

Proficiency testing for official laboratories for ^{137}Cs and ^{134}Cs determination in soil

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ABSTRACT

Incidents involving the release of caesium radioactive isotopes into the environment have prompted the adoption of necessary measures to protect the public. A network of official laboratories has been established across Poland to routinely measure the level of radioactive contamination in food. The participation of nine selected laboratories in proficiency testing serves both to demonstrate competence and to confirm the reliability of results. The certified reference material IAEA-478 "Radionuclides in Soil" was used for this testing. The value assigned from the certificate was determined on the basis of measurement results carried out by specialized laboratories. The International Atomic Energy Agency (IAEA) methodology was applied to evaluate the results, adopting criteria of trueness and precision that account for the measurement uncertainties estimated by the participants. The results obtained by the laboratories for ^{137}Cs and ^{134}Cs were within the reference values \pm uncertainty for these caesium radioisotopes. Based on the obtained proficiency tests results, it can be concluded that the official laboratories perform reliable determinations of ^{137}Cs and ^{134}Cs activity concentrations.

1. Introduction

Radionuclides, both naturally occurring and artificially produced, are readily detected through the emission of particles and photons following nuclear decay. Radioanalytical techniques use radiation to reflect the composition of materials, thus providing valuable information to various scientific disciplines (Pommé, 2022). The source of radioactive pollution in the world is global radioactive fallout, i.e. the fall of dust and radioactive substances from the atmosphere (created, for example, after a nuclear explosion or reactor failure) onto the earth's surface, which is spread by air currents over enormous distances. The released ^{137}Cs spread and settled on the ground, with most of the world's surface soils containing significant reserves of ^{137}Cs (Kyung-Ho et al., 2013). Lee et al. (2026) point to the need for reliable monitoring of marine radioactivity, which became critical after the Fukushima Daiichi nuclear power plant accident. Contaminated water contained radionuclides such as ^{134}Cs , ^{137}Cs , ^{131}I , and ^{90}Sr , which can have serious impacts on the environment and ecosystems. The main source of radioactive contamination in Europe was the Chernobyl power plant failure in 1986. As a result of this failure, a radioactive cloud spread over Poland, causing uneven environmental contamination. One of the most

dangerous radionuclides to enter the ecosystem is ^{137}Cs (Gembal et al., 2023; Guillitte et al., 1991; Hillel, 2008; Skwarzec, 2021). The introduction of radioactive caesium isotopes into the natural environment has necessitated continuous monitoring of food of animal origin for radioactive contamination (Czernski et al., 2024; Gembal et al., 2023; Official Journal of Laws, 2017, item 1246). Ensuring the reliability of radioactivity analysis results is crucial for monitoring results. Accredited laboratories use appropriate, tested, and validated methods, the fitness for purpose of which is demonstrated through participation in proficiency testing and intra-laboratory comparisons. Additionally, quality assurance is supported by the routine use of reference materials and quality control materials. (ISO/IEC and 17,025, 2017). Proficiency testing (PT) is a systematic interlaboratory comparison designed to assess the competence of laboratories in performing specific measurements and to facilitate the ongoing evaluation of their analytical performance (ISO/IEC 13528, 2015). Proficiency testing is very important, especially in laboratories, because it allows us to check whether the results obtained by a given laboratory are reliable and comparable to others. Proficiency testing is not just a "control" but a tool for continuous improvement and a guarantee that the test results can be considered reliable. Proficiency testing criteria are a set of rules used to assess

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whether a laboratory's results are valid and consistent with those of other program participants. They are based primarily on statistics and guidelines from standards such as ISO/IEC 17043 and ISO/IEC 17025. Lee et al. (2026) described a proficiency testing (PT) program organised by the Korea Research Institute for Standards and Science (KRISS) to evaluate the analytical capabilities of six national laboratories for determining radiocesium (^{137}Cs and ^{134}Cs) levels in seawater. In Poland and other EU countries, organising proficiency testing (PT) is one of the most important tasks of national reference laboratories. The Department of Chemical Research of Food and Feed of the National Veterinary Institute serves as the National Reference Laboratory for Radioactive Contamination and is responsible for conducting proficiency tests for official laboratories (Fig. 1) operating in the national system for monitoring radioactive contamination of food and feed (Gembal and Czerski, 2024) since year 2009. The aim of the proficiency testing (PT) program described in this article, organized by the Department of Chemical Research of Food and Feed, was to evaluate the analytical capabilities of nine national laboratories in the determination of radionuclides (^{137}Cs and ^{134}Cs) in soil.

2. Material and methods

2.1. Material for research

The International Atomic Energy Agency (IAEA) plays an important role in the production of reference materials, including Certified Reference Materials (CRMs), particularly in the areas of isotopic, environmental and radiochemical analysis. The IAEA produces CRMs containing radionuclides (e.g. in soil, water, sediment or food samples), which are used to calibrate equipment and validate analytical methods in laboratories. The study used the certified reference material IAEA-478 "Radionuclides in Soil" (IAEA, 2025). The raw material used to produce

this material was collected from an area near Gyömrő, Hungary (location: E19.22,625 and N47.23,724), where the soil has some of the lowest radionuclide content in the region. The raw material was fortified with radionuclides using precise dilutions of certified radioactive reference solutions from metrological institutes. After fortification, the material was homogenized and tested for uniformity. The material's grain size distribution ranges from 150 to 250 μm . The certified values and its uncertainty for radioactive concentrations from the certificate (determined based on measurement results from expert laboratories) were: $^{137}\text{Cs} - 65.0 \pm 0.9 \text{ Bq/kg}$, $^{134}\text{Cs} - 112.2 \pm 1.4 \text{ Bq/kg}$ (IAEA, 2025). In the reference laboratory, water content in the material was determined by repeated moisture measurements of subsamples weighing approximately 5 g using a moisture analyzer (RADWAG, MA 110.R.WH). Based on these measurements, the mass of the test object used in the PT was determined. The material was placed in a Marinelli measuring vessel (450 cm^3). The geometry of the measuring vessel matched the geometry of the calibration source used to calibrate the detectors. Information on assigned value, stability and homogeneity of the material was obtained from the CRM certificate (IAEA,2025).

2.1.1. Determining the assigned value

A certified reference material was used, which has a directly determined assigned value (IAEA, 2025). This specific value was assigned prior to the study, independent of participant performance. By definition, certified reference materials ensure proper measurement traceability.

2.1.2. Stability of the material

To test the short-term stability of the material, the following steps were taken: two bottles of the material were placed at $-25 \text{ }^\circ\text{C}$ and two bottles at $+70 \text{ }^\circ\text{C}$ for two weeks. After this time, three subsamples prepared from each bottle from two different temperature ranges were

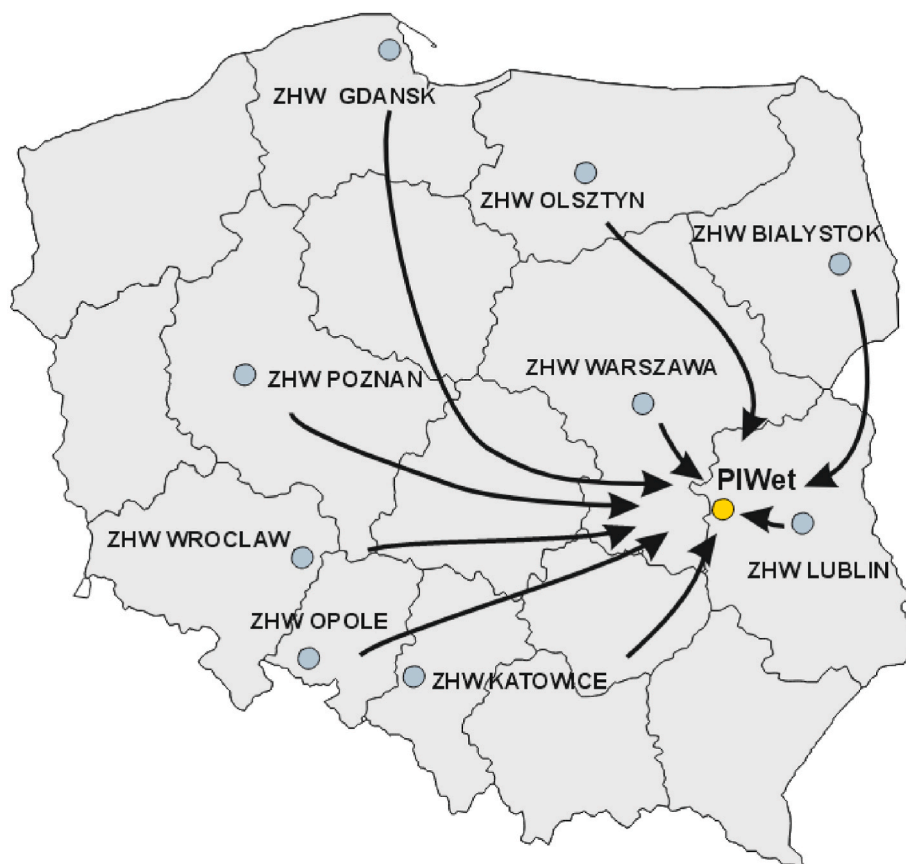


Fig. 1. A network of research laboratories conducting food monitoring studies.

subjected to the same analysis. The obtained results were analyzed and compared to reference values using the Zeta-scores. This confirmed the material's stability under various transport conditions. To test the long-term stability of the material, after two years of storage, the same samples were re-analyzed. The maximum discrepancy between the obtained Zeta-scores results and the reference values was randomly distributed between -1.79 and $+2.21$. The results demonstrated the long-term stability of the prepared material throughout the validity period of its certificate, assuming proper storage conditions were met. The work conducted showed that different transport conditions and long-term storage had no significant impact on the assigned values and their associated uncertainties (IAEA, 2025).

2.1.3. Homogeneity of the material

To ensure material homogeneity, three subsamples were used, taken from 11 randomly selected bottles from the production batch. Gamma-ray spectrometry measurement of the selected subsamples. To determine the final uncertainty budget and the minimum sample size to be tested, all radionuclides included in the material were assessed to determine the contribution of between and within bottle heterogeneity. No production trend was observed, and the obtained inter-bottle heterogeneity was 1.13%, which was less than the maximum target value of 5% (IAEA, 2025).

2.2. Instrumental analysis

Gamma-ray spectrometry is a widely used measurement technique for analysing various gamma-emitting caesium radioisotopes in environmental samples. Gamma-ray spectrometry was used to determine the radioactive concentrations of ^{137}Cs and ^{134}Cs using a high-purity germanium (HPGe) semiconductor detector and a NaI(Tl) scintillation detector supplied by Mirion Technologies (Atlanta, GA, USA) (Fig. 2). A multi-nuclide calibration source containing a mixture of appropriately selected isotopes was used to calibrate the detectors. All participants used the same measurement time of 72,000 s (20 h). The collected gamma spectra were analyzed using Genie 2000 software (Mirion Technologies, Atlanta, GA, USA) (Fig. 3).

2.3. Statistical analysis and laboratory performance evaluation

The statistical analysis of the results obtained during proficiency testing, but also the selection of appropriate tests and solutions depends on the type of PT program selected (ISO/IEC 17043, 2023; Konieczka and Namieśnik, 2007; Lee et al., 2026). A sequential proficiency testing program (ISO/IEC 17043, 2011) was used. The object was passed on to subsequent proficiency testing participants. ISO standards and guides are helpful normative documents addressing the use of statistical methods in PT programs. (ISO 13528, 2015; ISO/IEC 17043, 2023; IUPAC, 1991). In all proficiency tests, the statistical model used includes

four common steps for assessing participants' performance: determining the assigned value, calculating statistical indicators characterising the obtained results (e.g., relative load, assessment criteria - trueness and precision) assessing the achieved results, and preliminarily assessing the homogeneity and stability of the test object. The International Atomic Energy Agency (IAEA) methodology is used to test radioisotope proficiency (Shakhashiro et al., 2006). This approach uses criteria (trueness, precision) that account for participants' measurement uncertainty. Precision refers to a range where 95% of measurement results obtained from a single sample using the same method fall, while trueness describes how close the average of multiple measurements is to the true value. If the official laboratory submitted multiple measurement results, the average value was used for all calculations.

2.3.1. Relative load

The first step in determining the final score was to estimate the relative load. This parameter is calculated using the following equation:

$$OW = \frac{W_L - W_{IAEA}}{W_{IAEA}} \times 100(\%)$$

Where:

OW: relative laboratory load.

W_L : the value of activity concentration obtained by the laboratory.

W_{IAEA} : assigned value of activity concentration.

2.3.2. Assessment criteria

The proficiency test results were assessed based on the criteria of trueness and precision. For the trueness criterion, a proficiency test participant achieved a satisfactory result if the condition $A_1 \leq A_2$ was met.

$$A_1 = |W_{IAEA} - W_L|$$

$$A_2 = 2,58 \times \sqrt{N_{IAEA}^2 + N_L^2}$$

Where:

A_1, A_2 : trueness indicators.

W_{IAEA} : assigned value of activity concentration.

W_L : the value of activity concentration obtained by the laboratory.

N_{IAEA} : uncertainty of the reference material certificate.

N_L : uncertainty of reported by the laboratory.

The precision for each proficiency test participant was calculated using the equation:

$$PR = \sqrt{\left(\frac{N_{IAEA}}{W_{IAEA}}\right)^2 + \left(\frac{N_L}{W_L}\right)^2} \times 100(\%)$$

Where:

PR: precision.

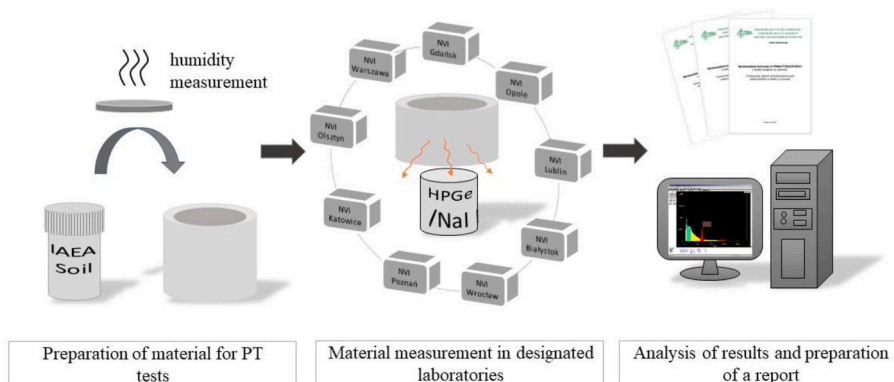


Fig. 2. Scheme of the proficiency tests carried out.

N_{IAEA} : uncertainty of the reference material certificate.
 N_L : uncertainty of reported by the laboratory.
 W_{IAEA} : assigned value of activity concentration.
 W_L : the value of activity concentration obtained by the laboratory.

Precision depends directly on measurement uncertainty. For a given proficiency test, a so-called limit of acceptable precision (LAP) is defined, which depends on the activity concentration of the analyte and the measurement itself. A proficiency test participant achieved an acceptable result if the condition $PR < LAP$ was met. A LAP of 20% was assumed for the proficiency test (Shakhashiro et al., 2006).

2.3.3. Final grade

Both evaluation criteria (trueness and precision) were considered in the final evaluation. A laboratory receives an acceptable result if it achieves satisfactory results in both evaluation criteria. If a laboratory fails to achieve acceptable result in one of the criteria, further verification is conducted. The relative load (OW) achieved by the proficiency test participant is compared to the maximum acceptable load (MAO). The MAO used in the proficiency test was 20%. (Shakhashiro et al., 2006). If the $OW < MAO$, the final assessment result is considered a "Warning". This situation typically arises in two cases: first, when the participant reports a result with little uncertainty, and the OW falls within the MAO. Second, when the participant's result is close to the assigned value, but the measurement uncertainty is large. If the $OW > MAO$, the final result is considered "Not Acceptable".

3. Results and discussion

3.1. Measurement of ^{137}Cs activity concentration and statistical analysis

Radionuclide ^{137}Cs is still present in the natural environment and is still present in measurable activity concentrations in food of animal origin. This is due to the relatively long half-life of this radioisotope, which is 30.2 years. It constitutes the main core of radiometric measurements and is most often used for evaluation in proficiency testing (PT) and interlaboratory comparisons (ILC). Official laboratories could report results using the HPGe detector, the NaI(Tl) detector, or both simultaneously. As part of the proficiency testing, 9 laboratories submitted 12 measurement results ^{137}Cs : 5 performed using the HPGe detector and 7 measurements using the NaI(Tl) detector. Two laboratories sent the results of measurements from two detectors simultaneously. The results obtained for ^{137}Cs (Table 1, column W_L) using the germanium HPGe detector ranged from 65.05 to 65.78 Bq·kg⁻¹ and were close to the reference value of 65.00 Bq·kg⁻¹. They were characterized by small scatter (mean: ≈65.4, standard deviation (SD): ≈0.31, repeatability (CV): ≈0.47 %). The results for ^{137}Cs using the NaI(Tl) scintillation detector were characterized by a larger scatter (mean: ≈62.1, standard

deviation (SD): ≈1.89, repeatability (CV): ≈3.05 %) and ranged from 59.50 to 64.52 Bq·kg⁻¹. In the next step, the trueness parameters were calculated: A_1 – taking into account the laboratory activity concentration result and the reference value activity concentration, and parameter A_2 – taking into account the laboratory uncertainty and the reference value uncertainty. These parameters took on different values. In the case of A_1 they ranged from 0.05 to 4.50, while in the case of A_2 they ranged from 3.76 to 8.68. In each case, the condition $A_1 \leq A_2$ was met (Table 1, column Pw). In the next step, the precision parameter was calculated, which depends directly on the measurement uncertainty. The precision parameters were in the range of 2.43 - 5.46 and in no case did they exceed the limit of permissible precision (LAP), the value of which was assumed to be 20% (Table 1, column PRw). Both evaluation criteria (trueness and precision) were taken into account in the final assessment, and the status of "Acceptable", "Warning" or "Not Acceptable" was adjusted accordingly. All laboratories achieved "Acceptable" performance on both criteria, achieving "Acceptable" results on the PT proficiency testing (Table 1, column OK). Detailed values are presented in Table 1.

Fig. 3 graphically presents the correctness indices A_1 and A_2 for the ^{137}Cs radioisotope. The proficiency test participants achieved an "Acceptable" status because the condition $A_1 \leq A_2$ was met.

Fig. 4 graphically depicts the precision parameters. Proficiency test participants achieved an "Acceptable" status because the condition $PR < LAP$ was met. The proficiency test assumed a LAP of 20%.

3.2. Measurement of ^{134}Cs activity concentration and statistical analysis

^{134}Cs does not currently occur in the natural environment. The half-life of this isotope is 2.1 years. As part of the proficiency testing, 9 laboratories submitted 12 measurement results ^{134}Cs : 5 performed using the HPGe detector and 7 measurements using the NaI(Tl) detector. Two laboratories simultaneously sent the results of measurements from two detectors. The results obtained for ^{134}Cs (Table 2, column W_L) using the germanium HPGe detector ranged from 110.24 to 114.70 Bq·kg⁻¹ and were close to the reference value of 112.20 Bq·kg⁻¹. They were characterized by small scatter (mean: ≈113.0, standard deviation (SD): ≈1.65, repeatability (CV): ≈1.46 %). The results for ^{134}Cs using the NaI(Tl) scintillation detector were characterized by a larger scatter (mean: ≈112.62, standard deviation (SD): ≈7.08, repeatability (CV): ≈6.28 %) and ranged from 103.10 to 125.80 Bq·kg⁻¹. In the next step, the trueness parameters were calculated: A_1 – taking into account the laboratory activity concentration result and the reference value activity concentration, and parameter A_2 – taking into account the laboratory uncertainty and the reference value uncertainty. In the case of A_1 they ranged from 0.50 to 13.60, while in the case of A_2 they ranged from 6.98 to 50.70. In each case, the condition $A_1 \leq A_2$ was met (Table 2, column

Table 1
Detailed summary of results for ^{137}Cs .

L	W_L	N_L	W_R	N	OW	A_1	A_2	P _w	PR	LAP	PR _w	OK
A HPGe	65,05	2,93	65,00	4,50	0,08	0,05	7,91	A	4,71	20	A	A
A NaI(Tl)	61,38	3,24	65,00	5,28	-5,57	3,62	8,68	A	5,46	20	A	A
B NaI(Tl)	63,10	2,70	65,00	4,27	-2,92	1,90	7,33	A	4,49	20	A	A
C NaI(Tl)	60,50	3,05	65,00	5,04	-6,92	4,50	8,20	A	5,23	20	A	A
D HPGe	65,50	2,95	65,00	4,50	0,77	0,50	7,96	A	4,71	20	A	A
D NaI(Tl)	59,50	2,75	65,00	4,62	-8,46	5,50	7,47	A	4,82	20	A	A
E HPGe	65,78	1,32	65,00	2,00	1,20	0,78	4,11	A	2,43	20	A	A
F HPGe	65,20	1,85	65,00	2,84	0,31	0,20	5,31	A	3,16	20	A	A
G NaI(Tl)	61,30	1,95	65,00	3,18	-5,69	3,70	5,54	A	3,47	20	A	A
H NaI(Tl)	64,15	2,73	65,00	4,26	-1,31	0,85	7,42	A	4,48	20	A	A
I HPGe	65,67	1,15	65,00	1,74	1,03	0,67	3,76	A	2,23	20	A	A
I NaI(Tl)	64,52	2,26	65,00	3,50	-0,74	0,48	6,28	A	3,77	20	A	A

Laboratory names are coded (A-I). Individual columns: L – lab code; W_L – the value of radioactive concentration obtained by the laboratory (Bq/kg); N_L – uncertainty reported by the laboratory (Bq/kg); W_R – reference value of radioactive concentration (Bq/kg); N – uncertainty (%); OW – relative laboratory load; A_1 , A_2 – trueness indicators; P_w – correctness result; PR – precision (%); PR_w – precision score; OK – final assessment result; results: A – Acceptable, W – Warning, N – Not Acceptable. The ^{137}Cs results reported by the laboratories were within the reference value±uncertainty range for this radioisotope.

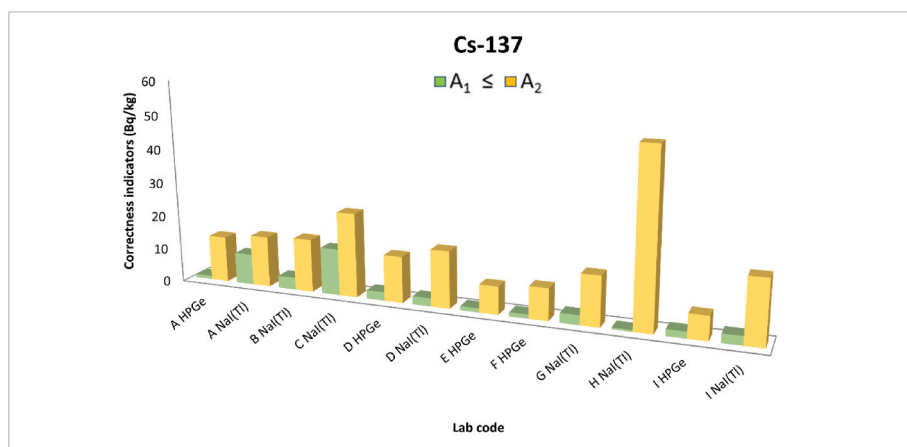


Fig. 3. Trueness indices A₁ and A₂ for ¹³⁷Cs.

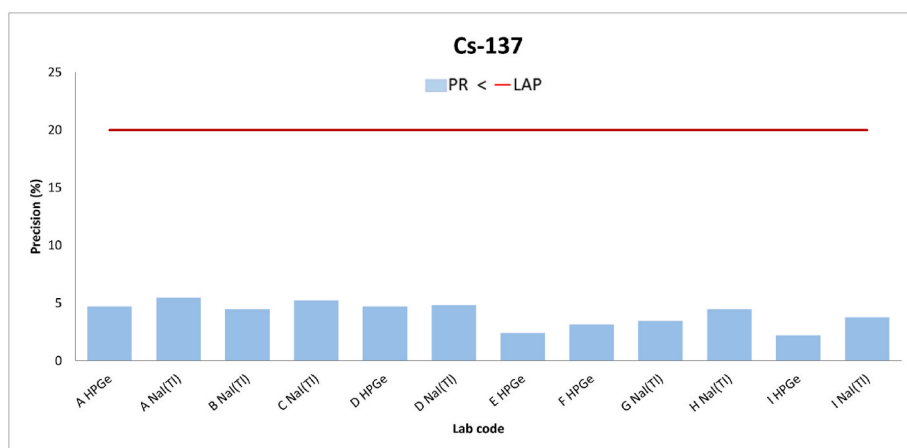


Fig. 4. Precision parameters for ¹³⁷Cs.

Table 2
Detailed summary of results for ¹³⁴Cs.

L	W _L	N _L	W _R	N [%]	OW [%]	A ₁	A ₂	P _w	PR [%]	LAP[%]	PR _w	OK
A-HPGe	113,21	5,05	112,20	4,46	0,90	1,01	13,52	A	4,63	20	A	A
A-NaI(Tl)	103,10	5,63	112,20	5,46	-8,11	9,10	14,96	A	5,60	20	A	A
B-NaI(Tl)	108,60	5,88	112,20	5,41	-3,21	3,60	15,59	A	5,56	20	A	A
C-NaI(Tl)	125,80	9,45	112,20	7,51	12,12	13,60	24,65	A	7,61	20	A	A
D-HPGe	114,70	5,05	112,20	4,40	2,23	2,50	13,52	A	4,58	20	A	A
D-NaI(Tl)	114,60	6,30	112,20	5,50	2,14	2,40	16,65	A	5,64	20	A	A
E-HPGe	113,41	2,84	112,20	2,50	1,08	1,21	8,16	A	2,79	20	A	A
F-HPGe	113,40	3,35	112,20	2,95	1,07	1,20	9,37	A	3,21	20	A	A
G-NaI(Tl)	115,00	5,45	112,20	4,74	2,50	2,80	14,52	A	4,90	20	A	A
H-NaI(Tl)	111,70	19,60	112,20	17,55	-0,45	0,50	50,70	A	17,59	20	A	A
I-HPGe	110,24	2,32	112,20	2,10	-1,75	1,96	6,98	A	2,44	20	A	A
I-NaI(Tl)	109,54	7,14	112,20	6,52	-2,37	2,66	18,77	A	6,64	20	A	A

Laboratory names are coded (A-I). Individual columns: L – lab code; W_L – the value of radioactive concentration obtained by the laboratory (Bq/kg); N_L – uncertainty reported by the laboratory (Bq/kg); W_R – reference value of radioactive concentration (Bq/kg); N – uncertainty (%); OW – relative laboratory load; A₁, A₂ – trueness indicators; P_w – correctness result; PR – precision (%); PR_w – precision score; OK – final assessment result; results: A – Acceptable, W – Warning, N – Not Acceptable. The ¹³⁴Cs results reported by the laboratories were within the reference value±uncertainty range for this radioisotope.

P_w). In the next step, the precision parameter was calculated, which depends directly on the measurement uncertainty. The precision parameters were in the range of 2.44 – 17.59 and in no case did they exceed the limit of permissible precision (LAP), the value of which was assumed to be 20% (Table 2, column PR_w). Both evaluation criteria (trueness and precision) were taken into account in the final assessment, and the status of “Acceptable”, “Warning” or “Not Acceptable” was adjusted accordingly. All laboratories achieved “Acceptable”

performance on both criteria, achieving “Acceptable” results on the PT proficiency testing (Table 2, column OK). Detailed values are presented in Table 2.

Fig. 5 graphically presents the trueness indices A₁ and A₂ for the ¹³⁴Cs radioisotope. The proficiency test participants received an “Acceptable” status because the condition A₁ ≤ A₂ was met.

Fig. 6 graphically presents the precision parameters for the ¹³⁴Cs radioisotope. Proficiency test participants were given an “Acceptable”

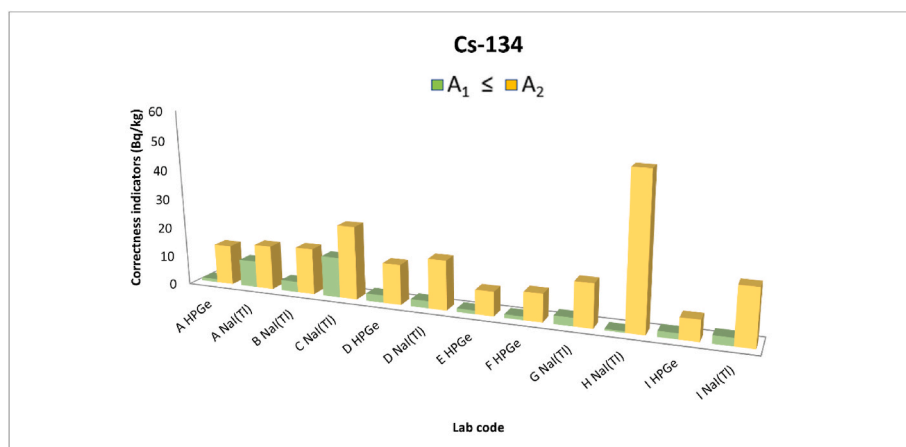


Fig. 5. Trueness indices A₁ and A₂ for ¹³⁴Cs.

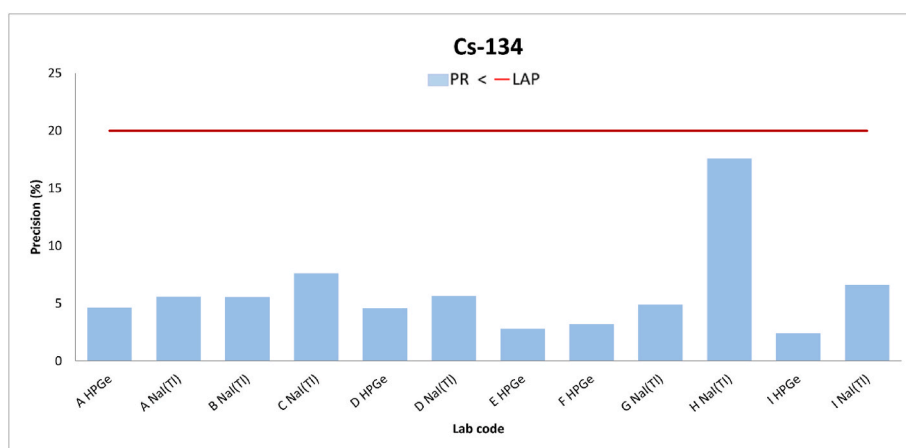


Fig. 6. Precision parameters for ¹³⁴Cs.

status because the PR < LAP condition was met. A LAP score of 20% was assumed for the competency test.

3.3. Discussion

International proficiency testing helps confirm the competence of reference laboratories. The International Atomic Energy Agency (IAEA) coordinates the work of the global network of Analytical Laboratories for the Measurement of Environmental Radioactivity (ALMERA). Shakhshiro et al. (2008) describes the organization of proficiency tests for radionuclide determination (⁵⁴Mn, ⁶⁰Co, ⁶⁵Zn, ¹⁰⁹Cd, ¹³⁴Cs, ¹³⁷Cs, ²⁴¹Am and ²¹⁰Pb) organised in 2006 for ALMERA members in three environmental matrices: water, grass and soil. The evaluation criteria, which were applied to over six hundred results from 38 laboratories in 29 countries, were based on acceptance for trueness and precision, and an appropriately adjusted status: “Acceptable”, “Warning” or “Not Acceptable” (Brookes et al., 1979). The majority of PT participants (78%) correctly assessed reliability and precision. The results are presented in the report (IAEA, 2007).

Regular participation in PT is a requirement for testing laboratories operating in accordance with ISO/IEC 17025, 2018. Obvious that comparisons should also be organised at the national level, for official laboratories, which is confirmed by the organisation of proficiency testing for the determination of caesium radioisotopes (¹³⁴Cs and ¹³⁷Cs) in soil for official laboratories in Poland described in this paper. This approach was also presented by Pantelić et al. (2010) when describing the organisation of proficiency testing in radiometric laboratories in

Serbia. The authors presented an assessment of the analytical performance of radionuclides determination (²⁴¹Am, ¹⁰⁹Cd, ⁵⁷Co, ⁶⁰Co, ¹³⁹Ce, ¹¹³Sn, ¹³⁷Cs and ⁸⁸Y) in water samples. The gamma spectrometry method was used. The proficiency test results were assessed against acceptance criteria for veracity and precision, and then given an “Acceptable” or “Not Acceptable” status depending on whether the criteria were met. (Shakhshiro et al., 2006). The majority (64.7%) of all reported results met the proficiency testing criteria, while 26.5% of results did not meet the established acceptance criteria (Pantelić et al., 2010).

In another paper, Lee et al. (2026) describe the organisation of proficiency testing for the determination of caesium radioisotopes (¹³⁴Cs and ¹³⁷Cs) in seawater. The research program was intended for 6 national laboratories in Korea. The studies were performed using gamma-ray spectrometry with a high-purity germanium (HPGe) detector. In this study, the analytical performance of participating laboratories was assessed using z'-scores. Participating laboratories were assessed according to the following criteria: z' ≤ 2 acceptable performance, 2 < z' < 3 warning signal, z' ≥ 3 unacceptable performance (ISO/IEC 13528, 2015). All laboratories participating in these PT studies achieved results within acceptable z'-score ranges.

In summary, participating in proficiency testing offers numerous benefits to laboratories. A significant advantage is that the resulting assessment is external, completely independent, and objective. First, it allows the confirm of whether the method used produces reliable results, verifies the competence of analysts, and verifies the correct operation of the equipment. Proficiency testing provides an answer to the question of

whether the method used is suitable for the intended use. Secondly, a positive proficiency test result confirms that the validation was performed correctly and allows verification of the uncertainty budget.

4. Conclusions

The collected test results were analyzed in accordance with commonly used international standards and methods. All nine laboratories achieved acceptable results in the proficiency testing. The overall assessment showed that 100% of the reported results met the adopted PT criteria.

These results confirm that the laboratories participating in the radioactive contamination monitoring network operate reliably and possess the appropriate competences.

Soil plays a significant role in the circulation of radionuclides in the food chain, making its analysis crucial, especially in the context of potential emergency situations. In such cases, the laboratories are prepared to test not only food but also environmental components.

Regular participation in proficiency testing remains crucial to maintaining a high level of competence in the laboratories and confirms the quality and reliability of the results obtained.

CRedit authorship contribution statement

Magdalena Gembal: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Paweł Czernski:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Małgorzata Warenik-Bany:** Writing – review & editing. **Piotr Jedziniak:** Supervision.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Magdalena Gembal reports was provided by National Veterinary Research Institute. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

References

- Brookes, C.J., Betteley, I.G., Loxston, S.M., 1979. *Fundamentals of Mathematics and Statistics*. Wiley, UK.
- Czernski, P., Gembal, M., Warenik-Bany, M., 2024. Caesium-137 in the muscles of game animals in 2015-2022 – levels and time trend. *J. Vet. Res.* 68, 263–270. <https://doi.org/10.2478/jvetres-2024-0026>.
- Gembal, M., Czernski, P., 2024. Polish State Veterinary Inspectorate Report 2024. National Veterinary Institute - National Research Institute, Department of Radiobiology, Pulawy.
- Gembal, M., Czernski, P., Milczarczyk, E., Warenik-Bany, M., 2023. Levels of caesium-137 in food of animal origin in Poland. *J. Vet. Res.* 67, 407–414. <https://doi.org/10.2478/jvetres-2023-0044>.
- Guillitte, O., Fraiture, A., Lambinon, J., 1991. Transfer of radionuclides in natural and semi-natural environments. *J. Appl. Sci.* 468–476.
- Hillel, D., 2008. *Soil in the environment. Soil Chemical Attributes and Processes*. Academic Press, Cambridge, MA, USA. <https://doi.org/10.1016/C2009-0-00041-5>.
- IAEA, 2007. Report on the IAEA–CU–2006–04 ALMERA Proficiency Test on the Determination of gamma-emitting Radionuclides. International Atomic Energy Agency. IAEA/AL/171.
- IAEA, 2025. INTERNATIONAL ATOMIC ENERGY AGENCY, Certified Reference Material Certificate IAEA-478. IAEA, Vienna (Certificate IAEA-478_Rev.01/2025-02-27).
- ISO/IEC 17043, 2023. Conformity Assessment - General Requirements for Proficiency Testing.
- ISO/IEC 13528, 2015. *Statistical Methods for Use in Proficiency Testing by Interlaboratory Comparison*.
- ISO/IEC 17025, 2018. *Testing and Calibration Laboratories*. Geneva. Switzerland.
- IUPAC, 1991. Technical report „the international harmonized protocol for the proficiency testing of analytical chemistry laboratories. *Pure Appl. Chem.* 65 (9), 2123–2144.
- Koniczka, P., Namieśnik, J., 2007. Evaluation and Quality Control of Analytical Measurement Results – in Polish (Ocena i Kontrola Jakości Wyników Pomiarów Analitycznych). Wydawnictwo Naukowo-Techniczne, Warszawa.
- Kyung-Ho, P., Tae-Woo, K., Won-Jik, K., Jae Woo, P., 2013. ¹³⁴Cs and ¹³⁷Cs radioactivity in soil and moss samples of Jeju Island after Fukushima nuclear reactor accident. *Appl. Radiat. Isot.* 81, 379–382. <https://doi.org/10.1016/j.apradiso.2013.03.066>.
- Lee, M., Lee, S.-H., Heo, Y.J., Ryoo, J., Yoonhee, J., 2026. Proficiency test for gamma-emitting radionuclides in seawater: a case study from South Korea. *Appl. Radiat. Isot.* 227, 112277. <https://doi.org/10.1016/j.apradiso.2025.112277>.
- Official Journal of Laws, 2017. Item 1246: Regulation of the Minister of Agriculture and Rural Development of 26 June 2017 on the Monitoring of Prohibited Substances, Chemical and Biological Residues, Medicinal Products and Radioactive Contamination (Rozporządzenie Ministra Rolnictwa i Rozwoju Wsi Z Dnia 26 Czerwca 2017 R. W Sprawie Monitorowania Substancji Niedozwolonych, Pozostałości Chemicznych, Biologicznych, Produktów Leczniczych i Skażeń Promieniotwórczych. *Dz. U.* 2017 Poz. 1246).
- Pantelić, G., Vuletić, V., Mitrović, R., 2010. Proficiency test of gamma spectrometry laboratories in Serbia. *Appl. Radiat. Isot.* 68 (Issues 7–8), 1270–1272. <https://doi.org/10.1016/j.apradiso.2009.11.011>.
- Pommé, S., 2022. Radionuclide metrology – confidence in radioactivity measurements. JRC technical report, EUR 31134 EN, European Commission, Geel., 2022. <https://doi.org/10.2760/666973>. ISBN 978-92-76-54093-9. <http://doi.org/10.2760/666973>.
- Shakhashiro, A., Fajgelj, A., Sansone, U., 2006. Comparison of different approaches to evaluate proficiency test data. In: *Combining and Reporting Analytical Results*. RSC Publishing, Cambridge, pp. 220–228.
- Shakhashiro, A., Trinkl, A., Sansone, U., 2008. The IAEA's 'ALMERA Network' proficiency test on the determination of gamma-emitting radionuclides: a test of results comparability. *Appl. Radiat. Isot.* 66, 1722–1725. <https://doi.org/10.1016/j.apradiso.2007.10.021>.
- Skwarzec, B., 2021. *Radiochemia Środowiskowa (Radiochemistry of the environment – in Polish)*. Wydawnictwo Uniwersytetu Gdańskiego, Gdańsk.