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**METROLOGY  
AND METROLOGY  
ASSURANCE 2024**

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September 7-11, 2024, Sozopol, Bulgaria

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# **PLENARY SESSION**

# Challenges to the Bulgarian Institute of Metrology (BIM) in ensuring traceability and implementing control of measuring instruments for alternative fuels

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**Abstract**— *With the growing demand for vehicles using alternative fuels, there needs to be a simple and accurate method to ensure metrological traceability and control of their charging systems. This paper aims to review the current situation in terms of the legislation, standards, available technical equipment in relation to alternative fuel cars, as well as challenges to the metrological community in Bulgaria to ensure metrological traceability and control of alternative fuel charging stations, in particular - for electrical energy and hydrogen.*

**Keywords**— *BIM, traceability, metrological control, EVSE, HCS, International and European policy on charging systems, alternative fuels*

## I. INTRODUCTION

In 2011 the European Commission adopted the 2050 Transport Strategy, aiming to reduce EU transport's dependence on oil. The strategy establishes 40 transport initiatives to increase mobility and remove significant barriers in key areas. It identifies battery and fuel cell electric vehicles as a solution for reducing air emissions and is considered essential technologies for the 60% cut in transport emissions by 2050, as measured against the 1990 levels.

In September 2015, at the United Nations' General Assembly, countries around the world signed up to the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals. Goal 7 "Affordable and clean energy" aims to ensure access to affordable, reliable, sustainable and modern energy for all.

The European Union is firmly committed to meeting the goals of the United Nations 2030 Agenda for Sustainable Development. In April 2021, the European Parliament and the member states took a further step with the agreement to increase efforts, with the objective of reducing 55% in 2030. Europe aims to be climate neutral in 2050.

Regarding Goal 7, one of the measures of the Union is the Regulation (EU) 2023/1804 on the deployment of alternative fuels infrastructure adopted by the European Parliament and the Council in September 2023.

The regulation entered into force on 13.04.2024 and according to its provisions:

- from 2025 onwards, fast recharging stations of at least 150 kW for cars and vans need to be installed every 60

km along the EU's main transport corridors, the so-called 'trans-European transport (TEN-T) network'

- recharging stations for heavy-duty vehicles with a minimum output of 350kW need to be deployed every 60 km along the TEN-T core network, and every 100 km on the larger TEN-T comprehensive network from 2025 onwards, with complete network coverage by 2030
- hydrogen refueling stations serving both cars and lorries must be deployed from 2030 onwards in all urban nodes and every 200 km along the TEN-T core network
- maritime ports welcoming a minimum number of large passenger vessels, or container vessels, must provide shore-side electricity for such vessels by 2030
- airports must provide electricity to stationary aircraft at all gates by 2025, and at all remote stands by 2030
- users of electric or hydrogen-fueled vehicles must be able to pay easily at recharging or refueling points with payment cards or contactless devices and without a need for a subscription and in full price transparency
- operators of recharging or refueling points must provide consumers full information through electronic means on the availability, waiting time or price at different stations.

In fulfillment of these goals, in recent years, the production and use of cars using alternative fuels - electric cars, hybrid cars, hydrogen electric cars, etc. - has increased worldwide.

Thus, the metrological community is faced with the task of ensuring the traceability of the measuring systems for alternative fuels, as well as the application of an appropriate form of metrological control in the purchase and sale of energy at charging stations.

## II. CHALLENGES IN ENSURING METROLOGICAL TRACEABILITY AND CONTROL OF ELECTRIC AND HYBRID VEHICLE CHARGING STATIONS

The mass entering of electric mobility requires an adequate infrastructure of charging stations for both urban and interurban mobility, the latter being more complex due to the limited autonomy of electric vehicles (the maximum energy stored in the batteries) and the time required for a full charge.

The correct measurement of energy transfer between the charging station and the electric vehicle requires legal metrological control (in order to ensure on the one hand - the trust and protection of consumers, and on the other - the credibility of the transactions carried out. This energy transfer is similar to electricity meters in that they measure the energy consumed, but there are several different aspects:

- energy is supplied and measured for different users (except in the case of home chargers) and appears more like a direct sale,
- charging stations can be powered with direct current and with different charging powers,
- charging stations are outdoors,
- the load is usually of unity power factor,
- the measuring instrument can be integrated into the station, etc.

In terms of public supply, they are more similar to gas stations. However, the charging stations are configured in such a way that there are different payment methods, in addition to the so-called ad hoc price, which is established when there is no prior contract. In addition, the design trend is that there is no user information screen and that the registration of the transaction is done by telematic means.

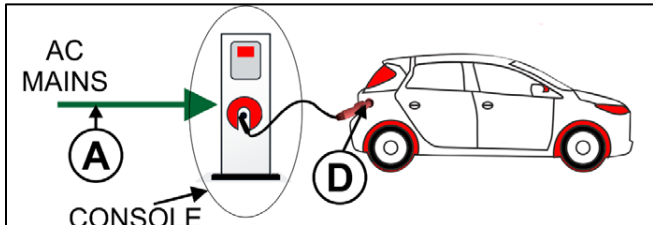


Fig. 1 – Unitary EVSE [1]

- A AC mains supply to the EVSE
- D Effective metering point is point of connection to the vehicle

This is a new metrological task that has been solved for the last 10<sup>th</sup> years and more:

*A. At international level:*

In order this task to be solved at international level the International Organization for Legal Metrology (OIML) has issued a guide (OIML G 22 Electric Vehicle Supply Equipment (EVSE) - Metrological and technical requirements; - Metrological controls and performance tests, Edition 2022 (E)). It is expected this guide to become a fine-tuned, more elaborate OIML Recommendation after the OIML Project Group finishes its work on it.

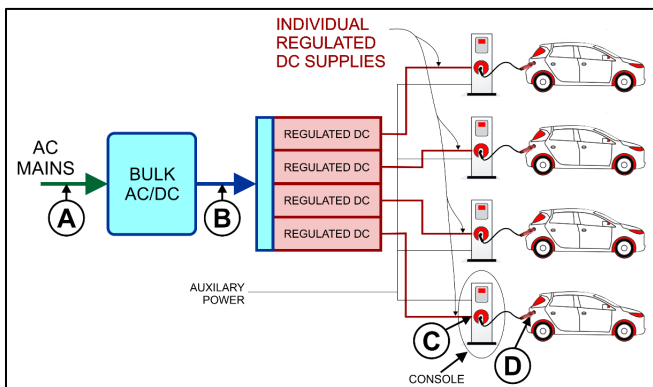


Fig. 2 – Complex DC EVSE [1]

- A AC mains supply to the EVSE
- B DC mains supply feed (generally at a fixed voltage, may be unregulated)
- C Regulated DC feed to a specific charging port
- D Effective metering point is point of connection to the vehicle

*B. At European level:*

At the moment, the European Commission is considering a project for a targeted amendment of Directive 2014/32/EU of the European Parliament and of the Council of 26 February 2014 on the harmonization of the legislation of the Member States on the making available on the market of measuring devices, in which project they will be laid down harmonized requirements for charging stations for electric vehicles and other vehicles running on alternative fuels.

*C. Some developed technical solutions for control of EVSE:*

- The USA:



Figure 3 - TESCO's Electric Vehicle Service Equipment (EVSE) Test System T4350.

TESCO's EVSE Test System tests the accuracy of energy delivery using a transactional mode compatible with Handbook 44 provisions. The T4350 can be used with either a Programmable Load Box, or the MitM Cable.

The T4350 supports:

- DC Fast Charge systems up to 350 A sustained at 1000 V DC.
- AC Level 1 and Level 2 systems up to 80 A maximum current
- The Programmable Load Box offers complete freedom and test automation.
- Any J1772 compatible EV can also be used as the test load by using an optional cable.

The Proximity and Pilot Control signal exchanges are fully verified for compliance with protocol requirements. All information for sites, equipment, test procedures and test results are stored in an internal database.

- GERMANY:



Figure 4 - Mobile measuring laboratory in the trunk

Whether for vehicle interoperability measurements in the field or compliance testing in the laboratory, the EVCA Multi Mobile gives an access to all charging standards for AC, DC-CCS Type 1 + 2, CHAdeMO and DC China (GB/T) in a portable rack that is ready for immediate use anywhere. Without mechanical mounting you activate the desired charging standard with the help of intuitive sliding flaps and can thus directly check the communication and the charging process for conformity to standards automatically and measure all details. Even complete test libraries for norm conformity tests can be conducted. The results are stored on a connected PC, where they can be analysed and evaluated live in real time, or afterwards using the user-friendly visualization.

### III. CHALLENGES IN ENSURING METROLOGICAL TRACEABILITY AND CONTROL OF HYDROGEN VEHICLE CHARGING STATIONS

Hydrogen is a clean alternative to petrochemicals that produces only water when used to power fuel cell electric vehicles (FCEV). Hydrogen refueling stations play a pivotal role in advancing hydrogen fuel cell vehicles. Ensuring the accuracy and reliability of these stations is crucial for their safe and efficient operation. Erroneous hydrogen measurement could lead to vehicle overcharging, inducing adverse conditions within hydrogen storage tanks and potential accidents.

The refueling station system boundary starts at the hydrogen supply source and ends with the inlet to the vehicle tank. The hydrogen can be supplied to a refueling station in either gaseous or liquid form. The components which are part of the refueling station vary and are dictated by the physical form of the hydrogen supplied (i.e. gaseous or liquid) and the working pressure of the vehicle tank. Most vehicle manufacturers have agreed to adopt a 700 bar vehicle storage system. The primary goal of a refueling station is to refuel vehicles to a 100% state of charge throughout the station's daily operations.

Hydrogen requires a completely different set of measurements - it is an extremely light, low-density gas, sold by weight rather than volume. If a FCEV was filled at atmospheric pressure ( $\sim 1$  bar) with 1 kg of hydrogen – sufficient for a journey of approximately 100 km – the vehicle would require a fuel tank 11 m<sup>3</sup> in size. As on average a FCEV requires 5-6 kg for a full tank, the gases' volume requires compressing at high pressures prior to filling – 700 bar for cars and 350 bar for larger vehicles.

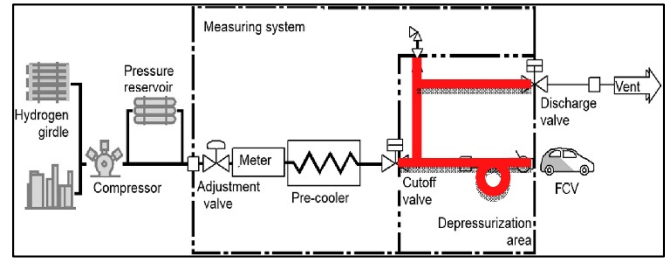


Figure 5 – Schematic depiction of HRS [2]

Whilst the solving of the metrological task for EVSE has made some progress internationally and regionally in ensuring that the amount of energy transferred is measured fairly and accurately, working on hydrogen vehicle refueling stations still faces some challenges. This metrological task has been solving in different developed countries for the last decade.

#### A. At international level:

To ensure the amount charged to FCEV drivers at hydrogen refuelling stations (HRS) is correct, OIML has published OIML-R139 which stipulates dispensers at HRS must be certified, delivering hydrogen with a maximum permissible measurement error of 2% or 4%, depending on the desired accuracy class.

#### B. At European level:

The European Union recognizes the importance of hydrogen technologies in achieving its environmental objectives, as highlighted in the European Green Deal and the Hydrogen Strategy for a Climate Neutral Europe. Hydrogen, with its multifunctionality as a feedstock, fuel, energy carrier, and storage medium, holds significant potential for reducing carbon emissions in challenging sectors.

Currently, the European Commission is considering a project for a targeted amendment of Directive 2014/32/EU of the European Parliament and of the Council of 26 February 2014 on the harmonization of the legislation of the Member States on the making available on the market of measuring devices, in which it is expected harmonized requirements to be laid down for hydrogen charging stations.

#### C. Some developed technical solutions for the control of hydrogen charging stations:

- The USA:



Figure 6: Side and Rear Views and the Display of the HyStEP Device

HyStEP [3] uses the test procedures set forth in CSA Hydrogen Gas Vehicles 4.3 to evaluate hydrogen refueling dispenser performance by connecting to dispensers installed in the field.

HyStEP collects a variety of communication and refueling data that, when analyzed by experts, is used to evaluate and validate numerous refueling parameters to determine conformance with SAE International J2601. CARB presents the test conditions, data, and observations to automakers so they can evaluate hydrogen refueling station performance

without having to perform the protocol tests with vehicles. HyStEP equipment is enclosed in a utility trailer platform and is towed by a vehicle operated by CARB engineers.

- SOUTH KOREA [4]:

The hybrid performance measurement system represents a groundbreaking apparatus that fuses mass and flow rate measurement techniques to offer accurate and reliable hydrogen fueling measurements. This system encompasses a Coriolis flowmeter for gauging mass flow rate and a load cell for measuring weight.

The hybrid performance measurement system is meticulously designed to minimize vibrations and external interference that might compromise measurement accuracy. The interaction between the Coriolis flowmeter and the load cell permits simultaneous and precise measurement of both mass flow rate and weight during hydrogen fueling operations.

The system encompasses a Coriolis flowmeter model HPC015 from Emerson, offering a maximum pressure of 96.3 MPa and a gas accuracy of 0.5%. The integrated scale is the PFK989-C300 model from Mettler Toledo, certified for explosion protection, with a maximum capacity of 300 kg and a readability of 0.5 g.

Furthermore, the system integrates various sensors, including pressure, temperature, and humidity sensors, to monitor environmental conditions during fueling. Real-time monitoring screens, present operators with critical information to ensure safe and efficient fueling operations. By amalgamating advanced measurement technologies and comprehensive monitoring capabilities, the hybrid performance measurement system offers an integrated solution for precise and simultaneous measurement of both hydrogen mass and flow rate during fueling operations.

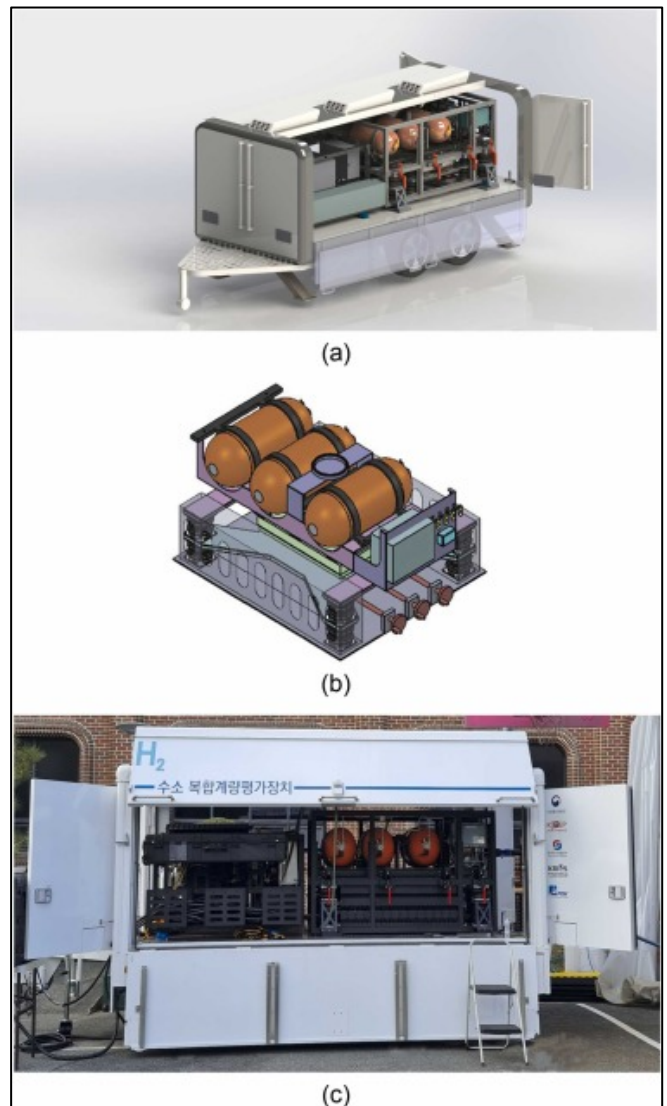


Figure. 7:  
(a) Exterior view of the hybrid performance measurement system (modeling)  
(b) Vessel and vibration-free system of the hybrid performance measurement system (modeling).  
(c) Open view of the hybrid performance measurement system (actual photo).

#### IV. CHALLENGES IN SOLVING THE METROLOGICAL TASKS FOR ENSURING TRACEABILITY AND CONTROL OF MEASURING INSTRUMENTS FOR ALTERNATIVE FUELS AT NATIONAL LEVEL

According to Statista [5] the electric vehicles market in Bulgaria has been experiencing steady growth in recent years, driven by a combination of customer preferences, market trends, local special circumstances, and underlying macroeconomic factors.

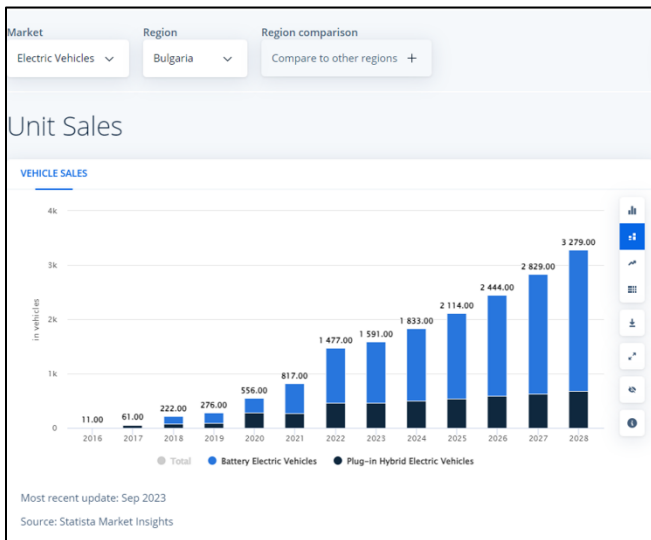


Figure 8 – Number of electrical and hybrid vehicles in Bulgaria

As the number of electric and hybrid vehicles increases, so does the number of charging stations for electric and hybrid vehicles.

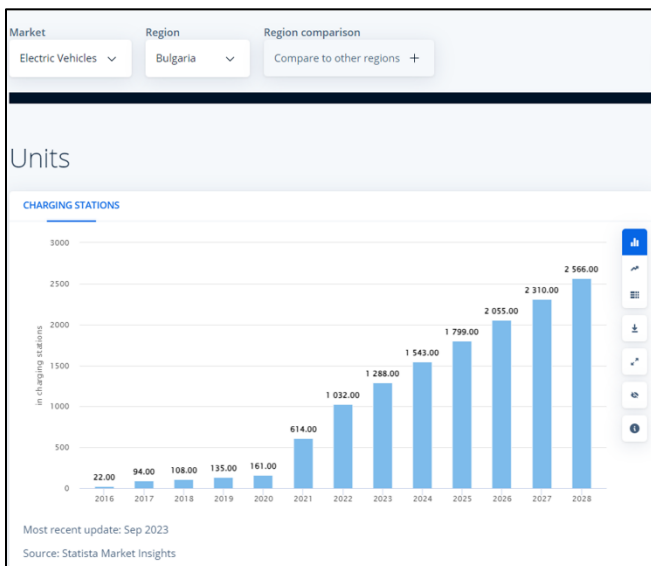


Figure 9 – Number of EVSE in Bulgaria

This is the reason why the metrological task for ensuring traceability and control of EVSE to be solved as soon as possible.

The task for the hydrogen charging stations is not so urgent, but considering that several TEN-T corridors pass through Bulgaria, actions should also be taken regarding the metrological assurance in this direction.

Current situation: No steps have been undertaken at the moment. Problems raised for solving this metrological task:

- No national or harmonized legislation at European level – different technical and metrological requirements in different EU states, different technical solutions;

- Lack of technical equipment and laboratories for implementation of the metrological control in Bulgaria;
- Lack of measurement standards for ensuring the metrological traceability;
- Lack of prepared staff.

According to Article 14 of the Regulation (EU) 2023/1804 by 31 December 2024, each Member State shall prepare and transmit to the Commission a draft national policy framework for the development of the market as regards alternative fuels in the transport sector and the deployment of the relevant infrastructure. The final national policy framework shall be drafted by 31 December 2025.

The task for drafting the national policy framework in Bulgaria is assigned to the Ministry of Transport and Communication.

BIM is making and will make every effort to ensure that the solving of the metrological tasks for measuring of alternative fuels is included as part of this national framework.

BIM is drafting a conception which objective is to support the deployment of alternative fuels infrastructure across the country through insuring the necessary controlling mechanisms related with the proper functioning of the charging stations for alternative fuels.

Planned activities in this conception are:

- Setting up methodology to ensure the traceability of measurements and implementation of control over the stations for alternative fuels (e.g. electricity and hydrogen ones);
- Establishment of laboratories (stationary and mobile ones) that are in compliance with the contemporary requirements for them and acquisition of respective equipment and technical devices;
- Capacity building.

At the moment, BIM is applying for financing the concept through the republican budget or by using the opportunities provided by operational programs, in particular - Operational Program Competitiveness and innovation in enterprises as a direct beneficiary.

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# Measurements and artificial intelligence. A new stage

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**Abstract**— In the forthcoming decades, the application of various artificial intelligence (AI) systems will become a pivotal and indispensable task for humanity. The solution to this task requires the implementation of digitalization in nearly all aspects of life. Concurrently, the application of AI-based systems in automated complexes including cyberphysical ones is becoming increasingly problematic due to the emergence of novel risks and the necessity to mitigate them. Following the approval of the EU AI Act in 2024, the challenges of standardization in this field are being discussed, including new approaches to limit the risks of the application of AI systems without impeding their development.

**Keywords**— artificial intelligence, artificial intelligence-based system, risks of application, standardization, expertise

## I. INTRODUCTION

Since the beginning of Industry 4.0, the application of artificial intelligence (AI) has become increasingly diverse. On moving to Industry 5.0, the long-term implications of AI will be a significant challenge to civilisation, presenting both opportunities and risks. In any industrialized country, most citizens will directly experience how AI affects them and those around them.

The measurement of the properties that characterize human physiology and the interrelationships of the inner organs, human abilities, knowledge and skills will prove to be realistic with the use of AI-based systems. Moreover, such systems will make it possible to quantitatively assess the dynamics of changes in these properties and to take measures that will allow changes for the better. This will improve the health of citizens and increase their satisfaction with life. In conjunction with comprehensive information assistance from municipal and city organizations, these factors will contribute to the creation of a comfortable social environment.

AI will facilitate the identification of the needs of citizens living in a particular neighborhood. The level of satisfaction with energy resources, drinking water, and air quality will become apparent. The necessity for the construction of nearby stores, theaters, sports facilities, banks, medical facilities, and educational institutions will be substantiated.

The integration of AI-based systems embedded in the control systems of unmanned vehicles, coupled with the optimization of traffic flows through cloud-based technology, will provide the safe and expedient delivery of passengers to their intended destinations.

The implementation of AI-based systems will markedly enhance the efficacy of machinery utilized in energetics, defense, agriculture, mining, scientific research, including in space, and so forth.

Metrology, as a “science of sciences” [1, 2] should contribute to improving the reliability of the above-mentioned major transformations resulting from the application of AI-based systems and to minimizing the potential risks associated with their use.

## II. AI-BASED MEASURING INSTRUMENTS IN THE STAGE OF INDUSTRY 4.0

### A. Application Features

Since the beginning of the 2nd decade of the 21st century, AI-based measuring instruments (AIMIs) have been characterized by the following key features:

- the constructive separation of core data processing facilities, using AI systems, into a separate unit;
- use of cloud technologies;
- rapid increase in the number of multiparametric quantities that are in demand for measurement.

The following are examples of the initial stages of the development of some AIMIs. Their feasibility has been demonstrated with the participation of the present paper authors to a greater or lesser extent:

- diagnostics of the state of health, taking into account the interrelation of various components of the body, which allows detecting diseases at the early stages, predicting complications and offering new methods of treatment [3];
- automatic control of production equipment, in which the process of unit operation with increased load is episodically adjusted to increase the reliability [4];
- automatic translation of phrases from one language into another, taking into consideration irony in their pronunciation [5];
- decoding of the content of emotionally colored acoustic signals emitted by animals [6].

This list does not include a number of other areas of the authors' work on the creation of AIMIs for various purposes. A significant part of them is related to the search for solutions that promote the formation of creative abilities and increase the impact of art works.

In the case of multiparametric quantities, each parameter must be a measurable quantity with a clearly defined measurement range and specified conditions. As a rule, such measurements require preliminary metrological studies involving specialists from various fields of knowledge.

The application of AI-based systems is associated with intensive digitization of incoming information flows in almost all areas of life.

In metrology, digitization implies:

- mass transition to digital standards and sensors with digital output, including sensors with embedded neural networks;
- prediction of changes in the values of measurands over the time interval between verifications/calibrations;
- automation of checking the trustworthiness of measurement results;
- use of reference procedures to ensure metrological traceability.

Digitization makes it possible to expand the scope of metrological research, which requires the participation of specialists from different fields of knowledge. Such creative collaboration is especially necessary in the development of methods for measuring multiparametric quantities, including the use of AIMI.

The difference between AIMIs and traditional measuring instruments is as follows:

- multitasking of the application;
- lack of transparency and explainability of the algorithms for obtaining the measurement results in case of using strong AI;
- a large number of different components in the equipment and its high cost, especially in the case of using strong AI;
- increased probability of deterioration of metrological characteristics during the interval between verifications and/or calibrations due to the multicomponent nature of the equipment and the influence of interferences.

#### *B. Specifics of standardizing AIMIs in the stage of Industry 4.0*

The expansion of the scope of AIMI application is accompanied by a gradual increase in the proportion of systems with strong intelligence among them. As a result, the importance of potential negative consequences caused by malfunctions in their operation is increasing. This phenomenon has led to an increase in the number of standards that establish the requirements for the structure of the AI-based systems and rules for working with them.

The Russian TC 164 on standardization “Artificial Intelligence”, which mirrors the ISO SC 42 “Artificial Intelligence” committee, has approved more than one hundred national standards (GOSTs R) and preliminary national standards (PNSTs) since 2019, both of a general nature and related to specific fields of such system application.

Most Russian standards refer to systems, including AIMIs, based on so-called weak intelligence, whose algorithm is known. If from preliminary experimental studies (conducted before type approval) it becomes clear that the algorithm of AI operation should be changed, the reason for this change is, as a rule, caused by correlations between

separate parameters of the multiparametric measurands, which were not revealed before. Once the algorithm has been modified, the AIMI can be submitted for approval of its type. If the necessity to change the algorithm is revealed during the operation of the measuring instrument, its type approval should be renewed with the corresponding correction of the documentation.

However, in the final stage of preparation for approval, there are 2 actual drafts of GOST R, which were developed in the State Research Center FGUP " D. I. Mendeleev Institute for Metrology" (VNIIM): “Measuring instruments based on artificial intelligence. Composition, structure, and fields of application. Main provisions” and “Measuring instruments based on artificial intelligence. Metrological maintenance. General requirements.” The drafts take into account the possibility of using both weak and strong intelligence in measuring instruments. The approval of the projects is planned for October 2024.

In addition to the various AIMI projects, there is an increasing number of projects on AI-based systems that focus on the processing of digital data streams, mostly unrelated to measurement information. These projects formulate processing rules that contribute to improving the validity of their results.

It is not rare to observe instances of negligence and even incompetence in draft standards. Identifying these defects and making recommendations to fix them often requires a considerable investment of time from the responsible professionals in the various organizations that are involved in reviewing or providing expertise for these documents. In some cases, specialists, who are not particularly interested in these drafts, approve them without conducting a thorough analysis.

To enhance the quality of standards developed by TC164, VNIIM specialists are proactively working to automate the examination of relevant projects.

This AI-based expert system must identify:

- duplication of requirements/provisions of approved fundamental documents;
- citation of separate sections of different standards without references to them;
- violation of the requirements of existing standards, e.g., ignoring standardized terminology, non-compliance with the rules of presentation and design of the draft standard, etc.

Following the experimental verification of the efficacy of the system being developed, a proposal for its modification can be put forth with the aim of enhancing the quality of development of ISO/IEC standards with analogous objectives. It should be noted that this procedure can only be undertaken with the consent of the corresponding standard developers.

#### *C. Risk of applying AI-based systems*

The most important problem associated with the use of AI-based systems is considered to be the risk of undesirable consequences.

The risk is primarily attributable to the deployment of AI-based systems in high-tech automated production environments, including those in the aerospace, medical,

defense, power (including nuclear), transportation, and mobile robotics sectors.

On the other hand, the risk is associated with the lack of information about the algorithms utilized in these systems.

The danger is exacerbated by the high probability that in the relatively near future, AI-based systems from different facilities will exchange data and form social connections.

The potential dangers of unregulated AI development have been widely discussed in academic literature, at international conferences, and in the press. Prominent scientists have also participated in these discussions.

The EU Artificial Intelligence Act [7], adopted in March 2024:

- establishes a common regulatory framework for AI within the EU;
- addresses the risks associated with the proliferation of AI-based systems;
- explores ways to mitigate these risks.

The Act encompasses a number of provisions pertaining to the regulation of AI-based systems. These include:

- rules governing the marketing, development and utilization of AI-based systems;
- prohibitions on specific techniques for implementing AI;
- specialized requirements for high-risk AI-based systems;
- harmonized transparency regulations with regard to information transformation for a range of AI-based systems.
- rules for monitoring the market and managing market surveillance.

The Act sets forth a series of requirements for a range of entities, including developers, suppliers, importers, and distributors, as well as for the systems and models adopted for development.

With regard to prohibited methods of AI, the Act makes reference, in particular, to those that have the potential to influence an individual on a subconscious level, with the consequence of causing physical and psychological harm.

A number of systems that are intended for use as lie detectors, emotion recognition systems, systems for the assessment of the education quality, systems related to migration management, and so forth, are characterized by a high level of risk.

A special EU Commission shall be established as the apex body. Each EU member state should establish bodies responsible for monitoring the AI situation, which should immediately notify the Commission of any serious incident. In turn, the Commission should, in cooperation with member states, establish and maintain a database of high-risk AI-based systems.

The EU has adopted a comprehensive and rigorous approach to AI regulation. Its regulatory framework for neural networks is characterized by a centralized oversight of

all stages of development and application, accompanied by rigorous pre-deployment testing protocols.

Simultaneously with the formulation of the Act, the current standard on risk management was being prepared [8].

In contrast to the EU, the US, UK, and Japan afford minimal control of AI. In China, lawmakers are striving to achieve a balance between safety and development.

In Russia, the proposal is to incorporate the regulations governing the work with AI into a document entitled “Digital Codex” and to gradually adjust them. Concurrently, attention is being directed towards the potential for the implementation of self-regulatory measures and a risk-oriented approach to the field of AI [9].

All areas in which AI can be applied are divided into groups. The first one comprises systems with an unacceptable level of risk, such as those related to judicial decisions or definitive medical diagnoses.

The second group includes high-risk systems affecting decisions related to education, transportation infrastructure, and so forth.

The third is limited-risk systems, where AI can be used if people know they are interacting with AI.

The fourth group relates to minimal risk in the use of AI: for example, in video games, in spam filtering programs, etc.

Automation of the reaction to cyberattacks greatly reduces response time and the risk of error, but the speed of attacks is also increasing. It is no longer possible to fully defend systems against cyber threats manually. More than 40% of organizations worldwide are using AI to detect and prevent attacks.

The aforementioned documents give rise to a number of questions. Primarily, it is necessary to ascertain which state organisations are responsible for making decisions regarding the attribution of a particular system to a specific group, as well as for implementing the inspection measures taken to ensure compliance with the requirements set out by ISO/IEC standard [8].

There exists an effective experience in carrying out metrological procedure such as type approval of measuring instruments, including those manufactured outside the country but widely used within it.

It is also of great importance that in different countries, monitoring of compliance with existing national standards is typically conducted by metrological organizations. Furthermore, during the process of type approval, it is customary in Russia and in a number of other countries, to assess the presence of built-in metrological self-checking (MSC) facilities in the number of analyzed subsystems of measuring complexes, including those that employ AIMIs.

The MSC means are designed to prevent the occurrence of complex malfunctions in any circuit, which is crucial for ensuring the reliability of the overall result. From a metrological standpoint, this approach guarantees the safety of the operational process. They signal the complex operator to stop the complex or automatically eliminate the fault. Correcting the distorted parameters or disconnecting a faulty circuit and connecting a backup (redundant) circuit can be used to eliminate the fault. These methods are commonly

referred to as MSC with automatic correction (MSCAC). MSC and MSCAC methods were first developed in VNIIM [10]. Their capabilities and implementation methods are described in several Russian national standards [11-13]. They have been also introduced in some standards of the United Kingdom and other countries (with different terminology and for a limited number of measurands) as well as in the ISO document [14].

AIMIs are usually embedded in expensive equipment. Consequently, by employing a reasoned prediction of the state of an embedded AIMI with MSC and MSCAC, the efficiency of the AIMI can be significantly enhanced. This can be achieved by reducing the downtime associated with metrological maintenance through the implementation of a more optimal verification/calibration interval duration.

In summary, the aforementioned practices provide a rationale for the delegation of responsibility to metrologists for the supervision of the requirement implementation to guarantee the safe use of AI-based systems.

### III. WAYS TO IMPROVE AI-BASED SYSTEMS

#### A. Proposals of the Authors Concerning Governmental Activities in This Direction

It is important that the practice of developing international ISO standards dedicated to the risk mitigation of AI-based systems be continued. In Russia and some other countries, it is advisable to translate and approve these standards as national standards, possibly with some modification, taking into account the legislation adopted in the country.

It would be advantageous if the leading national metrology centers of various countries (in Russia they are State Research Centers of Rosstandart) were tasked with developing the methodologies for

- the identification of AI-based systems in use and
- the evaluation of the efficacy of the measures taken to mitigate the potential risks associated with such systems.

This recommendation is based on the application of adopted standards for risk management and the experience that these centers have gained in the field of approving the type of measuring instruments. In order to increase the efficiency of this work, the above-mentioned metrology centers should be involved in the development of AI-based systems with strong intelligence.

A significant contribution to the solution to the problem under consideration can be the development of a state certification scheme for AI-based systems with an acceptable risk of use. This scheme should take into account the methods developed by leading metrology centers. Such a scheme should be oriented towards the creation of a unified view on the degree of system safety (by analogy with the view on the traceability of measurement results).

#### B. Proposals for Enhancing Reliability

In a way analogous to that applied in MSC and MSCAC, it is reasonable to supplement AI-based systems with the capacity to detect emerging defects. In the event of such a detection, the system should provide a corresponding signal to the operator.

It is expedient to equip AI-based systems belonging to the group with high risk of use with means of automatic correction of distortions, as well as with backup circuits and means of automatic switching of a part of information flow to these circuits.

The proposed measures would significantly reduce, though not entirely eliminate, the probability of the development and illegal dissemination of AI-based systems that could pose a threat to society, including those integrated into complexes with both technical and biological components.

### IV. CONCLUSIONS

The article presents a summary of the issues that necessitate fundamental changes in the work of metrologists.

In addition, it will be necessary not only to improve qualification on a continuous basis but also more and more often to take greater responsibility for decisions that can lead to large-scale economic losses and human tragedies.

Individuals who choose this profession must undergo a series of rigorous peer reviews. However, if successful, the subsequent course of their life will be greatly benefited.

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**SECTION I**  
***GENERAL ASPECTS OF METROLOGY.***  
***MEASUREMENT METHODS. UNITY AND***  
***ACCURACY OF MEASUREMENTS***

# INTERLABORATORY COMPARISON OF DIGITAL THERMOMETER IN THE TEMPERATURE RANGE FROM MINUS 40 °C TO 200 °C

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**Abstract** - A proficiency testing (PT) scheme by interlaboratory comparison on thermometry field was carried out with cooperation of Bulgarian Institute of Metrology (BIM) as a PT provider. The task of the comparison was to calibrate a Digital Thermometer with Pt100 probe in the temperature range from minus 40 °C to 200 °C. Six national laboratories were participated in this interlaboratory comparison. The details and the results of this comparison are given in this paper.

The main purposes of the comparison are to confirm satisfactory performance of laboratories or an alert that potential problems within require investigation, to confirm their technically competence in the field of temperature measurements, to validate their uncertainty claims, and to evaluate the method's performance metrics.

Successful performance provides added confidence to individual staff, management and internal and external clients.

**Keywords**— metrology, ILC, uncertainty

## I. INTRODUCTION

Digital Thermometers (DTs) are essential tools used in various industries for measuring temperature. Therefore, it is crucial to ensure that DTs provide accurate and reliable measurements. Calibration laboratories play a critical role in this process, as they are responsible for calibrating DTs to ensure that labs meet the required accuracy and traceability standards. One important aspect of ensuring the accuracy and quality of DT measurements is the Interlaboratory Comparison (ILC).

ILC involves comparing measurement results obtained by different laboratories using the same transfer item and can help identify any differences in measurement practices or equipment.

The standard ISO/IEC 17043 [3] specifies the general requirements for PT providers and covers the development, operation, and reporting of PT schemes. The standard aims are to ensure that the measurement results obtained by different laboratories are comparable and traceable to international measurement standards. Interlaboratory comparisons are proficiency testing activities that provide a quantifiable means of providing confidence in the quality of calibrations performed.

The reference laboratory was BIM. Performance statistics is used for evaluation of measurement results of

participating laboratories.  $E_n$  criteria is used in this comparison, in which participating laboratories report measurement uncertainties in accordance with EA 04/2 - Evaluation of the Uncertainty of Measurement in calibration [4].

## II. TRANSFER STANDARD

### A. Description

The transfer standard (PT item) was a Digital Thermometer (Fig.1.) with Pt100 temperature probe, provided by reference laboratory. Transfer standard's technical and metrological characteristics are given in TABLE I. The thermometer is very fragile so it had to be handled with extreme care.

Transfer standard was hand-carried from BIM to participating laboratories and vice versa.

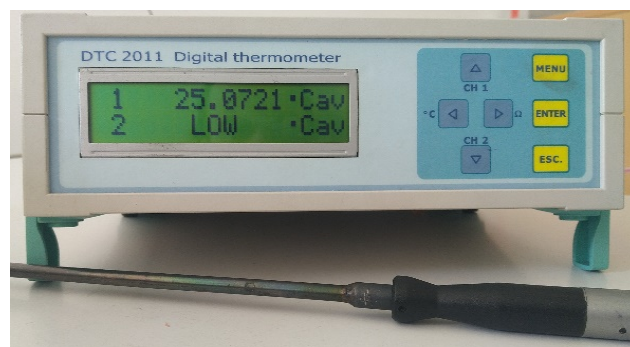


Fig. 1. The transfer standard

TABLE I. TRANSFER STANDARD CHARACTERISTICS

Model:	DTC 2011
Serial number:	01/2011
Resolution:	0,0001 °C
Accuracy:	
0 °C ÷ 30 °C	0,005 °C
-40 °C ÷ 0 °C and 30 °C ÷ 100 °C	0,01 °C
100 °C ÷ 200 °C	0,04 °C
Long term stability:	± 0,01 °C/year

### B. Stability

Stability of the selected transfer standard is one of the prerequisites for interlaboratory comparison measurement or proficiency tests. For this reason, the transfer standard was

tested before the measurements, and it was decided that it was suitable for this comparison. It was demonstrated to be sufficiently stable to ensure that it will not undergo any significant change throughout the conduct of the PT round, including storage and transportation.

The participants were required to make control measurement when receiving the standard at 0 °C (melting ice) before measurements for the stability checks and after that to send corresponding report to the reference lab.

### C. Traceability

The traceability is a key technical parameter required to substantiate the stated uncertainty of measurement resulting. The calibration of the transfer thermometer was performed with a standard platinum resistance thermometers with measurement traceability to primary standards of the SI units of measure (NPL, UK).

The PT item was chosen to provide sufficiently small uncertainty of the reference value with the calibration and measurement capabilities of the participants.

## III. MEASUREMENTS

A fully planned ILC technical protocol [1] in accordance with the ISO/IEC 17043 standard is key in the measurement process and evaluation. The agreed technical protocol established fixed nominal points to be measured in the temperature range of minus 40 °C and 200 °C and required participants to follow their own in-house procedure [6] to see their own capabilities.

The reference laboratory completed the initial measurement before sending the transfer thermometer to the participant. The transfer thermometer was returned to the reference laboratory once the participating laboratory had finished its measurement. The reference laboratory repeated the calibration of transfer thermometer. All measurements were carried out in accordance with the technical protocol's agreed-upon measurement schedule and the requirements set out in the subject of comparison's technical specifications [5].

The calibration was performed in dry block calibrators. The standard platinum resistance thermometer, Pt100 and standard digital thermometer F150, calibrated at fixed points from ITS-90, were used Fig.2. The measurement traceability is to National primary standard for temperature of Bulgaria.



Fig. 2. NPP Laboratory Standards

After finishing measurements, measurement procedure, equipments used at the comparison, measured temperature

values with their uncertainties were reported by each participating laboratory.

### A. Results

The measurement results obtained from each laboratory were compared against the reference values provided by a reference laboratory and the deviation of the participant laboratories' values with the given uncertainties were calculated.

The reference values and their associated uncertainties are determined in line with procedure of PT provider.

The standard uncertainty of the  $X_{REF}$  was determined using the following formula:

$$u_{REF} = \sqrt{u^2(X_{REF}) + u^2(X_{STAB})}, \text{ } ^\circ\text{C}$$

where:

$u(X_{REF})$  - reference laboratory standard uncertainty;

$u(X_{STAB})$  - the additional component of the stability of the PT item for the period of the performance of the comparison.

The expanded uncertainty of  $X_{REF}$ :

$$U_{REF} = 2u_{REF}, \text{ } ^\circ\text{C}$$

where:  $k = 2$  – coverage multiplier corresponding to a confidence interval of approximately 95%.

The criterion represents the normalized deviation of the result of each laboratory from the reference value.

$E_n$  is calculated using the formula:

$$E_n = \frac{X_{LAB} - X_{REF}}{\sqrt{U_{LAB}^2 + U_{REF}^2}}$$

where:

$X_{LAB}$  - is the participant's result;

$X_{REF}$  - is the reference value;

$U_{LAB}$  - the expanded uncertainty declared by the participating lab;

$U_{REF}$  - the expanded uncertainty declared by the reference lab.

$|E_n| \leq 1.0$  - the result is considered as satisfactory.

$|E_n| > 1.0$  - the result is considered as unsatisfactory.

Criterion for performance evaluation is based on statistical determination for  $E_n$  number, as describe in details in ISO/IEC 17043.

### B. Analysis of the results

The differences between the results of the participating laboratories to the reference laboratory and their uncertainties were presented graphically in Figures 3-10.

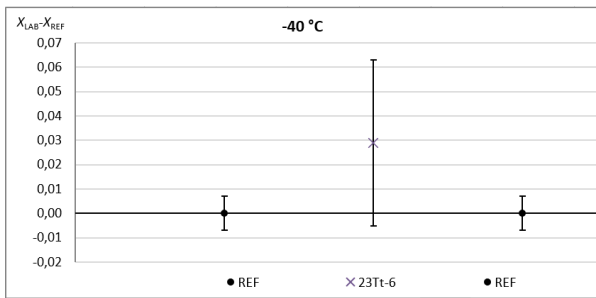


Fig. 3. Deviation from the reference values at -40 °C obtained by participating laboratories

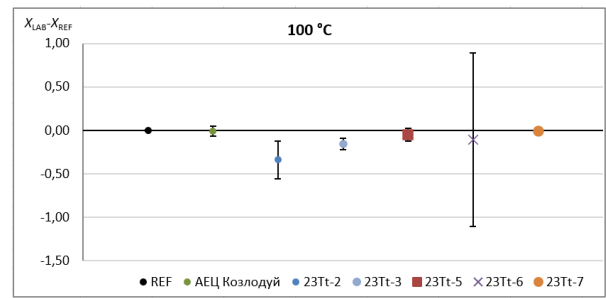


Fig. 8. Deviation from the reference values at 100 °C obtained by participating laboratories

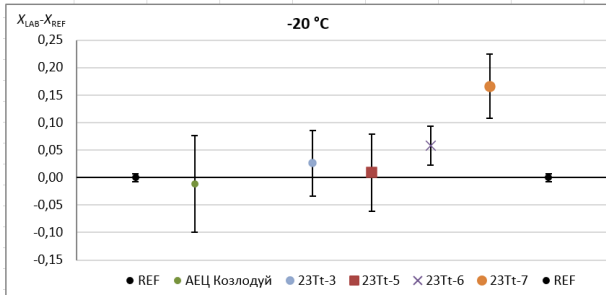


Fig. 4. Deviation from the reference values at -20 °C obtained by participating laboratories

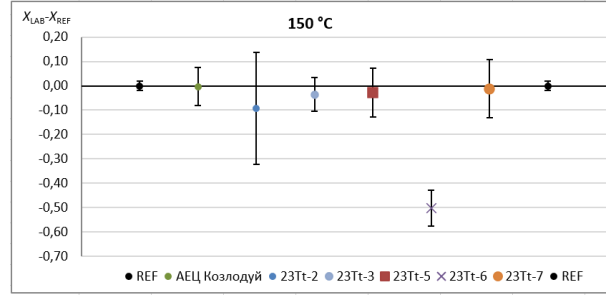


Fig. 9. Deviation from the reference values at 150 °C obtained by participating laboratories

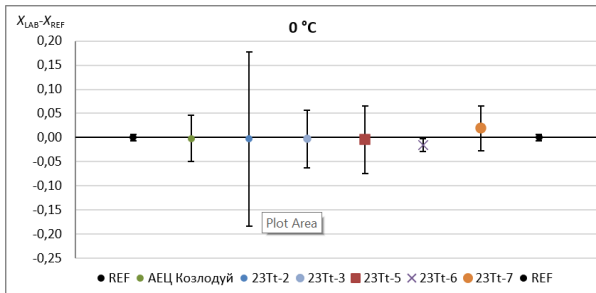


Fig. 5. Deviation from the reference values at 0 °C obtained by participating laboratories

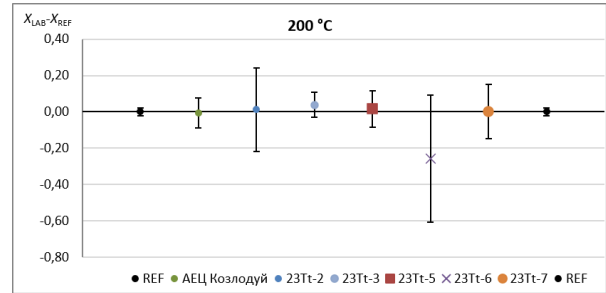


Fig. 10. Deviation from the reference values at 200 °C obtained by participating laboratories

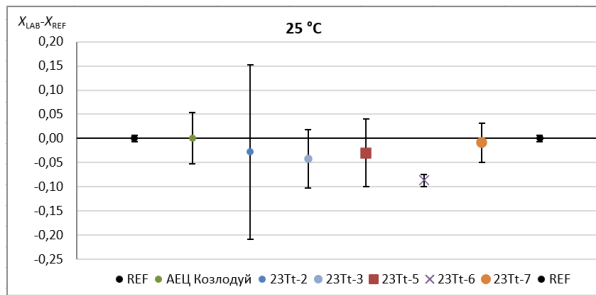


Fig. 6. Deviation from the reference values at 25 °C obtained by participating laboratories

The normalized errors for the selected temperatures can be seen in Table II and Figures 11-18.

Table II NORMALIZED ERRORS

Temp. Points, °C	$E_n$					
	23Tt-1	23Tt-2	23Tt-3	23Tt-5	23Tt-6	23Tt-7
-40	-	-	-	-	0,8	-
-20	0,1	-	0,4	0,1	1,6	2,8
0	0,0	0,0	0,1	0,1	1,1	0,4
25	0,0	0,2	0,7	0,4	5,9	0,2
50	0,0	0,3	0,4	0,2	1,6	0,1
100	0,2	1,5	2,3	0,7	4,4	0,2
150	0,0	0,4	0,5	0,3	6,6	0,1
200	0,1	0,1	0,5	0,2	0,7	0,0

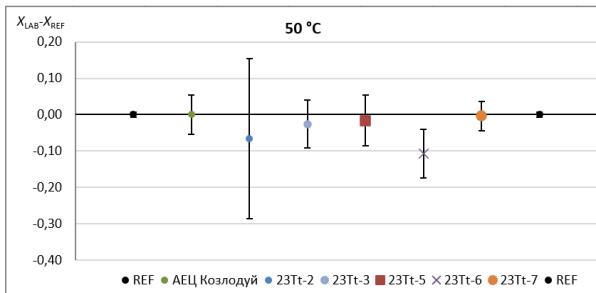


Fig. 7. Deviation from the reference values at 50 °C obtained by participating laboratories

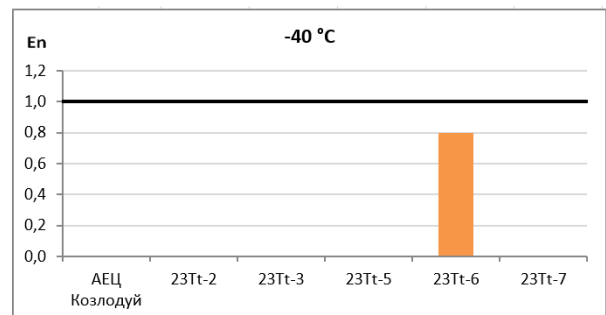


Fig. 11. The normalized error at -40 °C

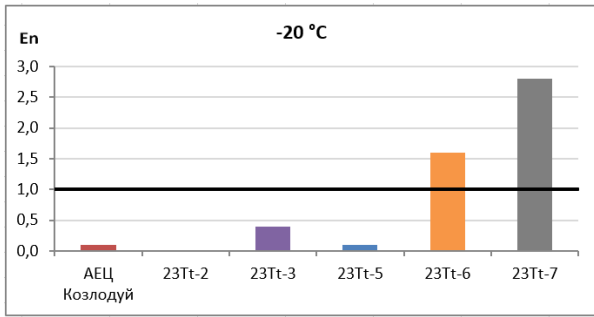


Fig. 12. The normalized error at -20 °C

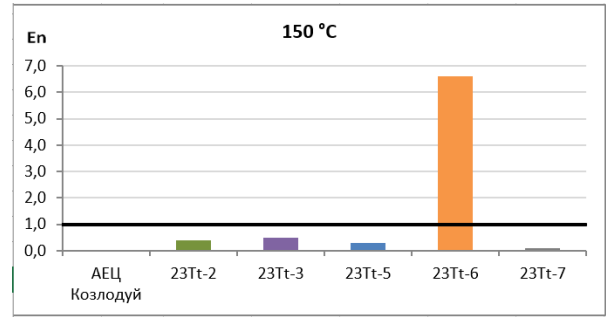


Fig. 17. The normalized error at 150 °C

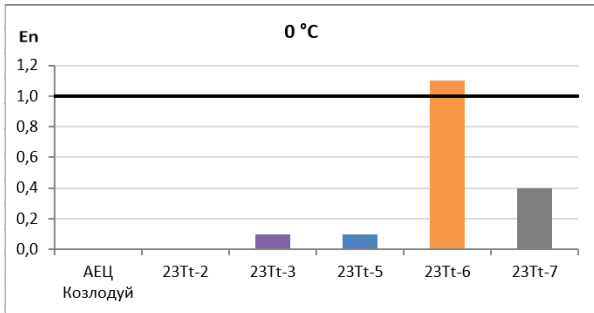


Fig. 13. The normalized error at 0 °C

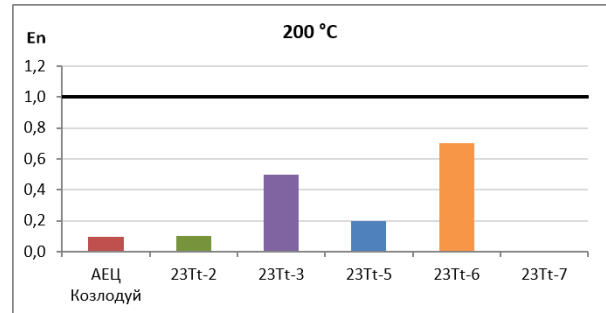


Fig. 18. The normalized error at 200 °C

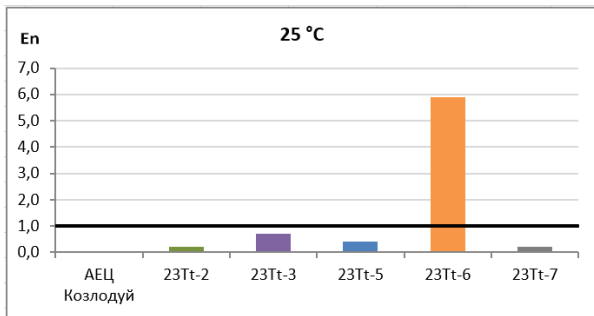


Fig. 14. The normalized error at 25 °C

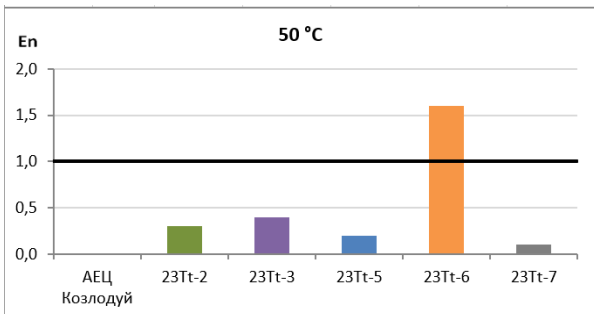


Fig. 15. The normalized error at 50 °C

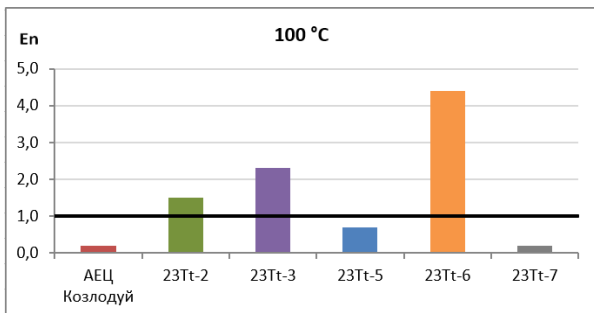


Fig. 16. The normalized error at 100 °C

The desired outcome is for the  $|E_n|$  value to be as close to zero as possible.

## VI. CONCLUSION

The comparison was very successful.

The results of the NPP lab in the PT Scheme BIM-TI-T-2023-01 for calibration of a Digital Thermometer with a range of up to 200 °C meet the satisfactory result criterion  $|E_n| \leq 1$  at all measurement points.

The laboratory demonstrates that it is technically competent and can produce technically valid results in calibration it performs for its clients. The laboratory met the general requirements defined in ISO/IEC 17025 and confirmed the efficiency of the procedures, instructions and other technical documentation needed to ensure the results of the Digital Thermometer calibration.

The laboratory improved its claimed calibration and measurement capabilities (CMC).

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**SECTION III**  
***MEASUREMENT AND INFORMATION***  
***SYSTEMS AND TECHNOLOGIES***

# Formation Of Nonlinear Trajectories Of Guaranteed Accuracy In Approximation Areas

\*Note: Sub – titles are not captured in Xplore and should not be used

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**Abstract**—An analytical method of limiting the complexity of neuro-fuzzy models is proposed: the number of input and output fuzzy variables, the number of linguistic rules, the number of terms of the corresponding fuzzy and linguistic variables, the coordinates of modal values on the axes of input and output fuzzy variables, the number of neurons in the intermediate layer, providing guaranteed accuracy of the realisation of the motion graph when approximating the step and exponential functions relating the required speed of motion  $V^2_i(s_i) = 2a_{\max} s_i$  on a given section  $S_i$  of the roadway and the maximum permissible acceleration (deceleration)  $a_{\max}$  of traffic.

**Keywords**—Complexity, guaranteed accuracy, fuzzy modelling, neural model.  $V_i(s_i)$

## I. INTRODUCTION (HEADING 1)

To control high-speed objects (works, drones, locomotives, automobile and air transport) with nonlinear and variable parameters operating under the influence of the environment (mass, wind, climbs, slopes, radii of motion trajectories, interference of variable intensity), it is necessary to perform nonlinear correction of parameters in the settings of control systems, to form specified nonlinear motion trajectories on the sections of motion, to limit the required speed of motion in the setting of the speed controller, etc. Digital modeling of trajectory problems in real time includes: movements of the representative point (an abstract point, which is put in correspondence with some real point on the working element of the controlled object) along the trajectory specified in the control program at the required speed  $V_i(s_i)$ . Developed an analytical method for determination of fuzzy and neural models depending on the accuracy of their implementation

**Problem Statement.** To control complex nonlinear moving objects (ROs) of rail transportation [1-5], it is necessary to have nonlinear correction of parameters in the settings of control systems, formation, with the required accuracy, of the given nonlinear trajectories of ROs movement on the passage

sections (e.g., drones, the schedule of the required speed of movement in the regulator set point) and others.

## II. ANALYSIS OF RECENT STUDIES

To control high-speed objects (works, drones, locomotives, motor and air transport) with nonlinear and variable parameters, functioning under the influence of the environment (mass, wind, elevations, gradients, radii of motion trajectories, disturbances of variable intensity), nonlinear correction of parameters in the settings of control systems, formation of specified nonlinear motion trajectories in motion sections, limitation of the required motion speed in the speed controller setpoint, etc. is necessary. Digital modelling of trajectory tasks in real time includes: movement of the image point (an abstract point that corresponds to some real point on the working body of the control object) along the trajectory specified in the control program with the required speed.  $V_i(s_i)$ . Nowadays, fuzzy [1, 3], neural and genetic algorithms [5], situational intelligent machines and adaptive controllers [6, 7, 8] are used to take into account all time-varying variables influencing the control process in the control law. The analysis of works has shown the absence of analytical dependencies for determining the complexity of models depending on the given accuracy of their implementation. In the work of Piegat A. [3], for example, when realising a fuzzy production model, the number of terms of input and output variables is recommended, with reference to studies on psychology (a person with average abilities is able to simultaneously store in memory from 5 to 9 information processes), to choose from 5 to 7. In [7, 8], a simplified estimate of the maximum number of second-order curve approximation sites by linear interpolation (trapezoidal method with guaranteed accuracy by the maximum deviation of the model curve or its area from the system curve is

obtained. The modelling of systems described by power functions of the form  $f_c(x) = \mu x^2$ .

**Purpose of work.** Justification of the analytical method of limiting the complexity of neuro-fuzzy models of formation of the required schedules of mobile objects movement on the sections of travel depending on the given accuracy of their implementation in the coordinates of the path to the end of the passage-determined speed of movement.

### III. MAIN PART

Let us consider an example of implementation of modelled systems of higher order of guaranteed accuracy, described by equations in the form of exponential functions of the form having 2l derivatives.

$$y_c = f_c(x) = a_l x^{2l} + a_{l-1} x^{2l-1} + \dots + a_1 x^1 + a_0, \quad (1)$$

Transformation of equation (1) for  $l=1$

$$y = f(x) = -\frac{a_2 x^2}{2b_0} - \frac{2a_1 x}{2b_0} - \frac{a_0}{2a_1},$$

is a curve (parabola) shifted relative to the origin. Moving the origin to the point  $O'$  with coordinates

$$x_c = x + \frac{a_1}{a_2}; \quad y_c = y + \frac{a_0}{2a_1} - \frac{a_1^2}{2b_0 a_2};$$

$$O' \left( -\frac{a_1}{a_2}; \frac{a_1^2}{2b_0 a_2} - \frac{a_0}{2a_1} \right);$$

gives the modelled system described by the parabola equation (2)

$$y_c = \mu x_c^2, \quad (2)$$

where

$$\mu = \frac{1}{2p} = -\frac{a_2}{2b_0}.$$

$p$  - distance from the focus to the directrix of the parabola.

For example, for  $2l \geq 2$ :

$$y_c = \mu \sqrt[2l]{x_c}, \quad y_c = \mu x_c^{l+1},$$

Consider the exponential functions  $Y_c = e^{f_c(x)}$ ,  $Y_c = 1 - e^{-f_c(x)}$ ,  $Y_c = a^{f_c(x)}$ ,

where, for example,  $f_c(x) = \mu x^2$  or  $f_c(x) = -\mu x^2$  - degree functions.

A typical curve of passenger train speed variation along the passage section is shown in Fig.1.

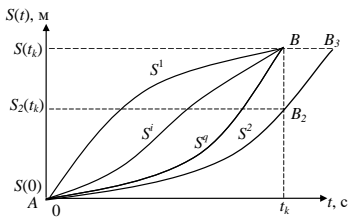


Fig. 1 Timetable of a passenger train passing through a section of traffic

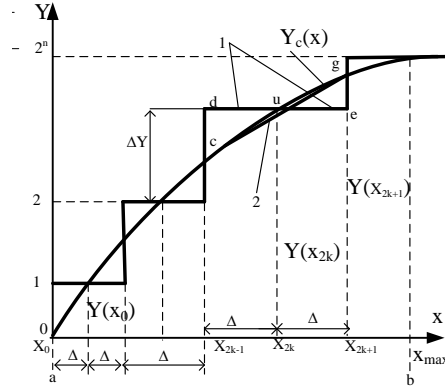
As can be seen from Fig. 1, the transfer of an object from the initial state  $S(0)$  to the final state  $S(t_k)$  for time  $t_k$  can be performed along one of the possible curves ( $S^1, \dots, S^q$ ) (trajectories). In this case, the value of the maximum permissible acceleration of the speed change may exceed the limits of permissible values  $\pm 0.7 \text{ m/c}^2$ . Having a traffic map (schedule) it is necessary to synthesise the control for individual traffic sections  $S^0, S^k$ . Then for acceleration sections the maximum permissible value of acceleration is in the range up to  $0.7 \text{ m/c}^2$ , for deceleration areas - up to  $-0.7 \text{ m/c}^2$  and for sections with constant speed - equal to zero.

Deviation of the travel speed in time from the required values will lead to a situation where the train either reaches the specified distance  $B_3$  another time  $t \neq t_k$ , in a given time  $t_k$  will travel a different distance  $B_2$ .

Therefore, the dependence plots of the approximated system and approximating model curves should be plotted in the coordinates required velocity -  $Y_k$ , path -  $x_k$ . In this case, the transfer of the object from the initial state  $S(0)$  to the final state  $S(t_k)$  in time is ensured  $t_k$ .

**Example of approximation** of the system curve graph

$Y_c = 1 - e^{-\mu x^2}$  by model curves approximated by the method of rectangles (stepped broken line - line 1) and by the method of trapezoids (line segments passing through neighboring points of the curve - 2), is shown in Fig. 2



$$Y_c = 1 - e^{y_{ci}} = 1 - e^{f_c(x_i)} = 1 - e^{-\mu x^2} - \text{system curve}$$

and model curves  $Y_m$ , approximated by the method of rectangles (curve 1) and the method of trapezoids (curve 2)

Fig. 2 Dependency plots of approximated system and approximating model curves

**Let us introduce for the function**  $Y_c = e^{f_c(x_i)} = e^{\mu x^2}$

designation:  $y_c = \ln(Y_c)$  and we obtain the curve (increasing parabola) as a power function (2).

The model of this system in [2] is similar to Fig. 1 and is represented in the form of straight line segments

$$\frac{y_m - y_1}{y_2 - y_1} = \frac{x - x_1}{x_2 - x_1}, \quad (3)$$

passing through the points with coordinates  $x_1, y_1$  and  $x_2, y_2$  located on the approximated curve  $y_c = f_c(x)$ , with a given maximum deviation error  $\Delta_{\max}$ .

Taking into account (1) in (2) [2] we made a substitution

$$\frac{y_m - f(x_1)}{f(x_2) - f(x_1)} = \frac{x - x_1}{x_2 - x_1}$$

which resulted in

$$y_m = \frac{x - x_1}{x_2 - x_1} [f(x_2) - f(x_1)] + f(x_1) . \quad (3)$$

The approximation  $\Delta$  error is defined as the maximum deviation between the system  $f_c(x)$  and model  $f(x)$  curves on the approximation section from the relation (4)

$$\Delta = y_m - y_c = \frac{x - x_1}{x_2 - x_1} [f(x_2) - f(x_1)] + f(x_1) - f_c(x) \quad (4)$$

The maximum error  $\Delta_{\max}$  is determined from the condition

$$\frac{\partial \Delta}{\partial x} = \frac{f(x_2) - f(x_1)}{x_2 - x_1} - \frac{\partial f_c(x)}{\partial x} = 0 \quad (5)$$

and the dependence of the coordinate of the next required point of the parabola abscissa  $x_2$  on the coordinate of the previous point  $x_1$  and the given value of the maximum error is obtained  $\Delta_{\max}$ .

Taking into account (1) in (5) we substitute

$$y_1 = \mu x_1^2, \text{ a } y_2 = \mu x_2^2 .$$

The result is

$$\frac{y_m - \mu x_1^2}{\mu(x_2^2 - x_1^2)} = \frac{x - x_1}{x_2 - x_1} \frac{x_2 + x_1}{x_2 + x_1} = \frac{(x - x_1)(x_2 + x_1)}{(x_2^2 - x_1^2)}$$

from where

$$y_m - \mu x_1^2 = \mu(x - x_1)(x_2 + x_1) = \mu(xx_2 + xx_1 - x_1x_2 - x_1^2)$$

or

$$y_m = \mu[(x_1 + x_2)x - x_1x_2] . \quad (6)$$

The approximation error is defined as the difference of

$$\Delta = y_m - y_c = \mu[(x_1 + x_2)x - x_1x_2 - x^2] . \quad (7)$$

The maximum error is determined from the condition

$$\frac{\partial \Delta}{\partial x} = \mu[x_1 + x_2 - 2x] = 0$$

from where

$$x = \frac{x_1 + x_2}{2} . \quad (8)$$

By substituting (8) into (7) and obtained the dependence (9) of the coordinate of the subsequent point  $x_2$  of the curve, on the coordinate of the previous point  $x_1$  and the given value of the maximum error  $\Delta_{\max}$

$$\Delta_{\max} = \mu \left[ \frac{(x_1 + x_2)(x_1 + x_2)}{2} - x_1x_2 - \frac{(x_1 + x_2)^2}{4} \right] ,$$

$$4\Delta_{\max} = \mu[(x_1 + x_2)^2 - 4x_1x_2] ,$$

$$4\Delta_{\max} = \mu[x_1^2 + 2x_1x_2 + x_2^2 - 4x_1x_2] = \mu[x_1^2 - 2x_1x_2 + x_2^2] = \mu(x_1 - x_2)^2 ,$$

from where

$$x_2 = x_1 \pm 2\sqrt{\frac{\Delta_{\max}}{\mu}} .$$

In general

$$x_{i+1} = x_i \pm 2\sqrt{\frac{\Delta_{\max}}{\mu}} . \quad (9)$$

$$n \geq \frac{b - a}{2\sqrt{\frac{\Delta_{\max}}{\mu}}} , \quad (10)$$

$$m = n + 1 \quad (11)$$

$$n^2 \geq \frac{b - a}{4\frac{\Delta_{\max}}{\mu}} = \frac{b - a}{\delta} \quad (12)$$

$$\text{At } b - a = 1 \quad \delta \geq \frac{b - a}{n^2} = \frac{4\Delta_{\max}}{\mu} \quad (13)$$

After defining the model points  $x_i$  and  $x_{i+1}$  we return to the previously adopted notations or  $Y_{ci} = e^{y_{ci}} = e^{f_c(x_i)} = e^{\mu x_i^2}$

or  $Y_{ci} = 1 - e^{-y_{ci}} = 1 - e^{-f_c(x_i)} = 1 - e^{-\mu x_i^2}$  and determine the

ordinates of the sought modal values  $Y_{ci}$  u  $Y_{c(i+1)}$  over the whole section  $b - a$  of the approximation from  $x_{\min} = a$

before  $x_{\max} = b$ , i.e. inputs and outputs of the fuzzy or neural model realizing the desired model

$$Y_c = e^{f_c(x)} = e^{\mu x^2} \text{ или } Y_{ci} = 1 - e^{-f_c(x_i)} = 1 - e^{-\mu x_i^2}$$

**Table 1** shows the required number of approximation sites  $n$  and the number of neurons or terms  $m$  of fuzzy variables  $x$ ,  $y$ , providing the formation of the given nonlinear motion trajectories of moving objects of guaranteed accuracy, according to the values of the relative approximation error  $\delta$  or absolute approximation error  $\Delta_{\max}$ . By selecting the required values  $\delta$  or  $\Delta_{\max}$  are determined the corresponding values  $n$  and  $m$ .

**Table 1** The required number of approximation sites  $n$  and the number of neurons or terms  $m$  of the exponential function, providing the formation of the given nonlinear motion trajectories of moving objects of guaranteed accuracy.

$n$	1	2	3	4	5	10	20
$m$	2	3	4	5	6	11	21
100* $\delta$ , %	100	25	11	6,25	4	1	0,25
100* $\Delta_{\max}$ %	25 $\mu$	6,25 $\mu$	2,75 $\mu$	1,6 $\mu$	1,0 $\mu$	0,25 $\mu$	0,06 $\mu$

Let's consider example 2 of realization of modeled systems of high order of guaranteed accuracy, by the method of linear approximation, described, for example, by equations in the form of trigonometric function of the following form

$$y_c(x) = y_{\max} \sin(\mu x) . \quad (14)$$

We set the value of relative error (quantum) of transformation:

$$\delta \leq \frac{\Delta y_{\max}}{y_{\max}}, \quad (15)$$

where  $n \geq \frac{b-a}{2\Delta_x} = \frac{1}{2\delta}$  - number of approximation sites

equal to the number of neurons or terms  $m$  of fuzzy variables  $x, y$ . From the known relation:

$$\frac{dy(x)}{dx} \approx \frac{\Delta y}{\Delta x}, \quad (16)$$

we obtain the maximum allowable rate of change of the signal:

$$\left. \frac{dy_c(x)}{dx} \right|_{\max} \approx \frac{\Delta y_{\max}}{\Delta x} = y_{\max} \mu \cos(\mu x) \Big|_{x=0} = y_{\max} \mu. \quad (17)$$

$$\text{Then } \frac{\Delta y_{\max}}{\mu y_{\max}} = 2\delta = \Delta x = x_{i+1} - x_i, \quad (18)$$

$$2\delta = \Delta x = x_{i+1} - x_i \quad (19)$$

from where we determine the coordinates of modal values of approximation nodes

$$x_{i+1} = x_i + 2\delta \quad (20)$$

**Table 2** shows the required number of approximation sites  $n$  and the number of neurons or terms  $m$  of fuzzy variables  $x, y$ , providing the formation of the given nonlinear motion trajectories of moving objects of guaranteed accuracy, according to the values of the relative approximation error  $\delta$  for modal values of the model function  $y_m(x_i)$ .

$$y_m(x_i) = y_{\max} \sin(\mu x_i) \quad (21)$$

Coordinates of modal values of approximation nodes can be chosen according to Table 1 and formulas (9), (10), (13).

**Table 2** Required number of approximation sites  $n$  and number of neurons or terms  $m$ , providing formation of trigonometric function of guaranteed accuracy

$n$	1	1	2	5	6	10	12	20
$m$	2	2	3	6	7	11	13	21
100*	100	50	25	10	8	5	4	2,5
$\delta, \%$								

In [7] an example of creating a fuzzy model for the system given by the dependence. "The belonging functions of values of input and output parameters of the model have the form shown in Fig. 2 and the system of rules is given:  $R_i: IF x_i = T_{xi} TO y_i = T_{yj}$ .

Fig. 3 shows the graphs of dependence  $y_c = \mu x^2$  (curve 1). According to [7], if the coordinates of the modal values of the terms of the input variable are  $x$  ( $T_{x0}, T_{x1}, T_{x2}, T_{x3}$ ) and the output variable -  $y$  ( $T_{y0}, T_{y1}, T_{y2}, T_{y3}$ ) are located uniformly on the XU axes, then the model (approximating) curve 2 is a straight line, because the nodal points of the model curve are at the intersection points of the coordinates of their modal values. This will lead to a large error of the fuzzy model 2. If the coordinates of the modal values of the terms of the output variable of the approximating curve of the fuzzy model are  $y_i=f(x_i)$  ( $T_{y0}, T_{y1}, T_{y2}, T_{y3}$ ) choose from the

condition  $y_i = \mu x_i^2$  (Fig. 4), then the nodal points of the model curve 2 will be located on the curve 1 unevenly, which will ensure the given modeling accuracy.

Figure 5 shows an example of the implementation of a simplified model using an ANC

Figure 6 shows the graphs of dependencies of the modeled curve  $y_c = \mu x^2$  (curve 1) and model curve 2 of the neural model, representing the sum of triangular activation functions of all neurons shifted by the value of  $x_i$ . If the coordinates of the modal values of the neuron activation functions are chosen from condition (9), where  $k_i$  - coefficients chosen from the condition  $k_i = \frac{y_{ci}}{x_i^2}$ , a  $y_{ci}$  - modal values of the

modeled curve in the approximation nodes  $x_i$  (Fig.5), then the nodal points of the model curve 2 will be located on the curve 1, which provides the given modeling accuracy."

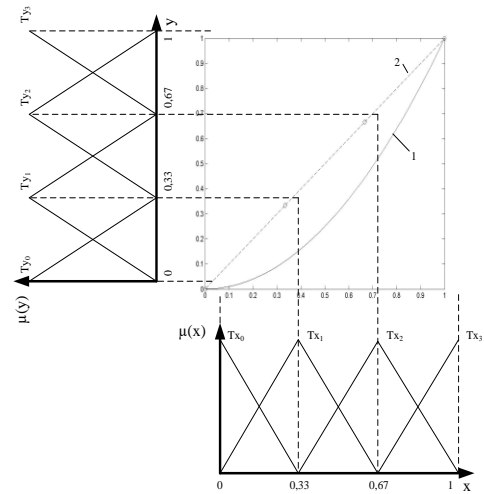


Figure 3. Values of triangular terms of input variable  $x$  ( $T_{x0}, T_{x1}, T_{x2}, T_{x3}$ ) and output variable  $y$  ( $T_{y0}, T_{y1}, T_{y2}, T_{y3}$ ), whose modal values are located uniformly on the coordinate axis  $XV$ .

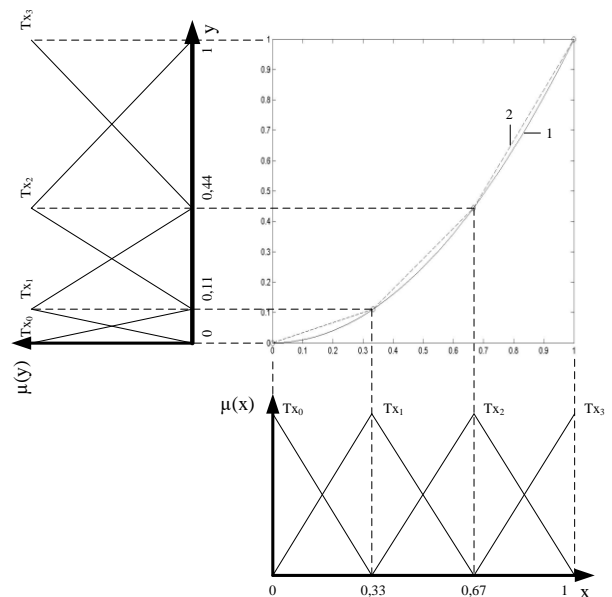


Figure 4. Values of triangular terms of input variable  $x$  ( $T_{x0}, T_{x1}, T_{x2}, T_{x3}$ ) and output variable  $y$  ( $T_{y0}, T_{y1}, T_{y2}, T_{y3}$ ),

whose modal values are located unevenly on the coordinate axes XY from the condition (9).

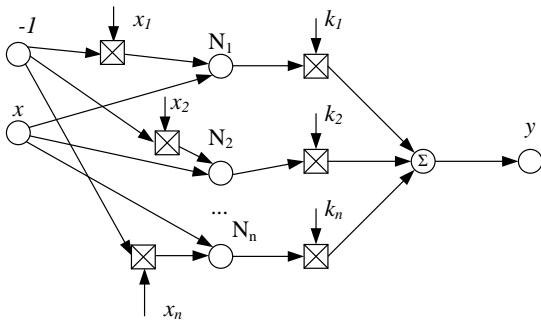


Figure 5. Neural model of guaranteed accuracy

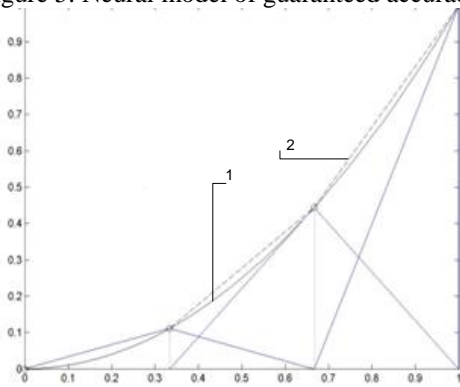


Figure 6. Dependency plots of the modeled curve  $y_c = \mu x^2$  (curve 1) and model curve 2 of the neural model

#### IV. FUZZY MODEL SIMULATION

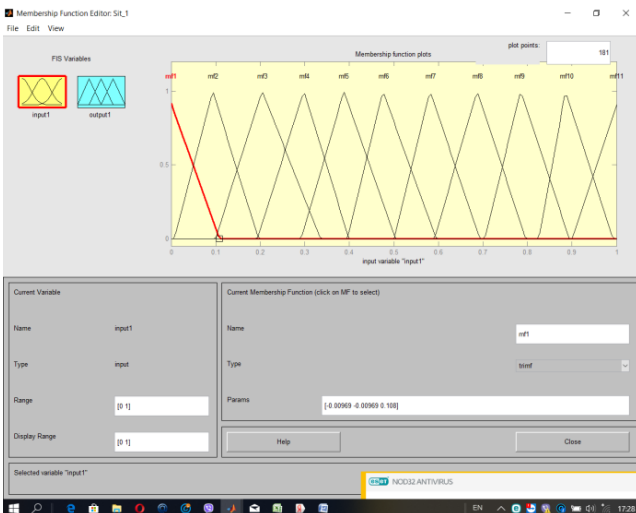


Fig. 6. Values of 11 triangular terms of the input variable x

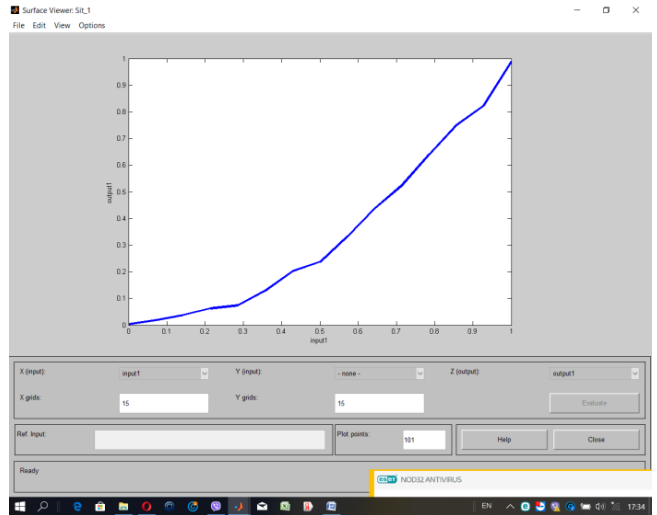


Fig.7. Graph of dependence of the modeled curve  $y_c = \mu x^2$  for 11 triangular terms of the input variable x and the output variable y

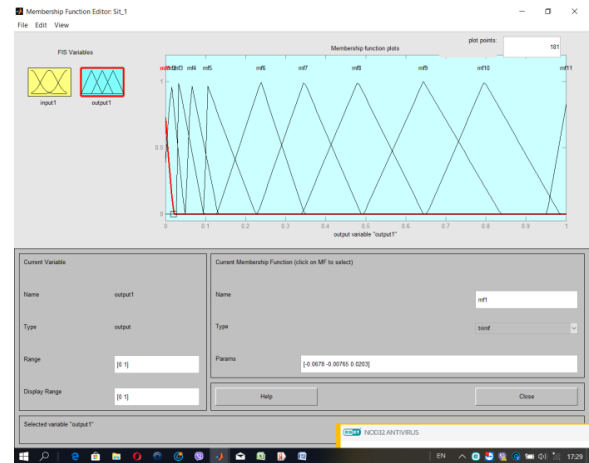


Fig. 8. Values of 11 triangular terms of the output variable y

#### V. SIMULATION ON NEURAL MODEL

Example of modeling on the neural model of dependence

$$y_m(x_i) = \cos(x_i), \text{ FOR } i=6$$

$$x=[0, .1, .2, .3, .4, .5, .6, .7, .8, .9, 1.57];$$

$$xc=[0, .2, .4, .6, .8, 1.57];$$

$$yc=\cos(xc)$$

$$yc = 1.0000 \ 0.9801 \ 0.9211 \ 0.8253 \ 0.6967 \ 0.0008$$

$$\text{plot}(xc, yc), \text{grid on}$$

$$xm=[0, .3, .5, .7, .9, 1.57];$$

$$ym=\cos(xm)$$

$$ym = 1.0000 \ 0.9553 \ 0.8776 \ 0.7648 \ 0.6216 \ 0.0008$$

$$\text{net}=\text{newrbe}(xm, ym);$$

$$\text{net}=\text{newrbe}(xm, ym);$$

$$ym=\text{sim}(\text{net}, xc)$$

$$ym = 1.0000 \ 0.9797 \ 0.9212 \ 0.8253 \ 0.6969 \ 0.0008$$

$$\text{plot}(xc, yc, xm, ym), \text{grid on}$$

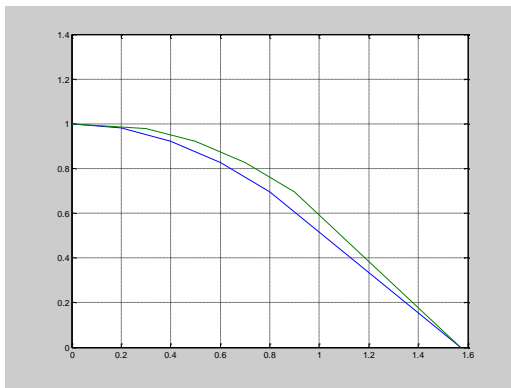


Fig. 9 Graph of dependence of the modeled curve  $y_m(x_i) = \cos(x_i)$  and the neural model net=newrbe ( $x_m, y_m$ ) for 6 approximation sections

```
e=yc - ym ;
e = 1.0e - 003 *
    - 0.0000 0.4095 - 0.1084 0.0844 - 0.1497 - 0.0000
e=100*abs(e)
e = 0.0000 0.0409 0.0108 0.0084 0.0150 0.0000
plot(xc, e), grid on
```

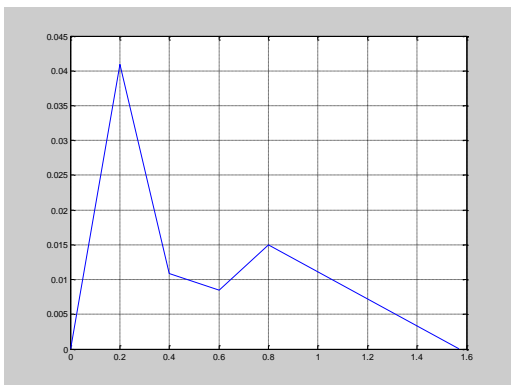


Fig. 10 Graph of dependence of the curve modeling error  $y_m(x_i) = \cos(x_i)$  for 6 approximation sections

## VI. RESULTS AND THEIR DISCUSSION

The analytical method of formation of nonlinear trajectories of guaranteed accuracy on approximation sections is proposed.

At realization of models there is a problem of estimation of their complexity (determination of minimum necessary

quantity of input and output fuzzy variables, linguistic rules, terms of corresponding fuzzy and linguistic variables, neurons in the intermediate layer of ANN or neuro – fuzzy systems, coordinates of modal values on the axes of input and output fuzzy variables, providing guaranteed accuracy of model realization).

The choice of coordinates of modal values of terms of input and output variables of fuzzy models, activation functions of neural models, number  $n$  of approximation sites and number  $m$  of belonging functions  $T_i$  of fuzzy model terms, number of activation functions of neurons  $N_i$  is carried out by formulas (6), (7), (8), depending on the given accuracy of their realization, and solves the specified problem.

Analysis of graphs of Fig.4 of dependencies of modelled curve  $yc$  by fuzzy model and graphs of neural model  $y_m(x_i)$  (Fig.6) showed, that the curve modeling errors at the approximation sites do not exceed the guaranteed accuracy limits specified in Tables 1 and 2.

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# Storage of data and preparation of reports from metrological inspection of measurement channels of electrical quantities from the OVATION system with MS Access database

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**Abstract:** The report describes the method of data storage and preparation of reports from metrological inspection of measurement channels of electrical quantities from the OVATION system at Kozloduy NPP Units 5 and 6. A brief description of the inspection methodology and the software platform used is provided. The stages of preparation of reporting documents and their storage are discussed.

**Keywords:** Measurement channel (MC), Ovation system, MS Access, metrological inspection, Fluke, automated work station.

## I. INTRODUCTION

The modern measuring systems used in Kozloduy NPP EAD measure more than one physical quantity and perform additional functions such as control and automation of technological processes, archiving of measurement results, etc.

Measurement channel - an electrical circuit of devices that measure a physical quantity. The first device converts the physical quantity into an electrical signal, and the last device displays the measurement result. A measurement channel is the smallest component of a measurement system that can independently perform the measurement process.

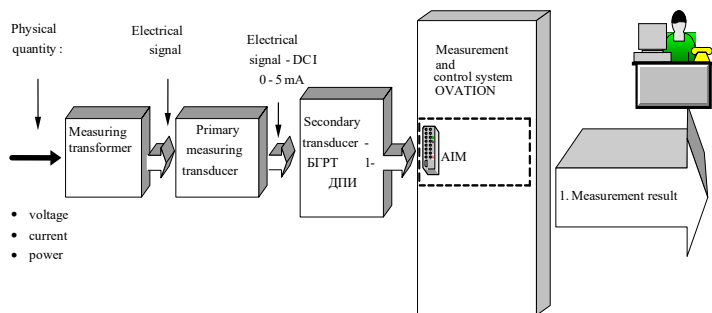


Fig. 1 Structure of a measurement channel with signal multiplication unit

II. Storage of data and preparation of reports from metrological inspection of measurement channels of electrical quantities from the OVATION system with MS Access database

### A. Metrological inspection of measurement channels of electrical quantities from the OVATION system

In metrological verification, a series of actions is performed to determine the compliance of the MC with the requirements for measurement accuracy by observing the following rules and sequence:

- The metrological verification is performed in a comprehensive manner for the entire measurement chain of the measurement channel in five evenly distributed points with values: 1 mA; 2 mA; 3 mA; 4 mA and 5 mA that correspond to 20%, 40%, 60%, 80% and 100% of the measurement channel's measuring range.
- From a calibrator, discrete direct current values corresponding to the above-mentioned verification points are sequentially set. For each verification point, following a suitable stabilisation period (establishing convergence of the readings to a certain value) the monitor displays the respective value measured by the measurement channel.
- The measurement result is expressed in units of the measured by the measurement channel quantity. The result is taken and recorded in the protocol.

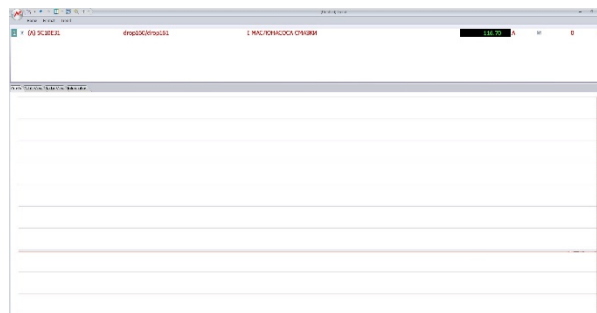


Fig. 2 Trend screen with loaded DB points

### B. Data storage and preparation of reports from metrological inspection

Microsoft Access is a powerful database management platform that is part of Microsoft Office.

It provides an intuitive interface that allows users to easily create, manage and analyse large amounts of information.

The developed application “Channels” is used for processing and storage of data from metrological inspections and generation of reporting documents.

➤ *Home menu*

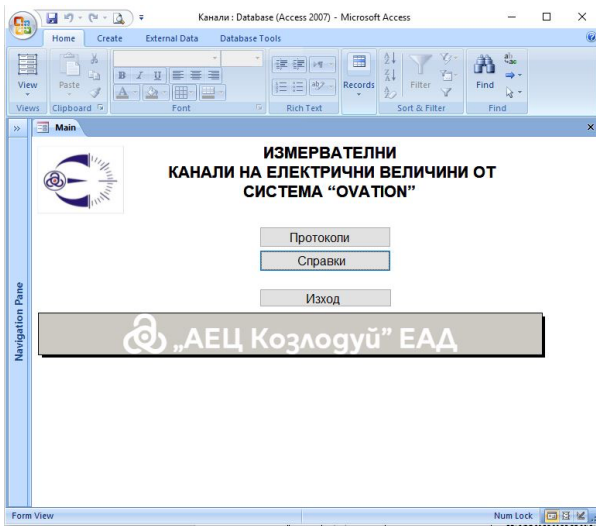


Fig. 3 “Channels” application home screen

There are two main options in the Home menu: Protocols and References.

➤ *Protocols menu*

It includes all forms for data entry and for generating reporting documents ("Protocol attachment" and "Certificate attachment").

Select an asset from the Bar code drop-down menu.

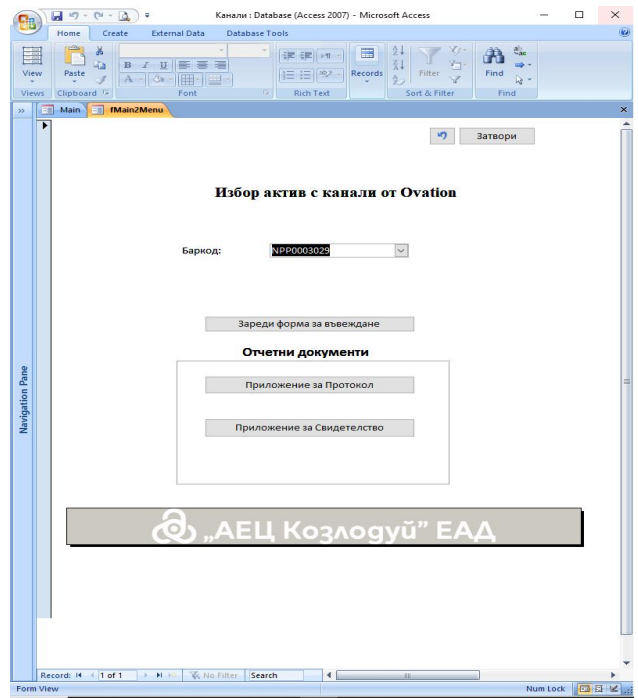


Fig. 4 Selection of Asset with channels from Ovation system

- *Load input form* - form for entering metrological inspection data.
- *Protocol attachment* - it automatically generates a protocol attachment with the results and conclusion of the metrological inspection
- *Certificate attachment* - it automatically generates a certificate attachment for the metrological inspection instruments
- *References*

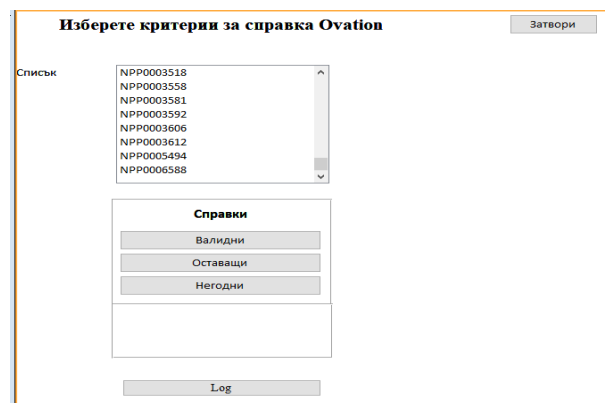


Fig. 5 References

The menu offers references by bar code as well as by validity status.

Баркод:

Техн. обозначение:

Секция:

Група:

Място:

Забележка:

Наименование на ИК

**Ток на ел. дв. на 5TG11D01**

Fig. 6 Data entry section 1

In the first section, the measurement channel data is entered as follows: asset bar code, technical designation, section, group, location and MC name.

Входни стойности:        Мерна ед.

Исходни стойности:

Разрядност 1:  номер по ред

Първичен ИП: Тип , Номер , Място

Вторичен ИП: Тип , Номер , Шкаф

Fig. 7 Data entry section 2

The second section describes the components of the measurement channel:

- Primary converter with its type, serial number and location.
- If the channel contains a secondary converter, it is described with the same data.
- Input/output parameters of the measuring quantity and characters.

От: 0	Пресметната ст-т	0	60	120	180	240	300	Доп. грешка ФВ	1,008
До: 300	Измерена ст-т	0	60,06	120,12	180,03	240,01	299,93	Доп. грешка, %	0,336
Вел-на А	Абс.грешка	0,000	0,060	0,120	0,030	0,010	-0,070		

Дата на проверка:

Период месеци:

Дата на сл. проверка:

Предишен ИК << Следващ ИК >>

Fig. 8 Data entry section 3

In the third section, the data from the metrological inspection are entered: measured values, date of inspection, period and date of next inspection. Details of the employee who carried out the inspection and the conclusion are also recorded.

Once all the data has been entered for all the assets, a protocol is generated.

ПРОТОКОЛ ОТ МЕТРОЛОГИЧНА ПРОВЕРКА		2482.МО.03.СВ.2.2821						
		ПРИЛОЖЕНИЕ 1, стр. 1 / 10						
Техн. обозначение: SEF15V01		Еталонен ел. сигнал: mA						
Първичен ИП: тип - идент. № TDD-LN-5012641, място - Вторичен ИП: тип - идент. № - шкаф/място -		0	1	2	3	4	5	
5.1 Проверка на грешката на измервателния канал		Изчислена ст-т на фаз. величина: V						
Наименование: Напрежение на SEF15, Обхват 0-500 V		Измерена ст-т на фаз. величина: V	0,000	100,000	200,000	300,000	400,000	500,000
		Абсолютна грешка: V	0,000	99,830	199,850	299,800	399,780	499,760
			0,000	-0,150	-0,050	-0,200	-0,220	-0,240
		Доп. грешка: 0,151%	0,755 V					
ЗАКЛЮЧЕНИЕ: ИК е годен и се допуска за използване								
Дата на проверка: 17.5.2024 г. Извършила проверка: М. Кюлянова								

Fig. 9 Protocol attachment

The protocol attachment is generated in pdf format and contains the following information:

- MC data
- measurement data
- details of the employee who carried out the inspection
- date of inspection
- conclusion.

СВИДЕТЕЛСТВО ЗА МЕТРОЛОГИЧНА ПРОВЕРКА				2482.МО.03.СВ.2.2821			
				ПРИЛОЖЕНИЕ 1 стр. 1/3			
№	Технически обозначение	Наименование на измервателния канал	Място	Първичен ИП тип/идентификационен №	Обхват	Вторичен ИП тип/идентификационен №	Абсолютна грешка/допуск
1	SEF15V01	Напрежение на SEF15	-	TKG6103-28110 - TDD-LN-5012641	0 - 500 V	-	0,755 V
2	SEF15V01	Напрежение на SEF11	-	TKG6103-28110 - TDD-LN-5012641	0 - 500 V	-	0,755 V
3	SEF15V01	Напрежение на SEF12	-	TKG6103-28110 - TDD-LN-5012641	0 - 500 V	-	0,755 V
4	SEF15V01	Напрежение на SEF13	-	TKG6103-28110 - TDD-LN-5012641	0 - 500 V	-	0,755 V
5	SEF15V01	Напрежение на SEF14	-	TKG6103-28110 - TDD-LN-5012641	0 - 500 V	-	0,755 V
6	SCV01V01	Налягане измерване 7 кат. 300 V	5HK46	252-XARW, 5HK46, 576890 08	0 - 432 V	-	0,602 V
7	SCV01V01	Налягане измерване 7 кат. 300 V	5HK46	252-XARW, 5HK46, 576890 08	0 - 432 V	-	0,602 V
8	5TG11E01	Ток на ел. дв. на 5TG11D01	5HK46	252-XARW, 5HK46, 576890 08	0 - 300 A	WCM-G02, 5HZ079/A07, 1908596	1,008 A
9	ZE10V02	Напрежение на ZE10	ZE10 ш.4	TKG4131-13114, ZE10 ш.4, TDD-301 57167	0 - 300 V	-	0,433 V
10	ZE10V02	Ток на батерия ZE10	-	TKG4131-13114, ZE10 ш.4, TDD-301 57167	1000 - 1000 A	-	3,020 A

Fig. 10 Certificate attachment

The certificate attachment contains a list of all verified measuring instruments. It is generated in pdf format.

### III. Conclusion.

Implementing an application to automate the generation of metrological inspection reports significantly reduces the processing time. Furthermore, it reduces the likelihood of subjective error. It demonstrates efficiency and reliability in data collection, storage and processing. This enables better management and control of the metrological inspection.

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- [2] Methodology for metrological verification of measurement channels for electrical quantities of OVATION system
- [3] Quality procedure. Reporting documents and marks from metrological inspection and calibration of measuring instruments

# Advanced Techniques for Quality Control in Remote Work Environment

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**Abstract**—This paper addresses a common case where a quality control needs to be performed in another country. For high end products quality control needs to be performed by both the producer and the seller of the item. The seller however may be on a budget that can't afford to travel to the different locations where his products are made or assembled. The paper provides a possible solution to this exact problem.

**Keywords**—VR, AR, remote control, robot, hand tracking, budget, manipulator, remote work, quality control, quality assurance;

## I. INTRODUCTION

The recent pandemic has prompted unconventional work practices, such as remote work, which can greatly benefit many professions, especially those where the physical workspace poses health risks. Apart from safety concerns, remote work also offers the advantage of reducing transportation costs for workers and the potential for hiring foreign labor. By using what has been learned from these practices it is possible to objectively understand what is effective and to what degree and make possible assumptions for further optimization of the way we do things.

## II. REQUIREMENTS

Our objective is quality control, but what do we really need to control the quality of our products. Smell is rarely a reliable sense and touch and feel of texture can be interpreted through sound and other means. Of course, everything depends on the product and what characteristics are important.

Actually, to a degree, quality control on the side of the reseller has twofold effect. Once is, obviously, to guarantee the quality towards their client, which in return further improves the value of that product. Guaranteed quality can be the reason why power tools, for example, of the exact same type can have 10 to 15 times the price difference. Power tools are given as example because with them branding only serves as a guarantee of quality and nothing more. They are rarely seen as luxury items, which can further affect the price, possibly tenfold and even far more.

The second effect of the quality control is to make sure the producer does not skimp on the quality of the produce. In the cases where a 100% quality control of the produce by the reseller may not be possible, it is important to guarantee the

randomness of the picked samples from the batches of produce.

All of these tasks and more can easily be performed by just being there, but that's actually the problem. We are not. But we can technically be there through a series of devices to substitute our presence. Where our eyes aren't, we can place cameras. Where our nose isn't, we can place chemical detectors and sensors to create graph of the detected particles and smell. Where touch is required, obviously, robotic hands can be placed there and to be controlled remotely through the internet. The list of requirements heavily depends on the product itself, but in this paper, we will go over the most common requirements.

And so, each requirement goes with its own device that fulfills it.

## III. THE HARDWARE

### A. On-Site Machinery

Primary among the requirements is the ability to manipulate the object, move it around, maybe squeeze it and so on. That can be cost effectively solved with the minimalistically designed robotic arm proposed for this paper.

In fact, this specific model in figure 1 was created for this paper and is by the same authors.

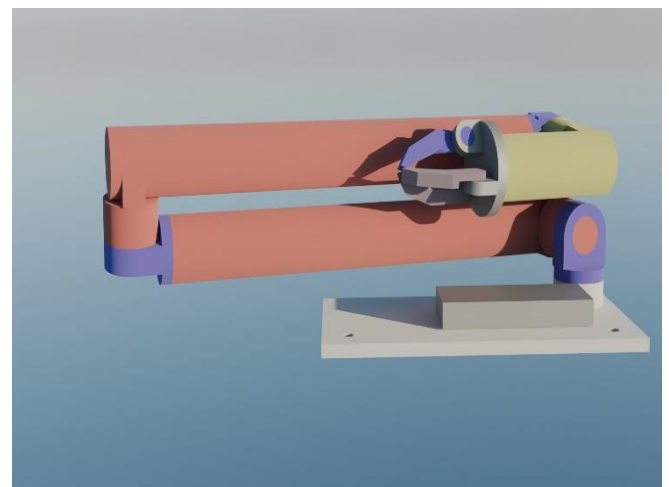


Fig.1. The robot arm

The budget robot comprises of step motors housed within polymer tubes, with a controller concealed within the gray box at the base.

In figures 2 and 3 we can see the installation process.

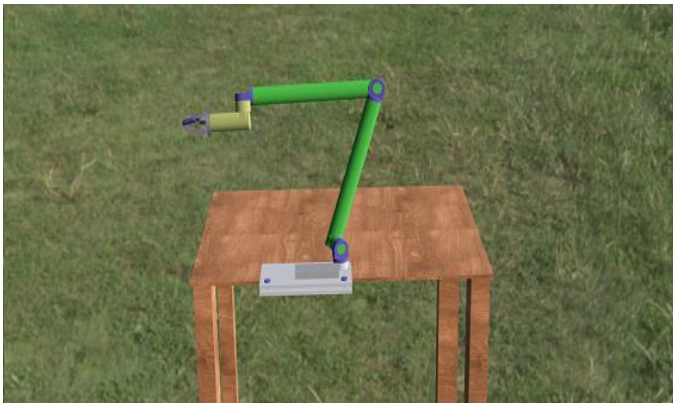


Fig. 2. Installed Robot

As seen in figure 2 the robot perfectly fits at the end of a work table that will also be used for the placement of the sample products. In figure 3 is a more detailed look at how the robot is attached to the table and as we can see it doesn't damage the table itself.

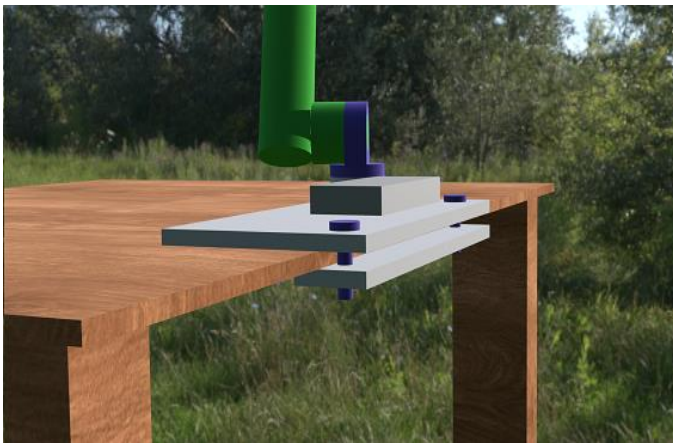


Fig. 3. Assembly Situation

The robot is meant to be cheap and easily portable. So that it can be placed in the various factories where the reseller has products that need examining. Another benefit would be if the robot becomes standard so that the production companies come in pre-equipped with the remote station for examining their produce. That can also help with examining new for the reseller products without the need of samples to be sent all the way to his country. This can save up weeks just from the transport.

A major factor when dealing with robot arms is the "hand" of the arm and what form it uses. As seen in figure 4 for the most common situation the absolute minimalistic pattern is picked.

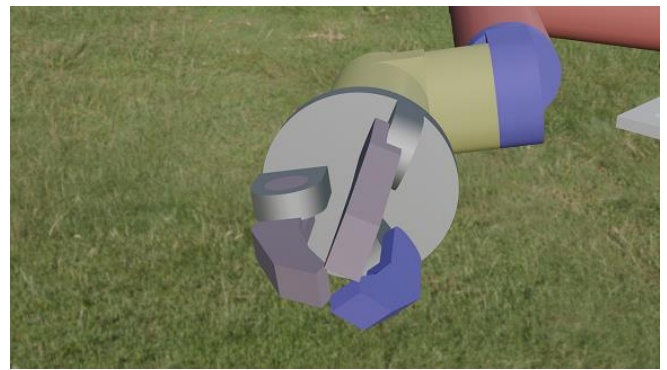


Fig. 4. Robot hand

The simpler the mechanism the less likely to require maintenance or have wear and tear that may affect its function. And by function, it means that this may affect how the user would feel both the hand and the samples when they use it. When a person uses a tool for a long time, they start to feel it like a part of their body even if there are no touch receptors and even there is no physical connection between them and the tool. Just by knowing from experience how strong the grip of the hand is they can determine how soft or squishy a product may be. And with a simpler mechanism is less likely for the results to differ between the first and the last sample for the day. Of course, they can be made as complex as they need to, possibly going as far as to make it near a fully functional human-like hand. The complexity of course will not affect the control of the robot as we are not moving it via buttons or some old-fashioned conventional methods of control. But that will be explained later in the paper.

#### B. Tool set for visual examination.



Fig 5. A camera mounted on a tripod [1]

One of the most obvious tools would be a camera and possibly an added speaker, so that the user can issue commands to the local assistant, if there is a such a person provided by the production company. The camera can be carried to the pile of product boxes before randomly picking the samples that will be used for the quality control. It is strictly important that the assistant is not left to their own devices to pick the samples as they may have placed high quality samples beforehand among a pile of low-quality produce and expect to "randomly" pick the few good ones.

Then the camera can be carried to the table with the robotic arm for the quality control process to begin.

#### IV. THE INTERFACE

This goes in its own chapter as it just may be the most important part of the paper. How do you control a robotic arm like it is yours? And to have that on a budget that is less than a plane ticket and a cheap motel.

Ironically the required hardware on the side of the producer is much higher than that of the reseller and if the robot and the camera are provided by the producer this value adding quality assurance may be just near for free on the side of the reseller. Except for the time of course but that is to be expected.

So, what is the necessary equipment from the side of the reseller? In figure 6 is all they may need to have for the task in this paper.



Fig. 6. Laptop and human hand recognition

The real magic is in the software and the ability to recognize the joints of the human hand. There are free software packages mostly developed through artificial intelligence that can recognize the hand and its motion. All the laptop would need is a good internet connection and a good web camera that can observe the user's hand.

Of course, more complex examples can always be implemented such as the use of VR headsets and fully actuated robots on the production floor. But for most common types of products when the reseller is on a smaller budget this can be sufficient. At least for the start.

Another method for a higher precision would be a device with built in accelerometer and possibly electronic gyroscope such as the device in figure 7.

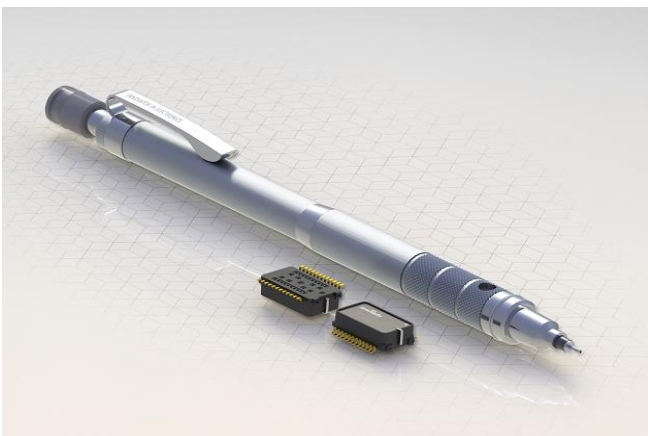


Fig. 7. A pen with accelerometer and a gyroscope [2]

Now as to why this type of device may be needed, it is actually simple. Control of execution. Another device would also be the joysticks that come with the VR headsets as seen on Fig 8.



Fig. 8. VR controllers [3]

The difference is in the quality of the control as you may feel that with hand recognition the control may be insufficient. That being said the software keeps improving, and the quality of the web camera is also a significant factor in all of this. And even at the date of writing this paper the quality of control via hand recognition is sufficient enough for most tasks aside of re-assembly and dis-assembly of a complex product.

#### V. THE SOFTWARE

The software aspect is pivotal to the project's success. On the surface there is a minimalistic robot with a controller, a worker(assistant) and a laptop with a web camera possibly on the other side of the planet. What makes everything work is the software, however it also has a few steps that need to be explained beforehand.

One of the main issues regarding the work with software is getting the reseller to prepare and install the software. If they have sufficient qualification and skill to do so, things would be easier and life would be good. That would also mean they would have higher expectation for the profit margins.

Another thing this paper provides is the opportunity to provide a service that skips the need for the reseller to understand and prepare the highly technical part and instead provides them with a service to remotely control the standard robot arm controllers without even installing anything on their laptops or computers.

The best way to do so is with a browser-based software. The recognition of the hand can still happen on the user's laptop and only the bones with their movement to go from the server of the site of the now added service provider and to be directly transferred to the robotic arm and then the camera signal in the production site to be transferred to the user's laptop.

Making it once and making it into a browser-based service does not have much difference in terms of the work involved. But the later provides far more value for almost the same amount of work. Also, most resellers do not have to be seen as competition as the products they understand and resell are most likely very different. And then there is the client pool which is also likely to differ as they come mostly from social media.

## VI. THINGS TO NOTE

### A. Possible tasks for the robot

The robot arm of course can be used for many different tasks other than quality control. When buying products, it is often cheaper to buy a batch instead of a single product and it is often that 1 or 2 may not have a purpose and are kept as reserve in case one of the used ones breaks or requires repair.

A possible implementation of the robot arm would be the arrangement and preparation of food for example. One of the main goals of this is not the food itself but the training with the robot arm and understanding its mobility. As seen in figure 9 a series of pre made meals would require the picking of the cut fruits and arranging them in the boxes.



Fig.9. Pre-made meal

On one side this is a laborious and if it's happening in the same place as the real body of the user they may as well use their own hands.

Another thing to note is in testing the setup. Having a professional chef or a relative from another town or a country prepare the user a meal can have both the emotional value as well as confirmation that the setup works.

As the 3-finger robot is able to hold a knife, move the fruits and sufficiently move tools to mix and move the items, the platform is perfectly sufficient in performing this kind of task.

There is a high possibility that this type of setups may extend far from the quality control task and into the creation

of remotely operated dark factories. A dark factory also known as a factory without humans is one of the directions our civilization is headed towards.

## VII. CONCLUSION

Modern technology, including neural networks, enables the automation of tasks previously considered unfeasible. While there are lower costs associated with hardware and software, it is also highly possible to automate the quality control of the products. Also, the robots themselves are inexpensive to build once you have the blueprint or at least a model to follow. Again, a quality-controlled product can cost way more than a prototype created solely to complete a task within a company.

Furthermore, the adoption of remote work solutions not only addresses immediate challenges, such as health risks in traditional work environments, but also opens up opportunities for greater workforce flexibility and inclusivity. Remote work allows for the integration of diverse talent pools, including people with physical disabilities.

Additionally, the scalability of this solution holds promise for industries beyond its current task and potentially revolutionizing sectors such as healthcare, education, and entertainment. The adaptability of the technology showcased in this project underscores its potential to transform various aspects of society while also driving innovation and efficiency across different fields.

Looking ahead, future research could explore enhancements to the current system, including advancements in gesture recognition technology, increased automation capabilities, and improved user interfaces. Additionally, one of the long-term impacts that is expected for this optimization is the ability for the reseller to go on a vacation and from his vacation place to check on the produce and its quality.

## ACKNOWLEDGMENT

The authors would like to thank the R&D sector at the Technical University of Sofia for the support.

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# The experience of the geodetic methods application for tanks calibration

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**Abstract**— The application of geodetic measurements, as the content of modern method of tanks calibration distinguishing from traditional volumetric methods, gives the considerable advantages for metrological practice in this field. These advantages are:

- **high efficiency** – measurement time of one tank with team of 1 specialist is from 0,1 to 1 hours depending on it capacity;
- **high accuracy** – error range of measurement capacity: for tank 5000 m<sup>3</sup> and more is  $\pm 0,03\%$ , for tank 50000 m<sup>3</sup> and more is  $\pm 0,01\%$ ;
- **all-weather in-field using availability**: – temperature range is from  $-15\text{ }^{\circ}\text{C}$  to  $+50\text{ }^{\circ}\text{C}$ , – humidity is up to 90 % (also in rain), – wind speed is up to 15 m/s; high safety level is based on contactless (remote) operation principle of using electronic total station or scanner.

To realize all the capabilities of modern geodetic measurement instruments the new software VGS had been developed by SE “Ukrmetrteststandart” scientists and technicians. This software allows to provide at least:

- **high accuracy ensured by centimeter to centimeter calculations** in graduation table of geometrical shape of the walls, bottom and other parts of the tank;
- **processing of the calibration measurements results for tanks with any shape of bottoms** – flat, coned up or down.

**Keywords**— tanks calibration, geodetic measurements, high accuracy, metrological practice, software

## I. INTRODUCTION

The traditional methods of tanks calibration, particularly of huge volume tanks, are gradually replaced by methods based on geodetic measurements with using modern scanning measurement instruments.

## II. METHODS OF TANKS CALIBRATION

These methods are applied to the calibration the tanks of various shapes and different volume: vertical cylindrical:

- steel (outside and inside);
- reinforced concrete (inside);
- spherical (outside and inside).

Capacity of the calibrated tanks varies from 50 m<sup>3</sup> to 500000 m<sup>3</sup>.

The realization of calibration by geodetic methods requires such facilities:

- a set of electronic total station and 3-D scanner;
- an approved method of calibration (verification) as normative document;
- special computer program.

To realize these methods the equipment has to ensure such measurements features:

Electronic total station:

Measurement accuracy:

- angular from 1" to 5";
- linear from 1 to 3 mm in the range from 2 to 200 m.



Fig.1. Spheric tank scanning

Electronic total stations and 3D-scanners ensure:

- contactless (remote) measurements of any point on the tank's surface;
- automatization of measurement at scanning of tank's wall surface;
- autosave results of all measurements in the memory of total station.

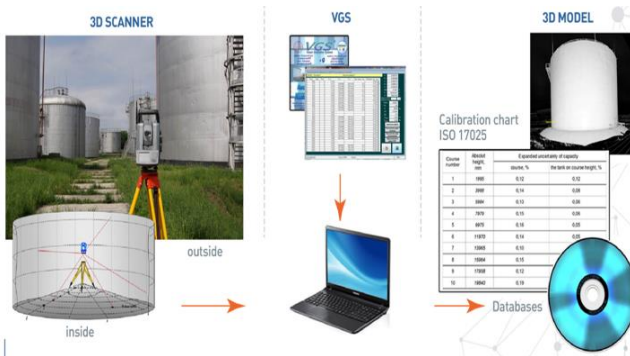


Fig.2. Tanks calibration data processing software

### III. DIFFERENT APPROACHES TO THE GEODETIC MEASUREMENT

Two different schemes of the geodetic measurement are available:

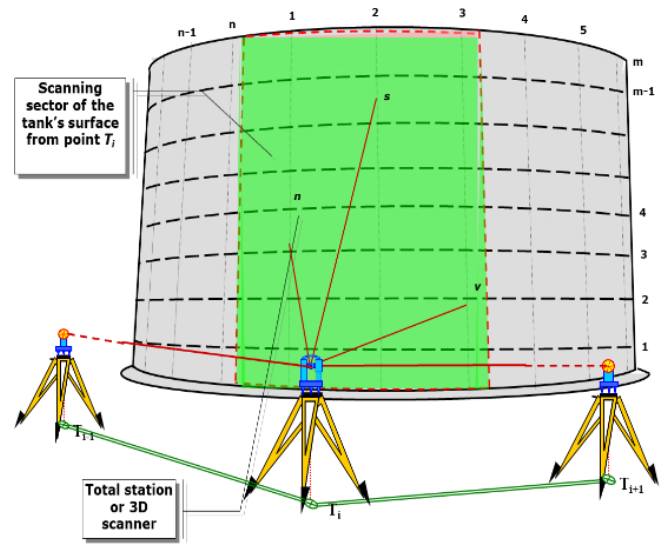


Fig.3. Geodetic coordination method outside of the tank

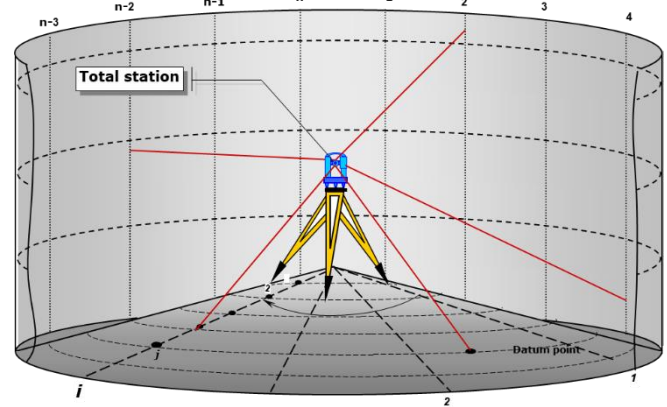


Fig.4. Geodetic coordination method inside of the tank

The essential of the method:

Results of measurements made by electronic total station are presented in polar coordinate system. Coordinates of the points are recalculated upon tank's wall surface into square space system.

Heights of all tank points (bottom, walls, details) are calculated relatively to the horizontal plane, which passes through zero of the graduation table.



Fig.5. Cylindric tank scanning



Fig.6. Cylindric tank scanning



Measure: horizontal, vertical angles and distances  
 The presentation of results: space coordinates X, Y, Z  
 Measurement range: from 0,2 to 300 m  
 Measurement uncertainty of coordinates: from 1 to 3 mm  
 Performance: from 100 thousand to 1 million points per second

Fig.7. 3D-scanners of leading manufacturers

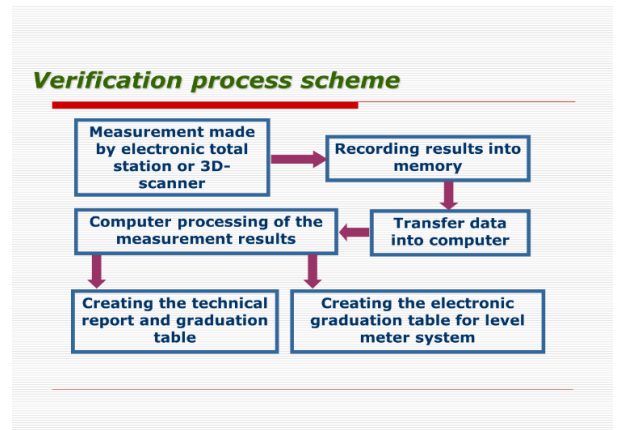


Fig.8. Verification process scheme

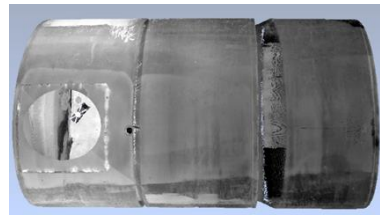
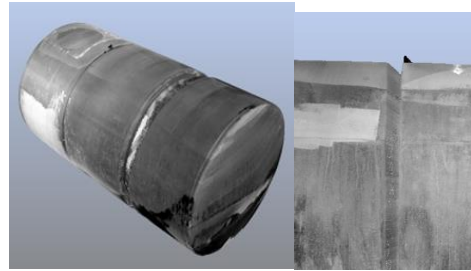


Fig. 9. 3D model of the scanned horizontal tank

3D model of the scanned tank is a cloud of points in result of measurement of 11 million points.

3D model can have distortions in the form of false points obtained from inner details and liquid surface.

3D model needs processing almost always.

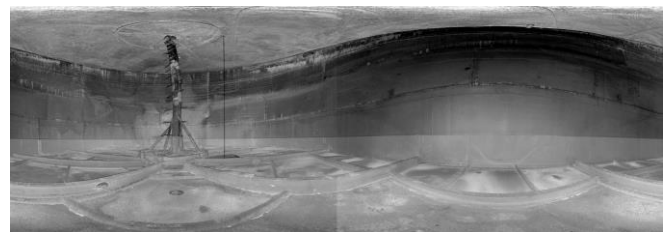
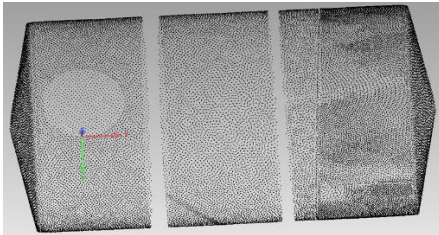


Fig. 10. Vertical tank panorama



Fig. 11. General view of tank in the Scene program



```
# Faro SCENE
# New Model
-0.8256000 0.0692000 1.1911000
-0.8227000 0.0970000 1.2019000
-0.8211000 0.0901000 1.1732000
-0.8206000 0.0732000 1.2196000
-0.8201000 0.0620000 1.1643000
-0.8175000 0.0399000 1.2150001
-0.8223000 0.0409000 1.1865000
-0.8175000 0.1249000 1.1970000
-0.8181000 0.1086000 1.2263000
-0.8165000 0.0930000 1.1454000
-0.8161000 0.1181000 1.1649000
-0.8149000 0.0516000 1.2446000
-0.8172000 0.0873000 1.2492000
-0.8154000 0.0290000 1.1536001
-0.8146000 0.0046000 1.2000001
-0.8191000 0.0130000 1.1748000
-0.8133000 0.0549000 1.1309000
-0.8119000 0.0139000 1.2333000
-0.8145000 0.1393000 1.2236000
-0.8101000 0.1479000 1.1800000
-0.8133000 0.1277000 1.2529000
-0.8097000 -0.0040000 1.1496000
-0.8076000 0.0169000 1.1238999
-0.8127000 -0.0225000 1.1705999
-0.8095000 -0.0357000 1.1980000
-0.8080000 -0.0187000 1.2281000
-0.8102000 0.1186000 1.1273000
-0.8096000 0.0883000 1.1149000
-0.8087000 0.1462000 1.1438000
-0.8102000 0.0605000 1.2771999
-0.8114000 0.0960000 1.2791000
-0.8088000 0.0256000 1.2656000
-0.8056000 0.0637000 1.0931999
```

Fig. 12. 3D model of tank after processing

Processing includes:

- inner details deletion;
- false points deletion;
- empty spaces filling (if necessary);
- model decimation to 50 - 100 thousand points;
- file of coordinates generation;
- transfer to VGS program for compiling graduation tables.

In «Internal details» window their unified geometrical parameters and absolute height are filled.

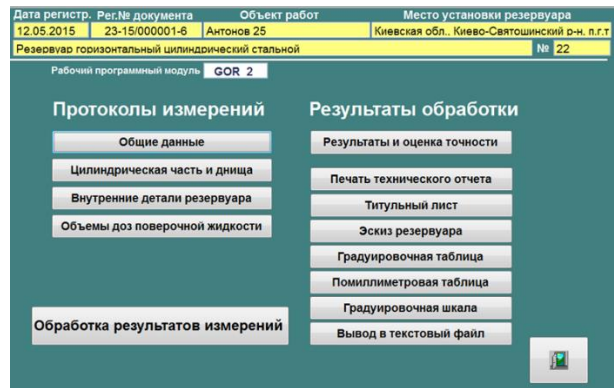


Fig. 13. «Internal details» window

In «General data» window measurement conditions and general characteristics of tank are filled.

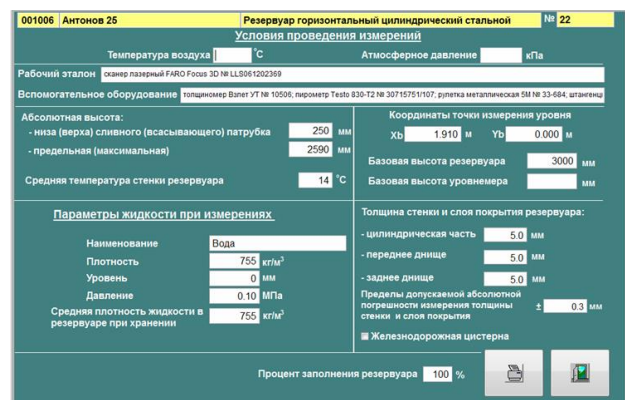


Fig. 14. «General data» window

Combination of measurement results by geometric and volumetric methods is possible for all tank types.

Geometrical tank parameters calculation by the least squares method:

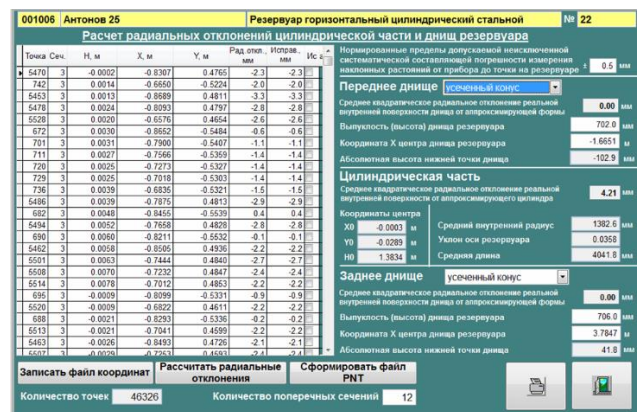


Fig. 15. Geometrical tank parameters calculation

Stages of calculation are the following:

- Coordinates file reading
- Automatic separation of points of cylindrical parts and bottoms

- Axis inclination, length and radius of the cylindrical part calculation
- Bottoms height calculation
- False points deletion in automatic mode
- Formation and measurement of the relief of the tank wall
- Evaluation of geometric parameters and capacity accuracy

Nominal tank capacity, m <sup>3</sup>	Specified uncertainty, % (±)		Actual (experimental), % (±)
	Strapping method	Using geodetic equipment	
To 3000	0,2	0,15	(0,1...0,05)
From 3000 to 5000	0,15	0,1	(0,05...0,03)
More than 5000	0,1	0,05	(0,03...0,01)

Fig. 16. Uncertainty of vertical tanks capacity measurement

Nominal tank capacity, m <sup>3</sup>	Specified uncertainty, % (±)			Actual (experimental), % (±)
	Volumetric	Measuring tape	Using geodetic equipment	
To 15	0,2 or 0,25	1,5	0,5	0,3...0,2
From 15 to 50	0,2 or 0,25	1,0	0,4	0,25...0,15
From 50 to 200	0,2 or 0,25	0,7	0,3	0,2...0,1
More than 200	0,2 or 0,25	0,5	0,2	0,15...0,08

Fig. 17. Uncertainty of vertical tanks capacity measurement

«VGS» program modules are the following:

- BASE (basic) – for creating and editing database of tank types and their sketches, tank owners, enterprises which perform calibration and graduation tables verification, and calibration methods database and technical report on tank calibration;
- VER – for vertical cylindrical steel tanks outside and inside, and reinforced concrete, and insulated inside tanks;
- GOR – for horizontal cylindrical steel tanks, railway tanks inside and outside with flat, conic, elliptical, spherical bottoms and bottoms in the form of spherical segments both convex and concave;
- SFE – for spherical tanks inside and outside;
- ELE – for vertical cylindrical tanks with elliptical and conical bottoms inside and outside;
- TRAN+ARMIG – for parallelepipedal and trench, bunker, casemate types and ship tanks, and other tanks of arbitrary geometrical shape inside



Fig. 18. «VGS» program modules

The advantages of the geodetic method using:  
 high efficiency – measurement time for one tank by one operator amount from 0,1 to 1 hour depending on capacity;

high accuracy – uncertainty range of capacity measured:  
 for tank 5000 m<sup>3</sup> and more ± 0,03 %  
 or 50000 m<sup>3</sup> and more ± 0,01 %;

all-weather availability:  
 temperature range is from – 15 °C to +50 °C  
 humidity is up 90 % (also in rain)  
 wind speed is up to 15 m/s;

high safety:  
 is based on contactless (remote) principle of electronic total station or scanner operation.

Especially developed software facilities ensure such advantages of geodetic methods application:

- high accuracy ensured by centimeter to centimeter calculations in graduation table of geometrical shape of the walls and other parts of the tank;
- processing of the calibration results for tanks of any shape of bottoms;
- possibility to combine the volumetric (filling) and geometrical methods while creating the graduation table.

#### IV. CONCLUSION

The geodetic methods are successfully used by metrologists of SE “Ukrmetrteststandart” already for more than 20 years. It is usually realized on real industrial objects. The number of calibrated by these methods tanks amount more than 10000.

And it was applied into metrological practice of Azerbaijan, Belarus, Kazakhstan, Russia, Turkmenistan, Ukraine.

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# Validation of ultrasonic welding machine using capability index

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## Abstract

Soldering in many cases is replaced by welding. At the same time, the need for technologies and methods to guarantee the quality of electrical connections is increasing. The present work is aimed at the most appropriate technology and the most appropriate method of validation, by implementing a machine capability index by which an ultrasonic welding machine for welding conductive materials is validated before introduction into operation in the production of end products that are on the roads, namely electric vehicle.

## Keywords

*electromobility, joining technology, ultrasonic welding machine, electrical connection, Cmk*

## I. INTRODUCTION

Applying the approach of first validating the machine before release it into operation gives many advantages for subsequent validation of the product and the process as whole, which in the SOP – Start of Production is going to reduce the overall variation in the production process. In the present work, the validation of the ultrasonic welding machine includes (figure 1):

1. Mechanical inspection and adjustment of the mechanical parts;

2. Checking with calibrated devices the output welding parameters in the entire possible range of the machine;

3. Selection of three standard products used specifically for validation, through a short-term study of 50 pcs. and performing capability study of the ultrasonic welding machine, by statistical index Cmk.

As seen in the Ishikawa diagram (fig. 2) the focus is on the machine and the measurement. After successful validation of the ultrasonic welding machine, it will help to be done further statistical studies on the other factors, in order to reduce the total variation of the ultrasonic welding process. The idea of machine validation is by using statistical method – Machine Capability and its machine capability index Cmk to demonstrate that machine has capability to produce parts conforming to specifications. This method gives reason to release the machine in production.

The specific moment here is that the focus falls on the machine and the measurements and also the study is for a short period of time, which is not considering the other factors and production noise during the exploitation of the machine and manufacturing process for long term. Cmk – Machine Capability Index is considered as short-term capability study used for Machine Validation.

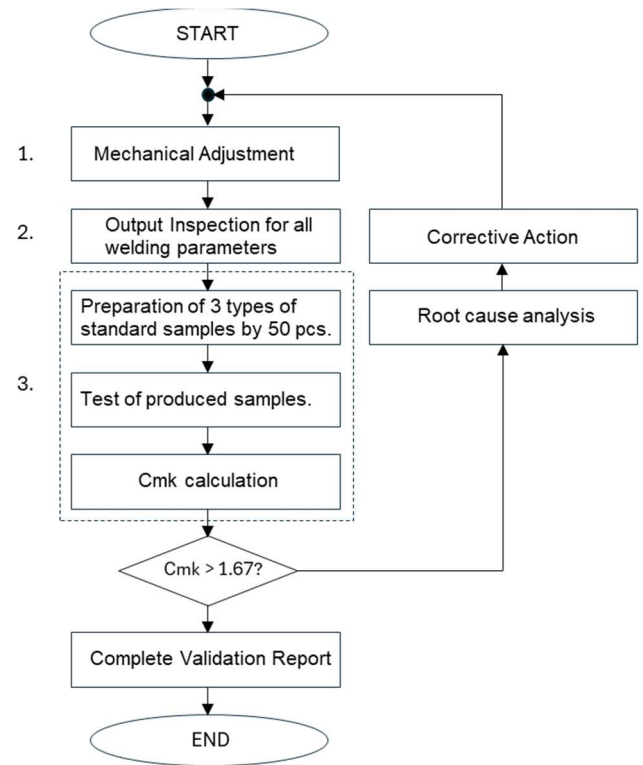


Fig. 1. Process flow of Ultrasonic Welding Machine Validation

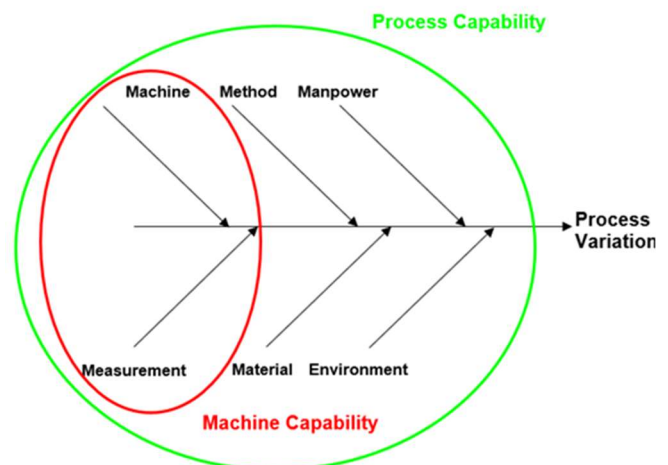


Fig. 2. Using Ishikawa Diagram for presenting that for Machine Validation the focus is on Machine Capability.

## II. METHOD

The special feature of the proposed validation method is that certain steps are followed before preparing the test samples for machine capability study (fig. 1). It is very important that

machine is inspected with external calibrated devices (inspection kit) and adjusted. By this approach all the values reported and recorded by the measuring system in the machine is true. In this case we guarantee that the integrated QMS – Quality Monitoring System in the machine is going to report correct data for SPC and support staff for process improvement. Considering the 3 main steps given in process flow on figure 1, means that machine validation criteria is that machine must cover the following 3 criteria's, in order to be validated and released in production:

- Mechanical adjustment to cover machine producer requirements;
- Output inspection of all welding parameters with external calibrated devices to be within permissible tolerances;
- Cmk for all the 3 splice combinations, which covers whole machine range, to be greater value than 1.67 ( $Cmk > 1.67$ ).

By covering the criteria's mentioned above, it is demonstrating that machine is capable, which allow to complete the documents for machine validation and release in production condition.

### 1. Mechanical inspections and adjustments of the mechanical parts

The mechanical adjustment of the parts is adjusted according to the machine manual released by the manufacturer. Normally are used torque wrenches and special standardised foil 0.02mm for adjustment the distance between anvil plate and sonotrode, which distance must be 0.02mm.

### 2. Checking with calibrated devices the output of welding parameters in the entire possible range of the machine

There are several steps to inspect the output of welding parameters and make necessary corrections or change the parts, which cannot cover the quality criteria for the output parameters.

- First is checked the the measuring system for height with special calibrated tools with switched off power. To be checked the measuring system and its detectability for the non-correct height, with special calibrated tools it is simulating higher and lower dimension with  $\pm 10\mu m$  and compare what Quality Monitoring System – QMS of the machine is displaying. If results are OK, then the heigh measuring system is OK, as well as the QMS regarding the height detection is OK, because it indicates correctly the values during the error simulation. If results are NOK – missing indication, or it is too high deviation in plus or minus direction, then most probable is that height measuring sensor must be changed.
- Checking the measuring system for width according to the instruction of machine producer. If corrections are needed, there are compensation methods mechanically or from machine software to be corrected. If deviation again is in presence, then most probable is that the step motor must be checked or replaced.
- Checking the oscillation system, if it is giving the necessary amplitude, amplitude must be about 23-

$25\mu m$  per side, it means in total 46-50  $\mu m$ . If measured amplitude is out of the admissible tolerances, then most probably the piezoelectric convertor must be replaced.

- Checking of pressure with calibrated pressure gauge. It is set up several pressure in the machine software and it is compared the real output pressure measured from the calibrated pressure gauge. If it is out of tolerance, it is checking the root-cause and if needed proportional valve must be changed. Checking the measuring system for the output of power. Normally is checked with standard accepted values: 1000W, 2000W and 3000W using a special simulator from the machine producer, it is tested what QMS is displaying as an output. In normal condition QMS displays correct values according to the tolerances given from the machine producer. If values are out of tolerance, most probably are some failures related with the ultrasonic generator.

If in step 2 (fig. 1) all results are OK, it means all the results are within tolerances given by the machine producer, only then it is proceeded to the next step – 3 (fig. 1).

### 3. Selection of three standard products used specifically for validation, throught a short-term study of 50 pcs. and performing capability study of the ultrasonic welding machine, by statistical index Cmk

Regarding the standard products used specifically for validation, it is chosen 3 different combinations of wires in order to cover whole ultrasonic welding machine range. It is chosen approximately lower, middle and highest cross-section possible to be welded by the Ultrasonic Welding Machine – UWM. Considering the machine practical welding range, it is chosen splice combinations from 1.05 mm<sup>2</sup> till 20mm<sup>2</sup>. The chose splice combinations are small size 1.05mm<sup>2</sup> splice cross-section (fig. 3), middle size splice cross-section 10mm<sup>2</sup> and large splice cross-section 20mm<sup>2</sup>.

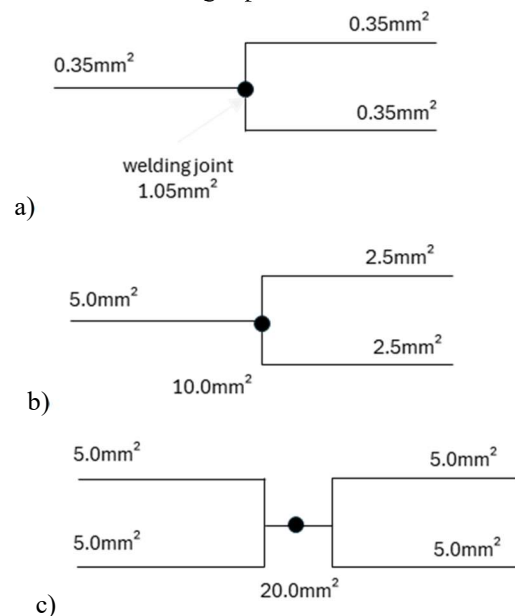


Fig. 3. Used standard splice combinations for Machine Validation purposes. a) 1x0.35mm<sup>2</sup>-2x0.35mm<sup>2</sup>, b) 1x5.0mm<sup>2</sup>-2x2.5mm<sup>2</sup>, c) 2x5.0mm<sup>2</sup>-2x5.0mm<sup>2</sup>

The important in presented machine validation method is that always the same splice cross-sections (combinations of copper stranded wires) are used for machine capability study, as a standard.

The formulas calculating the Cmk is presented:

$$C_{mkl} = \frac{\mu - L}{3\sigma} \quad (1)$$

$$C_{mku} = \frac{U - \mu}{3\sigma} \quad (2)$$

$$C_{mk} = \min \left[ \frac{U - \mu}{3\sigma}, \frac{\mu - L}{3\sigma} \right] \quad (3)$$

where

$C_{mk}$  – Machine Capability Index

$C_{mkl}$  – Machine Capability Index for Lower Value

$C_{mku}$  – Machine Capability Index for Upper Value

$U$  – Upper Specification Limit

$L$  – Lower Specification Limit

$\mu$  – Population of Mean Value

$\sigma$  – Standard Deviation

The Cmk calculations are done for the strength characteristic of the welding joint by pull out test. It means that obtained and processed values for Cmk calculations are from the pull out test. The number of samples size for every splice combination is 50 pieces, here is why below the machine capability index Cmk is added the value “50”. As for pull out test there is no defined upper limit it is used only the lower limit, it means that the calculation of Cmk is for unilateral process, here is why on the index below is added the letter “L” and in the end, a final machine capability index it looks like this:  $C_{mkl50}$ .

The machine capability index  $C_{mkl50}$  is read as following: Machine Capability Index estimating the machine capability for specification that consist lower limit only\*, using sample size of 50 pieces for capability study.

\*It means it is considered, just the LSL – unilaterally. It means that in case of good results, the mean value will be always more than LSL, assuming that the process output is approximately normally distributed.

### III. RESULTS

TABLE I. SUMMARY OF OBTAINED RESULTS FOR SPLICE COMBINATION A<sup>1</sup>

LSL for pull force = 60 N		
results	value	unit
min <sub>50</sub>	82.07	N
max <sub>50</sub>	101.66	N
R(Δ) <sub>50</sub>	19.59	N
μ <sub>50</sub>	91.52	N
σ	5.92	
<b>Cmkl<sub>50</sub></b>	<b>1.77</b>	

<sup>1</sup> Summary of obtained for the combination 3x0.35mm<sup>2</sup> (fig. 3a), LSL=60N and welding parameters: p=1.42bar, w=1.12mm, A=55%, E=130Ws.

TABLE II. SUMMARY OF OBTAINED RESULTS FOR SPLICE COMBINATION B<sup>2</sup>

LSL for pull force = 250 N		
results	value	unit
min <sub>50</sub>	446.12	N
max <sub>50</sub>	532.08	N
R(Δ) <sub>50</sub>	85.96	N
μ <sub>50</sub>	484.05	N
σ	28.30	
<b>Cmkl<sub>50</sub></b>	<b>2.76</b>	

<sup>2</sup> Summary of obtained for the combination 1x2.5-2x5.0mm<sup>2</sup> (fig. 3b), LSL=250N and welding parameters: p=3.33bar, w=4.37mm, A=100%, E=780Ws.

TABLE III. SUMMARY OF OBTAINED RESULTS FOR SPLICE COMBINATION C<sup>3</sup>

LSL for pull force = 380 N		
results	value	unit
min <sub>50</sub>	620.06	N
max <sub>50</sub>	875.76	N
R(Δ) <sub>50</sub>	255.70	N
μ <sub>50</sub>	702.95	N
σ	61.04	
<b>Cmkl<sub>50</sub></b>	<b>1.76</b>	

<sup>3</sup> Summary of obtained for the combination 4x5.0mm<sup>2</sup> (fig. 3c), LSL=380N and welding parameters: p=4.5bar, w=6.14mm, A=100%, E=1830Ws.

TABLE IV. SUMMARY OF OBTAINED CMK RESULTS

Splice Combination			
	Capability Index	<b>Cmkl<sub>50</sub></b>	<b>Cmkl<sub>50</sub></b>
Value	<b>1.77</b>	<b>2.76</b>	<b>1.76</b>

<sup>3</sup> Summary of obtained results for all 3 splice combinations used for Machine Validation – fig. 3.

On table IV is gives the obtained results from the 3 splice combinations. It can be seen that results are positive, as Cmk value is greater that the 1.67, as it was set at the beginning, as quality criteria for capable ultrasonic welding machine.

### IV. CONCLUSION

Based on the obtained results, it can be concluded that the ultrasonic welding machine has passed the validation criteria for all 3 steps of the machine validation process flow given in figure 1, because all results are positive. Machine is capable to produce quality splices to whole possible range Ultrasonic validation report can be completed with the obtained results and USWM can be release in production conditions for SOP.

It is reached the goal of the study:

- Ultrasonic Welding Machine is Validated successfully by using Machine Capability Index Cmk;

- Following certain process flow (fig. 1), the machine validation was done successfully from first time;
- The machine Validation method is implemented successfully and can be used in production for electric vehicles guaranteed reliable SOP and giving initial high quality of electrical connections/joints.

#### **Contribution:**

Through this study is presented approach for validation of ultrasonic welding machine for electrical connections/joints used for electrical vehicles.

It is introduced a new way of presenting the machine capability and it is introduced clear spelling, so that when capability index is seen to be understandable what is behind meaning.

#### **Innovation:**

This study is very actual for 2024 considering that future is for the electric vehicles, because future must be greener, reducing the harmful emissions. It is helping future developments for electric vehicles, where reliable electric connections of wires, batteries and HV electronics are highly required.

#### **Application in practice:**

This study is very practical oriented. The approach presented above and obtained experimental results can be applied directly for machine validations processes in

productions, where is produced electrical and electronic parts for electric vehicles.

#### **ACKNOWLEDGMENT**

I would like to express special Thanks to Mr. Gediminas Miežaitis, for his advices and support on the investigation activities.

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**SECTION VII**  
***IONIZING RADIATION MEASUREMENTS***

# Participation in interlaboratory comparisons, a quality criterion for radioanalytical laboratory measurements

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**Abstract** — The sustainability of quality assured and reliable environmental radiation monitoring is an essential element in the Radioecological Monitoring Program of Kozloduy NPP. Thus, ensuring reliable control and detection of all possible changes in the radiological situation in the vicinity of the nuclear facility.

The Lab capacity is based on well-established in practice, validated techniques and radioanalytical methods within the accreditation scope of the KNPP Radioecological Monitoring Testing Laboratory (RM-TL) according to EN ISO/IEC 17025.

The paper presents the RM-TL participation and experience in the 2022-2023 Interlaboratory Comparisons (ILC) and Proficiency Testing (PT). The statistical analyses show good compliance with the reference values, as a quality and precision guarantee in respect of the environmental monitoring performance at Kozloduy NPP. A good laboratory practice is in place in the radioanalytical field, comparable with the international level.

**Keywords** — interlaboratory, comparison, calibration, measurement, testing, radioanalytical, accreditation, ALMERA

## I. INTRODUCTION

There are 50 years of experience in detailed and systematic studies of all major environmental components – air, water, soil, plants, food, etc. The scope of monitoring comprises: Sampling, laboratory-based, and automated radiation monitoring within the 30-km supervised area (SA), and the on KNPP site. All the measurements are carried out by accredited ISO17025 RM Laboratory.

In scope of accreditation are various validated radioanalytical methods to assess and quantify technogenic radioactivity in the environment. The main tool for ensuring the quality of measurements and radioanalytical analyses is inter laboratory quality control (QC) by regular participation in interlaboratory comparisons (ILC) and proficiency tests (PT). Main results for 2023 are described in the paper.

ALMERA-IAEA Membership since 2005 of KNPP-RM Laboratory helps us to achieve comparability of analytical results, traceable to the SI system. ALMERA also contribute development of reliable radioanalytical methods;

## II. MAIN RADIOANALYTICAL METHODS

In RM Laboratory are used well-established in practice, validated techniques and radioanalytical methods (BJM/BJMK) within the accreditation scope of the Radioecological Monitoring Testing Laboratory (RM-TL) under БДC EN ISO 17025, as follow:

- Dosimetry – Thermo-luminescent dosimetry (TLD), Instrumental low-background dosimetry;
- Gamma-ray spectrometry (HPGe) – Direct spectrometry measurements, Radiocaesium in water (radio-chemical/RCh-analysis);
- Low-background radiometry – Total alpha/beta activity;
- Liquid scintillation spectrometry – Tritium in water, Tritium and carbon-14 in gas and aerosol emissions, Determination of Sr isotopes (RCh-analysis);
- Alpha spectrometry – Pu, Am Cm isotopes (RCh-analysis).

For the purposes of interlaboratory comparisons, validated methods BLM1, BLM2, BLM3, BLM4 and BLM5 are used. Measurement conditions are related to the sample activity and expected sensitivity (MDA) of analyses.

Benefits of Interlaboratory Comparisons (ILC) and Proficiency Testing (PT) are:

- Ensuring output comparability on a national and international level;
- Verifying the calibration of the testing equipment and devices;
- Verifying the laboratory analysis and measurement methods used;
- Personnel experience and development;
- Reliability of the reported results;
- Recognition of the laboratory's competence;
- Successful maintenance of the EN ISO/IEC 17025 accreditation;
- International collaboration and exchange of laboratory practices;
- ALMERA/IAEA membership (since 2005);
- Maintaining emergency preparedness, etc.

## III. QUALITY CONTROL OF LAB MEASUREMENTS

Quality assurance (QA) of measurements and analyses in the radioanalytical laboratory is a basic prerequisite for effective and reliable radiation control. It is necessary to perform QA at all stages of radioecological monitoring:

sampling, transportation and storage of samples, physicochemical preparation of samples, radiochemical analyses, measurement of radioactivity, calculations, evaluation and reporting of results. At the heart of this process is the analysis of samples for quality control, by conducting internal laboratory and external laboratory control.

Internal laboratory control includes:

- analyzing blank samples ("blank samples") in order to detect possible contamination of measuring equipment, laboratory equipment and reagents;
- analyzing labeled samples ("blind/spiked samples") containing a certain imported activity of one or more radionuclides;
- analyzing duplicate samples ("duplicate samples") to control the reproducibility of the results.

External laboratory control includes:

- analyzing standardized samples ('reference materials') with known chemical and radionuclide composition. In these cases, it is necessary that the matrices of the standardized samples correspond to or are close to those of the routinely determined samples;
- participation in national and/or international inter-laboratory comparisons of samples (inter-comparison samples).

The external laboratory control in the RM department is carried out through regular annual participation in international and national inter-laboratory comparisons. The analysis of comparative samples is the main criterion for guaranteeing the accuracy of the measurements and eliminating systematic errors in the overall course of the analyses, since the subjectivity associated with the internal laboratory control is completely avoided.

The results of the participation of the RM Department in the international and national inter-laboratory comparisons for 2023 and previous year show established good laboratory practice, in relation to the established statistical criteria.

For the past two years RM-TL participated internationally in PTB/BfS (Germany) ILC's, ALMERA/IAEA Proficiency Test, as well as Interproject Ltd ILC on national level. The results are subject to a thorough control during the accreditation audits by Executive Agency "Bulgarian Accreditation Service", according to the requirements of item 7.2.2 Validation of methods and item 7.7 Ensuring the validity of the results, БДС EN ISO/IEC 17025:2018.

#### IV. INTERLABORATORY COMPARISONS (ILC) AND PROFICIENCY TESTING (PT)

Results of RM-TL Participations in ILC & PT, 2022-2023:

1) BfS-PTB, Germany, Bericht 44. Ringversuch „Fortluft 2022“, Kontrolle der Eigenüberwachung radioaktiver Emissionen aus Kernkraftwerken (Fortluft) [1]:

- Gamma ray spectrometry (G1/BJM1) of filter, PTB No. 2022-1521
- 126 participants from Europe
- Samples (Spiked) radionuclides – <sup>57</sup>Co, <sup>60</sup>Co, <sup>95</sup>Zr, <sup>95</sup>Nb

- $\xi$  Evaluation of the laboratory participation, where the result may be:

Equation 1

$$\xi = \frac{\bar{A}_i - A_{\text{Soll}}}{\sqrt{u^2(A_i) + u^2(A_{\text{Soll}})}}$$

- $A_i$  and  $A_{\text{Soll}}$  : average value from laboratory measurements and Sollwert
- $u(A_i)$  and  $u(A_{\text{Soll}})$  : Standard uncertainty of the average laboratory value and Sollwert
- Acceptable,  $[z, \xi] \leq 2$ ; Warning,  $2 < [z, \xi] < 3$ ; Not acceptable,  $[z, \xi] \geq 3$

Radionuclide	Certified Value	RM-TL Value	Relative bias, %	$\xi$ – Score
	(A ± U), Bq/g			
<sup>57</sup> Co	3.08 ± 0.07	2.965 ± 0.043	-3.73	0.36
<sup>60</sup> Co	2.07 ± 0.05	1.974 ± 0.059	-4.62	0.40
<sup>95</sup> Zr	5.18 ± 0.21	4.930 ± 0.168	-4.82	0.42
<sup>95</sup> Nb	10.90 ± 0.46	10.744 ± 0.211	-1.42	0.09

Table 1

The analysis of reported results in Table 1 shows that:

- The average value of six reported measurements was used to evaluate the laboratory. (Lab. No 65)
- ISO 13528:2022, Statistical methods for use in proficiency testing by interlaboratory comparison were used.
- The obtained results show very good accuracy for low-active samples with relative bias from the reference value for all radionuclides below 4.8%.

2) BfS, Bestimmung von Alpha- und Betastrahlern in Wasser, Ringversuch 2/2022, BfS report UR – 01/2023 [2]

- Alpha (BJM4/5) and beta (BJM2/3) spectrometry, ICM of model and real water, BfS 1M/2022 and 1R/2022
- 56 participants from Europe
- Samples (spiked) radionuclides - <sup>3</sup>H, <sup>89</sup>Sr, <sup>90</sup>Sr, <sup>234</sup>U, <sup>235</sup>U, <sup>238</sup>U, <sup>238</sup>Pu, <sup>239/240</sup>Pu, <sup>241</sup>Am, <sup>244</sup>Cm
- The fit-for-purpose testing criteria [4] are as follows:
- Criterion,

Equation 2

$$Z_{\text{Wert}} = \frac{C_L - C_S}{S}$$

- Acceptable (A),  $[Z_{\text{Wert}}] \leq 2$
- Warning (W),  $2 < [Z_{\text{Wert}}] < 3$
- Not acceptable (N),  $[Z_{\text{Wert}}] \geq 3$
- $S = 0.1 \cdot C_S$  for ICM, L12/BJM2
- $S = 0.2 \cdot C_S$  for A24/BJM4/5, C11/BJM3
- $C_L$  : Average value from laboratory measurements L

- $C_S$ : Reference value (Sollwert)
- $S$ : Maximum acceptable relative bias (MARB)
- Criterion,

Equation 3

$$\zeta = \frac{C_L - C_S}{\sqrt{u^2(C_L) + u^2(C_S)}}$$

- $u(C_L)$ : Standard uncertainty of the average laboratory value (L) vs. the average value of all laboratories with excluded outliers.
- $u(C_S)$ : Standard relative reference value uncertainty (Sollwert)
- Applying both statistical criteria, the results are evaluated and shown in Table 2:

z	ζ	Critical comment	Recommended actions
< 2	< 2	Acceptable	not required
< 2	> 2	The result meets the accuracy criteria, but the measurement bias is larger than the one provided by the participants	Recalculation for the purpose of verifying the measurement uncertainty
> 2	< 2	The result is pretty inaccurate, the calculated measurement uncertainties are probably higher than the normally acceptable bias	Verify the reliability of the measurement method
> 2	> 2	The result is excessively inaccurate	Verify the method's fit-for-purpose features

Results for Probe 1/2022, Modellwasser					
Nuclide	Average RM-TL value (Mittelwert)	Reference value (Sollwert)	z-wert/ Evaluation	ζ-wert/ Evaluation	Accuracy, %
<sup>3</sup> H	42.9	39.8	0.772 / A	0.472 / A	+7.8
<sup>89</sup> Sr	72.4	85	0.744 / A	1.02 / A	-14.8
<sup>90</sup> Sr	11	12.7	0.663 / A	1.01 / A	-13.4
<sup>234</sup> U	0.796	0.840	0.530 / A	0.469 / A	-5.2
<sup>235</sup> U	0.0368	0.0390	0.577 / A	0.847 / A	-5.6
<sup>238</sup> U	0.800	0.857	0.665 / A	1.04 / A	-6.7
<sup>238</sup> Pu	0.611	0.757	0.964 / A	1.59 / A	-19.3
<sup>239/240</sup> Pu	0.814	0.898	0.468 / A	0.735 / A	-9.4
<sup>241</sup> Am	0.775	0.789	<0.10 / A	0.132 / A	-1.8
<sup>244</sup> Cm	0.472	0.551	0.721 / A	1.12 / A	-14.3

Results for Probe 2/2022, Realeswasser					
Nuclide	Average RM-TL value (Mittelwert)	Reference value (Sollwert)	z-wert/ Evaluation	ζ-wert/ Evaluation	Accuracy, %
<sup>3</sup> H	63.7	59.0	0.780 / A	0.461 / A	+8.0
<sup>90</sup> Sr	2.86	3.34	0.714 / A	1.04 / A	-14.4
<sup>234</sup> U	0.307	0.326	0.586 / A	0.492 / A	-5.8
<sup>235</sup> U	0.0159	0.0216	2.65 / W	3.73 / N	-26.4
<sup>238</sup> U	0.525	0.528	<0.10 / A	<0.10 / A	-0.6
<sup>238</sup> Pu	0.154	0.154	<0.10 / A	<0.10 / A	+0.0
<sup>239/240</sup> Pu	0.204	0.206	<0.10 / A	<0.10 / A	-1.0
<sup>241</sup> Am	0.221	0.228	0.160 / A	0.209 / A	-3.1
<sup>244</sup> Cm	0.199	0.190	0.239 / A	0.258 / A	+4.7

Table 2

The analysis of reported results shows that:

- The average value of two reported measurements is used for evaluating the laboratory. (lab. No 49- 1)
- ISO 13528:2022, Statistical methods for use in proficiency testing by ILC is applied.
- The model water results (Probe 1M/2022) are of good accuracy for the analyses within the accreditation scope and for the out of-scope analysis (<sup>234</sup>U, <sup>235</sup>U and <sup>238</sup>U are determined based on the ICM method), where the reference value bias (Sollwert) do not exceed 19.3% for low-active sample.
- The RM-TL criteria have been met (accuracy <15% for high-active samples and <30% for low-active samples).
- The two criteria of the organiser (z-wert > 2 and ζ-wert) of the comparison have been met for all nuclides.
- The real water results (Probe 1R/2022) are of good accuracy with expert-determined value bias (Gesamtmittelwert) not exceeding 14.4% for the accredited methods.
- <sup>234</sup>U, <sup>235</sup>U and <sup>238</sup>U have been determined based on the ICM method, which is outside the scope of the accredited methods at the RM-TL.
- Only for <sup>235</sup>U the accuracy is -26.4%, which results in z-wert > 2 and ζ-wert > 2, and the result is not acceptable.

3) BfS, Bestimmung von Gammastrahlern in Wasser Ringversuch 1/2023, BfS report UR – 01/2024 [3]

- Gamma spectrometry (BJM1) of model and real water, BfS 1M/2023 and 2R/2023
- 67 participants from Europe
- Samples (spiked) radionuclides – <sup>22</sup>Na, <sup>54</sup>Mn, <sup>57</sup>Co, <sup>60</sup>Co, <sup>88</sup>Y, <sup>134</sup>Cs, <sup>137</sup>Cs, <sup>133</sup>Ba, <sup>152</sup>Eu, <sup>212</sup>Pb, <sup>207</sup>Bi, <sup>241</sup>Am
- The fit-for-purpose testing criteria [4] are the same as previous BfS, Ringversuch 2/2022
- The obtained results are of very good accuracy, with the deviations from the reference value not exceeding 5.6 %. This confirms the high quality of gamma spectrometry measurements at RM-TL, KNPP.
- The two criteria of the comparison organizer are met for all nuclides. For <sup>60</sup>Co both estimates (z-wert and ζ-wert) do not exceed 0.1.

Results for Probe 1/2023, Modellwasser					
Nuclide	Average RM-TL value (Mittelwert)	Reference value (Sollwert)	z-wert/ Evaluation	ζ-wert/ Evaluation	Accuracy, %
<sup>54</sup> Mn	18.3	17.9	0.252 / A	0.301 / A	+2.2
<sup>57</sup> Co	23.1	23.6	0.250 / A	0.310 / A	-2.1
<sup>60</sup> Co	30.5	30.6	<0.10 / A	<0.10 / A	-0.3
<sup>134</sup> Cs	53.6	56.8	0.576 / A	0.753 / A	-5.6
<sup>137</sup> Cs	12.0	12.1	0.157 / A	0.192 / A	-0.8
<sup>241</sup> Am	4.22	4.09	0.318 / A	0.293 / A	+3.2

Results for Probe 2/2023, Realeswasser					
Nuclide	Average RM-TL value (Mittelwert)	Reference value (Sollwert)	z-wert/ Evaluation	ζ-wert/ Evaluation	Accuracy, %
<sup>22</sup> Na	1.99	2.04	0.245/A	0.272/A	-2.5
<sup>54</sup> Mn	0.274	0.265	0.321/A	0.249/A	3.4
<sup>60</sup> Co	3.46	3.49	< 0.10/A	< 0.10/A	-0.9
<sup>134</sup> Cs	3.76	3.58	0.503/A	0.555/A	5.0
<sup>137</sup> Cs	5.99	5.96	< 0.10/A	< 0.10/A	0.5
<sup>133</sup> Ba	2.01	2.04	0.172 /A	0.195/A	-1.5
<sup>152</sup> Eu	3.90	3.98	0.201/A	0.237/A	-2.0

Table 3

#### 4) IAEA-TERC-2023-02 ALMERA Proficiency Test

- Exercise for determination the content of man-made radionuclides in water, soil and surface contamination of a simulated filter. [6]
- A total of 99 laboratories successfully reported data in the IAEA-TERC-2023-02 ALMERA proficiency test exercise. Our laboratory is No.85.
- Target radionuclides – alpha, beta & gamma emitters
- 5 PT spiked samples: Sample 1 (water, <sup>60</sup>Co, <sup>241</sup>Am, <sup>3</sup>H, <sup>234</sup>U, <sup>235</sup>U, <sup>238</sup>U), Sample 2 (water, <sup>134</sup>Cs, <sup>137</sup>Cs, <sup>125</sup>Sb, <sup>90</sup>Sr), Sample 3 (QC), Sample 4 (Japanese soil, <sup>134</sup>Cs, <sup>137</sup>Cs), Sample 5 (filter, <sup>134</sup>Cs), Sample 6 (filter, <sup>134</sup>Cs)
- Evaluation criteria of results [7, 8]:

Results reported by participants were evaluated using the following stepwise approach. The evaluation follows the methodology applied for the annual IAEA proficiency testing schemes in the areas of radionuclide measurements and trace element analysis.

Relative bias (Samples 1, 2, 4, 5, 6 and 7) The relative bias is the relative difference between the reported and the target value (the best estimate of the true value)

Equation 4

$$Bias_{relative} = \frac{Value_{reported} - Value_{target}}{Value_{target}} * 100\%$$

The relative bias is compared to the Maximum Acceptable Relative Bias (MARB) which has been determined for each property value, considering the analytical methods, the analyte level in the sample and the complexity of the analysis. When  $|Bias_{relative}| \leq MARB$ , the result is rated "Accepted (A)" for trueness.

Evaluation approach for radionuclide activity concentration values (Samples 1, 2 and 4) and activity values per sample (Samples 5, 6 and 7) Based on fit-for-purpose and good laboratory practice principles, the expanded relative uncertainty should cover the relative bias (as defined in 2.1): The P value corresponds to the relative combined uncertainty of the relative bias:

Equation 5

$$P = \sqrt{\left(\frac{u_{target}}{A_{target}}\right)^2 + \left(\frac{u_{reported}}{A_{reported}}\right)^2} * 100\%$$

The relative bias is then compared to the expanded uncertainty of the relative bias:

Equation 6

$$|Bias_{relative}| \leq k * P$$

where k is the coverage factor: k = 2.58 for a level of confidence of 99%. When the above criterion is fulfilled, the reported result is not significantly different from the target values considering the uncertainties associated with both values. The reported uncertainty of measurement is large enough to cover the bias of the method. In addition, the P value is compared to the MARB.  $P \leq MARB$

When this criterion is fulfilled, the measurement uncertainty is not overestimated and fit-for-purpose in relation to the MARB criterion of this PT exercise. When both criteria related to the measurement uncertainty are fulfilled, the reported result is rated "accepted (A)" for precision (measurement uncertainty). The result is rated "Not Accepted (N)" for precision if either of the two conditions are not fulfilled. The final score is assigned according to the detailed evaluation described above. The possible scores are listed below:

- "Accepted (A)" when both, trueness and precision were rated "Accepted"
- "Not Accepted (N)" when the trueness rating is "Not Accepted"
- "Warning (W)" when the trueness rating is "Accepted" but the precision rating is "Not Accepted"

Evaluation parameters calculated for intercomparison analyte values. Z-Score

The Z score provides information on the trueness of the reported value in relation to the standard deviation for proficiency assessment  $\sigma_{PT}$ , which is assigned based on fitness for purpose.

Equation 7

$$z = \frac{Value_{reported} - Value_{target}}{\sigma_{PT}}$$

The following criteria apply for performance ratings based on obtained z scores

- $|z| \leq 2$  ... accepted (A)
- $2 < |z| < 3$  ... questionable (Q)
- $|z| \geq 3$  ... not accepted (N)
- Reported results for the analyzed PT samples are evaluated as follows:

Results for Sample 1 (water)				
Nuclide	Reference values	RM-TL value (Lab. 85)	Rel. Bias %	P-Test %
	Activity (A ± u), Bq/kg			
<sup>3</sup> H	29.0 ± 1.5	33.66 ± 5.05	16.07	15.87
<sup>60</sup> Co	14.7 ± 0.7	14.4 ± 0.7	- 2.04	6.80
<sup>241</sup> Am	22.3 ± 1.1	22.8 ± 1.1	2.24	6.90
<sup>234</sup> U	5.44 ± 0.27	4.80 ± 0.48	- 11.76	11.16
<sup>235</sup> U	0.260 ± 0.01	0.221 ± 0.018	- 15.00	9.01
<sup>238</sup> U	5.60 ± 0.28	4.82 ± 0.38	- 13.93	9.34

Results for Sample 2 (water)				
Nuclide	Reference values	RM-TL value (Lab. 85)	Rel. Bias %	P-Test %
	Activity (A ± u), Bq/kg			
<sup>125</sup> Sb	73.0 ± 3.6	71.4 ± 7.1	-2.19	11.10
<sup>134</sup> Cs	40.0 ± 2.0	38.6 ± 3.9	- 3.50	11.27
<sup>137</sup> Cs	44.1 ± 2.2	44.6 ± 2.2	1.13	7.02
<sup>90</sup> Sr	14.2 ± 0.7	14.1 ± 2.0	- 0.70	15.02

Results for Sample 4 (Japanese soil)				
Nuclide	Reference values	RM-TL value (Lab. 85)	Rel. Bias %	P-Test %
	Activity (A ± u), Bq/kg			
<sup>134</sup> Cs	6.93 ± 0.50	6.9 ± 0.7	-0.43	12.45
<sup>137</sup> Cs	270 ± 17	284 ± 14	5.19	8.00

Results for Sample 5 (simulated filter)				
Nuclide	Reference values	RM-TL value (Lab. 85)	Rel. Bias %	P-Test %
	Activity (A ± u), Bq/kg			
<sup>134</sup> Cs	5.40 ± 0.21	5.1 ± 0.5	-5.56	10.55

Results for Sample 6 (simulated filter)				
Nuclide	Reference values	RM-TL value (Lab. 85)	Rel. Bias %	P-Test %
	Activity (A ± u), Bq/kg			
<sup>134</sup> Cs	7.84 ± 0.31	7.6 ± 0.7	-3.06	10.02

Table 4

The final rating for all radionuclides reported by LI-RM in the five analyzed samples is an "accepted" result status, which corresponds to a satisfactory performance.

The participation of LI-RM in 2023 in the proficiency test IAEA-TERC-2023-02, organized by the International Atomic Energy Agency (IAEA, Austria), with tests to determine gamma-, alpha- and beta-emitting radionuclides in water samples, gamma-emitting radionuclides in soil and a simulated filter has been evaluated by the organizer as successful in terms of accuracy and uncertainty for all nuclides in and out of accreditation range.

A high accuracy was achieved in the analysis of the samples for the gamma-emitting radionuclides for the measured matrices (max deviations from the reference values did not exceed 5.56 %). The max deviation from the reference activity of <sup>3</sup>H is +16.1 %, while for the reference activity of <sup>90</sup>Sr does not exceed 0.7%.

The competence and qualification of the laboratory personnel, as well as the suitability and correct application of the validated in-laboratory methods are confirmed.

5) ILC by INTERPROJECT LTD under a technical project for fit-for-purpose testing No. IP-UW-199/2023

- RM-TL participates in fit-for purpose test No. IP-UW-199/2023 under laboratory No. PIBU/16-14.
- Tests to determine natural uranium, total alpha activity and total beta activity.
- Underground (spring) water sample
- Technical device - Low-background alpha/beta radiometric instrumentation Protean TC/09/PR
- Total alpha in compliance with "Methodology to determine total alpha activity in water" - BJM8/2010
- Total beta under "Methodology to determine total beta activity in air, water, milk, and vegetation" - BJM7/2010
- Natural uranium is in accordance with ISO 17294-2 „Water quality - Application of inductively coupled plasma mass spectrometry (ICP-MS), Part 2: Determination of selected elements including uranium" [5], where ICP mass-spectrometer is used.
- Four results for each of the water sample measurement indicators have been submitted.
- The Z-criterion and 3S-criterion for evaluation have been applied,

Equation 8

$$z_i = \left| \frac{X_i - \bar{X}}{S} \right|$$

- where  $X_i$  is the average result and  $S_i$  is the RMS bias
- The participation is successful if both criteria are met:  $X - 2S \leq X_i \leq X + 2S$        $-2 \leq z_i \leq 2$

Parameter	Assigned value, $X \pm S$	RM-TL value $X_i \pm S_i$	$Z_i$ Cl: $X \pm 1S$	Evaluation
	Activity (A ± u), Bq/kg			
<b>Total alpha</b>	1.42 ± 0.83	1.23 ± 0.30	-0.23	Acceptable
<b>Total beta</b>	0.57 ± 0.24	0.36 ± 0.01	- 0.87	Acceptable
<b>Natural uranium</b>	0.079 ± 0.016	0.081 ± 0.001	0.16	Acceptable

Table 5

The analysis of reported results shows that:

- The participation is evaluated as successful for all characteristics (Certificate No IP-UW-199-14/ 2023).
- The results from IP-UW-199-14/2023 can be used to validate BJM8/2010 for  $\alpha/\beta$  instrumentation, TC/09/PR.

## V. CONCLUSIONS

- The quality of the performed analyses and measurements is ensured on a national and international level via regular participations in

prestigious interlaboratory comparisons (ILC) and proficiency tests (PT), organised by IAEA-ALMERA, BfS-PTB, National ILC providers, etc.

- A good laboratory practice (GLP) has been established in conformity with leading international standards.
- Kozloduy NPP's radioecological monitoring accreditation under ISO 17025 (БСА № 154ЛН) is an official recognition of its competence and reliability.
- The available analytical capacity and technical instrumentation for on-site and environmental radiation monitoring provide reliable monitoring of the radiation status with an option to detect any deviation from typical background levels.



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# Participation of Laboratories of Personal Dosimetry, Control Centre (Kozloduy NPP EAD), in European Interlaboratory Comparison EIVIC-2020

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**Abstract:** The paper presents the results of the interlaboratory comparison EIVIC-2020 in which laboratories performing whole-body measurement of gamma-emitters took part. Measurements and analysis were performed on provided by the Organiser anthropomorphic phantoms containing unknown gamma-emitting radionuclides with unknown activity. The results of the measurements performed by the participants were processed by the Organiser and compared with target (assigned) activity values assessed using specific criteria according to the standards ISO 28218 and ISO 13528.

**Keywords:** Interlaboratory comparison, gamma-spectrometry, whole-body counting, target (assigned) value.

## I. INTRODUCTION

The interlaboratory comparison is a project of the European Commission (EC, DG-ENER). The project is coordinated by the EURADOS (European Radiation Dosimetry Group), together with the IRSN-France and BfS-Germany and in collaboration with the CIEMAT-Spain and the KIT-Germany. The subject of the European interlaboratory comparison are instruments for measurement of gamma-emitters in a human body. 43 whole-body counters from 21 countries took part in the intercomparison.

The determination of the content of man-made radionuclides in the human body is part of a method to estimate the radionuclides intake and the expected individual effective dose from internal exposure. The Whole-Body Counting Section, Inspection Body Type C, Personal Dosimetry Control Centre participated with two gamma-spectrometry systems – WBC-1 and WBC-2, and the purpose of the participation was to check the technical preparedness and competency in the area of whole-body counting. Following the announcement of intercomparison results, an internal

analysis is carried out and, if required, measures are taken to improve the quality of the work in respect of calibration of the systems and subsequent measurements.

## II. THE INTERCOMPARISON OBJECTS WERE THE COUNTERS IN OPERATION.

The WBC-1 and WBC-2 gamma-spectrometry systems are designed to determine the presence of man-made gamma-emitting radionuclides and their activities in the human body. The two systems perform measurements with fixed semiconductor high purity germanium detector (HPGe Canberra in WBC-1 and ORTEC in WBC-2 with relative efficiency 45% and 70%, respectively) with bed-type geometry through horizontal linear scanning of the whole body. Lead and copper protection is built around the detector to ensure low background measurement conditions.

## III. ANTHROPOMORPHIC PHANTOMS AND CALIBRATION OF THE SYSTEMS

Phantoms equipped with sealed gamma-emitting nuclides were used for calibration of gamma-spectrometry systems intended for measurement of activity incorporated in a human body. The phantoms are models of human bodies with a wide range of shapes, sizes and materials used. The advantage of modular phantoms is their ability to resemble human bodies in different sizes through a certain number of separate modules [1].

Modular phantom MΦ2-02 ([2] and references cited in it) which imitates homogeneously distributed in a human body activity was used for calibration of gamma-spectrometry systems WBC-1 and WBC-2. It was produced in Dosimetry and Radiation Protection laboratory, Faculty of Physics at Sofia University “St. Kliment Ohridski” in 2002, and the metrological verification of its characteristics and its certificate validity was extended to 2026. (Certificate: HIQM-CPM-9-364-2016). It consists of 180 identical

modules made of cestilen ( $\rho = 0.96 \text{ g/cm}^3$ ,  $Z_{\text{eff}} \approx 5.5$ ) in a parallelepiped shape containing certified activity of  $^{152}\text{Eu}$  (traceable to NPL UK) and  $^{241}\text{Am}$  (traceable to ČMI) nuclides. The activity is incorporated in 4 symmetrically aligned hermetically sealed holes in each module [2]. The nuclides used provide a spectrum with sufficient number of peaks of complete gamma-quantum energy absorption in an energy range 60 keV to 1408 keV. The calibration by energy, energy resolution, and efficiency in a peak of complete energy absorption is performed by the personnel of WBC Section of Inspection Body Type C, Personal Dosimetry Control Centre using system-specific software. For routine operations depending on the dimensions (mass and height) of the subject to be measured, four measurement geometries are used (60 kg/170 cm, 70 kg/170 cm, 80 kg/180 cm and 90 kg/180 cm), and respective calibration is performed for each of them.

#### IV. MEASUREMENTS AND PROCESSING OF THE RESULTS

For the interlaboratory comparison purposes, the Organiser provided us with modular phantom „Saint-Petersburg brick phantom“ equipped with several sets of sealed sources for the implementation of separate tasks. The modules are made of tissue equivalent material (polyethylene) in the shape of bricks. There are several types of bricks with holes in which sealed sources are placed. For the purpose of the tasks two configurations of modules were used with mass of 70 kg and 90 kg, containing specific set of radioactive sources depending on the task, in compliance with the instructions provided by the Organiser. The sealed sources were produced of polyvinyl chloride tubes filled with hardened epoxy resin blended with radionuclide solution and hermetically sealed [3].

Five configurations of the provided modular phantom equipped with radioactive sources with unknown radionuclides and unknown activity were performed. The phantom simulates internal contamination of an adult with a mass of 70 kg or 90 kg. During the implementation of the intercomparison tasks, calibrations were used provided with the MΦ2-02 phantom that are used in our daily work. This complies with the requirement set by the Organiser the presented results (identified radionuclides and their activities) to be obtained in routine measurement conditions. The measured activity at the moment of measuring each nuclide from the separate tasks was reported in Becquerel (Bq) and extended uncertainty with coverage factor  $k = 2$ .

The activity  $A$  of the incorporated in the body radionuclide can be calculated by the equation:

$$A = \frac{n}{\varepsilon\eta} f_D f_S f_P,$$

where:

$n$  - net count rate in a peak of complete gamma-quantum energy absorption;  
 $\varepsilon$  - efficiency of registration of gamma-quantum with certain energy;  
 $\eta$  - quantum yield for a certain nuclide and the relevant energy of emitted gamma-quantum;

$f_D$  - dimensionless number related to the activity distribution inside the body;  
 $f_S$  - dimensionless number related to the dimensions of the body - mass and height;  
 $f_P$  - dimensionless number related to the position of the body during the measurement.

The values of each of the three dimensionless numbers  $f_D$ ,  $f_S$  and  $f_P$  is one, and the values of their relative uncertainties included in gamma-spectrometry analysis are presented in Table A.

The combined relative uncertainty of the whole body activity  $w_A$  can be presented with the following equation:

$$w_A = \sqrt{w_n^2 + w_\varepsilon^2 + w_\eta^2 + w_D^2 + w_S^2 + w_P^2}$$

TABLE A  
SAMPLE BUDGET OF THE UNCERTAINTY

Input value	Relative uncertainty
$n$	20%
$\varepsilon$	2.2 % - 3.5 %
$\eta$	0.001%
$f_D$	10%
$f_S$	1.55%
$f_P$	1%

#### V. RESULTS OF THE INTERCOMPARISON

The Organiser analysed the values reported by the participants after correction of the radioactive decay until the reference dates 01.05.2021 for Tasks 1, 2, 4 and 5, and 01.05.2021 or 10.08.2021 for Task 3.

The statistical processing of data provided by the participants was carried out by IRSN using the software ProLab<sup>TM</sup> and consisted of the following [3]:

- Distribution of the results;
- Search for aberrant values (Grubbs method);
- Relative bias according to standard ISO 28218;
- z-score according to standard ISO 13528.

For an assigned activity value the Organiser considers the consensus value from participants determined using a Robust statistical method. This value is used as a target value during the intercomparison.

The evaluation of the performance of participants was carried out according to two criteria:

- **Bias** (ISO 28218) relative deviation of the reported value from the target value and defined as:

$$\text{Bias} = \frac{a_{\text{Reported}} - A_{\text{Target}}}{A_{\text{Target}}} * 100 [\%],$$

where:

$a_{\text{Reported}}$  - activity as a result of a routine measurement (value provided by a participant);

$A_{\text{Target}}$  - activity target value (assigned value).

According to the recommendations of ISO 28218, the relative deviation of the result should be in the range of -25% to +50% compared to the assigned value.

- **z-score** (ISO 13528) indicator of a participant's performance compared to other participants, defined as:

$$z \text{ score} = \frac{a_{\text{Reported}} - A_{\text{Target}}}{\hat{\sigma}}$$

where:

$a_{\text{Reported}}$  - activity as a result of a routine measurement (value provided by a participant);

$A_{\text{Target}}$  - activity target value (assigned value);

$\hat{\sigma}$  - standard deviation (Robust SD), obtained from the statistic processing of the results provided by the participants.

According to the recommendations of ISO 13528:

When  $|z \text{ score}| \leq 2$ : the result is acceptable;

When  $2 < |z \text{ score}| < 3$ : the result is "questionable", requires further internal analysis;

When  $|z \text{ score}| \geq 3$ : the result is unacceptable.

Each of the participants in the comparison is identified by an individual code, with gamma-spectrometry systems WBC-1 and WBC-2 identified by codes ID Lab. 9 and ID Lab. 24, respectively. The results of the statistical processing of the data presented by the participants, which was performed by the Organiser, are presented in tabular form for each task. Then, the results obtained by us for each task using the two gamma-spectrometry systems (WBC-1 and WBC-2) are presented, as well as their evaluation according to the two criteria applied. The activities presented in the tables are with decay correction to a reference date 01.05.2021 (except for Tables 5 and 6 for which the reference date is 10.08.2021).

### Task 1: Victor phantom, 70 kg: $^{60}\text{Co}$ , $^{133}\text{Ba}$ , $^{137}\text{Cs}$

The sources used in Task 1 are identified as  $^{60}\text{Co}$ ,  $^{133}\text{Ba}$  and  $^{137}\text{Cs}$  [4]. Summarised data from the evaluation of their activities are presented in Tables 1 and 2.

TABLE 1  
RESULTS OF THE STATISTICAL PROCESSING OF THE DATA PRESENTED  
BY THE PARTICIPANTS [3]

Task 1 -Victor	$^{60}\text{Co}$	$^{133}\text{Ba}$	$^{137}\text{Cs}$
<b>Robust mean (assigned value) (A ± u), Bq</b>	<b>1183 ± 25</b>	<b>2836 ± 62</b>	<b>3787 ± 65</b>
Standard Deviation (SD) (Robust SD), Bq	155	388	412
Relative SD, %	13.12	13.68	10.87

TABLE 2  
RESULTS FROM WBC-1 AND WBC-2 PERFORMANCE

	Task 1 -Victor	$^{60}\text{Co}$	$^{133}\text{Ba}$	$^{137}\text{Cs}$
<b>WBC-1</b>	<b>Activity (A ± u), Bq</b>	<b>1097 ± 177</b>	<b>2638 ± 368</b>	<b>3407 ± 489</b>
	Bias, %	-7.29	-6.99	-10.02
	z-score	-0.56	-0.51	-0.92
<b>WBC-2</b>	<b>Activity (A ± u), Bq</b>	<b>1114 ± 191</b>	<b>2752 ± 487</b>	<b>3431 ± 542</b>
	Bias, %	-5.80	-2.96	-9.39
	z-score	-0.44	-0.22	-0.86

### Task 2: Emergency phantom, 90 kg: $^{134}\text{Cs}$ , $^{137}\text{Cs}$

The sources used in Task 2 are identified as  $^{134}\text{Cs}$  and  $^{137}\text{Cs}$  [4]. Summarised data from the evaluation of their activities are presented in Tables 3 and 4.

TABLE 3  
RESULTS OF THE STATISTICAL PROCESSING OF THE DATA PRESENTED  
BY THE PARTICIPANTS [3]

Task 2 - Emergency	$^{134}\text{Cs}$	$^{137}\text{Cs}$
<b>Robust mean (assigned value) (A ± u), Bq</b>	<b>3455 ± 50</b>	<b>2996 ± 60</b>
Standard Deviation (SD) (Robust SD), Bq	313	382
Relative SD, %	9.07	12.75

TABLE 4  
RESULTS FROM WBC-1 AND WBC-2 PERFORMANCE

	Task 2 - Emergency	$^{134}\text{Cs}$	$^{137}\text{Cs}$
<b>WBC-1</b>	<b>Activity (A ± u), Bq</b>	<b>3497 ± 474</b>	<b>3113 ± 458</b>
	Bias, %	1.21	3.89
	z-score	0.13	0.31
<b>WBC-2</b>	<b>Activity (A ± u), Bq</b>	<b>3649 ± 578</b>	<b>3340 ± 527</b>
	Bias, %	5.61	11.47
	z-score	0.62	0.90

### Task 3: Medicine phantom, 70 kg: $^{68}\text{Ge}/^{68}\text{Ga}$ , $^{88}\text{Y}$

The sources used in Task 3 are identified as  $^{68}\text{Ge}/^{68}\text{Ga}$  (in equilibrium) and  $^{88}\text{Y}$  [4]. Summarised data from the evaluation of their activities are presented in Tables 5 and 6.

TABLE 5  
RESULTS OF THE STATISTICAL PROCESSING OF THE DATA PRESENTED  
BY THE PARTICIPANTS [3]

Task 3 - Medicine	$^{68}\text{Ge}/^{68}\text{Ga}$	$^{88}\text{Y}$
<b>Robust mean (assigned value) (A ± u), Bq</b>	<b>4219 ± 151</b>	<b>4263 ± 127</b>
Standard Deviation (SD) (Robust SD), Bq	428	595
Relative SD, %	10.15	13.96

TABLE 6  
RESULTS FROM WBC-1 AND WBC-2 PERFORMANCE

	Task 3 - Medicine	$^{68}\text{Ge}/^{68}\text{Ga}$	$^{88}\text{Y}$
<b>WBC-1</b>	<b>Activity (A ± u), Bq</b>	<b>4010 ± 535</b>	<b>3861 ± 561</b>
	Bias, %	-4.95	-9.44
	z-score	-0.49	-0.68
<b>WBC-2</b>	<b>Activity (A ± u), Bq</b>	<b>4127 ± 602</b>	<b>4247 ± 655</b>
	Bias, %	-2.19	-0.36
	z-score	-0.22	-0.03

### Task 4: Calibration phantom, 70 kg: $^{133}\text{Ba}$ , $^{152}\text{Eu}$

The sources used in Task 4 are identified as  $^{133}\text{Ba}$  and  $^{152}\text{Eu}$  [4]. Summarised data from the evaluation of their activities are presented in Tables 7 and 8.

TABLE 7  
RESULTS OF THE STATISTICAL PROCESSING OF THE DATA PRESENTED  
BY THE PARTICIPANTS [3]

Task 4 - Calibration	$^{133}\text{Ba}$	$^{152}\text{Eu}$
<b>Robust mean (assigned value) (A ± u), Bq</b>	<b>20535 ± 460</b>	<b>25730 ± 728</b>
Standard Deviation (SD) (Robust SD), Bq	2106	3258
Relative SD, %	10.26	12.66

TABLE 8  
RESULTS FROM WBC-1 AND WBC-2 PERFORMANCE

	Task 4 - Calibration	<sup>133</sup> Ba	<sup>152</sup> Eu
WBC-1	Activity (A ± u), Bq	19253 ± 2460	24807 ± 3159
	Bias, %	-6.24	-3.59
	z-score	-0.61	-0.28
WBC-2	Activity (A ± u), Bq	20094 ± 2685	25493 ± 3346
	Bias, %	-2.15	-0.92
	z-score	-0.21	-0.07

### Task 5: Calibration phantom, 90 kg: <sup>133</sup>Ba, <sup>152</sup>Eu

The sources used in Task 5 are identified as <sup>133</sup>Ba and <sup>152</sup>Eu [4]. Summarised data from the evaluation of their activities are presented in Tables 9 and 10.

TABLE 9  
RESULTS OF THE STATISTICAL PROCESSING OF THE DATA PRESENTED  
BY THE PARTICIPANTS [3]

Task 5 - Calibration	<sup>133</sup> Ba	<sup>152</sup> Eu
<b>Robust mean (assigned value) (A ± u), Bq</b>	<b>25782 ± 496</b>	<b>32668 ± 685</b>
Standard Deviation (SD)	2760	3750
(Robust SD), Bq	10.71	11.48
Relative SD, %		

TABLE 10  
RESULTS FROM WBC-1 AND WBC-2 PERFORMANCE

	Task 5 - Calibration	<sup>133</sup> Ba	<sup>152</sup> Eu
WBC-1	Activity (A ± u), Bq	27092 ± 3449	33707 ± 4281
	Bias, %	5.08	3.18
	z-score	0.47	0.28
WBC-2	Activity (A ± u), Bq	27770 ± 3650	33875 ± 4431
	Bias, %	7.71	3.69
	z-score	0.72	0.32

It should be noted that the the nuclide configuration in Tasks 4 and 5 is appropriate for calibration of whole body counting gamma-spectrometry systems because it covers a wide range of energy (80 keV to 1408 keV) and the activity level is such that it can provide maximum measurement time for collecting enough statistical information.

## VI. CONCLUSION

The results from the participation in the interlaboratory comparison indicate a very good performance of Inspection Body Type C - Personal Dosimetry Control Centre in the area of whole-body counting. The determined activities of the radionuclides in the different tasks show excellent reproducibility of results obtained from both of the gamma-spectrometry systems. The calculated deviations compared to the assigned values are in the range of -10.02 % to +11.47 % (as per recommendations ISO 28218 the permissible range is -25 % to +50 %). The highest absolute value obtained for the z-score is 0.92. All of this is a proof for the correct calibration using the MΦ2-02 modular phantom and confirms the competency of the staff performing the activities related to whole body counting.

The high accuracy reached in determining the gamma-emitting radionuclides in the human body, evidence for which are the results from the

participation in the the EIVIC-2020 interlaboratory comparison, is a prerequisite for a maximum realistic assessment of the expected individual effective dose due to internal exposure.

### References:

1. Boshkova T., Minev L. et al., 1997, *Assessment of the activity incorporated in the human body by means of HPGe detector*, Physica Medica XIII Suppl. 1, p. 378
2. Boshkova T., Mitev K., 2016, *Verification of fitness of "Certified reference material – module" (CRM) – phantom for calibration of gamma-spectrometry systems "whole body counter" with germanium detectors, property of Kozloduy NPP EAD, in order to extend the term of validity of CRM – module CO/I 364-2002" Report on the performance of contract No. 85600011/31.08.2015*
3. Franck D., Meisenberg O., Antonia López M. A., Beaumont T., Buchholz W., Navarro J.F., Pérez B., Hürkamp K., Vanhavere F., EURADOS Report 2023-03 Oberschleißheim, October 2023, „EIVIC-2020: European In-Vivo Intercomparison Exercise 2020 - Organisation of a European Interlaboratory Comparison on Whole-Body Counting” <https://eurados.sckcen.be/sites/eurados/files/uploads/Report-Publications/Reports/2023/EURADOS%20Report%2023-03.pdf>.
4. Nuclear data, Laboratoire National Henrie Bequerel, LNE-LNHB/CEA <http://www.nucleide.org/>.

# INTERLABORATORY COMPARISONS ON MEASUREMENT OF ANTHROPOGENIC RADIONUCLIDES IN WATER AND SOIL AND SURFACE CONTAMINATION OF A SIMULATED FILTER.

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**Abstract:** The report presents the results of the participation of Ionising Radiation Measurement Laboratory, Metrology Assurance Department of Kozloduy NPP in interlaboratory comparisons IAEA-TERC-2022 and IAEA-TERC-2023 held in the period 30.06.2022 ÷ 07.10.2022 and 10.07.2023÷06.10.2023 on measurement of surface alpha and beta contamination of a simulated filter with surface contamination.

**Keywords:** interlaboratory comparison, surface contamination, contamination.

## 1. INTRODUCTION

The interlaboratory comparisons IAEA-TERC-2022-01 and IAEA-TERC-2023-01 on measurement of anthropogenic radionuclides in water, soil and surface contamination of a simulated filter are organised by the International Atomic Energy Agency (IAEA).

The main objective of our participation in interlaboratory comparisons is to demonstrate the laboratory competency in measurements in the field of surface contamination by comparing the results of our measurements with the results obtained by the International Atomic Energy Agency with subsequent analysis and identification of measures, if needed, to improve the performance by reviewing measurement methods and measuring equipment calibration.

125 laboratories from different countries participated in the interlaboratory comparison in 2022, and 128 laboratories participated in the comparison in 2023.

Due to the large number of participants, the reference laboratory needs a long period of time to process the results, therefore the report with the results is published in the following calendar year.

## 2. OBJECTS OF THE COMPARISON

The Ionising Radiation Measurement Laboratory, Metrology Assurance Department of Kozloduy NPP participated in comparison of a simulated filter with surface contamination (Sample 5) in IAEA-TERC-2022-01 and simulated filter with surface contamination (Sample 7) in IAEA-TERC-2023-01, which were prepared and provided to all participants.

The results of IAEA-TERC-2022-01 comparison for Sample 5 shall be declared in (counts.cm<sup>-2</sup>/second) for nuclides <sup>239</sup>Pu and <sup>90</sup>Sr by

01 January 2022. Sample 7 represented a wide-area filter with dimensions 15x10 cm and area 150 cm<sup>2</sup>.

The result of IAEA-TERC-2023-01 comparison for Sample 7 shall be declared in Bq/sample for nuclide <sup>90</sup>Sr by 01 January 2023. The filter represented a circle with area 18 cm<sup>2</sup>.

## 3. EQUIPMENT AND STANDARDS USED FOR THE TWO COMPARISONS

### 3.1. Equipment

➤ *Interlaboratory comparison IAEA-TERC-2022-01*

RDS-31 Multi-purpose Survey Meter ID No. 2900079 with detector unit type ABP 150, ID No. 1602649. The Survey Meter has valid certificates for metrological verification and calibration. The metrological characteristics of the Survey Meter are shown in Table 1.

Table 1

-	α	β		
Background, s <sup>-1</sup>	α < 0,1	β < 8		
Measuring range, s <sup>-1</sup>	0.1÷100,000	6÷100,000		
-	<sup>241</sup> Am	<sup>60</sup> Co	<sup>60</sup> Cs	<sup>60</sup> Sr/ <sup>90</sup> Y
Efficiency 4π, %	21	13	25	30
Efficiency 2π, %	44	23	35	44

➤ *Interlaboratory comparison IAEA-TERC-2023-01*

Alpha/Beta Counting System iSolo500L, ID No. 13000009. The counter has valid certificates for metrological verification and calibration. The metrological characteristics of the counter are shown in Table 2.

Table 2

-	α	β
Background, cpm	α < 0,1	β < 8,3
Energy range, MeV	3.0÷6.4	0.125÷2.2
Efficiency 4π, %	<sup>241</sup> Am	<sup>60</sup> Sr/ <sup>90</sup> Y
	30	22

### 3.2. Standards

➤ *Interlaboratory comparison IAEA-TERC-2022-01*

The standard radioactive sources used in the calibration have valid calibration certificates. The uncertainty of the standards is shown in Table 3.

Table 3

Type	ID No.	Nuclide	u, %	Calibration certificate
SIR 07032	AK-7384	<sup>90</sup> Sr	2,5	031531/25.09.2017
6П9	10082	<sup>239</sup> Pu	5,7	16.MO.CBK.712

➤ *Interlaboratory comparison IAEA-TERC-2023-01*

The standard radioactive source used in the calibration has a valid calibration certificate. The uncertainty of the standard is shown in Table 4.

Table 4

Type	ID No.	Nuclide	u, %	Calibration certificate
EM145	355039	<sup>90</sup> Sr/ <sup>90</sup> Y	2,0	21-ИИЛ/25.09.2017

#### 4. MEASUREMENT AND PROCESSING OF THE RESULTS

The equipment used in the measurement shall be calibrated by suitable radioactive sources in compliance with [1]. Filter measurement and processing of the results shall be carried out in compliance with [2].

The instructions [3] and [4] provided by the International Atomic Energy Agency were followed in measurement and processing of the results for the two comparisons.

Uncertainty budgets were prepared to determine the uncertainty of the measurements. In general case the uncertainty of the measurements is calculated by equation (1)

$$u(\text{report}) = \sqrt{u_n^2 + u_e^2 + u_w^2} \quad (1)$$

where:

$u_n$  is the uncertainty of the measurements

$u_e$  is the uncertainty of the standard radioactive source

$u_w$  is the uncertainty of the non-homogeneity of the detector unit

The evaluation of the performance of participants is carried out using the Z-Score:

$$z = \frac{|VALUE_{reported} - VALUE_{target}|}{robust\ SD} \quad (2)$$

where:

$VALUE_{reported}$  is the measured value

$VALUE_{target}$  is the target value declared by the International Atomic Energy Agency

$robust\ SD$  is the net root mean square uncertainty of the target value

If:

Z-Score < 2 the result is acceptable (A)

2 > Z-Score > 3 the result is "Warning" (W)

Z-Score > 3 the result is "Not accepted" (N)

#### 5. COMPARISON RESULTS

The participants in the comparison are assigned individual codes. The Ionising Radiation Measurement Laboratory was assigned code 280.

The results, depending of the reports submitted by the participants, were provided in the FINAL REPORTS dated 14 November 2022 and 23 November 2023.

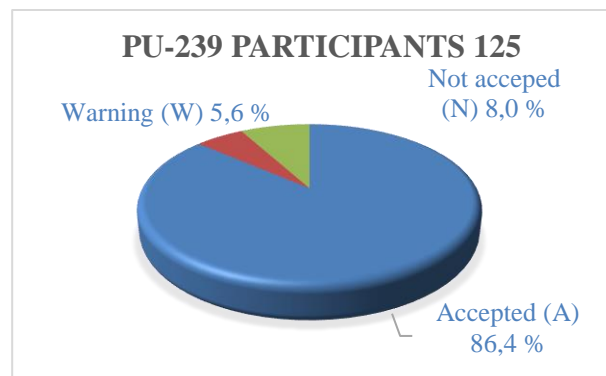
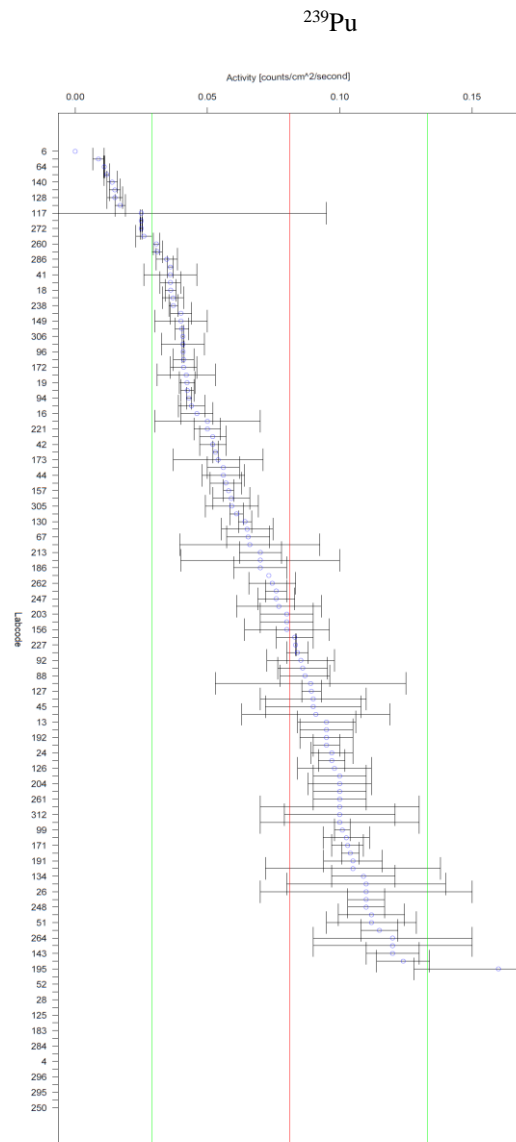
#### 5.1. Interlaboratory comparison IAEA-TERC-2022-01

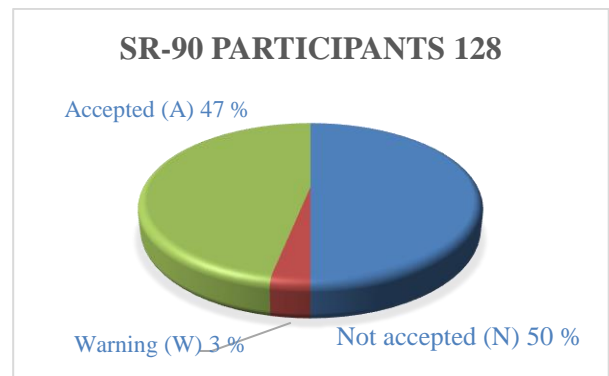
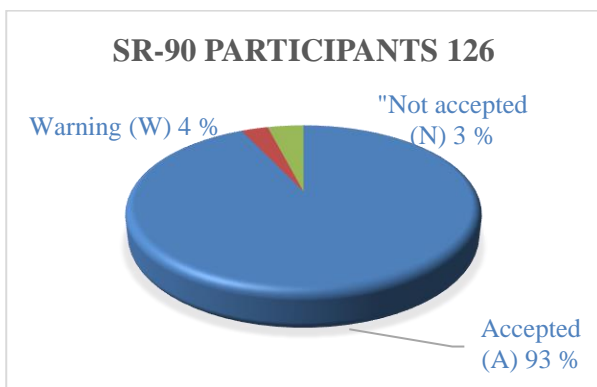
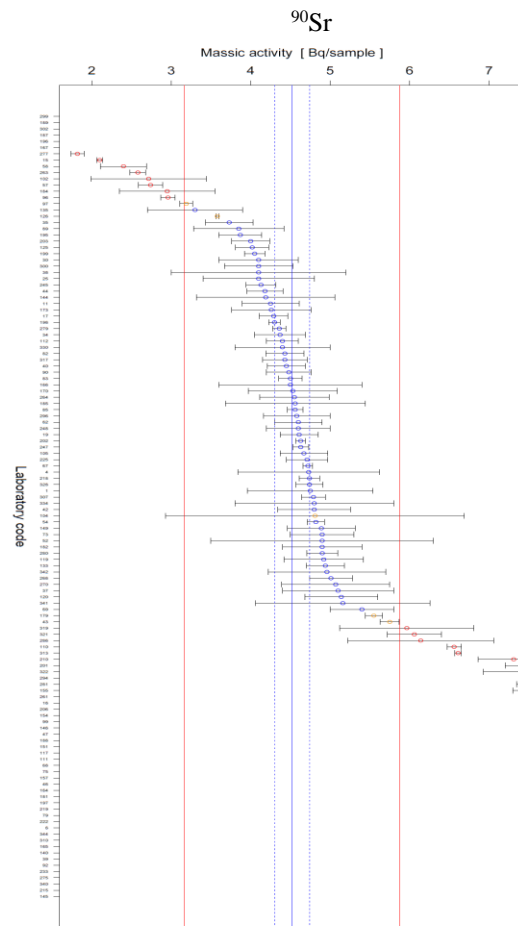
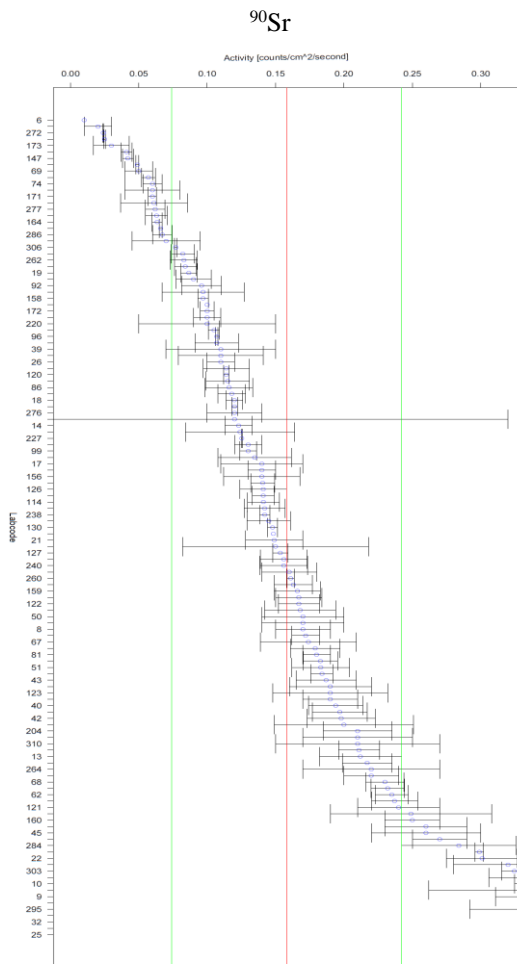
The results of Ionising Radiation Measurement Laboratory are shown in Table 5.

Table 5

Nuclide	$VALUE_{target}$	$SD_{target}$	$VALUE_{report}$	$SD_{report}$	Z-Score
	(counts.cm <sup>-2</sup> )/second				
<sup>239</sup> Pu	0,081	0,052	0,1025	0,0087	0,41
<sup>90</sup> Sr	0,158	0,052	0,1828	0,0125	0,30

The graphs below show the results of all participants for Sample 5.





**5.2. Interlaboratory comparison IAEA-TERC-2023-01**

The results of Ionising Radiation Measurement Laboratory are shown in Table 6.

Table 6

Nuclide	VALUE <sub>target</sub>	SD <sub>target</sub>	VALUE <sub>report</sub>	SD <sub>report</sub>	RB	MARB
	Bq				%	%
<sup>90</sup> Sr	4,520	0,220	4,901	0,196	8,4	30,0

The graphs below show the results of all participants for Sample 7.

**6. CONCLUSION**

The results of the Ionising Radiation Measurement Laboratory obtained in the interlaboratory comparisons show that the radiometric measurements of the surface contamination are performed in the laboratory at a very good level following the standards in the field. The positive results obtained in the comparisons show that the measurements methods and the radiometric equipment calibration performed in the laboratory are appropriate and the results obtained are credible.

## References:

- [1] 82.MO.00.MT.688 Methodology for calibration of radiometers for surface alpha/beta contamination measurement
- [2] 82.MO.00.MT.689 Methodology for metrological verification of portable radiometers for surface alpha/beta contamination measurement
- [3] Instructions\_2022
- [4] Instructions\_2023
- [5] IAEA-TERC-2022-01WorldWide Open Proficiency Test Exercise, Individual Evaluation Report Part I
- [6] IAEA-TERC-2023-01 World Wide Open Proficiency Test Exercise, Pie-charts, S-Shapes and Reported Results with Scores

# METROLOGICAL ASSURANCE OF NEUTRON DOSIMETERS AT KOZLODUY NPP EAD

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*Summary:* This report discusses the metrology assurance of electronic personal dosimeters and portable dosimeters used to measure neutron radiation.

It contains a short description of the methods used to ensure metrological traceability and reliability of the individual dose measurement and radiation control performed using the various types of neutron radiation measuring instrumentation.

**Keywords:** Neutron dosimeters, metrology assurance, calibration, metrological verification

## 1. Introduction

Ionising radiation measurement is performed in multiple fields of production and monitoring activities at Kozloduy NPP EAD and is particularly important in the area of radiation protection.

The metrology assurance of neutron dosimeters allows precise and reliable measurement using equipment used at various Kozloduy NPP EAD structural units.

The metrology assurance of ionising radiation measurements at Kozloduy NPP EAD is performed by the Ionising Radiation Measurement Laboratory and the Ionising Radiation Measurement Laboratory at the Lovech-based Directorate General 'Measures and Measuring Instruments' (DG MMI) and is an important prerequisite for ensuring compliance with:

- technical specifications;
- radiation protection requirements;
- dose exposure limits of personnel working in an ionising radiation environment;
- ALARA;
- Measurements Act

Kozloduy NPP EAD implements personal dose rate monitoring for its staff as part of radiation monitoring activities aimed to ensure people are protected against the harmful impact of ionising radiation, in compliance with the Regulation on Radiation Protection (updated), State Official Gazette, No. 16 from 20 February 2018, In effect as of 20 February 2018, Regulation No. 32 on the Conditions and Procedures for Performing Personal Dosimetry Monitoring of the Individuals Working with Sources of Ionising Radiation.

Kozloduy NPP EAD uses electronic personal dosimeters for neutron radiation type EPD-N2 made by MGP Instruments, France.

Portable neutron dosimeters are used to perform radiation technological monitoring of premises, items and equipment in the controlled area. They are also used in the transportation of spent nuclear fuel. The portable dosimeters used to measure neutron radiation at Kozloduy NPP are produced by various companies and include the following types: ДКC-96 (DKS-96), MKC-01P (MKS-01R), FH40G-L, NSN31045, 2222A, LB 134.

## 2. Metrology Assurance Activities

To ensure the expected high quality and reliability of measurement results meeting national and international standards, Kozloduy NPP EAD performs metrological assurance of electronic personal dosimeters used for personal dosimetric monitoring, and of portable dosimeters used for neutron radiation monitoring.

The main metrological assurance activities include:

- organising and conducting initial and follow-up metrological verification;
- measuring equipment calibration;
- maintaining reference material and ensuring traceability of measurements.

Metrological verifications are aimed to verify the metrological characteristics and their compliance with their intended use requirements. It guarantees the correctness of the measurements.

Follow-up periodic inspections and calibration are subject to planning and are performed for all measurement instrumentation used at Kozloduy NPP EAD. There is annual programme in place for the metrology assurance of measurement instrumentation subject to periodic verification and calibration over the coming calendar year.

## 3. Metrology Assurance of Electronic Personal Dosimeters

Electronic personal dosimeters are used to perform operating personal dose rate monitoring of the staff when working inside the controlled area of Units 5&6, the spent fuel storage facility, fuel transportation and other places where neutron fluxes are present.

Electronic personal dosimeters are calibrated in personal equivalent dose  $H_p(10)$  of neutron radiation.

Electronic personal dosimeters are used as additional alarm dosimeters. Electronic personal dosimeters serve for preventive monitoring aimed to ensure daily individual dose exposure rates are not exceeded.



Fig. 1 EPD N2 electronic personal dosimeters used to measure neutron radiation.

To ensure the expected high quality and reliability of the measurement results metrological assurance of the electronic personal dosimeters is performed, including: type approval, calibration, initial and follow-up metrological verification.

The type is approved by the Bulgarian Metrology Institute (BMI) at the production stage or upon the imports in line with the provisions of the Measurements Act.

Initial and follow-up metrology verification of the electronic personal dosimeters is performed by the experts at the Directorate General 'Measures and Measuring Instruments' (DG MMI) with the Bulgarian Metrology Institute and licensed laboratories in accordance with Art. 5 of the Measurements Act and the Ordinance on Measuring Instruments, Subject to Metrological Control.

Electronic personal dosimeters are calibrated by their producer and, if necessary, during verification using special software.

After repairs related to the accuracy of their measurements, electronic personal dosimeters always undergo additional metrology verification.

Every year, the Metrology Assurance Department plans and organises the follow-up periodic verification of electronic personal dosimeters.

#### 4. Metrology Assurance of Portable Dosimeters Used to Measure Neutron Radiation

Portable dosimeters are used to monitor radiation at the site of Kozloduy NPP EAD.

Dosimeters are calibrated in equivalent neutron radiation dose units.



Fig. 2 Portable neutron radiation monitoring tool MKC-08 (MKC-08), ДКС-96 (DKS-96) with БДМН-96 (BDMN-96) detector unit.

Metrology assurance activities include: type approval, calibration, initial and follow-up metrological verification.

The type is approved by the Bulgarian Metrology Institute (BMI) at the production stage or upon the imports in line with the provisions of the Measurements Act.

The initial and follow-up metrological verification of all dosimeters used under Art. 5 of the Measurements Act and in accordance with the Ordinance on Measurement Instruments, Subject to Metrological Control, are performed by experts at the Directorate General 'Measures and Measuring Instruments' (DG MMI) with the Bulgarian Metrology Institute.

Portable dosimeters used in Kozloduy NPP EAD's controlled area for technological radiation monitoring are subject to company verification performed at the Ionising Radiation Measurement Laboratory.

Dosimeters are calibrated by the producers and, if necessary, as part of their verification.

After repairs related to the accuracy of the measurements, dosimeters always undergo additional metrology verification.

Every year, the Metrology Assurance Department plans and organises the follow-up periodic verification of portable dosimeters.

#### 5. Metrology Assurance of Portable Dosimeters Used to Measure Neutron Radiation

To evidence its competence and ability to obtain valid results, the Ionising Radiation Measurement Laboratory at Kozloduy NPP EAD complies with the requirements of БДС EN ISO/IEC 17025:2018 - General requirements for the competence, impartiality and consistent operation of laboratories.

In compliance with this document, the laboratory plans and performs activities to take into account all risks and possibilities. This increases efficiency, improves the accuracy of results and prevents negative impact. The laboratory is responsible for defining all risks and possibilities that should be considered.

The activities and documents meeting the requirements of БДC EN ISO/IEC 17025:2018 include:

- Measurement processes
- Measurement instruments and systems
- Ensuring measurement traceability
- Measurement methods
- Measurement conditions

All metrological verification activities are carried out following established methodologies.

Electronic personal dosimeters and portable dosimeters used to measure neutron fluxes under Art. 5 of the Measurements Act are verified by the Directorate General 'Measures and Measuring Instruments' (DG MMI) in Lovech following the respective methodologies established by the Chairperson of the Bulgarian Metrology Institute.

Portable dosimeters that are subject to company verification at Kozloduy NPP EAD's Ionising Radiation Measurement Laboratory are verified based on a methodology approved by the Head of the Quality Division.

Depending on the type of the metrological verification of neutron radiation measurement instruments, metrology assurance may include:

- Identifying the main error
- Indications linearity in the inspected scope
- Measurement scope check
- Audio signal scope
- Statistical fluctuations check
- Defining radiation source reference value (if necessary).

All standard sources of ionising radiation used at Kozloduy NPP are traceable to the initial standards in Germany, the Czech Republic, Russia, USA, etc., as well as to the national standards in Bulgaria, via certification and recertification, if needed.

The processing of a group of results obtained after each verification step is performed immediately after its completion in order to make a decision whether to continue or terminate the verification or to perform additional actions, settings, etc.

The outputs of initial and follow-up verification are documented in a metrological verification report.

All measurement instruments that meet the requirements are issued verification certificates and are marked as fit for use.

All measurement instruments that do not meet the requirements are issued a notice that they are not fit for use and are marked accordingly.

## 6. Conclusion

The Ionising Radiation Measurement Laboratory at Kozloduy NPP EAD is responsible for the metrology assurance of a large number of measurements and measurement instruments used in industrial and regulatory metrology. The principles and the methods of metrology assurance applied in the laboratory comply with the current international and national trends in the development of metrology assurance.

The Measures Act currently in force complies with the requirements for harmonisation of the legislation of the Republic of Bulgaria with the legislation of the European Union and includes the following provisions:

- The metrology assurance of process measurements shall be the obligation and responsibility of the respective structural units;
  - the maintenance and development of all references and facilities shall be the obligation and responsibility of the structural units, as well.

Thus, the responsibility of the corresponding structural units is enhanced in order to ensure the quality of measurements. For ionising radiation measurement - the responsibility for the safe and environmentally friendly electricity generation.

Therefore, the Ionising Radiation Measurement Laboratory at Kozloduy NPP EAD has focused its efforts on the metrological assurance of process measurements: developing programmes to assure the quality of all measurements, measuring instruments calibration, improving and developing the reference base, enhancing the quality of metrological verification, developing measurement methods, receiving inspection, etc.

## References:

- [1] Measurements Act
- [2] Ordinance on the Measuring Instruments, Subject to Metrological Control
- [3] БДС EN 61526:2013 Radiation Protection Instrumentation. Measurement of personal dose equivalents  $H_p(10)$  and  $H_p(0,07)$  for X, gamma, neutron and beta radiations. Direct reading personal dose equivalent meters (IEC 61526:2010, amended)
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- [5] МП-26-04/2017 Methods for Metrological Assurance of Portable Instruments for Neutron Radiation Monitoring
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# TECHNICAL UNIVERSITY OF SOFIA

## RESEARCH AND DEVELOPMENT SECTOR OF TECHNICAL UNIVERSITY OF SOFIA

The Technical University of Sofia is a modern educational and research institution, with highly qualified lecturers, researchers, engineers and technicians. The laboratory facilities with advanced equipment and qualified research staff provide high-quality scientific and experimental research.

The main goal of the Technical University of Sofia is its establishment as the leading European scientific and research center. Through its infrastructure, research potential and network of contacts, the University supports the solution of many scientific and engineering problems related to the needs of society.

Technical University of Sofia conducts a variety of applied research activities and provides opportunities for technology transfer at national and international level through the following units:

- Research and development sector
- "Technical University of Sofia – Technologies" Ltd.
- Small enterprises
- Educational-experimental enterprise
- The publishing house of the Technical University of Sofia

An important role for the establishment of TU-Sofia as a leading educational and research engineer center in the country and the region has the numerous annual scientific forums, united in the unique format "Science Days of TU-Sofia".

The strong international character, the high scientific level of the presented research findings and papers, included in proceedings, referenced and indexed in leading international science databases, and the significant support of the industrial partners make this forum an efficient environment for the transfer of knowledge, ideas and technologies from science to industry and business.

The introduced e-learning system E-SCIENCE provides the opportunity to obtain unified, complete and comprehensive information on scientific activities, projects and the scientists' career development. The system provides ways and methods for finding optimal management decisions and improves the effectiveness of research and applied work. Thanks to the publications module, updated daily, bibliographic data and summaries of scientific papers, publications, and posters are available on the web.

Training and Sport Wellness base "LAZUR" is the host of the annual international scientific conferences "Science Days of TU-Sofia" in the town of Sozopol, where the scientific elite of Bulgaria and the world is held.

The forums organized by the TU-Sofia are a meeting place for scientists from different research fields, challenged to transform innovative ideas into products and services that create sustainable partnerships between science and business, build high-skilled human potential, giving new skills that provides prepared researchers and specialists.

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