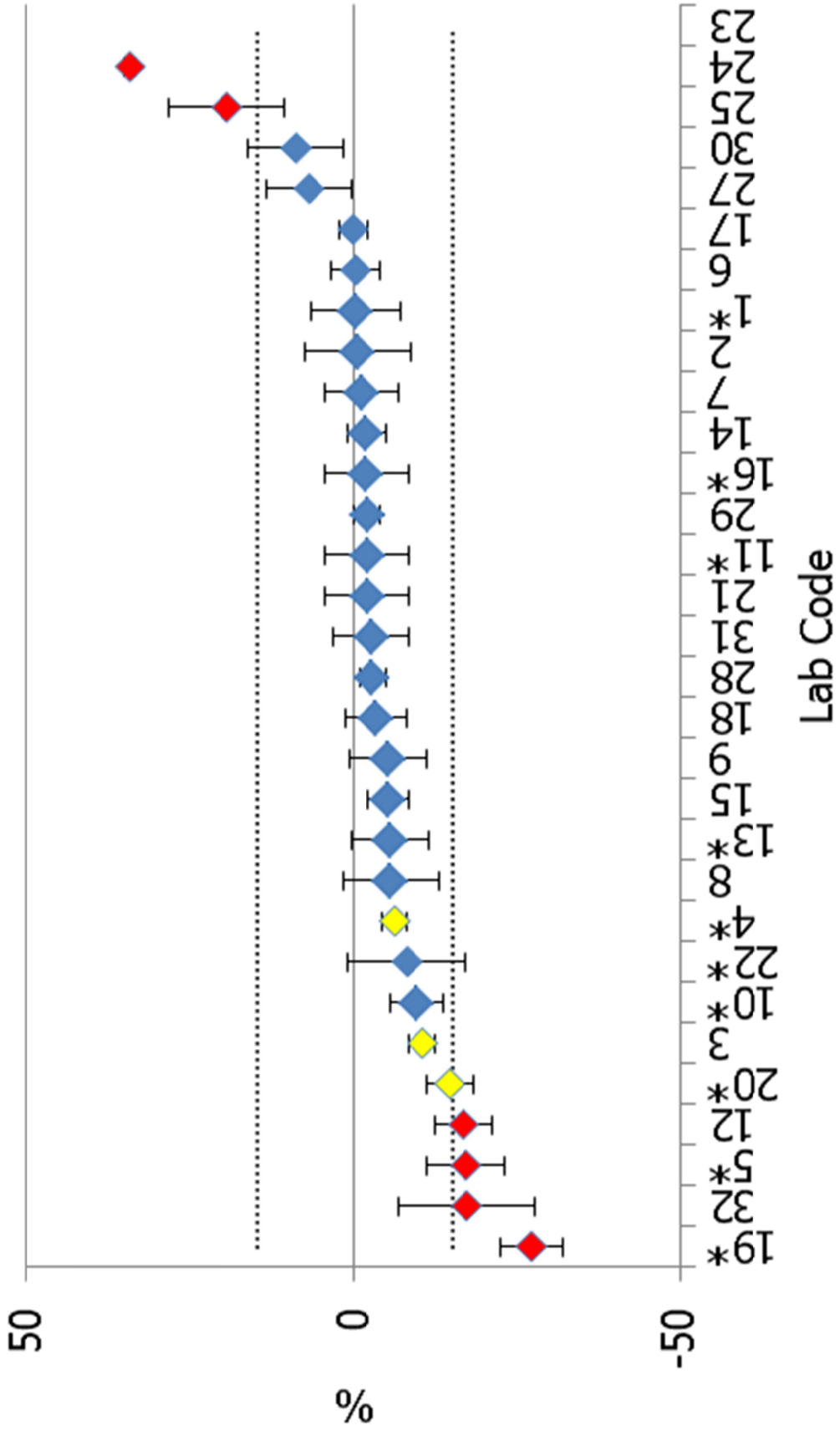


*FIG. 4. Cs-134 bias.*

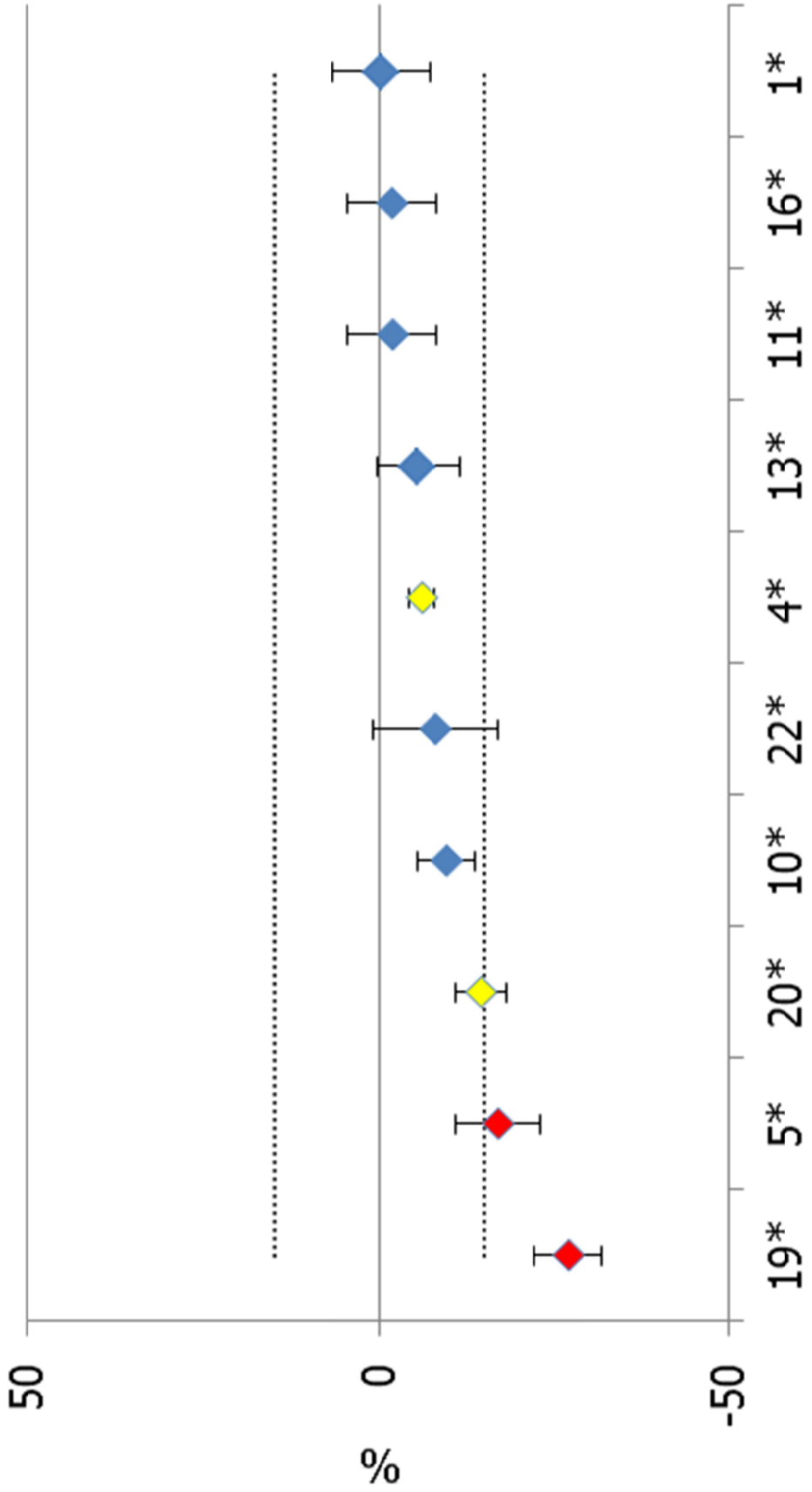


*FIG. 5. Cs-134 bias RCA RAS/07/021 participants.*

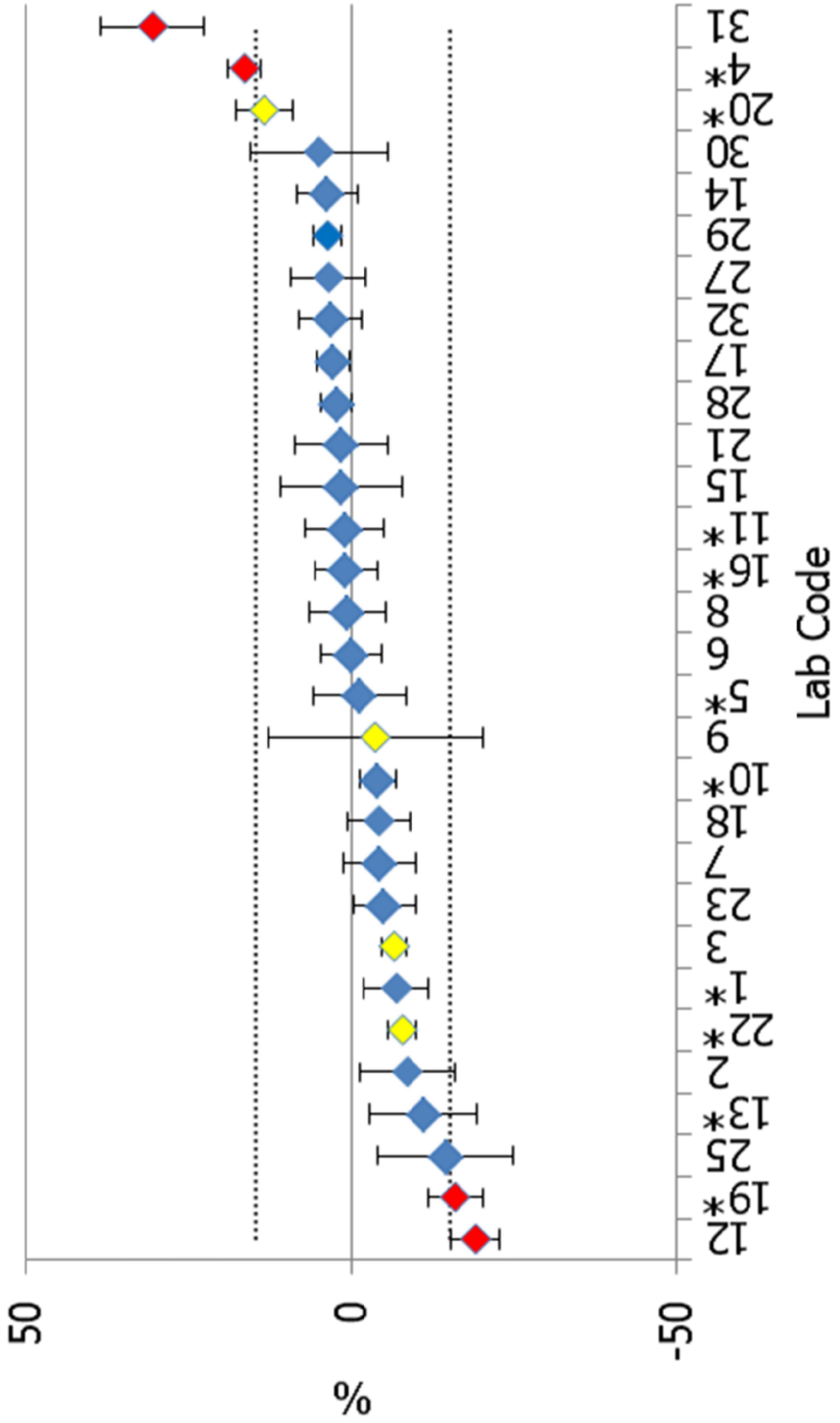


*FIG. 6. Cs-137 bias.*

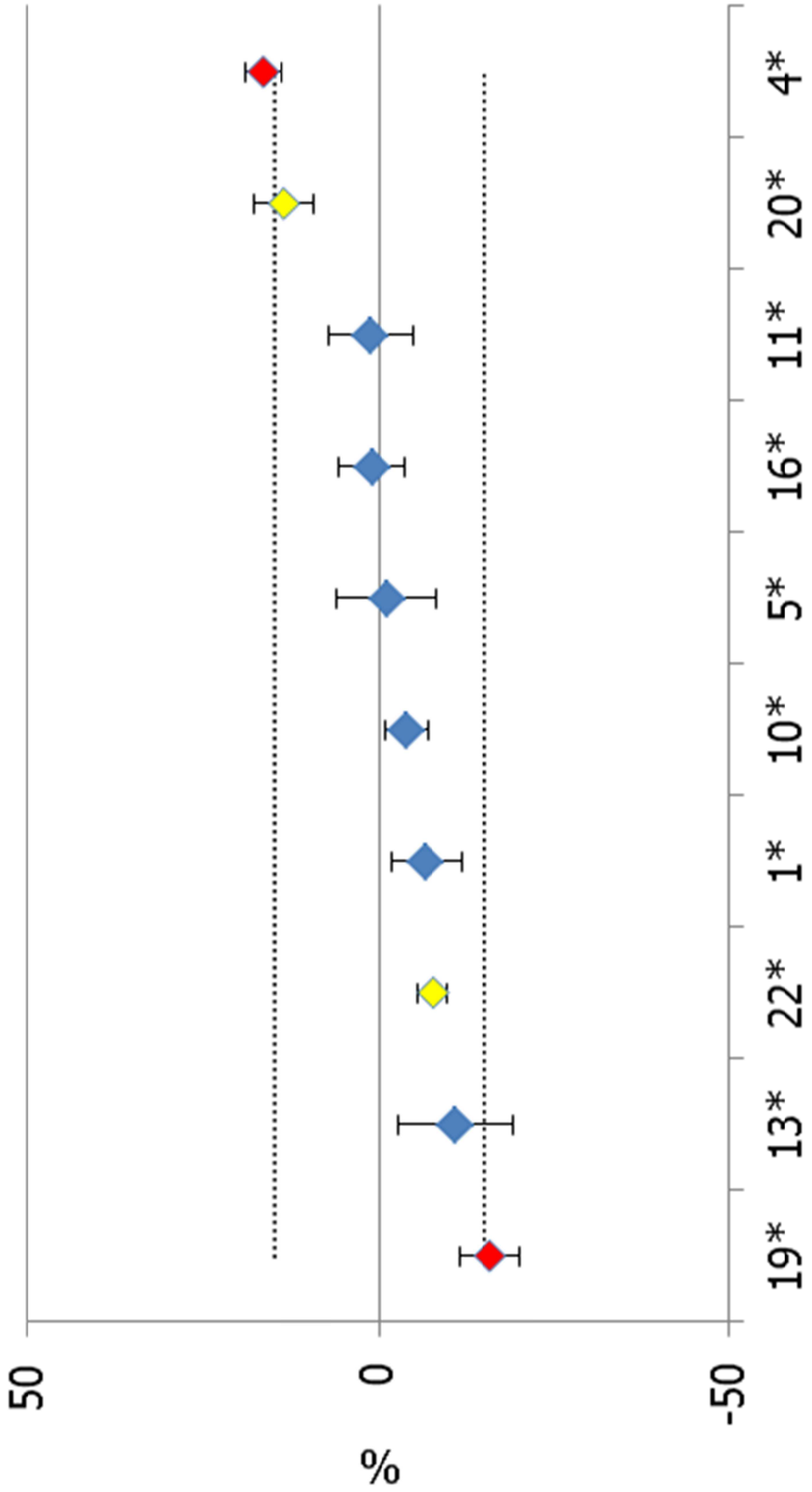


*FIG. 7. Cs-137 bias RCA RAS/07/021 participants.*

## 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | – | – | 0.1788 | 0.0011 | – | – | – | – | – | – | Not reported |
| $^{134}$Cs | 0.342 | 0.024 | 0.3433 | 0.0014 | –0.4 | 6.9 | 18 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.403 | 0.022 | 0.432 | 0.003 | –6.8 | 5.4 | 13 | Pass | Pass | Pass | Accepted |

* 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | 0.18 | 0.02 | 0.1740 | 0.0011 | 3.5 | 11 | 30 | Pass | Pass | Pass | Accepted |
| $^{134}$Cs | 0.332 | 0.027 | 0.3339 | 0.0013 | –0.6 | 8.1 | 21 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.385 | 0.031 | 0.421 | 0.003 | –8.5 | 8.1 | 19 | Pass | Pass | Pass | Accepted |

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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | 0.208 | 0.008 | 0.1768 | 0.0011 | 18 | 3.7 | 11 | Pass | Pass | Fail | Warning |
| $^{134}$Cs | 0.304 | 0.007 | 0.3393 | 0.0014 | –10 | 2.2 | 5.0 | Pass | Pass | Fail | Warning |
| $^{137}$Cs | 0.400 | 0.008 | 0.428 | 0.003 | –6.4 | 2.1 | 5.1 | Pass | Pass | Fail | Warning |

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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | 0.130 | 0.024 | 0.1743 | 0.0011 | –25 | 18 | 36 | Fail | Pass | Pass | Not accepted |
| $^{134}$Cs | 0.314 | 0.006 | 0.3344 | 0.0013 | –6.2 | 1.9 | 4.6 | Pass | Pass | Fail | Warning |
| $^{137}$Cs | 0.491 | 0.010 | 0.421 | 0.003 | 17 | 2.2 | 6.4 | Fail | Pass | Fail | Not 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | 0.110 | 0.005 | 0.1759 | 0.0011 | –37 | 4.6 | 7.5 | Fail | Pass | Fail | Not accepted |
| $^{134}$Cs | 0.28 | 0.02 | 0.3375 | 0.0014 | –17 | 7.2 | 15 | Fail | Pass | Fail | Not accepted |
| $^{137}$Cs | 0.42 | 0.03 | 0.425 | 0.003 | –1.2 | 7.2 | 18 | Pass | Pass | Pass | Accepted |

* 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | 0.162 | 0.020 | 0.1724 | 0.0010 | –6.0 | 12 | 29 | Pass | Pass | Pass | Accepted |
| $^{134}$Cs | 0.330 | 0.013 | 0.3308 | 0.0013 | –0.2 | 3.8 | 9.8 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.417 | 0.019 | 0.417 | 0.003 | 0.1 | 4.6 | 12 | Pass | Pass | Pass | Accepted |

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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | – | – | 0.1766 | 0.0011 | – | – | – | – | – | – | Not reported |
| $^{134}$Cs | 0.335 | 0.019 | 0.3389 | 0.0014 | –1.2 | 5.5 | 14 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.409 | 0.024 | 0.427 | 0.003 | –4.2 | 5.9 | 15 | Pass | Pass | Pass | Accepted |

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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | 0.17 | 0.02 | 0.1767 | 0.0011 | –3.8 | 12 | 29 | Pass | Pass | Pass | Accepted |
| $^{134}$Cs | 0.320 | 0.025 | 0.3391 | 0.0014 | –5.6 | 7.8 | 19 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.430 | 0.025 | 0.427 | 0.003 | 0.6 | 5.8 | 15 | Pass | Pass | Pass | Accepted |

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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | 0.205 | 0.016 | 0.1758 | 0.0011 | 17 | 7.8 | 23 | Pass | Pass | Pass | Accepted |
| $^{134}$Cs | 0.32 | 0.02 | 0.3373 | 0.0014 | –5.1 | 6.3 | 15 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.41 | 0.07 | 0.425 | 0.003 | –3.5 | 17 | 42 | Pass | Fail | Pass | Warning |

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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | 0.317 | 0.016 | 0.1753 | 0.0011 | 81 | 4.9 | 23 | Fail | Pass | Fail | Not accepted |
| $^{134}$Cs | 0.304 | 0.014 | 0.3365 | 0.0014 | –9.7 | 4.5 | 10 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.407 | 0.012 | 0.424 | 0.003 | –4.0 | 3.0 | 7.5 | Pass | Pass | Pass | 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | 0.174 | 0.010 | 0.1770 | 0.0011 | –1.7 | 5.8 | 15 | Pass | Pass | Pass | Accepted |
| $^{134}$Cs | 0.333 | 0.022 | 0.3397 | 0.0014 | –2.0 | 6.5 | 16 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.433 | 0.026 | 0.428 | 0.003 | 1.2 | 6.0 | 16 | Pass | Pass | Pass | Accepted |

* RCA RAS/7/021 participant

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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | – | – | 0.1782 | 0.0011 | – | – | – | – | – | – | Not reported |
| $^{134}$Cs | 0.285 | 0.015 | 0.3420 | 0.0014 | –17 | 5.1 | 11 | Fail | Pass | Fail | Not accepted |
| $^{137}$Cs | 0.349 | 0.016 | 0.431 | 0.003 | –19 | 4.6 | 9.7 | Fail | Pass | Fail | 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | – | – | 0.1767 | 0.0011 | – | – | – | – | – | – | Not reported |
| $^{134}$Cs | 0.32 | 0.02 | 0.3391 | 0.0014 | –5.6 | 6.3 | 15 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.380 | 0.035 | 0.427 | 0.003 | –11 | 9.2 | 21 | Pass | Pass | Pass | Accepted |

* RCA RAS/7/021 participant

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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | – | – | 0.1752 | 0.0011 | – | – | – | – | – | – | Not reported |
| $^{134}$Cs | 0.33 | 0.01 | 0.3362 | 0.0014 | –1.9 | 3.1 | 7.7 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.44 | 0.02 | 0.424 | 0.003 | 3.9 | 4.6 | 12 | Pass | Pass | Pass | Accepted |

LABORATORY CODE 15.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | – | – | 0.1780 | 0.0011 | – | – | – | – | – | – | Not reported |
| $^{134}$Cs | 0.324 | 0.011 | 0.3416 | 0.0014 | –5.2 | 3.3 | 8.0 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.44 | 0.04 | 0.430 | 0.003 | 1.5 | 9.2 | 24 | Pass | Pass | Pass | Accepted |

LABORATORY CODE 16*.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | – | – | 0.1737 | 0.0011 | – | – | – | – | – | – | Not reported |
| $^{134}$Cs | 0.327 | 0.021 | 0.3333 | 0.0013 | –1.9 | 6.4 | 16 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.424 | 0.020 | 0.420 | 0.003 | 1.0 | 4.8 | 12 | Pass | Pass | Pass | Accepted |

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LABORATORY CODE 17.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | 0.174 | 0.003 | 0.1721 | 0.0010 | 1.1 | 1.8 | 4.8 | Pass | Pass | Pass | Accepted |
| $^{134}$Cs | 0.331 | 0.007 | 0.3303 | 0.0013 | 0.2 | 2.2 | 5.6 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.428 | 0.010 | 0.416 | 0.003 | 2.8 | 2.4 | 6.4 | Pass | Pass | Pass | Accepted |

LABORATORY CODE 18.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | – | – | 0.1725 | 0.0011 | – | – | – | – | – | – | Not reported |
| $^{134}$Cs | 0.320 | 0.015 | 0.3311 | 0.0013 | –3.4 | 4.7 | 12 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.40 | 0.02 | 0.417 | 0.003 | –4.1 | 5.0 | 12 | Pass | Pass | Pass | Accepted |

LABORATORY CODE 19*.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | 0.129 | 0.015 | 0.1729 | 0.0011 | –25 | 11 | 22 | Fail | Pass | Fail | Not accepted |
| $^{134}$Cs | 0.242 | 0.016 | 0.3318 | 0.0013 | –27 | 6.6 | 12 | Fail | Pass | Fail | Not accepted |
| $^{137}$Cs | 0.352 | 0.018 | 0.418 | 0.003 | –16 | 5.0 | 11 | Fail | Pass | Fail | Not accepted |

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LABORATORY CODE 20*.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | – | – | 0.1745 | 0.0011 | – | – | – | – | – | – | Not reported |
| $^{134}$Cs | 0.286 | 0.012 | 0.3348 | 0.0013 | –15 | 4.2 | 9.3 | Pass | Pass | Fail | Warning |
| $^{137}$Cs | 0.479 | 0.018 | 0.422 | 0.003 | 14 | 3.8 | 11 | Pass | Pass | Fail | Warning |

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LABORATORY CODE 21.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | – | – | 0.1761 | 0.0011 | – | – | – | – | – | – | Not reported |
| $^{134}$Cs | 0.331 | 0.022 | 0.3379 | 0.0014 | –2.0 | 6.5 | 16 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.433 | 0.030 | 0.426 | 0.003 | 1.7 | 7.0 | 18 | Pass | Pass | Pass | Accepted |

LABORATORY CODE 22*.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | – | – | 0.1757 | 0.0011 | – | – | – | – | – | – | Not reported |
| $^{134}$Cs | 0.310 | 0.031 | 0.3372 | 0.0014 | –8.1 | 9.8 | 23 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.392 | 0.009 | 0.425 | 0.003 | –7.7 | 2.3 | 5.4 | Pass | Pass | Fail | Warning |

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LABORATORY CODE 23.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | – | – | 0.1786 | 0.0011 | – | – | – | – | – | – | Not reported |
| $^{134}$Cs | 0.56 | 0.03 | 0.3427 | 0.0014 | 63 | 5.4 | 23 | Fail | Pass | Fail | Not accepted |
| $^{137}$Cs | 0.41 | 0.02 | 0.432 | 0.003 | –5.0 | 4.9 | 12 | Pass | Pass | Pass | Accepted |

LABORATORY CODE 24.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | – | – | 0.1748 | 0.0011 | – | – | – | – | – | – | Not reported |
| $^{134}$Cs | 0.450 | 0.003 | 0.3355 | 0.0013 | 34 | 0.7 | 2.2 | Fail | Pass | Fail | Not accepted |
| $^{137}$Cs | – | – | 0.423 | 0.003 | – | – | – | – | – | – | Not reported |

LABORATORY CODE 25.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | – | – | 0.1788 | 0.0011 | – | – | – | – | – | – | Not reported |
| $^{134}$Cs | 0.41 | 0.03 | 0.3431 | 0.0014 | 19 | 7.3 | 23 | Fail | Pass | Pass | Not accepted |
| $^{137}$Cs | 0.370 | 0.045 | 0.432 | 0.003 | –14 | 12 | 27 | Pass | Pass | Pass | Accepted |

LABORATORY CODE 26*.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | – | – | 0.1733 | 0.0011 | – | – | – | – | – | – | Not reported |
| $^{134}$Cs | < 1.6 | – | 0.3326 | 0.0013 | – | – | – | – | – | – | Not evaluated |
| $^{137}$Cs | < 1.3 | – | 0.419 | 0.003 | – | – | – | – | – | – | Not evaluated |

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LABORATORY CODE 27.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | – | – | 0.1744 | 0.0011 | – | – | – | – | – | – | Not reported |
| $^{134}$Cs | 0.358 | 0.022 | 0.3346 | 0.0013 | 6.9 | 6.1 | 17 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.437 | 0.024 | 0.422 | 0.003 | 3.6 | 5.6 | 15 | Pass | Pass | Pass | Accepted |

LABORATORY CODE 28.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | – | – | 0.1737 | 0.0011 | – | – | – | – | – | – | Not reported |
| $^{134}$Cs | 0.324 | 0.007 | 0.3334 | 0.0013 | –2.8 | 2.1 | 5.4 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.430 | 0.009 | 0.420 | 0.003 | 2.4 | 2.2 | 5.8 | Pass | Pass | Pass | Accepted |

LABORATORY CODE 29.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | – | – | 0.1754 | 0.0011 | – | – | – | – | – | – | Not reported |
| $^{134}$Cs | 0.330 | 0.007 | 0.3366 | 0.0014 | –2.0 | 2.1 | 5.4 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.440 | 0.009 | 0.424 | 0.003 | 3.8 | 2.2 | 5.8 | Pass | Pass | Pass | Accepted |

LABORATORY CODE 30.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | 0.174 | 0.010 | 0.1770 | 0.0011 | –1.7 | 5.5 | 14 | Pass | Pass | Pass | Accepted |
| $^{134}$Cs | 0.370 | 0.025 | 0.3397 | 0.0014 | 8.9 | 6.8 | 19 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.450 | 0.045 | 0.428 | 0.003 | 5.1 | 10 | 27 | Pass | Pass | Pass | Accepted |

LABORATORY CODE 31.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | 0.175 | 0.006 | 0.1776 | 0.0011 | –1.4 | 3.6 | 9.0 | Pass | Pass | Pass | Accepted |
| $^{134}$Cs | 0.332 | 0.020 | 0.3408 | 0.0014 | –2.6 | 6.0 | 15 | Pass | Pass | Pass | Accepted |
| $^{137}$Cs | 0.561 | 0.034 | 0.429 | 0.003 | 31 | 6.0 | 20 | Fail | Pass | Fail | Not accepted |

LABORATORY CODE 32.

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{90}$Sr | – | – | 0.1761 | 0.0011 | – | – | – | – | – | – | Not reported |
| $^{134}$Cs | 0.280 | 0.035 | 0.3379 | 0.0014 | –17 | 13 | 27 | Fail | Pass | Pass | Not accepted |
| $^{137}$Cs | 0.44 | 0.02 | 0.426 | 0.003 | 3.3 | 4.6 | 12 | Pass | Pass | Pass | Accepted |

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