National Physical Laboratory

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Environmental Radioactivity Proficiency Test Exercise 2023/24

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Environmental Radioactivity Proficiency Test Exercise 2023/24

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ABSTRACT

The results of NPL's twenty-ninth Environmental Radioactivity Proficiency Test Exercise are reported. There were five different sample types offered: an aqueous mixture of one alpha-emitting radionuclide and three beta-emitting radionuclides (designated 'AB'), an aqueous mixture of three alpha-emitting radionuclides ('A1'), an aqueous mixture of three beta-emitting radionuclides ('B1'), an aqueous mixture of five gamma-emitting radionuclides ('GH'), and a second aqueous mixture of four gamma-emitting radionuclides ('GL'). In total, over 400 results were submitted (excluding gross measurements).

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Assigned Values (reference time 2023-06-01 12:00 UTC)

Radionuclide (AB)	Assigned Value (Bq g^{-1})
^{3}H	13.24 ± 0.38
^{63}Ni	3.589 ± 0.034
^{90}Sr	3.549 ± 0.019
^{241}Am	11.618 ± 0.092
Radionuclide (A1)	**Assigned Value (Bq kg^{-1})**
^{226}Ra	45.4 ± 1.1
^{241}Am	88.14 ± 0.70
^{244}Cm	21.641 ± 0.066
Radionuclide (B1)	**Assigned Value (Bq g^{-1})**
^{3}H	0.2821 ± 0.0094
^{14}C	0.4031 ± 0.0036
^{36}Cl	0.2187 ± 0.0015
Radionuclide (GH)	**Assigned Value (Bq g^{-1})**
^{22}Na	8.674 ± 0.066
^{60}Co	31.23 ± 0.22
^{133}Ba	38.84 ± 0.54
^{137}Cs	13.20 ± 0.20
^{155}Eu	7.63 ± 0.28
Radionuclide (GL)	**Assigned Value (Bq kg^{-1})**
^{54}Mn	17.22 ± 0.36
^{65}Zn	29.67 ± 0.44
^{139}Ce	44.41 ± 0.78
^{210}Pb	13.67 ± 0.30

UNCERTAINTIES

The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k = 2, providing a coverage probability of approximately 95 %. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

CONTENTS

1. SUMMARY

This Environmental Radioactivity Proficiency Test Exercise (PTE) was the twenty-ninth in a series of annual exercises run by NPL over the last 35 years. These exercises help analysts to identify metrology challenges and support UKAS accreditations in the quantification of radionuclides. A range of sample types were made available during previous exercises. These have been mostly aqueous but have on occasion included solid materials, which have been introduced subject to availability. This exercise consisted of aqueous solutions only with five sample types made available to the participants, summarised in Table 1.

Table 1 Summary of samples available to the participants for this proficiency test exercise.

Sample Type	Sample Type Code	Radionuclides	Activity per Unit Mass Range
Alpha Beta	AB	One alpha- and three beta-emitting radionuclides in dilute nitric acid	1 – 20 Bq g^{-1}
Alpha One	A1	Three alpha-emitting radionuclides in dilute nitric acid	5 – 100 Bq kg^{-1}
Beta One	B1	Three beta-emitting radionuclides in 0.01 M NaOH solution	0.1 – 1 Bq g^{-1}
Gamma High	GH	Five gamma-ray emitting radionuclides in dilute nitric acid	1 – 50 Bq g^{-1}
Gamma Low	GL	Four gamma-ray emitting radionuclides in dilute nitric acid	1 – 50 Bq kg^{-1}

The main objective of this exercise remains consistent with previous exercises and was to assess the performance of the participating laboratories. NPL acted as the exercise coordinator, preparing and distributing the samples to participants who identified and quantified the activity per unit mass of the radionuclides present in the samples. NPL then collected, analysed and interpreted the results which were compiled and are presented this report.

NPL allocated each participant with a unique laboratory code number (if not already allocated in a previous exercise in this series). The allocation of laboratory numbers is done in confidence so that no third parties may identify the participants by their allocated code number. The participants were asked to add their code numbers to their Reporting Forms, and the code numbers would be used by NPL to label the results in the final report.

Each sample type was prepared in bulk by combining weighed aliquots of radioactive standards with a weighed amount of carrier solution and then diluting the mixture further to

achieve the target activity per unit mass. Dilution factors were measured gravimetrically and were validated using radiometric counting techniques; liquid scintillation counting or high-purity germanium (HPGe) gamma spectrometry. The Assigned Value for each radionuclide was calculated from the division of the standardised activity per unit mass of the original standard solution by the dilution factor(s). The activities per unit mass of the radionuclides in the aqueous sample types were traceable to national standards of radioactivity, and therefore to the international measurement system.

The standard uncertainty of the Assigned Values for each radionuclide was derived from the uncertainty components attributed to the activity of the standardised parent solution, the gravimetric dilution and the decay correction to the reference time. These uncertainties have been evaluated and validated in accordance with the requirements of UKAS.

Throughout this report, unless otherwise stated, all uncertainties quoted in this report are combined standard uncertainties with no coverage factor applied.

The bulk solution was subdivided into (typically) 50 bottles and where applicable the homogeneity was checked by gamma spectrometry. The stability of solution was checked by counting one or more bottles of each sample type at NPL at regular intervals throughout the course of the exercise; all solutions were found to be stable.

Participants' data were analysed to provide the deviation, and the associated standard uncertainty, from the assigned value. The participants' performance was then assessed using the method described in section 2.

After receipt of the results from the participants, the Power-Moderated Mean (PMM, Pommé, 2012) was calculated for each radionuclide. This provides a more robust estimate than the weighted mean in the event of discrepant data sets. For mutually consistent data, the method approaches the weighted mean, the weights being the reciprocals of the variances associated with the measured values. For data suspected of inconsistency, the weighting is moderated by augmenting laboratory variances by a common amount and/or by decreasing the power of weighting factors. For increasingly discrepant data sets, there is a smooth transition from the weighted mean to the arithmetic mean.

The PMM was also calculated for the following quantities:

- Sample Type AB gross beta
- Sample Type B1 gross beta
- Sample Type A1 gross alpha

There were no cases where the PMM was used as the Assigned Value. Note that consensus values based on the PMM are not traceable to national standards of radioactivity. The PMM of the gross measurements is provided as an indicator and has not been used for performance assessment. It is for this reason results for gross measurements do not appear in the main body of the report. The gross measurements are given in APPENDIX I.

The dispatch of the samples was subcontracted to the following organisations:

The Courier Company (UK) Limited
11 James Way Marshall Court
Milton Keynes, MK1 1SU, UK

Circle Express
Unit 1
Polar Park
Bath Rd
West Drayton, UB7 0EX, UK

2. TREATMENT OF DATA

The data were analysed using the same methods as in the 2022 exercise (van Es et al., 2023).

The deviation 'D' from the assigned value from each laboratory value was calculated from:

$$D = \frac{L - N}{N} = \left(\frac{L}{N} - 1\right) \qquad [1]$$

The standard uncertainty (*k*=1) 'u_D' of the deviation was calculated from:

$$u_D = \frac{L}{N}\sqrt{\left(\frac{u_L}{L}\right)^2 + \left(\frac{u_N}{N}\right)^2} \qquad [2]$$

The quantities zeta (ζ), the relative uncertainty of a laboratory's value (R_L) and the z-score were calculated from:

$$\zeta = \frac{L - N}{\sqrt{u_L^2 + u_N^2}} \qquad [3]$$

$$R_L = \frac{u_L}{L} \qquad [4]$$

$$z = \frac{L - N}{\sigma_p} = \frac{L - N}{0.05823\ N} \qquad [5]$$

where:

L is the participant's value;
N is the Assigned Value;
u_L is the standard uncertainty of the participants' value;
u_N is the standard uncertainty of the Assigned Value;
σ_p is the standard uncertainty for proficiency assessment.

The value of the standard uncertainty for proficiency assessment σ_p is chosen by perception (viz. ISO 13528:2022 paragraph 8.2). It corresponds to a level of performance that NPL would wish laboratories to be able to achieve. It corresponds to a deviation *D* of 15 % (at a 99 % confidence level). In other words, any result with a deviation *D* smaller than $\pm$ 15 % will pass the z-test.

Note that the z-score presented is as defined in ISO 13528:2022 rather than the commonly understood z-score and is used to reject results on based a maximum percentage deviation.

The zeta and *z*-scores were used to determine whether the difference between the participant's value and the Assigned Value was significantly different from zero. The Interquartile Range outlier test (Harms and Gilligan, 2011) was used to determine whether the relative uncertainty R_L was significantly larger than the other values in the data set. Note that this test is unable to identify outliers if the data set is smaller than seven.

Results for which the absolute values of the zeta score and the *z*-score are both $\leq$ 2.576 and for which R_L is not significantly larger than the other values in the data set are taken to mean that the participant's value is 'in agreement' with the Assigned Value. These results are plotted in white in this report.

If (i) R_L is significantly larger than the other values in the data set, or (ii) the result passes the zeta test but not the *z*-test (i.e., there is a large deviation from the Assigned Value combined with a large uncertainty), or (iii) the result passes the *z*-test but not the zeta test (where the deviation is less than 15 % from the Assigned Value but the standard uncertainty is insufficient result in agreement with the Assigned Value), the participant's value is classified as 'questionable' (plotted in yellow).

If the absolute values of both the zeta score and the *z*-score are greater than 2.576, then the participant's value is classified as 'discrepant' from the Assigned Value (plotted in red), regardless of the value of R_L.

A result was only classified as 'in agreement' when the three tests (the zeta test, the relative uncertainty outlier test and the z-test) were passed. A failure to pass one of these tests resulted in a classification 'questionable'. Failure of both the zeta test and the z-test resulted in a classification 'discrepant'. The classification criteria used to assess the performance of participants are summarised in Table 2.

Table 2 Summary of data classification criteria

zeta test	R_L test	*z* test	Classification
pass	pass	pass	in agreement
pass	fail	pass	questionable
fail	pass	pass	questionable
pass	-	fail	questionable
fail	-	fail	discrepant

3. SUMMARY OF PARTICIPANTS RESULTS

The summary of classification results for each radionuclide in each sample type is provided in Table 3. The number of samples dispatched is assumed to be the number of samples ordered by participants. Please note when interpreting this table that participants may have ordered multiple samples and/or chosen to not submit results. In the instance that a laboratory has submitted multiple results for a given radionuclide all results will appear as a count in the table.

Table 3 Summary of classifications for each radionuclide in each sample type.

Radionuclide	No. of samples dispatched	Pass	Questionable	Fail
AB				
^{3}H	30	20	2	1
^{63}Ni		11	3	3
^{90}Sr		20	1	3
^{241}Am		25	0	1
A1				
^{226}Ra	17	6	2	3
^{241}Am		8	0	3
^{244}Cm		6	0	4
B1				
^{3}H	30	21	2	4
^{14}C		16	2	4
^{36}Cl		9	2	2
GH				
^{22}Na	34	21	9	3
^{60}Co		32	3	0
^{133}Ba		24	8	2
^{137}Cs		29	6	0
^{155}Eu		27	5	2
GL				
^{54}Mn	26	22	2	0
^{65}Zn		21	3	0
^{139}Ce		22	1	1
^{210}Pb		11	4	1

In addition to the analyses of individual participants' data as described in section 2, the PMM of the reported results for each radionuclide was compared with the NPL Assigned Values. The results are given in Tables 4 - 8. The tests as described in section 2 are used to assess the agreement between these values. The reference time is 2023-06-01 12:00 UTC.

Table 4 AB summary

Radionuclide	NPL Assigned Values ($Bq\ g^{-1}$)	PMM ($Bq\ g^{-1}$)	Deviation %	Zeta	Critical Value
^{3}H	13.24 ± 0.19	12.97 ± 0.20	−2.0	−0.98	2.64
^{63}Ni	3.589 ± 0.017	3.416 ± 0.057	−4.8	−2.90	2.98
^{90}Sr	3.5493 ± 0.0095	3.511 ± 0.032	−1.1	−1.15	2.80
^{241}Am	11.618 ± 0.046	11.689 ± 0.081	0.6	0.77	2.70

Table 5 A1 summary

Radionuclide	NPL Assigned Values ($Bq\ kg^{-1}$)	PMM ($Bq\ g^{-1}$)	Deviation %	Zeta	Critical Value
^{226}Ra	45.44 ± 0.57	41.0 ± 1.1	−9.8	−3.63	3.11
^{241}Am	88.14 ± 0.35	88.1 ± 1.1	0.0	−0.04	3.11
^{244}Cm	21.641 ± 0.033	19.40 ± 0.92	−10.3	−2.42	3.36

Table 6 B1 summary

Radionuclide	NPL Assigned Values (Bq g^{-1})	PMM (Bq g^{-1})	Deviation %	Zeta	Critical Value
^{3}H	0.2821 ± 0.0047	0.2852 ± 0.0031	1.1	0.54	2.58
^{14}C	0.4031 ± 0.0018	0.4034 ± 0.0065	0.1	0.05	2.86
^{36}Cl	0.21867 ± 0.00076	0.2124 ± 0.0050	−2.9	−1.23	3.17

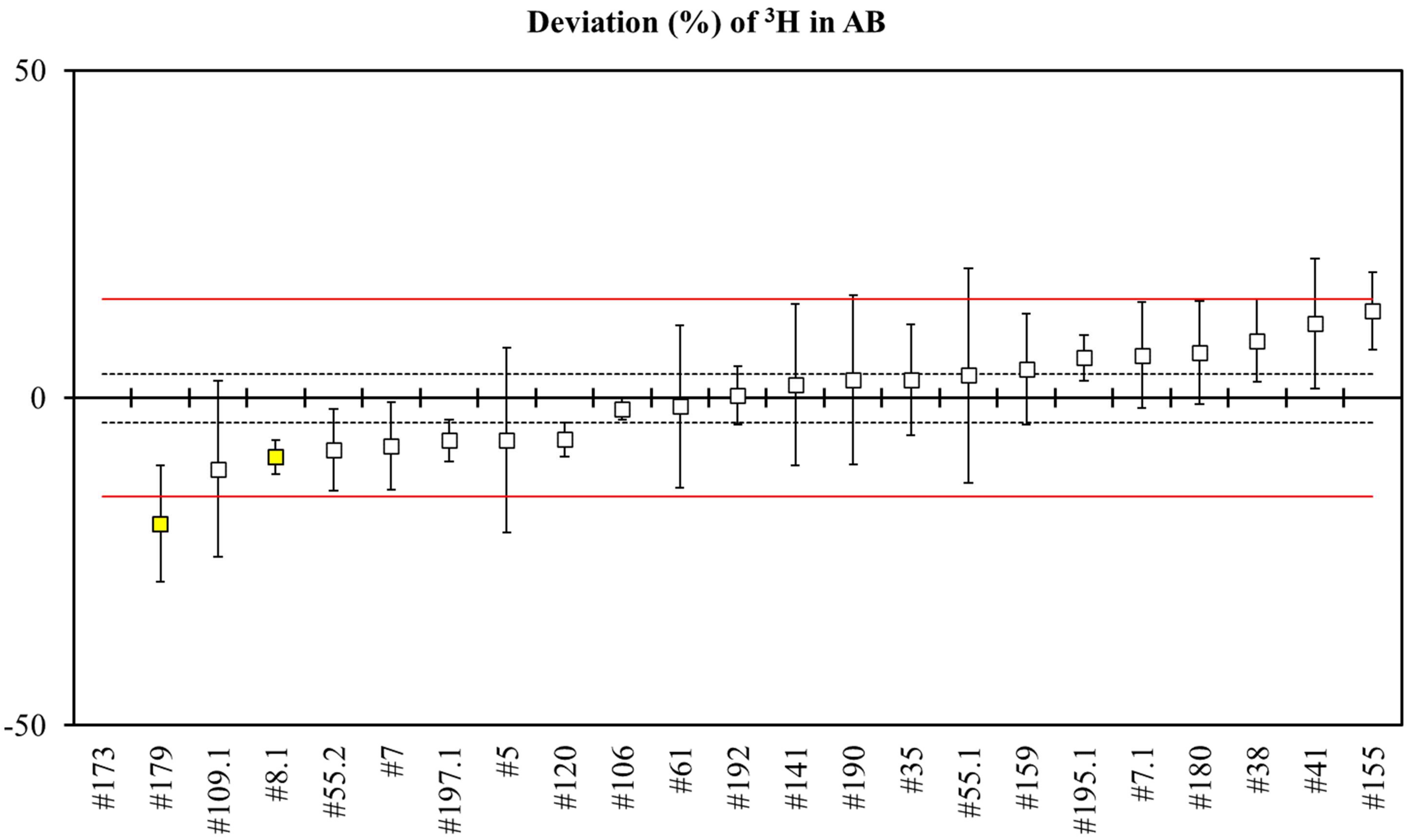
Table 7 GH summary

Radionuclide	NPL Assigned Values (Bq g^{-1})	PMM (Bq g^{-1})	Deviation %	Zeta	Critical Value
^{22}Na	8.674 ± 0.033	8.459 ± 0.069	−2.5	−2.82	2.70
^{60}Co	31.23 ± 0.11	30.833 ± 0.079	−1.3	−2.94	2.58
^{133}Ba	38.84 ± 0.27	37.92 ± 0.27	−2.4	−2.43	2.63
^{137}Cs	13.201 ± 0.098	12.928 ± 0.052	−2.1	−2.46	2.58
^{155}Eu	7.63 ± 0.14	7.654 ± 0.061	0.3	0.15	2.58

Table 8 GL summary

Radionuclide	NPL Assigned Values (Bq kg^{-1})	PMM (Bq g^{-1})	Deviation %	Zeta	Critical Value
^{54}Mn	17.22 ± 0.18	17.25 ± 0.14	0.2	0.12	2.58
^{65}Zn	29.67 ± 0.22	29.82 ± 0.27	0.5	0.43	2.66
^{139}Ce	44.41 ± 0.39	45.31 ± 0.44	2.0	1.54	2.65
^{210}Pb	13.67 ± 0.15	14.42 ± 0.29	5.5	2.27	2.82

4. ALPHA BETA (AB) DEVIATION PLOTS


Deviation (%) of ³H in AB
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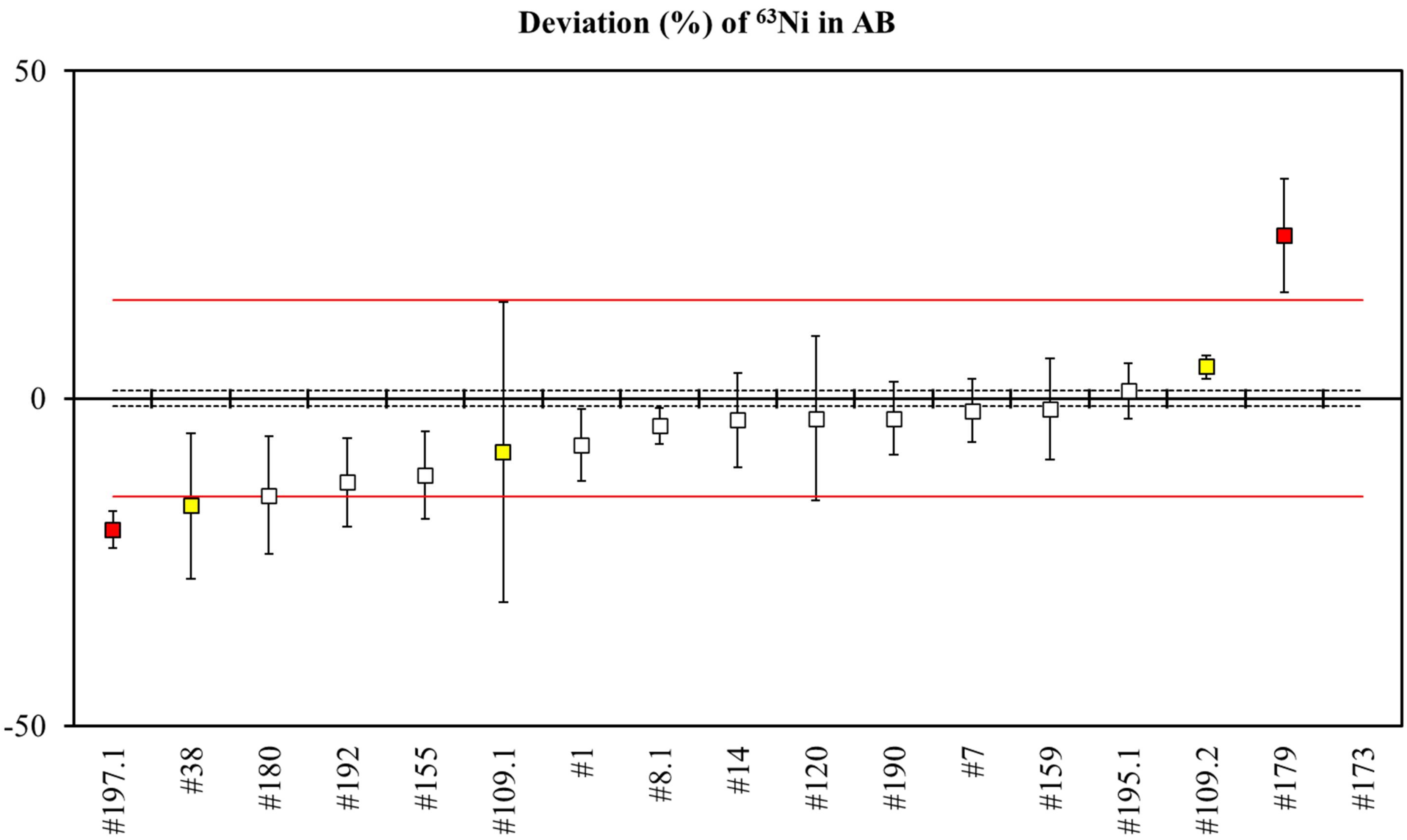
#180
#38
#41
#155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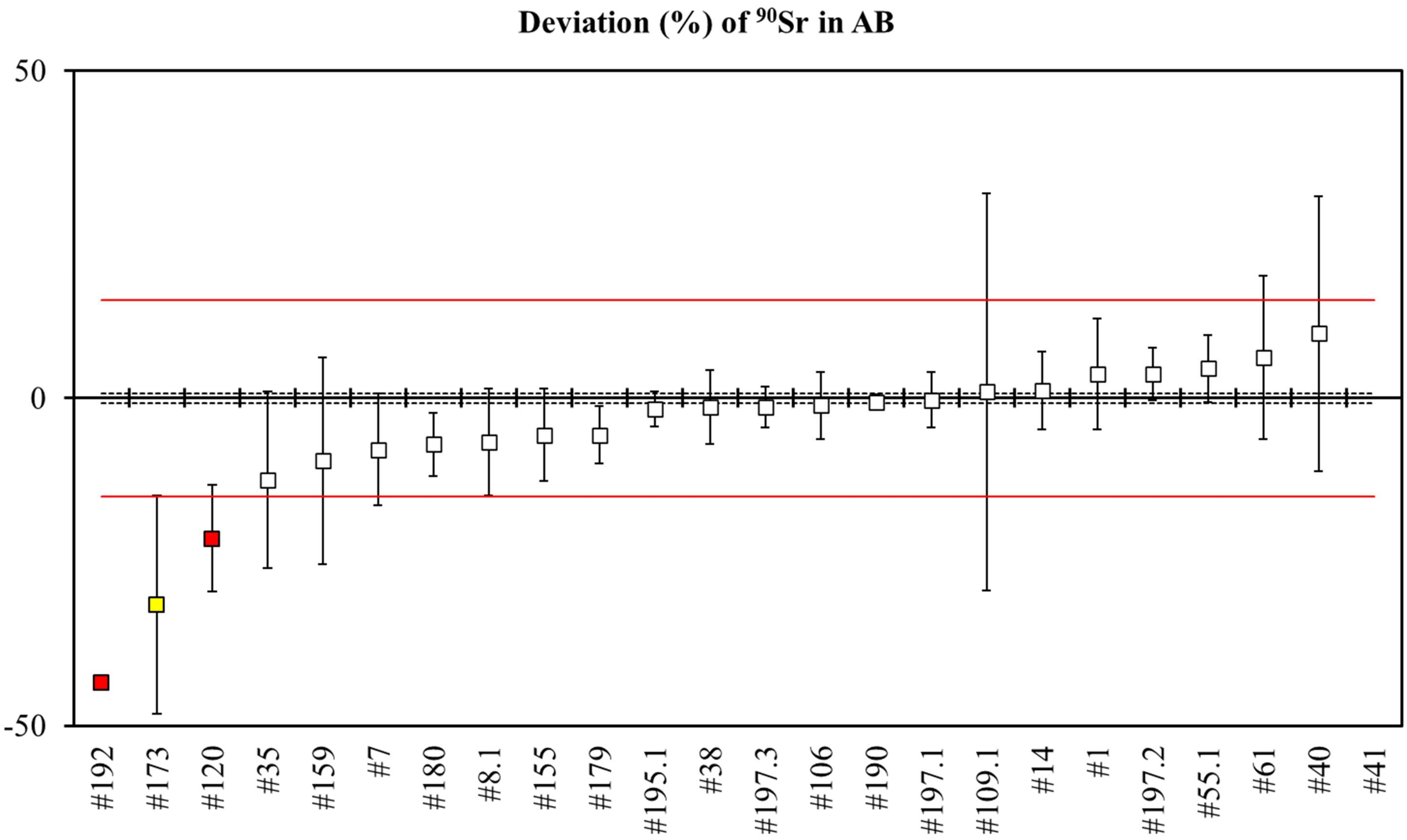
#109.2
#179
#173


Deviation (%) of ^{90}Sr in AB
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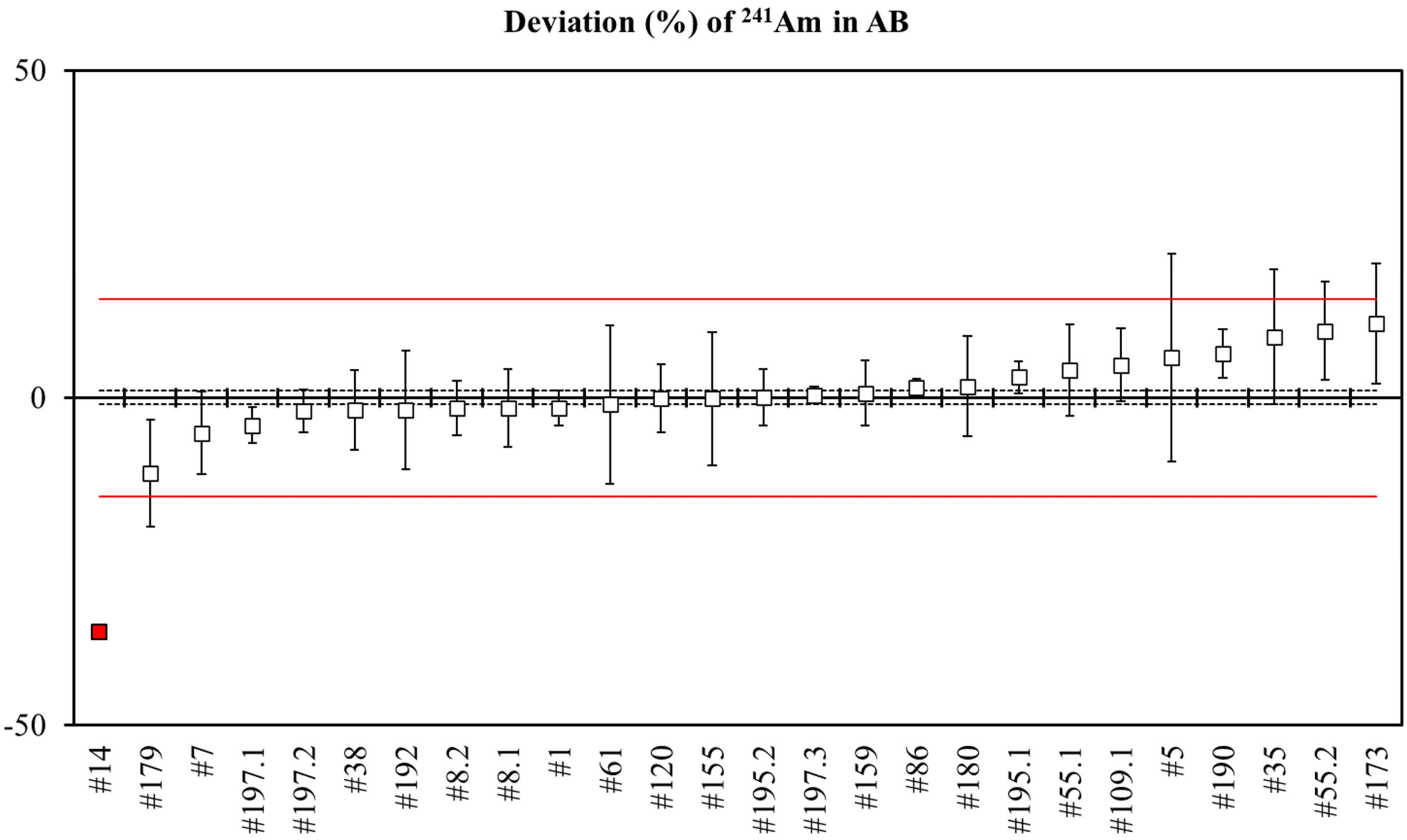
Deviation (%) of ^{241}Am in AB
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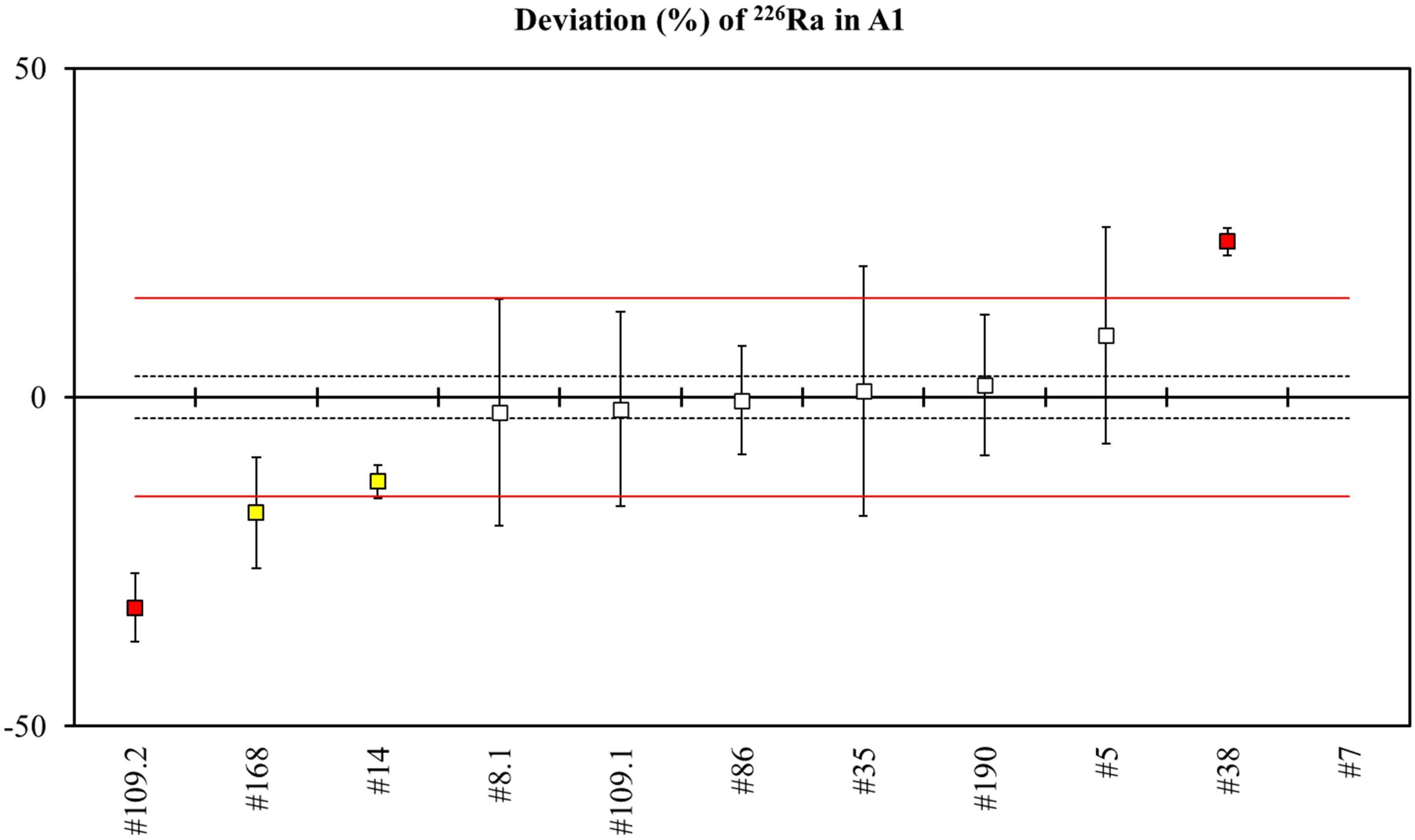
5. ALPHA ONE (A1) DEVIATION PLOTS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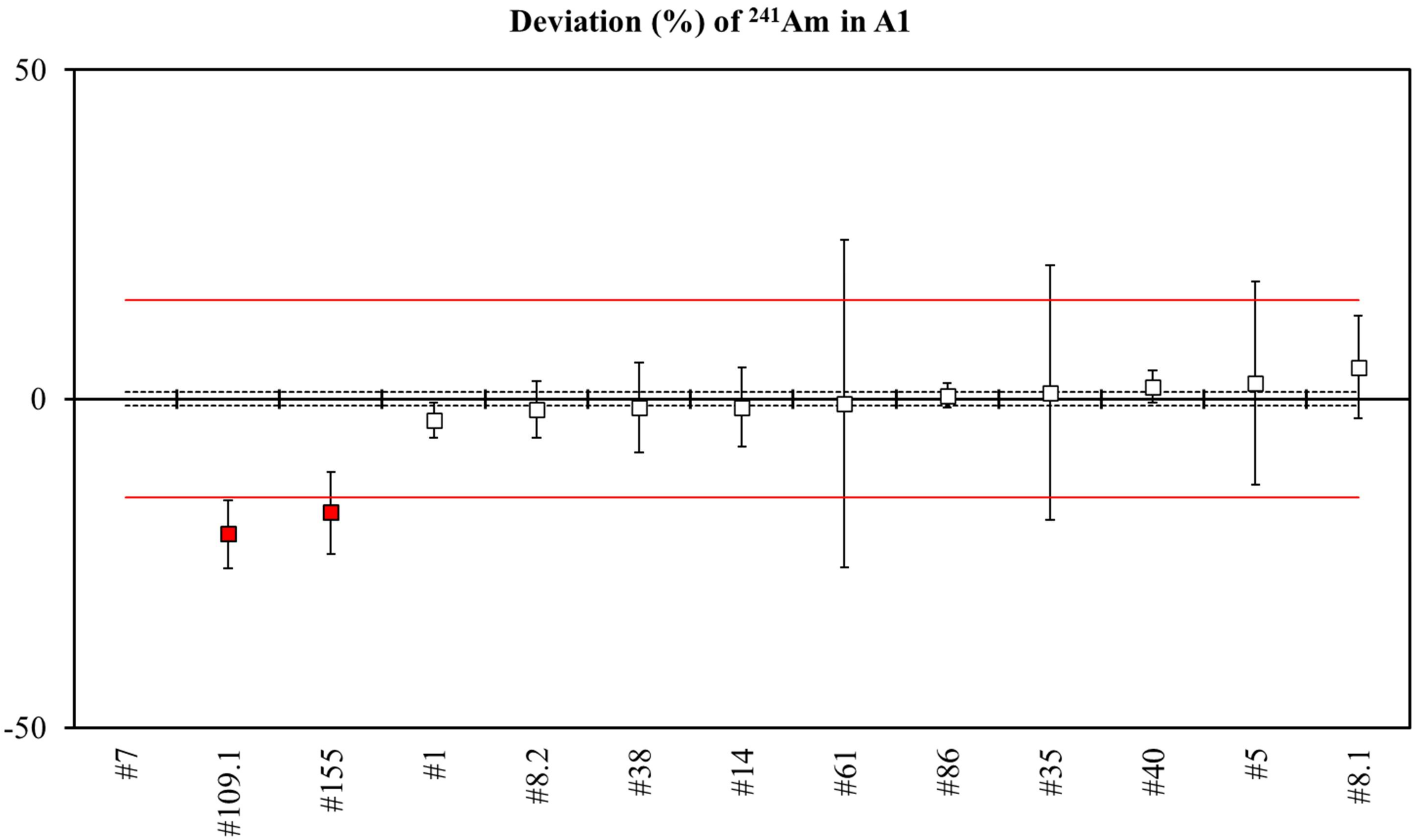

Deviation (%) of ^{241}Am in A1
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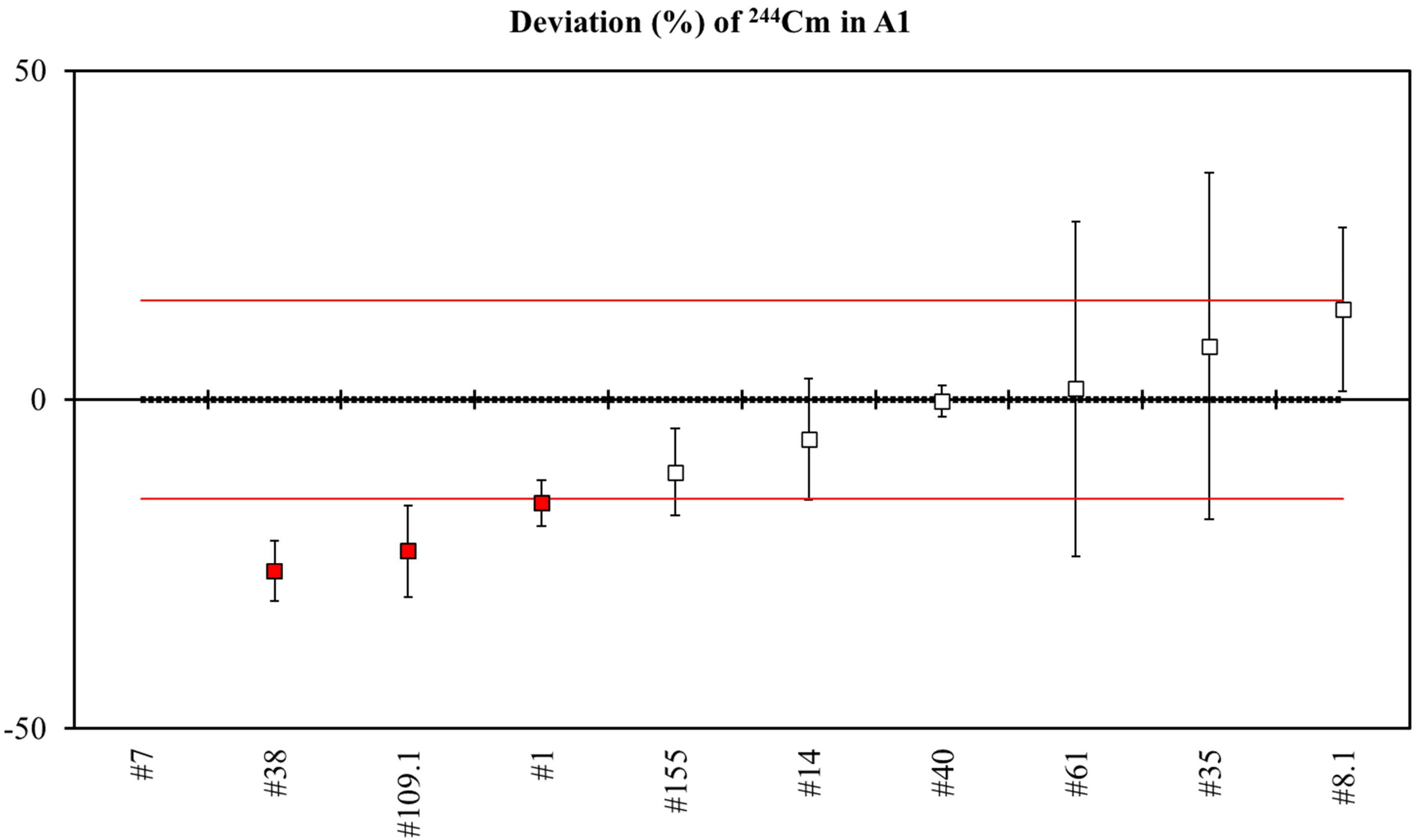
#86
#35
#40
#5
#8.1


Deviation (%) of 244Cm in A1
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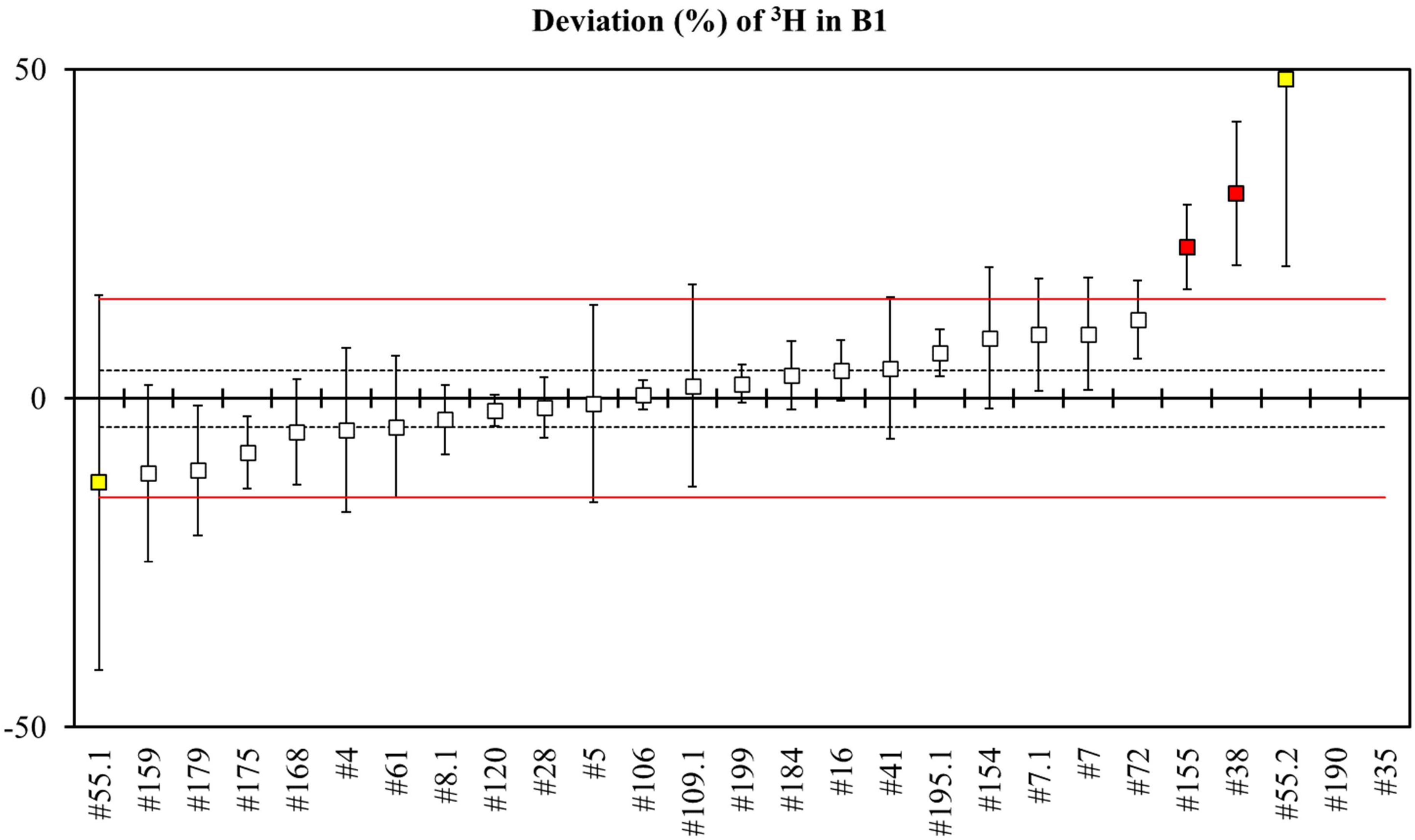
6. BETA ONE (B1) DEVIATION PLOTS


Deviation (%) of ^{3}H in B1
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#179
#175
#168
#4
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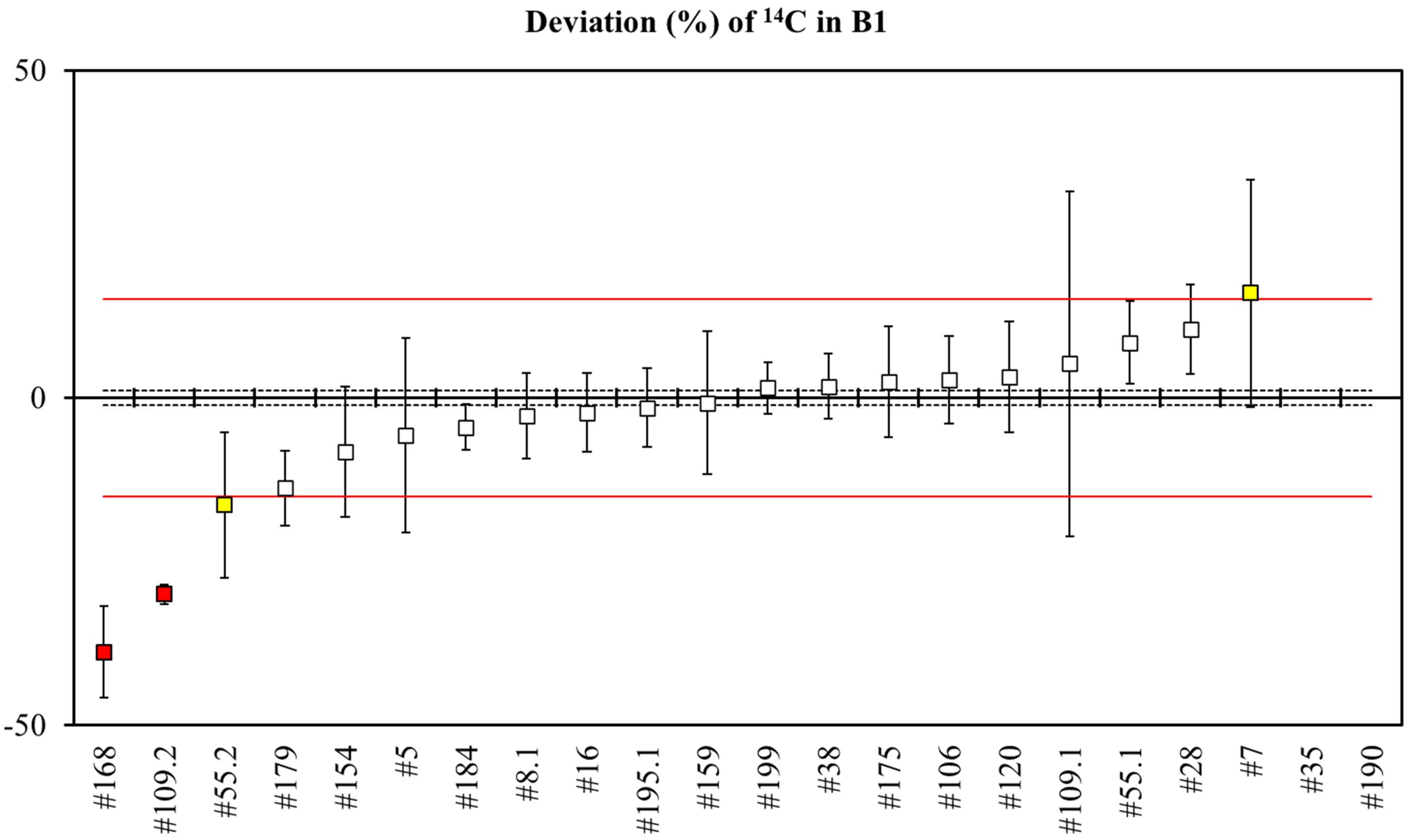
#55.2
#190
#35


Deviation (%) of 14C in B1
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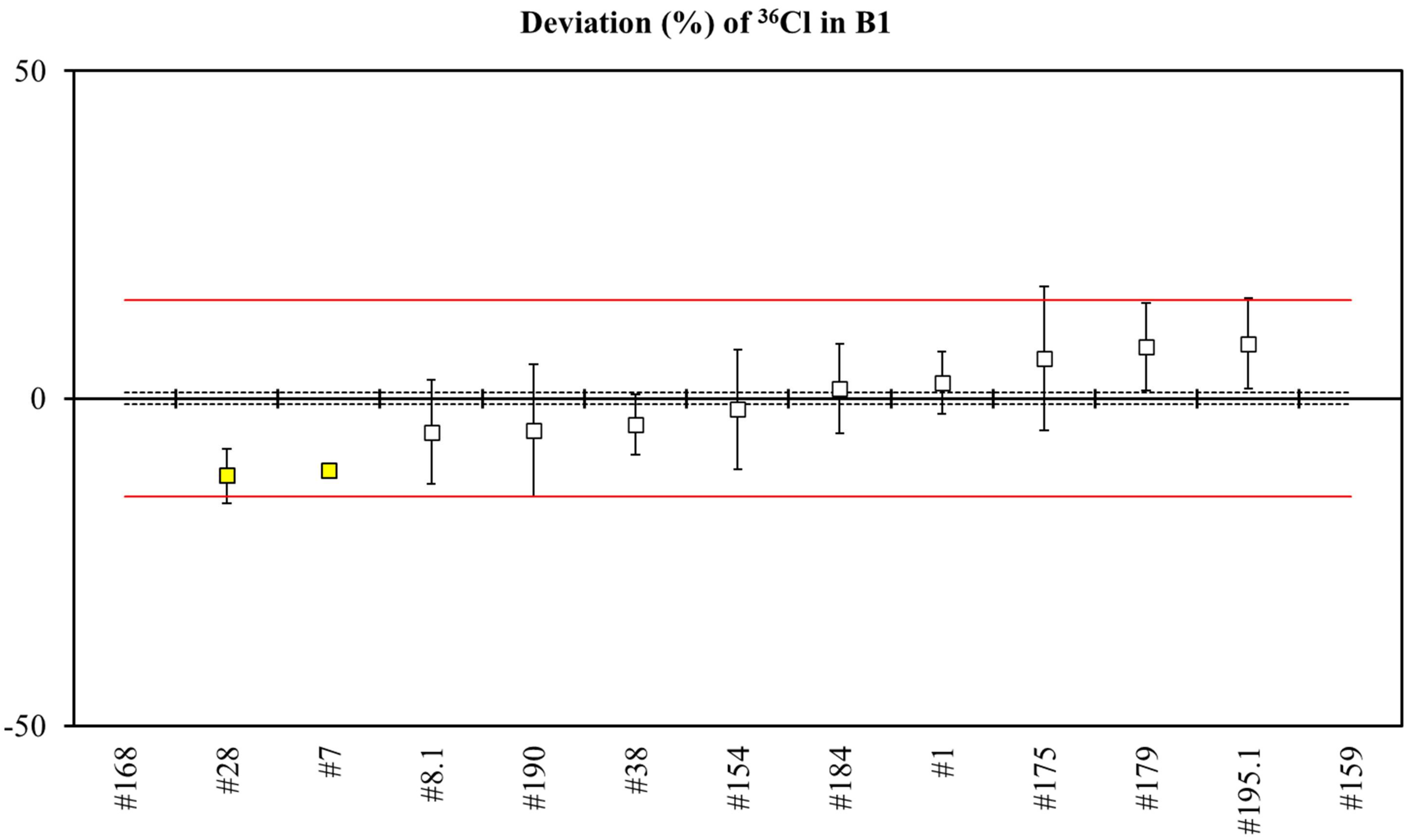
#28
#7
#35
#190


Deviation (%) of 36Cl in B1
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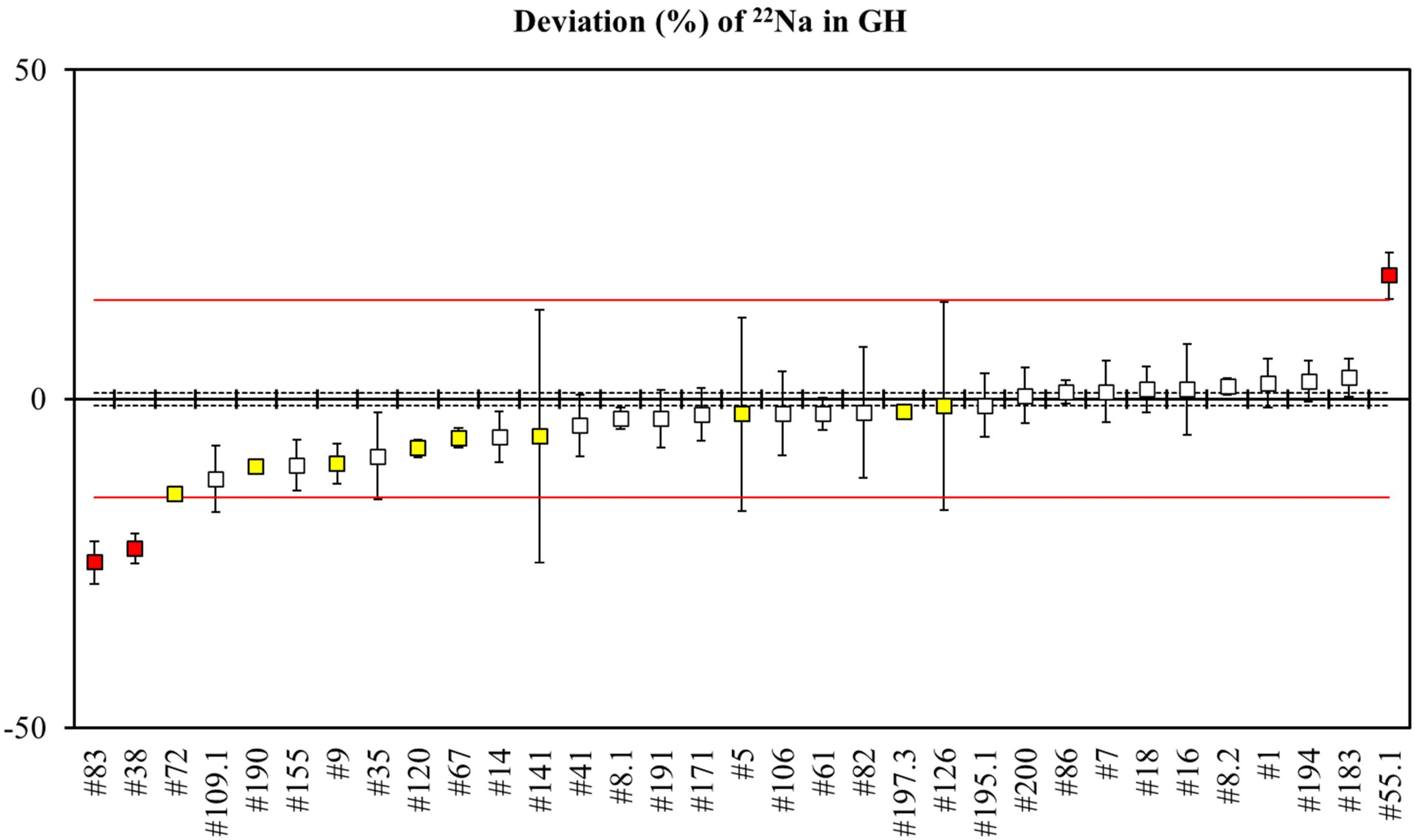
#159

7. GAMMA HIGH (GH) DEVIATION PLOTS



Deviation (%) of ^{22}Na in GH
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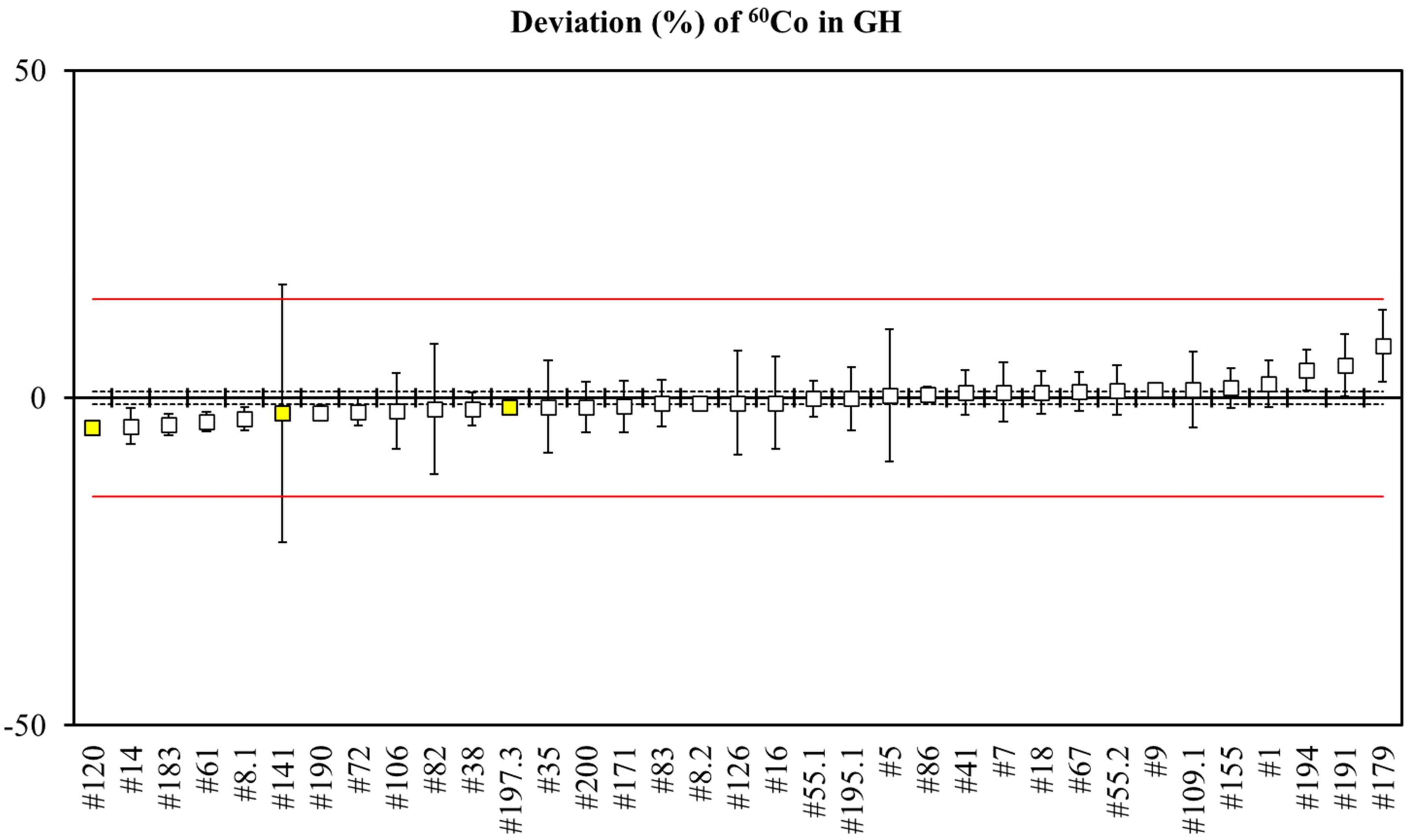
Deviation (%) of 60Co in GH
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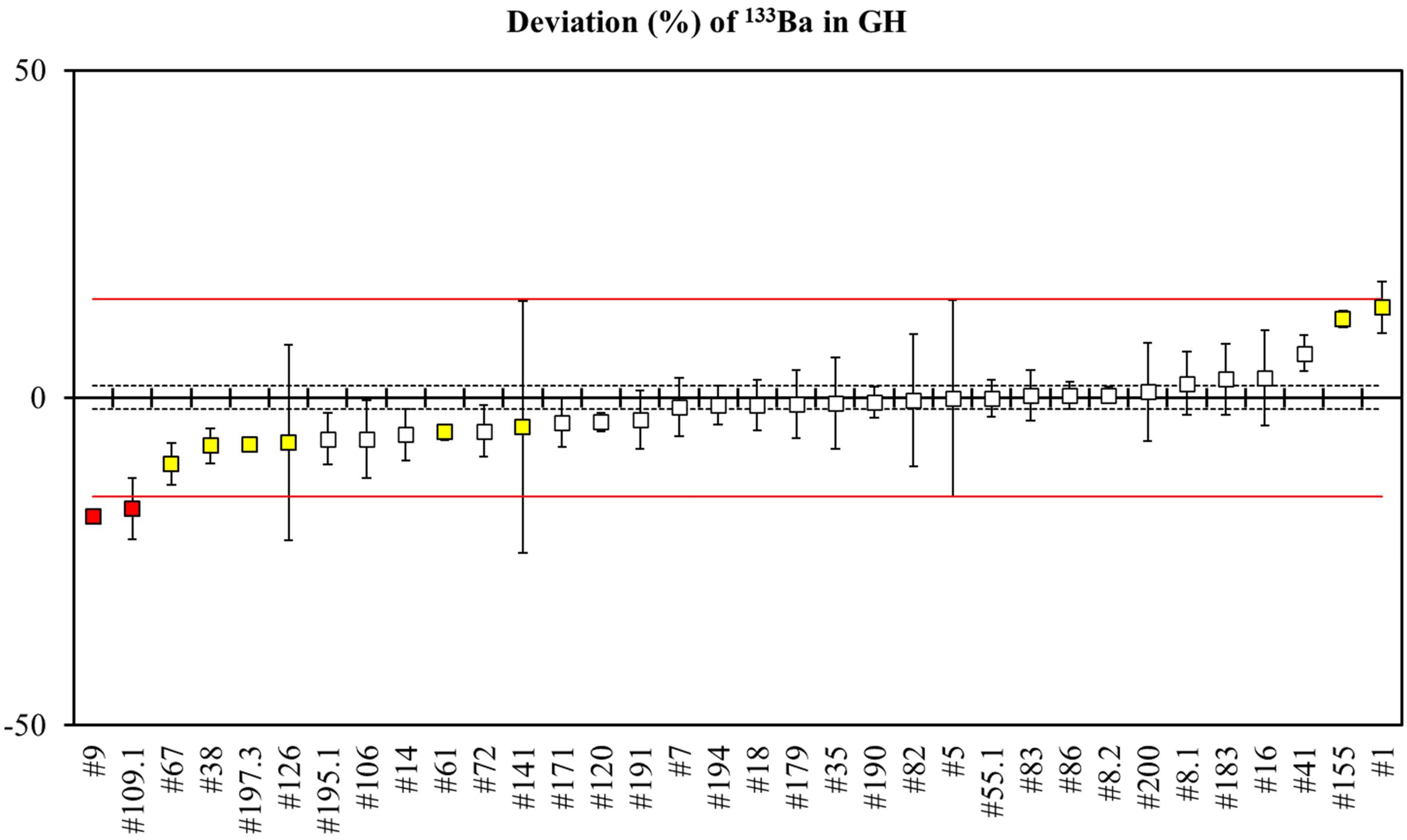
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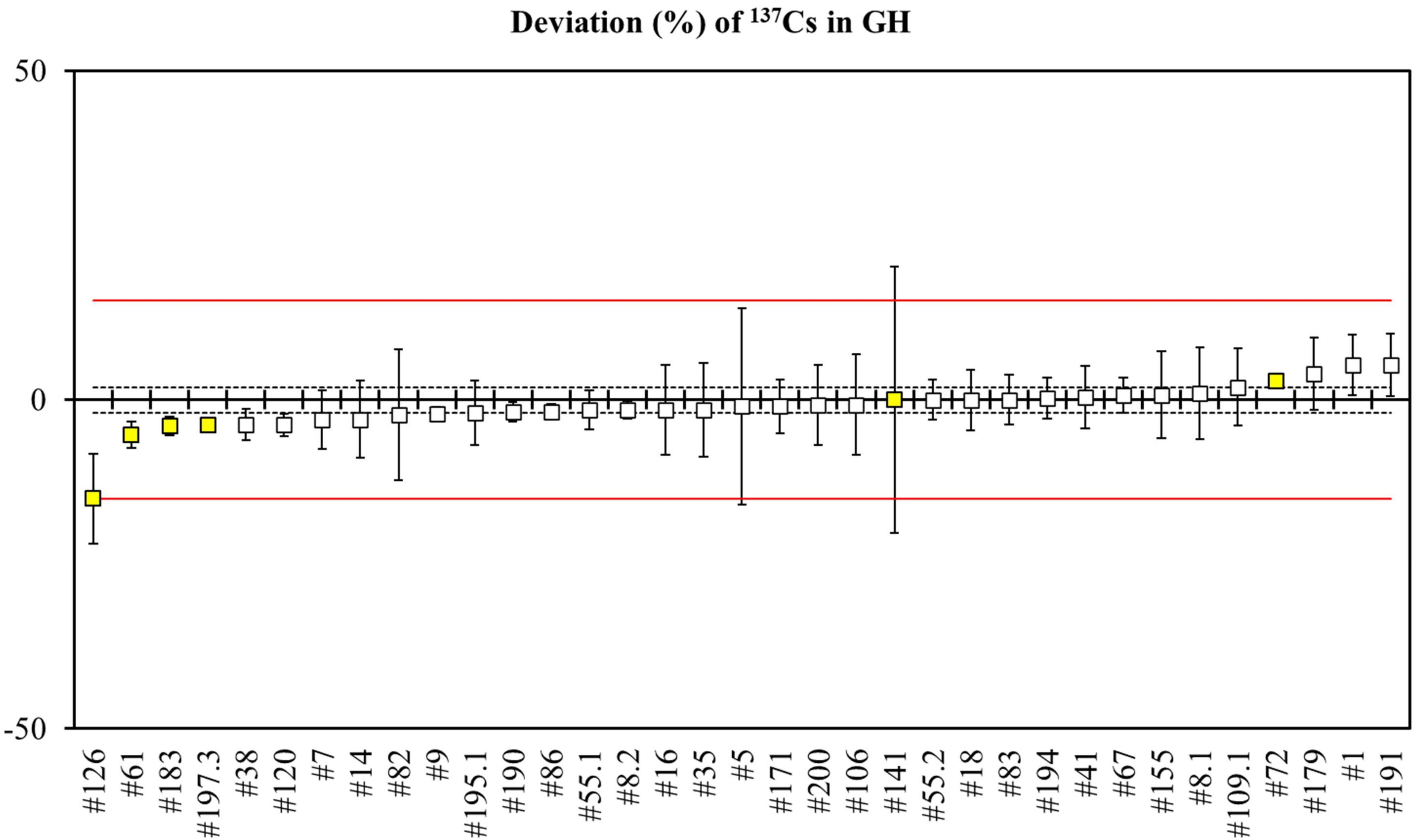
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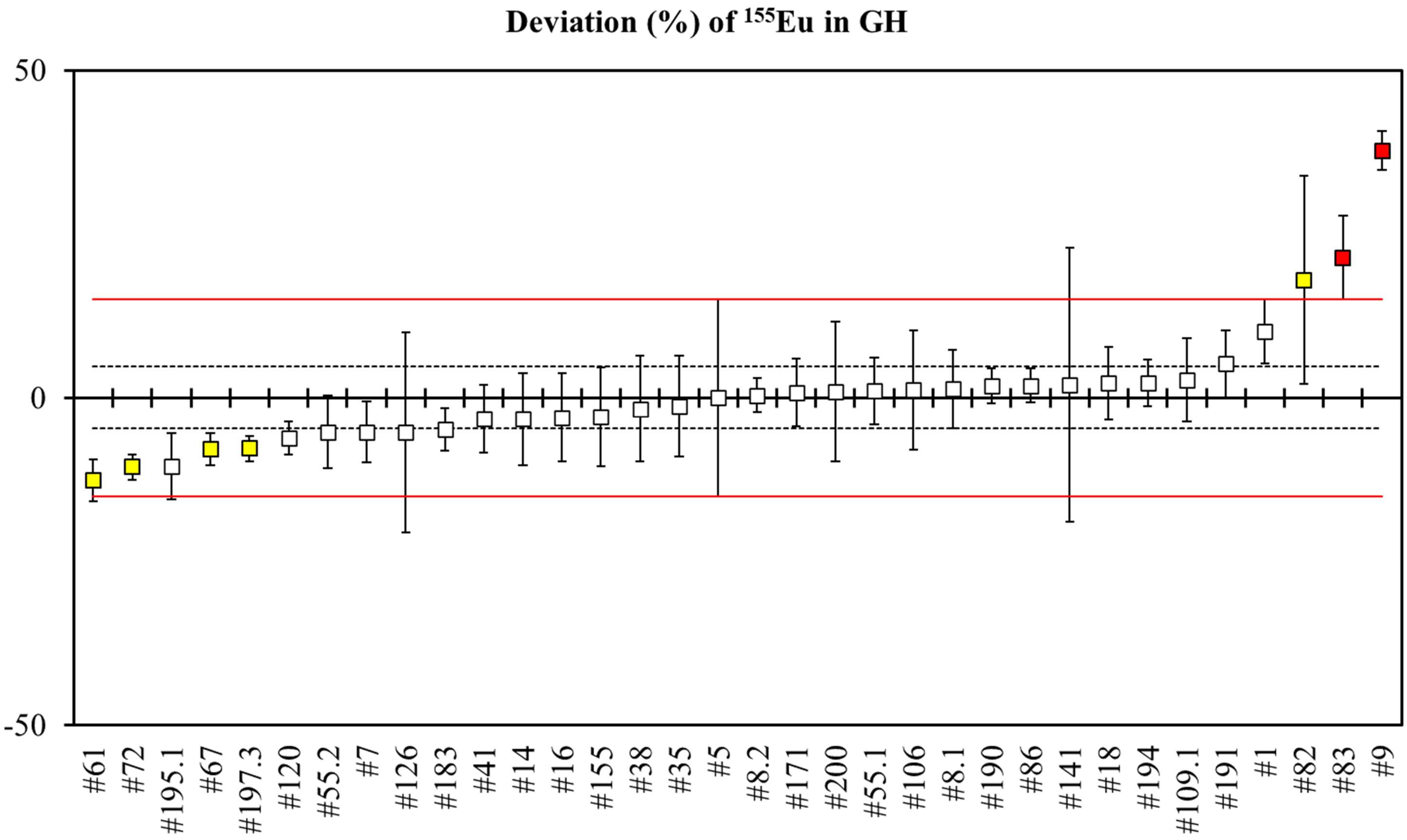
Deviation (%) of ^{155}Eu in GH
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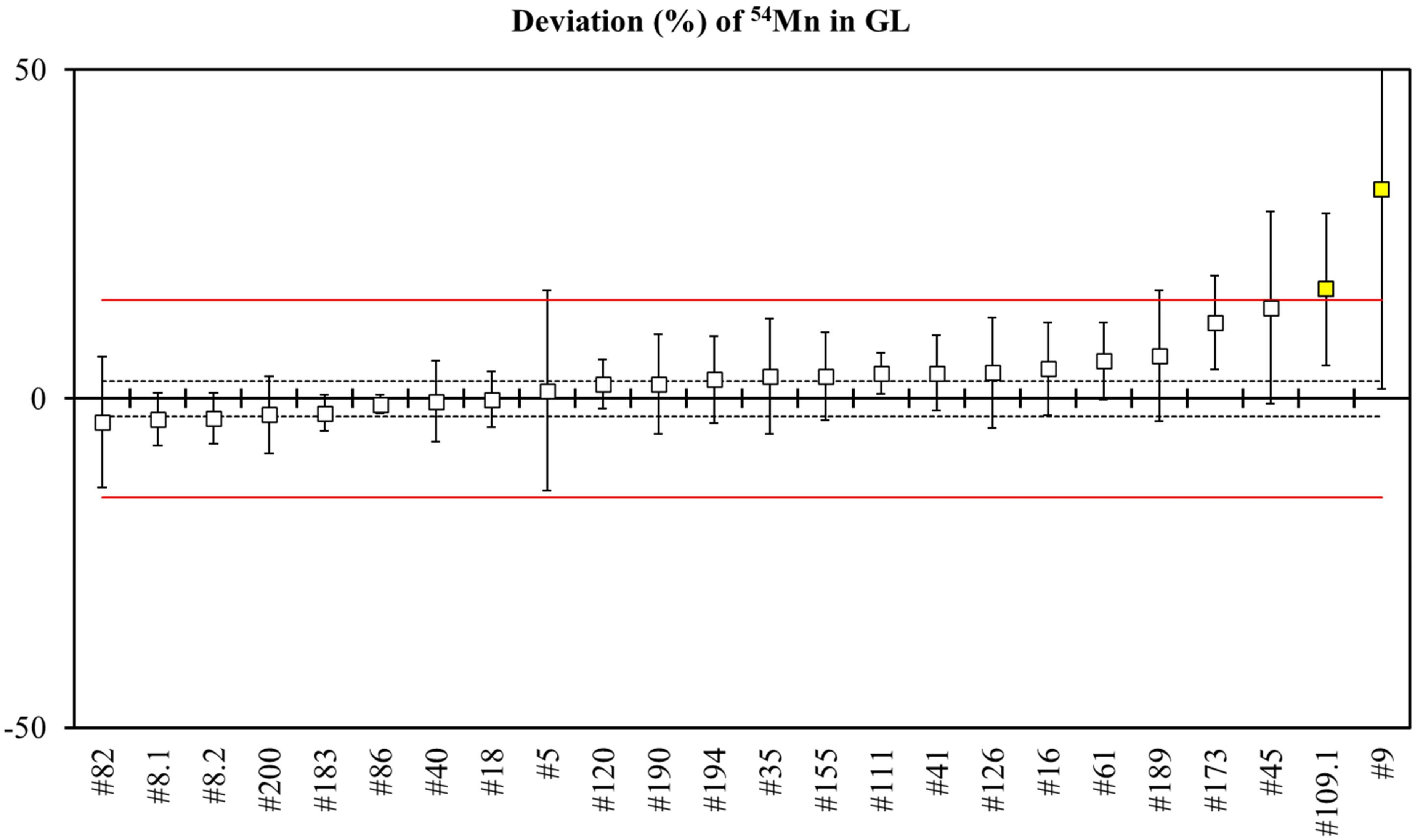
8. GAMMA LOW (GL) DEVIATION PLOTS


Deviation (%) of ^{54}Mn in GL
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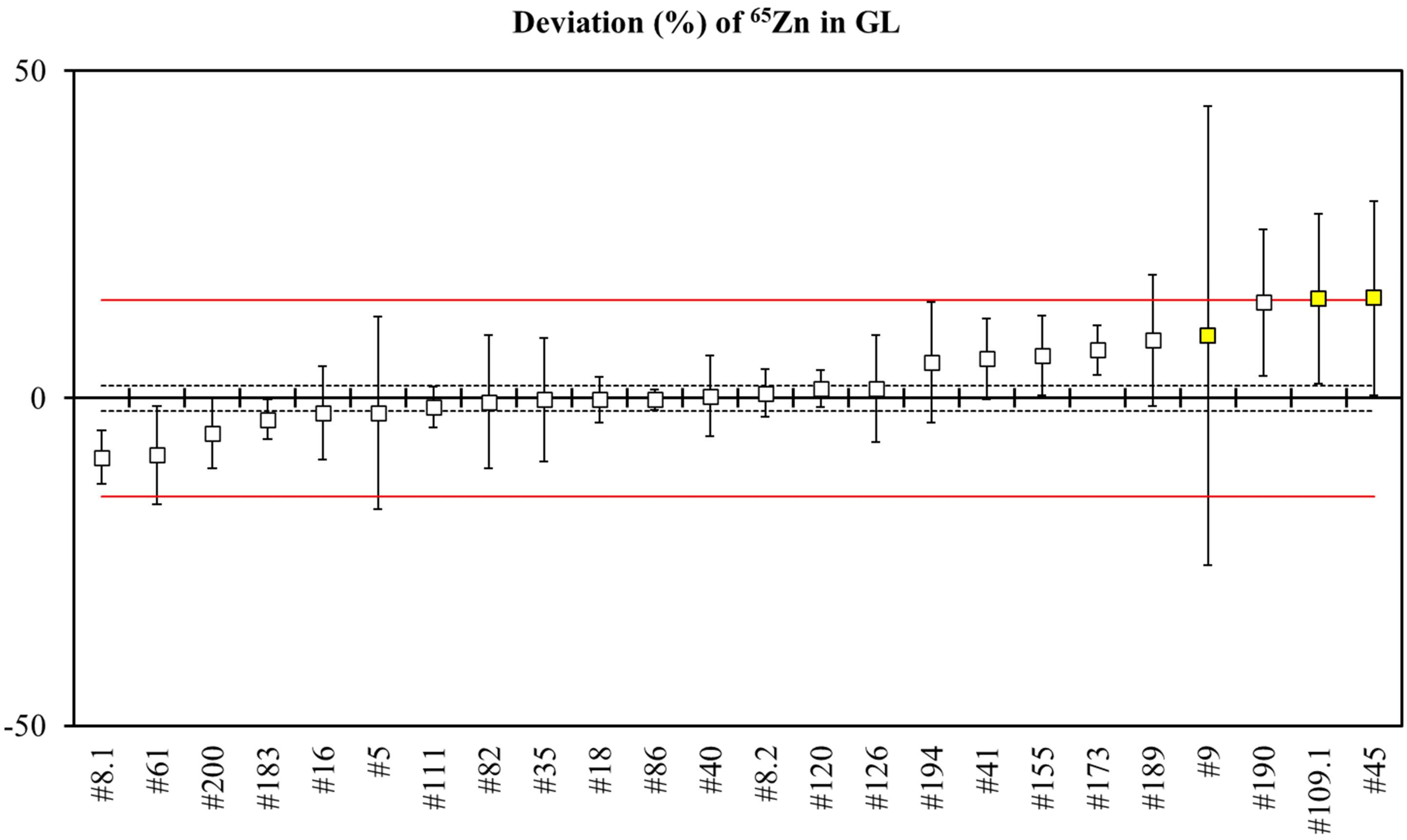
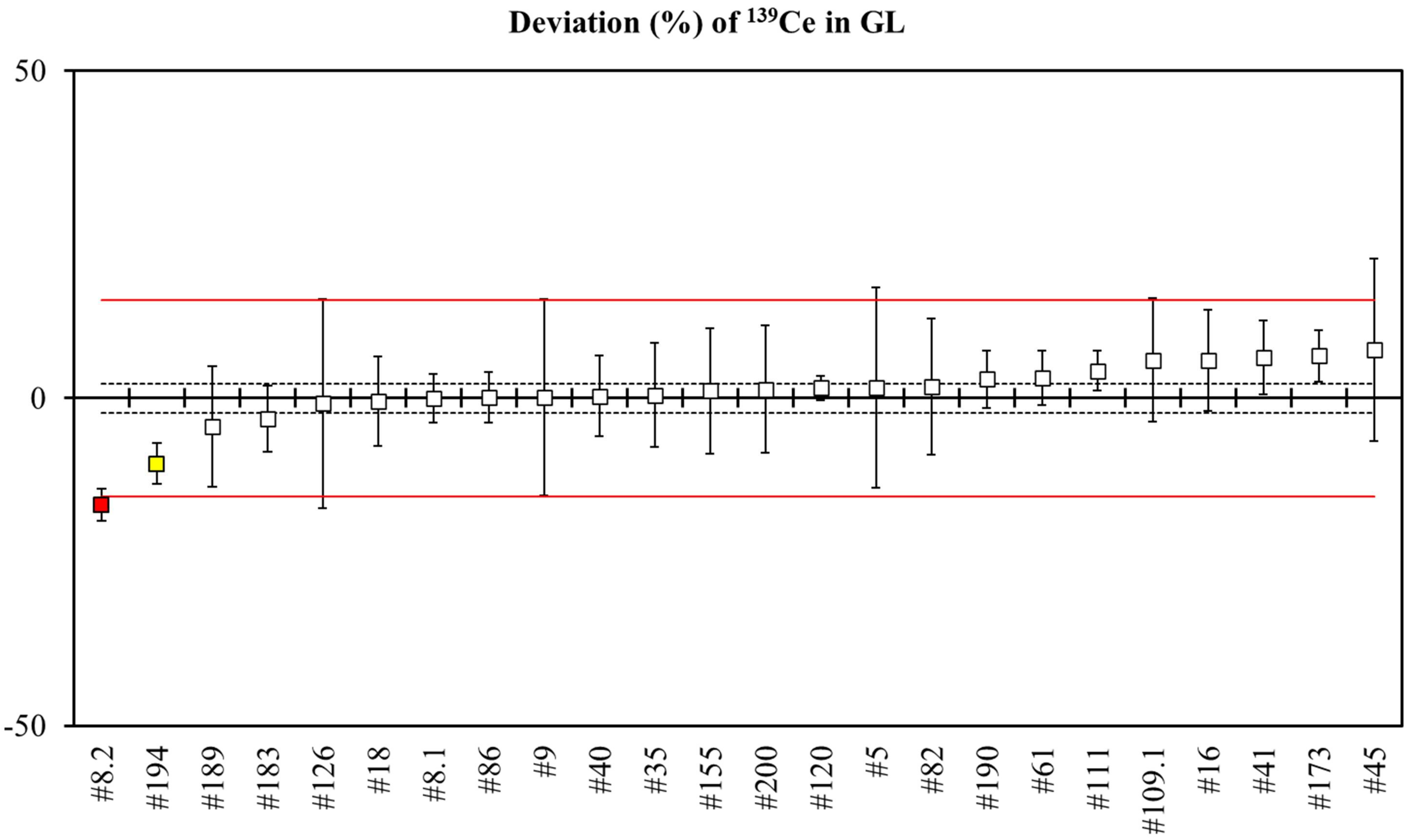
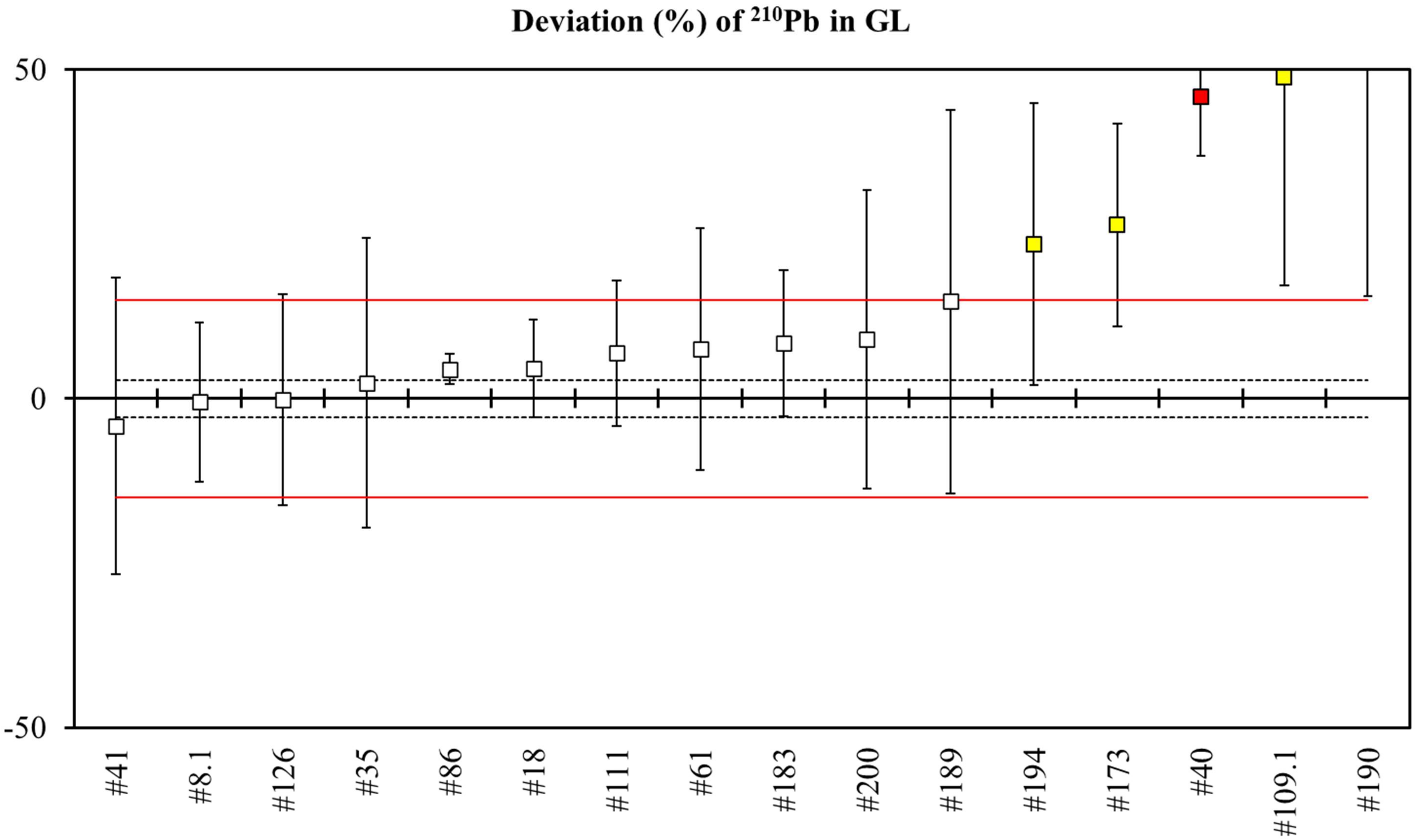
#109.1
#9


Deviation (%) of 65Zn in GL
50
0
-50
#8.1
#61
#200
#183
#16
#5
#111
#82
#35
#18
#86
#40
#8.2
#120
#126
#194
#41
#155
#173
#189
#9
#190
#109.1
#45

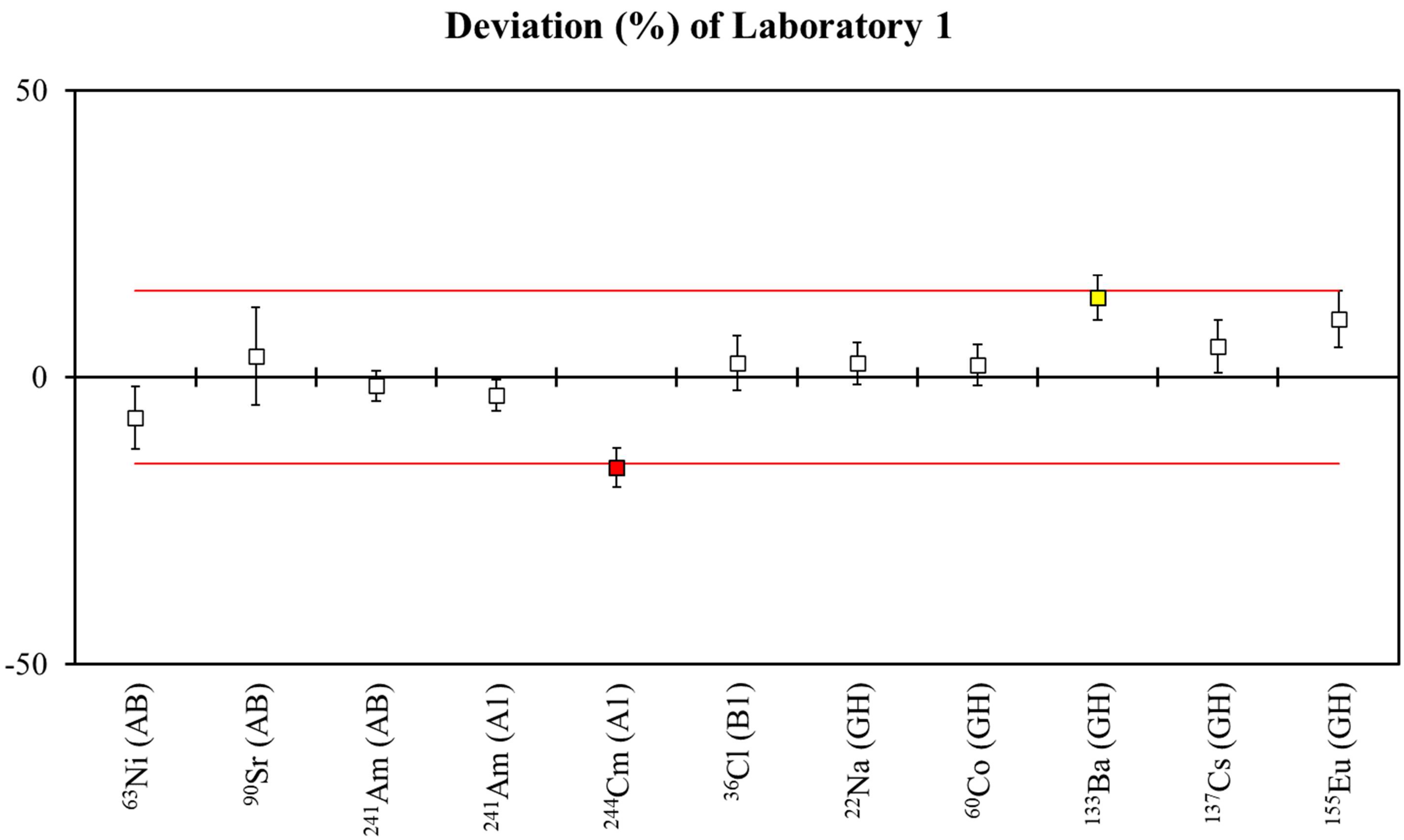

Deviation (%) of ^{139}Ce in GL
50
0
-50
#8.2
#194
#189
#183
#126
#18
#8.1
#86
#9
#40
#35
#155
#200
#120
#5
#82
#190
#61
#111
#109.1
#16
#41
#173
#45


Deviation (%) of 210Pb in GL
50
0
-50
#41
#8.1
#126
#35
#86
#18
#111
#61
#183
#200
#189
#194
#173
#40
#109.1
#190

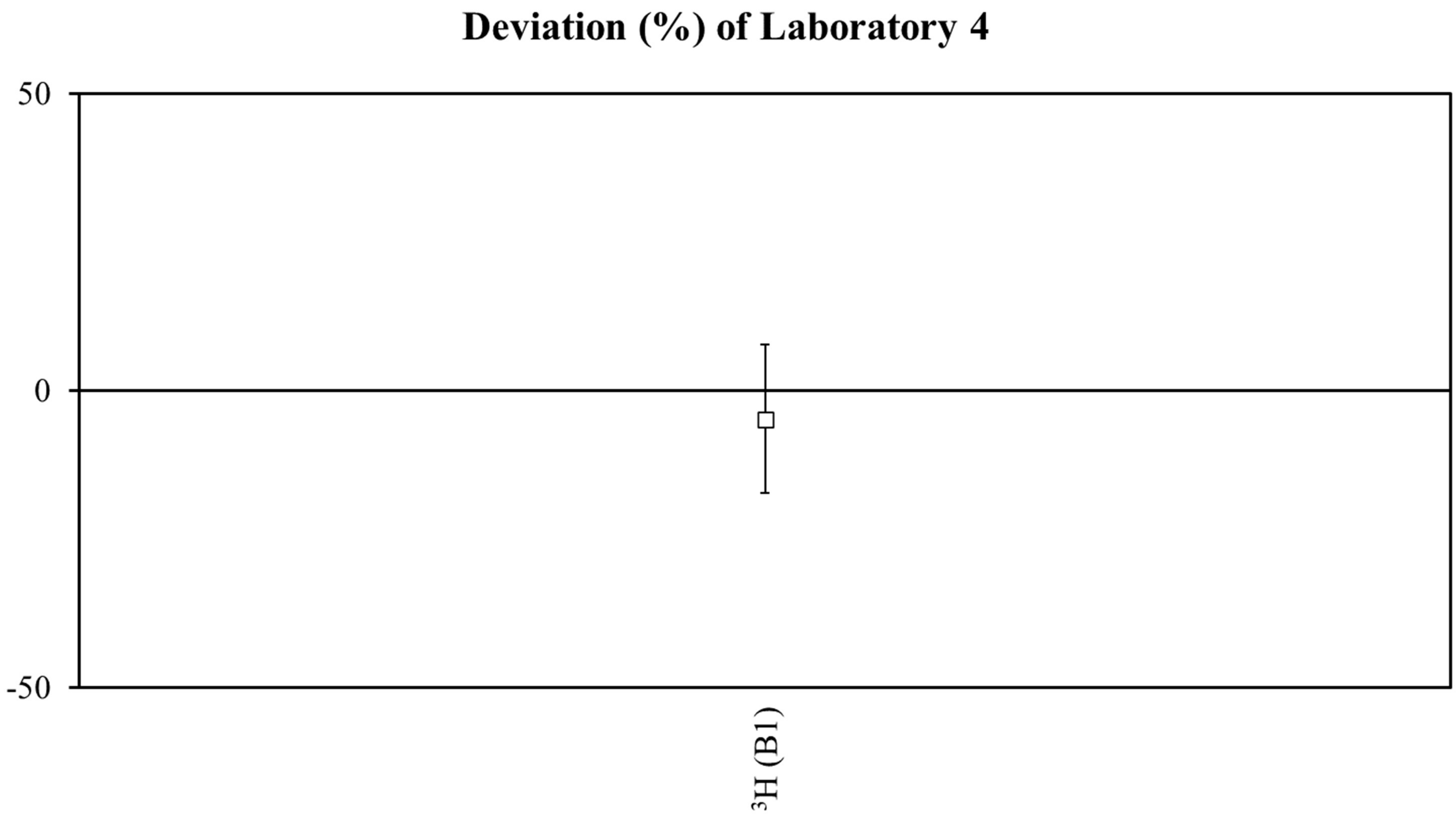
9. DEVIATION PLOTS AND TABULATED RESULTS ARRANGED BY LAB NUMBER

NOTE:

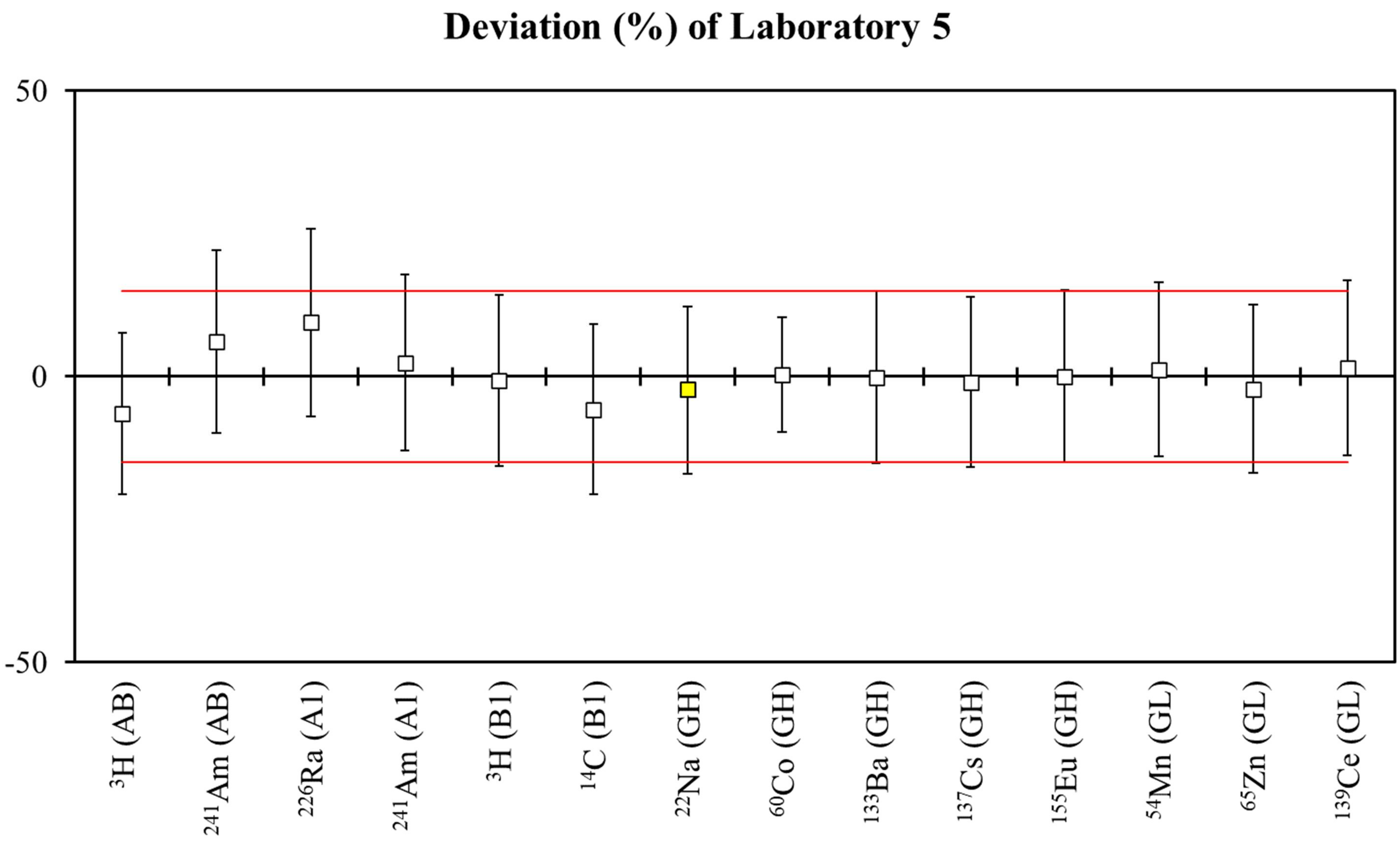
1. Data are quoted rounded, at k = 1 (standard uncertainty). Data analysis was carried out on data as reported (i.e. before rounding). Uncertainties have been rounded to two significant figures.
2. Units of the Assigned Values and the reported results are as follows:
   a. AB – Bq g^{-1}
   b. A1 – Bq kg^{-1}
   c. B1 – Bq g^{-1}
   d. GH – Bq g^{-1}
   e. GL – Bq kg^{-1}


Deviation (%) of Laboratory 1
50
0
-50
63Ni (AB)
90Sr (AB)
241Am (AB)
241Am (A1)
244Cm (A1)
36Cl (B1)
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)

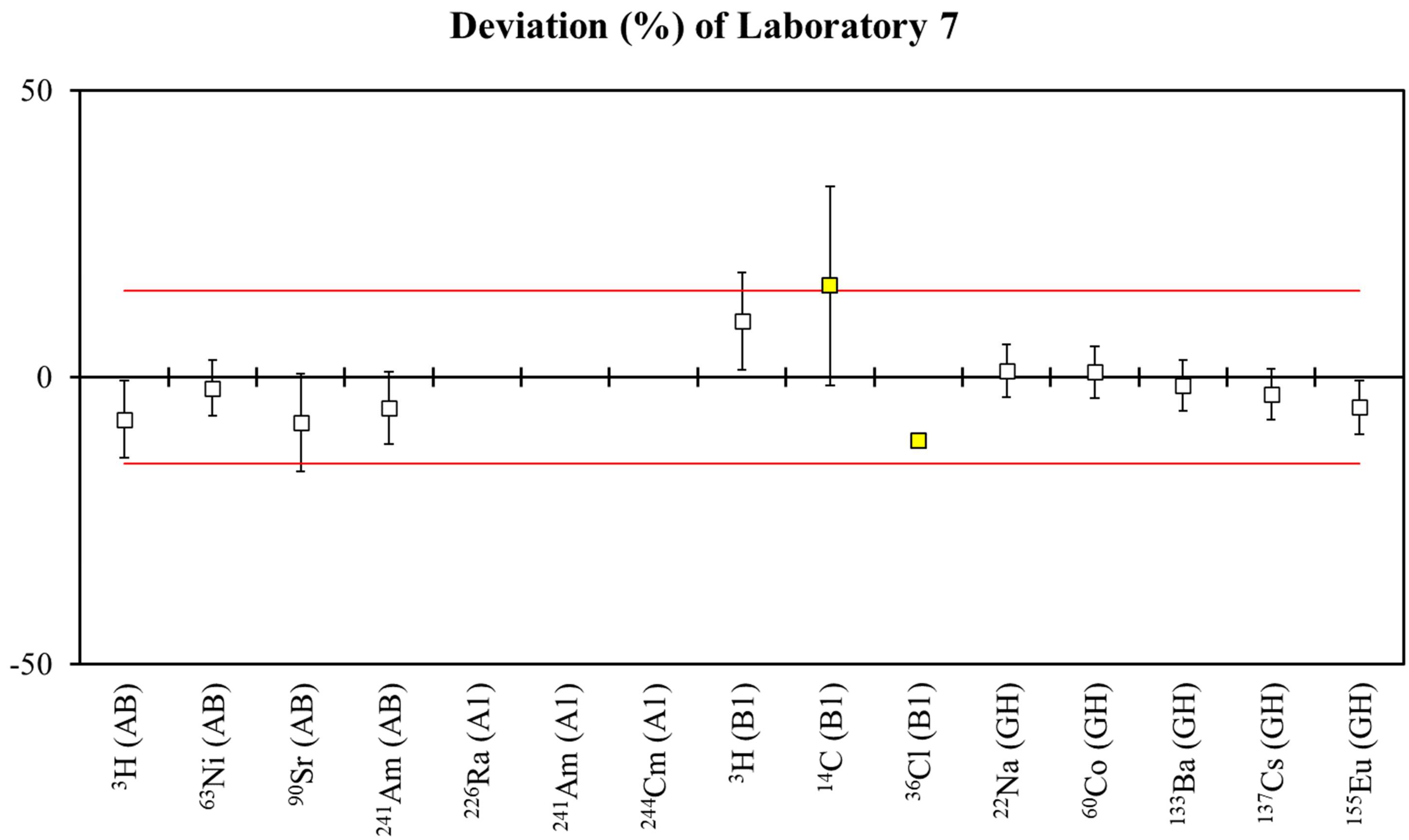
Radionuclide	Laboratory 1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{63}Ni (AB)	3.34 ± 0.20	3.589 ± 0.017	-7.0	-1.28	-1.21
^{90}Sr (AB)	3.68 ± 0.30	3.5493 ± 0.0095	3.6	0.43	0.63
^{241}Am (AB)	11.44 ± 0.31	11.618 ± 0.046	-1.5	-0.56	-0.26
^{241}Am (A1)	85.3 ± 2.4	88.14 ± 0.35	-3.2	-1.19	-0.55
^{244}Cm (A1)	18.23 ± 0.74	21.641 ± 0.033	-15.8	-4.59	-2.71
^{36}Cl (B1)	0.224 ± 0.010	0.21867 ± 0.00076	2.4	0.52	0.42
^{22}Na (GH)	8.88 ± 0.32	8.674 ± 0.033	2.4	0.64	0.41
^{60}Co (GH)	31.9 ± 1.1	31.23 ± 0.11	2.1	0.61	0.37
^{133}Ba (GH)	44.2 ± 1.5	38.84 ± 0.27	13.8	3.52	2.37
^{137}Cs (GH)	13.90 ± 0.60	13.201 ± 0.098	5.3	1.15	0.91
^{155}Eu (GH)	8.40 ± 0.34	7.63 ± 0.14	10.1	2.09	1.73


Deviation (%) of Laboratory 4
50
0
-50
^{3}H (B1)

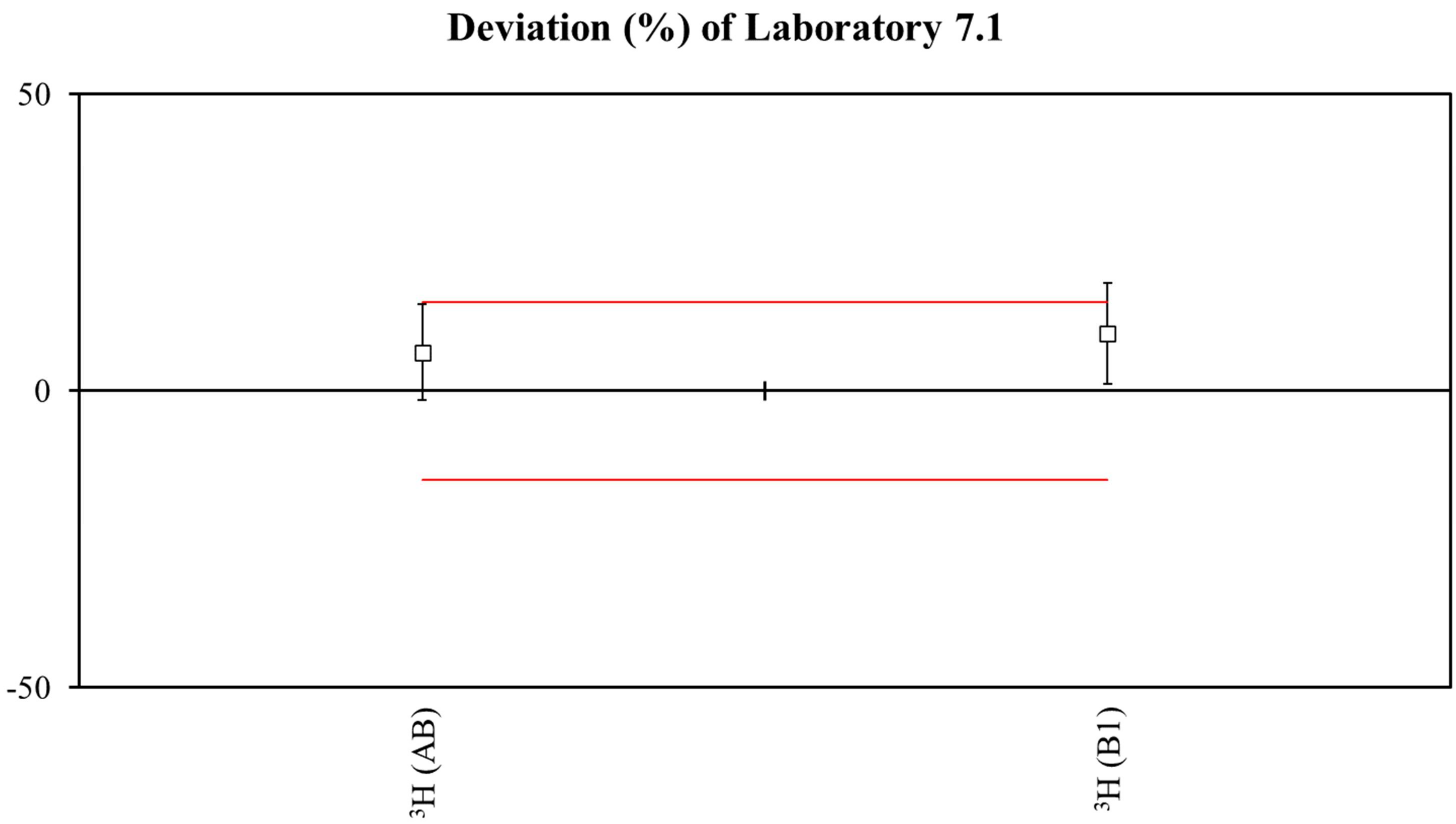
Radionuclide	Laboratory 4	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.269 ± 0.035	0.2821 ± 0.0047	-4.8	-0.39	-0.83


Deviation (%) of Laboratory 5
50
0
-50
3H (AB)
241Am (AB)
226Ra (A1)
241Am (A1)
3H (B1)
14C (B1)
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)
54Mn (GL)
65Zn (GL)
139Ce (GL)

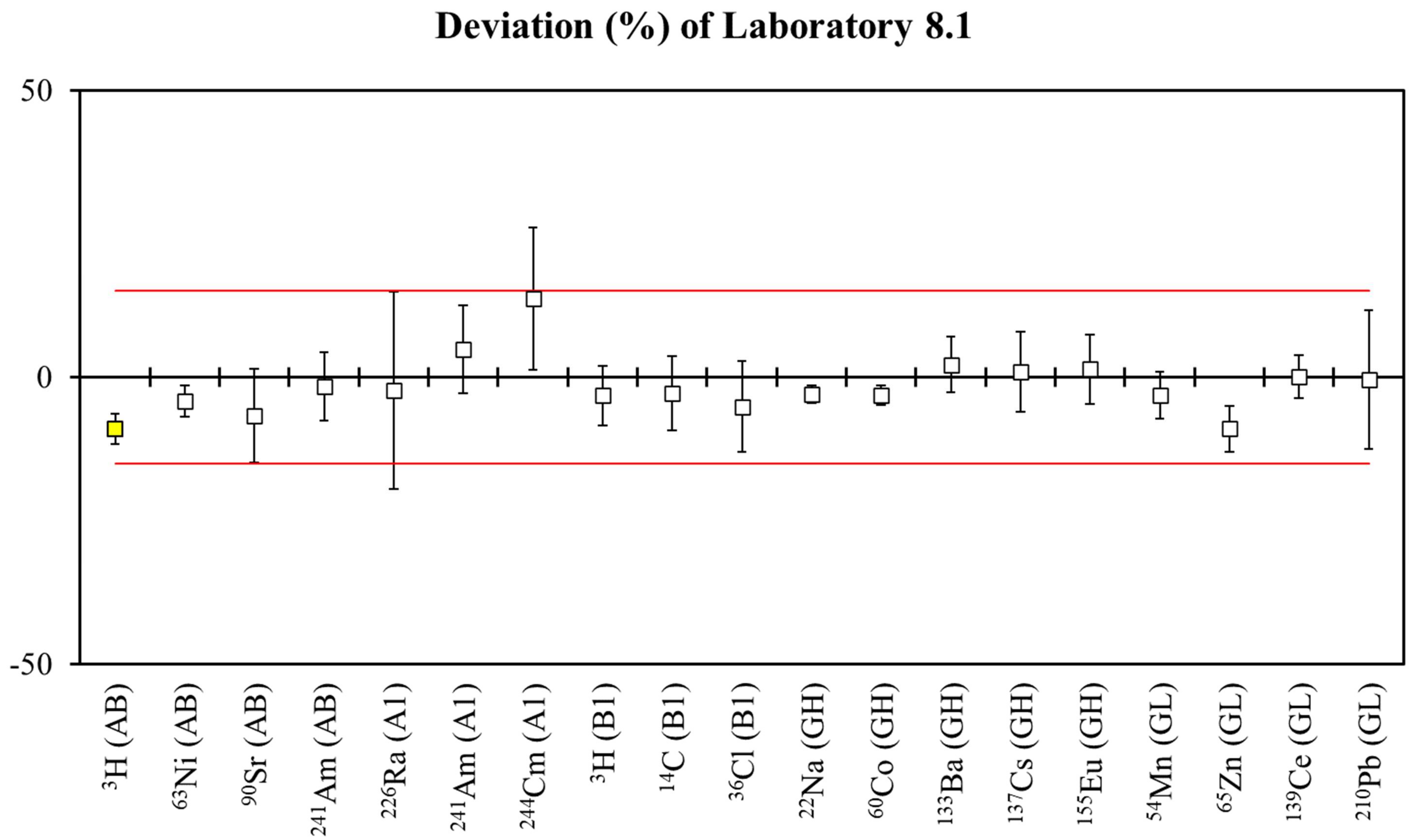
Radionuclide	Laboratory 5	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	12.4 ± 1.9	13.24 ± 0.19	-6.4	-0.45	-1.10
^{241}Am (AB)	12.3 ± 1.9	11.618 ± 0.046	6.1	0.38	1.05
^{226}Ra (A1)	49.7 ± 7.5	45.44 ± 0.57	9.4	0.57	1.62
^{241}Am (A1)	90 ± 14	88.14 ± 0.35	2.4	0.16	0.41
^{3}H (B1)	0.280 ± 0.042	0.2821 ± 0.0047	-0.7	-0.05	-0.13
^{14}C (B1)	0.380 ± 0.060	0.4031 ± 0.0018	-5.7	-0.38	-0.98
^{22}Na (GH)	8.5 ± 1.3	8.674 ± 0.033	-2.4	-0.16	-0.40
^{60}Co (GH)	31.4 ± 3.1	31.23 ± 0.11	0.4	0.04	0.07
^{133}Ba (GH)	38.8 ± 5.8	38.84 ± 0.27	-0.1	-0.01	-0.02
^{137}Cs (GH)	13.1 ± 2.0	13.201 ± 0.098	-1.0	-0.07	-0.17
^{155}Eu (GH)	7.6 ± 1.1	7.63 ± 0.14	0.0	0.00	0.00
^{54}Mn (GL)	17.4 ± 2.6	17.22 ± 0.18	1.2	0.08	0.21
^{65}Zn (GL)	29.0 ± 4.4	29.67 ± 0.22	-2.2	-0.15	-0.38
^{139}Ce (GL)	45.1 ± 6.8	44.41 ± 0.39	1.6	0.10	0.27


Deviation (%) of Laboratory 7
50
0
-50
^{3}H (AB)
^{63}Ni (AB)
^{90}Sr (AB)
^{241}Am (AB)
^{226}Ra (A1)
^{241}Am (A1)
^{244}Cm (A1)
^{3}H (B1)
^{14}C (B1)
^{36}Cl (B1)
^{22}Na (GH)
^{60}Co (GH)
^{133}Ba (GH)
^{137}Cs (GH)
^{155}Eu (GH)

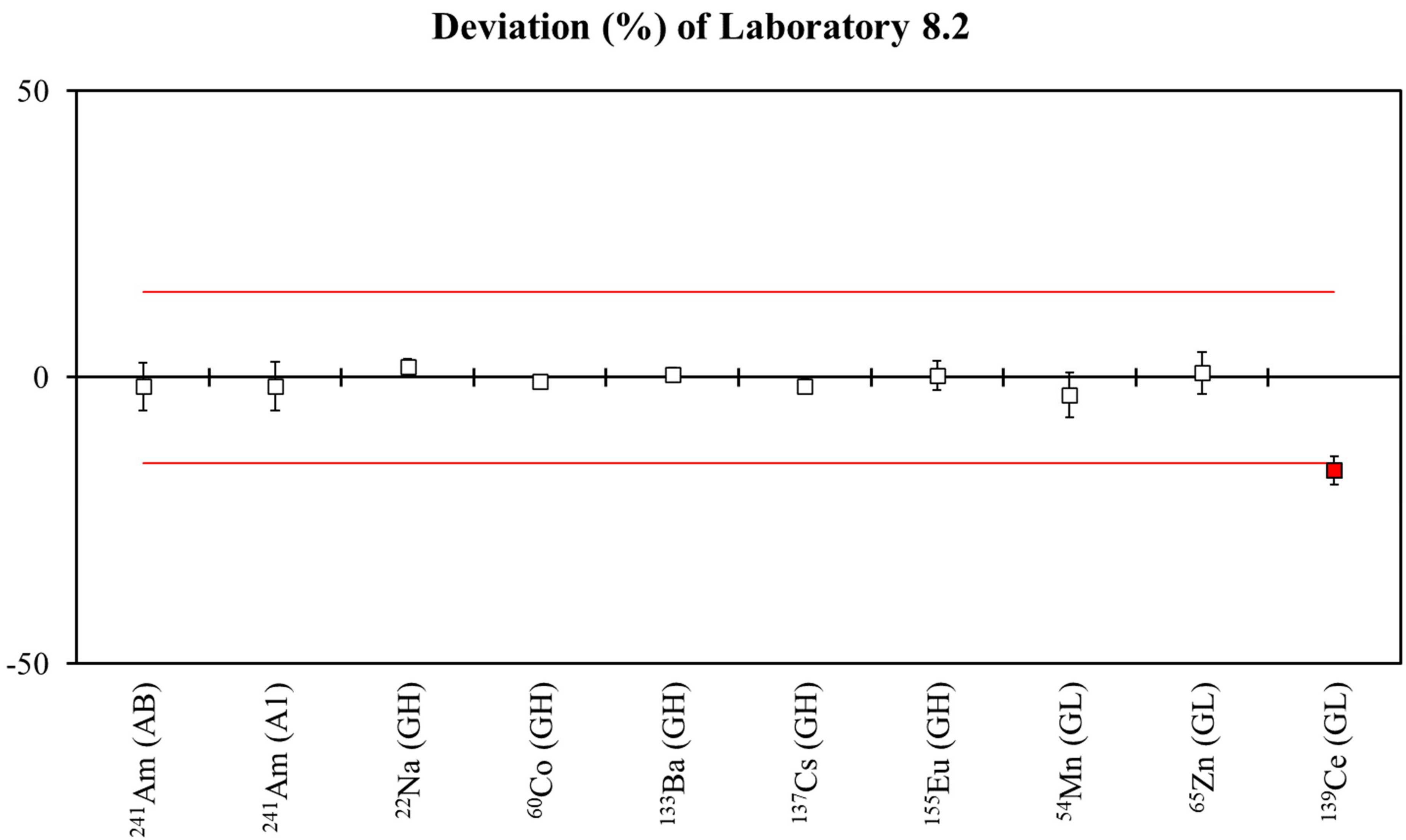
Radionuclide	Laboratory 7	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	12.27 ± 0.88	13.24 ± 0.19	-7.3	-1.08	-1.26
^{63}Ni (AB)	3.52 ± 0.17	3.589 ± 0.017	-1.9	-0.39	-0.32
^{90}Sr (AB)	3.27 ± 0.30	3.5493 ± 0.0095	-7.9	-0.92	-1.35
^{241}Am (AB)	10.99 ± 0.73	11.618 ± 0.046	-5.4	-0.86	-0.92
^{226}Ra (A1)	80.3 ± 8.7	45.44 ± 0.57	76.7	3.98	13.17
^{241}Am (A1)	30.2 ± 2.8	88.14 ± 0.35	-65.8	-20.71	-11.30
^{244}Cm (A1)	6.37 ± 0.78	21.641 ± 0.033	-70.5	-19.65	-12.12
^{3}H (B1)	0.310 ± 0.024	0.2821 ± 0.0047	9.8	1.15	1.68
^{14}C (B1)	0.4670 ± 0.07	0.4031 ± 0.0018	15.9	0.92	2.74
^{36}Cl (B1)	0.1945 ± 0.0021	0.21867 ± 0.00076	-11.1	-10.82	-1.90
^{22}Na (GH)	8.77 ± 0.40	8.674 ± 0.033	1.1	0.24	0.19
^{60}Co (GH)	31.5 ± 1.4	31.23 ± 0.11	0.9	0.19	0.15
^{133}Ba (GH)	38.3 ± 1.7	38.84 ± 0.27	-1.4	-0.31	-0.24
^{137}Cs (GH)	12.80 ± 0.58	13.201 ± 0.098	-3.0	-0.68	-0.52
^{155}Eu (GH)	7.23 ± 0.33	7.63 ± 0.14	-5.2	-1.12	-0.90


Deviation (%) of Laboratory 7.1
50
0
-50
3H (AB)
3H (B1)

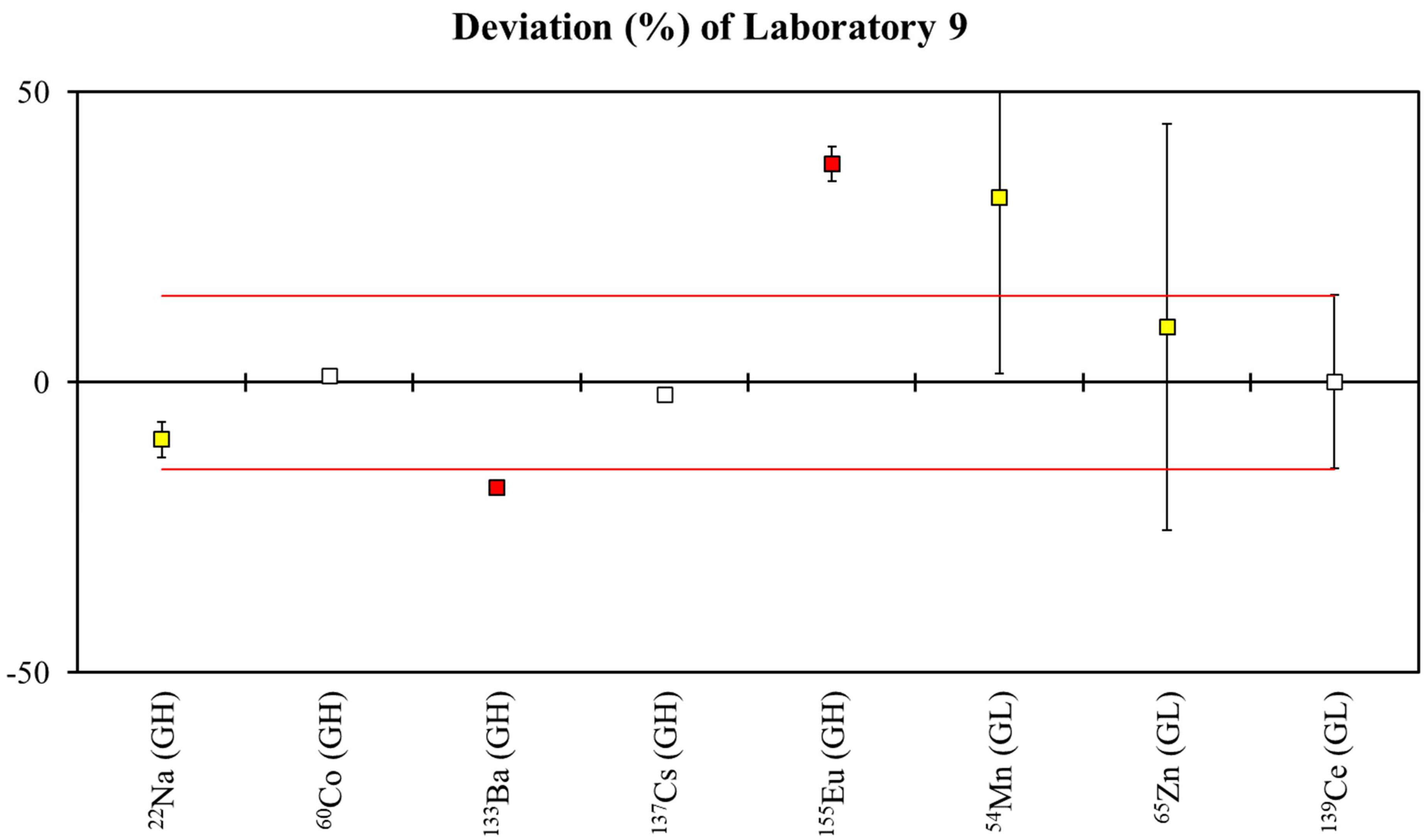
Radionuclide	Laboratory 7.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	14.1 ± 1.1	13.24 ± 0.19	6.5	0.81	1.12
^{3}H (B1)	0.310 ± 0.024	0.2821 ± 0.0047	9.7	1.14	1.67


Deviation (%) of Laboratory 8.1
50
0
-50
^{3}H (AB)
^{63}Ni (AB)
^{90}Sr (AB)
^{241}Am (AB)
^{226}Ra (A1)
^{241}Am (A1)
^{244}Cm (A1)
^{3}H (B1)
^{14}C (B1)
^{36}Cl (B1)
^{22}Na (GH)
^{60}Co (GH)
^{133}Ba (GH)
^{137}Cs (GH)
^{155}Eu (GH)
^{54}Mn (GL)
^{65}Zn (GL)
^{139}Ce (GL)
^{210}Pb (GL)

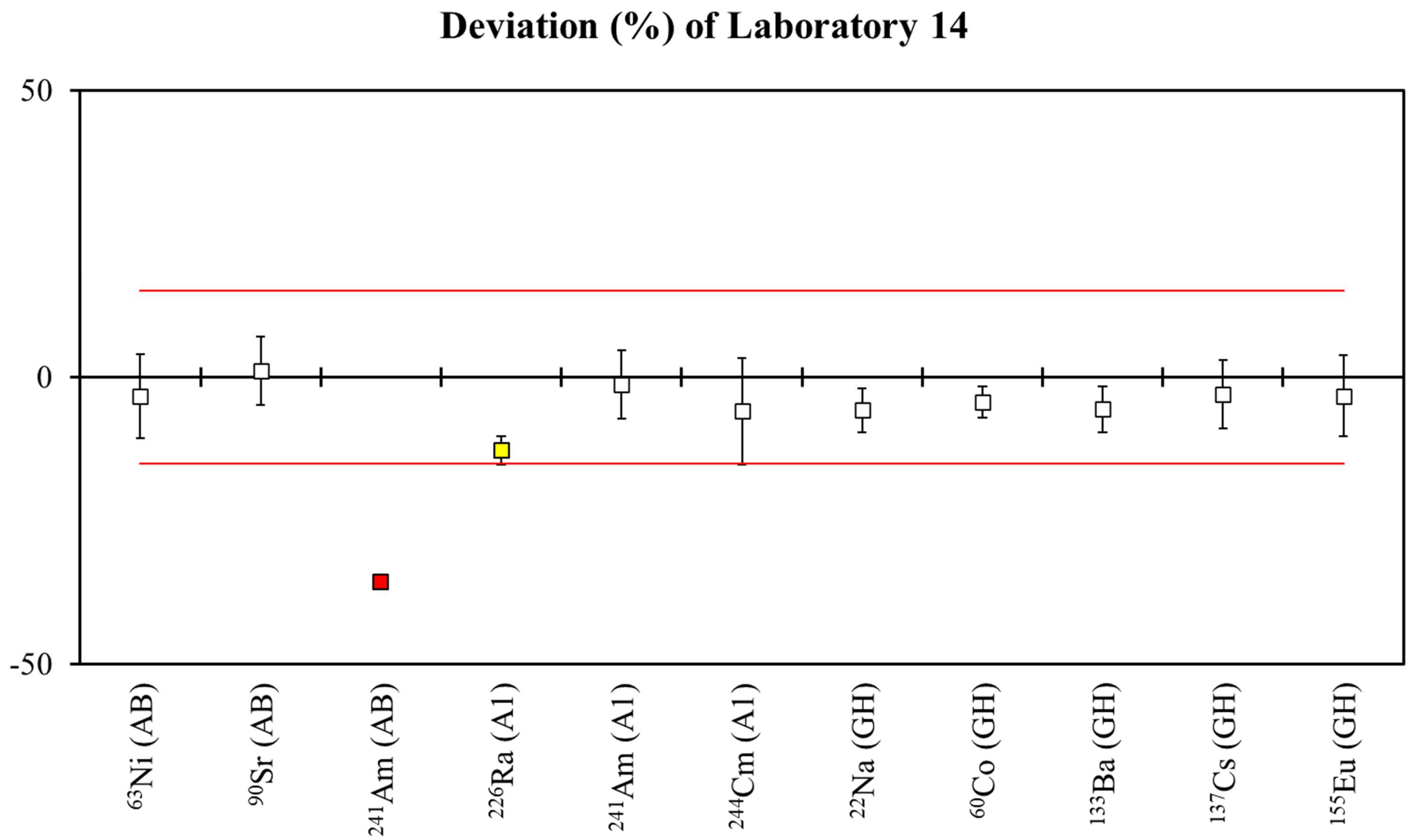
Radionuclide	Laboratory 8.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	12.05 ± 0.30	13.24 ± 0.19	-9.0	-3.35	-1.54
^{63}Ni (AB)	3.440 ± 0.097	3.589 ± 0.017	-4.2	-1.51	-0.71
^{90}Sr (AB)	3.31 ± 0.29	3.5493 ± 0.0095	-6.7	-0.82	-1.16
^{241}Am (AB)	11.43 ± 0.69	11.618 ± 0.046	-1.6	-0.27	-0.28
^{226}Ra (A1)	44.4 ± 7.8	45.44 ± 0.57	-2.3	-0.13	-0.39
^{241}Am (A1)	92.4 ± 6.8	88.14 ± 0.35	4.8	0.63	0.83
^{244}Cm (A1)	24.6 ± 2.7	21.641 ± 0.033	13.7	1.10	2.35
^{3}H (B1)	0.273 ± 0.014	0.2821 ± 0.0047	-3.2	-0.62	-0.55
^{14}C (B1)	0.392 ± 0.026	0.4031 ± 0.0018	-2.8	-0.43	-0.47
^{36}Cl (B1)	0.207 ± 0.017	0.21867 ± 0.00076	-5.2	-0.65	-0.89
^{22}Na (GH)	8.42 ± 0.14	8.674 ± 0.033	-3.0	-1.86	-0.51
^{60}Co (GH)	30.24 ± 0.54	31.23 ± 0.11	-3.2	-1.79	-0.54
^{133}Ba (GH)	39.7 ± 1.9	38.84 ± 0.27	2.2	0.45	0.38
^{137}Cs (GH)	13.33 ± 0.92	13.201 ± 0.098	1.0	0.14	0.17
^{155}Eu (GH)	7.73 ± 0.43	7.63 ± 0.14	1.3	0.23	0.23
^{54}Mn (GL)	16.68 ± 0.68	17.22 ± 0.18	-3.1	-0.77	-0.54
^{65}Zn (GL)	27.0 ± 1.2	29.67 ± 0.22	-9.0	-2.22	-1.55
^{139}Ce (GL)	44.4 ± 1.6	44.41 ± 0.39	0.0	0.00	0.00
^{210}Pb (GL)	13.6 ± 1.6	13.67 ± 0.15	-0.5	-0.04	-0.09


Deviation (%) of Laboratory 8.2
50
0
-50
241Am (AB)
241Am (A1)
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)
54Mn (GL)
65Zn (GL)
139Ce (GL)

Radionuclide	Laboratory 8.2	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{241}Am (AB)	11.43 ± 0.48	11.618 ± 0.046	-1.6	-0.39	-0.28
^{241}Am (A1)	86.7 ± 3.7	88.14 ± 0.35	-1.6	-0.37	-0.27
^{22}Na (GH)	8.84 ± 0.10	8.674 ± 0.033	1.9	1.52	0.33
^{60}Co (GH)	31.00 ± 0.22	31.23 ± 0.11	-0.7	-0.94	-0.13
^{133}Ba (GH)	39.00 ± 0.42	38.84 ± 0.27	0.4	0.32	0.07
^{137}Cs (GH)	13.00 ± 0.15	13.201 ± 0.098	-1.5	-1.14	-0.26
^{155}Eu (GH)	7.66 ± 0.14	7.63 ± 0.14	0.4	0.15	0.07
^{54}Mn (GL)	16.70 ± 0.65	17.22 ± 0.18	-3.0	-0.78	-0.52
^{65}Zn (GL)	29.9 ± 1.1	29.67 ± 0.22	0.8	0.21	0.13
^{139}Ce (GL)	37.2 ± 1.0	44.41 ± 0.39	-16.2	-6.55	-2.79

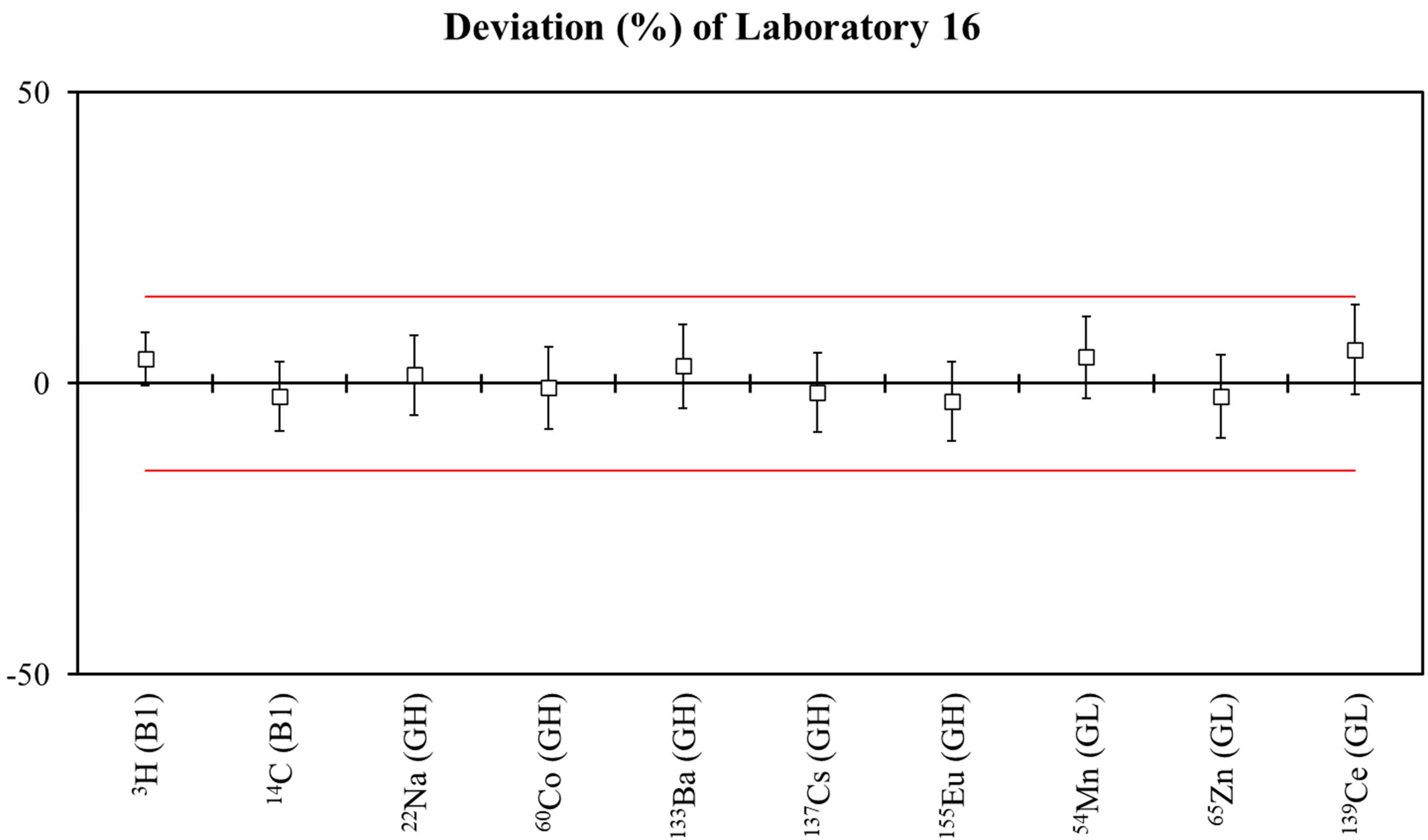

Deviation (%) of Laboratory 9
50
0
-50
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)
54Mn (GL)
65Zn (GL)
139Ce (GL)

Radionuclide	Laboratory 9	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{22}Na (GH)	7.82 ± 0.27	8.674 ± 0.033	-9.8	-3.19	-1.69
^{60}Co (GH)	31.62 ± 0.16	31.23 ± 0.11	1.3	2.06	0.22
^{133}Ba (GH)	31.79 ± 0.14	38.84 ± 0.27	-18.2	-23.31	-3.12
^{137}Cs (GH)	12.92 ± 0.10	13.201 ± 0.098	-2.1	-1.94	-0.36
^{155}Eu (GH)	10.51 ± 0.12	7.63 ± 0.14	37.7	15.66	6.47
^{54}Mn (GL)	22.7 ± 5.2	17.22 ± 0.18	31.8	1.05	5.46
^{65}Zn (GL)	33 ± 10	29.67 ± 0.22	9.6	0.27	1.64
^{139}Ce (GL)	44.5 ± 6.6	44.41 ± 0.39	0.1	0.01	0.02

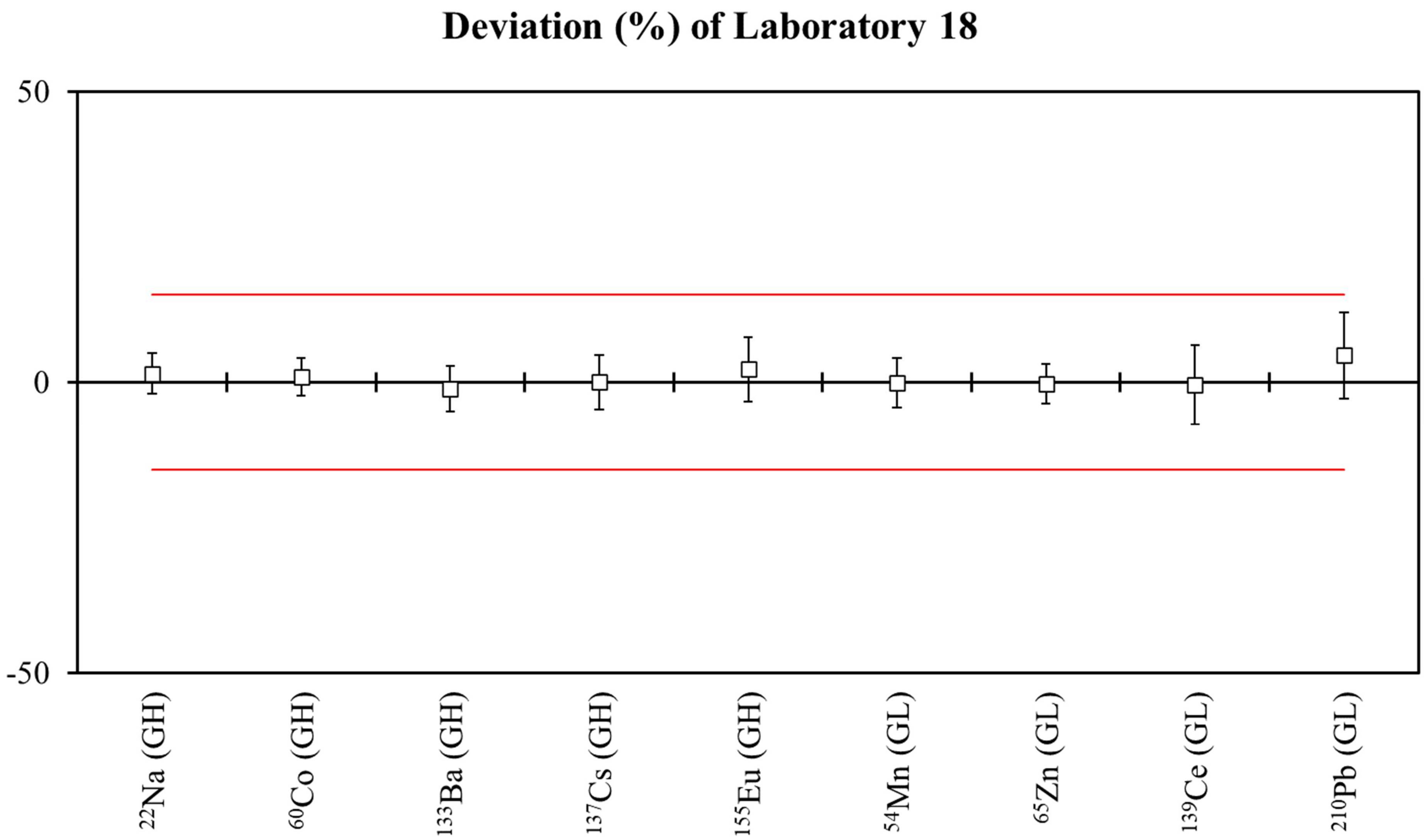

Deviation (%) of Laboratory 14
50
0
-50
63Ni (AB)
90Sr (AB)
241Am (AB)
226Ra (A1)
241Am (A1)
244Cm (A1)
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)

Radionuclide	Laboratory 14	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{63}Ni (AB)	3.47 ± 0.26	3.589 ± 0.017	-3.3	-0.46	-0.57
^{90}Sr (AB)	3.59 ± 0.21	3.5493 ± 0.0095	1.1	0.19	0.20
^{241}Am (AB)	7.46 ± 0.00[2]	11.618 ± 0.046	-35.8	-90.39	-6.15
^{226}Ra (A1)	39.6 ± 1.0	45.44 ± 0.57	-12.8	-4.93	-2.19
^{241}Am (A1)	87.0 ± 5.3	88.14 ± 0.35	-1.3	-0.21	-0.22
^{244}Cm (A1)	20.4 ± 2.0	21.641 ± 0.033	-6.0	-0.65	-1.02
^{22}Na (GH)	8.17 ± 0.33	8.674 ± 0.033	-5.8	-1.52	-0.99
^{60}Co (GH)	29.88 ± 0.85	31.23 ± 0.11	-4.3	-1.59	-0.74
^{133}Ba (GH)	36.7 ± 1.5	38.84 ± 0.27	-5.6	-1.43	-0.97
^{137}Cs (GH)	12.81 ± 0.77	13.201 ± 0.098	-3.0	-0.51	-0.51
^{155}Eu (GH)	7.38 ± 0.52	7.63 ± 0.14	-3.2	-0.46	-0.56

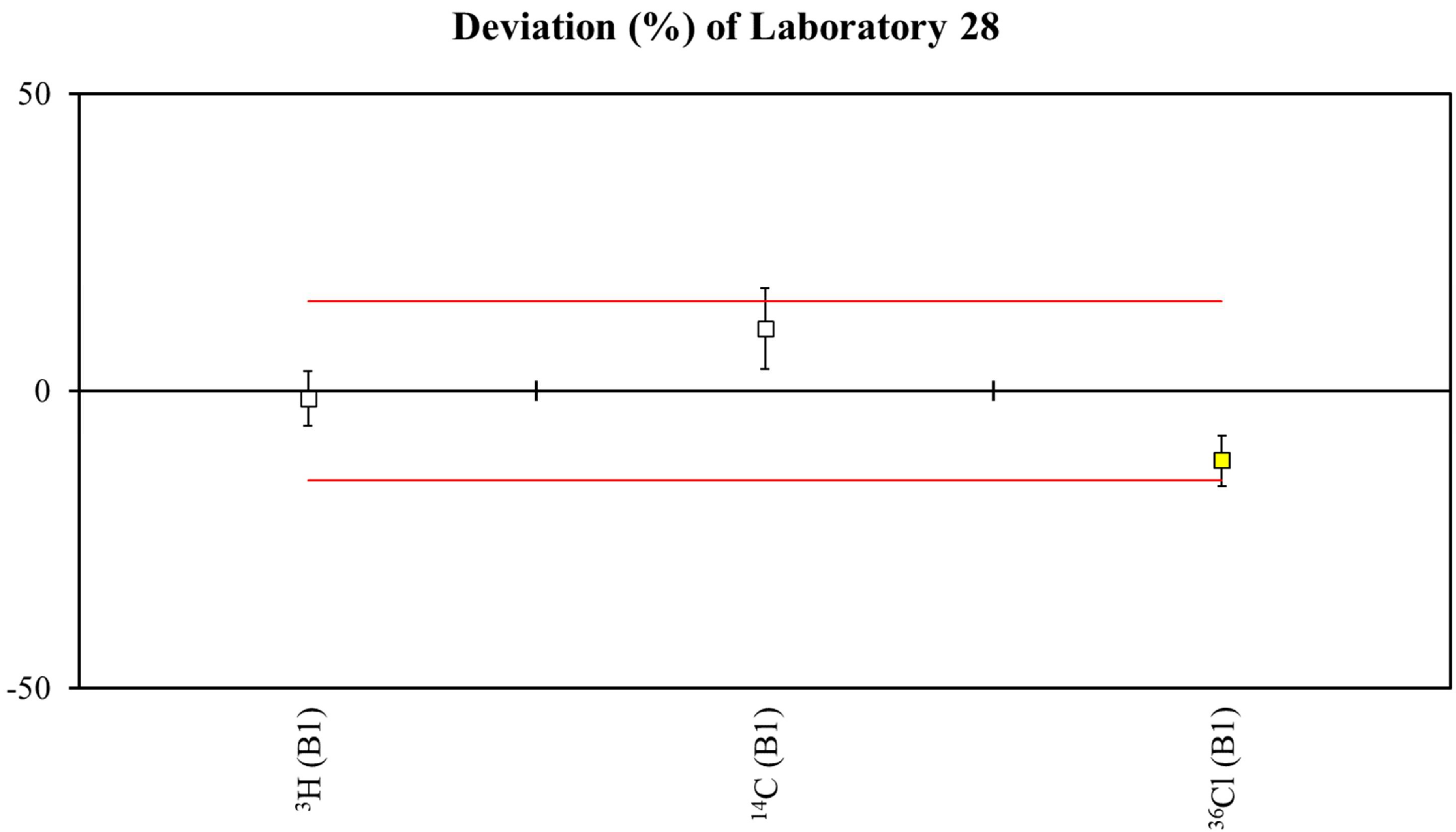
[2] Note, the laboratory did not provide a corresponding uncertainty for the measured value. An uncertainty value of “0” has been included in the report, as stated in the reporting form.


Deviation (%) of Laboratory 16
50
0
-50
^{3}H (B1)
^{14}C (B1)
^{22}Na (GH)
^{60}Co (GH)
^{133}Ba (GH)
^{137}Cs (GH)
^{155}Eu (GH)
^{54}Mn (GL)
^{65}Zn (GL)
^{139}Ce (GL)

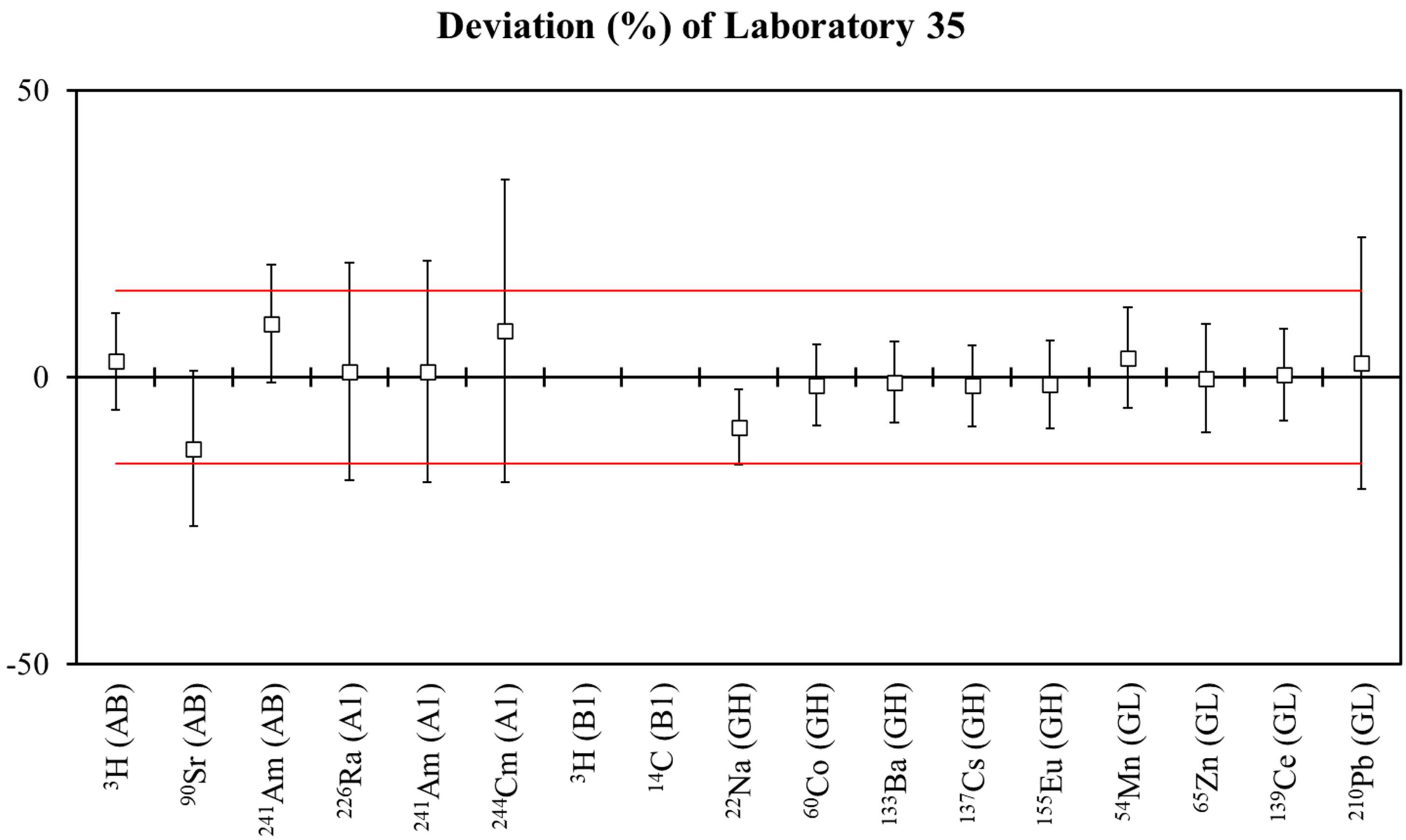
Radionuclide	Laboratory 16	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.294 ± 0.012	0.2821 ± 0.0047	4.2	0.92	0.72
^{14}C (B1)	0.394 ± 0.024	0.4031 ± 0.0018	-2.3	-0.38	-0.39
^{22}Na (GH)	8.80 ± 0.60	8.674 ± 0.033	1.5	0.21	0.25
^{60}Co (GH)	31.0 ± 2.2	31.23 ± 0.11	-0.7	-0.10	-0.13
^{133}Ba (GH)	40.0 ± 2.8	38.84 ± 0.27	3.0	0.41	0.51
^{137}Cs (GH)	13.00 ± 0.90	13.201 ± 0.098	-1.5	-0.22	-0.26
^{155}Eu (GH)	7.40 ± 0.50	7.63 ± 0.14	-3.0	-0.44	-0.52
^{54}Mn (GL)	18.0 ± 1.2	17.22 ± 0.18	4.5	0.64	0.78
^{65}Zn (GL)	29.0 ± 2.1	29.67 ± 0.22	-2.3	-0.32	-0.39
^{139}Ce (GL)	47.0 ± 3.4	44.41 ± 0.39	5.8	0.76	1.00


Deviation (%) of Laboratory 18
50
0
-50
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)
54Mn (GL)
65Zn (GL)
139Ce (GL)
210Pb (GL)

Radionuclide	Laboratory 18	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{22}Na (GH)	8.80 ± 0.30	8.674 ± 0.033	1.5	0.42	0.25
^{60}Co (GH)	31.5 ± 1.0	31.23 ± 0.11	0.9	0.27	0.15
^{133}Ba (GH)	38.4 ± 1.5	38.84 ± 0.27	-1.1	-0.29	-0.19
^{137}Cs (GH)	13.20 ± 0.60	13.201 ± 0.098	0.0	0.00	0.00
^{155}Eu (GH)	7.80 ± 0.40	7.63 ± 0.14	2.2	0.40	0.38
^{54}Mn (GL)	17.20 ± 0.70	17.22 ± 0.18	-0.1	-0.03	-0.02
^{65}Zn (GL)	29.6 ± 1.0	29.67 ± 0.22	-0.2	-0.07	-0.04
^{139}Ce (GL)	44.2 ± 3.0	44.41 ± 0.39	-0.5	-0.07	-0.08
^{210}Pb (GL)	14.3 ± 1.0	13.67 ± 0.15	4.6	0.62	0.79


Deviation (%) of Laboratory 28
50
0
-50
3H (B1)
14C (B1)
36Cl (B1)

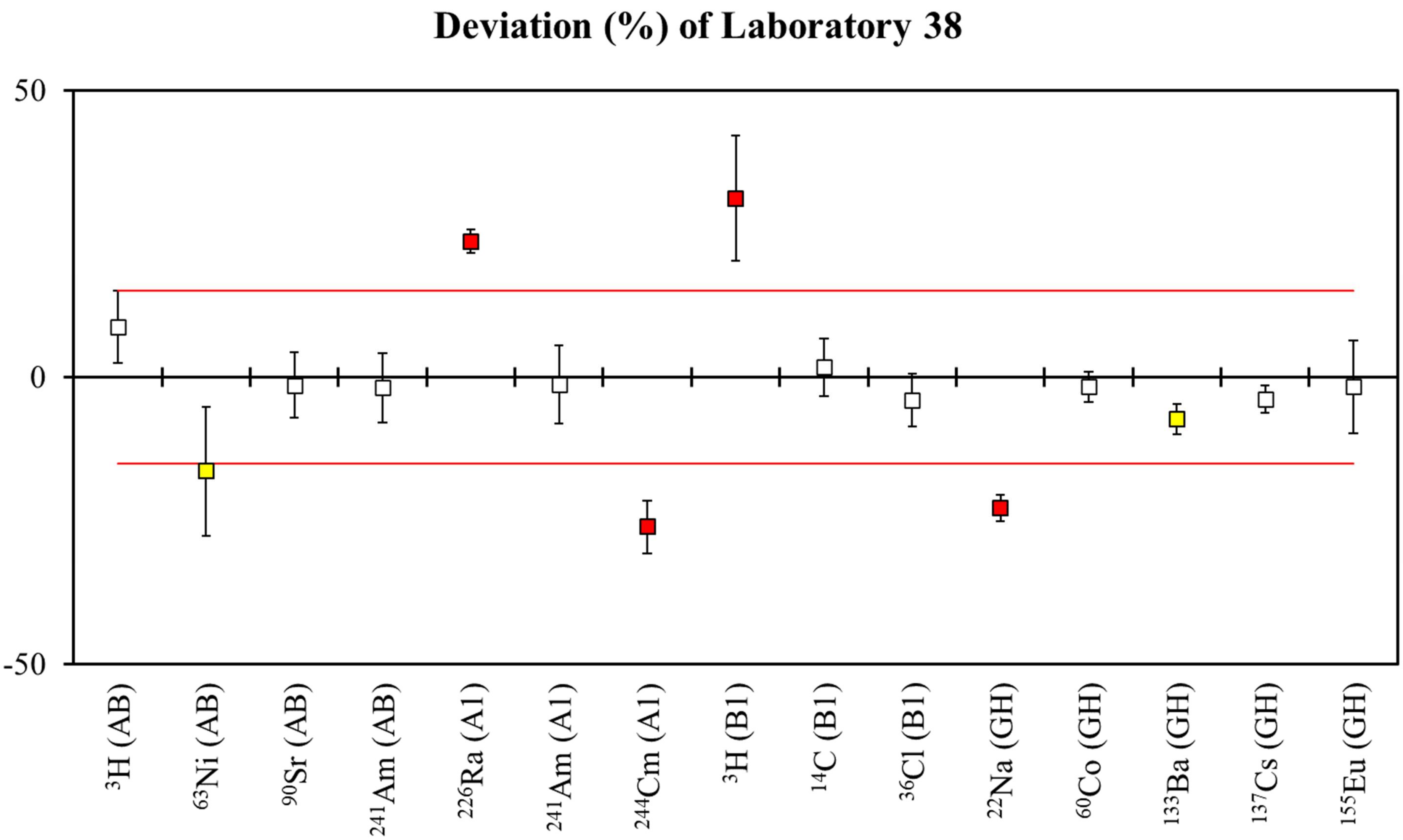
Radionuclide	Laboratory 28	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.278 ± 0.012	0.2821 ± 0.0047	-1.3	-0.29	-0.23
^{14}C (B1)	0.445 ± 0.027	0.4031 ± 0.0018	10.5	1.54	1.80
^{36}Cl (B1)	0.1928 ± 0.0091	0.21867 ± 0.00076	-11.8	-2.83	-2.03



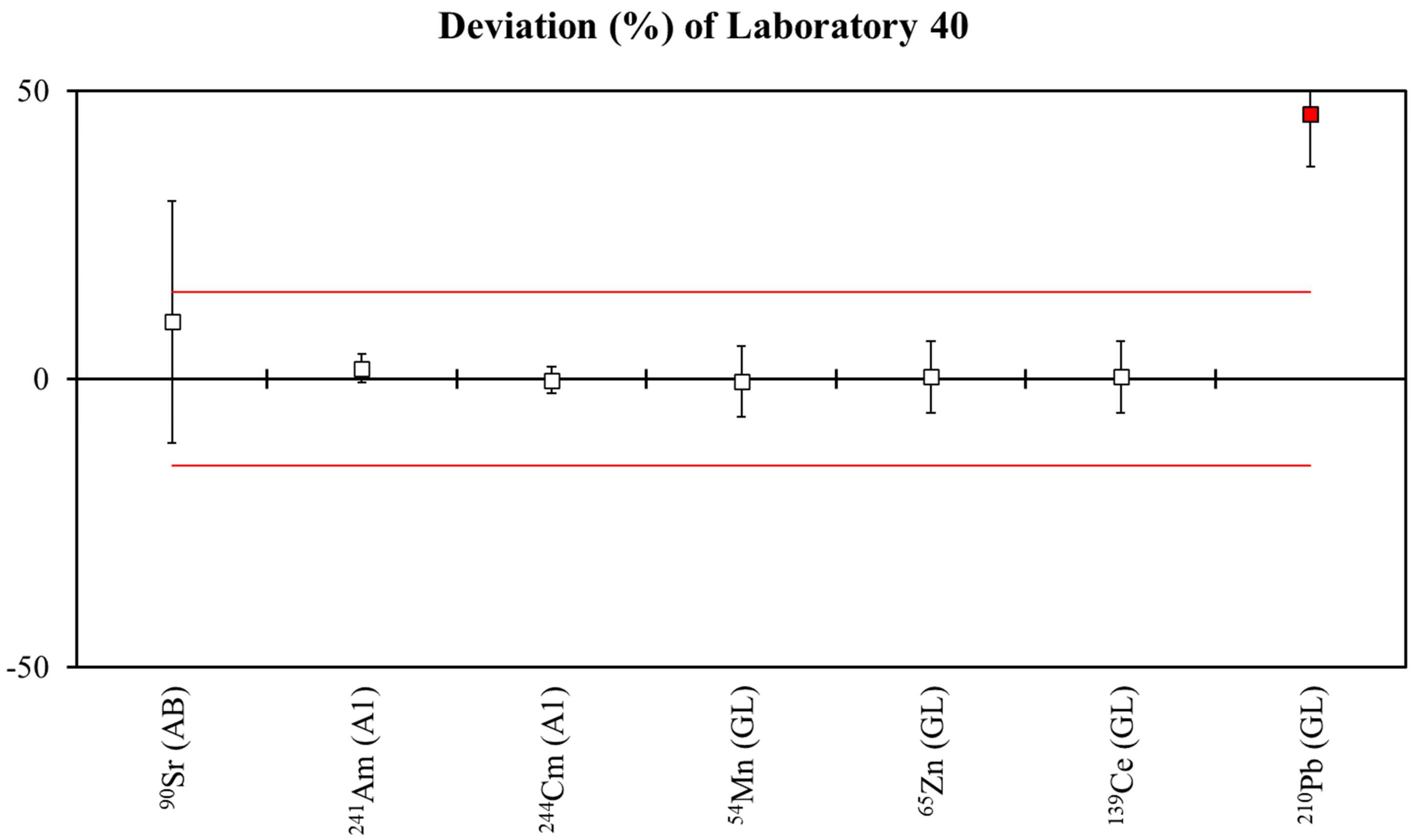
Deviation (%) of Laboratory 35
50
0
-50
3H (AB)
90Sr (AB)
241Am (AB)
226Ra (A1)
241Am (A1)
244Cm (A1)
3H (B1)
14C (B1)
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)
54Mn (GL)
65Zn (GL)
139Ce (GL)
210Pb (GL)

Radionuclide	Laboratory 35	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	13.6 ± 1.1	13.24 ± 0.19	2.7	0.32	0.47
^{90}Sr (AB)	3.11 ± 0.48	3.5493 ± 0.0095	-12.4	-0.92	-2.14
^{241}Am (AB)	12.7 ± 1.2	11.618 ± 0.046	9.3	0.90	1.60
^{226}Ra (A1)	45.9 ± 8.6	45.44 ± 0.57	1.0	0.05	0.16
^{241}Am (A1)	89 ± 17	88.14 ± 0.35	1.0	0.05	0.17
^{244}Cm (A1)	23.4 ± 5.7	21.641 ± 0.033	8.1	0.31	1.40
^{3}H (B1)	286 ± 20[3]	0.2821 ± 0.0047	101282.5	14.29	17393.52
^{14}C (B1)	263 ± 28	0.4031 ± 0.0018	65144.4	9.38	11187.42
^{22}Na (GH)	7.92 ± 0.57	8.674 ± 0.033	-8.7	-1.32	-1.49
^{60}Co (GH)	30.8 ± 2.2	31.23 ± 0.11	-1.4	-0.20	-0.24
^{133}Ba (GH)	38.5 ± 2.7	38.84 ± 0.27	-0.9	-0.13	-0.15
^{137}Cs (GH)	13.00 ± 0.93	13.201 ± 0.098	-1.5	-0.21	-0.26
^{155}Eu (GH)	7.53 ± 0.57	7.63 ± 0.14	-1.3	-0.17	-0.23
^{54}Mn (GL)	17.8 ± 1.5	17.22 ± 0.18	3.4	0.38	0.58
^{65}Zn (GL)	29.6 ± 2.8	29.67 ± 0.22	-0.2	-0.02	-0.04
^{139}Ce (GL)	44.6 ± 3.5	44.41 ± 0.39	0.4	0.05	0.07
^{210}Pb (GL)	14.0 ± 3.0	13.67 ± 0.15	2.4	0.11	0.41

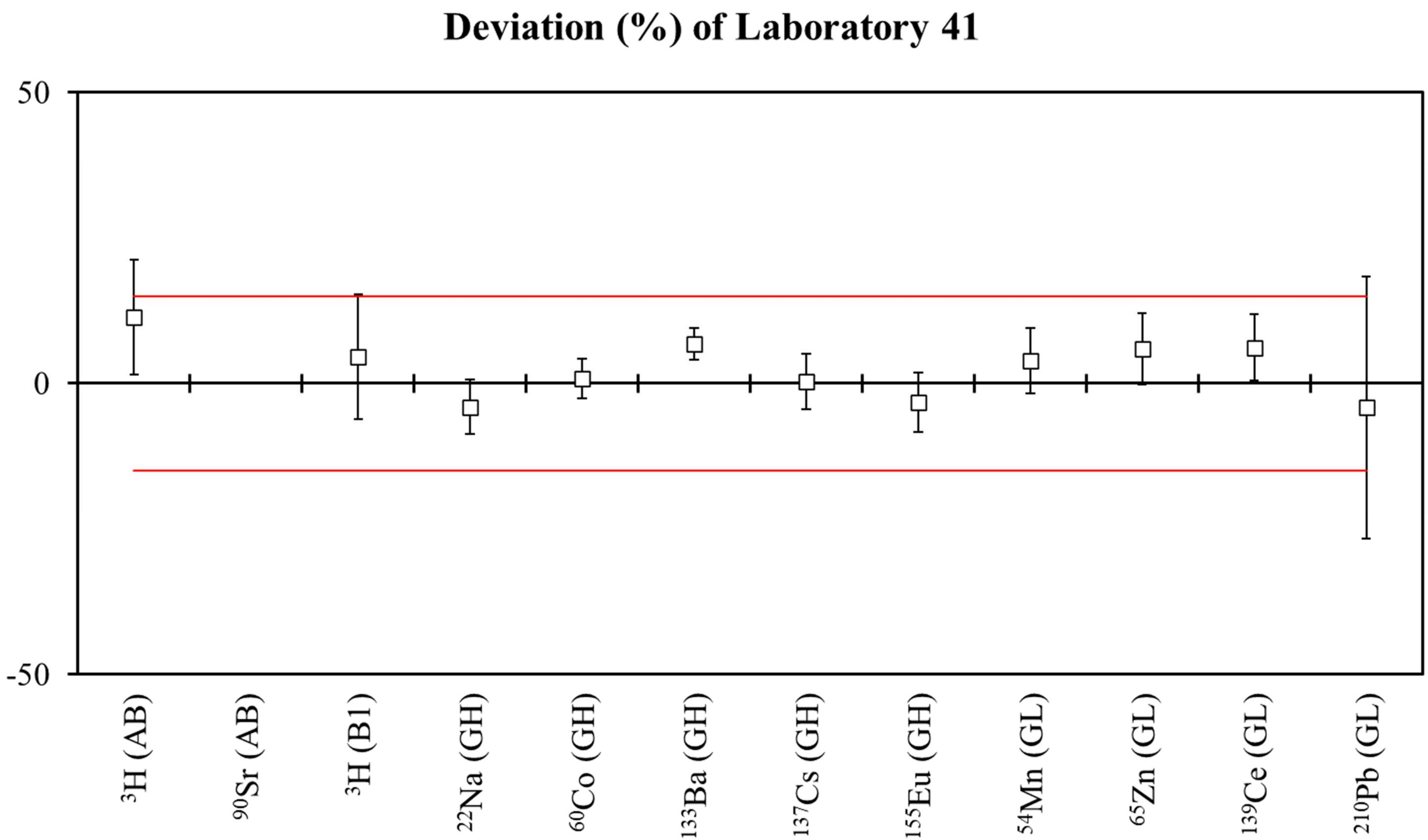
[3]Note, this laboratory has confirmed that they mistakenly reported ^{3}H and ^{14}C, in the B1 sample type, in Bq kg^{-1} not Bq g^{-1} as stated in the reporting form.


Deviation (%) of Laboratory 38
50
0
-50
3H (AB)
63Ni (AB)
90Sr (AB)
241Am (AB)
226Ra (A1)
241Am (A1)
244Cm (A1)
3H (B1)
14C (B1)
36Cl (B1)
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)

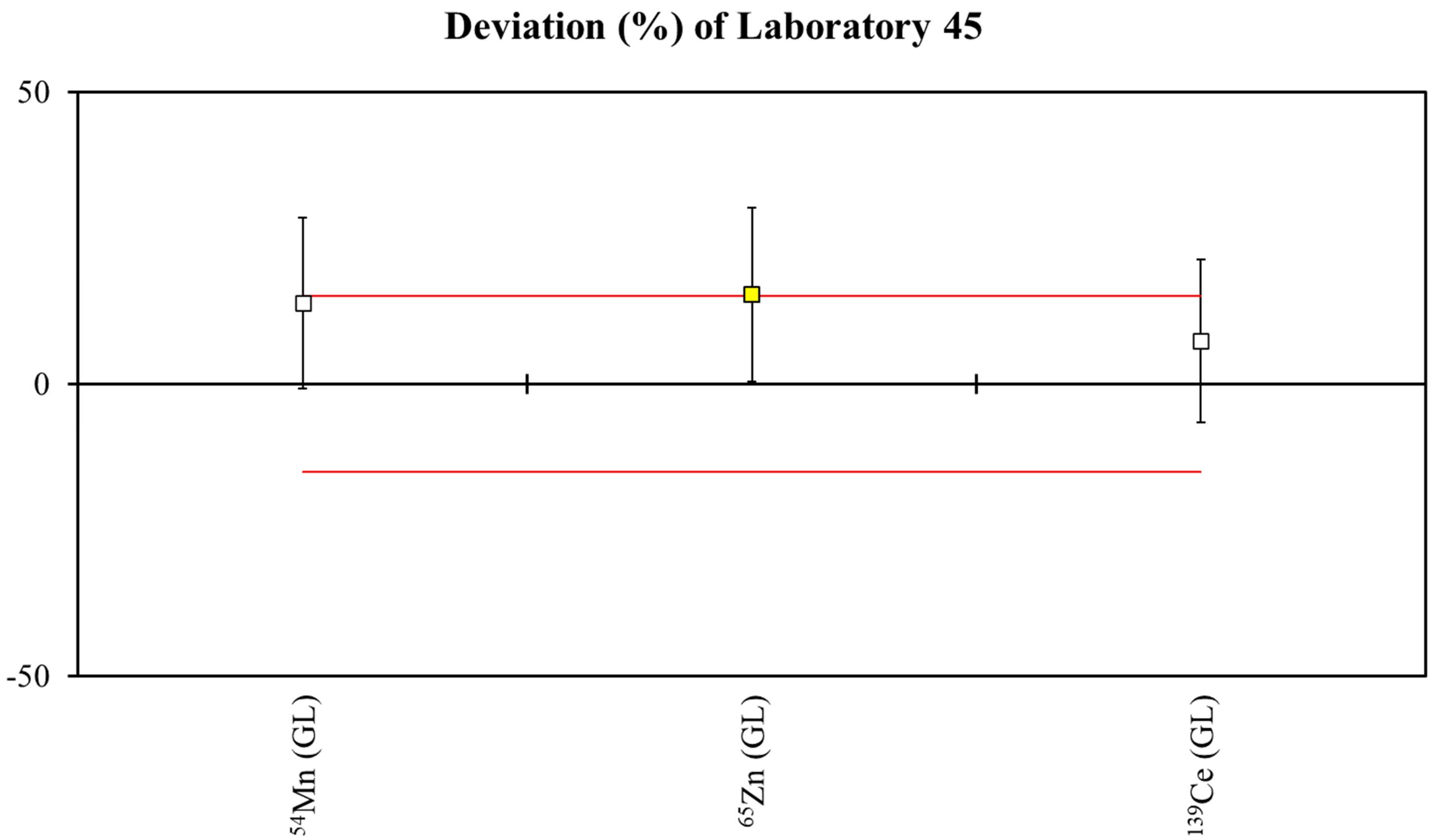
Radionuclide	Laboratory 38	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	14.40 ± 0.80	13.24 ± 0.19	8.8	1.41	1.50
^{63}Ni (AB)	3.00 ± 0.40	3.589 ± 0.017	-16.4	-1.47	-2.82
^{90}Sr (AB)	3.50 ± 0.20	3.5493 ± 0.0095	-1.4	-0.25	-0.24
^{241}Am (AB)	11.40 ± 0.70	11.618 ± 0.046	-1.9	-0.31	-0.32
^{226}Ra (A1)	56.20 ± 0.60	45.44 ± 0.57	23.7	13.00	4.07
^{241}Am (A1)	87.0 ± 6.0	88.14 ± 0.35	-1.3	-0.19	-0.22
^{244}Cm (A1)	16.0 ± 1.0	21.641 ± 0.033	-26.1	-5.64	-4.48
^{3}H (B1)	0.370 ± 0.030	0.2821 ± 0.0047	31.2	2.89	5.35
^{14}C (B1)	0.410 ± 0.020	0.4031 ± 0.0018	1.7	0.34	0.29
^{36}Cl (B1)	0.210 ± 0.010	0.21867 ± 0.00076	-4.0	-0.86	-0.68
^{22}Na (GH)	6.70 ± 0.20	8.674 ± 0.033	-22.8	-9.74	-3.91
^{60}Co (GH)	30.70 ± 0.80	31.23 ± 0.11	-1.7	-0.66	-0.29
^{133}Ba (GH)	36.0 ± 1.0	38.84 ± 0.27	-7.3	-2.74	-1.26
^{137}Cs (GH)	12.70 ± 0.30	13.201 ± 0.098	-3.8	-1.59	-0.65
^{155}Eu (GH)	7.50 ± 0.60	7.63 ± 0.14	-1.7	-0.21	-0.29


Deviation (%) of Laboratory 40
50
0
-50
90Sr (AB)
241Am (A1)
244Cm (A1)
54Mn (GL)
65Zn (GL)
139Ce (GL)
210Pb (GL)

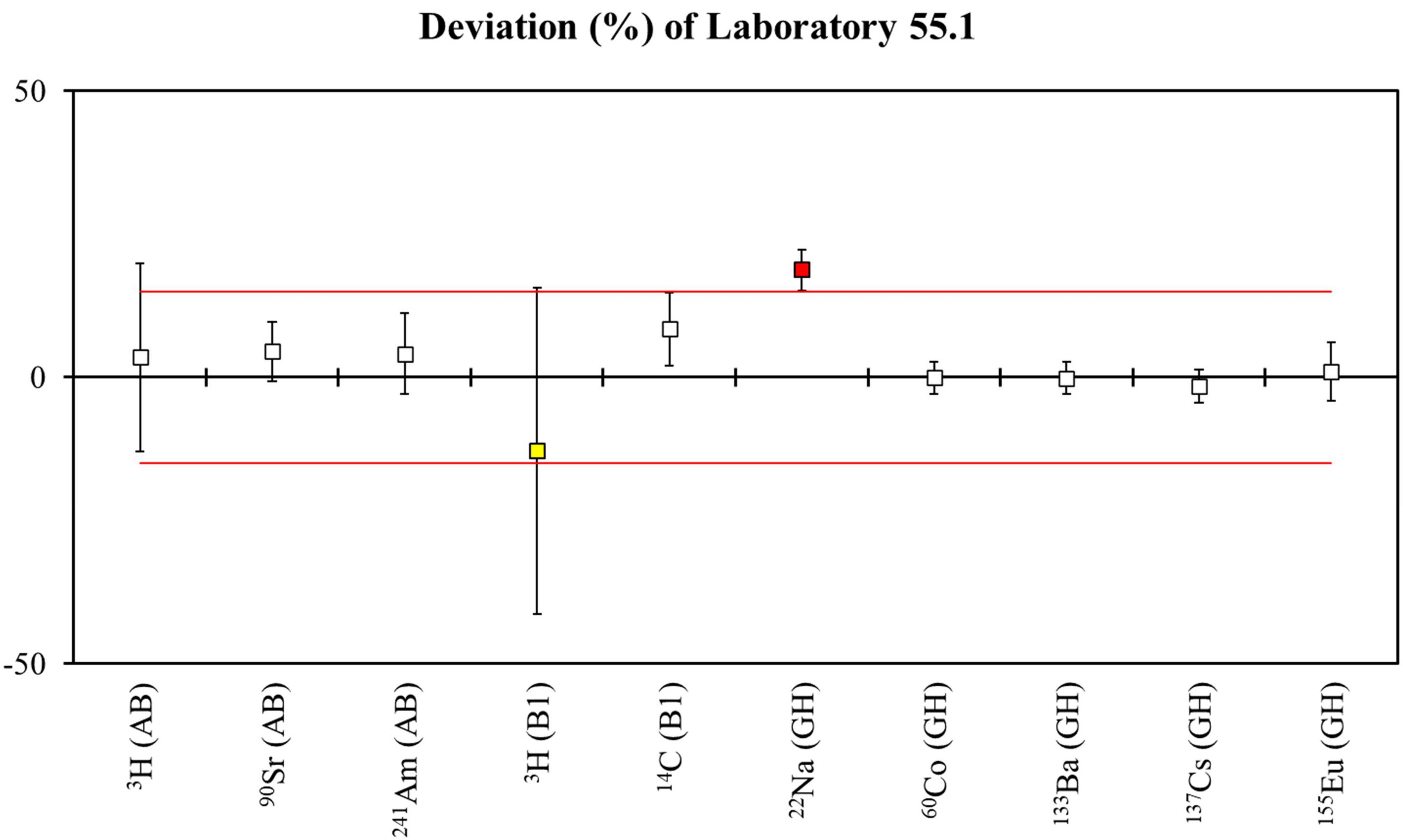
Radionuclide	Laboratory 40	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{90}Sr (AB)	3.90 ± 0.74	3.5493 ± 0.0095	9.9	0.47	1.70
^{241}Am (A1)	89.8 ± 2.1	88.14 ± 0.35	1.9	0.78	0.32
^{244}Cm (A1)	21.59 ± 0.50	21.641 ± 0.033	-0.2	-0.11	-0.04
^{54}Mn (GL)	17.2 ± 1.0	17.22 ± 0.18	-0.4	-0.07	-0.07
^{65}Zn (GL)	29.8 ± 1.8	29.67 ± 0.22	0.3	0.05	0.06
^{139}Ce (GL)	44.6 ± 2.7	44.41 ± 0.39	0.3	0.05	0.06
^{210}Pb (GL)	19.9 ± 1.2	13.67 ± 0.15	45.9	5.12	7.88


Deviation (%) of Laboratory 41
50
0
-50
3H (AB)
90Sr (AB)
3H (B1)
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)
54Mn (GL)
65Zn (GL)
139Ce (GL)
210Pb (GL)

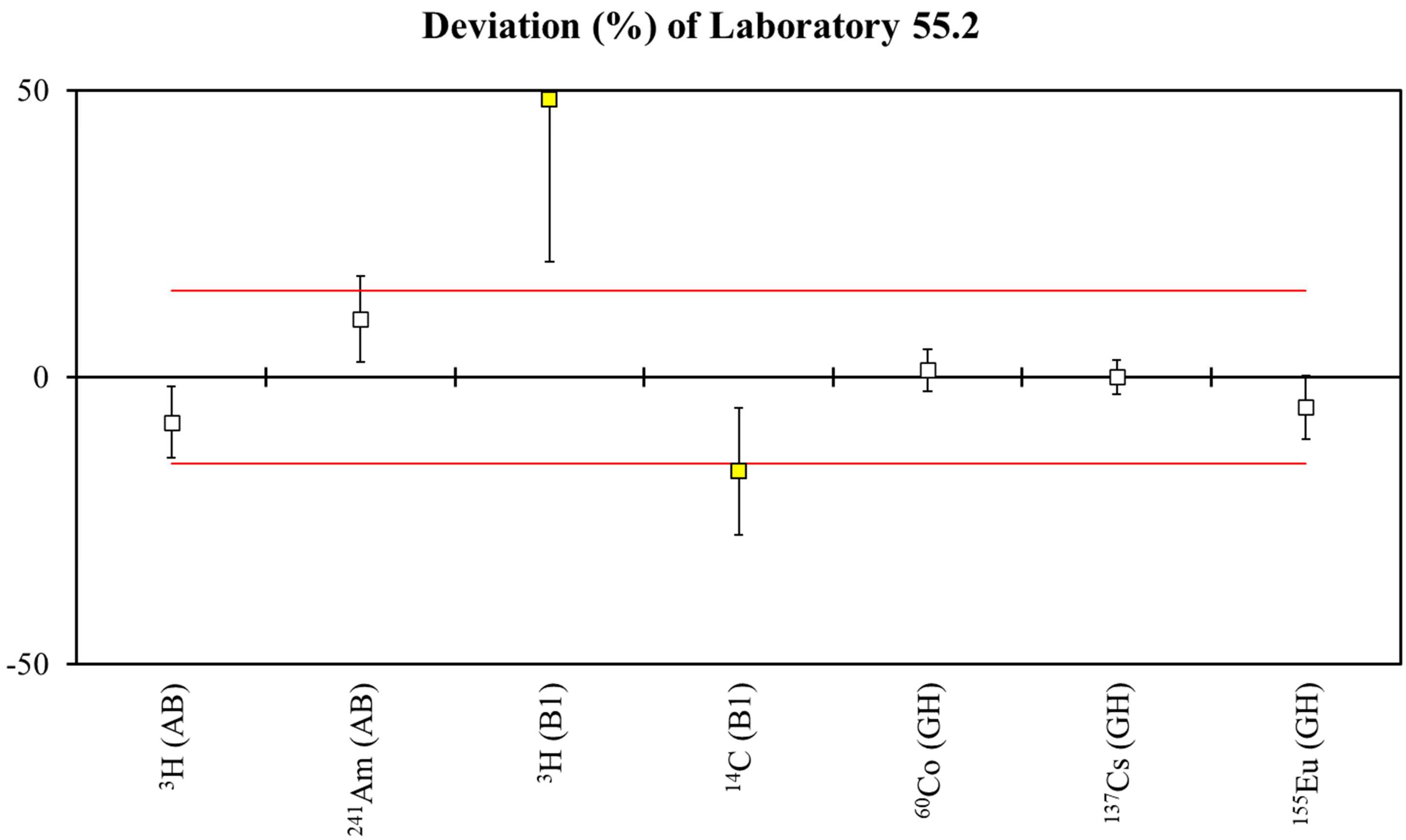
Radionuclide	Laboratory 41	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	14.7 ± 1.3	13.24 ± 0.19	11.4	1.15	1.95
^{90}Sr (AB)	14.1 ± 1.5	3.5493 ± 0.0095	297.6	7.29	51.11
^{3}H (B1)	0.295 ± 0.030	0.2821 ± 0.0047	4.6	0.42	0.79
^{22}Na (GH)	8.32 ± 0.40	8.674 ± 0.033	-4.0	-0.87	-0.69
^{60}Co (GH)	31.5 ± 1.1	31.23 ± 0.11	0.8	0.23	0.14
^{133}Ba (GH)	41.5 ± 1.0	38.84 ± 0.27	6.8	2.55	1.17
^{137}Cs (GH)	13.25 ± 0.62	13.201 ± 0.098	0.4	0.08	0.06
^{155}Eu (GH)	7.38 ± 0.37	7.63 ± 0.14	-3.3	-0.63	-0.56
^{54}Mn (GL)	17.89 ± 0.96	17.22 ± 0.18	3.9	0.69	0.67
^{65}Zn (GL)	31.5 ± 1.8	29.67 ± 0.22	6.0	0.98	1.03
^{139}Ce (GL)	47.2 ± 2.5	44.41 ± 0.39	6.2	1.10	1.06
^{210}Pb (GL)	13.1 ± 3.1	13.67 ± 0.15	-4.2	-0.18	-0.72


Deviation (%) of Laboratory 45
50
0
-50
54Mn (GL)
65Zn (GL)
139Ce (GL)

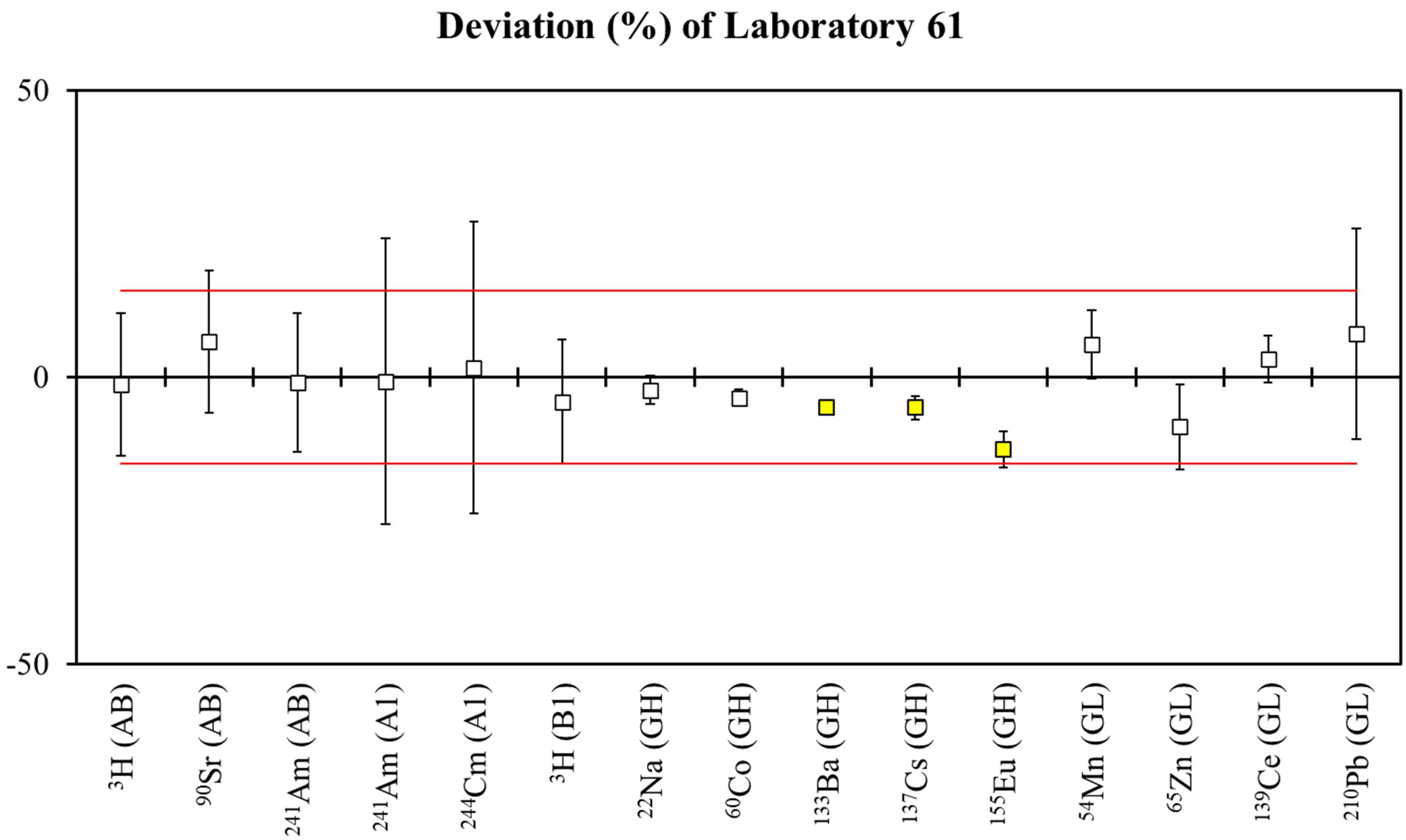
Radionuclide	Laboratory 45	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{54}Mn (GL)	19.6 ± 2.5	17.22 ± 0.18	13.8	0.95	2.37
^{65}Zn (GL)	34.2 ± 4.4	29.67 ± 0.22	15.3	1.03	2.62
^{139}Ce (GL)	47.7 ± 6.2	44.41 ± 0.39	7.4	0.53	1.27


Deviation (%) of Laboratory 55.1
50
0
-50
3H (AB)
90Sr (AB)
241Am (AB)
3H (B1)
14C (B1)
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)

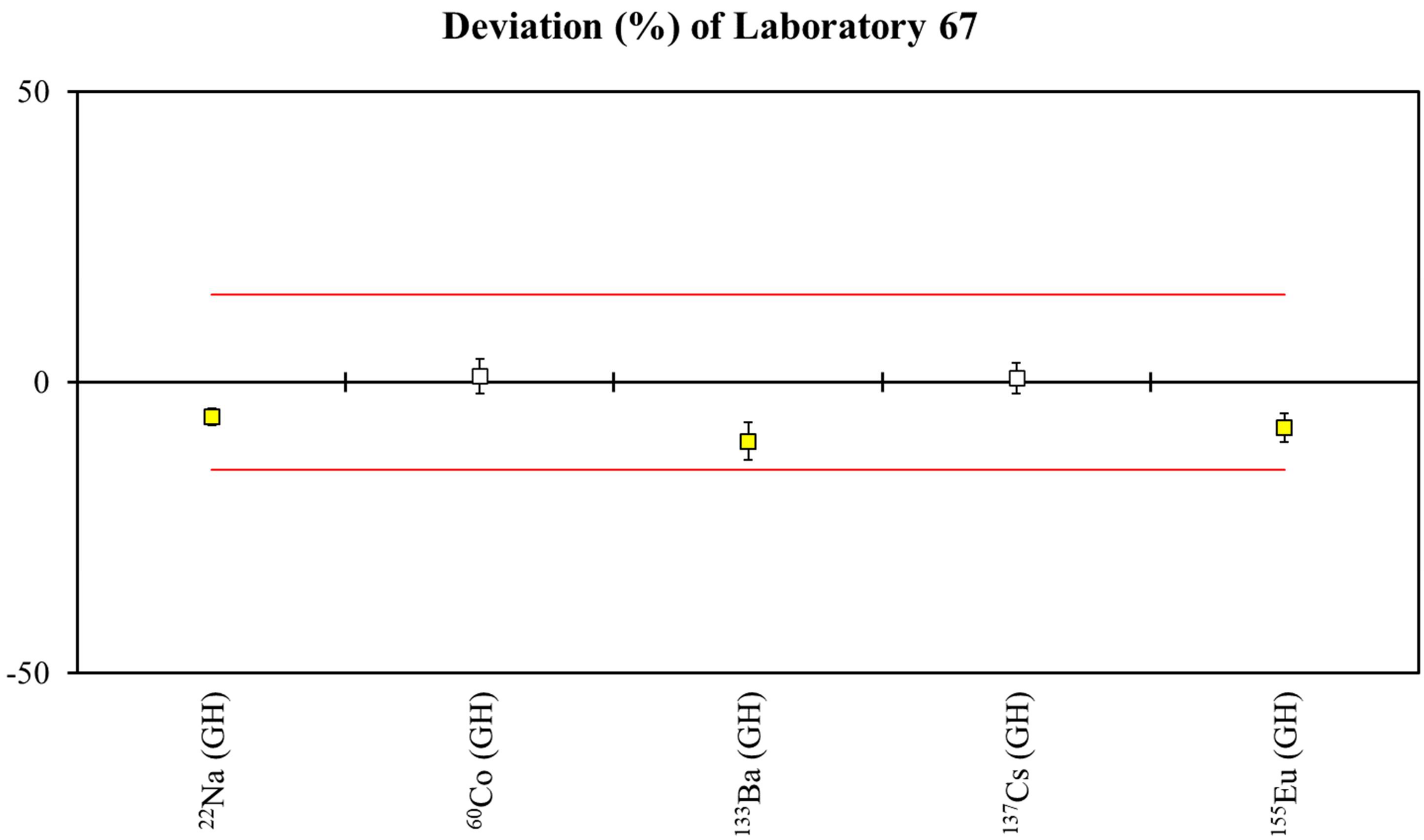
Radionuclide	Laboratory 55.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	13.7 ± 2.2	13.24 ± 0.19	3.5	0.21	0.60
^{90}Sr (AB)	3.71 ± 0.18	3.5493 ± 0.0095	4.5	0.88	0.78
^{241}Am (AB)	12.10 ± 0.81	11.618 ± 0.046	4.1	0.59	0.71
^{3}H (B1)	0.246 ± 0.080	0.2821 ± 0.0047	-12.8	-0.45	-2.20
^{14}C (B1)	0.437 ± 0.025	0.4031 ± 0.0018	8.4	1.33	1.44
^{22}Na (GH)	10.30 ± 0.31	8.674 ± 0.033	18.7	5.30	3.22
^{60}Co (GH)	31.20 ± 0.86	31.23 ± 0.11	-0.1	-0.03	-0.02
^{133}Ba (GH)	38.8 ± 1.1	38.84 ± 0.27	-0.1	-0.04	-0.02
^{137}Cs (GH)	13.00 ± 0.38	13.201 ± 0.098	-1.5	-0.52	-0.26
^{155}Eu (GH)	7.71 ± 0.37	7.63 ± 0.14	1.0	0.20	0.18


Deviation (%) of Laboratory 55.2
50
0
-50
3H (AB)
241Am (AB)
3H (B1)
14C (B1)
60Co (GH)
137Cs (GH)
155Eu (GH)

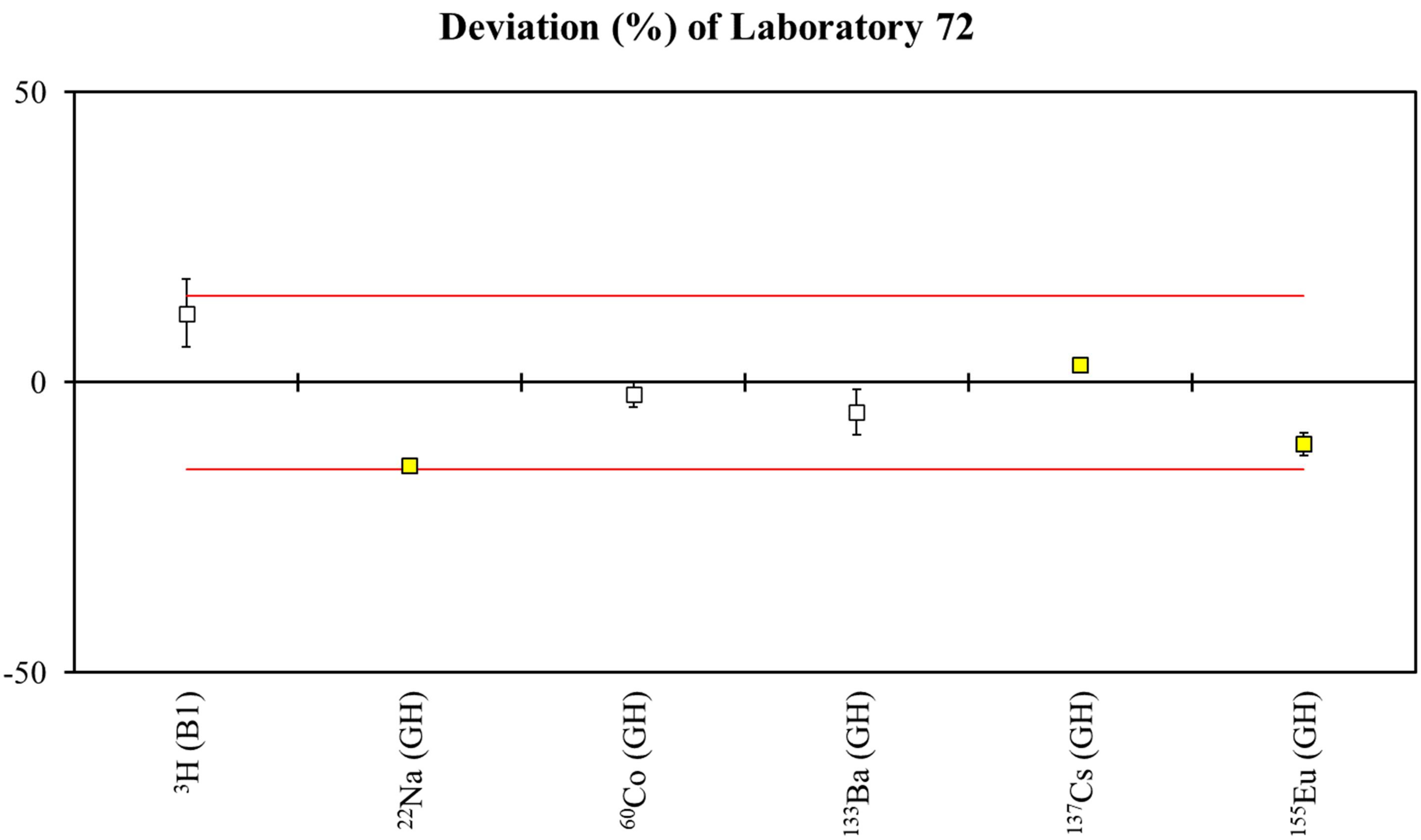
Radionuclide	Laboratory 55.2	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	12.20 ± 0.81	13.24 ± 0.19	-7.9	-1.26	-1.35
^{241}Am (AB)	12.80 ± 0.87	11.618 ± 0.046	10.2	1.36	1.75
^{3}H (B1)	0.419 ± 0.080	0.2821 ± 0.0047	48.5	1.71	8.33
^{14}C (B1)	0.337 ± 0.045	0.4031 ± 0.0018	-16.4	-1.48	-2.82
^{60}Co (GH)	31.6 ± 1.2	31.23 ± 0.11	1.2	0.32	0.20
^{137}Cs (GH)	13.20 ± 0.38	13.201 ± 0.098	0.0	0.00	0.00
^{155}Eu (GH)	7.23 ± 0.40	7.63 ± 0.14	-5.2	-0.94	-0.90


Deviation (%) of Laboratory 61
50
0
-50
3H (AB)
90Sr (AB)
241Am (AB)
241Am (A1)
244Cm (A1)
3H (B1)
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)
54Mn (GL)
65Zn (GL)
139Ce (GL)
210Pb (GL)

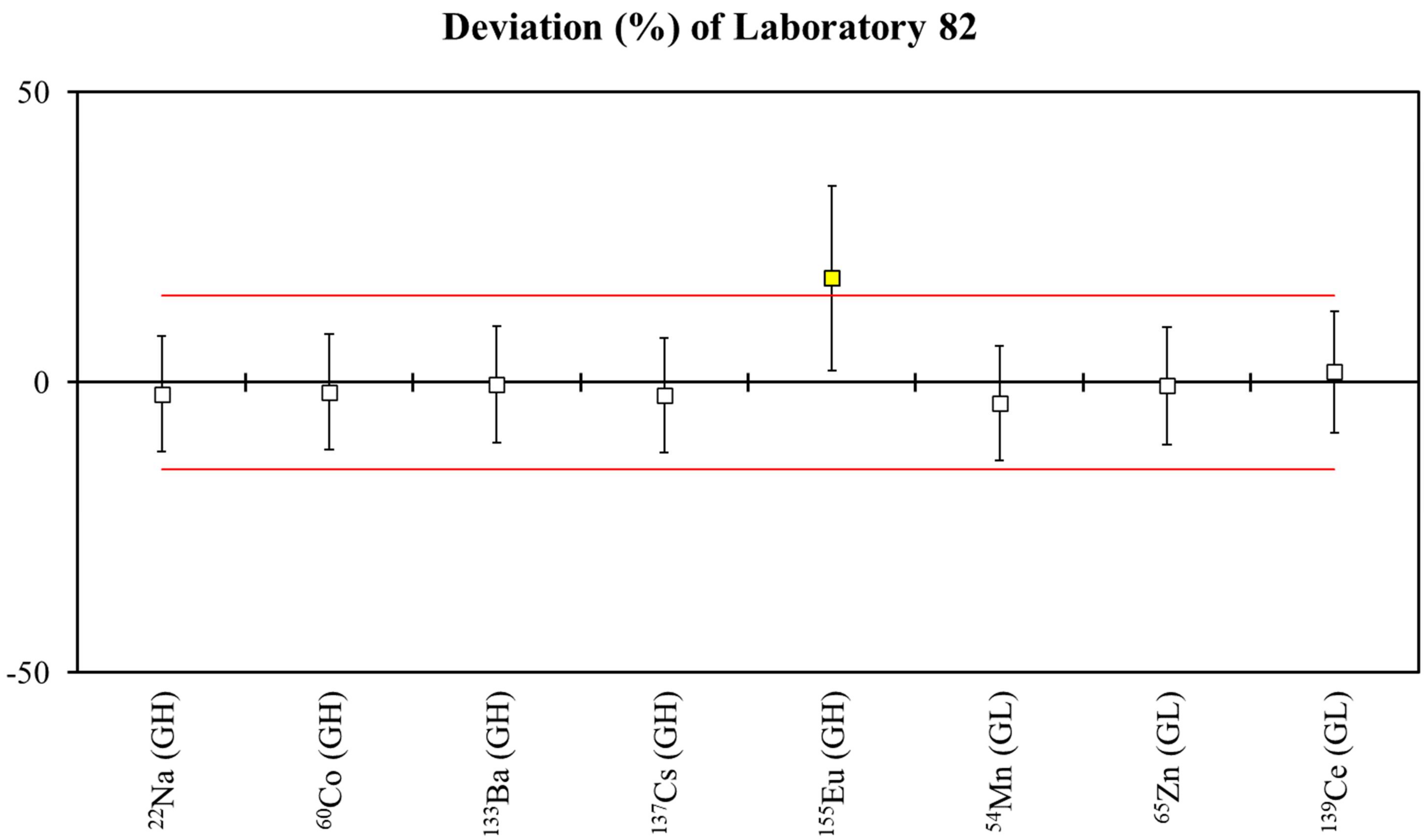
Radionuclide	Laboratory 61	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	13.1 ± 1.6	13.24 ± 0.19	-1.3	-0.10	-0.22
^{90}Sr (AB)	3.77 ± 0.44	3.5493 ± 0.0095	6.2	0.50	1.07
^{241}Am (AB)	11.5 ± 1.4	11.618 ± 0.046	-1.0	-0.08	-0.17
^{241}Am (A1)	88 ± 22	88.14 ± 0.35	-0.7	-0.03	-0.12
^{244}Cm (A1)	22.0 ± 5.5	21.641 ± 0.033	1.7	0.07	0.28
^{3}H (B1)	0.270 ± 0.030	0.2821 ± 0.0047	-4.3	-0.40	-0.74
^{22}Na (GH)	8.48 ± 0.21	8.674 ± 0.033	-2.2	-0.91	-0.38
^{60}Co (GH)	30.10 ± 0.43	31.23 ± 0.11	-3.6	-2.55	-0.62
^{133}Ba (GH)	36.80 ± 0.38	38.84 ± 0.27	-5.3	-4.38	-0.90
^{137}Cs (GH)	12.50 ± 0.25	13.201 ± 0.098	-5.3	-2.61	-0.91
^{155}Eu (GH)	6.67 ± 0.21	7.63 ± 0.14	-12.6	-3.80	-2.16
^{54}Mn (GL)	18.2 ± 1.0	17.22 ± 0.18	5.7	0.96	0.98
^{65}Zn (GL)	27.1 ± 2.2	29.67 ± 0.22	-8.7	-1.16	-1.49
^{139}Ce (GL)	45.8 ± 1.8	44.41 ± 0.39	3.1	0.75	0.54
^{210}Pb (GL)	14.7 ± 2.5	13.67 ± 0.15	7.5	0.41	1.29


Deviation (%) of Laboratory 67
50
0
-50
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)

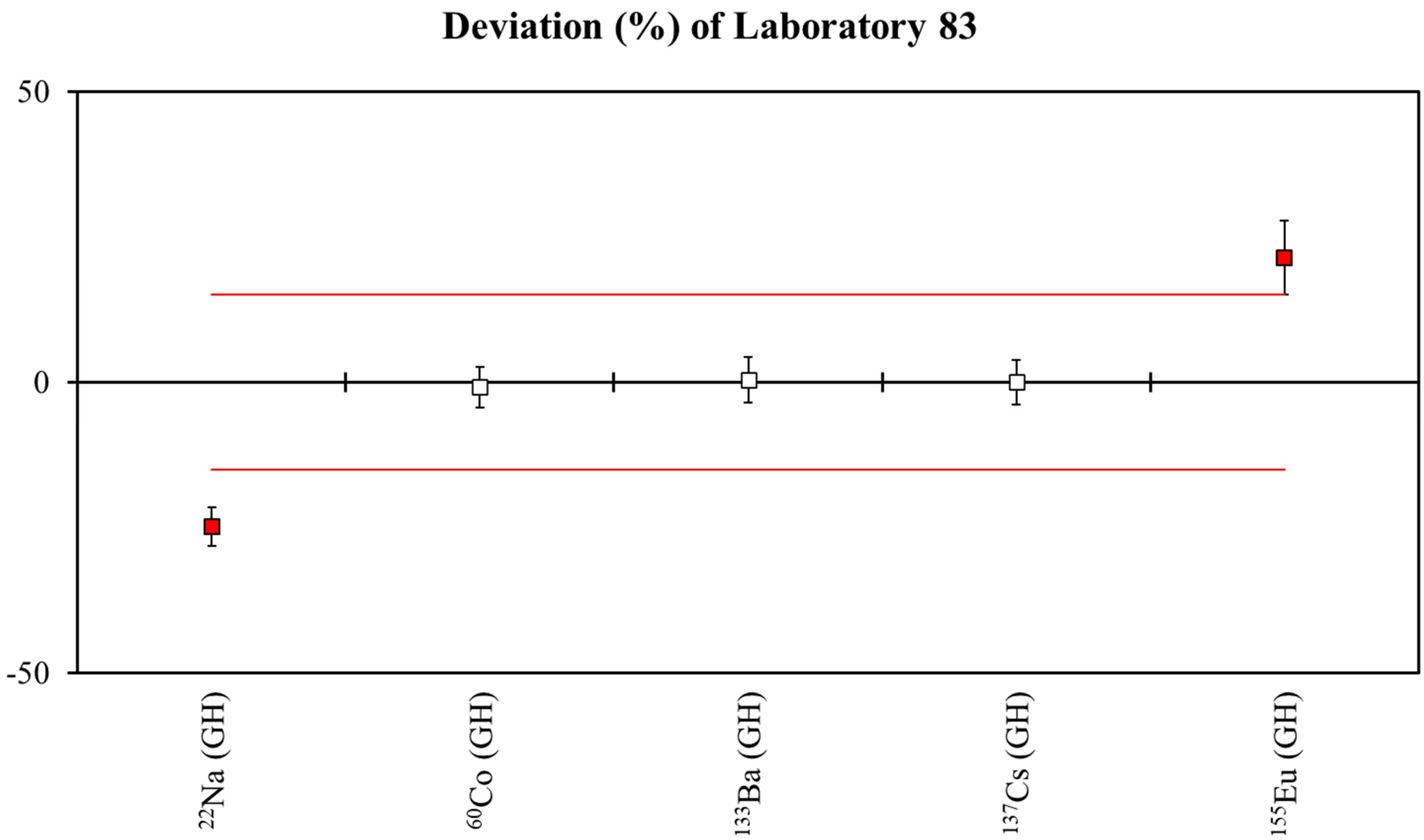
Radionuclide	Laboratory 67	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{22}Na (GH)	8.16 ± 0.13	8.674 ± 0.033	-6.0	-3.96	-1.02
^{60}Co (GH)	31.55 ± 0.93	31.23 ± 0.11	1.0	0.34	0.17
^{133}Ba (GH)	34.9 ± 1.2	38.84 ± 0.27	-10.2	-3.16	-1.74
^{137}Cs (GH)	13.29 ± 0.33	13.201 ± 0.098	0.7	0.26	0.12
^{155}Eu (GH)	7.03 ± 0.14	7.63 ± 0.14	-7.8	-3.04	-1.35


Deviation (%) of Laboratory 72
50
0
-50
^{3}H (B1)
^{22}Na (GH)
^{60}Co (GH)
^{133}Ba (GH)
^{137}Cs (GH)
^{155}Eu (GH)

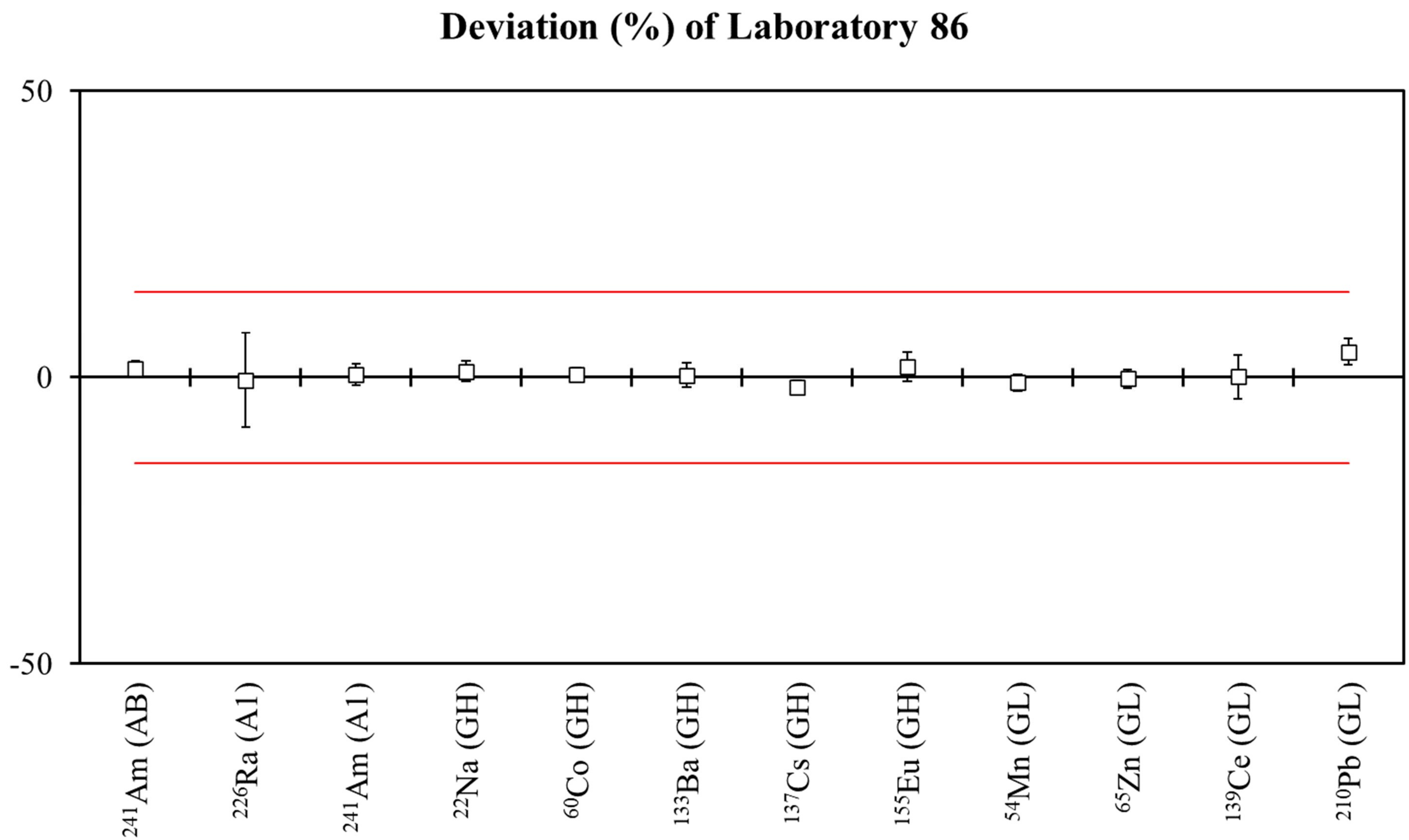
Radionuclide	Laboratory 72	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.316 ± 0.016	0.2821 ± 0.0047	11.9	2.04	2.05
^{22}Na (GH)	7.419 ± 0.074	8.674 ± 0.033	-14.5	-15.43	-2.48
^{60}Co (GH)	30.57 ± 0.67	31.23 ± 0.11	-2.1	-0.97	-0.36
^{133}Ba (GH)	36.9 ± 1.5	38.84 ± 0.27	-5.1	-1.30	-0.87
^{137}Cs (GH)	13.584 ± 0.044	13.201 ± 0.098	2.9	3.57	0.50
^{155}Eu (GH)	6.822 ± 0.083	7.63 ± 0.14	-10.6	-4.96	-1.82


Deviation (%) of Laboratory 82
50
0
-50
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)
54Mn (GL)
65Zn (GL)
139Ce (GL)

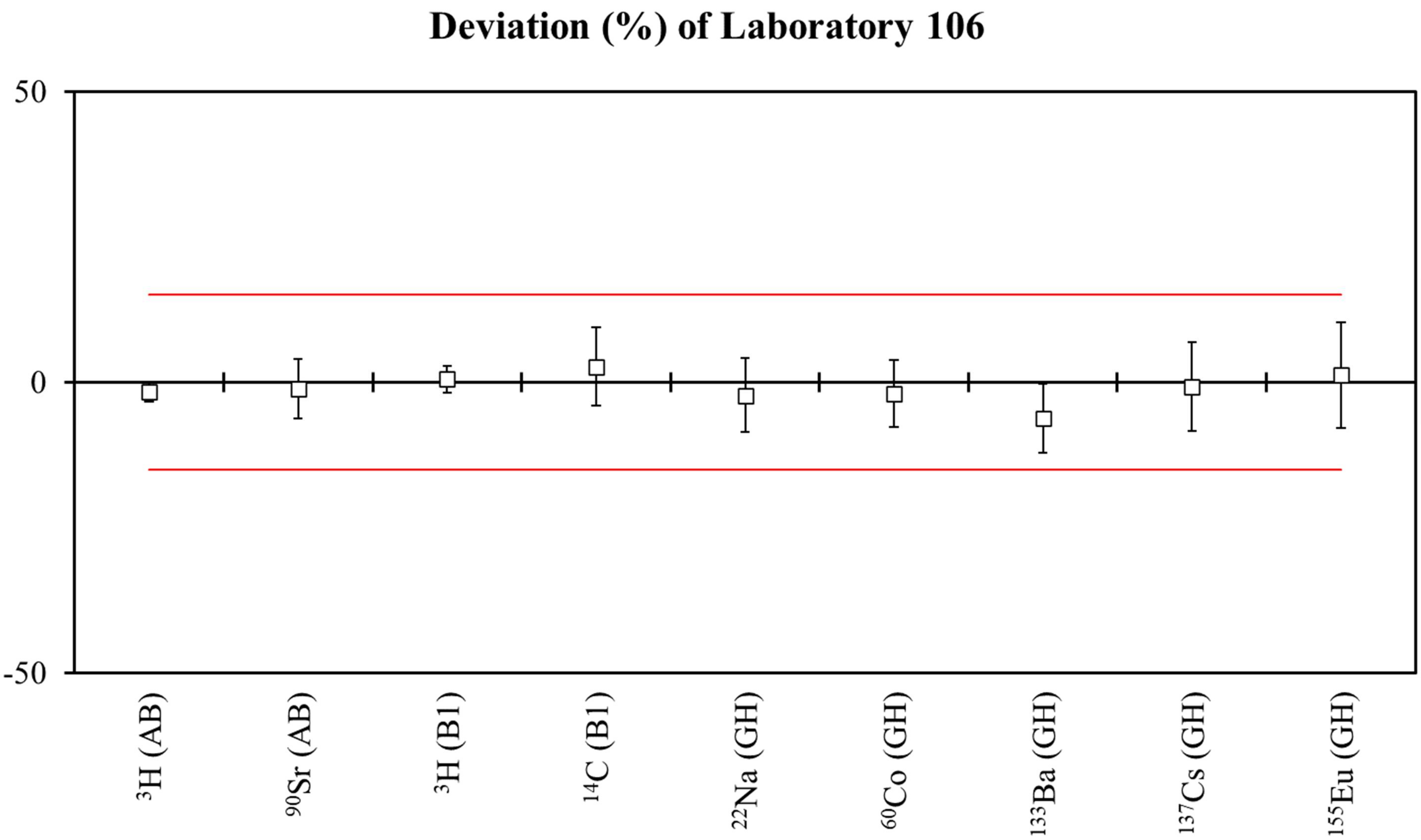
Radionuclide	Laboratory 82	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{22}Na (GH)	8.50 ± 0.86	8.674 ± 0.033	-2.0	-0.20	-0.34
^{60}Co (GH)	30.7 ± 3.1	31.23 ± 0.11	-1.7	-0.17	-0.29
^{133}Ba (GH)	38.7 ± 3.9	38.84 ± 0.27	-0.4	-0.04	-0.06
^{137}Cs (GH)	12.9 ± 1.3	13.201 ± 0.098	-2.3	-0.23	-0.39
^{155}Eu (GH)	9.0 ± 1.2	7.63 ± 0.14	18.0	1.13	3.08
^{54}Mn (GL)	16.6 ± 1.7	17.22 ± 0.18	-3.6	-0.36	-0.62
^{65}Zn (GL)	29.5 ± 3.0	29.67 ± 0.22	-0.6	-0.06	-0.10
^{139}Ce (GL)	45.2 ± 4.6	44.41 ± 0.39	1.8	0.17	0.31


Deviation (%) of Laboratory 83
50
0
-50
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)

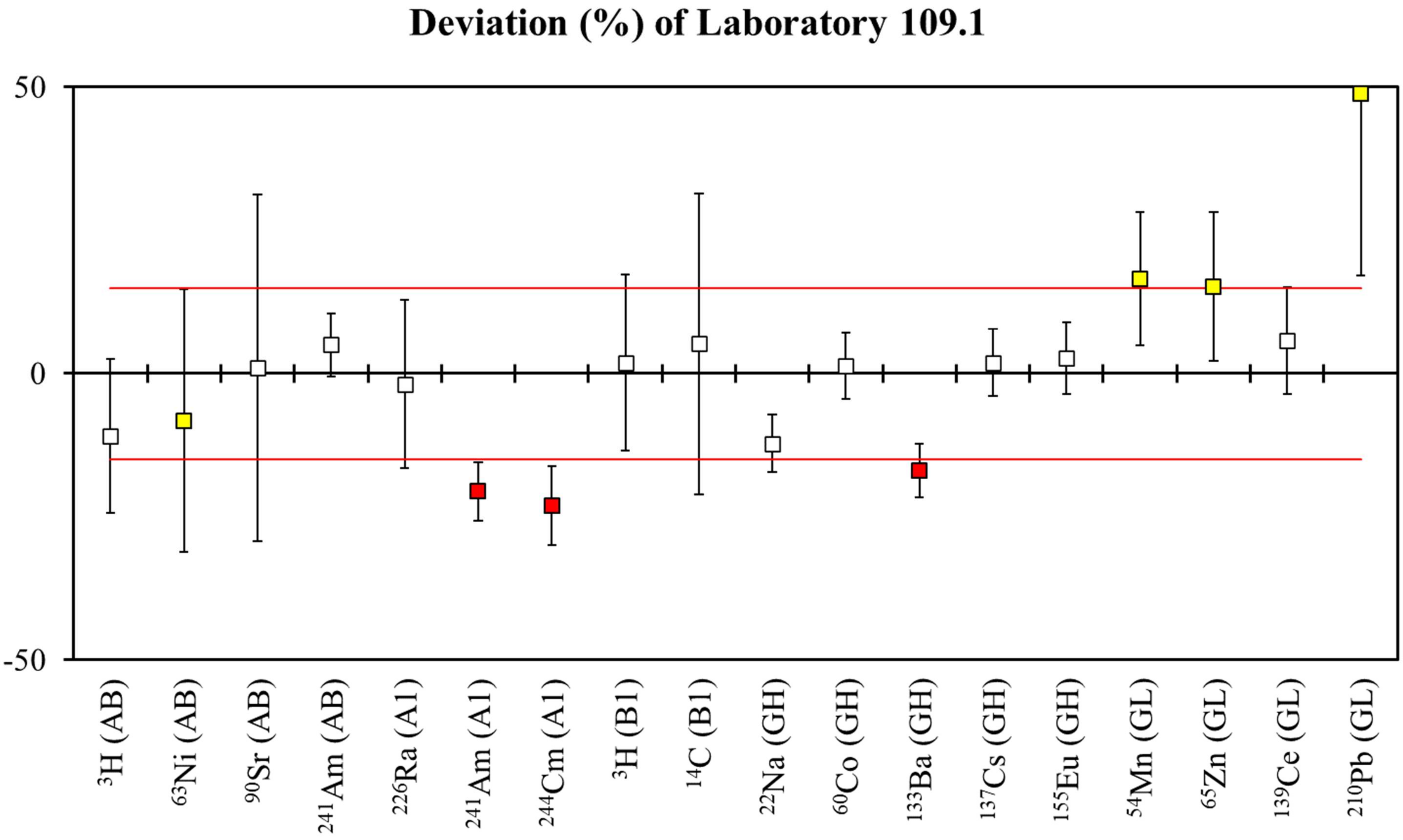
Radionuclide	Laboratory 83	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{22}Na (GH)	6.52 ± 0.28	8.674 ± 0.033	-24.9	-7.57	-4.27
^{60}Co (GH)	31.0 ± 1.1	31.23 ± 0.11	-0.8	-0.24	-0.14
^{133}Ba (GH)	39.0 ± 1.5	38.84 ± 0.27	0.3	0.09	0.06
^{137}Cs (GH)	13.20 ± 0.49	13.201 ± 0.098	0.0	0.00	0.00
^{155}Eu (GH)	9.26 ± 0.46	7.63 ± 0.14	21.4	3.41	3.67


Deviation (%) of Laboratory 86
50
0
-50
241Am (AB)
226Ra (A1)
241Am (A1)
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)
54Mn (GL)
65Zn (GL)
139Ce (GL)
210Pb (GL)

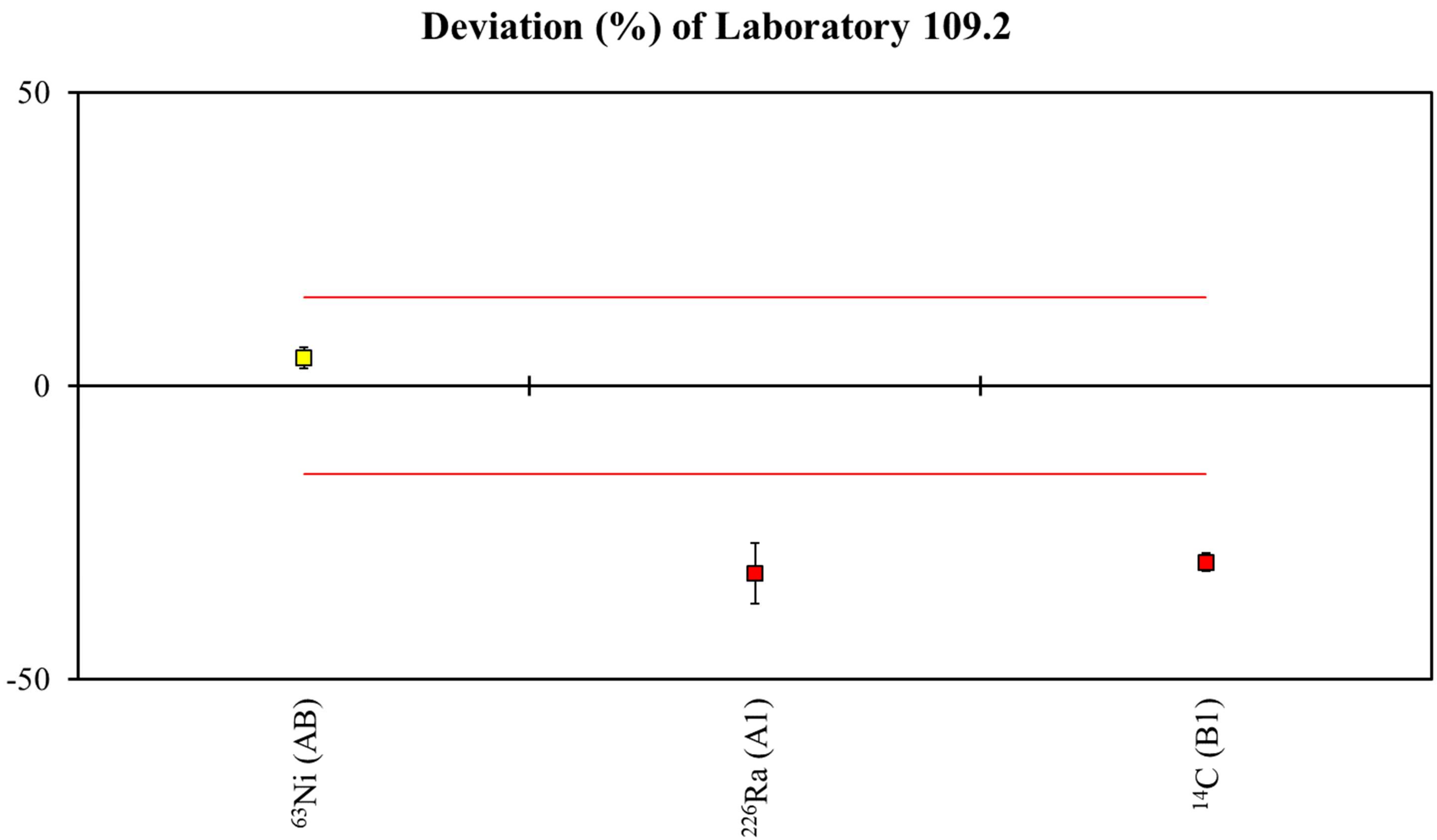
Radionuclide	Laboratory 86	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{241}Am (AB)	11.80 ± 0.15	11.618 ± 0.046	1.5	1.11	0.26
^{226}Ra (A1)	45.2 ± 3.7	45.44 ± 0.57	-0.4	-0.05	-0.08
^{241}Am (A1)	88.6 ± 1.6	88.14 ± 0.35	0.5	0.28	0.09
^{22}Na (GH)	8.77 ± 0.16	8.674 ± 0.033	1.1	0.58	0.18
^{60}Co (GH)	31.41 ± 0.33	31.23 ± 0.11	0.6	0.52	0.10
^{133}Ba (GH)	38.98 ± 0.78	38.84 ± 0.27	0.4	0.17	0.06
^{137}Cs (GH)	12.97 ± 0.12	13.201 ± 0.098	-1.8	-1.48	-0.30
^{155}Eu (GH)	7.77 ± 0.14	7.63 ± 0.14	1.9	0.74	0.32
^{54}Mn (GL)	17.07 ± 0.17	17.22 ± 0.18	-0.9	-0.63	-0.15
^{65}Zn (GL)	29.60 ± 0.42	29.67 ± 0.22	-0.2	-0.14	-0.04
^{139}Ce (GL)	44.4 ± 1.7	44.41 ± 0.39	0.1	0.02	0.01
^{210}Pb (GL)	14.28 ± 0.27	13.67 ± 0.15	4.5	1.97	0.77


Deviation (%) of Laboratory 106
50
0
-50
3H (AB)
90Sr (AB)
3H (B1)
14C (B1)
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)

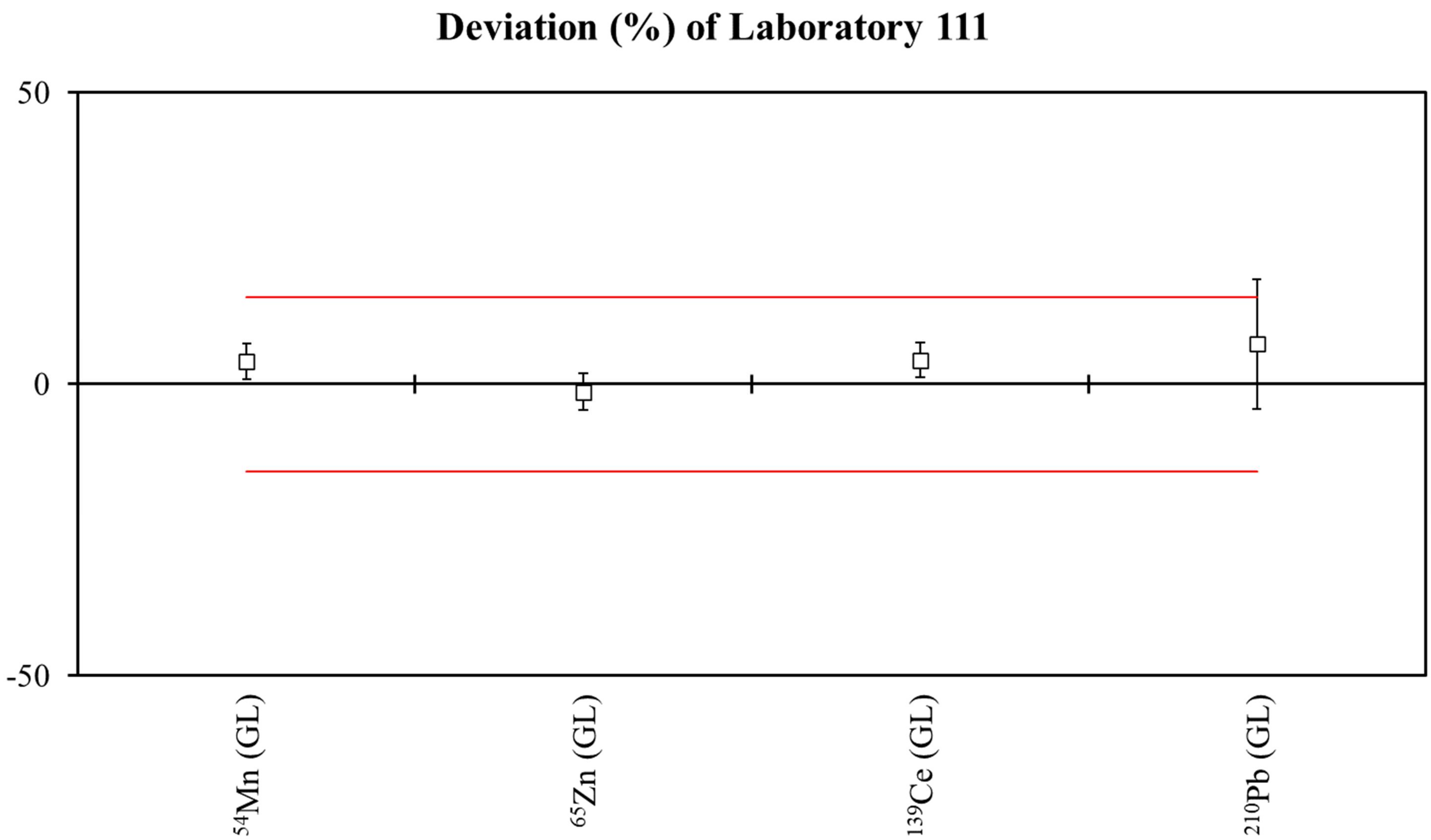
Radionuclide	Laboratory 106	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	13.02 ± 0.11	13.24 ± 0.19	-1.7	-1.00	-0.29
^{90}Sr (AB)	3.51 ± 0.18	3.5493 ± 0.0095	-1.1	-0.22	-0.19
^{3}H (B1)	0.2836 ± 0.0044	0.2821 ± 0.0047	0.5	0.23	0.09
^{14}C (B1)	0.414 ± 0.027	0.4031 ± 0.0018	2.7	0.40	0.46
^{22}Na (GH)	8.48 ± 0.55	8.674 ± 0.033	-2.2	-0.35	-0.38
^{60}Co (GH)	30.6 ± 1.8	31.23 ± 0.11	-2.0	-0.35	-0.35
^{133}Ba (GH)	36.4 ± 2.3	38.84 ± 0.27	-6.3	-1.05	-1.08
^{137}Cs (GH)	13.1 ± 1.0	13.201 ± 0.098	-0.8	-0.10	-0.13
^{155}Eu (GH)	7.72 ± 0.68	7.63 ± 0.14	1.2	0.13	0.20


Deviation (%) of Laboratory 109.1
50
0
-50
^{3}H (AB)
^{63}Ni (AB)
^{90}Sr (AB)
^{241}Am (AB)
^{226}Ra (A1)
^{241}Am (A1)
^{244}Cm (A1)
^{3}H (B1)
^{14}C (B1)
^{22}Na (GH)
^{60}Co (GH)
^{133}Ba (GH)
^{137}Cs (GH)
^{155}Eu (GH)
^{54}Mn (GL)
^{65}Zn (GL)
^{139}Ce (GL)
^{210}Pb (GL)

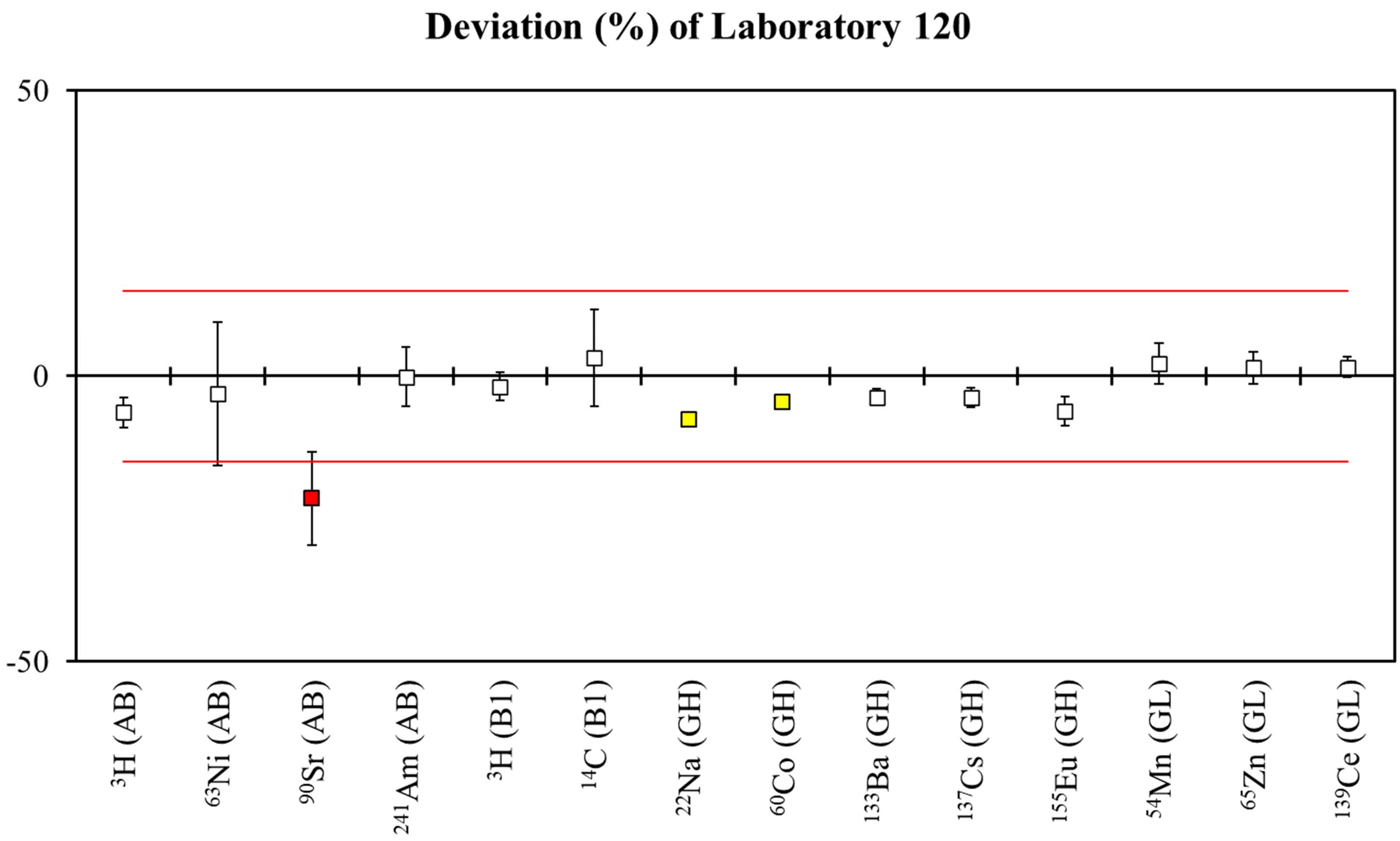
Radionuclide	Laboratory 109.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	11.8 ± 1.8	13.24 ± 0.19	-10.8	-0.81	-1.86
^{63}Ni (AB)	3.29 ± 0.82	3.589 ± 0.017	-8.2	-0.36	-1.41
^{90}Sr (AB)	3.6 ± 1.1	3.5493 ± 0.0095	1.0	0.03	0.17
^{241}Am (AB)	12.20 ± 0.64	11.618 ± 0.046	5.0	0.90	0.86
^{226}Ra (A1)	44.6 ± 6.7	45.44 ± 0.57	-1.8	-0.12	-0.31
^{241}Am (A1)	70.0 ± 4.6	88.14 ± 0.35	-20.6	-3.98	-3.53
^{244}Cm (A1)	16.7 ± 1.5	21.641 ± 0.033	-23.1	-3.33	-3.96
^{3}H (B1)	0.287 ± 0.043	0.2821 ± 0.0047	1.9	0.12	0.33
^{14}C (B1)	0.42 ± 0.11	0.4031 ± 0.0018	5.2	0.20	0.90
^{22}Na (GH)	7.62 ± 0.43	8.674 ± 0.033	-12.2	-2.43	-2.09
^{60}Co (GH)	31.6 ± 1.8	31.23 ± 0.11	1.3	0.22	0.22
^{133}Ba (GH)	32.3 ± 1.8	38.84 ± 0.27	-16.9	-3.60	-2.91
^{137}Cs (GH)	13.45 ± 0.77	13.201 ± 0.098	1.9	0.32	0.32
^{155}Eu (GH)	7.84 ± 0.46	7.63 ± 0.14	2.7	0.42	0.46
^{54}Mn (GL)	20.1 ± 2.0	17.22 ± 0.18	16.6	1.43	2.85
^{65}Zn (GL)	34.2 ± 3.8	29.67 ± 0.22	15.2	1.17	2.61
^{139}Ce (GL)	47.0 ± 4.2	44.41 ± 0.39	5.8	0.61	0.99
^{210}Pb (GL)	20.3 ± 4.3	13.67 ± 0.15	48.8	1.54	8.38


Deviation (%) of Laboratory 109.2
50
0
-50
63Ni (AB)
226Ra (A1)
14C (B1)

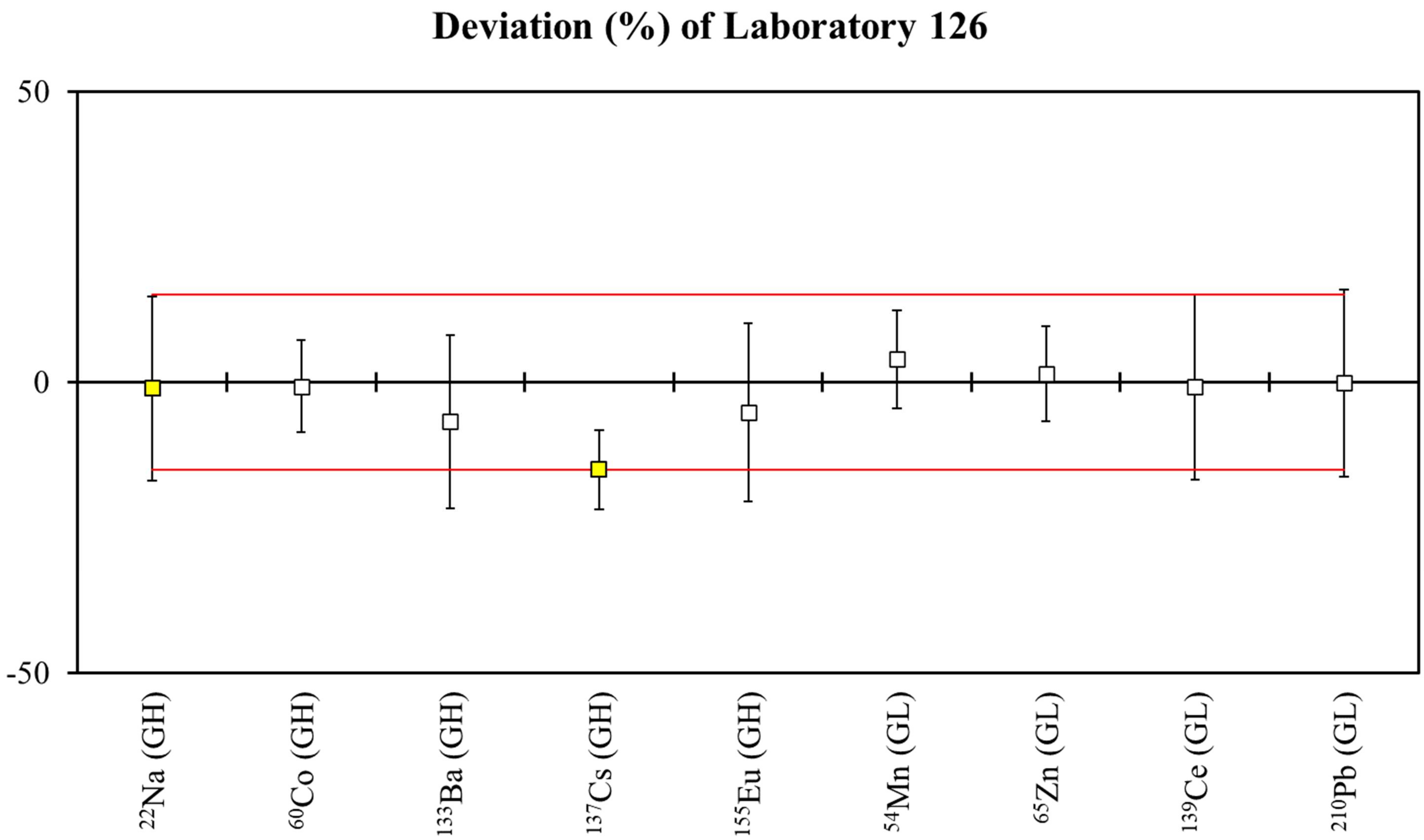
Radionuclide	Laboratory 109.2	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{63}Ni (AB)	3.760 ± 0.064	3.589 ± 0.017	4.8	2.60	0.82
^{226}Ra (A1)	30.9 ± 2.3	45.44 ± 0.57	-32.0	-6.06	-5.50
^{14}C (B1)	0.2820 ± 0.0060	0.4031 ± 0.0018	-30.0	-19.33	-5.16


Deviation (%) of Laboratory 111
50
0
-50
54Mn (GL)
65Zn (GL)
139Ce (GL)
210Pb (GL)

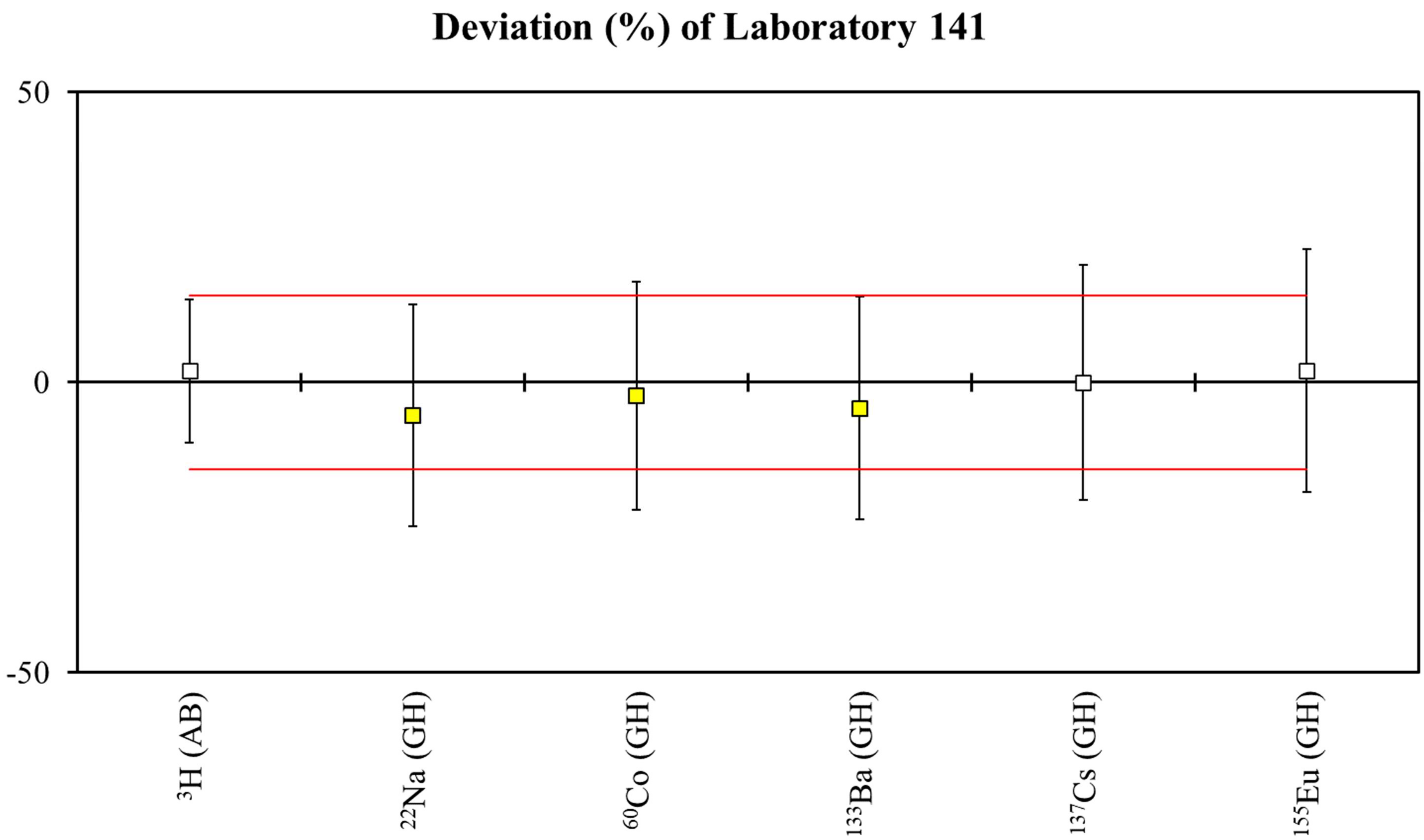
Radionuclide	Laboratory 111	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{54}Mn (GL)	17.89 ± 0.50	17.22 ± 0.18	3.9	1.26	0.67
^{65}Zn (GL)	29.28 ± 0.90	29.67 ± 0.22	-1.3	-0.42	-0.23
^{139}Ce (GL)	46.3 ± 1.3	44.41 ± 0.39	4.1	1.37	0.71
^{210}Pb (GL)	14.6 ± 1.5	13.67 ± 0.15	6.9	0.62	1.18


Deviation (%) of Laboratory 120
50
0
-50
3H (AB)
63Ni (AB)
90Sr (AB)
241Am (AB)
3H (B1)
14C (B1)
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)
54Mn (GL)
65Zn (GL)
139Ce (GL)

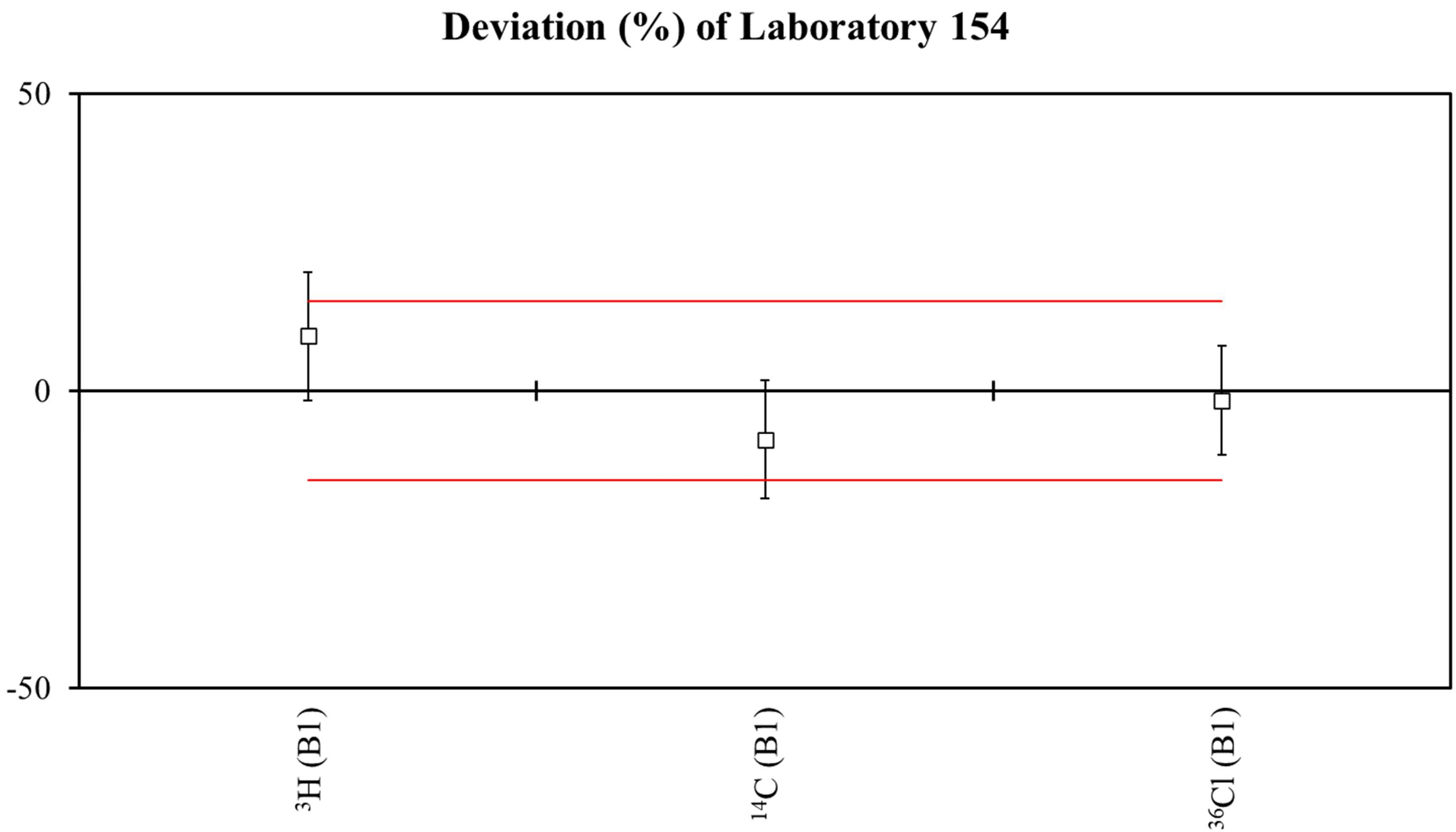
Radionuclide	Laboratory 120	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	12.40 ± 0.30	13.24 ± 0.19	-6.3	-2.37	-1.09
^{63}Ni (AB)	3.48 ± 0.45	3.589 ± 0.017	-3.0	-0.24	-0.52
^{90}Sr (AB)	2.79 ± 0.29	3.5493 ± 0.0095	-21.4	-2.62	-3.67
^{241}Am (AB)	11.60 ± 0.60	11.618 ± 0.046	-0.2	-0.03	-0.03
^{3}H (B1)	0.2770 ± 0.0050	0.2821 ± 0.0047	-1.8	-0.74	-0.31
^{14}C (B1)	0.416 ± 0.034	0.4031 ± 0.0018	3.2	0.38	0.55
^{22}Na (GH)	8.02 ± 0.11	8.674 ± 0.033	-7.5	-5.69	-1.29
^{60}Co (GH)	29.80 ± 0.30	31.23 ± 0.11	-4.6	-4.48	-0.79
^{133}Ba (GH)	37.40 ± 0.50	38.84 ± 0.27	-3.7	-2.53	-0.64
^{137}Cs (GH)	12.70 ± 0.20	13.201 ± 0.098	-3.8	-2.25	-0.65
^{155}Eu (GH)	7.16 ± 0.14	7.63 ± 0.14	-6.2	-2.37	-1.06
^{54}Mn (GL)	17.60 ± 0.60	17.22 ± 0.18	2.2	0.61	0.38
^{65}Zn (GL)	30.10 ± 0.80	29.67 ± 0.22	1.4	0.52	0.25
^{139}Ce (GL)	45.10 ± 0.70	44.41 ± 0.39	1.6	0.86	0.27


Deviation (%) of Laboratory 126
50
0
-50
^{22}Na (GH)
^{60}Co (GH)
^{133}Ba (GH)
^{137}Cs (GH)
^{155}Eu (GH)
^{54}Mn (GL)
^{65}Zn (GL)
^{139}Ce (GL)
^{210}Pb (GL)

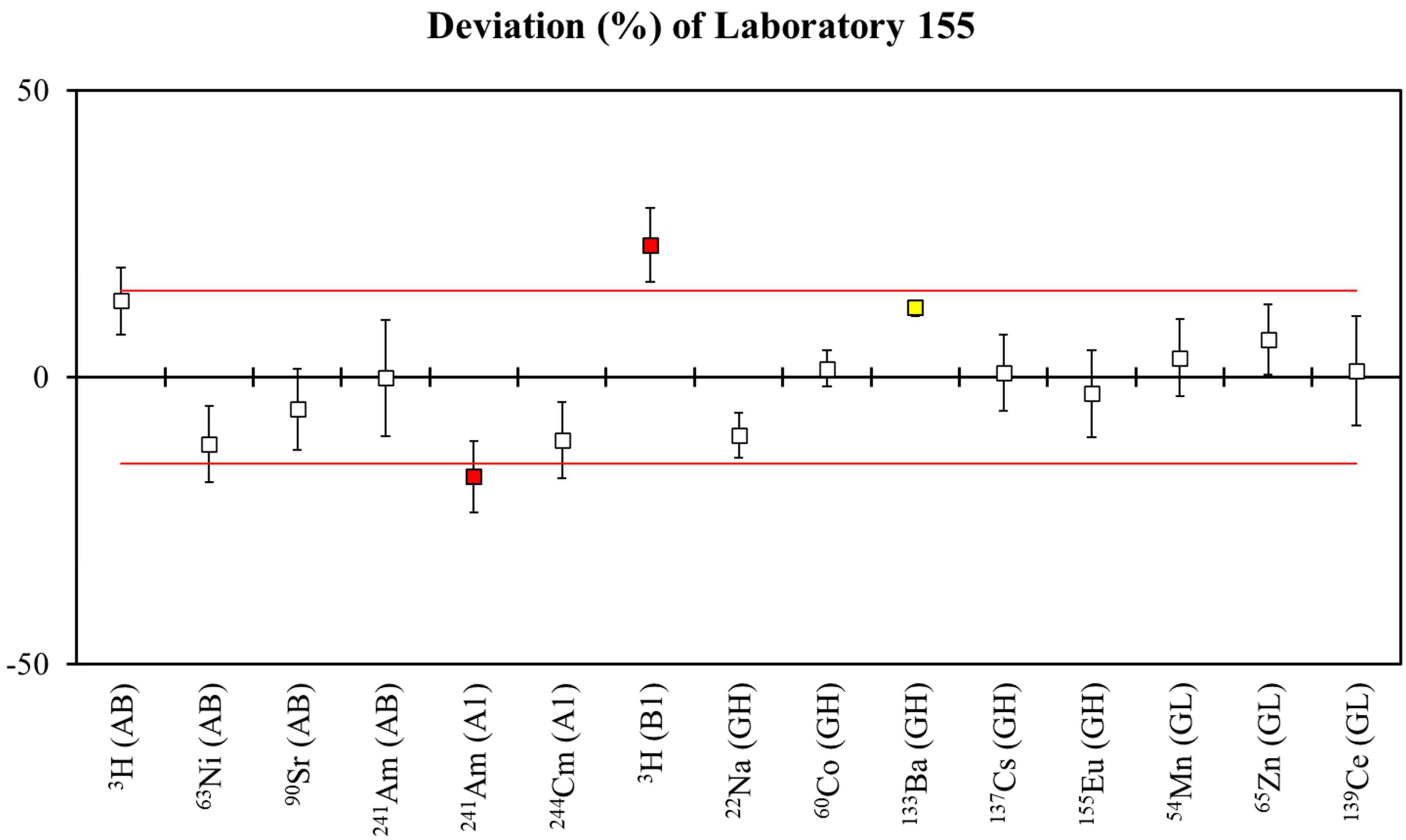
Radionuclide	Laboratory 126	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{22}Na (GH)	8.6 ± 1.4	8.674 ± 0.033	-1.1	-0.07	-0.19
^{60}Co (GH)	31.0 ± 2.5	31.23 ± 0.11	-0.7	-0.09	-0.13
^{133}Ba (GH)	36.2 ± 5.8	38.84 ± 0.27	-6.8	-0.46	-1.17
^{137}Cs (GH)	11.22 ± 0.90	13.201 ± 0.098	-15.0	-2.19	-2.58
^{155}Eu (GH)	7.2 ± 1.2	7.63 ± 0.14	-5.2	-0.34	-0.90
^{54}Mn (GL)	17.9 ± 1.4	17.22 ± 0.18	3.9	0.47	0.68
^{65}Zn (GL)	30.1 ± 2.4	29.67 ± 0.22	1.4	0.18	0.25
^{139}Ce (GL)	44.0 ± 7.0	44.41 ± 0.39	-0.8	-0.05	-0.14
^{210}Pb (GL)	13.6 ± 2.2	13.67 ± 0.15	-0.2	-0.01	-0.03


Deviation (%) of Laboratory 141
50
0
-50
3H (AB)
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)

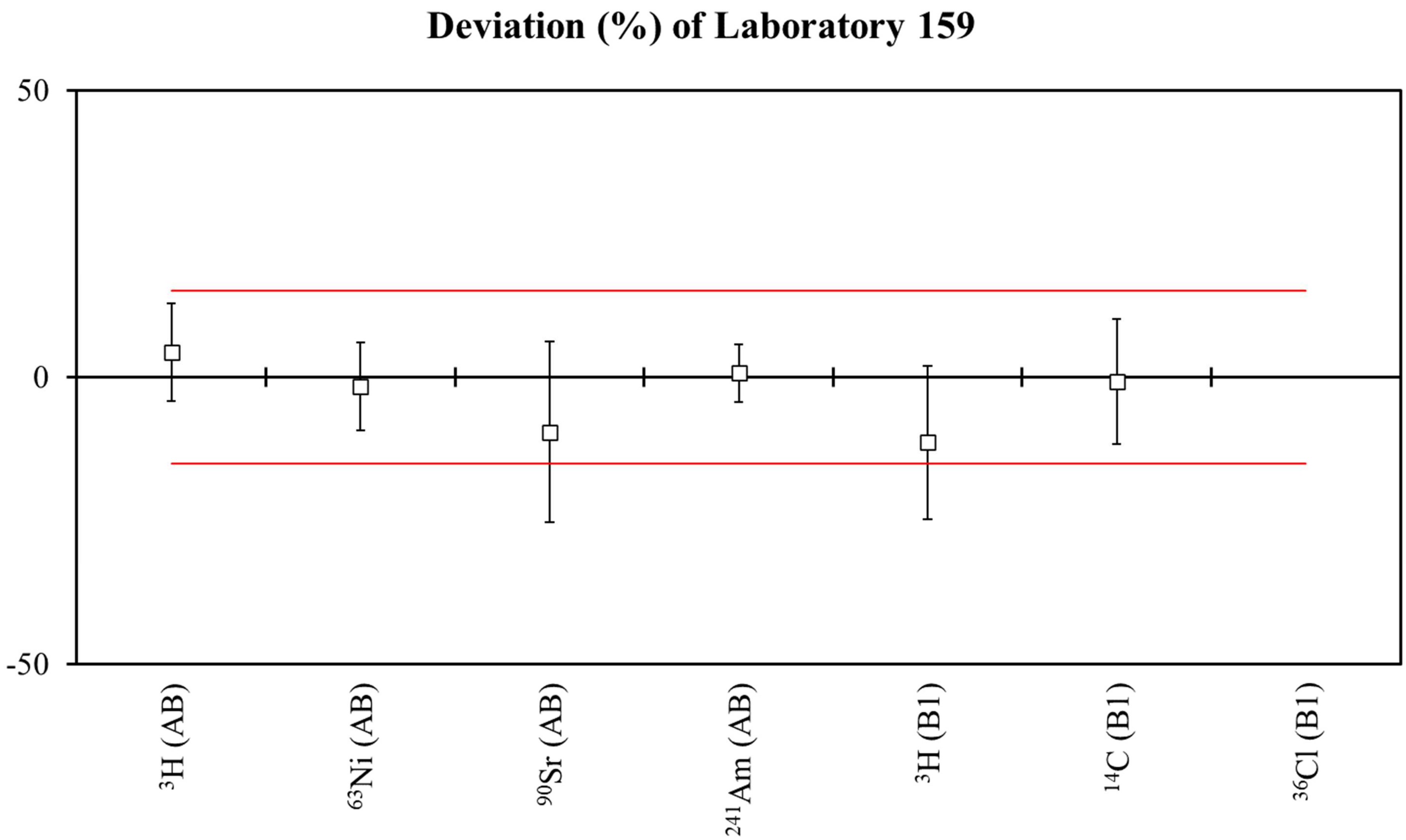
Radionuclide	Laboratory 141	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	13.5 ± 1.6	13.24 ± 0.19	2.0	0.16	0.34
^{22}Na (GH)	8.2 ± 1.7	8.674 ± 0.033	-5.7	-0.30	-0.98
^{60}Co (GH)	30.5 ± 6.2	31.23 ± 0.11	-2.3	-0.12	-0.40
^{133}Ba (GH)	37.1 ± 7.5	38.84 ± 0.27	-4.5	-0.23	-0.77
^{137}Cs (GH)	13.2 ± 2.7	13.201 ± 0.098	0.0	0.00	0.00
^{155}Eu (GH)	7.8 ± 1.6	7.63 ± 0.14	2.0	0.09	0.34


Deviation (%) of Laboratory 154
50
0
-50
^{3}H (B1)
^{14}C (B1)
^{36}Cl (B1)

Radionuclide	Laboratory 154	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.308 ± 0.030	0.2821 ± 0.0047	9.2	0.85	1.58
^{14}C (B1)	0.370 ± 0.040	0.4031 ± 0.0018	-8.2	-0.83	-1.41
^{36}Cl (B1)	0.215 ± 0.020	0.21867 ± 0.00076	-1.7	-0.18	-0.29

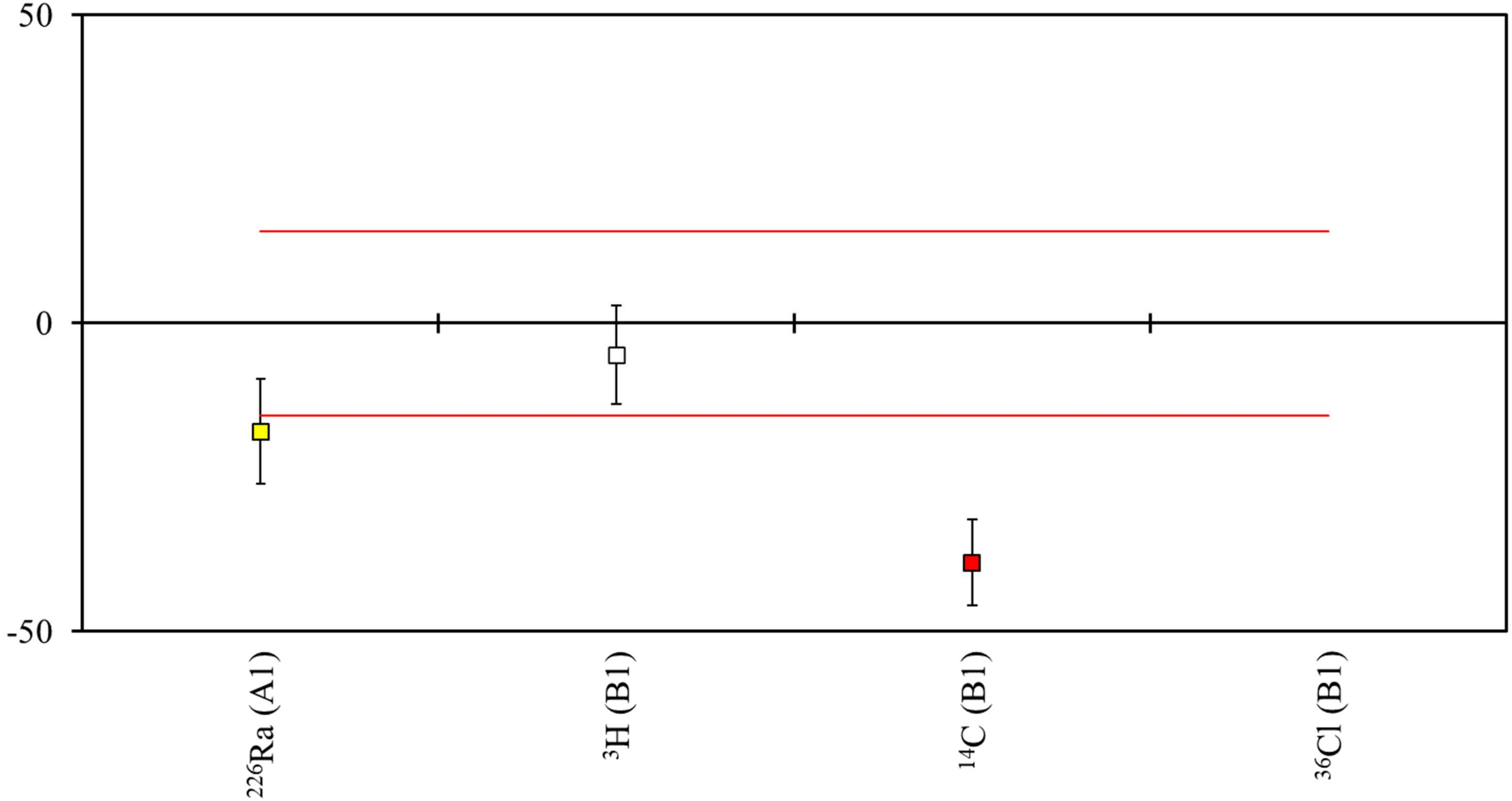

Deviation (%) of Laboratory 155
50
0
-50
3H (AB)
63Ni (AB)
90Sr (AB)
241Am (AB)
241Am (A1)
244Cm (A1)
3H (B1)
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)
54Mn (GL)
65Zn (GL)
139Ce (GL)

Radionuclide	Laboratory 155	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	15.00 ± 0.75	13.24 ± 0.19	13.3	2.27	2.28
^{63}Ni (AB)	3.17 ± 0.24	3.589 ± 0.017	-11.7	-1.76	-2.00
^{90}Sr (AB)	3.35 ± 0.25	3.5493 ± 0.0095	-5.6	-0.80	-0.96
^{241}Am (AB)	11.6 ± 1.2	11.618 ± 0.046	-0.2	-0.02	-0.03
^{241}Am (A1)	72.9 ± 5.5	88.14 ± 0.35	-17.3	-2.78	-2.97
^{244}Cm (A1)	19.3 ± 1.4	21.641 ± 0.033	-11.0	-1.65	-1.89
^{3}H (B1)	0.347 ± 0.017	0.2821 ± 0.0047	23.0	3.60	3.95
^{22}Na (GH)	7.80 ± 0.34	8.674 ± 0.033	-10.1	-2.57	-1.73
^{60}Co (GH)	31.70 ± 0.96	31.23 ± 0.11	1.5	0.49	0.26
^{133}Ba (GH)	43.50 ± 0.42	38.84 ± 0.27	12.0	9.41	2.06
^{137}Cs (GH)	13.30 ± 0.87	13.201 ± 0.098	0.7	0.11	0.13
^{155}Eu (GH)	7.41 ± 0.56	7.63 ± 0.14	-2.9	-0.38	-0.50
^{54}Mn (GL)	17.8 ± 1.1	17.22 ± 0.18	3.4	0.50	0.58
^{65}Zn (GL)	31.6 ± 1.8	29.67 ± 0.22	6.5	1.06	1.12
^{139}Ce (GL)	44.9 ± 4.2	44.41 ± 0.39	1.1	0.12	0.19

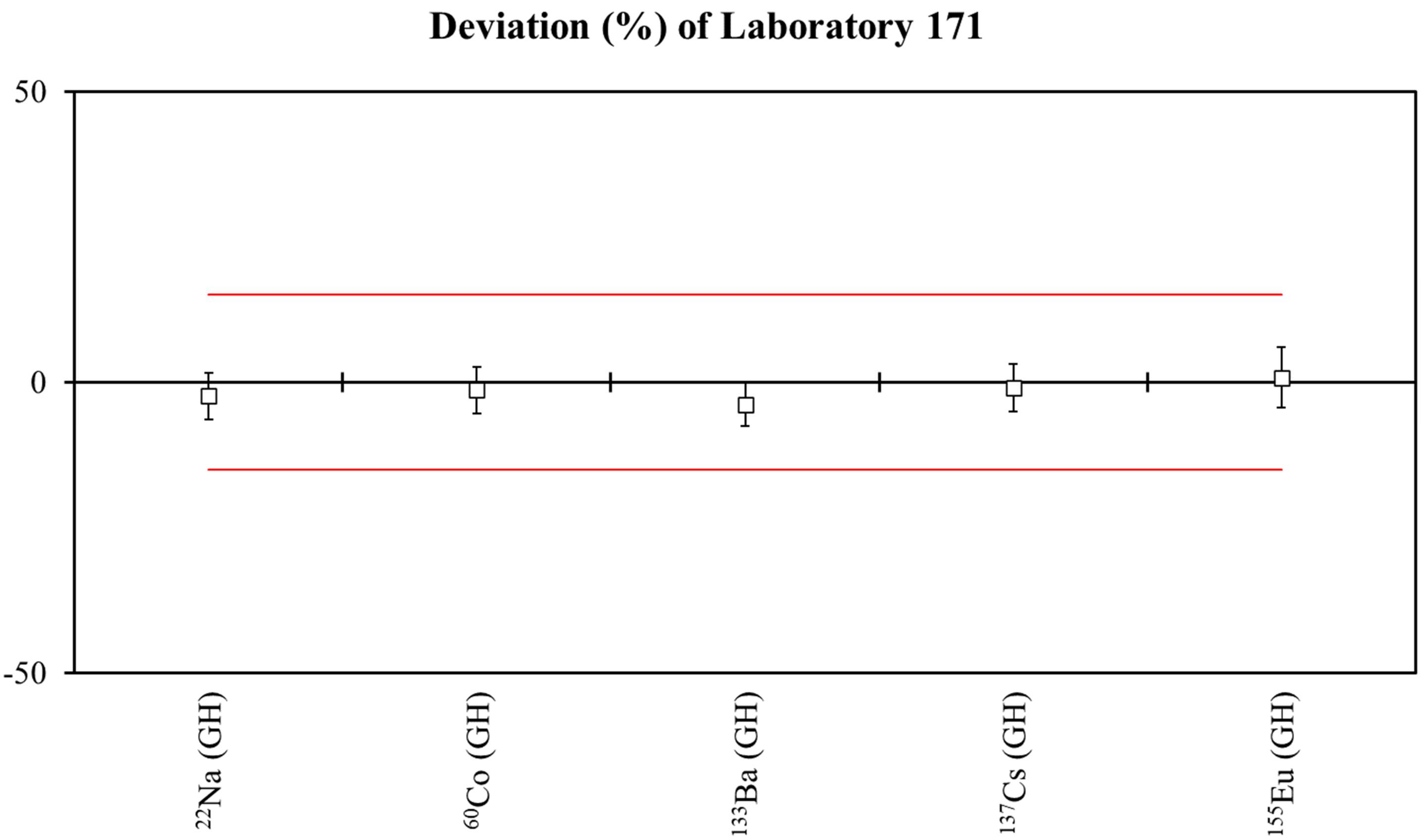

Deviation (%) of Laboratory 159
50
0
-50
3H (AB)
63Ni (AB)
90Sr (AB)
241Am (AB)
3H (B1)
14C (B1)
36Cl (B1)

Radionuclide	Laboratory 159	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	13.8 ± 1.1	13.24 ± 0.19	4.4	0.52	0.75
^{63}Ni (AB)	3.53 ± 0.28	3.589 ± 0.017	-1.6	-0.21	-0.28
^{90}Sr (AB)	3.21 ± 0.56	3.5493 ± 0.0095	-9.6	-0.61	-1.64
^{241}Am (AB)	11.70 ± 0.58	11.618 ± 0.046	0.7	0.14	0.12
^{3}H (B1)	0.250 ± 0.038	0.2821 ± 0.0047	-11.4	-0.85	-1.95
^{14}C (B1)	0.400 ± 0.044	0.4031 ± 0.0018	-0.8	-0.07	-0.13
^{36}Cl (B1)	4.03 ± 0.61	0.21867 ± 0.00076	1743.0	6.30	299.32

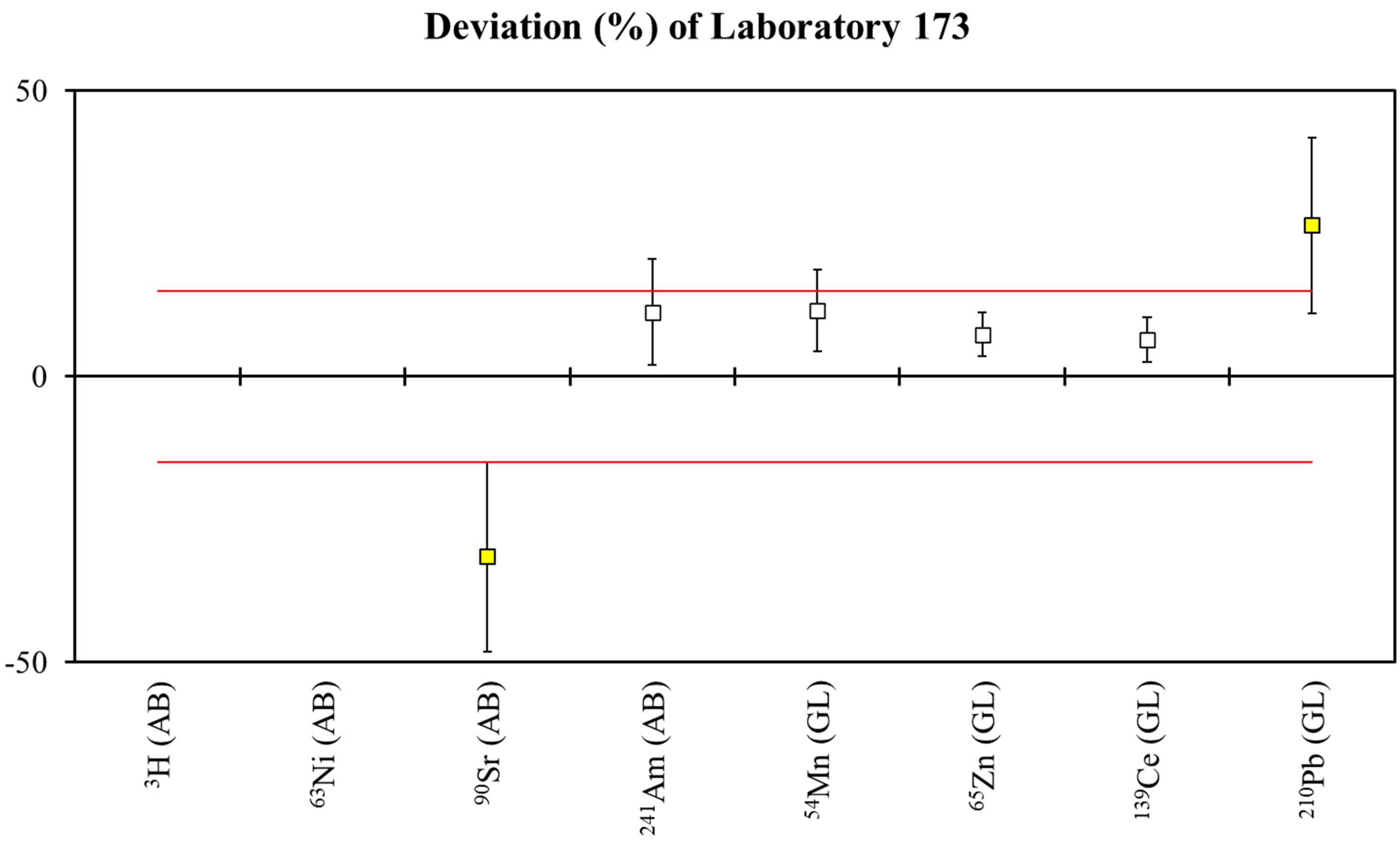
Deviation (%) of Laboratory 168



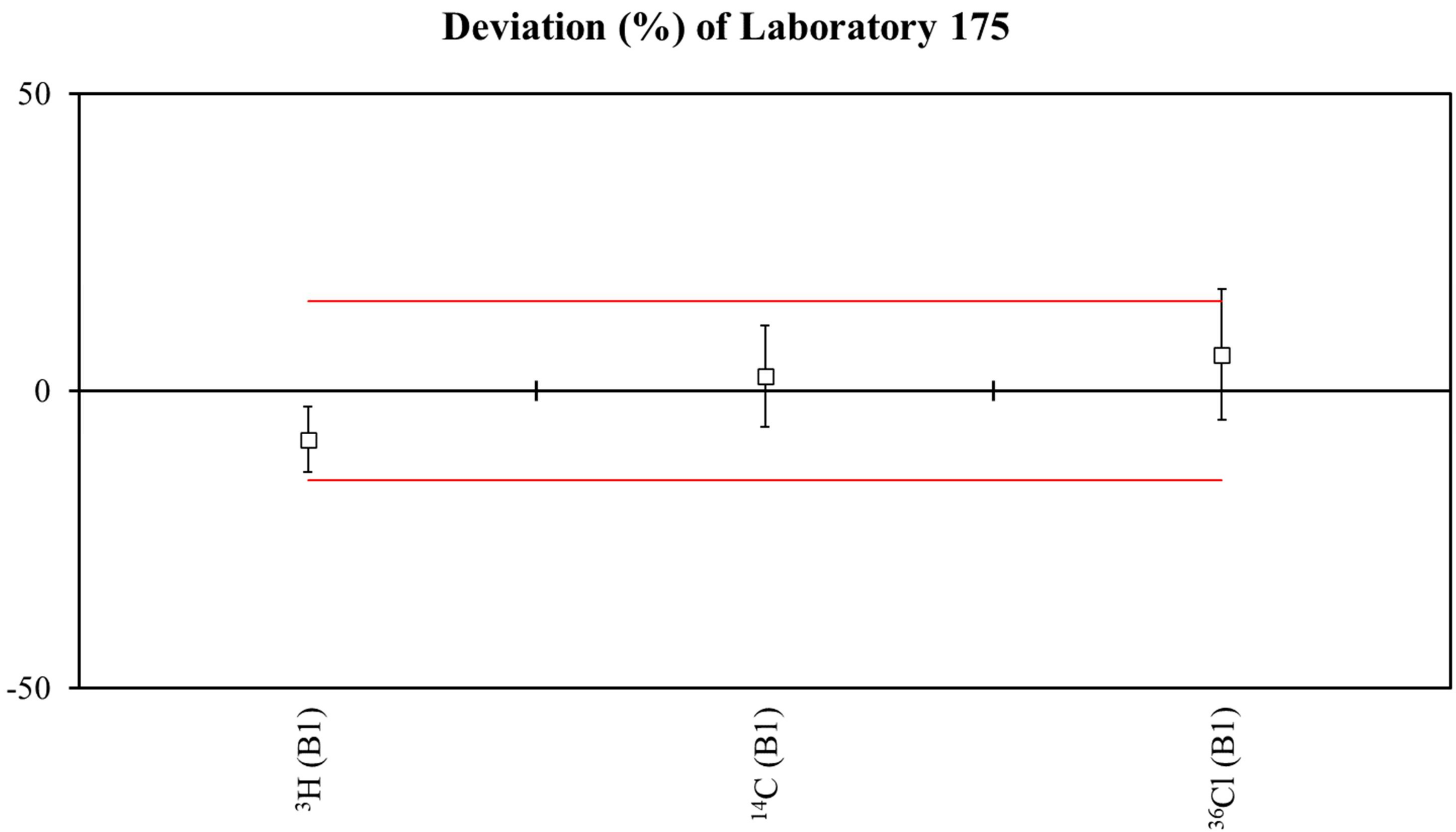
Radionuclide	Laboratory 168	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{226}Ra (A1)	37.5 ± 3.8	45.44 ± 0.57	-17.5	-2.05	-3.01
^{3}H (B1)	0.268 ± 0.022	0.2821 ± 0.0047	-5.1	-0.63	-0.87
^{14}C (B1)	0.246 ± 0.028	0.4031 ± 0.0018	-38.9	-5.57	-6.67
^{36}Cl (B1)	0.0703 ± 0.0087	0.21867 ± 0.00076	-67.8	-16.96	-11.65


Deviation (%) of Laboratory 171
50
0
-50
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)

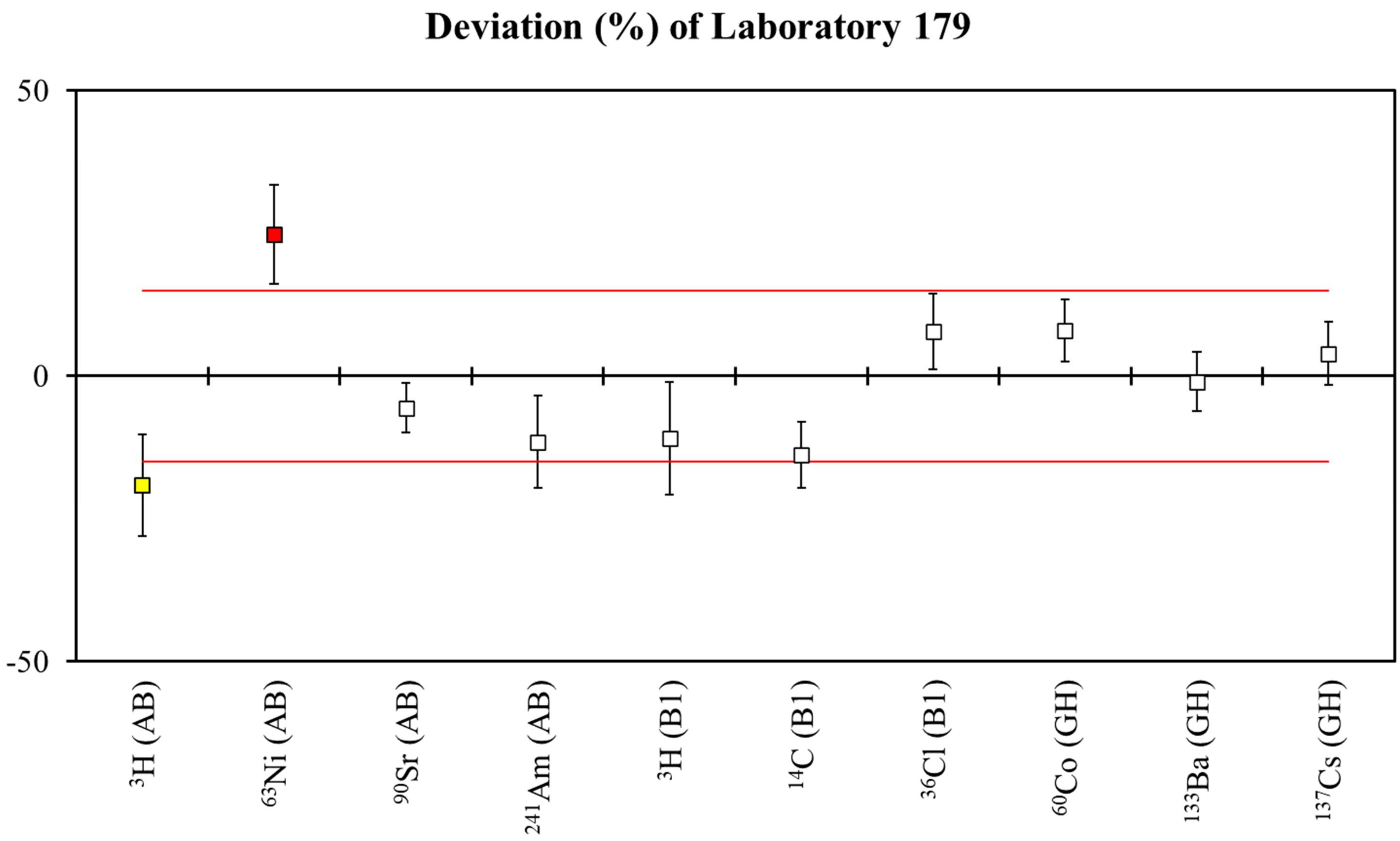
Radionuclide	Laboratory 171	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{22}Na (GH)	8.47 ± 0.35	8.674 ± 0.033	-2.4	-0.60	-0.41
^{60}Co (GH)	30.8 ± 1.2	31.23 ± 0.11	-1.3	-0.33	-0.22
^{133}Ba (GH)	37.4 ± 1.4	38.84 ± 0.27	-3.8	-1.02	-0.65
^{137}Cs (GH)	13.08 ± 0.53	13.201 ± 0.098	-1.0	-0.23	-0.16
^{155}Eu (GH)	7.69 ± 0.37	7.63 ± 0.14	0.8	0.15	0.13


Deviation (%) of Laboratory 173
50
0
-50
^{3}H (AB)
^{63}Ni (AB)
^{90}Sr (AB)
^{241}Am (AB)
^{54}Mn (GL)
^{65}Zn (GL)
^{139}Ce (GL)
^{210}Pb (GL)

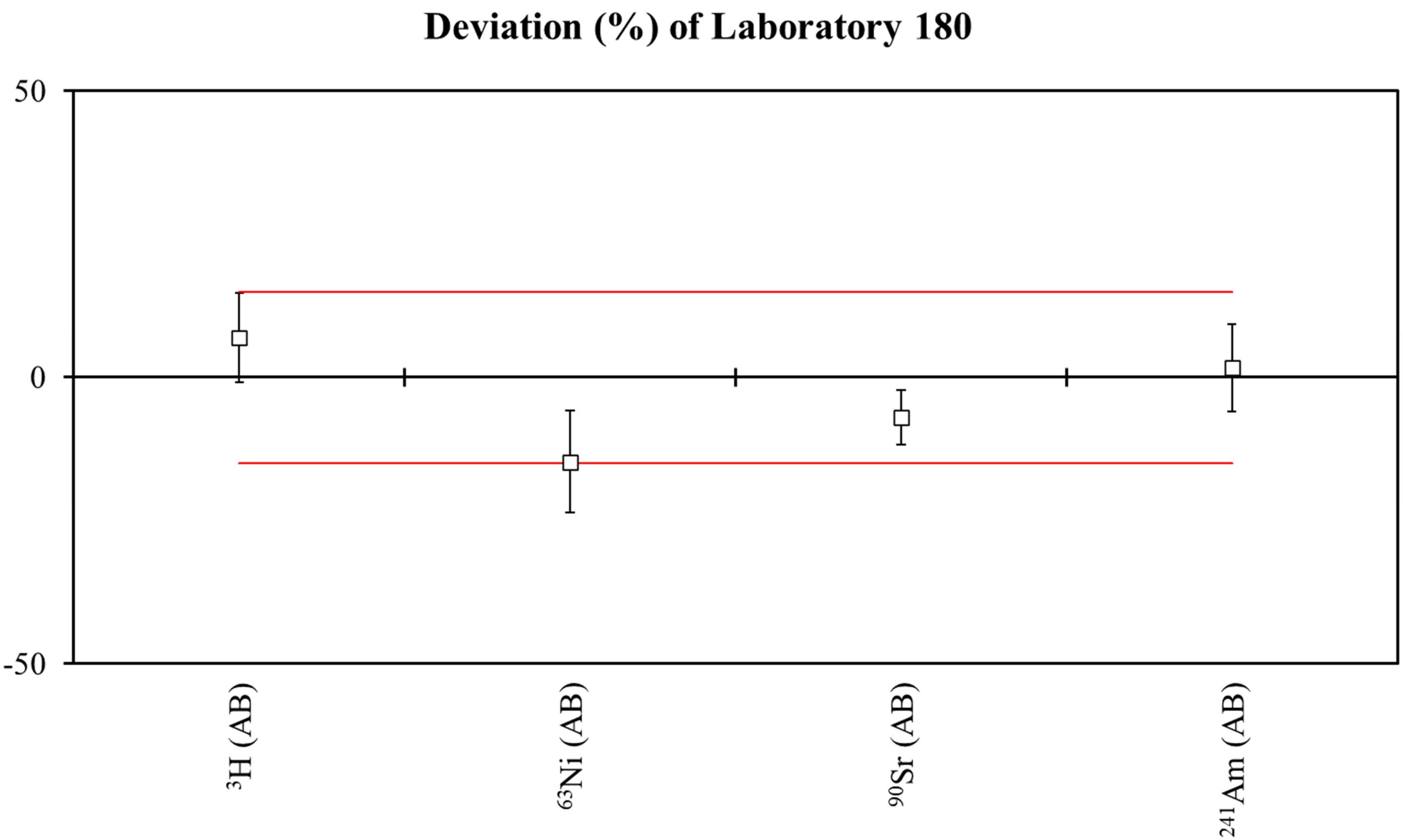
Radionuclide	Laboratory 173	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	5.97 ± 0.56	13.24 ± 0.19	-54.9	-12.29	-9.43
^{63}Ni (AB)	10.01 ± 0.79	3.589 ± 0.017	178.9	8.13	30.72
^{90}Sr (AB)	2.43 ± 0.59	3.5493 ± 0.0095	-31.5	-1.90	-5.42
^{241}Am (AB)	12.9 ± 1.1	11.618 ± 0.046	11.3	1.23	1.94
^{54}Mn (GL)	19.2 ± 1.2	17.22 ± 0.18	11.6	1.64	1.98
^{65}Zn (GL)	31.9 ± 1.1	29.67 ± 0.22	7.4	1.95	1.27
^{139}Ce (GL)	47.3 ± 1.7	44.41 ± 0.39	6.4	1.64	1.11
^{210}Pb (GL)	17.3 ± 2.1	13.67 ± 0.15	26.4	1.71	4.54


Deviation (%) of Laboratory 175
50
0
-50
^{3}H (B1)
^{14}C (B1)
^{36}Cl (B1)

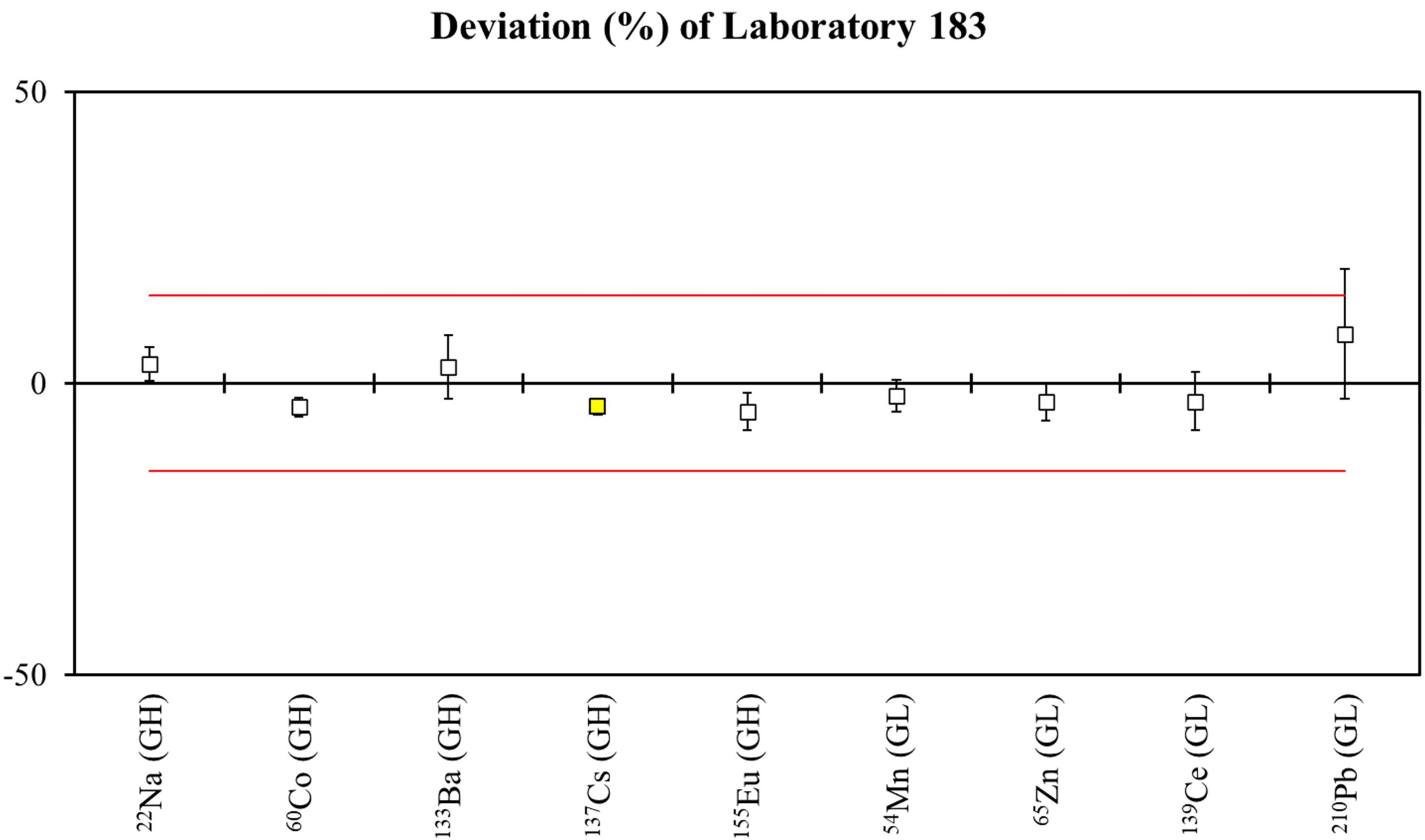
Radionuclide	Laboratory 175	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.259 ± 0.015	0.2821 ± 0.0047	-8.2	-1.47	-1.41
^{14}C (B1)	0.413 ± 0.034	0.4031 ± 0.0018	2.5	0.29	0.42
^{36}Cl (B1)	0.232 ± 0.024	0.21867 ± 0.00076	6.1	0.56	1.05


Deviation (%) of Laboratory 179
50
0
-50
3H (AB)
63Ni (AB)
90Sr (AB)
241Am (AB)
3H (B1)
14C (B1)
36Cl (B1)
60Co (GH)
133Ba (GH)
137Cs (GH)

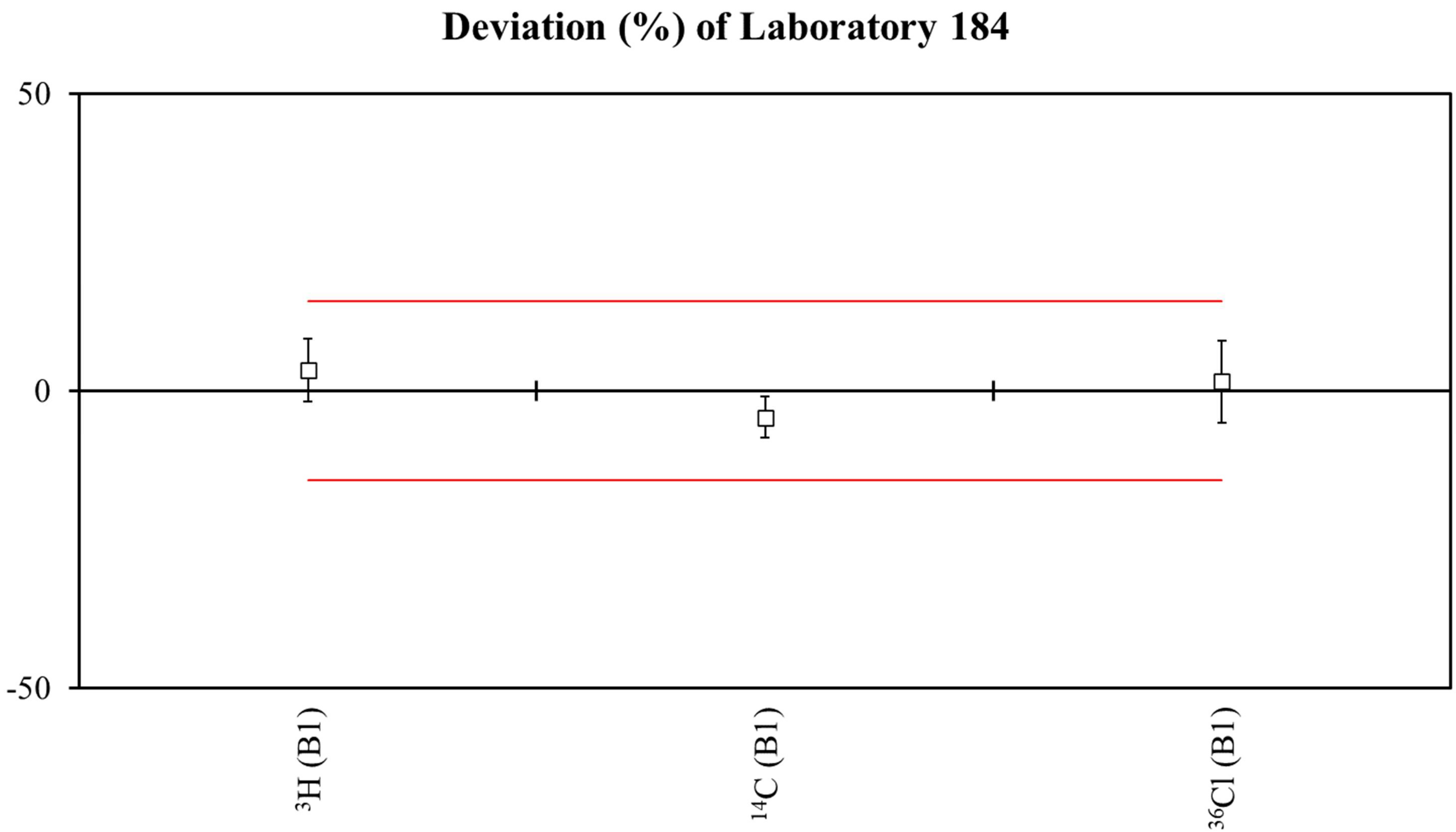
Radionuclide	Laboratory 179	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	10.7 ± 1.2	13.24 ± 0.19	-19.2	-2.14	-3.30
^{63}Ni (AB)	4.48 ± 0.31	3.589 ± 0.017	24.8	2.86	4.26
^{90}Sr (AB)	3.35 ± 0.15	3.5493 ± 0.0095	-5.6	-1.28	-0.96
^{241}Am (AB)	10.28 ± 0.94	11.618 ± 0.046	-11.5	-1.42	-1.98
^{3}H (B1)	0.251 ± 0.028	0.2821 ± 0.0047	-11.0	-1.11	-1.88
^{14}C (B1)	0.348 ± 0.023	0.4031 ± 0.0018	-13.8	-2.40	-2.37
^{36}Cl (B1)	0.236 ± 0.015	0.21867 ± 0.00076	7.9	1.19	1.35
^{60}Co (GH)	33.7 ± 1.7	31.23 ± 0.11	8.0	1.46	1.38
^{133}Ba (GH)	38.5 ± 2.0	38.84 ± 0.27	-1.0	-0.18	-0.16
^{137}Cs (GH)	13.72 ± 0.72	13.201 ± 0.098	4.0	0.72	0.68


Deviation (%) of Laboratory 180
50
0
-50
3H (AB)
63Ni (AB)
90Sr (AB)
241Am (AB)

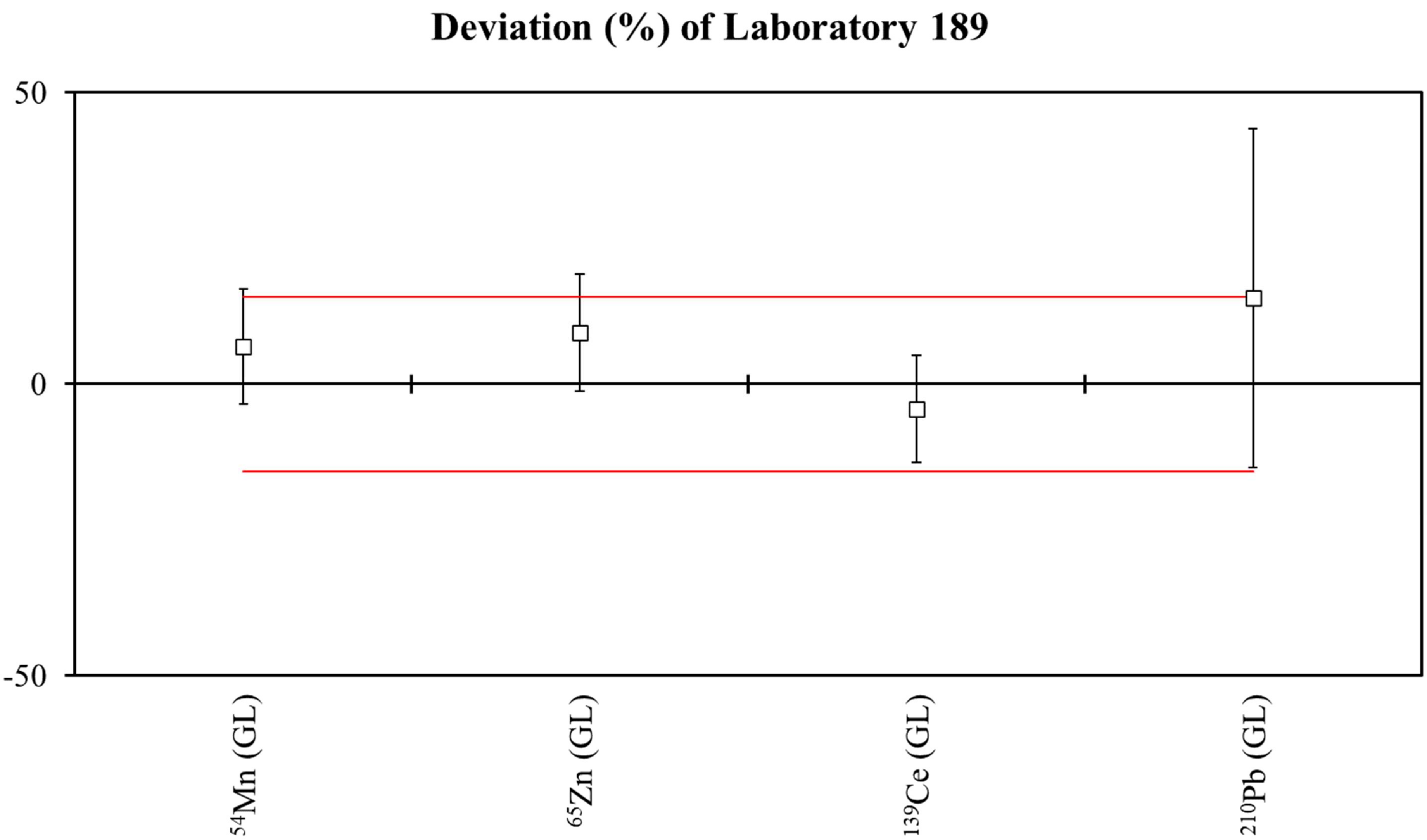
Radionuclide	Laboratory 180	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	14.2 ± 1.0	13.24 ± 0.19	6.9	0.89	1.19
^{63}Ni (AB)	3.06 ± 0.32	3.589 ± 0.017	-14.7	-1.65	-2.53
^{90}Sr (AB)	3.30 ± 0.17	3.5493 ± 0.0095	-7.0	-1.46	-1.21
^{241}Am (AB)	11.82 ± 0.89	11.618 ± 0.046	1.7	0.23	0.30


Deviation (%) of Laboratory 183
50
0
-50
^{22}Na (GH)
^{60}Co (GH)
^{133}Ba (GH)
^{137}Cs (GH)
^{155}Eu (GH)
^{54}Mn (GL)
^{65}Zn (GL)
^{139}Ce (GL)
^{210}Pb (GL)

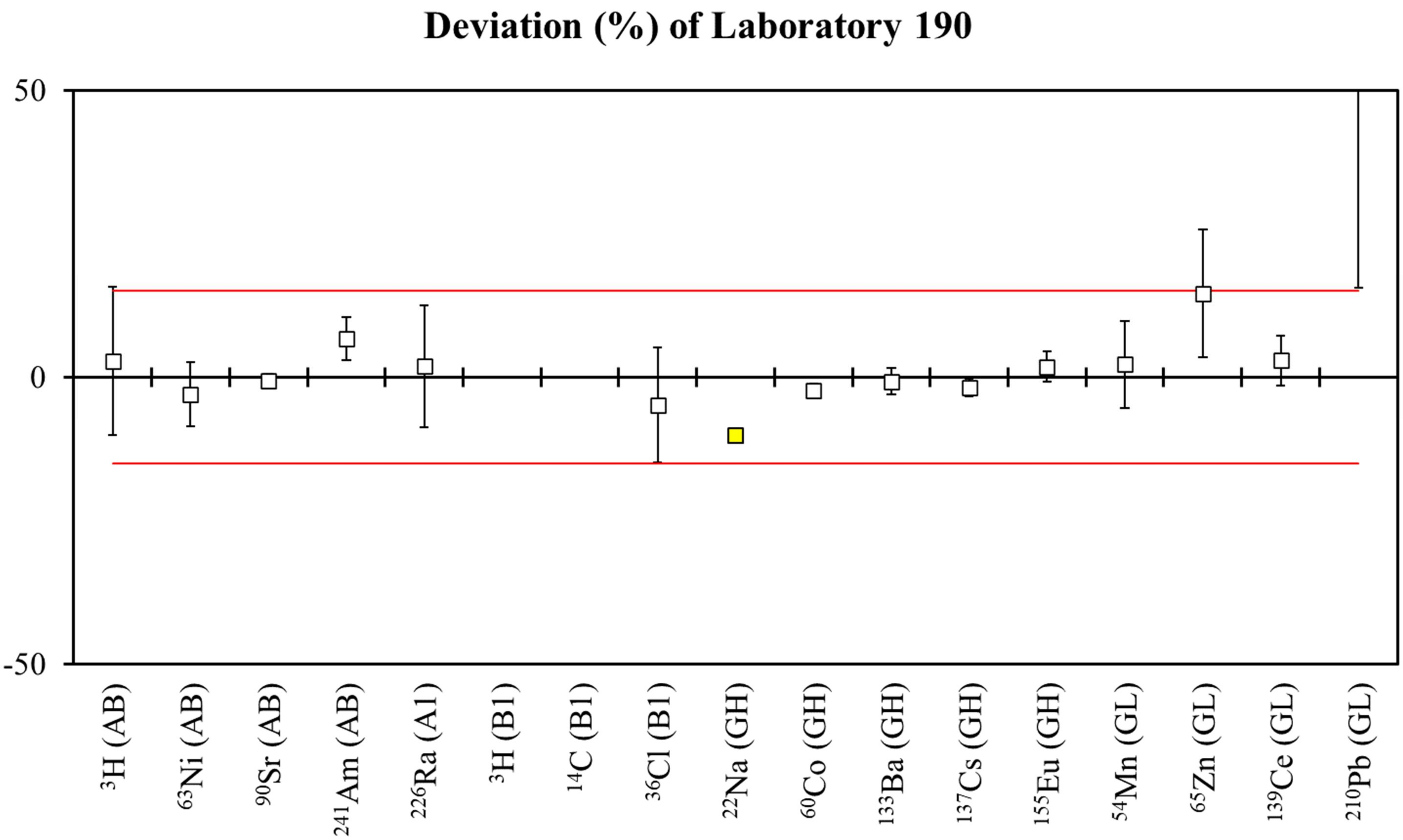
Radionuclide	Laboratory 183	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{22}Na (GH)	8.96 ± 0.25	8.674 ± 0.033	3.2	1.13	0.56
^{60}Co (GH)	29.96 ± 0.49	31.23 ± 0.11	-4.1	-2.50	-0.70
^{133}Ba (GH)	39.9 ± 2.1	38.84 ± 0.27	2.9	0.53	0.49
^{137}Cs (GH)	12.68 ± 0.16	13.201 ± 0.098	-4.0	-2.82	-0.68
^{155}Eu (GH)	7.26 ± 0.21	7.63 ± 0.14	-4.9	-1.48	-0.84
^{54}Mn (GL)	16.84 ± 0.44	17.22 ± 0.18	-2.2	-0.81	-0.38
^{65}Zn (GL)	28.71 ± 0.89	29.67 ± 0.22	-3.2	-1.05	-0.56
^{139}Ce (GL)	43.0 ± 2.2	44.41 ± 0.39	-3.1	-0.62	-0.53
^{210}Pb (GL)	14.8 ± 1.5	13.67 ± 0.15	8.4	0.76	1.45


Deviation (%) of Laboratory 184
50
0
-50
^{3}H (B1)
^{14}C (B1)
^{36}Cl (B1)

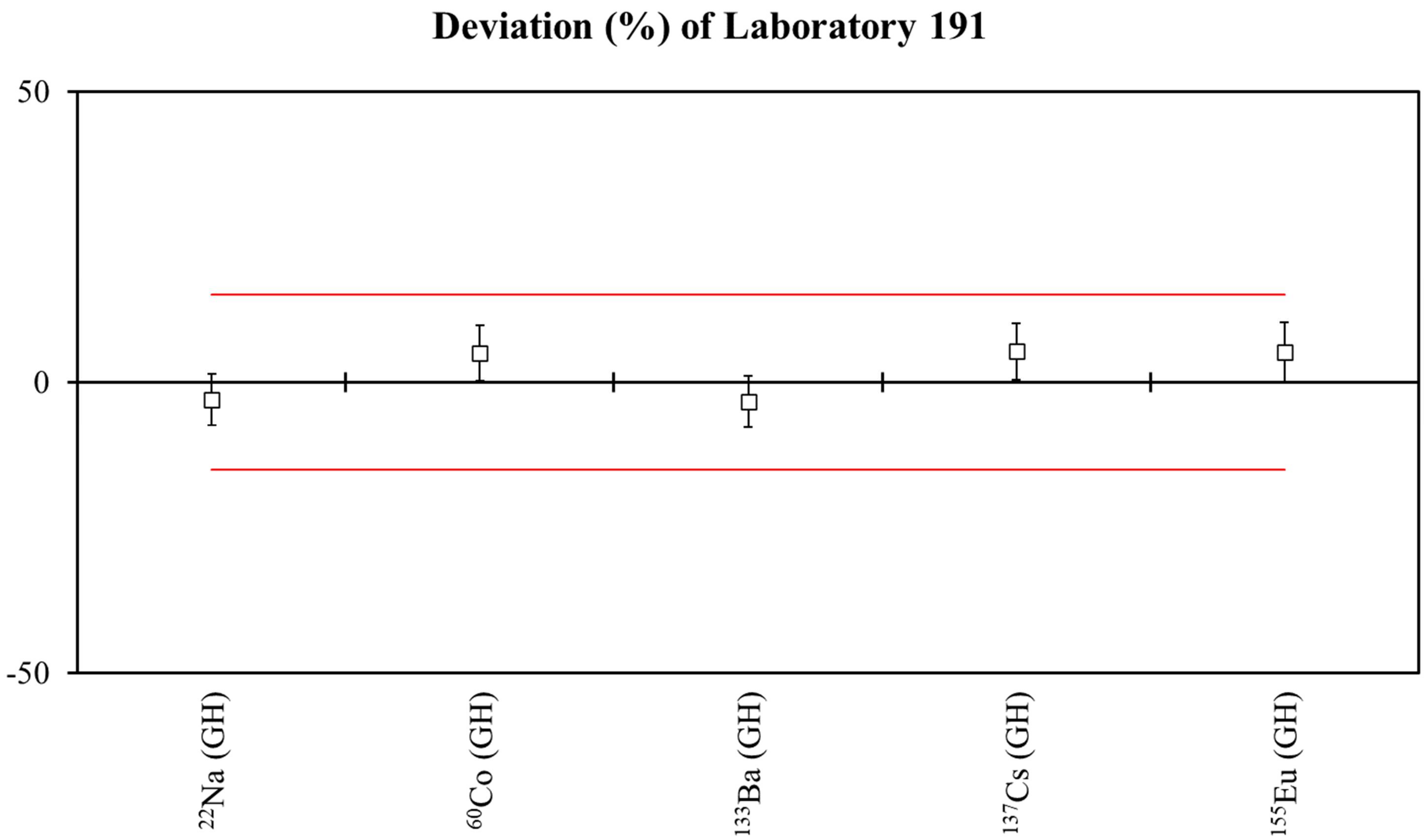
Radionuclide	Laboratory 184	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.292 ± 0.014	0.2821 ± 0.0047	3.5	0.67	0.60
^{14}C (B1)	0.385 ± 0.014	0.4031 ± 0.0018	-4.5	-1.28	-0.77
^{36}Cl (B1)	0.222 ± 0.015	0.21867 ± 0.00076	1.5	0.22	0.26


Deviation (%) of Laboratory 189
50
0
-50
^{54}Mn (GL)
^{65}Zn (GL)
^{139}Ce (GL)
^{210}Pb (GL)

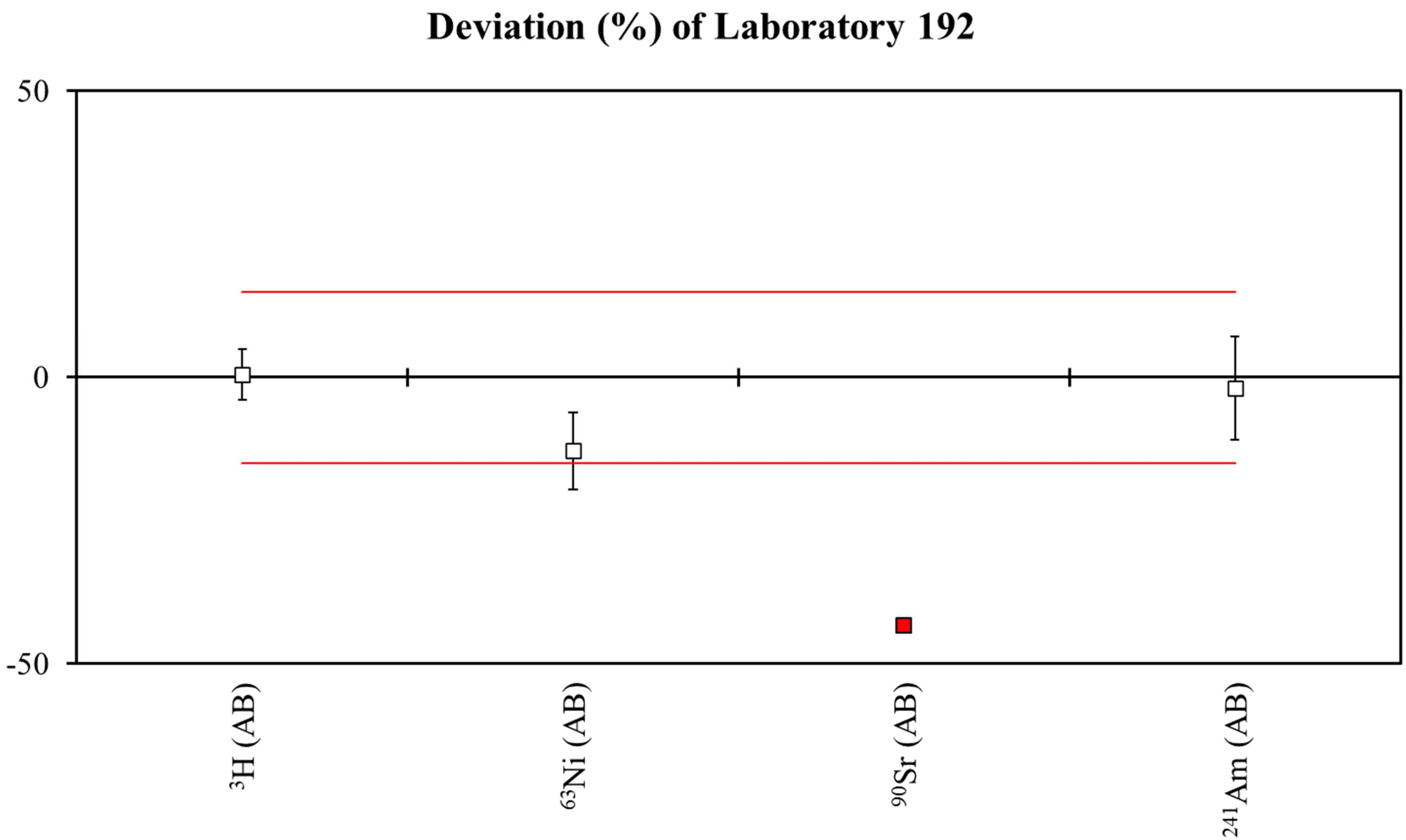
Radionuclide	Laboratory 189	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{54}Mn (GL)	18.3 ± 1.7	17.22 ± 0.18	6.5	0.65	1.11
^{65}Zn (GL)	32.3 ± 3.0	29.67 ± 0.22	8.8	0.88	1.52
^{139}Ce (GL)	42.5 ± 4.0	44.41 ± 0.39	-4.3	-0.47	-0.74
^{210}Pb (GL)	15.7 ± 4.0	13.67 ± 0.15	14.7	0.51	2.53


Deviation (%) of Laboratory 190
50
0
-50
3H (AB)
63Ni (AB)
90Sr (AB)
241Am (AB)
226Ra (A1)
3H (B1)
14C (B1)
36Cl (B1)
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)
54Mn (GL)
65Zn (GL)
139Ce (GL)
210Pb (GL)

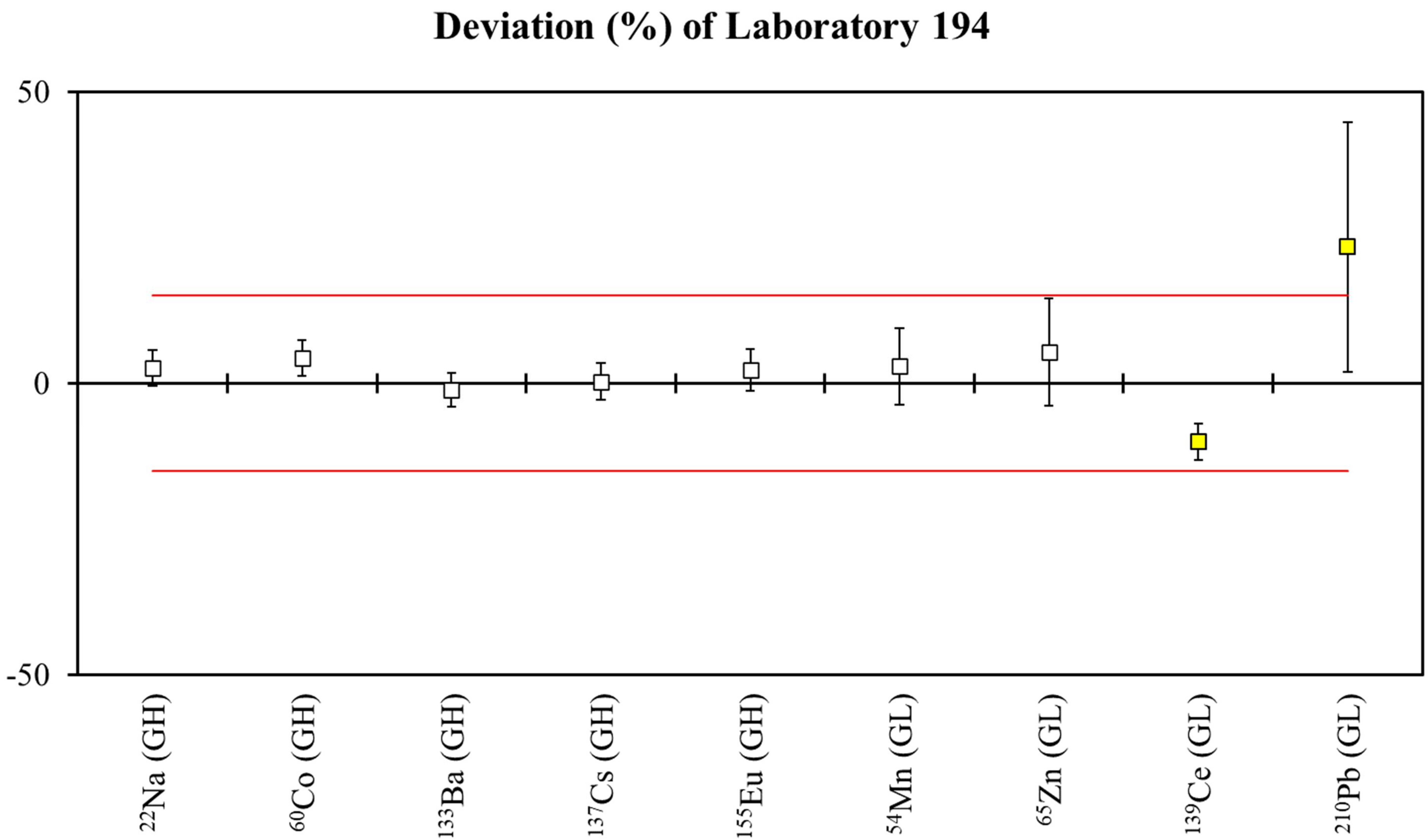
Radionuclide	Laboratory 190	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	13.6 ± 1.7	13.24 ± 0.19	2.7	0.21	0.47
^{63}Ni (AB)	3.48 ± 0.20	3.589 ± 0.017	-3.0	-0.54	-0.52
^{90}Sr (AB)	3.530 ± 0.038	3.5493 ± 0.0095	-0.5	-0.49	-0.09
^{241}Am (AB)	12.40 ± 0.43	11.618 ± 0.046	6.7	1.81	1.16
^{226}Ra (A1)	46.3 ± 4.8	45.44 ± 0.57	1.9	0.18	0.33
^{3}H (B1)	252 ± 65	0.2821 ± 0.0047	89230.0	3.87	15323.72
^{14}C (B1)	392 ± 36	0.4031 ± 0.0018	97146.3	10.88	16683.21
^{36}Cl (B1)	0.208 ± 0.022	0.21867 ± 0.00076	-4.9	-0.48	-0.84
^{22}Na (GH)	7.782 ± 0.093	8.674 ± 0.033	-10.3	-9.04	-1.77
^{60}Co (GH)	30.50 ± 0.36	31.23 ± 0.11	-2.3	-1.94	-0.40
^{133}Ba (GH)	38.57 ± 0.87	38.84 ± 0.27	-0.7	-0.30	-0.12
^{137}Cs (GH)	12.96 ± 0.18	13.201 ± 0.098	-1.8	-1.18	-0.31
^{155}Eu (GH)	7.77 ± 0.14	7.63 ± 0.14	1.8	0.71	0.32
^{54}Mn (GL)	17.6 ± 1.3	17.22 ± 0.18	2.2	0.29	0.38
^{65}Zn (GL)	34.0 ± 3.3	29.67 ± 0.22	14.6	1.31	2.51
^{139}Ce (GL)	45.7 ± 1.9	44.41 ± 0.39	2.9	0.67	0.50
^{210}Pb (GL)	22.8 ± 7.0	13.67 ± 0.15	66.8	1.30	11.47


Deviation (%) of Laboratory 191
50
0
-50
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)

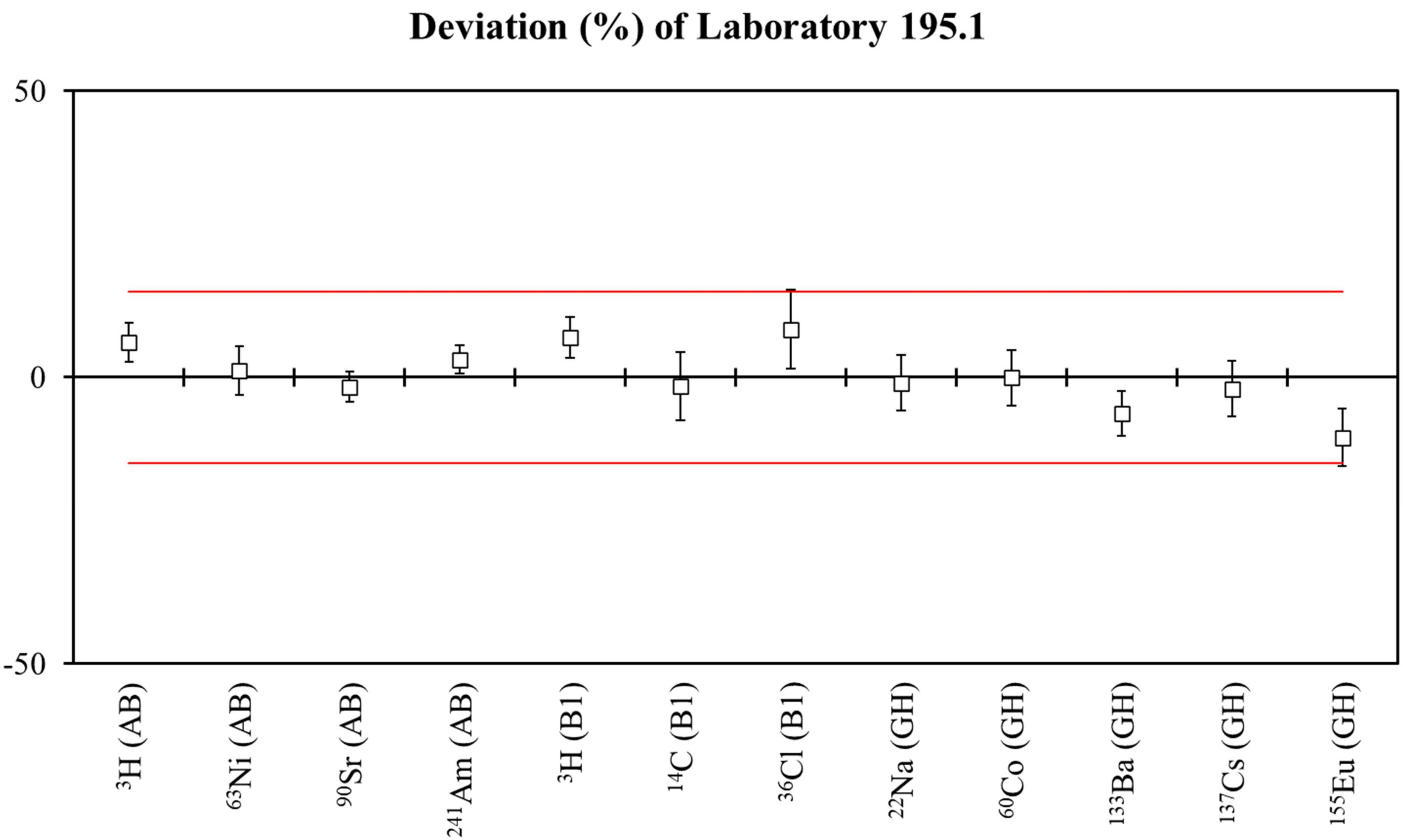
Radionuclide	Laboratory 191	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{22}Na (GH)	8.42 ± 0.38	8.674 ± 0.033	-3.0	-0.68	-0.51
^{60}Co (GH)	32.8 ± 1.5	31.23 ± 0.11	5.0	1.05	0.85
^{133}Ba (GH)	37.5 ± 1.7	38.84 ± 0.27	-3.3	-0.76	-0.57
^{137}Cs (GH)	13.90 ± 0.63	13.201 ± 0.098	5.3	1.10	0.91
^{155}Eu (GH)	8.03 ± 0.36	7.63 ± 0.14	5.2	1.02	0.89


Deviation (%) of Laboratory 192
50
0
-50
^{3}H (AB)
^{63}Ni (AB)
^{90}Sr (AB)
^{241}Am (AB)

Radionuclide	Laboratory 192	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	13.30 ± 0.56	13.24 ± 0.19	0.5	0.10	0.08
^{63}Ni (AB)	3.13 ± 0.24	3.589 ± 0.017	-12.8	-1.91	-2.20
^{90}Sr (AB)	2.010 ± 0.033	3.5493 ± 0.0095	-43.4	-44.33	-7.45
^{241}Am (AB)	11.4 ± 1.1	11.618 ± 0.046	-1.9	-0.21	-0.32

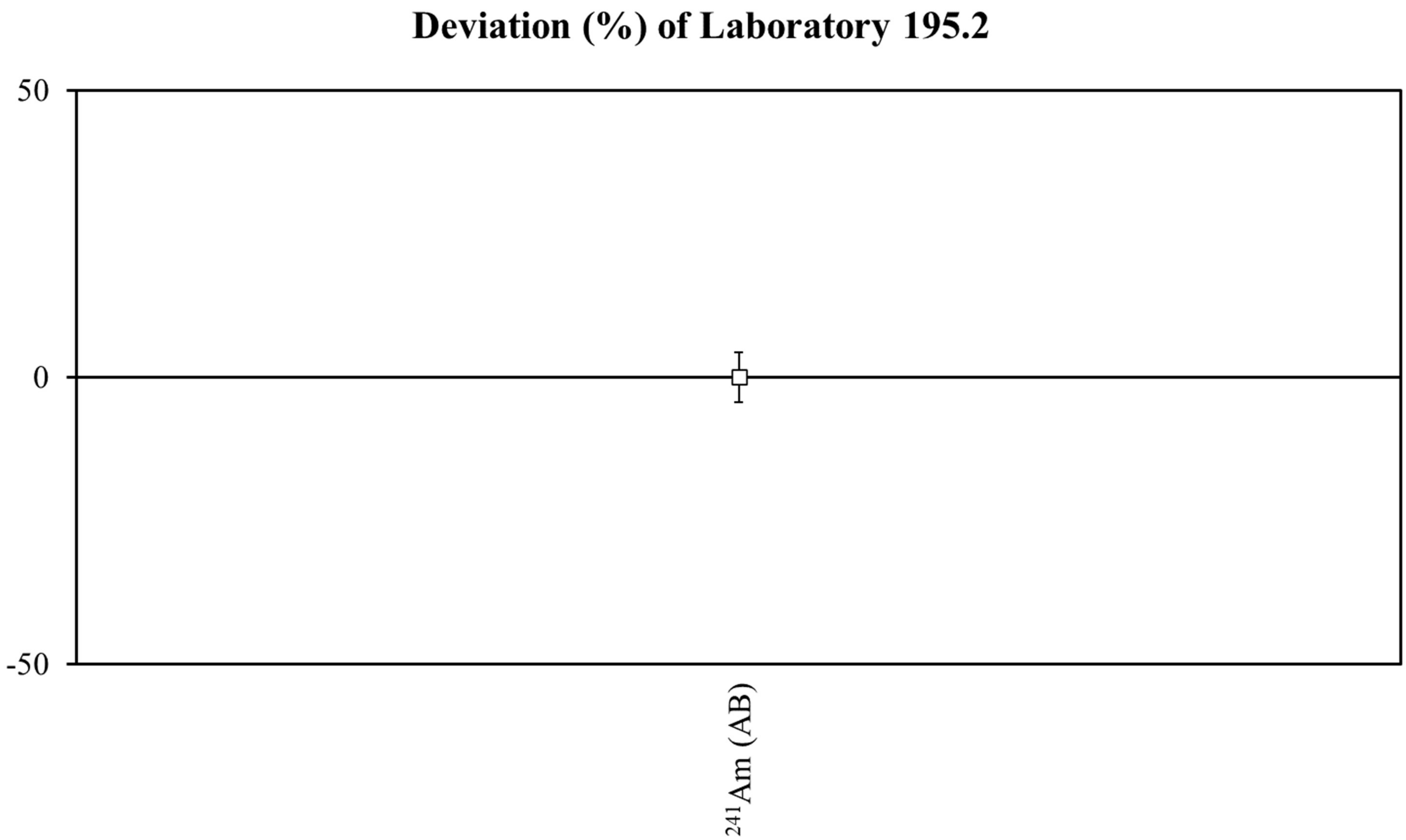

Deviation (%) of Laboratory 194
50
0
-50
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)
54Mn (GL)
65Zn (GL)
139Ce (GL)
210Pb (GL)

Radionuclide	Laboratory 194	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{22}Na (GH)	8.90 ± 0.27	8.674 ± 0.033	2.6	0.85	0.45
^{60}Co (GH)	32.57 ± 0.96	31.23 ± 0.11	4.3	1.39	0.74
^{133}Ba (GH)	38.4 ± 1.1	38.84 ± 0.27	-1.1	-0.39	-0.20
^{137}Cs (GH)	13.24 ± 0.40	13.201 ± 0.098	0.3	0.09	0.05
^{155}Eu (GH)	7.80 ± 0.23	7.63 ± 0.14	2.3	0.64	0.39
^{54}Mn (GL)	17.7 ± 1.1	17.22 ± 0.18	2.9	0.44	0.50
^{65}Zn (GL)	31.3 ± 2.7	29.67 ± 0.22	5.4	0.59	0.93
^{139}Ce (GL)	40.0 ± 1.3	44.41 ± 0.39	-10.0	-3.16	-1.72
^{210}Pb (GL)	16.9 ± 2.9	13.67 ± 0.15	23.4	1.09	4.02

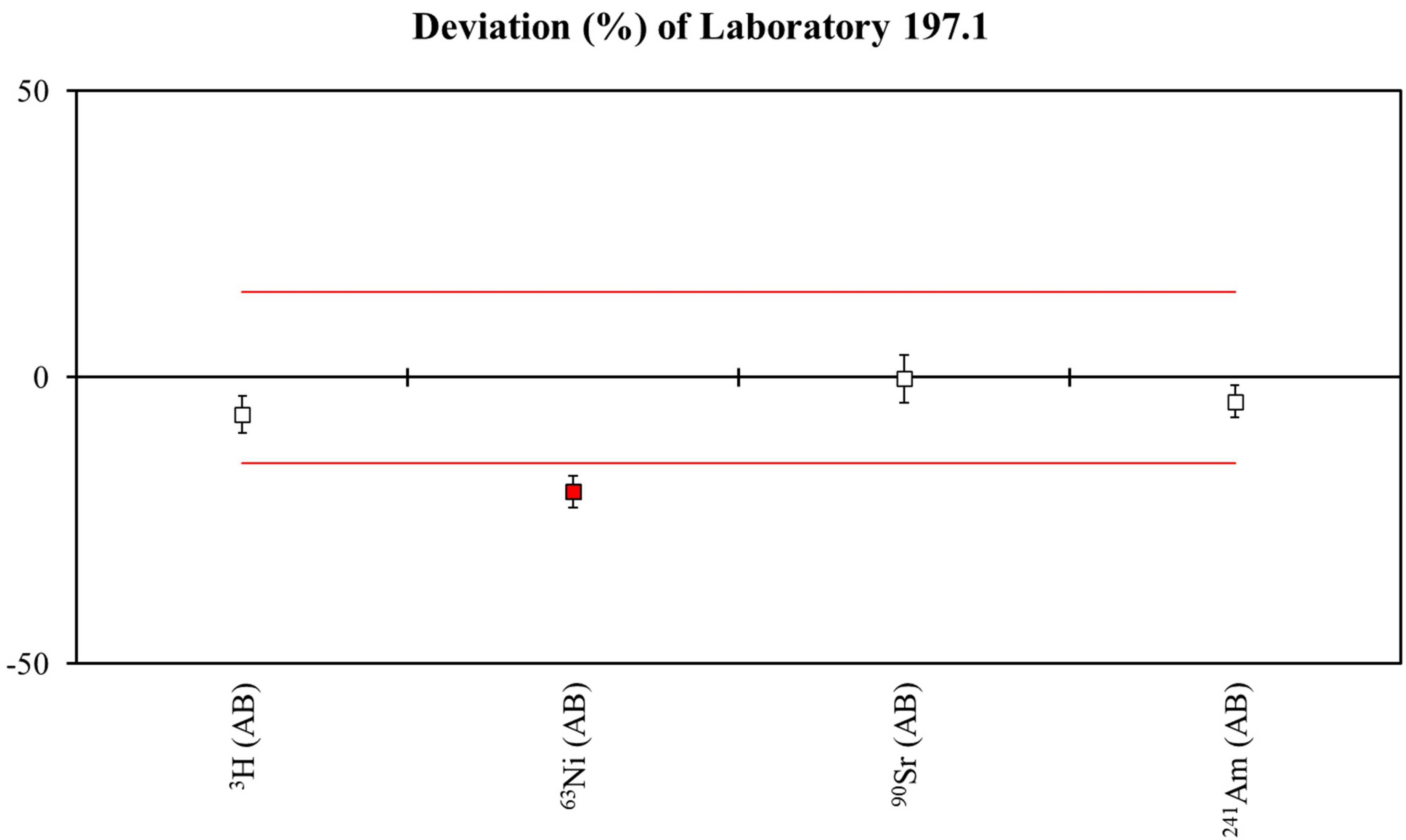


Deviation (%) of Laboratory 195.1
50
0
-50
^{3}H (AB)
^{63}Ni (AB)
^{90}Sr (AB)
^{241}Am (AB)
^{3}H (B1)
^{14}C (B1)
^{36}Cl (B1)
^{22}Na (GH)
^{60}Co (GH)
^{133}Ba (GH)
^{137}Cs (GH)
^{155}Eu (GH)

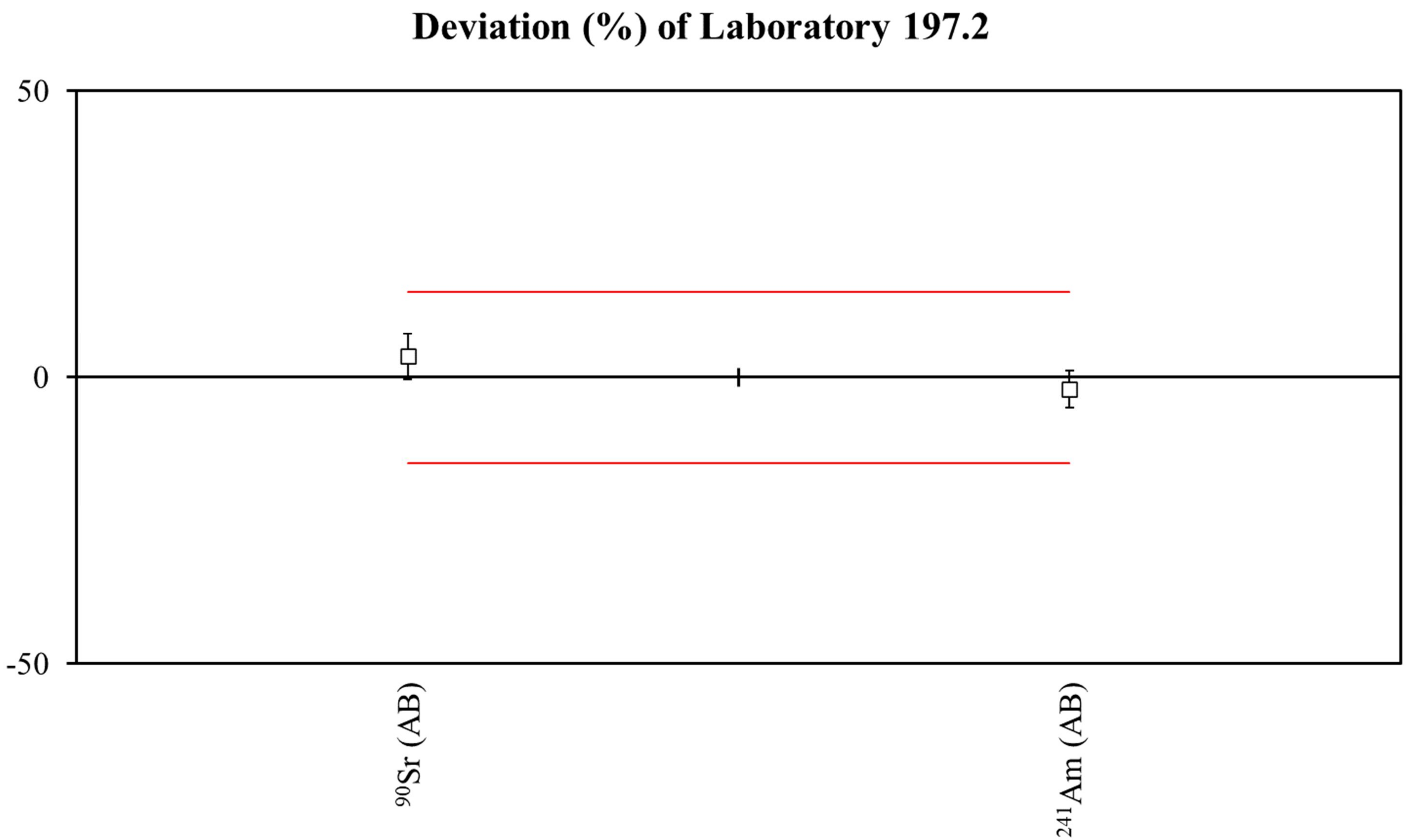
Radionuclide	Laboratory 195.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	14.05 ± 0.41	13.24 ± 0.19	6.1	1.79	1.05
^{63}Ni (AB)	3.63 ± 0.15	3.589 ± 0.017	1.1	0.27	0.20
^{90}Sr (AB)	3.491 ± 0.095	3.5493 ± 0.0095	-1.6	-0.61	-0.28
^{241}Am (AB)	11.98 ± 0.28	11.618 ± 0.046	3.1	1.28	0.54
^{3}H (B1)	0.3017 ± 0.0088	0.2821 ± 0.0047	6.9	1.96	1.19
^{14}C (B1)	0.397 ± 0.024	0.4031 ± 0.0018	-1.5	-0.25	-0.26
^{36}Cl (B1)	0.237 ± 0.015	0.21867 ± 0.00076	8.4	1.22	1.44
^{22}Na (GH)	8.59 ± 0.42	8.674 ± 0.033	-1.0	-0.20	-0.17
^{60}Co (GH)	31.2 ± 1.5	31.23 ± 0.11	-0.1	-0.02	-0.02
^{133}Ba (GH)	36.4 ± 1.5	38.84 ± 0.27	-6.3	-1.60	-1.08
^{137}Cs (GH)	12.94 ± 0.63	13.201 ± 0.098	-2.0	-0.41	-0.34
^{155}Eu (GH)	6.83 ± 0.36	7.63 ± 0.14	-10.5	-2.07	-1.80


Deviation (%) of Laboratory 195.2
50
0
-50
^{241}Am (AB)

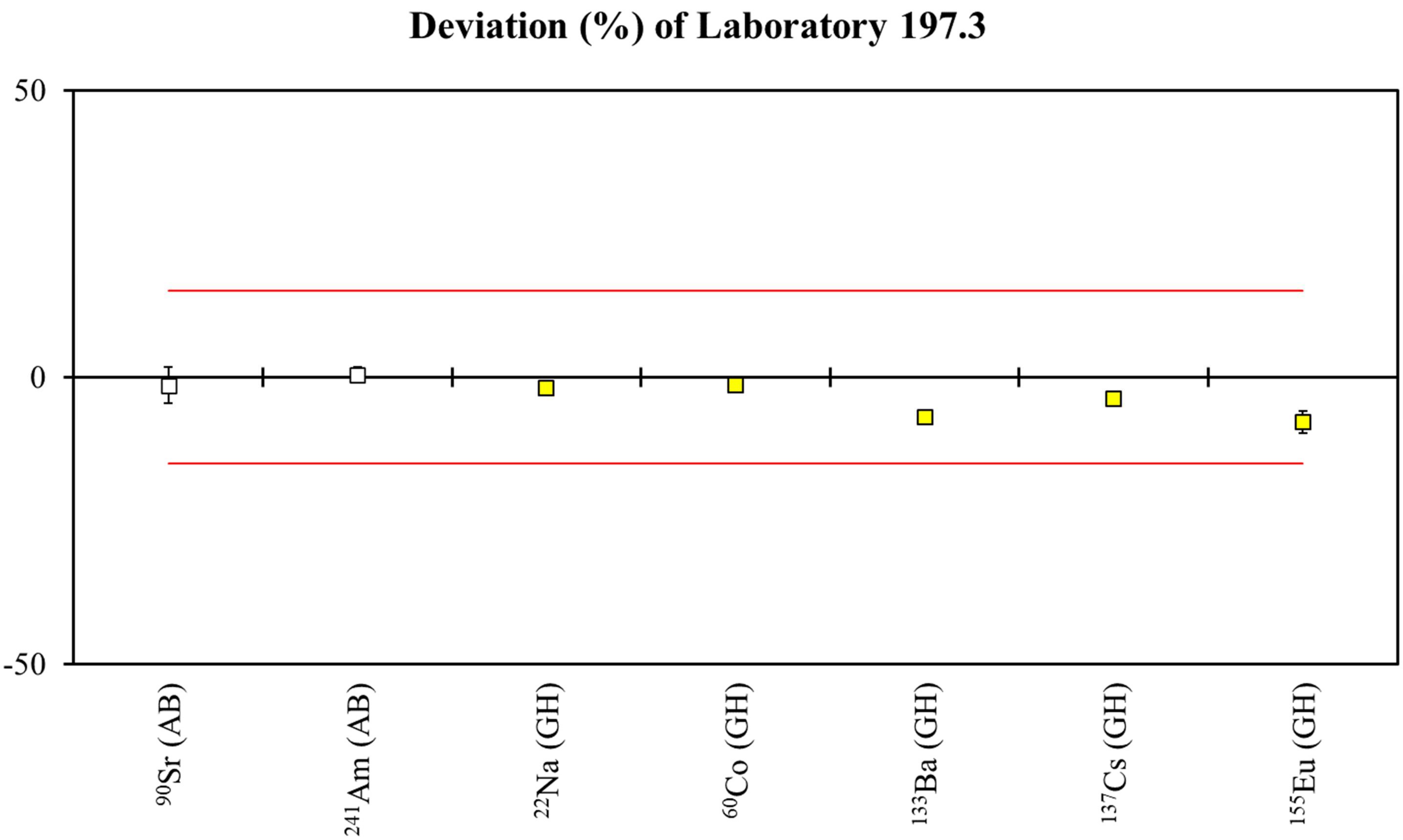
Radionuclide	Laboratory 195.2	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{241}Am (AB)	11.62 ± 0.50	11.618 ± 0.046	0.0	0.00	0.00


Deviation (%) of Laboratory 197.1
50
0
-50
^{3}H (AB)
^{63}Ni (AB)
^{90}Sr (AB)
^{241}Am (AB)

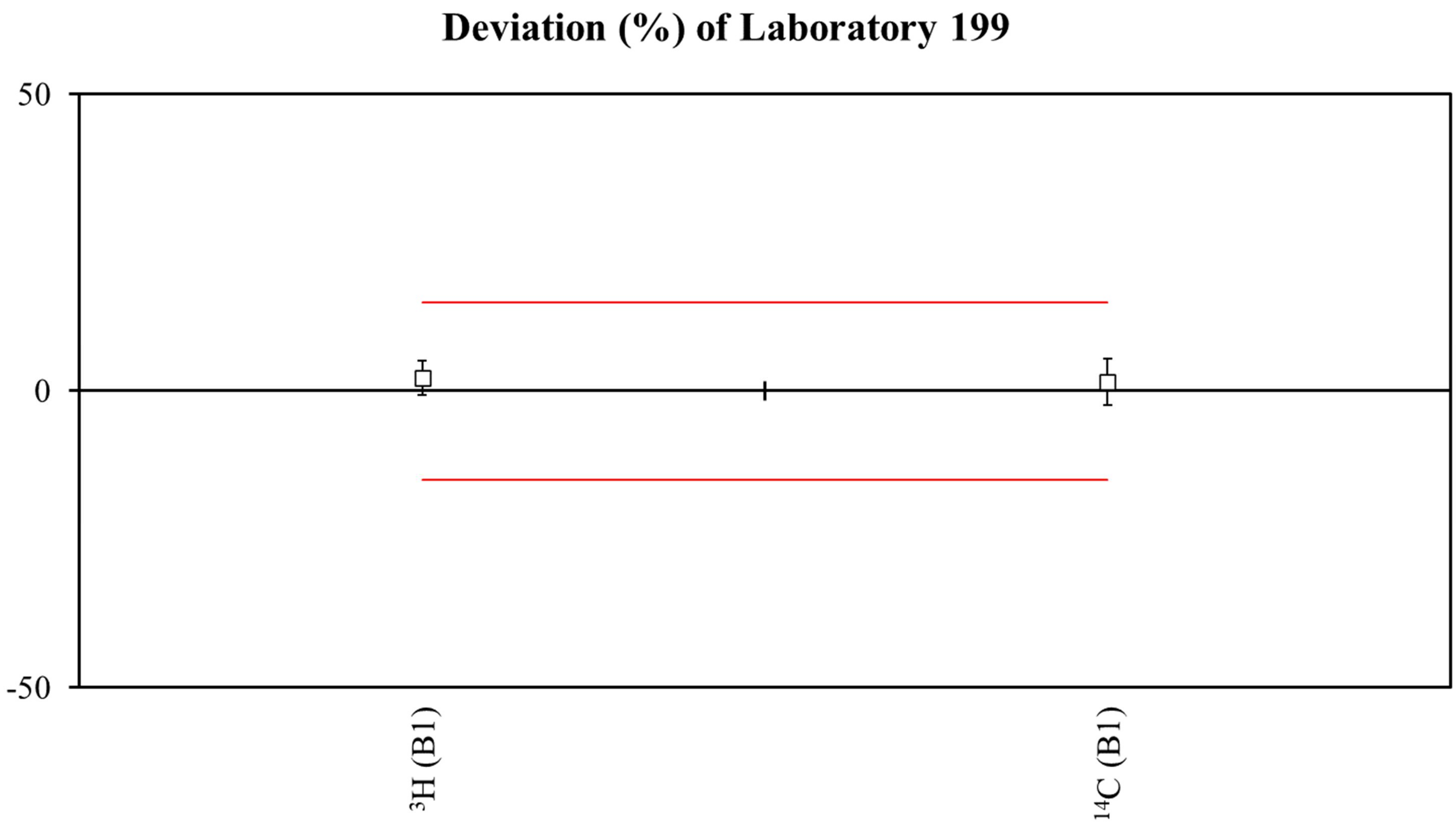
Radionuclide	Laboratory 197.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	12.38 ± 0.38	13.24 ± 0.19	-6.5	-2.02	-1.12
^{63}Ni (AB)	2.87 ± 0.10	3.589 ± 0.017	-20.0	-7.09	-3.44
^{90}Sr (AB)	3.54 ± 0.15	3.5493 ± 0.0095	-0.3	-0.06	-0.04
^{241}Am (AB)	11.13 ± 0.32	11.618 ± 0.046	-4.2	-1.51	-0.72


Deviation (%) of Laboratory 197.2
50
0
-50
90Sr (AB)
241Am (AB)

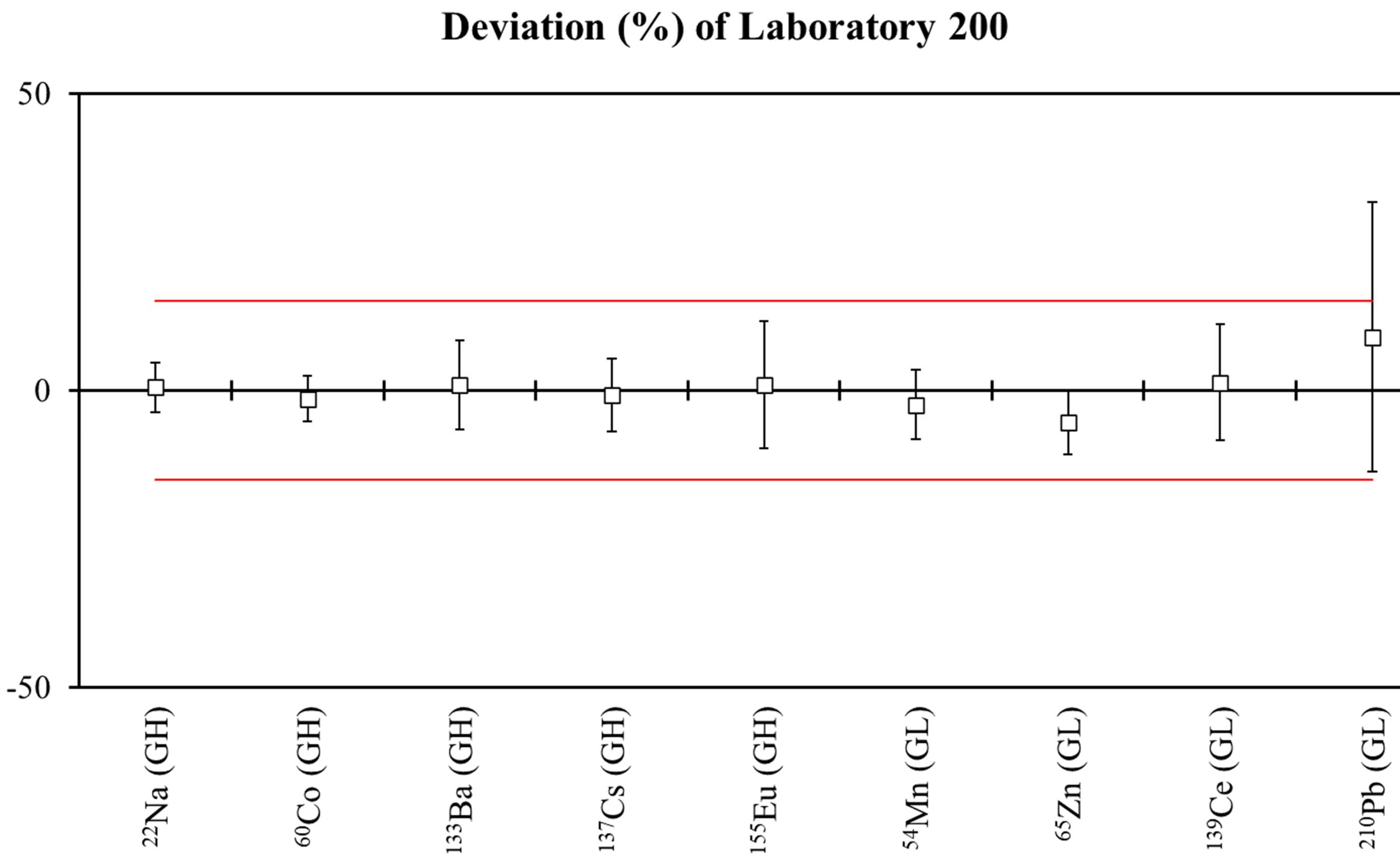
Radionuclide	Laboratory 197.2	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{90}Sr (AB)	3.68 ± 0.14	3.5493 ± 0.0095	3.7	0.93	0.63
^{241}Am (AB)	11.38 ± 0.38	11.618 ± 0.046	-2.0	-0.62	-0.35


Deviation (%) of Laboratory 197.3
50
0
-50
^{90}Sr (AB)
^{241}Am (AB)
^{22}Na (GH)
^{60}Co (GH)
^{133}Ba (GH)
^{137}Cs (GH)
^{155}Eu (GH)

Radionuclide	Laboratory 197.3	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{90}Sr (AB)	3.50 ± 0.11	3.5493 ± 0.0095	-1.4	-0.45	-0.24
^{241}Am (AB)	11.67 ± 0.14	11.618 ± 0.046	0.4	0.33	0.07
^{22}Na (GH)	8.507 ± 0.051	8.674 ± 0.033	-1.9	-2.75	-0.33
^{60}Co (GH)	30.790 ± 0.092	31.23 ± 0.11	-1.4	-3.06	-0.24
^{133}Ba (GH)	36.10 ± 0.14	38.84 ± 0.27	-7.1	-8.96	-1.21
^{137}Cs (GH)	12.699 ± 0.051	13.201 ± 0.098	-3.8	-4.55	-0.65
^{155}Eu (GH)	7.035 ± 0.077	7.63 ± 0.14	-7.8	-3.72	-1.34


Deviation (%) of Laboratory 199
50
0
-50
3H (B1)
14C (B1)

Radionuclide	Laboratory 199	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.2884 ± 0.0065	0.2821 ± 0.0047	2.2	0.79	0.38
^{14}C (B1)	0.409 ± 0.016	0.4031 ± 0.0018	1.5	0.38	0.25


Deviation (%) of Laboratory 200
50
0
-50
22Na (GH)
60Co (GH)
133Ba (GH)
137Cs (GH)
155Eu (GH)
54Mn (GL)
65Zn (GL)
139Ce (GL)
210Pb (GL)

Radionuclide	Laboratory 200	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{22}Na (GH)	8.72 ± 0.36	8.674 ± 0.033	0.5	0.13	0.09
^{60}Co (GH)	30.8 ± 1.2	31.23 ± 0.11	-1.4	-0.36	-0.24
^{133}Ba (GH)	39.2 ± 2.9	38.84 ± 0.27	0.9	0.12	0.16
^{137}Cs (GH)	13.10 ± 0.80	13.201 ± 0.098	-0.8	-0.13	-0.13
^{155}Eu (GH)	7.70 ± 0.80	7.63 ± 0.14	0.9	0.09	0.16
^{54}Mn (GL)	16.8 ± 1.0	17.22 ± 0.18	-2.4	-0.41	-0.42
^{65}Zn (GL)	28.1 ± 1.6	29.67 ± 0.22	-5.3	-0.97	-0.91
^{139}Ce (GL)	45.0 ± 4.3	44.41 ± 0.39	1.3	0.14	0.23
^{210}Pb (GL)	14.9 ± 3.1	13.67 ± 0.15	9.0	0.40	1.55

10. DISCUSSION

The accurate and precise measurement of radionuclides in the environment is critical for the assessment of the radiological impact and risk to the public and environment. This is the case for both routine analysis and in the instance of a nuclear or radiological emergency. This exercise aims to assess the capability of participants to perform such measurements. It is for this reason that some radionuclides appear routinely in the exercise, such as ^{3}H, ^{14}C, ^{90}Sr, ^{210}Pb and ^{241}Am. The following section of this report discusses the results for the 2023/24 Environmental Radioactivity Proficiency Test Exercise.

As part of the reporting process alongside the reporting form, which allows participants to submit their measured values, laboratories were also invited to submit a techniques form. In some instances, participating laboratories who submitted measured values, did not submit the methods used during their analysis. The information provided in the text below refers to a subset of participants who did report such information. For NPL to provide performance-related feedback, it is encouraged that participants detail the methods and techniques used.

Any standards used throughout calibration or yield calculations should be traceable back to the International System of Units. Such standards can be acquired from a variety of commercial suppliers, including National Metrology Institutes. Activity standards should be traceable to the Becquerel and mass standards to the Kilogram.

This exercise included results for numerous measurands using an array of methodologies. The measurement uncertainties resulting from for each method will consist of different components and should be assessed in accordance with the 'Guide to the Expression of Uncertainty in Measurement' (JCGM 100:2008). Participants are encouraged to review their uncertainty budgets to ensure that they are comprehensive and provide a reasonable estimation of the overall uncertainty. There are instances throughout the report where results are marked as questionable due to failing the relative uncertainty test. It is suggested, in these instances that participants review their uncertainty budgets. Following review, if the uncertainty budget is believed to be comprehensive it might be that the R_L test failed as a result of differences in the applied method as compared with other participating laboratories.

Please note that the half-lives quoted below are taken from the Decay Data Evaluation Project (DDEP), where a "year" is defined as 365.24219878 d (BIPM, 2004).

10.1 Tritium in AB

Tritium (H-3) is a low-energy beta emitter (β-max, 18.564 keV), with a half-life of 12.312 (25) a (BIPM, 2004). Tritium and hydrogen occur in the same physicochemical forms, despite their difference in atomic mass. Tritiated water ($[^{3}H]H_2O$) is the most abundant form of tritium in the natural environment; tritium is also observed in gaseous form in the atmosphere and bound to organic matter in the biosphere (organically bound tritium). It is important to note that for the analysis of organically bound tritium; its determination requires additional chemical processing such as chemical oxidation or combustion.

The predominant challenge in measuring the activity per unit mass of ^{3}H in the AB sample type is the separation of the ^{3}H from other beta emitting isotopes in the sample type (^{63}Ni and ^{90}Sr) prior to measurement. This can be achieved either through chemical separation or by setting regions of interest during measurement when using liquid scintillation counting (LSC).

Of those who reported the detection technique, all (16) stated that they used Liquid Scintillation Counting (LSC) to measure ^{3}H. The specific instruments reported as being used included a Quantulus 1220 (Perkin Elmer/Wallac), a Tri Carb 2910 TR (Perkin Elmer) and a Hidex 300SL TDCR counter.

A key factor in accurate measurement of ^{3}H is quench, and the degree of which varies between samples. A quench correction should be carried out for each sample. A quench curve is often necessary, and it must be specific to the type of sample being measured. A single quench curve is only applicable for the instrument it was derived for, the type of scintillation cocktail, and ratio of sample to scintillation cocktail. For LSC the instrument response must be routinely measured with check sources of known activity. These check sources must cover the energy range to be used during the measurement of unknown samples. The instrument response is usually determined by monitoring background, alongside ^{3}H and ^{14}C check sources which are routinely supplied alongside LSC instruments. It is advised that the results of these checks are plotted on a Shewhart control chart and analysed in line with ISO recommendations (ISO 7870-2).

Out of the laboratories that reported details of their methods of separation the majority (9) used distillation, with other laboratories using combustion (1), oxidation (1), pyrolysis (2). Alternatively, two laboratories opted for chemical separation. Of the results submitted 87% were in agreement, 9 % were questionable and 4 % were discrepant.

10.2 Nickel-63 in AB

Nickel-63 (Ni-63) in an anthropogenic radionuclide with a half-life of 98.7 (24) a that decays to ^{63}Cu (β-max, 66.980 (15) keV (BIPM, 2004)). Nickel-63 is primarily generated by neutron capture of the stable isotope ^{62}Ni in nuclear reactors and is also found in trace amounts from cosmic ray interactions. Due to its low-energy beta emissions, ^{63}Ni poses a minimal external radiation hazard but can be a concern if inhaled or ingested, as it can accumulate in the body, particularly in the liver and kidneys. Nickle-63 is important in environmental monitoring and contamination assessments, especially in areas near nuclear facilities and in nuclear waste management, where it is monitored for its long-term radiological impact and potential release into the environment.

Of the results submitted 65 % were in agreement, 18 % were questionable and 18 % were discrepant, this is the lowest agreement out of the AB sample nuclides. Of the 15 laboratories, 11 reported their detection technique all of which use LSC to measure ^{63}Ni, with two laboratories also using Inductively Coupled Mass Spectrometry (ICP-MS) to measure stable Ni for to monitor the chemical yield.

It is important to note that the AB sample matrix contained stable nickel, as a carrier for the ^{63}Ni, which if unaccounted for could result in the recoveries being over estimated. Reported techniques for chemical separation favoured extraction chromatography, with solvent extraction, ion exchange, and solid phase extraction also being used. There was one example of a multi-stage radiochemical treatment using precipitation, purification, and ion exchange.

10.3 Strontium-90 in AB

The strontium isotopes of importance in radiological measurements in the environment are ^{89}Sr and ^{90}Sr. Strontium-90 (Sr-90) is the more significant from an environmental protection point of view as a result of its long half-life of 28.80 (7) a (BIPM 2004), compared to the ^{89}Sr half-life of 50.57 (3) d which is of more significance for emergency response following a radiological incident or accident. Strontium-90 is a beta emitter having a maximum beta energy of 586.1 (22) keV (BIPM 2004) to ^{90}Y (which itself is a β-emitter). Strontium-90 is a high yield fission product and had been released into the environment in large quantities following nuclear weapons tests, nuclear power plant incidents and nuclear fuel reprocessing industries. Its widespread presence and bioaccumulative properties make it a key focus in radiological protection and environmental monitoring.

The main challenge when measuring the ^{90}Sr activity per unit mass is the need for a radiochemical separation from the other radionuclides present in the sample, additionally with the presence of ^{89}Sr which could interfere with the measurement of ^{90}Sr. Multiple methods comprising of various techniques may be used, including decay and/or ingrowth counting, separation of ^{90}Y followed by Cerenkov and LSC counting and/or spectral deconvolution. ISO 13160:2021 describes robust test methods for measurement of ^{89}Sr and ^{90}Sr in water by LSC and proportional counting.

Of the reporting laboratories 20 out of the 22 provided techniques forms. Multiple separation methods for ^{90}Sr were reported, including (co)precipitation, liquid extraction, solid phase extraction, evaporation, ion exchange and most commonly extraction chromatography. Of those who reported a detection technique as LSC (10), proportional counting (6), and a combination of gamma spectrometry (GS) and LSC (1). Strontium-85, stable Sr and Y were used as tracers. Of the results submitted 83 % were in agreement and 13 % were discrepant.

10.4 Americium-241 in AB

Americium-241 (Am-241) has a half-life of 432.6 (6) a and is a beta decay product from ^{241}Pu produced in nuclear reactors. It is an alpha emitter, with the most probable emissions being 5.485 MeV (84.45 %) and 5.443 MeV (13.23 %) (BIPM 2004). Americium-241 is considered the most important radioisotope of Am for environmental measurements due to the other long-lived isotope ^{243}Am being produced in nuclear reactors in smaller activities compared to ^{241}Am.

Of the results submitted, 96 % were in agreement and 4 % were discrepant, this is a significant improvement from last year's exercise where only 76 % were in agreement, 14 % were questionable and 10 % were discrepant. Reviewing the techniques forms details that of those who reported their detection technique the majority (10) used Alpha Spectrometry (AS), with five using GS, two using GS and AS and one using AS and ion chamber (IC). All but one laboratories who noted using a tracer (12) used ^{243}Am, the other tracer used was ^{236}Pu which was used as a recovery and counting efficiency monitor.

10.5 Radium-226 in A1

Radium-226 (Ra-226) has a half-life of 1600 (7) a and is part of the ^{238}U decay series. It decays primarily alpha emission, with the most probable being 4.784 MeV (94.45 %) (BIPM 2004). Radium-226 is a significant radionuclide for environmental measurements due to its relatively long half-life and its presence in various natural and anthropogenic environments. It can be found in soil, water, and sediments, often as a result of the natural decay of uranium minerals, but also from human activities such as uranium mining, phosphate fertiliser production, and the disposal of radioactive waste. The measurement of ^{226}Ra is crucial for assessing radiological hazards and environmental contamination, as well as for the study of natural radioactivity and the impact of human activities on the environment.

This year saw 11 results submitted for ^{226}Ra. Of these results only 55 % were in agreement, 18 % questionable and 27 % were discrepant. Radium-226 is not routinely included in the exercise and the results for ^{226}Ra have the lowest agreement out of all the radionuclides in this years exercise. From the participants that submitted techniques forms (8) three reported using GS as a detection technique, two used AS, one used proportional counting, one used LSC and one used LSC and GS. Tracers included ^{133}Ba, ^{225}Ra and ^{232}U as a recovery and counting efficiency monitor.

Overall, there was a low bias in the results, this was in part due to two questionable results which were measured by LSC. The lower measurement activity from LSC may have been due to a number of factors such as interference from other α-emitters in the sample type. The presence of other α-emitting radionuclides, such as ^{241}Am and ^{244}Cm, in the sample could cause quenching effects in the liquid scintillation cocktail. Quenching reduces the light output per decay event, making it harder for the scintillation counter to detect lower-energy alpha particles effectively. This may have resulted in a reduced count rate for ^{226}Ra which following the establishment of secular equilibrium include the measurement of daughter radionuclides. It is also possible for liquid scintillation counters to discriminate between alpha and beta particles based on their different energy ranges. However, in the presence of multiple alpha emitters with overlapping energy ranges, it may be challenging to correctly set regions and identify counts from ^{226}Ra, leading to an underestimation of its activity. One of the reporting laboratories stated that they used co-precipitation of ^{226}Ra with Ba to separate prior to measurement. During measurement by LSC, following an ingrowth period, if the precipitate was not homogeneously mixed in the scintillation cocktail, it could result in localised quenching or potential self-attenuation, leading to lower detection efficiency and a reduced count rate.

10.6 Americium-241 in A1

Americium-241 (Am-241) has a half-life of 432.6 (6) a (BIPM, 2004) and is a beta decay product from ^{241}Pu produced in nuclear reactors. More details on ^{241}Am are described in section 10.4.

Of the reporting laboratories (12) 11 provided techniques forms which detailed the most popular detection technique as AS with eight reporting to use this, the remaining three reported to have used GS. Out of those who listed their separation and radiochemistry methods, extraction chromatography was most used. Two laboratories reported using electrodeposition as a source preparation technique. Of these results 77 % were in agreement and 23 % were discrepant, this is an increase in discrepant values from the 6 % last year.

10.7 Curium-244 in A1

Curium-244 (Cm-244) has a half-life of 18.11 (3) a (BIPM, 2004) and is produced by multiple neutron activations of ^{238}U, ^{239}Pu and ^{243}Am. It decays via emission of alpha particles to ^{240}Pu. It is an anthropogenic radionuclide and occurs in the environment because of weapons tests and discharges from the nuclear industry. The primary difficulty in measuring the ^{244}Cm activity per unit mass is the need for a radiochemical separation from the other radionuclides present in the sample as well as the absence of an appropriate curium chemical yield tracer. Americium is frequently considered a chemical analogue for Cm yet as the radiochemical separation become more specific, i.e. through the use of extractive compounds rather than using ion exchange, the suitability becomes limited.

There were only nine results submitted for ^{244}Cm this year, of which 67 % were in agreement, an improvement from 47 % last year, and 33 % were discrepant. Out of those who submitted techniques forms all (8) used AS as a detection technique and ^{243}Am as a tracer. Out of those who listed their separation and radiochemistry methods extraction chromatography was used the most followed by ion exchange and precipitation, and solid phase extraction. Two laboratories reported using electrodeposition as a source preparation technique.

10.8 Tritium in B1

With a half-life of 12.312 (25) a, ^{3}H decays via beta minus emission to the ^{3}He with a β-max of 18.564 (3) keV (BIPM, 2004). The main challenge in measuring the tritiated water activity per unit mass is the need for a radiochemical separation from other beta-emitters i.e. ^{14}C in the B1 sample type. The B1 sample matrix is an alkaline solution.

Out of the 26 who submitted results, 21 also provided a techniques form where all used LSC as their detection technique. Of the 18 that listed separation methods, the majority (15) used distillation, two used pyrolysis and one used combustion. Out of these results 77 % were in agreement, 8 % were questionable and 15 % were discrepant. It is suspected that laboratory 190 have reported using the wrong units. Laboratory 35 confirmed reporting with the incorrect unit for both ^{3}H and ^{14}C in the B1 sample type.

10.9 Carbon-14 in B1

Carbon-14 has a half-life of 5700 (30) a, and is a β-emitter which decays to stable nitrogen (^{14}N) with a β-max of 156.476 (4) keV (BIPM, 2004). Carbon-14 is produced naturally in the Earth’s atmosphere through the interaction of cosmic rays with ^{14}N. It is important for environmental measurements, particularly in studies of organic material and dating of archaeological and geological samples, due to its presence in living organisms. Its relatively long half-life and natural production make it a valuable tracer for understanding carbon cycling in the environment and assessing anthropogenic impacts on carbon reservoirs. The primary issue in measuring the activity per unit mass of ^{14}C in B1 is the requirement for a radiochemical separation from ^{3}H.

Out of those who reported a detection technique, all (17) stated that they used LSC with traceable C-14, $BaCO_3$ and Na_2CO_3 being listed as tracers by four laboratories. A number of separation method were listed the most used being combustion and oxidation followed by precipitation, pyrolysis, absorption and evaporation. From the results submitted, 71 % were in agreement, 10 % were questionable and 19 % were discrepant. This is an increase in discrepant results from 5% last year. It is suspected that laboratory 190 have reported using the wrong units.

10.10 Chlorine-36 in B1

Chlorine-36 (Cl-36) is a long-lived radionuclide with a half-life of 302,000 (4,000) a (BIPM, 2004) This long-lived nuclide is produced by neutron activation of ^{35}Cl. It decays by beta minus emissions (E_{max} = 709 keV) to ^{36}Ar (98.1 %) and by electron capture (1.9 %) and beta plus emissions (0.0015 %) to ^{36}S. It occurs in some environmental samples, due to discharges from the nuclear industry. It is also produced in the atmosphere through interactions between cosmic rays and ^{36}Ar, as well as by neutron activation of chlorine in surface rocks and soils. Due to its long half-life and production in both the atmosphere and lithosphere, ^{36}Cl is an important tracer for studying the movement of water (and chloride ions) in the environment, as well as for dating groundwater, ice, and geological formations. Its widespread occurrence and persistence make it valuable for environmental measurements, particularly in hydrology and paleoclimatology.

This year saw 13 results submitted for ^{36}Cl. Of these results 69 % were in agreement, 15 % were questionable and 15 % were discrepant. Out of those who reported a detection technique (11), 10 stated that they used LSC and the other used proportional counting. Precipitation was the most common separation technique subsequently ion exchange, extraction chromatography, and solid phase extraction. A range of tracers were listed these included ^{36}Cl, ^{14}C, NaCl, stable Cl, KCl, and KI. When using stable Cl as a yield tracer it is important to account for Cl which may already be present in the sample type and consider sources of contamination during the radiochemistry, this is particularly important for low-level activity measurements.

10.11 Sample Types GH and GL

Both the GH and GL sample type contained radionuclides covering a broad range of emission energies. For the GH sample type the highest characteristic peak routinely used for measurement is the 1332.5 keV emission for ^{60}Co and the lowest was the 86.5 keV peak for ^{155}Eu. Similarly for the GL sample type the highest was 1115.5 keV for ^{65}Zn and the lowest was the 46.6 keV peak for ^{210}Pb. The activity range for the GH and GL sample type was approximately 7-40 Bq g^{-1} and 13-45 Bq kg^{-1} per radionuclide respectively.

All reported detection techniques for GH and GL samples (218) were done via gamma spectrometry and 22 reported using a mix standard as a tracer or for calibration. From the results submitted GL had high percentage agreements in all the nuclides apart from ^{210}Pb with 69 %. *The single gamma-ray emission of ^{210}Pb is of 46.59 keV ($I\gamma$ = 4.252(4))). The low energy and low intensity of this emission can present a significant measurement challenge. For example, the energy can be outside the range of the measured efficiency calibration of laboratory's gamma-ray detectors. The GL sample type had low activity per unit mass for ^{210}Pb, similar to that of environmental samples (i.e. Bq kg^{-1} levels), coupled with the low intensity of the emission this means that accurate subtraction of the background is critical for accurate measurement. If the background radiation level is high, variable, or not properly accounted for, it may result in a higher net count rate for the ^{210}Pb peak, thus causing an overestimation.

As for GH, the nuclide with the lowest percentage agreement was ^{22}Na with 64 %. Measuring ^{22}Na by gamma spectrometry presents several challenges, many of which relate to the sum effect of its photon emissions. The presence of summing can complicate the interpretation of a spectrum, through sum peaks, and make quantitative measurements challenging. In the GH sample type, four out of the five radionuclides present experience summing effects: ^{22}Na, ^{60}Co, ^{133}Ba and ^{155}Eu. In the case of ^{22}Na the summing of the 511 keV annihilation photon and the 1292 keV photon reducing the net count rate of the individual peaks, thereby causing an underestimation of ^{22}Na activity if not accounted for correctly. Three results were discrepant due to failing the relative uncertainty test as their uncertainties was larger than that of other reporting laboratories. It may be that these laboratories have reasonable uncertainty budgets for their measurement procedure and that other laboratories are underestimating their uncertainties. Information on the measurement of gamma emitting radionuclides in aqueous sample types is defined in ISO 10703:2021. Participants are advised to review uncertainty budgets, regardless of their result. Information on the uncertainty components (Type A and Type B) that contribute to an uncertainty budget relating to gamma spectrometry may be found in BS EN ISO 20042:2019.

When measuring gamma-emitting radionuclides by GS, several considerations must be made to ensure accurate and reliable results including the effects of coincidence summing, geometry corrections, density corrections, self-absorption and background radiation.

11. REFERENCES

van Es, E. et al., 2023. Environmental Radioactivity Proficiency Test Exercise 2022. NPL Report IR 65. Available at

https://www.npl.co.uk/products-services/radioactivity/environmental-pte

Harms, A. and Gilligan, C., 2011. Environmental Radioactivity Proficiency Test Exercise 2010. NPL Report IR 26. Available at

https://www.npl.co.uk/products-services/radioactivity/environmental-pte

Pommé, S., 2012. Determination of a reference value, associated standard uncertainty and degrees of equivalence. European Commission Scientific and Technical Research series. ISSN 1831-9424 (online), ISBN 978-92-79-25104-7 (pdf).

Pommé, S., 2015. Determination of a reference value and its uncertainty through a power-moderated mean. Metrologia, 52, S200

BS ISO 13528:2022. Statistical methods for use in proficiency testing by inter-laboratory comparison.

BIPM, IEC, IFCC, ILAC, ISO, IUPAC, IUPAP, and OIML. Evaluation of measurement data | Guide to the expression of uncertainty in measurement. Joint Committee for Guides in Metrology, JCGM 100:2008. https://www.bipm.org/documents/20126/2071204/JCGM_100_2008_E.pdf/cb0ef43f-baa5-11cf-3f85-4dcd86f77bd6.

BIPM, 2004. Monographie BIPM-7-Table of Radionuclides, Seven Volumes, CEA/LNE-LNHB, 91191 Gif-sur-Yvette, France and BIPM, Pavillon de Breteuil, 92312 Sèvres, France. (Nuclear data – Laboratoire National Henri Becquerel (lnhb.fr)).

ISO 7870-2:2023. Control charts — Part 2: Shewhart control charts

ISO 13160:2021 Water quality — Strontium 90 and strontium 89 — Test methods using liquid scintillation counting or proportional counting

ISO 10703:2021. Water quality — Gamma-ray emitting radionuclides — Test method using high resolution gamma-ray spectrometry

BS EN ISO 20042:2019. Measurement of radioactivity — Gamma-ray emitting radionuclides — Generic test method using gamma-ray spectrometry

12. ACKNOWLEDGEMENTS

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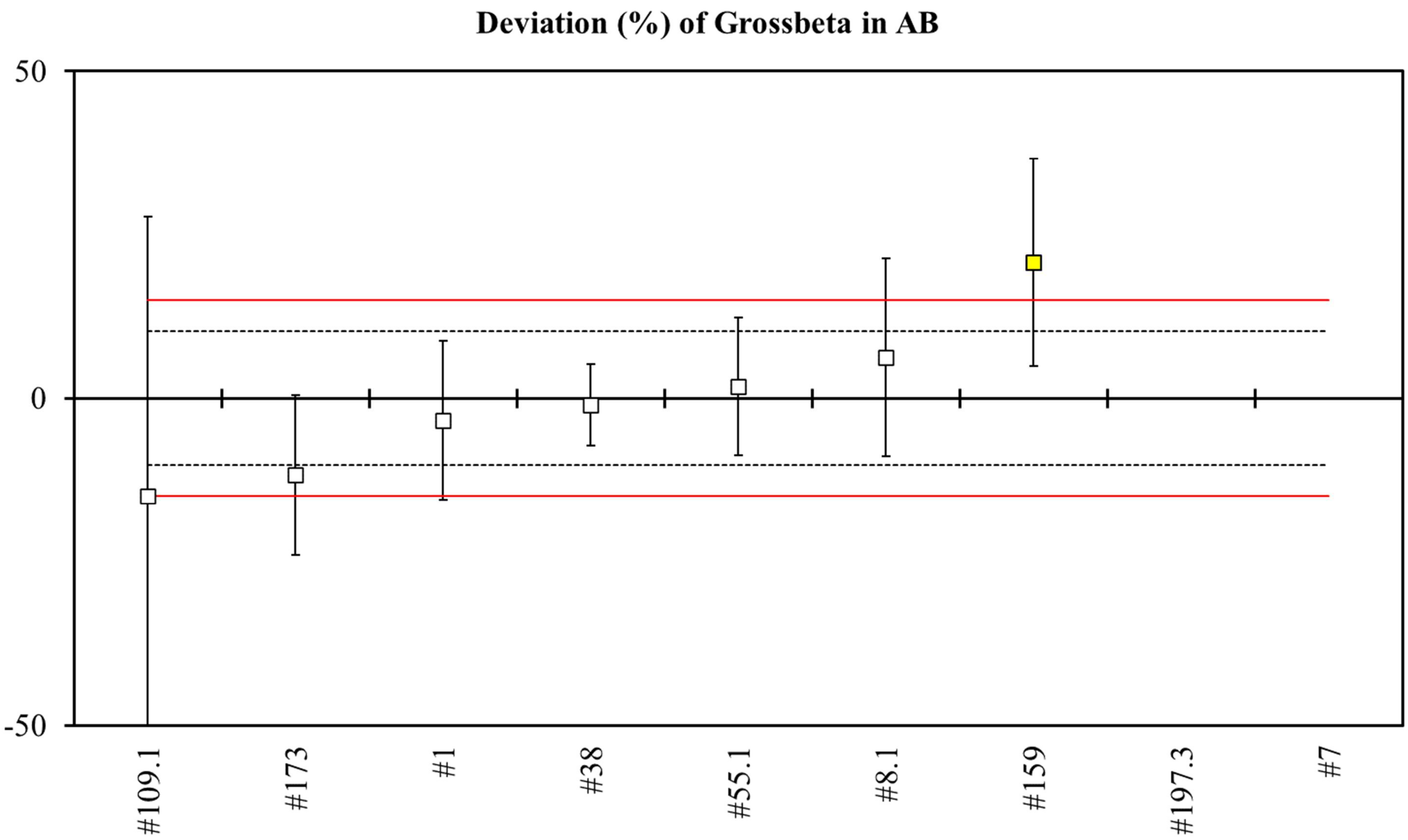
13. APPENDICES

NPL has not used the PMM as the Assigned Value for the gross measurements due to the limited number of results submitted, the spread of those results and the variation in measurement techniques used.

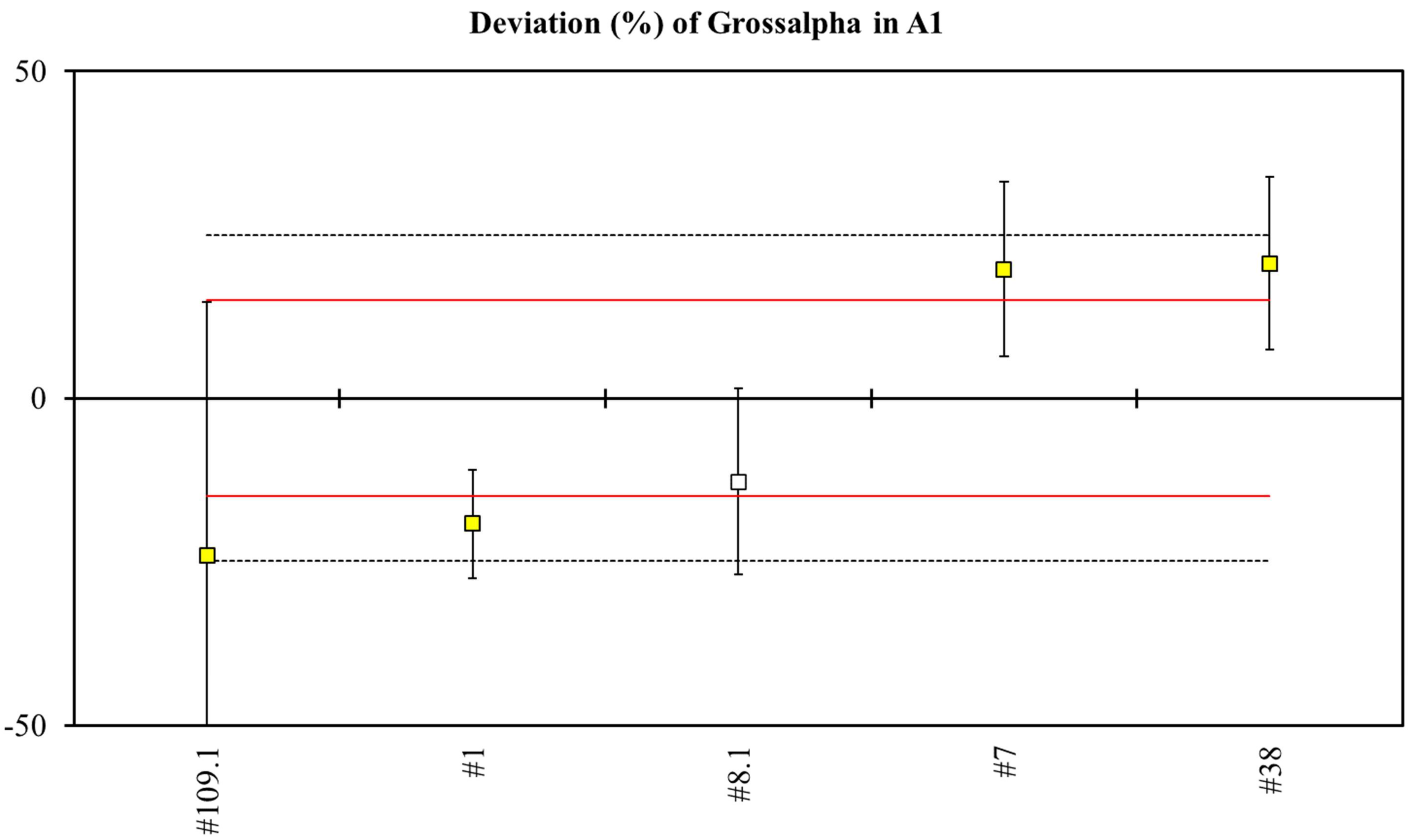
The values provided in the following tables are the PMM of the submitted results and are not traceable to national standards of radioactivity. The PMM of the gross measurements is provided as an indicator and has not been used for performance assessment. It is for this reason results for gross measurements do not appear in the main body of the report.

A1 Gross radionuclide measurements summary

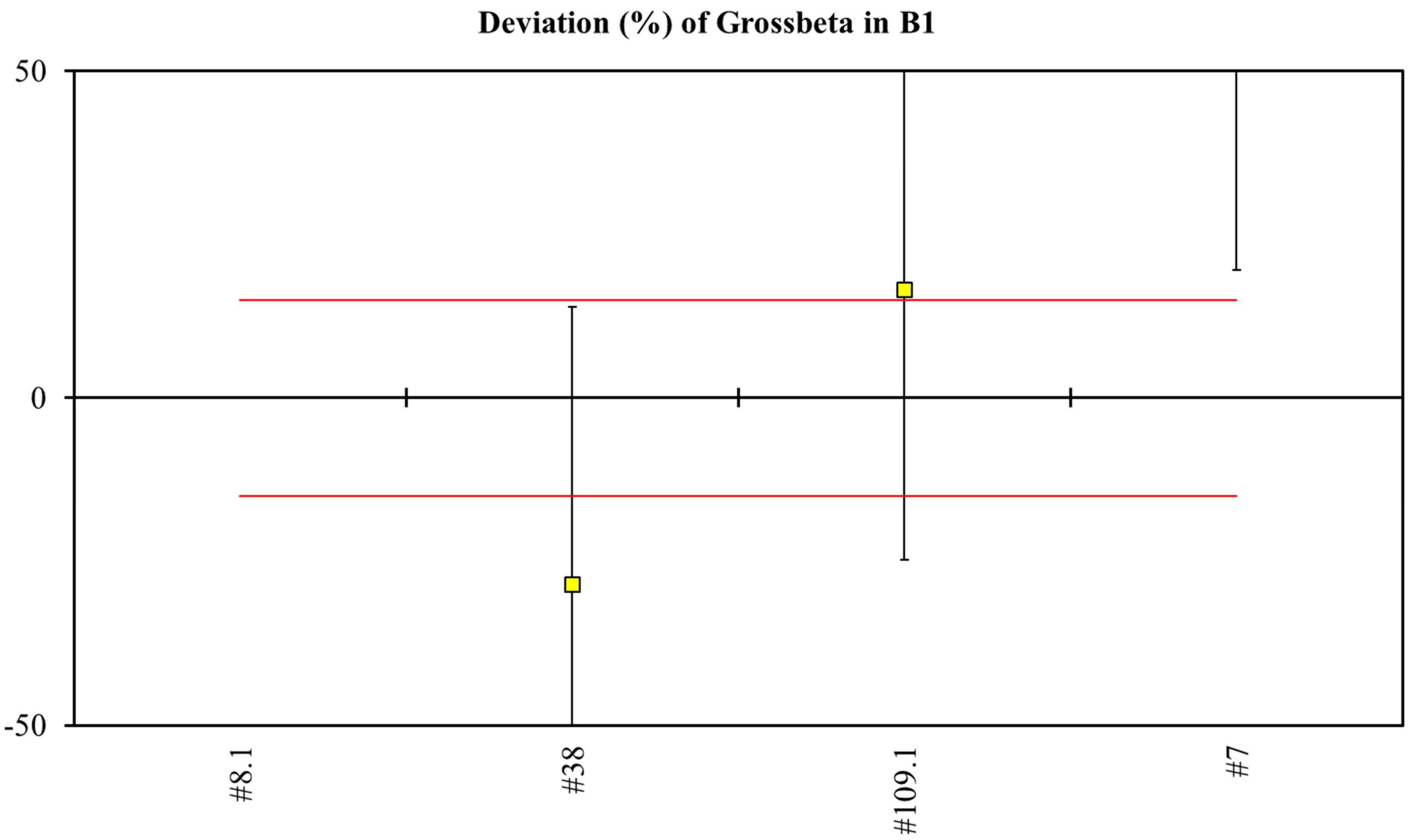
Measurement	PMM
Gross beta (AB)	8.28 ± 0.33 Bq g^{-1}
Gross alpha (A1)	228 ± 22 Bq kg^{-1}
Gross beta (B1)	0.56 ± 0.18 Bq g^{-1}


Deviation (%) of Grossbeta in AB
50
0
-50
#109.1
#173
#1
#38
#55.1
#8.1
#159
#197.3
#7

Lab Code	Lab Activity	Zeta	Z Score	Deviation
1	8.00 ± 0.95	-0.28	-0.58	-3
7	23.63 ± 1.82	8.28	31.83	185
8.1	8.8 ± 1.2	0.42	1.08	6
38	8.2 ± 0.4	-0.15	-0.17	-1
55.1	8.43 ± 0.80	0.17	0.31	2
109.1	7.04 ± 3.52	-0.35	-2.57	-15
159	10 ± 1.25	1.33	3.57	21
173	7.31 ± 0.97	-0.95	2.01	-12
197.3	18.785 ± 0.019	31.78	21.79	127


Deviation (%) of Grossalpha in A1
50
0
-50
#109.1
#1
#8.1
#7
#38

Lab Code	Lab Activity	Zeta	Z Score	Deviation
1	184.1 ± 6.2	-1.92	-3.31	-19
7	273 ± 15	1.69	3.39	20
8.1	199 ± 26	-0.85	-2.18	-13
38	275 ± 14	1.80	3.54	21
109.1	173 ± 87	-0.61	-4.13	-24


Deviation (%) of Grossbeta in B1
50
0
-50
#8.1
#38
#109.1
#7

Lab Code	Lab Activity	Zeta	Z Score	Deviation
7	0.987 ± 0.014	2.36	13.08	76
8.1	0.1710 ± 0.0013	-2.16	-11.93	-69
38	0.4 ± 0.2	-0.59	-4.91	-29
109.1	0.652 ± 0.098	0.45	2.83	16

[END OF REPORT]