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# Scientific basis and practical application of formalization by making decisions taking into account the uncertainty of the results of gas analyzers in the process of comparison

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**Abstract.** In the work done, the current state of comparison of gas analyzers was studied, and the issue of formalizing the results by making decisions based on the international recommendations of ILAC-G8:09/2019 was studied. The problems arising in the processing of the results of the comparison of gas analyzers are studied, and recommendations are given to consider the risks affecting them. Differences, shortcomings, and advances between benchmarking and calibration are discussed. No need for repeated comparison of calibrated dies, recognition of calibration result during comparison was studied. The difference between measurement uncertainty and error was studied. Making decisions on the basis of international recommendations ILAC-G8:09/2019 in the application of measurement results in the process of comparison of measurement uncertainty. Recommendations are made for establishing a line of defense in decision-making. At the National Institute of Metrology of Uzbekistan, the experimental results were processed and decisions were made based on the international recommendations of ILAC-G8:09/2019. The importance of selection of calibration points in comparison was studied and recommendations were made.

## 1 Introduction

The invention relates to instrumentation. In the process of comparison of gas analyzers, the formalization of the results is considered an important factor, because the result obtained from the processing of the comparison results is guaranteed by the state and the metrological service body to maintain the reliability of the measuring instruments for a certain period of time, and the metrological characteristics confirmed in the production. We know that currently, in the processing of comparison results, the concept of error is promoted in the countries of the Commonwealth of Independent States, according to which the permissible absolute error and relative errors of the measuring instrument are calculated, and these indicators are adjusted to the accuracy indicators specified by the manufacturer, and

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comparison certificates are issued. Basic absolute error value when processing comparison results according to GOST 8.618 [1-5]

$$\Delta_i = C_i - C_i^P, \tag{1}$$

where Si is the measured value of the pre-explosion concentration of the analyzed component when using the i-th gas mixture (converted to the indicator of the display of the measuring instrument or from the value of the output signal), the lower concentration limit of % flame spread; SiP is the real or calculated value of the pre-explosion concentration of the determined component of the i-th gas mixture, the lower concentration limit of % flame spread.

The value of the basic relative error of the measuring instrument di % is calculated according to the following formula: [2-4]

$$\delta_i = \frac{(C_i - C_i^P)}{(C_i^P)} \cdot 100 \tag{2}$$

For each ΔT °C due to the change in ambient temperature under operating conditions, the absolute additional error of the measuring device ΔSt, the value of the lower concentration limit of the spread is calculated according to the following formula [7-8]

$$\Delta C_t = \frac{(C_t - C_{t_0})}{t - t_0} \cdot \Delta T, \tag{3}$$

where St is the value of the lower concentration limit of the pre-explosion concentration O'V, % distribution of the analyte component measured at the temperature value corresponding to the upper (lower) value of the operating conditions; Ct0 is the measured value of the pre-explosion concentration of the component determined at a certain temperature, the lower concentration limit of % diffusion; ΔT is the range of environmental temperature changes, for which additional permissible error limits are determined due to the effect of temperature, °C; t is the value of the ambient temperature corresponding to the upper (lower) value of the working conditions of the measuring instrument, °C; t0 is the value of the ambient temperature at which the main error is detected (normal conditions), °C [9].

For each ΔT °C due to the change in ambient temperature under operating conditions, the value of the lower concentration limit of the relative additional error ΔSt, % of the distribution of the measuring device is calculated according to the following formula [10]

$$\delta C_t = \frac{(C_t - C_{t_0}) \cdot \Delta T}{C_t \cdot (t - t_0)} \cdot 100 \tag{4}$$

The results of determining the additional error of the measuring instrument are considered positive if the values of the additional error are determined during type approval tests and do not exceed the limits specified in the operating instructions of the measuring instrument for the relevant operating conditions [11-13].

If the results of the comparison are reproduced using formulas 1, 2, 3, and 4 given above, a number of shortcomings may arise in the process, these shortcomings include the randomness of the results obtained from the measurements, the possible gross errors, the distribution patterns of the results in the process of performing some measurements, the size we can see the metrological observability of the standard in the transfer of the size, the operator effect not being taken into account during the comparison process, and a number of similar effects. Through the processing system of such results, we can see that the compared measuring instruments maintain their metrological characteristics at the specified time, or the observation factor of the inconsistency of the results to the given error deviation is very low [14].

## 2 Methodology

Currently, according to clause 6.5 of the ISO/IEC 17025:2017 [7, 15,16] standard, metrological traceability of the results of measurements carried out in laboratories should be ensured. Accordingly, it is necessary to calibrate the measurements performed in laboratory conditions and to assess the uncertainty of the measurement results. We know that some types of measuring instruments, including gas analyzers, can be used simultaneously to obtain results in production processes and laboratory conditions. Of course, a question arises, if the measuring instrument is calibrated, it is necessary to compare it separately. In such cases, measuring instruments are carried out on the basis of the law of the country in which they are performed. For example, in the legislation of the Republic of Uzbekistan on metrology and by-laws, it is not stated that it is not necessary to compare calibrated measuring instruments, but according to Article 26 of the law on metrology, the results of the calibration of measuring instruments performed by the Accredited metrology service can be used for comparing measuring instruments. But there are no manuals on how to do this. In most countries of the Commonwealth of Independent States, this procedure is established by law with the recognition of results. but according to Article 26 of the Metrology Law, it is established that the results of the calibration of measuring instruments performed by the Accredited Metrology Service can be used in the comparison of measuring instruments. But there are no manuals on how to do this. In most countries of the Commonwealth of Independent States, this procedure is established by law with the recognition of results. but according to Article 26 of the [5] Metrology Law, it is established that the results of the calibration of measuring instruments performed by the Accredited Metrology Service can be used in the comparison of measuring instruments. But there are no manuals on how to do this. In most countries of the Commonwealth of Independent States, this procedure is established by law with the recognition of results.

If the types of activities of the metrology services of European countries and their existing methodologies are followed, the performance of any measurements and the confirmation of the metrological characteristics of the measurements are performed through calibration. And through the results of calibration, we can see that the comparison and type approval of the measuring instrument is carried out. In the process of comparison and type approval, the concept of error is determined by the manufacturer only by the maximum deviation limits of the error that can occur in the measurements of the measuring instrument, which can be absolute or relative errors. We know that the processing of calibration results is done through the concept of uncertainty. The reason for applying the concept of uncertainty in the calibration process, when processing the results of measurements, all factors affecting the reliability of the results are taken into account. These parameters include the accuracy of calibration tools, the competence of calibration specialists, the static and dynamic nature of the structures, the degrees of accuracy, etc.

In today's modern and developing measurement system, a new concept of decision-making is emerging. When making decisions, assessment of the reliability of measurement results and verification of compliance with established norms and requirements is carried out with due regard for international recommendations.

ILAC-G8:09/2019 [1, 17] i s a guideline developed by the international organization ILAC on decision-making in conformity assessment. This document is widely used by international accreditation organizations and conformity assessment bodies. In this document, the general points of view of making decisions and confirming compliance with the results of experimental measurements of experts and laboratory staff are presented. It is necessary for employees to take into account the risks associated with static data when making decisions in research conducted in laboratories. If the legislation does not provide specific instructions for making decisions, then laboratories should work based on these rules.

In fact, what it is needed for - comparison or calibration laboratories are used to evaluate the risks that may occur in confirming the results obtained in accordance with a certain regulatory document, to reduce errors. As an example, when the maximum permissible error limit of the measuring instrument is set at 3%, if the main relative error is processed to 2.9% using the concept of error in the process of comparison, the comparing employee is obliged to formalize this result as being in accordance with the normative document. Then the deviations in formalizing the measurement results, the risks of the influence of the errors of the tools used in the comparison on the measurement results are not taken into account. Decision-making rules serve to reduce these risks.

Moving on to the practical part of decision-making, the ILAC-G8:09/2019 guideline recommendation recommends establishing a buffer (w) before the requirements, taking into account the risks that may affect the results of the laboratory measurements, this buffer serves to avoid some of the risks listed above.

The protection line is the distance between the maximum or minimum value of the hazard-free area that can affect the measurements and the required indicator, it is determined by the value calculated on the basis of the formula 5 and is placed in the range of the measurement results

$$w=|TL-AL| \quad (5)$$

where TL is the maximum or minimum value of the hazard-free area; AL is the required pointer value

These values are represented in a graph in order to make the results understandable in Figure 1. Here we can see that among the specified requirements, Xl is listed together with the expected uncertainty of the measurement results.

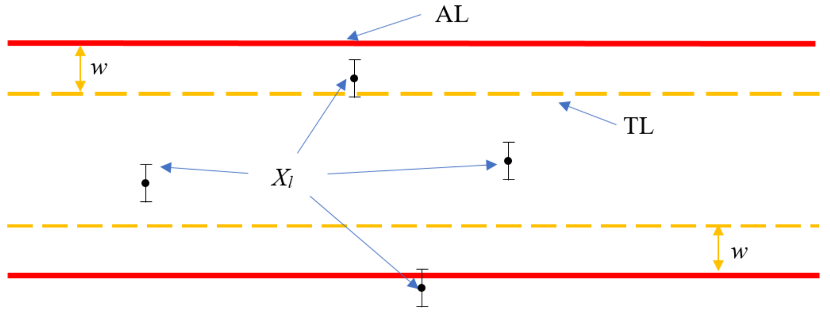


**Fig. 1.** Application of decision-making in assessing the accuracy of the results of measurements.

Now let's look at the descriptions of the result that fell in these areas (Figure 2). Accordingly, it is recommended to make decisions about measurement results in 4 ways, these are [3, 18] :

- if the measurement results are below the protection line and the required accuracy, the results of the measurements are considered acceptable;
- if the measurement results are between the protection line and the required accuracy, the measurement result is considered to be conditionally compliant;
- if the measurement results are higher than the required accuracy, but between the protection line and the required accuracy, taking into account its uncertainties, the measurement result is considered conditionally inconsistent;
- if the measurement results are above the protection line and the required accuracy, it is decided that the measurement result is inconsistent.

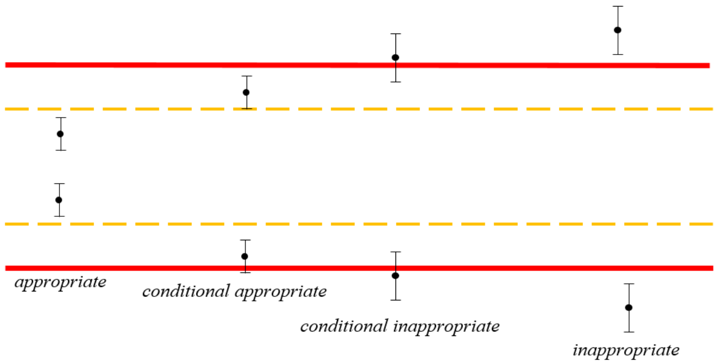


**Fig. 2.** Conditions for making decisions when evaluating the results of measurements.

The reasons for conditionally compliant or conditionally non-compliant results are the risks affecting the results of the measurements listed above. In case of conditional decisions, it is recommended to carry out the measurements again, if these results are repeated more than 3 times in conditional conditions, it is necessary to carry out measurements from another laboratory or to set the protective lines for carrying out measurements. [8-12]

There are a number of ways to establish a line of defense for decision-making based on international recommendation ILAC-G8:09/2019, which are listed in Table 1 [1, 19].

**Table 1.** Methods of conformity decision rule.

| Decision making rules | Defense line | Defined risk |
|---|---|---|
| 6 sigma | 3U | The chance of false positives is less than 1 ppm |
| 3 sigma | 1.5U | The probability of false acceptance is less than 0.16 % |
| ILAC-G8:09 | 1 U | The probability of false positives is less than 2.5% |
| ISO 14253-1:2017 | 0.83 U | The chance of getting it wrong is less than 5% |
| Normal intake | 0 | The probability of getting it wrong is less than 50% |
| Unimportant | - IS | The probability of false rejection is less than 2.5% |
| Customer proposal | | The customer can determine the amount of protection line himself |

## 3 Realization of the concept

In comparison and calibration laboratories, it is recommended to use a quantity at risk less than 5% of the cases, with a false rejection probability of less than 2.5%. Based on these, we can make the following decision-making graph (Figure 3) for comparison and calibration laboratories [4].

So, we can conclude from this graph that if the measurement result is between the lower protection line and 0, the measuring tool is in compliance with the requirement, and if the measurement result is between the required accuracy limit (the upper limit of the error of the measuring tool) and the lower protection line, the measuring tool is conditionally in compliance with the requirement, the measurement result is high protection.

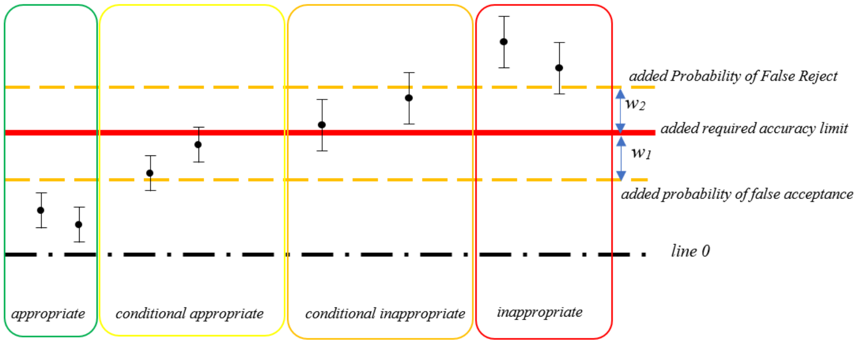


**Fig. 3.** The following decision graph for reference and calibration laboratories where: w1=0.85U or less; w2=U.

If it is between the line and the required accuracy limit, the measuring tool is conditionally non-compliant, and if the measurement result is above the upper protection line, it is the basis for deciding that this measuring tool is non-compliant [2].

**Table 2.** Calibration results of gas analyzer Autotest 02.02 against carbon monoxide (CO) gas.

| No | calibration component (standard sample) concentration %, (SO) | Gas analyzer values being calibrated, Xli | removal | Expanded Uncertainty |
|---|---|---|---|---|
| 1 | 1.27 | 1.28 | 0.005 | 0.116 |
| 2 | | 1.27 | | |
| 1 | 2.47 | 2.56 | 0.107 | 0.119 |
| 2 | | 2.59 | | |
| 1 | 4.28 | 4.34 | 0.050 | 0.117 |
| 2 | | 4.32 | | |

We consider the use of calibration results in the formalization of comparison by decision-making with experimental examples. As an example, if we consider the comparison of the Gas analyzer Avtotest 02.02 calibrated at the National Metrology Institute of Uzbekistan through the calibration results presented in Table 2.

From these results, it can be seen that this gas analyzer was calibrated at 3 points of the measurement range of carbon dioxide, and at these points, the concentration of the component (standard sample) transferred to the gas analyzer, the indicator value of the gas analyzer being calibrated, the deviation from the truth of the measurement results, and the extended uncertainty are presented.

First of all, we are required to determine the required accuracy limit (the maximum error limit of the measuring instrument) of the tested gas analyzer Autotest 02.02, this value is A=3% for the gas analyzer Autotest 02.02 carbon oxide.

If we analyze the results at 3 points from the results presented in table 2: $X_1=0.005\pm0.116$; $X_2=0.107\pm0.119$; $X_3=0.05\pm0.117$. Here, X is the combined expression of the deviation and uncertainty of the results.

As a next step, we determine the amount of protection lines ($w_1$, $w_2$), we get U, the largest uncertainty in determining the protection line in such multi-result measurements. $U_{max}=0.119\%$

W1=0.83U=0.099 %
W2=U=0.119 %
Based on the above results, we make a graph of decision-making, Figure 4.

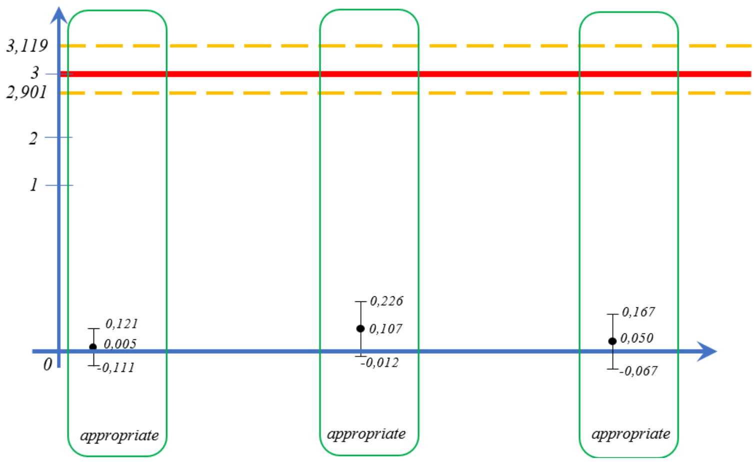


**Fig. 4.** Autotest 02.02 gas analyzer calibration results graph in decision-making.

From the image presented in Figure 4, we can see that the gas analyzer was found to be compliant at 3 calibration points. Based on the calibration results of this gas analyzer, we can issue a performance certificate.

It is important to remember that the available calibration points cover the full range of the measuring instrument when making comparisons through calibration results. Analyzing most of the comparison methods, we can see that the calibration results along the measurement range should not be less than 3 points, these points should be spread over the measurement range: the first point should be 0-30%, the second point should be 30-70%, the third point should be 70-100% must.

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