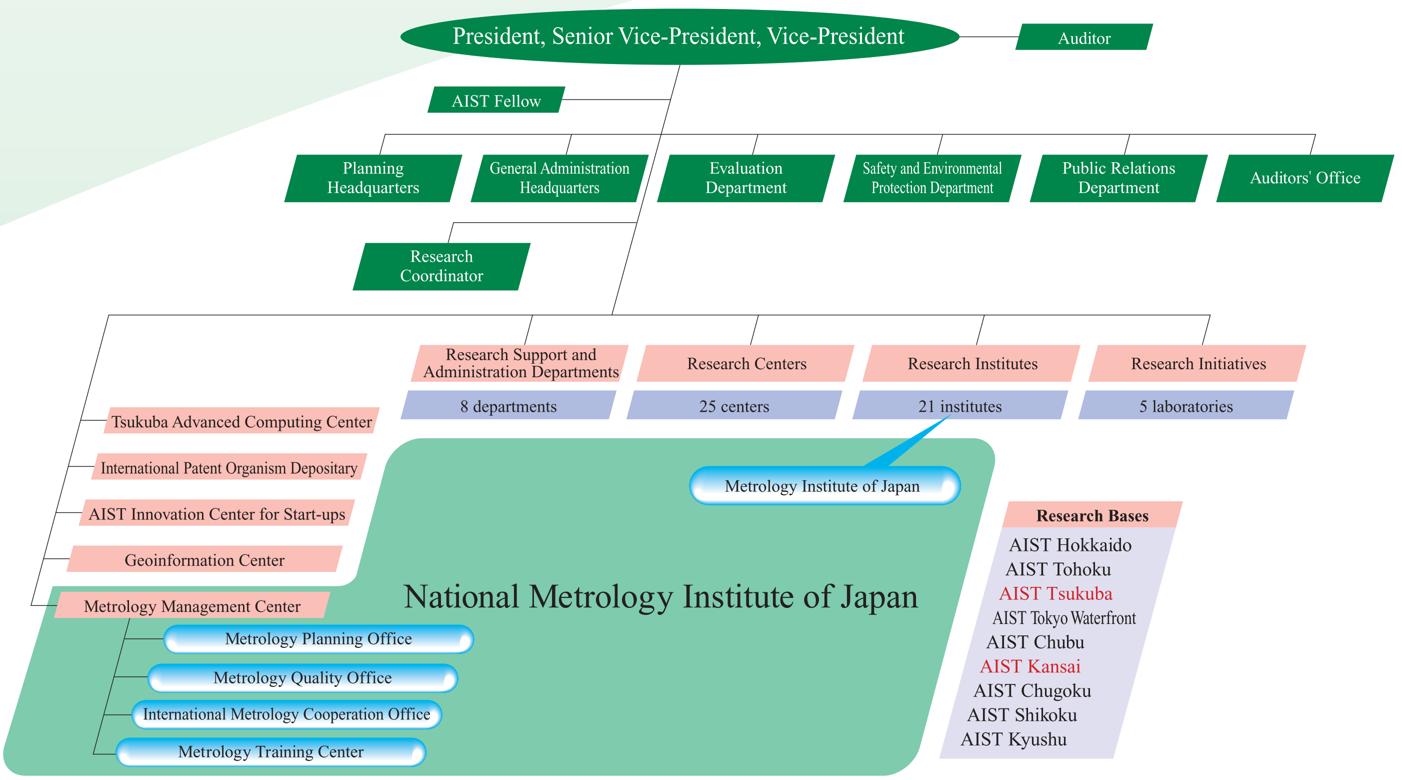
# Measurement Standards and How They Support Society

NMIJ

The development of measurement standards is one of the most important missions of the National Institute of Advanced Industrial Science and Technology (AIST), and is expected to show significant growth. As the core organization concerned with measurement standards in Japan, NMIJ conducts various activities both at home and abroad, while integrating the development of measurement standards with other related activities. “The Metrology Institute of Japan (MIJ)” is in charge of research and development. MIJ is structured so that its divisions correspond to the ten Consultative Committees of the International Committee for Weights and Measures (Comité International des Poids et Mesures, CIPM), which was organized according to the Meter Convention, and also has divisions specifically designed for handling legal metrology. Aware of the significance of training measurement experts in order to provide, disseminate, and publicize measurement standards efficiently, the Metrology Management Center has been set up, consisting of the Metrology Planning Office, the Metrology Quality Office, the International Metrology Cooperation Office and the Metrology Training Center. Working closely with one another like a single unit, MIJ and the Metrology Management Center continuously strive to establish, maintain and provide a wide variety of measurement standards for our country.



Feature

# Measurement Standards and How They

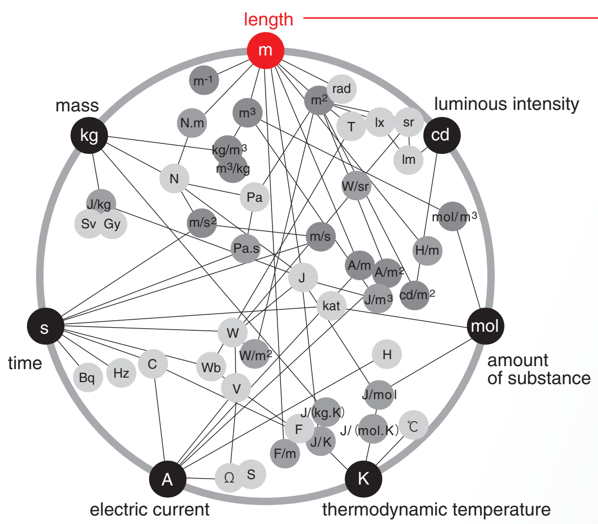
Akira ONO, Research Coordinator

Whenever we buy, sell or exchange any kind of item, we use a remarkably broad array of units. Each of these units is determined according to a standard gradation, or measurement standard. Thanks to the existence of these measurement standards, we can carry out an infinite array of activities and transactions with the confidence that we know exactly how much of each item we are dealing in.

For today's advanced technologies, such as nanotechnology and biotechnology, ever more precise measurement standards are required. The importance of such precise measurement is growing constantly.

How are these measurement standards defined? How are they established and propagated for general use?

**The World of the International System of Units (SI)**

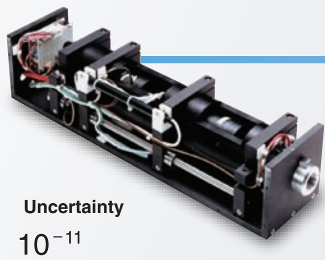



All SI units are derived from of the seven basic units. These units are mutually interconnected. For example, the unit of time (s) is necessary to define length.

### National Standards for Length

Iodine-stabilized He-Ne laser

Iodine-stabilized He-Ne lasers provide an extremely stable light source at a wavelength of 633 nm. These lasers can realize an accurate "ruler" with a scale division of half the wavelength, using an interferometer. They are also used as a secondary measurement standard.



Uncertainty

$10^{-11}$

(precision to 0.1 mm when measuring 10,000 km)

### Practical Standards

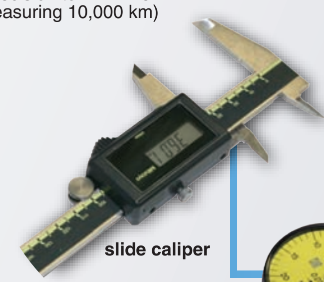
Gauge blocks account for approximately 80% of the practical length standards presently in use. A gauge block is one of the end standards in a block shape. The distance between its two ends is used directly as a length standard. Because of that, there are over a hundred of them that are different in size. Their shapes are maintained by precision polishing and their absolute length can be realized with better than 0.05 μm precision.

$10^{-7}$

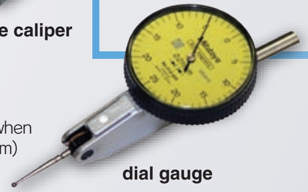
(precision to 1 m when measuring 10,000 km)

### Measuring devices for general use

Various kinds of measuring devices used for manufacturing, such as slide calipers, micrometers and dial gauges, are included in this category.



slide caliper



dial gauge

$10^{-5}$

(precision to 100 m when measuring 10,000 km)

*nm (nanometer; 1 nm = 1/100 millionth of a meter)

# The Role of Measurement Standards Units and Measures

Hirokazu MATSUMOTO,
Deputy Director, Metrology Institute of Japan

## Units and Measures

The exchange of materials is an indispensable part of our everyday lives. Yet the greater the quantity and variety of material exchanged, the more difficult it becomes to exchange items directly. Precise information about those items is needed in order to exchange them. For this purpose, a wide range of units is employed.

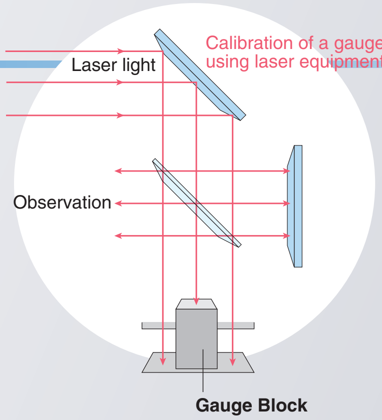
To use these units, a sufficiently large community of users must accept the use of a common set of measures in their everyday lives. If the gradations in these measures – the units – differ among the people conveying information about a given item or transaction and those receiving it, or if the people involved lack confidence in them, it becomes impossible to conduct transactions with confidence, For this reason, measures represent a keystone supporting our modern society.

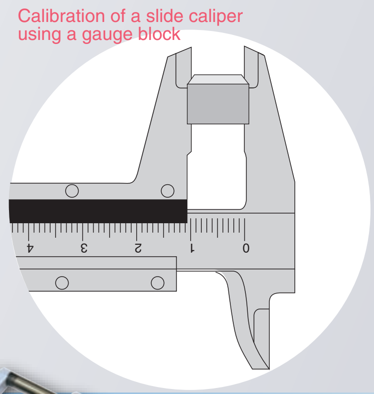
## Measurement Standards for Better Safety and Security

### Allowing lab-test results to be used anywhere in the world

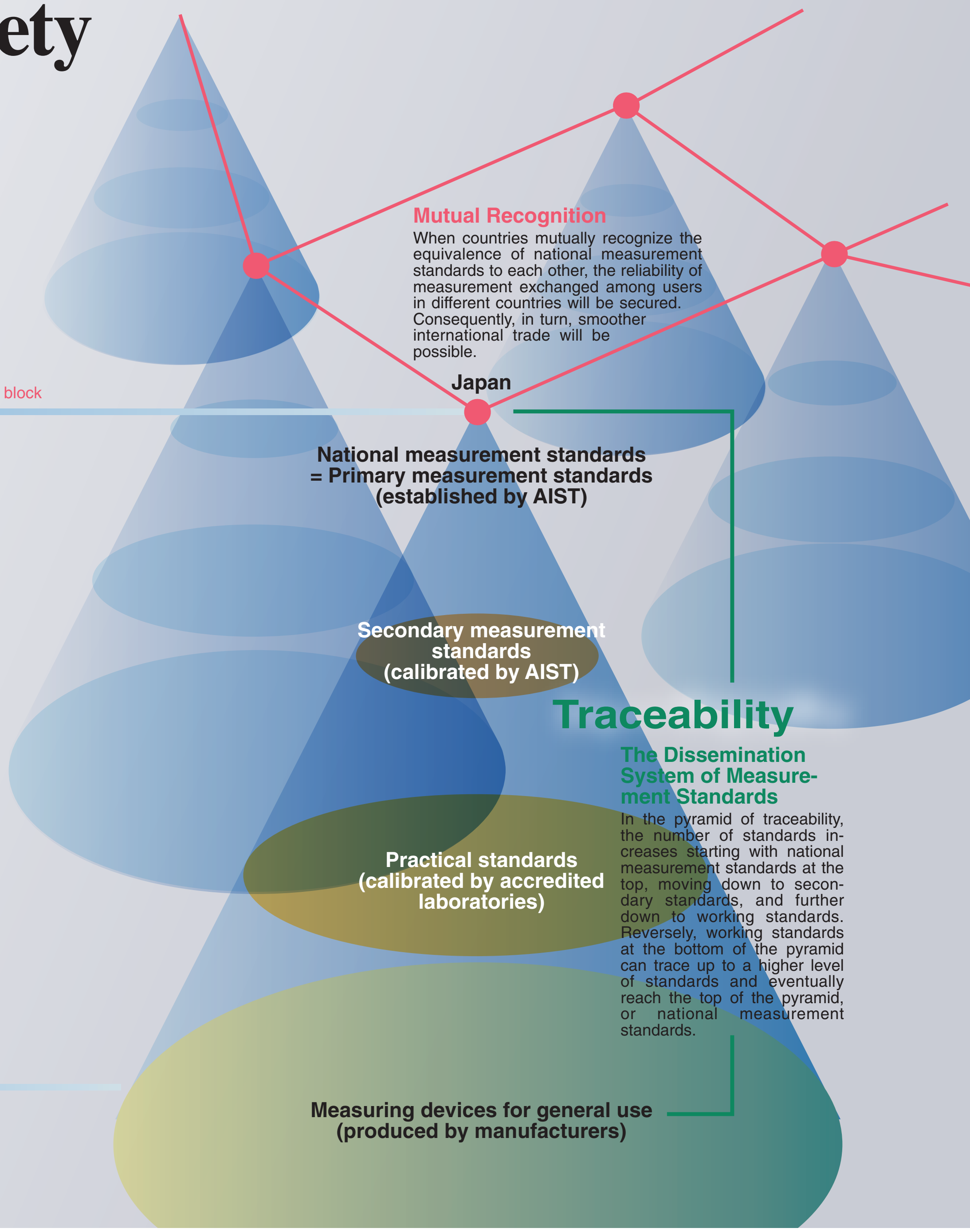
In lab tests, blood and urine samples are used to measure levels of cholesterol, gamma-GTP, urinary proteins and the like, to ensure that patients' levels of these substances are normal. These values must be identical (within a reasonable range) at any hospital in the world. If they are not, great confusion and danger may result. Incidentally, no measurement standards for cholesterol have yet been established. AIST is currently working to develop measurement standards for cholesterol and other key blood components.

# Support Society



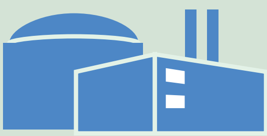





Toshihide IHARA, Manager, Metrology Planning Office, Metrology Management Center

## Measuring Critical Water-Supply Flowrate in Nuclear Reactors

Nuclear power plants work by splitting atoms to heat water. The resultant steam drives a turbine, which turns an electrical generator. After passing through the turbine, the water vapor (which is uncontaminated by radiation) is cooled and returned to the water supply, where it is once more sent to the nuclear reactor. Because this flow volume is used to control the amount of heat generated by the nuclear reactor, obtaining an accurate assessment of the water flow is crucially important for the safety and generating efficiency of the power plant. At AIST, we are hard at work developing highly precise technologies for measuring water-supply flow volumes in nuclear reactors.



## Monitoring Electromagnetic Environments

Mobile telephones generate redio waves. To prevent such emissions from interfering with pacemakers and other medical devices, mobile phone use is prohibited in hospitals and on trains. Production of electronic devices, such as PCs, is governed by international standards regarding unnecessary generation of radio waves. In Japan, such devices are thus requlated to ensure product safety. AIST prepares the measurement standards needed to monitor and control these high-frequency electromagnetic environments.

## Traceability in Measurement Standards

Measurement standards are the means by which standard gradations are stipulated to establish various units. In Japan, the National Measurement Institute of Japan (NMIJ), a center within the National Institute of Advanced Industrial Science and Technology (AIST), determines the national standards upon which measurement standards are based. NMIJ develops and supplies standards that are trusted not only throughout Japan, but in many countries overseas as well.

To make national standards available throughout society, a system of *traceability* must be established. Traceability is provided by a verifiable system for assuring that the units of measurement applied in a given environment are identical with a higher national or international standard for that unit. This article examines how traceability works, using units of length as an example. The standard for length, the measure that stands at the apex of any traceability system, an elaborately constructed physical model representing one meter of length. For 70 years, this physical model of the meter served as the national standard for length in Japan. The problem with the use of physical models, of course, is that the loss of the physical model on which the system is based would result in chaos. For this reason, efforts were made to develop a scientific method of defining the meter. Eventually, in 1960, wavelengths of light came to be used to determine gradation, and "one meter" was defined as 1,650,763.73 times the wavelength of the light emitted by an atom of krypton.

This innovation allowed length to be established using contactless techniques. It reduced uncertainty regarding the accuracy of the measurement value by two orders of magnitude, thereby greatly improving the technological basis upon which modern industry is founded. ("Uncertainty" is a measure of precision; it is the range in which the true value is sure to be found.) A further advance occurred in 1983, when the speed of light was used to redefine "one meter" as the distance that light propagates in a vacuum in 1/299,792,548 of one second. The national standard for "one meter" is thus obtained from a stabilized wavelength produced by an iodine-stabilized helium-neon (He-Ne) laser.

However, the instruments we use on a daily basis were not produced with direct comparison with this national standard. Rather, the standard is transferred from a designated standard device representing the national standard to a secondary standard device. The gradations on the secondary standard device are compared with those on the designated standard device, to "calibrate" the device, or verify its precision. This check can only be performed by an accredited calibration laboratory. Using a technology called wavelength interference, laser wavelengths can be used to accurately calibrate the gradations on a wide range of standard devices. The wavelengths of He-Ne lasers are then used on the secondary standard device as well. By this process, capable private-sector calibration laboratories can calibrate a practical standard device (a gauge block or other simple device that can be used as a standard device by any end user). In the next phase, the gradations on this practical standard device are transferred to the calipers, micrometers, and other devices used by the end user. Here again, this work must be performed by an accredited laboratory.

Japan's private-sector calibration laboratories boast an exceptionally high level of technology. Today, some 35 accredited laboratories use the designated secondary standard devices in their possession to perform calibration. Standing at the top of the calibration pyramid, these certified operators play an extremely vital role in modern industry: the number of practical standard devices each laboratory has calibrated runs to the hundreds of thousands; and the number of types of general instruments to which the calibrations on those practical standard devices are transferred number in the tens of millions for each accredited laboratory. Because the traceability system forms a pyramid, calibration is remarkably cost-effective in Japan, conveying national standards to the nation' s users with enviably low levels of uncertainty.

## International Mutual Recognition

As industrial technology and business operations become increasingly global in nature, the importance of interaction with other countries is rising dramatically. These interactions depend on the ability to trust the measurement standards used by each country; one country's units must be interchangeable with all others'. For this reason, the international community has been grappling with the need to establish mechanisms to preserve the equivalence of various countries' measurement standards and provide society with measurement standards that each country can recognize, so that the inspection and test data of each country are interchangeable. This interchangeability is called the "international mutual recognition" of measurement standards. Today 57 signatory countries and regions are members of the International Bureau of Weights and Measures (BIPM), the international standards body established by the Meter Convention.

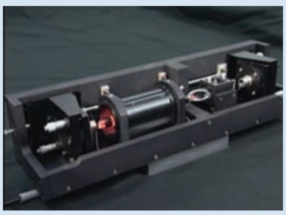
Countries signatory to the international mutual recognition process are required to prepare quality manuals, conduct

## Optical Comb: A leading-edge technology for optical frequency measurement

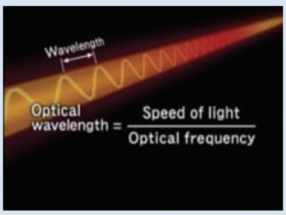
Hajime INABA, Wavelength Standards Section, Time and Frequency Division, Metrology Institute of Japan

The unit of length, the meter, is determined using red light from an iodine-stabilized He-Ne laser (ISHN laser) as a ruler (1). A laser is a wave; its cycle length is called the wavelength. How do we determine the laser wavelength? An optical wavelength is calculated from the optical frequency (2). In the case of an ISHN laser, the optical frequency is approximately 474 THz (1THz =1 terahertz = $10^{12}$ Hz). Therefore, the wavelength is approximately 633 nm because the speed of light is defined as 299,792.458 km/s.

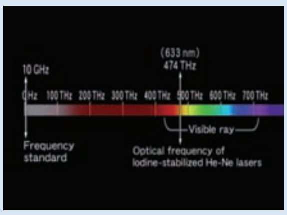
We now come to the question of how the optical frequency of the laser is measured. We must measure an optical frequency using the frequency standard, which is approximately 10 GHz microwave generated from a cesium atomic clock. However, the optical frequency of an iodine-stabilized He-Ne laser is approximately 474 THz, which is more than ten thousand times higher than the cesium frequency (3). Therefore, measuring an



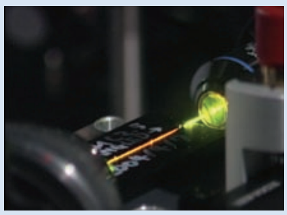
(1) Iodine stabilized He-Ne laser




(2) Relationship between optical wavelength and frequency




(3) Frequency gap between the frequency standard and the laser



(4) Photonic crystal fiber

fully transparent international comparisons, and submit to peer reviews by specialists from other countries. Standards that pass this rigorous process are registered in the BIPM database. Officially in operation from 2004 onward, this system will soon allow measurements gathered in other countries to be accepted "as is" in one's own country, contributing significantly to smooth trade operations and economic growth.

## Legally Designated Measurements That Protect the Security of Our Everyday Lives

Takeshi ITO, Metrology Planning Office, Metrology Management Center

Measuring instruments for commercial transactions and certifications that have a remarkably pervasive influence on private consumers are under strict legal control. For instance, they must pass mandatory verification before they enter the market. They are called "specified measuring instruments".

Today, there are 25 categories of legal measuring instruments in Japan. Meters for water, gas and electricity, for example, are requisite in daily life. Aside from these, in the real world, weighing instruments to weigh foods in retail shops, alcohol hydrometers to determine the alcoholicity in liquors, fuel dispensers at gas stations, and taximeters in taxis are helping people without always being noticed. Sphygmomanometers and clinical thermometers used for health management at home are similarly required to pass verification.

For environmental measurement, sound level meters and vibration level meters are examples of specified measuring instruments. Concerning the contamination of air, soil and water, measuring instruments to determine minute quantities of pollutant such as dioxin, which have drawn public attention, are also subject to verification.

The period of validity of verification is limited. Specified measuring instruments must be subjected to regular inspections to guarantee their accuracy.

Conventional mechanical instruments have adopted more and more advanced electronics, such as CPUs. In this trend, new-generation measuring instruments have been introduced. They can be applied to, for example, centralized screening systems using LANs and the Internet, energy supply management and its distribution system with consolidated databases of measuring results. In addition, they are able to interact with mobile devices such as mobile phones and may allow the popularization of electronic money with IC chips. Those innovations have brought drastic changes in the practices of transactions and logistic systems. Specified measuring instruments are playing valuable roles in this society. They have become more and more important as they incorporate increasingly advanced technology.

On the other hand, these remarkable advances also pose a problem. To ensure the measurement accuracy, legal regulation has mainly dealt with hardware, which has been sufficient so far. However, it has been expanded to installed software today, because the development of information technology has increased the risk of illicit interference and falsification. To meet the emerging needs of software protection, AIST is engaged in the research of this field.


Taxi meter


Noise meter


Gas meter


Water meter


Commercial weighing scale

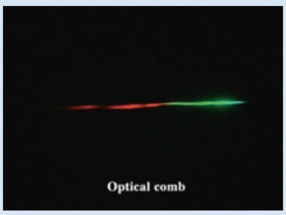
optical frequency using the cesium frequency as a standard was extremely difficult.

At AIST, the investigation of optical frequency measurement has proceeded. As a result, we have developed a special light optical frequency comb, which is a bridge between the microwave frequency region and the optical frequency region. An optical frequency comb can be generated using a femto-second mode-locked laser and a photonic crystal fiber (4).

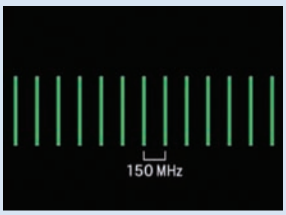
As shown in the photo (5), this optical frequency comb involves various color components, similarly to a rainbow. However, its micro-structure is not continuous like a rainbow but discrete like a comb (6).

The frequency intervals of a comb are uniform. If the intervals are locked to an atomic clock, these comb frequencies are also determined accurately (7). A locked optical comb appears as though a million stabilized lasers form a line at uniform intervals (8).

Various laser frequencies can be measured over 1000 times more accurately than conventional techniques by using an optical comb as an optical frequency ruler. These accurate lasers will improve semiconductor processing precision, for example. Furthermore, using this technique, contributions to the optical communications are expected.

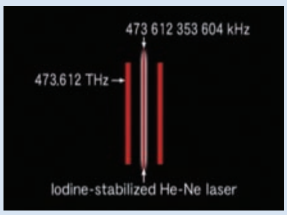


(5) Optical comb



(6) Magnified optical comb (Conceptual figure)


(7) Frequency counter



(8) Frequency measurement of a laser using an optical comb as a frequency ruler

# Measurement Standards at Production Sites: Automobiles

Tomohiro MOCHIZUKI,
Measurement Engineering Department, Nissan Motor Co., Ltd.

## Measurement Standards Indispensable for Automobile Inspections

To retain a satisfied customer base, we, automobile manufacturers, must guarantee the quality of the vehicles we sell, and reduce production costs by reducing defects through quality control. For both of these tasks, measurement standards and measurement management occupy a position of vital importance.

Quality control in the automobile manufacturing process proceeds in a step-by-step manner. First, inspection occurs at the level of individual parts. Manufacturers must strictly guarantee that parts pass national regulations concerning the basic functions of parts (running, turning, stopping, etc.). Important security parts such as brakes and chassis are subjected to particularly stringent checks.

Finally, when the car is fully assembled and ready to be shipped to market, a final inspection of the vehicle's performance and various other factors is conducted. The list of items tested in this inspection is daunting, yet all items must be identical to the test items used by the Land Transportation Bureau. Once the vehicle is passed on to the inspection line, each inspection item is tested and adjusted in order.

The measurement standards used in production processes such as these are traceable to national standards. A collection of 93 in-house standard devices is used in common by all companies for precision management. At the level of secondary standard devices, about 400 such devices, which are calibrated using the at-house standard devices, are in use at all worksites. Because the items produced at each plant vary from auto bodies to engines and many other components, some 50–60 secondary standards are required to manage the instruments used in inspection.

## The Increasing Importance of Traceability

As multifaceted and complex as the inspection of completed vehicles is, for all of the basic items inspected — brakes, wheel alignment, speedometer, exhaust and much more — traceability must be assured. No variance can be tolerated, even though the same engines may be produced at different plants or the same type of cars may be built in different countries.

Moreover, unlike the conventional practice in the industry, parts and device suppliers anywhere around the world can actually provide their products even if they are not part of our corporate group. For that reason too, the importance of traceability in measurement is rapidly rising to manage the quality of the parts and devices we use. For example, Nissan and Renault require their suppliers to conform to common quality requirements, including ISO/TS 16949 — a set of quality system requirements that applies to the automobile industry.

Under these exacting conditions, manufacturers need to maintain highly precise in-house measurement standards and conduct continuous training of calibration technicians, expecting them to improve their skills to sophisticated levels. Toward this end, we are working proactively to secure certifications in various measurement categories from the Japan Calibration Service System (JCSS), which is considered to be the Japanese version of ISO/IEC 17025. For instance, Nissan is already fully certified in two categories: length (end measures) and electricity (DC voltage).

The advance of economic globalization is driving a steady increase in the import and export of automobiles. Each importing country has its own set of laws governing these products. In many countries, the traceability requirements are stricter than those in Japan.

Ultimately, we would like to establish a one-stop testing process — a system in which, meeting common requirements, countries would accept one another's measurements based on mutual trust in the measurement standards of each country. Because no such system yet exists, the international trade of automobiles still involves complicated and time-consuming processes. We must write test reports that follow the legal requirements of each country. These requirements can be broadly divided between the North American and European type, with many countries outside these two regions choosing to adopt one or the other.

## Responding to Advances in Technology

Today's automobiles are becoming more technologically sophisticated with each passing year. The rate of this advance is accelerating. Not surprisingly, the measurement standards required to build these products are changing in number and variety at a blistering pace. For example, as more automobiles are

**Photo 1 Welding process on a production line**
A battery of robots carries out the work with high precision. (Photo courtesy of Nissan Motor Co. Ltd.)


**Photo 2 Installing an engine unit**
Human skills and measurement standards play a vital role in ensuring the safety and trustworthiness of automobiles. (Photo courtesy of Nissan Motor Co. Ltd.)

**Photo 3 Final inspection of a product fresh off the production line**
A wide variety of measuring instruments are used. (Photo courtesy of Nissan Motor Co. Ltd.)

installed with fuel cells, standards for electrical power, hydrogen and chemical reactions must be devised and adopted. These new needs may arise full-blown within the space of a year, but responding as quickly with the standards they require is no easy matter.

At the same pace as the technology furnished to customers, we must rush to calibrate our products according to newly mandated standards. For all automakers, this process presents a formidable challenge in the coming years.

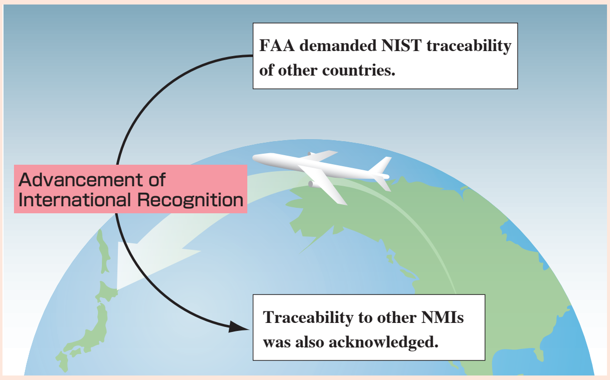
## Measurement Standards in Aircraft Maintenance

Toshirou ITOU,
Quality Assurance Department, Japan Airlines

For airline companies, nothing is more decisive for the safety of passengers than aircraft maintenance. Following a tragic airplane crash in 1996, the United States Federal Aviation Administration (FAA) handed down a requirement that all instruments used in the maintenance of US-registered aircraft provide National Institute of Standards and Technology (NIST) traceability, whether the maintenance provider is based in the United States, Japan, or any other country.

Aircraft maintenance requires a dizzying variety of instruments micrometers, calipers, torque wrenches, thermometers, thermocouples, voltage meters, ammeters and others. Ensuring NIST traceability for each and every one of these instruments was grievously time-consuming and incurred enormous costs. Unable to square this circle alone, Japan's airlines turned to the then Agency of Industrial Science and Technology (AIST) for advice. This consultation produced an arrangement between AIST and NIST for cooperation in the field of measurement standards. In addition, the two agencies used the results of comparisons of individual measurement standards mutually to persuade the FAA that these measurement standards were equivalent.

In this way, Japan's airlines were able to win exemptions from the FAA's traceability requirements, allowing them to deploy instruments traceable to Japanese standards in the maintenance of US-registered aircraft and their parts. At about the same time, in 1999, a global Mutual Recognition Arrangement (MRA) was concluded with respect to the field of measurement standards. This framework lent impetus to the development of an organized system of international comparison and mutual recognition for measurement standards on a global scale.




As a result of these developments, in July 2003, the requirements contained in the FAA Advisory Circular, a notice of FAA inspection operation, were changed, clearly permitting the application of NIST or other national measurement institutes' traceability provisions.

# Measuring Gene Quantities

Mamoru KAWAHARASAKI,
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Deoxyribonucleic acid (DNA) consists of a characteristic double-helix formed by four nucleotides, called bases, which pair specifically with one of the other bases, in bonds called base pairs (Figure 1). The genes, blueprints of all organisms, are written by these four bases.

## Measuring Genes by Amplifying Genes

How can we measure gene quantities? At present, for gene quantification, the fastest and most accurate method is a technique called "quantitative PCR". Quantitative PCR combines the polymerase chain reaction (PCR) method with measurement of genes using fluorescent dyes. The PCR method, which is a gene amplification method, amplifies a specific gene with a certain base sequence to twice its size by single reaction. Theoretically, by a continuous reaction (i.e. chain reaction), a single gene can be amplified infinitely (in practice, the reaction will be stopped by lack of available reagent, the heat degradation of enzyme activity, and so on). This technique allows even small quantities of genes, which had originally been impossible to measure, to be quantified with reasonable accuracy.

To measure the amplified gene, several fluorescent dyes are used. Usually, the time needed to reach the threshold fluorescence intensity in the PCR gene amplification is measured. If the original gene quantity before the amplification is small, this interval will be longer; if the original quantity is large, the threshold will be reached more quickly. By creating a graph showing the relationship between the predetermined standard gene quantities and the times to reach the threshold fluorescence intensity, and by measuring the time taken for an unknown quantity of a sample, it is possible to measure the gene quantity in the original sample (Figure 2). The special equipment needed to carry out quantitative PCR is commercially available (see photo).

This measurement technology is used to quantify the amount of genetically modified organisms (soybeans, corn, etc.) in foodstuffs. Future uses may include such medical applications as predicting the time for the onset of AIDS.

**Photo**
The left black device is a LightCycler®(Roche Diagnostics, GmbH, Germany) ; the right square one is a PRISM®-7900 (Applied Biosystems, USA).

At present, AIST is participating in the development of international protocols to support the reliability of genetic measurement using quantitative PCR, in cooperation with Consultative Committee of Amount of Substances (CCQM) under the Meter Convention.

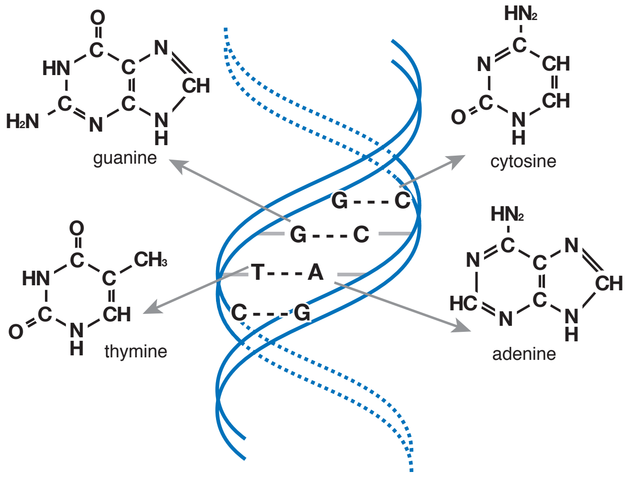


**Figure 1 The structure of DNA**
Genetic information is written by four bases: adenine, thymine, cytosine and guanine.

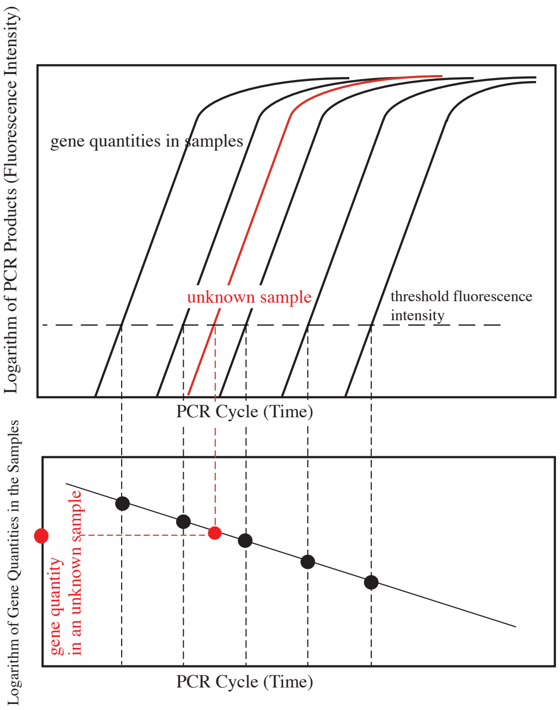


**Figure 2 Principle of quantitative PCR**
Using a genetic sample whose quantity is already known, the time to reach a threshold level of fluorescence is measured and plotted on a graph. This graph is then used to measure the quantity of the gene in the sample whose genetic quantity was previously unknown.

# The Development and Spread of Nanotechnology and Related Measurement Standards

Toshiyuki FUJIMOTO,
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Research and development in nanotechnology is making impressive strides. Surprisingly, the roots of this discipline are ancient, even prehistoric. It is known, for example, that the civilizations of Mesopotamia created colored glass such as eye beads, which they fashioned into jewelry and the like. Much later, around 500 AD, stained-glass techniques that had been developed in the Byzantine Empire began to find currency through much of the ancient world.

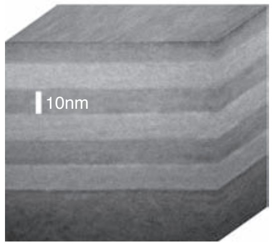
## Nanotechnology Blooms in the Age of Advanced Measurement Technology

Recent advances in measurement technology have opened an exciting new chapter in nanotechnology. Ancient "nanotechnologies" guided by rough experience are taking on new life, thanks to measurement technology. Developers can now manipulate the colors in stained glass with high precision, based on a clearer understanding of the relationship between color and the oxides and metal particles embedded in the stained glass. Today these particles are being manipulated at the nanoscale level to develop new functional materials, requiring measurement technologies with unprecedented resolution and quantitative sensitivity.

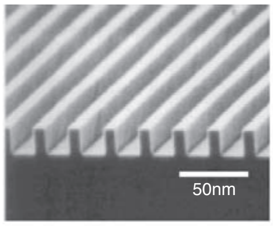
Nanotechnology makes use of unique functions discovered in individual structures and configurations thereof on a nanometer (billionth of a meter) scale, yielding new and unprecedented applications that transcend conventional scientific disciplines. To maximize the benefit from these unique properties, these tiny individual structures and the functions discovered for them must be evaluated in terms of universal values. The most effective route to achieving this ability is to introduce measurement standards that offer a universality transcending the differences among disciplines. AIST's NMIJ is at the forefront of activities to prove the equivalence of Japan's national measurement standards with international standards. Among the many benefits of this research is its effectiveness in protecting intellectual property rights.

NMIJ is working proactively to develop a battery of valuable measurement standards. For example, NMIJ is working on certified reference materials for scales that are useful as measures for the evaluation of various nanoscale three-dimensional structures, which form the building-blocks of nanotechnology. Evaluation methods and certified reference materials for the sizes of nanoparticles and nanopores are also under development. To serve the need for design and evaluation of optical recording media, the demand for which is growing exponentially, NMIJ is devising methods of evaluating the thermal properties of nanoscale fields and interfaces. This Institute is also working on methods of evaluating the density and hardness of ultrathin films. AIST expects that these new measurement standards will not only find application in certain specialized fields, but will also serve as the foundation on which the fusion and integration of nanotechnology with other fields is maximized.

**The World's Finest Scales with Minimum Measurements of Several Nanometers**



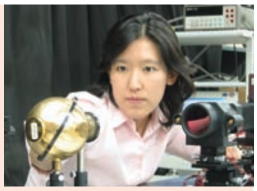

Schematic representation of a nanoscale for depth direction




Schematic representation of a nanoscale for in-plane direction

## A Young Researcher Offers Her Views

Yukiko SHIMIZU,
The editor interviews a young scientist, Dr. Yukiko Shimizu, Radiation Thermometry Section, Temperature and Humidity Division, Metrology Institute of Japan



—What is your research activity?

I'm constructing a dissemination system of the radiation temperature standard in the middle temperature range from 100°C to 500°C. Radiation thermometers are widely used in the fields of industry and science. Non contact and fast determination of the temperature of even nano scale material can be achieved using radiation thermometers. We have already constructed a fast detection system with an infrared radiation thermometer and a laser source modulated at very high frequency. We succeeded in measuring the temperature and thermal conductivity of a 10μm thick metal thin film with a time constant of 300 nanoseconds. This technology should lead to the development of the next-generation measurement standards such as nano-scale temperature standards.

—What interests you in this line of research?

Many national institutes of standards are now competing in the construction of radiation temperature standards in the middle temperature range. It is challenging to develop a more accurate standard in an original way. It may have enormous impacts in the fields of science and technology. Research on temperature standards in the nanoscale domain necessarily goes hand-in-hand with the development of leading-edge measurement technologies.

—What are your future prospects?

Although the principle of thermal-radiation thermometry is based on the Planck radiation formula and the quantum devices such as semiconductor detectors, but the actual measurement processes are being developed on the classical physics technologies such as design and fabrication of black-body furnaces and set up of geometrical optics. By introducing techniques of micro-optics and quantum optics, we hope to develop a new thermal radiation measurement standard which is more accurate, faster, and easier to use. Specific techniques we are working on include high-resolution measurement of wavelength dependence of Planck radiation by using those of quantum optics and molecular spectroscopy.

# Using the Avogadro Constant as a New Standard for Mass

Kenichi FUJII,
Fluid Properties Section, Material Properties and Metrological Statistics Division, Metrology Institute of Japan

Most people who have studied chemistry will probably remember an eccentric portrait of Italian physicist Amedeo Avogadro (1776—1856) that crops up in many textbooks. Avogadro hypothesized that equal volumes of gases at the same temperature and pressure contain equal numbers of molecules. This principle, now known as Avogadro's law, is today one of the most fundamental laws for physics and chemistry.

## Improving the Accuracy of the Avogadro Constant

How many molecules are contained in 1 mole of gas? Avogradro does not offer a specific number for this quantity. At the time, no proof of the existence of atoms and molecules existed, and the theory on which these entities are based had not yet been validated experimentally. Today the internationally accepted value for the Avogadro constant is 6.022 1415 $\times 10^{23}$ $mol^{-1}$ (recommended in 2002 by the Committee on Data for Science and Technology (CODATA)). The constant is defined as the number of atoms or molecules in a single mole, which in turn is defined as 0.012 kg of $^{12}C$. Since the beginning of the 20th century, numerous researchers have engaged in an interminable series of tests and measurements, striving to find an accurate value for the Avogadro constant. Since the 1920s, when X-ray diffraction was deployed for the first time, the accuracy of these measurements has steadily increased. The most startling progress of all has come the past decade, thanks to the emergence of the X-ray crystal density method and growth technologies for silicon crystals.

Because the Avogadro constant is such a fundamental constant in physics and chemistry, the discovery of more accurate values for this number is of monumental importance for basic chemistry. The implications are likely to be felt not just in laboratories, but in broad areas of everyday life as well, because of one radical outcome: the redefinition of the basic unit of mass, the kilogram.

## Redefining the Kilogram

Of all the weights and measures that form the basis of the International System of Units, only the kilogram, the unit of mass, continues to be based on a material artifact. As discussed above, all of the other base units have already been redefined using physical principles. For example, the unit of time, the second, is based on the radiation period of the cesium atom; the meter, the basis of length, is defined in terms of the distance light travels in a vacuum within a defined period of time.

In its premises in the suburbs of Paris, the International Bureau of Weights and Measures (BIPM) houses the artifact that serves as the standard for the kilogram. Each country signatory to the Metre Convention holds a copy of this artifact. Every 30 years or so, these copies are shipped to Paris for recalibration. Meanwhile, the mass of the artifact itself fluctuates over time, rising as ambient gases are adsorbed on its surface and shrinking whenever it is cleaned. Naturally, these fluctuations compromise the stability upon which the present definition depends. The international community has therefore reached an agreement in principle to redefine the kilogram according to a defined number of atoms, using as accurate a value for the Avogadro constant as possible.

## Toward an Atomic Mass Standard

The National Metrology Institute of Japan (NMIJ) is striving to find the most accurate value for the Avogradro constant, using a silicon single-crystal sphere precisely ground to 1 kg. First, the diameter of the high-purity silicon sphere is measured using laser interferometry to obtain a highly precise measure of volume. The density of the sphere is then measured in vacuum, and its lattice constant (the gap between the atoms) and molar mass (average atomic weight based on the three stable isotopes of silicon existing in nature) are determined.

Drawing on these data, in 2002 NMIJ succeeded in determining the Avogadro constant with an uncertainty of $10^{-7}$ level. This breakthrough contributed significantly to finding the most reliable value for the Avogadro constant as listed above. Based on our value as one of the fundamental input data, CODATA has conducted a comprehensive revision of no fewer than 200 fundamental physical constants.

Future efforts are intended to further reduce isotopic impurities and improve the measurement accuracy to a few parts in $10^8$, thereby realizing a new standard for mass based on the Avogadro constant. Through joint research on the international level, the current definition of the kilogram should be obsolete within 10 to 20 years, ushering in a much more readily verifiable and universally reproducible standard for mass.

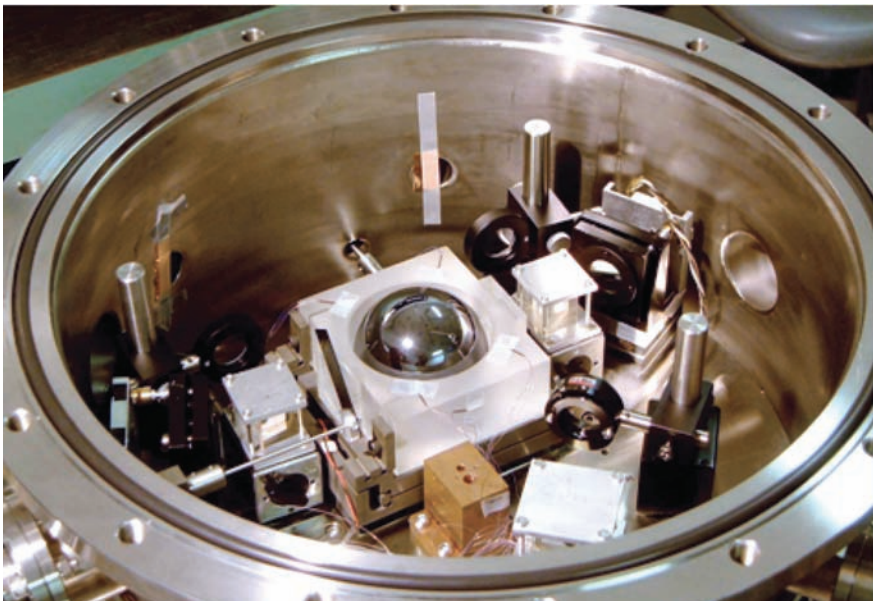


**Photo Using laser interferometry to measure the diameter of the silicon sphere**

# Next-Generation Standards for High Temperatures

Yoshiro YAMADA,
Radiation Thermometry Section, Temperature and Humidity Division, Metrology Institute of Japan

## A Novel Idea for a High-Temperature Fixed Point

Establishing standards for temperature, a physical quantity that is not easy to grasp, depends widely on repeatability of the temperature under which phase transitions occur in a substance. Formerly, temperature was defined on the centigrade scale, using a scale of 100 gradations from the boiling point of water to its freezing point. Today scientists use the Kelvin scale, in which the triple point of water is used to define the unit kelvin of the thermodynamic temperature. Additionally, a wide range of other fixed points, including the freezing points of pure metals, are used to realize and to disseminate the temperature scale.

Creating a fixed point, however, poses many difficulties at temperatures above 1000˚C, where matter reacts violently with other matter; the highest fixed point that can currently be used is approximately 1085˚C — the freezing point of high-purity copper. Attempts to use metals with higher melting points have failed because the graphite crucible used to contain the molten reference metal reacts with it, rendering the results unusable.

At NMIJ, we devised a new method that substitutes a metal-carbon alloy in place of a pure metal, thereby eliminating the graphite-metal reaction. By including carbon in the metal alloy at the composition known as a eutectic, the graphite-metal reaction can be prevented from proceeding further. As a result, highly reproducible melting and freezing points are obtained. NMIJ has succeeded in establishing nine distinct fixed points, from 1153˚C to 2474˚C, using carbon eutectics of a wide variety of metals. We have also demonstrated that fixed points can be obtained at temperatures above 3000˚C, using eutectics of carbon and metal carbides.

## How Made-in-Japan Technologies Are Becoming World Standards

For these "made-in-Japan" standards technologies to win acceptance as true global standards, it is necessary to demonstrate temperature reproducibility and determine temperature values with high precision. These tasks cannot be achieved in Japan alone; it must be demonstrated that the temperatures can be reproduced by anyone, anywhere in the world. Worldwide agreement depends on independent verification of temperature values by the world's leading research institutes. Many of these national metrology institutes are now involved in their research activities in this field. NMIJ is actively transferring knowledge and experience to many national metrology institutes, promoting information exchange and collaborative investigation, while working to maintain its global lead.

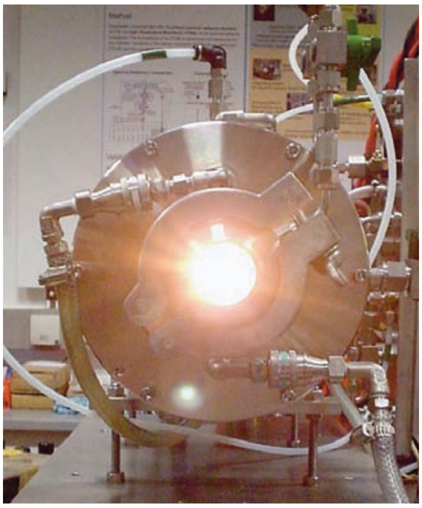


**Photo High-temperature fixed-point furnace for radiation thermometer calibration (Ru-C eutectic point)**

The International Temperature Scale, the international convention on temperature standards that is revised approximately every 20 years, comes up for revision within a few years. When the International Temperature Scale is next redefined, significant changes can be expected in the upper temperature ranges, where greater precision is an urgent necessity for industries such as materials and energy.

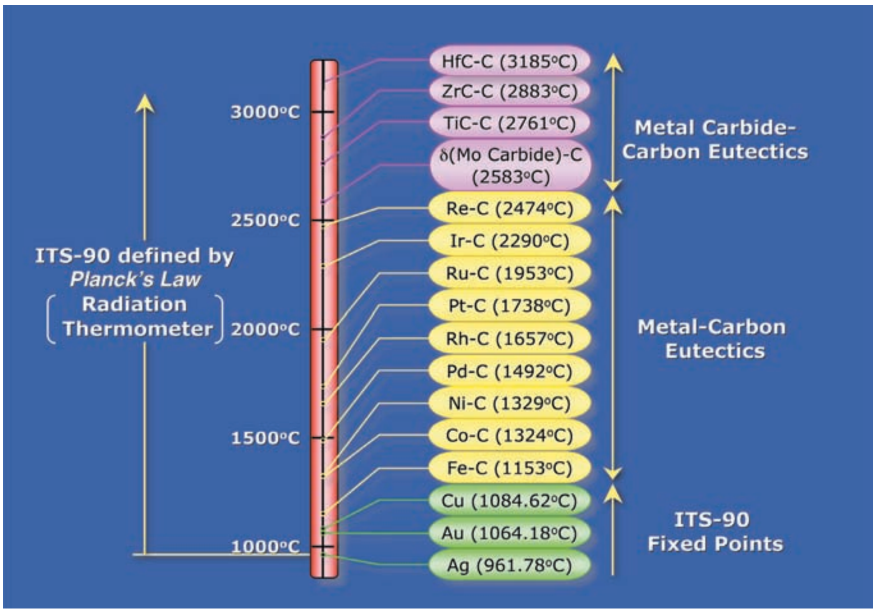



**Figure High-temperature fixed points using metal (carbide)-carbon eutectics**

# Current Status of International Mutual Recognition and Future Directions

Mitsuru TANAKA,
Director, Metrology Institute of Japan

## Measurement Standards in Everyday Life: Development and Maintenance

As our modern world grows more complex and advanced, the measurement standards on which it depends continue to expand both in the types of standard measures established and the purposes to which they are applied. The requirements upon which various quarters of society insist for these standards are demanding and complex: Technological development depends on uncompromising precision; manufacturers must find the standards easy to use for quality-control purposes; the array of available reference materials must be wide-ranging and comprehensive, to be an effective tool in environmental regulation, and so on.

Moreover, each country must underwrite the reliability of these measurement standards. The role of NMIJ/AIST is to create and support national standards and disseminate the measurement standards introduced. Thereby, it can provide a guarantee of reliability to people everywhere who use and depend on measurement results. The people who receive these measurement results from NMIJ use them to supply measurement standards at the next level, which in turn informs the next level of standards, until the work of NMIJ pervades every facet of modern Japanese society.

Of course, the chain is no stronger than its weakest link: reliability must be vouchsafed in every part of this process of supplying measurement standards. This is why traceability, the series of links that join these various measurement standards together to ensure their reliability, is extremely important. NMIJ is the organization that creates the framework that guarantees the traceability of measurement standards to Japan's national standards.

## The Deployment of International Mutual Recognition and Japan's Response

With the relentless advance of globalization, imported products are bought and sold and technologies exchanged with ever-increasing frequency. When this happens, if the mutual traceability of the measures — the measurement standards — on which they are based cannot be guaranteed, evaluating the product or technology correctly becomes impossible. Because it is impracticable to verify this traceability every time a product is sold or a technology is transferred, the international community has struck upon the idea of guaranteeing the inter-reliability of each measurement standard in advance, so that mutual traceability can be guaranteed whenever the occasion demands. This system of measurement standards is known as International Mutual Recognition.

In Japan, the institution that is responsible for International Mutual Recognition is NMIJ. To fulfill its responsibilities, NMIJ continuously conducts international comparisons of national measurement standards and peer reviews by measurement standard experts. Under the Meter Convention, for example, in 1999 the national metrology institutes of numerous countries signed a mutual recognition arrangement. Preparations are being made to put this agreement in force from 2004 forward. As an enthusiastic participant in this arrangement, NMIJ has published an impressive body of outstanding results in international comparisons and enjoys a sterling reputation on the international stage.

NMIJ's brief differs from region to region. In the Asia-Pacific region, with whose countries and regions Japan has long enjoyed especially close ties of business and technological development, NMIJ has taken a leadership role in improving the region's measurement standards technologies. In the markets of North America and Europe, assuring quantitative and qualitative accuracy in measurement standards is an important issue in supporting the competitiveness of Japanese products and technologies.

## The Next Five Years: Targets and Challenges

NMIJ follows a road map (Figure 1) that calls for the creation and dissemination of some 500 national standards, over the 10-year period from the beginning of its first four-year plan (2001–2004). In scope and ambition, this road map is the equal of that pursued by the United States. The basic component of this road map involves the preparation of some

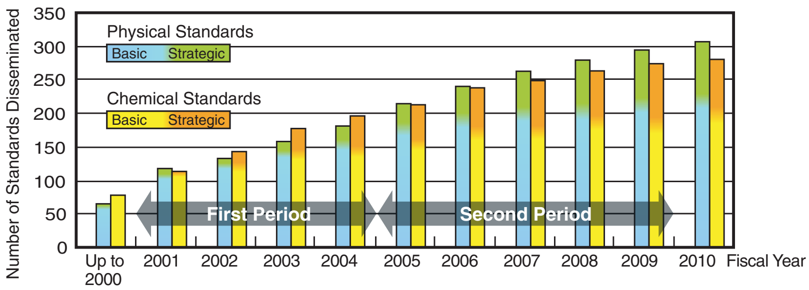



Figure 1: NMIJ's plan of measurement standards

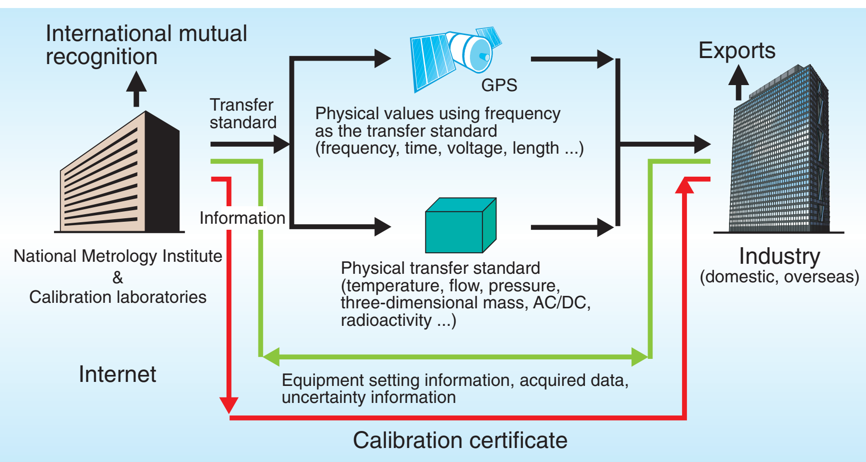



Figure 2: New format for dissemination of standards (remote calibration: e-trace)

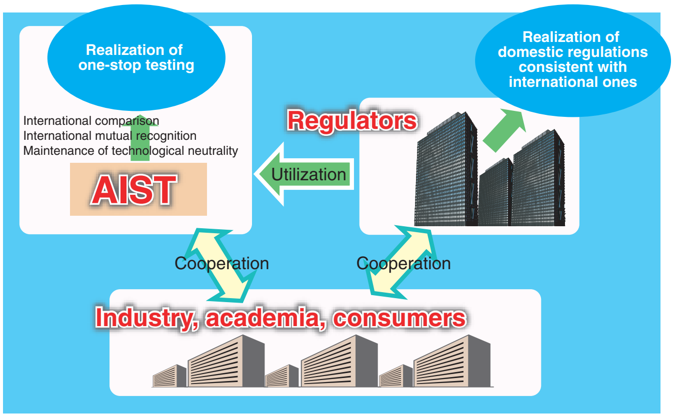



**Figure 3: System for reliability and international consistency in measurement**

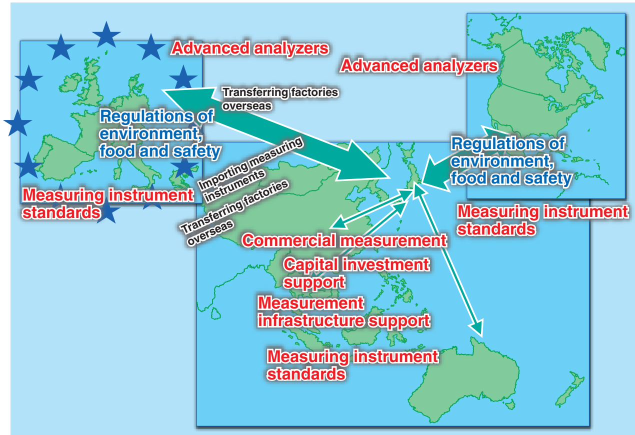



**Figure 4: Japan's response to the emerging tri-polar leadership structure in the world**

300 standards. NMIJ is steadily pressing forward in the execution of this plan. In the second four-year plan, beginning fiscal 2005, NMIJ will augment this basic corpus of standards, aiming to establish and extend measurement standards in certain strategic fields, in view of Japan' s global position in the world of industrial technology.

Unlike the national metrology institutes of other advanced countries, AIST incorporates not only National Metrology Institute of Japan (NMIJ), but a host of other agencies as well, devoted to the fields of biotechnology, the environment, energy and IT. It also conducts vigorous programs of exchange in each category. As such, NMIJ can be expected to create national standards that will lead the world in reference materials for biotechnology, clinical pathology, medicine, the environment and nanotechnology, and in technologies for evaluating the reliability of instrumentation software.

Today's industries require flexibility in the dissemination of measurement standards. Users must be able to choose the level of reliability that is appropriate for them, according to the time and cost required to obtain the standards. Accordingly, NMIJ will be hard at work technically optimizing the formats by which measurement standards are delivered. We are developing remote calibration technologies, using electronic communications and IT to deliver highly reliable measurement standards to users in remote locations (Figure 2). These efforts include ongoing research to speed up the supply of time and voltage standards and to develop new formats for the supply of radioactivity and temperature standards.

Another issue of vital importance at NMIJ is the development of greater reliability in national and international standards. As described above, NMIJ is participating in joint international research on the Avogadro constant to develop a new generation of highly accurate standards for mass that do not depend on artificial physical models for the kilogram. It is using alloys to establish standards for high temperatures. In all of these critically important efforts, NMIJ plays a world-leading role.

## Emerging Needs in Measurement Standards

As those fields in which measurement standards are used continue to expand, it is of paramount importance to ensure that measurements conducted in Japan can be reliably traced to international measurement standards. This process of traceability forms part of the technological bedrock underpinning the sustainability of economic activity and R&D in Japan. To execute this process smoothly, a nationwide system must be designed for the creation and dissemination of national standards, to ensure traceability in the standards used to materials and technologies and in the regulations that govern society. Industry, government and academia must work closely to introduce a level of sophistication beyond that of conventional physical and chemical standards (Figure 3).

The call to action is no less urgent on the international front, where the contours of the process are often shaped by conflicting national agendas. The United States continues to insist strongly on its own national measurement standards, while the European Union is busily unifying measurement standards as it knits itself into a cohesive economic bloc. Moreover, the Asian-Pacific region is emerging as factory to the world and an immense market in its own right. Consequently, these three different powers form a tri-polar configuration strengthening internal ties within themselves (Figure 4). Under these circumstances, expectations are high both at home and abroad for Japan to continue to play a leadership role in the Asian-Pacific region. To serve such expectations, surrounded by a unique jumble of advanced industrial powerhouses and developing nations, Japan should keep making suggestions as to what direction the region should take with regard to measurement standards. At the same time, Japan should show her presence on the world stage by maintaining a high global profile for Japan's measurement standards.

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