National Physical Laboratory

NPL FINAL REPORT

ENVIRONMENTAL RADIOACTIVITY PROFICIENCY TEST EXERCISE 2022

VAN ES, E M, PEARCE, A K AND BURKE, S

SEPTEMBER 2023

UKAS PROFICIENCY TESTING 0016

Environmental Radioactivity Proficiency Test Exercise 2022

van Es, E M†, Pearce, A K and Burke, S
Medical, Marine and Nuclear Department

ABSTRACT

The results of NPL's twenty-eighth Environmental Radioactivity Proficiency Test Exercise are reported. Five different sample types were 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 five gamma-emitting radionuclides ('GL'). In total, 477 results were submitted (excluding gross measurements).

† PTE coordinator (email: elsje.van.es@npl.co.uk; telephone: +44 (0) 208 943 8596

ISSN 1754-2952

https://doi.org/10.47120/npl.IR61

National Physical Laboratory

Hampton Road, Teddington, Middlesex, TW11 0LW

Approved on behalf of NPLML by Ben Russell,

Science Area Leader, Nuclear Metrology Group, Medical, Marine and Nuclear Department

Assigned Values (reference time 2022-06-01 12:00 UTC)

Radionuclide (AB)	Assigned Value (Bq g^{-1})
^{3}H	5.63 ± 0.12
^{63}Ni	7.55 ± 0.17
^{90}Sr	3.703 ± 0.023
^{238}Pu	13.745 ± 0.091
Radionuclide (A1)	**Assigned Value (Bq kg^{-1})**
^{238}U	6.14 ± 0.16
^{241}Am	21.29 ± 0.64
^{244}Cm	18.37 ± 0.16
Radionuclide (B1)	**Assigned Value (Bq g^{-1})**
^{3}H	0.2421 ± 0.0095
^{14}C	0.2425 ± 0.0029
^{129}I	0.1555 ± 0.0018
Radionuclide (GH)	**Assigned Value (Bq g^{-1})**
^{60}Co	20.86 ± 0.20
^{88}Y	13.67 ± 0.18
^{133}Ba	8.60 ± 0.15
^{137}Cs	19.79 ± 0.32
^{139}Ce	44.76 ± 0.84
Radionuclide (GL)	**Assigned Value (Bq kg^{-1})**
^{54}Mn	42.69 ± 0.50
^{65}Zn	38.93 ± 0.56
^{134}Cs	12.93 ± 0.19
^{210}Pb	21.78 ± 0.46
^{241}Am	48.22 ± 0.38

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-eighth in a series of annual exercises run by NPL over the last 30 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	Contents	Nominal mass supplied	Activity range
Alpha Beta	AB	One alpha- and three beta-emitting radionuclides in dilute nitric acid	20 g	1 – 20 Bq g^{-1}
Alpha One	A1	Three‡ alpha-emitting radionuclides in dilute nitric acid	500 g	1 – 25 Bq kg^{-1}
Beta One	B1	Three beta-emitting radionuclides in 0.01 M NaOH solution	500 g	0.1 – 1 Bq g^{-1}
Gamma High	GH	Five gamma-ray emitting radionuclides in dilute nitric acid	100 g	1 – 50 Bq g^{-1}
Gamma Low	GL	Five gamma-ray emitting radionuclides in dilute nitric acid	500 g	1 – 50 Bq kg^{-1}

As in previous years, the main objective 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 into a report.

Each participant was allocated by NPL a unique laboratory code number (if not already allocated in a previous PTE in this series). This was done in confidence so that no third parties could 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 PTE 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 verified radiometrically through either 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 A1 sample type contained natural uranium and some decay progeny but participants were only asked to report for ^{238}U.

The standard uncertainty of the Assigned Value 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 corresponding confidence interval is approximately 68 %.

The bulk solution was subdivided into (typically) 50 bottles and homogeneity was checked by gamma spectrometry where applicable. Solution stability was checked by counting one or more bottles of each sample type at NPL at regular intervals throughout the course of the PTE; 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

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

2. TREATMENT OF DATA

The data were analysed using the same methods as in the 2021 exercise (van Es et al., 2022).

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

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

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

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

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

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

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

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

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 13528:2015 paragraph 6.3). 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 13528:2015 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 despatched is assumed to be the number of samples ordered by participants. Participants may have ordered multiple samples and/or chosen to not submit results. The number of no results is for indication only and does not relate to a failed result as it is considered that all radionuclides in a sample may not be relevant for a particular participant and that they have only reported for those radionuclides relevant to their test regimes.

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

Radionuclide	Number of samples despatched	Pass	Questionable	Fail	No Result
AB					
^{3}H	33	18	1	3	4
^{63}Ni		14	1	2	8
^{90}Sr		18	2	1	3
^{238}Pu		16	3	2	4
A1					
^{238}U	22	18	0	0	2
^{241}Am		15	2	1	1
^{244}Cm		7	4	4	3
B1					
^{3}H	30	21	3	1	1
^{14}C		18	2	1	5
^{129}I		11	3	0	11
GH					
^{60}Co	31	29	2	1	0
^{88}Y		31	0	1	0
^{133}Ba		26	3	2	1
^{137}Cs		30	1	1	0
^{139}Ce		28	2	1	1

Radionuclide	Number of samples despatched	Pass	Questionable	Fail	No Result
GL					
^{54}Mn	28	25	2	0	0
^{65}Zn		22	4	1	0
^{134}Cs		23	3	1	0
^{210}Pb		11	7	2	6
^{241}Am		23	3	0	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 2022-06-01 12:00:00 UTC.

Table 4 AB Summary

Radionuclide	NPL Assigned Values (Bq g^{-1})	PMM (Bq g^{-1})	Deviation %	Zeta	Critical value
^{3}H	5.633 ± 0.061	5.584 ± 0.059	− 0.9	− 0.58	2.65
^{63}Ni	7.550 ± 0.083	7.04 ± 0.12	− 6.8	− 3.40	2.77
^{90}Sr	3.703 ± 0.011	3.630 ± 0.050	− 2.0	− 1.41	2.83
^{238}Pu	13.745 ± 0.046	13.68 ± 0.12	− 0.5	− 0.51	2.85

Table 5 A1 Summary

Radionuclide	NPL Assigned Values (Bq kg^{-1})	PMM (Bq kg^{-1})	Deviation %	Zeta	Critical value
^{238}U	6.143 ± 0.080	6.283 ± 0.079	2.3	1.25	2.65
^{241}Am	21.29 ± 0.32	21.24 ± 0.40	− 0.2	− 0.09	2.72
^{244}Cm	18.367 ± 0.082	15.86 ± 0.74	− 13.7	− 3.36	3.01

Table 6 B1 Summary

Radionuclide	NPL Assigned Values (Bq g^{-1})	PMM (Bq g^{-1})	Deviation %	Zeta	Critical value
^{3}H	0.2421 ± 0.0048	0.2375 ± 0.0025	− 1.9	− 0.85	2.58
^{14}C	0.2425 ± 0.0015	0.2372 ± 0.0045	− 2.2	− 1.13	2.85
^{129}I	0.15545 ± 0.00091	0.1579 ± 0.0036	1.5	0.64	2.98

Table 7 GH Summary

Radionuclide	NPL Assigned Values (Bq g^{-1})	PMM (Bq g^{-1})	Deviation %	Zeta	Critical value
^{60}Co	20.86 ± 0.10	21.09 ± 0.12	1.1	1.47	2.64
^{88}Y	13.665 ± 0.088	13.502 ± 0.097	− 1.2	− 1.24	2.63
^{133}Ba	8.598 ± 0.075	8.602 ± 0.072	0.0	0.03	2.58
^{137}Cs	19.79 ± 0.16	20.03 ± 0.12	1.2	1.2	2.58
^{139}Ce	44.76 ± 0.42	44.6 ± 0.3	− 0.4	− 0.32	2.58

Table 8 GL Summary

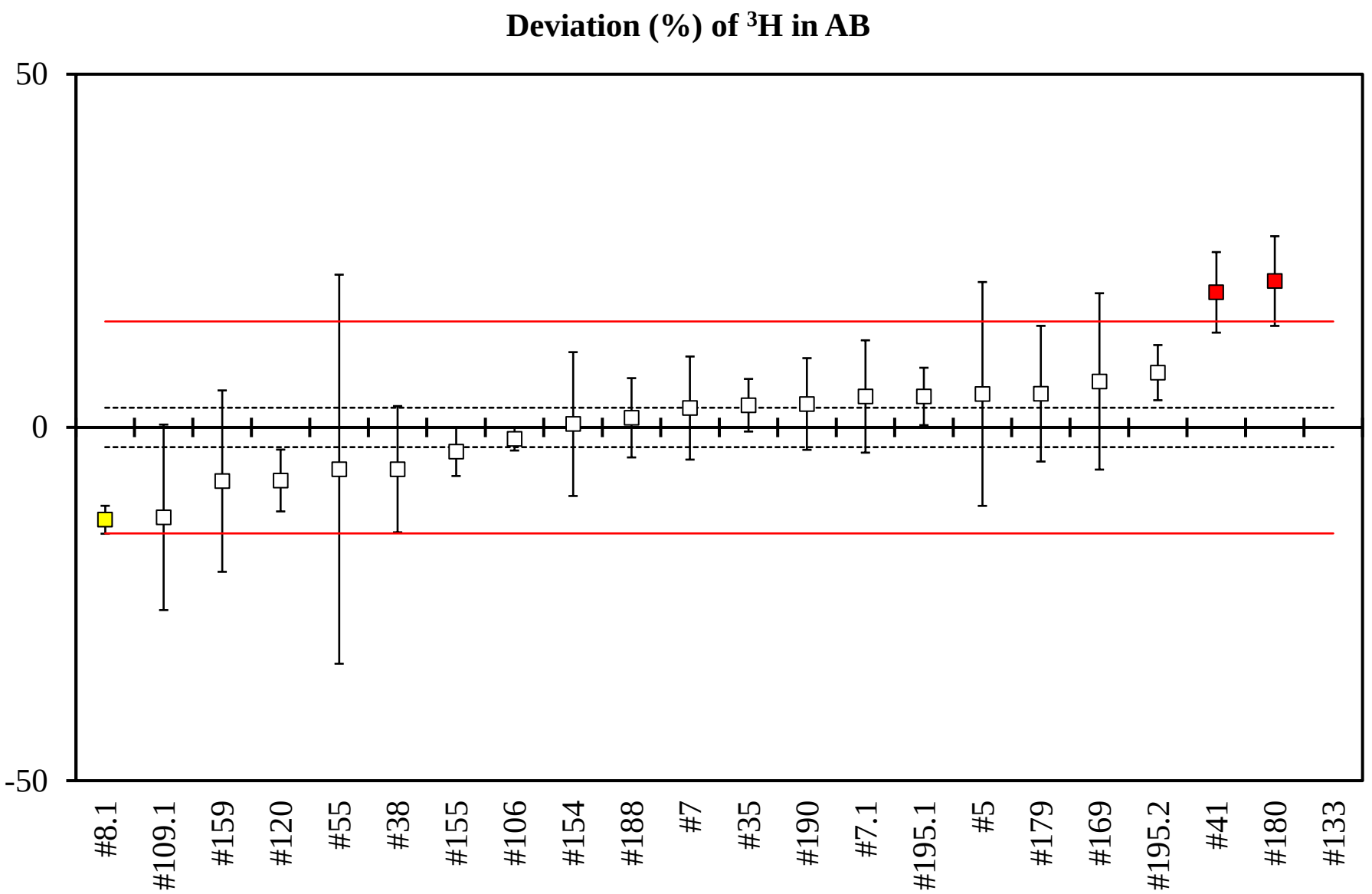
Radionuclide	NPL Assigned Values (Bq kg^{-1})	PMM (Bq kg^{-1})	Deviation %	Zeta	Critical value
^{54}Mn	42.69 ± 0.25	42.95 ± 0.38[§]	− 0.3	0.34	2.64
^{65}Zn	38.93 ± 0.28	38.52 ± 0.32	− 1.1	− 0.98	2.64
^{134}Cs	12.932 ± 0.093	12.64 ± 0.14	− 2.2	− 1.77	2.68
^{210}Pb	21.78 ± 0.23	19.91 ± 0.70	− 8.6	− 2.54	2.81
^{241}Am	48.22 ± 0.19	47.37 ± 0.46	− 1.8	− 1.70	2.75

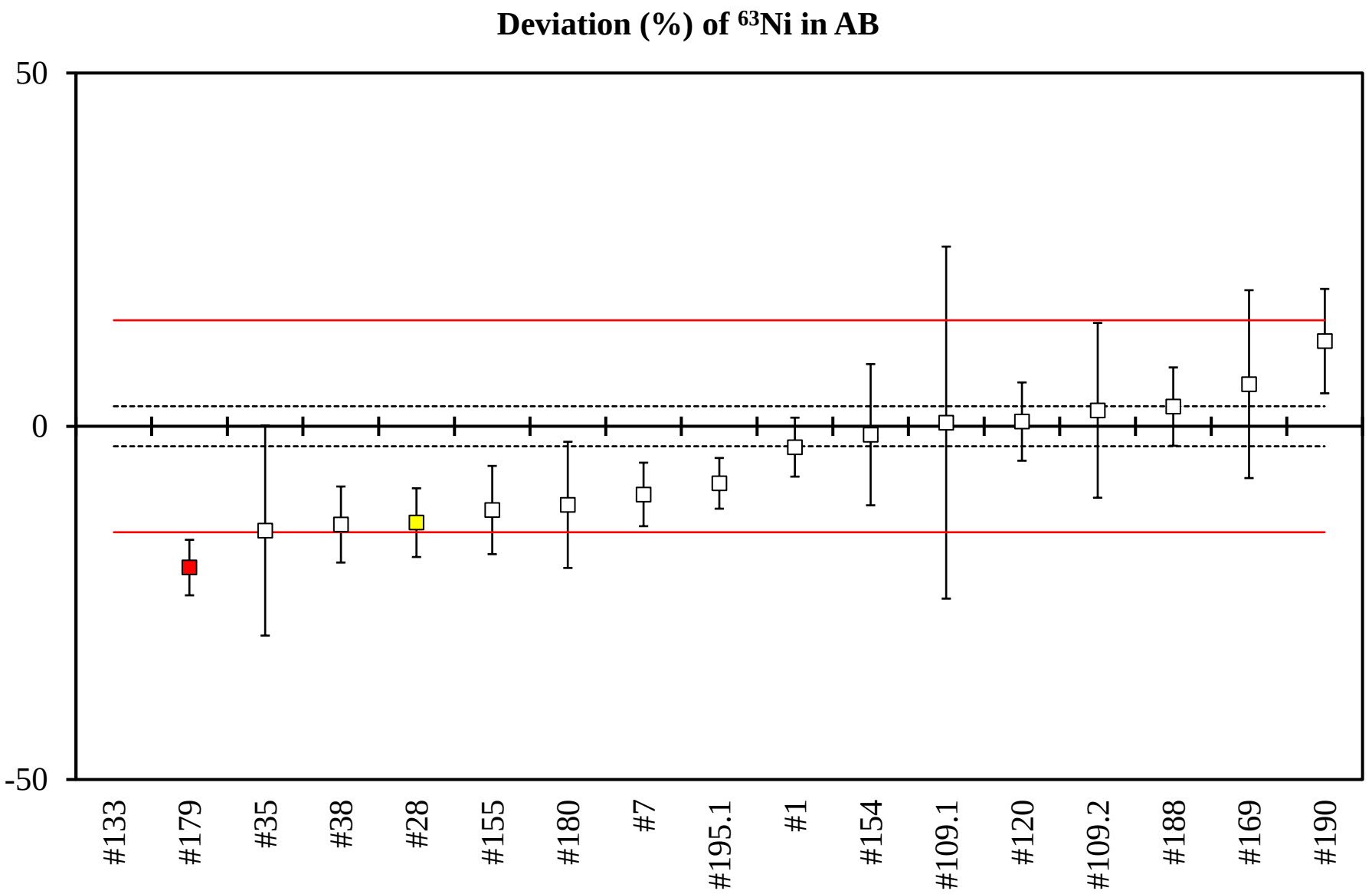
[§]The algorithm used to calculate the PMM could find no optimum solution. The value which elimated the least results was selected.

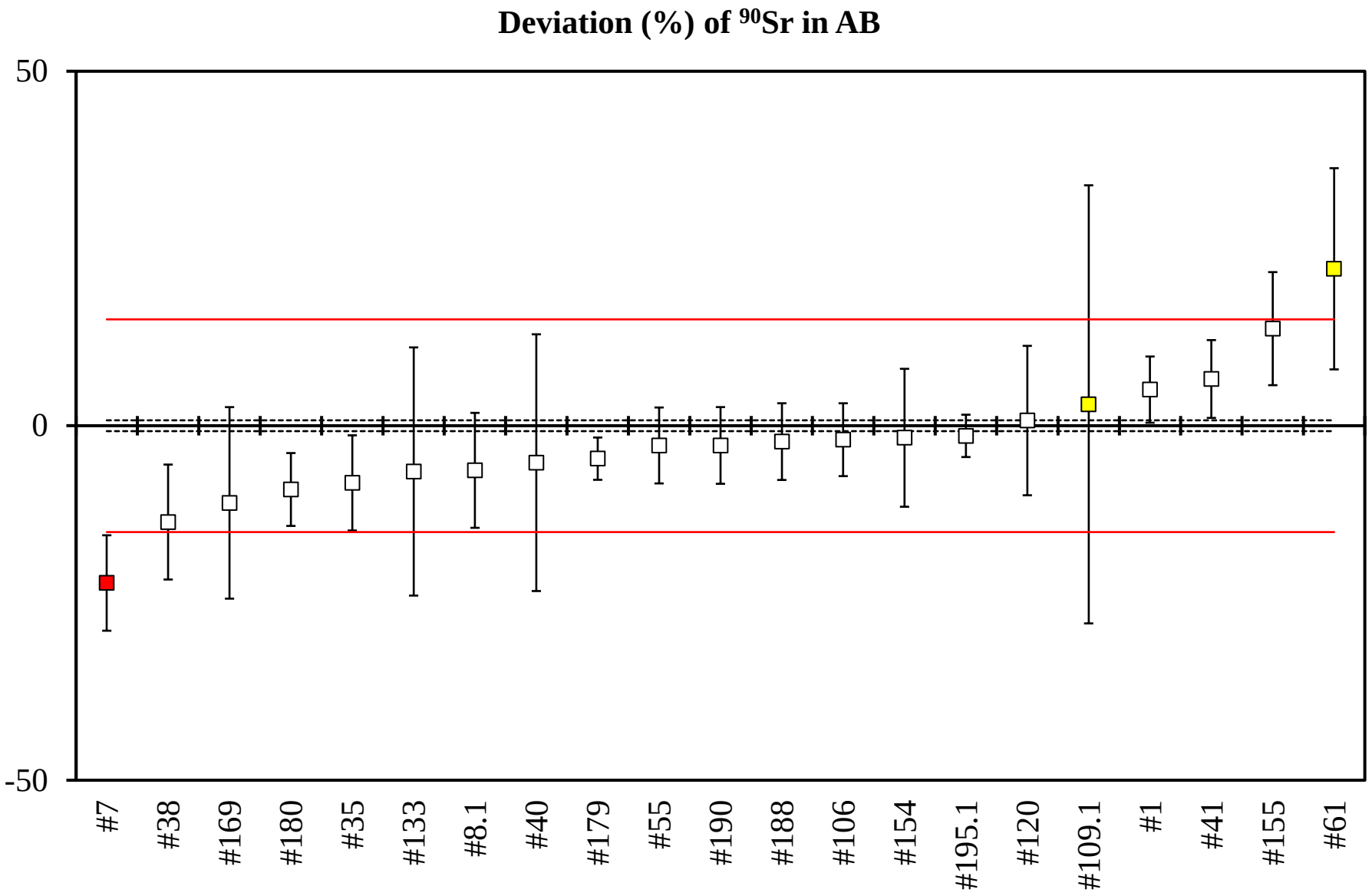
4. ALPHA BETA (AB) DEVIATION PLOTS

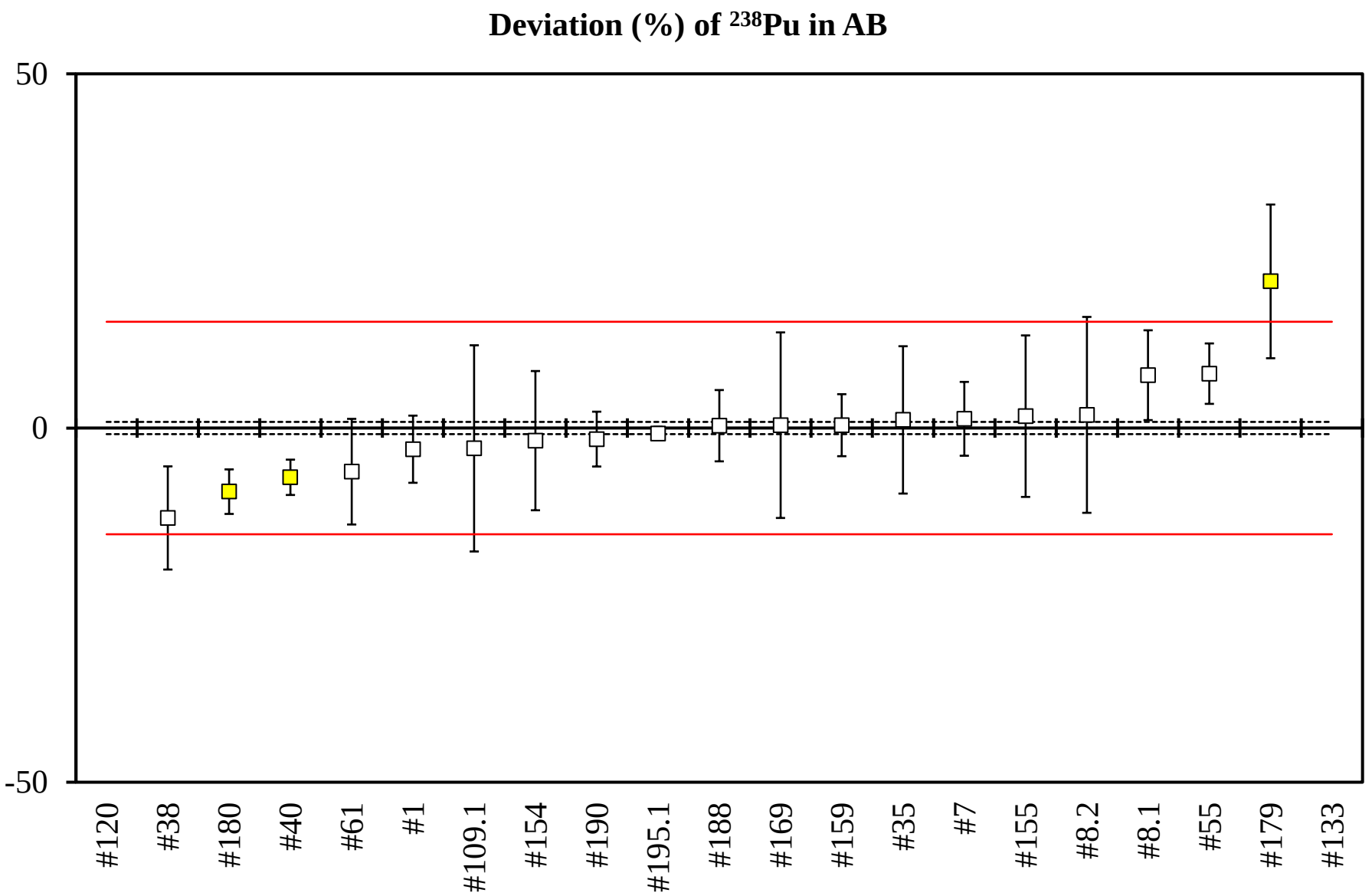
NOTE:

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}

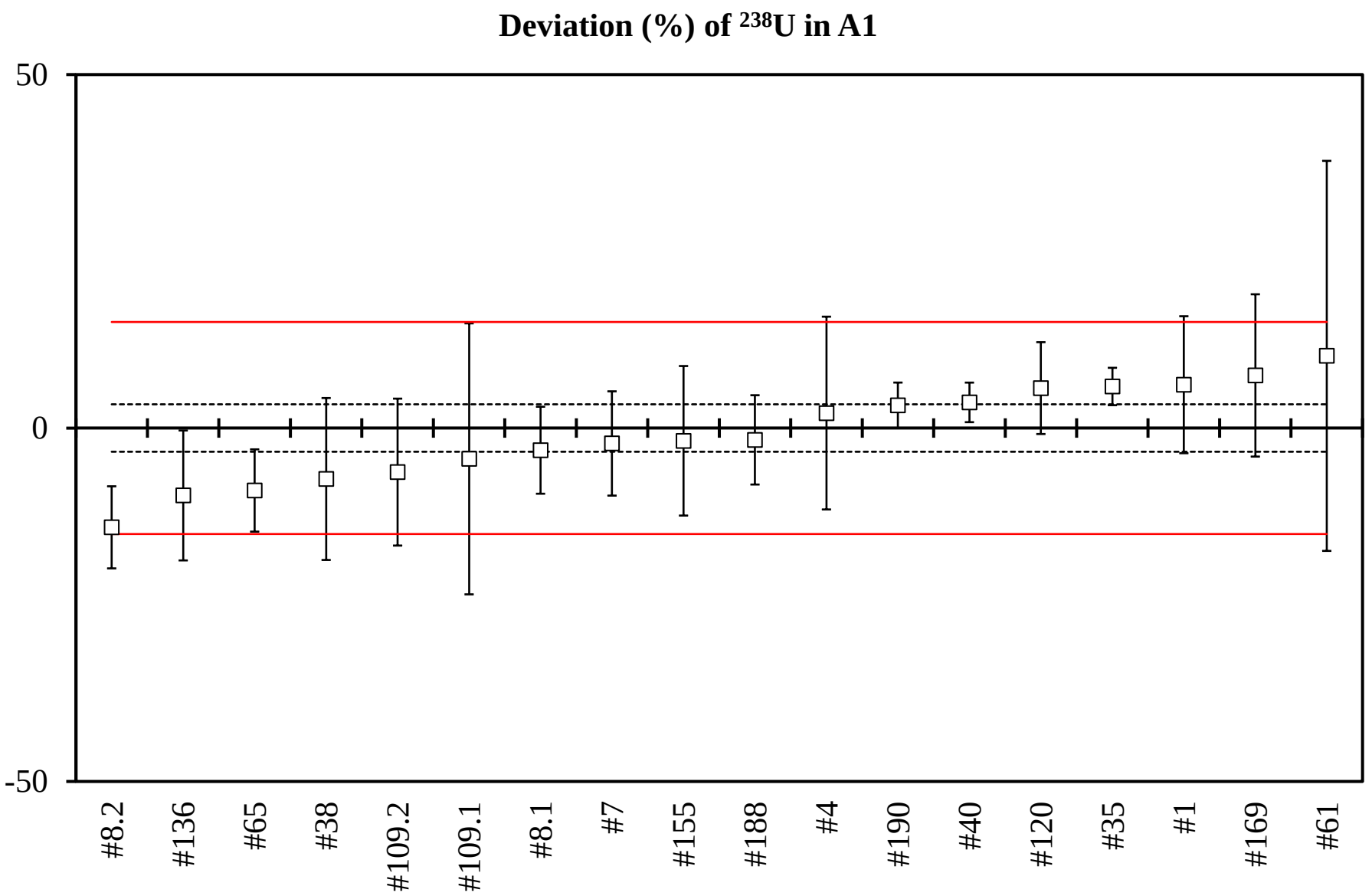

Deviation (%) of 3H in AB
50
0
-50
#8.1
#109.1
#159
#120
#55
#38
#155
#106
#154
#188
#7
#35
#190
#7.1
#195.1
#5
#179
#169
#195.2
#41
#180
#133

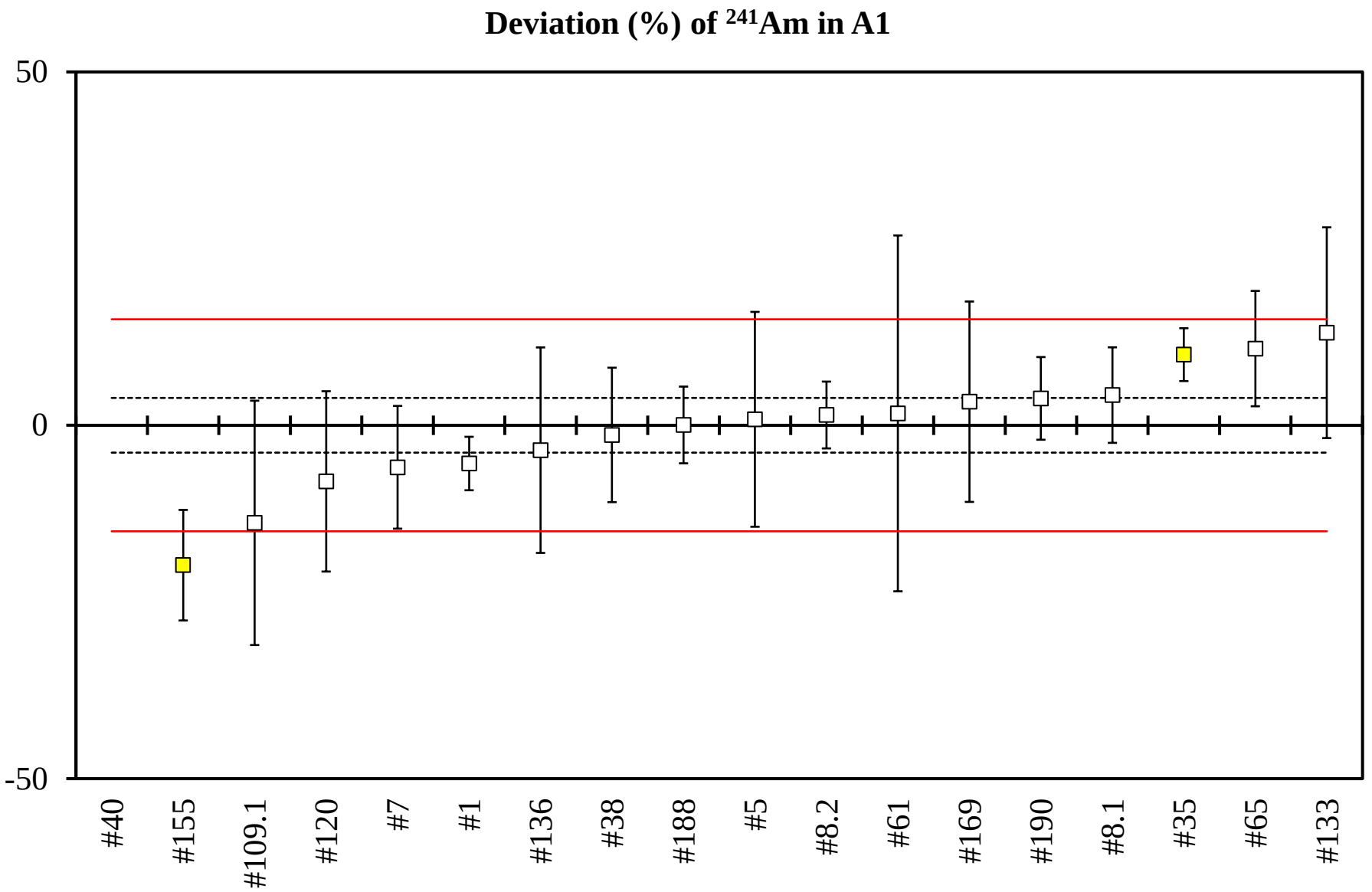

Deviation (%) of 63Ni in AB
50
0
-50
#133
#179
#35
#38
#28
#155
#180
#7
#195.1
#1
#154
#109.1
#120
#109.2
#188
#169
#190

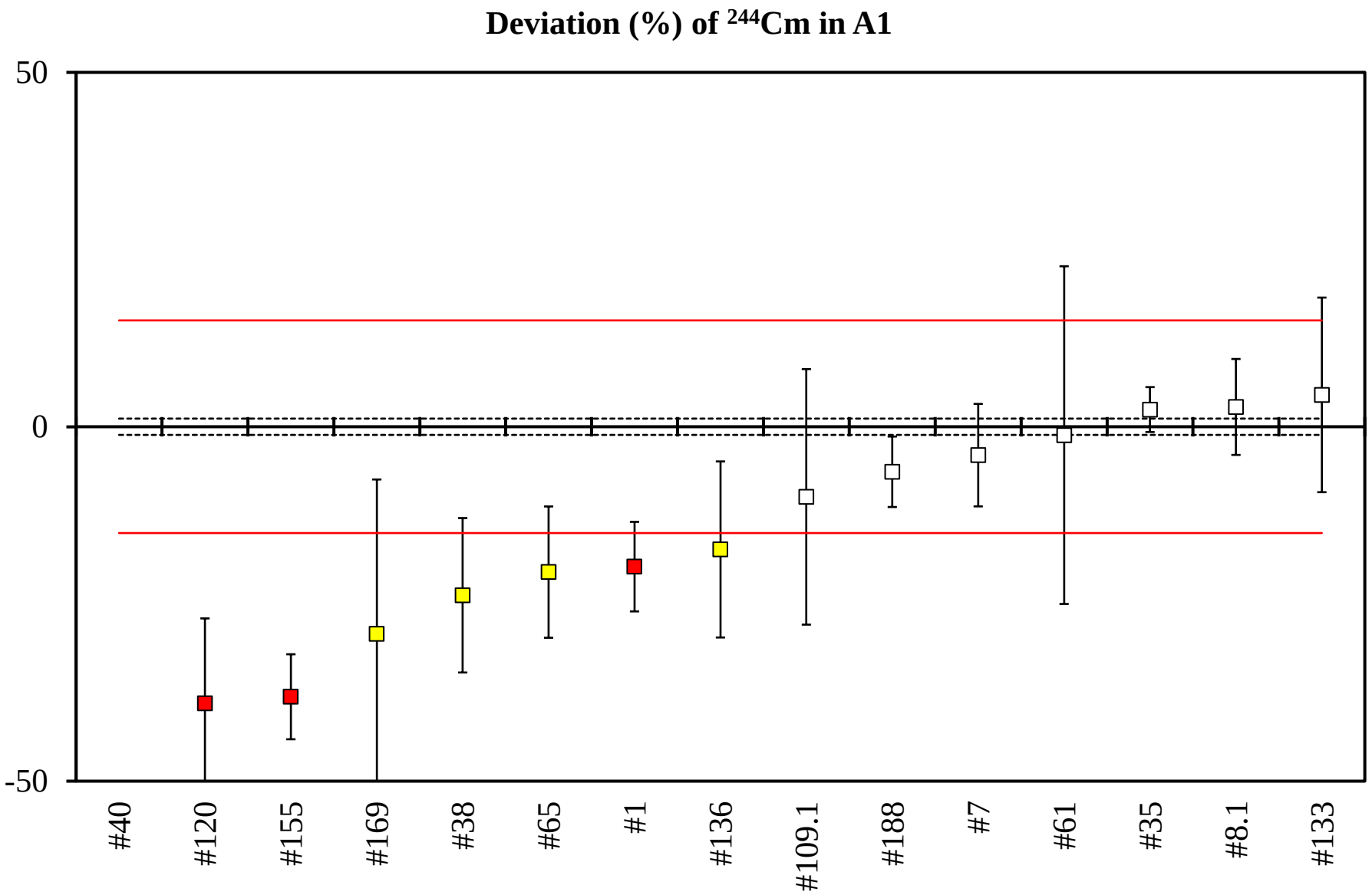

Deviation (%) of 90Sr in AB
50
0
-50
#7
#38
#169
#180
#35
#133
#8.1
#40
#179
#55
#190
#188
#106
#154
#195.1
#120
#109.1
#1
#41
#155
#61


Deviation (%) of 238Pu in AB
50
0
-50
#120
#38
#180
#40
#61
#1
#109.1
#154
#190
#195.1
#188
#169
#159
#35
#7
#155
#8.2
#8.1
#55
#179
#133

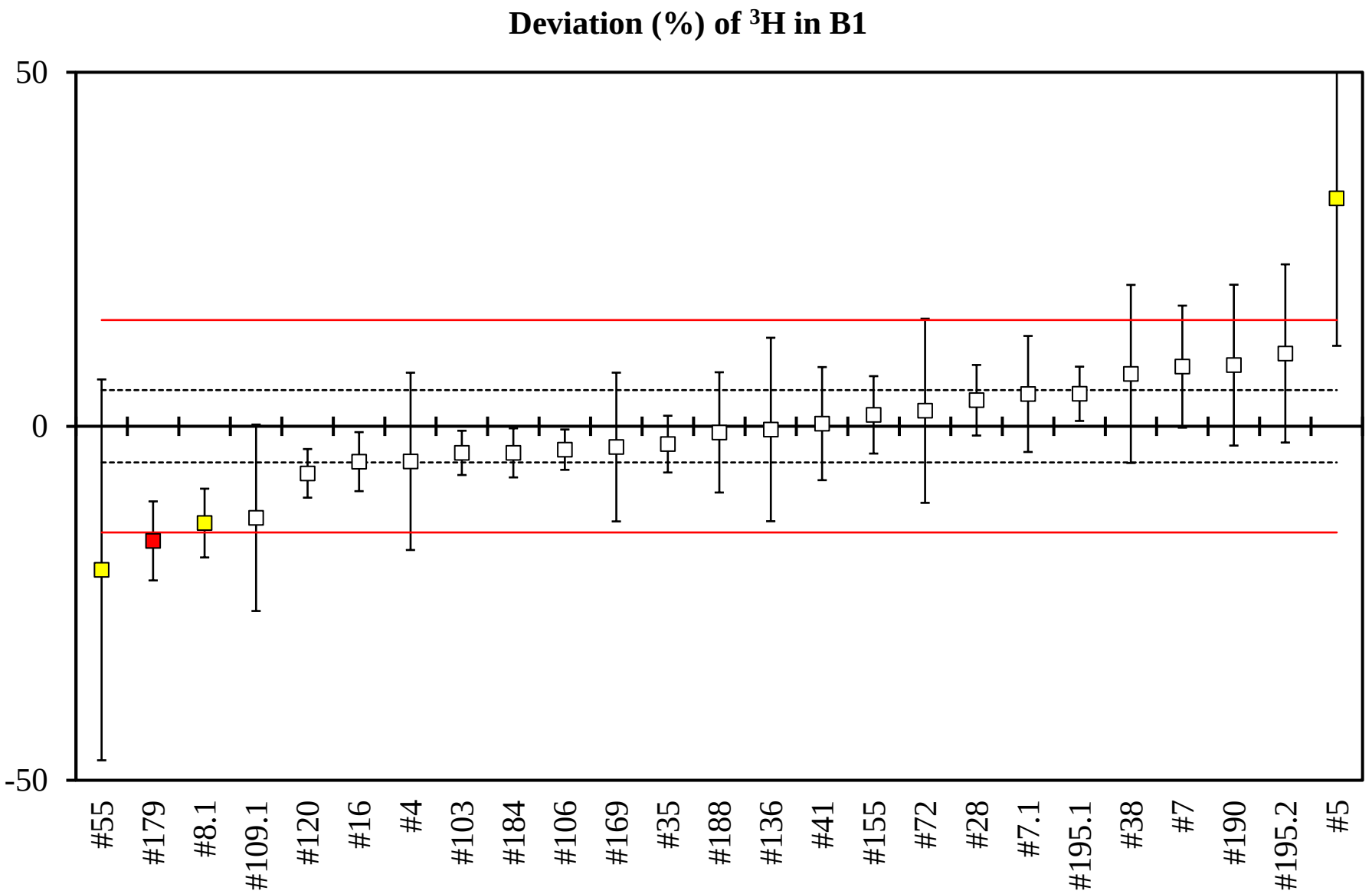
5. ALPHA ONE (A1) DEVIATION PLOTS

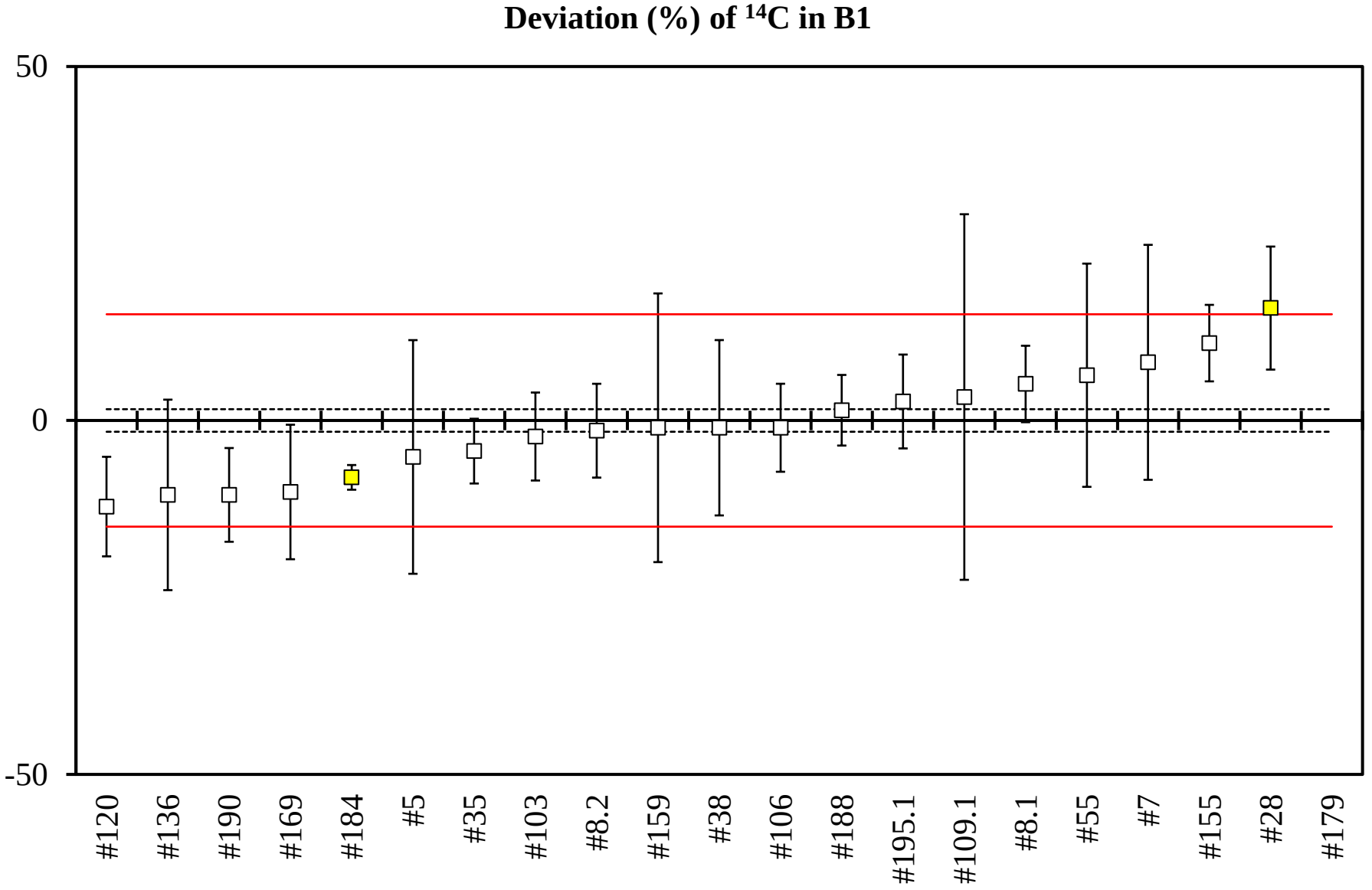

Deviation (%) of 238U in A1
50
0
-50
#8.2
#136
#65
#38
#109.2
#109.1
#8.1
#7
#155
#188
#4
#190
#40
#120
#35
#1
#169
#61

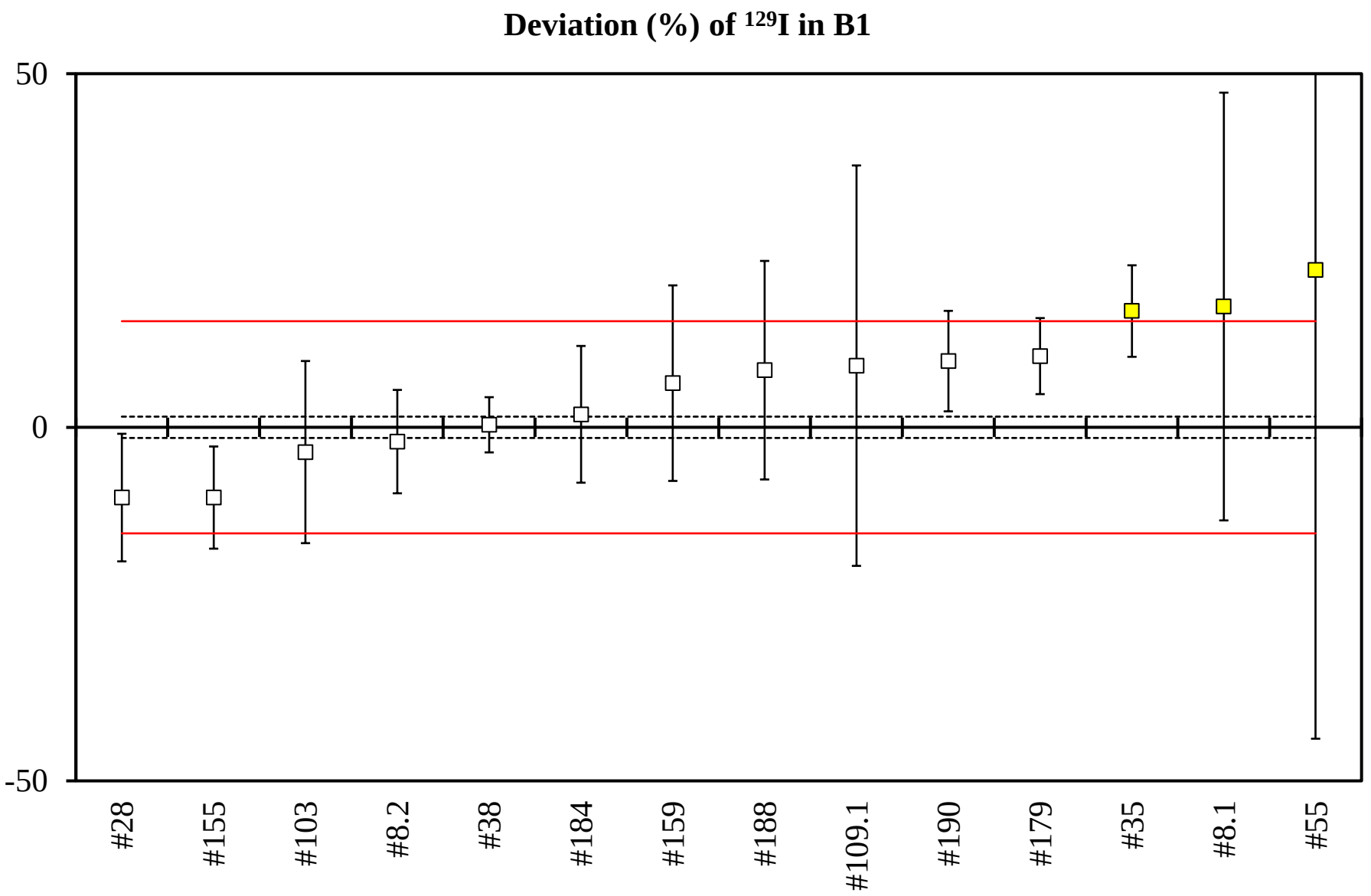

Deviation (%) of 241Am in A1
50
0
-50
#40
#155
#109.1
#120
#7
#1
#136
#38
#188
#5
#8.2
#61
#169
#190
#8.1
#35
#65
#133


Deviation (%) of 244Cm in A1
50
0
-50
#40
#120
#155
#169
#38
#65
#1
#136
#109.1
#188
#7
#61
#35
#8.1
#133

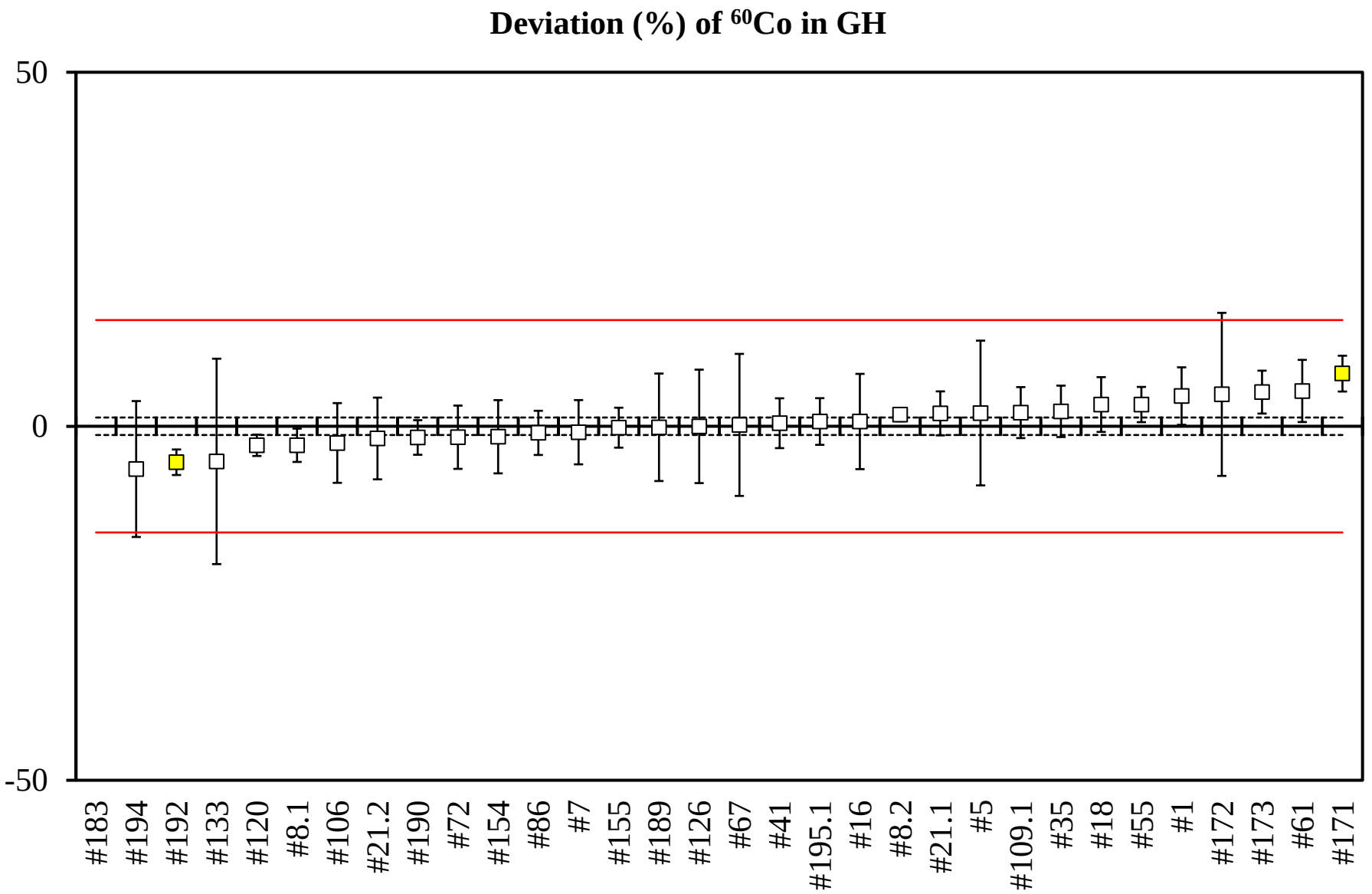
6. BETA ONE (B1) DEVIATION PLOTS

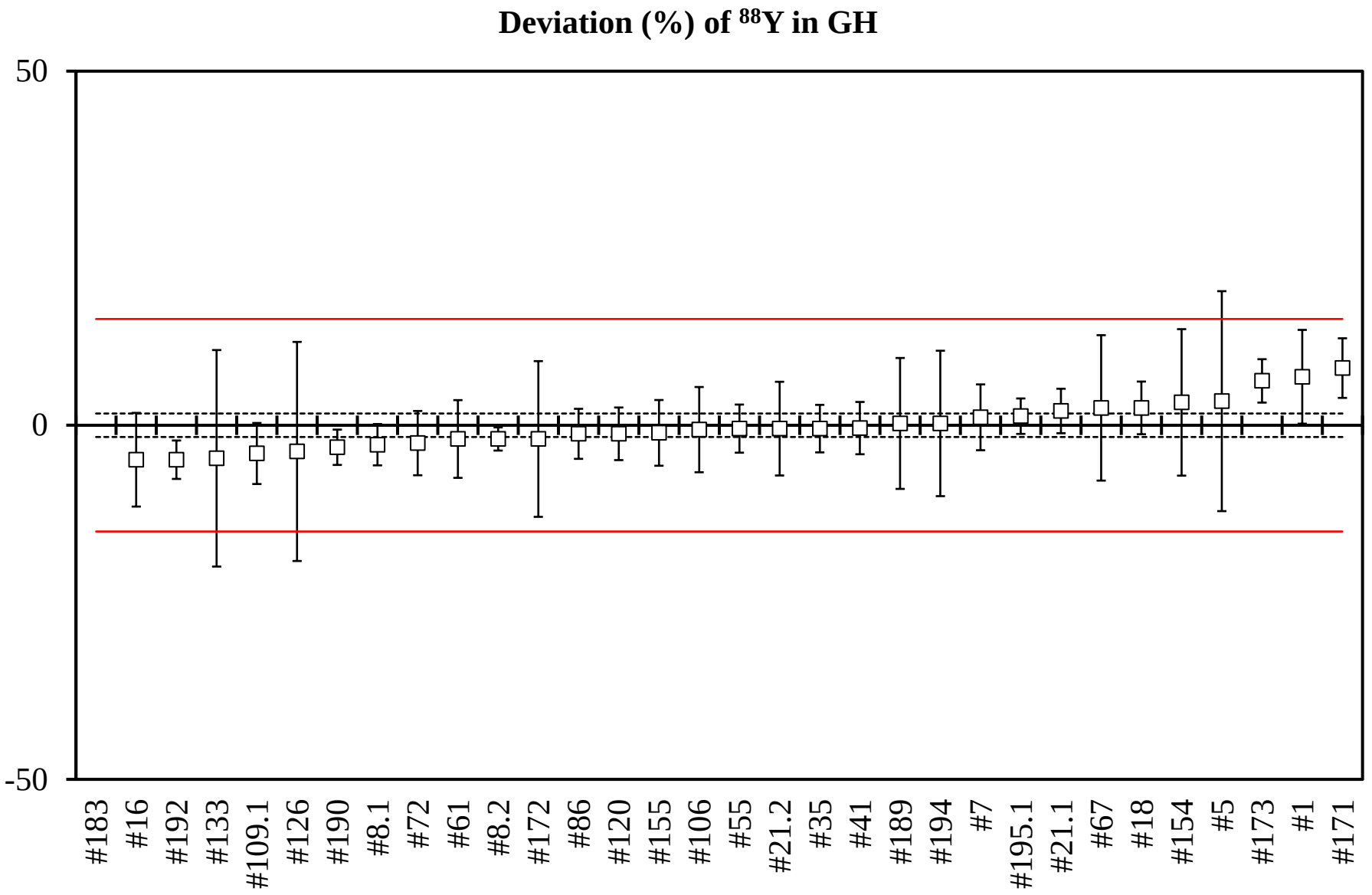

Deviation (%) of 3H in B1
50
0
-50
#55
#179
#8.1
#109.1
#120
#16
#4
#103
#184
#106
#169
#35
#188
#136
#41
#155
#72
#28
#7.1
#195.1
#38
#7
#190
#195.2
#5

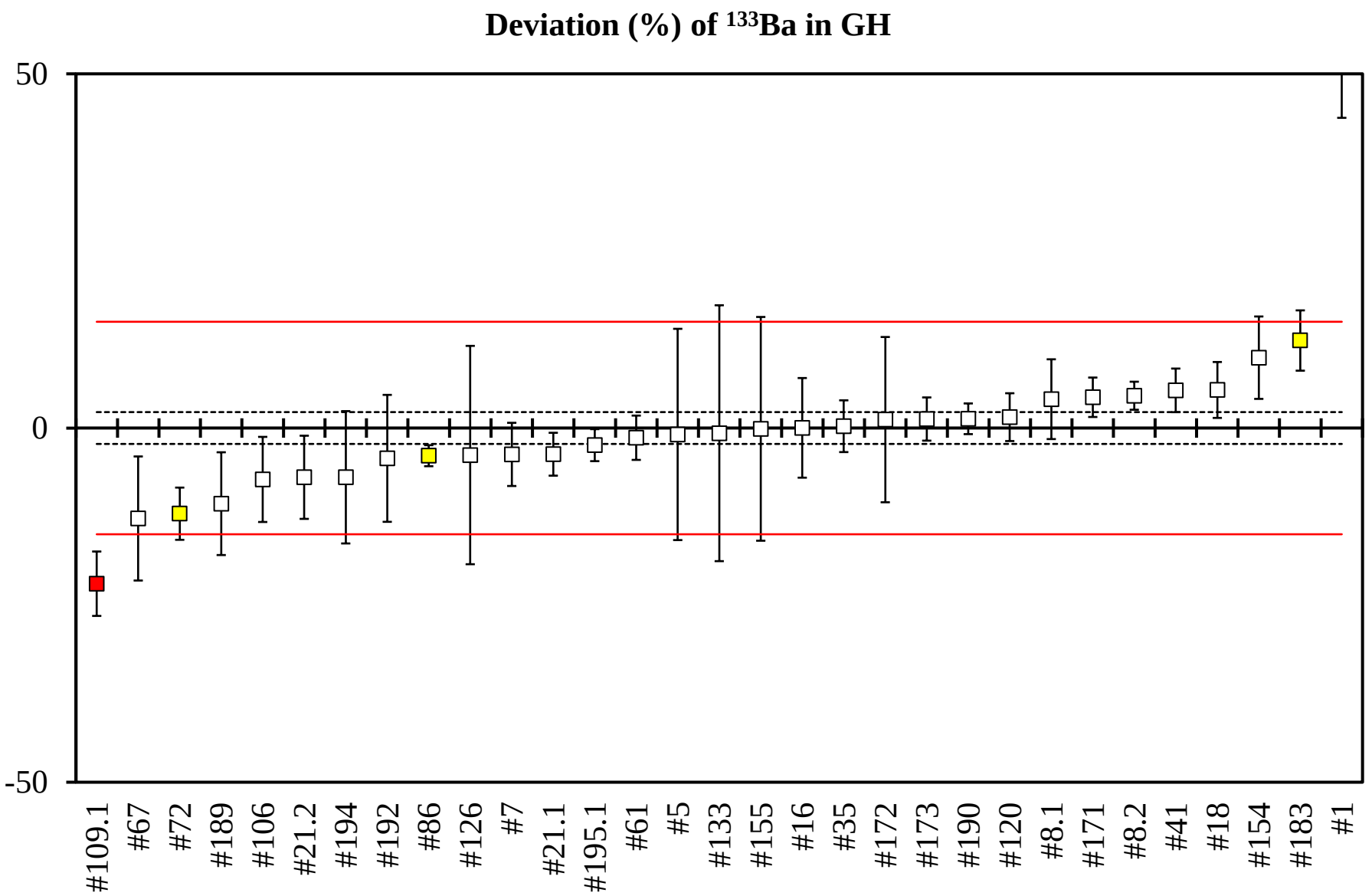

Deviation (%) of 14C in B1
50
0
-50
#120
#136
#190
#169
#184
#5
#35
#103
#8.2
#159
#38
#106
#188
#195.1
#109.1
#8.1
#55
#7
#155
#28
#179

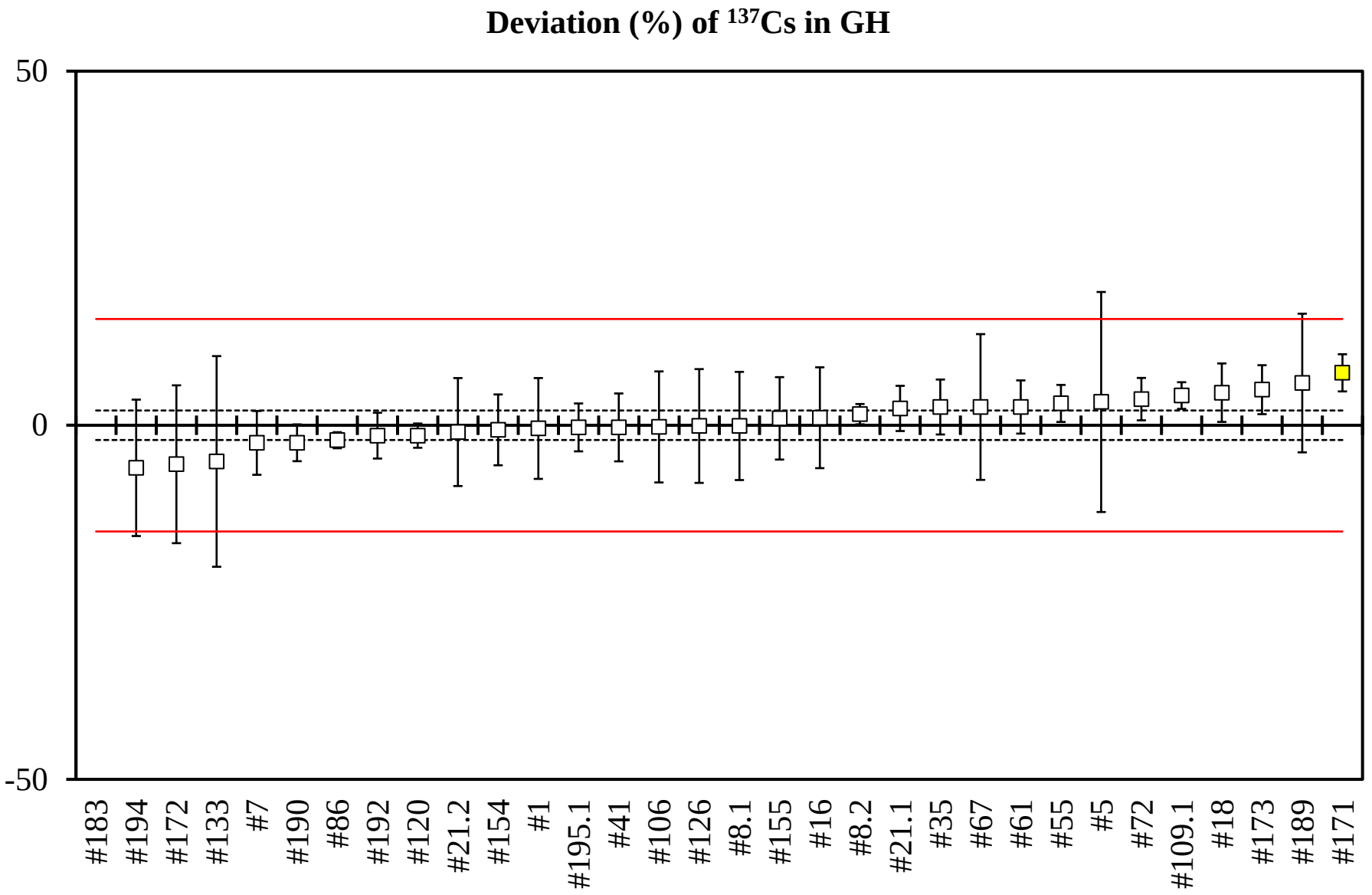

Deviation (%) of 129I in B1
50
0
-50
#28
#155
#103
#8.2
#38
#184
#159
#188
#109.1
#190
#179
#35
#8.1
#55

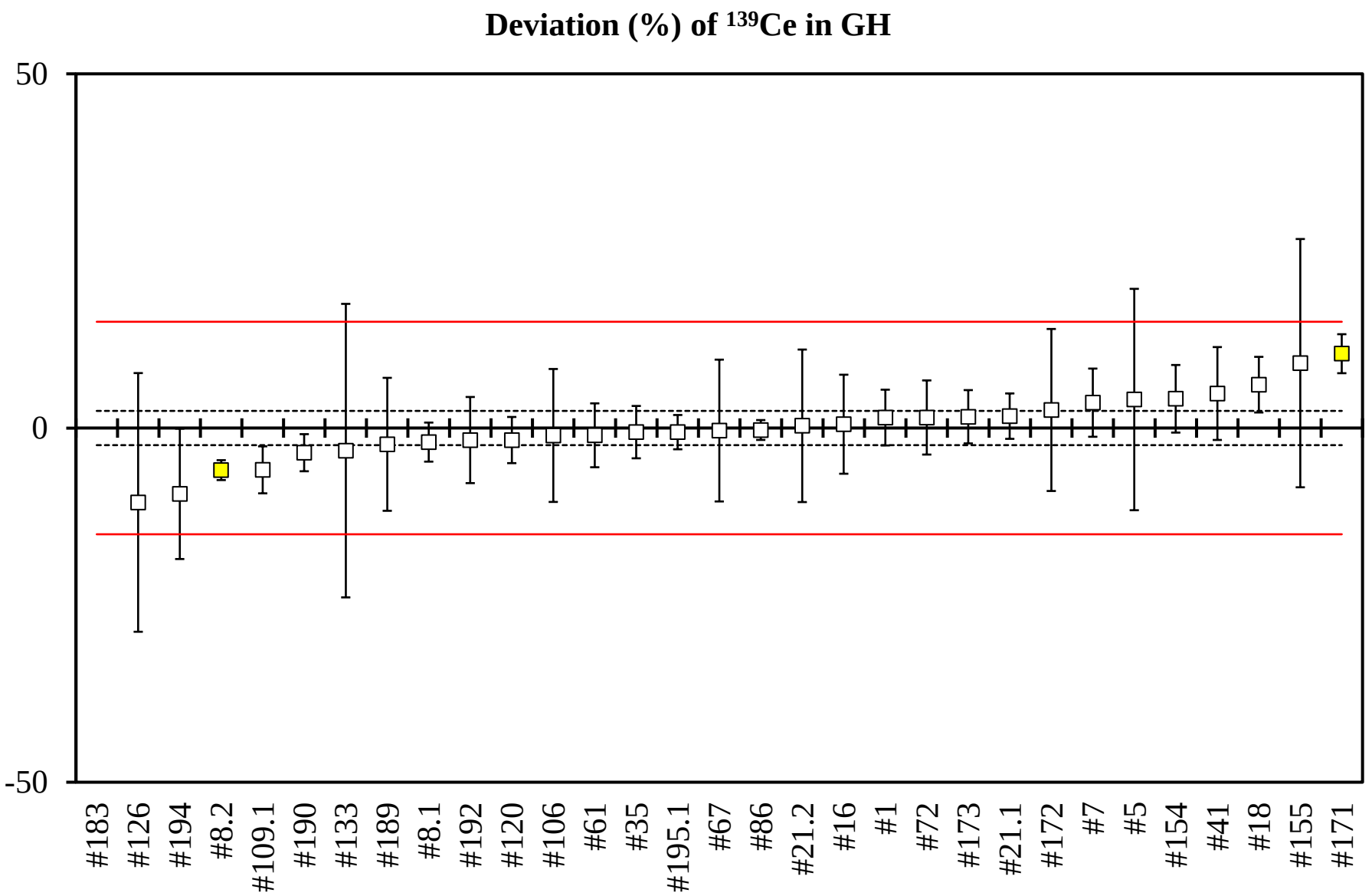
7. GAMMA HIGH (GH) DEVIATION PLOTS


Deviation (%) of 60Co in GH
50
0
-50
#183
#194
#192
#133
#120
#8.1
#106
#21.2
#190
#72
#154
#86
#7
#155
#189
#126
#67
#41
#195.1
#16
#8.2
#21.1
#5
#109.1
#35
#18
#55
#1
#172
#173
#61
#171

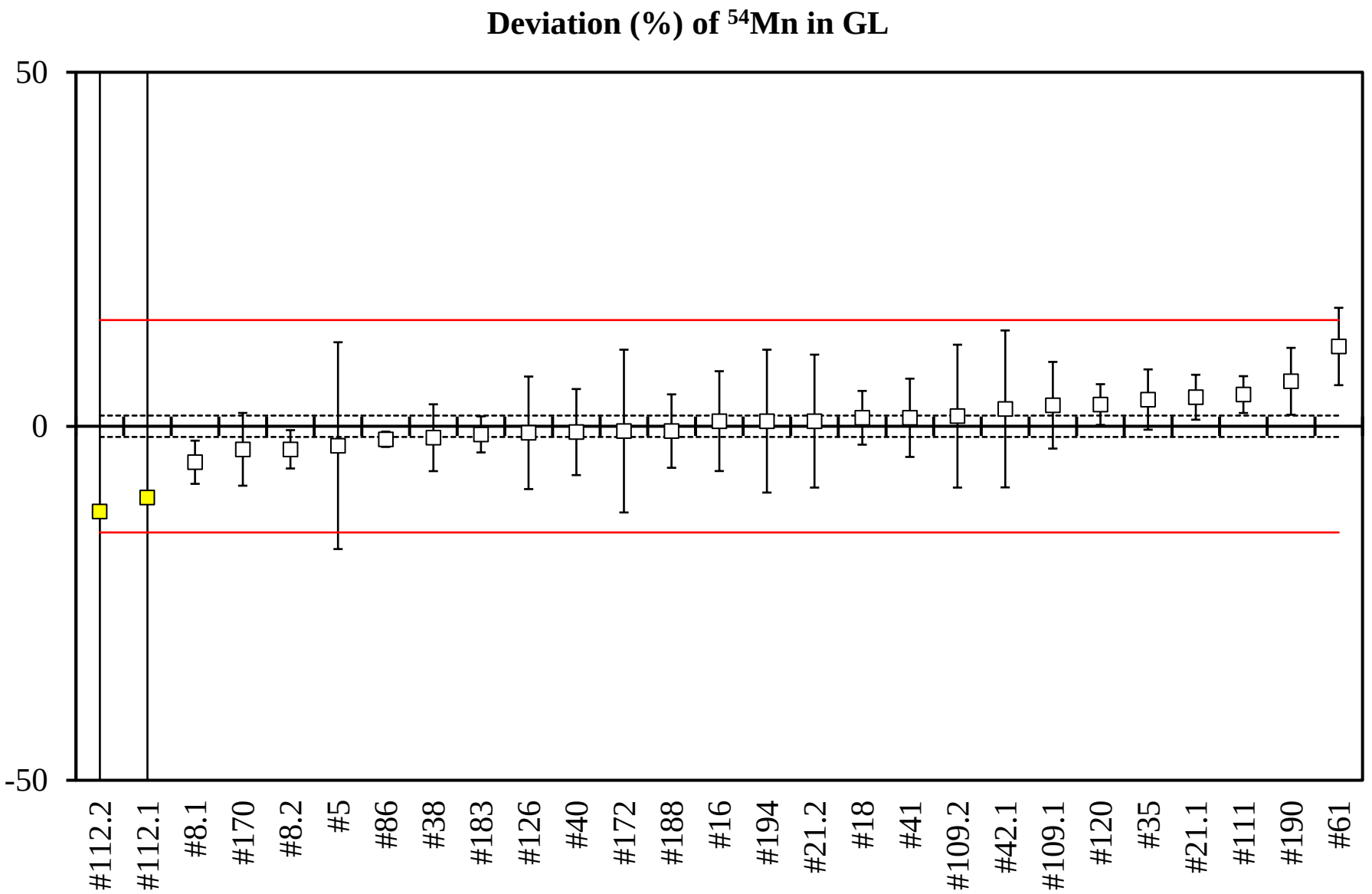

Deviation (%) of 88Y in GH
50
0
-50
#183
#16
#192
#133
#109.1
#126
#190
#8.1
#72
#61
#8.2
#172
#86
#120
#155
#106
#55
#21.2
#35
#41
#189
#194
#7
#195.1
#21.1
#67
#18
#154
#5
#173
#1
#171

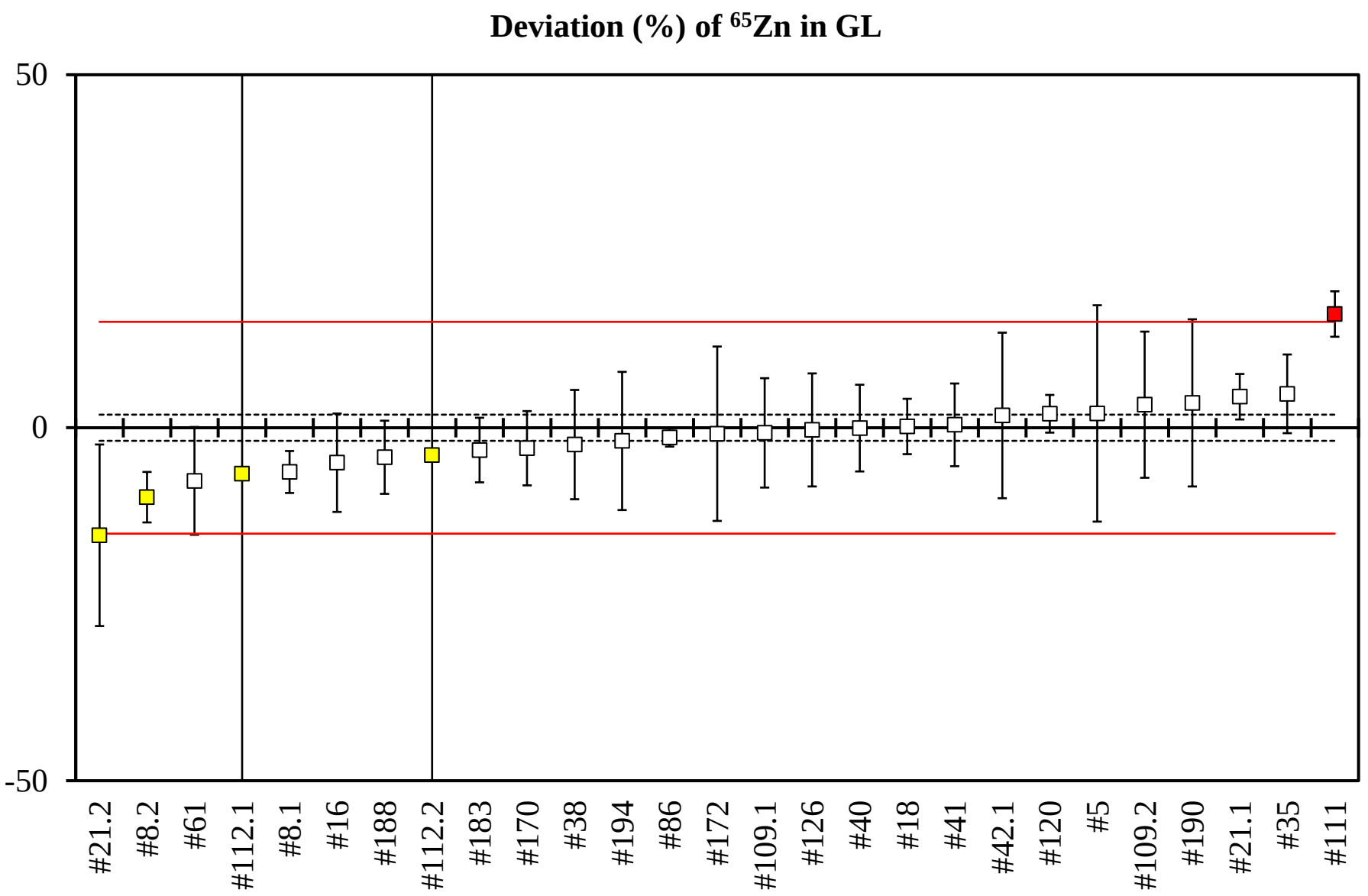

Deviation (%) of 133Ba in GH
50
0
-50
#109.1
#67
#72
#189
#106
#21.2
#194
#192
#86
#126
#7
#21.1
#195.1
#61
#5
#133
#155
#16
#35
#172
#173
#190
#120
#8.1
#171
#8.2
#41
#18
#154
#183
#1

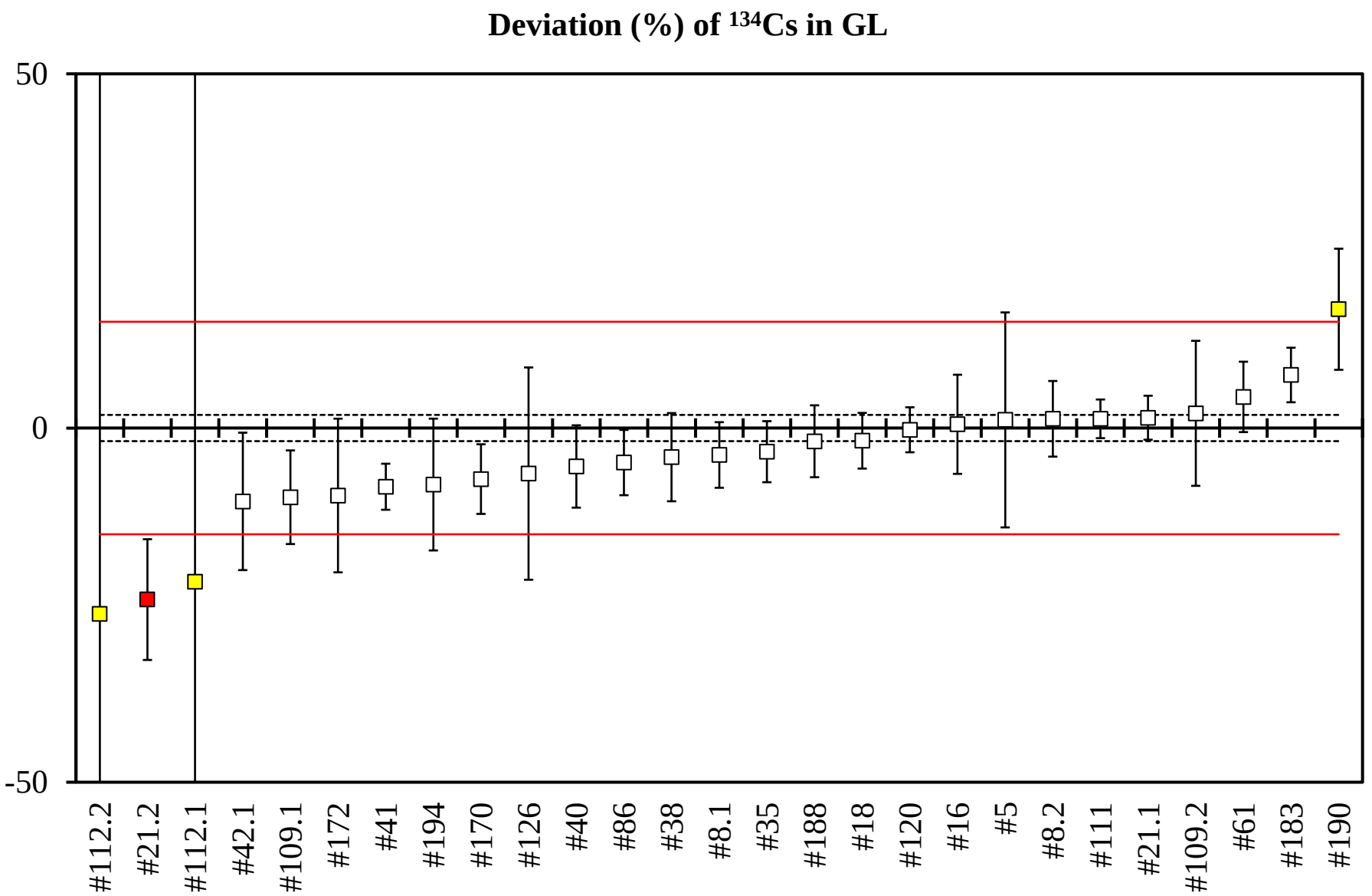

Deviation (%) of 137Cs in GH
50
0
-50
#183
#194
#172
#133
#7
#190
#86
#192
#120
#21.2
#154
#1
#195.1
#41
#106
#126
#8.1
#155
#16
#8.2
#21.1
#35
#67
#61
#55
#5
#72
#109.1
#18
#173
#189
#171

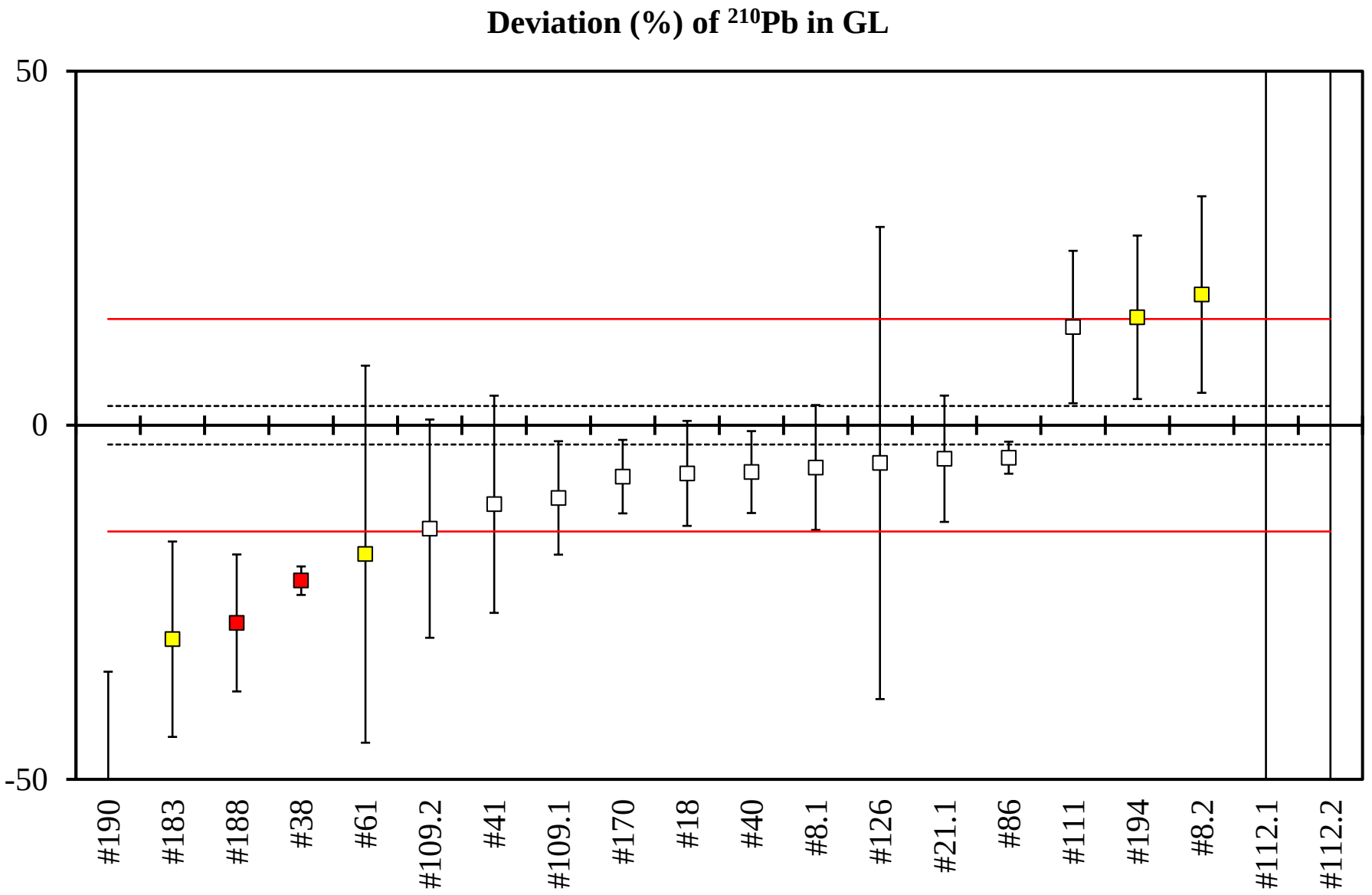

Deviation (%) of 139Ce in GH
50
0
-50
#183
#126
#194
#8.2
#109.1
#190
#133
#189
#8.1
#192
#120
#106
#61
#35
#195.1
#67
#86
#21.2
#16
#1
#72
#173
#21.1
#172
#7
#5
#154
#41
#18
#155
#171

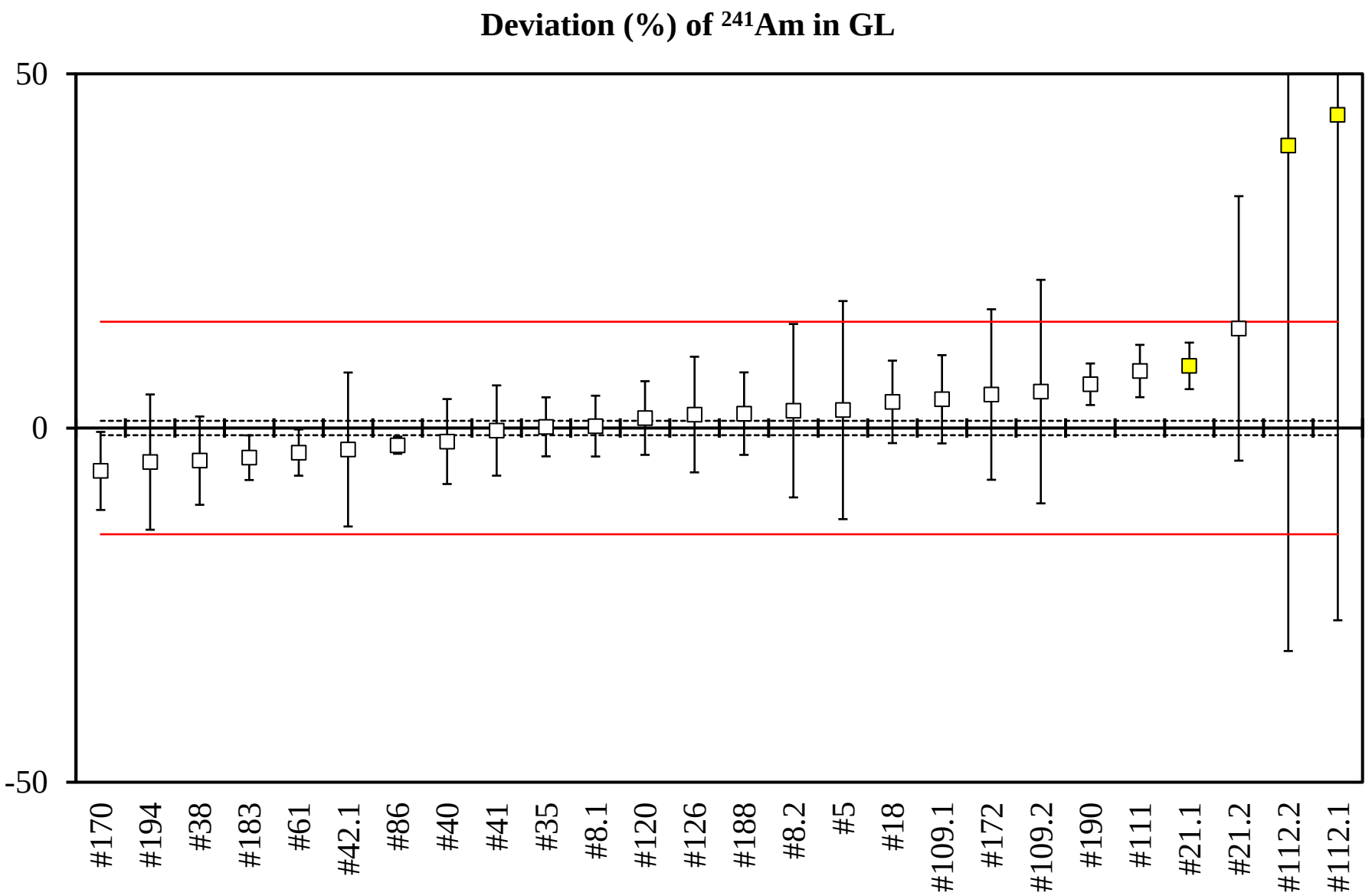
8. GAMMA LOW (GL) DEVIATION PLOTS


Deviation (%) of 54Mn in GL
50
0
-50
#112.2
#112.1
#8.1
#170
#8.2
#5
#86
#38
#183
#126
#40
#172
#188
#16
#194
#21.2
#18
#41
#109.2
#42.1
#109.1
#120
#35
#21.1
#111
#190
#61

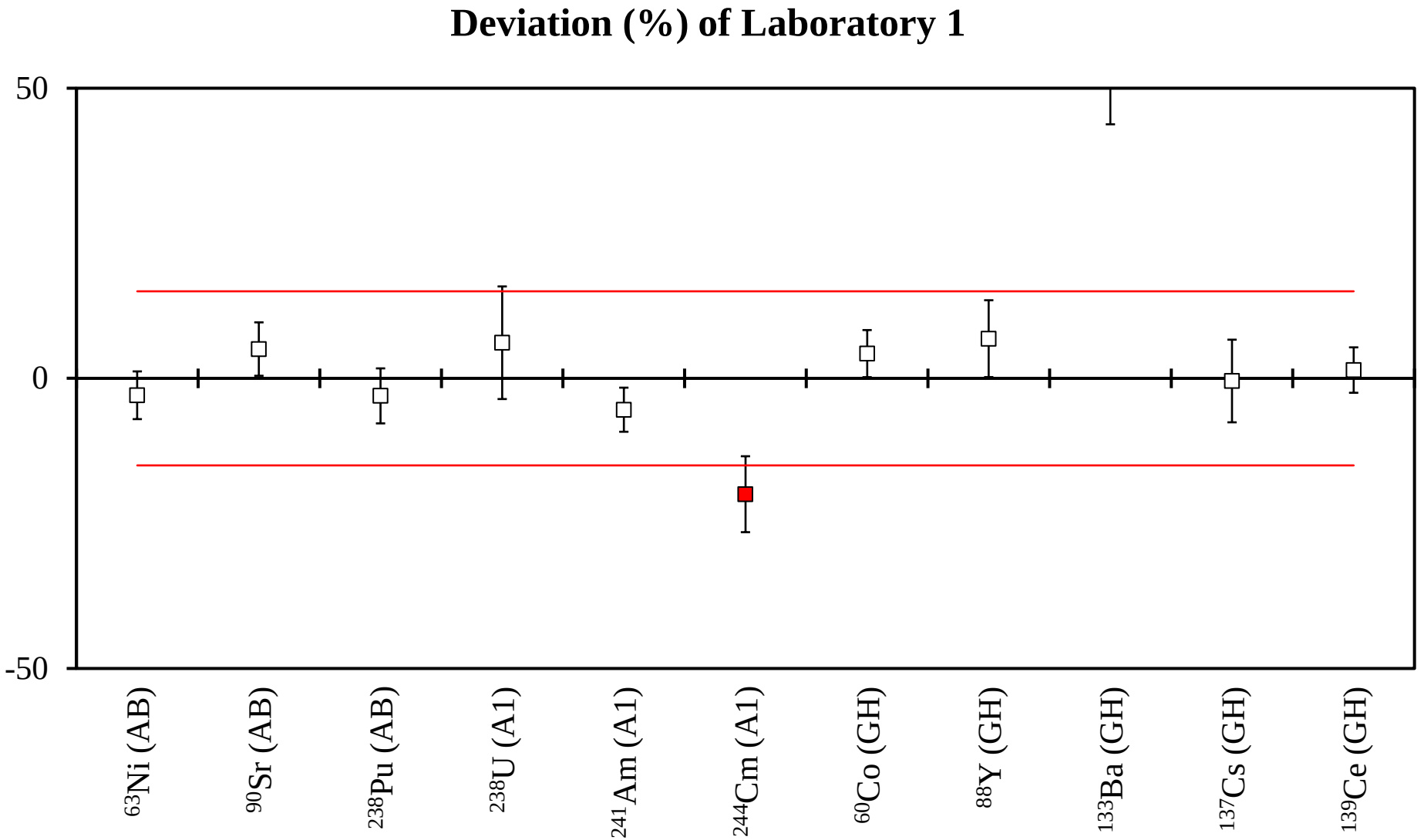

Deviation (%) of 65Zn in GL
50
0
-50
#21.2
#8.2
#61
#112.1
#8.1
#16
#188
#112.2
#183
#170
#38
#194
#86
#172
#109.1
#126
#40
#18
#41
#42.1
#120
#5
#109.2
#190
#21.1
#35
#111


Deviation (%) of 134Cs in GL
50
0
-50
#112.2
#21.2
#112.1
#42.1
#109.1
#172
#41
#194
#170
#126
#40
#86
#38
#8.1
#35
#188
#18
#120
#16
#5
#8.2
#111
#21.1
#109.2
#61
#183
#190

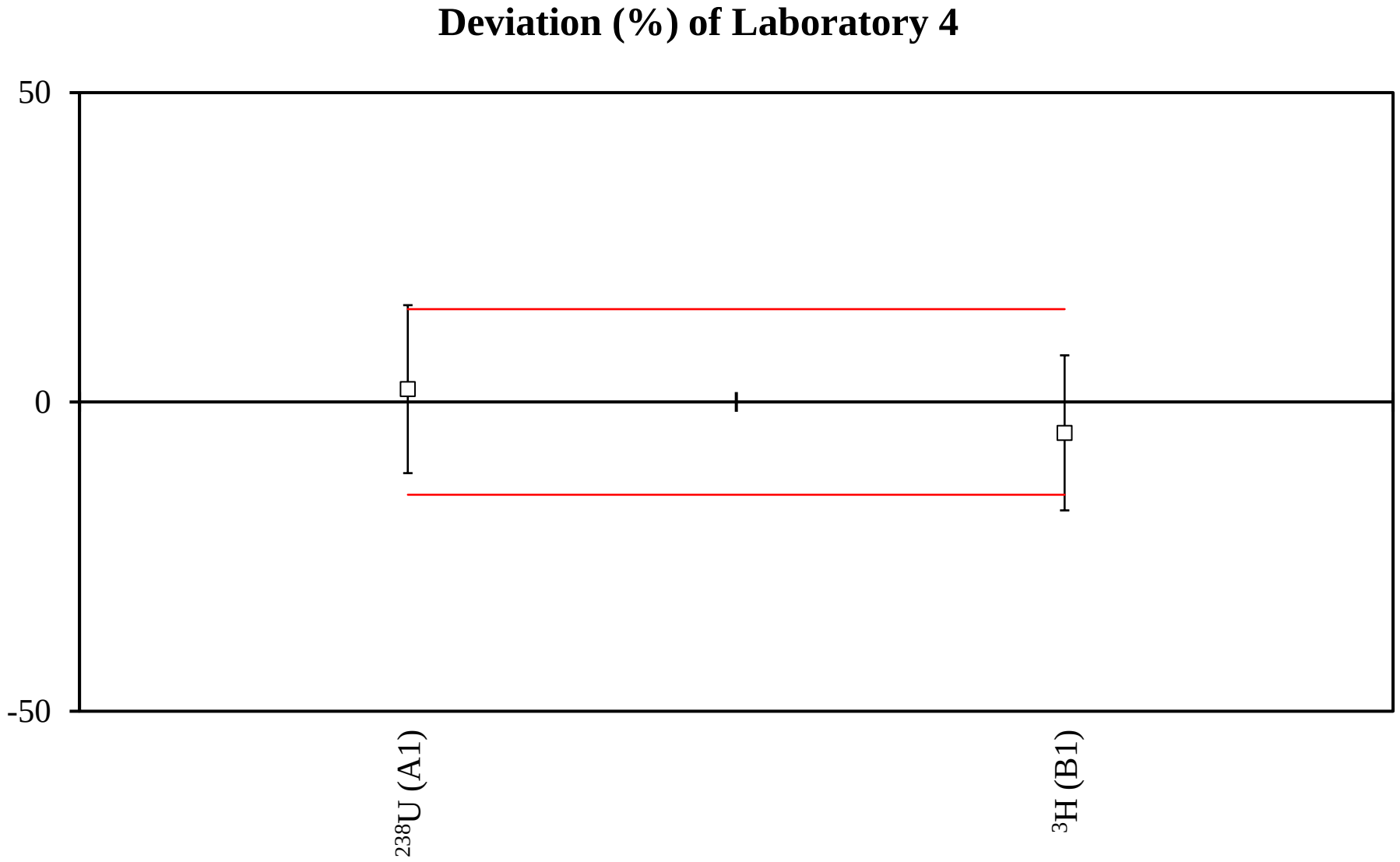

Deviation (%) of 210Pb in GL
50
0
-50
#190
#183
#188
#38
#61
#109.2
#41
#109.1
#170
#18
#40
#8.1
#126
#21.1
#86
#111
#194
#8.2
#112.1
#112.2


Deviation (%) of 241Am in GL
50
0
-50
#170
#194
#38
#183
#61
#42.1
#86
#40
#41
#35
#8.1
#120
#126
#188
#8.2
#5
#18
#109.1
#172
#109.2
#190
#111
#21.1
#21.2
#112.2
#112.1

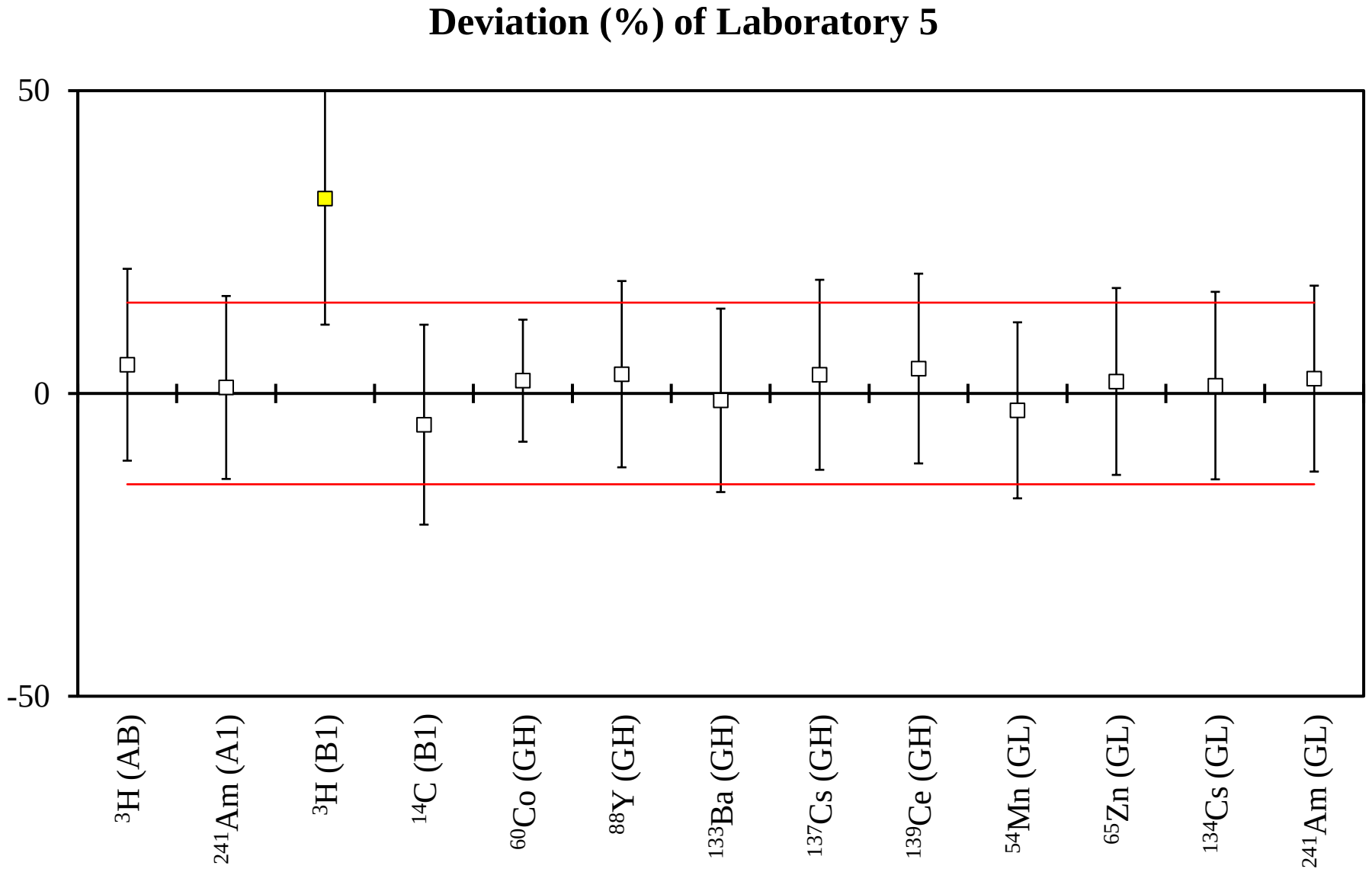
9. DEVIATION PLOTS AND TABULATED RESULTS ARRANGED BY LAB NUMBER


Deviation (%) of Laboratory 1
50
0
-50
63Ni (AB)
90Sr (AB)
238Pu (AB)
238U (A1)
241Am (A1)
244Cm (A1)
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)

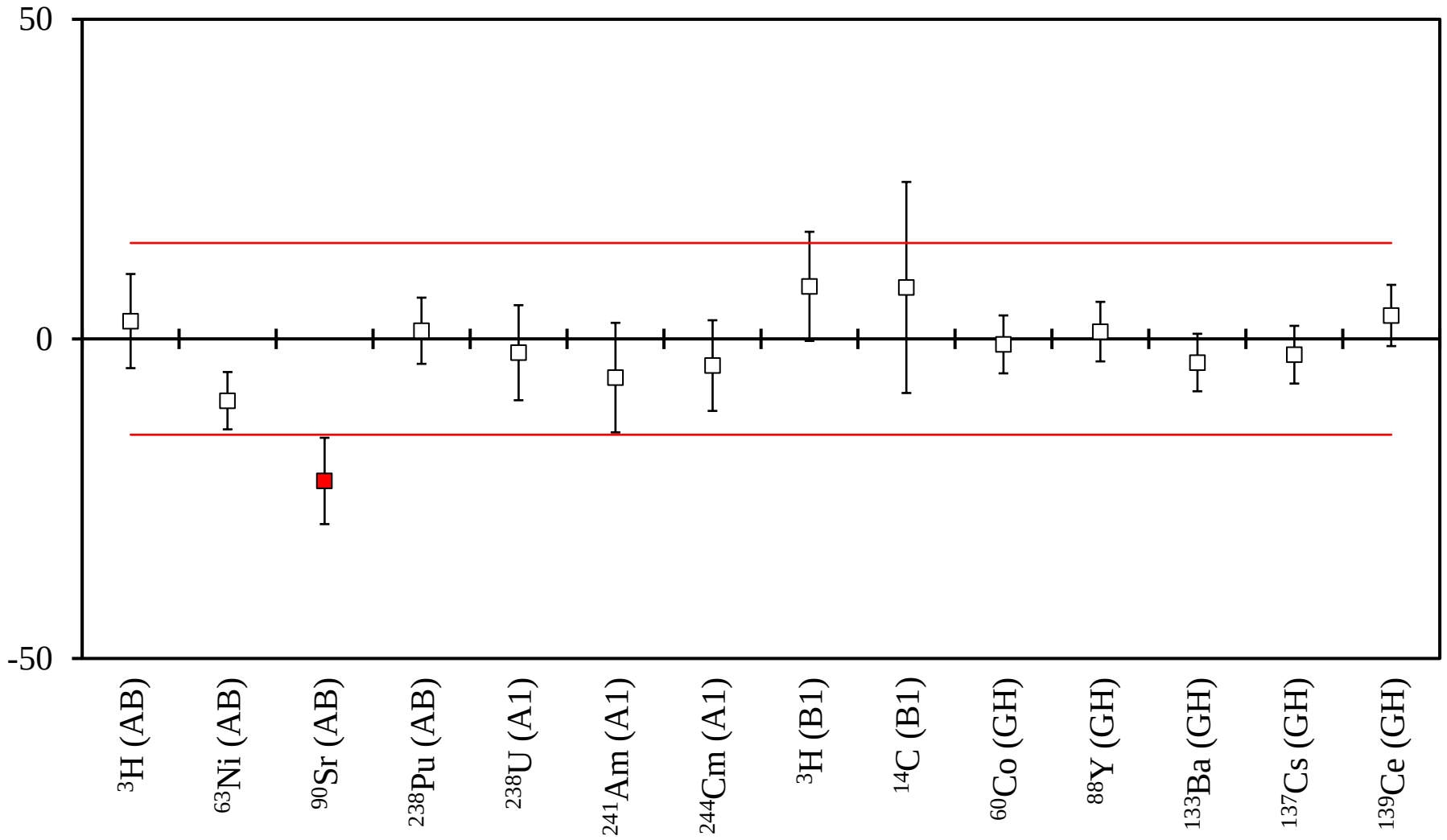
Radionuclide	Laboratory 1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{63}Ni (AB)	7.33 ± 0.30	7.550 ± 0.083	− 3.0	− 0.71	− 0.51
^{90}Sr (AB)	3.89 ± 0.17	3.703 ± 0.011	5.1	1.09	0.87
^{238}Pu (AB)	13.33 ± 0.65	13.745 ± 0.046	− 3.0	− 0.63	− 0.51
^{238}U (A1)	6.52 ± 0.59	6.143 ± 0.080	6.1	0.63	1.05
^{241}Am (A1)	20.14 ± 0.75	21.29 ± 0.32	− 5.4	− 1.42	− 0.93
^{244}Cm (A1)	14.7 ± 1.2	18.367 ± 0.082	− 19.7	− 3.12	− 3.39
^{60}Co (GH)	21.75 ± 0.84	20.86 ± 0.10	4.3	1.05	0.73
^{88}Y (GH)	14.60 ± 0.90	13.665 ± 0.088	6.8	1.03	1.18
^{133}Ba (GH)	13.29 ± 0.92	8.598 ± 0.075	54.6	5.08	9.37
^{137}Cs (GH)	19.7 ± 1.4	19.79 ± 0.16	− 0.5	− 0.06	− 0.08
^{139}Ce (GH)	45.4 ± 1.7	44.76 ± 0.42	1.5	0.37	0.25


Deviation (%) of Laboratory 4
50
0
-50
238U (A1)
3H (B1)

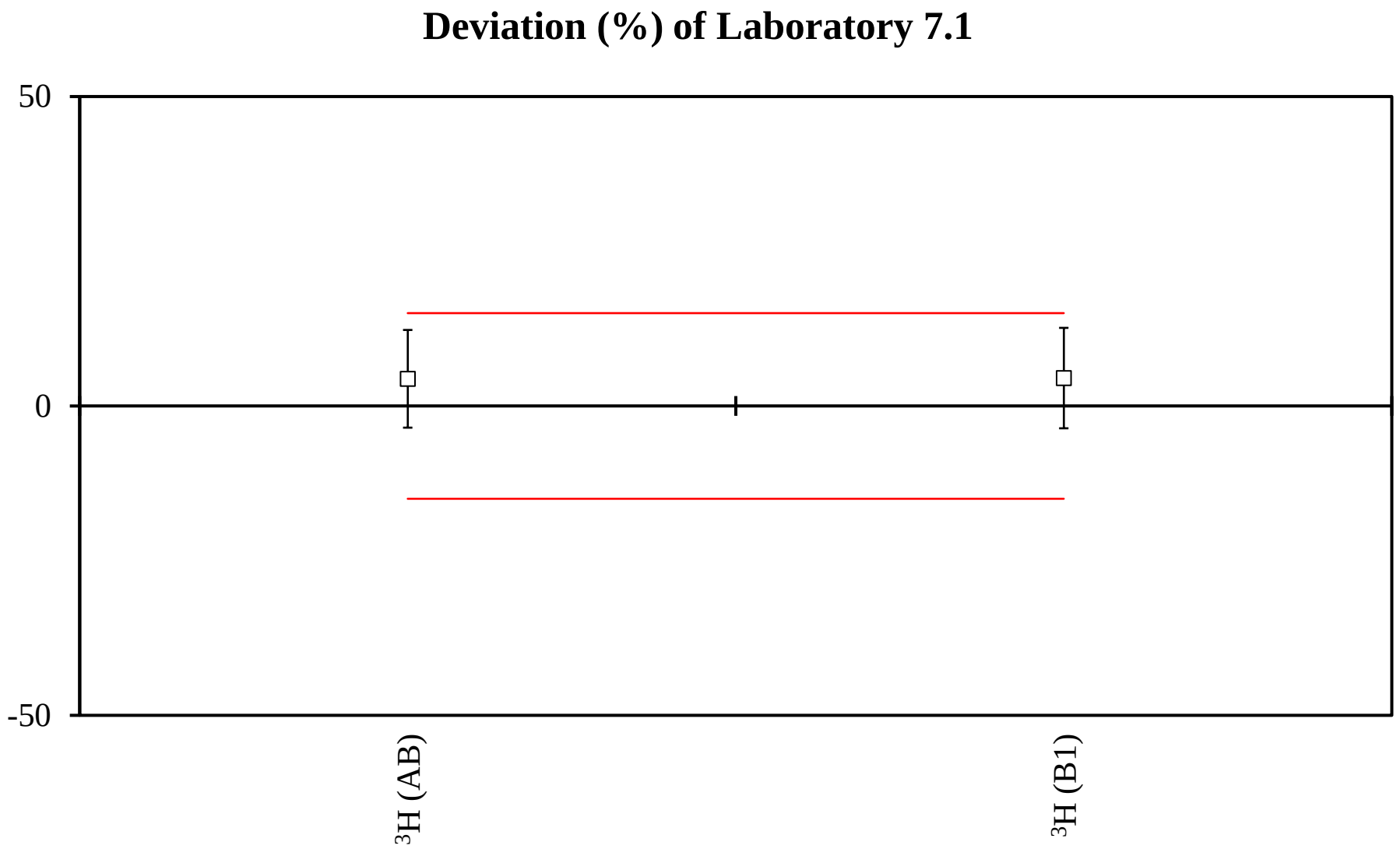
Radionuclide	Laboratory 4	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{238}U (A1)	6.27 ± 0.83	6.143 ± 0.080	2.1	0.16	0.36
^{3}H (B1)	0.230 ± 0.030	0.2421 ± 0.0048	− 5.0	− 0.40	− 0.85


Deviation (%) of Laboratory 5
50
0
-50
3H (AB)
241Am (A1)
3H (B1)
14C (B1)
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)
54Mn (GL)
65Zn (GL)
134Cs (GL)
241Am (GL)

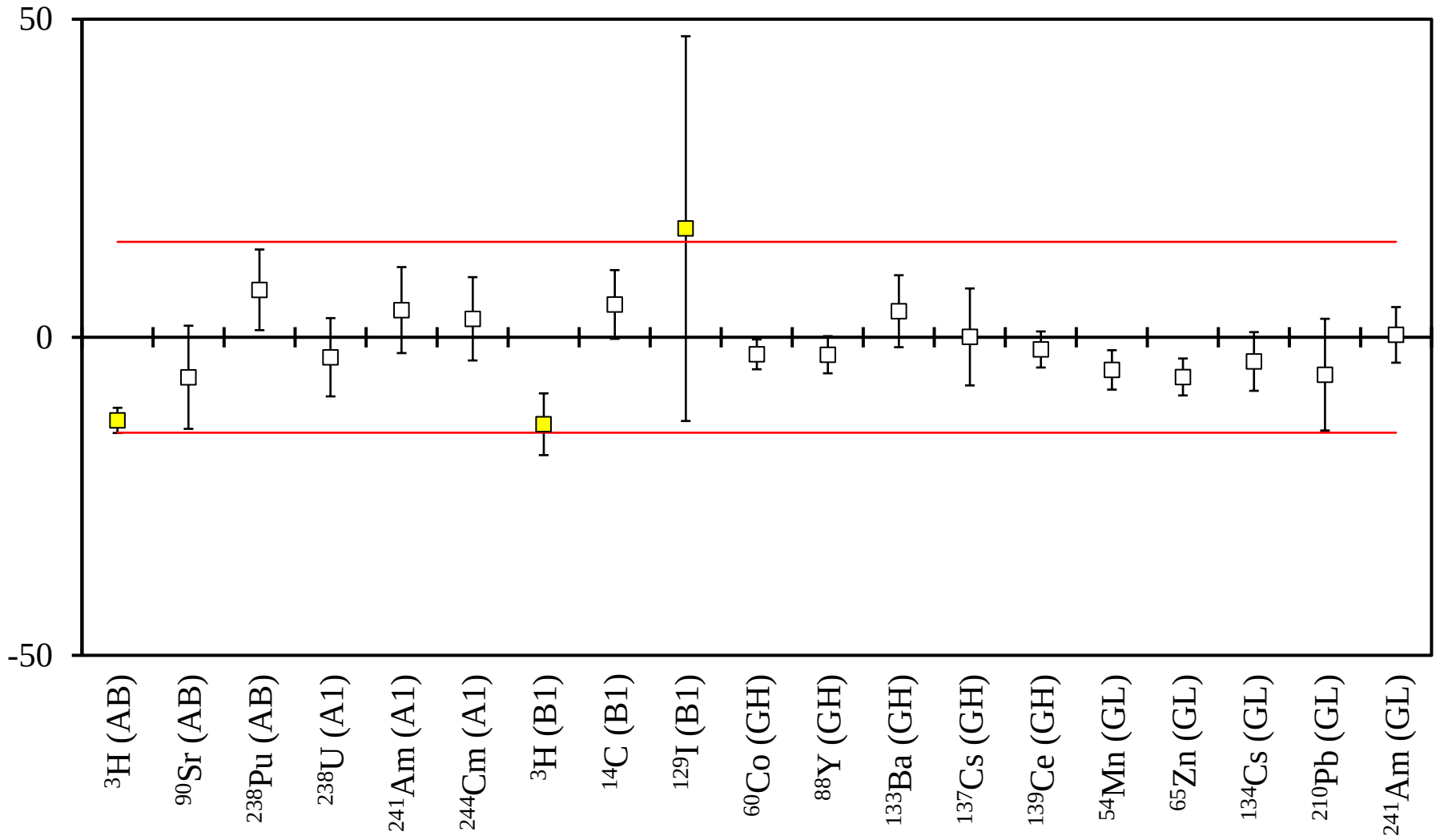
Radionuclide	Laboratory 5	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	5.90 ± 0.89	5.633 ± 0.061	4.7	0.30	0.81
^{241}Am (A1)	21.5 ± 3.2	21.29 ± 0.32	0.8	0.06	0.15
^{3}H (B1)	0.320 ± 0.050	0.2421 ± 0.0048	32.2	1.55	5.53
^{14}C (B1)	0.230 ± 0.040	0.2425 ± 0.0015	− 5.2	− 0.31	− 0.89
^{60}Co (GH)	21.3 ± 2.1	20.86 ± 0.10	1.9	0.18	0.32
^{88}Y (GH)	14.1 ± 2.1	13.665 ± 0.088	3.4	0.22	0.58
^{133}Ba (GH)	8.5 ± 1.3	8.598 ± 0.075	− 0.9	− 0.06	− 0.16
^{137}Cs (GH)	20.4 ± 3.1	19.79 ± 0.16	3.3	0.21	0.56
^{139}Ce (GH)	46.6 ± 7.0	44.76 ± 0.42	4.0	0.26	0.69
^{54}Mn (GL)	41.5 ± 6.2	42.69 ± 0.25	− 2.7	− 0.19	− 0.47
^{65}Zn (GL)	39.7 ± 6.0	38.93 ± 0.28	2.0	0.13	0.35
^{134}Cs (GL)	13.1 ± 2.0	12.932 ± 0.093	1.1	0.08	0.20
^{241}Am (GL)	49.4 ± 7.4	48.22 ± 0.19	2.5	0.16	0.43


Deviation (%) of Laboratory 7
50
0
-50
3H (AB)
63Ni (AB)
90Sr (AB)
238Pu (AB)
238U (A1)
241Am (A1)
244Cm (A1)
3H (B1)
14C (B1)
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)

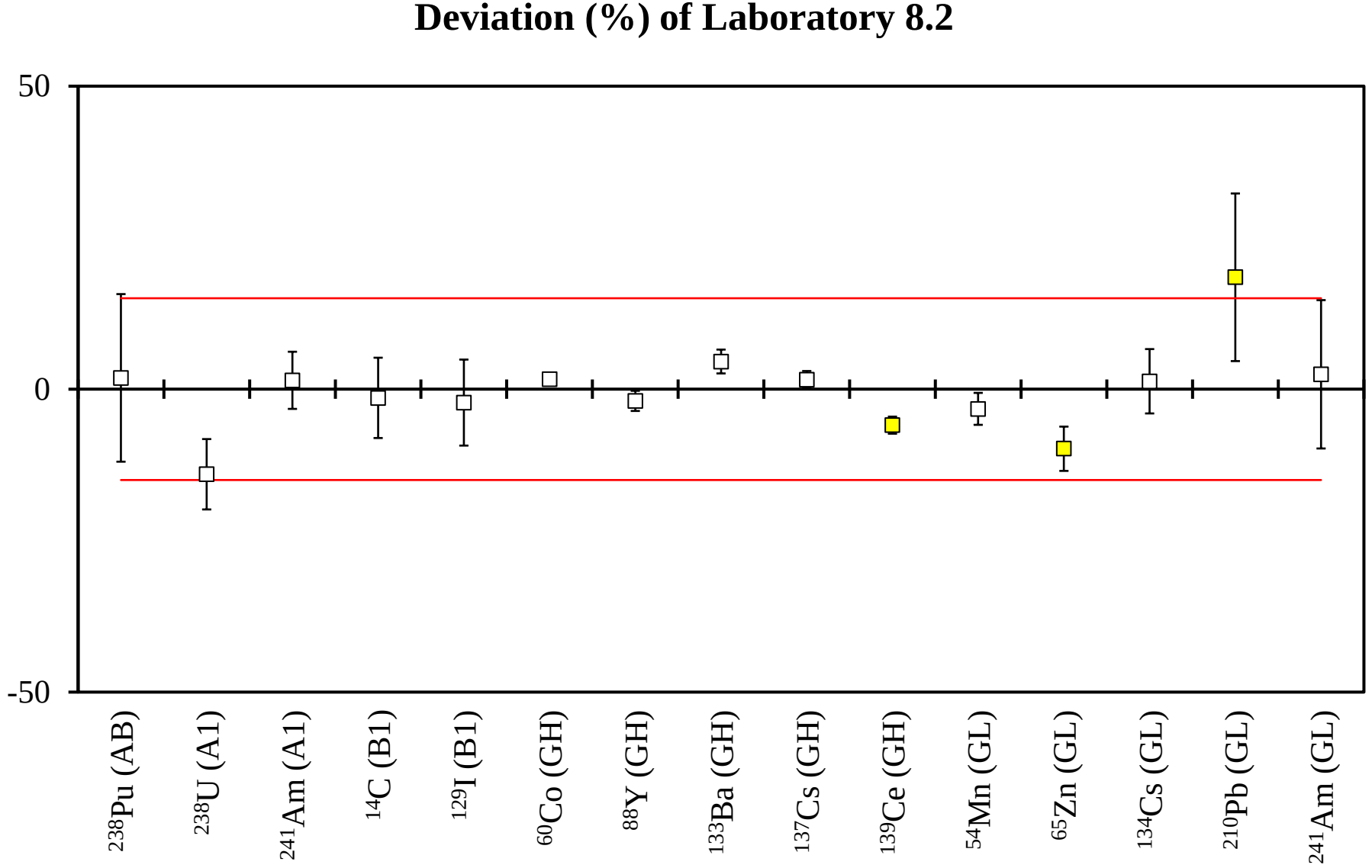
Radionuclide	Laboratory 7	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	5.79 ± 0.41	5.633 ± 0.061	2.7	0.38	0.47
^{63}Ni (AB)	6.82 ± 0.33	7.550 ± 0.083	− 9.7	− 2.13	− 1.66
^{90}Sr (AB)	2.88 ± 0.25	3.703 ± 0.011	− 22.2	− 3.29	− 3.81
^{238}Pu (AB)	13.92 ± 0.71	13.745 ± 0.046	1.3	0.25	0.22
^{238}U (A1)	6.01 ± 0.45	6.143 ± 0.080	− 2.2	− 0.30	− 0.38
^{241}Am (A1)	20.0 ± 1.8	21.29 ± 0.32	− 5.9	− 0.68	− 1.02
^{244}Cm (A1)	17.6 ± 1.3	18.367 ± 0.082	− 4.0	− 0.55	− 0.69
^{3}H (B1)	0.262 ± 0.020	0.2421 ± 0.0048	8.4	0.98	1.45
^{14}C (B1)	0.262 ± 0.040	0.2425 ± 0.0015	8.2	0.49	1.41
^{60}Co (GH)	20.68 ± 0.94	20.86 ± 0.10	− 0.8	− 0.19	− 0.14
^{88}Y (GH)	13.82 ± 0.63	13.665 ± 0.088	1.1	0.24	0.19
^{133}Ba (GH)	8.28 ± 0.38	8.598 ± 0.075	− 3.7	− 0.83	− 0.64
^{137}Cs (GH)	19.30 ± 0.88	19.79 ± 0.16	− 2.5	− 0.55	− 0.43
^{139}Ce (GH)	46.4 ± 2.1	44.76 ± 0.42	3.6	0.74	0.61


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

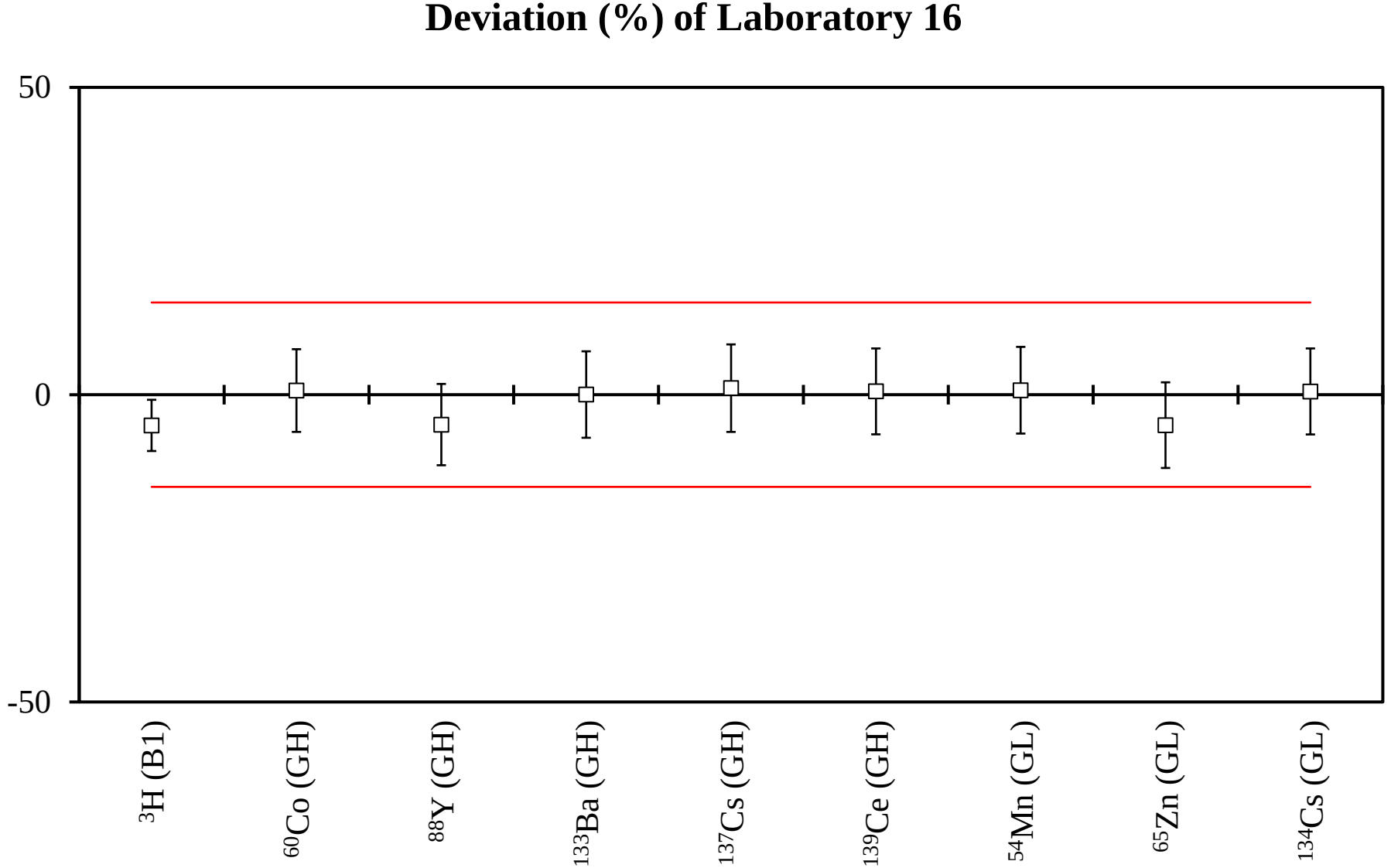
Radionuclide	Laboratory 7.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	5.88 ± 0.44	5.633 ± 0.061	4.4	0.55	0.75
^{3}H (B1)	0.253 ± 0.019	0.2421 ± 0.0048	4.6	0.56	0.78


Deviation (%) of Laboratory 8.1
50
0
-50
3H (AB)
90Sr (AB)
238Pu (AB)
238U (A1)
241Am (A1)
244Cm (A1)
3H (B1)
14C (B1)
129I (B1)
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)
54Mn (GL)
65Zn (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

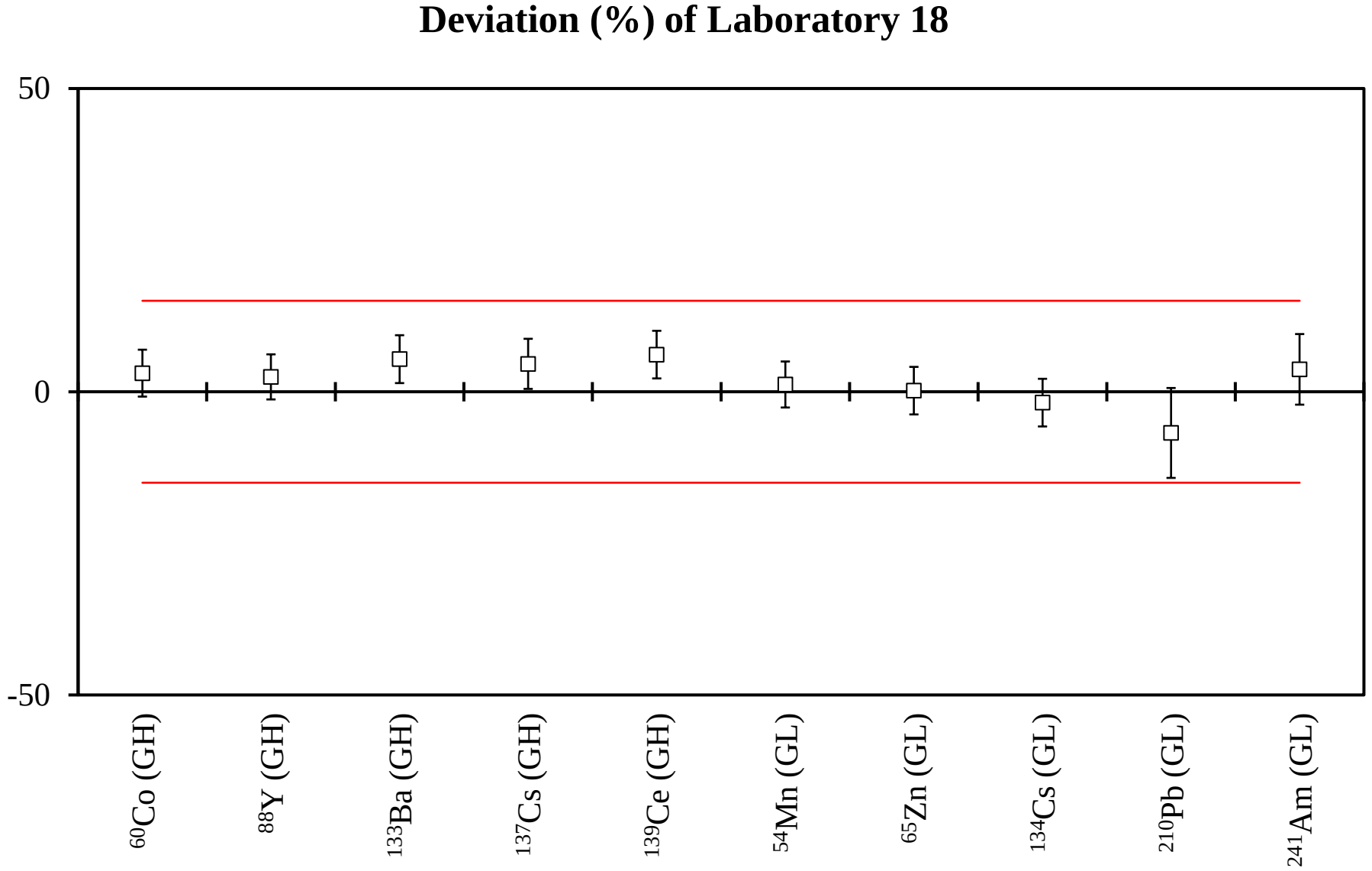
Radionuclide	Laboratory 8.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	4.897 ± 0.098	5.633 ± 0.061	− 13.1	− 6.38	− 2.24
^{90}Sr (AB)	3.47 ± 0.30	3.703 ± 0.011	− 6.3	− 0.78	− 1.08
^{238}Pu (AB)	14.77 ± 0.87	13.745 ± 0.046	7.5	1.18	1.28
^{238}U (A1)	5.95 ± 0.37	6.143 ± 0.080	− 3.1	− 0.51	− 0.54
^{241}Am (A1)	22.2 ± 1.4	21.29 ± 0.32	4.3	0.63	0.73
^{244}Cm (A1)	18.9 ± 1.2	18.367 ± 0.082	2.8	0.41	0.48
^{3}H (B1)	0.209 ± 0.011	0.2421 ± 0.0048	− 13.7	− 2.76	− 2.35
^{14}C (B1)	0.255 ± 0.013	0.2425 ± 0.0015	5.2	0.96	0.89
^{129}I (B1)	0.182 ± 0.047	0.15545 ± 0.00091	17.1	0.56	2.93
^{60}Co (GH)	20.30 ± 0.48	20.86 ± 0.10	− 2.7	− 1.14	− 0.46
^{88}Y (GH)	13.29 ± 0.39	13.665 ± 0.088	− 2.7	− 0.94	− 0.47
^{133}Ba (GH)	8.95 ± 0.48	8.598 ± 0.075	4.1	0.72	0.70
^{137}Cs (GH)	19.8 ± 1.5	19.79 ± 0.16	0.1	0.01	0.02
^{139}Ce (GH)	43.9 ± 1.2	44.76 ± 0.42	− 2.0	− 0.72	− 0.34
^{54}Mn (GL)	40.5 ± 1.3	42.69 ± 0.25	− 5.1	− 1.66	− 0.87
^{65}Zn (GL)	36.5 ± 1.1	38.93 ± 0.28	− 6.3	− 2.10	− 1.08
^{134}Cs (GL)	12.44 ± 0.59	12.932 ± 0.093	− 3.8	− 0.82	− 0.65
^{210}Pb (GL)	20.5 ± 1.9	21.78 ± 0.23	− 6.0	− 0.68	− 1.03
^{241}Am (GL)	48.4 ± 2.1	48.22 ± 0.19	0.3	0.06	0.05


Deviation (%) of Laboratory 8.2
50
0
-50
238Pu (AB)
238U (A1)
241Am (A1)
14C (B1)
129I (B1)
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)
54Mn (GL)
65Zn (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

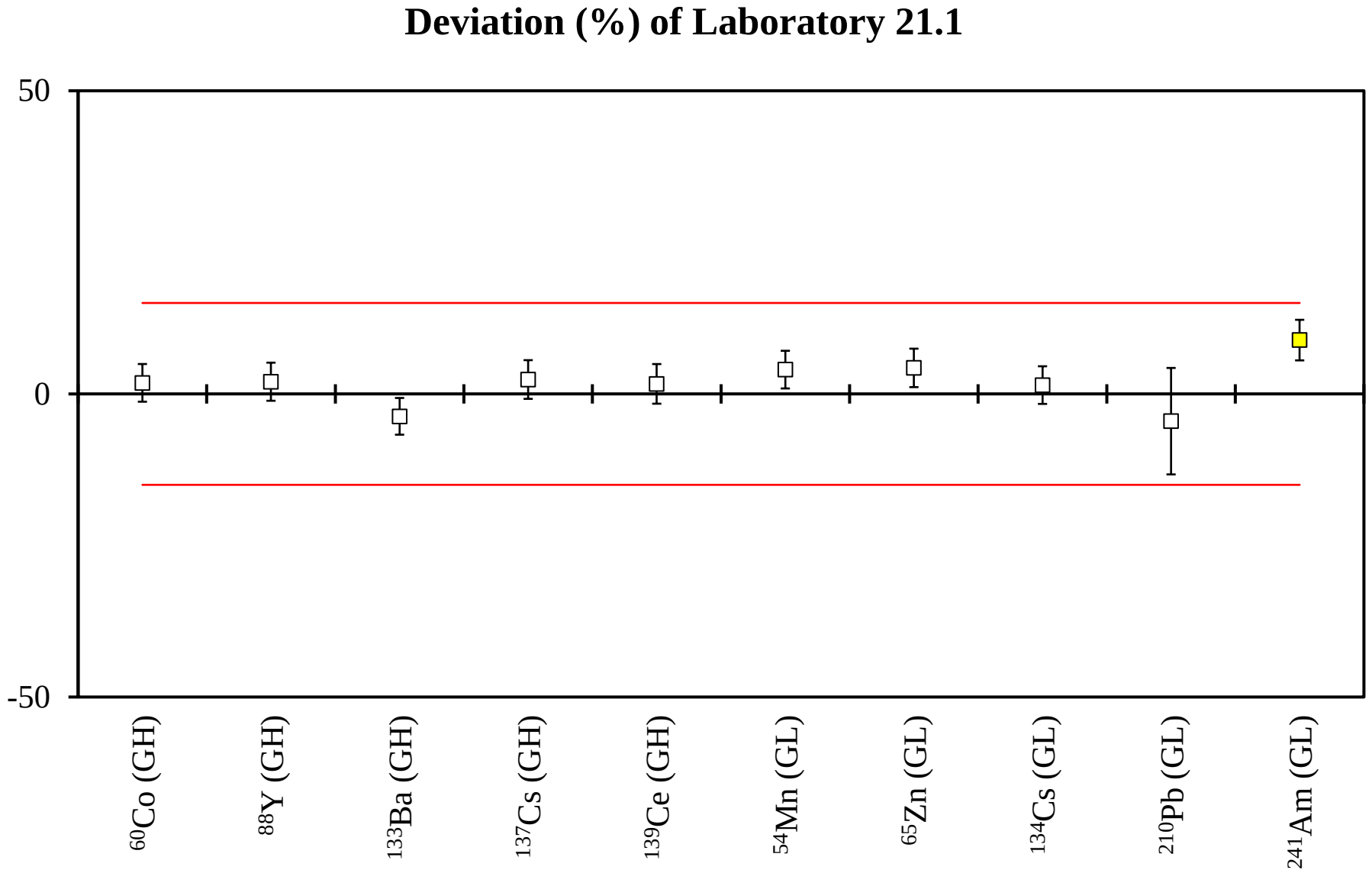
Radionuclide	Laboratory 8.2	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{238}Pu (AB)	14.0 ± 1.9	13.745 ± 0.046	1.9	0.13	0.32
^{238}U (A1)	5.28 ± 0.35	6.143 ± 0.080	− 14.0	− 2.40	− 2.41
^{241}Am (A1)	21.60 ± 0.95	21.29 ± 0.32	1.5	0.31	0.25
^{14}C (B1)	0.239 ± 0.016	0.2425 ± 0.0015	− 1.4	− 0.22	− 0.25
^{129}I (B1)	0.152 ± 0.011	0.15545 ± 0.00091	− 2.0	− 0.28	− 0.35
^{60}Co (GH)	21.20 ± 0.16	20.86 ± 0.10	1.6	1.77	0.28
^{88}Y (GH)	13.40 ± 0.21	13.665 ± 0.088	− 1.9	− 1.18	− 0.33
^{133}Ba (GH)	8.99 ± 0.15	8.598 ± 0.075	4.6	2.33	0.78
^{137}Cs (GH)	20.10 ± 0.23	19.79 ± 0.16	1.6	1.10	0.27
^{139}Ce (GH)	42.10 ± 0.49	44.76 ± 0.42	− 5.9	− 4.13	− 1.02
^{54}Mn (GL)	41.3 ± 1.1	42.69 ± 0.25	− 3.3	− 1.20	− 0.56
^{65}Zn (GL)	35.1 ± 1.4	38.93 ± 0.28	− 9.8	− 2.74	− 1.69
^{134}Cs (GL)	13.10 ± 0.68	12.932 ± 0.093	1.3	0.24	0.22
^{210}Pb (GL)	25.8 ± 3.0	21.78 ± 0.23	18.5	1.33	3.17
^{241}Am (GL)	49.4 ± 5.9	48.22 ± 0.19	2.4	0.20	0.42


Deviation (%) of Laboratory 16
50
0
-50
3H (B1)
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)
54Mn (GL)
65Zn (GL)
134Cs (GL)

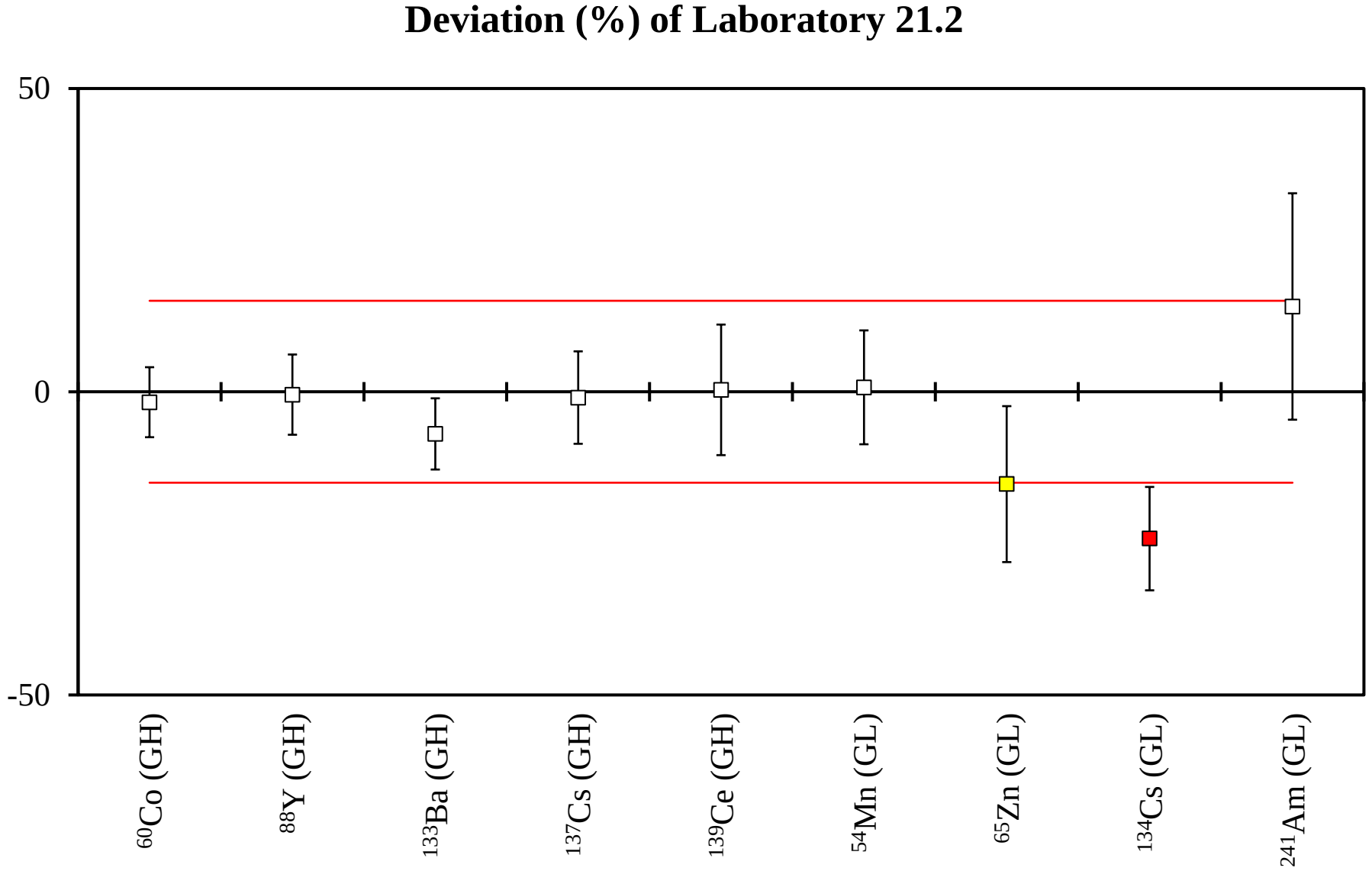
Radionuclide	Laboratory 16	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.230 ± 0.009	0.2421 ± 0.0048	− 5.0	− 1.19	− 0.86
^{60}Co (GH)	21.0 ± 1.4	20.86 ± 0.10	0.7	0.10	0.12
^{88}Y (GH)	13.00 ± 0.90	13.665 ± 0.088	− 4.9	− 0.74	− 0.84
^{133}Ba (GH)	8.6 ± 0.6	8.598 ± 0.075	0.0	0.00	0.00
^{137}Cs (GH)	20.0 ± 1.4	19.79 ± 0.16	1.1	0.15	0.18
^{139}Ce (GH)	45.0 ± 3.1	44.76 ± 0.42	0.5	0.08	0.09
^{54}Mn (GL)	43.0 ± 3.0	42.69 ± 0.25	0.7	0.10	0.12
^{65}Zn (GL)	37.0 ± 2.7	38.93 ± 0.28	− 5.0	− 0.71	− 0.85
^{134}Cs (GL)	13.00 ± 0.90	12.932 ± 0.093	0.5	0.08	0.09


Deviation (%) of Laboratory 18
50
0
-50
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)
54Mn (GL)
65Zn (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

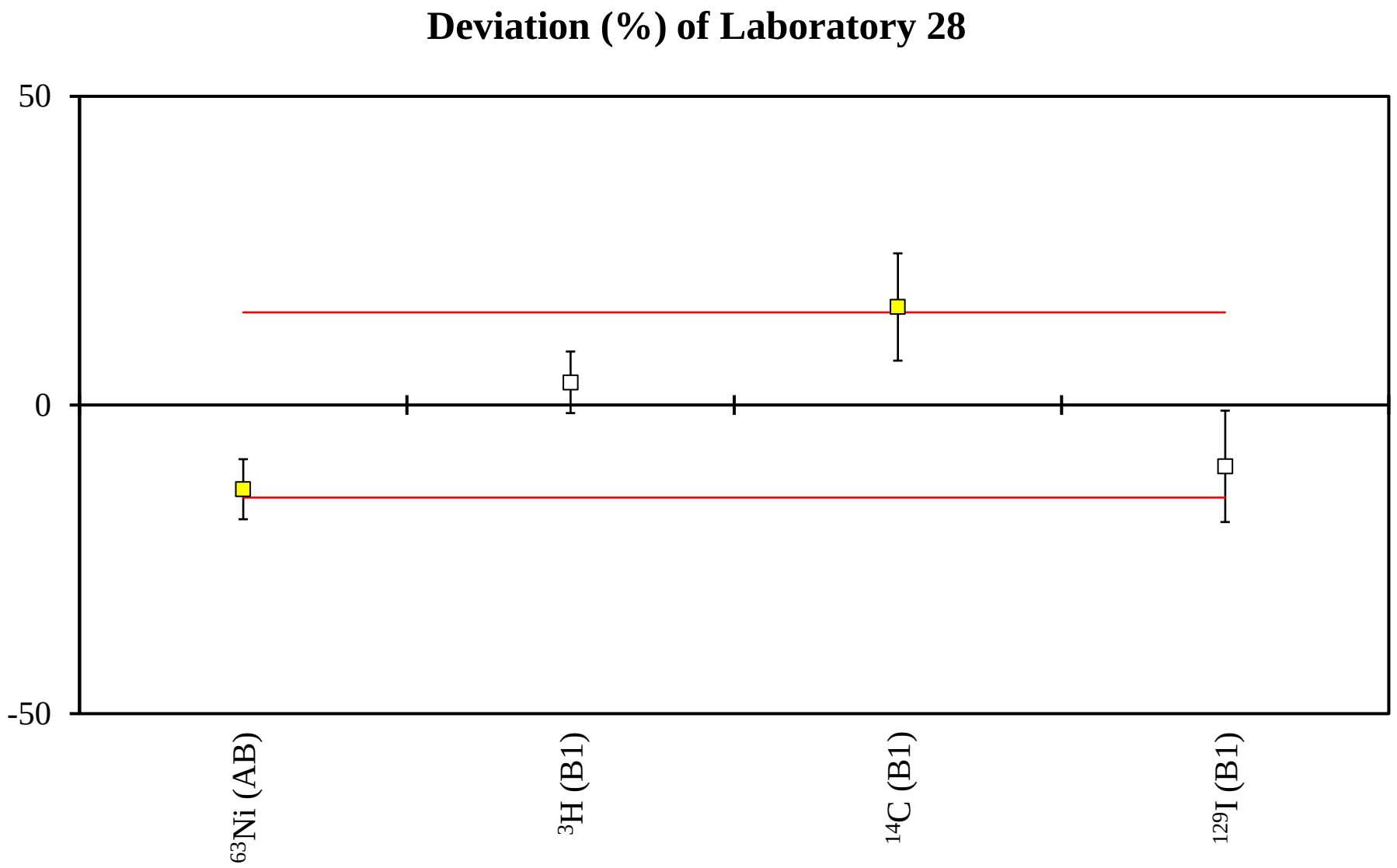
Radionuclide	Laboratory 18	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{60}Co (GH)	21.50 ± 0.80	20.86 ± 0.10	3.1	0.79	0.53
^{88}Y (GH)	14.00 ± 0.50	13.665 ± 0.088	2.5	0.66	0.42
^{133}Ba (GH)	9.06 ± 0.33	8.598 ± 0.075	5.4	1.37	0.92
^{137}Cs (GH)	20.70 ± 0.80	19.79 ± 0.16	4.6	1.12	0.79
^{139}Ce (GH)	47.5 ± 1.7	44.76 ± 0.42	6.1	1.56	1.05
^{54}Mn (GL)	43.2 ± 1.6	42.69 ± 0.25	1.2	0.31	0.21
^{65}Zn (GL)	39.0 ± 1.5	38.93 ± 0.28	0.2	0.05	0.03
^{134}Cs (GL)	12.70 ± 0.50	12.932 ± 0.093	− 1.8	− 0.46	− 0.31
^{210}Pb (GL)	20.3 ± 1.6	21.78 ± 0.23	− 6.8	− 0.92	− 1.17
^{241}Am (GL)	50.0 ± 2.8	48.22 ± 0.19	3.7	0.63	0.63


Deviation (%) of Laboratory 21.1
50
0
-50
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)
54Mn (GL)
65Zn (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

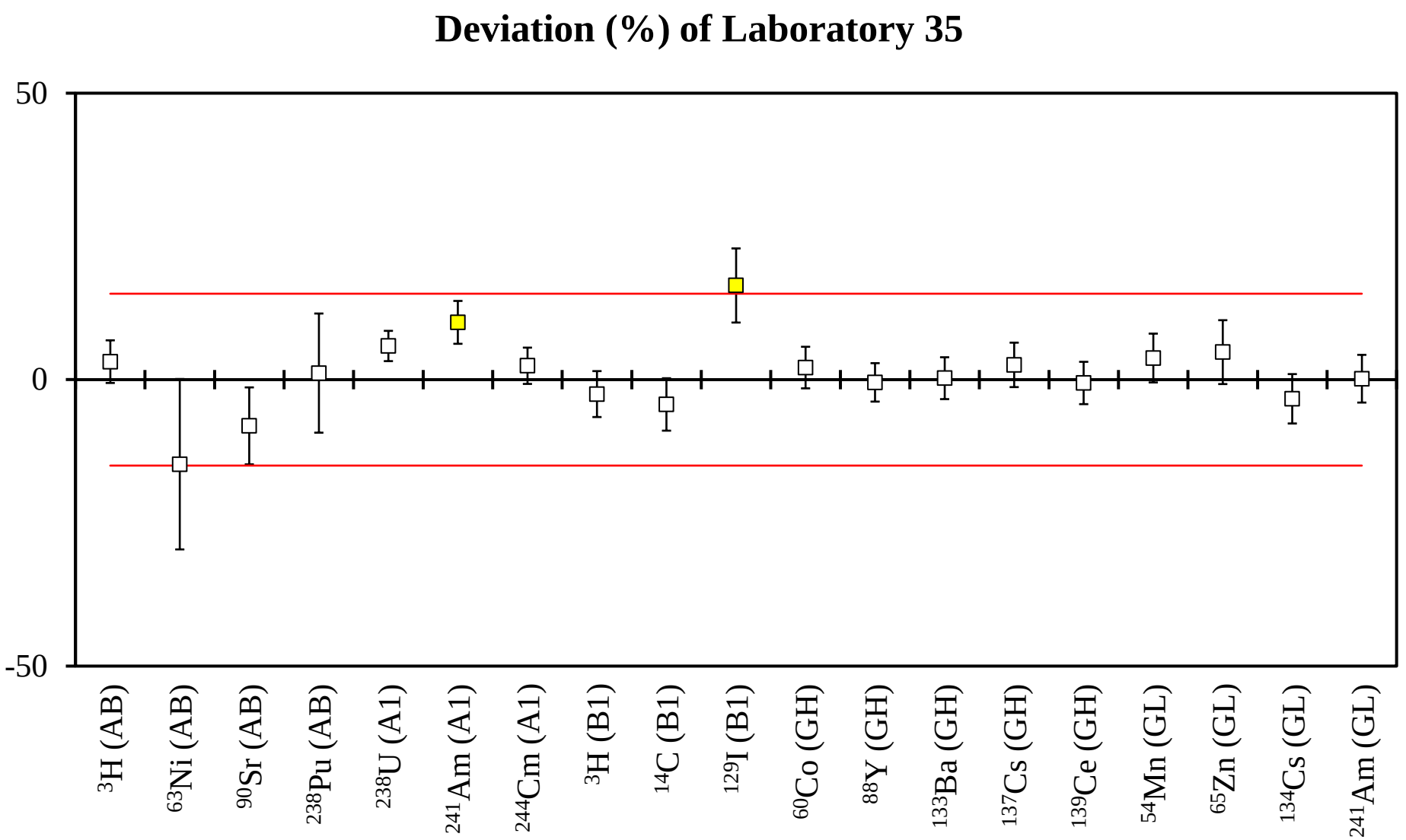
Radionuclide	Laboratory 21.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{60}Co (GH)	21.24 ± 0.64	20.86 ± 0.10	1.8	0.59	0.31
^{88}Y (GH)	13.94 ± 0.42	13.665 ± 0.088	2.0	0.64	0.35
^{133}Ba (GH)	8.28 ± 0.25	8.598 ± 0.075	− 3.7	− 1.22	− 0.64
^{137}Cs (GH)	20.26 ± 0.61	19.79 ± 0.16	2.4	0.75	0.41
^{139}Ce (GH)	45.5 ± 1.4	44.76 ± 0.42	1.7	0.52	0.29
^{54}Mn (GL)	44.4 ± 1.3	42.69 ± 0.25	4.1	1.29	0.70
^{65}Zn (GL)	40.6 ± 1.2	38.93 ± 0.28	4.4	1.37	0.75
^{134}Cs (GL)	13.12 ± 0.39	12.932 ± 0.093	1.5	0.47	0.25
^{210}Pb (GL)	20.8 ± 1.9	21.78 ± 0.23	− 4.7	− 0.53	− 0.81
^{241}Am (GL)	52.5 ± 1.6	48.22 ± 0.19	8.8	2.67	1.51


Deviation (%) of Laboratory 21.2
50
0
-50
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)
54Mn (GL)
65Zn (GL)
134Cs (GL)
241Am (GL)

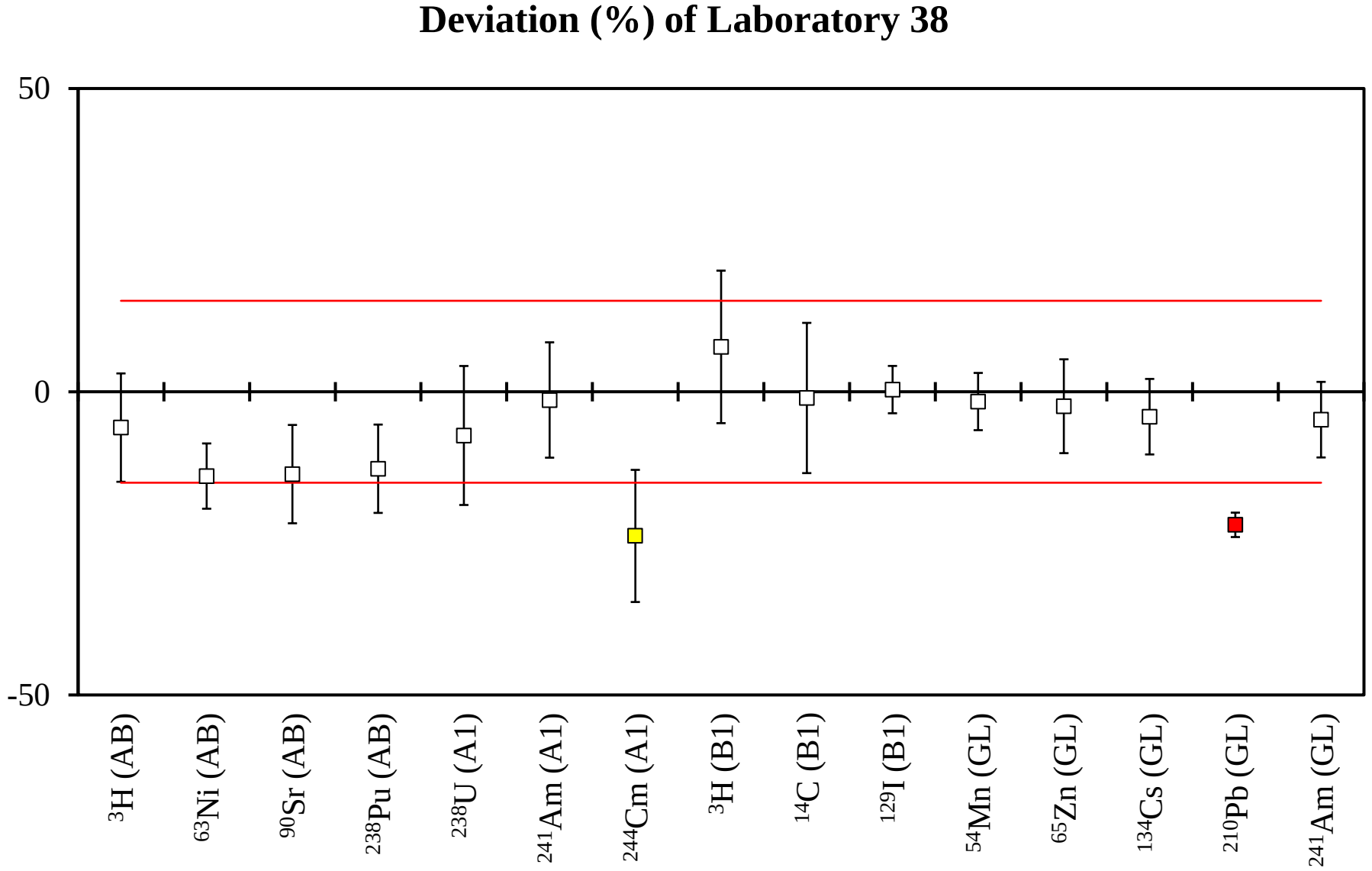
Radionuclide	Laboratory 21.2	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{60}Co (GH)	20.5 ± 1.2	20.86 ± 0.10	− 1.7	− 0.30	− 0.30
^{88}Y (GH)	13.60 ± 0.90	13.665 ± 0.088	− 0.5	− 0.07	− 0.08
^{133}Ba (GH)	8.00 ± 0.50	8.598 ± 0.075	− 7.0	− 1.18	− 1.19
^{137}Cs (GH)	19.6 ± 1.5	19.79 ± 0.16	− 1.0	− 0.13	− 0.16
^{139}Ce (GH)	44.9 ± 4.8	44.76 ± 0.42	0.3	0.03	0.05
^{54}Mn (GL)	43.0 ± 4.0	42.69 ± 0.25	0.7	0.08	0.12
^{65}Zn (GL)	33.0 ± 5.0	38.93 ± 0.28	− 15.2	− 1.18	− 2.62
^{134}Cs (GL)	9.8 ± 1.1	12.932 ± 0.093	− 24.2	− 2.84	− 4.16
^{241}Am (GL)	55.0 ± 9.0	48.22 ± 0.19	14.1	0.75	2.41


Deviation (%) of Laboratory 28
50
0
-50
63Ni (AB)
3H (B1)
14C (B1)
129I (B1)

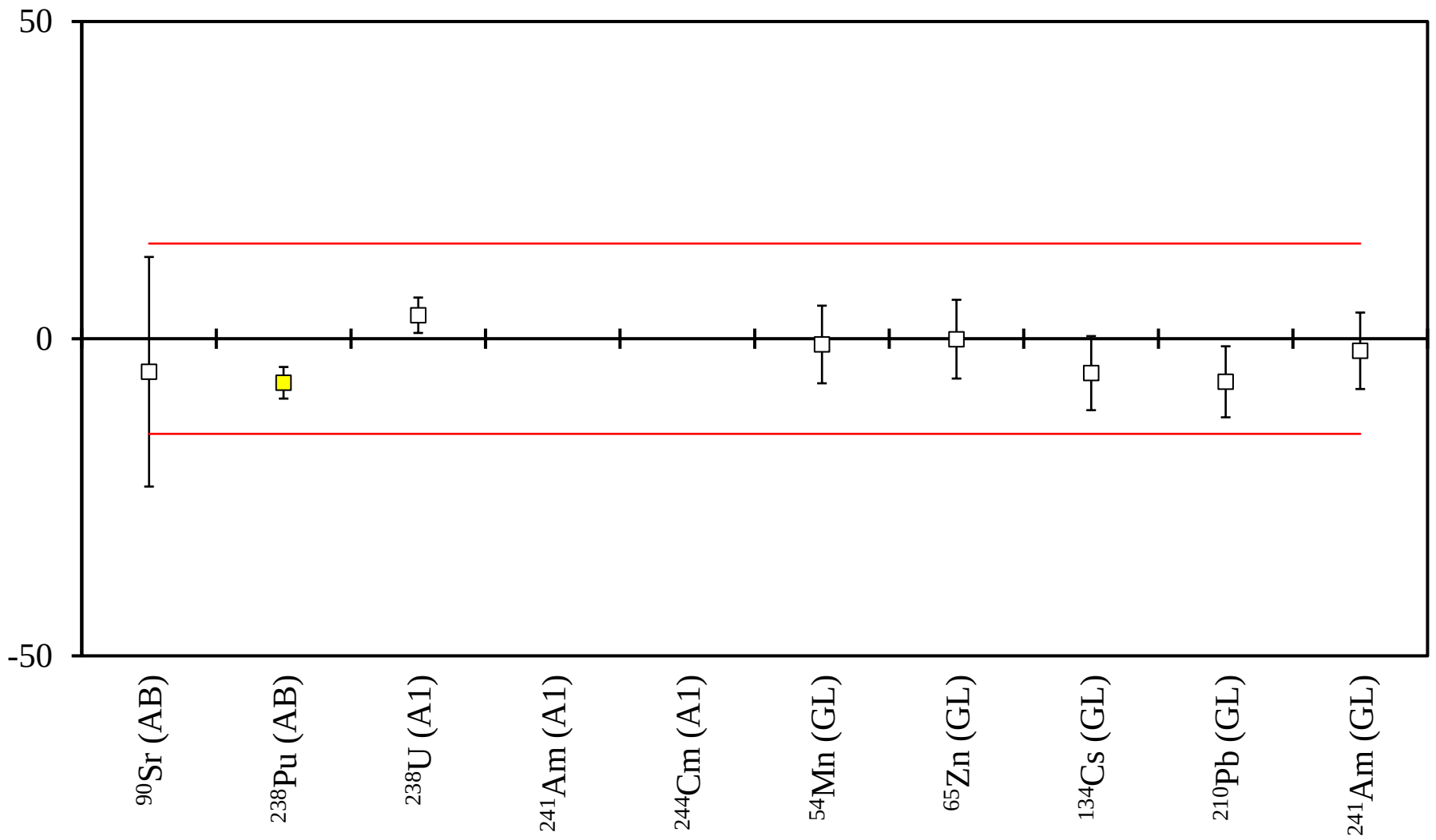
Radionuclide	Laboratory 28	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{63}Ni (AB)	6.52 ± 0.36	7.550 ± 0.083	− 13.6	− 2.79	− 2.34
^{3}H (B1)	0.251 ± 0.011	0.2421 ± 0.0048	3.7	0.74	0.63
^{14}C (B1)	0.281 ± 0.021	0.2425 ± 0.0015	15.9	1.83	2.73
^{129}I (B1)	0.140 ± 0.014	0.15545 ± 0.00091	− 9.9	− 1.10	− 1.71


Deviation (%) of Laboratory 35
50
0
-50
3H (AB)
63Ni (AB)
90Sr (AB)
238Pu (AB)
238U (A1)
241Am (A1)
244Cm (A1)
3H (B1)
14C (B1)
129I (B1)
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)
54Mn (GL)
65Zn (GL)
134Cs (GL)
241Am (GL)

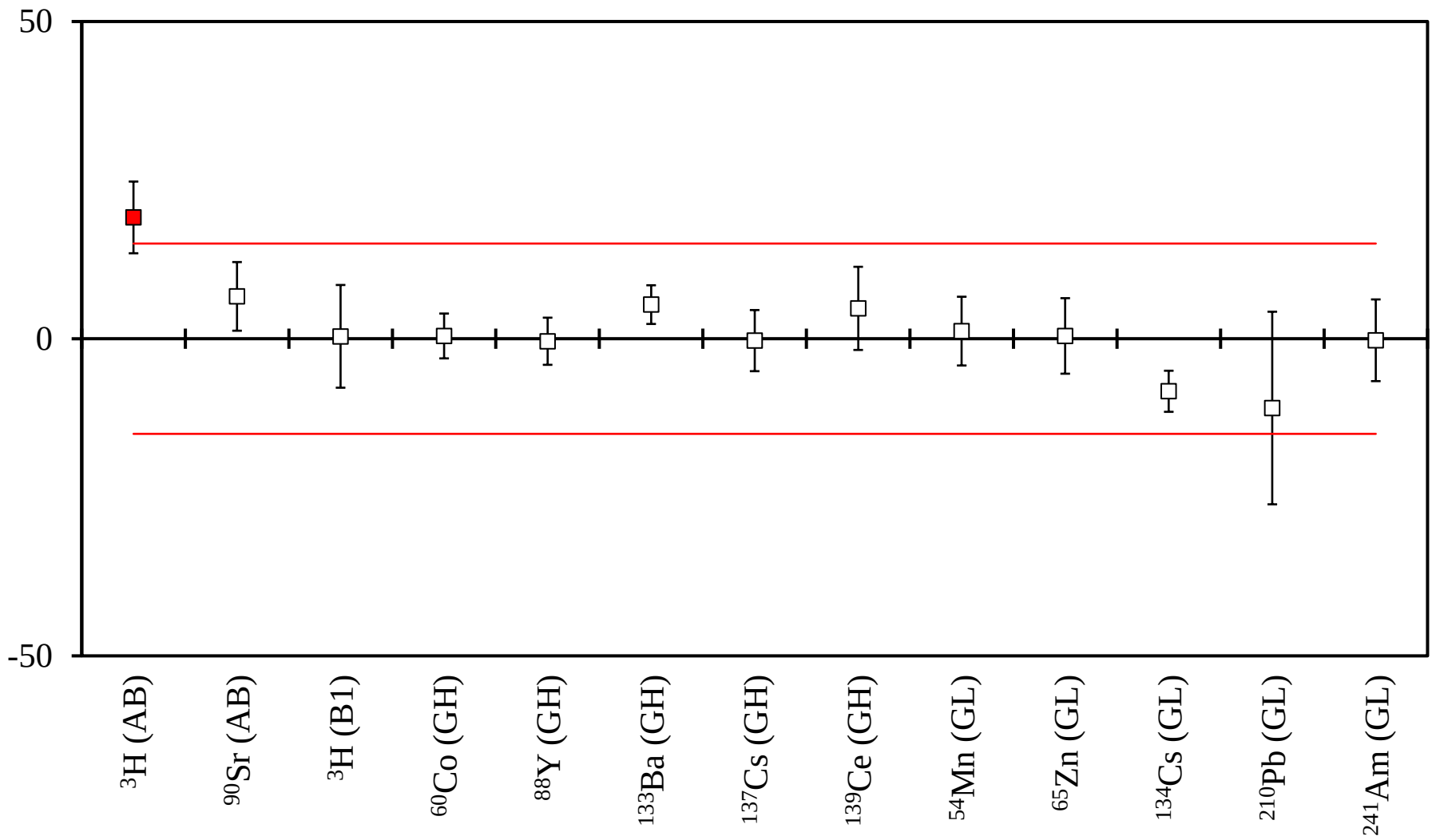
Radionuclide	Laboratory 35	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	5.81 ± 0.20	5.633 ± 0.061	3.1	0.85	0.54
^{63}Ni (AB)	6.4 ± 1.1	7.550 ± 0.083	− 14.8	− 0.99	− 2.54
^{90}Sr (AB)	3.40 ± 0.25	3.703 ± 0.011	− 8.1	− 1.20	− 1.39
^{238}Pu (AB)	13.9 ± 1.4	13.745 ± 0.046	1.1	0.11	0.20
^{238}U (A1)	6.50 ± 0.14	6.143 ± 0.080	5.9	2.26	1.01
^{241}Am (A1)	23.42 ± 0.71	21.29 ± 0.32	10.0	2.72	1.72
^{244}Cm (A1)	18.81 ± 0.58	18.367 ± 0.082	2.4	0.77	0.42
^{3}H (B1)	0.2360 ± 0.0085	0.2421 ± 0.0048	− 2.5	− 0.62	− 0.43
^{14}C (B1)	0.232 ± 0.011	0.2425 ± 0.0015	− 4.3	− 0.95	− 0.74
^{129}I (B1)	0.181 ± 0.010	0.15545 ± 0.00091	16.4	2.54	2.82
^{60}Co (GH)	21.30 ± 0.75	20.86 ± 0.10	2.1	0.58	0.36
^{88}Y (GH)	13.60 ± 0.45	13.665 ± 0.088	− 0.5	− 0.14	− 0.08
^{133}Ba (GH)	8.62 ± 0.31	8.598 ± 0.075	0.3	0.07	0.04
^{137}Cs (GH)	20.30 ± 0.75	19.79 ± 0.16	2.6	0.67	0.44
^{139}Ce (GH)	44.5 ± 1.6	44.76 ± 0.42	− 0.6	− 0.16	− 0.10
^{54}Mn (GL)	44.3 ± 1.8	42.69 ± 0.25	3.8	0.89	0.65
^{65}Zn (GL)	40.8 ± 2.2	38.93 ± 0.28	4.8	0.86	0.82
^{134}Cs (GL)	12.50 ± 0.55	12.932 ± 0.093	− 3.3	− 0.77	− 0.57
^{241}Am (GL)	48.3 ± 2.0	48.22 ± 0.19	0.2	0.04	0.03


Deviation (%) of Laboratory 38
50
0
-50
3H (AB)
63Ni (AB)
90Sr (AB)
238Pu (AB)
238U (A1)
241Am (A1)
244Cm (A1)
3H (B1)
14C (B1)
129I (B1)
54Mn (GL)
65Zn (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

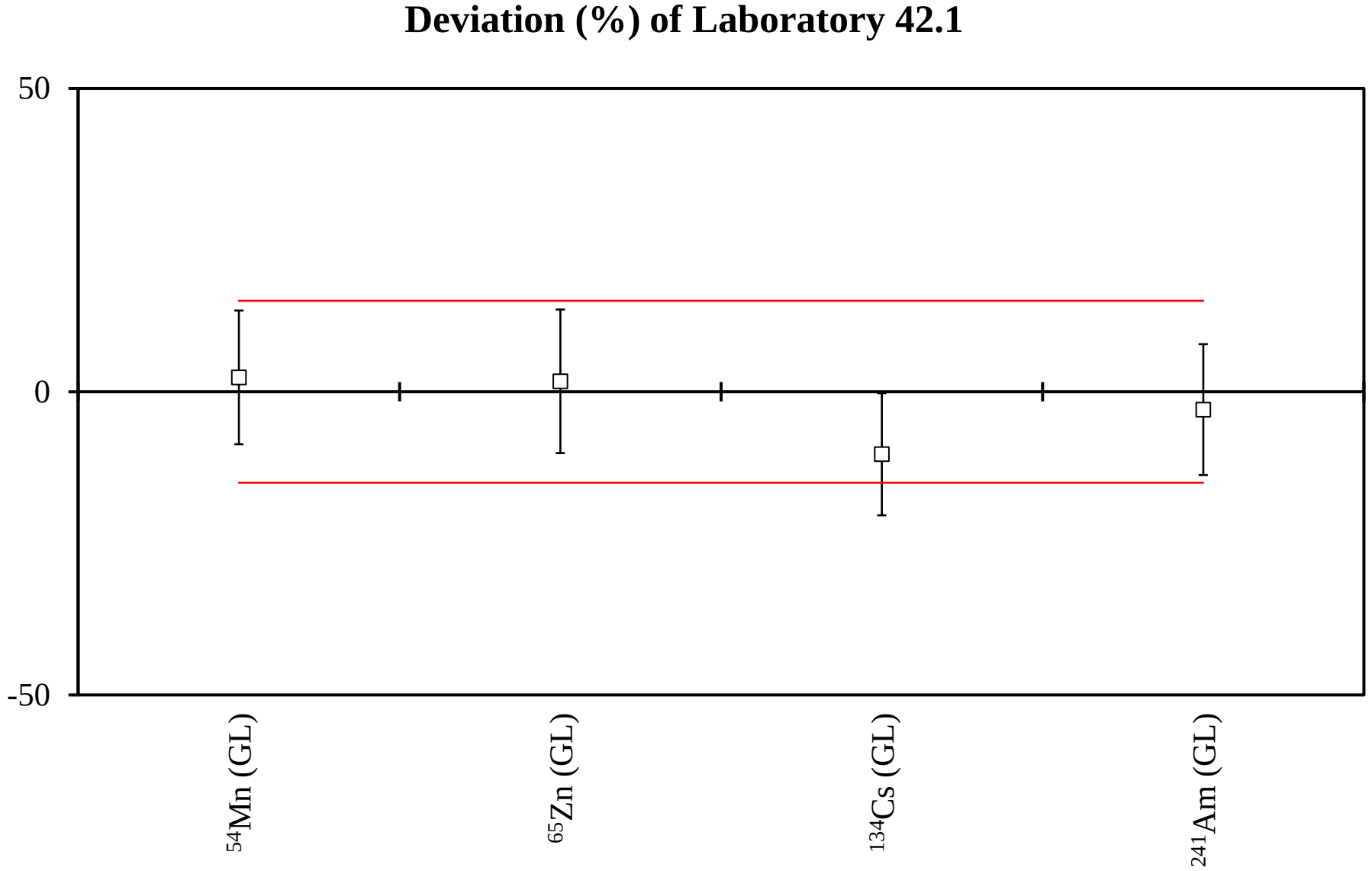
Radionuclide	Laboratory 38	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	5.30 ± 0.50	5.633 ± 0.061	− 5.9	− 0.66	− 1.02
^{63}Ni (AB)	6.50 ± 0.40	7.550 ± 0.083	− 13.9	− 2.57	− 2.39
^{90}Sr (AB)	3.2 ± 0.3	3.703 ± 0.011	− 13.6	− 1.68	− 2.33
^{238}Pu (AB)	12.0 ± 1.0	13.745 ± 0.046	− 12.7	− 1.74	− 2.18
^{238}U (A1)	5.7 ± 0.7	6.143 ± 0.080	− 7.2	− 0.63	− 1.24
^{241}Am (A1)	21.0 ± 2.0	21.29 ± 0.32	− 1.4	− 0.14	− 0.23
^{244}Cm (A1)	14.0 ± 2.0	18.367 ± 0.082	− 23.8	− 2.18	− 4.08
^{3}H (B1)	0.26 ± 0.03	0.2421 ± 0.0048	7.4	0.59	1.27
^{14}C (B1)	0.24 ± 0.03	0.2425 ± 0.0015	− 1.0	− 0.08	− 0.18
^{129}I (B1)	0.1560 ± 0.0060	0.15545 ± 0.00091	0.4	0.09	0.06
^{54}Mn (GL)	42.0 ± 2.0	42.69 ± 0.25	− 1.6	− 0.34	− 0.28
^{65}Zn (GL)	38.0 ± 3.0	38.93 ± 0.28	− 2.4	− 0.31	− 0.41
^{134}Cs (GL)	12.40 ± 0.80	12.932 ± 0.093	− 4.1	− 0.66	− 0.71
^{210}Pb (GL)	17.00 ± 0.40	21.78 ± 0.23	− 21.9	− 10.36	− 3.77
^{241}Am (GL)	46.0 ± 3.0	48.22 ± 0.19	− 4.6	− 0.74	− 0.79


Deviation (%) of Laboratory 40
50
0
-50
90Sr (AB)
238Pu (AB)
238U (A1)
241Am (A1)
244Cm (A1)
54Mn (GL)
65Zn (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

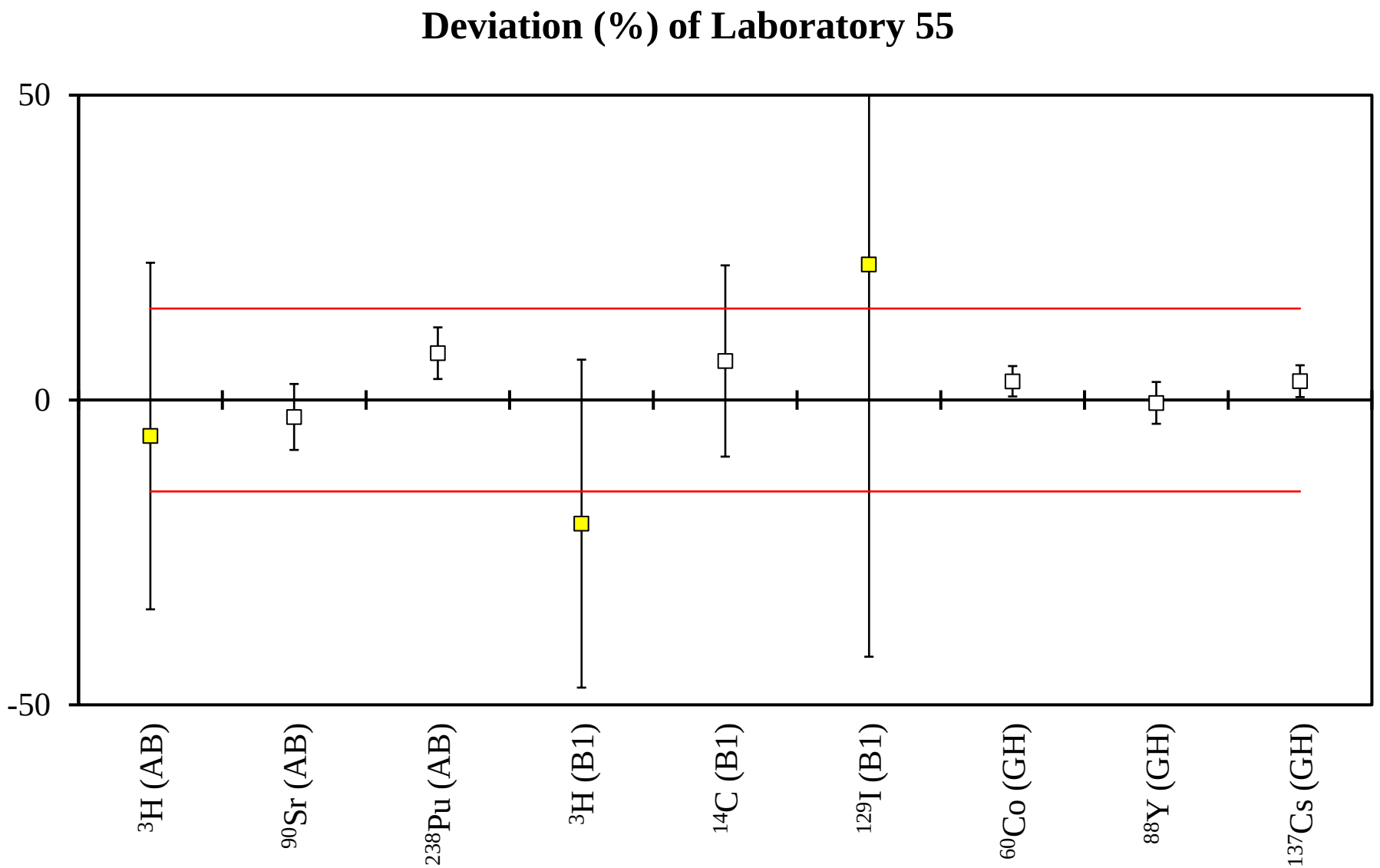
Radionuclide	Laboratory 40	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{90}Sr (AB)	3.51 ± 0.67	3.703 ± 0.011	− 5.2	− 0.29	− 0.90
^{238}Pu (AB)	12.79 ± 0.34	13.745 ± 0.046	− 7.0	− 2.79	− 1.19
^{238}U (A1)	6.37 ± 0.15	6.143 ± 0.080	3.6	1.31	0.62
^{241}Am (A1)	1.519 ± 0.038	21.29 ± 0.32	− 92.9	− 61.35	− 15.95
^{244}Cm (A1)	1.472 ± 0.037	18.367 ± 0.082	− 92.0	− 187.80	− 15.80
^{54}Mn (GL)	42.3 ± 2.6	42.69 ± 0.25	− 0.8	− 0.13	− 0.14
^{65}Zn (GL)	38.9 ± 2.4	38.93 ± 0.28	− 0.1	− 0.01	− 0.01
^{134}Cs (GL)	12.23 ± 0.75	12.932 ± 0.093	− 5.4	− 0.93	− 0.93
^{210}Pb (GL)	20.3 ± 1.2	21.78 ± 0.23	− 6.6	− 1.14	− 1.14
^{241}Am (GL)	47.3 ± 2.9	48.22 ± 0.19	− 1.9	− 0.32	− 0.33


Deviation (%) of Laboratory 41
50
0
-50
3H (AB)
90Sr (AB)
3H (B1)
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)
54Mn (GL)
65Zn (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

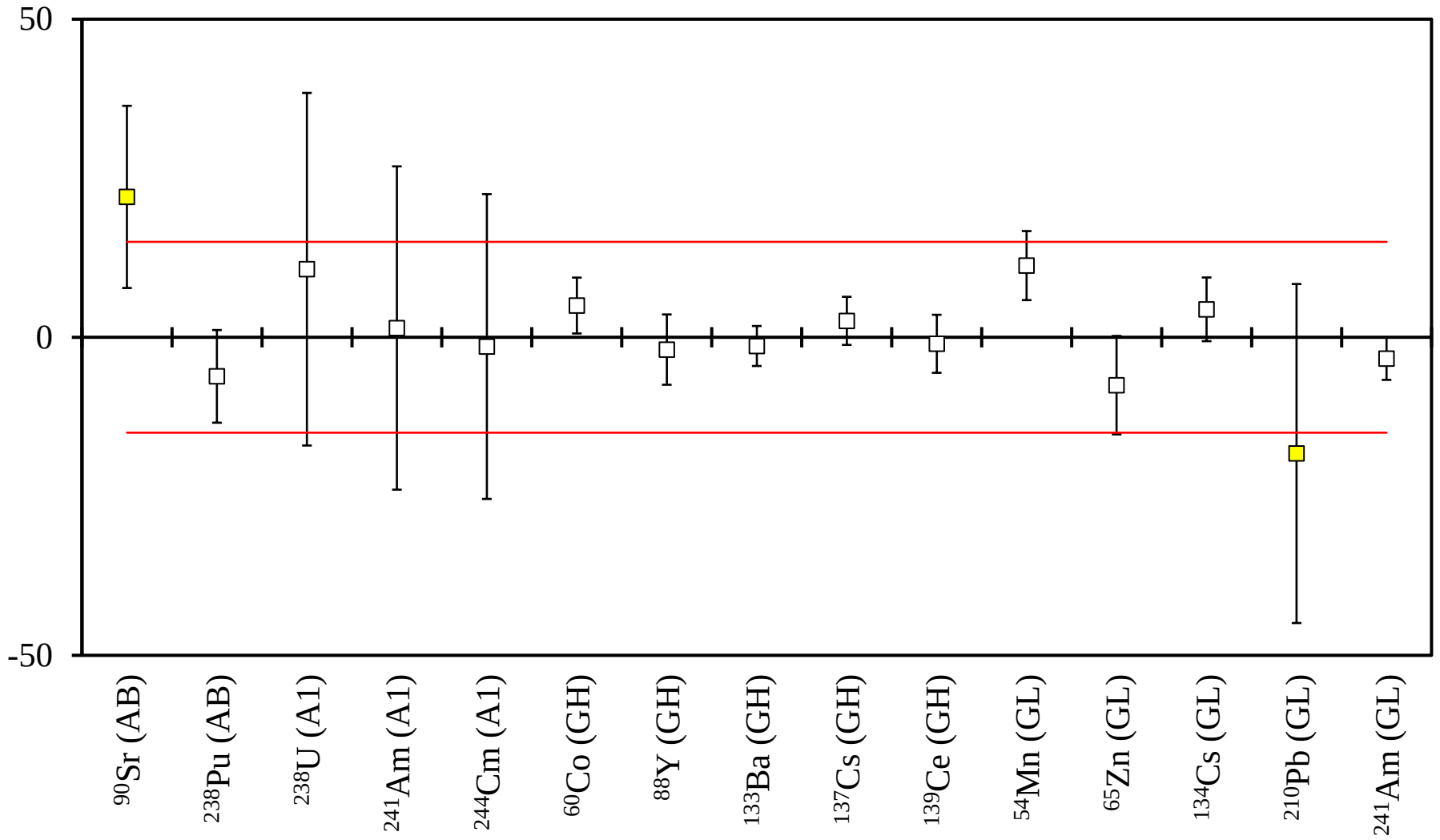
Radionuclide	Laboratory 41	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	6.71 ± 0.31	5.633 ± 0.061	19.1	3.38	3.28
^{90}Sr (AB)	3.95 ± 0.20	3.703 ± 0.011	6.6	1.20	1.13
^{3}H (B1)	0.243 ± 0.019	0.2421 ± 0.0048	0.4	0.05	0.06
^{60}Co (GH)	20.95 ± 0.73	20.86 ± 0.10	0.4	0.12	0.07
^{88}Y (GH)	13.61 ± 0.50	13.665 ± 0.088	− 0.4	− 0.11	− 0.07
^{133}Ba (GH)	9.06 ± 0.25	8.598 ± 0.075	5.3	1.73	0.91
^{137}Cs (GH)	19.73 ± 0.94	19.79 ± 0.16	− 0.3	− 0.06	− 0.05
^{139}Ce (GH)	46.9 ± 2.9	44.76 ± 0.42	4.9	0.74	0.84
^{54}Mn (GL)	43.2 ± 2.3	42.69 ± 0.25	1.2	0.22	0.21
^{65}Zn (GL)	39.1 ± 2.3	38.93 ± 0.28	0.4	0.07	0.07
^{134}Cs (GL)	11.86 ± 0.41	12.932 ± 0.093	− 8.3	− 2.54	− 1.42
^{210}Pb (GL)	19.4 ± 3.3	21.78 ± 0.23	− 11.2	− 0.73	− 1.92
^{241}Am (GL)	48.1 ± 3.1	48.22 ± 0.19	− 0.2	− 0.06	− 0.06


Deviation (%) of Laboratory 42.1
50
0
-50
54Mn (GL)
65Zn (GL)
134Cs (GL)
241Am (GL)

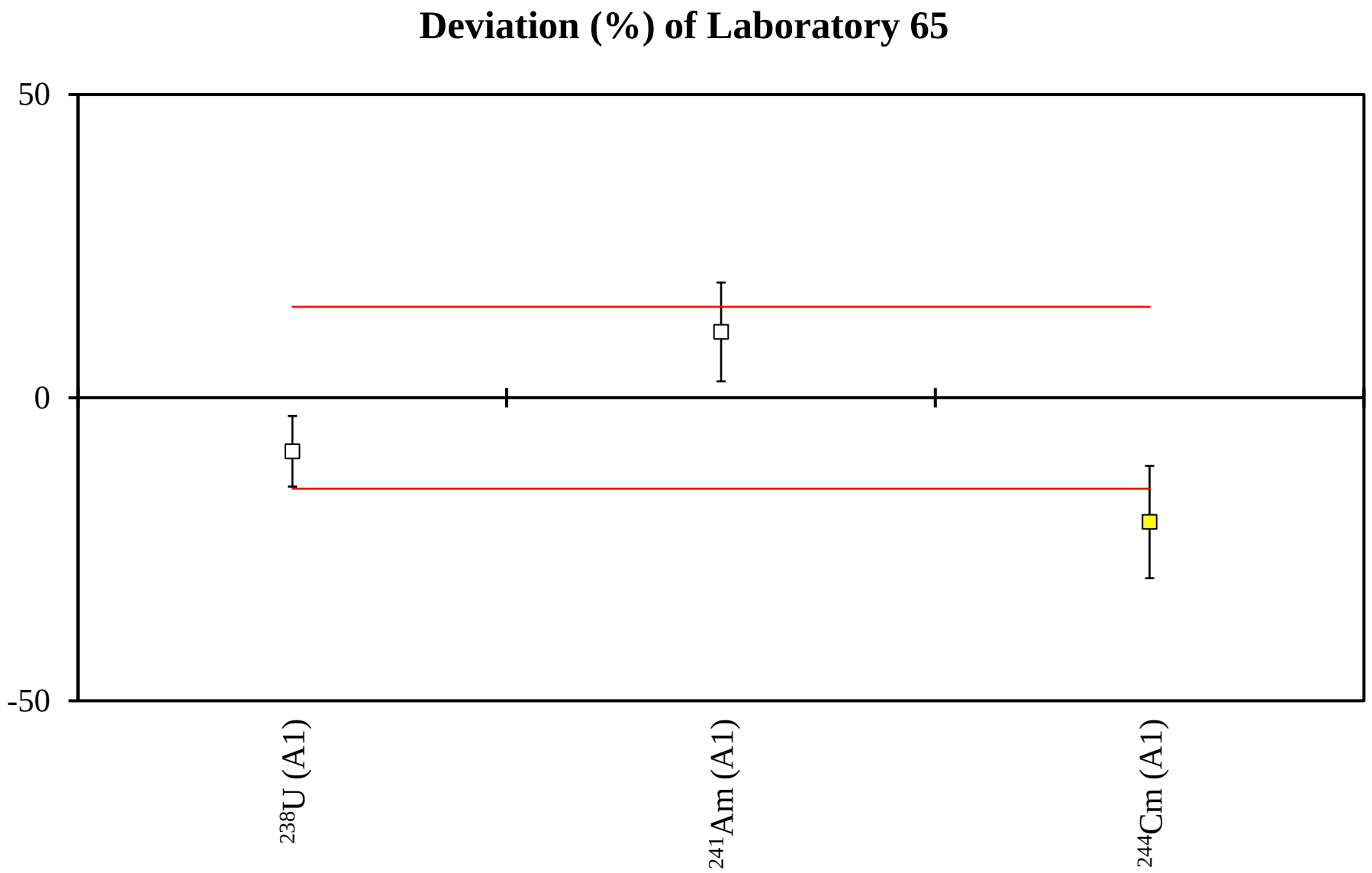
Radionuclide	Laboratory 42.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{54}Mn (GL)	43.7 ± 4.7	42.69 ± 0.25	2.4	0.22	0.42
^{65}Zn (GL)	39.6 ± 4.6	38.93 ± 0.28	1.7	0.15	0.30
^{134}Cs (GL)	11.6 ± 1.3	12.932 ± 0.093	− 10.4	− 1.07	− 1.78
^{241}Am (GL)	46.8 ± 5.2	48.22 ± 0.19	− 3.0	− 0.28	− 0.52


Deviation (%) of Laboratory 55
50
0
-50
3H (AB)
90Sr (AB)
238Pu (AB)
3H (B1)
14C (B1)
129I (B1)
60Co (GH)
88Y (GH)
137Cs (GH)

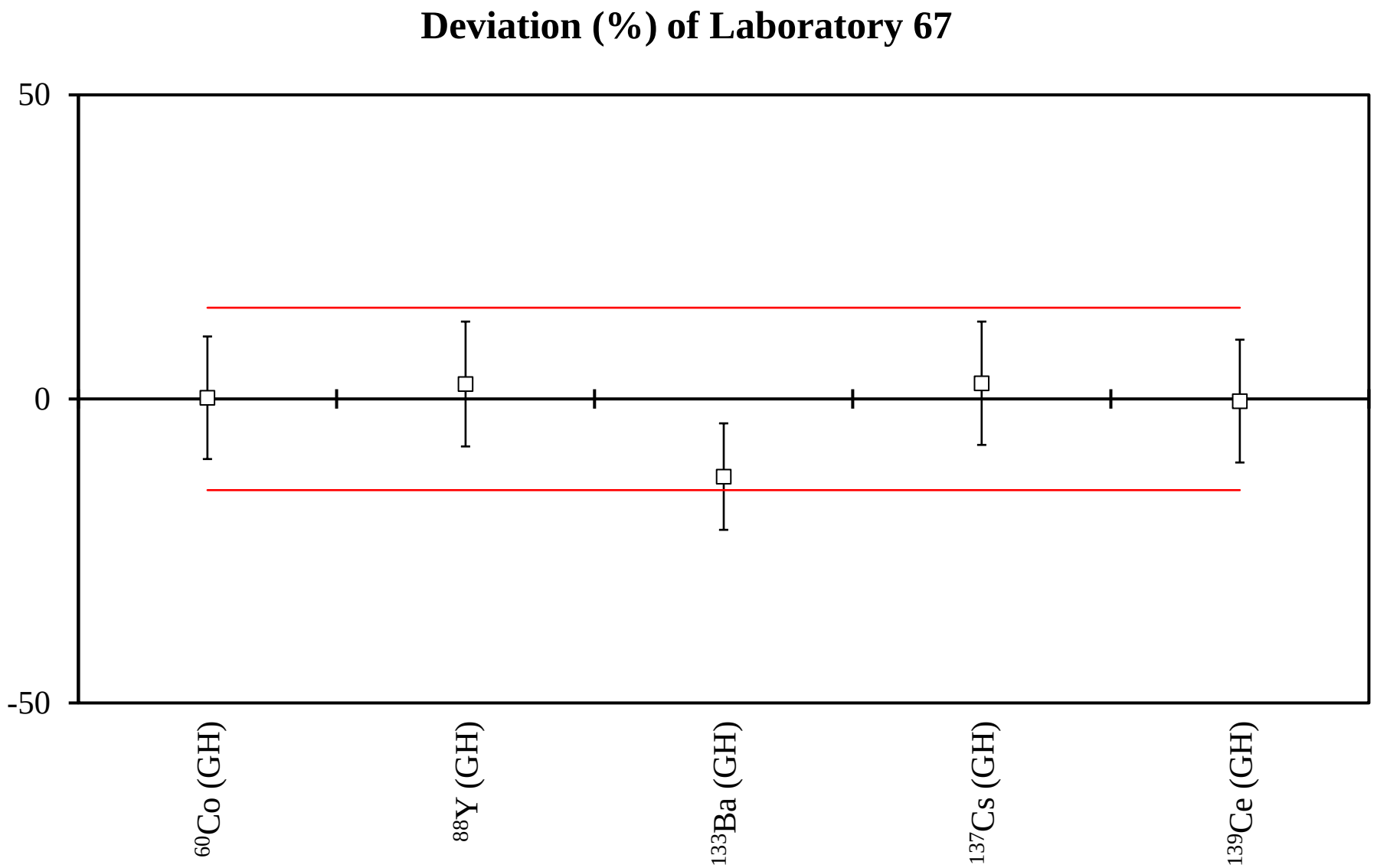
Radionuclide	Laboratory 55	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	5.3 ± 1.6	5.633 ± 0.061	− 5.9	− 0.21	− 1.02
^{90}Sr (AB)	3.60 ± 0.20	3.703 ± 0.011	− 2.8	− 0.52	− 0.48
^{238}Pu (AB)	14.80 ± 0.58	13.745 ± 0.046	7.7	1.80	1.32
^{3}H (B1)	0.193 ± 0.065	0.2421 ± 0.0048	− 20.3	− 0.75	− 3.48
^{14}C (B1)	0.258 ± 0.038	0.2425 ± 0.0015	6.4	0.41	1.10
^{129}I (B1)	0.19 ± 0.10	0.15545 ± 0.00091	22.2	0.34	3.82
^{60}Co (GH)	21.50 ± 0.51	20.86 ± 0.10	3.1	1.23	0.53
^{88}Y (GH)	13.60 ± 0.46	13.665 ± 0.088	− 0.5	− 0.14	− 0.08
^{137}Cs (GH)	20.40 ± 0.49	19.79 ± 0.16	3.1	1.18	0.53


Deviation (%) of Laboratory 61
50
0
-50
90Sr (AB)
238Pu (AB)
238U (A1)
241Am (A1)
244Cm (A1)
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)
54Mn (GL)
65Zn (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

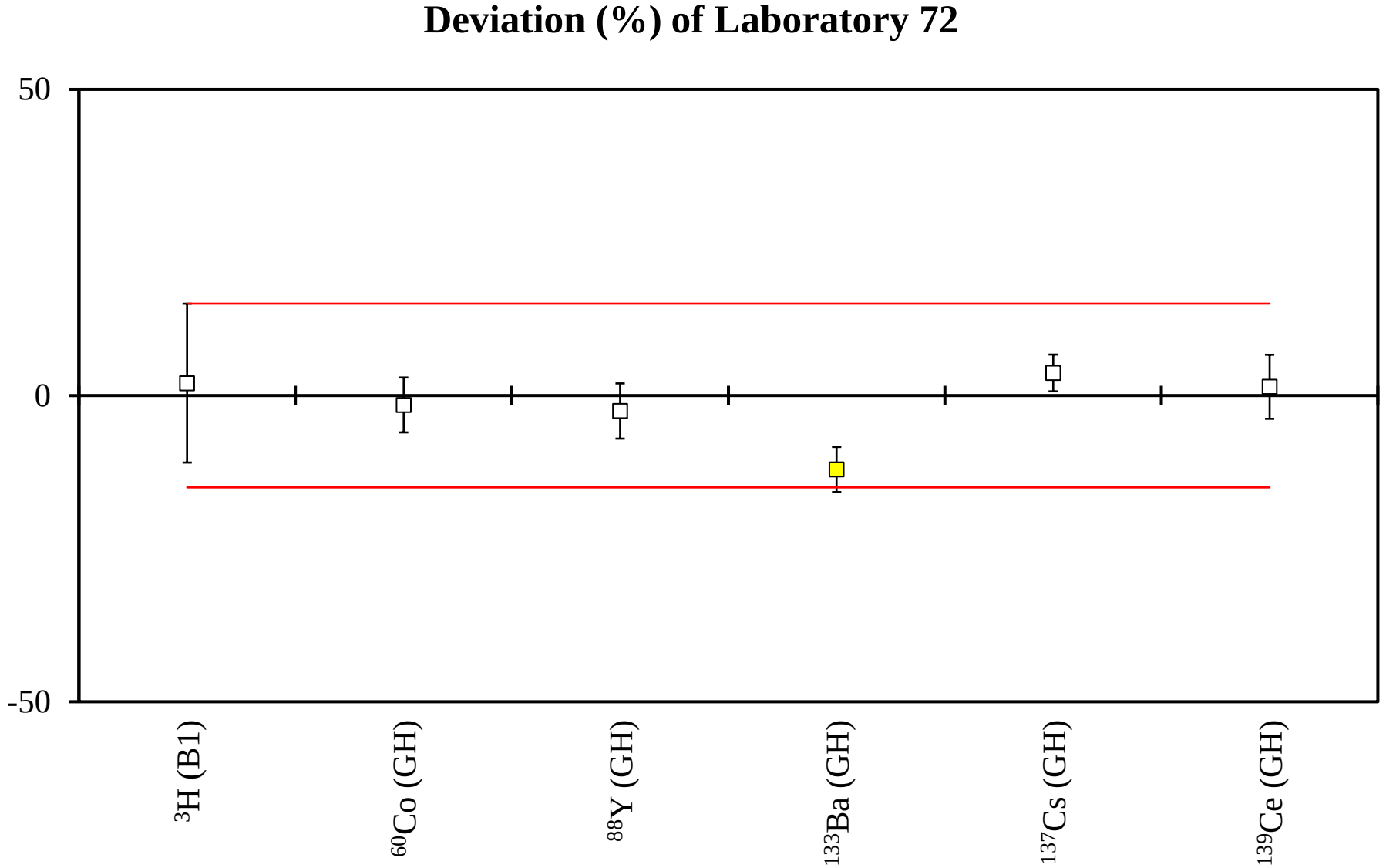
Radionuclide	Laboratory 61	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{90}Sr (AB)	4.52 ± 0.53	3.703 ± 0.011	22.1	1.56	3.80
^{238}Pu (AB)	12.9 ± 1.0	13.745 ± 0.046	− 6.2	− 0.83	− 1.06
^{238}U (A1)	6.8 ± 1.7	6.143 ± 0.080	10.2	0.37	1.75
^{241}Am (A1)	21.6 ± 5.4	21.29 ± 0.32	1.7	0.07	0.29
^{244}Cm (A1)	18.1 ± 4.4	18.367 ± 0.082	− 1.2	− 0.05	− 0.20
^{60}Co (GH)	21.90 ± 0.91	20.86 ± 0.10	5.0	1.14	0.86
^{88}Y (GH)	13.40 ± 0.75	13.665 ± 0.088	− 1.9	− 0.35	− 0.33
^{133}Ba (GH)	8.48 ± 0.26	8.598 ± 0.075	− 1.4	− 0.44	− 0.24
^{137}Cs (GH)	20.30 ± 0.73	19.79 ± 0.16	2.6	0.69	0.44
^{139}Ce (GH)	44.3 ± 2.0	44.76 ± 0.42	− 1.0	− 0.23	− 0.18
^{54}Mn (GL)	47.5 ± 2.3	42.69 ± 0.25	11.3	2.07	1.93
^{65}Zn (GL)	36.0 ± 3.0	38.93 ± 0.28	− 7.5	− 0.99	− 1.29
^{134}Cs (GL)	13.50 ± 0.64	12.932 ± 0.093	4.4	0.89	0.75
^{210}Pb (GL)	17.8 ± 5.8	21.78 ± 0.23	− 18.2	-0.68	− 3.13
^{241}Am (GL)	46.6 ± 1.6	48.22 ± 0.19	− 3.5	− 1.06	-0.59


Deviation (%) of Laboratory 65
50
0
-50
238U (A1)
241Am (A1)
244Cm (A1)

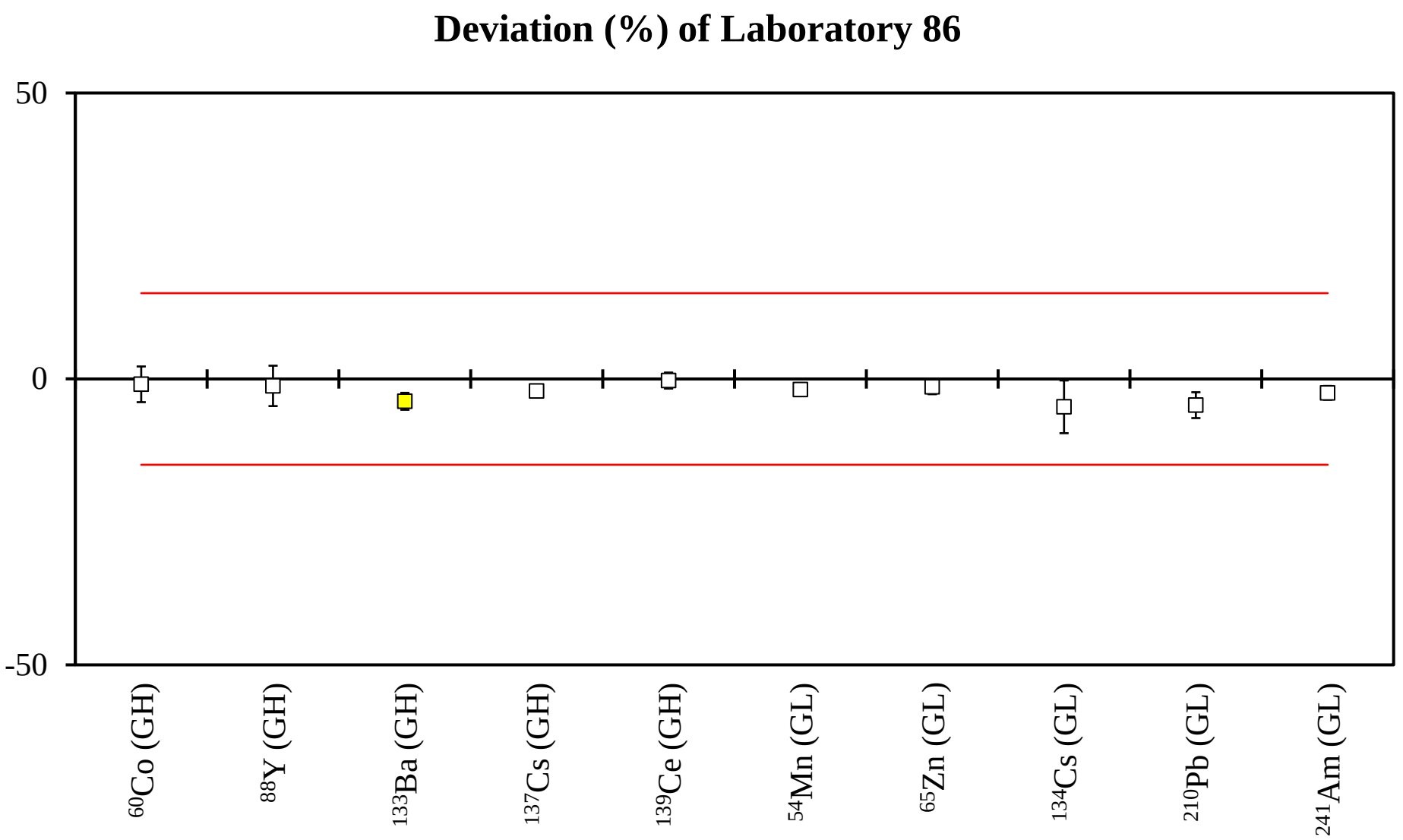
Radionuclide	Laboratory 65	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{238}U (A1)	5.60 ± 0.35	6.143 ± 0.080	− 8.8	− 1.51	− 1.52
^{241}Am (A1)	23.6 ± 1.7	21.29 ± 0.32	10.9	1.34	1.86
^{244}Cm (A1)	14.6 ± 1.7	18.367 ± 0.082	− 20.5	− 2.21	− 3.52


Deviation (%) of Laboratory 67
50
0
-50
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)

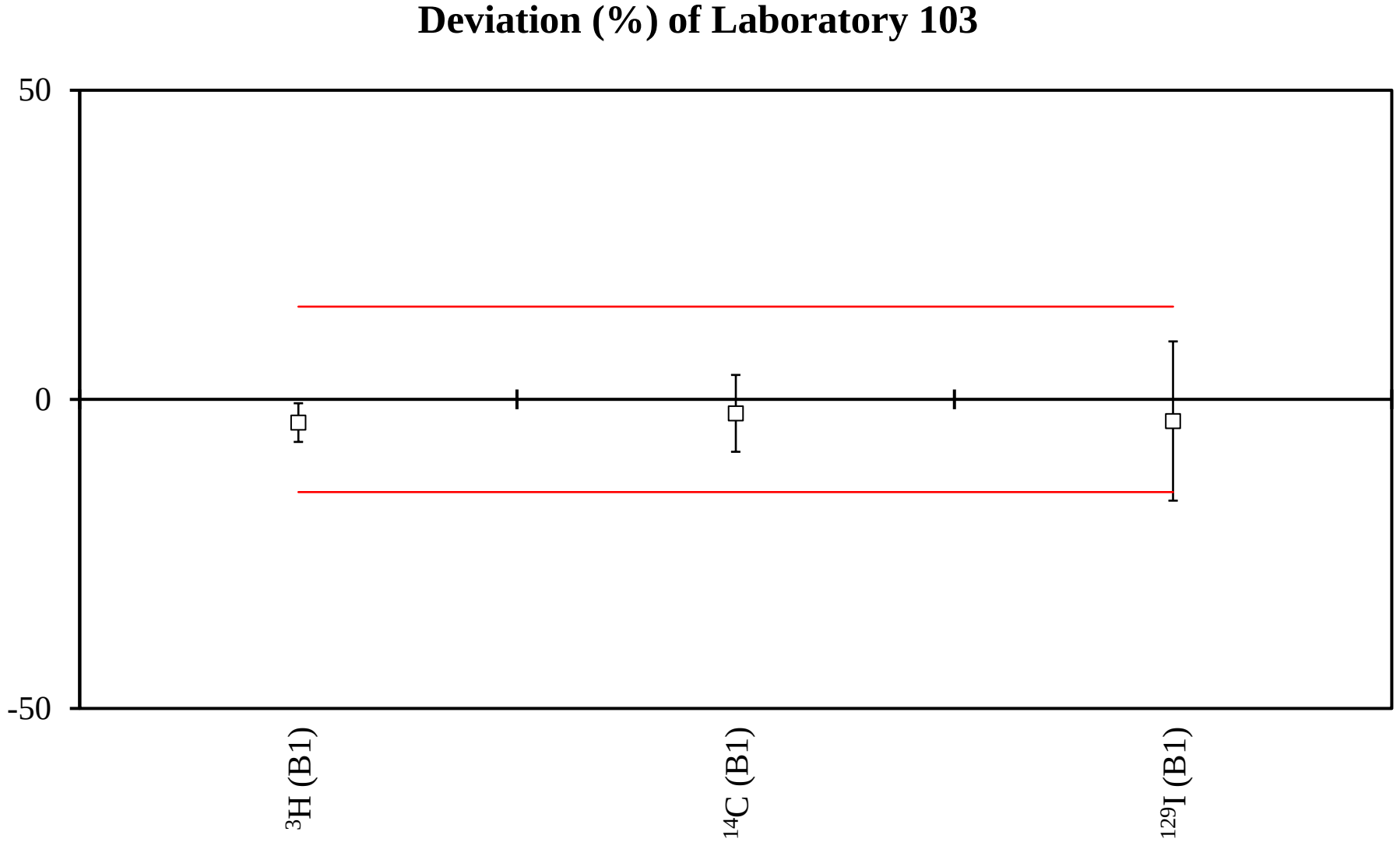
Radionuclide	Laboratory 67	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{60}Co (GH)	20.9 ± 2.1	20.86 ± 0.10	0.2	0.02	0.03
^{88}Y (GH)	14.0 ± 1.4	13.665 ± 0.088	2.5	0.24	0.42
^{133}Ba (GH)	7.50 ± 0.75	8.598 ± 0.075	− 12.8	− 1.46	− 2.19
^{137}Cs (GH)	20.3 ± 2.0	19.79 ± 0.16	2.6	0.25	0.44
^{139}Ce (GH)	44.6 ± 4.5	44.76 ± 0.42	− 0.4	− 0.04	− 0.06


Deviation (%) of Laboratory 72
50
0
-50
3H (B1)
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)

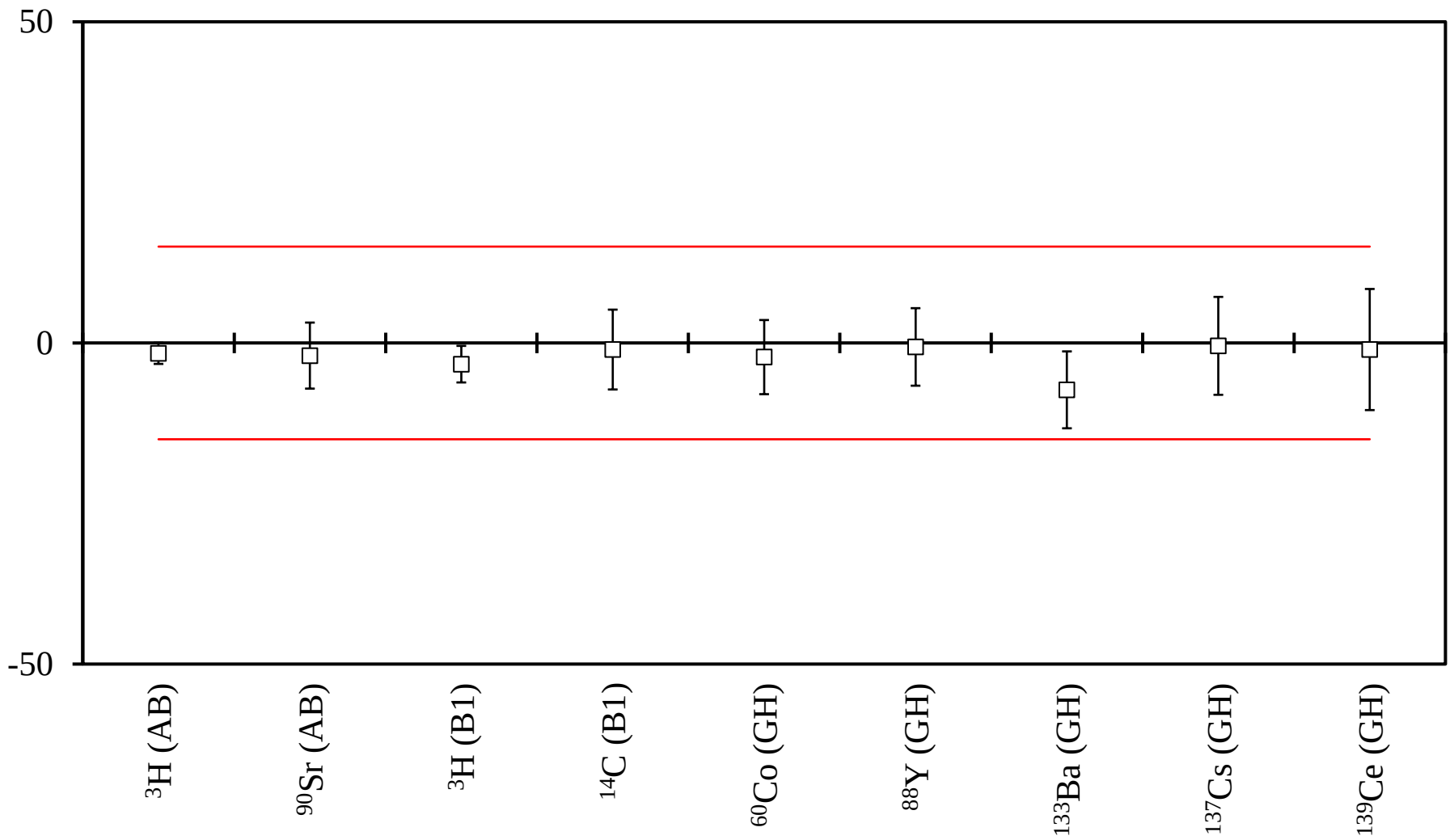
Radionuclide	Laboratory 72	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.247 ± 0.031	0.2421 ± 0.0048	2.2	0.17	0.38
^{60}Co (GH)	20.54 ± 0.93	20.86 ± 0.10	− 1.5	− 0.35	− 0.27
^{88}Y (GH)	13.32 ± 0.61	13.665 ± 0.088	− 2.5	− 0.56	− 0.43
^{133}Ba (GH)	7.56 ± 0.31	8.598 ± 0.075	− 12.1	− 3.26	− 2.08
^{137}Cs (GH)	20.52 ± 0.57	19.79 ± 0.16	3.7	1.24	0.63
^{139}Ce (GH)	45.4 ± 2.3	44.76 ± 0.42	1.5	0.28	0.26


Deviation (%) of Laboratory 86
50
0
-50
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)
54Mn (GL)
65Zn (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

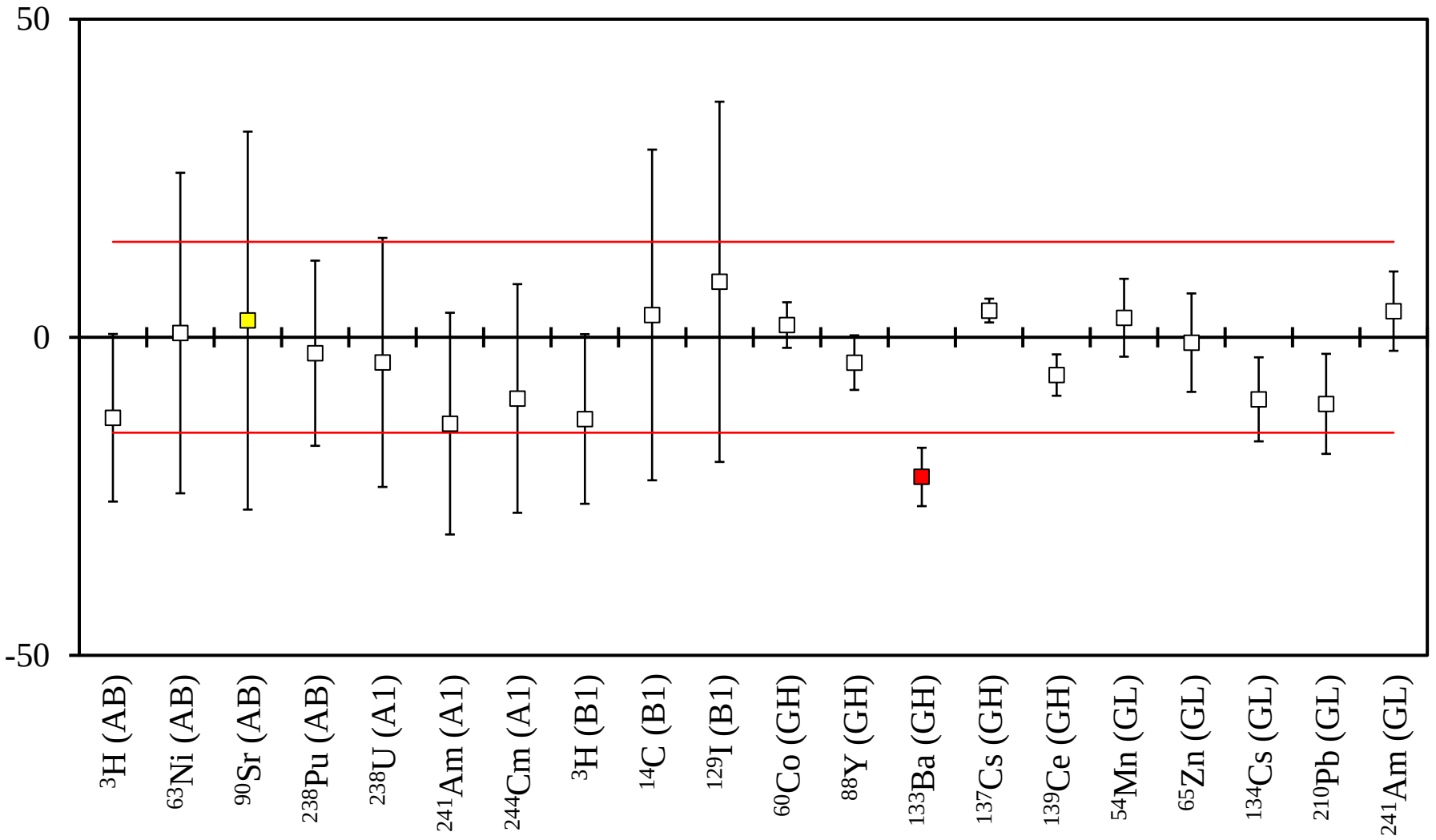
Radionuclide	Laboratory 86	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{60}Co (GH)	20.67 ± 0.64	20.86 ± 0.10	− 0.9	− 0.30	− 0.16
^{88}Y (GH)	13.50 ± 0.47	13.665 ± 0.088	− 1.2	− 0.34	− 0.21
^{133}Ba (GH)	8.26 ± 0.11	8.598 ± 0.075	− 3.9	− 2.60	− 0.67
^{137}Cs (GH)	19.37 ± 0.16	19.79 ± 0.16	− 2.1	− 1.85	− 0.36
^{139}Ce (GH)	44.64 ± 0.47	44.76 ± 0.42	− 0.3	− 0.20	− 0.05
^{54}Mn (GL)	41.90 ± 0.39	42.69 ± 0.25	− 1.8	− 1.69	− 0.32
^{65}Zn (GL)	38.39 ± 0.42	38.93 ± 0.28	− 1.4	− 1.08	− 0.24
^{134}Cs (GL)	12.30 ± 0.59	12.932 ± 0.093	− 4.9	− 1.06	− 0.84
^{210}Pb (GL)	20.78 ± 0.44	21.78 ± 0.23	− 4.6	− 2.01	− 0.79
^{241}Am (GL)	47.05 ± 0.55	48.22 ± 0.19	− 2.4	− 2.01	− 0.42


Deviation (%) of Laboratory 103
50
0
-50
^{3}H (B1)
^{14}C (B1)
^{129}I (B1)

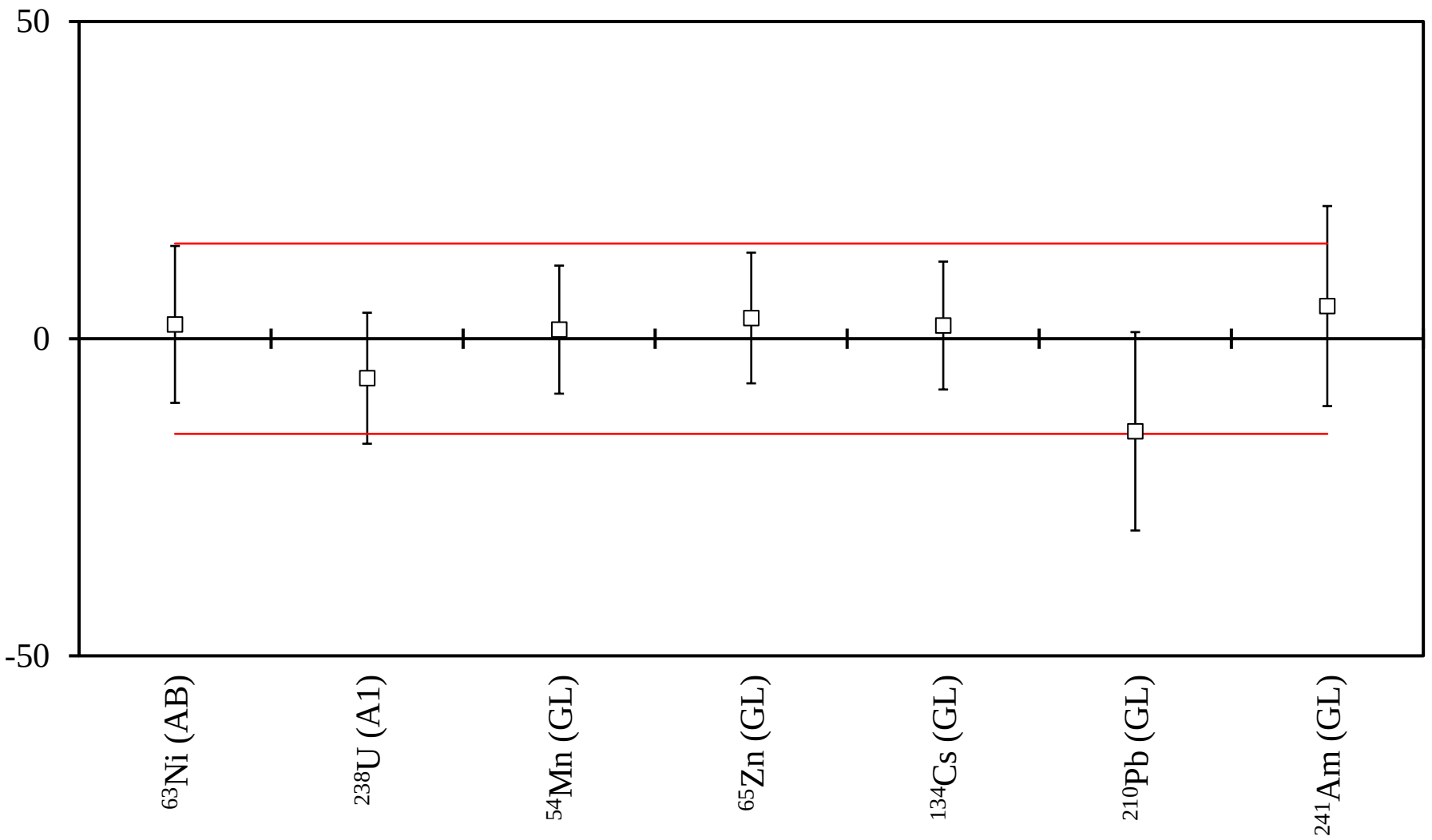
Radionuclide	Laboratory 103	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.2330 ± 0.0060	0.2421 ± 0.0048	− 3.8	− 1.18	− 0.65
^{14}C (B1)	0.237 ± 0.015	0.2425 ± 0.0015	− 2.3	− 0.36	− 0.39
^{129}I (B1)	0.150 ± 0.020	0.15545 ± 0.00091	− 3.5	− 0.27	− 0.60


Deviation (%) of Laboratory 106
50
0
-50
^{3}H (AB)
^{90}Sr (AB)
^{3}H (B1)
^{14}C (B1)
^{60}Co (GH)
^{88}Y (GH)
^{133}Ba (GH)
^{137}Cs (GH)
^{139}Ce (GH)

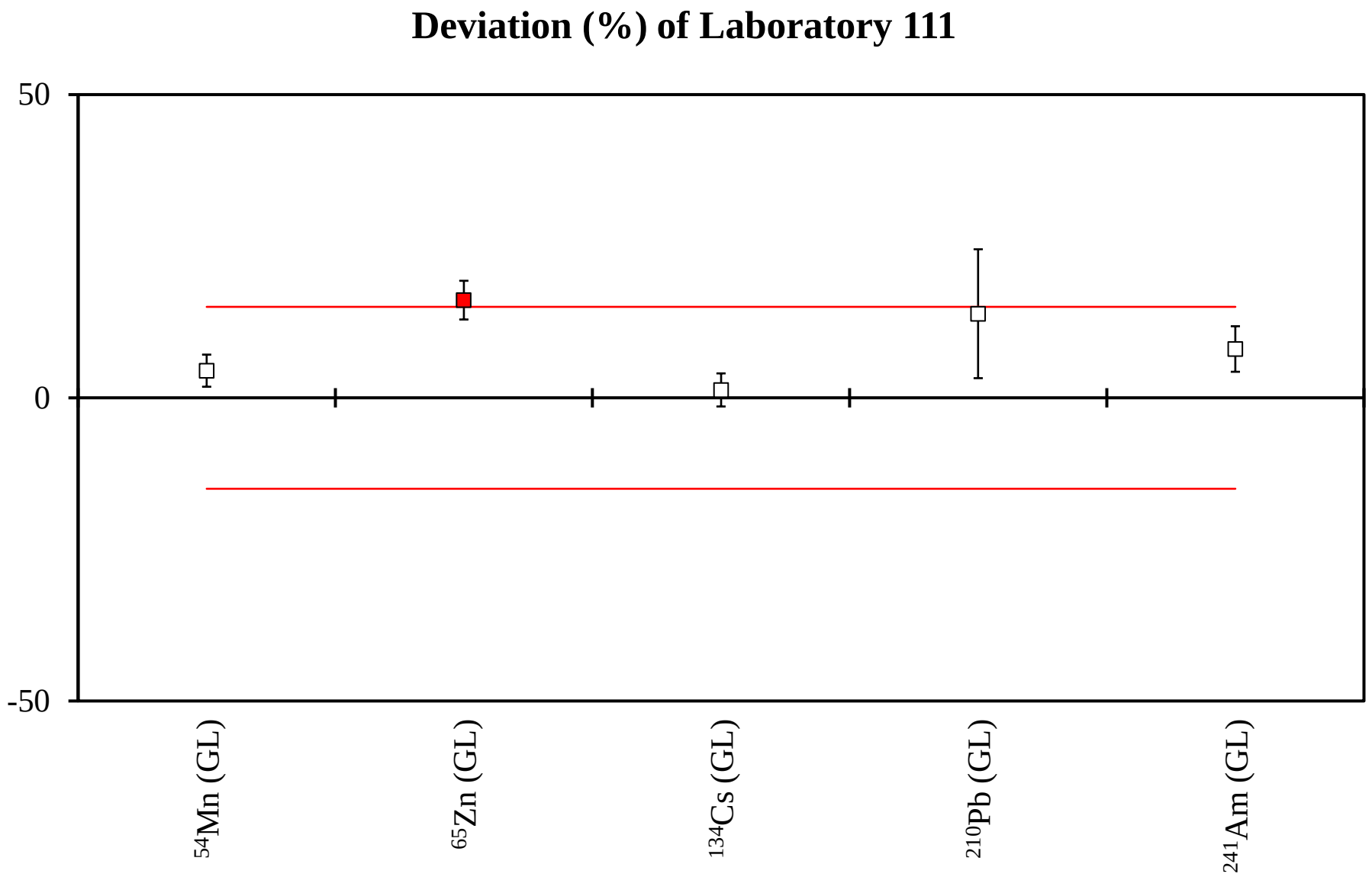
Radionuclide	Laboratory 106	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	5.542 ± 0.071	5.633 ± 0.061	− 1.6	− 0.97	− 0.28
^{90}Sr (AB)	3.63 ± 0.19	3.703 ± 0.011	− 2.0	− 0.38	− 0.34
^{3}H (B1)	0.2341 ± 0.0051	0.2421 ± 0.0048	− 3.3	− 1.14	− 0.57
^{14}C (B1)	0.240 ± 0.015	0.2425 ± 0.0015	− 1.0	− 0.17	− 0.18
^{60}Co (GH)	20.4 ± 1.2	20.86 ± 0.10	− 2.4	− 0.42	− 0.41
^{88}Y (GH)	13.58 ± 0.82	13.665 ± 0.088	− 0.6	− 0.10	− 0.11
^{133}Ba (GH)	7.97 ± 0.51	8.598 ± 0.075	− 7.3	− 1.21	− 1.25
^{137}Cs (GH)	19.7 ± 1.5	19.79 ± 0.16	− 0.2	− 0.03	− 0.04
^{139}Ce (GH)	44.3 ± 4.2	44.76 ± 0.42	− 1.0	− 0.11	− 0.18


Deviation (%) of Laboratory 109.1
50
0
-50
3H (AB)
63Ni (AB)
90Sr (AB)
238Pu (AB)
238U (A1)
241Am (A1)
244Cm (A1)
3H (B1)
14C (B1)
129I (B1)
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)
54Mn (GL)
65Zn (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

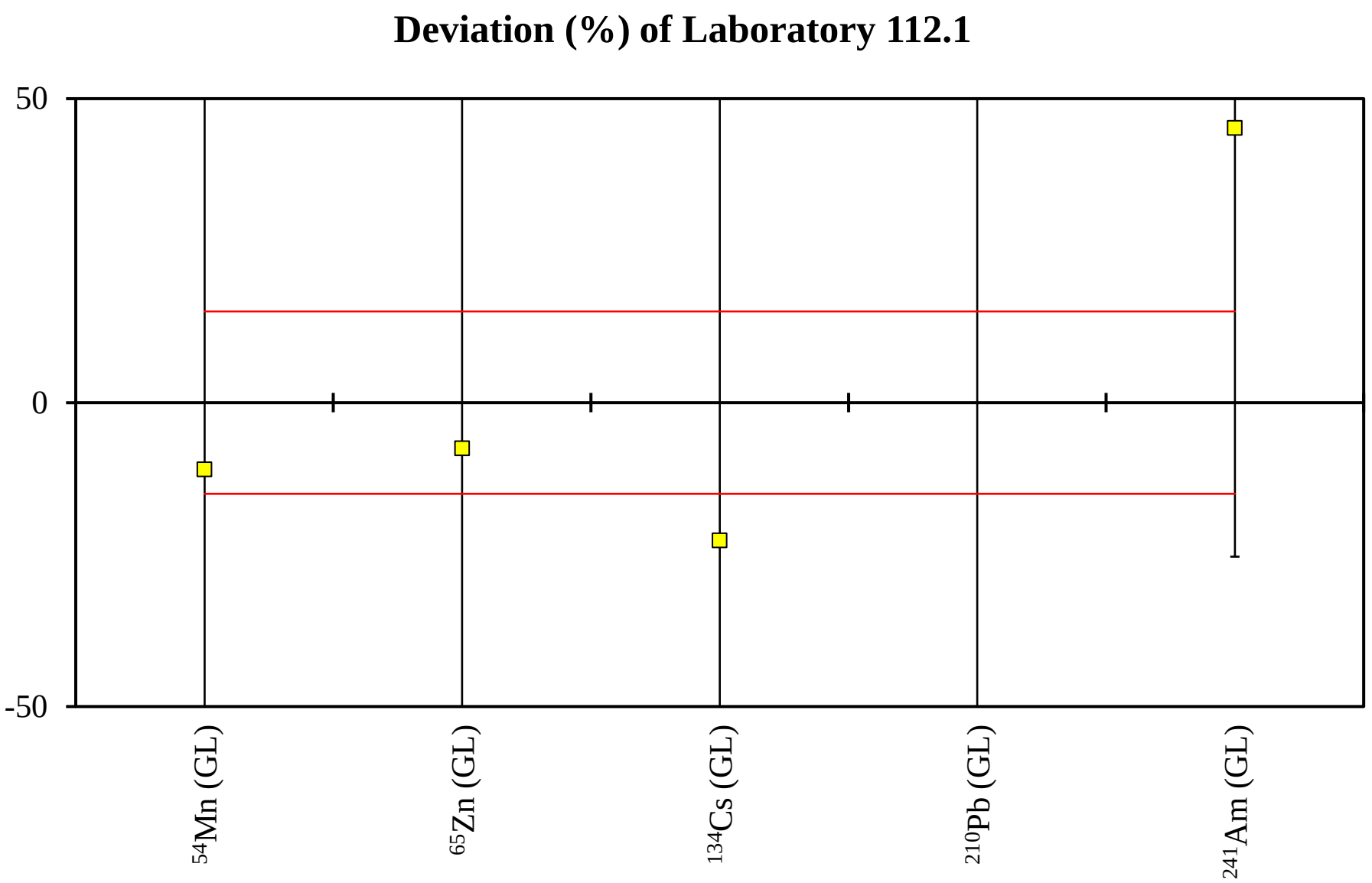
Radionuclide	Laboratory 109.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	4.92 ± 0.74	5.633 ± 0.061	− 12.7	− 0.97	− 2.19
^{63}Ni (AB)	7.6 ± 1.9	7.550 ± 0.083	0.5	0.02	0.09
^{90}Sr (AB)	3.8 ± 1.1	3.703 ± 0.011	3.0	0.10	0.52
^{238}Pu (AB)	13.4 ± 2.0	13.745 ± 0.046	− 2.9	− 0.20	− 0.49
^{238}U (A1)	5.9 ± 1.2	6.143 ± 0.080	− 4.4	− 0.23	− 0.75
^{241}Am (A1)	18.4 ± 3.7	21.29 ± 0.32	− 13.8	− 0.80	− 2.37
^{244}Cm (A1)	16.6 ± 3.3	18.367 ± 0.082	− 9.9	− 0.55	− 1.70
^{3}H (B1)	0.211 ± 0.032	0.2421 ± 0.0048	− 12.9	− 0.98	− 2.22
^{14}C (B1)	0.251 ± 0.063	0.2425 ± 0.0015	3.3	0.13	0.57
^{129}I (B1)	0.169 ± 0.044	0.15545 ± 0.00091	8.7	0.31	1.50
^{60}Co (GH)	21.26 ± 0.74	20.86 ± 0.10	1.9	0.54	0.33
^{88}Y (GH)	13.12 ± 0.58	13.665 ± 0.088	− 4.0	− 0.92	− 0.68
^{133}Ba (GH)	6.71 ± 0.39	8.598 ± 0.075	− 22.0	− 4.80	− 3.77
^{137}Cs (GH)	20.62 ± 0.33	19.79 ± 0.16	4.2	2.24	0.72
^{139}Ce (GH)	42.1 ± 1.4	44.76 ± 0.42	− 5.9	− 1.77	− 1.01
^{54}Mn (GL)	44.0 ± 2.6	42.69 ± 0.25	3.0	0.49	0.51
^{65}Zn (GL)	38.6 ± 3.0	38.93 ± 0.28	− 0.7	− 0.09	− 0.13
^{134}Cs (GL)	11.67 ± 0.85	12.932 ± 0.093	− 9.8	− 1.48	− 1.68
^{210}Pb (GL)	19.5 ± 1.7	21.78 ± 0.23	− 10.3	− 1.28	− 1.76
^{241}Am (GL)	50.2 ± 3.0	48.22 ± 0.19	4.1	0.65	0.70


Deviation (%) of Laboratory 109.2
50
0
-50
63Ni (AB)
238U (A1)
54Mn (GL)
65Zn (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

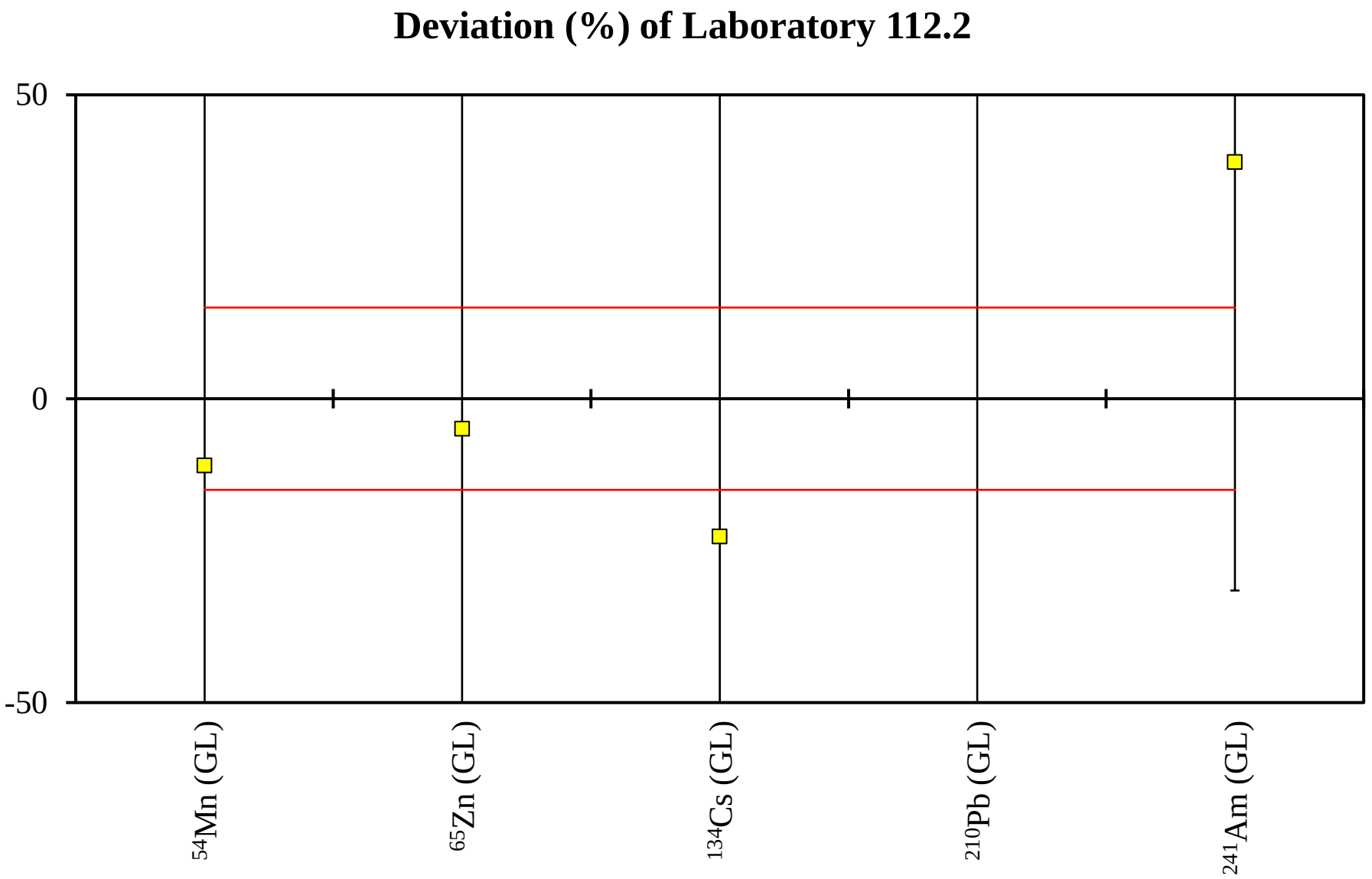
Radionuclide	Laboratory 109.2	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{63}Ni (AB)	7.72 ± 0.93	7.550 ± 0.083	2.3	0.18	0.39
^{238}U (A1)	5.76 ± 0.63	6.143 ± 0.080	− 6.2	− 0.60	− 1.07
^{54}Mn (GL)	43.3 ± 4.3	42.69 ± 0.25	1.4	0.14	0.25
^{65}Zn (GL)	40.2 ± 4.0	38.93 ± 0.28	3.3	0.32	0.56
^{134}Cs (GL)	13.2 ± 1.3	12.932 ± 0.093	2.1	0.20	0.36
^{210}Pb (GL)	18.6 ± 3.4	21.78 ± 0.23	− 14.6	− 0.95	− 2.51
^{241}Am (GL)	50.7 ± 7.6	48.22 ± 0.19	5.1	0.33	0.88


Deviation (%) of Laboratory 111
50
0
-50
54Mn (GL)
65Zn (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

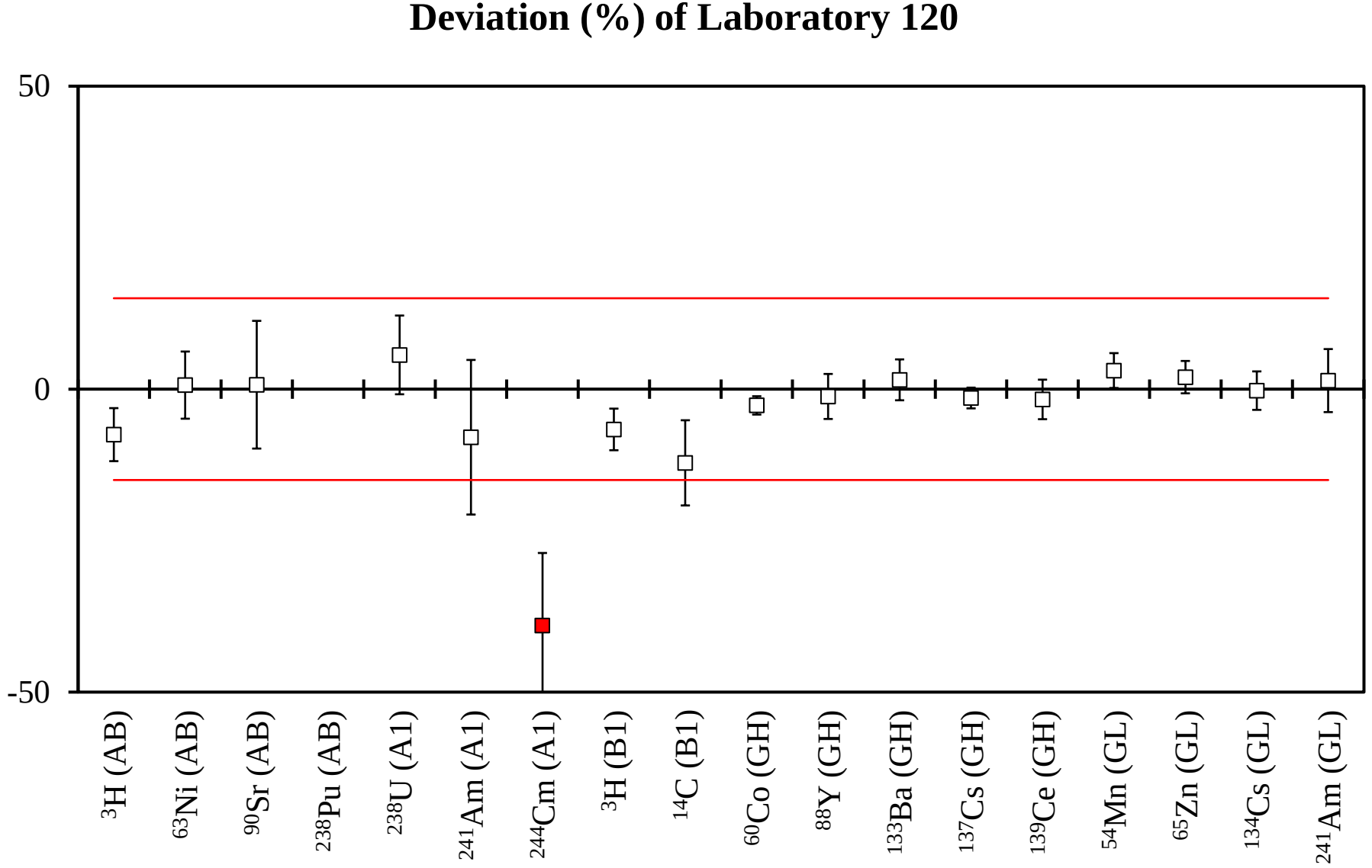
Radionuclide	Laboratory 111	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{54}Mn (GL)	44.6 ± 1.1	42.69 ± 0.25	4.5	1.72	0.77
^{65}Zn (GL)	45.2 ± 1.2	38.93 ± 0.28	16.1	5.05	2.77
^{134}Cs (GL)	13.10 ± 0.34	12.932 ± 0.093	1.3	0.48	0.22
^{210}Pb (GL)	24.8 ± 2.3	21.78 ± 0.23	13.9	1.29	2.38
^{241}Am (GL)	52.1 ± 1.8	48.22 ± 0.19	8.0	2.18	1.38


Deviation (%) of Laboratory 112.1
50
0
-50
54Mn (GL)
65Zn (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

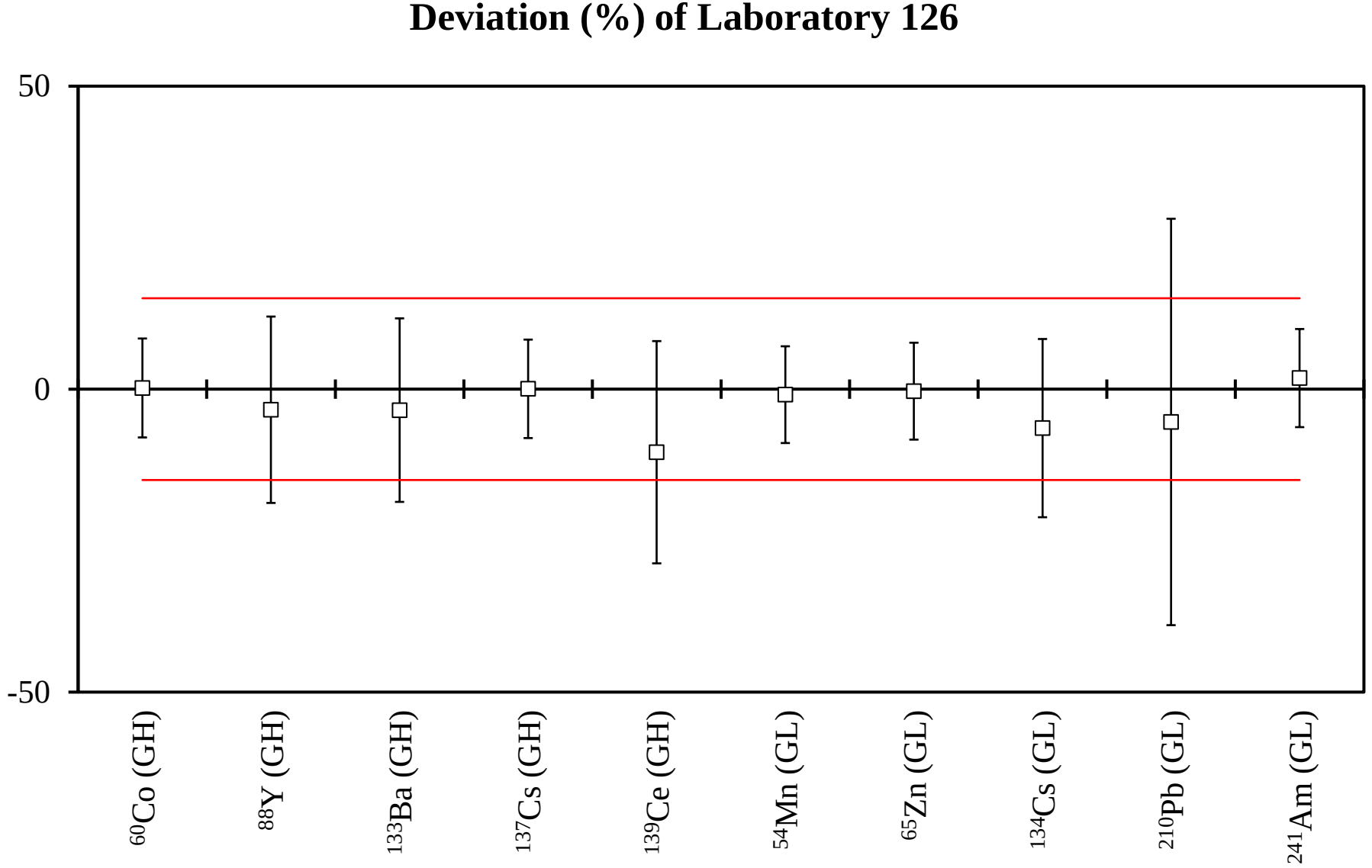
Radionuclide	Laboratory 112.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{54}Mn (GL)	38 ± 35	42.69 ± 0.25	− 10.1	− 0.12	− 1.73
^{65}Zn (GL)	36 ± 35	38.93 ± 0.28	− 6.5	− 0.07	− 1.12
^{134}Cs (GL)	10 ± 35	12.932 ± 0.093	− 21.7	− 0.08	− 3.73
^{210}Pb (GL)	33 ± 60	21.78 ± 0.23	52.5	0.19	9.02
^{241}Am (GL)	70 ± 34	48.22 ± 0.19	44.2	0.62	7.59


Deviation (%) of Laboratory 112.2
50
0
-50
54Mn (GL)
65Zn (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

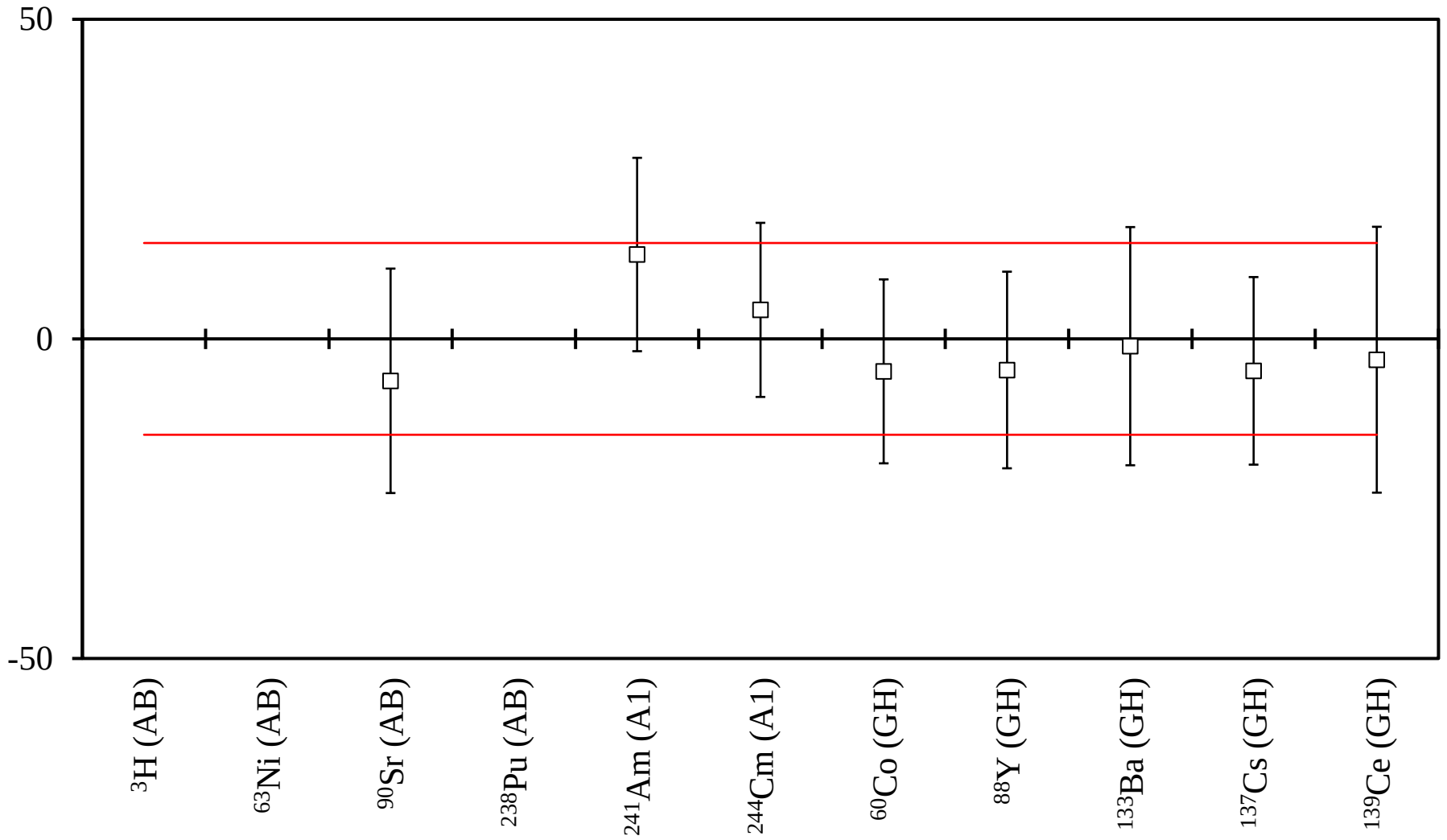
Radionuclide	Laboratory 112.2	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{54}Mn (GL)	38 ± 35	42.69 ± 0.25	− 12.0	− 0.15	− 2.07
^{65}Zn (GL)	37 ± 35	38.93 ± 0.28	− 3.9	− 0.04	− 0.67
^{134}Cs (GL)	10 ± 35	12.932 ± 0.093	− 26.2	− 0.10	− 4.51
^{210}Pb (GL)	37 ± 55	21.78 ± 0.23	69.9	0.28	11.89
^{241}Am (GL)	67 ± 34	48.22 ± 0.19	38.9	0.56	6.85


Deviation (%) of Laboratory 120
50
0
-50
3H (AB)
63Ni (AB)
90Sr (AB)
238Pu (AB)
238U (A1)
241Am (A1)
244Cm (A1)
3H (B1)
14C (B1)
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)
54Mn (GL)
65Zn (GL)
134Cs (GL)
241Am (GL)

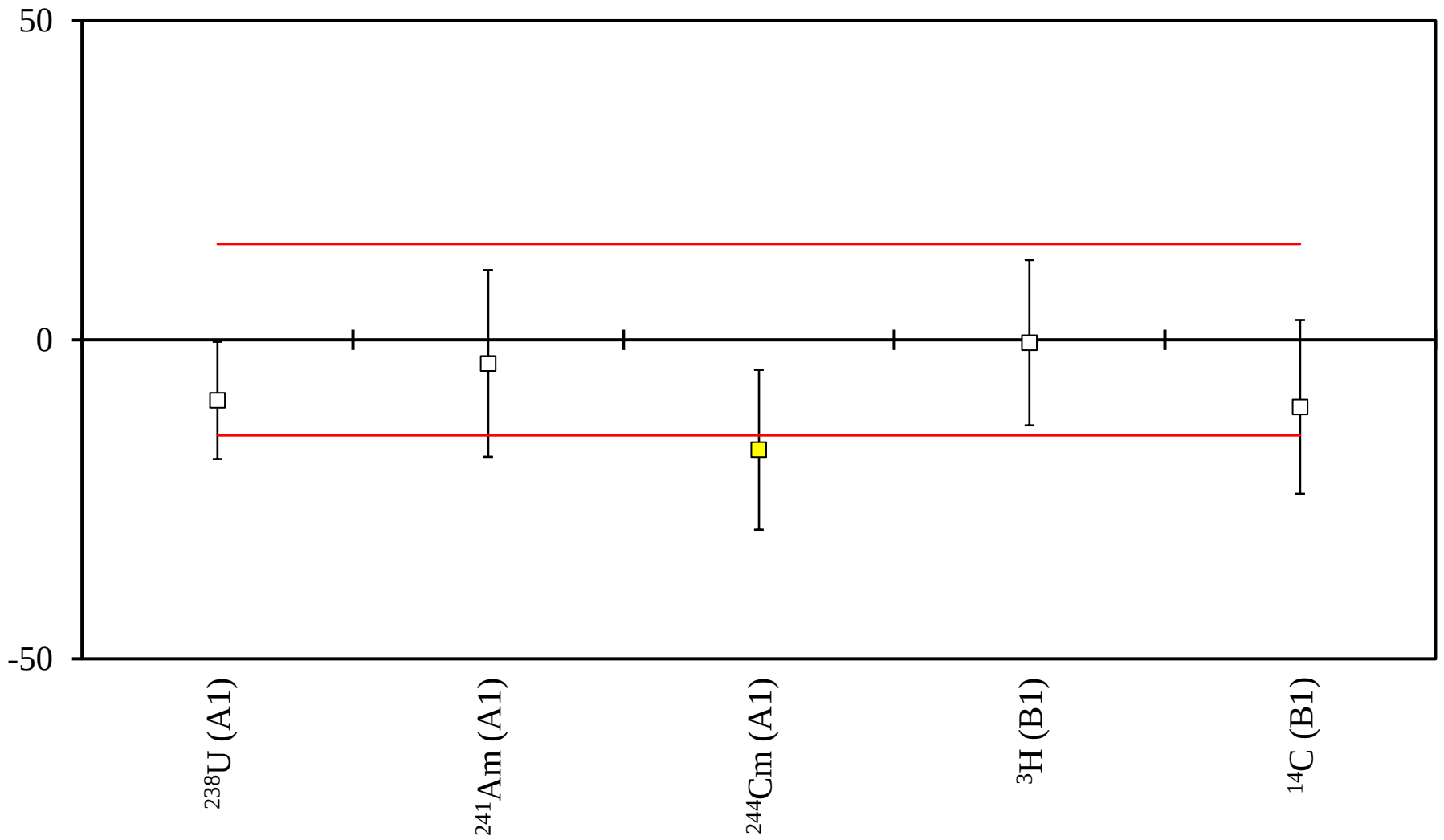
Radionuclide	Laboratory 120	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	5.21 ± 0.24	5.633 ± 0.061	− 7.5	− 1.71	− 1.29
^{63}Ni (AB)	7.60 ± 0.41	7.550 ± 0.083	0.7	0.12	0.11
^{90}Sr (AB)	3.73 ± 0.39	3.703 ± 0.011	0.7	0.07	0.13
^{238}Pu (AB)	4.81 ± 0.25	13.745 ± 0.046	− 65.0	− 35.15	− 11.16
^{238}U (A1)	6.49 ± 0.39	6.143 ± 0.080	5.6	0.87	0.97
^{241}Am (A1)	19.6 ± 2.7	21.29 ± 0.32	− 7.9	− 0.62	− 1.36
^{244}Cm (A1)	11.2 ± 2.2	18.367 ± 0.082	− 39.0	− 3.26	− 6.70
^{3}H (B1)	0.2260 ± 0.0070	0.2421 ± 0.0048	− 6.7	− 1.90	− 1.14
^{14}C (B1)	0.213 ± 0.017	0.2425 ± 0.0015	− 12.2	− 1.73	− 2.09
^{60}Co (GH)	20.3 ± 0.3	20.86 ± 0.10	− 2.7	− 1.77	− 0.46
^{88}Y (GH)	13.50 ± 0.50	13.665 ± 0.088	− 1.2	− 0.33	− 0.21
^{133}Ba (GH)	8.73 ± 0.28	8.598 ± 0.075	1.5	0.46	0.26
^{137}Cs (GH)	19.5 ± 0.3	19.79 ± 0.16	− 1.5	− 0.85	− 0.25
^{139}Ce (GH)	44.0 ± 1.4	44.76 ± 0.42	− 1.7	− 0.52	− 0.29
^{54}Mn (GL)	44.0 ± 1.2	42.69 ± 0.25	3.1	1.07	0.53
^{65}Zn (GL)	39.7 ± 1.0	38.93 ± 0.28	2.0	0.74	0.34
^{134}Cs (GL)	12.90 ± 0.40	12.932 ± 0.093	− 0.2	− 0.08	− 0.04
^{241}Am (GL)	48.9 ± 2.5	48.22 ± 0.19	1.4	0.27	0.24


Deviation (%) of Laboratory 126
50
0
-50
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)
54Mn (GL)
65Zn (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

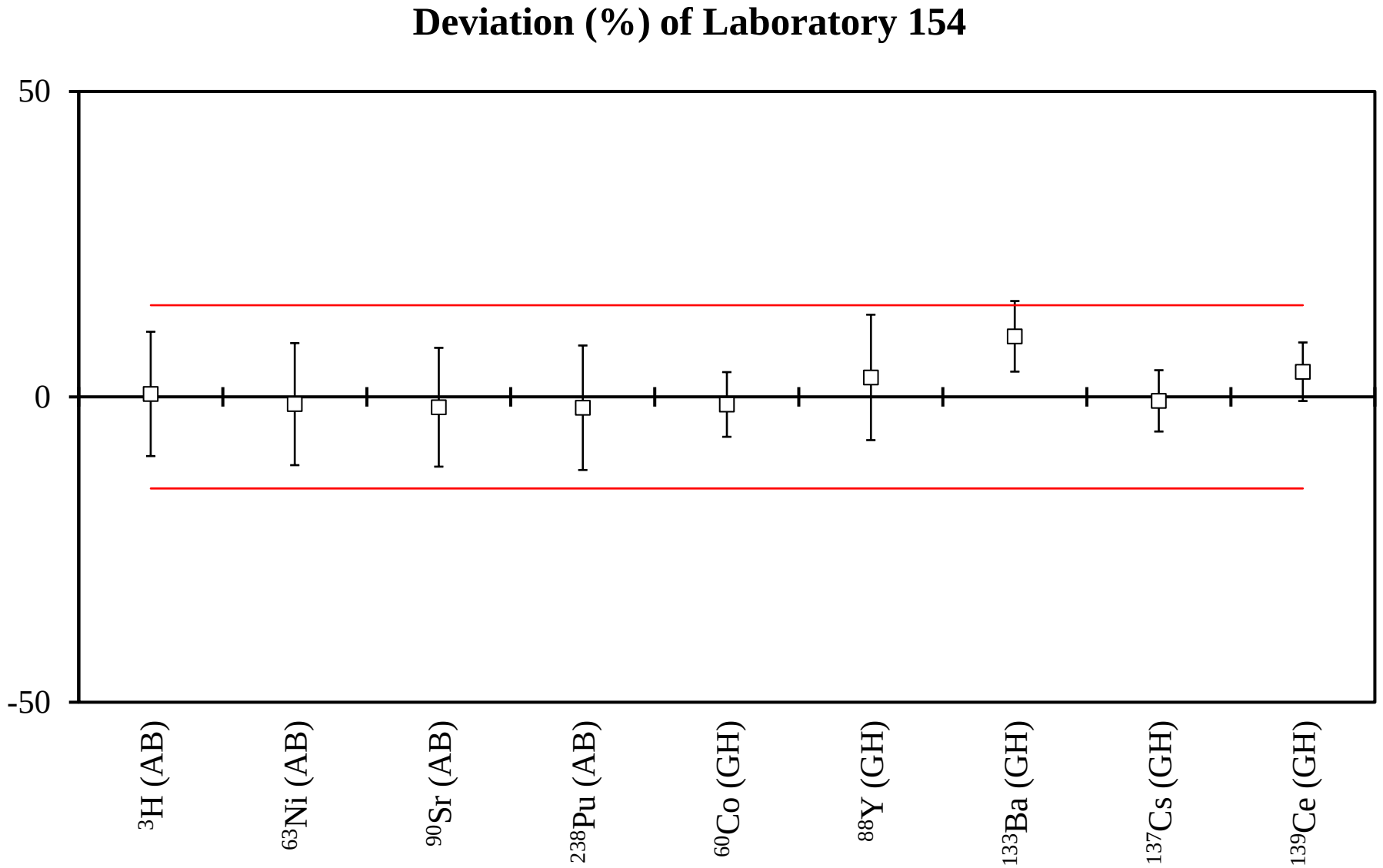
Radionuclide	Laboratory 126	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{60}Co (GH)	20.9 ± 1.7	20.86 ± 0.10	0.0	0.00	0.00
^{88}Y (GH)	13.2 ± 2.1	13.665 ± 0.088	− 3.7	− 0.24	− 0.64
^{133}Ba (GH)	8.3 ± 1.3	8.598 ± 0.075	− 3.5	− 0.25	− 0.66
^{137}Cs (GH)	19.8 ± 1.6	19.79 ± 0.16	− 0.1	0.01	0.02
^{139}Ce (GH)	40.1 ± 8.2	44.76 ± 0.42	− 10.5	− 0.58	− 1.80
^{54}Mn (GL)	42.3 ± 3.4	42.69 ± 0.25	− 0.9	− 0.12	− 0.16
^{65}Zn (GL)	38.8 ± 3.1	38.93 ± 0.28	− 0.3	− 0.04	− 0.05
^{134}Cs (GL)	12.1 ± 1.9	12.932 ± 0.093	− 6.4	− 0.43	− 1.10
^{210}Pb (GL)	20.6 ± 7.3	21.78 ± 0.23	− 5.3	− 0.16	− 0.92
^{241}Am (GL)	49.1 ± 3.9	48.22 ± 0.19	1.9	0.23	0.33


Deviation (%) of Laboratory 133
50
0
-50
3H (AB)
63Ni (AB)
90Sr (AB)
238Pu (AB)
241Am (A1)
244Cm (A1)
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)

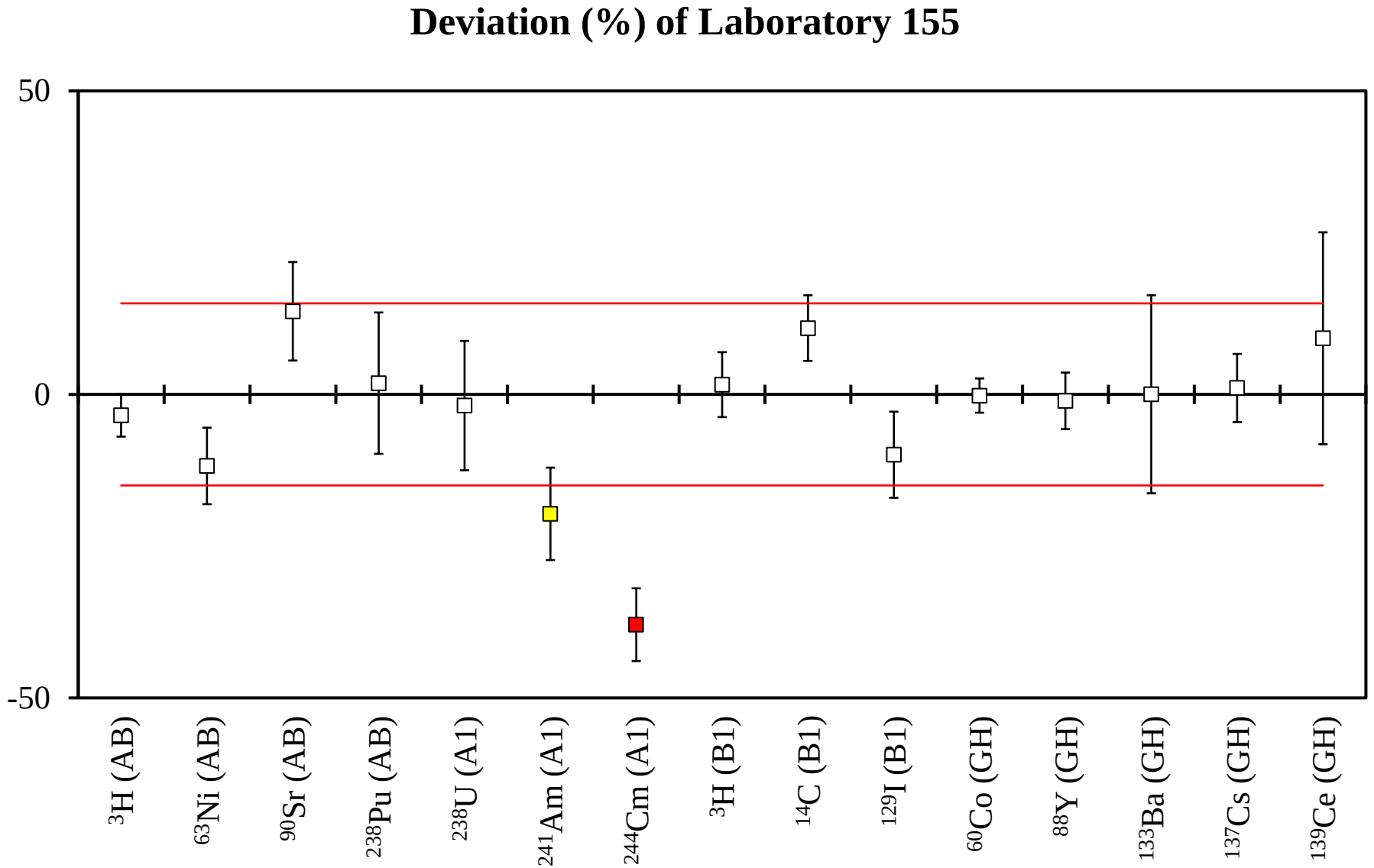
Radionuclide	Laboratory 133	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	82.78 ± 0.47	5.633 ± 0.061	1369.6	162.71	235.20
^{63}Ni (AB)	1.47 ± 0.57	7.550 ± 0.083	− 80.5	− 10.50	− 13.82
^{90}Sr (AB)	3.46 ± 0.65	3.703 ± 0.011	− 6.5	− 0.37	− 1.11
^{238}Pu (AB)	27.7 ± 3.8	13.745 ± 0.046	101.2	3.66	17.38
^{241}Am (A1)	24.1 ± 3.2	21.29 ± 0.32	13.1	0.88	2.25
^{244}Cm (A1)	19.2 ± 2.5	18.367 ± 0.082	4.5	0.33	0.77
^{60}Co (GH)	19.8 ± 3.0	20.86 ± 0.10	− 5.0	− 0.34	− 0.85
^{88}Y (GH)	13.0 ± 2.1	13.665 ± 0.088	− 4.7	− 0.31	− 0.80
^{133}Ba (GH)	8.5 ± 1.6	8.598 ± 0.075	− 0.7	− 0.04	− 0.13
^{137}Cs (GH)	18.8 ± 2.9	19.79 ± 0.16	− 5.1	− 0.34	− 0.88
^{139}Ce (GH)	43.3 ± 9.3	44.76 ± 0.42	− 3.2	− 0.15	− 0.55


Deviation (%) of Laboratory 136
50
0
-50
238U (A1)
241Am (A1)
244Cm (A1)
3H (B1)
14C (B1)

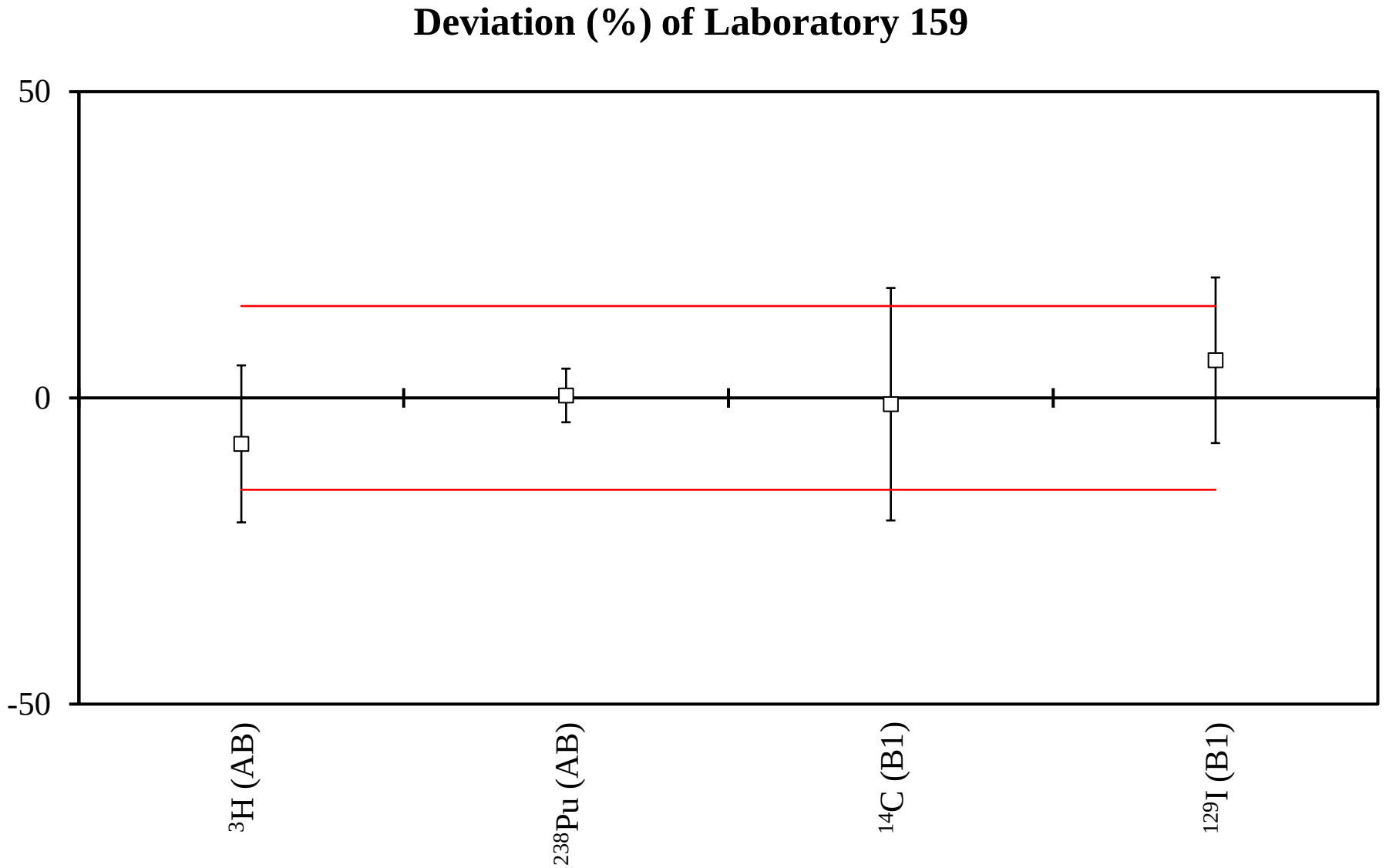
Radionuclide	Laboratory 136	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{238}U (A1)	5.56 ± 0.56	6.143 ± 0.080	− 9.5	− 1.04	− 1.64
^{241}Am (A1)	20.5 ± 3.1	21.29 ± 0.32	− 3.5	− 0.24	− 0.60
^{244}Cm (A1)	15.2 ± 2.3	18.367 ± 0.082	− 17.3	− 1.39	− 2.97
^{3}H (B1)	0.241 ± 0.031	0.2421 ± 0.0048	− 0.5	− 0.04	− 0.08
^{14}C (B1)	0.217 ± 0.033	0.2425 ± 0.0015	− 10.5	− 0.78	− 1.81


Deviation (%) of Laboratory 154
50
0
-50
3H (AB)
63Ni (AB)
90Sr (AB)
238Pu (AB)
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)

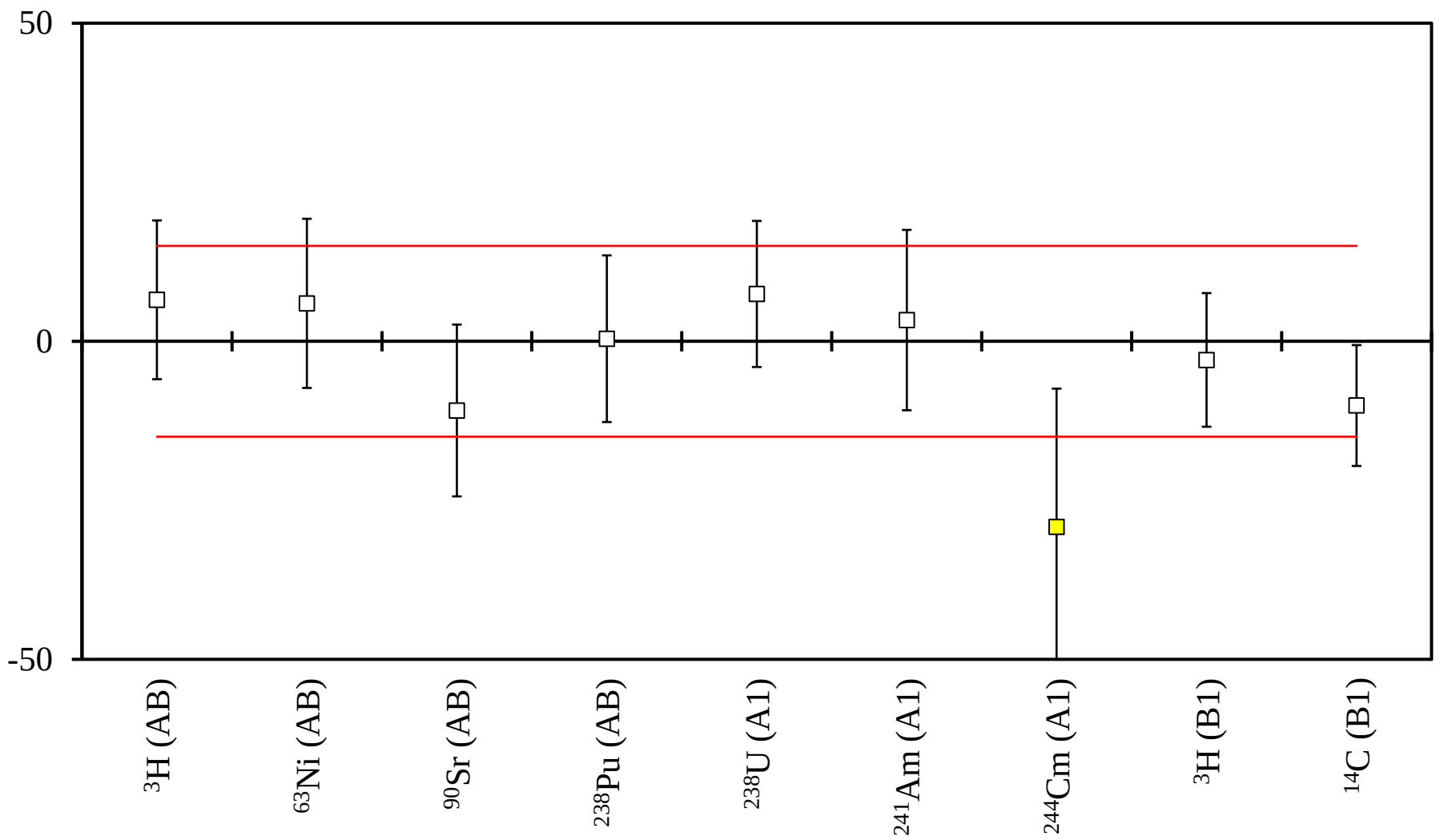
Radionuclide	Laboratory 154	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	5.66 ± 0.57	5.633 ± 0.061	0.5	0.05	0.08
^{63}Ni (AB)	7.46 ± 0.75	7.550 ± 0.083	− 1.2	− 0.12	− 0.20
^{90}Sr (AB)	3.64 ± 0.36	3.703 ± 0.011	− 1.7	− 0.17	− 0.29
^{238}Pu (AB)	13.5 ± 1.4	13.745 ± 0.046	− 1.8	− 0.18	− 0.31
^{60}Co (GH)	20.6 ± 1.1	20.86 ± 0.10	− 1.5	− 0.29	− 0.25
^{88}Y (GH)	14.1 ± 1.4	13.665 ± 0.088	3.2	0.31	0.55
^{133}Ba (GH)	9.45 ± 0.49	8.598 ± 0.075	9.9	1.71	1.71
^{137}Cs (GH)	19.66 ± 0.98	19.79 ± 0.16	− 0.6	− 0.13	− 0.11
^{139}Ce (GH)	46.6 ± 2.1	44.76 ± 0.42	4.1	0.87	0.71


Deviation (%) of Laboratory 155
50
0
-50
3H (AB)
63Ni (AB)
90Sr (AB)
238Pu (AB)
238U (A1)
241Am (A1)
244Cm (A1)
3H (B1)
14C (B1)
129I (B1)
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)

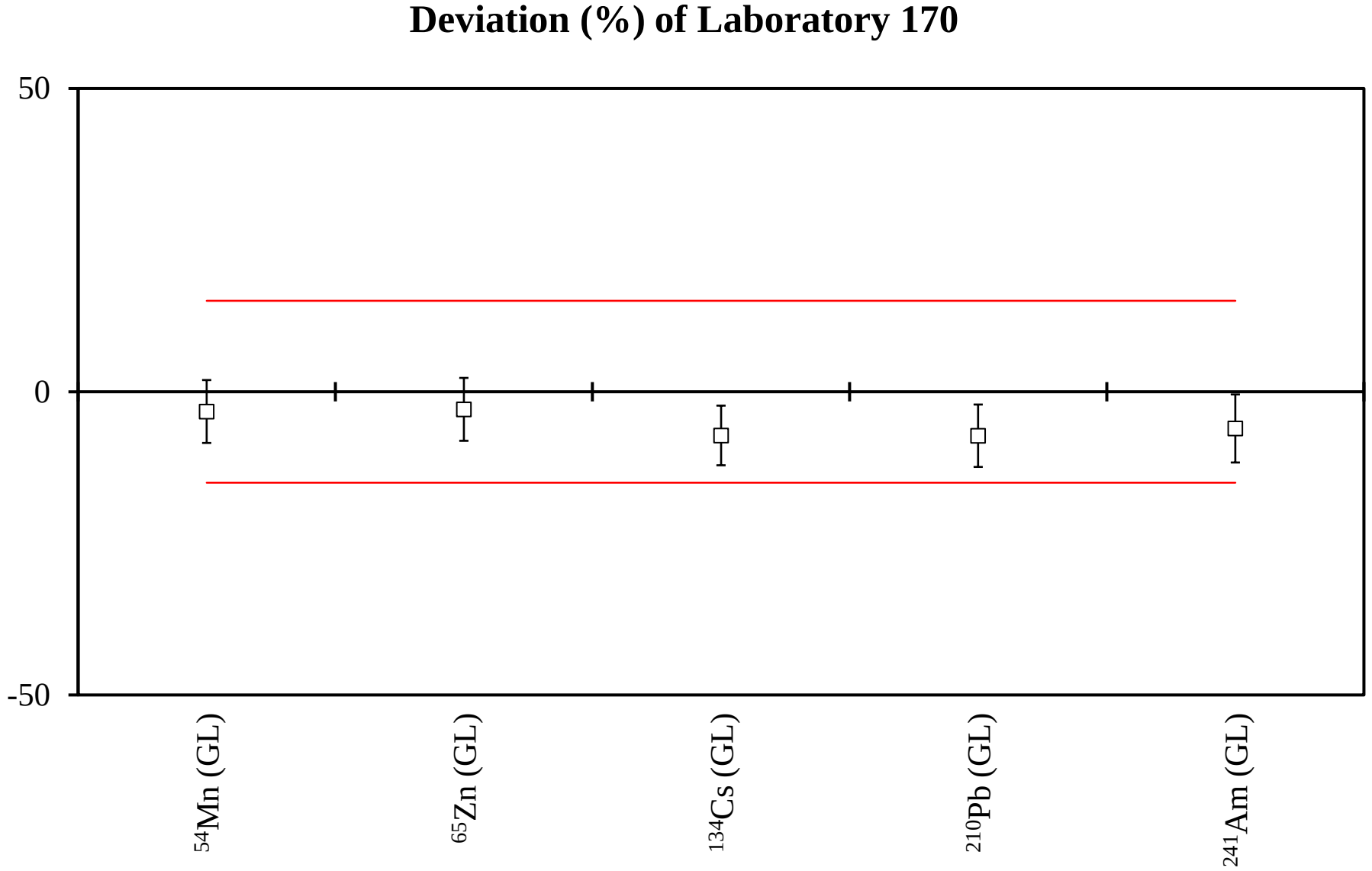
Radionuclide	Laboratory 155	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	5.44 ± 0.19	5.633 ± 0.061	− 3.4	− 0.99	− 0.59
^{63}Ni (AB)	6.66 ± 0.47	7.550 ± 0.083	− 11.9	− 1.89	− 2.04
^{90}Sr (AB)	4.21 ± 0.30	3.703 ± 0.011	13.7	1.72	2.35
^{238}Pu (AB)	14.0 ± 1.6	13.745 ± 0.046	1.7	0.15	0.29
^{238}U (A1)	6.03 ± 0.65	6.143 ± 0.080	− 1.8	− 0.17	− 0.31
^{241}Am (A1)	17.1 ± 1.6	21.29 ± 0.32	− 19.8	− 2.52	− 3.40
^{244}Cm (A1)	11.4 ± 1.1	18.367 ± 0.082	− 38.1	− 6.34	− 6.54
^{3}H (B1)	0.246 ± 0.012	0.2421 ± 0.0048	1.6	0.30	0.28
^{14}C (B1)	0.269 ± 0.013	0.2425 ± 0.0015	10.9	2.03	1.88
^{129}I (B1)	0.140 ± 0.011	0.15545 ± 0.00091	− 9.9	− 1.40	− 1.71
^{60}Co (GH)	20.82 ± 0.58	20.86 ± 0.10	− 0.2	− 0.07	− 0.03
^{88}Y (GH)	13.52 ± 0.63	13.665 ± 0.088	− 1.1	− 0.23	− 0.18
^{133}Ba (GH)	8.6 ± 1.4	8.598 ± 0.075	− 0.1	− 0.01	− 0.02
^{137}Cs (GH)	20.0 ± 1.1	19.79 ± 0.16	1.0	0.17	0.17
^{139}Ce (GH)	48.9 ± 7.8	44.76 ± 0.42	9.2	0.52	1.57


Deviation (%) of Laboratory 159
50
0
-50
^{3}H (AB)
^{238}Pu (AB)
^{14}C (B1)
^{129}I (B1)

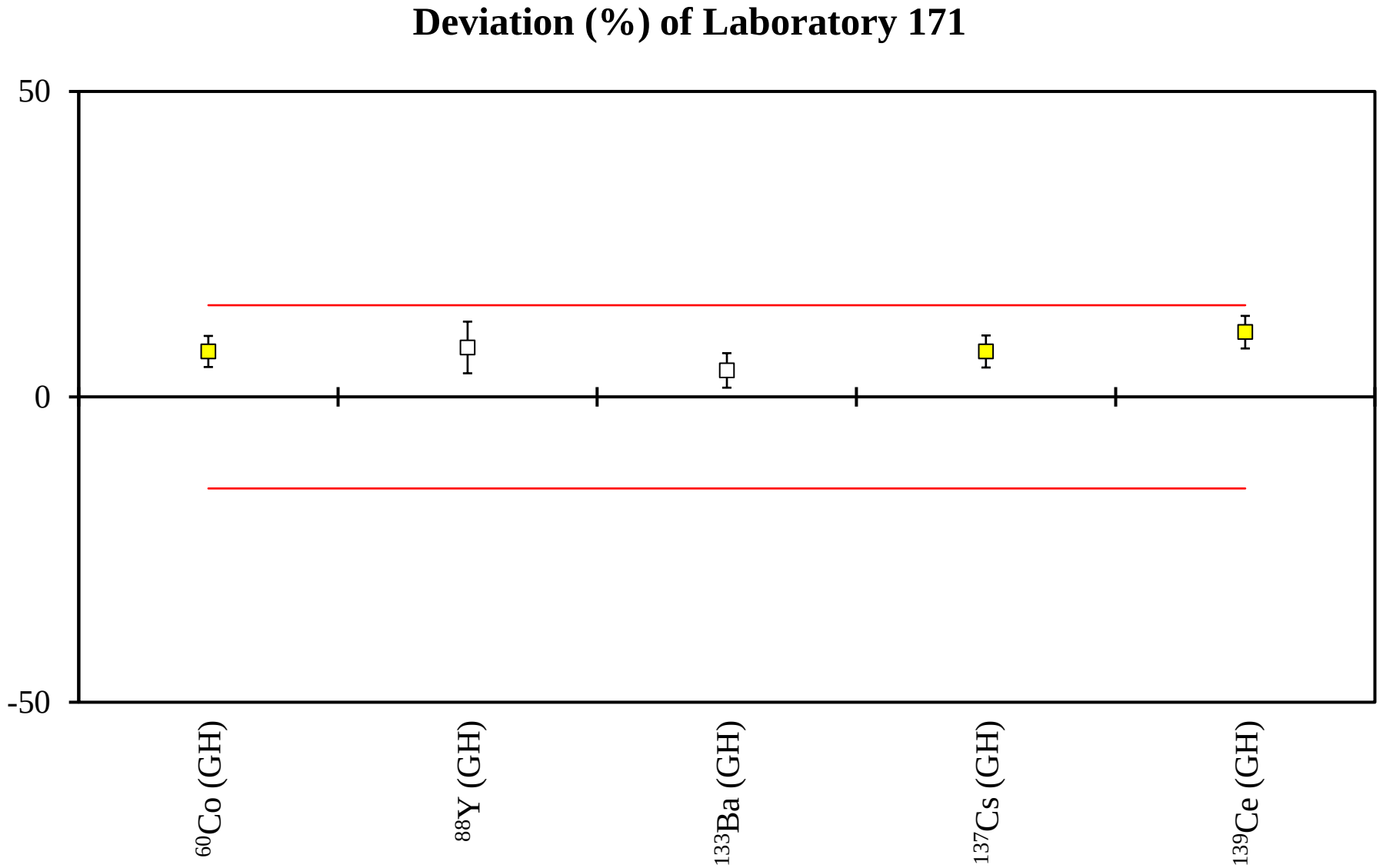
Radionuclide	Laboratory 159	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	5.21 ± 0.72	5.633 ± 0.061	− 7.6	− 0.59	− 1.30
^{238}Pu (AB)	13.8 ± 0.6	13.745 ± 0.046	0.4	0.09	0.07
^{14}C (B1)	0.240 ± 0.046	0.2425 ± 0.0015	− 1.0	− 0.05	− 0.18
^{129}I (B1)	0.165 ± 0.021	0.15545 ± 0.00091	6.2	0.45	1.06


Deviation (%) of Laboratory 169
50
0
-50
^{3}H (AB)
^{63}Ni (AB)
^{90}Sr (AB)
^{238}Pu (AB)
^{238}U (A1)
^{241}Am (A1)
^{244}Cm (A1)
^{3}H (B1)
^{14}C (B1)

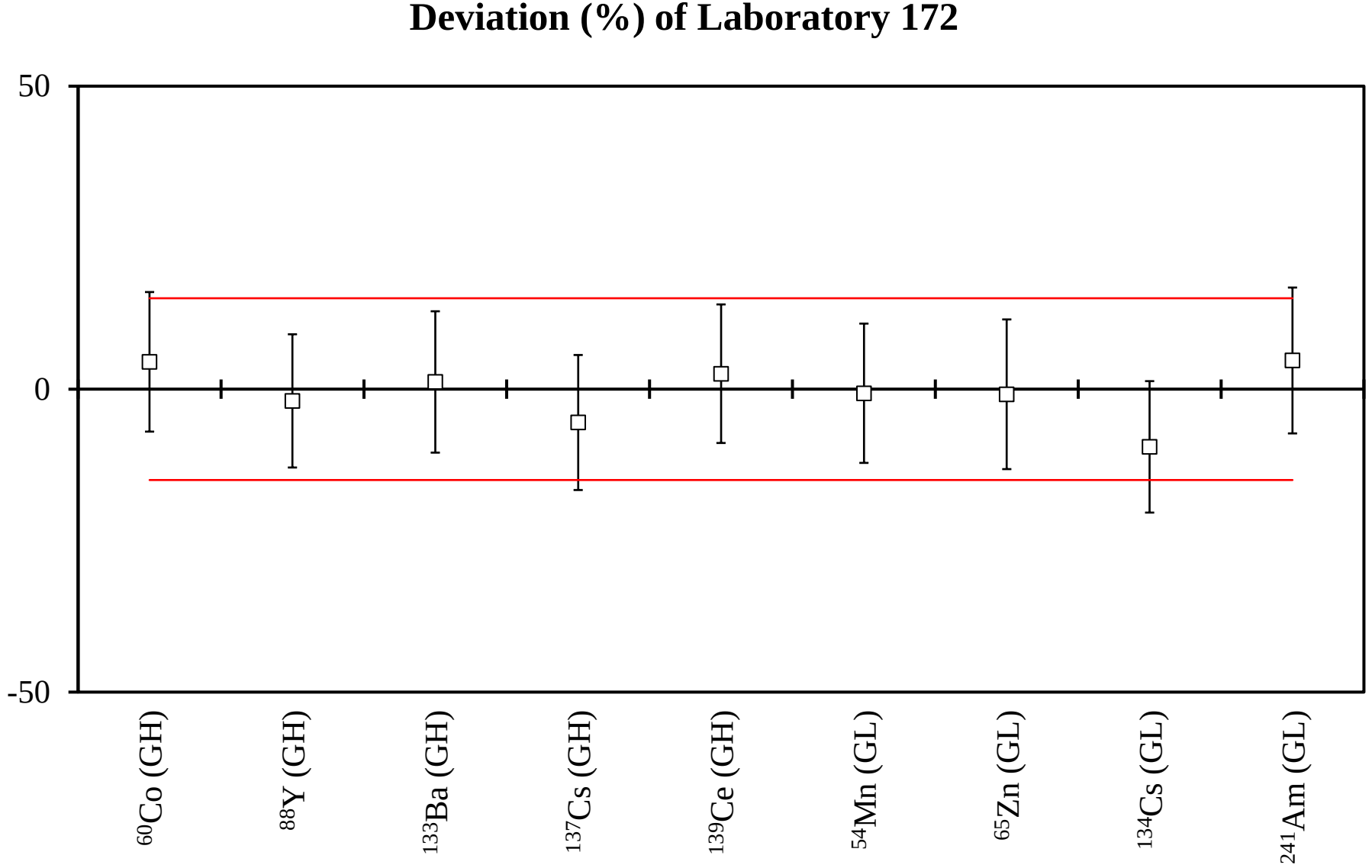
Radionuclide	Laboratory 169	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	6.0 ± 0.7	5.633 ± 0.061	6.5	0.52	1.12
^{63}Ni (AB)	8.0 ± 1.0	7.550 ± 0.083	6.0	0.45	1.02
^{90}Sr (AB)	3.30 ± 0.50	3.703 ± 0.011	− 10.9	− 0.81	− 1.87
^{238}Pu (AB)	13.8 ± 1.8	13.745 ± 0.046	0.4	0.03	0.07
^{238}U (A1)	6.6 ± 0.7	6.143 ± 0.080	7.4	0.65	1.28
^{241}Am (A1)	22.0 ± 3.0	21.29 ± 0.32	3.3	0.24	0.57
^{244}Cm (A1)	13.0 ± 4.0	18.367 ± 0.082	− 29.2	− 1.34	− 5.02
^{3}H (B1)	0.235 ± 0.025	0.2421 ± 0.0048	− 2.9	− 0.28	− 0.50
^{14}C (B1)	0.218 ± 0.023	0.2425 ± 0.0015	− 10.1	− 1.06	− 1.74


Deviation (%) of Laboratory 170
50
0
-50
54Mn (GL)
65Zn (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

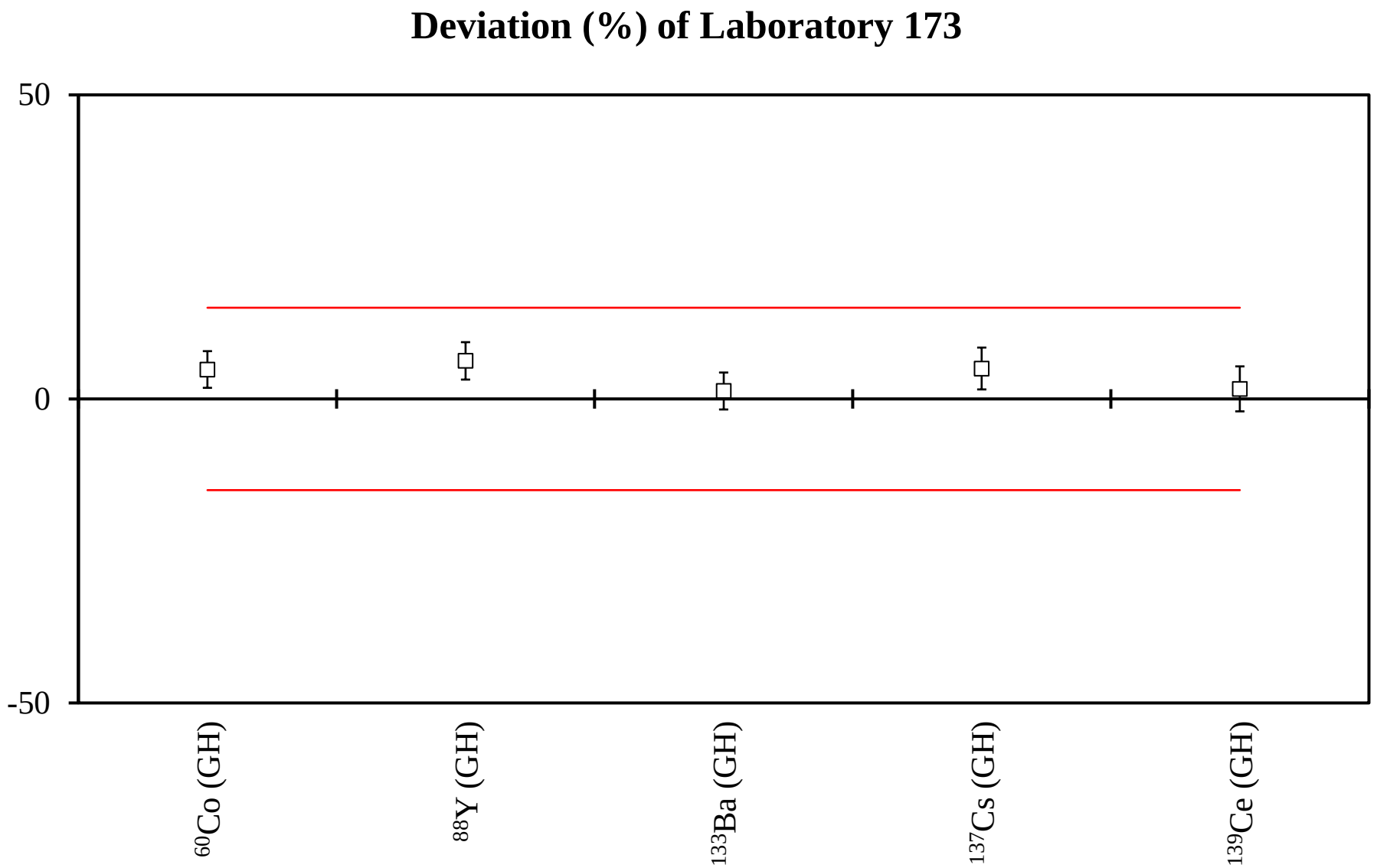
Radionuclide	Laboratory 170	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{54}Mn (GL)	41.3 ± 2.2	42.69 ± 0.25	− 3.3	− 0.63	− 0.56
^{65}Zn (GL)	37.8 ± 2.0	38.93 ± 0.28	− 2.9	− 0.55	− 0.50
^{134}Cs (GL)	12.00 ± 0.63	12.932 ± 0.093	− 7.2	− 1.46	− 1.24
^{210}Pb (GL)	20.2 ± 1.1	21.78 ± 0.23	− 7.3	− 1.39	− 1.25
^{241}Am (GL)	45.3 ± 2.7	48.22 ± 0.19	− 6.1	− 1.10	− 1.04


Deviation (%) of Laboratory 171
50
0
-50
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)

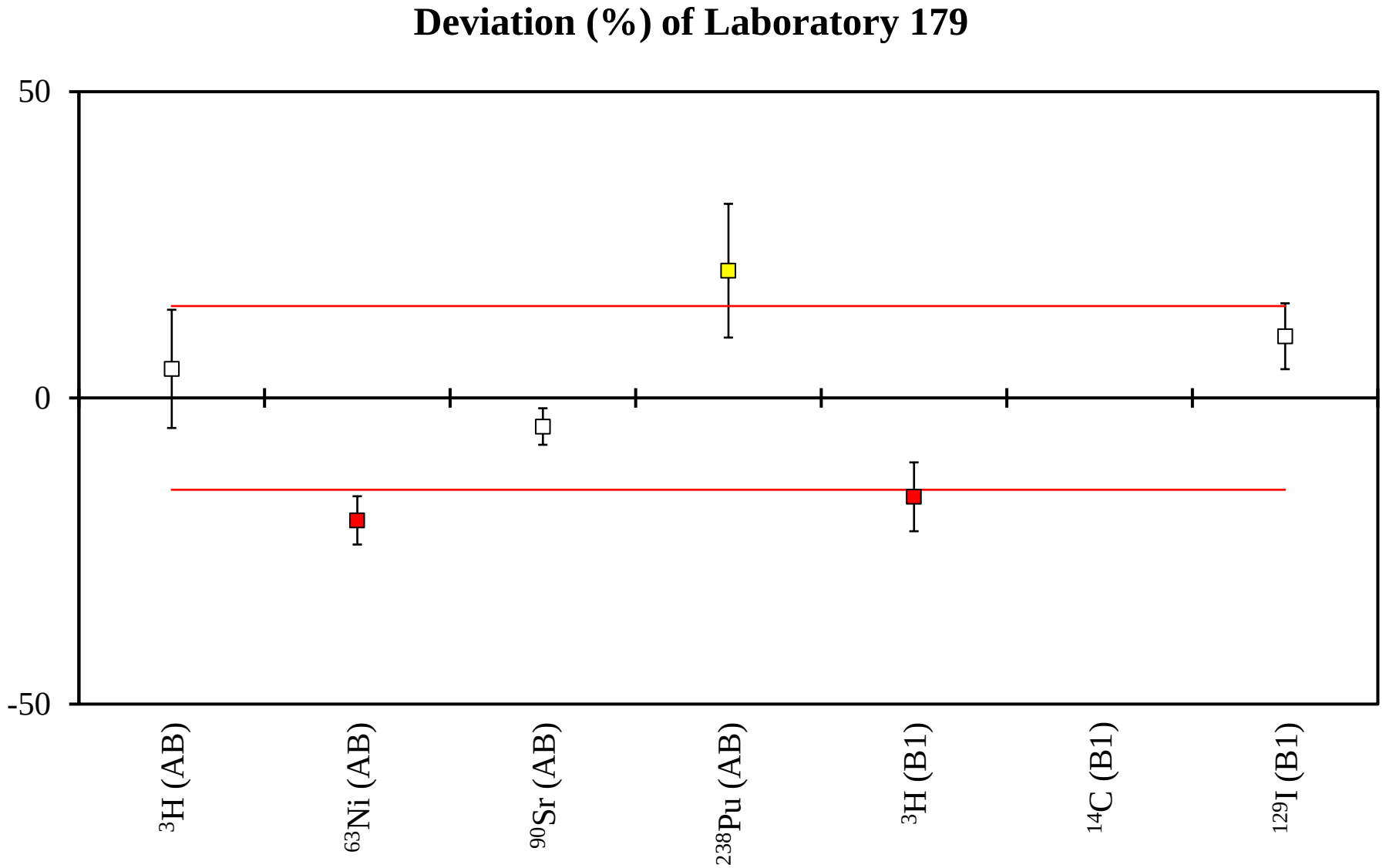
Radionuclide	Laboratory 171	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{60}Co (GH)	22.41 ± 0.52	20.86 ± 0.10	7.4	2.95	1.28
^{88}Y (GH)	14.77 ± 0.57	13.665 ± 0.088	8.1	1.92	1.39
^{133}Ba (GH)	8.97 ± 0.23	8.598 ± 0.075	4.3	1.57	0.75
^{137}Cs (GH)	21.26 ± 0.49	19.79 ± 0.16	7.4	2.84	1.28
^{139}Ce (GH)	49.5 ± 1.1	44.76 ± 0.42	10.5	3.86	1.80


Deviation (%) of Laboratory 172
50
0
-50
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)
54Mn (GL)
65Zn (GL)
134Cs (GL)
241Am (GL)

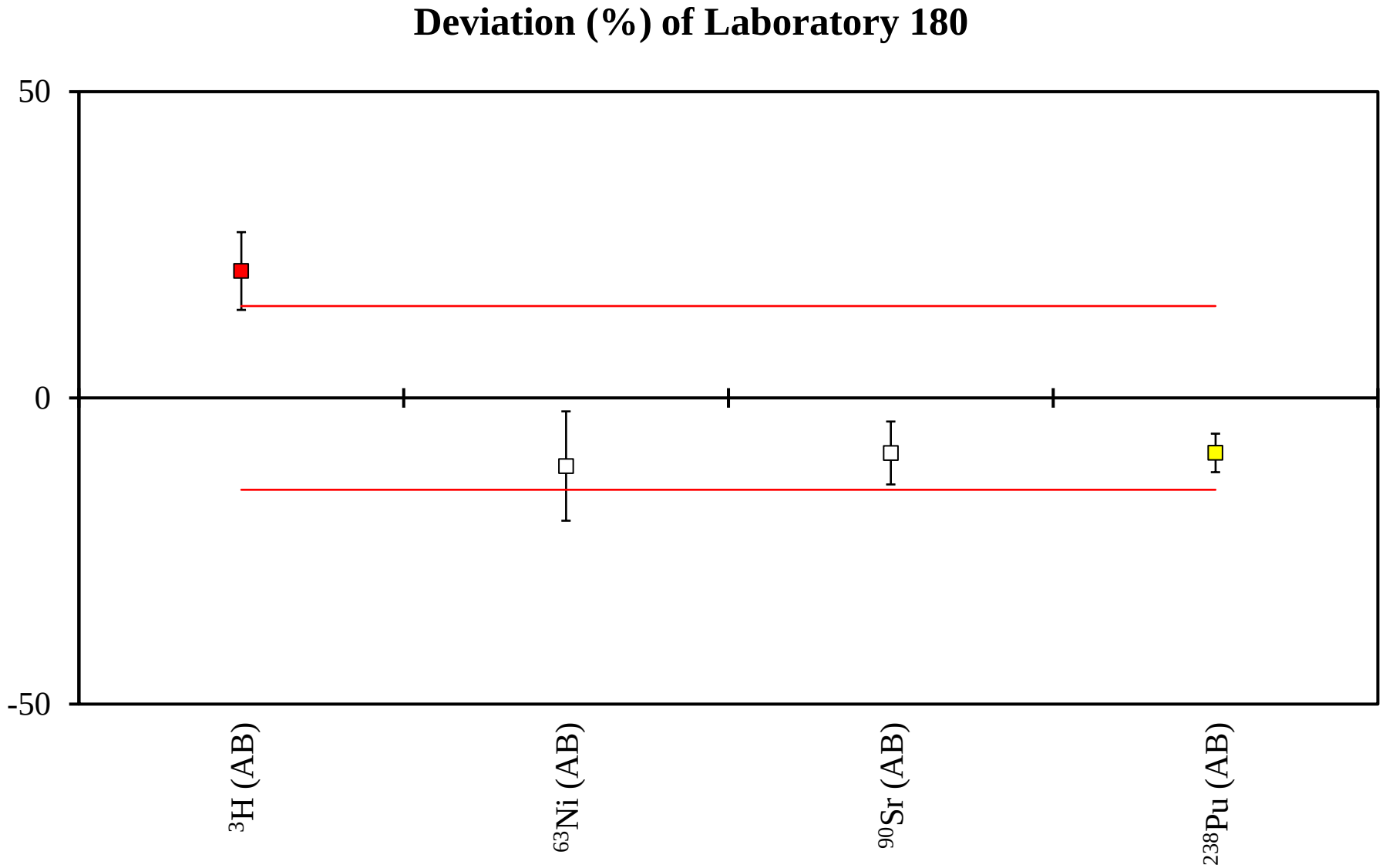
Radionuclide	Laboratory 172	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{60}Co (GH)	21.8 ± 2.4	20.86 ± 0.10	4.5	0.39	0.77
^{88}Y (GH)	13.4 ± 1.5	13.665 ± 0.088	− 1.9	− 0.18	− 0.33
^{133}Ba (GH)	8.7 ± 1.0	8.598 ± 0.075	1.2	0.10	0.20
^{137}Cs (GH)	18.7 ± 2.2	19.79 ± 0.16	− 5.5	− 0.49	− 0.95
^{139}Ce (GH)	45.9 ± 5.1	44.76 ± 0.42	2.5	0.22	0.44
^{54}Mn (GL)	42.4 ± 4.9	42.69 ± 0.25	− 0.7	− 0.06	− 0.12
^{65}Zn (GL)	38.6 ± 4.8	38.93 ± 0.28	− 0.8	− 0.07	− 0.15
^{134}Cs (GL)	11.7 ± 1.4	12.932 ± 0.093	− 9.5	− 0.88	− 1.64
^{241}Am (GL)	50.5 ± 5.8	48.22 ± 0.19	4.7	0.39	0.81


Deviation (%) of Laboratory 173
50
0
-50
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)

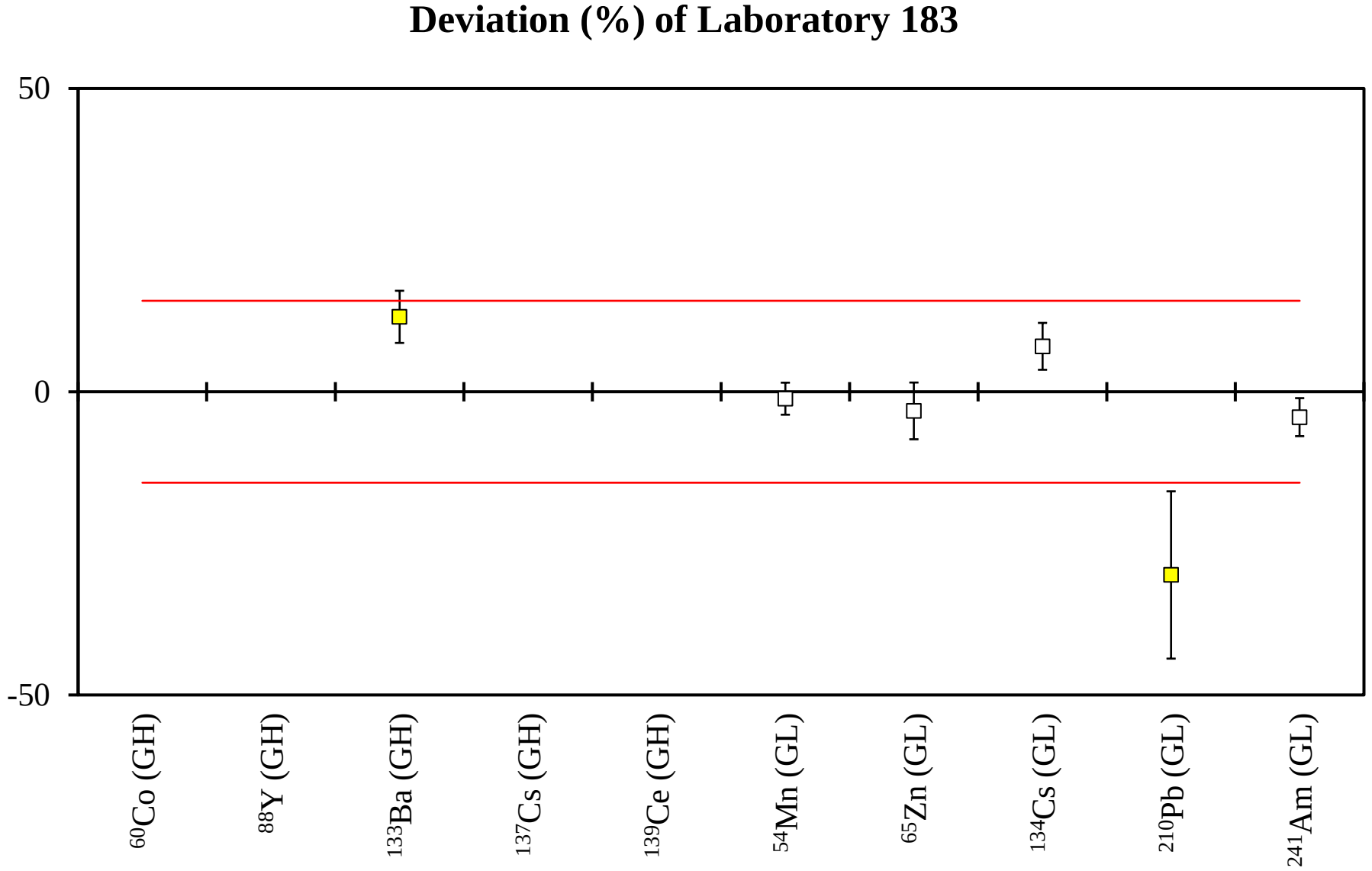
Radionuclide	Laboratory 173	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{60}Co (GH)	21.87 ± 0.62	20.86 ± 0.10	4.8	1.59	0.83
^{88}Y (GH)	14.52 ± 0.41	13.665 ± 0.088	6.3	2.05	1.08
^{133}Ba (GH)	8.71 ± 0.25	8.598 ± 0.075	1.3	0.42	0.22
^{137}Cs (GH)	20.78 ± 0.66	19.79 ± 0.16	5.0	1.46	0.86
^{139}Ce (GH)	45.5 ± 1.6	44.76 ± 0.42	1.6	0.42	0.27


Deviation (%) of Laboratory 179
50
0
-50
^{3}H (AB)
^{63}Ni (AB)
^{90}Sr (AB)
^{238}Pu (AB)
^{3}H (B1)
^{14}C (B1)
^{129}I (B1)

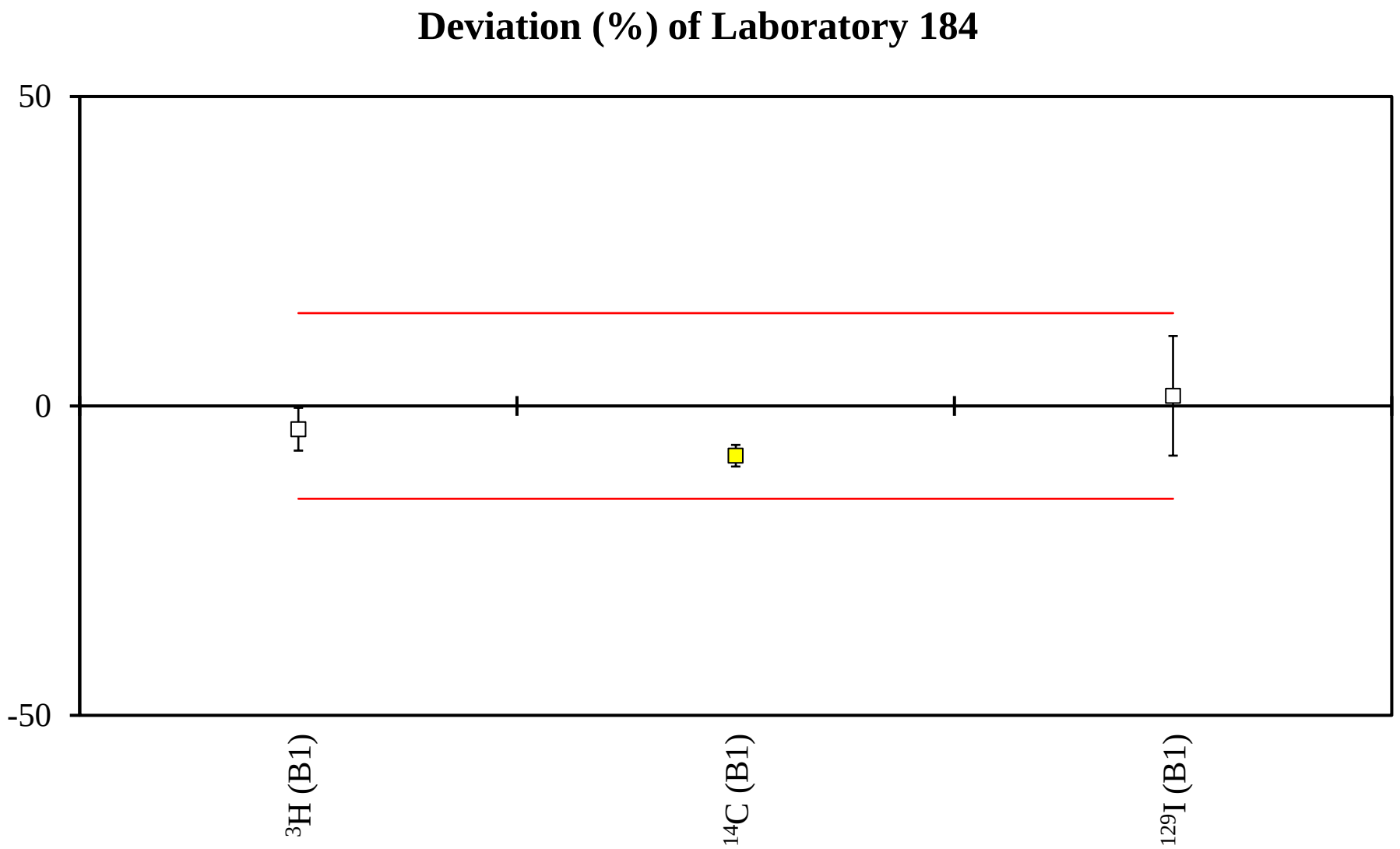
Radionuclide	Laboratory 179	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	5.90 ± 0.54	5.633 ± 0.061	4.8	0.50	0.82
^{63}Ni (AB)	6.04 ± 0.29	7.550 ± 0.083	− 20.0	− 5.02	− 3.43
^{90}Sr (AB)	3.53 ± 0.11	3.703 ± 0.011	− 4.6	− 1.56	− 0.80
^{238}Pu (AB)	16.6 ± 1.5	13.745 ± 0.046	20.7	1.91	3.55
^{3}H (B1)	0.203 ± 0.013	0.2421 ± 0.0048	− 16.2	− 2.82	− 2.78
^{14}C (B1)	0.398 ± 0.027	0.2425 ± 0.0015	64.0	5.75	11.00
^{129}I (B1)	0.1711 ± 0.0083	0.15545 ± 0.00091	10.1	1.87	1.73


Deviation (%) of Laboratory 180
50
0
-50
^{3}H (AB)
^{63}Ni (AB)
^{90}Sr (AB)
^{238}Pu (AB)

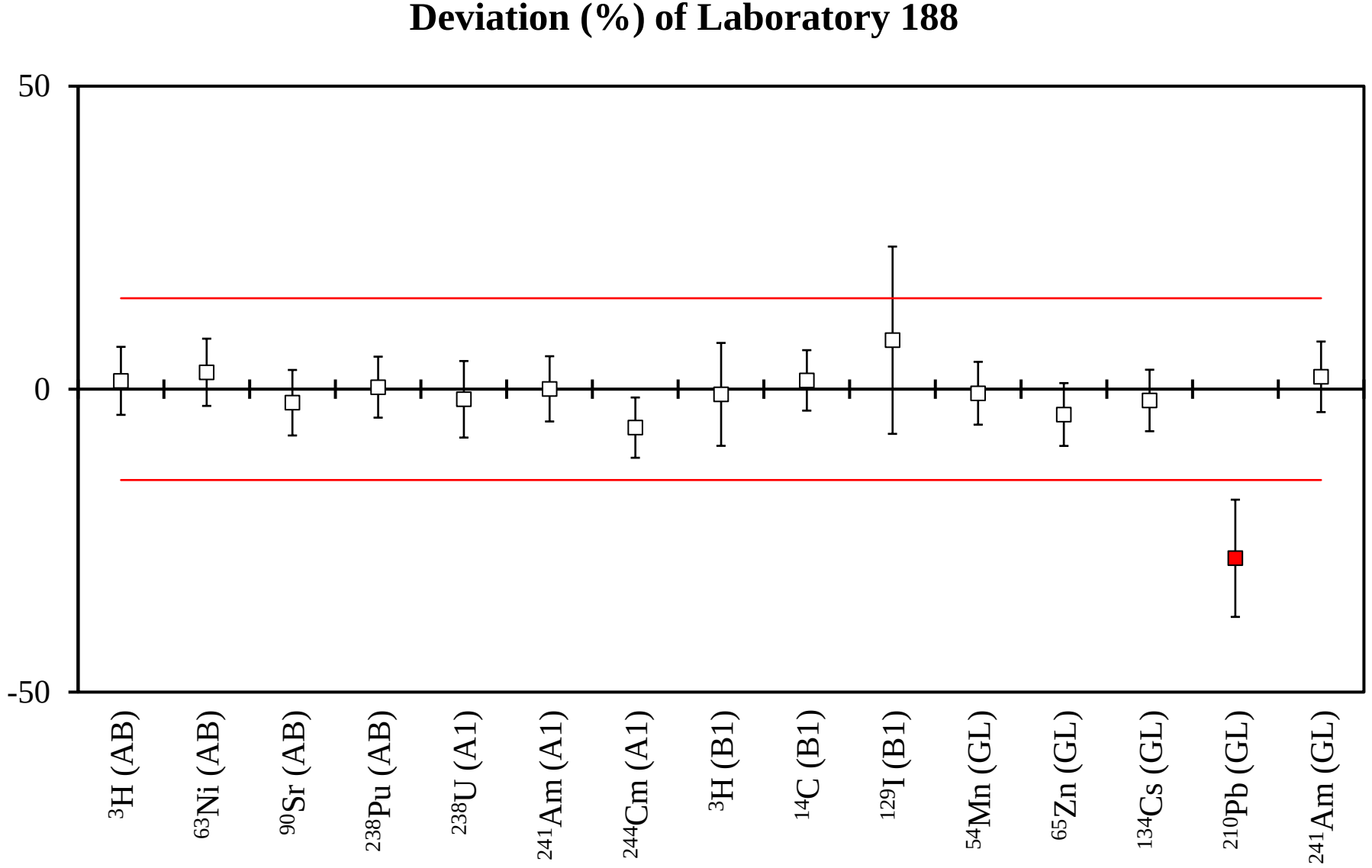
Radionuclide	Laboratory 180	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	6.80 ± 0.35	5.633 ± 0.061	20.7	3.28	3.56
^{63}Ni (AB)	6.71 ± 0.67	7.550 ± 0.083	− 11.1	− 1.24	− 1.91
^{90}Sr (AB)	3.37 ± 0.19	3.703 ± 0.011	− 9.0	− 1.75	− 1.54
^{238}Pu (AB)	12.51 ± 0.43	13.745 ± 0.046	− 9.0	− 2.86	− 1.54


Deviation (%) of Laboratory 183
50
0
-50
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)
54Mn (GL)
65Zn (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

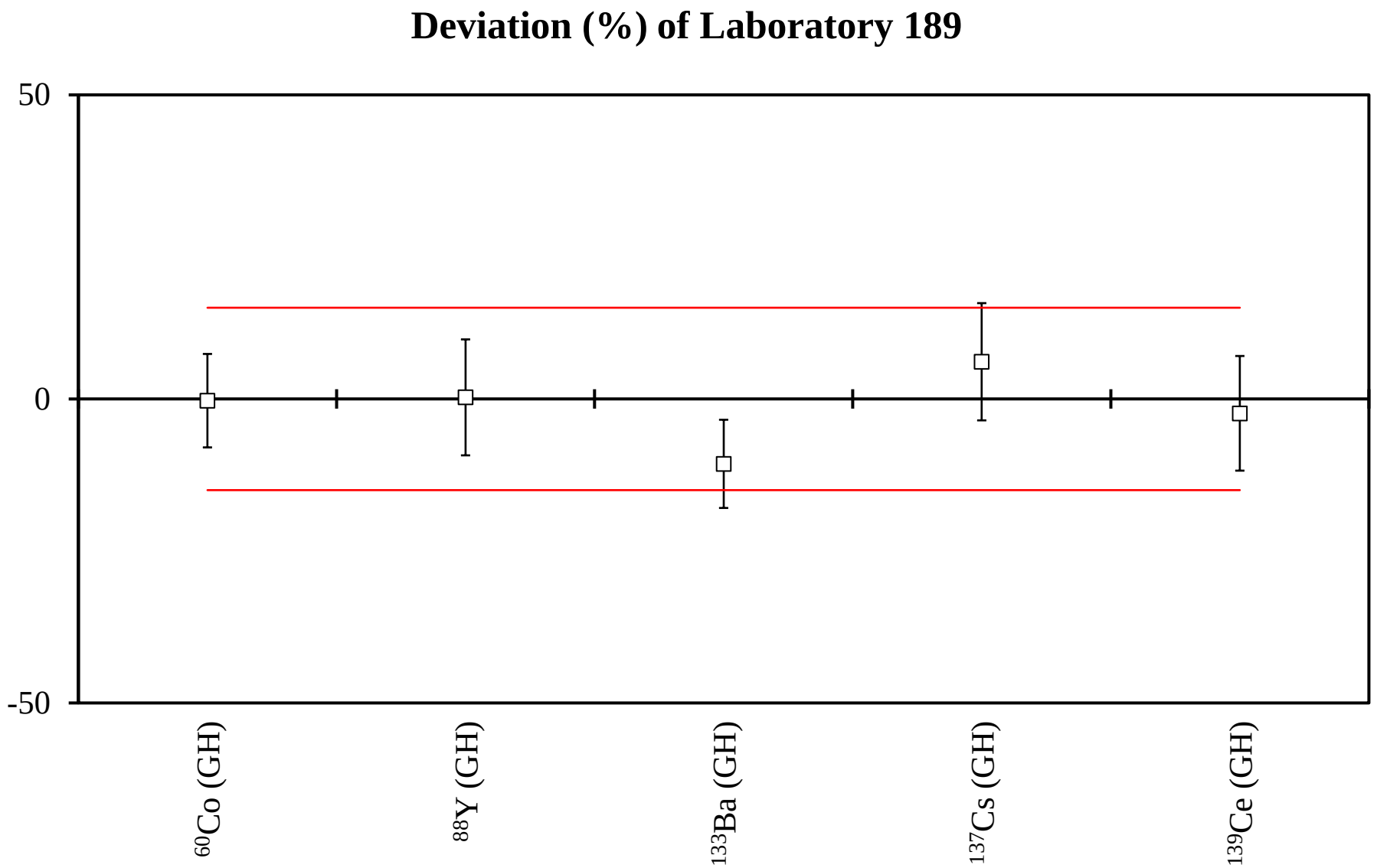
Radionuclide	Laboratory 183	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{60}Co (GH)	7.07 ± 0.17	20.86 ± 0.10	− 66.1	− 10.22	− 11.35
^{88}Y (GH)	4.59 ± 0.13	13.665 ± 0.088	− 66.4	− 58.42	− 11.40
^{133}Ba (GH)	9.66 ± 0.36	8.598 ± 0.075	12.4	2.92	2.12
^{137}Cs (GH)	6.69 ± 0.11	19.79 ± 0.16	− 66.2	− 67.07	− 11.37
^{139}Ce (GH)	14.50 ± 0.45	44.76 ± 0.42	− 67.6	− 48.98	− 11.61
^{54}Mn (GL)	42.2 ± 1.1	42.69 ± 0.25	− 1.1	− 0.45	− 0.20
^{65}Zn (GL)	37.7 ± 1.8	38.93 ± 0.28	− 3.2	− 0.69	− 0.54
^{134}Cs (GL)	13.90 ± 0.49	12.932 ± 0.093	7.5	1.95	1.29
^{210}Pb (GL)	15.2 ± 3.0	21.78 ± 0.23	− 30.2	− 2.19	− 5.19
^{241}Am (GL)	46.2 ± 1.5	48.22 ± 0.19	− 4.2	− 1.33	− 0.72


Deviation (%) of Laboratory 184
50
0
-50
3H (B1)
14C (B1)
129I (B1)

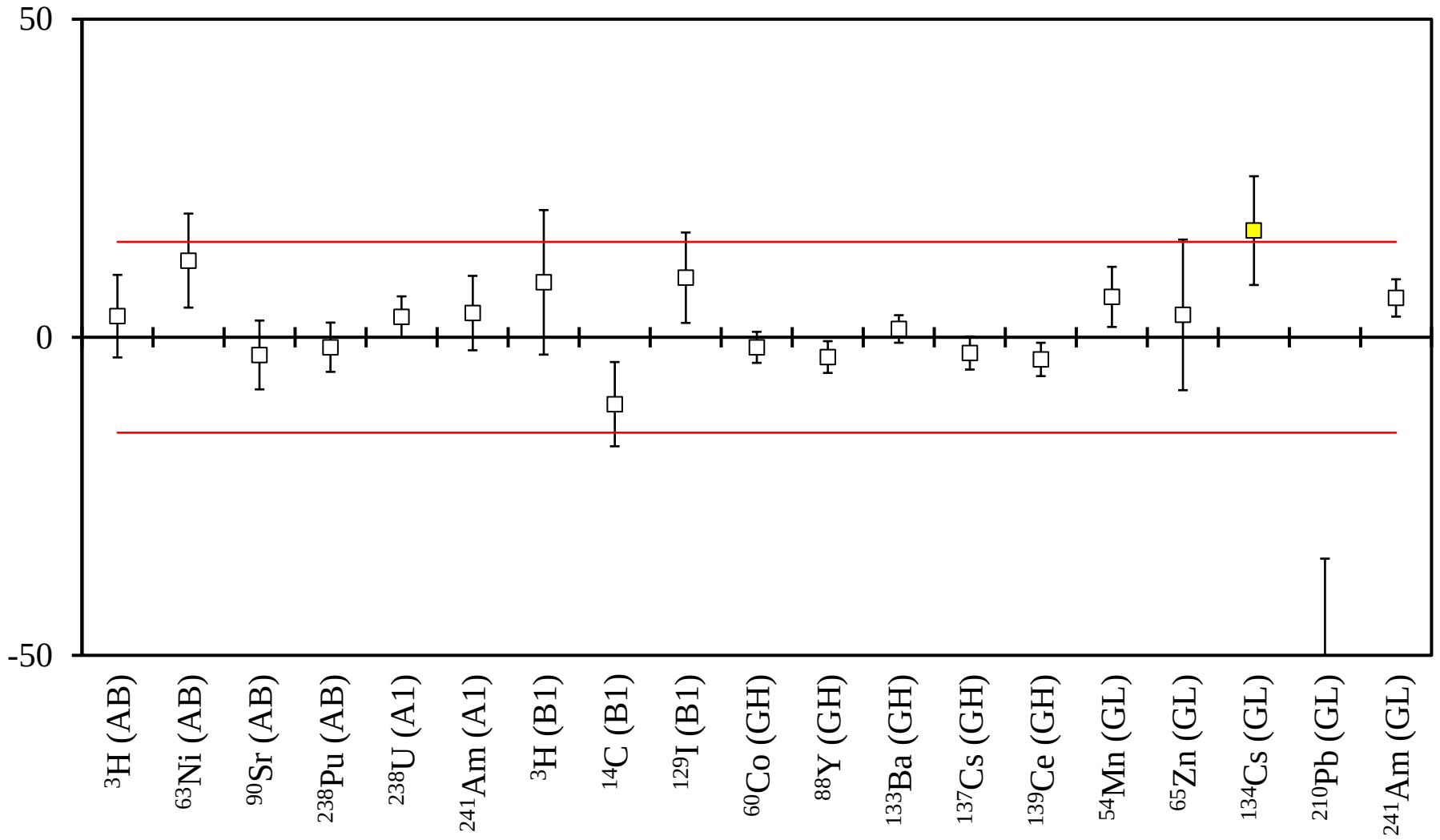
Radionuclide	Laboratory 184	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.2330 ± 0.0070	0.2421 ± 0.0048	− 3.8	− 1.07	− 0.65
^{14}C (B1)	0.2230 ± 0.0040	0.2425 ± 0.0015	− 8.0	− 4.56	− 1.38
^{129}I (B1)	0.158 ± 0.015	0.15545 ± 0.00091	1.6	0.19	0.31


Deviation (%) of Laboratory 188
50
0
-50
3H (AB)
63Ni (AB)
90Sr (AB)
238Pu (AB)
238U (A1)
241Am (A1)
244Cm (A1)
3H (B1)
14C (B1)
129I (B1)
54Mn (GL)
65Zn (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

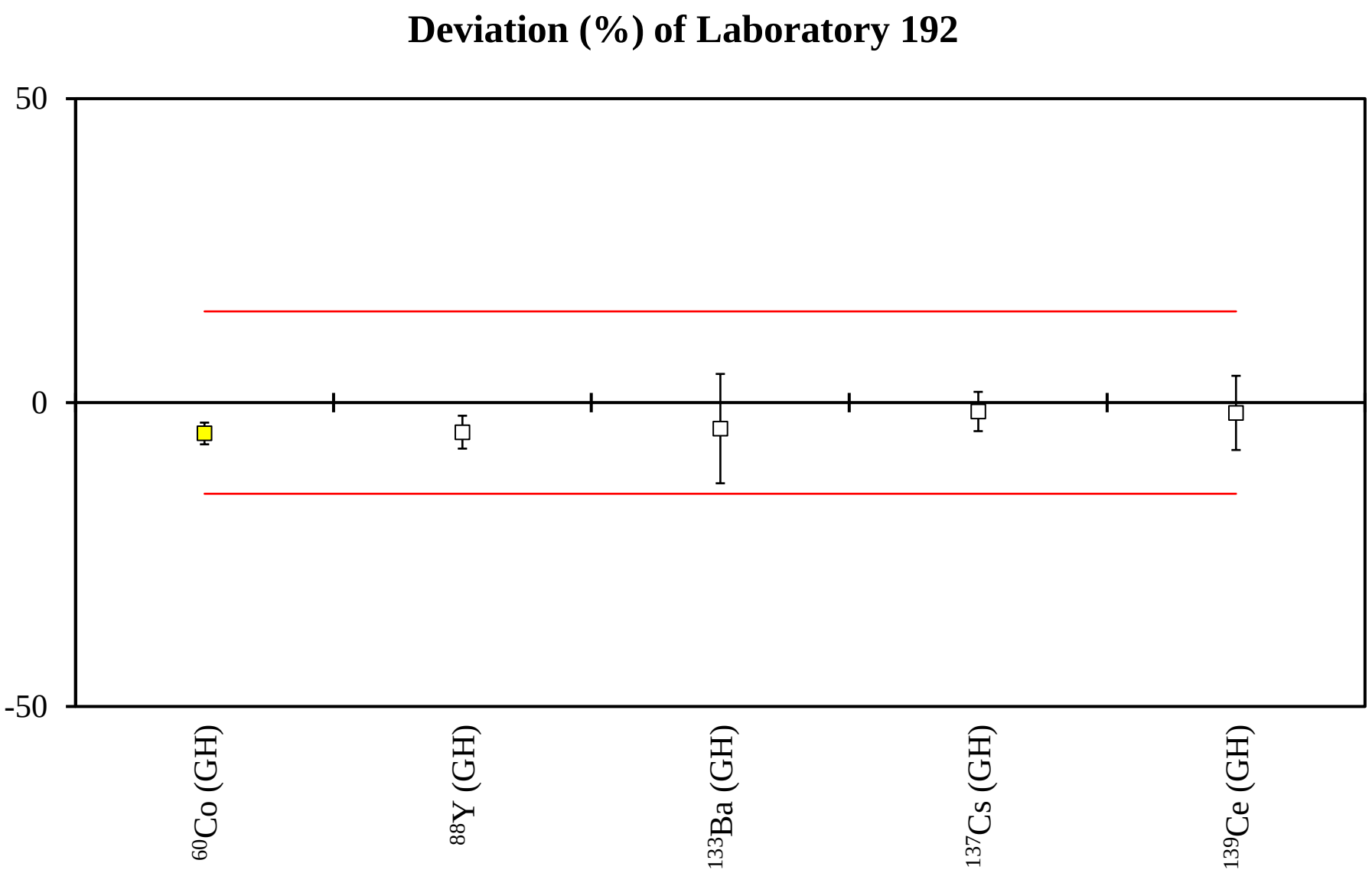
Radionuclide	Laboratory 188	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	5.71 ± 0.31	5.633 ± 0.061	1.4	0.24	0.23
^{63}Ni (AB)	7.76 ± 0.41	7.550 ± 0.083	2.8	0.50	0.48
^{90}Sr (AB)	3.62 ± 0.20	3.703 ± 0.011	− 2.2	− 0.41	− 0.38
^{238}Pu (AB)	13.79 ± 0.69	13.745 ± 0.046	0.3	0.07	0.06
^{238}U (A1)	6.04 ± 0.38	6.143 ± 0.080	− 1.7	− 0.27	− 0.29
^{241}Am (A1)	21.3 ± 1.1	21.29 ± 0.32	0.0	0.01	0.01
^{244}Cm (A1)	17.20 ± 0.91	18.367 ± 0.082	− 6.4	− 1.28	− 1.09
^{3}H (B1)	0.240 ± 0.020	0.2421 ± 0.0048	− 0.9	− 0.10	− 0.15
^{14}C (B1)	0.246 ± 0.012	0.2425 ± 0.0015	1.4	0.29	0.25
^{129}I (B1)	0.168 ± 0.024	0.15545 ± 0.00091	8.1	0.52	1.39
^{54}Mn (GL)	42.4 ± 2.2	42.69 ± 0.25	− 0.7	− 0.13	− 0.12
^{65}Zn (GL)	37.3 ± 2.0	38.93 ± 0.28	− 4.2	− 0.81	− 0.72
^{134}Cs (GL)	12.69 ± 0.65	12.932 ± 0.093	− 1.9	− 0.37	− 0.32
^{210}Pb (GL)	15.7 ± 2.1	21.78 ± 0.23	− 27.9	− 2.88	− 4.79
^{241}Am (GL)	49.2 ± 2.8	48.22 ± 0.19	2.0	0.35	0.35


Deviation (%) of Laboratory 189
50
0
-50
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)

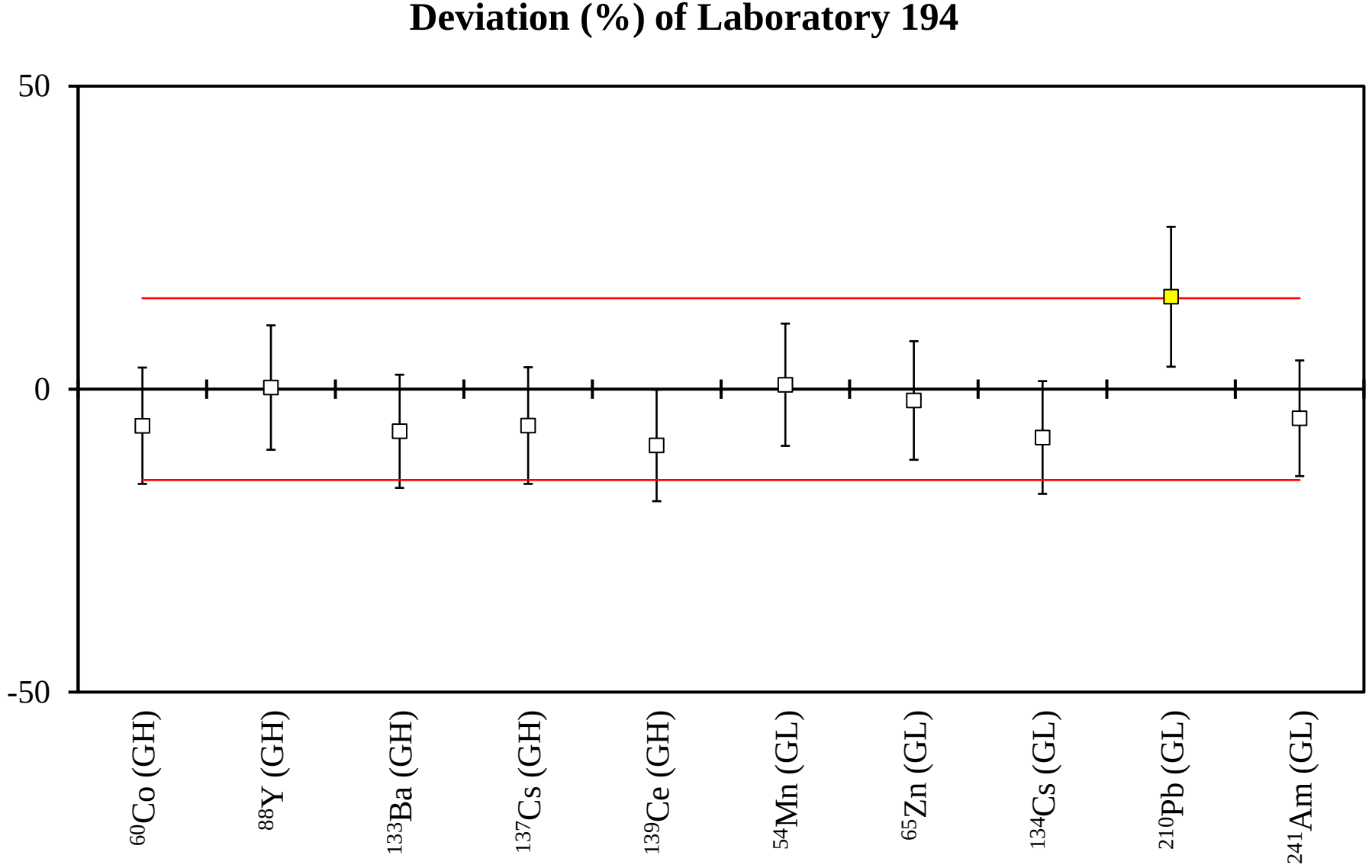
Radionuclide	Laboratory 189	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{60}Co (GH)	20.8 ± 1.6	20.86 ± 0.10	− 0.3	− 0.02	− 0.02
^{88}Y (GH)	13.7 ± 1.3	13.665 ± 0.088	0.3	0.03	0.04
^{133}Ba (GH)	7.68 ± 0.62	8.598 ± 0.075	− 10.7	− 1.47	− 1.83
^{137}Cs (GH)	21.0 ± 1.9	19.79 ± 0.16	6.1	0.61	1.02
^{139}Ce (GH)	43.7 ± 4.2	44.76 ± 0.42	− 2.4	− 0.25	− 0.40


Deviation (%) of Laboratory 190
50
0
-50
3H (AB)
63Ni (AB)
90Sr (AB)
238Pu (AB)
238U (A1)
241Am (A1)
3H (B1)
14C (B1)
129I (B1)
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)
54Mn (GL)
65Zn (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

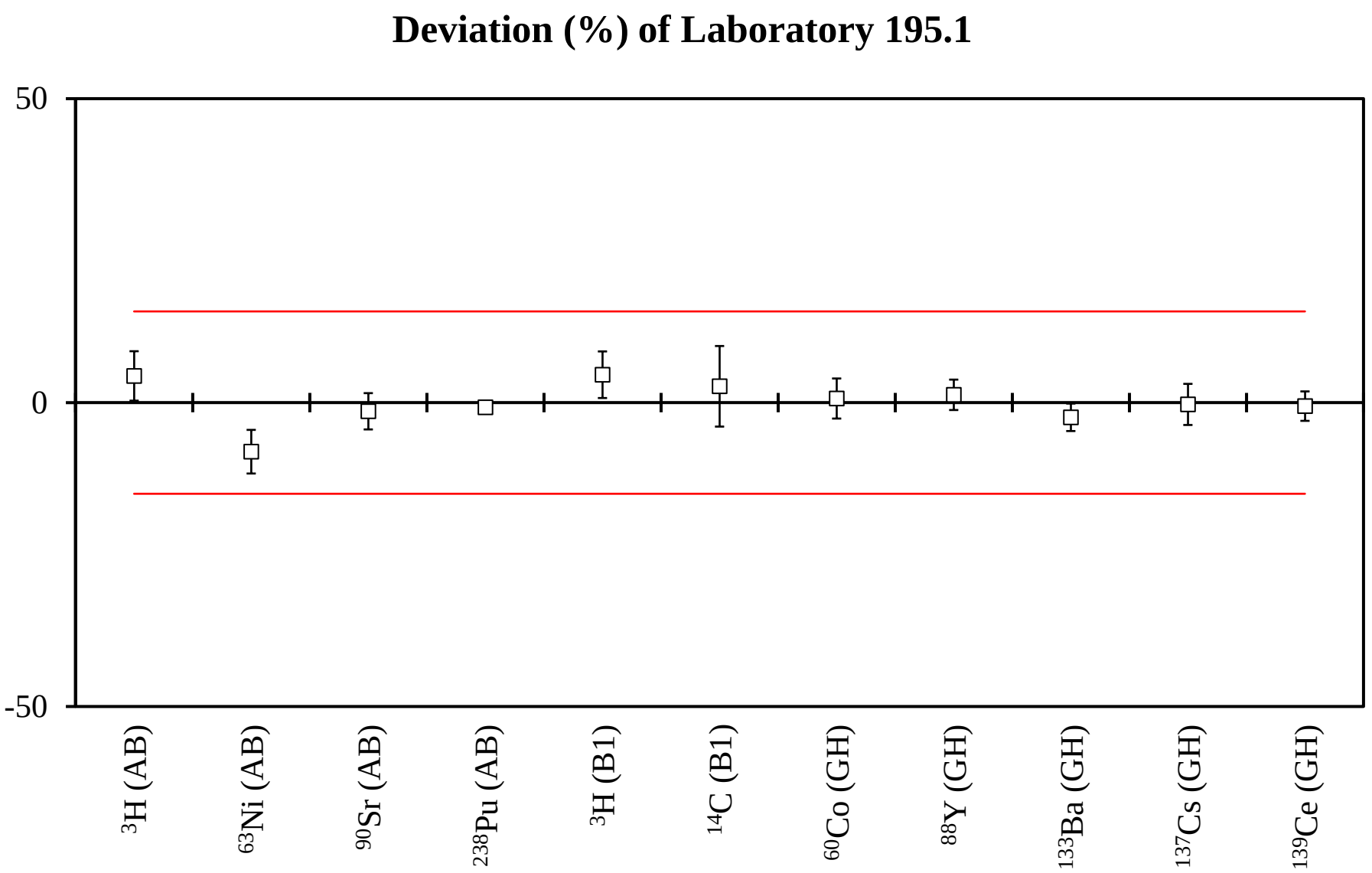
Radionuclide	Laboratory 190	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	5.82 ± 0.36	5.633 ± 0.061	3.3	0.51	0.57
^{63}Ni (AB)	8.46 ± 0.55	7.550 ± 0.083	12.1	1.64	2.07
^{90}Sr (AB)	3.60 ± 0.20	3.703 ± 0.011	− 2.8	− 0.51	− 0.48
^{238}Pu (AB)	13.53 ± 0.53	13.745 ± 0.046	− 1.6	− 0.40	− 0.27
^{238}U (A1)	6.34 ± 0.18	6.143 ± 0.080	3.2	1.00	0.55
^{241}Am (A1)	22.1 ± 1.2	21.29 ± 0.32	3.8	0.65	0.65
^{3}H (B1)	0.263 ± 0.027	0.2421 ± 0.0048	8.6	0.76	1.48
^{14}C (B1)	0.217 ± 0.016	0.2425 ± 0.0015	− 10.5	− 1.59	− 1.81
^{129}I (B1)	0.170 ± 0.011	0.15545 ± 0.00091	9.4	1.32	1.61
^{60}Co (GH)	20.53 ± 0.50	20.86 ± 0.10	− 1.6	− 0.65	− 0.27
^{88}Y (GH)	13.24 ± 0.33	13.665 ± 0.088	− 3.1	− 1.24	− 0.53
^{133}Ba (GH)	8.71 ± 0.17	8.598 ± 0.075	1.3	0.60	0.22
^{137}Cs (GH)	19.30 ± 0.49	19.79 ± 0.16	− 2.5	− 0.95	− 0.43
^{139}Ce (GH)	43.2 ± 1.1	44.76 ± 0.42	− 3.5	− 1.32	− 0.60
^{54}Mn (GL)	45.4 ± 2.0	42.69 ± 0.25	6.3	1.34	1.09
^{65}Zn (GL)	40.3 ± 4.6	38.93 ± 0.28	3.5	0.30	0.60
^{134}Cs (GL)	15.1 ± 1.1	12.932 ± 0.093	16.8	1.96	2.88
^{210}Pb (GL)	7.6 ± 6.6	21.78 ± 0.23	− 65.1	− 2.15	− 11.18
^{241}Am (GL)	51.2 ± 1.4	48.22 ± 0.19	6.2	2.11	1.06


Deviation (%) of Laboratory 192
50
0
-50
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)

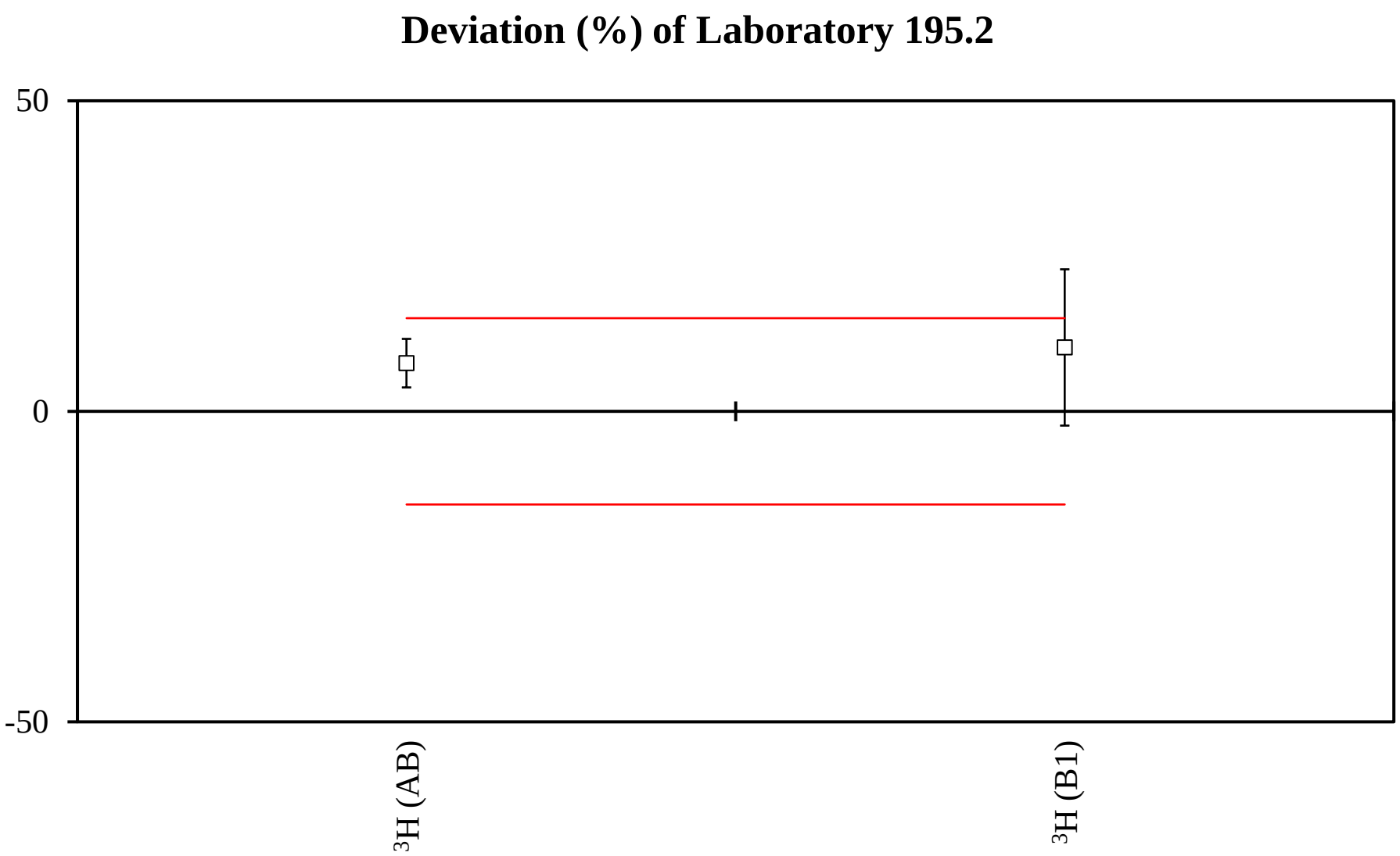
Radionuclide	Laboratory 192	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{60}Co (GH)	19.80 ± 0.36	20.86 ± 0.10	− 5.1	− 2.81	− 0.87
^{88}Y (GH)	13.00 ± 0.36	13.665 ± 0.088	− 4.9	− 1.79	− 0.84
^{133}Ba (GH)	8.23 ± 0.77	8.598 ± 0.075	− 4.3	− 0.48	− 0.74
^{137}Cs (GH)	19.50 ± 0.62	19.79 ± 0.16	− 1.5	− 0.45	− 0.25
^{139}Ce (GH)	44.0 ± 2.7	44.76 ± 0.42	− 1.7	− 0.28	− 0.29


Deviation (%) of Laboratory 194
50
0
-50
60Co (GH)
88Y (GH)
133Ba (GH)
137Cs (GH)
139Ce (GH)
54Mn (GL)
65Zn (GL)
134Cs (GL)
210Pb (GL)
241Am (GL)

Radionuclide	Laboratory 194	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{60}Co (GH)	19.6 ± 2.0	20.86 ± 0.10	− 6.0	− 0.63	− 1.04
^{88}Y (GH)	13.7 ± 1.4	13.665 ± 0.088	0.3	0.02	0.04
^{133}Ba (GH)	8.00 ± 0.80	8.598 ± 0.075	− 7.0	− 0.74	− 1.19
^{137}Cs (GH)	18.6 ± 1.9	19.79 ± 0.16	− 6.0	− 0.62	− 1.03
^{139}Ce (GH)	40.6 ± 4.1	44.76 ± 0.42	− 9.3	− 1.01	− 1.60
^{54}Mn (GL)	43.0 ± 4.3	42.69 ± 0.25	0.7	0.07	0.12
^{65}Zn (GL)	38.2 ± 3.8	38.93 ± 0.28	− 1.9	− 0.19	− 0.32
^{134}Cs (GL)	11.9 ± 1.2	12.932 ± 0.093	− 8.0	− 0.86	− 1.37
^{210}Pb (GL)	25.1 ± 2.5	21.78 ± 0.23	15.2	1.32	2.62
^{241}Am (GL)	45.9 ± 4.6	48.22 ± 0.19	− 4.8	− 0.50	− 0.83


Deviation (%) of Laboratory 195.1
50
0
-50
^{3}H (AB)
^{63}Ni (AB)
^{90}Sr (AB)
^{238}Pu (AB)
^{3}H (B1)
^{14}C (B1)
^{60}Co (GH)
^{88}Y (GH)
^{133}Ba (GH)
^{137}Cs (GH)
^{139}Ce (GH)

Radionuclide	Laboratory 195.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	5.88 ± 0.22	5.633 ± 0.061	4.4	1.08	0.75
^{63}Ni (AB)	6.94 ± 0.26	7.550 ± 0.083	− 8.1	− 2.24	− 1.39
^{90}Sr (AB)	3.65 ± 0.11	3.703 ± 0.011	− 1.4	− 0.48	− 0.25
^{238}Pu (AB)	13.64 ± 0.12	13.745 ± 0.046	− 0.8	− 0.82	− 0.13
^{3}H (B1)	0.2532 ± 0.0078	0.2421 ± 0.0048	4.6	1.21	0.79
^{14}C (B1)	0.249 ± 0.016	0.2425 ± 0.0015	2.7	0.40	0.46
^{60}Co (GH)	21.00 ± 0.68	20.86 ± 0.10	0.7	0.20	0.12
^{88}Y (GH)	13.84 ± 0.33	13.665 ± 0.088	1.3	0.51	0.22
^{133}Ba (GH)	8.39 ± 0.18	8.598 ± 0.075	− 2.4	− 1.07	− 0.42
^{137}Cs (GH)	19.73 ± 0.65	19.79 ± 0.16	− 0.3	− 0.09	− 0.05
^{139}Ce (GH)	44.5 ± 1.0	44.76 ± 0.42	− 0.6	− 0.24	− 0.10


Deviation (%) of Laboratory 195.2
50
0
-50
^{3}H (AB)
^{3}H (B1)

Radionuclide	Laboratory 195.2	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	6.07 ± 0.21	5.633 ± 0.061	7.8	2.00	1.33
^{3}H (B1)	0.267 ± 0.030	0.2421 ± 0.0048	10.3	0.82	1.77

10. DISCUSSION

Accurate and precise measurement of the activity per unit mass of radionuclides in the environment is critical for the assessment of the radiological impact and risk to the public and environment for both routine analysis and in the instance of a nuclear or radiological emergency situation. For this reason, some radionuclides routinely appear in the exercise such as ^{3}H, ^{14}C, ^{90}Sr, ^{210}Pb, ^{238}U and ^{241}Am. The following section discusses the reported results for the 2022 Environmental Proficiency Test Exercise.

It should also be noted that in some cases participants did not report methods and/or techniques used through submission of a techniques form. The information provided below, therefore, refers to a subset of participants (for each radionuclide) 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 during calibration or yield calculations should be traceable to the International System of Units, and can be obtained from a number of commercial suppliers and National Metrology Institutes. More specifically, activity standards should be traceable to the Becquerel and mass standards to the kilogram.

This exercise included results for multiple measurands using a variety of methodologies. The measurement uncertainties arising for each method will include 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. Throughout the report there are instances where results are marked as questionable due to failing the relative uncertainty test. In these instances, it is suggested that participants' review their uncertainty budgets. Following review, if the uncertainty budget is deemed to be comprehensive it may be that the R_L test failed due to differences in the applied method as compared with other participating laboratories.

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

10.1 Tritium in AB

Tritium is a low-energy beta emitter (β_{max}, 18.564 keV), with a half-life of 12.312 (25) a (BIPM, 2004). Despite the difference in mass between tritium and hydrogen, they occur in the same physicochemical forms. The most common form of tritium in the natural environment is tritiated water (HTO), tritium is also found in gaseous form in the atmosphere and in forms bonded to organic matter in the biosphere (organically bound tritium or OBT).

The main difficulty 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, ^{63}Ni and ^{90}Sr in the sample type. This may be achieved either by chemical separation or by setting regions of interest during measurement when using liquid scintillation counting (LSC). Of the results submitted 82 % were in agreement, 5 % were questionable and 14 % were discrepant. There does not appear to be any systematic bias (deviation, − 0.9 %) between participants' results and the NPL value. This is a similar performance to the 2021 exercise where 86 % were in agreement, 5 % were questionable and 10 % were discrepant.

Of those who reported the detection technique, all (20) stated that they used LSC to measure ^{3}H. Specific instruments reported as being used included a Quantulus 1220 (Perkin Elmer/Wallac) and a Tri Carb 3180 TR/SL (Perkin Elmer).

Quench is an important consideration and the degree of quench varies between samples. This means that for accurate results a quench correction should be carried out for each sample. A quench curve is often required and it must be specific to the type of sample being measured. A single quench curve is only valid for a given instrument, type of scintillation cocktail, and ratio of sample to scintillation cocktail. For LSC it is important to routinely check

instrument response using sources of known activity, covering the energy range to be measured. This is typically done by monitoring the background, as well as ^{3}H and ^{14}C check sources which are routinely supplied with liquid scintillation counters. It is recommended that the results of these checks be plotted on a Shewhart control chart and analysed in line with ISO recommendations (ISO 7870-2)[4].

Most of the participants who provided details of their methods achieved separation between ^{3}H and the other beta emitters using either combustion, distillation or pyrolysis. Distillation was the most used technique, with 13 of the 20 reporting participants', reporting it as the separation technique for ^{3}H in the AB sample type. One laboratory submitted two methods; one with distillation and the other by pyrolysis, with both results in agreement with the NPL value.

10.2 Nickel-63 in AB

Nickel-63 is an anthropogenic radionuclide with a half-life of 98.7 (24) a that decays to ^{63}Cu with a maximum beta energy of 66.980 (15) keV (BIPM, 2004). Nickel-63 is generated by neutron capture of the stable isotope ^{62}Ni.

Of the results submitted 82 % were in agreement, 6 % were questionable and 12 % were discrepant. There was a systematic bias (deviation, − 6.8 %) between participants' results and the NPL value. Reviewing the techniques form submitted, there was no identifiable trend pointing to why this may have been. Of those who reported the detection technique, 15 report using LSC and one laboratory reporting using proportional counting.

Recoveries were generally monitored through an inactive spike of nickel with measurements by ICP-OES and ICP-MS with other laboratories opting for the use of parallel standards of ^{63}Ni. 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 lead to the recoveries being over estimated. Reported techniques for chemical separation of ^{63}Ni predominantly used dimethylglyoxime (DMG) either for precipitation, solvent extraction or chromatography using Ni/Nickel Resin (TrisKem International/Eichrom). Anion exchange chromatography was also performed following precipitation of Ni as a hydroxide.

10.5 Strontium-90 in AB

The strontium isotopes of significance in radiological measurements in the environment are ^{89}Sr and ^{90}Sr. Strontium-90 is the more significant from an environmental protection perspective most likely due to 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 importance for emergency response following a radiological incident or accident. Strontium-90 is a high fission yield product and has been released into the environment in large amounts following nuclear weapon tests, nuclear power plant incidents, and nuclear fuel reprocessing industries.

Strontium-90 is a beta emitter with the most probable emission having a maximum beta energy of 586.1 (22) keV (BIPM, 2004). The main difficulty in measuring the ^{90}Sr activity per unit mass is the need for a radiochemical separation from the other radionuclides present in the sample, combined with the presence of ^{89}Sr which may interfere with the measurement of ^{90}Sr. Again, several methods consisting 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 details robust test methods for measurement of ^{89}Sr and ^{90}Sr in water by LSC and proportional counting.

Of the results submitted 86 % were in agreement, 10 % were questionable and 5 % were discrepant. There was no significant systematic bias (deviation, − 2.0 %) between

[4]Tritium (^{3}H) efficiency is expected to reduce with time.

participants' results and the NPL value. This is a similar performance to the 2021 exercise where 90 % were in agreement and 10 % were questionable.

Of the reporting laboratories 20 of the 21 provided techniques form. This detailed the pre-treatment and separation techniques used. The most common reported separation technique was extraction chromatography (11), many of whom stated using Sr resin (TrisKem International/Eichrom Technologies).

Laboratories reported using LSC (13), Cherenkov counting (4) and proportional counting (3), as the detection technique. The chemical yield was determined using ICP-MS measurement of stable strontium (^{88}Sr) with other laboratories opting to add ^{85}Sr as an internal tracer with measurements by gamma spectrometry. Parallel standards containing ^{90}Sr were also used.

The PMM of LSC, Cherenkov counting and proportional counting results were as follows:

Liquid Scintillation Counting: (3.639 ± 0.060) Bq g^{-1}
Cherenkov Counting: (3.47 ± 0.28) Bq g^{-1}
Proportional Counting: (3.57 ± 0.14) Bq g^{-1}

These results suggest there is no significant difference between results obtained using each method. Due to the size of the dataset and the varied methods leading up to the final analysis it is difficult to confirm. No notable differences between measurement methods have been observed from ^{90}Sr in recent exercises which provides more confidence in that observation. The lower standard uncertainty on the PMM result for LSC does not explicitly indicate a more precise technique but a more consistent dataset.

10.4 Plutonium-238 in AB

Plutonium-238 is an anthropogenic radionuclide present in the environment from atmospheric weapons testing. Plutonium-238, with a half-life of 87.74 (3) a, decays 100 % by alpha decay to ^{234}U (BIPM, 2004).

The main difficulty in measuring the ^{238}Pu activity per unit mass with alpha spectrometry is the need for a radiochemical separation of the sample (especially the ^{241}Am 5.486 MeV and 5.443 MeV peaks which interfere with the 5.499 MeV and 5.456 MeV peaks of ^{238}Pu)(BIPM, 2004). It is possible to determine ^{238}Pu by gamma spectrometry, although the emission probability (0.0397(8) %) and energy for the 43.5 keV peak are low meaning it is unfeasible at the activity per unit mass of this exercise here. This year’s exercise saw 21 results for ^{238}Pu in AB, of these results submitted 76 % were in agreement, 14 % were questionable and 10 % were discrepant. There was no significant systematic bias (deviation, − 0.5 %) between participants' results and the NPL value.

Of the 21 reporting laboratories, 20 provided a techniques form. Multiple methodologies for radiochemical separation were described, including: anion and cation exchange chromatography preceded by varied oxidation and precipitation steps, and extraction chromatography with UTEVA and TRU resin (TrisKem International) was also described. The only recorded source preparation technique for alpha spectrometry was electrodeposition. The dominant tracer for recovery and counting efficiency was ^{242}Pu with one laboratory opting for ^{236}Pu. The result reporting using ^{236}Pu provided a result in agreement with the NPL reference value.

The dominant detection technique for ^{238}Pu was alpha spectrometry (19) with the other laboratory opting for alpha scintillation with a ZnS photon multiplier tube. The alpha scintillation result was in agreement with the NPL value.

10.5 Uranium-238 in A1

Uranium-238 is a naturally occurring terrestrial radionuclide meaning it occurs naturally in soils, minerals, rocks and water. It can also be derived from a wide variety of anthropogenic

sources including phosphate fertilisers, mining wastes, fly ash from coal-fired power plants, and defence use.

Uranium-238 has a half-life of 4.468 (5) × 10^9 a (BIPM, 2004) and can be measured by alpha spectrometry, gamma spectrometry (of decay products) and mass spectrometry. The main difficulty in measuring the ^{238}U activity per unit mass with alpha spectrometry is the need for a radiochemical separation from the other radionuclides present in the sample. This year's exercise saw 18 results reported for ^{238}U in the A1 sample type. Of these results, 100 % were in agreement which is an improvement on the results from the 2021 exercise where 88 % were in agreement, 6 % were questionable and 6 % were discrepant. There was no significant systematic bias (deviation, 2.3 %) between participants' results and the NPL value.

Of the 18 reporting laboratories, 16 provided a techniques form. Many different methodologies for radiochemical separation were reported including cation and anion exchange chromatography, and liquid extraction. The most common detection technique for ^{238}U was alpha spectrometry (14) with two laboratories opting to measure ^{238}U by mass spectrometry.

10.6 Americium-241 in A1

Americium 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 5.486 MeV (84.45 %) and 5.443 MeV (13.23 %)(BIPM, 2004). Americium-241 is the most significant radioisotope of americium for environmental measurements as the other long-lived isotope ^{243}Am is produced in nuclear reactors in smaller activities compared to ^{241}Am.

Americium-241 can be measured by three different measurement techniques: alpha spectrometry, gamma spectrometry and mass spectrometry. The main difficulty in measuring the ^{241}Am activity per unit mass with alpha spectrometry is the need for a radiochemical separation from the other radionuclides present in the sample. Although not present in the A1 sample type this is especially true for the ^{238}Pu 5.46 MeV and 5.50 MeV peaks which interfere with the 5.44 MeV and 5.49 MeV peaks of ^{241}Am.

This year saw 18 results submitted for ^{241}Am in the A1 sample type. Of these results, 83 % were in agreement, 11 % were questionable and 6 % were discrepant. There was no significant systematic bias (deviation, −0.2 %) between participants' results and the NPL value.

For the participants who submitted techniques forms 13 stated using alpha spectrometry, with ^{243}Am as a tracer, and three stated using gamma spectrometry. The two laboratories who reported discrepant results did not submit a techniques form.

The PPM of alpha spectrometry and gamma spectrometry results were as follows:

Alpha Spectrometry: (21.07 ± 0.51) Bq g^{-1}
Gamma Spectrometry: (21.77 ± 0.76) Bq g^{-1}

These results suggest there is no significant difference between results obtained using each detection technique in this exercise.

10.7 Curium-244

This nuclide is produced by multiple neutron activations of ^{238}U, ^{239}Pu and ^{243}Am. It decays by emission of alpha particles to ^{240}Pu. It is an anthropogenic radionuclide and occurs in the environment as a result of weapon tests and discharges from the nuclear industry. The main 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 and the absence of a suitable curium chemical yield tracer. Americium is often considered a chemical analogue for curium but as separations get more specific the suitability of americium becomes limited. This year's exercise saw 15 results for ^{244}Cu in A1. There were 15 results submitted for ^{244}Cm in the AB

sample type and of the results submitted 47 % were in agreement, 27 % were questionable and 27 % were discrepant. There was a systematic bias (deviation, − 13.7 %) between participants' results and the NPL value. Due to the level of detail provided in the techniques forms submitted NPL is unable to speculate as to why this may be.

For the participants who submitted techniques forms all 13 used alpha spectrometry as the measurement technique using ^{243}Am as a tracer. All of those who detailed a source preparation technique used electrodeposition (6). A range of radiochemical separation techniques were described, including both column chromatography and solid phase extraction.

10.8 Tritium in B1

Tritium has a half-life of 12.312 (25) a and decays by beta minus emission to the ^{3}He with a β_{max} of 18.564 (3) keV (BIPM, 2004). The main difficulty in measuring the tritiated water activity per unit mass is the need for a radiochemical separation from other beta-emitters i.e. ^{14}C and ^{99}Tc in the B1 sample type. The B1 sample matrix is an alkaline solution.

This year's exercise saw 25 results reported, which is less than the number of results submitted in the 2021 exercise (31). Of the results submitted 84 % were in agreement, 12 % were questionable and 4 % were discrepant. There was no significant systematic bias (deviation, − 1.9 %) between participants' results and the NPL value. All participants who reported their techniques (24) stated that they used LSC to measure the ^{3}H.

Of the participants who described their methodologies, 16 used distillation to isolate ^{3}H from other interfering radionuclides, with other participants opting for a pyrolysis-based method.

10.9 Carbon-14 in B1

Carbon-14 has a half-life of 5700 (30) a and decays by beta minus emission to stable nitrogen (^{14}N) with a β_{max} of 156.476 (4) keV (BIPM, 2004) The main difficulty in measuring the activity per unit mass of ^{14}C in B1 is the need for a radiochemical separation from ^{3}H and ^{99}Tc.

This year's exercise saw 21 results reported, which is a similar number of results submitted to the 2021 exercise (23). Of the results submitted 86 % were in agreement, 10 % were questionable and 5 % were discrepant. The percentage of results that were in agreement (86 %) and questionable (10 %) saw an improvement in comparison to last year's exercise with 78 % being in agreement and 13 % being questionable. There was no significant systematic bias (deviation, − 2.2 %)

All participants submitted a techniques form and stated that they used LSC to measure ^{14}C. Of those that gave detail of their measurement technique (17) the most common separation method was precipitation with the majority of the participants using barium carbonate.

10.10 Iodine-129 in B1

Iodine-129 is primarily formed in nucelar reactors as a fission product from both uranium and plutonium based fuels. It is the predominant radioactive isotope of iodine present in spent irradiated reactor fuels and is present in environmental samples, due to nuclear weapons testing, nuclear incidents and routine discharges from nuclear reprocessing sites. It is present in the environment at low activity concentrations but is still considered important in radiological protection due to its long half-life of 16.1 (7) × 10^{6} a (BIPM, 2005). There are a number of challenges in measuring the activity per unit mass of ^{129}I in B1, including the low energy and intensity of the gamma emission and the need for a radiochemical separation from ^{3}H and ^{14}C prior to liquid scintillation counting.

This years exercise saw 14 results submitted for ^{129}I. Of the results submitted 79 % were in agreement and 21 % were questionable. This is a slight improvement on the 2020 exercise which saw 65 % in agreement, 29 % questionable and 6 % discrepant. There was no significant deviatiation (deviation, − 1.5 %) between participants' results and the NPL value.

A variety of detection techniques were used for ^{129}I in the B1 sample including, gamma spectrometry (8), LSC (5), and mass spectrometry (1).

The PPM of gamma spectrometry and LSC results were as follows:

Gamma Spectrometry: (0.1647 ± 0.0060) Bq g^{-1}
Liquid Scintillation Counting: (0.1604 ± 0.0064) Bq g^{-1}

The results from this exercise and from previous exercises suggest there is no significant difference between results obtained using gamma spectrometry and those obtained using liquid scintillation counting. Results obtained by mass spectrometry have also been in agreement, although the data set is quite small. When measuring ^{129}I by mass spectrometry there are a number of considerations including: ensuring ^{129}I calibration standards, when used, are matrix matched, considering the ^{127}I content in the sample which causes tailing or dihydride interferences, and how to correct for isobaric ^{129}Xe interference from the plasma.

10.11 Sample Types GH and GL

Both the GH and GL sample type included radionuclides covering a wide range of emission energies. The GL sample for this year's exercise contained higher activities per unit mass of ^{241}Am than both the 2021 and 2020 exercises. All but one of the reported measurements for the GH and GL sample types were carried out by gamma spectrometry. The one alternate measurement technique was used for ^{241}Am. This measurement was by alpha scintillation and the reported result was in agreement with the NPL value.

As observed in Table 8, there is a discrepancy between the Assigned Value and the PMM for the ^{210}Pb in the GL sample. There is a low bias of the PMM with a deviation of – 8.6 % (zeta-score = 2.54, critical value = 2.81) from the Assigned Value. For laboratories routinely measuring ^{210}Pb it is recommended that they use a ^{210}Pb standard to create an efficiency calibration or at the minimum ensure they are using a calibration standard that covers the energy range. It is also important when measuring low energy gamma emitters to matrix match standards or to perform a density correction.

For the cases of ^{60}Co, ^{133}Ba, ^{134}Cs and ^{139}Ce true coincidence summing (TCS) of emissions needs to be considered where the source to detector geometry is close. For ^{139}Ce this is due to an X-ray gamma coincidence. This can be of a particular challenge for those radionuclides with low-energy gamma-ray emissions in coincidence with other gamma rays, e.g. ^{133}Ba, where the total efficiency modelled at the lower energy can be difficult to determine accurately. Well detectors and Marinelli beakers are routinely used in the measurement of environmental samples due to their high counting efficiency, allowing for low minimum detectable activities or statistical uncertainties. Placing the sample in the well, or around the detector in the case of Marinelli beaker makes the solid angle covered by the crystal larger and results in a high detection efficiency. However, the high efficiency results in increased TCS effects. It is therefore important to account for these TCS effects to ensure accurate measurements.

More guidance and information on measurement of gamma emitting radionuclides in aqueous sample types are defined in ISO 10703:2021. Participants are advised to review their uncertainty budgets. Information on the uncertainty components (Type A and Type B) that contribute to a uncertainty budget relating to gamma spectrometry may be found in BS EN ISO 20042:2019. This exercise was used to identify a detector issue which Laboratory 183 used to measure the GH sample type. Laboratory 112 is encouraged to review their uncertainties and how these are determined.

11. REFERENCES

van Es, E. et al., 2022. Environmental Radioactivity Proficiency Test Exercise 2020. NPL Report IR 61. 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 13528:2015. Statistical methods for use in proficiency testing by inter-laboratory comparisons.

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.

UKAS, 2022. M3003 The Expression of Uncertainty and Confidence in Measurement. Edition 5. September 2022. https://www.ukas.com/wp-content/uploads/schedule_uploads/759162/M3003-The-Expression-of-Uncertainty-and-Confidence-in-Measurement.pdf

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 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

The authors wish to thank the participating organisations for the time and effort they have put into analysing the samples. They also thank colleagues Daniel Ainsworth and Steph Perry for handling the despatch of samples. They also wish to thank Anu Bhaisare, Frankie Falksohn, and Svetlana Kolmogorova for their help in preparing the samples and Arzu Arinc for her role as Senior Quality Lead. The authors thank Robert Shearman and Sotiris Ioannidis for their expertise in gamma spectrometry.The authors also wish to thank Sean Collins for his support in processing the participants' data and Diane Morrell for assisting with communications with participants.

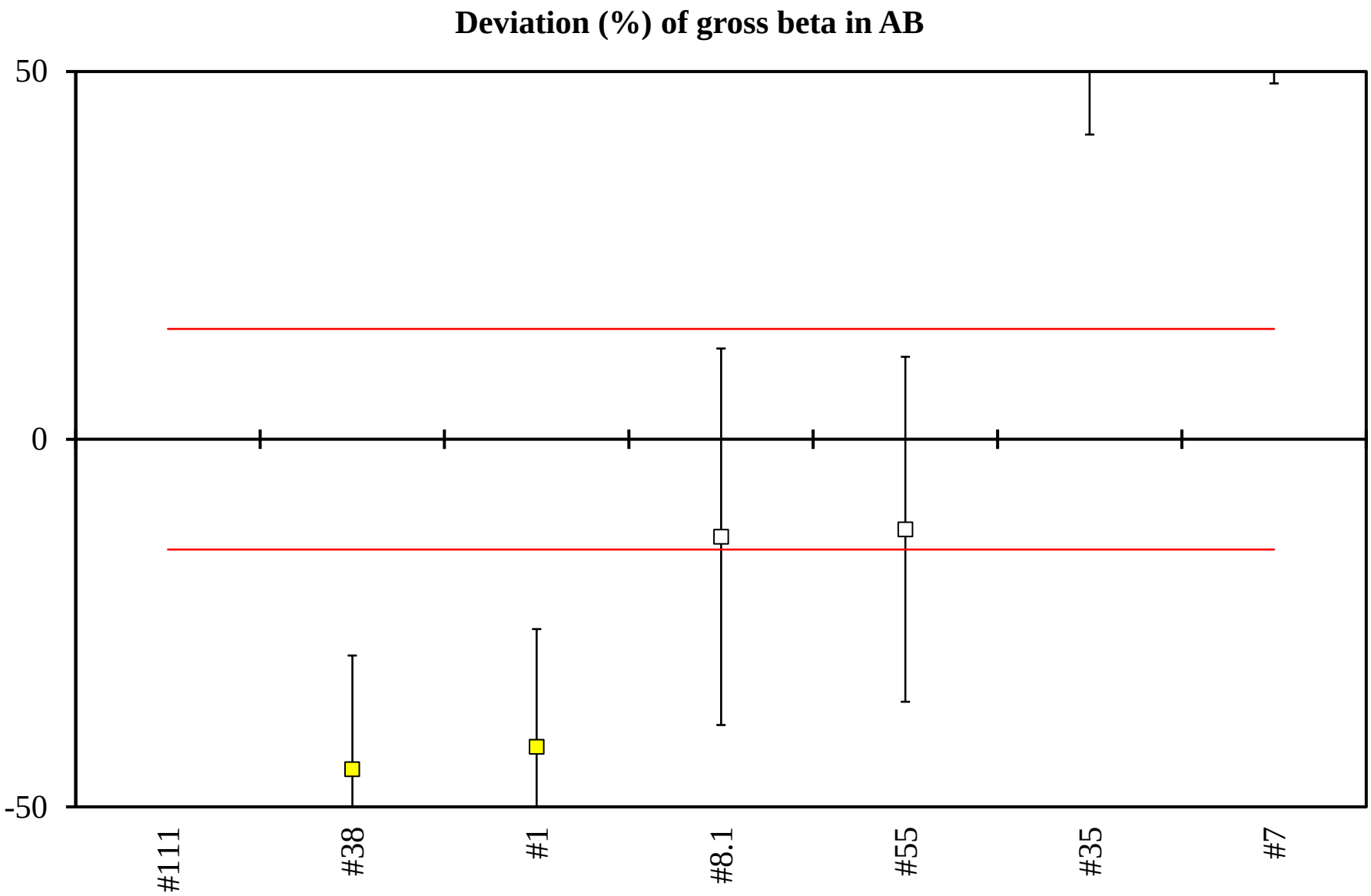
13. APPENDICES

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.

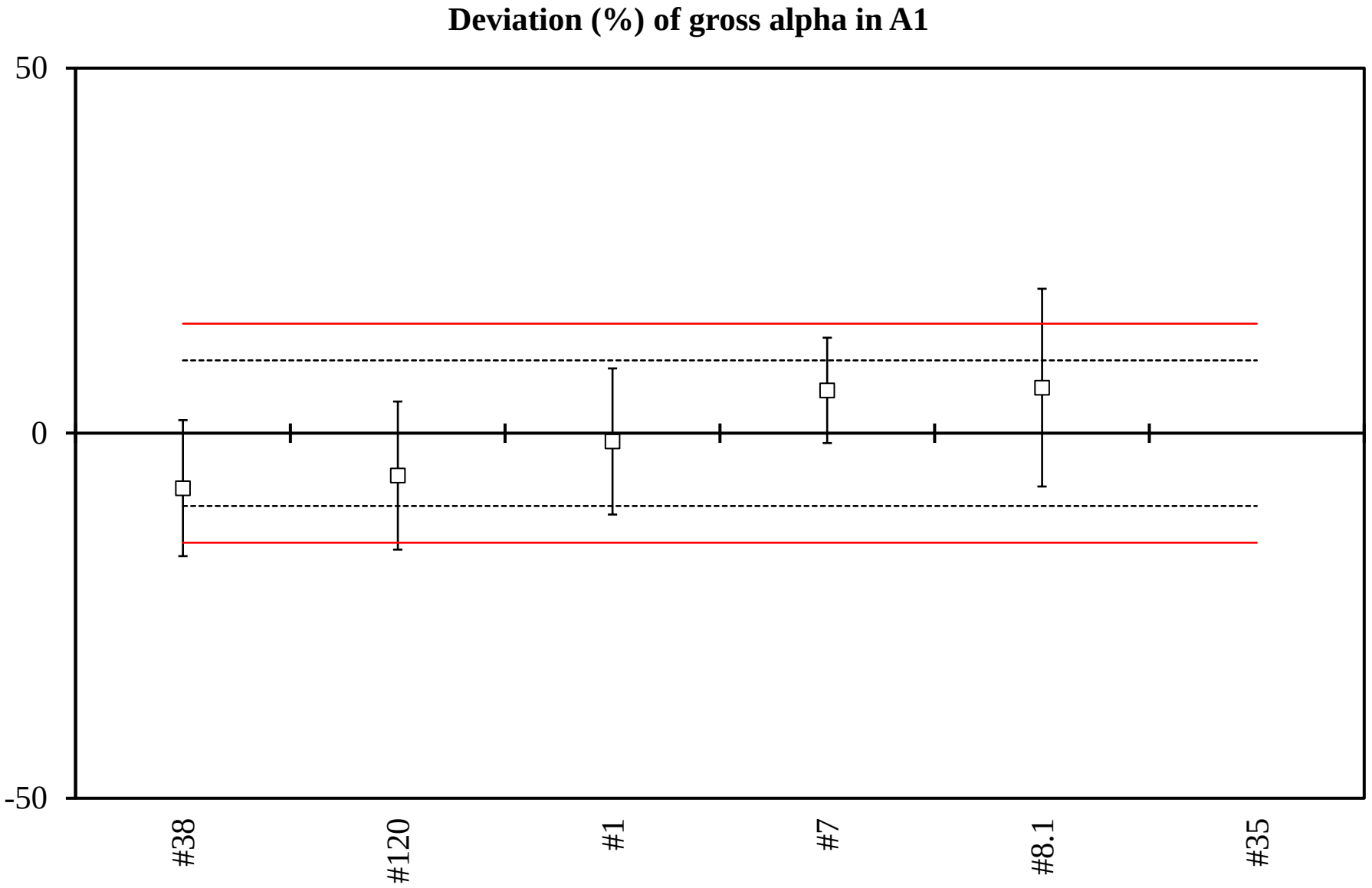
The values provided in the following tables are the PMM of the submitted results and are not traceable to national standards of radioactivity. The PMM of the gross measurements is provided as an indicator and has not been used for performance assessment. It is for this reason results for gross measurements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

A 1 Gross radionuclide measurements summary

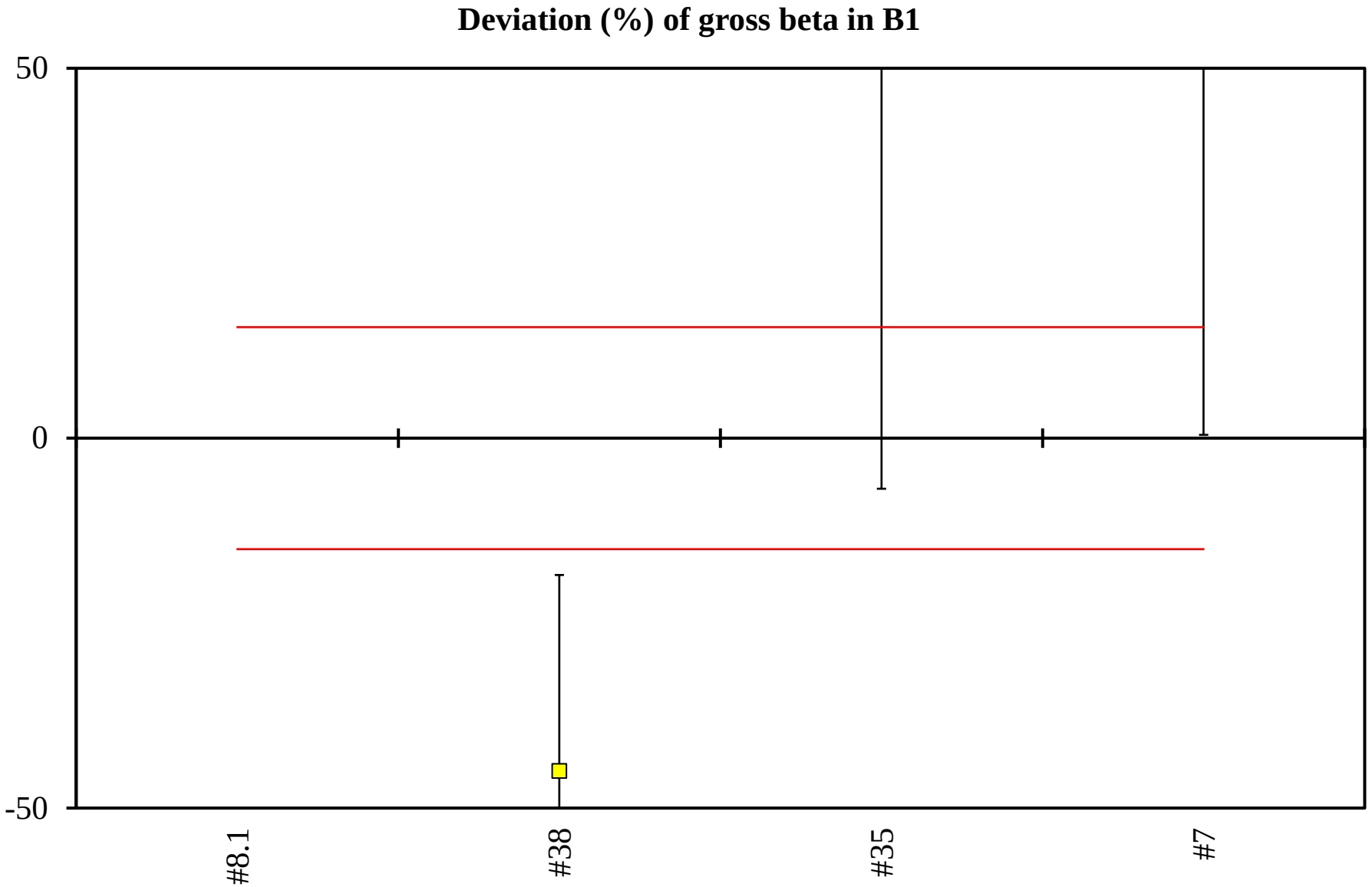
Measurement	PMM
Gross beta (AB)	9.8 ± 2.6 Bq g^{-1}
Gross alpha (A1)	46.5 ± 1.8 Bq kg^{-1}
Gross beta (B1)	0.40 ± 0.17 Bq g^{-1}


Deviation (%) of gross beta in AB
50
0
-50
#111
#38
#1
#8.1
#55
#35
#7

Lab Code	Lab Activity	Zeta	Z Score	Deviation
1	5.7 ± 0.42	− 1.56	− 7.18	− 42
7	20.093801 ± 1.55107252	3.40	18.04	105
8.1	8.5 ± 1.1	− 0.46	− 2.28	− 13
35	19.054185 ± 1.191267955	3.24	16.22	94
38	5.4 ± 0.5	− 1.66	− 7.71	− 45
55	8.6 ± 0.282	− 0.46	− 2.10	− 12
111	2.06 ± 0.036	− 2.98	− 13.56	− 79


Deviation (%) of gross alpha in A1
50
0
-50
#38
#120
#1
#7
#8.1
#35

Lab Code	Lab Activity	Zeta	Z Score	Deviation
1	45.9707 ± 4.3	− 0.11	− 0.20	− 1
7	49.225642 ± 2.759772026	0.83	1.01	6
8.1	49.4 ± 6	0.46	1.07	6
35	95.826024 ± 1.053457339	23.65	18.22	106
38	43 ± 4	− 0.80	− 1.29	− 8
120	43.8 ± 4.4	− 0.57	− 1.00	− 6


Deviation (%) of gross beta in B1
50
0
-50
#8.1
#38
#35
#7

Lab Code	Lab Activity	Zeta	Z Score	Deviation
7	0.707742 ± 0.05605727	1.72	13.21	77
8.1	0.01456 ± 0.00055	− 2.27	− 16.55	− 96
35	0.649 ± 0.017124544	1.46	10.69	62
38	0.22 ± 0.05	− 1.02	− 7.73	− 45

[END OF REPORT]