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# NATIONAL DEMAND FOR METROLOGY AND ITS DEVELOPMENT IN THE FIRST DECADES OF THE 21st CENTURY

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Passing on to the XXI century does not mean just change of the calendar everyday life of humanity: it coincides with the passage from the stage of scientific and technical progress to scientific and technological epoch. One of the most important tasks of the moment arises in this connection – determining national demand for metrology and its development in the first decades of the new century.

The problems relating to this fact are multidimensional to the same extent as metrology itself with its scientific and legal bases and extremely important practical results obtained in the development and realization of the Russian national system of measurement traceability (GSI), which is one of the largest and most important constituent parts of the international measurement traceability system soldered by the principles of the Meter Convention.

In today's world of numerous scientific and technical relationships, national demand for metrology naturally becomes part of international demand for the latter. Abounding problems of the international cooperation facing the national Governments increase the requirements for the international uniformity of measurements and stress the importance of international recognition of measurement and test services. These problems define the presence of a steady tendency towards globalization of the world trade, joint manufacturing of goods at the international level, increasing technical sophistication of a great number of produce and services, as well as the growing role of public health, security and environmental protection issues.

The International Committee of Weights and Measures (CIPM) has noted that commercial agreements between States and Economical Regions require, at present, from the parties signing contracts to recognize the results of measurements and tests carried out by any party. This highlighted key point of the importance for the trade of the equivalence of measurements, services and tests will largely govern national measurement systems. It is against such background that the discussion of future national demands in respect of metrology and international cooperation takes place.

Those aspects of metrology where the international cooperation will be continued and, in many cases, intensified, include measurement units, development of national measurement standards and showing their equivalence at the international level, as well as accreditation of laboratories, legal metrology and the corresponding written standards. The Meter Convention signed in XIX century for the sake of making provision for the interests of the international trade, having withstood by time the test of the fundamental principles laid in it, has not lost its vital importance to this very day.

Nonetheless, it has already appeared expedient that at the present stage of the international cooperation certain measures should be undertaken that would allow to national metrological institutes of the Member States of the Convention to show in the most impartial way the degree of equivalence of their national measurement standards.

This method implies periodic carrying out a vast range of so called "key comparisons" of standards and coordinating such comparisons organized by Consultative Committees of the CIPM and by Regional Metrology Organizations (RMO). The publication of the results of these comparisons and their analysis in the corresponding Consultative Committees gives nowadays the possibility to a large (and not only to metrological and economical) community to be in the know of the data that are being accumulated and defining the equivalence degree of national standards of the countries participating in the said comparisons. In order to define the existing and future demand for metrology, it is very important to realize which old and new services will be called for by the users. It is widely known, nowadays, that all spheres of human activity, to a large extent, rest upon measurements and metrology.

Let us look at the far from complete list of some most significant and important users. At the present transitional stage these are such areas of science and technology as: precision engineering, laser beam technology, electronics, geodesy, seismology, space-system engineering, electron optics, aeronautical and space engineering, metallurgy, research activities, medicine and health protection, robotics, nuclear industry and power engineering, nondestructive check, preservation of the environment, exploration activity, agro industrial complex, measuring technology, technological innovations and high technology, the latter deserving special and steadfast attention.

Another very important point should be mentioned: both in the past and at present the number of measurements where users require higher accuracies of measurement has been constantly growing. When, in 1875, the Meter Convention was signed, special stress was laid on measurements of length, mass and related quantities with regard to the needs of trade and commercial activity. Other fields of metrology appeared and grew in accordance with their importance for users in connection with the results of the scientific and technical progress. So, electrical measurements reached the front line in early XX century, ionizing radiations after the World War II, and metrology in chemistry just recently. Today the advancement of society toward high technology is getting faster and demands a wide range of new complex measurements.

As an example we can mention the requirements to measurements for information technologies, micro-fabrication technologies, and nanotechnologies, as well as for defining the performance of new materials and high speed processes. Likewise, the existing measurements in such sophisticated fields as medicine, health protection, biotechnology, quality rating of foodstuffs and medical drugs, environmental protection and, on the whole, metrological assurance of vital activity systems of man, put forward pressing requirements for more reliable measurements in chemistry and biology, as well as in the traditional fields of physics and technology.

National and international metrology is far from being able to satisfy the needs in these fields, and in order to be in keeping with them, there is much new to be done in the current decade. In the majority of performed measurements it is very important for the user that similar results were obtained in the permissible limits of uncertainties when carrying out the corresponding measurements in different places, by different groups and at different time. It is also important that the results of measurements could be easily transferred to other interested groups and be accepted by them as reliable ones. Such needs of users directly define some principal requirements for metrology which are called for now and will be claimed in future both at national and international levels. First of all there should be a universal use of the common system of measurement units tightly related to the fundamental physics. The creation of the International System of Units (SI) resulted in a considerable progress in attaining this purpose. At present, the SI is used in science and technology almost universally, and for the largest part of the international trade and in the production of goods using high technologies it has almost totally replaced the previous old system of national units.

Measurements carried out by all users must be based upon the equivalent physical reproduction of measurement units. This can be achieved under the condition that the measurements are traced either to one and the same standard, the accuracy of which is maintained at the international level, or to national measurement standards that, as has been said, are equivalent to each other in permissible levels of uncertainty.

The Governments of the State participating in the worldwide economical cooperation understand increasingly better the economical and social advantages of possessing the efficient national measurement system, as well as the importance of such system as an instrument of industrial competitiveness. Therefore there can be no doubts that national measurement systems will always serve as principal building blocks of the universal system of measurement traceability. That is why it is necessary to care for each one separately. A comprehensive national measurement system comprises several levels and responsibility fields related to measurement units and national measurement standards, accreditation of laboratories, legal metrology, normative documents, etc.

The development and establishment of national measurement standards is the most important duty of national metrology institutes. It is suggested that the creation of regional metrology institutes would spare the need to have metrological institutes in every country. These suggestions overlook the fact that modern metrological institute are something more than just warehouses for measurement standards. The is vitally important component of measurement infrastructure able to provide technical consulting in a wide range and to render assistance to Government, to industry and to a wide public in the issues relating to measurements. The efficiency of metrological institutes increases, naturally, with the growth of interest towards cooperation at the regional level. But in the foreseeable future it will became a norm for each country to maintain its own metrological institute that will have the direct access to Government, industry and to other users.

In most countries-members of the Meter Convention the role of the National Centre of Standards is assumed by only one metrological institute. However, there is another practice as well.

In particular, in this country, in Russia, there has been formed a system of national metrological institutes that assume functions of the centres of standards in different measurement fields. So, in the Main Centre of the State Standards (D.I. Mendeleyev VNIIM) are maintained and actively used 56 State Standards: standards of the four principal units (meter, kilogram, ampere, Kelvin) and standards of the most important derived units in the fields of mechanics, nuclear physics, chemistry, thermal physics and that-like. The State Standard of another principal unit, the second, was developed and is maintained at VNIIFTRI, the State Primary Standard and the system of secondary standards in the fields of optics and lighting technology were developed and are maintained at VNIIOFI. A number of standards of derived units were developed and are maintained in the Ural Institute of Metrology, in Siberian Metrological Institutes in the cities of Novosibirsk, Irkutsk, Kazan. Some standards are also kept at VNIIMS.

What is important is that the requirements of the highest possible accuracy for the State Standards make them belong with the category of especially important and unique objects in the country. It is explained by the fact that in order to obtain the highest possible accuracy, it is necessary to use the latest achievements of science and technology, to ensure the maximum thoroughness of manufacturing principal blocks and components of a standard, to make utmost tough requirements to the conditions of reproducing a unit excluding all possible external effects and to make scrupulous and finest experiments using the newly developed standard installations. Standard are the valuables of a particular national importance. And not only due to their own cost, although it is quite high, but also, and to a greater extent, due to the importance of a standard as the basis of the national system of ensuring the traceability of measurements in the corresponding measurement field. A high scientific and technical level characterizes the present date condition of the base of standards in Russia.

Most Russian national standards do not yield, as far as accuracy is concerned, to foreign ones, which is confirmed by the results of international comparisons, and, on the whole, do meet the requirements of domestic science and industry. However, as is shown by the world experience, the development of metrology, the cost of maintaining the national measurement system at a high up-to date level attains (40 – 70) x $10^{-6}$ of the gross domestic product, and the renewal period for technical means of metrology permanently decreases, being at present 15 – 20 years. That is to say, in order to keep unchanged the situation with the base of standards, it is necessary, as was mentioned by Dr. T. Quinn, Director of the International Bureau of Weights and Measures (BIPM), that Governments should maintain their metrological laboratories and, what is the most important, their active scientific base. Without lengthy scientific researches it is impossible to meet the industrial requirements for standard measurements, while a scientific base once lost, can be restored only owing to huge expense of money and time.

## PROSPECTS OF DEVELOPMENT OF STANDARDS

As is known, the technical progress can pretend to be trustworthy only if it is founded on components of something really existing. Therefore one must proceed from those components of the base of Russian standards that have been designed, modernized and studied as objects of possible developments. Recently, high accuracies and reliability of standards based on quantum effects have been attained and in future we can anticipate development of a number of other standards, e.g. new standard of ampere based on the indirect method measurement of the dc current unit as the relation of units reproduced by standards of the volt on the basis of the quantum Josephson effect and standards of the ohm based on the quantum Hall effect.

It should be anticipated that for reproducing and maintaining derived units new methods based on quantum effects and physical constants will appear, that will allow reproducing units of physical quantities with an accuracy close to the quantum standards irrespective of external conditions, geographical place and time. Such gauges could be regarded a eternal ones.

We can foreknow [4] that many modern standards will be based on quantum effects. As for the dimensionality of derived quantities, for the most part they are related to the basic quantities and units, such as length, mass, electrical current. If we succeed in creating the standard of mass on the basis of possibilities offered by the nuclear physics, it is evident that a considerable part of standards will be represented by the same very “eternal gauges”. Among the other physics-metrological problems connected with the prospects of development there is the pronounced problem of further increasing the accuracy of length measurements not only in the already mastered middle range, but also in submicron and nano-micron range, as well as in the range of large and super-large lengths. Does not subside the interest for solving problems in such technologically important and thriving field of metrology as dynamic measurements. Therefore there is urgent demand for searching and development of methods and means of high precision measurements and metrological assurance in seismology.

Problems of metrology in gravimetry represent a large complex that not only has not disappeared, but even have become more complicated in connection with the adoption of ITS-90 (International Temperature Scale-90). Just as a short respite can be regarded the attained improvement in standards of volt and ohm on the basis of the corresponding macroscopic quantum effects, because the onrush of electronics in science intensive technologies will already in the near future set new tough requirements for the accuracy of electrical measurements. And, at last, among vitally important problems of XXI century I can mention the problems of ecology, the solution of which will demand revolutionary changes from metrology in a large number of physicochemical measurements: gas analysis, measurements of composition and properties of substances, materials and so on, as well as in measurements of ionizing radiation parameters.

There is one more thing to say concerning the completeness of the list of present-day metrological problems. Seeking to remain on the grounds of revealing, first of all, practical problems for science and technology, the author, at the same time, does not lose sight of a large complex of problems from the field of quantum mechanics, solid-state physics and other fields of the fundamental science where results of measurements, as a rule, confirm or disprove claims on discovering new physical laws, theories and that-like.

One more thing. The scientific metrology is a most important resource of both natural science and science intensive technologies. In a large number of cases it impartially determine their development pace. Anticipatorily developing, it pretty often advances so rapidly, that physicists, chemists and technologists do not have time to provide for its needs with new discoveries and researches. All this can be explained by the fact that nowadays, as never before, metrology evidently exists and develops not for the sake of internal ends in themselves, but rather for the sake of highest service both to the fundamental scientific search and to onrush of technology that realizes newest programs of scientific and technological advance.

The most important task of metrology in industry nowadays and for the near future will be the work aimed at metrological assurance of technological reequipment of Russian enterprises. As has shown the problem analyzing conference held in St. Petersburg in 2002, it concerns mechanical engineering enterprises on the whole: instrument-making, shipbuilding and aircraft construction, power mechanical engineering, etc.

This work must be also carried out in the near future at extractive industry enterprises and reprocessors. It must be carried out by coordinated efforts of metrologists, specialists of the National Metrological Services and specialists of enterprises of different patterns of ownership. The target programs assuring the critical mass of support of those technologies, due to which the growth of national economy and industry is only possible, are based on the technological reequipment representing only one of many national demand for metrology governed by the fact that on the condition of the metrological system equally depends all scientific, technological, economical and social infrastructure of the State. In other words, the realization of the task of developing science and defense industry is summoned to guarantee the ecological security in the field of medicine, health protection, mutually beneficial partnership of Russia in the common free market zone, and so on.

We have shown the status quo of the present-day links of measurements and metrology with science, industry and trade.

When will this “tomorrow” come? It depends on fields of measurement. However, already by 2010 they will be substantiated and by 2015, almost in all cases, inevitable. Accuracies of the second, metre, volt and ohm will probably be increased more than ten times. The accuracy of Kelvin, candela and kilogram are awaiting the next technological leap forward to be increased, which can also tell upon the definitions of these units. On what one can found these estimates? As is has already been said, on the extrapolation of tendencies of the developments in instrument-making industry, on the growth of the number of measured parameters, increase in the share of dynamic measurements, on a wide implementation of computers and automation of the instrument-making in the flexible manufacturing systems.

The list of stimulating factors governing such development as far back as not long ago was headed by electronics, but nowadays it is the security of the vital activity of the human society on the whole where must be included the use of complex measurements in such fields as medicine, biotechnology, expert examination of foodstuffs and medical drugs, protection of the environment. It is also vitally important to further considerably increase the accuracy of calculation of the energy supply and to develop energy-saving technologies. When forecasting the progress in measurements and metrology, one should not lose sight of such objective factors as the constant, as has been already said, growth of the number of measured physical quantities and parameters. It is quite probable that by 2015 their number may attain 2000 – 2500. At the same time, the revolution in development and making of sensors also deserves constant and steadfast attention.

These two phenomena: the growth of the number of measured quantities and the number of types of different sensors, just as mercury on a glass, are bent on scattering as far as possible, as a result of which the problems of the international system of traceability of measurements do not become simple, but are getting complicated considerably, both at global and national levels. It follows from all the above said that the firmness of the principles of the Metre Convention, as the main Law of the metrological community adopted in XIX century, keep safe for the new century as well, and the scientific and technical means that we will use in the framework of the International System of Measurement Traceability must be selected from the arsenal of science and technology of the XXI$^{st}$ century.

Let us conclude all the above said by the words of a Russian metrologist Nikolai Ivanovich Tiurin: "When a majestic and beautiful building has been built, nobody thinks of measurements, but just measurements and their accuracy are the foundation of its strength and beauty".

We leave the audience in the unbounded world of measurements with the hope that this lecture allows, in a certain measure, to determine the correct course of navigation on this ocean. The more often we will recall the universal and fundamental role of metrology in our life, the easier it may be done. On my own behalf, I would like to say once again: metrology is like the air we breathe – it is noticed when it is lacking.

REFERENCES

[1] Report of CIPM to Governments of countries-members of the Metre Convention, 1997, Paris.

[2] V.A. Kuznetsov, G.V. Yalunina: General metrology, "Standards" Publishers, 2001.

[3] Yu.V. Tarbeyev: Fundamental problems of theoretical metrology, Russian Metrology Encyclopedia, Liki Rossii Publishers, 2001.

[4] Yu.V. Tarbeyev: Present-day physicometrological problems, Russian Metrology Encyclopedia, Liki Rossii Publishers, 2001.

[5] W. Kose: International trade requires internationally accepted measurement certificates, ATD, Braunschweig, Germany, 1997.

[6] Mutual recognition of national measurement standards and of calibration and measurement certificates issued by national metrology institutes, Paris, 14 October 1999.