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23189

Metrology in Developing Economies

Establishment of a National Measurement System

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANISATION

(inner page)

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FOREWORD

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Acknowledgements

UNIDO wishes to acknowledge gratefully the following organisations for providing materials and granting permission to reproduce them in the document :

African Regional Organisation for Standardization (ARSO)

Asia Pacific Legal Metrology Forum (APLMF)

Asia Pacific Metrology Program (APMP)

Cooperation Metrologique (COOMET)

Dept. of Commerce, United States Government

National Institute of Standards & Technology (NIST)

European Metrology Cooperation (EUROMET)

International Organisation of Legal Metrology (OIML)

SADC Cooperation in Measurement Traceability (SADCMET)

The European co-operation in legal metrology (WELMEC)

The Inter American Metrology System (SIM)

The International Bureau of Weights and Measures (BIPM)

The International Measurement Confederation (IMEKO)

The author wishes to express his grateful thanks Dr. Eberhard Seiler and Dr.Ulrich Diekmann of Physikalisch-Technische Bundesanstalt (PTB) for reading the manuscript and making valuable comments. Thanks are also due to Dr. Jeffrey H. Williams of the BIPM for providing the sections on the Meter Convention and activities of BIPM.

CONTENTS

1 INTRODUCTION

The contribution made by a national measurement system to the economic and social development of a country is significant. . It has been estimated that in industrialized countries measurement and related operations account for 4 % to 6 % of the Gross National Product. Accurate and internationally traceable measurements are required for trade, industry , health, environment and many other developmental activities.

A national measurement system that provides the necessary technical and administrative infrastructure to allow people and organisations to make physical measurements to the accuracies they require is needed in all countries, developing or developed. Such a system is a public asset and governments all over the world have accepted the responsibility for funding the vital infrastructural work associated with national measurement systems.

In today's globalised world, trade takes place on the basis of standards and specifications. To make sure that goods and services comply with standards a multitude of tests are performed. The accuracy of the test result is critically dependant on the measurements made. These in turn depends on the national *measurement standards and their linkage to the international measurement system. The continual* increase of the complexity of modern technology demands more accuracy, wider range and greater coherence of measurement standards both at the national and international levels.

Strong national measurement systems capable of delivering the desired benefits do not emerge spontaneously. Decisive steps have to be taken to establish the necessary legal and organisational structure. Also, a considerable period of time is required to develop a national measurement system to its full potential.

2 DEVELOPMENT OF MEASUREMENT SYSTEMS

2.1 Early history

The most fundamental standards consciously and deliberately evolved by the ancients were those for weights and measures. These laid the foundations of present day measurement systems. The earliest metrological activity has been traced back to prehistoric times. For example, a beam balance dated to 5000 B.C. has been found in a tomb in Nagada in Egypt. Specimens of standardized weights in ratios of 1: 2: 4: 8 and a decimally sub divided length scale have been unearthed at several sites of Indus valley. They are dated to about 3500 B.C.

It is well known that Sumerians and Babylonians had well developed systems of numbers. The very high level of astronomy and advanced status of time measurement in these early Mesapotamic cultures contributed much to the development of science in later periods in the rest of the world. There is evidence that well established measurement systems existed in the Indus Valley and Mohenjedaro civilizations. In fact the number system we use today known as the "Indo-Arabic" numbers with positional notation for the *symbols 1-9 and the concept of zero was introduced into western societies* by an English monk who translated the books of the Arab writer Al-Khawanizmi into Latin in the 12th century.

2.2 Development of the metric system of units[1]

In France, at the end of the 15th century, the "Pile de Charlemagne" defined the "Livre poids du marc" (490 g) and its (nondecimal) subdivisions, and around 1670 the "Toise du Chatelet" the French foot, was introduced as one sixth of the length of the "Pied du Roi" (32.5 cm). The "pouce," the "lime" and the "point" were defined by successively dividing the French foot by twelve. These were known as 'Paris Measures'. At the end of the 16th century, Queen Elizabeth I of England, introduced the "avoir du poids" weight of 1 pound (453 g) divided into 16 ounces and the yard divided into 3 feet (30.5 cm), each foot being 12 inches. In spite of these valuable attempts to unify weights and measures an infinite variety continued to exist in Europe.

In the course of the 17th and l8th centuries not only leading people in government circles, but also scientists who were making the first important steps in the development of experimental sciences, were disturbed by the existing disorder and uncertainty of weights and measures. In 1742 a group of scientists made a careful comparison between the so-called 'Paris Measures' and those used in England at that time, with the result that the French "pied" and "livre" were found to be larger than the English "foot" and "pound" by 6 and 8 percent respectively. Scientists started to search for a suitable universal system that would be identical in all countries and not bound to any nationality.

Two very different propositions were made for the choice of the basic unit of' length, one being the length of a seconds pendulum and the other being a basic length related to the length of an arc of the meridian. The first proposal had already been made by the French astronomer Mouton (1670) and by Huijghens (1673) and was supported by the Royal Society of England. In France Talleyrand in 1790 made a formal proposal to the French Constituent Assembly in this same direction, but the French Academy of' Sciences rejected the proposal for the well known reason that the length of the seconds pendulum depends on the gravitational acceleration and therefore differs from place to place on the earth. The Academy favored the alternative proposal and on its recommendation the Constituent Assembly, in 1791 adopted the principle of a system of weights and measures based entirely on one base unit of length, the "metre," defined to be equal to one ten-millionth of the length of' the quadrant of the earth meridian. Units of area and capacity were defined as decimal multiples and submultiples of the square metre and the cubic metre respectively and the unit of mass as the mass of a cubic decimetre of water at the temperature of maximum density (4 ^{0}C). The system was to be entirely decimal, using prefixes like milli (1/1000). centi (1/100), deci (1/10) and deca (10), hecto (100) and kilo (1000) to be added to the names of the units to indicate submultiples and multiples. Because of its foundation entirely on the metre this system was known as 'Systeme Metrique' the name through which the system would gradually spread all over the world. Unfortunately, however, the English and American governments considered the French proposal impracticable and decided to derive their basic unit of length from the seconds pendulum.

Soon after this decision Delambre and Méchain measured the arc of the meridian between Dunkerque and Barcelona. Lavoisier and others made careful measurements of the mass of a known volume of water. On the basis of these measurements an end standard made of sintered platinum representing the metre and a platinum standard kilogram were constructed and deposited on June 22, 1799 in the 'Archives de la Republique' in Paris. These two standards were the starting point for the whole development of the present universally adopted International System of Units.

However, the metre and the kilogram "des Archives," the two basic standards for length and mass which were legally given the values of 1 metre and 1 kilogram respectively, represented a system of weights and measures based on two material standards, which in the future might easily be found to deviate from their

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[1] Reproduced from an Article by J. de Boer, in NBS Special Publication 420 –International Bureau of Weights and Measures 1875-1975, May 1975.

origin; the length of the quadrant of the earth meridian and the simple numerical value for density of water agreed upon by definition. In fact it was found later that the 'Mitre des Archives' is about 0.2 mm shorter than one ten-millionth of the length of the quadrant of the meridian and that the mass of the "Kilogramme des Archives" is equal to that of 1.000 028 cubic decimetres of water at the maximum density instead of 1 cubic decimetre exactly.

In 1821 the metric system was introduced by law in Holland. Belgium, and Luxembourg. Spain, Colombia, Mexico, Portugal. Italy, and many other countries followed. In 1864 the use of metric weights and measures concurrently with those of the imperial system was authorized in Great Britain and a few years later the metric system was introduced in Germany.

During the world exhibition of Paris in 1867 a great many scientists, impressed by the tremendous industrial development in the world, created a Committee for Weights and Measures, with the special task of creating more uniformity in the world. Following this valuable initiative the French government in 1869 invited numerous countries to send delegates to Paris for an "International Commission for the Metre". A total of 24 countries attended the meetings held in August 1872. The great majority of those present at the meetings felt that the metre and kilogram which were conserved in the 'Archives de Paris' should be the reference for new prototypes and for copies to be constructed and distributed among the participating countries.

Unfortunately the work was interrupted by the Franco-Prussian war but in 1872 the same Commission, then consisting of delegates representing 30 countries, met again and confirmed its previous decision to construct new prototypes of the metre and the kilogram and to provide a large number of copies, all made from one single melt of a special platinum-iridium alloy with 10 percent iridium. The standards of the metre were line-standards with an X-shaped cross section. The values of the new prototypes were based on the metre and the kilogram in the 'Archives.'

On 1st March 1875, the French Government convened the 'Conference Diplometique du Metre' to which 20 countries had sent representatives and scientists who were authorized to sign for their governments. These delegates approved the proposals made by the Commission, so that finally on 20 May 1875 the 'Convention of the Metre' (Convention du Metre) was signed officially by representatives of seventeen nations.

3 INTERNATIONAL AND REGIONAL ORGANISATIONS

3.1 Convention of the metre

The simplicity of the decimal metric system helped it met the need for rapid and reliable measurements demanded by, for example, the growth of industry and social and economic exchange throughout the 19th century. Consequently, this period saw a steady increase in the number of countries adopting the metric system, which meant that copies of the original prototypes were needed as national standards. To ensure uniformity in making copies of the original prototypes, the Bureau International des Poids et Mesures (BIPM) was founded by an international diplomatic treaty known as the Metre Convention signed on 20 May 1875 in Paris, as an international organization.

3.2 The BIPM, the CIPM and the CGPM

The Bureau International des Poids et Mesures (BIPM) was created by Article One of the Metre Convention of 1875. Article Three of the Convention created the International Committee for

Weights and Measures (the abbreviation of the French name is CIPM) which directs and supervises the work of the BIPM. The BIPM is situated on a site given to the CIPM by the French Government in 1875, at the edge of the *Parc de Saint-Cloud* in a suburb of Paris.

It was clear at that time that units and standards of measurements needed to be agreed internationally. Indeed, the continuing importance of discussing metrology at the international and intergovernmental level is today seen in the meetings of the General Conference on Weights and Measures (the abbreviation of the French name is CGPM, created by Article Three of the Metre Convention), which currently meets every four years bringing together representatives of the signatories of the Metre Convention to vote on Resolutions establishing the range of work of the BIPM.

3.3 The role of the BIPM

Since the signing of the Metre Convention, all copies of the original prototype of the kilogram have been manufactured at the BIPM, as were originally all copies of the prototype of the metre. This essential role set the stage for the BIPM to begin its stewardship of the worldwide system of measurement. With time, however, the world's measurement system evolved and the base units of the International System of Units (SI) are now increasingly based on fundamental constants of nature rather than artefacts. For example, in the 1960s, science had advanced to the point where it was possible for appropriately equipped laboratory to define the metre in terms of the wavelength of a particular atomic emission line and, consequently, the artefact prototype of the metre lost its importance.

The BIPM is an international body with responsibility for the world's system of measurements, providing the basis for a single, coherent system of measurements traceable to the International System of Units. Where traceability to the SI is not yet possible, measurements traceable to other internationally accepted references such as the biological standards used in the clinical sciences are adopted. Here the BIPM works closely with other international bodies such as the World Health Organization. This work evolves continually as developments in science have always afforded opportunities for progress in measurement precision.

Responsibility for the world's system of units takes many forms, from direct dissemination of units (as in the case of mass and time) to coordination through international comparisons of national measurement standards (as in length, electricity and ionizing radiation). To achieve the goal of worldwide uniformity of measurement, the BIPM provides appropriate scientific and technical expertise, and collaborates with other institutions and organizations. The principle tasks of the BIPM are:

- Scientific and technical work to improve measurement standards and to provide reference systems or measurements for the world's national metrology institutes (NMIs).
- Specific technical services in support of NMIs, such as undertaking certain international comparisons for the practical realization of base and derived units of the SI.
- Global coordination of metrology, such as the operation of the CIPM Mutual Recognition Arrangement (CIPM MRA).
- To maintain and disseminate the text of the International System of Units.
- Relations with other organizations.
- Information and publicity.

Three principal activities are undertaken:

- Establishment and maintenance of reference standards;
- Selected research programmes directed to the improvement of reference standards, comparisons or measurement techniques;
- Organization of and participation in international comparisons and calibrations.

The CIPM has set up a number of Consultative Committees, which bring together the world's experts in their fields as advisers on scientific and technical matters. Among the tasks of these Committees are detailed considerations of advances in science and technology that directly influence metrology, the preparation of Recommendations for discussion at the CIPM and, perhaps, the CGPM, the identification, planning and execution of key comparisons of national measurement standards, and the provision of advice to the CIPM on the scientific work in the laboratories of the BIPM.

Presently, there are ten Consultative Committees which met at regular intervals:
Consultative Committee for Acoustics, Ultrasound and Vibration,
Consultative Committee for Electricity and Magnetism,
Consultative Committee for Length,
Consultative Committee for Mass and Related Quantities,
Consultative Committee for Photometry and Radiometry,
Consultative Committee for Amount of Substance - Metrology in Chemistry,
Consultative Committee for Ionizing Radiation,
Consultative Committee for Thermometry,
Consultative Committee for Time and Frequency, and
Consultative Committee for Units.

It is through these Consultative Committees that the BIPM is able to consult with the experts in the world's national metrology institutes, who meet to deal with, for example, matters concerning the definitions of units and the techniques of comparison and calibration. In addition, joint committees have been established to consider issues such as the appropriate international approach to the estimation of measurement uncertainty and a common vocabulary for metrology.

The growth of the number of NMIs and the emergence of regional economic groupings has meant that regional metrology groups have become an essential way of addressing specific regional needs. The Regional Metrology Organizations (RMOs) play a vital role in encouraging coherence in international metrology and adherence to the goals of the Metre Convention within their respective regions and between their regions.

3.4 CIPM Mutual Recognition Arrangement

The reliability of the international measurement system depends on work by each NMI to base its measurements and measurement uncertainties on units that are as widely accepted as possible, the SI, and to compare its measurements with those of other NMIs to establish their mutual equivalence. An NMI will therefore regularly participate in measurement comparisons with other NMIs. The purpose of these comparisons is to ensure that realizations of the SI units by participating NMIs are equivalent within known uncertainties, thus creating a uniform global metrology system. In many cases these are multilateral comparisons coordinated by the BIPM and the RMOs.

In order to extend and fully document the practice of comparisons and declarations of equivalence, in 1999 the CIPM launched a Mutual Recognition Arrangement (CIPM MRA) between Members of the Metre Convention and Associate States and Economies of the CGPM. The CIPM MRA establishes a formal system within which participating metrology laboratories, signatories and other designated institutes establish the degree of equivalence of their national measurement standards via a peer-review of the technical capabilities; as well as the mutual recognition of their calibration and measurement certificates. This degree of equivalence is technically supported through a series of 'key' measurement comparisons between the participating laboratories which establishes a basis for comparing and linking measurements across international boundaries.

> *"Under the MRA, all participating institutes recognize the validity of each other's calibration and measurement certificates, ranges and measurement uncertainties specified in Appendix C of the KCDB."*
>
> Quote from the MRA.

The CIPM MRA has put metrology at the forefront of international science, and made it an essential support of global trade and the elimination of technical barriers to trade. It provides reliable, comprehensive and transparent technical data on the performance of metrology laboratories, which may be used to provide interested parties with a sound technical basis for wider agreements related to international trade and regulatory affairs.

To support the CIPM MRA, the BIPM Key Comparison database (KCDB) was created to provide free public access to the results of key comparisons and calibration and measurement capabilities of participating laboratories. The KCDB database is maintained on the BIPM website (www.kcdb.org) and search engines enable users to access comparison results and compare national calibration and measurement capabilities in many areas of chemistry and physics. The KCDB also provides the degrees of equivalence among calibration and measurement capabilities from national metrology institutes.

The launch of the CIPM MRA in October 1999 was a major step for the Metre Convention. Indeed, some say it was as important as the 1875 Convention itself. This arrangement assures the traceability of measurements to the SI and provides a measure of comparability and equivalence among the national metrology services. As a result of the work carried out within the CIPM MRA, metrology laboratories are now more confident of the technical basis for their calibration services and they, as well as the BIPM, have learned a great deal about some of the limitations in current measurement services. The CIPM MRA helps to reduce technical barriers to trade by providing the technical basis used for wider agreements negotiated for international trade, commerce and regulatory affairs.

Whilst the technical coverage of the KCDB and the CIPM MRA is presently focused on physics, engineering and chemistry, the future will see related developments in the areas of laboratory medicine and food as the established framework can be applied to these new sectors. Already in laboratory medicine, the Joint Committee for Traceability in Laboratory Medicine is creating a similar database of reference materials and processes. Key and other comparisons are underway to help provide the technical underpinning for this work. In this way, sound metrology practice will be applied to new activities, which are of benefit to human health and quality of life.

For further information about the BIPM, its history, its scientific work and role in the international coordination of metrology, please see the BIPM website at http://www.bipm.org

3.5 The International Organisation of legal metrology (OIML)

The International Organisation of legal metrology (OIML) was established in 1955 to promote the global harmonization of legal metrology procedures. As a result of decisions made by the CGPM and the CIPM (International Committee of Weights and Measures) in 1933 and 1935, the first International Conference on Practical Metrology was convened by the French Government in July 1937. This Conference, which was attended by representatives from forty countries, was intended to establish a Permanent International Consultative Committee for Practical Metrology acting as an advisory body to the CGPM.

However, the Conference decided instead to create a Provisional Committee of Legal Metrology aimed at preparing the establishment of a permanent international body for legal metrology. However due to the uncertain international situation during this period the Consultative Committee was unable to meet until 1950. When the committee finally met in Paris, the preparation of a convention to establish an international organization for legal metrology started.. The meetings of the Committee and the intense activity which followed resulted in the signing in 1955 by 24 countries of the convention establishing the International Organization of Legal Metrology.

The OIML has developed a worldwide technical structure that provides its members with metrological guidelines for the elaboration of national regulations and regional requirements concerning the manufacture and use of measuring instruments for legal metrology applications.

3.5.1 OIML Membership

The OIML membership includes 'member states', and 'corresponding members'. The 'member states' are countries that participate actively in technical activities, and the 'corresponding members' participate as observers.

3.5.2 OIML Publications

The OIML develops model regulations, International Recommendations, which provide Members with an internationally agreed-upon basis for the establishment of national legislation on various categories of measuring instruments. Given the increasing national implementation of OIML guidelines, more and more manufacturers are referring to OIML International Recommendations to ensure that their products meet international specifications for metrological performance and testing.

OIML Draft Recommendations and Documents are developed by Technical Committees or Subcommittees which are formed by the Member States. Certain international and regional institutions also participate on a consultative basis.

OIML has signed cooperative agreements with ISO and IEC, with the objective of avoiding contradictory requirements, so that manufacturers and users of measuring instruments, test laboratories, etc. may use OIML publications together with those of ISO and IEC.

Most of the OIML publications can be downloaded from the OIML web site. (Please see website bibliography)

3.5.3 OIML certificate system

The OIML Certificate System for Measuring Instruments was introduced in 1991 to facilitate *administrative* procedures and lower the costs associated with the international trade of measuring instruments subject to legal requirements.

The System provides for a manufacturer to obtain an OIML Certificate and a Test Report indicating that a given instrument type (pattern) complies with the requirements of the relevant OIML International Recommendations. Certificates are delivered by OIML Member States that have established one or several issuing authorities for processing of applications.

OIML Certificates are accepted by national metrology services on a voluntary basis. The certificate system simplifies the type (pattern) approval process for manufacturers and metrology authorities by eliminating duplication of test procedures in individual member countries.

The OIML web site lists OIML Certificates registered, the list of categories of instruments covered by the system, the addresses of issuing authorities and recipients of certificates (applicants and manufacturers).

Further information on the System, particularly *concerning the rules and conditions for the application*, issue, and use of OIML Certificates, may be found in OIML Publication B 3.

3.5.4 OIML Mutual Acceptance Arrangement (MAA)

In addition to the OIML Certificate System, the OIML has developed a Mutual Acceptance Arrangement (MAA) which is related to OIML Type Evaluations. This Arrangement - and its framework - are defined in OIML publications B 10-1 and B 10-2.

The implementation of the MAA began in January 2005 and currently covers measuring instruments related to OIML R 60 (Load cells) and OIML R 76 (Nonautomatic weighing instruments) - fields in which a large number of OIML Certificates of Conformity are issued.

The aim of the MAA is for the participants to accept and utilize test reports validated by an OIML Certificate of Conformity. To this end, participants in the MAA are either Issuing Participants or Utilizing Participants. Issuing Participants are Issuing Authorities which will issue OIML Certificates of Conformity *under the MAA. Test reports associated with these OIML Certificates will be accepted and utilized by* Utilizing Participants to issue, for instance, national type approvals.

The MAA helps national legal metrology bodies of member countries to utilise the facilities and competences of other countries' bodies, especially in cases where they do not themselves possess such facilities at national level.

3.6 The International Measurement Confederation (IMEKO)

The International Measurement Confederation (IMEKO), is a federation of scientific and technical Societies concerned with measurement science and technology. It promotes the international exchange of scientific and technical information relating to developments in measurement techniques, instrument design and manufacture and in the application of instrumentation in scientific research and in industry.

IMEKO is a non-governmental federation of 35 member organizations individually concerned with the advancement of measurement technology. Its fundamental objectives are the promotion of international interchange of scientific and technical information in the field of measurement and instrumentation and the enhancement of international co-operation among scientists and engineers from research and industry. Founded in 1958, the Confederation has consultative status with UNESCO and UNIDO.

3.7 Regional metrology organisations (RMOs)

There are several regional metrology organisations around the world . The most active of these are :

- *Asia Pacific Metrology Program (APMP)* – A grouping of national metrology institutes of asia pacific countries. APMP has been operating in the Asia-Pacific since its inception as a Commonwealth Science Council initiative in 1977. As such, it is the oldest continually operating metrological grouping in the world. APMP worked closely with BIPM and other Regional Metrology Organisations to establish the global MRA and has an active intercomparison programme geared towards providing its members with access to the BIPM key comparison database,

- *Asia Pacific Legal metrology Forum (APLMF)*- The Asia-Pacific Legal Metrology Forum (APLMF) is a grouping of legal metrology authorities in the Asia-Pacific Economic Cooperation (APEC) economies and other economies on the Pacific Rim, whose objective is the development of legal metrology and the promotion of free and open trade in the region through the harmonisation and removal of technical or administrative barriers to trade in the field of legal metrology.

  As one of the regional organisations working in close liaison with the OIML, the APLMF promotes communication and interaction among the legal metrology organisations and seeks harmonisation of legal metrology in the Asia-Pacific region.

- *European Metrology Cooperation (EUROMET)*- EUROMET is the regional metrology organisation of Europe and is a voluntary collaboration between the national metrology institutes in the EU, EFTA and EU Accession States. It was established by a Memorandum of Understanding in 1987 and originated from the Western European Metrology Club (WEMC), which was initiated by a conference on metrology in Western Europe in 1973.

  EUROMET has the following specific tasks:
    - Provision of a framework for collaborative research projects and inter-laboratory comparisons between the member national metrology institutes,
    - Co-ordination of major investments for metrological facilities,
    - Transfer of expertise in the field of primary or national standards between the members,
    - Provision of information on resources and services, and
    - co-operation with the calibration services and legal metrology services in Europe.

- *The European co-operation in legal metrology (WELMEC)*- The European co-operation in legal metrology WELMEC was established by a Memorandum of Understanding in 1990 signed by 15 member countries of the EU and 3 EFTA countries, in connection with the preparation and enforcement of the "New Approach" directives. This name was changed to "European co-operation in legal metrology" in 1995 but remains synonymous with WELMEC. Since that time WELMEC has accepted associated membership of countries, which have signed agreements with the European Union. WELMEC members are the national legal metrology authorities in the EU and EFTA member countries, whilst national legal metrology authorities in those countries that are in transition to membership of the EU are associate members.

  The goals of WELMEC are to:
  - develop mutual confidence between the legal metrology authorities in Europe
  - harmonise legal metrology activities and

- foster the exchange of information between all bodies concerned.

- *Cooperation Metrologique (COOMET)* - COOMET is a regional organization originally of national metrological institutions of the countries of Central and Eastern Europe including CIS countries. COOMET was founded in June 1991 and renamed as "Euro-Asian cooperation of state metrology institutions" in May 2000. COOMET is open for metrology institutions of other regions to join as the associate members.

  The present members of COOMET are metrological institutions of Belarus, Bulgaria, Germany (associate member), Kazakhstan, Kyrgyzstan, DPR of Korea (associate member), Cuba (associate member), Lithuania, Moldova, Russia, Romania, Slovakia, Uzbekistan and Ukraine.

  The basic activity of COOMET is cooperation in the following areas: measurement standards of physical quantities, legal metrology, accreditation and quality management systems, information and training.

- *SADC Cooperation in Measurement Traceability (SADCMET)*- SADC is the Southern African Development Community and 14 countries are signatories to the SADC Treaty. The "Memorandum of Understanding on Cooperation in Standardisation, Quality Assurance, Accreditation and Metrology in the Southern African Development Community", the SADC SQAM programme was signed in 2000. This Memorandum of Understanding established the SADC SQAM Programme and its constituent regional structures SADCA, SADCMET, SADCMEL, SADCSTAN and SQAMEG with the goal of removing Technical Barriers to Trade.

  The SADC Cooperation in Measurement Traceability SADCMET was established in 2000.
  The aims of SADACMET are to coordinate the metrology activities and services in the southern African region and provision of regional calibration and testing facilities.

- *The Inter American Metrology System (SIM)*- SIM for "Sistema Interamericano de Metrologia", was formed by agreement among the national metrology organisations of the 34 member nations of the Organization of American States (OAS). Created to promote international, particularly Inter American, and regional cooperation in metrology, SIM is committed to the implementation of a global measurement system within the Americas, in which all users can have confidence.

  SIM comprises of five sub regional bodies :

  - NORAMET for North America
  - CARIMET for the Caribbean
  - CAMET for Central America
  - ANDIMET for the Andean countries
  - SURAMET for South America

  SIM also covers legal metrology issues in the Americas. The objective of the Legal Metrology Working Group is the harmonisation of legal metrology requirements and activities in the Americas in accordance with OIML Recommendations and Documents.

4 SCIENTIFIC, INDUSTRIAL AND LEGAL METROLOGY

4.1 Scientific metrology

Scientific metrology deals with the organisation and development of measurement standards and with their maintenance (highest level). The primary function of scientific metrology is to establish the representation and reproduction of units of measurement with the requisite level of accuracy. In addition scientific metrology constantly endeavors to improve existing measurement techniques and to discover new ones.

Scientific metrology has been divided into nine technical subject fields by BIPM, namely mass, electricity, length, time and frequency, thermometry, ionising radiation & radioactivity, photometry and radiometry, acoustics and amount of substance. Recently, the term 'Fundamental Metrology' has been used to describe the highest level of accuracy within a given field. Fundamental metrology may therefore be described as the top level branch of scientific metrology

To perform scientific metrology activities at the highest level a full fledged scientific research institute is needed. Where the needs of the country do not warrant such a sophisticated establishment or where the available resources do not permit its establishment and upkeep, the service may be in simpler form, probably integrated with either the legal or industrial metrology service.

4.2 Industrial metrology

Industrial metrology is mainly concerned with the measurement of length, mass volume, temperature, pressure, voltage , current and a host of other physical and chemical parameters needed for industrial production and process control. The maintenance of accurate dimensional and other physical parameters of manufactured products to ensure that they conform to prescribed quality standards is another important function carried out by industrial metrology services.

One important field of Industrial metrology is "Engineering metrology" or "dimensional metrology". Interchangeability of components, which is taken for granted presently, owes its success to gauging and accurate measurements made possible by the advances made in this branch of metrology.

Industrial metrology laboratories provide services for the calibration of measuring instruments used in the industrial and other sectors of the economy, such as manufacturing and quality control of products, construction, mining, energy, communications and environment control. The facilities of an industrial metrology system also include the metrology laboratories of industrial enterprises. The reference standards employed by the industrial metrology system should traceable to National Measurement Standards.

4.3 Legal metrology

Legal metrology is sometimes referred to as 'weights and measures'. It is responsible for the legal / regulatory control of weights and measures by law with a view to ensuring a fair deal and correct measurement in commercial transactions. Measurements concerning human health and safety are also usually covered by legal metrology services.

In commercial transactions, according to the classical concept, legal metrology has to ensure that articles or goods offered for sale are weighed or measured accurately in the presence of the purchaser. However, in the modern context, this concept has taken a slightly different meaning, in that legal control is exercised not only at the point of sale but also at the packaging stage in a producer's premises, especially in the case of prepackaged consumer items, e.g.: butter, soft drinks, milk etc.

The legal metrology service usually consists of a main laboratory and branch laboratories (and offices) distributed geographically to serve the different provinces of a country. The service should deploy sufficient working standards to be used by its officers for the verification of legal weights and measures. These working standards must be periodically verified against reference standards that are traceable to National Measurement Standards by suitable linkage arrangements consisting of calibration methods and equipment. The legal metrology service should also have facilities for checking the suitability of types of measuring instruments for use in commercial transactions (pattern approval). The legal metrology system is operated within a legal framework consisting of a metrology law and a series of metrology regulations. The legal control of weighing and measuring equipment consists of a number of activities :

4.3.1 Pattern (Type) approval

Pattern approval is the process of approval of the design characteristics of a measuring instrument to verify that the instrument can provide reliable measurements over a period of time. It is carried out by a systematic examination and testing of the performance of one or more specimens of an specific type (pattern) of measuring instrument against documented requirements, (usually national regulations based on OIML recommendations). If the instrument complies with the requirements of the relevant regulation, a certificate is issued permitting that type to be used in the regulated area for a specific period of time.

The OIML certificate system has made it possible for those countries with limited capability to carry out pattern approvals. See section 3.6.3,

4.3.2 Initial verification

Initial verification of a measuring instrument is a series of tests and visual examinations carried out to determine whether an instrument manufactured to replicate a given pattern conforms to that pattern and to regulations, and that its metrological characteristics lie within the limits required for initial verification of copies of that pattern. If the instrument passes all tests and examinations, it is given legal character by its acceptance as evidenced by stamping and/or issuance of a certificate of verification.

Any instrument not previously verified may undergo initial verification. Requirements for initial verification may, depending upon the regulations in the jurisdiction, attach to the pattern, the category of instruments, the accuracy class of the pattern, or to the specific application of any one instrument.

4.3.3 Subsequent verification

Subsequent verification of a measuring instrument is a series of tests and visual examinations, usually carried out at the place of use by an official of the legal metrology service (inspector), to ascertain whether the instrument, having been in use for some time since the previous verification, continues to conform to, regulations and maintains its metrological characteristics within required limits. If the instrument passes all tests and examinations, its legal character is either confirmed or re-established by its acceptance as evidenced by stamping and/or issuance of a certificate of verification.

Requirements for subsequent verification in general differ from, and often are less stringent than those for initial verification. These requirements may, depending upon the regulations in the jurisdiction, attach to the pattern or its accuracy class, the category of instruments, or to the specific application of any one instrument.

4.3.4 Market surveillance

Market surveillance refers to the activity carried out by local legal metrology authorities to make sure that weighing and measuring equipment used by traders and other commercial organisations have been verified and stamped.

The surveillance policy operated by a local legal metrology authority is the means by which both consumer protection and the fairness of commercial transactions are ensured in the marketplace. Generally, the surveillance policy provides for periodical inspection and/or random surveillance to be made on instruments in order to ascertain whether they maintain a steady level of performance within the required accuracy limits during a stated period fixed by law.

Another aspect of market surveillance is in respect of pre-packaged goods. A large number of consumer items found in the market place, in developed as well as developing countries are in pre-packaged form. Thus it is necessary to include these items within the regular surveillance system of the local legal metrology authority. In the past, the requirement for pre packages was that every individual pack should contain not less than the declared quantity. (in length units, mass units, volume units or number of items).The modern practice is to use the average system. In the average system, the mean of a sample of items selected should be not les than the declared quantity. However a certain number of packages in the sample are allowed to be below the declared quantity. This method is more practicable and economical as normal variations found in the packing process are recognised. This would make packing operation economical and thus pass the savings to the consumer in the form a reduction in price. However the task of the legal metrology authorities has been made more difficult, as specialised statistical knowledge is required to carry out surveillance operations. 'OIML Recommendation R 87- Net content in packages', contains the details of the average system for pre-packages.

4.4 Development strategy

Ideally, the above mentioned elements should be integrated in the framework of a comprehensive national metrology system. This integration should ensure proper coordination of activities and the provision of necessary support activities such as metrology training and promotion of public awareness.

For obvious reasons, the development of complete metrology systems can take place only in gradual steps. Therefore, a planned strategy clearly identifying the needs of the country and goals to be achieved should be drawn up. The following three important factors should be considered in such a strategy:

a) The scarcity of both material and human resources in most developing countries.
b) The long period required for the firm establishment of the requisite institutions (for building, equipping, training and operation).
c) The demand for the services involved will be limited in the initial period (especially for industrial and scientific metrology services), but will increase gradually in step with the industrial development of the country.

It is advisable to adopt a development strategy based on the following concepts:

a) Mobilisation of resources at the national, regional and international levels for the judicious planning and implementation of a comprehensive national development programme.

b) Caution over facilities which are over sophisticated and not warranted by the present or foreseeable needs and duplication of existing facilities.
c) Maximum utilization of available resources by integrating and coordinating related activities and by sharing the existing facilities at the national and regional levels.

5 LEGISLATION

5.1 Overview

The initial legislation required for the establishment and operation of metrological activity is basically a single law to enforce legal regulation of weights and measures. This law is commonly known as the "Weights and Measures Law". In some countries it is known as the "National Measurement Standards Law".

If a new National Standards Body (NSB) is envisaged, a separate law to set up this body will be required. This law is generally known as the "National Standards Law". In addition to the basic law, a number of regulations outlining the detailed procedures for implementing the various provisions contained in the basic law would be required.

5.2 Metrology Law (National Measurement Standards Law)

The Metrology Law should prescribe:

- the legal and authorized units of measurement and their field of application;
- the national institution having the custody of the measurement standards or charged with the realization of the units,
- the type of activity for which legal control of measures and measuring instruments is required,
- the type of activity for which metrological control of product quantity is prescribed (e.g. prepackages),
- the national body in charge of legal metrological control,
- The mode of operation of legal control, (verification, stamping pattern approval, etc.),
- The responsibilities and powers of weights and measures inspectors, the authority to collect fees for services rendered, and
- Offences and fines.

As laws generally take a long time between their drafting and the time they come into force, it is advisable that the text should not contain technical elements subject to frequent changes. Furthermore, it is advisable not to introduce definitions of the basic units of the International System of Units (SI), but to refer to the decisions of the General Conference of Weights and Measures (CGPM) or include them in a regulation to be issued separately.. The list of permitted units of measurement may be included as an annex (schedule) to the law.

Definitions of the derived SI units may probably not be required except possibly in a few cases (temperature, force, pressure, etc.). However, if such definitions are felt to be necessary, it may be preferable to include them in a regulation rather than in the basic law. The OIML International Document D 2 "Legal Units of Measurement" gives details of how such formulation may be written.

The OIML International Document D 1 "Elements for a Law on Metrology" gives recommendations on the contents of the metrology law .

5.3 Regulations

Regulations are introduced to amplify and give technical details of the main provisions enacted in the law. The regulations generally cover:

- Definitions of SI base units and if necessary derived units,
- Provisions for model approval, initial and subsequent verification, verification stamps, seals, etc,
- Limits of error permitted on initial and subsequent verification,
- Custody, and care of standards and equipment;
- The frequency of comparison of standards with a higher level standard,
- Requirements for beam scales, balances and other instruments used by inspectors,
- Technical requirements of weighing and measuring instruments used for trade purposes;
- Inspectors responsibilities;
- Denominations, units and test methods for prepackaged goods; and
- Schedule of fees for services rendered.

The OIML publication " G 15 Guidelines for the establishment of simplified legal metrology regulations" gives detailed information on metrology regulations.

6 INSTITUTIONAL ARRANGEMENTS

6.1 Overview

There are three vital organisations needed in a country to implement standardisation and measurement activities, namely the National Standards Body (NSB), the National Metrology Institute (NMI) and the legal metrology service. In most developing countries, the metrology activities are limited to those of legal metrology. As the industrial base of the country develops, the need for several industrial metrology facilities would be felt. Initially these would be provided by industrial metrology laboratories. With further development, a national institute that would take custody of national measurement standards and provide traceability to secondary level measurement laboratories may be set up. Thus, the initial activity of a national measurement laboratory of a developing country would be the custodianship of national measurement standards and provision of calibration services. The calibration of reference standards used by the legal metrology service would also be a duty of national laboratory.

The further development of metrology would then be a matter of extending the scope of the national laboratory with initiation of scientific metrology activities. Such an institute is generally known as a 'National Metrology Institute (NMI)'. However, for a majority of developing countries scientific metrology would not be of immediate benefit and expenditure to maintain this expensive operation may not be justified. Countries in this category would be able to benefit by establishing cooperative programs with an NMI of a foreign country (e.g. PTB of Germany has collaborative arrangements with a number of developing countries) and regional programmes (See Section 3.4) already in operation.

In most developed countries, at least the NSB and the NMI are separate bodies. e.g. United Kingdom, USA, Germany, France, Australia. In Germany and USA the NMI is also responsible for the legal metrology service. Many developing countries and economies in transition however, have utilised the concept of integrated standardisation and incorporated the activities of the national measurement institution and the legal metrology service as part of the organisational structure of the NSB. Many different models are being used for the purpose.

For example in Singapore (a recently developed country) the NSB, the NMI and the legal metrology service are divisions of SPRING (Standards, Productivity and Innovation Board). Malaysia has used a different model where the NSB is a Government Dept, (Dept. of Standards Malaysia) but yet the real standardisation and measurement activities are carried out by a fully govt. owned but corporatised body known as SIRIM (Standards and Industrial Research Institute of Malaysia) . SIRIM conducts standardisation and measurement activities on behalf of the Dept. of Standards Malaysia. One of its divisions is the NMI where Malaysia's national measurement standards are maintained. Legal metrology however is carried out by a separate Govt. dept, but in close co-operation with SIRIM. In South Africa, Kenya, Uganda, and Mauritius and many other developing countries, the NSB is responsible for both standardisation and national measurement activities.

The incorporation of the activities of the NSB and the NMI in a single body is an effective way of maximizing the resources of a developing country. However, the implementation of this concept might be difficult in some countries , if there is an already functioning and long established legal metrology service. Considerable resistance will have to be overcome to restructure well established institutions.

Thus, no clear cut recommendation can be given as to the detailed organisational structure that should be followed for implementing metrology activities in a developing country. Each country has to evolve a system best suited to its needs at the time. In doing this, it is best to keep in mind that a single institution where standardisation, industrial metrology and legal metrology are carried out would reduce the expenditure and maximize the utilisation of the available material and human resources.

The two models presently prevalent in most of the countries are shown in Figures 1 and 2 respectively.

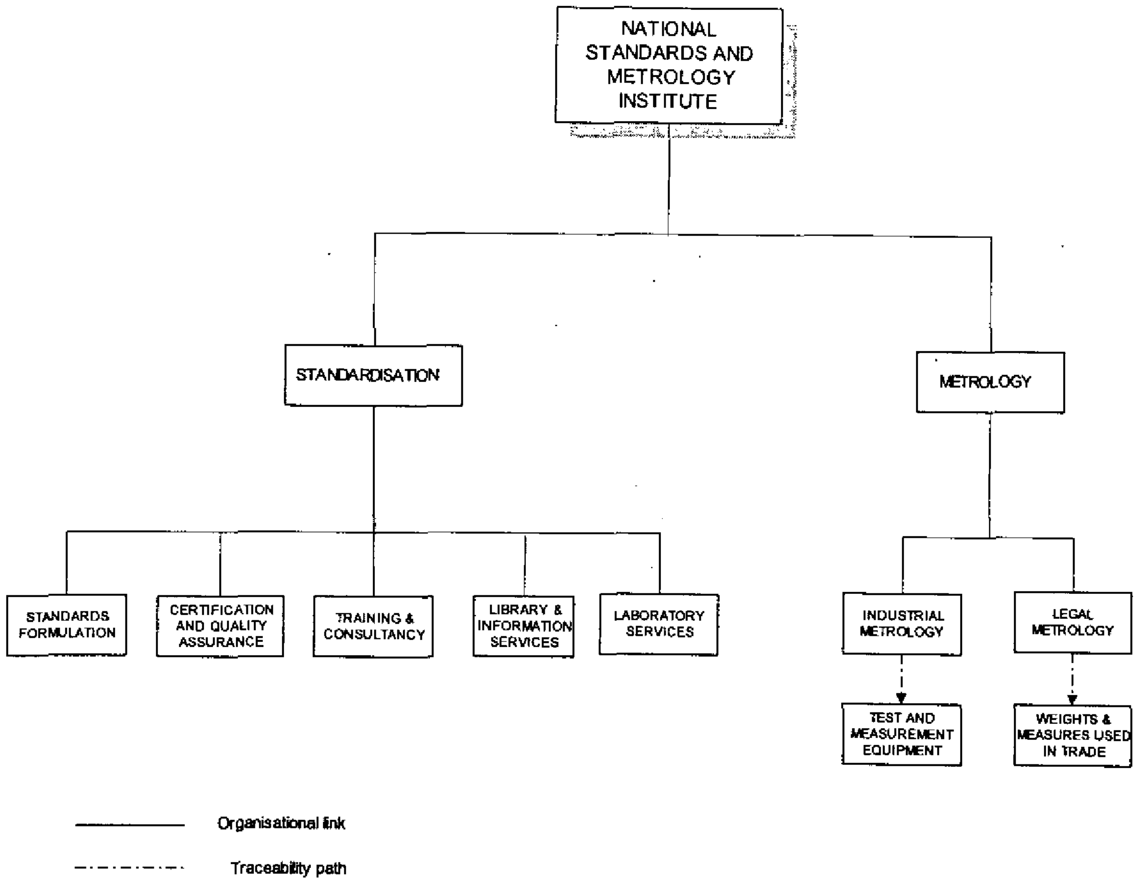


Figure 1: Integrated National Standards and Metrology Institute

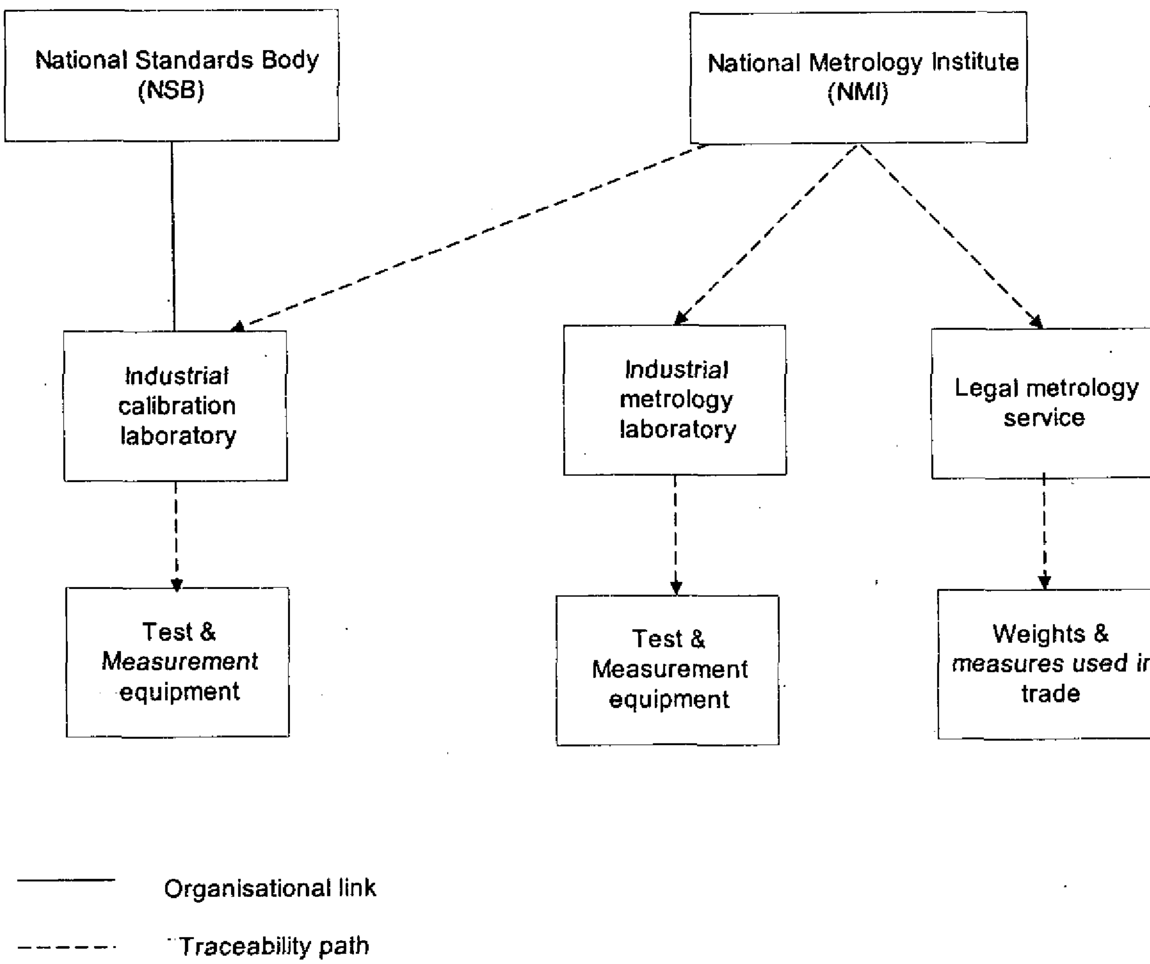


Figure 2: Separate National Standards Body and National Metrology Institute

6.2 National measurement standards

A country should establish national measurement standards according to its needs. When relevant, these national measurement standards will be primary realizations of the SI units (for mass a copy of the international prototype of the kilogram), and in other cases, the national measurement standards may just be secondary measurement standards traceable to primary measurement standards of another country.

For quantities whose traceability can be easily obtained by the users and by calibration laboratories directly to national standards of another country, and when the traceability provided by this direct reference is acceptable to the national accreditation scheme, a national measurement standard may not be necessary.

For some quantities, establishing and maintaining a primary standard may be considered a too heavy financial cost for some countries, so that an agreement may be discussed within a group of neighboring countries to share the costs of setting up and maintaining such a primary standard.

6.3 Traceability

For a particular measurement standard, or measuring instrument, 'traceability' means, that Its value has been determined by an 'unbroken chain of comparisons' with a series of higher level standards culminating in the primary standard (SI definition) for the quantity, usually maintained by the BIPM or other internationally recognized laboratory.

The establishment and maintenance of traceability of the measurement standards used at different levels of the metrological hierarchy is therefore vitally important. The responsibility of establishing and maintaining traceability to BIPM or other international laboratory of the highest level national standards rests with the institute responsible for custodianship of national measurement standards. The responsibility for maintaining traceability of secondary and working standards as well as test and measuring instruments devolves on the organisations holding this equipment.

The traceability chain is illustrated in Figure 3.

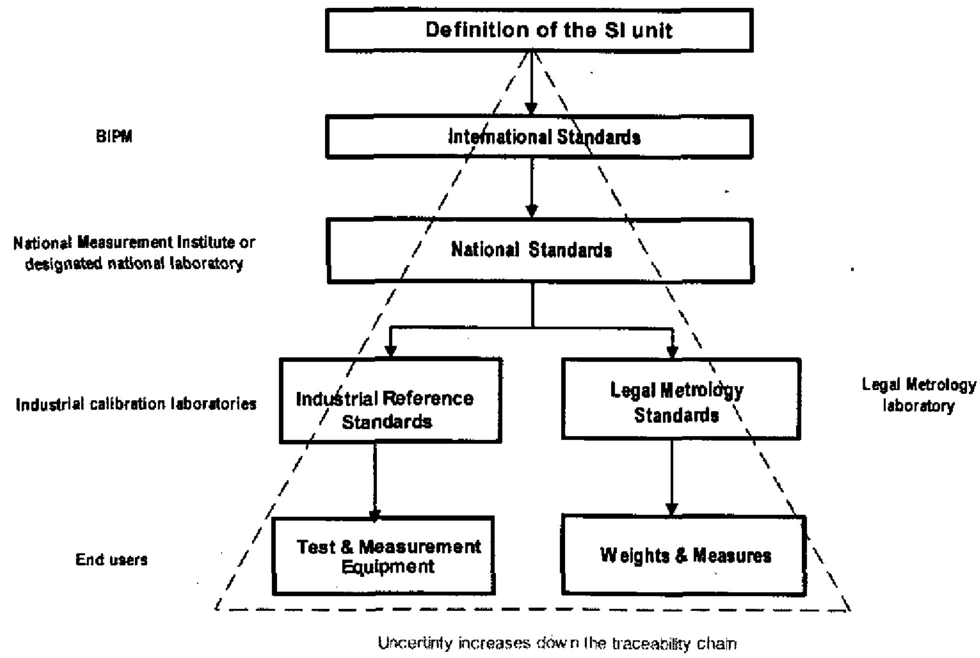


Figure 3- The traceability chain

7 LABORATORIES

The recommendations made in this chapter applies to legal metrology as well as scientific/industrial metrology laboratories. However in the case of legal metrology in most developing countries only length, mass, volume, flow and electrical energy meter testing laboratories will be required.

7.1 Division of activities

The fields of measurement likely to be covered in a metrology laboratory may be divided into the following groups:

- Mass,
- Volume (and flow) of liquids,
- Length and angle (dimensional metrology);
- Force and hardness,
- Pressure;
- Temperature and humidity;
- Gas measurements (volume and mass);
- Electrical measurements;
- Frequency and time;
- Photometry;
- Physico-chemical measurements (density, viscosity, sugar content, etc.);
- Ionizing radiation; and
- Acoustics.

The most important fields from the point of view legal and industrial metrology would be dimensional (particularly length), mass, volume and measurement of flow of liquids. Next in priority would be temperature, force, hardness, pressure, electrical parameters, frequency and time.

Temperature measurements and calibration of thermometers will become important especially if the country has a well developed food processing industry or petroleum production or refining facilities. Calibration of furnaces and thermometers are important for the mining industry, particularly mining and processing of precious and industrial metals.

In countries where the use of gas meters is limited to a laboratory or a few industrial applications it is not worth setting up a special laboratory for basic calibration of gas meters. Bottled gas is generally measured by mass and thus comes under the control of inspection services technically related to the mass department.

Calibration of tensile and compression testing machines as used in building materials, textile, rubber and plastics industries would require setting up of facilities for force measurement. A sufficiently developed metal working or metallurgical industry would require hardness and pressure measurement facilities.

The setting up of an electrical measurements laboratory has to be weighed carefully taking into consideration the need for calibration of electrical measuring instruments, particularly electrical energy recording meters. As a metrology laboratory develops, electrical calibrations become necessary for its own work, e.g. thermometer calibrations nowadays involve a great amount of electrical measuring equipment which require periodic calibration. Besides, digital instruments used in a number of fields and process control instrumentation also require periodic calibration.

Time and frequency measurement is another area which may be needed, but again should be assessed on the particular requirements of the scientific and industrial communities in the country. Generally speaking, the average citizen rarely requires the time of day to better than a few seconds. Transport services, radio and TV stations require time to an accuracy of about one second, as do celestial navigators who constitute the largest body of users requiring time to accuracies better than a few seconds. A country's initial requirement for a time service is modest; a time of day accuracy of tens of milliseconds would suffice.

However, new technologies exploiting the high precision of time measurement are rapidly developing. Navigational systems relying on time accuracies between 10 microseconds and 100 nanoseconds are already available and are being used increasingly on civil as well as military ships and aircraft.

Communications in the form of broadcast radio, TV, and telecommunications (land lines and mobile) are vital to the development of a country. The electro magnetic spectrum is a finite resource and the need to use the spectrum more efficiently leads to greater demands on frequency accuracy. Therefore, some form of frequency standard would be necessary.

A recent development is chemical metrology. The extensive use of automated instruments such as auto analysers, spectro photometers , X ray fluorescence analysers etc., have brought in a whole new array of problems to the measurement scientist for calibration of these instruments. Also the introduction of quality systems in test laboratories based on the requirements of ISO 17025 international standard has made it imperative that analytical test instruments are calibrated regularly. Thus many NMIs have commenced activities in a new measurement discipline known as chemical metrology. The main activity of this new field is the preparation and certification of reference materials known as Standard Reference Materials (SRM) and Certified Reference Materials(CRM). The newly emerging NMI of a developing country may not be able to acquire all the facilities and skills required for chemical metrology. However such a laboratory should acquire the needed SRMs and CRMs to provide a service to its clientale.

7.2 Location and site

Many factors need to be taken into consideration in selecting a site for setting up of a metrology laboratory. The major factors that would influence the decision are:

a) The measurement parameters (e.g. mass, length, etc.) for which laboratories will be built,
b) The sensitivity and the accuracy of the equipment that will be housed in the buildings,
c) The average atmospheric temperature and its diurnal and seasonal variation,
d) Proximity to sources of vibration, such as busy highways, heavy industrial plant, etc.,
e) Proximity to sources of high electro-magnetic radiation, such as radio and TV transmitting stations, high powered microwave antennas, high voltage power lines, etc.
f) *The cleanliness of the atmosphere with respect to dust and other polluting particles.*

It is also necessary to take into account the nature of the site and its environment, e.g. a leveled site is preferable to a sloping site such as on the side of a hillock unless advantage is to be gained by constructing some of the laboratories within the hillock.

The sensitivity and the accuracy of the equipment and the measurement procedure largely determine the temperature and humidity stability needed within the laboratories. For example, mass measurement equipment of high accuracy (1 in 10^6) would require temperature stabilisation to $\pm$ 0.5°C or better.

Achievement of a stable temperature within the laboratory will be more economical and convenient if the outside temperature variation is not excessive. Therefore, it is necessary to consider the atmospheric conditions of the site, particularly the temperature variation in relation to the equipment to be housed before a decision on the site location of the laboratory is finalized.

Another important consideration in locating laboratories is their proximity to interfering influence quantities, particularly, vibrations and electro-magnetic radiations. It is desirable to locate laboratories as far away as possible from major highways, industrial sites generating vibrations and dust and radio and TV transmitters, telecommunication antennas, high voltage power lines etc.

Dust and other polluting particles in the atmosphere is another source of interference in metrological work and one which would give rise to considerable expenditure, as specialised filtering equipment would have to be installed to keep the internal environment of the laboratories free of dust, although generally no stringent requirements are laid down in this respect.

7.3 Laboratory buildings

7.3.1 Estimation of area of laboratories

The nature and size of the buildings will again be largely determined by the facilities to be set up. The main criteria to be taken into consideration are:

(a) The measurement parameters for which laboratories will be built,
(b) The physical area required by the major equipment to be housed within the laboratories,
(c) The working area required for measurement and calibration purposes,
(d) The storage area required for spares and ancillary equipment, such as air conditioning equipment, fume cupboards, workshops, etc.,
(e) The area required to house the members of staff; and
(f) Additional space for toilets, corridors etc.

A detailed analysis should be carried out under each of the above headings to quantify the total space requirements. In the case of large laboratories, it is the general practice to provide separate rooms for individual measurement parameters, e.g. mass, length, temperature, etc.

In the case of a nucleus laboratory a single room or a few rooms may be provided, but in this case the rooms must be located in such a way that future expansion could take place without serious disruption to the existing facilities and services.

7.4 General requirements for laboratory buildings

A number of metrology laboratory buildings have been constructed using very special designs to obtain thermal insulation enclosing quite large laboratory rooms. However, in view of costs it may be advisable to make use of current dimensional modules and materials, but to pay special attention to arrangement of double walls, insulation and special air conditioning for some of the laborato'y rooms within the limits imposed by the building modules adopted.

The size and form of the site will decide the best configuration for a laboratory. The building should be oriented away from direct sunlight appearing on the longer face, i.e. preferably facing the north or north-west side for countries in the northern hemisphere and facing the south or south-west for countries in the southern hemisphere.

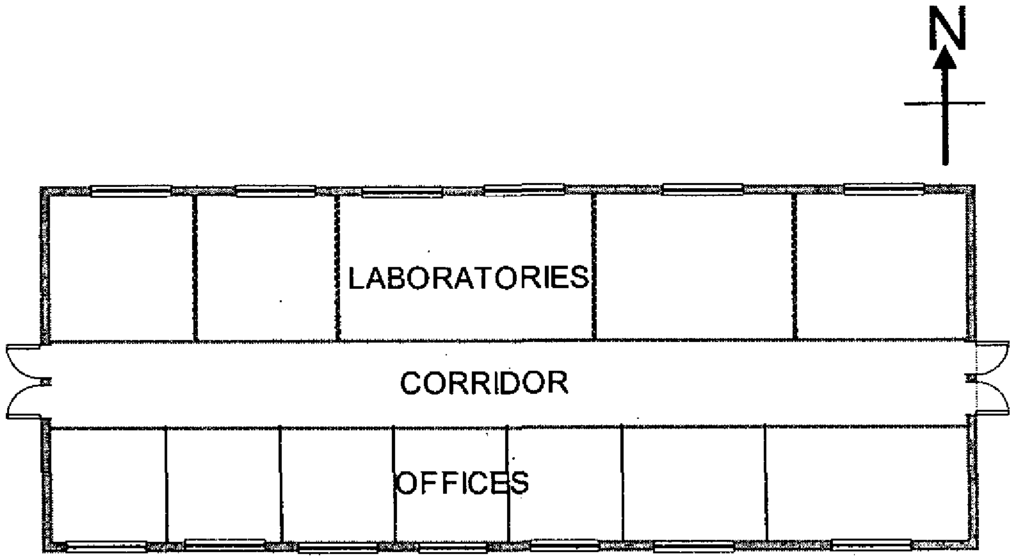
The building usually consists of a reinforced concrete structure with walls preferably made of high quality bricks or if these are not available of hollow concrete building blocks. Reinforced concrete walls or wall elements should be avoided for various reasons (vibration, difficulties in fixing equipment on walls, low thermal insulation, etc.).

Internal wall separations can usually be made of bricks to allow for modifications when required. In several laboratories where very flat and clean wall surfaces are required, the walls should receive a suitable finish by application of plaster and paint in dry atmosphere, and resistant anti-fungus paint in countries with high humidity or in wet laboratories.

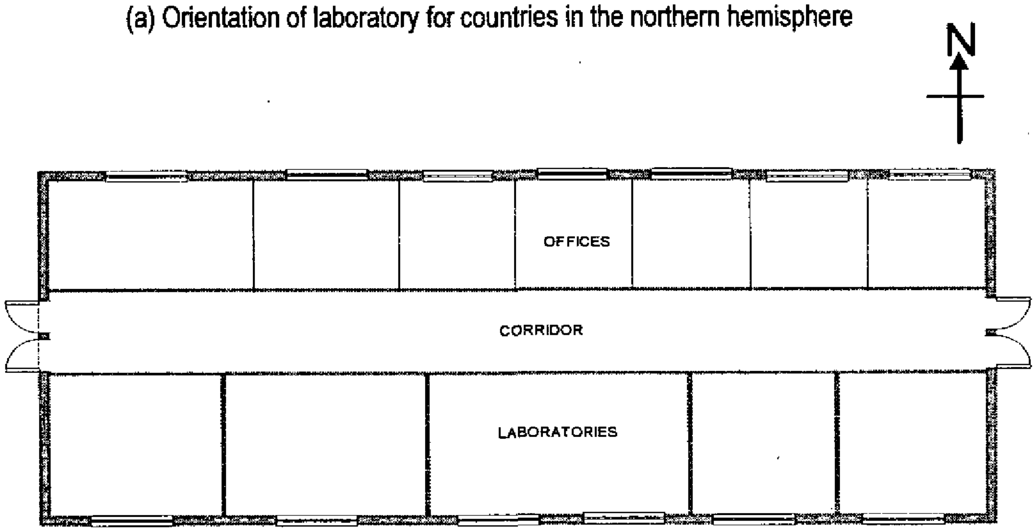
Generally a module of 5 metres is suitable. The length of the building or each wing of the buildings should be limited to 6 or 7 modules maximum, both from the structural point of view and for convenience of communications. The windows should not be too large (2 windows per full-module with glass panels of about 1000 mm wide). The free room height inside the rooms shall generally be at least 3200 mm so as to allow false ceilings for air conditioning to be installed in some of the rooms and in all corridors.

The corridors should be sufficiently large (at least 2 m wide) so that carts with equipment can easily be moved around. Finally, it is very important that staircases and doors are sufficiently large so that the measuring equipment and furniture can easily be moved around when required (single doors 800 mm for offices, 1000 mm for laboratories, 2 x 800 mm (or 1000 mm) for double doors in laboratories). If buildings of several floors are considered, it will be most useful to install a lift of adequate capacity to service the floors.

Floor covering is frequently a problem and subject to compromise. It should be load and wear resistant, hard, not subject to dust retention or abrasion, not produce static electricity, not be slippery when wet, easy to clean, fire resistant and finally, at least in the laboratories and offices be attractive. Load resistant



(a) Orientation of laboratory for countries in the northern hemisphere



(b) Orientation of lab for countries in the southern hemisphere

Figure 4 –Orientation of laboratory

high quality stone agglomerate or non glossy ceramic tiles may do in corridors and passages and in the wet laboratories. However, for most other laboratories a hard plastic tiling must be found which is not subject to build-up of static electricity. Vinyl-asbestos tiles have been largely used in the past and were generally found satisfactory except that they were easily breakable if not placed on a fully flat support.

However, since anything containing asbestos is considered to be a health hazard some countries may not allow the use of vinyl-asbestos tile on surfaces. Taking into account the great variety of supplies in most parts of the world it is advised that this matter be carefully investigated with architects and contractors by considering all the above-mentioned requirements. In any case the preparation of the floors must be perfect and load-resistant and the tiles or other covering must be sufficiently hard, to withstand without indentation or breakage, point loads produced by a mass of at least 100 kg on a surface of only one square centimeter.

When central air conditioning for comfort is to be installed, it is necessary to provide a special room on each floor for the heat exchanger and ventilation equipment (air handling). In addition, several test rooms will have to be equipped with independent air conditioning units which can be controlled with high accuracy. A suitable space adjacent to each test room must thus also be provided for these units. The central air conditioning plant should be placed in a special building outside the main metrology building.

7.4.1 Control of environmental parameters (temperature, humidity and air flow)

Regardless of the climate and independent of the heating or cooling provided for comfort, metrology laboratories require special climatisers to obtain reproducible and comparable test results. The principal aim is to obtain:

- A stable temperature,
- Reasonably low air humidity, and
- Small air flow (especially in mass laboratories)

Generally, there are no stringent requirements on dust except that all intakes of fresh air must be filtered and all windows must be dust tight.

The stability of temperature is more important than the exact setting of the ambient temperature. The keeping of constant temperature may be achieved in a number of ways. The insulation of the measurement area from external surfaces that may have a different temperature is vital. This can generally be done by using an additional wall thus providing a hollow space or by fixing a layer of insulation material (e.g.Styropur) on the interior surface of the walls . In most laboratories it is also necessary to avoid direct sunlight.

The use of a central air conditioner with individual servo-mechanical damper control in each room is a very effective method to achieve close control of temperature and could be used when several adjacent laboratories have to be temperature controlled and kept at the same mean temperature. However, when the volume of the activities related to very high accuracy are limited it is better to provide independent laboratory air conditioners with high accuracy temperature control.

It is particularly important that the air conditioning units are provided with precision controls of temperature and humidity through sensors which can be suitably positioned in the laboratory room. Many individual air conditioners are in fact only provided with internal controls and mainly intended to keep the temperature within a few degrees while usually allowing for heat dissipation and fresh air intake. It is, therefore, necessary to provide the contractors with complete data (lay out drawings, number of staff in each *laboratory, heat generating sources and outside weather conditions) to design the system to meet the* environmental requirements.

Table 1-Environmental conditions of laboratories

Laboratory	Temperature	Admissible temperature Variation, °C	Maximum air flow rate, m/s
Dimensional metrology	20°C (or 23°C)*	±0.5	0.2
Mass	23°C	± 0.5	0.2
Thermometry	23°C	± 1	0.2
Pressure and force	23°C	± 1	0.2
Electrical	23°C	± 0.5	0.2
Electrical energy	23°C	± 1	0.2

In the case of the mass standards laboratory the requirements are not stringent as regards the value of the ambient temperature itself which can usually have any value between 18°C and 27°C. However, it must be ensured that the temperature is kept stable within at least ± 0.5°C for periods of several hours to provide enough stability during a series of mass comparisons. High-accuracy electronic balances may in this respect require temperature stabilization for longer periods than classical mechanical balances. Furthermore, air-draft and pressure variations must be avoided. In this respect , many mass laboratories *presently follow the recommendations given in* OIML R 111 *reproduced in Table 2.*

Table 2-Environmental conditions for mass laboratory

Class of Weight	*Temperature change during calibration*	*Relative humidity of air*
E1	±0.3°C per hour with the maximum variation not exceeding ± 0.5 °C per 12 hours	In the range 40 % to 60 % with a maximum variation not exceeding ± 5 % per four hours
E2	±0.7°C per hour with the maximum variation not exceeding ± 1.0 °C per 12 hours.	In the range 40 % to 60 % with a maximum variation not exceeding ± 10 % per four hours
F1	±1.5 °C per hour with the maximum variation not exceeding ± 2.0 °C per 12 hours.	In the range 40 % to 60 % with a maximum variation not exceeding ± 15 % per four hours
F2	±2.0 °C per hour with the maximum variation not exceeding ± 3.5 °C per 12 hours.	should be in range 40 % to 60 % with a maximum variation not exceeding ± 15 % per four hours
M1	±3.0 °C per hour with the maximum variation not exceeding ± 5.0 °C per 12 hours.	should be in range 40 % to 60 % with a maximum variation not exceeding ± 15 % *per four hours*

(Extracted from OIML R 111 : 2005 , courtesy of International organisation of Legal Metrology)

Relative humidity for all rooms should not exceed 60% under most unfavorable weather conditions. In practice, the temperature variations will usually be double the above indicated target data. Experience seems to show, however, that the prescribed design data have to be lower to avoid the provision of too rough temperature control. The indication of the number of staff in the rooms will allow the contractor to calculate the amount of fresh air intake.

As regards humidity, the most troublesome effect in metrology is generally the risk of condensation leading to corrosion of mechanical instruments, lowering of insulation or even breakdown of electronic equipment.

The relative humidity (percentage) varies greatly with temperature, thus in a room with constant moisture content (mass of water) it may typically increase by 5% for a decrease in temperature of only 1 °C. Therefore, to be on the safe side and avoid condensation, the relative humidity should not be allowed to be higher than 60% in metrology rooms. Furthermore, the air conditioning of these rooms should work continuously and in any case not be subject to daily interruptions that will in most cases lead to condensation both on metrology equipment and in air conditioning ducts.

7.4.2 Equipment for laboratories

Equipping metrology laboratories is a highly capital intensive task and, therefore, should be undertaken after a careful investigation and analysis of the actual requirements of the country. General guidelines applicable to legal and industrial metrology are provided here. Specifications and other details of most of the equipment requirements for legal metrology are given in OIML publications. However, expert advice should be sought before procurement of metrology equipment due to the heavy costs involved.

The vital question to resolve in equipping laboratories is to determine which measurement parameters would be catered for. The situation for legal metrology facilities for most developing countries is similar. Mass, length, volume and flow are the most needed measurement areas. In a few countries there may be a necessity for verification of electricity meters and gas meters.

The requirements of industrial metrology would depend on the industrial status of the country. Temperature, force, hardness, pressure, electrical quantities (voltage, current and resistance) are the most needed measurement areas. Facilities in photometry may also be required if manufacture of electric bulbs and fluorescent tubes is undertaken in the country.

It is necessary to determine the accuracy and the range of each of the equipment required. Excepting the National Primary or Reference Standards which must be of an accuracy level compatible with international traceability requirements, the other equipment need only be at a level sufficient for calibration requirements of industry. The best way to resolve these considerations is to carry out a national survey of measurement needs within the country. The survey should be sufficiently comprehensive to cover a majority of measurement areas. The survey may be carried out by means of a questionnaire sent to all manufacturing, processing and service organizations in the country. It will be found that the response to a postal survey will generally be not more than 30 to 40 percent, and that a few visits will need to be undertaken by a metrologist or a similarly qualified person to fill in the missing gaps of the survey. The results of the national survey will be most useful for planning purposes even if only about 50 to 60 percent of the organizations operating in the country had been covered.

The maintenance, repair and calibration of metrology equipment is a costly and troublesome operation especially in developing countries. Therefore, it is advisable to procure only those equipment which are vitally necessary to carry out the intended functions of the organization. The equipment should not be obsolete in design. Avoid over sophistication. These precautions should minimise operational costs and maintenance expenses.

It is good practice to include at the time of the initial order, a few spares such as fuses, electronic components, etc., which cannot be procured easily in the country. Although in the case of test equipment, availability of repair and servicing facilities at an accredited agent within the country or region is an important consideration, the same cannot be said for metrological equipment due to their very specialized nature.

7.5 Quality management system

It is necessary to take several precautions in order to ensure the validity and accuracy of calibration results. The most important steps are :

- Setting up of a quality management system based on the ISO/IEC 17025 international standard,
- Carrying out regular internal quality assurance procedures,
- Participation in proficiency testing and inter laboratory comparison programs and
- To obtain accreditation from an internationally recognized accreditation body.

The setting up of a quality management system requires the preparation and implementation of at least three main documents :

- Quality manual ,
- Procedures manual and
- Methods manual

The quality manual gives the policies the laboratory would follow to implement the management and technical requirements of the ISO 17025 standard. The details of implementation of the policies indicated in the quality manual are elaborated in the procedures manual. The methods manual is a collection of the test, calibration and verification methods used in the laboratory.

The implementation of the quality management system requires maintenance of records of all aspects of the laboratory's activities. For this purpose a collection of recording forms are used. Generally these form a part of the procedures manual.

Regular internal audits, at least once every six months would reveal non conformances and would improve the operational effectiveness of the quality management system.

8 STAFF

Metrology laboratories (Industrial, scientific or legal) require staff at basically, five levels:

- Head of laboratory,
- Metrology Engineers ,
- Metrology Technicians,
- Weights & Measures Inspectors,
- Support staff.

8.1 Head of laboratory

The head of laboratory takes overall responsibility for the administration and technical functions of the laboratory and should be a senior person who has had sufficient experience in the operation of a metrology laboratory. Generally he/she should possess a degree or advanced diploma in a physical science or engineering and have a minimum of five years of working experience in a metrology laboratory.

8.2 Metrology engineers

The bulk of the complicated scientific work of a metrology laboratory is carried out by Metrology Engineers. The term 'Metrology Engineer' defines the qualification of a specialist, who has completed his/her under graduate education and has been properly trained in the field of metrology and measuring instruments, either as an integral part of the basic engineering or science degree programme or through specialized programmes in measurement science.

The main duties of a metrology engineer attached to a legal metrology service would be verification of working standards against secondary standards, testing of equipment for pattern approval, and assisting in the enforcement of the metrology law and its regulations.

A metrology engineer attached to scientific or industrial metrology laboratory would have to carry out a number activities in the field he has received training and acquired experience. These would generally be industrial calibrations, maintenance and calibration of measurement standards, taking care of the environmental conditions of the laboratory. Some of the metrology engineers would also be called upon to perform the duties arising from the maintenance of the quality management system of the laboratory.

The selection procedure must not only recognize the academic background, but other qualities of the candidates, such as patience and the ability to examine and analyse a problem critically.

8.3 Metrology Technicians

Metrology Technicians are essentially technical support staff to perform tasks under the supervision of the metrology engineers. The recruitment qualification is completion of secondary education including Physics, Chemistry or Mathematics as subjects.

8.4 Weights & Measures Inspectors

Many legal metrology services designate some of their officers as 'Weights & Measures Inspectors'. These officers are specially trained in the technical aspects of weights & measures equipment as well as in the enforcement of the metrology law and its regulations. The powers of enforcement are usually defined in the metrology law. The recruitment qualification is certificate of secondary education followed by 2 years of pre university education in physics, mathematics and language or graduate in science(physics or mathematics).

The main duties of weights and measures inspectors are inspections, reporting, assisting in approval schemes, being chief local office etc.

8.5 Support staff

Support staff are non-technical staff that would assist the operation of the laboratory. These are categories such as secretaries, typists and minor staff.

8.6 Number of staff

The number of staff required will depend on the number different laboratories that are to be operated. At the initial stage of development one or two metrology engineers per laboratory will be sufficient. As the service grows, more metrology engineers and technicians will be required. A minimum of one technician per laboratory should be recruited at the commencement so that they can receive training on the job.

8.7 Staff for legal metrology

A legal metrology service is generally headed by a metrology engineer who is designated Director, or Chief Inspector of Weights and Measures. The Director is responsible for the overall administration, *formulation of policy and development activities of the service.*

The technical work of verification and pattern approval of weights and measures and enforcement of the metrology law and regulations is carried out by a cadre of 'Metrology Engineers' and 'Technicians'.

The numbers of the different categories of staff needed initially and for subsequent development of the service will depend on a number of factors, primarily the complexity of trade and commerce, population and the number of administrative districts or provinces in the country (geographical extent). A legal metrology service, to be effective has to operate at the district or provincial level. The number of metrology engineers and technicians needed to carry out the regulatory activities within a district or province will depend on the geographical extent ,population and the level of development of the district or province. Generally at least one or two metrology engineers and several technicians will be required.

8.8 Training of metrology personnel

The training of metrology personnel is treated under two different headings, namely scientific / industrial metrology personnel and legal metrology personnel.

8.8.1 Scientific and industrial metrology personnel

8.8.1.1 Metrology engineers and technicians

Both metrology engineers and technicians should be given a general theoretical training in the following fields :

a) Fundamental concepts of measurement,

b) Essential principles and methods of obtaining measurement data in various measurement fields,

c) Essential measuring instruments, sensors and systems of analog and digital signal processing,

d) Methods of analyzing measurement results, evaluation of errors and uncertainties together with the application of computers,

e) Methods of testing measuring instruments when exposed to influence factors,

f) Methods of analyzing the dynamic characteristics of measuring instruments,

g) Basic economics, the organization of work and management of quality,

This will be followed by more specialised training in the specific area of work the metrology engineer or the technician is assigned to work. Thus those who are assigned to a mass laboratory would be trained in 'mass metrology' and those assigned any other field would be trained in that specific field. The training would consist of both theoretical and practical phases.

Further specialised training may be given by sending the engineers and technicians to a well developed metrology laboratory or institute providing training in metrology. Generally, one or two staff members should be trained in mechanical metrology, (mass, length and engineering metrology) electrical metrology, thermometry, etc. depending on the need in each country. It is prudent to distribute the training among several members of staff so as to build a certain amount of redundancy. The retention of highly trained and skilled staff is a difficult process and, therefore, consideration should be given to this issue in awarding training opportunities.

8.8.2 Legal metrology personnel

The persons who are assigned to work in the legal metrology area would require a slightly different approach in their training. These personnel may be also be initially trained in the topics given in the section 8.8.1. In addition they will require training in the following areas :

a) National metrology law and other national laws, in particular the penal law and procedure,

b) General regulations concerning legal metrology and the particular regulations applicable to weighing and measuring equipment,

c) Principles of construction and operation of weighing and measuring instruments the metrology service has to test and verify,

Facilities for overseas training are available at a number of national standards laboratories and legal metrology services. Specific details of these may be obtained from the publications of the OIML and national measurement laboratories.

9 PHYSICAL INFRASTRUCTURE DEVELOPMENT

9.1 Revenue generation

The cost of establishment and operation of a national metrology system is considerable. By charging fees for the services provided some fraction of the operational costs can be recovered. Areas of revenue generation include the following:

9.2 Verification of weighing and measuring equipment

Verification and stamping of weights and measures equipment used in trade is a statutory obligation on the part of the user. A significant amount of revenue could be generated from this operation. A realistic scale of fees should be fixed and given in a 'Regulation'. In fixing the scale of fees, the actual costs to be incurred over the period of validity of the verification need to be estimated. In general, the unit cost worked out on the basis of staff salaries, transportation costs, depreciation of the standard equipment and overheads may become unrealistically high. In such an event, the verification fee may be fixed as a percentage of not less than 50% of the actual costs.

In any case, the verification fees should not be fixed at a level which would make it difficult for a majority of the users to get their equipment verified and, stamped. Such a situation would negate the very objective of a legal metrology service, namely affording protection to the consumer by verifying a majority of weighing and measuring equipment used in the country.

9.3 Fees from calibration services

The revenue that can be generated from this operation at the initial stages of development of a metrology service may be small. Nevertheless, it is an area which should be developed as the future potential of a calibration service to generate revenue is considerable.

Calibration of laboratory balances, (single pan analytical and top loading types) and sets of weights used in laboratories are services that can be rendered with a minimum outlay on capital expenditure. The service could then be extended to other measurement parameters, such as length (micrometers, vernier calipers and measuring tapes), temperature (liquid in glass thermometers, thermocouples, platinum-resistance thermometers) and pressure (pressure gauges) as the service develops. Another possible area for development without much capital outlay is the calibration of vehicle and storage tanks used for handling of petroleum products.

9.4 Consultancy services

Although provision of consultancy services may not be a feasible proposition at the early stage of development of a metrology service, it is an area which should not be totally neglected. While being a revenue earner such a service would make an important and significant contribution to the industries of a developing economy. However, in order to initiate consultancy services, moderate facilities and staff with some experience are needed.

9.5 Government support.

A national metrology service would naturally depend on Government support for a large component of its operational expenditure. This is usually provided in the national budget, in the form of recurrent and development budgets.

The recurrent budget usually includes staff salaries and other running expenditure. The capital budget would usually provide for purchase of land, construction of laboratories and purchase of capital equipment including motor vehicles. Generally, it is difficult to obtain funds for capital development and particularly in the short term. The chances of obtaining funds from the national budget for capital development purposes will be much improved if the expenditure is spread over a number of years. Generally a period of 3 to 5 years, depending on the circumstances of the individual country is suitable. Planning authorities of national Governments would also be more disposed to provide funds, if the utilisation of the funds could be indicated in a project plan. The project plan should provide a detailed programme of activities of the capital development project.

9.6 Financial and technical assistance from regional and international organizations

9.6.1 Technical assistance from UNIDO

The following technical assistance is available from UNIDO:

(i) Advice on initiation and development of a national measurement system including specific advice on legislation and organisational structures for national metrology services,

(ii) Recommendations and funds for procurement of metrology equipment,
(iii) Guidance on design of laboratories,
(iv) Technical guides and standard specifications on metrology.

Sometimes are funds are also available from the United Nations Development Programme(UNDP).The United Nations Industrial Development Organization (UNIDO) usually acts as the Executing Agency for UNDP funded projects.

9.6.2 Bilateral aid from donor Governments and agencies

It is also possible to obtain funding and technical assistance from a number of donor Governments and agencies. These are normally worked out on a Government to Government or bilateral basis, and proposals should be made to the planning authorities of the respective Governments. In making a proposal it is necessary to outline the salient features of the project, including the approximate cost, duration and the benefits that would accrue to the country.

10 BIBLIOGRAPHY

OIML Publications

1. International Organization of Legal Metrology (OIML) - Bulletin No. 105, Dec. 1986, Pg 28-35.
2. D 1 - EN ,Elements for a Law on Metrology ,2004
3. D 2 - EN ,Legal units of measurement ,1999
4. D 2-Amend - EN ,Legal units of measurement: Amendment, 2004
5. D 3 - EN ,Legal qualification of measuring instruments ,1979
6. D 5 - EN ,Principles for the establishment of hierarchy schemes for measuring instruments ,1982
7. D 8 - EN Measurement standards. Choice, recognition, use, conservation and documentation (Revision combining D 6 + D8) , 2004
8. D 9 - EN ,Principles of metrological supervision
9. D 12 - EN ,Fields of use of measuring instruments subject to verification ,1986
10. D 13 - EN Guidelines for bi- or multilateral arrangements on the recognition of: test results - pattern approvals - verifications ,1986
11. D 14 - EN ,Training and qualification of legal metrology personnel ,2004
12. D 16 - EN ,Principles of assurance of metrological control ,1986
13. D 19 - EN ,Pattern evaluation and pattern approval ,1988
14. D 20 - EN ,Initial and subsequent verification of measuring instruments and processes ,1988
15. D 23 - EN ,Principles for metrological control of equipment used for verification ,1993
16. D 27 - EN ,Initial verification of measuring instruments using the manufacturer's quality management system ,2001
17. V 1 , International vocabulary of terms in legal metrology (bilingual French-English) ,2000
18. V 2 ,International vocabulary of basic and general terms in metrology (bilingual French-English) ,1993
19. B 3-OIML Certificate System for Measuring Instruments,2003
20. B 10-1 - EN ,Framework for a Mutual Acceptance Arrangement on OIML Type Evaluations (MAA) ,2004
21. B 10-2 - EN ,Checklists for Issuing Authorities and Testing Laboratories carrying out OIML Type Evaluations , 2004
22. G 7 - EN ,Guide to calibration ,1989
23. G 8 - EN ,Guide to practical temperature measurements ,1991
24. G 9 ,Metrology training - Synthesis and bibliography , 1987
25. G 10 - EN , Verification equipment for national Metrology Services ,1986

26. G 11 ,Mobile equipment for the verification of road weighbridges (bilingual French-English) ,1992

27. G 12 ,Suppliers of verification equipment (bilingual French-English) ,1987

28. G 13 - EN ,Planning of metrology and testing laboratories , 1989

29. G 15 - EN ,Guidelines for the establishment of simplified metrology regulations ,1992.

30. International Organisation of Legal Metrology, International Recommendation 87 ,1989 .

Other publications

31. The International Bureau of Weights and Measures, 1875-1975, NBS special Publication 420, US Department of Commerce, 1975.

32. Blevin, W.R., National and international needs relating to metrology : International collaborations and the role of the BIPM, CIPM, 1998.

33. Kovalevsky, J and Kaarls. R, Evolving Needs for Metrology in Trade, Industry and Society and the Role of the BIPM, CIPM, 2003.

Appendix 1- Useful web addresses

Organisation	Web address
EA European co-operation Accreditation	www.european-accreditation.org
IAAC Inter American Accreditation Cooperation	www.iaac-accreditation.org
APLAC Asia Pacific Laboratory Accreditation Cooperation	www.ianz.govt.nz/aplac/
EUROMET European Metrology Cooperation	www.euromet.org
SIM Inter-American Metrology System	www.sim-metrologia.org.br
BIPM Bureau International des Poids et Mesures	www.bipm.fr
APLMF Asia-Pacific Legal metrology forum	www.aplmf.org
WELMEC	www.welmec.org
OIML	www.oiml.org
BIPM	www.bipm.org
SACMET	www.sac met.org
APMP Asia Pacific Metrology Program	www.nmij.jp/apmp/
SADACMET	www.sadacmet.org
ILAC	www.ilac.org