Metrology

Measurement in Sport

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World
Metrology Day
20 May 2008

World Metrology Day

Message 2008

No games without Measurement

Andrew Wallard running the ½ mile in 1970.

Dear Metrology Friends and Colleagues world-wide,

As a young man, I was a half-mile[†] runner. Then, aged eighteen, the only metrology which concerned me was whether my time was below 2 minutes… with the occasional brief anxieties about the friction between the track and my running shoes. Today, metrology matters more than ever before in all sports. As 2008 is an Olympic year, for our World Metrology Day this May, we must all aim to bring home the message that precise measurement is vital in today's sports and genuinely important to today's sportsmen and women.

We are all currently aware of the increasingly vigorous competition at every level of sport – amateur as well as professional - as athletes coax their minds and muscles to deliver continuously improved performance. Measurements, as well as photographic images, play a big role in judging their performance: races can be lost by hundredths of a second or field events by fractions of a millimetre. A photo finish may capture that fractional moment pictorially, and can be used to decide the winner, but it does not help us to compare one athlete's performance with his/her own personal best or with someone else's in previous competition. Indeed it is accurate measurement which inspires our confidence in fair play. Local conditions need to be factored in, for example, so that athletes don't gain an unfair advantage through wind speed or temperature. The equipment used – whether weights, racing bicycles or even footballs - needs to be checked precisely. We can attribute improved track times to better shoes, better track surfaces, better training – yes – but no-one would suggest that the second is longer now than in the past or that the metre is shorter. We take it for granted that our units are stable in space and time.

BIPM

The metrology behind the Games, of course, varies in its difficulty and in its impact, as the posters prepared for this year's World Metrology Day show all too clearly. Perhaps the most difficult and controversial problems of all involve the monitoring of performance-enhancing drugs. Careers can be destroyed and medals humiliatingly withdrawn if an athlete is proved to have been taking such drugs or is found cheating. Here at the International Bureau of Weights and Measures (BIPM) we have worked with the World Anti-Doping Agency (WADA) and the National Measurement Institute of Australia (NMIA) to allow a number of National Metrology Institutes (NMIs) to participate in international comparisons of measurements of the levels of performance-enhancing drugs. This activity has confirmed that high levels of confidence in the testing process can be achieved if such measurements are carried out carefully in accredited and well managed laboratories. The necessity for drug testing is, unfortunately, one of the more unpleasant and "un-sportive" aspects of contemporary competition. Random sampling of blood and urine has become commonplace – something never even contemplated amongst my contemporaries. With better measurement and more sensitive testing processes we can all hope that this aspect of sporting life can be greatly reduced or, even one day, eliminated.

Australian Government

National Measurement Institute

However, the message of World Metrology Day 2008 (WMD 2008) reaches even more deeply into the fundamentals of sport. Fairness and comparability of performance are the two basic

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[†] ½ mile = 804.672 metre

criteria on which competition is based. At the heart of this is careful measurement of almost every aspect of sport. Clearly the basic concepts of time, height and distance are obvious elements of track and field athletics, swimming, cycling, to name just a few. We may believe that the basic metrology is self-evident but we all need to take account of a number of extra factors which influence the results. The temperature of water in a swimming pool has a significant influence on a lane length. A light javelin used by one athlete, rather than another, may increase the distance of a throw by an amount which may make all the difference between a Gold medal and a Silver one. As we know from Formula One motor sport, advanced materials can make huge differences. The skill of the driver is enhanced by the skill of the engineer. In recent years, we have seen the use of advanced materials in the manufacture of the pole used in a pole vault, of oars and boats used in rowing events, or in a lightweight bicycle where engineering design has created machines which are as elegant as they are fast. Sport has always provided a warm welcome for new and challenging materials – carbon fibres, for example, found one of their first applications in golf clubs during the nineteen eighties.

The supporting posters and booklets, which have been produced for WMD 2008, highlight many more, sometimes less expected, influence-factors which have to be monitored and checked against references. Whilst sport metrology may not always be as sophisticated or as demanding as in other areas where measurement is important, it nevertheless requires the core cultures of precise measurement: accurate and calibrated reference standards and an appreciation of uncertainty. Today, indeed, reference standards do seem to be widely accepted as important, but that only constitutes part of the equation: uncertainty poses more of a problem. A judge wants to be given a yes/no answer to questions about whether a wind-speed, a weight, a possible level of drugs is within the acceptable limits or not. This is a difficult challenge for us metrologists who always tend to build in the acceptance of an uncertainty with our measurements. We know that no measurement can ever be without error but it is often hard to persuade – or even educate – legislators, regulators or others, that lack of precision is a natural fact of life. In sport, perhaps, the levels of acceptable precision may be such that the highest levels of metrology may not be needed, but we must aspire to it, nevertheless. Elsewhere in legislation and regulation, the case may be clearer cut.

On this broader front, the BIPM is working hard with other intergovernmental organizations. We want to see how we can help, especially by using the data on accuracy and uncertainty which we glean from international comparisons and the uncertainties which NMIs, and those laboratories which depend on them, associate with their calibration services. We work with the accreditation community and specialised bodies such as the International Federation of Clinical Chemistry (IFCC), the World Meteorological Organization (WMO), the Food and Agriculture Organization (FAO), and many others who have specialised knowledge of their application areas to encourage greater attention by them, and the communities they represent, to traceability and uncertainty. We have already achieved significant successes and have attracted new partners and collaborators but more needs to be done. We welcome contacts and collaborations with all who wish to improve measurement practice in their areas of specialist expertise. I hope we are not over-confident in saying that we have very nearly achieved this goal in most areas of physics and engineering. The new challenges for us all lie in chemical metrology, and in traceability of measurements in nutrition, forensic science, and medicine, for example.

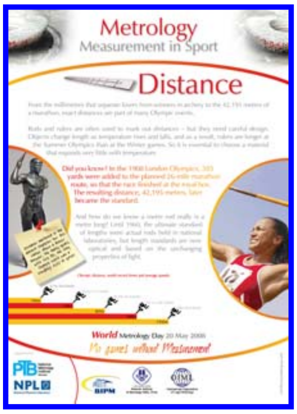
Last year, the theme "Measurements in our Environment," attracted a huge amount of attention from NMIs and other international bodies. Some 85 national events to mark WMD were held in 63 Member States and Associates, as well as in States which have, as yet, no formal links with the BIPM. In partnership with the *Physikalisch-Technische Bundesanstalt* (PTB) in Germany and the National Metrology Institute of South Africa (NMISA), the BIPM prepared an initial poster for WMD 2007 which, with the collaboration of a number of other NMIs, was translated into 18 languages, giving 32 versions of the poster. I know that we shall greatly exceed this number of languages for the poster for 2008. This is an unprecedented level of success, far exceeding anything of which I ever dreamed when my first World Metrology Day message was launched in 2004.

2007 World Metrology Day poster

2008 World Metrology Day poster

Our new partners for 2008 include the National Physical Laboratory (NPL) in the UK who have updated a previous brochure on "Measurement in Sport" and intend to promote it to a general public. Their brochure, as with other WMD material, is available for translation. We are also delighted to be working with the International Organization of Legal Metrology (OIML) and the National Institute of Metrology (NIM) in China, and we wish our Chinese colleagues every success in their hosting of the Olympic Games.

These new partners have come to join in the increasing success and impact of World Metrology Day in previous years and I am sure that the 2008 event will be followed by tens of thousands of metrologists world-wide, as well as by many others through national days or other initiatives.



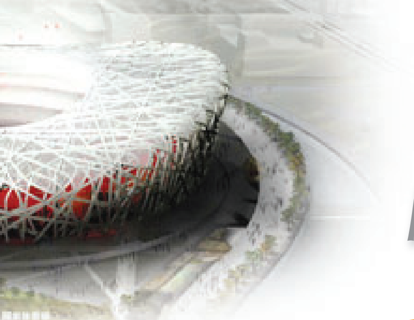
Individual pages/posters from the 2008 World Metrology Day brochure

Our motto for 2008, "No games without Measurement," may be stating the obvious but we all know that measurement is important to nearly all aspects of society. So let us use WMD 2008 to press our message home to a particular group of people with whom we may normally have little contact, in the hope that they will appreciate what we do for them! Let us all hope they may go on to appreciate the importance of good measurement in its broadest contexts in our world.

I wish you all a happy and successful World Metrology Day… Now, where did I put those old running shoes?

Andrew Wallard

Andrew Wallard
Director of the BIPM



Metrology

Measurement in Sport

Pressure

To ensure fairness in the Olympics, it is important to check the pressures of inflatable sports balls like footballs and volleyballs: the pressure inside a ball affects its bounce, so standardising the pressure ensures balls behave as the players expect.

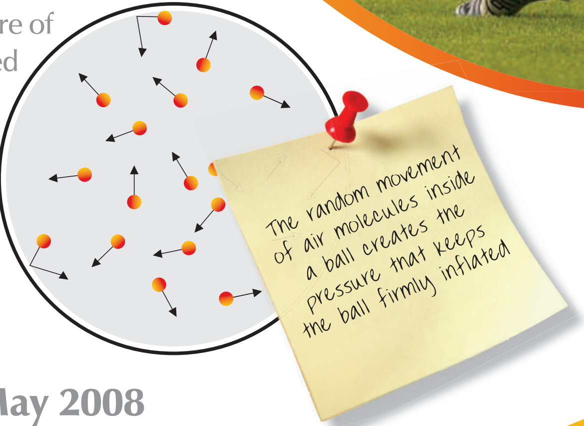
The pressure of the air in a sports ball is measured by a pressure gauge, and pressure gauges are checked against pressure balances

Pressure is defined as force per unit area, and the SI unit of pressure is the pascal, which is one newton per square metre – and a newton is about the force with which an apple presses onto the hand. The normal atmospheric pressure at sea level is about 100 thousand pascals, and the pressure inside an Olympic football is 180 thousand pascals.

Did you know? The Olympics held at the highest elevation were those at Mexico City, 1968, held at 2300 metres above sea level. At that altitude, atmospheric pressure is about 25% less than at sea-level, and athletes from lower-lying countries suffered from the lack of oxygen.

Pressure gauge instrument used to measure ball pressure

In practice, quite a wide margin is permitted on the pressures of balls used in the Olympics The reason for this is that the pressure of air depends on its temperature, and the temperature of a ball changes throughout a game: when it is dropped from warm hands into cold mud, for instance.



The random movement of air molecules inside a ball creates the pressure that keeps the ball firmly inflated

Pressure is the force of impact of air molecules – so the more molecules are squeezed into a football, the higher the pressure inside it. Heating the ball makes the molecules move faster and hit harder, so that also increases the pressure.

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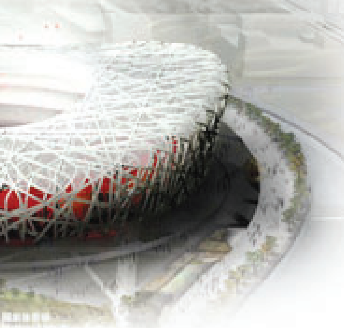

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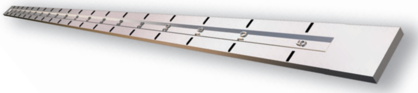
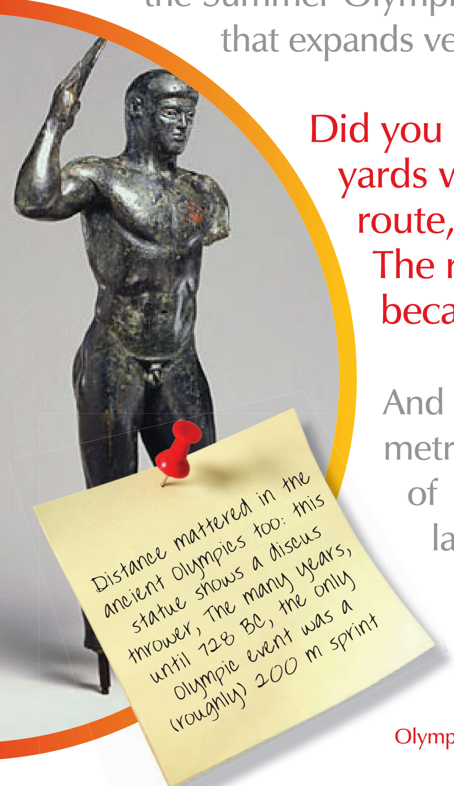


Distance

From the millimetres that separate losers from winners in archery to the 42,195 metres of a marathon, exact distances are part of many Olympic events.

Rods and rulers are often used to mark out distances – but they need careful design. Objects change length as temperature rises and falls, and as a result, rulers are longer at the Summer Olympics than at the Winter games. So it is essential to choose a material that expands very little with temperature.

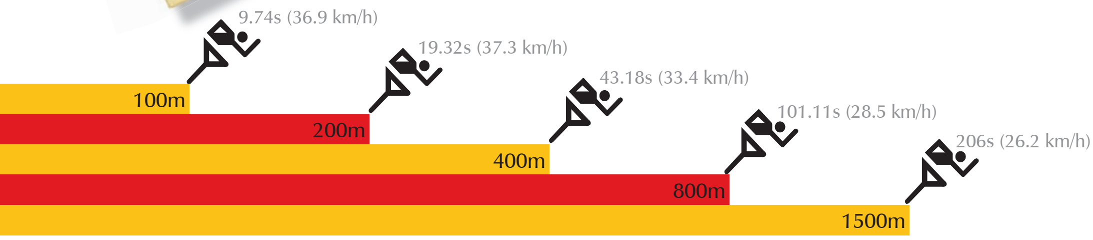
Did you know? In the 1908 London Olympics, 385 yards were added to the planned 26-mile marathon route, so that the race finished at the royal box. The resulting distance, 42,195 metres, later became the standard.



Distance mattered in the ancient Olympics too: this statue shows a discus thrower, The many years, until 728 BC, the only Olympic event was a (roughly) 200 m sprint

And how do we know a metre rod really is a metre long? Until 1960, the ultimate standard of lengths were actual rods held in national laboratories, but length standards are now optical and based on the unchanging properties of light.

Olympic distance, world record times and average speeds



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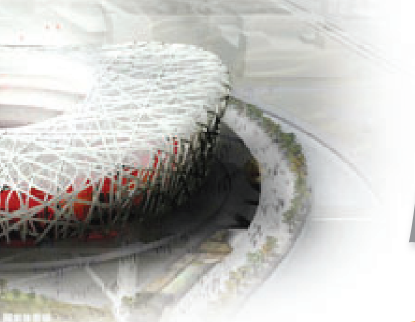

Metrology

Measurement in Sport

Mass

Olympic weights are colour-coded: from 25 kg (red) to 500 g (black)

Mass – the quantity we feel as weight – is a part of every Olympic sport. Not only is the mass of practically every item of equipment specified, athletes too are sorted into groups according to their mass. For instance, adult male weightlifters are divided into 8 classes according to their body mass.

If an item of equipment is a few grams heavier or lighter than specified, the athlete could be disqualified, so accurate weighing machines are essential.

Did you know? Olympic weightlifting rules require weighing machines to be accurate to 0.005 %.

How do we know these machines give the right answers? Because their performance is evaluated by weighing **standard weights** of exact values, to check they display the correct values.

nested in three bell jars, is the lump of metal known as the International Prototype of the Kilogram

Did you know? In the 1960 Olympics, Charles Vinci had to lose 680 grams in less than two hours to compete at his official weight class. He managed it by running, sweating and a haircut.

We know how heavy the standard weights are by comparing them with the weight of the **National Prototype of the Kilogram** in the host country of the sporting event.

In turn, the National Prototypes of the Kilogram are checked against the weight of a lump of metal (a mixture of platinum and iridium) which is kept in Paris – the **International Prototype of the Kilogram**.

So, in the end, every weight in the world is compared with the International Prototype – which is why the International Prototype is priceless.

Javelin weighing at the 1908 Olympics

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Metrology

Measurement in Sport

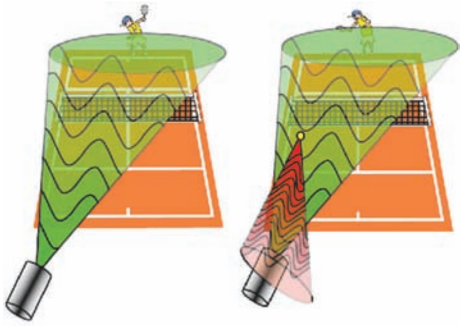
Speed

Speed is key to winning many Olympic events, but it is not used to score any of them.

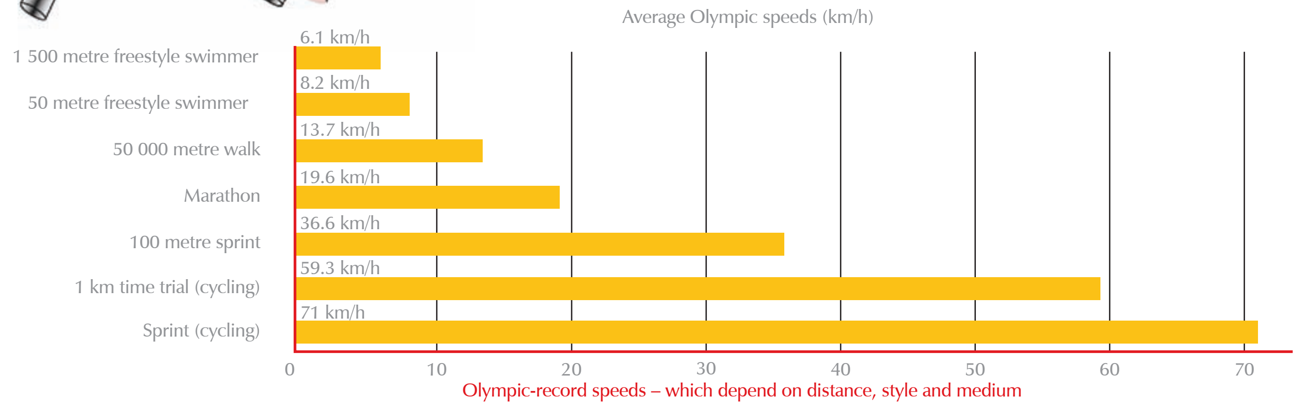
Speed is the distance travelled in a certain time, so in the Olympics it is usually these two quantities that are measured.

Did you know? Asafa Powell of Jamaica is officially the fastest man in the world, running 100m in 9.74 seconds (an average speed of about 37 km/h).

Many Olympic cyclists make use of speedometers to keep track of their performance, and marathon runners use GPS receivers to determine their speeds. Another way to measure speed is by a Doppler radar system (see diagram).



The Doppler effect means that the light from an object approaching you becomes slightly more blue (or more red if the object is receding). The changes are too small to see. The effect applies to radio waves and sound too – which is why a motor bike or train whistle falls in pitch as the vehicle passes. For the Olympics, it is radio waves that are used.



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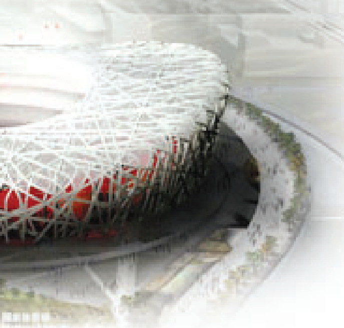

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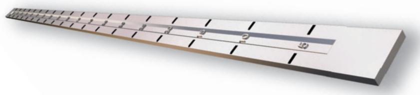
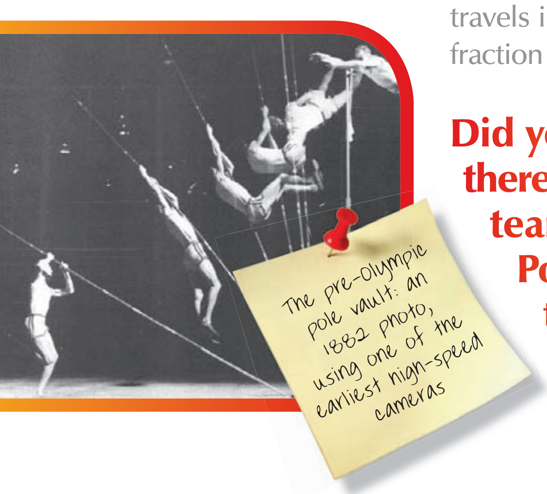


Height

The high jump and pole-vault are the obvious Olympic events where height matters – but they're not the only ones. Goals, nets, hurdles, diving boards – all of them have to be at set up at specified distances from the ground.

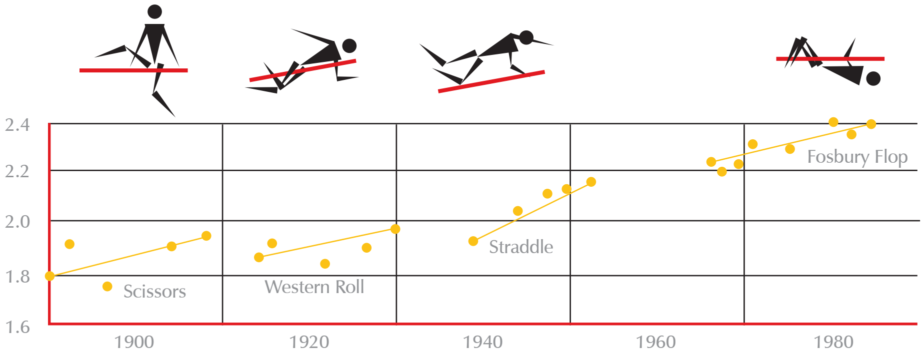
Did you know? In the 1936 Olympics, during the basketball tournament, the International Basketball Federation imposed a rule banning all players taller than 1.905 m (6 feet 3 inches). The rule was withdrawn following an objection.

In 1791 the unit of length was defined as one–ten-millionth of the distance from equator to pole through Paris and given the name – metre. But because the Earth's shape changes constantly, it was necessary to define the metre in terms of universal properties that do not change. Today we define the metre as the distance that light travels in space during a very small and precisely defined fraction of a second.



The pre-Olympic pole vault: an 1882 photo, using one of the earliest high-speed cameras

Did you know? In the 1964 Olympics, there were complaints from the Hungarian team that the shallowness of the Water Polo pool allowed the taller Yugoslav team to stand on the bottom with their heads above the surface.



Style matters: changing high jump techniques over the last century meant sudden increases in record heights.

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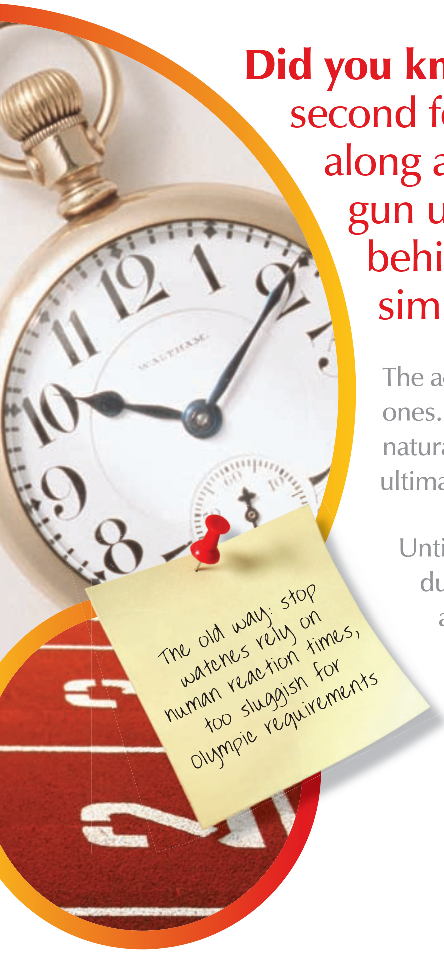
Time

Accurate timing is key to many Olympic events, with hundredths of a second often being all that separates winners from losers.

The exact measurement of time is a very well-developed science, and the world's most accurate clocks would not lose or gain a second in thirty million years. What is more challenging in the Olympics is deciding and determining exactly what events are to be timed – such as what counts as the end of a race. For instance, the 100 m sprint ends when a runner's torso reaches a point exactly over the finish line – and this event is measured by an automatic "slit-video" camera, which scans the finishing line up to 2000 times a second. Human judges then view the images to decide who wins.

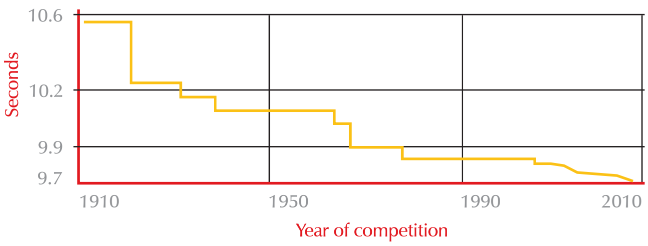


The old way: stop watches rely on human reaction times, too sluggish for Olympic requirements

Did you know? It takes a few hundredths of a second for the sound of a starting pistol to travel along a row of runners, so those closer to the gun used to hear it first. Now, loudspeakers behind each runner relay the sound simultaneously.

The accuracy of a clock is checked by being compared with more accurate ones. Most clocks, including those used at the Olympics, are based on the natural "tick" of a crystal of quartz. The accuracy of this tick is compared ultimately with that of an atomic clock.

Until 1956, the second was defined as 1/86,400 of a day – but the day's length varies due to the irregular spin of the Earth, so the second is now defined in terms of an atomic radiation.



Athletes have accelerated over the last century: this graph shows the progressively lower times taken to run the men's 100 metres. Note the change in the uncertainty of results once the manual timing is replaced by automatic electronic timing in 1976.

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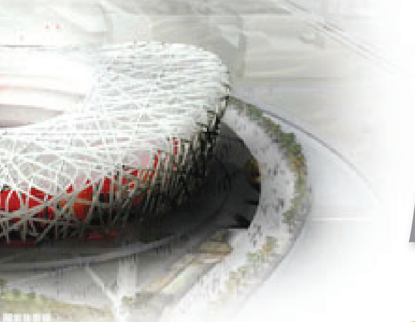


Metrology

Measurement in Sport

Amount of Substance

Fairness is crucial to Olympic events, and that means performance-enhancing drugs are banned, and frequent drug testing is essential.

The use of performance-enhancing drugs in sports is not new – Thomas Hicks won the marathon at the 1904 Olympics, thanks to being dosed by his coach with a cocktail of strychnine and brandy (before and during the event!) Following a rise in both drug use and in the awareness of this problem, the International Olympic Committee banned doping in 1967. Today, the **World Anti-Doping Agency (WADA)** specifies which performance-enhancing drugs are banned.

Did you know? Drug testing in the Olympics first took place in the Cycling Team Time Trial race at the 1964 games.

What matters is the number of molecules of the drug in an athlete's body. The SI unit for the amount of substance is the mole: one mole of a drug molecule is 602,214,179,000,000,000,000,000 identical copies of that molecule.

There are three main ways to test for drugs:

Today there are over 300 performance-enhancing drugs and similar substances banned for Olympic athletes.

Mass spectrometry

Samples are vaporised and then ionised. A magnet sends the ions in different directions depending on their masses, so they are identified by their arrival positions. This is a highly accurate but expensive process.

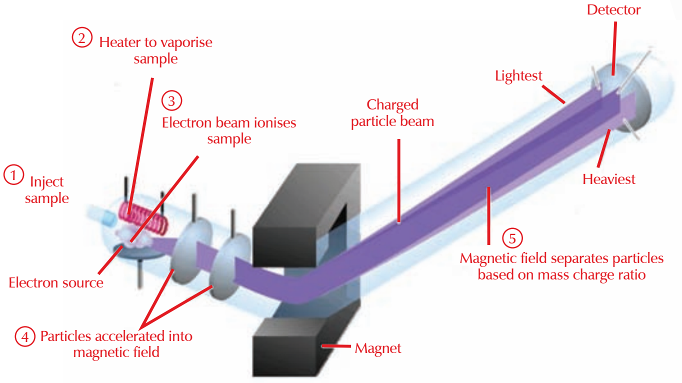
Gas chromatography

Samples are vaporised and passed through a tube filled with a mixture of silicon grains and liquid. Different components of the sample travel at different speeds through the tube and so arrive in turn at a detector to be identified. This is relatively inexpensive, but cannot differentiate components with the same travel speed.

Immuno-assays

Antibodies are introduced to the sample, and react to the presence of the drug. The strength of the response is a measure of the amount of drug present. Immuno-assays are simpler but less accurate than the other tests.

How a mass spectrometer works



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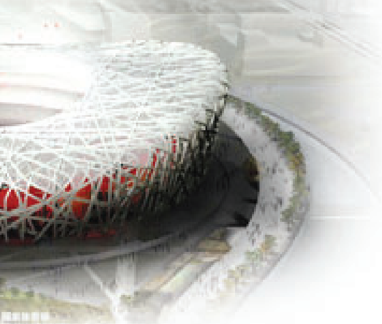


Metrology
Measurement in Sport

Dosimetry

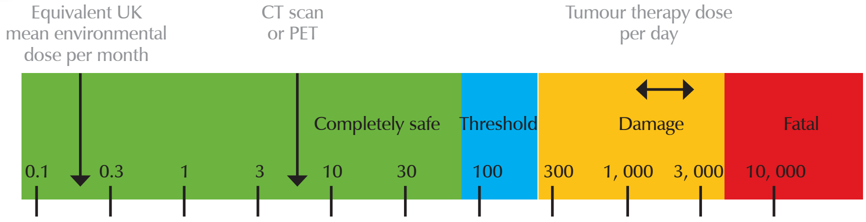
Bodies are machines, and athlete's bodies are machines that are trained and tested to the limit – so they often need to be checked for damage. X-rays allow us to see inside the body to check its structures, but, in their passage through flesh and bone, X-rays cause damage of many kinds. So, it is important to ensure that X ray machines are powerful enough to produce clear images, but not so powerful that the health risk is unnecessarily high.

Did you know? A space shuttle astronaut on a one-week mission receives about the same dose of radiation as an average person does in three years.

When X-rays pass through air some of the atoms are stripped of outer electrons and become ions. The amount of this ionisation is a measure of the intensity of the X-ray beam. To check the output of an X-ray machine a probe called a dosemeter measures the amount of ionisation produced.

Usually, the dosemeters are sent to a laboratory to undergo these tests. Every year or so, the laboratories send their own equipment to their National Measurement institute to be checked.

The SI unit of radiation dose is the sievert, equivalent to one joule of energy per kilogram of matter. The following chart shows the effects of different doses in millisieverts (thousandths of a sievert). A single diagnostic X-ray is about 0.01 to 0.1 millisieverts.



Radiation dose (log scale)

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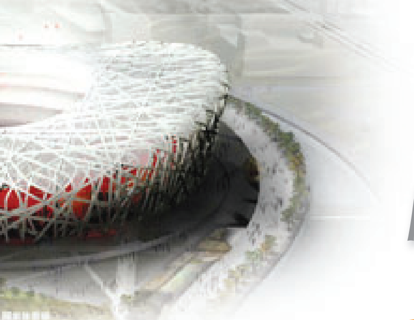


Metrology

Measurement in Sport

Traceability

The accuracy of the second, as transmitted by microwave signals, is better than 1 in 100,000,000,000 – a clock this accurate would lose or gain less than one second in 3000 years. This accuracy is needed in many applications like the navigational systems which enable the automatic landing of aircrafts today.

Everything that is measured is based ultimately on a primary standard. In mass, the primary standard is the lump of metal (a mixture of platinum and iridium) which is kept in Paris – the International prototype of the kilogram. In other base quantities, these primary standards are given in the form of a "recipe" based on the unchanging properties of nature such as the speed of light – so that even if all the metrology laboratories in the world disappeared, all the primary standards could be recreated. (There is research at present into replacing the International prototype of the kilogram with a similar "recipe".)

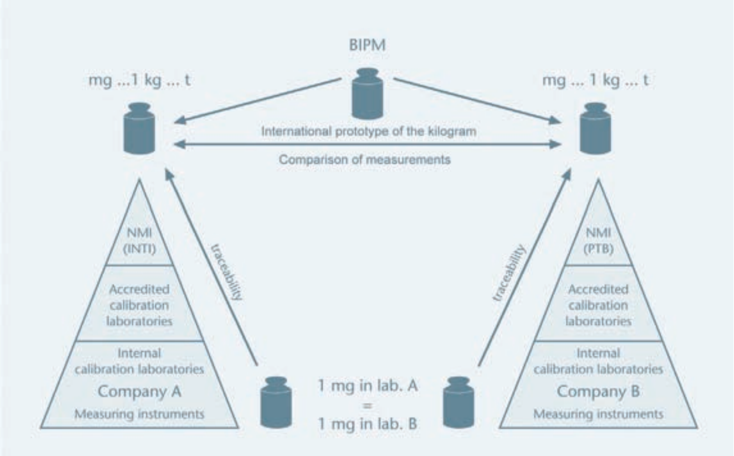
Primary standards are defined with incredible accuracy, but there would be little point in this if accurate measurements were only possible in metrology laboratories.

So, how do we know our watches, bathroom scales, or rulers are accurate?

There is always a chain of **traceable measurements** – watches, scales and rulers are set by the factories that make them, using devices which are checked against a working standard in a metrology laboratory. The testing laboratories use reference standards, checked finally by national metrology institutes (NMI) against primary standards. The national metrology institutes of the world, in collaboration with the International Bureau of Weights and Measures (BIPM), ensures that all the primary standards give consistent answers.

Future primary standard for mass being developed at the BIPM

Assuring traceability works like this:



first successful atomic clock built by Louis Essen in 1955 at the National Physical Laboratory in the UK

The International Bureau of Weights and Measures in the outskirts of Paris, France

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Metrology

Measurement in Sport

Standard Units and the SI System

Quantity	Unit	Based on
Length	metre	Distance travelled by light in a specified fraction of a second
Mass	kilogram	Mass of the International prototype of the kilogram
Time	second	Frequency of a particular type of light
Electric current	ampere	Flow of electricity required to produce a specified force between conductors
Temperature	kelvin	A fraction of the temperature of water at its triple point (where water, ice and water-vapour co-exist)
Amount of substance	mole	Number of atoms in a specified mass of carbon
Luminous intensity	candela	Intensity of light-source of a particular colour

Everything that is measured has a unit associated with it, from wind chill to heat insulation, and there are thousands of such units in use around the world.

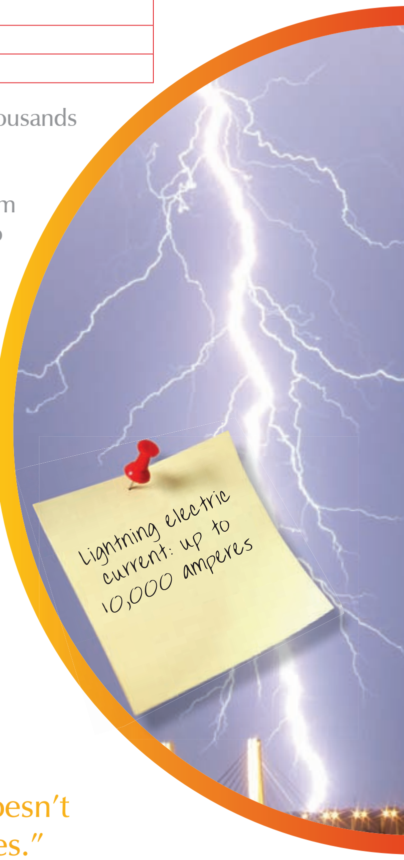
The first step in simplifying this is the metric system – so while distance units like the mile, hand or ångström are still in use, the internationally recognised standard unit of legnth is the metre. Where distances are too short or long to be measured in metres, new units are defined simply by multiplying or dividing the metre by ten as many times as necessary (left).

SI Prefixes

Prefix	Symbol	Multiply by
Yotta-	Y	1 000 000 000 000 000 000 000 000
Zetta-	Z	1 000 000 000 000 000 000 000 000 000 000 000 000 000
Exa-	E	1 000 000 000 000 000 000
Peta-	P	1 000 000 000 000 000
Tera-	T	1 000 000 000 000
Giga-	G	1 000 000 000
Mega-	M	1 000 000
myria-	My	10 000
kilo-	k	1000
hecto-	h	100
deka-	da	10
deci-	d	0.1
centi-	c	0.01
milli-	m	0.001
micro-	u (mμ)	0.000 001
nano-	n	0.000 000 001
pico-	p	0.000 000 000 001
femto-	f	0.000 000 000 000 001
atto-	a	0.000 000 000 000 000 001
zepto-	z	0.000 000 000 000 000 000 001
yocto-	y	0.000 000 000 000 000 000 000 001

Engineers and scientist have shown that it is possible to reduce all necessary units to just seven **base units**. These base units are the core of the SI (le **S**ystème **i**nternational d'unités).

Did you know? In the 1968 Olympics, gold medallist pole vaulter, Robert Seagren, decided to skip the 5.35 metre height – a gamble which paid off when he cleared the 5.40 metre. "If I'd known the metric system better I might not have passed that high – 5.35 metres doesn't sound as high as 17 feet 6½ inches."



Many other units are based on combinations of the base units. For instance, force is measured in newtons, but 1 newton = (1 kilogram) X (1 metre per second per second). Such units, created by combinations of the base units are called **derived units**.

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