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**Environmental Radioactivity
Proficiency Test Exercise 2017 – Final Report**

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Environmental Radioactivity Proficiency Test Exercise 2017 – Final Report

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ABSTRACT

The results of NPL's twenty-third Environmental Radioactivity Proficiency Test Exercise are reported. Five different sample types were offered: an aqueous mixture of one alpha emitter and three beta emitters (designated 'AB'), an aqueous mixture of three alpha emitters ('A1'), an aqueous mixture of three beta emitters ('B1'), an aqueous mixture of three gamma emitters ('GH') and a second aqueous mixture of three gamma emitters ('GL'). In total, 383 results were submitted; 380 were analysed and, of these, 79% were found to be 'In Agreement' with the NPL Assigned Values.

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Assigned Values (reference time 2017-06-01 1200 UTC)

Nuclide (AB)	Assigned Value (Bq g^{-1})
^{3}H	16.85 ± 0.42
^{63}Ni	10.15 ± 0.22
^{90}Sr	2.292 ± 0.020
^{238}Pu	15.428 ± 0.070
Nuclide (A1)	**Assigned Value (Bq kg^{-1})**
^{232}Th	0.779 ± 0.015
^{233}U	18.00 ± 0.11
^{241}Am	9.211 ± 0.052
Nuclide (B1)	**Assigned Value (Bq g^{-1})**
^{3}H	0.3049 ± 0.0092
^{14}C	0.2404 ± 0.0032
^{36}Cl	0.1977 ± 0.0016
Nuclide (GH)	**Assigned Value (Bq g^{-1})**
^{133}Ba	18.73 ± 0.54
^{137}Cs	3.996 ± 0.056
^{154}Eu	6.36 ± 0.10
Nuclide (GL)	**Assigned Value (Bq kg^{-1})**
^{134}Cs	18.78 ± 0.30
^{210}Pb	16.11 ± 0.34
^{241}Am	2.394 ± 0.016

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-third in a series of such exercises run by NPL over the last 29 years. The exercises help analysts to identify measurement problems and also support UKAS accreditations in this area; they are run on an annual basis. A range of sample types have been made available over the course of these exercises; these have been mostly aqueous in nature, although in recent years solid samples have been included.

Five sample types were made available for analysis in the 2017 PTE:

(i)   **AB**: a mixture of one α-emitting radionuclide and three β-emitting radionuclides
20 g of dilute nitric acid (1 – 20 Bq g^{-1} per radionuclide)

(ii)   **A1:** a mixture of three α-emitting radionuclides
500 g of dilute nitric acid (0.5 – 20 Bq kg^{-1} per radionuclide)

(iii)   **B1**: a mixture of three β-emitting radionuclides
500 g of very dilute NaOH solution (0.1 – 2 Bq g^{-1} per radionuclide)

(iv)   **GH**: a 'high-level' mixture of three γ-emitting radionuclides
100 g of dilute nitric acid (1 – 20 Bq g^{-1} per radionuclide)

(v)   **GL**: a 'low-level' mixture of three γ-emitting radionuclides
500 g of dilute nitric acid (1 – 20 Bq kg^{-1} per radionuclide)

As in previous years, the main objective was to assess the performance of the participating laboratories. This required the participants to identify (and/or measure) the activity per unit mass of the radionuclides present in the samples, whereas the tasks of NPL were to prepare and distribute the samples, to collect, analyse and interpret the results and to compile an exercise 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 which participant had which 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.

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.

Each aqueous sample type was prepared (as a bulk sample) by combining weighed aliquots of standard solutions of the individual radionuclides 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 by counting sources prepared at the various dilution levels using either liquid scintillation counting or gamma spectrometry. The Assigned Value for each nuclide was calculated by dividing the activity per unit mass of the original standard solution by the dilution factor(s). The bulk solution was subdivided into (typically) 40 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.

The Power-Moderated Weighted Mean (PMWM) (Pommé, 2012) of the participants' values for each nuclide in the aqueous sample types was also calculated. 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 PMWM of participants' results were also calculated for each of the following quantities, and a decision was made in each case as to whether or not to use the PMWM as an Assigned Value:

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

Note that consensus values based on the PMWM are not traceable to national standards of radioactivity.

The NPL data analysis method is described in Section 2 and the Assigned Values and PMWM values are summarised in Section 3.

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

DG Global Forwarding
Legacy House
Hanworth Trading Estate
Hampton Rd West
Feltham TW13 6DH

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

Note that, unless otherwise stated, all uncertainties quoted in this report are standard uncertainties multiplied by a coverage factor of k = 1, providing a level of confidence of approximately 68 %.

2. TREATMENT OF DATA

The data were analysed using the same methods as in the 2016 exercise (Dean et al., 2016). The deviation 'D' from the assigned value from each laboratory value was calculated from:

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

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

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

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

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

$$R_L = \frac{u_L}{L} \tag{4}$$

$$z = \frac{L-N}{\sigma_p} = \frac{L-N}{0.05823\,N} \tag{5}$$

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 13528:2005 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 13528:2005 rather than the commonly understood z-score and is used to reject results on the basis of 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 7.

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 there is a small deviation from the Assigned Value and a small uncertainty), 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.

Table 1 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 reference time is 2017-06-01 12:00 UTC.

Table 2   AB summary

Nuclide (AB)	NPL Assigned Values (Bq g⁻¹)	PMWM (Bq g⁻¹)	Deviation (%)	Zeta	Critical Value
³H	16.85 ± 0.21	16.30 ± 0.12	-3.3	-2.28	2.58
⁶³Ni	10.15 ± 0.11	9.10 ± 0.67	-10.3	-1.54	2.95
⁹⁰Sr	2.292 ± 0.010	2.279 ± 0.023	-0.6	-0.53	2.74
²³⁸Pu	15.428 ± 0.035	15.49 ± 0.16	0.4	0.37	2.88

Table 3   A1 summary

Nuclide (A1)	NPL Assigned Values (Bq kg⁻¹)	PMWM (Bq kg⁻¹)	Deviation (%)	Zeta	Critical Value
²³²Th	0.7792 ± 0.0075	0.763 ± 0.014	-2.1	-1.00	2.95
²³³U	17.996 ± 0.054	17.93 ± 0.17	-0.4	-0.38	2.88
²⁴¹Am	9.211 ± 0.026	9.25 ± 0.11	0.4	0.35	2.83

Table 4   B1 summary

Nuclide (B1)	NPL Assigned Values (Bq g^{-1})	PMWM (Bq g^{-1})	Deviation (%)	Zeta	Critical Value
^{3}H	0.3049 ± 0.0046	0.2980 ± 0.0030	-2.3	-1.26	2.58
^{14}C	0.2404 ± 0.0016	0.2437 ± 0.0048	1.4	0.66	2.88
^{36}Cl	0.19774 ± 0.00080	0.1875 ± 0.0033	-5.2	-3.04	3.11

Table 5   GH summary

Nuclide (GH)	NPL Assigned Values (Bq g^{-1})	PMWM (Bq g^{-1})	Deviation (%)	Zeta	Critical Value
^{133}Ba	18.73 ± 0.27	18.37 ± 0.14	-1.9	-1.17	2.58
^{137}Cs	3.996 ± 0.028	4.014 ± 0.019	0.4	0.53	2.58
^{154}Eu	6.363 ± 0.051	6.111 ± 0.049	-4.0	-3.59	2.58

Table 6   GL summary

Nuclide (GL)	NPL Assigned Values (Bq kg^{-1})	PMWM (Bq kg^{-1})	Deviation (%)	Zeta	Critical Value
^{134}Cs	18.78 ± 0.15	18.14 ± 0.14	-3.4	-3.01	2.58
^{210}Pb	16.11 ± 0.17	16.86 ± 0.38	4.6	1.78	2.77
^{241}Am	2.3943 ± 0.0078	2.518 ± 0.041	5.2	2.94	2.76

Table 7   Gross nuclide measurements summary

| Nuclides	PMWM
Gross beta (AB)	(4.62 ± 0.49) Bq g^{-1}
Gross alpha (A1)	(29.3 ± 1.0) Bq kg^{-1}
Gross beta (B1)	Value not used (see Section 10)

4. Alpha Beta (AB) Deviation Plots

Deviation (%) of ^3H in AB
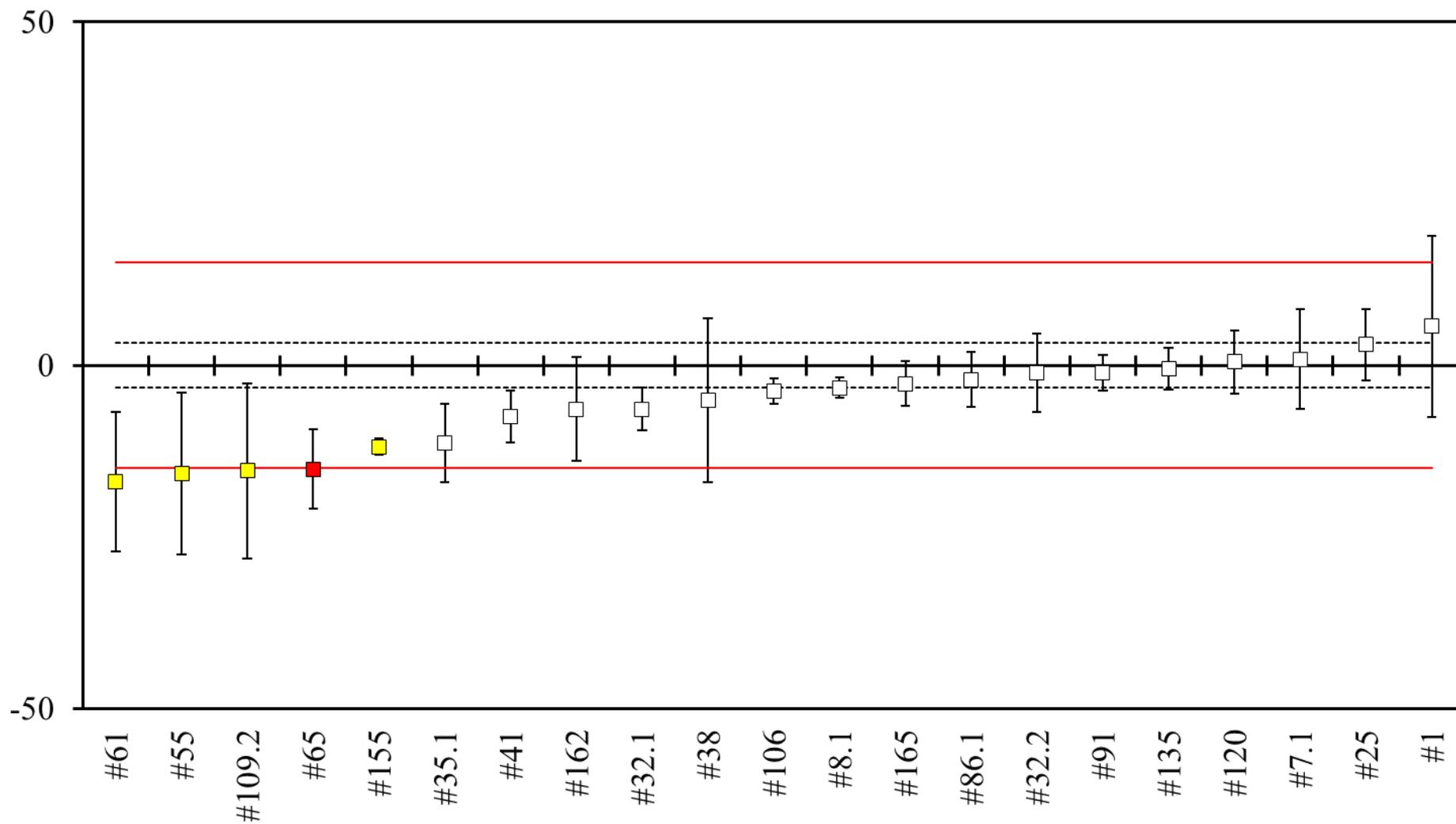
Deviation (%) of ^{63}Ni in AB
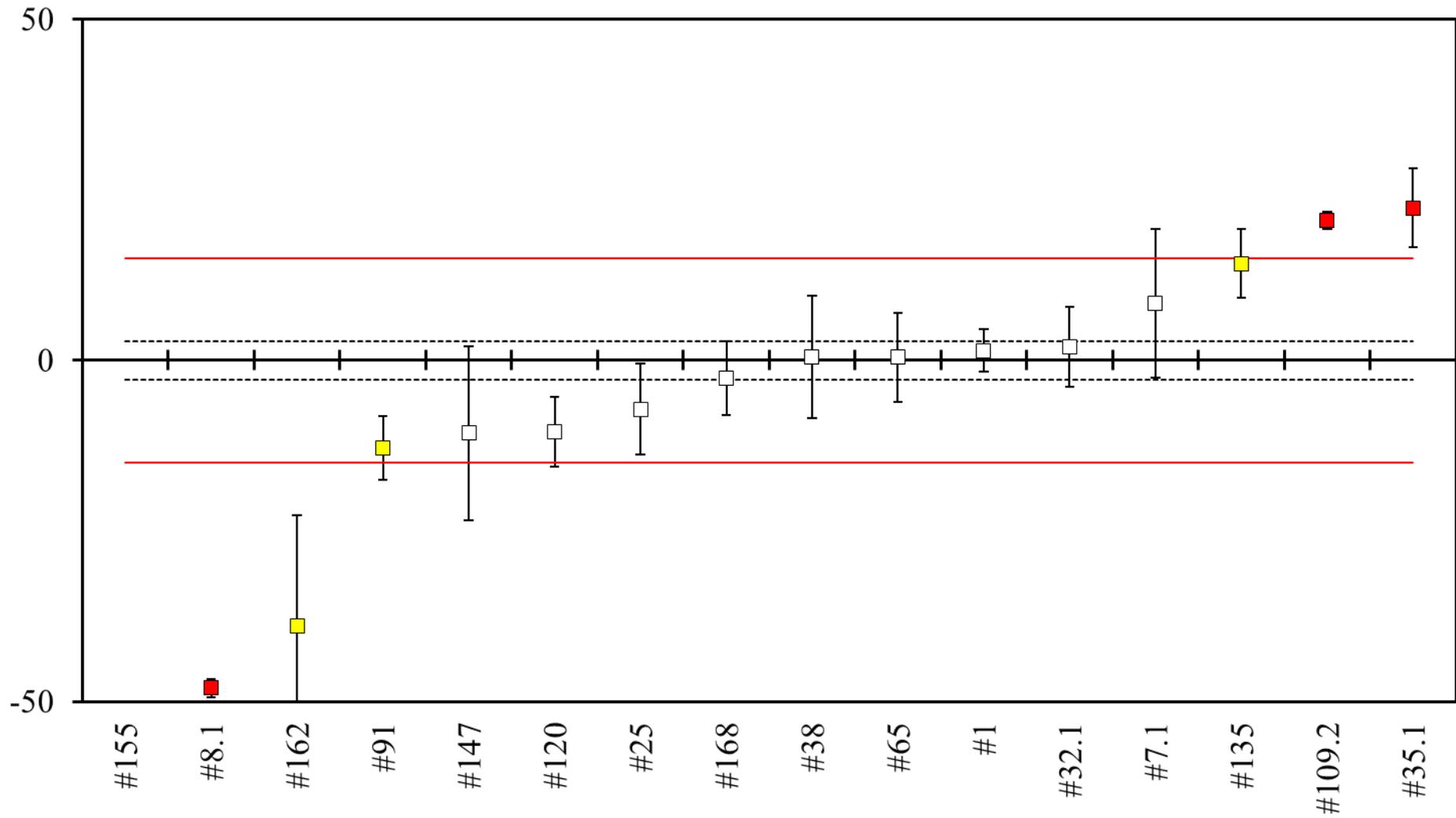
Deviation (%) of ^{90}Sr in AB
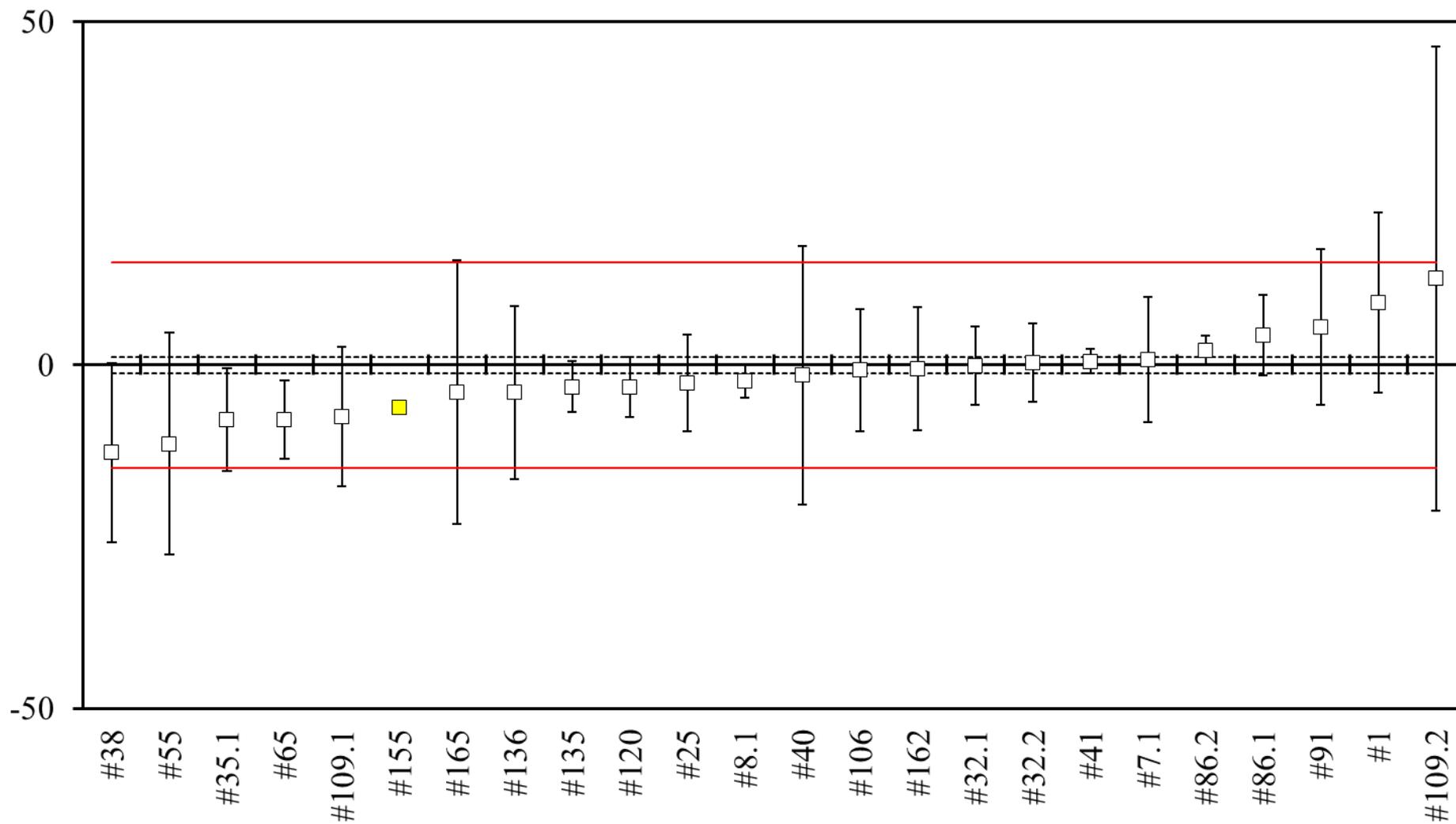
Deviation (%) of ^{238}Pu in AB
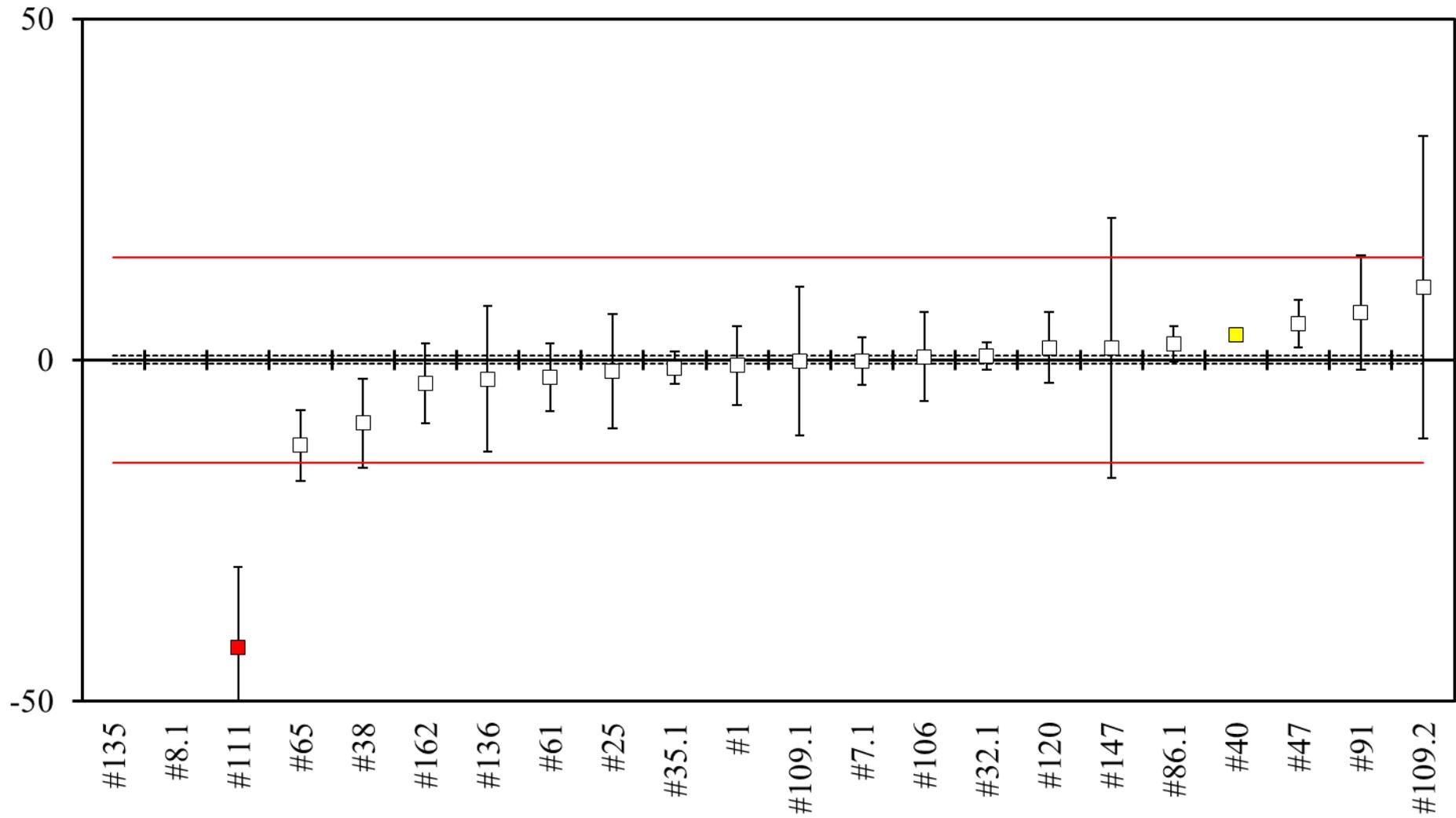
Deviation (%) of Grossbeta in AB
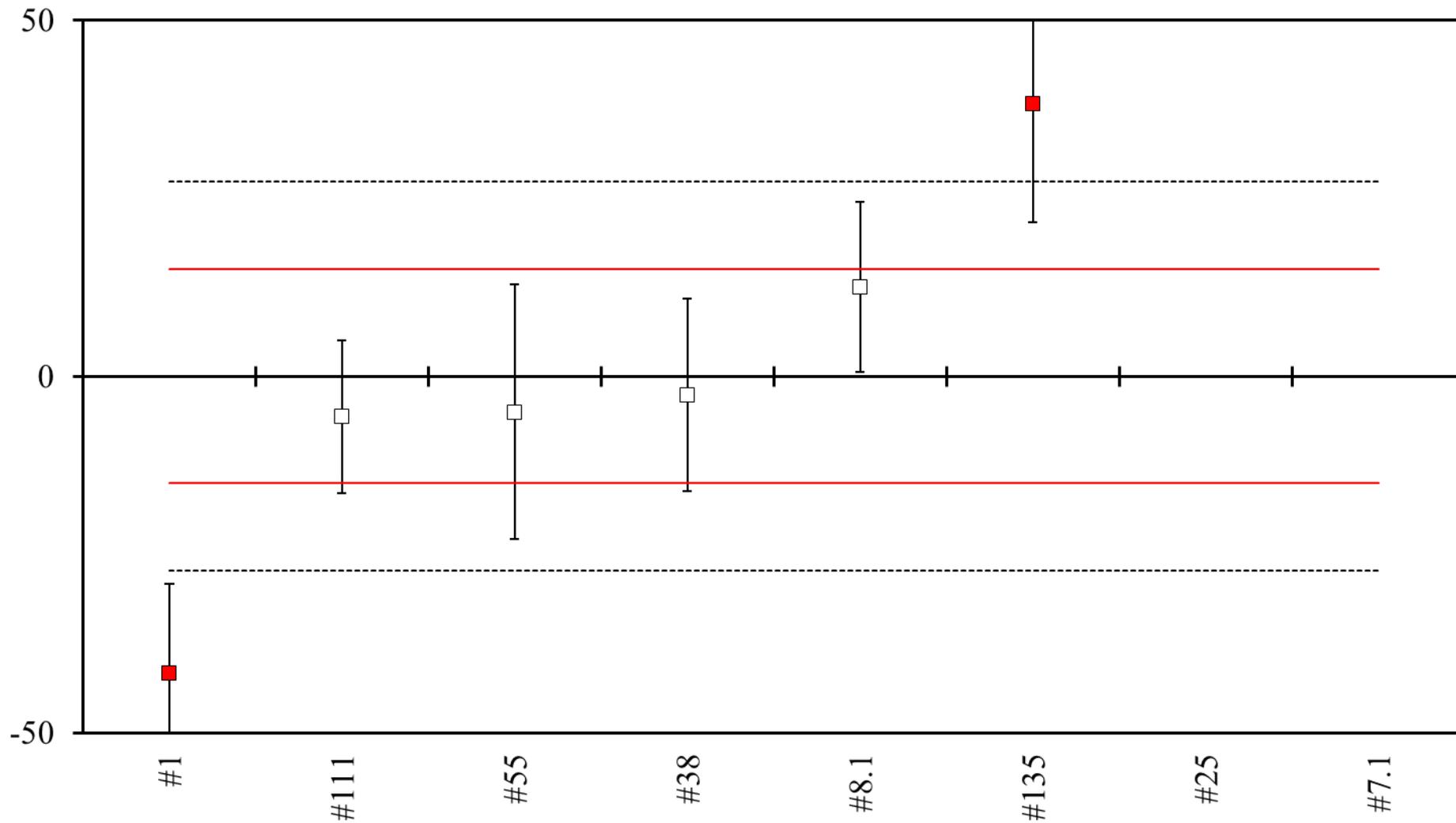
5. Alpha One (A1) Deviation Plots

Deviation (%) of ^{232}Th in A1
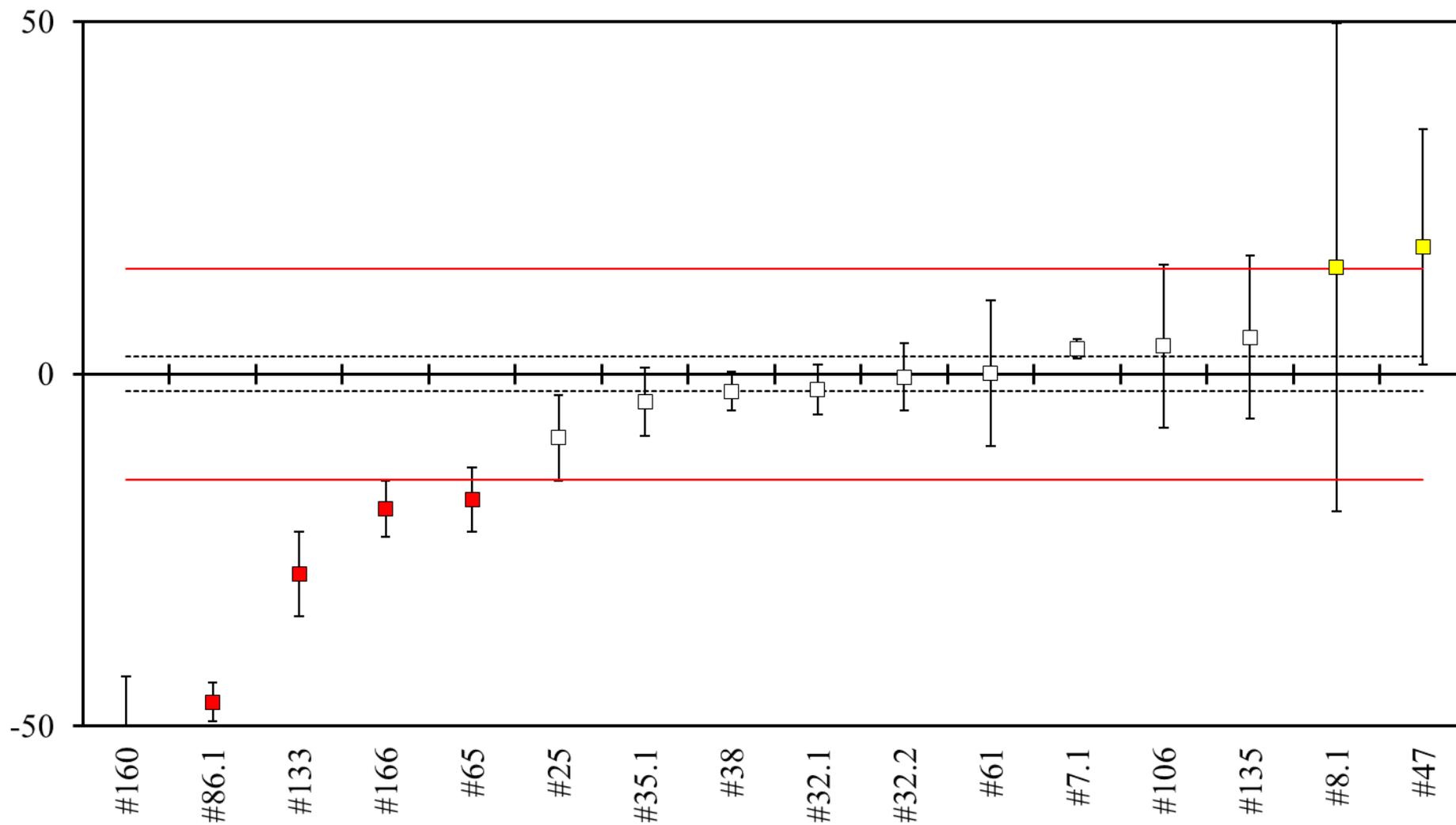
Deviation (%) of ^{233}U in A1
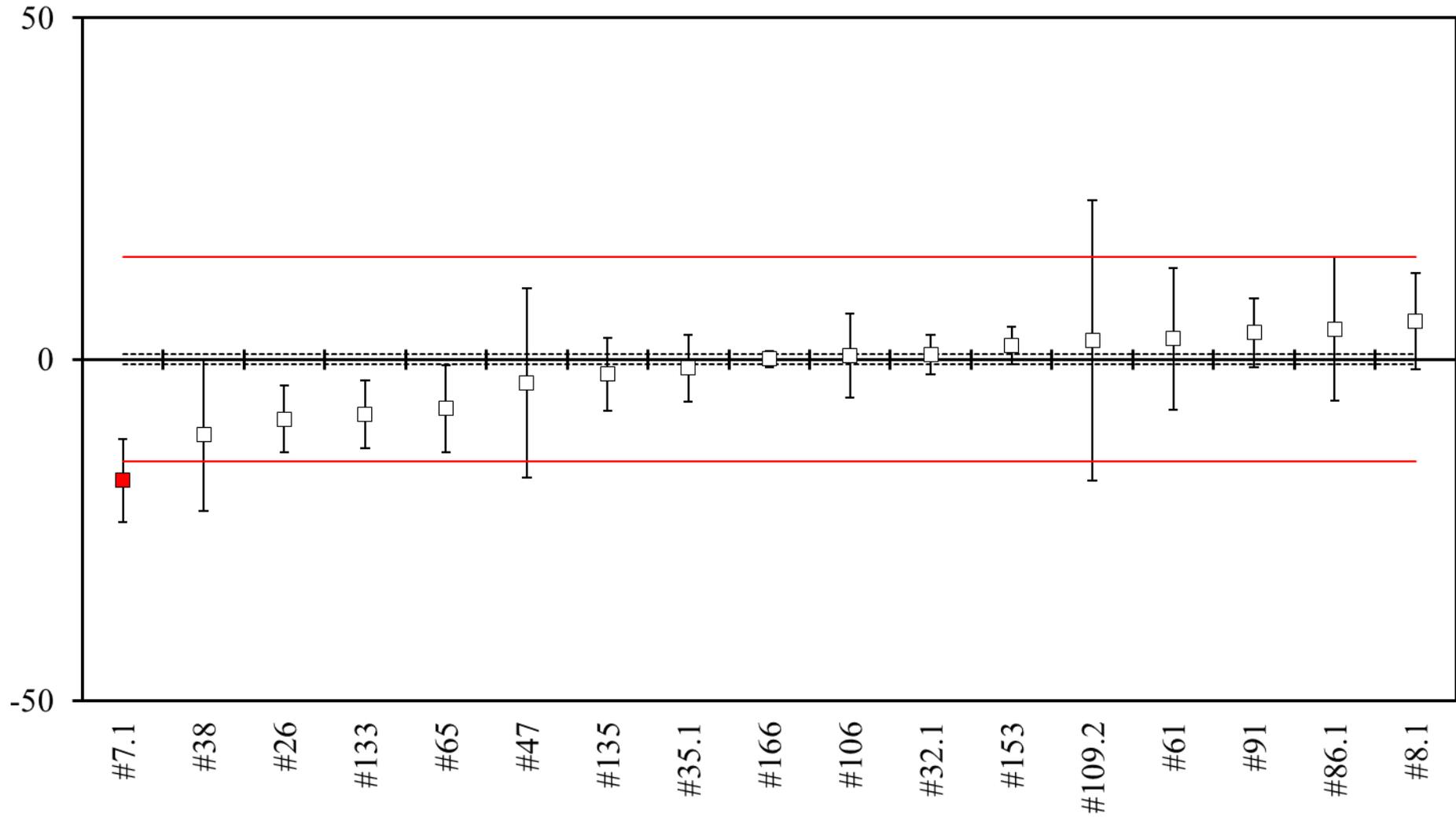
Deviation (%) of ^{241}Am in A1
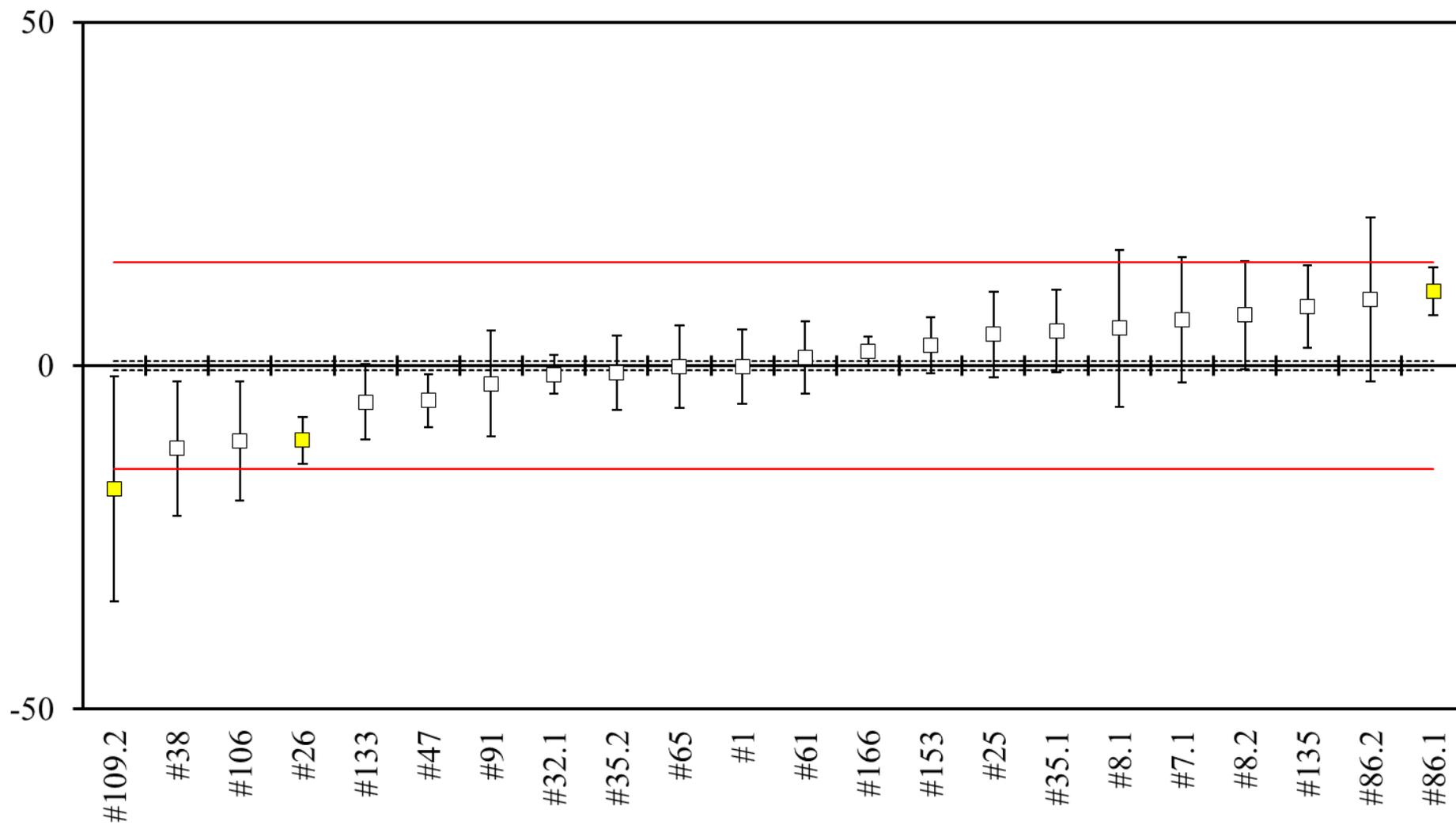
Deviation (%) of Grossalpha in A1
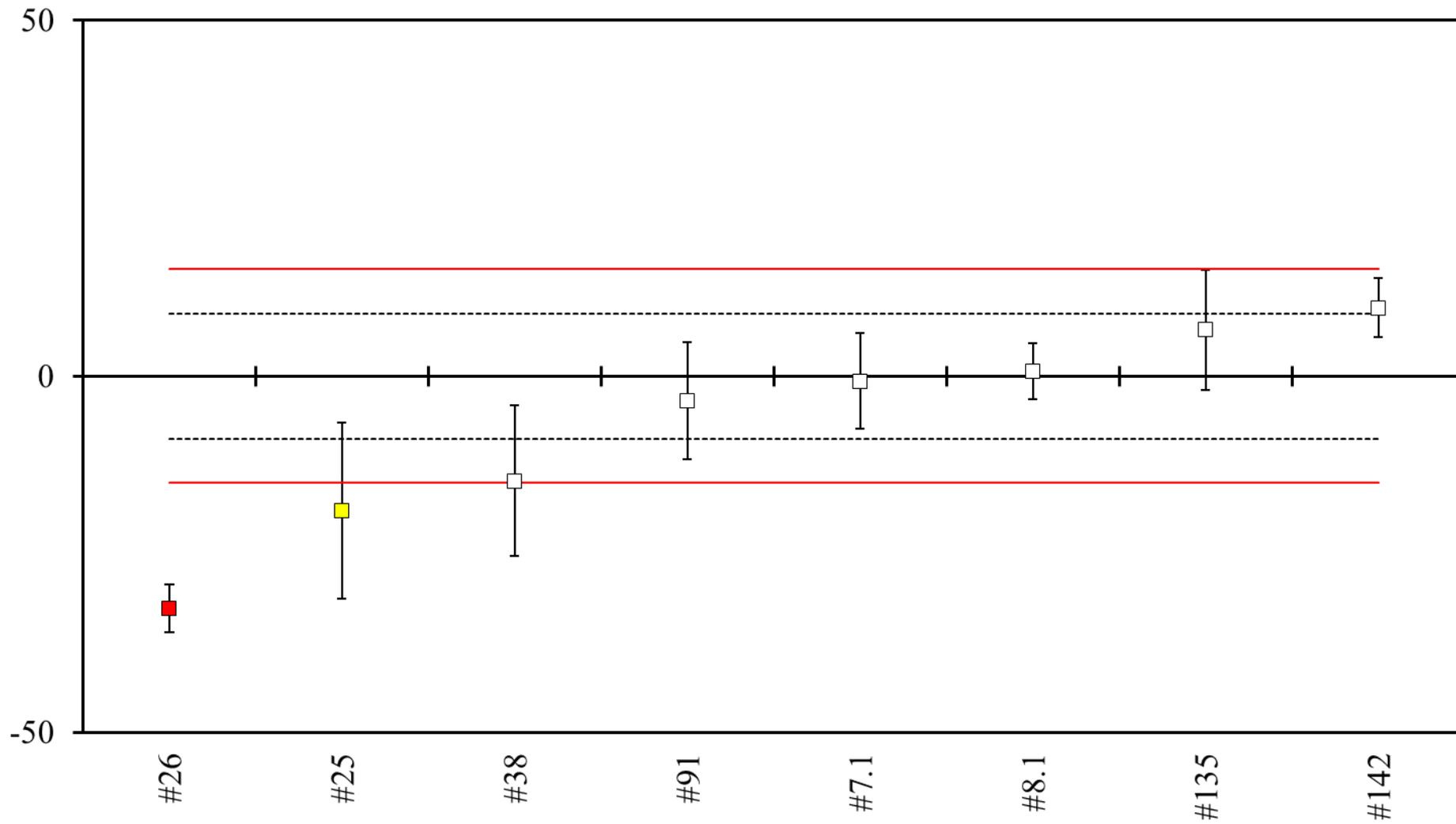
6. Beta One (B1) Deviation Plots

Deviation (%) of ³H in B1
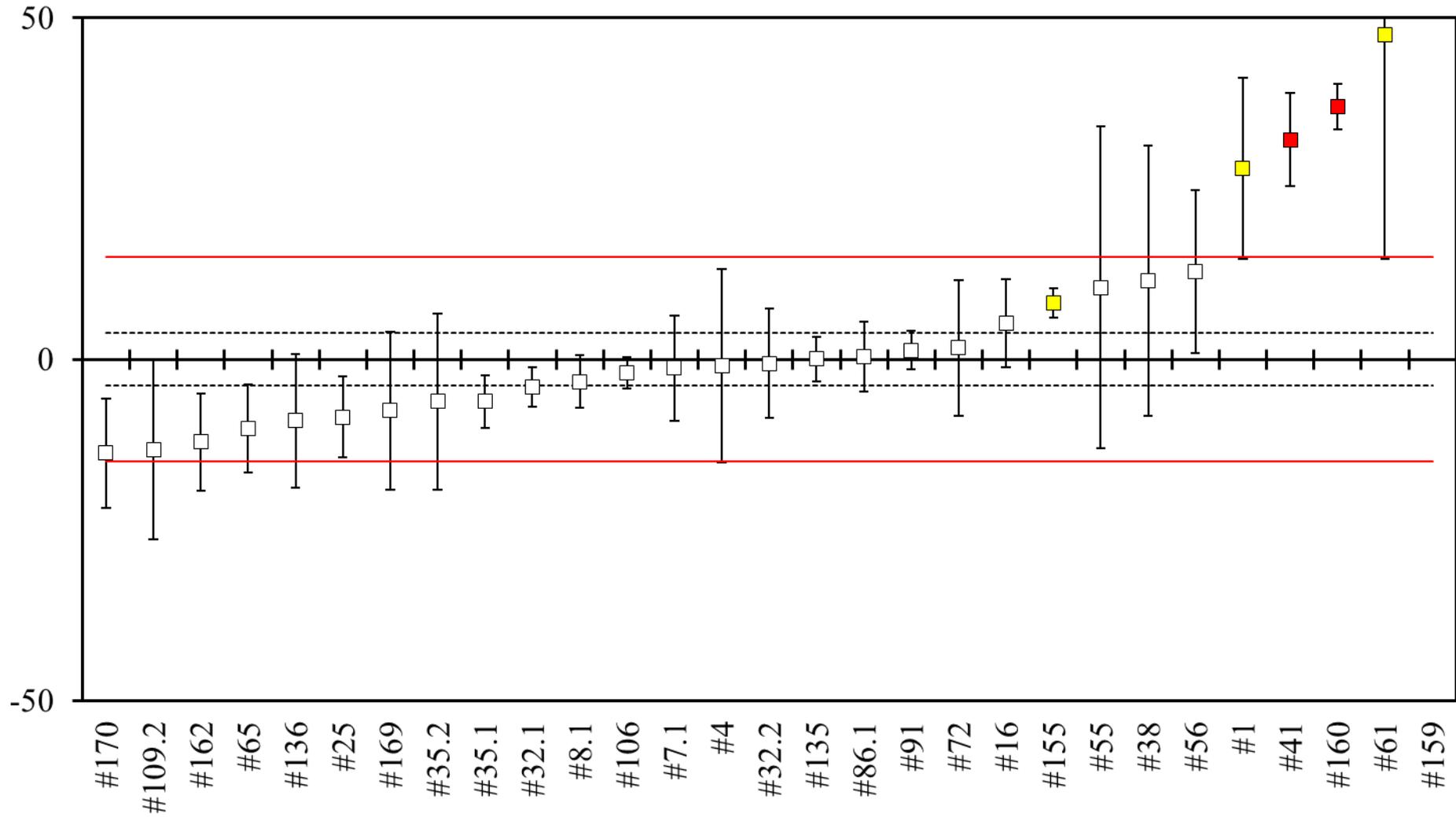
Deviation (%) of ^{14}C in B1
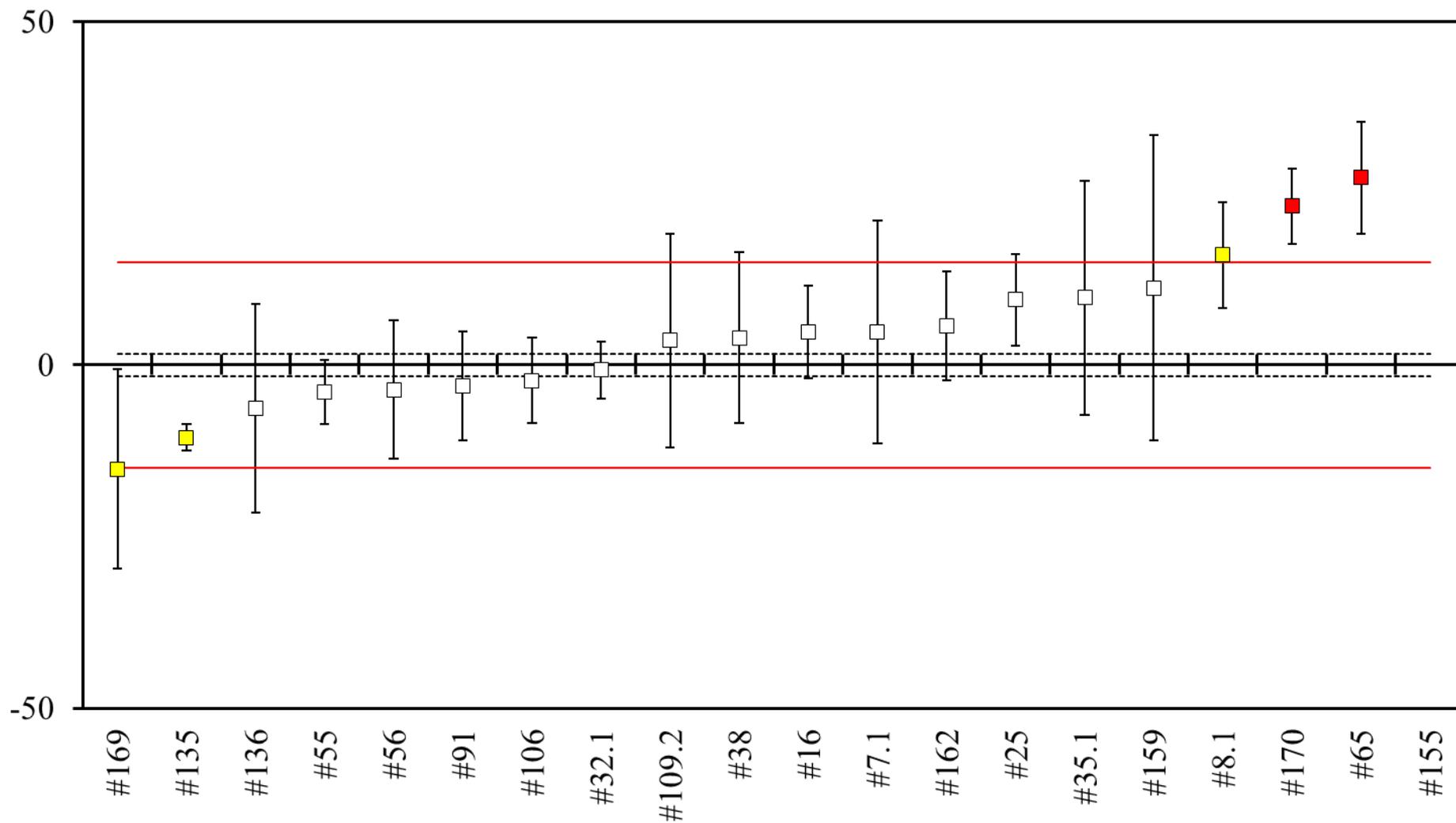
Deviation (%) of ^{36}Cl in B1
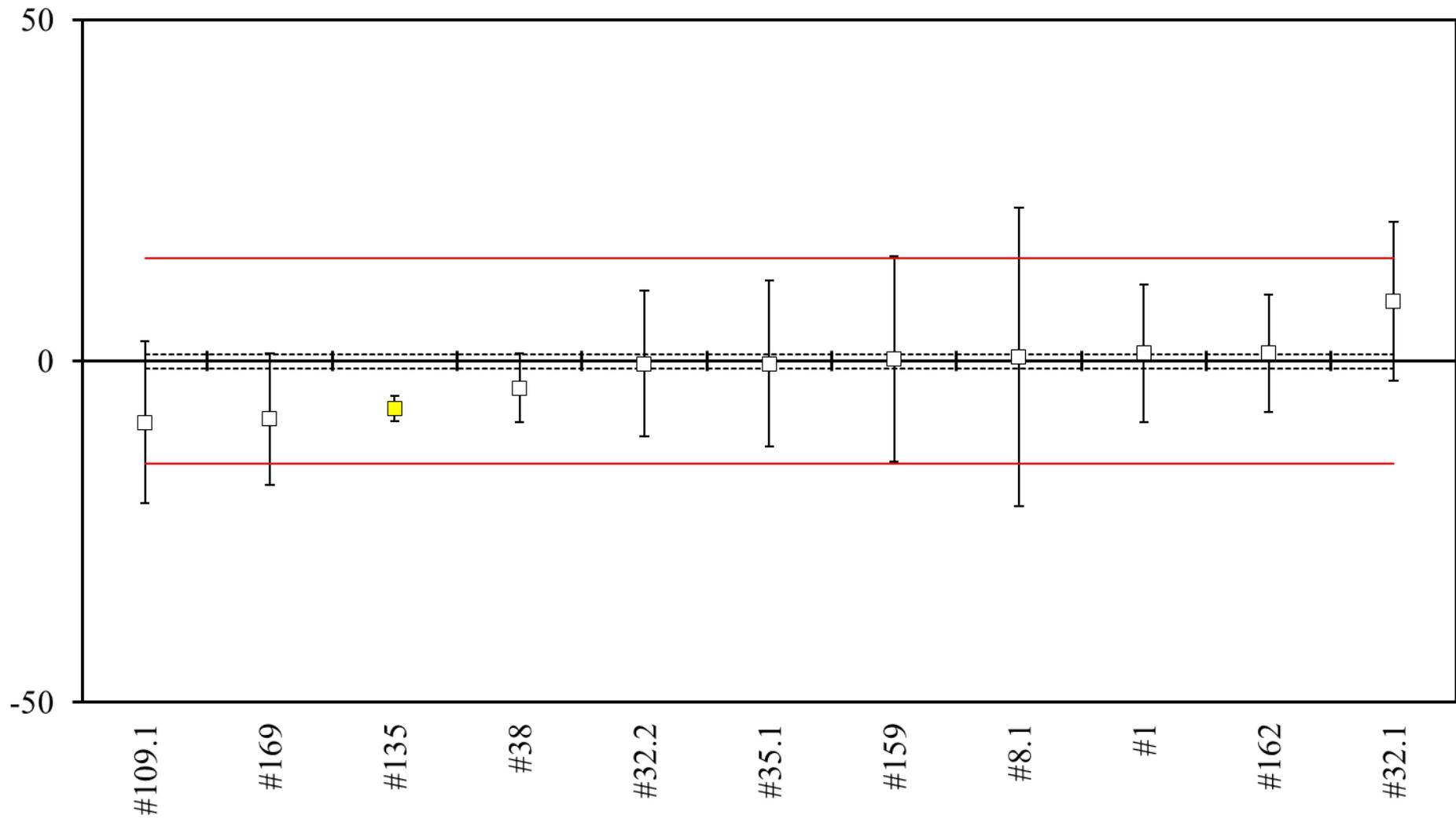
7. Gamma High (GH) Deviation Plots

Deviation (%) of ^{133}Ba in GH
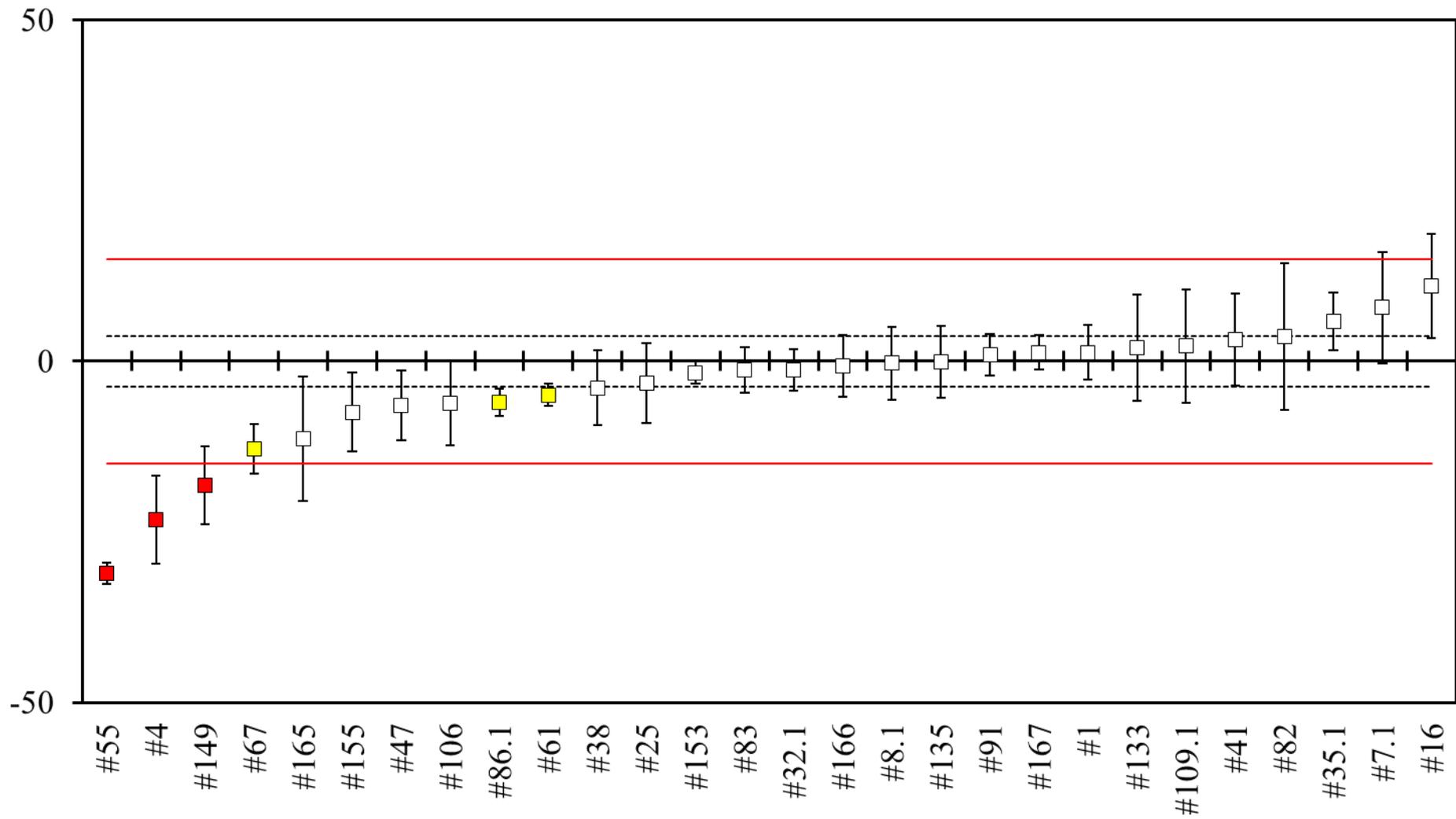
Deviation (%) of ^{137}Cs in GH
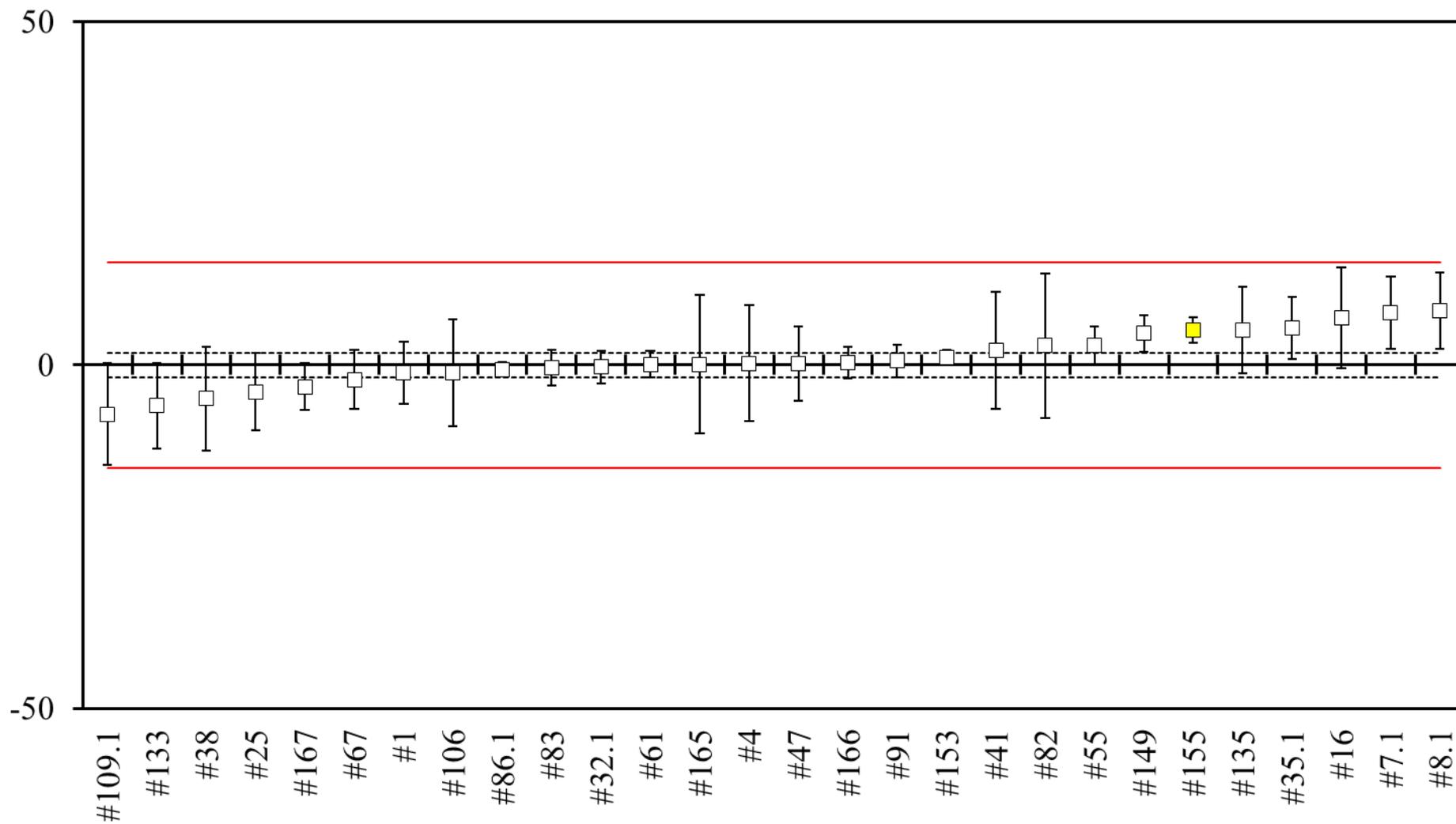
Deviation (%) of ^{154}Eu in GH
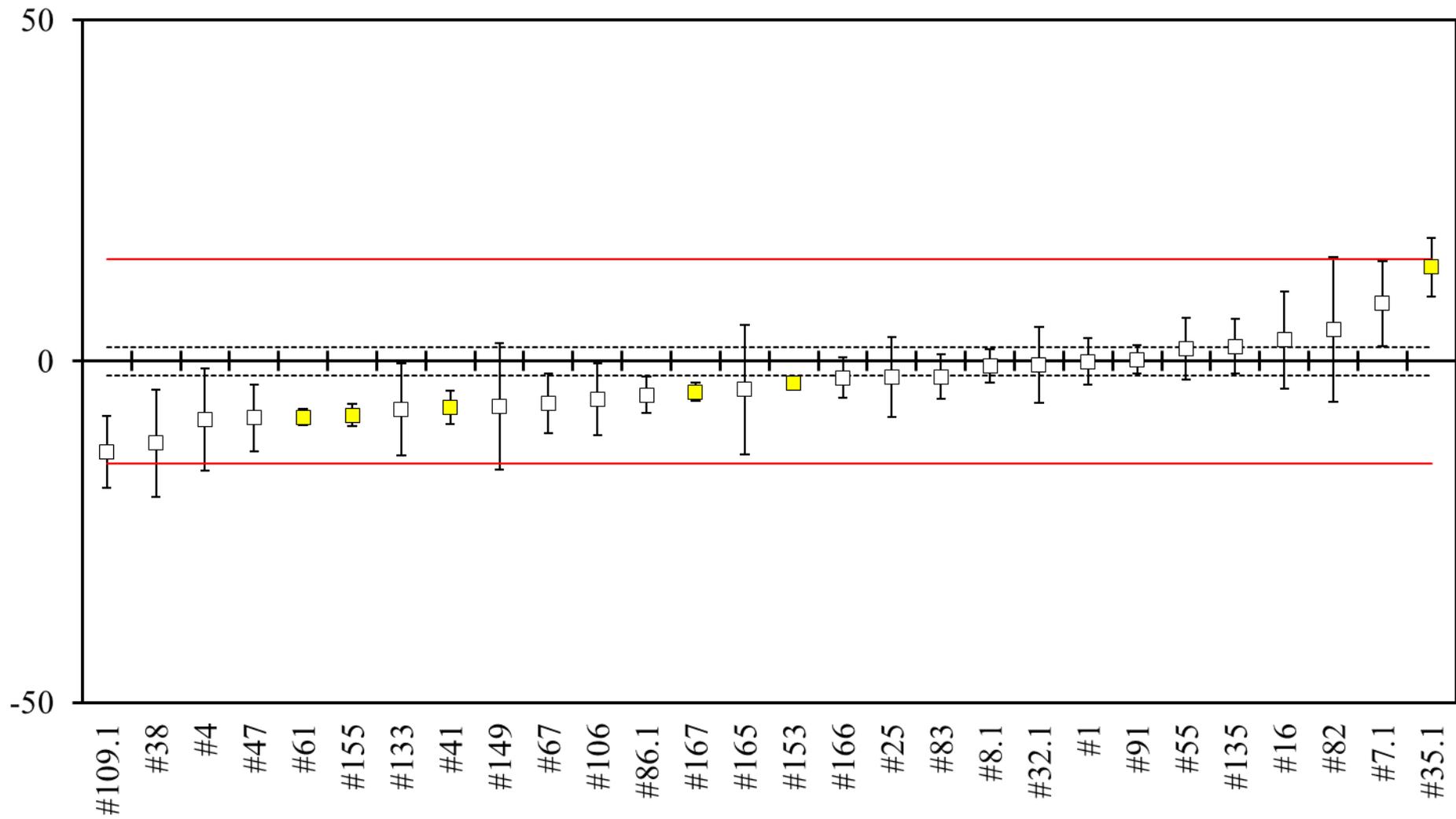
8. Gamma Low (GL) Deviation Plots

Deviation (%) of ^{134}Cs in GL
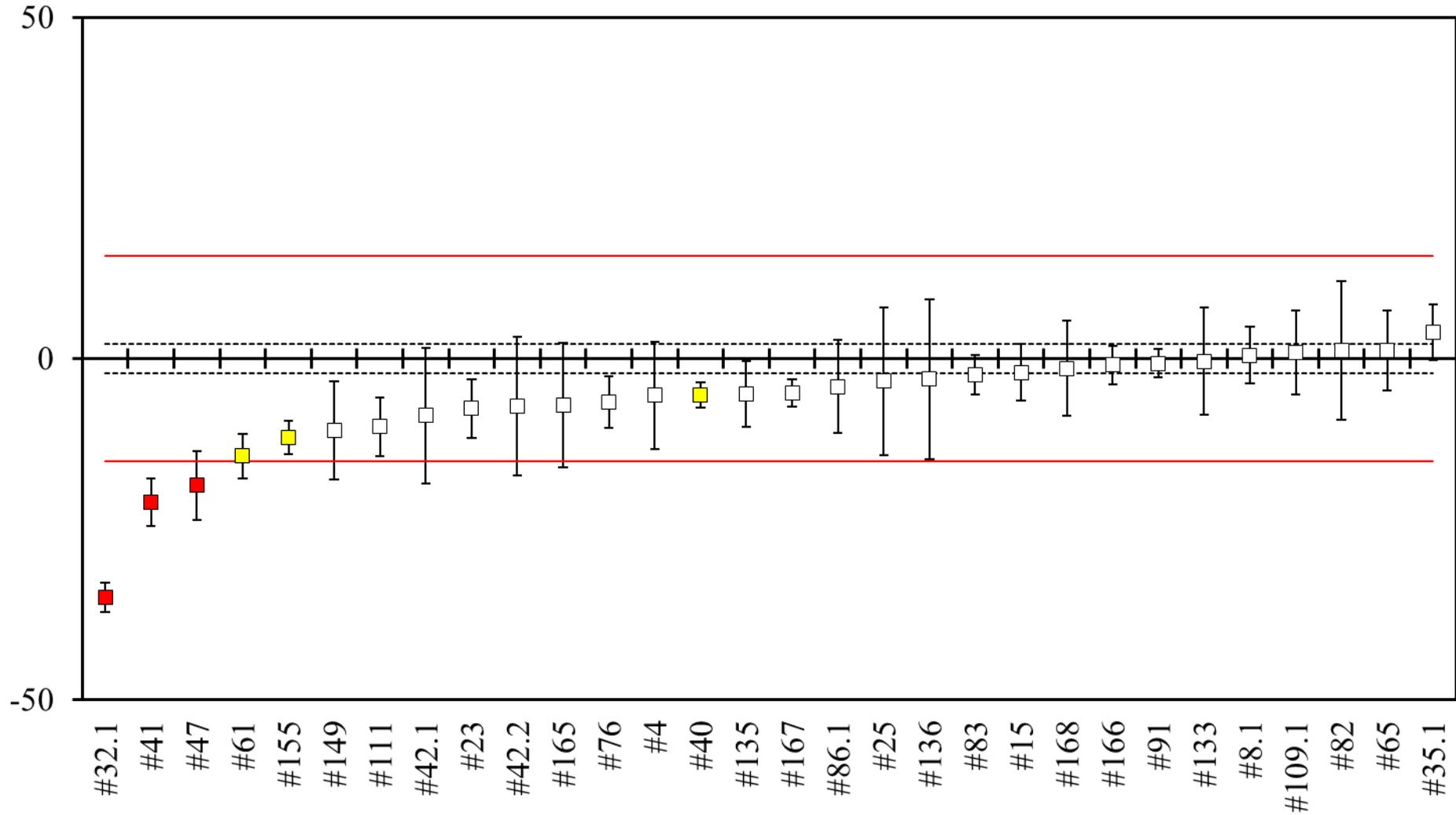
Deviation (%) of ^{210}Pb in GL
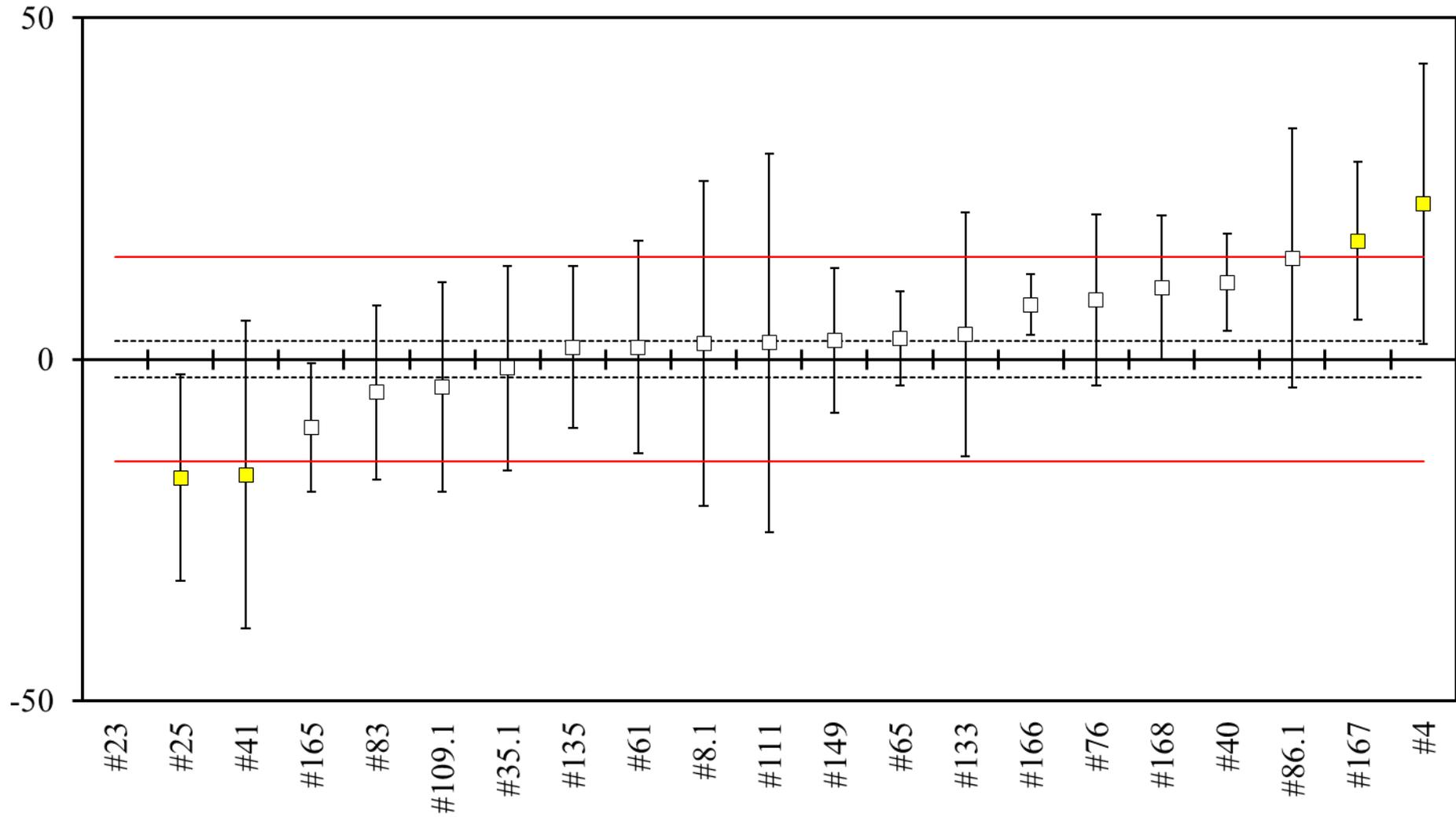
Deviation (%) of ^{241}Am in GL
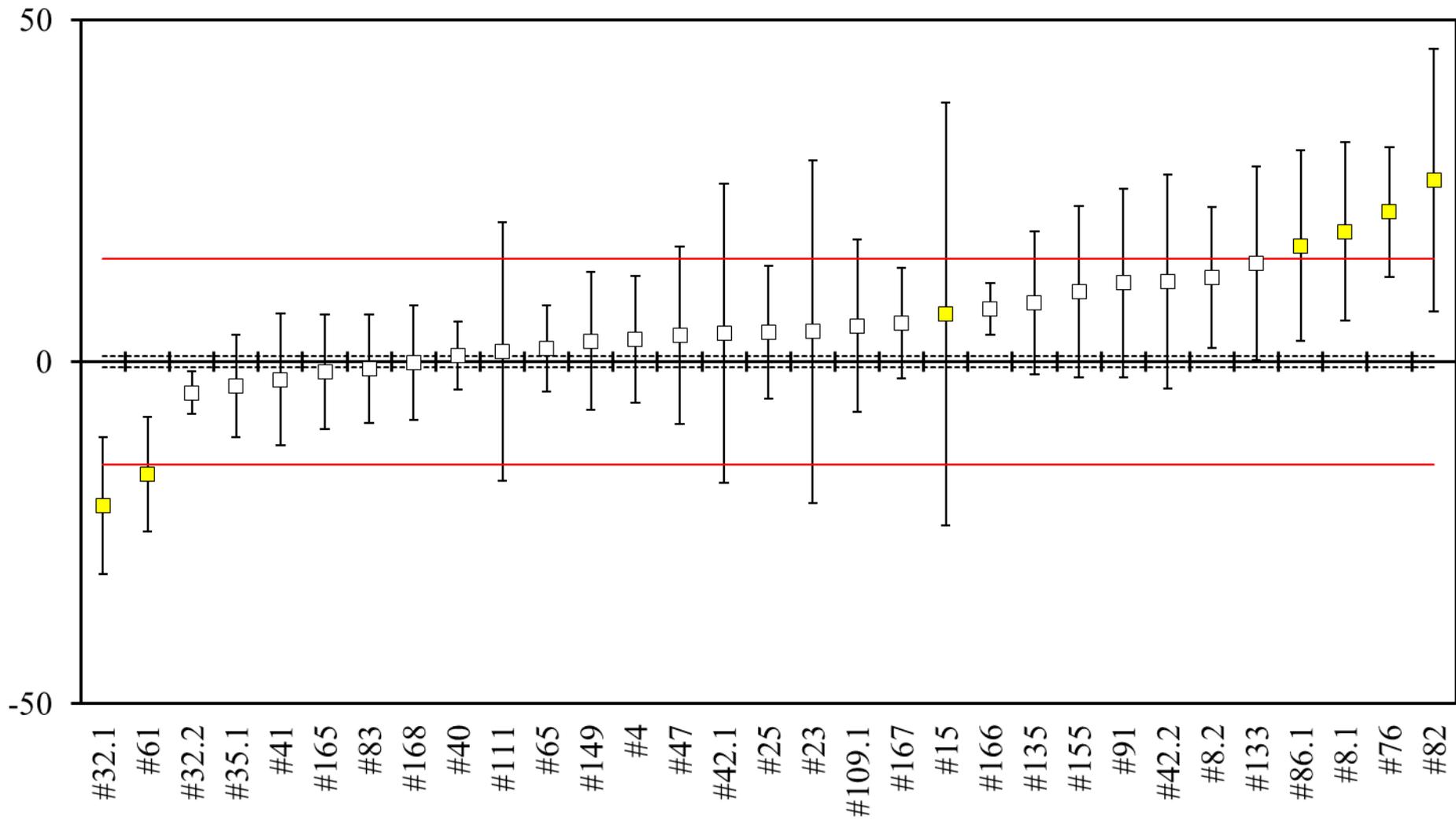
9. Deviation Plots and Tabulated Results Arranged by Lab Number

NOTE:

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

Deviation (%) of Laboratory 1
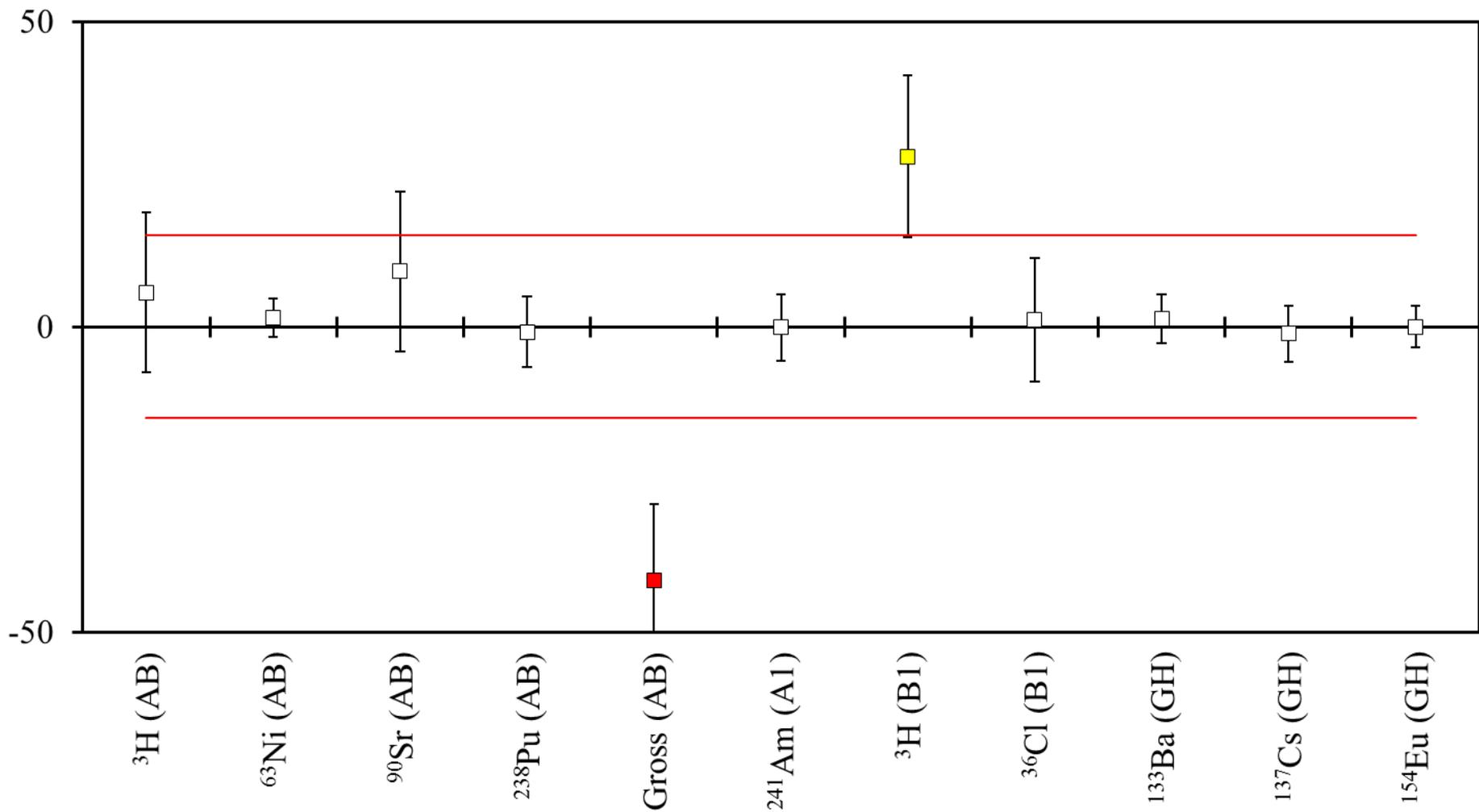
Radionuclide	Laboratory 1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	17.8 ± 2.2	16.85 ± 0.21	5.6	0.43	0.97
^{63}Ni (AB)	10.3 ± 0.3	10.15 ± 0.11	1.5	0.47	0.25
^{90}Sr (AB)	2.5 ± 0.3	2.292 ± 0.010	9.1	0.69	1.56
^{238}Pu (AB)	15.30 ± 0.90	15.428 ± 0.035	-0.8	-0.14	-0.14
Gross beta (AB)	2.70 ± 0.50	4.62 ± 0.49	-41.6	-2.74	-7.14
^{241}Am (A1)	9.20 ± 0.50	9.211 ± 0.026	-0.1	-0.02	-0.02
^{3}H (B1)	0.390 ± 0.040	0.3049 ± 0.0046	27.9	2.11	4.79
^{36}Cl (B1)	0.200 ± 0.020	0.19774 ± 0.00080	1.1	0.11	0.20
^{133}Ba (GH)	18.970 ± 0.7	18.73 ± 0.27	1.3	0.32	0.22
^{137}Cs (GH)	3.95 ± 0.18	3.996 ± 0.028	-1.2	-0.25	-0.20
^{154}Eu (GH)	6.36 ± 0.21	6.363 ± 0.051	0.0	-0.01	-0.01

Deviation (%) of Laboratory 4
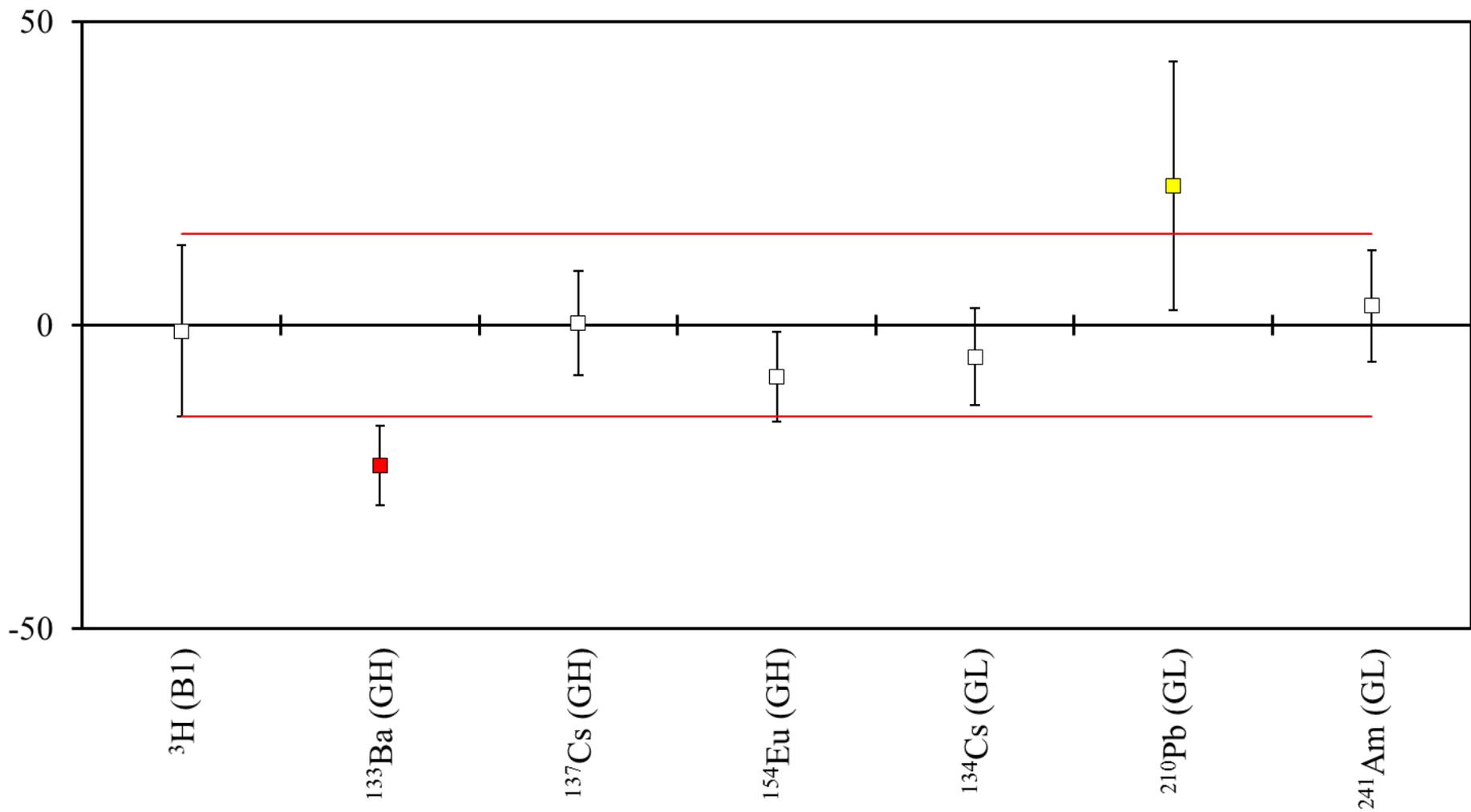
Radionuclide	Laboratory 4	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.302 ± 0.043	0.3049 ± 0.0046	-1.0	-0.07	-0.16
^{133}Ba (GH)	14.4 ± 1.2	18.73 ± 0.27	-23.1	-3.52	-3.97
^{137}Cs (GH)	4.01 ± 0.34	3.996 ± 0.028	0.4	0.04	0.06
^{154}Eu (GH)	5.82 ± 0.47	6.363 ± 0.051	-8.5	-1.15	-1.47
^{134}Cs (GL)	17.8 ± 1.5	18.78 ± 0.15	-5.2	-0.65	-0.90
^{210}Pb (GL)	19.8 ± 3.3	16.11 ± 0.17	22.9	1.12	3.93
^{241}Am (GL)	2.47 ± 0.22	2.3943 ± 0.0078	3.2	0.34	0.54

Deviation (%) of Laboratory 7.1
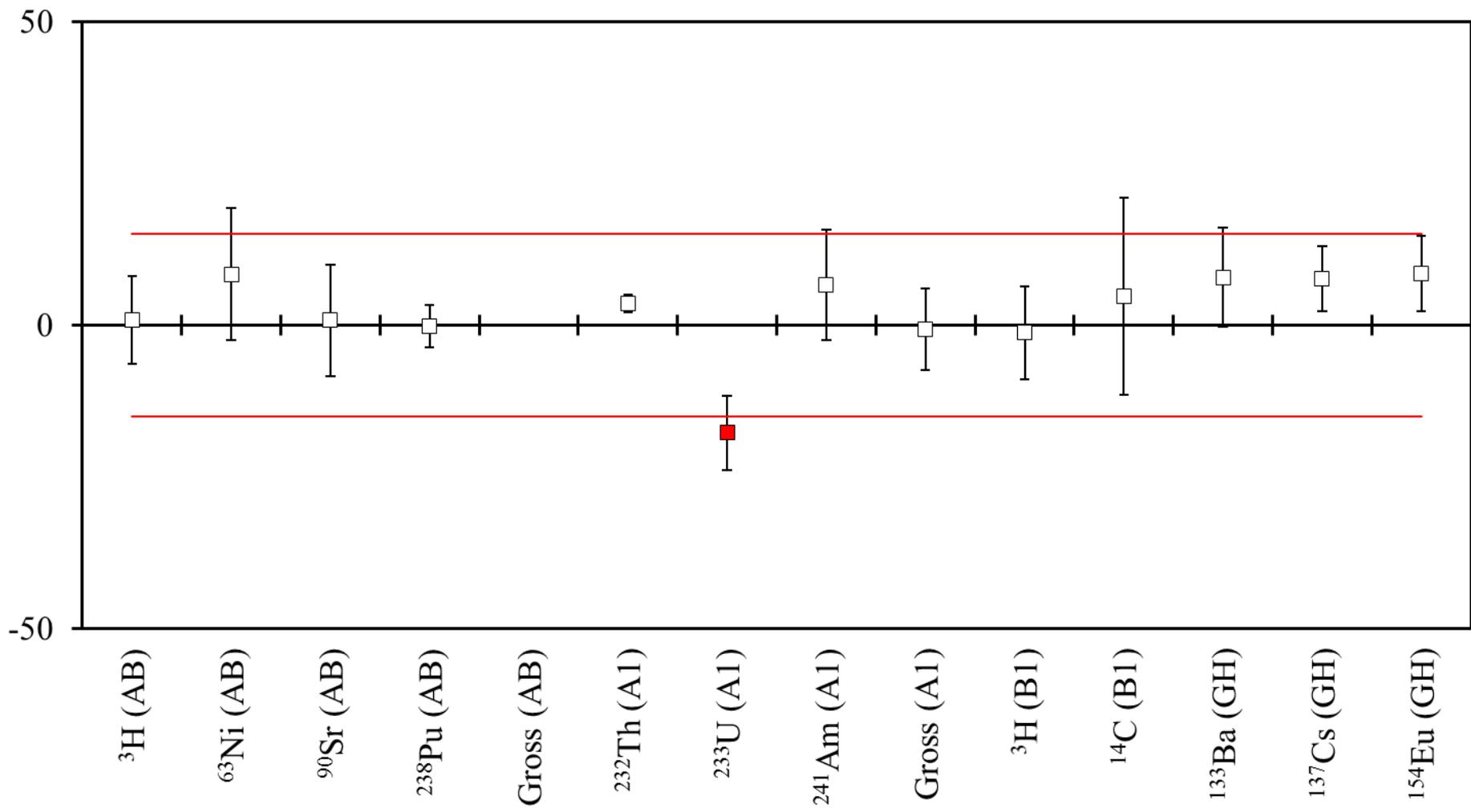
Radionuclide	Laboratory 7.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	17.0 ± 1.2	16.85 ± 0.21	0.9	0.12	0.15
^{63}Ni (AB)	11.0 ± 1.1	10.15 ± 0.11	8.4	0.77	1.44
^{90}Sr (AB)	2.31 ± 0.21	2.292 ± 0.010	0.8	0.09	0.13
^{238}Pu (AB)	15.40 ± 0.53	15.428 ± 0.035	-0.2	-0.05	-0.03
Gross beta (AB)	40.6 ± 3.1	4.62 ± 0.49	778.8	11.46	133.74
^{232}Th (A1)	0.8070 ± 0.0078	0.7792 ± 0.0075	3.6	2.57	0.61
^{233}U (A1)	14.8 ± 1.1	17.996 ± 0.054	-17.8	-2.90	-3.05
^{241}Am (A1)	9.82 ± 0.84	9.211 ± 0.026	6.6	0.72	1.14
Gross alpha (A1)	29.1 ± 1.7	29.3 ± 1.0	-0.7	-0.10	-0.12
^{3}H (B1)	0.301 ± 0.023	0.3049 ± 0.0046	-1.3	-0.17	-0.22
^{14}C (B1)	0.252 ± 0.039	0.2404 ± 0.0016	4.8	0.30	0.83
Gross beta (B1)	0.696 ± 0.055	-	-	-	-
^{133}Ba (GH)	20.2 ± 1.5	18.73 ± 0.27	7.8	0.96	1.35
^{137}Cs (GH)	4.30 ± 0.21	3.996 ± 0.028	7.6	1.43	1.31
^{154}Eu (GH)	6.90 ± 0.39	6.363 ± 0.051	8.4	1.37	1.45

Deviation (%) of Laboratory 8.1
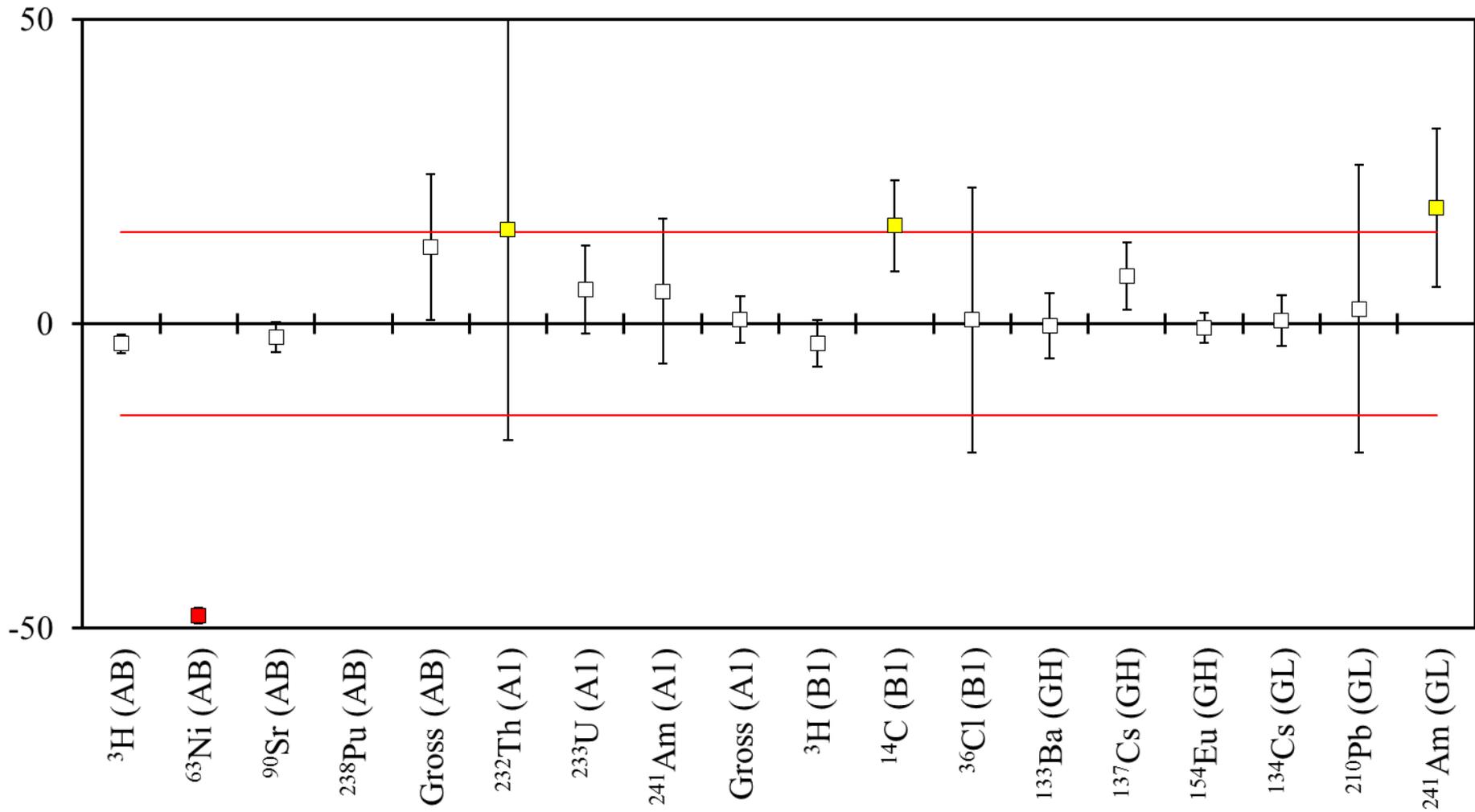
Radionuclide	Laboratory 8.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	16.30 ± 0.16	16.85 ± 0.21	-3.3	-2.08	-0.56
^{63}Ni (AB)	5.28 ± 0.12	10.15 ± 0.11	-48.0	-29.92	-8.24
^{90}Sr (AB)	2.240 ± 0.055	2.292 ± 0.010	-2.3	-0.93	-0.39
^{238}Pu (AB)	1.60 ± 0.11	15.428 ± 0.035	-89.6	-119.79	-15.39
Gross beta (AB)	5.200 ± 0.020	4.62 ± 0.49	12.6	1.18	2.16
^{232}Th (A1)	0.90 ± 0.27	0.7792 ± 0.0075	15.5	0.45	2.66
^{233}U (A1)	19.0 ± 1.3	17.996 ± 0.054	5.6	0.77	0.96
^{241}Am (A1)	9.7 ± 1.1	9.211 ± 0.026	5.3	0.44	0.91
Gross alpha (A1)	29.50 ± 0.53	29.3 ± 1.0	0.7	0.18	0.12
^{3}H (B1)	0.295 ± 0.011	0.3049 ± 0.0046	-3.2	-0.83	-0.56
^{14}C (B1)	0.279 ± 0.018	0.2404 ± 0.0016	16.1	2.14	2.76
^{36}Cl (B1)	0.199 ± 0.043	0.19774 ± 0.00080	0.6	0.03	0.11
^{133}Ba (GH)	18.67 ± 0.97	18.73 ± 0.27	-0.3	-0.06	-0.06
^{137}Cs (GH)	4.31 ± 0.22	3.996 ± 0.028	7.9	1.42	1.35
^{154}Eu (GH)	6.32 ± 0.15	6.363 ± 0.051	-0.7	-0.27	-0.12
^{134}Cs (GL)	18.87 ± 0.76	18.78 ± 0.15	0.5	0.12	0.08
^{210}Pb (GL)	16.5 ± 3.8	16.11 ± 0.17	2.4	0.10	0.42
^{241}Am (GL)	2.85 ± 0.31	2.3943 ± 0.0078	19.0	1.47	3.27

Deviation (%) of Laboratory 8.2
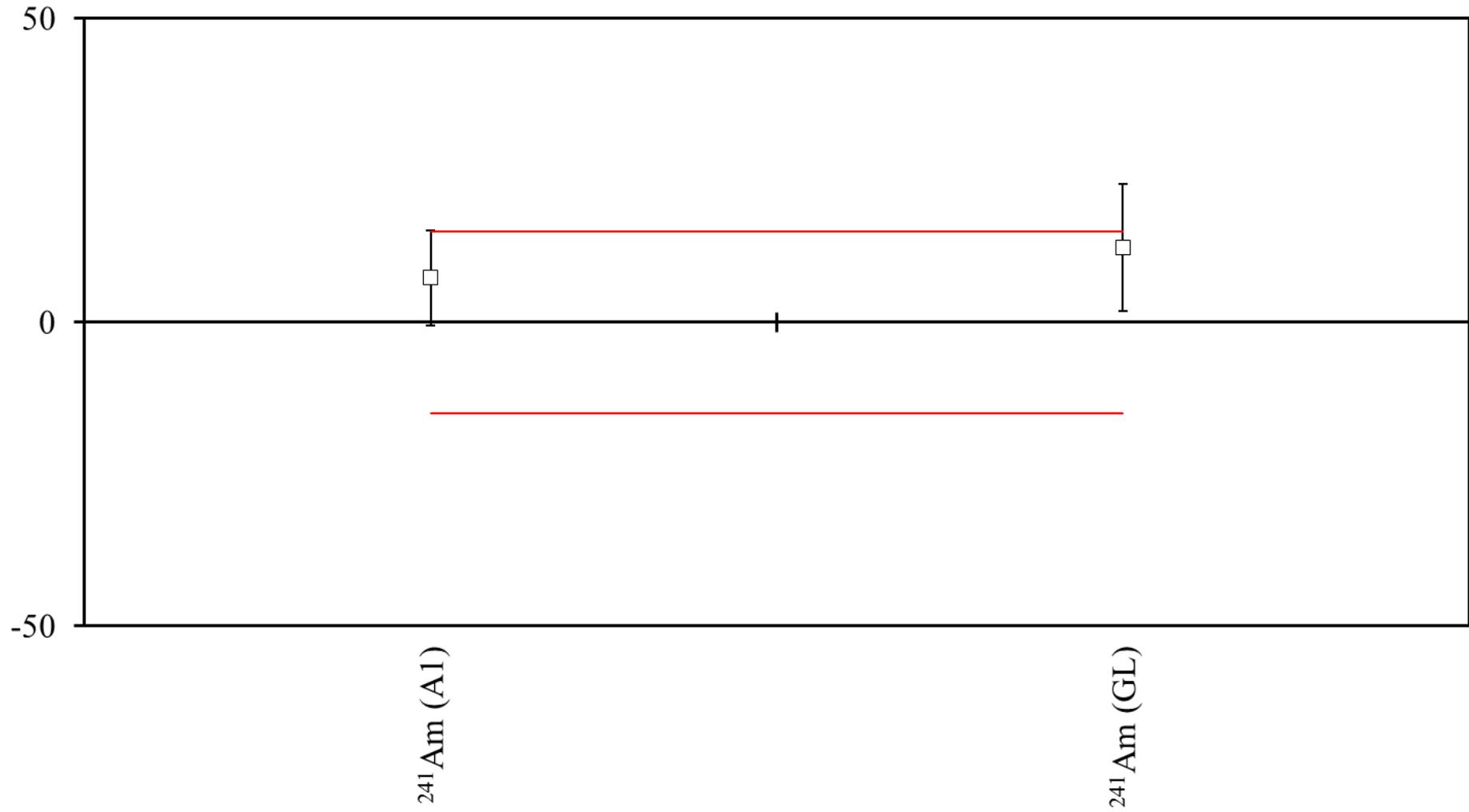
Radionuclide	Laboratory 8.2	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{241}Am (A1)	9.89 ± 0.72	9.211 ± 0.026	7.4	0.94	1.27
^{241}Am (GL)	2.69 ± 0.25	2.3943 ± 0.0078	12.4	1.18	2.12

Deviation (%) of Laboratory 15
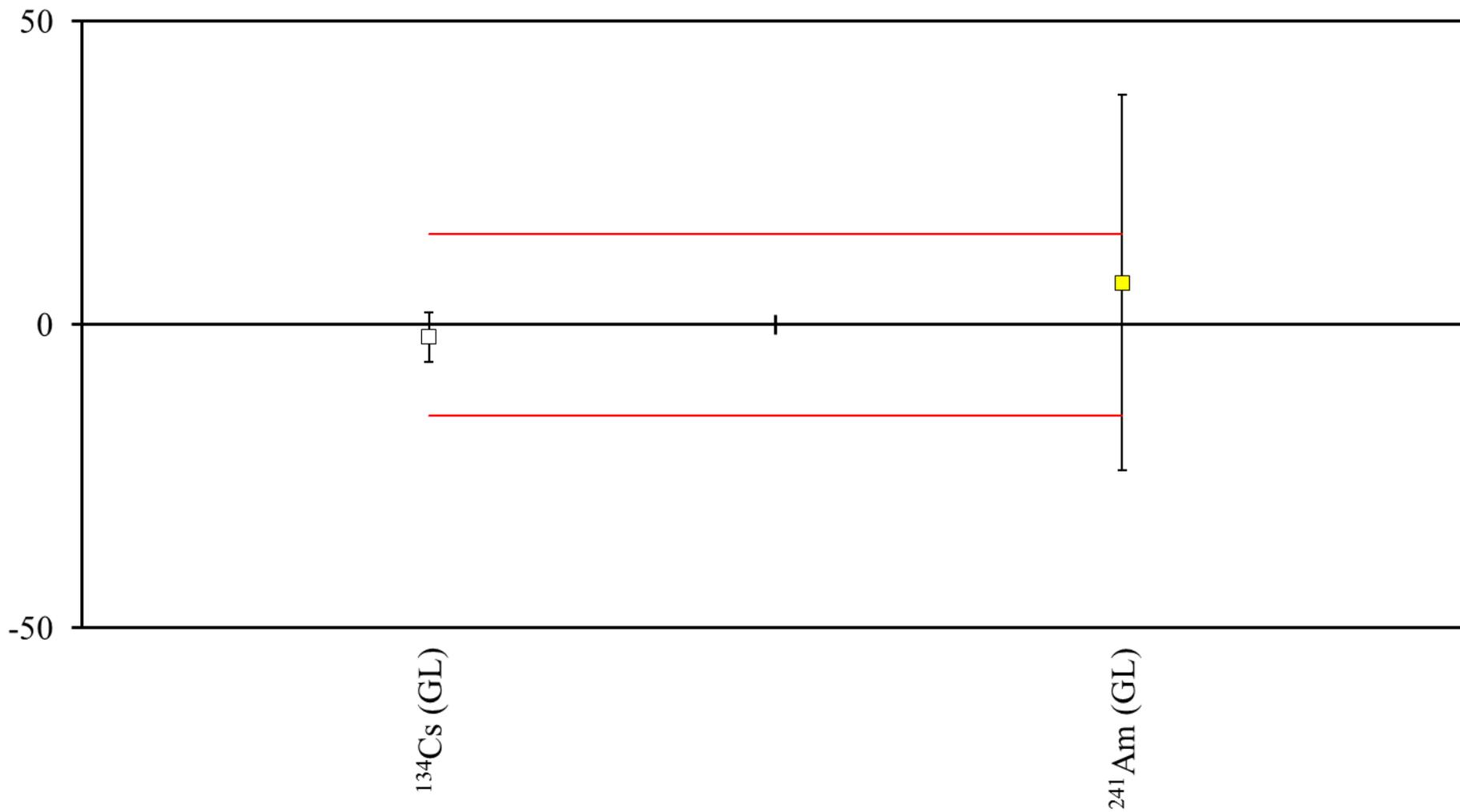
Radionuclide	Laboratory 15	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{134}Cs (GL)	18.40 ± 0.76	18.78 ± 0.15	-2.0	-0.49	-0.35
^{241}Am (GL)	2.56 ± 0.74	2.3943 ± 0.0078	6.9	0.22	1.19

Deviation (%) of Laboratory 16
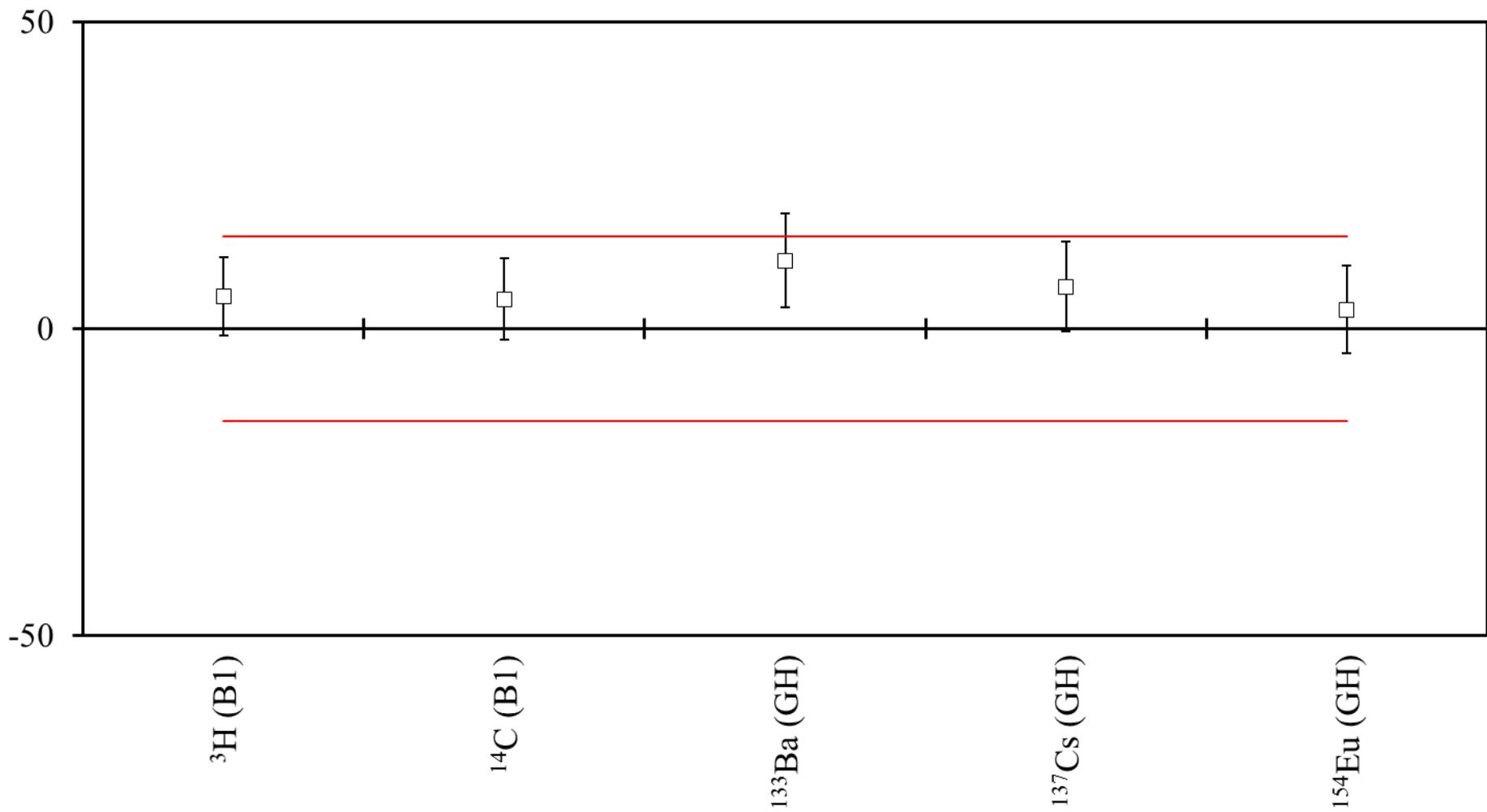
Radionuclide	Laboratory 16	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.321 ± 0.019	0.3049 ± 0.0046	5.3	0.82	0.91
^{14}C (B1)	0.252 ± 0.016	0.2404 ± 0.0016	4.8	0.72	0.83
^{133}Ba (GH)	20.8 ± 1.4	18.73 ± 0.27	11.1	1.45	1.90
^{137}Cs (GH)	4.27 ± 0.29	3.996 ± 0.028	6.9	0.94	1.18
^{154}Eu (GH)	6.56 ± 0.45	6.363 ± 0.051	3.1	0.43	0.53

Deviation (%) of Laboratory 23
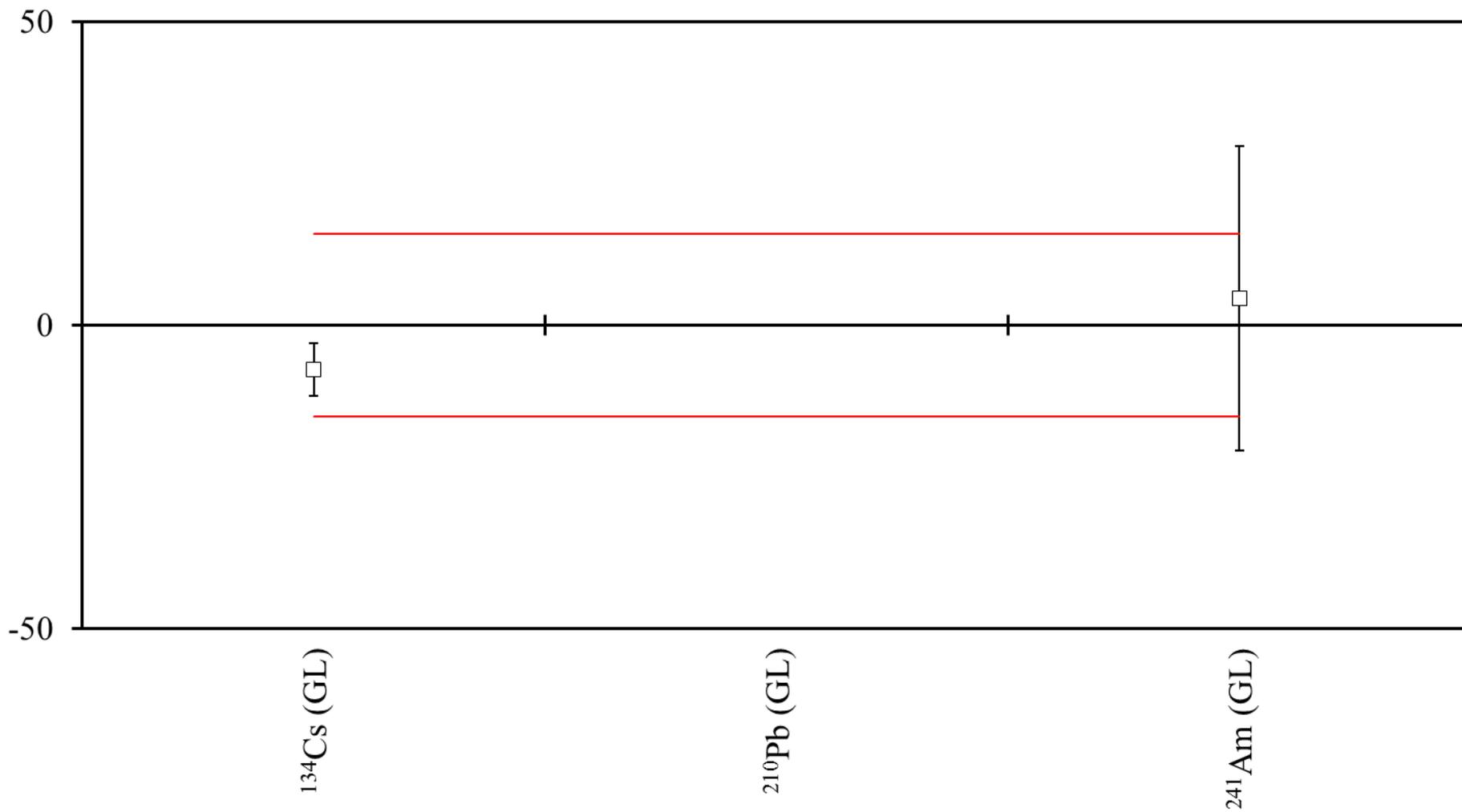
Radionuclide	Laboratory 23	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{134}Cs (GL)	17.40 ± 0.80	18.78 ± 0.15	-7.3	-1.70	-1.26
^{210}Pb (GL)	3.00 ± 0.97	16.11 ± 0.17	-81.4	-13.31	-13.98
^{241}Am (GL)	2.5 ± 0.6	2.3943 ± 0.0078	4.4	0.18	0.76

Deviation (%) of Laboratory 25
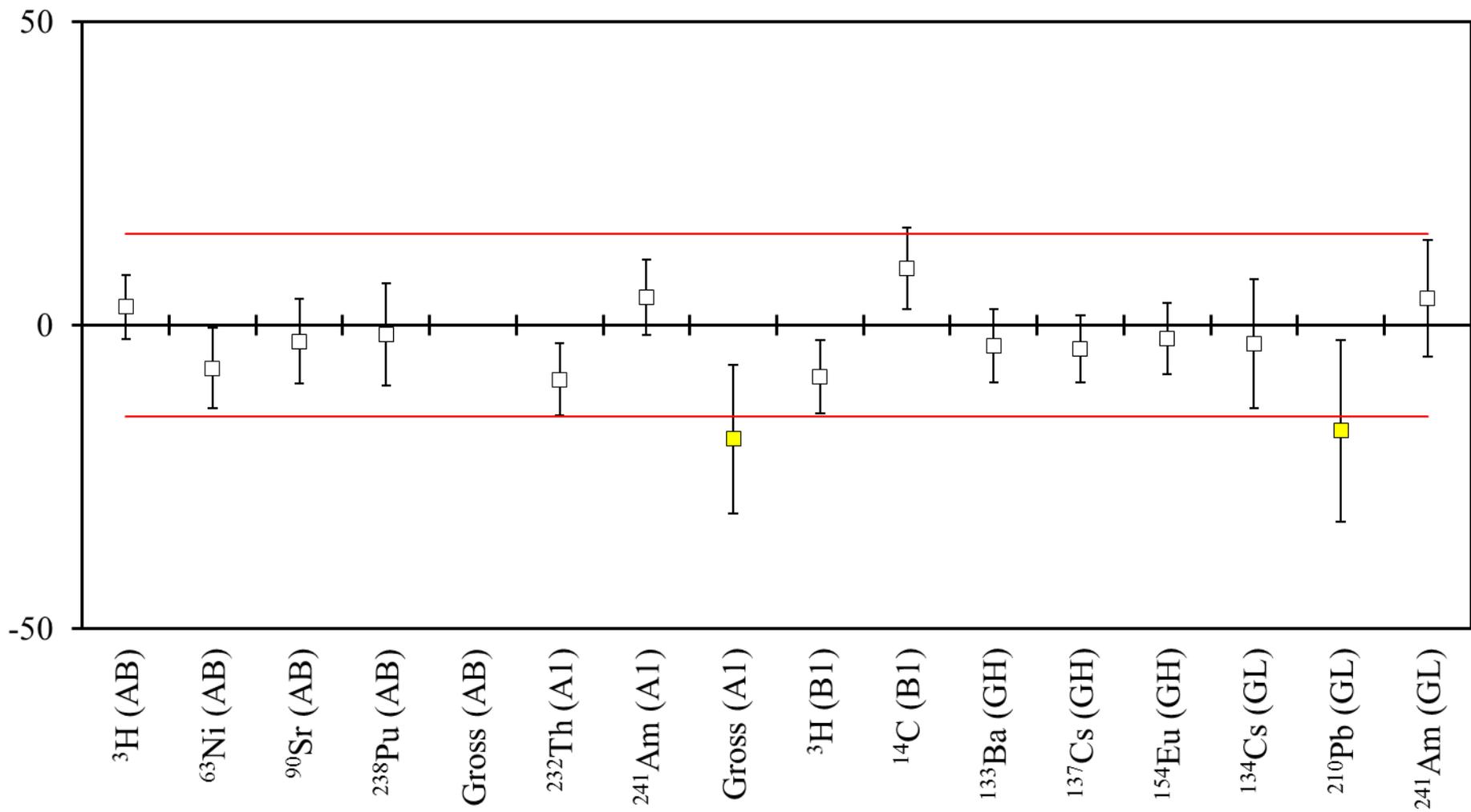
Radionuclide	Laboratory 25	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	17.35 ± 0.85	16.85 ± 0.21	3.0	0.57	0.51
^{63}Ni (AB)	9.43 ± 0.67	10.15 ± 0.11	-7.1	-1.06	-1.22
^{90}Sr (AB)	2.23 ± 0.16	2.292 ± 0.010	-2.7	-0.39	-0.46
^{238}Pu (AB)	15.2 ± 1.3	15.428 ± 0.035	-1.5	-0.18	-0.25
Gross beta (AB)	11.60 ± 0.94	4.62 ± 0.49	151.1	6.58	25.95
^{232}Th (A1)	0.709 ± 0.046	0.7792 ± 0.0075	-9.0	-1.51	-1.55
^{241}Am (A1)	9.63 ± 0.57	9.211 ± 0.026	4.5	0.73	0.78
Gross alpha (A1)	23.8 ± 3.5	29.3 ± 1.0	-18.8	-1.51	-3.22
^{3}H (B1)	0.279 ± 0.018	0.3049 ± 0.0046	-8.5	-1.39	-1.46
^{14}C (B1)	0.263 ± 0.016	0.2404 ± 0.0016	9.4	1.41	1.61
^{133}Ba (GH)	18.1 ± 1.1	18.73 ± 0.27	-3.4	-0.56	-0.58
^{137}Cs (GH)	3.84 ± 0.22	3.996 ± 0.028	-3.9	-0.70	-0.67
^{154}Eu (GH)	6.22 ± 0.37	6.363 ± 0.051	-2.2	-0.38	-0.39
^{134}Cs (GL)	18.2 ± 2.0	18.78 ± 0.15	-3.1	-0.29	-0.53
^{210}Pb (GL)	13.3 ± 2.4	16.11 ± 0.17	-17.4	-1.17	-3.00
^{241}Am (GL)	2.50 ± 0.23	2.3943 ± 0.0078	4.4	0.46	0.76

Deviation (%) of Laboratory 26
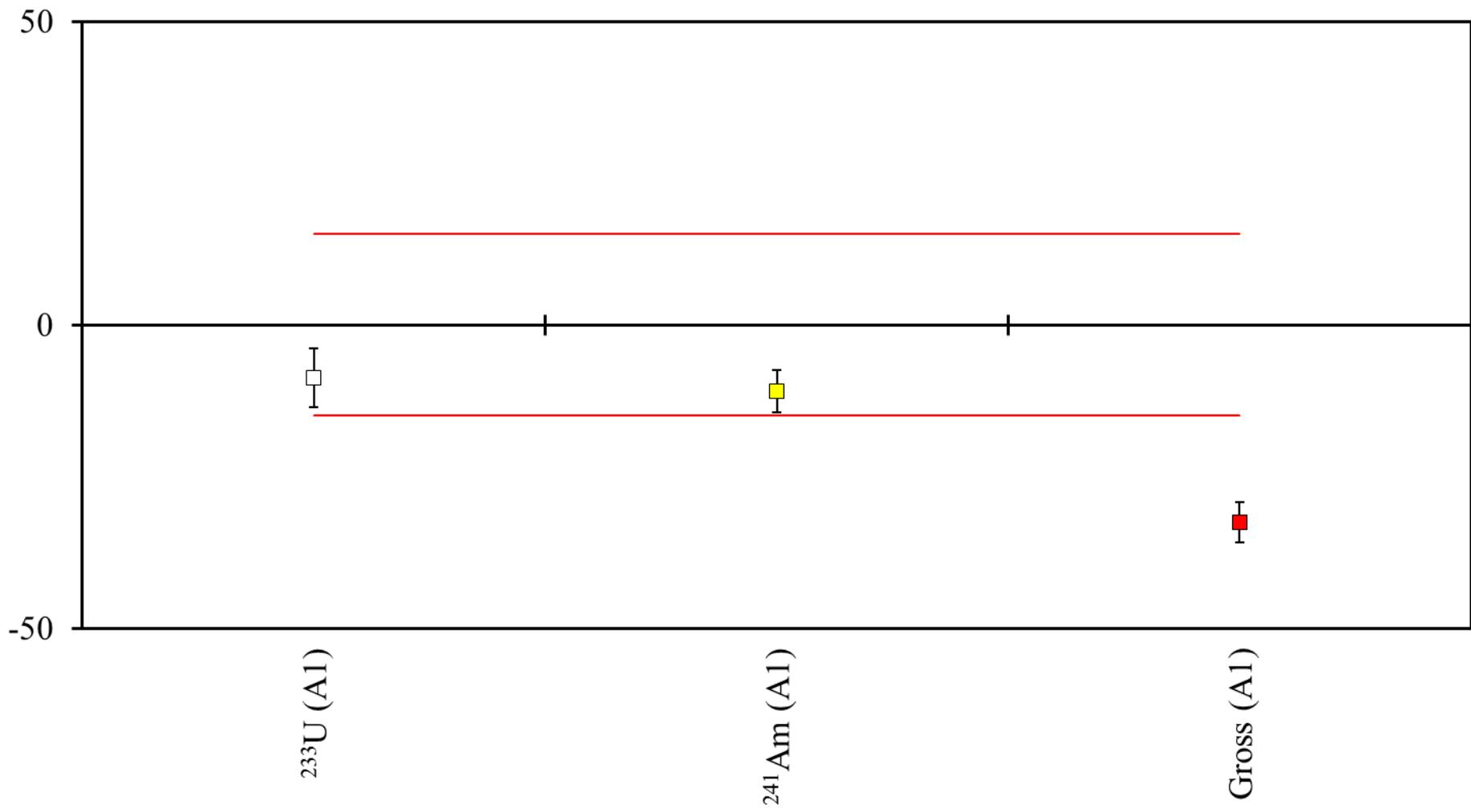
Radionuclide	Laboratory 26	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{233}U (A1)	16.42 ± 0.88	17.996 ± 0.054	-8.8	-1.79	-1.50
^{241}Am (A1)	8.21 ± 0.32	9.211 ± 0.026	-10.9	-3.12	-1.87
Gross alpha (A1)	19.75 ± 0.71	29.3 ± 1.0	-32.6	-7.79	-5.60

Deviation (%) of Laboratory 32.1
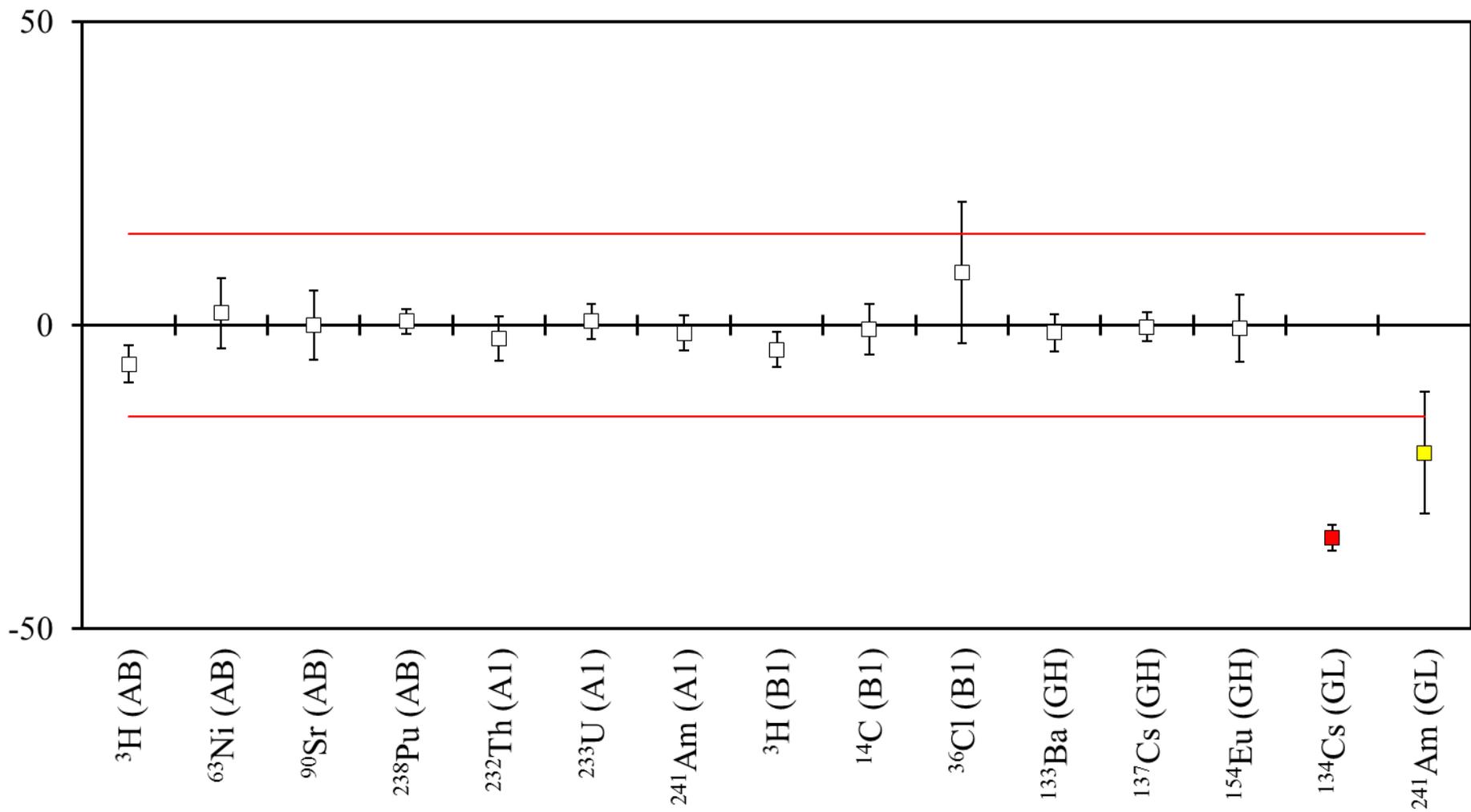
Radionuclide	Laboratory 32.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	15.77 ± 0.48	16.85 ± 0.21	-6.4	-2.06	-1.10
^{63}Ni (AB)	10.35 ± 0.58	10.15 ± 0.11	2.0	0.34	0.34
^{90}Sr (AB)	2.29 ± 0.13	2.292 ± 0.010	-0.1	-0.02	-0.01
^{238}Pu (AB)	15.52 ± 0.31	15.428 ± 0.035	0.6	0.29	0.10
^{232}Th (A1)	0.762 ± 0.027	0.7792 ± 0.0075	-2.2	-0.61	-0.38
^{233}U (A1)	18.11 ± 0.52	17.996 ± 0.054	0.6	0.22	0.11
^{241}Am (A1)	9.09 ± 0.26	9.211 ± 0.026	-1.3	-0.46	-0.23
^{3}H (B1)	0.2926 ± 0.0077	0.3049 ± 0.0046	-4.0	-1.37	-0.69
^{14}C (B1)	0.2387 ± 0.0099	0.2404 ± 0.0016	-0.7	-0.17	-0.12
^{36}Cl (B1)	0.215 ± 0.023	0.19774 ± 0.00080	8.7	0.75	1.50
^{133}Ba (GH)	18.49 ± 0.50	18.73 ± 0.27	-1.3	-0.42	-0.22
^{137}Cs (GH)	3.985 ± 0.090	3.996 ± 0.028	-0.3	-0.12	-0.05
^{154}Eu (GH)	6.33 ± 0.35	6.363 ± 0.051	-0.5	-0.09	-0.09
^{134}Cs (GL)	12.20 ± 0.40	18.78 ± 0.15	-35.0	-15.40	-6.02
^{241}Am (GL)	1.89 ± 0.24	2.3943 ± 0.0078	-21.1	-2.10	-3.62

Deviation (%) of Laboratory 32.2
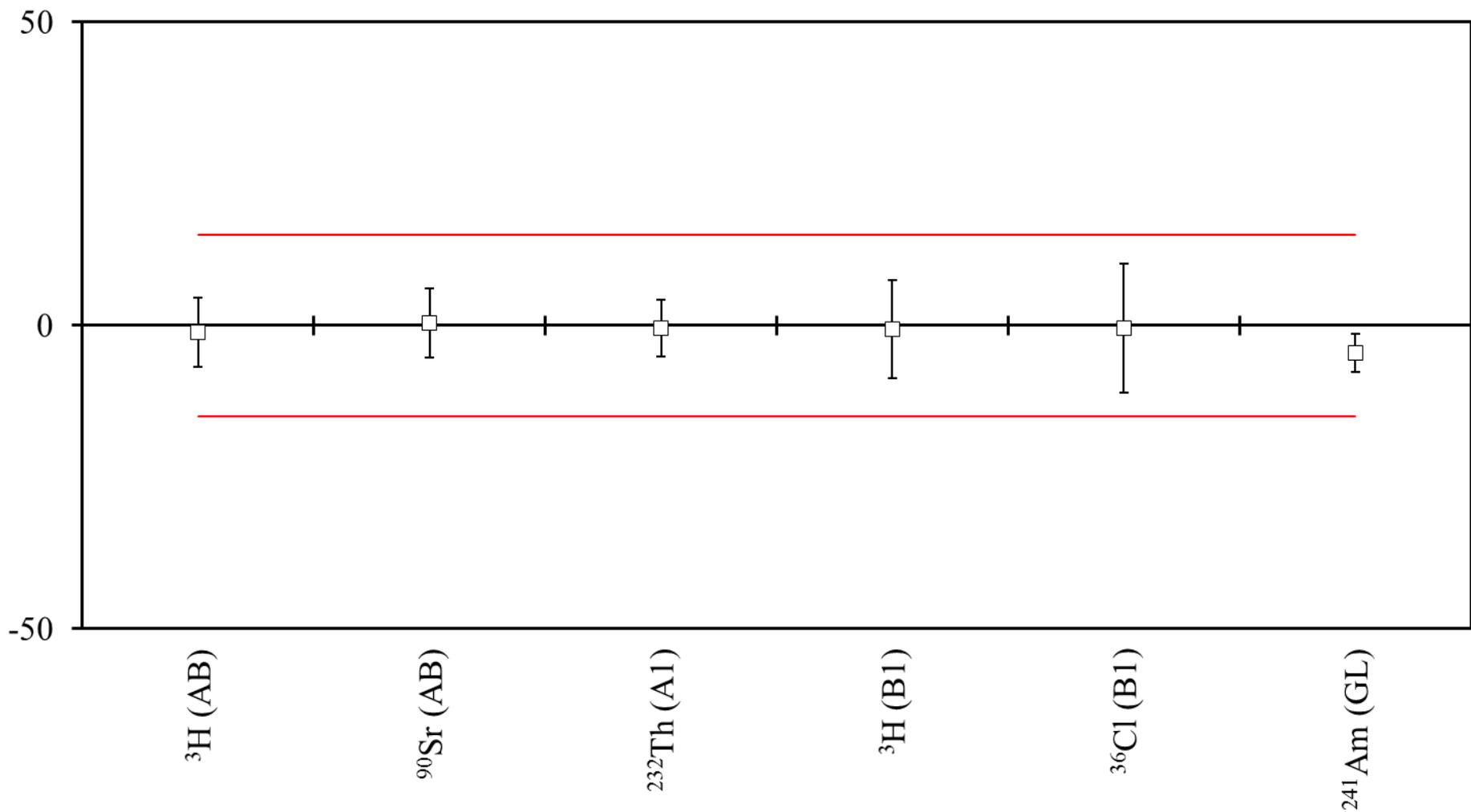
Radionuclide	Laboratory 32.2	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	16.66 ± 0.93	16.85 ± 0.21	-1.1	-0.20	-0.19
^{90}Sr (AB)	2.30 ± 0.13	2.292 ± 0.010	0.3	0.06	0.06
^{232}Th (A1)	0.776 ± 0.036	0.7792 ± 0.0075	-0.4	-0.09	-0.07
^{3}H (B1)	0.303 ± 0.024	0.3049 ± 0.0046	-0.6	-0.08	-0.11
^{36}Cl (B1)	0.197 ± 0.021	0.19774 ± 0.00080	-0.4	-0.04	-0.06
^{241}Am (GL)	2.285 ± 0.074	2.3943 ± 0.0078	-4.6	-1.47	-0.78

Deviation (%) of Laboratory 35.1
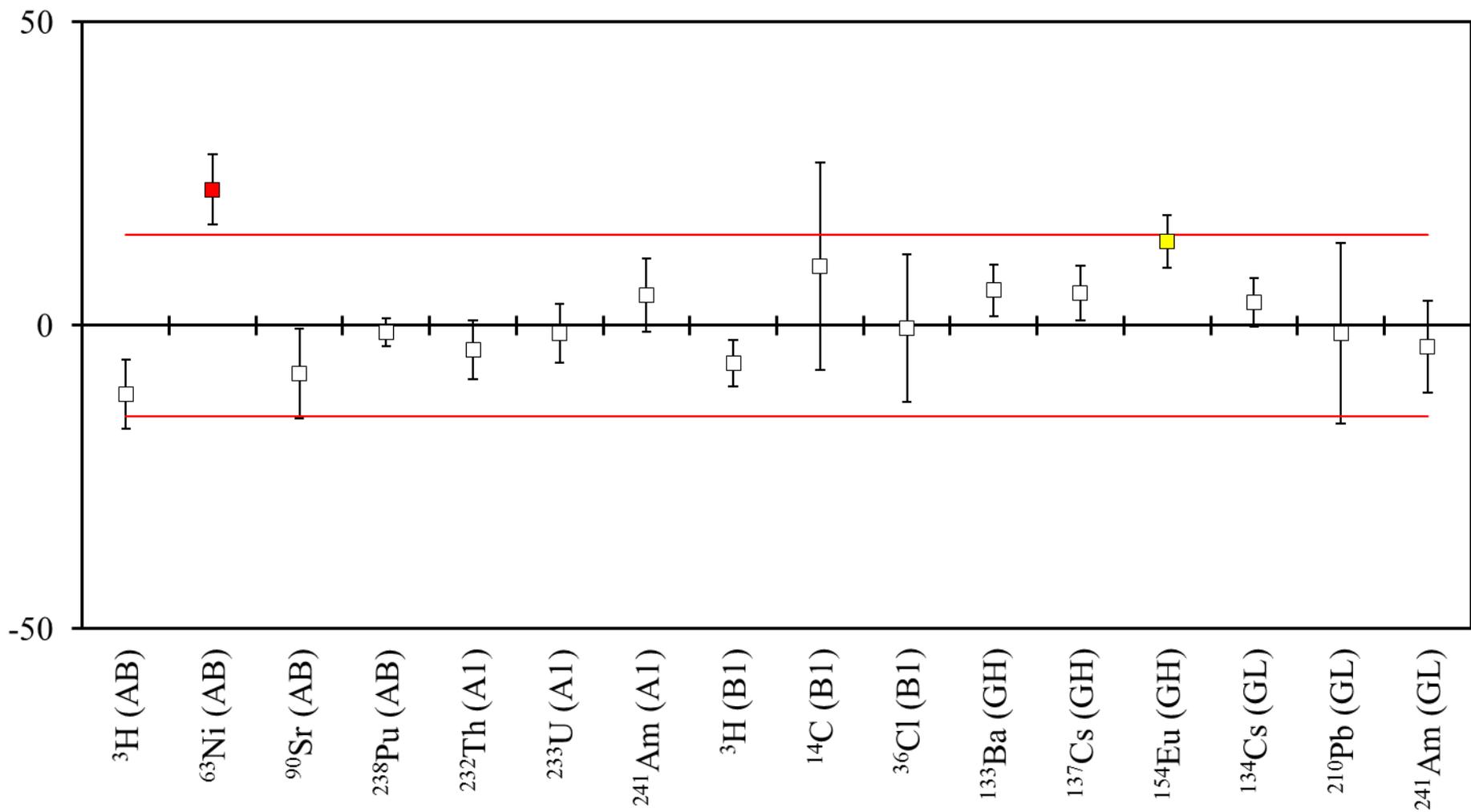
Radionuclide	Laboratory 35.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	14.94 ± 0.95	16.85 ± 0.21	-11.3	-1.96	-1.95
^{63}Ni (AB)	12.42 ± 0.57	10.15 ± 0.11	22.4	3.91	3.84
^{90}Sr (AB)	2.11 ± 0.17	2.292 ± 0.010	-7.9	-1.07	-1.36
^{238}Pu (AB)	15.25 ± 0.36	15.428 ± 0.035	-1.2	-0.49	-0.20
^{232}Th (A1)	0.748 ± 0.037	0.7792 ± 0.0075	-4.0	-0.83	-0.69
^{233}U (A1)	17.76 ± 0.88	17.996 ± 0.054	-1.3	-0.27	-0.23
^{241}Am (A1)	9.67 ± 0.55	9.211 ± 0.026	5.0	0.83	0.86
^{3}H (B1)	0.286 ± 0.011	0.3049 ± 0.0046	-6.2	-1.59	-1.06
^{14}C (B1)	0.264 ± 0.041	0.2404 ± 0.0016	9.8	0.58	1.69
^{36}Cl (B1)	0.197 ± 0.024	0.19774 ± 0.00080	-0.4	-0.03	-0.06
^{133}Ba (GH)	19.82 ± 0.74	18.73 ± 0.27	5.8	1.38	1.00
^{137}Cs (GH)	4.21 ± 0.18	3.996 ± 0.028	5.4	1.17	0.92
^{154}Eu (GH)	7.24 ± 0.27	6.363 ± 0.051	13.8	3.19	2.37
^{134}Cs (GL)	19.50 ± 0.74	18.78 ± 0.15	3.8	0.95	0.66
^{210}Pb (GL)	15.9 ± 2.4	16.11 ± 0.17	-1.3	-0.09	-0.22
^{241}Am (GL)	2.31 ± 0.18	2.3943 ± 0.0078	-3.5	-0.47	-0.60

Deviation (%) of Laboratory 35.2
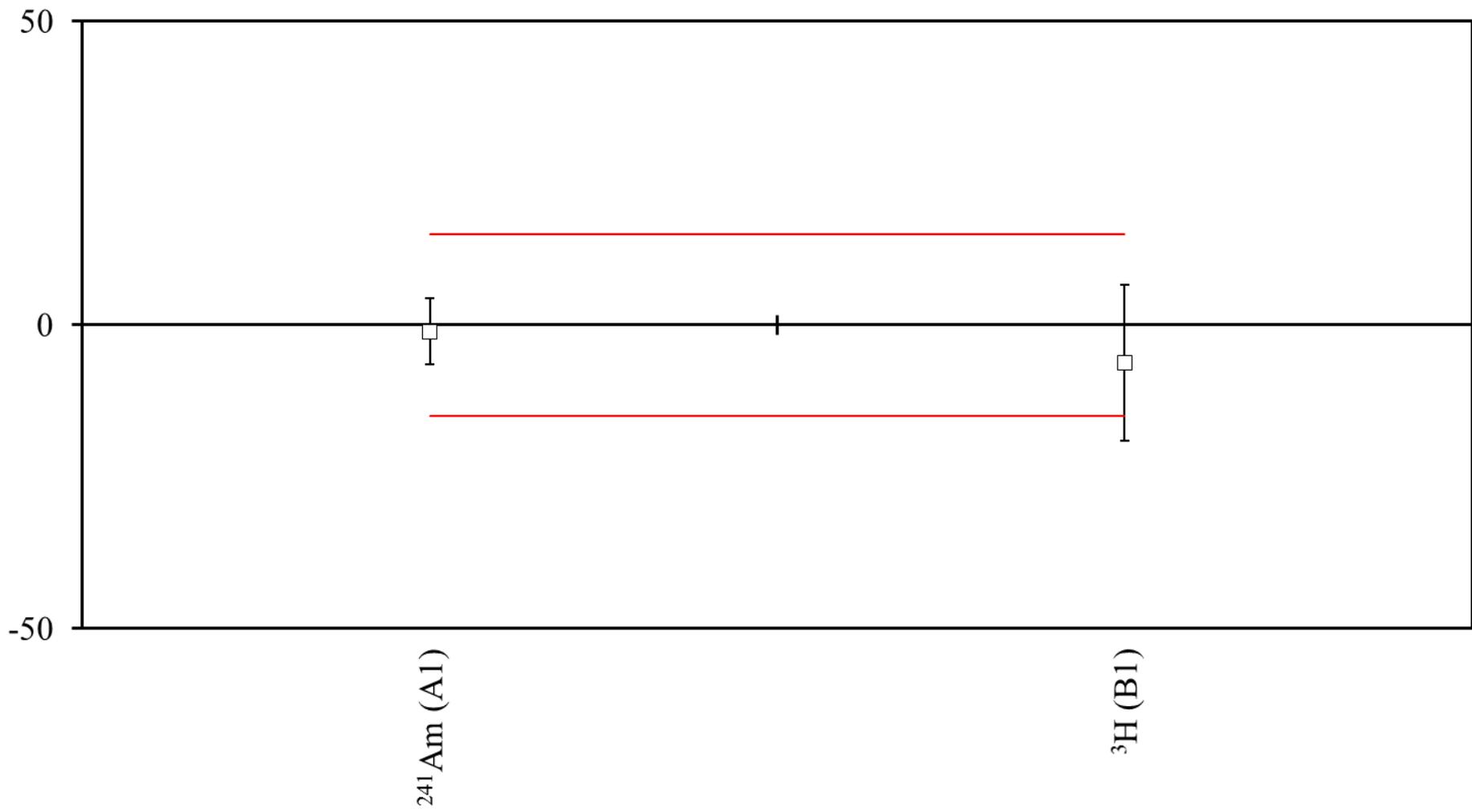
Radionuclide	Laboratory 35.2	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{241}Am (A1)	9.11 ± 0.50	9.211 ± 0.026	-1.1	-0.20	-0.19
^{3}H (B1)	0.286 ± 0.039	0.3049 ± 0.0046	-6.2	-0.48	-1.06

Deviation (%) of Laboratory 38
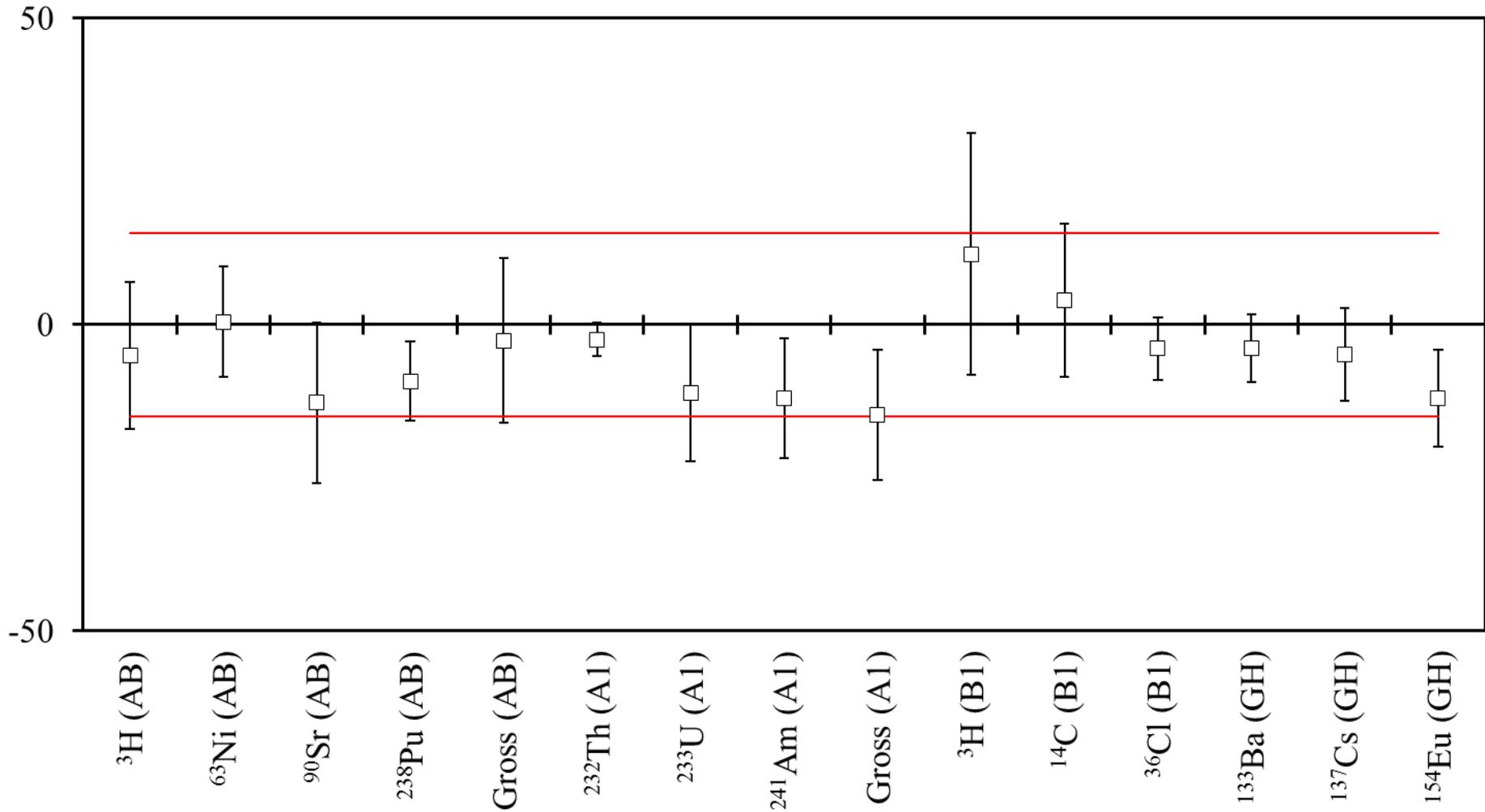
Radionuclide	Laboratory 38	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	16.0 ± 2.0	16.85 ± 0.21	-5.0	-0.42	-0.87
^{63}Ni (AB)	10.20 ± 0.90	10.15 ± 0.11	0.5	0.06	0.08
^{90}Sr (AB)	2.0 ± 0.3	2.292 ± 0.010	-12.7	-0.97	-2.19
^{238}Pu (AB)	14.0 ± 1.0	15.428 ± 0.035	-9.3	-1.43	-1.59
Gross beta (AB)	4.50 ± 0.40	4.62 ± 0.49	-2.6	-0.19	-0.45
^{232}Th (A1)	0.760 ± 0.020	0.7792 ± 0.0075	-2.5	-0.90	-0.42
^{233}U (A1)	16.0 ± 2.0	17.996 ± 0.054	-11.1	-1.00	-1.90
^{241}Am (A1)	8.10 ± 0.90	9.211 ± 0.026	-12.1	-1.23	-2.07
Gross alpha (A1)	25.0 ± 3.0	29.3 ± 1.0	-14.7	-1.36	-2.52
^{3}H (B1)	0.34 ± 0.06	0.3049 ± 0.0046	11.5	0.58	1.98
^{14}C (B1)	0.25 ± 0.03	0.2404 ± 0.0016	4.0	0.32	0.69
^{36}Cl (B1)	0.190 ± 0.010	0.19774 ± 0.00080	-3.9	-0.77	-0.67
^{133}Ba (GH)	18.0 ± 1.0	18.73 ± 0.27	-3.9	-0.70	-0.67
^{137}Cs (GH)	3.8 ± 0.3	3.996 ± 0.028	-4.9	-0.65	-0.84
^{154}Eu (GH)	5.60 ± 0.50	6.363 ± 0.051	-12.0	-1.52	-2.06

Deviation (%) of Laboratory 40
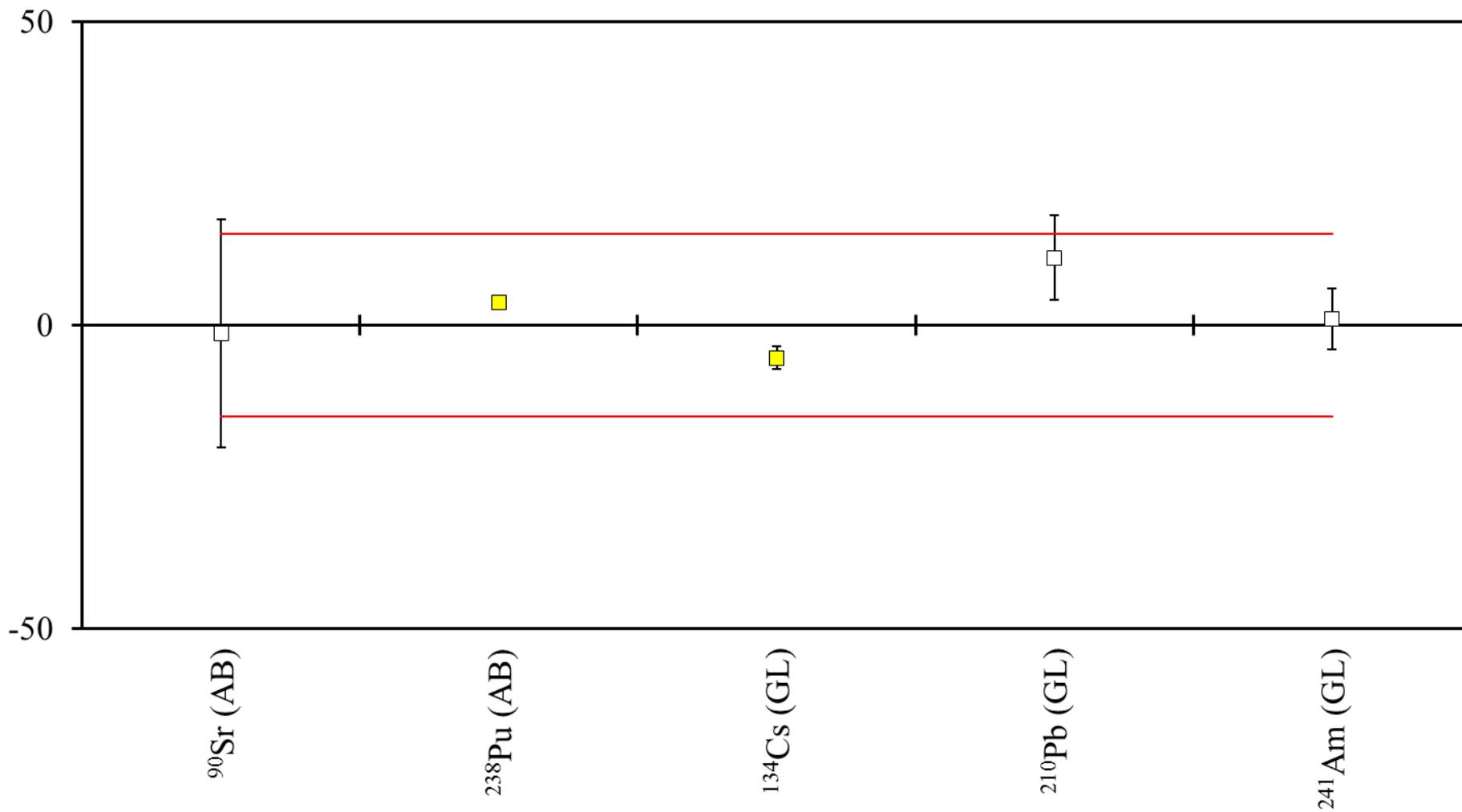
Radionuclide	Laboratory 40	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{90}Sr (AB)	2.26 ± 0.43	2.292 ± 0.010	-1.4	-0.07	-0.24
^{238}Pu (AB)	16.01 ± 0.11	15.428 ± 0.035	3.8	5.04	0.65
^{134}Cs (GL)	17.77 ± 0.32	18.78 ± 0.15	-5.4	-2.86	-0.92
^{210}Pb (GL)	17.9 ± 1.1	16.11 ± 0.17	11.1	1.61	1.91
^{241}Am (GL)	2.42 ± 0.12	2.3943 ± 0.0078	1.1	0.21	0.18

Deviation (%) of Laboratory 41
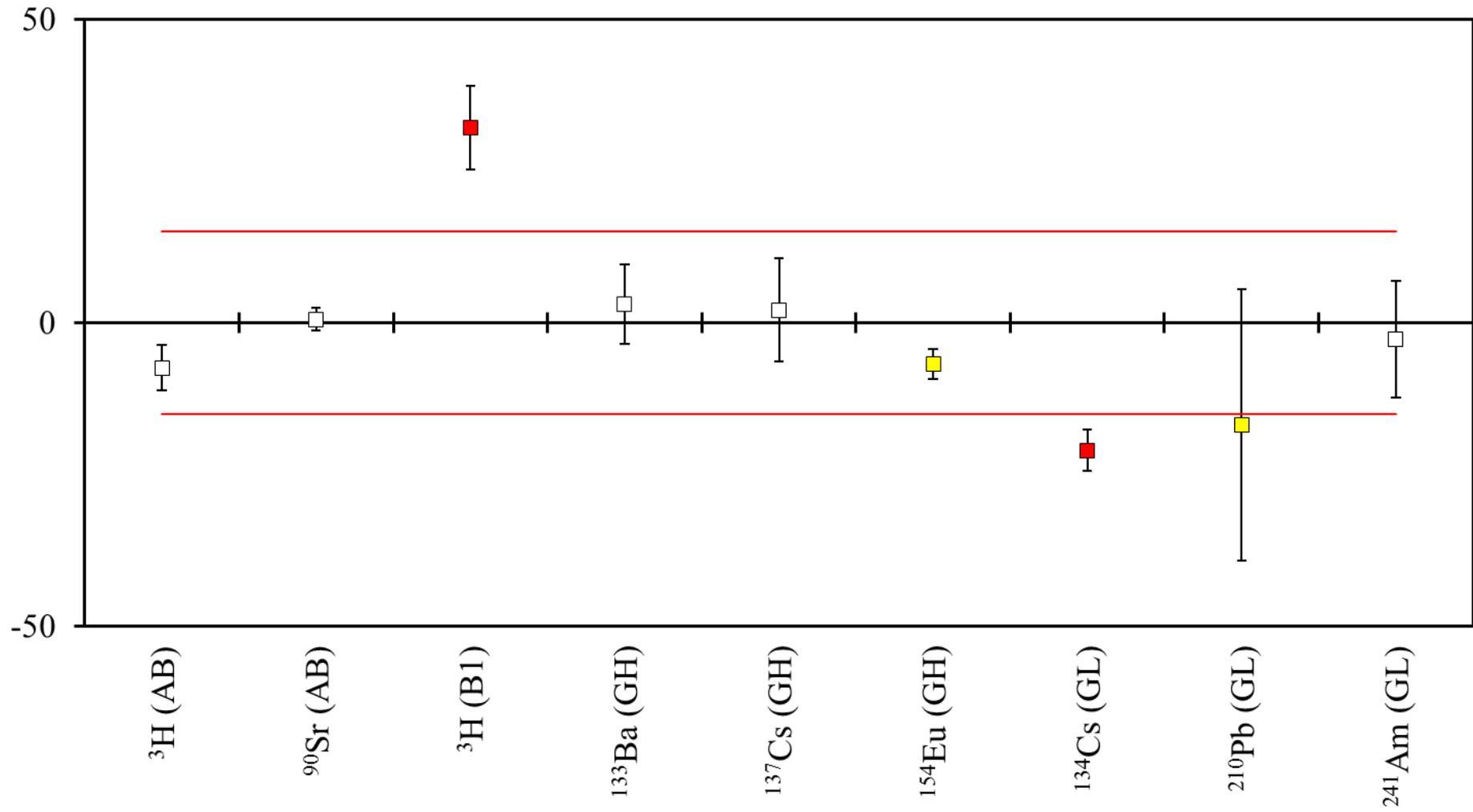
Radionuclide	Laboratory 41	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	15.590 ± 0.6	16.85 ± 0.21	-7.5	-1.98	-1.28
^{90}Sr (AB)	2.305 ± 0.040	2.292 ± 0.010	0.6	0.32	0.10
^{3}H (B1)	0.403 ± 0.020	0.3049 ± 0.0046	32.2	4.78	5.53
^{133}Ba (GH)	19.3 ± 1.2	18.73 ± 0.27	3.0	0.46	0.52
^{137}Cs (GH)	4.08 ± 0.34	3.996 ± 0.028	2.1	0.25	0.36
^{154}Eu (GH)	5.93 ± 0.15	6.363 ± 0.051	-6.8	-2.73	-1.17
^{134}Cs (GL)	14.83 ± 0.64	18.78 ± 0.15	-21.0	-6.01	-3.61
^{210}Pb (GL)	13.4 ± 3.6	16.11 ± 0.17	-16.8	-0.75	-2.89
^{241}Am (GL)	2.33 ± 0.23	2.3943 ± 0.0078	-2.7	-0.28	-0.46

Deviation (%) of Laboratory 42.1
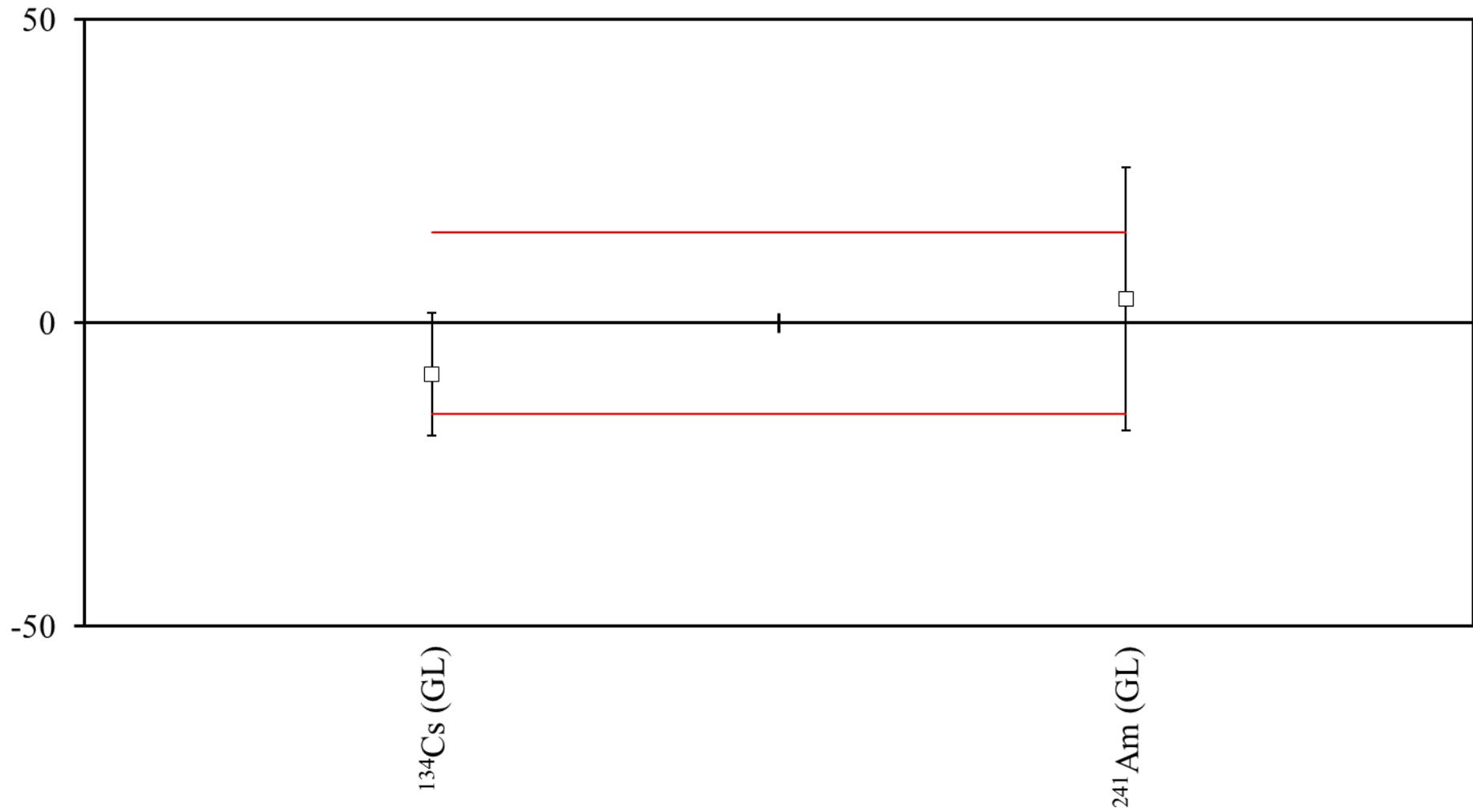
Radionuclide	Laboratory 42.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{134}Cs (GL)	17.2 ± 1.9	18.78 ± 0.15	-8.4	-0.83	-1.44
^{241}Am (GL)	2.49 ± 0.52	2.3943 ± 0.0078	4.0	0.18	0.69

Deviation (%) of Laboratory 42.2
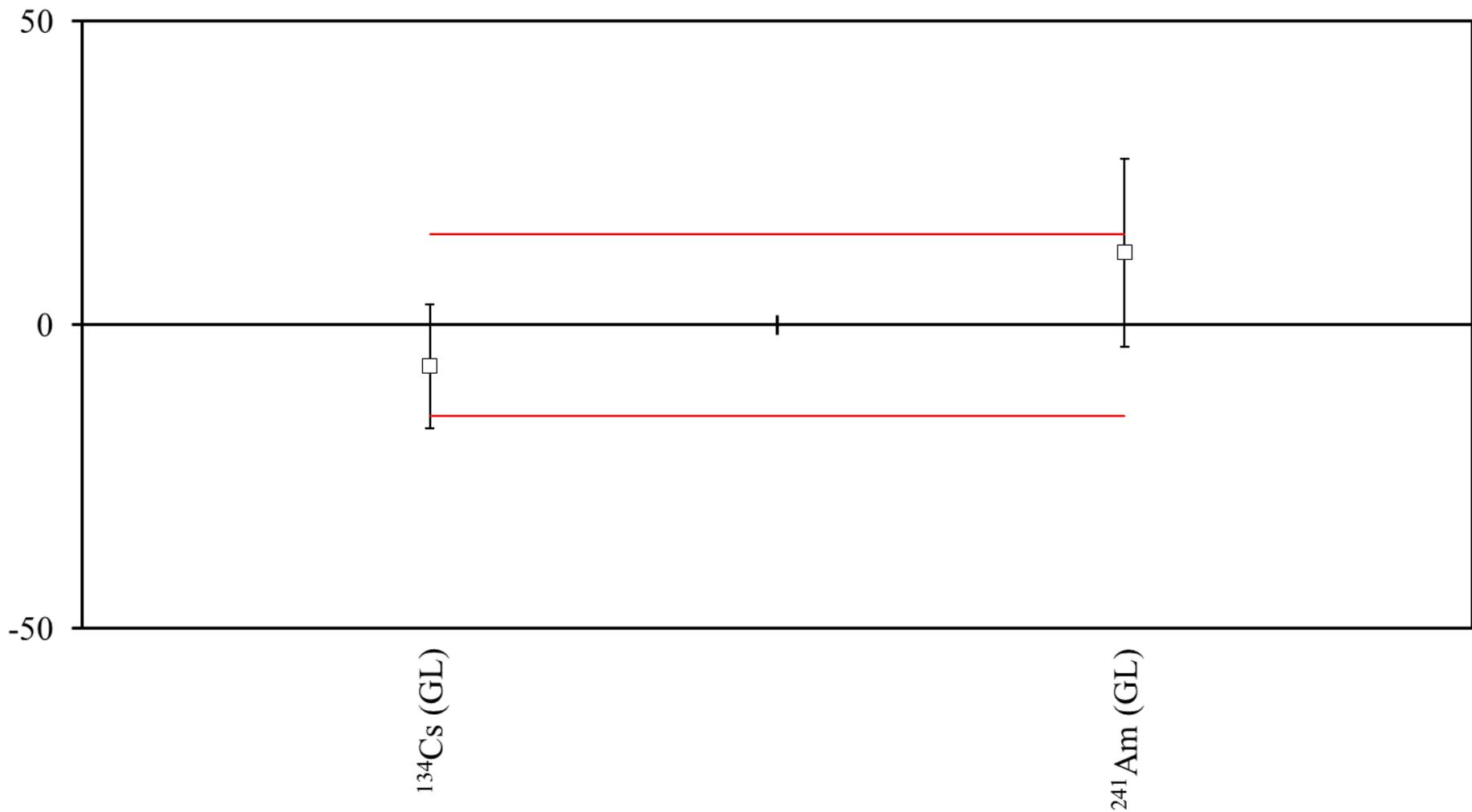
Radionuclide	Laboratory 42.2	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{134}Cs (GL)	17.5 ± 1.9	18.78 ± 0.15	-6.8	-0.67	-1.17
^{241}Am (GL)	2.68 ± 0.37	2.3943 ± 0.0078	11.9	0.77	2.05

Deviation (%) of Laboratory 47
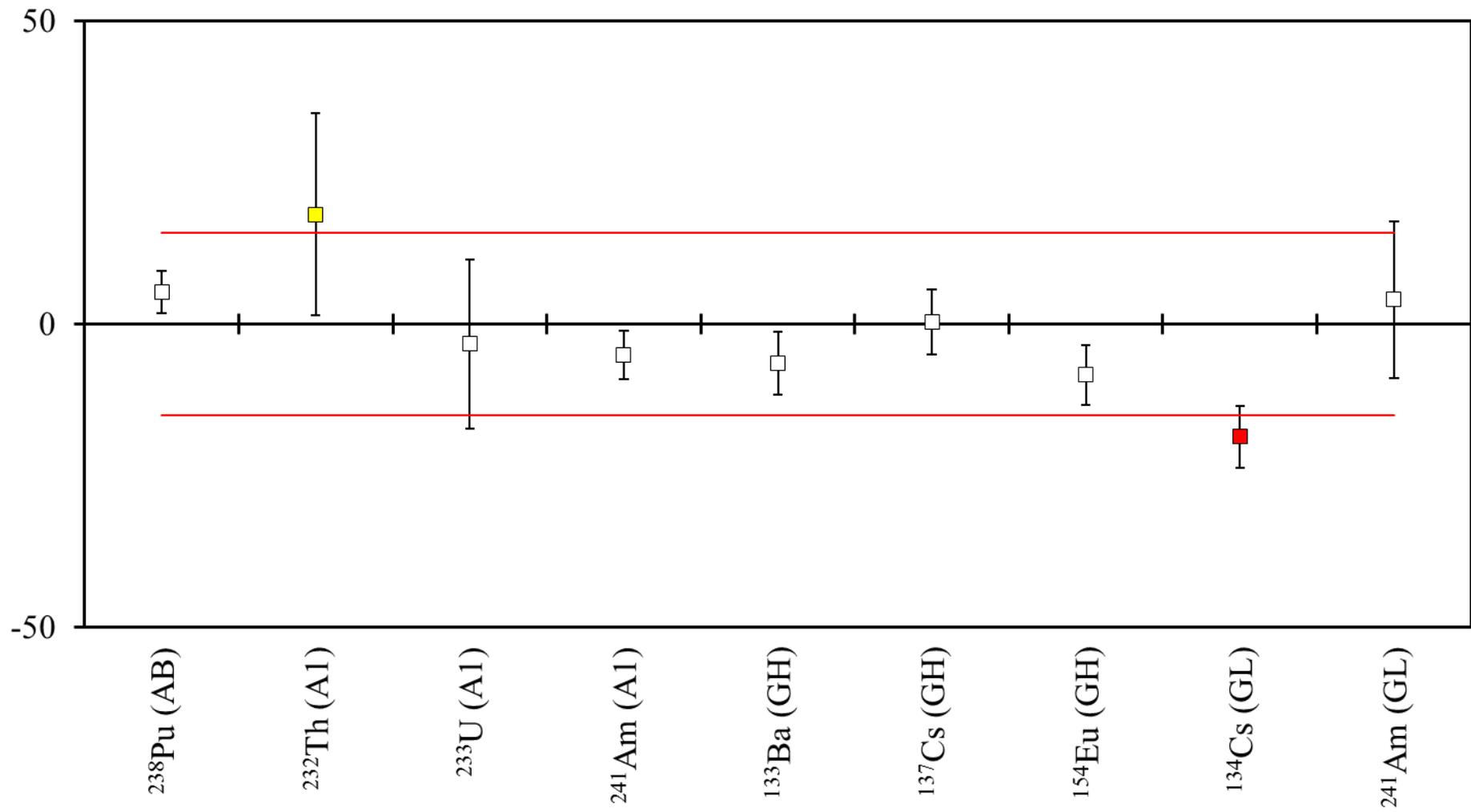
Radionuclide	Laboratory 47	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{238}Pu (AB)	16.24 ± 0.53	15.428 ± 0.035	5.3	1.53	0.90
^{232}Th (A1)	0.92 ± 0.13	0.7792 ± 0.0075	18.1	1.08	3.10
^{233}U (A1)	17.4 ± 2.5	17.996 ± 0.054	-3.3	-0.24	-0.57
^{241}Am (A1)	8.74 ± 0.36	9.211 ± 0.026	-5.1	-1.30	-0.88
^{133}Ba (GH)	17.51 ± 0.93	18.73 ± 0.27	-6.5	-1.26	-1.12
^{137}Cs (GH)	4.01 ± 0.21	3.996 ± 0.028	0.4	0.07	0.06
^{154}Eu (GH)	5.83 ± 0.31	6.363 ± 0.051	-8.4	-1.70	-1.44
^{134}Cs (GL)	15.29 ± 0.95	18.78 ± 0.15	-18.6	-3.63	-3.19
^{241}Am (GL)	2.49 ± 0.31	2.3943 ± 0.0078	4.0	0.31	0.69

Deviation (%) of Laboratory 55
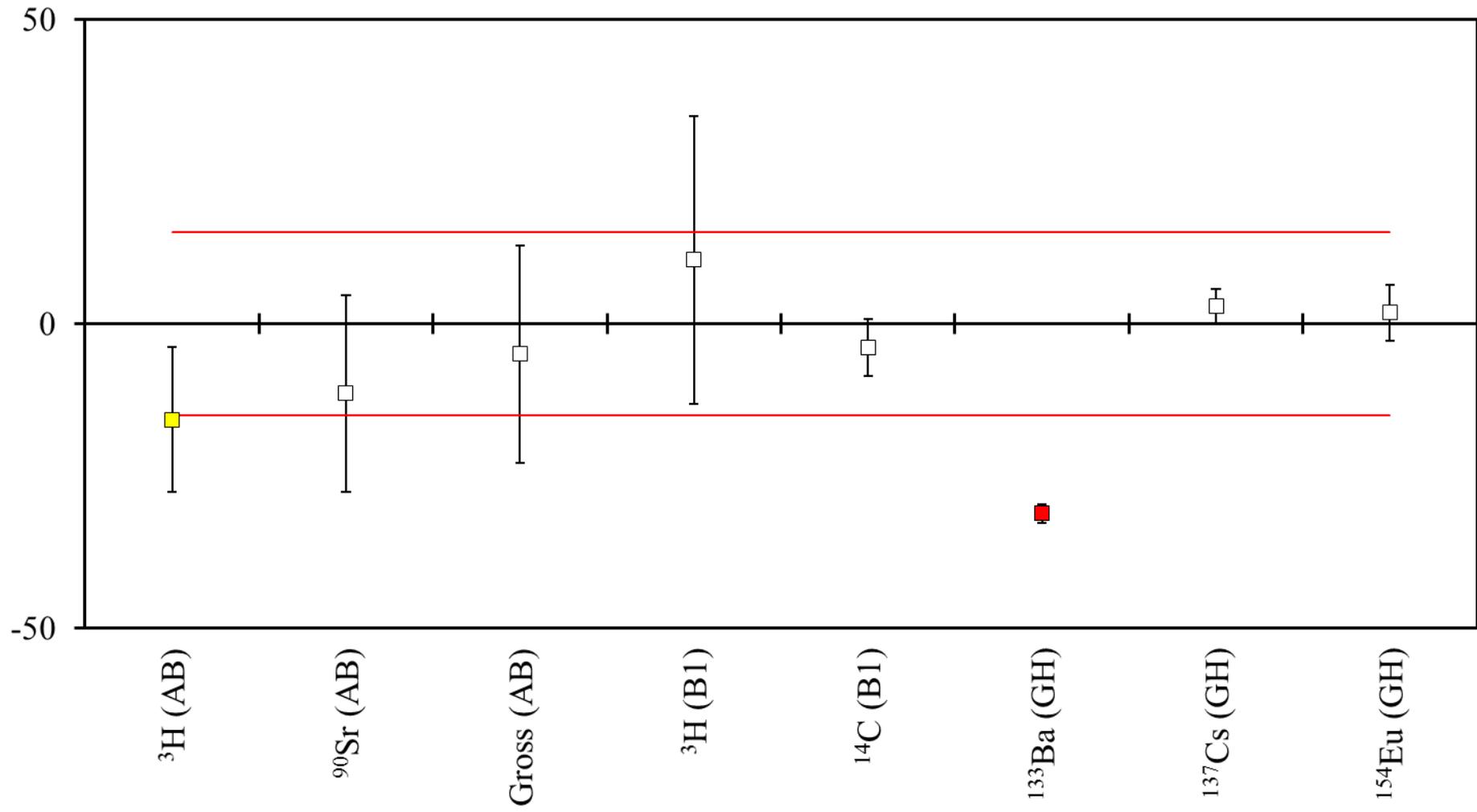
Radionuclide	Laboratory 55	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	14.2 ± 2.0	16.85 ± 0.21	-15.7	-1.32	-2.70
^{90}Sr (AB)	2.03 ± 0.37	2.292 ± 0.010	-11.4	-0.71	-1.96
Gross beta (AB)	4.39 ± 0.68	4.62 ± 0.49	-5.0	-0.27	-0.85
^{3}H (B1)	0.337 ± 0.072	0.3049 ± 0.0046	10.5	0.44	1.81
^{14}C (B1)	0.231 ± 0.011	0.2404 ± 0.0016	-3.9	-0.85	-0.67
^{133}Ba (GH)	12.90 ± 0.22	18.73 ± 0.27	-31.1	-16.74	-5.35
^{137}Cs (GH)	4.11 ± 0.11	3.996 ± 0.028	2.9	1.00	0.49
^{154}Eu (GH)	6.48 ± 0.29	6.363 ± 0.051	1.8	0.40	0.32

Deviation (%) of Laboratory 56
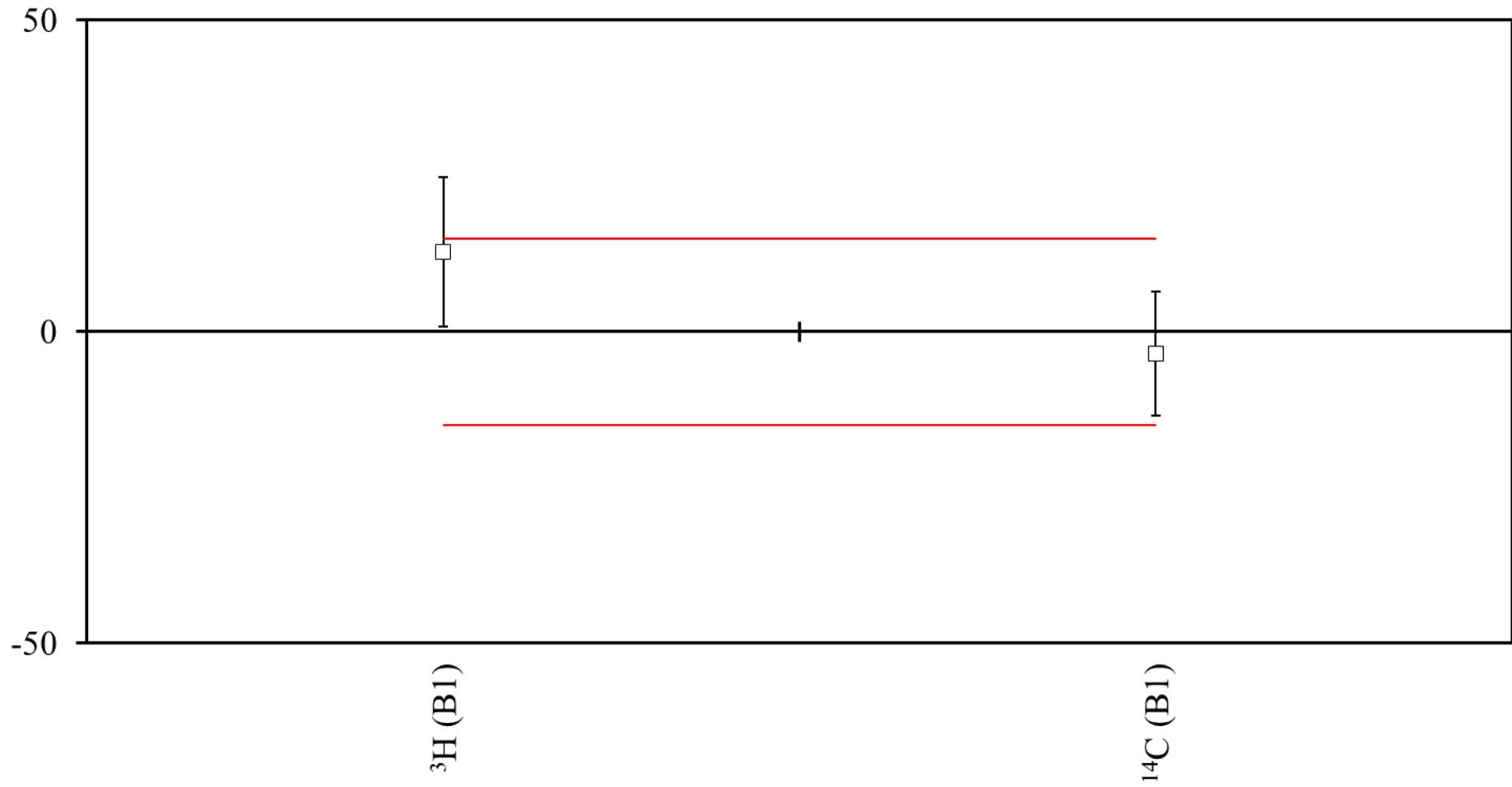
Radionuclide	Laboratory 56	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.344 ± 0.036	0.3049 ± 0.0046	12.8	1.08	2.20
^{14}C (B1)	0.232 ± 0.024	0.2404 ± 0.0016	-3.5	-0.35	-0.60

Deviation (%) of Laboratory 61
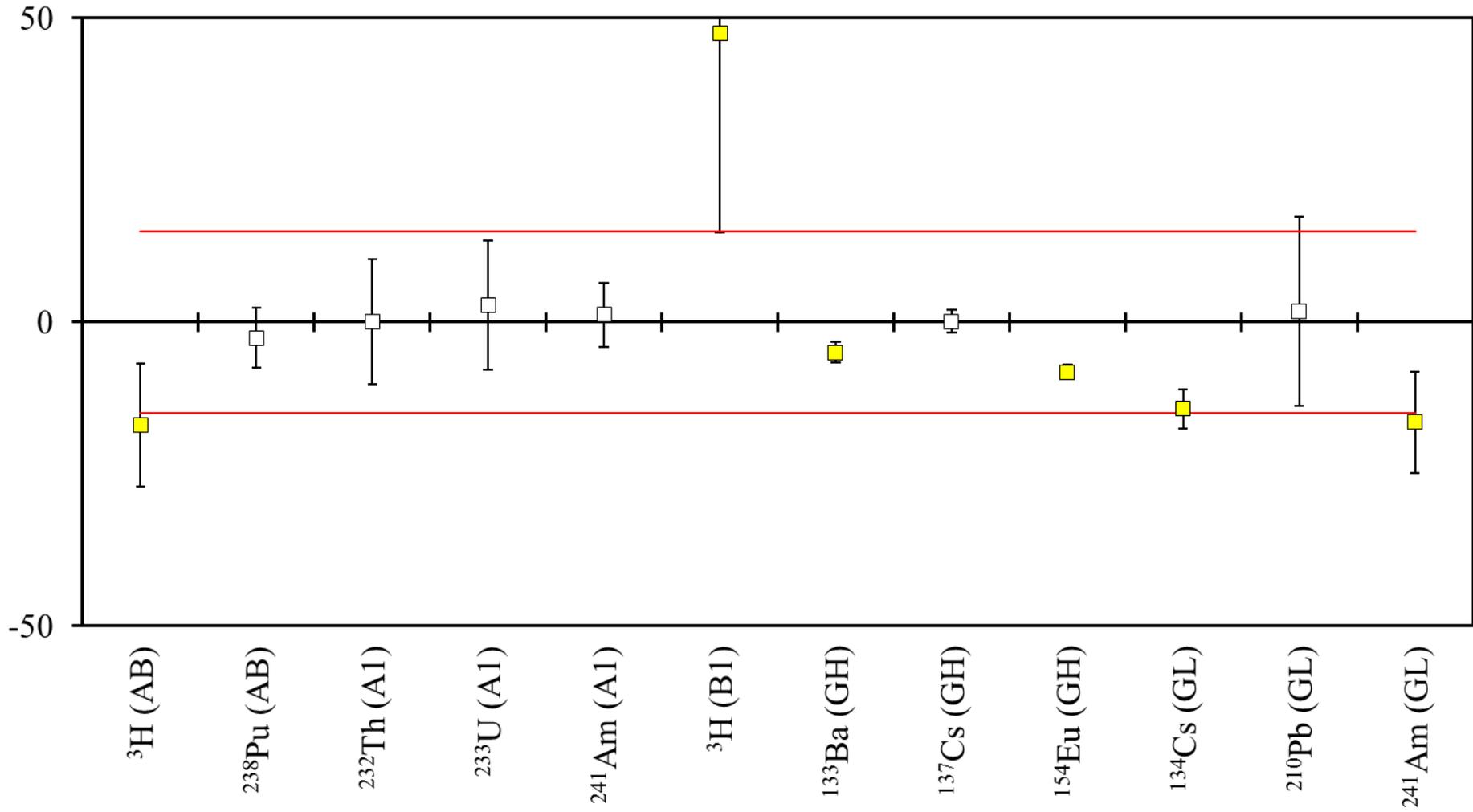
Radionuclide	Laboratory 61	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	14.0 ± 1.7	16.85 ± 0.21	-16.9	-1.66	-2.90
^{238}Pu (AB)	15.03 ± 0.77	15.428 ± 0.035	-2.6	-0.52	-0.44
^{232}Th (A1)	0.780 ± 0.080	0.7792 ± 0.0075	0.1	0.01	0.02
^{233}U (A1)	18.5 ± 1.9	17.996 ± 0.054	2.8	0.27	0.48
^{241}Am (A1)	9.32 ± 0.48	9.211 ± 0.026	1.2	0.23	0.20
^{3}H (B1)	0.45 ± 0.10	0.3049 ± 0.0046	47.6	1.45	8.17
^{133}Ba (GH)	17.80 ± 0.17	18.73 ± 0.27	-5.0	-2.91	-0.85
^{137}Cs (GH)	4.00 ± 0.07	3.996 ± 0.028	0.1	0.05	0.02
^{154}Eu (GH)	5.84 ± 0.06	6.363 ± 0.051	-8.2	-6.64	-1.41
^{134}Cs (GL)	16.1 ± 0.6	18.78 ± 0.15	-14.3	-4.33	-2.45
^{210}Pb (GL)	16.4 ± 2.5	16.11 ± 0.17	1.8	0.12	0.31
^{241}Am (GL)	2.00 ± 0.20	2.3943 ± 0.0078	-16.5	-1.97	-2.83

Deviation (%) of Laboratory 65
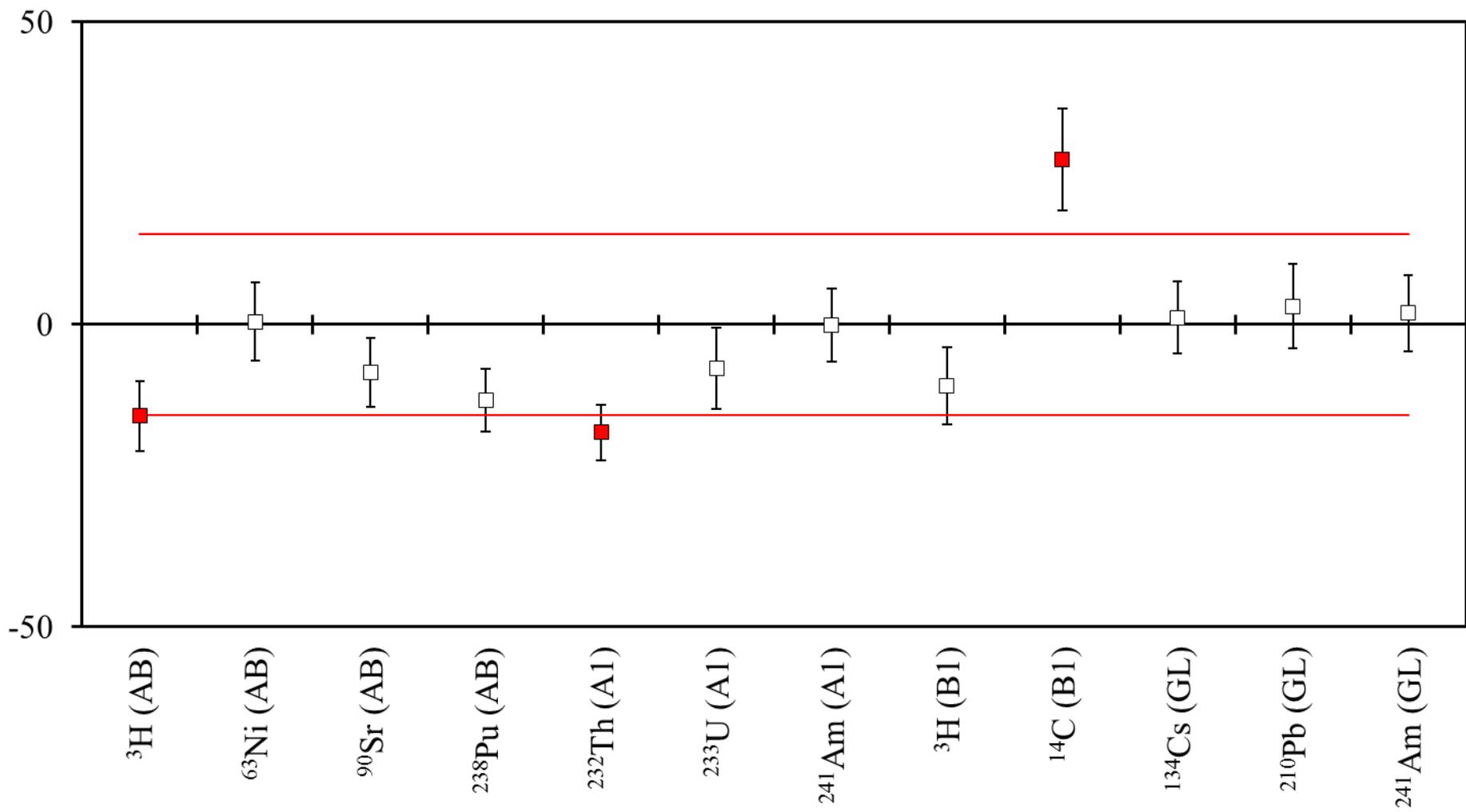
Radionuclide	Laboratory 65	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	14.30 ± 0.95	16.85 ± 0.21	-15.1	-2.62	-2.60
^{63}Ni (AB)	10.20 ± 0.65	10.15 ± 0.11	0.5	0.08	0.08
^{90}Sr (AB)	2.11 ± 0.13	2.292 ± 0.010	-7.9	-1.40	-1.36
^{238}Pu (AB)	13.50 ± 0.80	15.428 ± 0.035	-12.5	-2.41	-2.15
^{232}Th (A1)	0.640 ± 0.035	0.7792 ± 0.0075	-17.9	-3.89	-3.07
^{233}U (A1)	16.7 ± 1.2	17.996 ± 0.054	-7.2	-1.08	-1.24
^{241}Am (A1)	9.20 ± 0.55	9.211 ± 0.026	-0.1	-0.02	-0.02
^{3}H (B1)	0.274 ± 0.019	0.3049 ± 0.0046	-10.1	-1.58	-1.74
^{14}C (B1)	0.306 ± 0.020	0.2404 ± 0.0016	27.3	3.27	4.69
^{134}Cs (GL)	19.0 ± 1.1	18.78 ± 0.15	1.2	0.20	0.20
^{210}Pb (GL)	16.6 ± 1.1	16.11 ± 0.17	3.0	0.44	0.52
^{241}Am (GL)	2.44 ± 0.15	2.3943 ± 0.0078	1.9	0.30	0.33

Deviation (%) of Laboratory 67
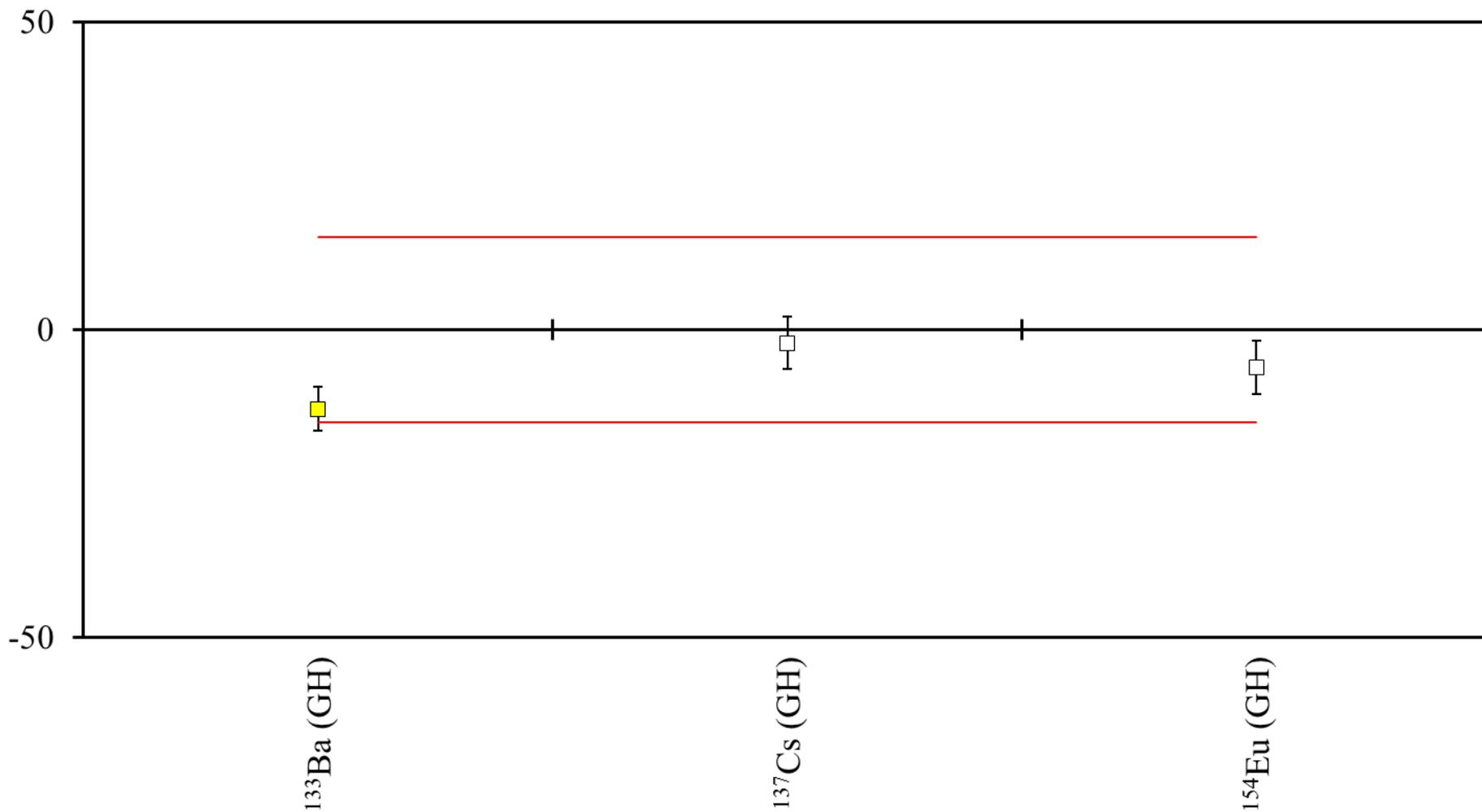
Radionuclide	Laboratory 67	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{133}Ba (GH)	16.32 ± 0.63	18.73 ± 0.27	-12.9	-3.52	-2.21
^{137}Cs (GH)	3.91 ± 0.17	3.996 ± 0.028	-2.2	-0.50	-0.37
^{154}Eu (GH)	5.97 ± 0.27	6.363 ± 0.051	-6.2	-1.43	-1.06

Deviation (%) of Laboratory 72
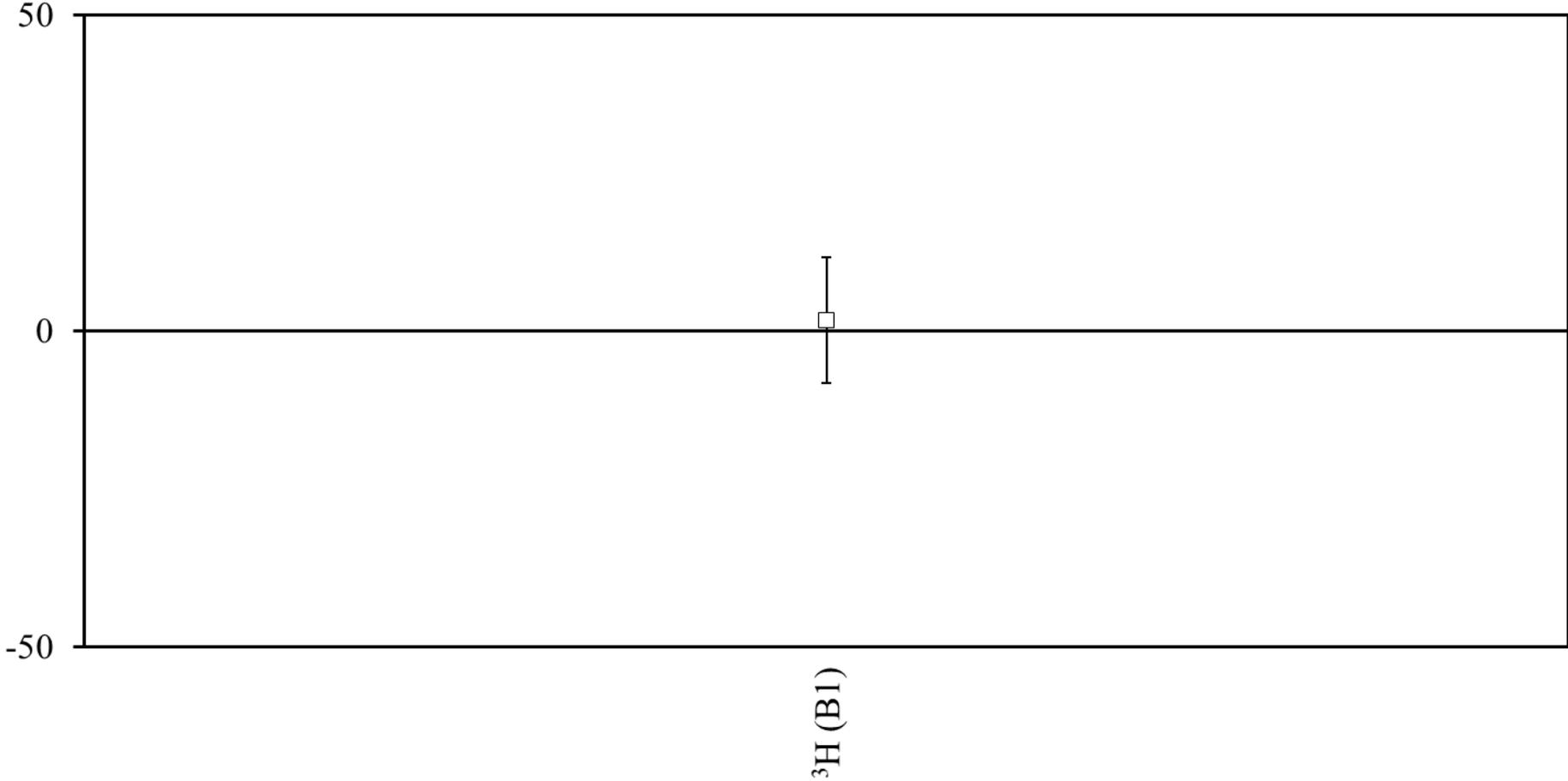
Radionuclide	Laboratory 72	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.31 ± 0.03	0.3049 ± 0.0046	1.7	0.17	0.29

Deviation (%) of Laboratory 76
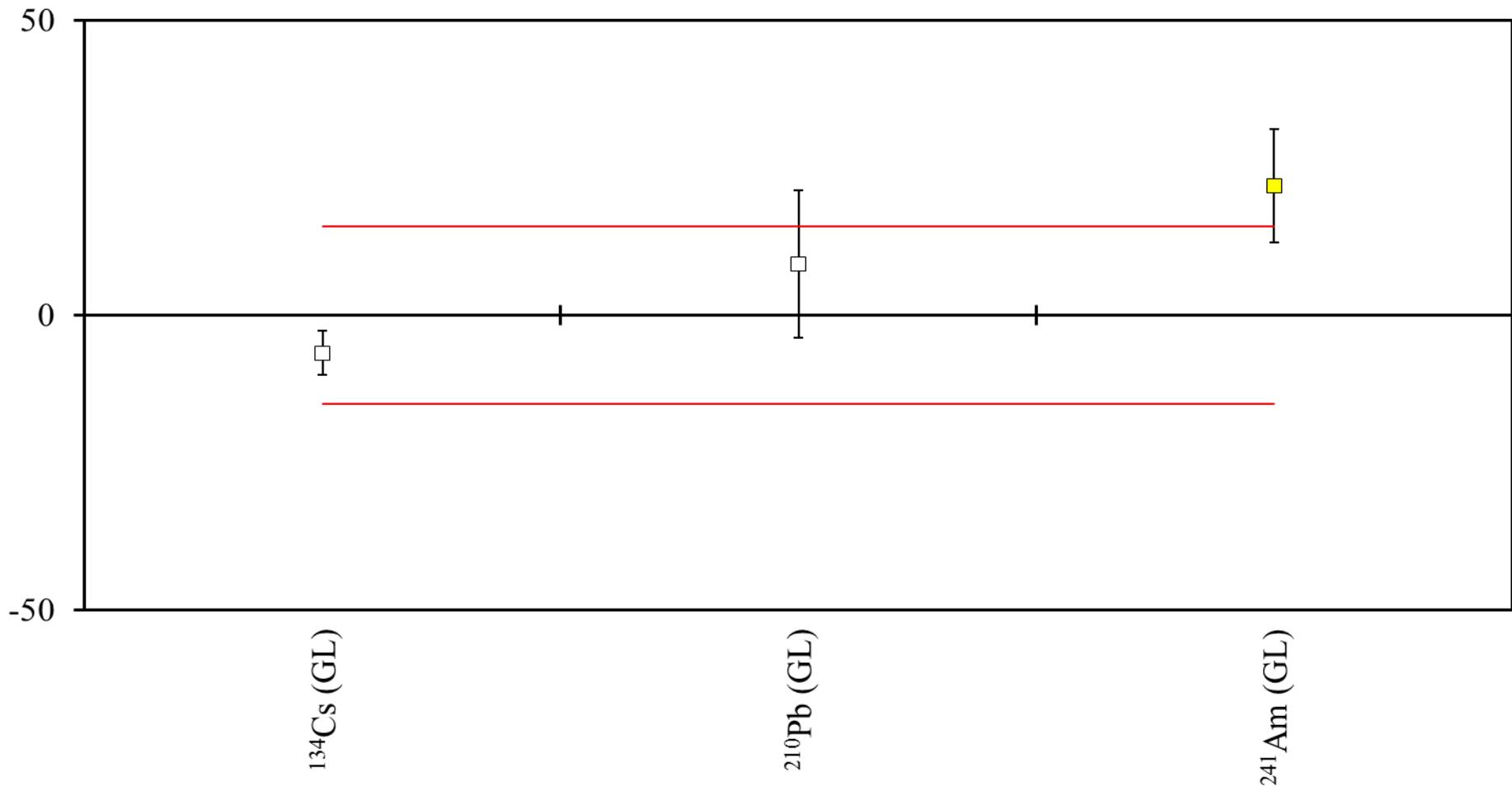
Radionuclide	Laboratory 76	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{134}Cs (GL)	17.57 ± 0.69	18.78 ± 0.15	-6.4	-1.71	-1.11
^{210}Pb (GL)	17.5 ± 2.0	16.11 ± 0.17	8.6	0.69	1.48
^{241}Am (GL)	2.92 ± 0.23	2.3943 ± 0.0078	22.0	2.28	3.77

Deviation (%) of Laboratory 82
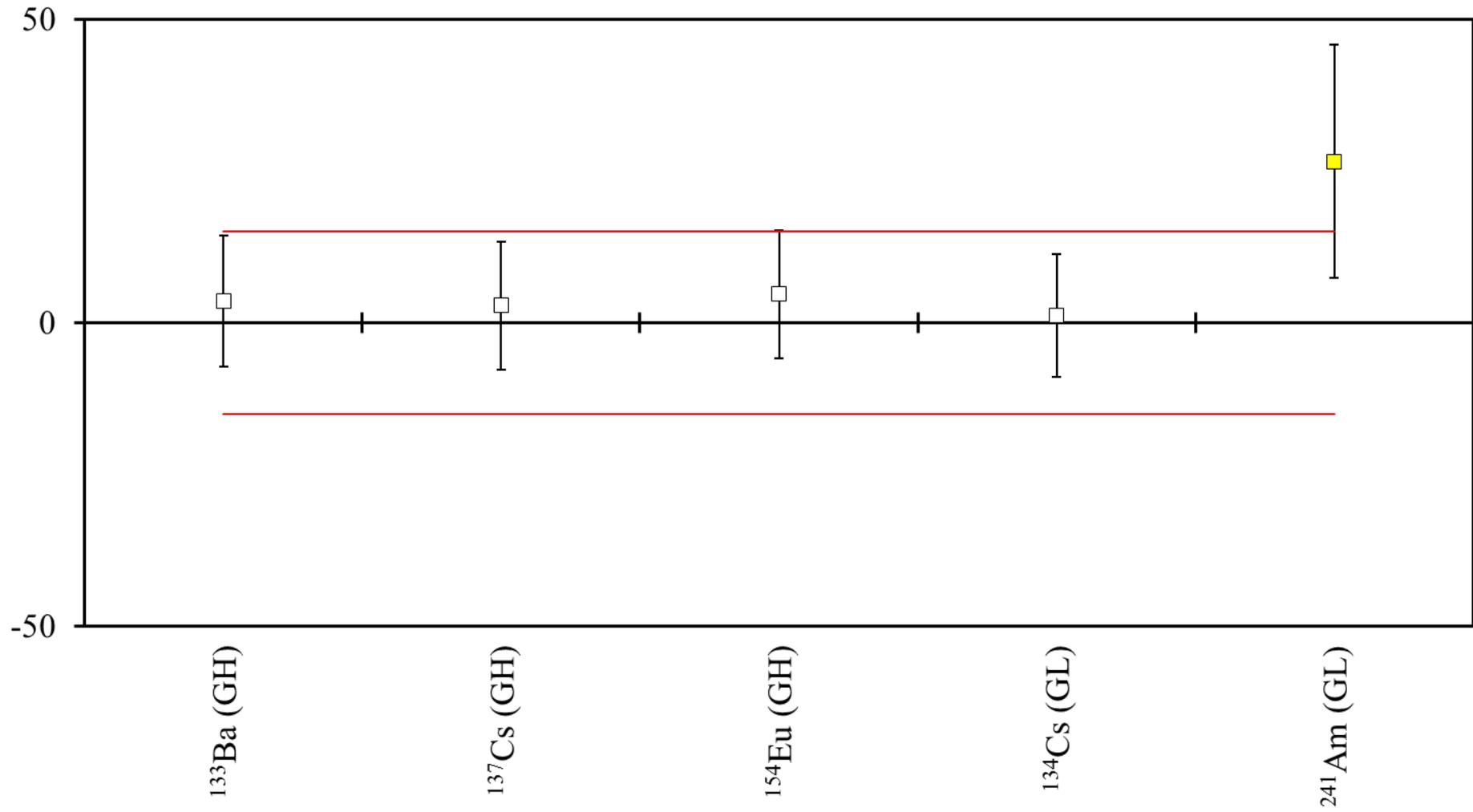
Radionuclide	Laboratory 82	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{133}Ba (GH)	19.4 ± 2.0	18.73 ± 0.27	3.6	0.33	0.61
^{137}Cs (GH)	4.11 ± 0.42	3.996 ± 0.028	2.9	0.27	0.49
^{154}Eu (GH)	6.66 ± 0.67	6.363 ± 0.051	4.7	0.44	0.80
^{134}Cs (GL)	19.0 ± 1.9	18.78 ± 0.15	1.2	0.12	0.20
^{241}Am (GL)	3.03 ± 0.46	2.3943 ± 0.0078	26.6	1.38	4.56

Deviation (%) of Laboratory 83
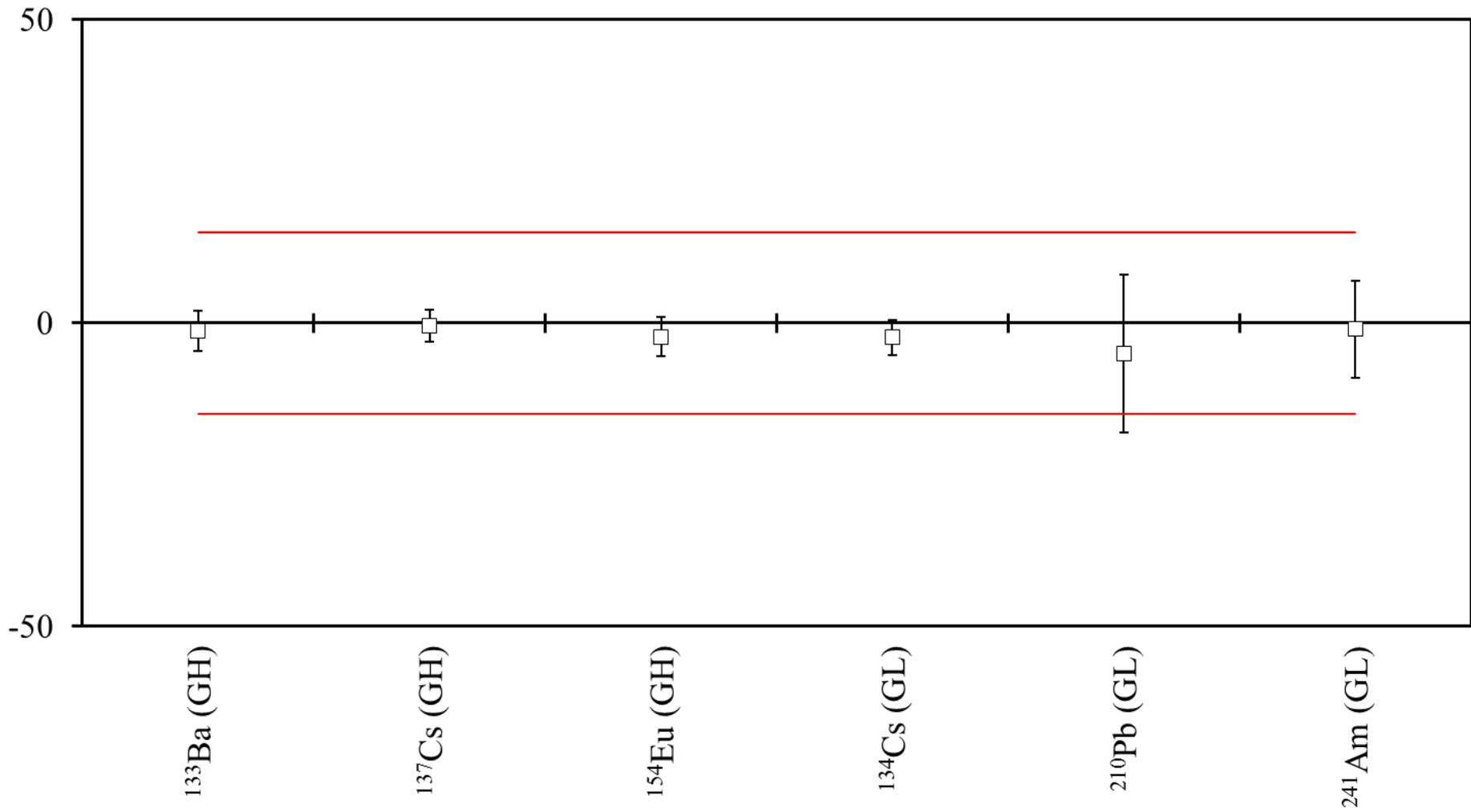
Radionuclide	Laboratory 83	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{133}Ba (GH)	18.49 ± 0.57	18.73 ± 0.27	-1.3	-0.38	-0.22
^{137}Cs (GH)	3.98 ± 0.10	3.996 ± 0.028	-0.4	-0.15	-0.07
^{154}Eu (GH)	6.22 ± 0.20	6.363 ± 0.051	-2.2	-0.69	-0.39
^{134}Cs (GL)	18.34 ± 0.52	18.78 ± 0.15	-2.3	-0.81	-0.40
^{210}Pb (GL)	15.3 ± 2.1	16.11 ± 0.17	-5.0	-0.38	-0.86
^{241}Am (GL)	2.37 ± 0.19	2.3943 ± 0.0078	-1.0	-0.13	-0.17

Deviation (%) of Laboratory 86.1
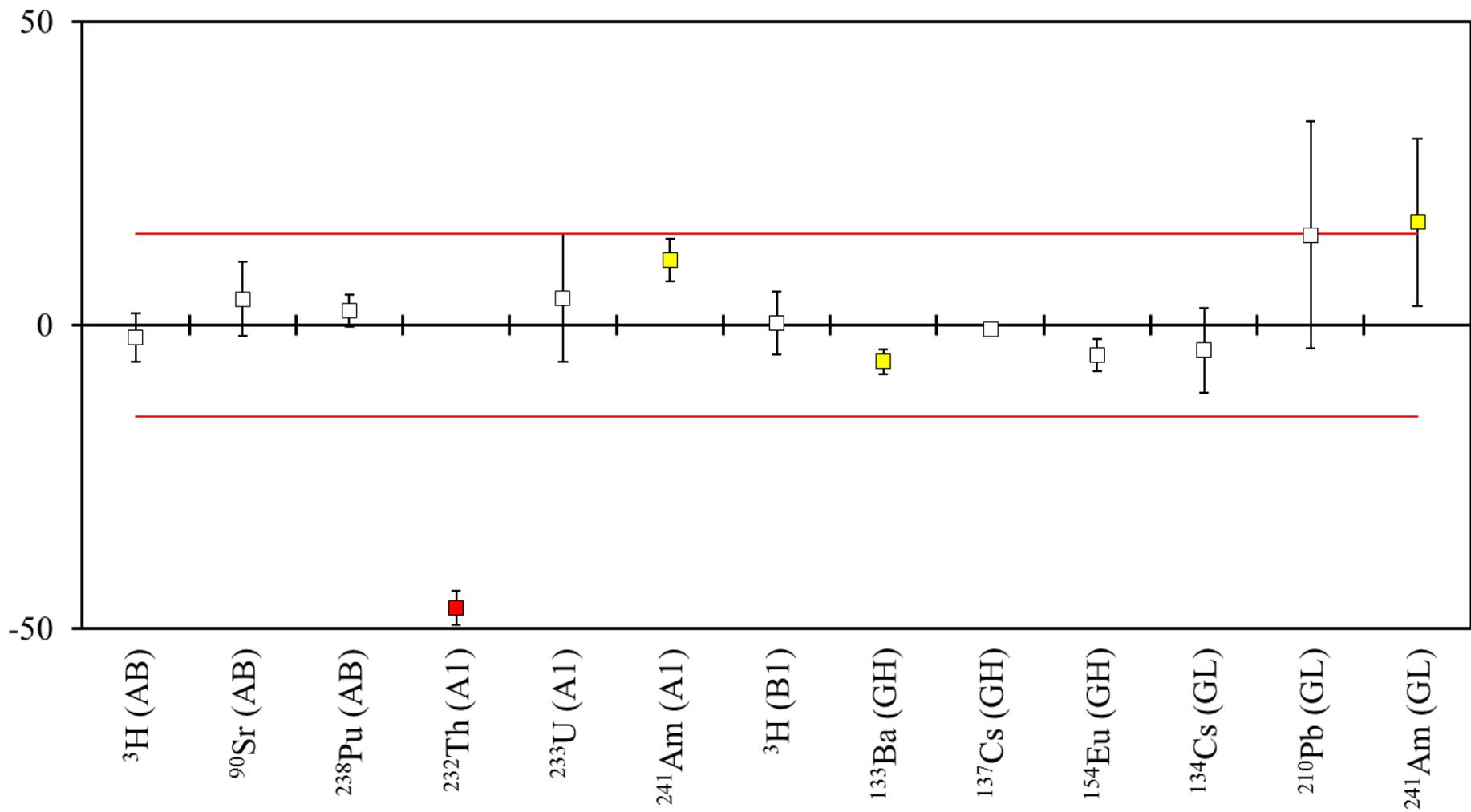
Radionuclide	Laboratory 86.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	16.50 ± 0.64	16.85 ± 0.21	-2.1	-0.52	-0.36
^{90}Sr (AB)	2.39 ± 0.14	2.292 ± 0.010	4.3	0.70	0.73
^{238}Pu (AB)	15.80 ± 0.40	15.428 ± 0.035	2.4	0.93	0.41
^{232}Th (A1)	0.416 ± 0.021	0.7792 ± 0.0075	-46.6	-16.29	-8.00
^{233}U (A1)	18.8 ± 1.9	17.996 ± 0.054	4.5	0.42	0.77
^{241}Am (A1)	10.20 ± 0.32	9.211 ± 0.026	10.7	3.08	1.84
^{3}H (B1)	0.306 ± 0.015	0.3049 ± 0.0046	0.4	0.07	0.06
^{133}Ba (GH)	17.60 ± 0.28	18.73 ± 0.27	-6.0	-2.91	-1.04
^{137}Cs (GH)	3.970 ± 0.033	3.996 ± 0.028	-0.7	-0.60	-0.11
^{154}Eu (GH)	6.05 ± 0.16	6.363 ± 0.051	-4.9	-1.86	-0.84
^{134}Cs (GL)	18.0 ± 1.3	18.78 ± 0.15	-4.2	-0.60	-0.71
^{210}Pb (GL)	18.5 ± 3.0	16.11 ± 0.17	14.8	0.80	2.55
^{241}Am (GL)	2.80 ± 0.33	2.3943 ± 0.0078	16.9	1.23	2.91

Deviation (%) of Laboratory 86.2
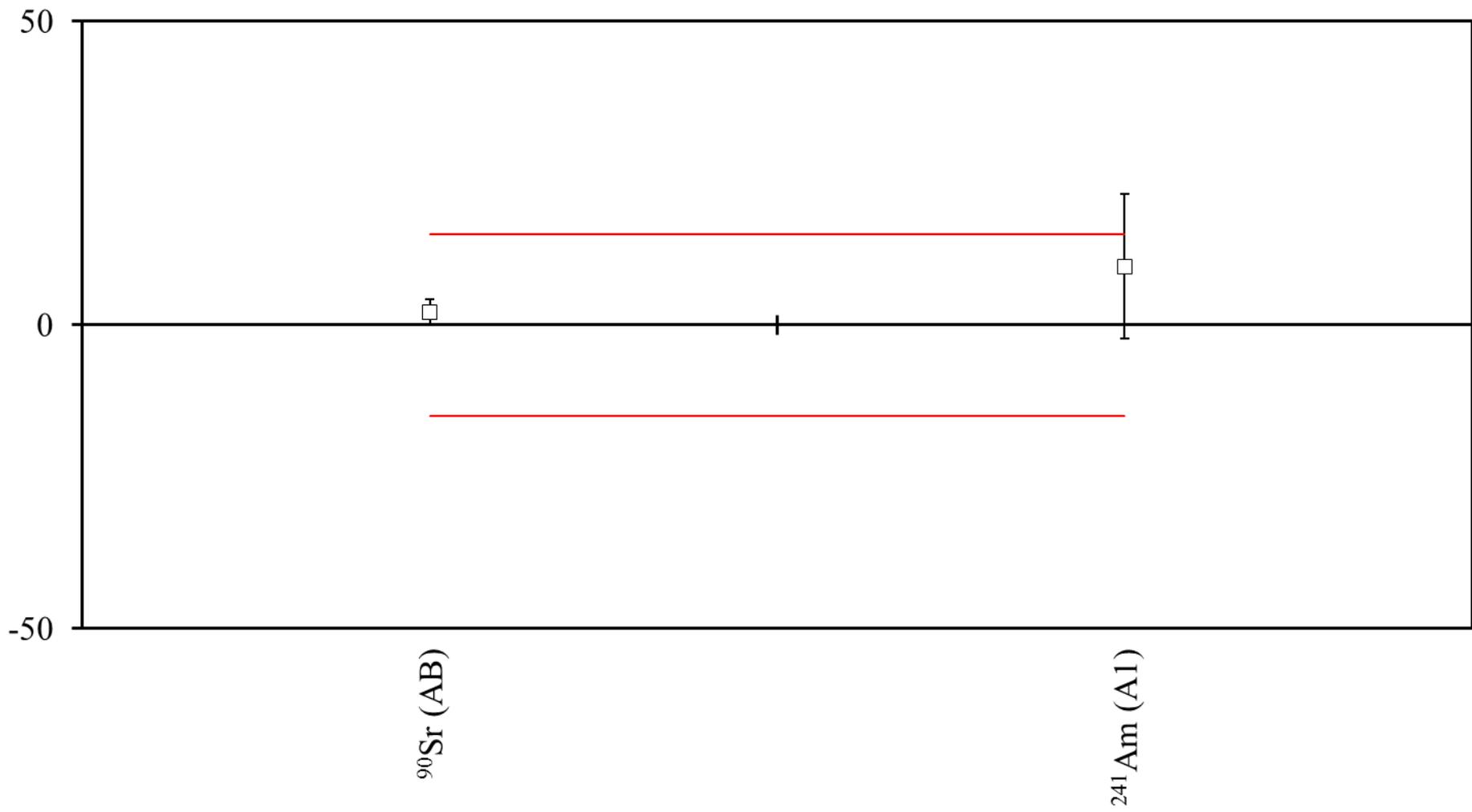
Radionuclide	Laboratory 86.2	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{90}Sr (AB)	2.342 ± 0.047	2.292 ± 0.010	2.2	1.04	0.37
^{241}Am (A1)	10.1 ± 1.1	9.211 ± 0.026	9.7	0.81	1.66

Deviation (%) of Laboratory 91
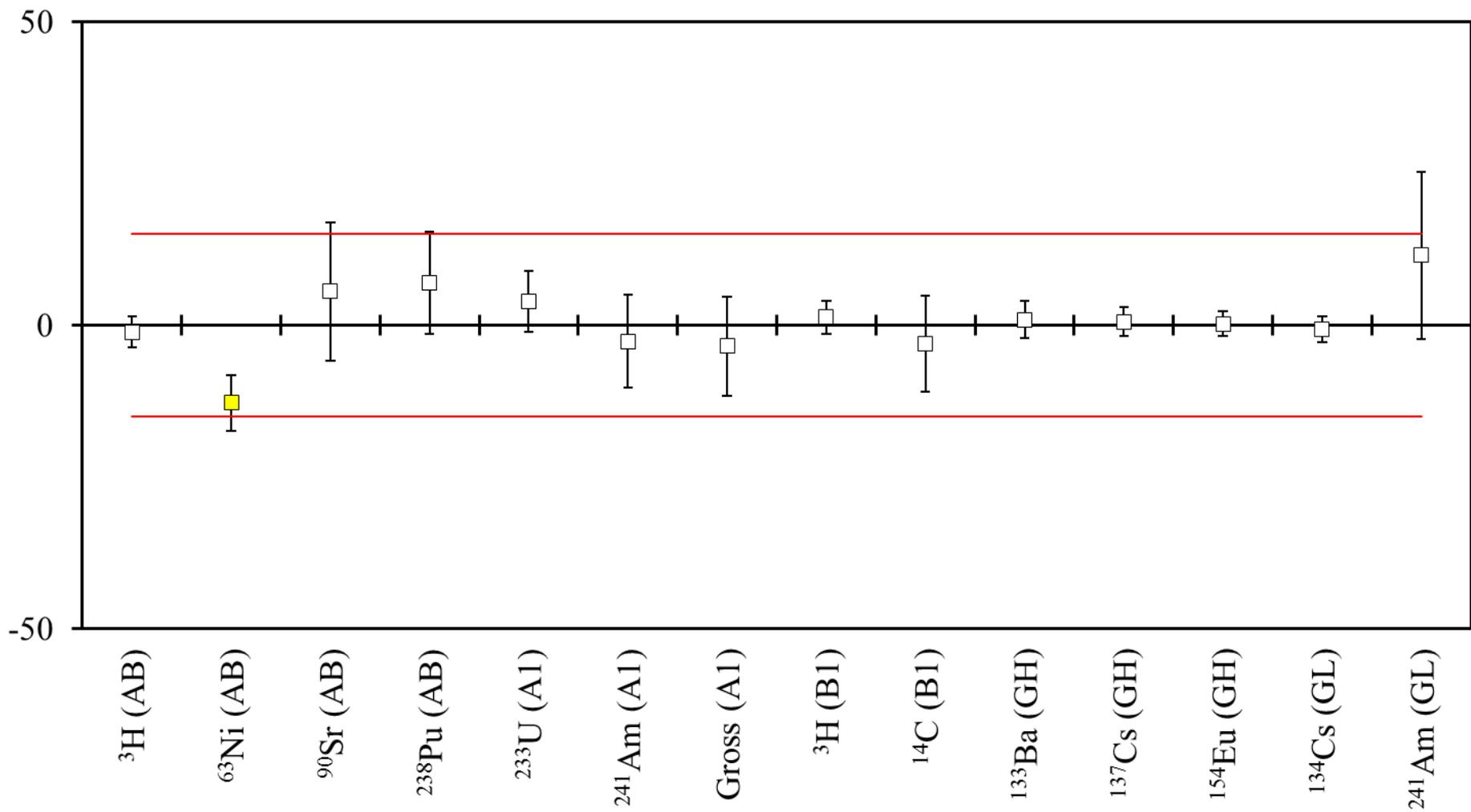
Radionuclide	Laboratory 91	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	16.66 ± 0.38	16.85 ± 0.21	-1.1	-0.44	-0.19
^{63}Ni (AB)	8.85 ± 0.46	10.15 ± 0.11	-12.8	-2.75	-2.20
^{90}Sr (AB)	2.42 ± 0.26	2.292 ± 0.010	5.6	0.49	0.96
^{238}Pu (AB)	16.5 ± 1.3	15.428 ± 0.035	6.9	0.82	1.19
^{233}U (A1)	18.70 ± 0.90	17.996 ± 0.054	3.9	0.78	0.67
^{241}Am (A1)	8.97 ± 0.71	9.211 ± 0.026	-2.6	-0.34	-0.45
Gross alpha (A1)	28.3 ± 2.2	29.3 ± 1.0	-3.4	-0.41	-0.59
^{3}H (B1)	0.3090 ± 0.0070	0.3049 ± 0.0046	1.3	0.49	0.23
^{14}C (B1)	0.233 ± 0.019	0.2404 ± 0.0016	-3.1	-0.39	-0.53
^{133}Ba (GH)	18.90 ± 0.50	18.73 ± 0.27	0.9	0.30	0.16
^{137}Cs (GH)	4.02 ± 0.09	3.996 ± 0.028	0.6	0.25	0.10
^{154}Eu (GH)	6.38 ± 0.12	6.363 ± 0.051	0.3	0.13	0.05
^{134}Cs (GL)	18.65 ± 0.37	18.78 ± 0.15	-0.7	-0.33	-0.12
^{241}Am (GL)	2.67 ± 0.33	2.3943 ± 0.0078	11.5	0.84	1.98

Deviation (%) of Laboratory 106
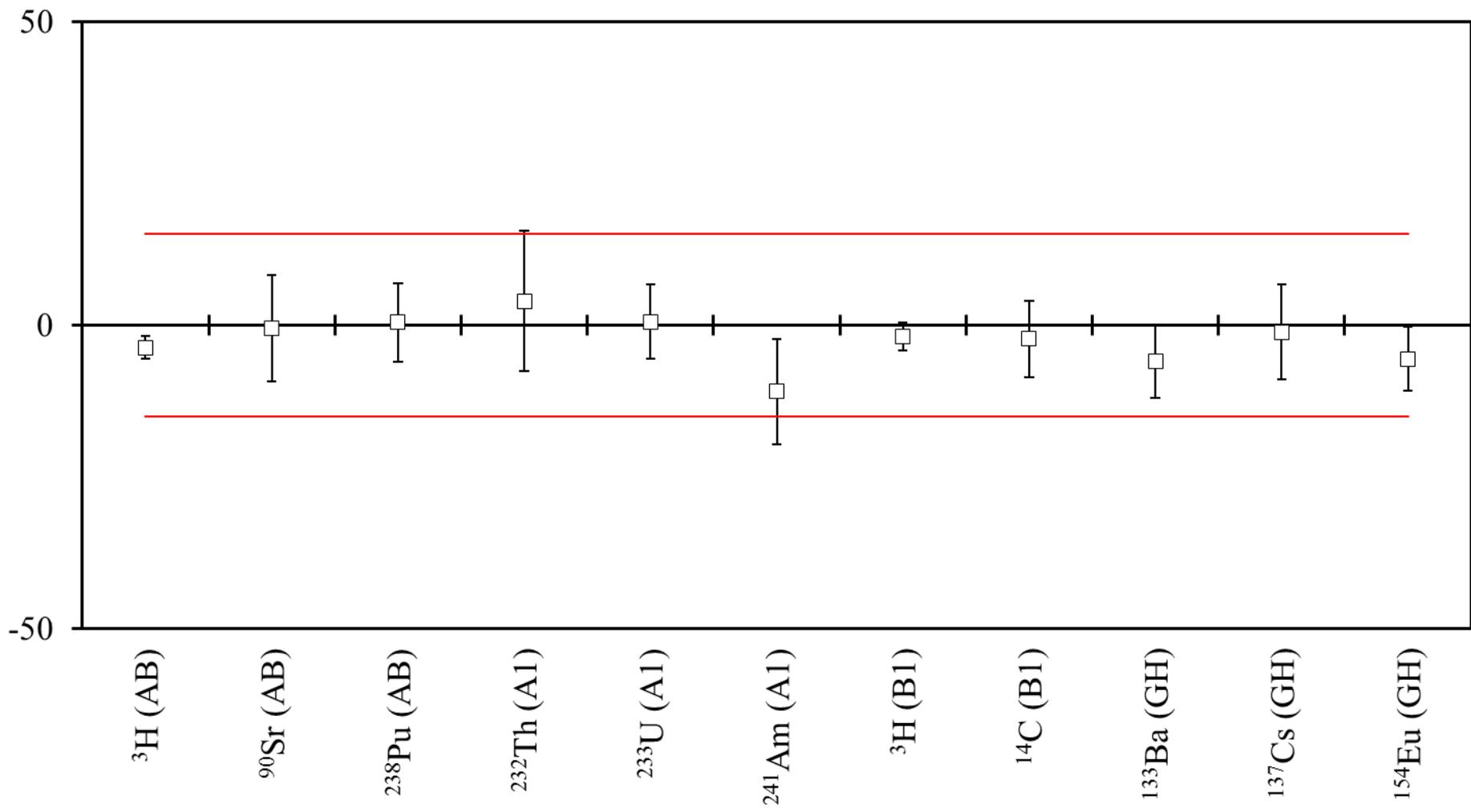
Radionuclide	Laboratory 106	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	16.22 ± 0.24	16.85 ± 0.21	-3.7	-1.98	-0.64
^{90}Sr (AB)	2.28 ± 0.20	2.292 ± 0.010	-0.5	-0.06	-0.09
^{238}Pu (AB)	15.5 ± 1.0	15.428 ± 0.035	0.5	0.07	0.08
^{232}Th (A1)	0.81 ± 0.09	0.7792 ± 0.0075	4.0	0.34	0.68
^{233}U (A1)	18.1 ± 1.1	17.996 ± 0.054	0.6	0.09	0.10
^{241}Am (A1)	8.20 ± 0.80	9.211 ± 0.026	-11.0	-1.26	-1.88
^{3}H (B1)	0.2990 ± 0.0053	0.3049 ± 0.0046	-1.9	-0.84	-0.33
^{14}C (B1)	0.235 ± 0.015	0.2404 ± 0.0016	-2.2	-0.36	-0.39
^{133}Ba (GH)	17.6 ± 1.1	18.73 ± 0.27	-6.0	-1.00	-1.04
^{137}Cs (GH)	3.95 ± 0.31	3.996 ± 0.028	-1.2	-0.15	-0.20
^{154}Eu (GH)	6.01 ± 0.33	6.363 ± 0.051	-5.5	-1.06	-0.95

Deviation (%) of Laboratory 109.1
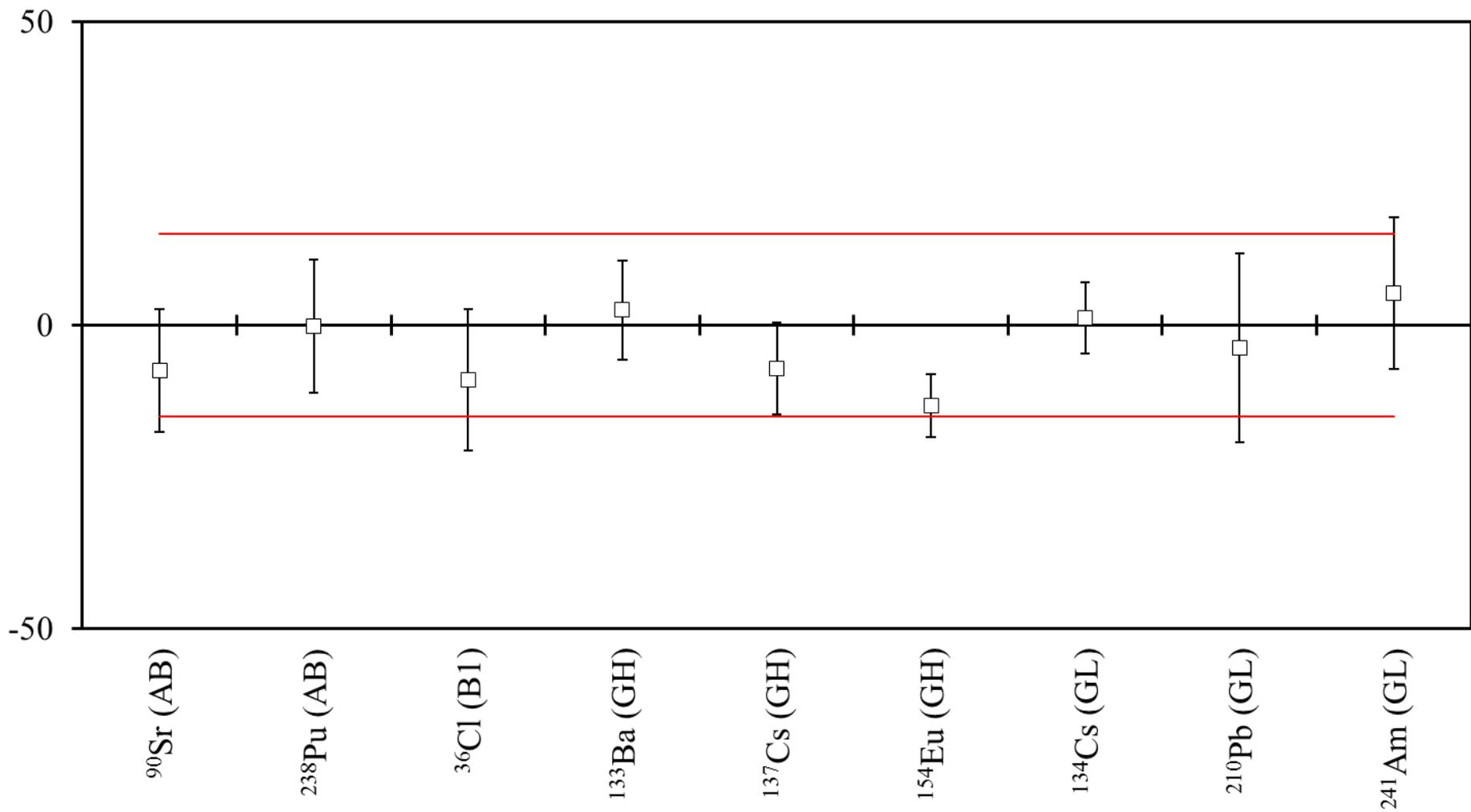
Radionuclide	Laboratory 109.1	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{90}Sr (AB)	2.12 ± 0.23	2.292 ± 0.010	-7.5	-0.75	-1.29
^{238}Pu (AB)	15.4 ± 1.7	15.428 ± 0.035	-0.2	-0.02	-0.03
^{36}Cl (B1)	0.180 ± 0.023	0.19774 ± 0.00080	-9.0	-0.77	-1.54
^{133}Ba (GH)	19.2 ± 1.5	18.73 ± 0.27	2.5	0.31	0.43
^{137}Cs (GH)	3.710 ± 0.3	3.996 ± 0.028	-7.2	-0.95	-1.23
^{154}Eu (GH)	5.52 ± 0.33	6.363 ± 0.051	-13.2	-2.52	-2.28
^{134}Cs (GL)	19.0 ± 1.1	18.78 ± 0.15	1.2	0.20	0.20
^{210}Pb (GL)	15.5 ± 2.5	16.11 ± 0.17	-3.8	-0.24	-0.65
^{241}Am (GL)	2.520 ± 0.3	2.3943 ± 0.0078	5.2	0.42	0.90

Deviation (%) of Laboratory 109.2
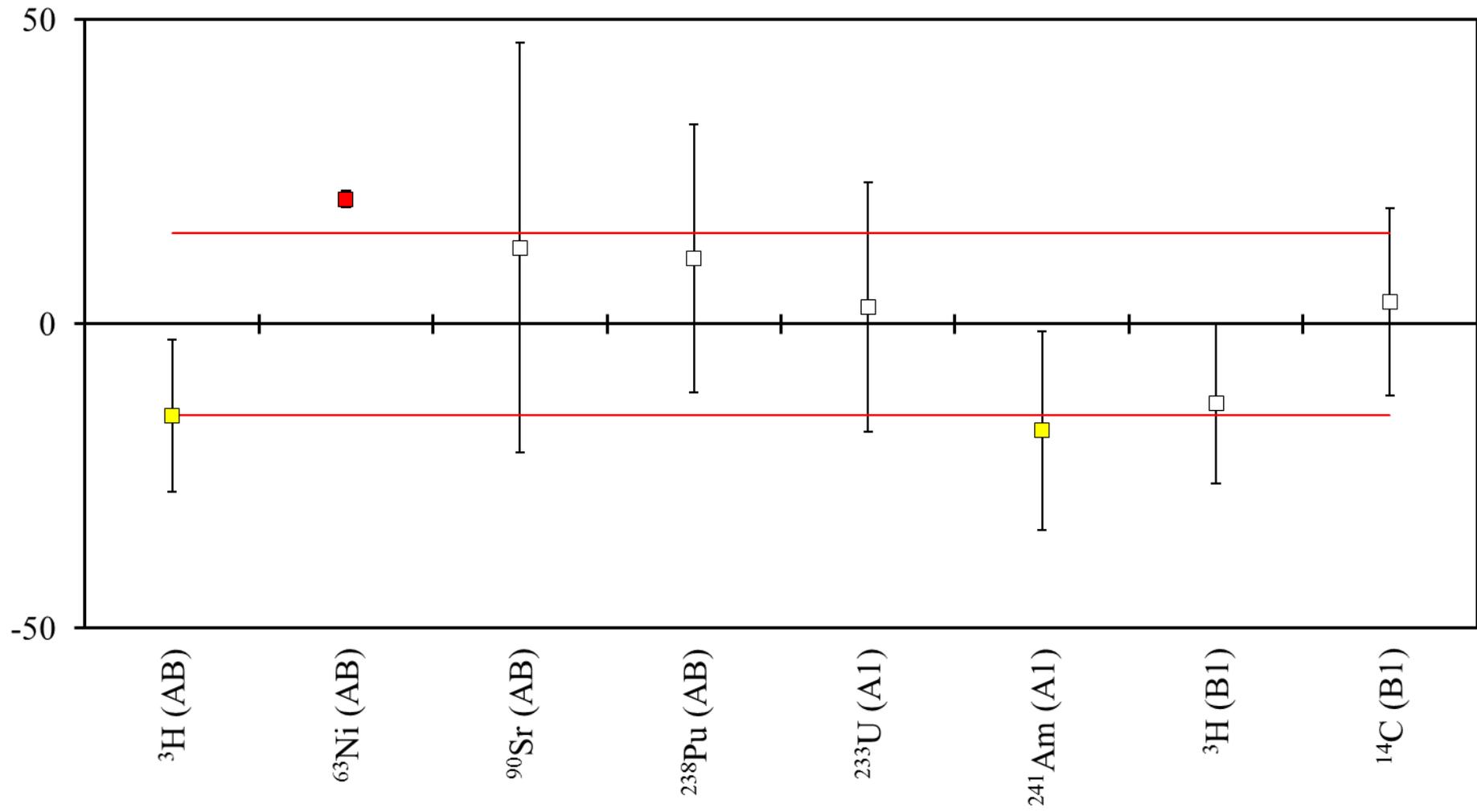
Radionuclide	Laboratory 109.2	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	14.3 ± 2.1	16.85 ± 0.21	-15.1	-1.21	-2.60
^{63}Ni (AB)	(Reported as 12.2347 with uncertainty of 0)	10.15 ± 0.11	20.5	18.95	3.53
^{90}Sr (AB)	2.58 ± 0.77	2.292 ± 0.010	12.6	0.37	2.16
^{238}Pu (AB)	17.1 ± 3.4	15.428 ± 0.035	10.8	0.49	1.86
^{233}U (A1)	18.5 ± 3.7	17.996 ± 0.054	2.8	0.14	0.48
^{241}Am (A1)	7.6 ± 1.5	9.211 ± 0.026	-17.5	-1.07	-3.00
^{3}H (B1)	0.265 ± 0.040	0.3049 ± 0.0046	-13.1	-0.99	-2.25
^{14}C (B1)	0.249 ± 0.037	0.2404 ± 0.0016	3.6	0.23	0.61

Deviation (%) of Laboratory 111
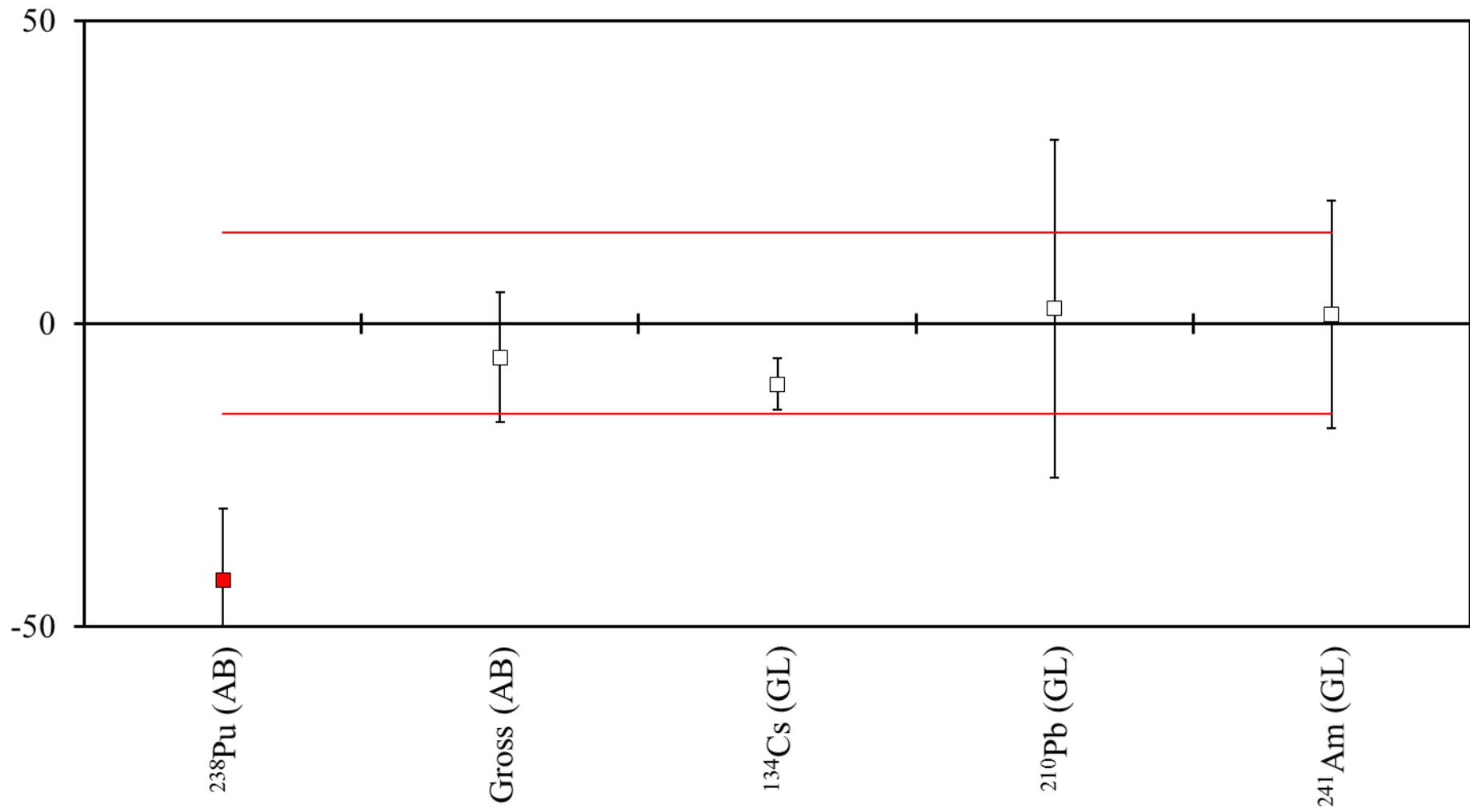
Radionuclide	Laboratory 111	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{238}Pu (AB)	8.9 ± 1.8	15.428 ± 0.035	-42.3	-3.63	-7.27
Gross beta (AB)	4.36 ± 0.18	4.62 ± 0.49	-5.6	-0.50	-0.97
^{134}Cs (GL)	16.90 ± 0.80	18.78 ± 0.15	-10.0	-2.31	-1.72
^{210}Pb (GL)	16.5 ± 4.5	16.11 ± 0.17	2.4	0.09	0.42
^{241}Am (GL)	2.43 ± 0.45	2.3943 ± 0.0078	1.5	0.08	0.26

Deviation (%) of Laboratory 120
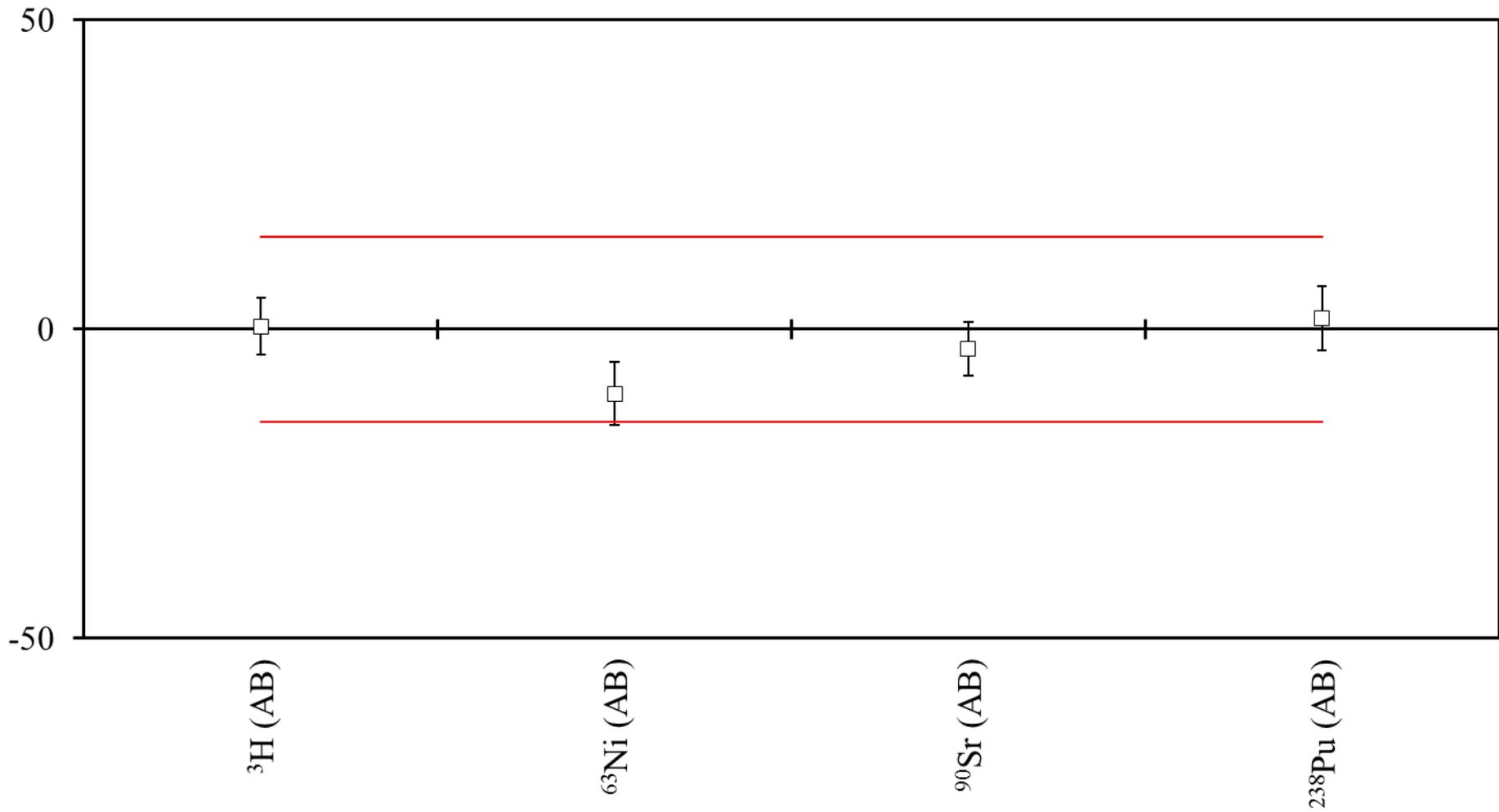
Radionuclide	Laboratory 120	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	16.93 ± 0.74	16.85 ± 0.21	0.5	0.10	0.08
^{63}Ni (AB)	9.09 ± 0.51	10.15 ± 0.11	-10.4	-2.03	-1.79
^{90}Sr (AB)	2.22 ± 0.10	2.292 ± 0.010	-3.1	-0.72	-0.54
^{238}Pu (AB)	15.70 ± 0.80	15.428 ± 0.035	1.8	0.34	0.30

Deviation (%) of Laboratory 133
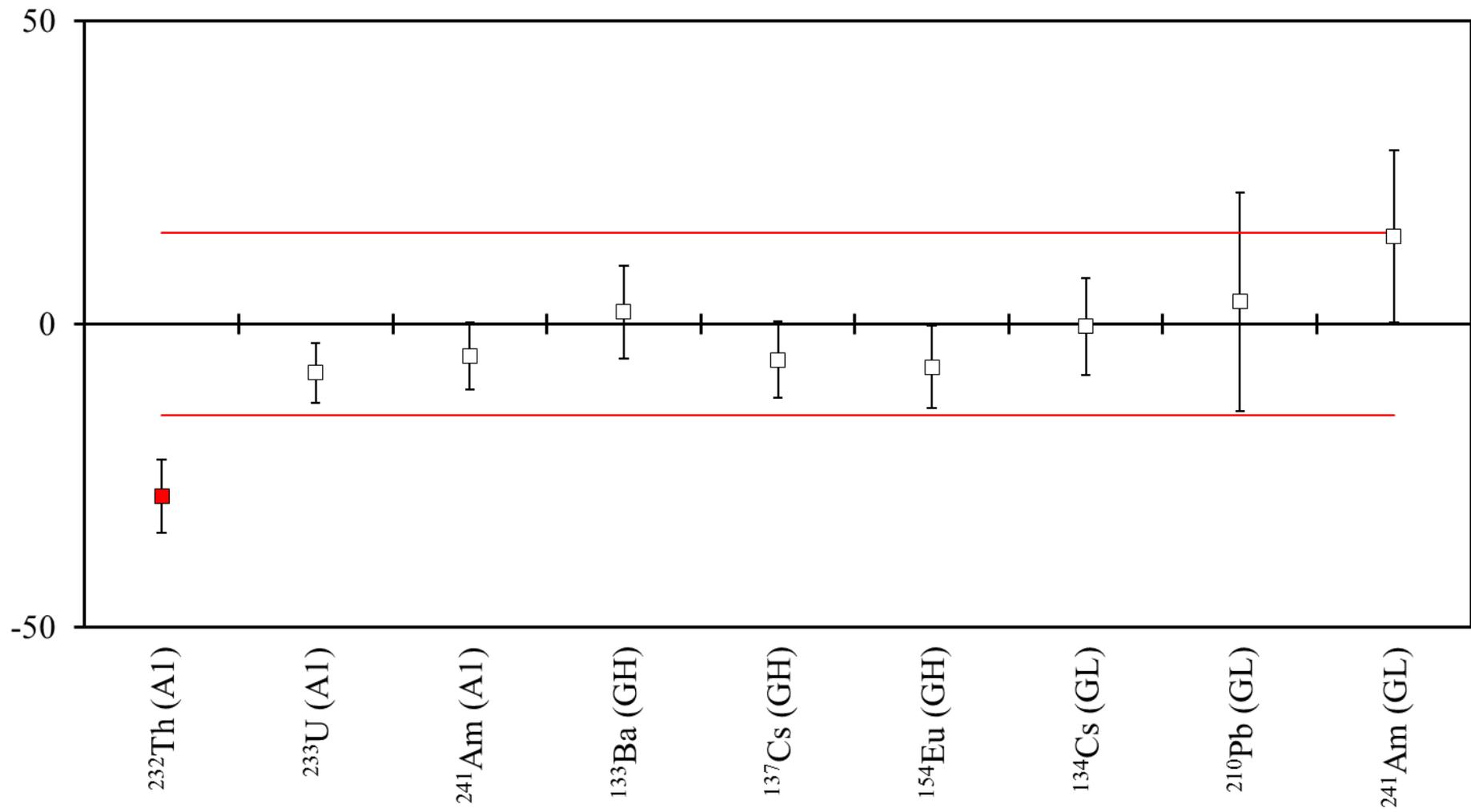
Radionuclide	Laboratory 133	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{232}Th (A1)	0.558 ± 0.047	0.7792 ± 0.0075	-28.4	-4.65	-4.88
^{233}U (A1)	16.54 ± 0.90	17.996 ± 0.054	-8.1	-1.61	-1.39
^{241}Am (A1)	8.72 ± 0.51	9.211 ± 0.026	-5.3	-0.96	-0.92
^{133}Ba (GH)	19.1 ± 1.4	18.73 ± 0.27	2.0	0.26	0.34
^{137}Cs (GH)	3.76 ± 0.25	3.996 ± 0.028	-5.9	-0.94	-1.01
^{154}Eu (GH)	5.91 ± 0.43	6.363 ± 0.051	-7.1	-1.05	-1.22
^{134}Cs (GL)	18.7 ± 1.5	18.78 ± 0.15	-0.4	-0.05	-0.07
^{210}Pb (GL)	16.7 ± 2.9	16.11 ± 0.17	3.7	0.20	0.63
^{241}Am (GL)	2.74 ± 0.34	2.3943 ± 0.0078	14.4	1.02	2.48

Deviation (%) of Laboratory 135
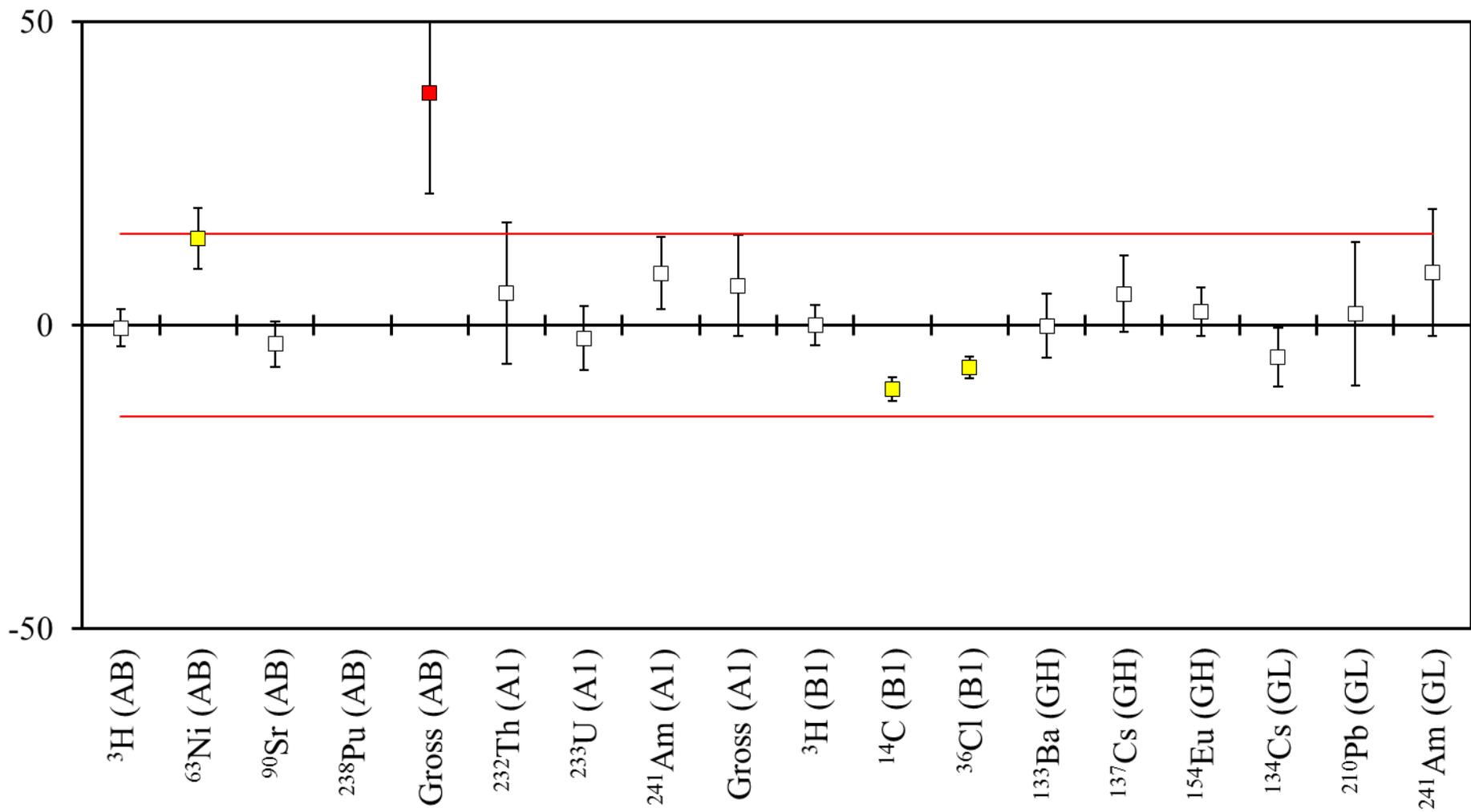
Radionuclide	Laboratory 135	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	16.77 ± 0.47	16.85 ± 0.21	-0.5	-0.16	-0.08
^{63}Ni (AB)	11.60 ± 0.50	10.15 ± 0.11	14.3	2.83	2.45
^{90}Sr (AB)	2.220 ± 0.085	2.292 ± 0.010	-3.1	-0.84	-0.54
^{238}Pu (AB)	0.1550 ± 0.0055	15.428 ± 0.035	-99.0	-431.08	-17.00
Gross beta (AB)	6.39 ± 0.36	4.62 ± 0.49	38.3	2.91	6.58
^{232}Th (A1)	0.82 ± 0.09	0.7792 ± 0.0075	5.2	0.45	0.90
^{233}U (A1)	17.60 ± 0.95	17.996 ± 0.054	-2.2	-0.42	-0.38
^{241}Am (A1)	10.00 ± 0.55	9.211 ± 0.026	8.6	1.43	1.47
Gross alpha (A1)	31.2 ± 2.2	29.3 ± 1.0	6.5	0.79	1.11
^{3}H (B1)	0.305 ± 0.009	0.3049 ± 0.0046	0.0	0.01	0.01
^{14}C (B1)	0.2150 ± 0.0045	0.2404 ± 0.0016	-10.6	-5.32	-1.81
^{36}Cl (B1)	0.1840 ± 0.0035	0.19774 ± 0.00080	-6.9	-3.83	-1.19
Gross beta (B1)	0.250 ± 0.020	-	-	-	-
^{133}Ba (GH)	18.70 ± 0.95	18.73 ± 0.27	-0.2	-0.03	-0.03
^{137}Cs (GH)	4.20 ± 0.25	3.996 ± 0.028	5.1	0.81	0.88
^{154}Eu (GH)	6.50 ± 0.25	6.363 ± 0.051	2.2	0.54	0.37
^{134}Cs (GL)	17.80 ± 0.90	18.78 ± 0.15	-5.2	-1.07	-0.90
^{210}Pb (GL)	16.4 ± 1.9	16.11 ± 0.17	1.8	0.15	0.31
^{241}Am (GL)	2.60 ± 0.25	2.3943 ± 0.0078	8.6	0.82	1.48

Deviation (%) of Laboratory 136
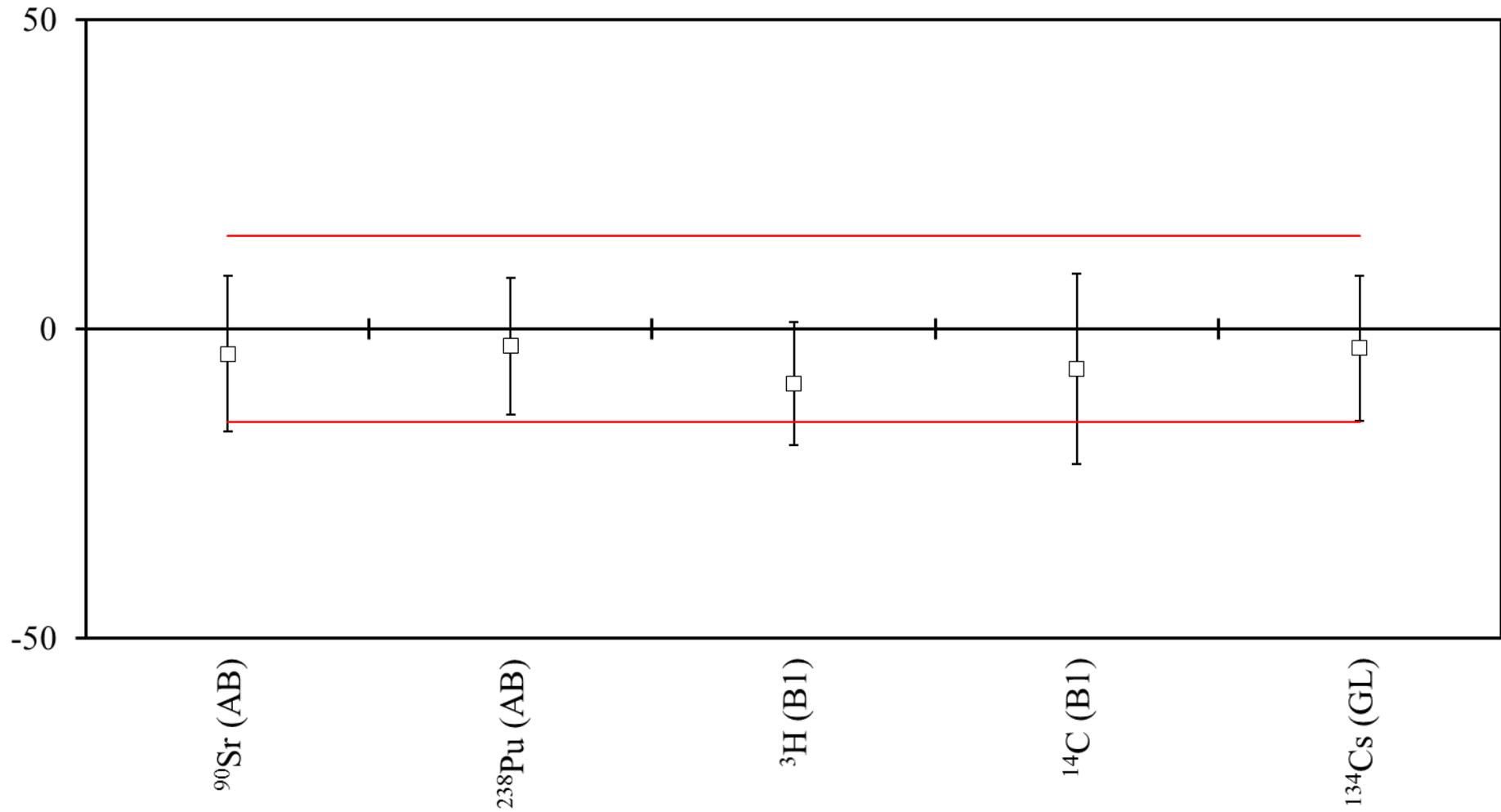
Radionuclide	Laboratory 136	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{90}Sr (AB)	2.20 ± 0.29	2.292 ± 0.010	-4.0	-0.32	-0.69
^{238}Pu (AB)	15.0 ± 1.7	15.428 ± 0.035	-2.8	-0.25	-0.48
^{3}H (B1)	0.2780 ± 0.03	0.3049 ± 0.0046	-8.8	-0.89	-1.52
^{14}C (B1)	0.225 ± 0.037	0.2404 ± 0.0016	-6.4	-0.42	-1.10
^{134}Cs (GL)	18.2 ± 2.2	18.78 ± 0.15	-3.1	-0.26	-0.53

Deviation (%) of Laboratory 142

Radionuclide	Laboratory 142	NPL Assigned Value	Deviation /%	Zeta	Z Score
Gross alpha (A1)	32.12 ± 0.52	29.3 ± 1.0	9.6	2.50	1.65

Deviation (%) of Laboratory 147
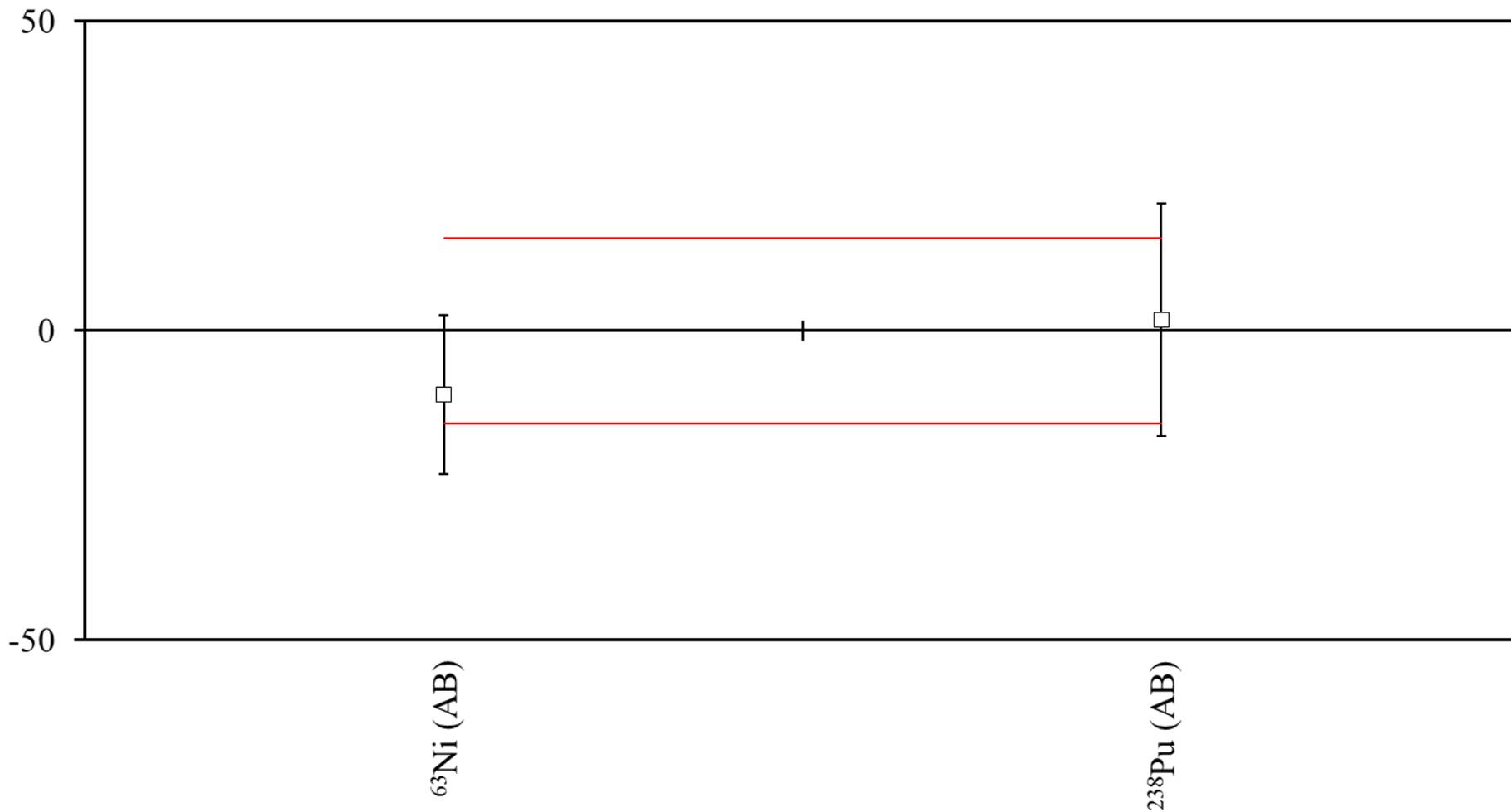
Radionuclide	Laboratory 147	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{63}Ni (AB)	9.1 ± 1.3	10.15 ± 0.11	-10.3	-0.80	-1.78
^{238}Pu (AB)	15.7 ± 2.9	15.428 ± 0.035	1.8	0.09	0.30

Deviation (%) of Laboratory 149
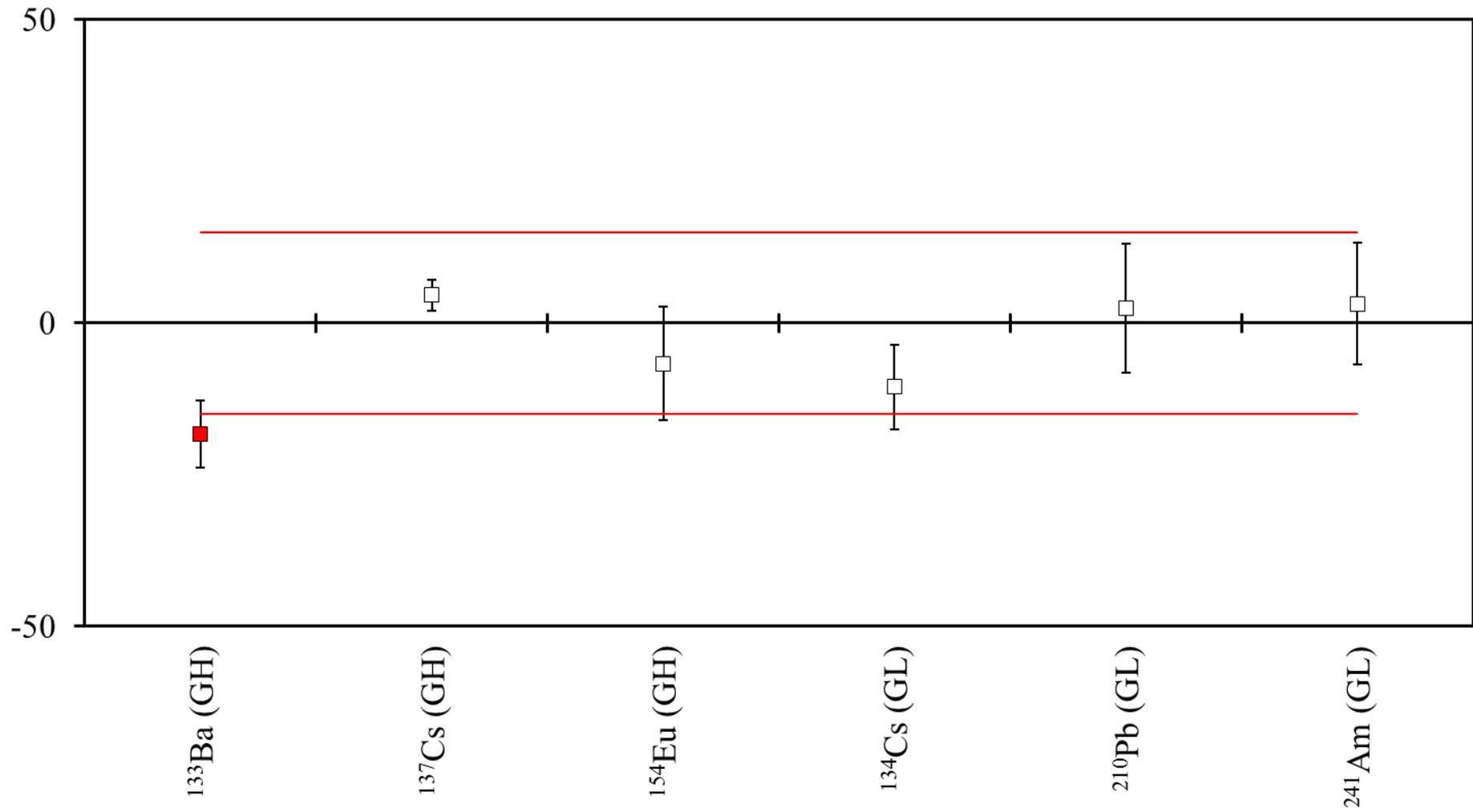
Radionuclide	Laboratory 149	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{133}Ba (GH)	15.3 ± 1.0	18.73 ± 0.27	-18.3	-3.31	-3.14
^{137}Cs (GH)	4.18 ± 0.10	3.996 ± 0.028	4.6	1.77	0.79
^{154}Eu (GH)	5.94 ± 0.59	6.363 ± 0.051	-6.6	-0.71	-1.14
^{134}Cs (GL)	16.8 ± 1.3	18.78 ± 0.15	-10.5	-1.51	-1.81
^{210}Pb (GL)	16.5 ± 1.7	16.11 ± 0.17	2.4	0.23	0.42
^{241}Am (GL)	2.47 ± 0.24	2.3943 ± 0.0078	3.2	0.32	0.54

Deviation (%) of Laboratory 153
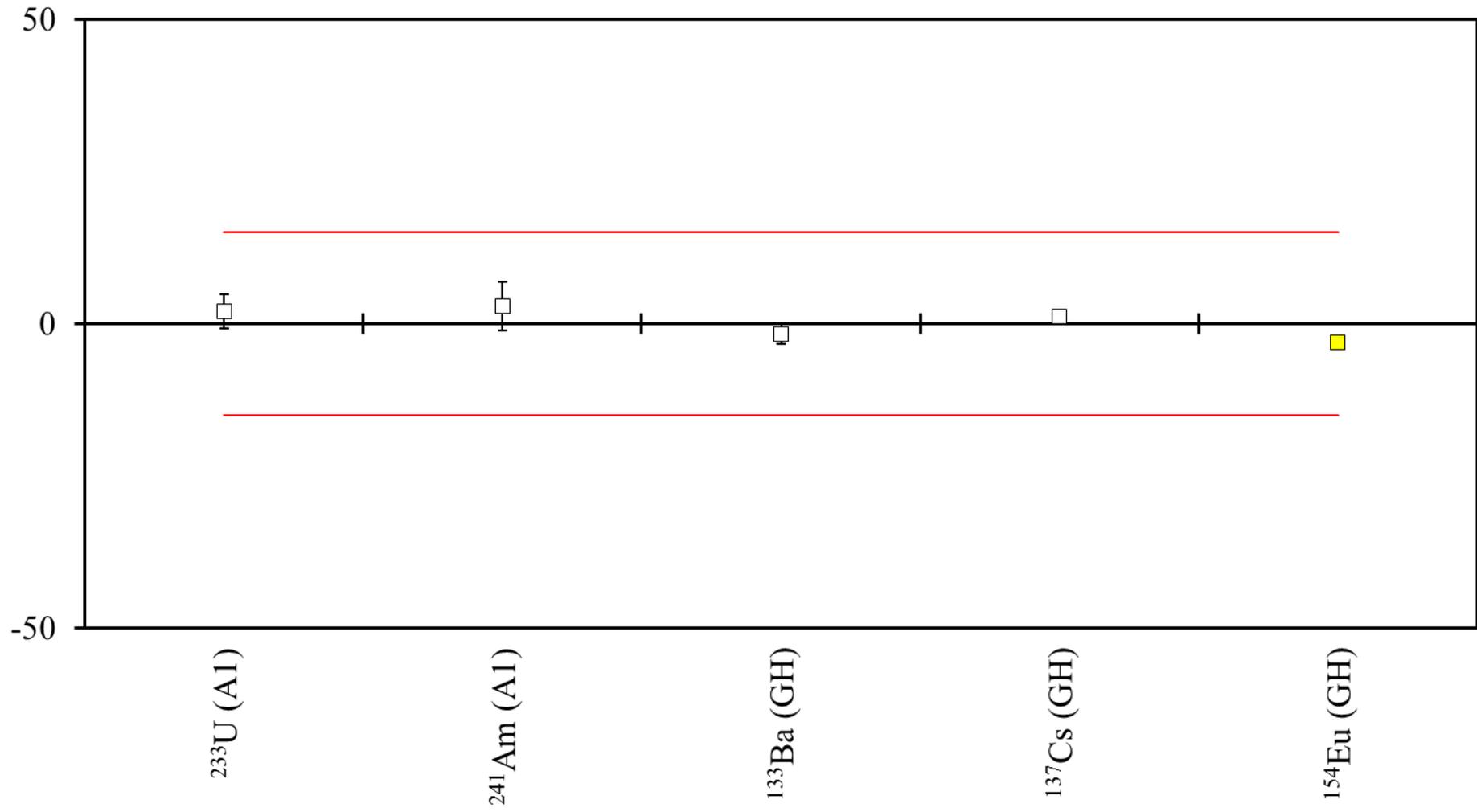
Radionuclide	Laboratory 153	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{233}U (A1)	18.36 ± 0.49	17.996 ± 0.054	2.0	0.74	0.35
^{241}Am (A1)	9.48 ± 0.37	9.211 ± 0.026	2.9	0.73	0.50
^{133}Ba (GH)	18.42 ± 0.17	18.73 ± 0.27	-1.7	-0.97	-0.28
^{137}Cs (GH)	4.042 ± 0.033	3.996 ± 0.028	1.2	1.06	0.20
^{154}Eu (GH)	6.163 ± 0.022	6.363 ± 0.051	-3.1	-3.60	-0.54

Deviation (%) of Laboratory 155
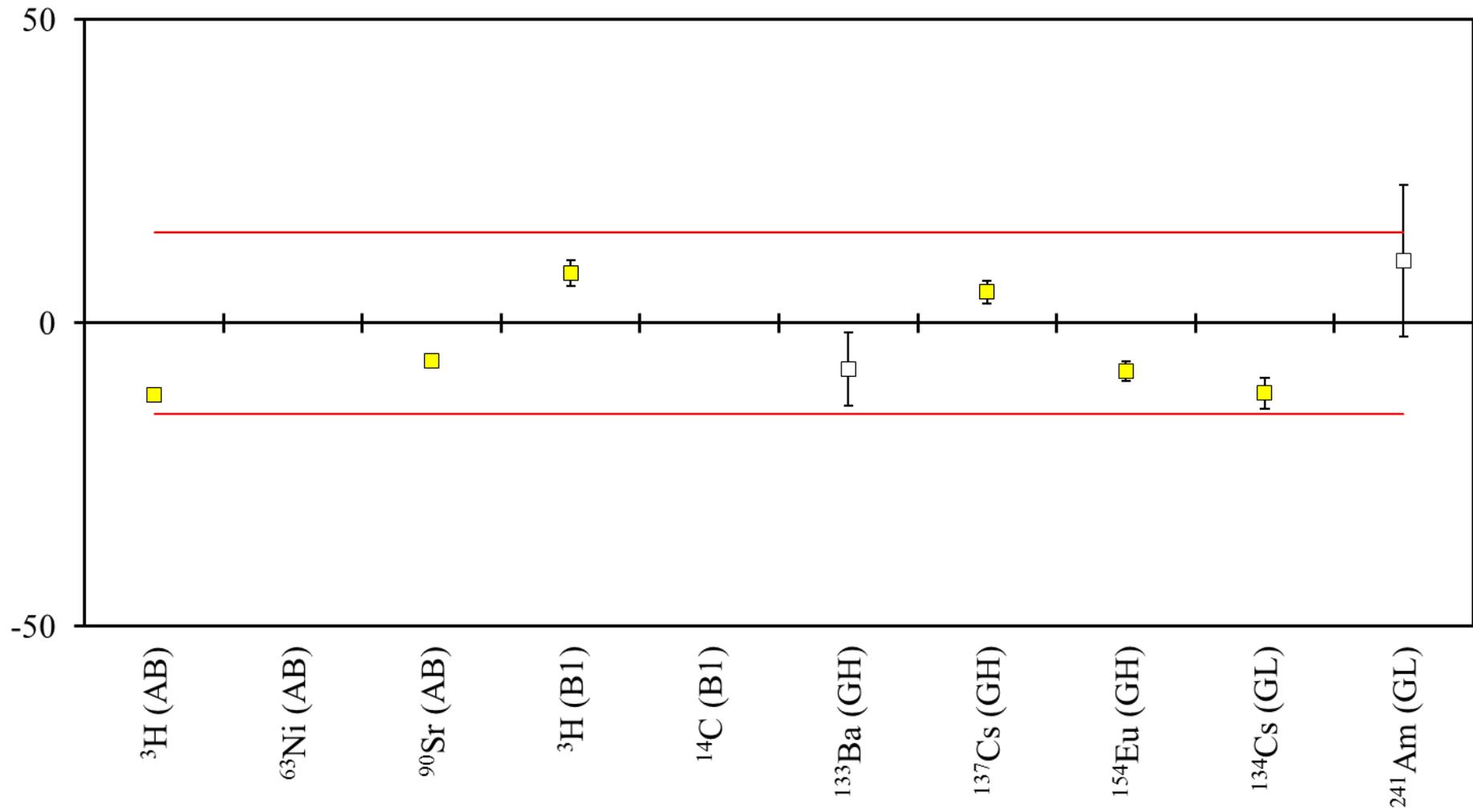
Radionuclide	Laboratory 155	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	14.850 ± 0.047	16.85 ± 0.21	-11.9	-9.29	-2.04
^{63}Ni (AB)	2.6420 ± 0.0065	10.15 ± 0.11	-74.0	-68.14	-12.70
^{90}Sr (AB)	2.150 ± 0.014	2.292 ± 0.010	-6.2	-8.25	-1.06
^{3}H (B1)	0.3300 ± 0.0045	0.3049 ± 0.0046	8.2	3.90	1.41
^{14}C (B1)	0.5021 ± 0.0028	0.2404 ± 0.0016	108.9	81.15	18.69
^{133}Ba (GH)	17.3 ± 1.1	18.73 ± 0.27	-7.6	-1.26	-1.31
^{137}Cs (GH)	4.20 ± 0.07	3.996 ± 0.028	5.1	2.71	0.88
^{154}Eu (GH)	5.86 ± 0.09	6.363 ± 0.051	-7.9	-4.86	-1.36
^{134}Cs (GL)	16.61 ± 0.45	18.78 ± 0.15	-11.6	-4.57	-1.98
^{241}Am (GL)	2.640 ± 0.3	2.3943 ± 0.0078	10.3	0.82	1.76

Deviation (%) of Laboratory 159
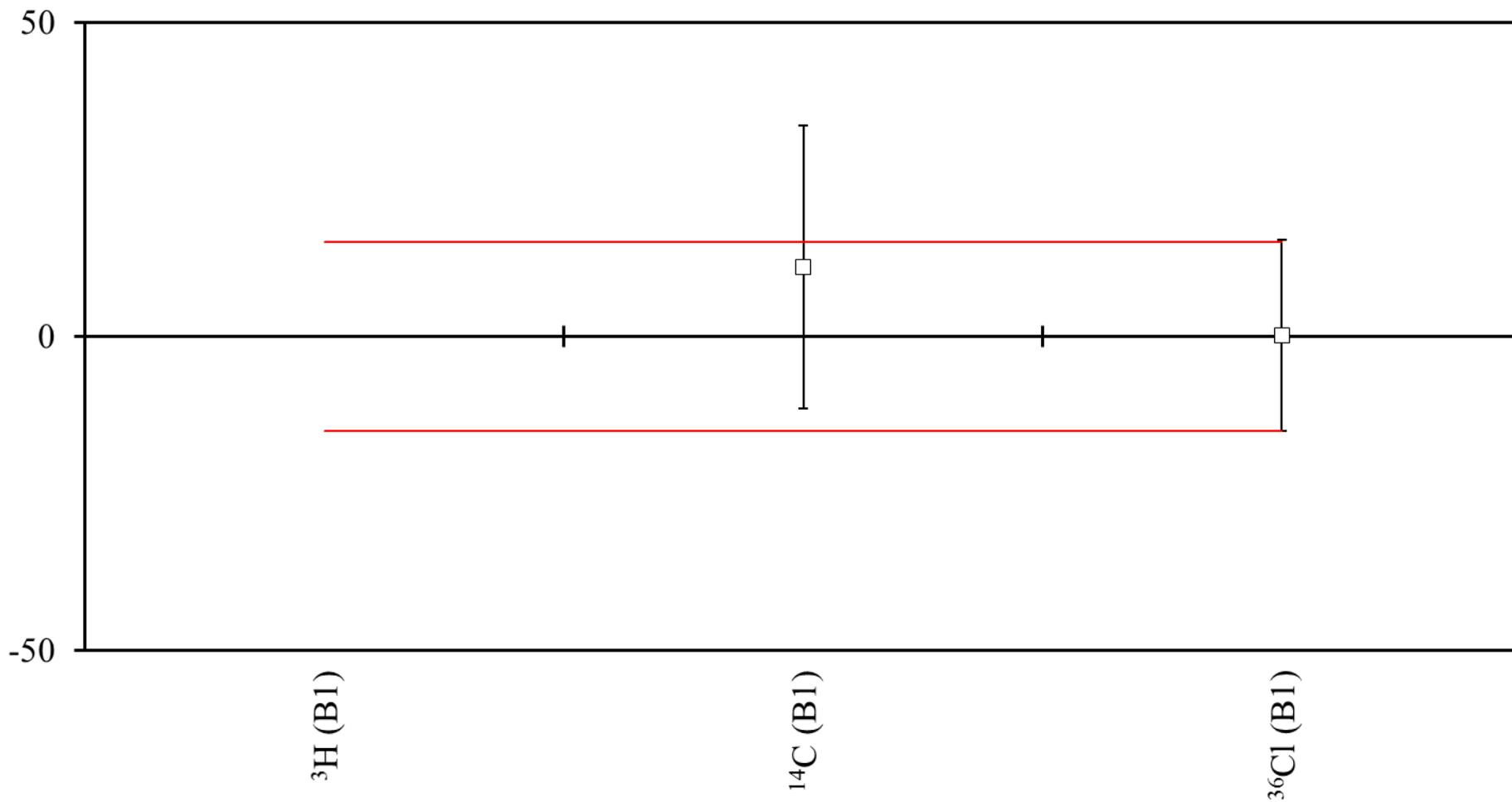
Radionuclide	Laboratory 159	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.634 ± 0.095	0.3049 ± 0.0046	107.9	3.46	18.54
^{14}C (B1)	0.267 ± 0.054	0.2404 ± 0.0016	11.1	0.49	1.90
^{36}Cl (B1)	0.1980 ± 0.03	0.19774 ± 0.00080	0.1	0.01	0.02
Gross beta (B1)	0.286 ± 0.080	-	-	-	-

Deviation (%) of Laboratory 160
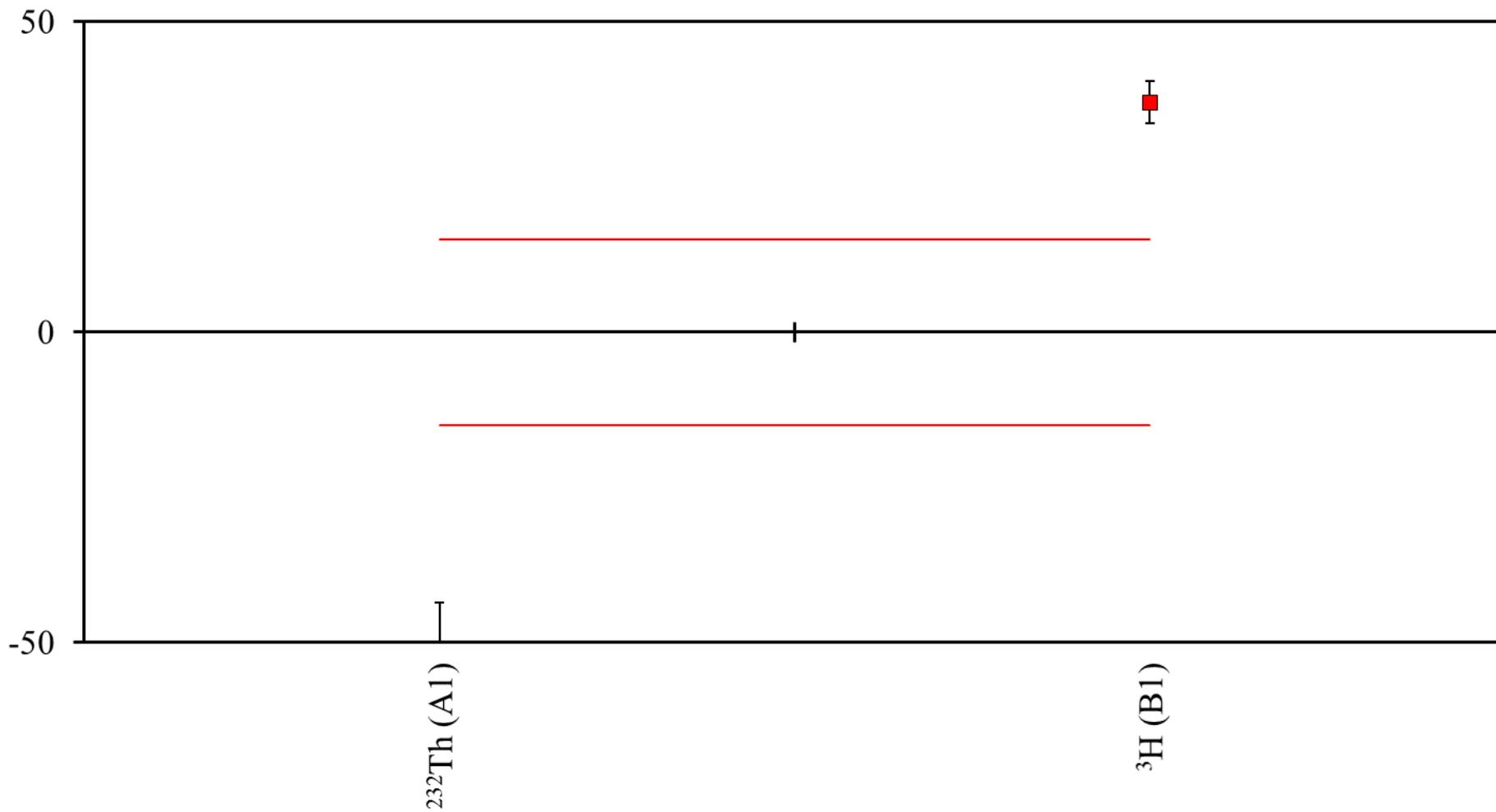
Radionuclide	Laboratory 160	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{232}Th (A1)	0.32 ± 0.12	0.7792 ± 0.0075	-58.9	-3.82	-10.12
^{3}H (B1)	0.4178 ± 0.0081	0.3049 ± 0.0046	37.0	12.12	6.36

Deviation (%) of Laboratory 162
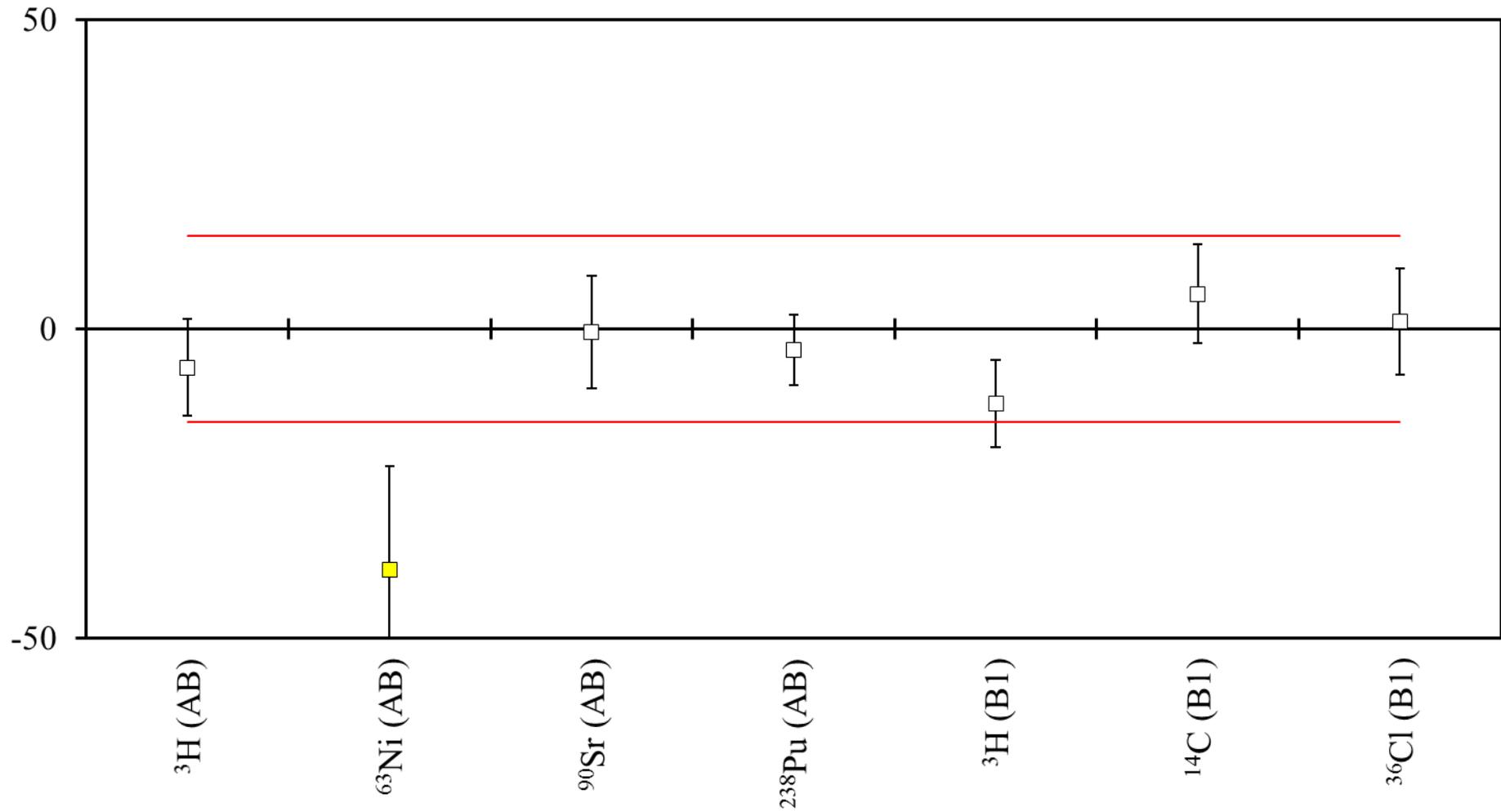
Radionuclide	Laboratory 162	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	15.8 ± 1.3	16.85 ± 0.21	-6.2	-0.80	-1.07
^{63}Ni (AB)	6.2 ± 1.7	10.15 ± 0.11	-38.9	-2.32	-6.68
^{90}Sr (AB)	2.28 ± 0.21	2.292 ± 0.010	-0.5	-0.06	-0.09
^{238}Pu (AB)	14.90 ± 0.89	15.428 ± 0.035	-3.4	-0.59	-0.59
^{3}H (B1)	0.268 ± 0.021	0.3049 ± 0.0046	-12.1	-1.72	-2.08
^{14}C (B1)	0.254 ± 0.019	0.2404 ± 0.0016	5.7	0.71	0.97
^{36}Cl (B1)	0.200 ± 0.017	0.19774 ± 0.00080	1.1	0.13	0.20

Deviation (%) of Laboratory 165
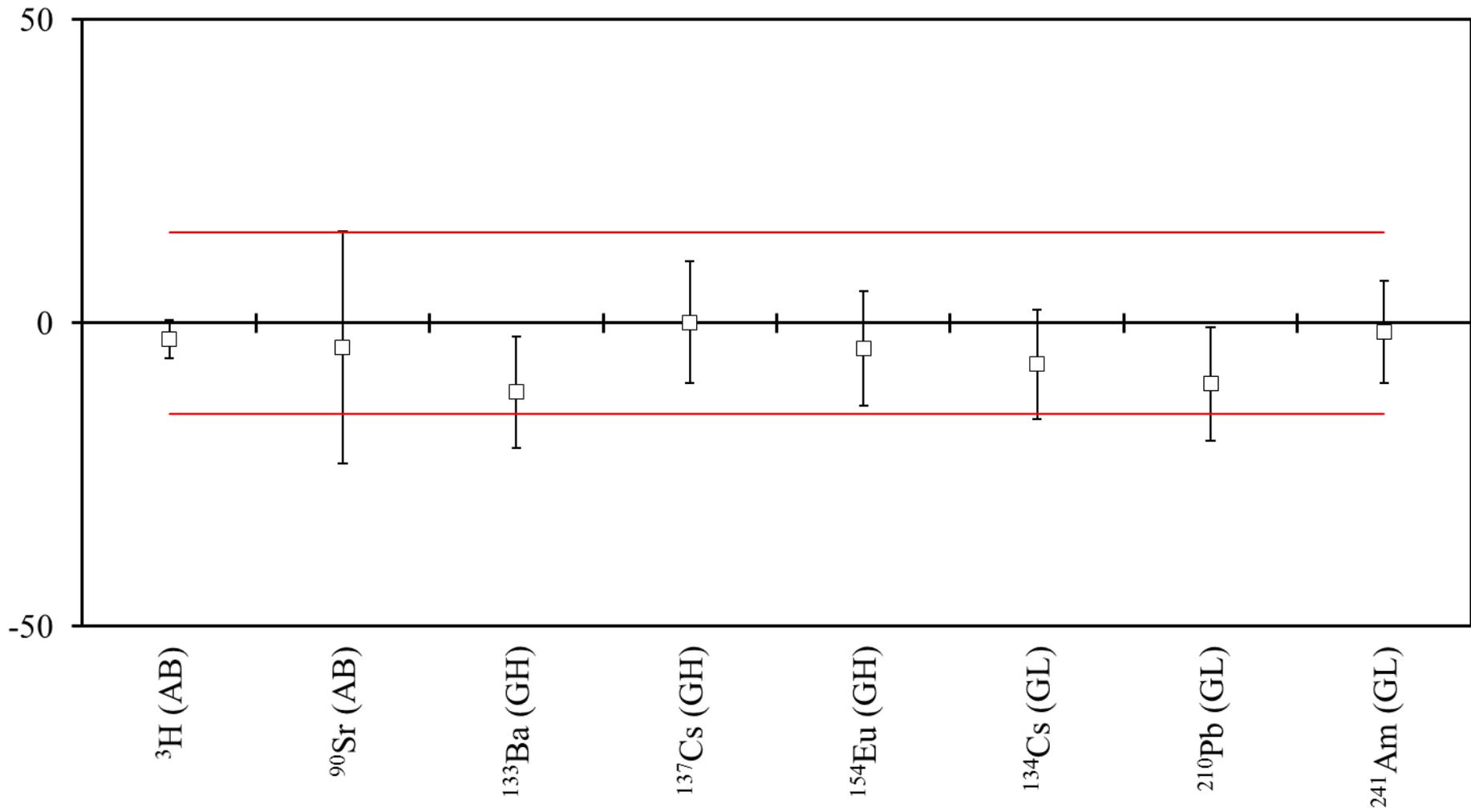
Radionuclide	Laboratory 165	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (AB)	16.40 ± 0.50	16.85 ± 0.21	-2.7	-0.83	-0.46
^{90}Sr (AB)	2.20 ± 0.44	2.292 ± 0.010	-4.0	-0.21	-0.69
^{133}Ba (GH)	16.6 ± 1.7	18.73 ± 0.27	-11.4	-1.24	-1.95
^{137}Cs (GH)	4.00 ± 0.40	3.996 ± 0.028	0.1	0.01	0.02
^{154}Eu (GH)	6.1 ± 0.6	6.363 ± 0.051	-4.1	-0.44	-0.71
^{134}Cs (GL)	17.5 ± 1.7	18.78 ± 0.15	-6.8	-0.75	-1.17
^{210}Pb (GL)	14.5 ± 1.5	16.11 ± 0.17	-10.0	-1.07	-1.72
^{241}Am (GL)	2.36 ± 0.20	2.3943 ± 0.0078	-1.4	-0.17	-0.25

Deviation (%) of Laboratory 166
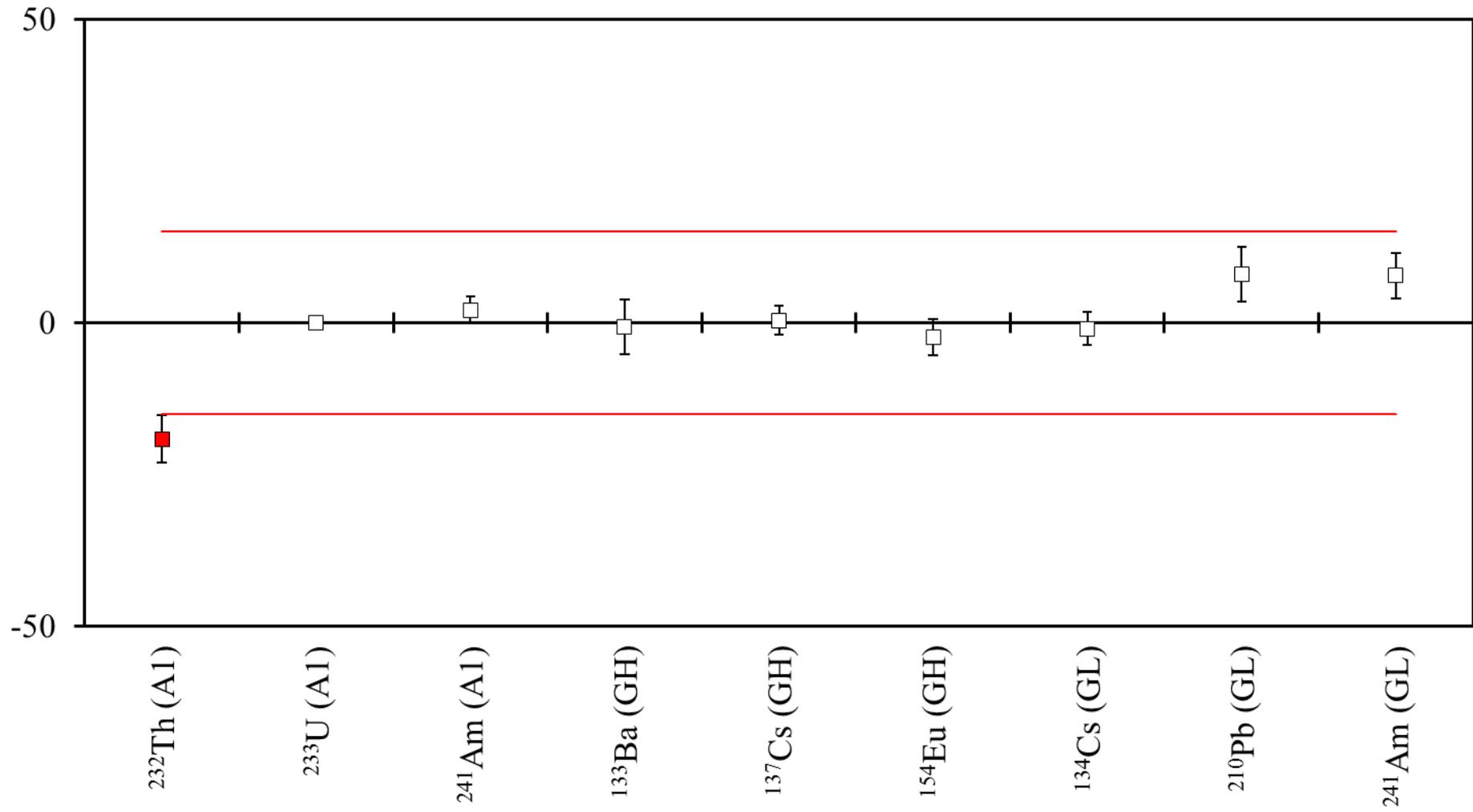
Radionuclide	Laboratory 166	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{232}Th (A1)	0.63 ± 0.03	0.7792 ± 0.0075	-19.1	-4.82	-3.29
^{233}U (A1)	18.00 ± 0.20	17.996 ± 0.054	0.0	0.02	0.00
^{241}Am (A1)	9.40 ± 0.20	9.211 ± 0.026	2.1	0.94	0.35
^{133}Ba (GH)	18.60 ± 0.80	18.73 ± 0.27	-0.7	-0.15	-0.12
^{137}Cs (GH)	4.01 ± 0.09	3.996 ± 0.028	0.4	0.15	0.06
^{154}Eu (GH)	6.21 ± 0.18	6.363 ± 0.051	-2.4	-0.82	-0.41
^{134}Cs (GL)	18.60 ± 0.50	18.78 ± 0.15	-1.0	-0.34	-0.16
^{210}Pb (GL)	17.4 ± 0.7	16.11 ± 0.17	8.0	1.79	1.38
^{241}Am (GL)	2.58 ± 0.09	2.3943 ± 0.0078	7.8	2.06	1.33

Deviation (%) of Laboratory 167
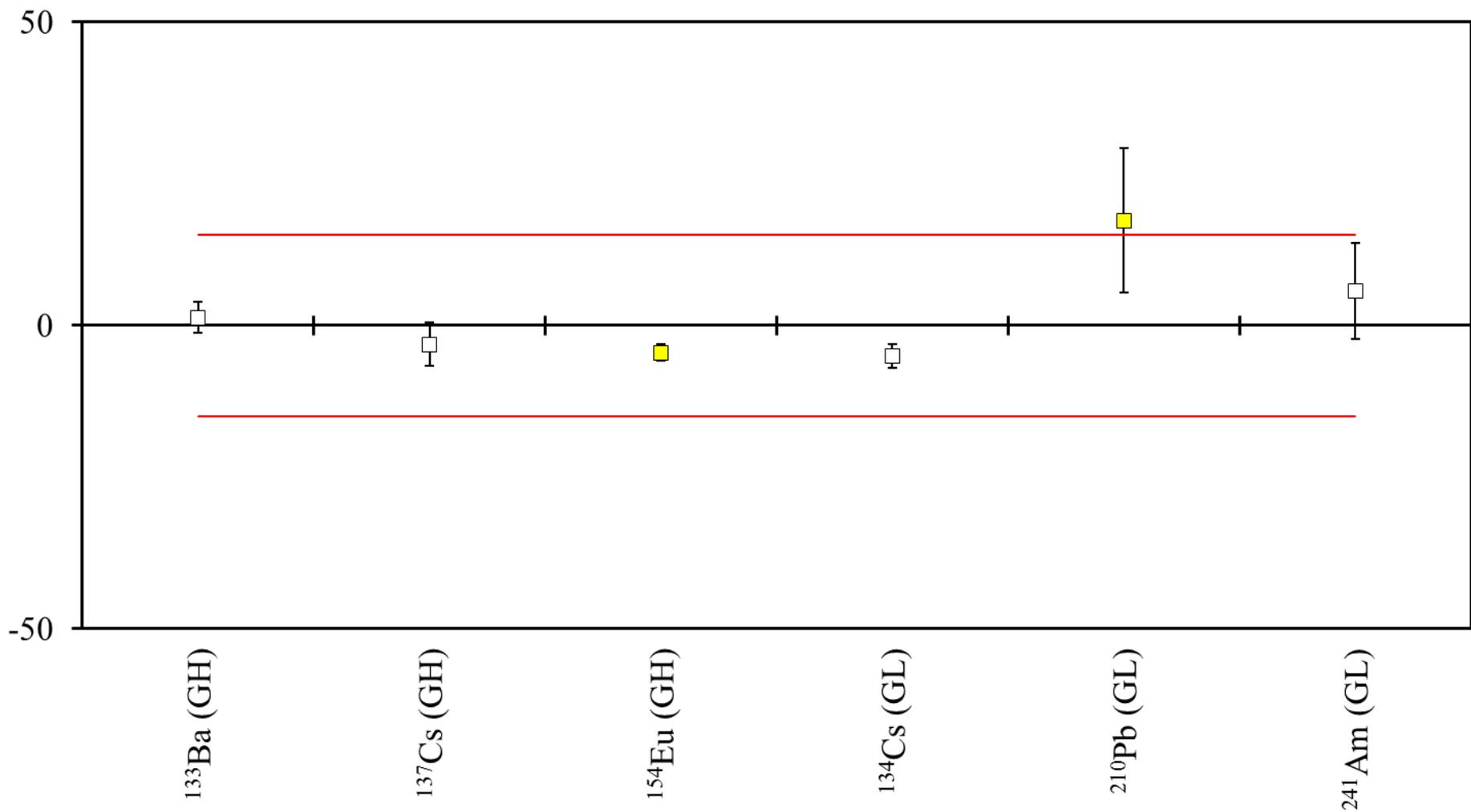
Radionuclide	Laboratory 167	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{133}Ba (GH)	18.97 ± 0.39	18.73 ± 0.27	1.3	0.51	0.22
^{137}Cs (GH)	3.87 ± 0.14	3.996 ± 0.028	-3.2	-0.88	-0.54
^{154}Eu (GH)	6.076 ± 0.072	6.363 ± 0.051	-4.5	-3.25	-0.77
^{134}Cs (GL)	17.84 ± 0.35	18.78 ± 0.15	-5.0	-2.47	-0.86
^{210}Pb (GL)	18.9 ± 1.9	16.11 ± 0.17	17.3	1.46	2.97
^{241}Am (GL)	2.53 ± 0.19	2.3943 ± 0.0078	5.7	0.71	0.97

Deviation (%) of Laboratory 168
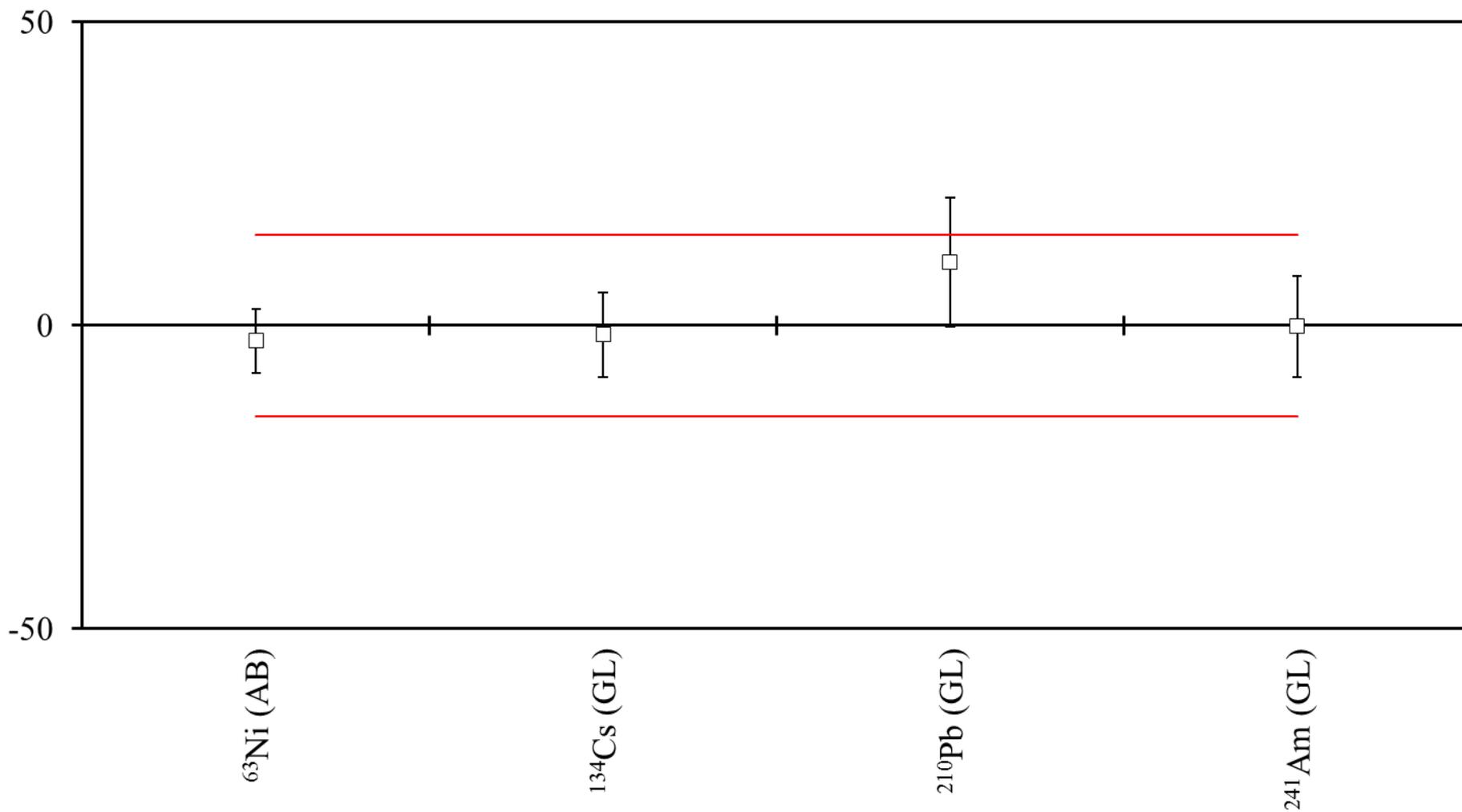
Radionuclide	Laboratory 168	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{63}Ni (AB)	9.89 ± 0.53	10.15 ± 0.11	-2.6	-0.48	-0.44
^{134}Cs (GL)	18.5 ± 1.3	18.78 ± 0.15	-1.5	-0.21	-0.26
^{210}Pb (GL)	17.8 ± 1.7	16.11 ± 0.17	10.5	0.99	1.80
^{241}Am (GL)	2.39 ± 0.20	2.3943 ± 0.0078	-0.2	-0.02	-0.03

Deviation (%) of Laboratory 169
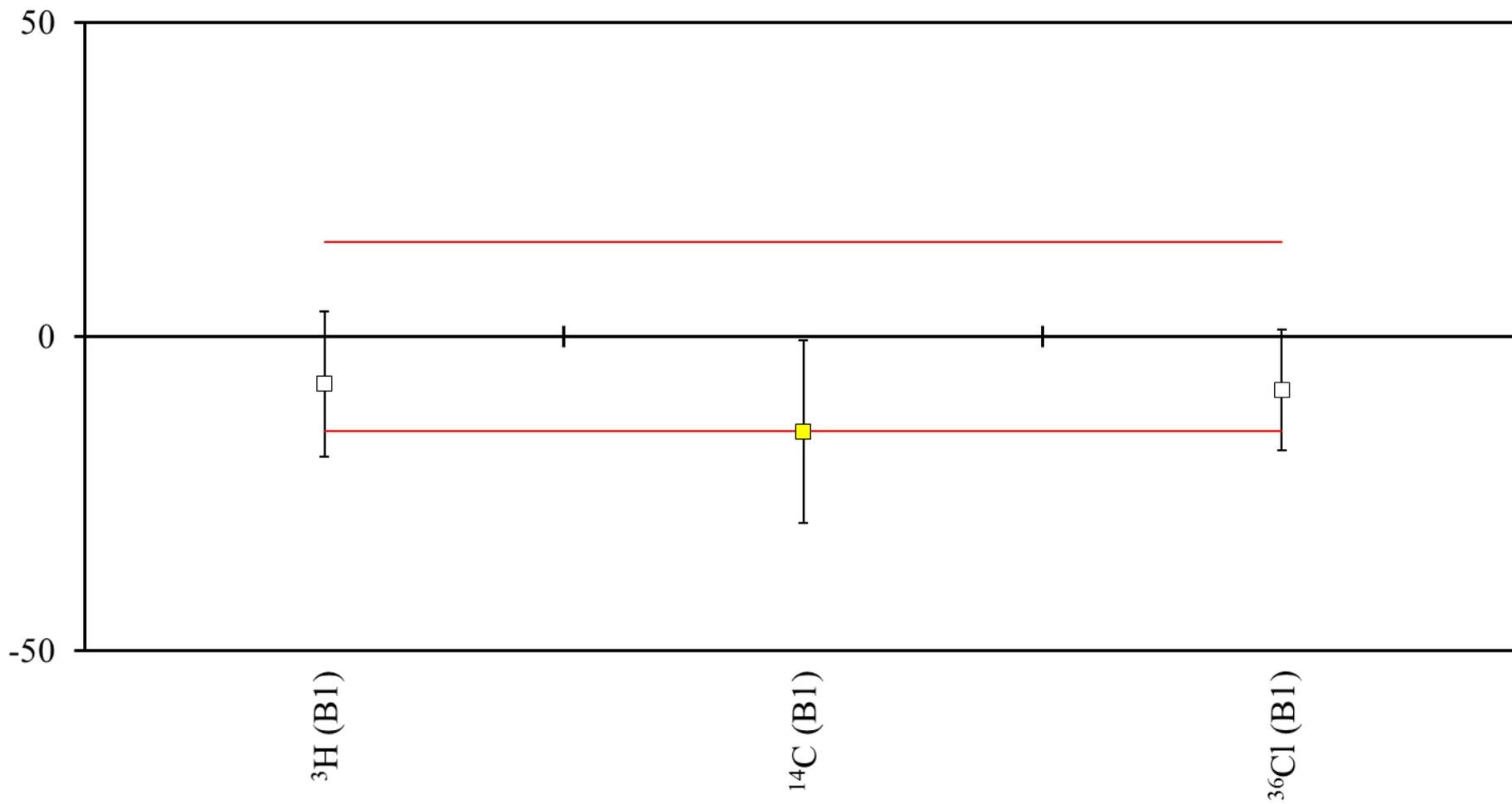
Radionuclide	Laboratory 169	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.282 ± 0.035	0.3049 ± 0.0046	-7.5	-0.65	-1.29
^{14}C (B1)	0.204 ± 0.035	0.2404 ± 0.0016	-15.1	-1.04	-2.60
^{36}Cl (B1)	0.181 ± 0.019	0.19774 ± 0.00080	-8.5	-0.88	-1.45

Deviation (%) of Laboratory 170
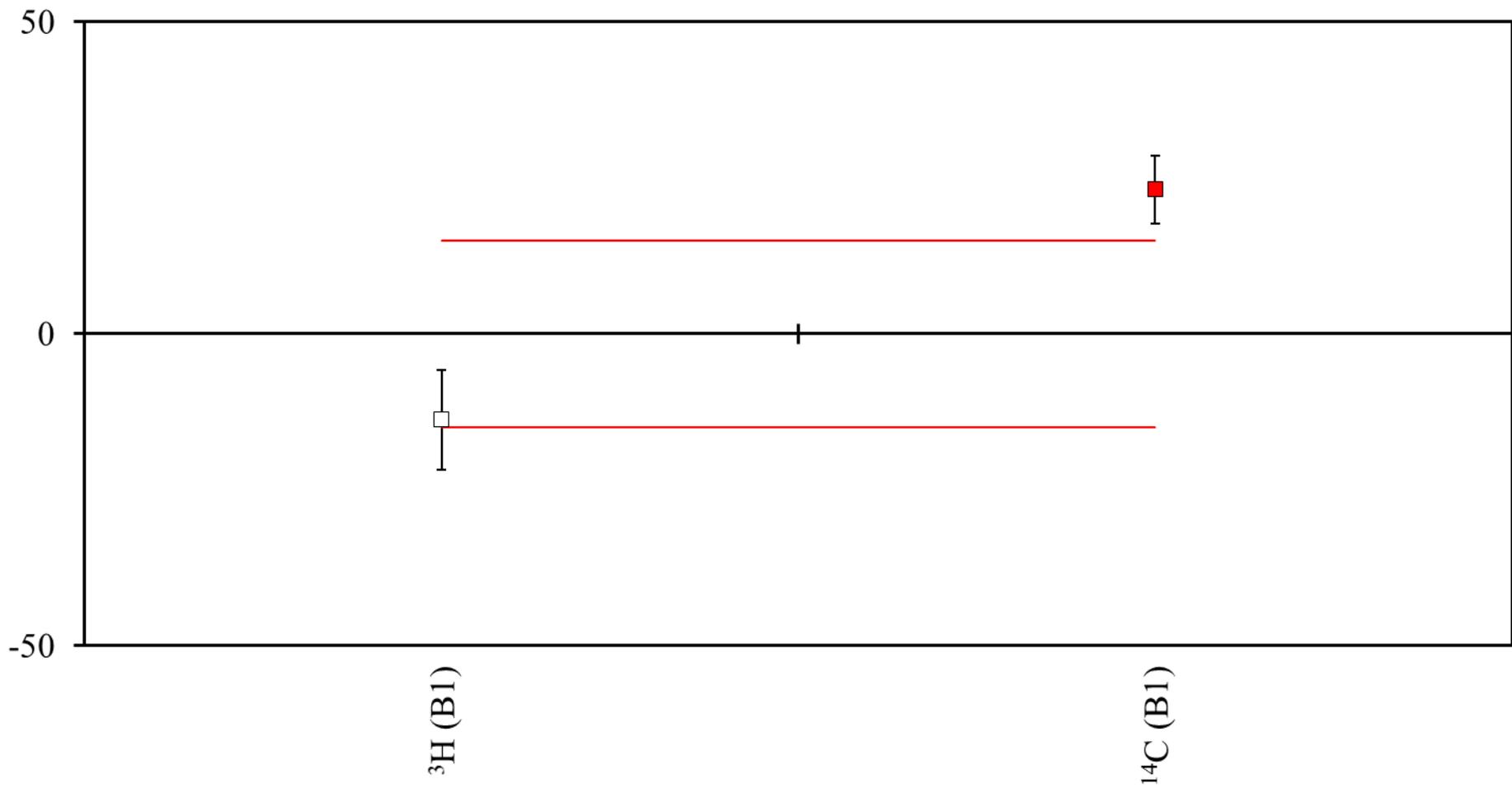
Radionuclide	Laboratory 170	NPL Assigned Value	Deviation /%	Zeta	Z Score
^{3}H (B1)	0.263 ± 0.024	0.3049 ± 0.0046	-13.7	-1.71	-2.36
^{14}C (B1)	0.296 ± 0.013	0.2404 ± 0.0016	23.1	4.24	3.97

10. DISCUSSION

Please note that in some cases the participants did not report methods and / or standards and tracers used. The comments on methods and standards below refer, therefore, to the subset of participants (for each nuclide) who did report such information.

11.1 ^{3}H in AB and B1

The overall performance level for ^{3}H in B1 was slightly lower that observed in the 2016 PTE, with 23 out of the 29 results submitted being in agreement with the Assigned Value (AV). All the participants used Liquid Scintillation Counting (LSC) to measure this radionuclide. In the majority of cases, the nuclide was separated from the mixture by distillation, combustion or pyrolysis. One participant used a G E Healthcare standard, three used Eckert and Ziegler standards and the other participants did not specify the provenance of the standard used.

The dataset for ^{3}H in AB was smaller (21), with 16 being in agreement with NPL (the same overall level of performance as in the 2016 PTE), and the above comments on methods apply. Two of the questionable results were from participants who had submitted questionable data for B1, and curiously they were both lower than the AV (whereas, for both participants, the results for B1 had been higher than the AV).

Insufficient information was provided to explain the questionable and discrepant ^{3}H data for either AB or B1.

11.2 ^{63}Ni in AB

Sixteen results were submitted for this radionuclide, and in every case LSC was the measurement technique used. Most laboratories reported having used a separation procedure (e.g. involving precipitation, solvent extraction or ion exchange chromatography). Five participants reported using ICP-MS or ICP-OES for the determination of chemical recovery. Overall, nine results agreed with the AV – a lower level of performance than that observed in the 2015 NPL PTE (when this nuclide was last included). Insufficient information was provided to explain the discrepant or questionable results observed.

11.3 ^{90}Sr in AB

Twenty-four results were submitted for this nuclide, with all but one being in agreement with NPL – a higher overall level of performance than in the 2016 PTE. A range of specific separation methods were used, including precipitation, ion- exchange chromatography and extraction chromatography. LSC (nine participants), Cerenkov counting (five participants), proportional counting (six participants), alpha/beta counting (one participant) and beta counting (one participant) were all cited as methods.

The Power-Moderated Weighted Mean values (PMWM) of the LSC, Cerenkov and proportional counting results were as follows:

LSC: (2.209 ± 0.031) Bq g^{-1}
Cerenkov: (2.288 ± 0.051) Bq g^{-1}
Proportional counting: (2.250 ± 0.053) Bq g^{-1}

These results suggest there is no significant difference between the three datasets, but these are small datasets, each with variations of the specific method used (e.g. different separation techniques and calibration standards), so it is difficult to draw conclusions without carrying out a more detailed study.

Two ^{90}Sr standards providers were cited (Eckert and Ziegler, and CMI) although most were not specified. Three participants used a ^{85}Sr yield tracer.

11.4 ^{238}Pu in AB

Twenty-two results were submitted for ^{238}Pu; all but four were in agreement with the AV. Alpha spectrometry was used by all but one of the participants (one used a proportional counter and obtained a discrepant result, which may be significant). Eleven participants used a ^{242}Pu tracer, four used ^{236}Pu and one used ^{241}Am.

11.5 ^{232}Th in A1

The level of performance for this radionuclide was distinctly lower than in the 2016 PTE, with only 9 out of the 16 submitted results being in agreement with the AV. Ten participants used alpha spectrometry, four used ICP-MS and one used gamma spectrometry. The PMWM values for alpha spectrometry and ICP-MS were as follows:

Alpha spectrometry: (0.704 ± 0.029) Bq g^{-1}
ICPMS: (0.690 ± 0.092) Bq g^{-1}

These results suggest there is no significant difference between the two methods, but the comments made in 11.3 above again apply.

Seven participants used a ^{229}Th tracer; others cited ^{230}Th and non-specified standards, and one used a sample from a previous NPL PTE (it should be noted that NPL's PTE aqueous samples, although normally prepared using materials traceable to national standards of radioactivity, are intended to be used as test samples only and not as calibration standards).

11.6 ^{233}U in A1

The overall level of performance for this nuclide was high, with 16 out of 17 results being in agreement with the AV. A range of separation methods were cited, including ion-exchange chromatography and extraction chromatography. Twelve participants used alpha spectrometry to measure the separated nuclide, and two used ICP-MS. Seven reported using ^{232}U standards; other standards cited included ^{233}U and, again, a sample from a previous NPL PTE.

11.7 ^{241}Am in A1

Most of the results submitted for this radionuclide (19 out of 22) agreed with the AV. All but one of the participants used alpha spectrometry; ion-exchange chromatography and extraction chromatography were used as the separation technique in many cases. Thirteen participants cited use of an ^{243}Am tracer. One participant assayed the sample using a gamma spectrometer calibrated with an NPL mixed radionuclide standard.

11.8 ^{14}C in B1

In total, 20 results were submitted for this nuclide, with 14 agreeing with NPL, a lower level of performance than in the 2016 PTE. All participants used LSC; precipitation and combustion methods were often cited for sample pre-treatment. One participant cited use of an Amersham standard, but in all other cases either the provenance of the standard used was not cited, or no standard at all was cited. Again, insufficient information was provided to explain questionable or discrepant results.

11.9 ^{36}Cl in B1

The dataset for this nuclide was smaller, with 10 out of an 11 reported results being in agreement with NPL – very similar to the performance level observed in the 2016 PTE. Nine participants used LSC and one used gas-flow proportional counting. Five participants each cited specific separation techniques.

11.9   Gross alpha and gross beta results for AB, A1 and B1

In each case, the PMWM of the submitted results was calculated. Due to the large uncertainty on the PMWM of the reported values for gross beta activity in Sample Type B1, it was decided not to declare an Assigned Value for this quantity. For the other quantities (gross alpha in AB and gross alpha in A1), the PMWM was adopted as the Assigned Value.

For AB gross beta, 8 results were submitted (4 being in agreement with the AV) and the spread of results was very wide. In interpreting this dataset, it should be noted that NPL did not specify a standard method for gross beta analysis and the participants were free to use any method they wished. In most cases, participants used proportional counters (some calibrated using ^{90}Sr / ^{90}Y standards), which perhaps explains why the PMWM is very similar to the AV for ^{90}Sr alone (corrected by a factor of 2 for the presence of ^{90}Y in equilibrium). In cases where the participant has used a method such as LSC where the sensitivity to the lower-energy betas is greater, one would expect a result of the same order of magnitude to the summed AVs of all the nuclides (again, with a correction for ^{90}Y), and this may explain at least one of the discrepant results observed.

Turning to A1 gross alpha, 8 results were submitted and 6 were in agreement with NPL. Techniques included LSC, ZnS counting and gas-flow proportional counting. Some participants used ^{239}Pu or ^{241}Am standards. The spread of results was much lower than for AB gross beta above, and there are no particular comments to make.

11.10   Sample Types GH and GL

All measurements were carried out using high-resolution gamma spectrometry. Prior to measurement, two participants diluted their GH samples, two diluted their GL samples and one reduced the volume of their GL sample, but otherwise no sample pre-treatment of either GH or GL was reported. Laboratories calibrated their detectors using mixed radionuclide standards from CERCA LEA, Eckert and Ziegler, NPL, or from unspecified suppliers. The German accreditation body Deutsche Akkreditierungsstelle (DAkkS) was also cited.

Twenty-eight datasets were submitted for GH. The numbers of results in agreement with NPL by nuclide were: ^{133}Ba (22), ^{137}Cs (27) and ^{154}Eu (22).

The number of results submitted for GL nuclides varied; the numbers of results in agreement by nuclide were: ^{134}Cs (24 out of 30 results submitted), ^{210}Pb (16 out of 21) and ^{241}Am (24 out of 31). The radionuclide ^{210}Pb is difficult to measure at low energies due to the high presence in background, the need to extrapolate from ^{241}Am in most cases, and matrix/density corrections required compared with the standard.

11. REFERENCES

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12. ACKNOWLEDGEMENTS