

Metrology

4.1 INTRODUCTION

In everyday life, metrology is hardly ostentatious, but its calm surface covers depths of knowledge that only a few are familiar with but that most use without thinking twice—confident that they are sharing a common perception of what is meant by expressions, such as meter, kilogram, and liter, for example, or confident that cell phones will connect, Global Positioning System (GPS) instruments will take us to the right address, and pilots will land aircraft safely. This *confidence* is vital in enabling metrology to link human activities together across geographic and professional boundaries.

Just as important is the *accuracy* of measurements—from the everyday use of weights and measures to the absolute cutting edge of technology, from the liter of fuel purchased to the accuracy of time measurement gaining or losing a second in millions of years. Accuracy of measurement has massive resource implications. It is therefore important to differentiate between the metrology needs of a low- or middle-income country and those of a country involved in fundamental research to transpose the definition of a measurement standard based on the laws of physics (see module 4 of the QI Toolkit) into measuring equipment for the same. This differentiation can be expressed as shown in table 4.1.

Any evaluation of the metrology system of the country is therefore heavily dependent on its level of development and the demands of the stakeholders. The establishment of a national metrology institute (NMI) as one of the fundamental organizations of the quality infrastructure (QI) is important, but even more important is the level of technology the NMI must operate to balance resource constraints with the country's needs. An evaluation of the metrology system of the country is therefore incomplete without knowledge of the actual demands of industry, authorities, and society.

Metrology is normally separated into three categories with different levels of complexity and accuracy but with known interdependencies (see module 3 of the QI Toolkit):

- *Scientific metrology*, which concerns the organization, development, and maintenance of measurement standards

TABLE 4.1 Maturity levels of a national metrology institute

NMI CHARACTERISTIC	RUDIMENTARY (LITTLE OR NO METROLOGY)	BASIC (LOW- TO MIDDLE-INCOME COUNTRY APPROACH)	ADVANCED (ECONOMYWIDE APPROACH, SECTORAL APPROACH)	MATURE (INNOVATIVE, CUTTING-EDGE TECHNOLOGY)
NMI laboratory infrastructure	No NMI; legal metrology department is only entity	A number of “basic basket” laboratories (including the appropriate accuracy levels)	Laboratories (including the CMCs) defined through economywide surveys Laboratories (including the CMCs) defined through sectoral international benchmark	High-level laboratories for innovative sector
International recognition	None	Through accreditation or CMC declarations	Through CMC declarations (or accreditation)	Through CMC declarations
Membership	None	Active RMO member	Active RMO member BIPM membership OIML membership	Active RMO member BIPM membership OIML membership Active in BIPM committees
Services	Calibration services	Calibration services	Calibration services Reference materials Intercomparisons Proficiency tests	Calibration services Reference materials Intercomparisons Proficiency tests Metrological consultancy Research
Secondary laboratories	None	None to some secondary calibration laboratories	Several calibration laboratories Loose network of calibration laboratories	Strong network of calibration laboratories coordinated by the NMI
Human resources	Training on the job	Training on the job	Training on the job Training courses in metrology	Training on the job Training courses in metrology Metrologist as a professional profile
Demand orientation	Not really	Demand surveys, mostly through projects	Demand surveys Stakeholder participation and consultative mechanism	Strong instruments and constructs to ensure demand orientation

Note: BIPM = International Bureau for Weights and Measures; CMC = calibration and measurement capability; NMI = national metrology institute; OIML = International Organization of Legal Metrology; RMO = regional metrology organization. The point of departure of the table is the NMI. It is possible, however, that a country may have only a weak NMI, whereas there may be independent calibration laboratories that deliver appropriate services, with their measurement standards traceable to other countries’ measurement standards. If this is the case, then the table should be adjusted in an appropriate manner by the experts conducting the evaluation.

- *Industrial metrology*, which concerns the adequate functioning of measuring instruments used in industry, production, and testing processes
- *Legal metrology*, which concerns the accuracy of measurements where these influence the transparency of economical transactions, health, safety, and compliance with legislation.

Legal metrology is covered in section 11: Legal Metrology. The building blocks of the NMI relating to the four pillars are listed in table 4.2.

To depict the pillars and building blocks in a graphical way that would indicate the state of metrology in a country at a glance, they can be put together as shown in figure 4.1. For a complete description of the construction, interpretation, and use of this graphic or of the matching radar diagram, see section 1: Comprehensive QI Assessment.

TABLE 4.2 Pillars and building blocks of the national metrology institute (NMI)

PILLAR	BUILDING BLOCK	
	NO.	DESCRIPTION
1: Legal and institutional framework	1	Metrology strategy
	2	Legal entity
	3	Autonomy
	4	Legal standing of national measurement standards
	5	Governance
	6	Financial sustainability
2: Administration and infrastructure	7	Chief executive officer
	8	Organizational structure
	9	Management and personnel
	10	Premises
	11	Equipment
	12	Quality system documentation
3: Service delivery and technical competency	13	Metrologists
	14	Interlaboratory and key comparisons
	15	Calibration and measurement capability
	16	Calibration service
4: External relations and recognition	17	Training system
	18	Liaison with regional organizations
	19	Liaison with international organizations
	20	Coordination within the QI
	21	Designated institutes
	22	Stakeholder engagement

Note: QI = quality infrastructure.

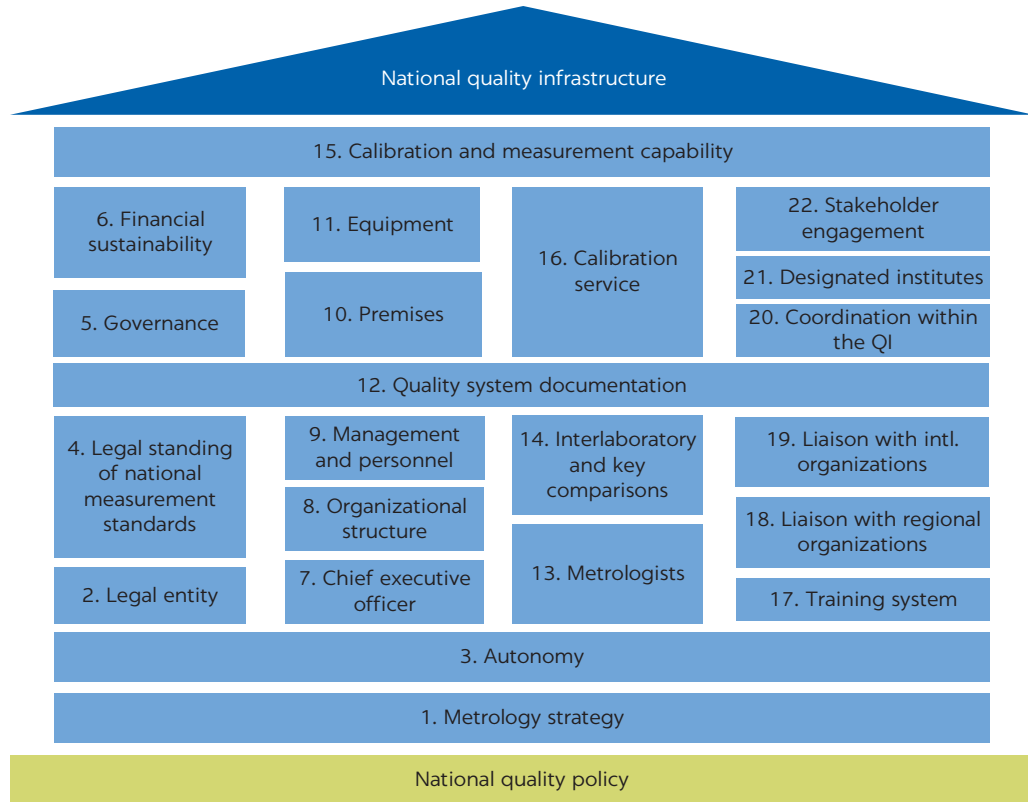
4.2 PILLAR 1: LEGAL AND INSTITUTIONAL FRAMEWORK

4.2.1 Benchmark and significance

The NMI must be an identifiable legal entity operating within an agreed-upon policy framework of the government. Its mandate should include a clear and unambiguous statement regarding the establishment and maintenance of the national measurement standards. Without such policy and legal backup, the NMI may find it difficult to carry out its fundamental responsibilities, namely, the realization of the definitions of the national measurement units and the diffusion of accurate and trustworthy measurements through traceability chains within the country.

Regarding its governance, the NMI should follow a more open and transparent model, with stakeholders having a meaningful influence on strategy, rather than a top-down system controlled by public servants. The latter will stifle innovation and render the NMI less able to serve its main stakeholder groups effectively. The stakeholders also play an important part in determining the level of accuracy that a national measurement standard should have in order to meet stated needs.

FIGURE 4.1
House of metrology for a national quality infrastructure



Note: QI = quality infrastructure. The four “pillars” of the QI—represented by the blue columns containing the “building block” numbers—are as follows (left to right): “legal and institutional framework,” “administration and infrastructure,” “service delivery and technical competency,” and “external relations and recognition.”

4.2.2 Metrology strategy (building block no. 1)

What is meant

Major	<p>Following on from the quality policy (see subsection 2.1: Quality Policy), a metrology strategy gives meaning to the implementation of the quality policy regarding the establishment and maintenance of national measurement standards and the diffusion of accurate and trustworthy measurements in the country. The metrology strategy is about</p> <ul style="list-style-type: none"> • Making the right choices regarding the metrology services to offer and the customers to focus on; • Getting stakeholder support for the NMI; and • Building capacity in the NMI to fulfill its part in the most innovative, effective, and efficient way.
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How can it be demonstrated?

The metrology strategy can be seen as an intended plan to set a pattern, create a unique position, follow a specific perspective, and implement a specific tactic—all to enable the NMI to make a difference to a critical mass of the right customers and to connect its purpose with those of its customers and external stakeholders (Minzberg, Ahlstrand, and Lampel 1998).

The metrology strategy should be a formal document approved at least by the NMI board or council, and in some countries even by the minister or cabinet, depending on national custom and practice. It should be publicly available—that is, on the NMI website or in hard copy. The activities, business plans, and budgets of the NMI should be aligned with the metrology strategy to ensure its implementation.

Existing information/reporting/monitoring

- NMI board or council papers
- NMI website
- Relevant ministry (for example, Trade and Industry) website
- Annual reports of the NMI
- Available metrology services

4.2.3 Legal entity (building block no. 2)

What is meant

Fundamental	The NMI shall be a legal entity, or a defined part of a legal entity, such that it can be held legally responsible for the establishment and maintenance of national measurement standards and for the diffusion of accurate and trustworthy measurements within the country. The NMI is often a governmental department or an institution of public law (such as a statutory body), although private sector institutions are also possible. It may be an independent institution, but it can also be combined with the legal metrology department or with the national standards body (NSB).
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How can it be demonstrated?

The NMI should be established by a legislative instrument, such as a Metrology Act or a similar law. The legislative instrument must define, at a minimum, the NMI's governance, financial provisions, responsibilities, and functions, as well as the establishment and maintenance of national measurement standards. The NMI's responsibilities should include representing the country in regional and international metrology forums.

To ensure that the responsibilities and functions of the NMI remain relevant in a changing international and regional metrology environment, the legislative instrument should be reviewed and modernized at regular intervals, typically five to eight years. Failure to do so could hinder the NMI in achieving its mandate at the national, regional, or international level in the medium to long term.

Existing information/reporting/monitoring

- Metrology Act, decree, regulation, or similar law
- NMI's website and annual reports

4.2.4 Autonomy (building block no. 3)

What is meant

Major	It is good practice for an NMI to move toward a market-economy model of increased institutional autonomy, as opposed to being fully controlled by the government. This gives it the management responsibility and freedom to operate effectively in the marketplace (Racine 2011).
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How can it be demonstrated?

There are generally nine elements that can be considered to determine a legal autonomy index of the NMI. This is not an absolute number but a good indicator. Does the NMI have the autonomy and the authority to

- Decide which measurement standards are considered to be the national standards;
- Officially designate other institutions to be custodians of national measurement standards;
- Determine the positions and staffing of its workforce;
- Determine the salaries of its workforce;
- Select its workforce;
- Determine its own budget and income;
- Create new administrative divisions;
- Offer new services or initiate new activities; and
- Solicit membership in international or regional metrology organizations and sign international agreements?

Existing information/reporting/monitoring

- Metrology Act, decree, regulation, or similar law
- NMI council or board policy papers
- NMI's website and annual reports
- Government regulations regarding rules of employment (if the NMI is a governmental or public body)

4.2.5 Legal standing of national measurement standards (building block no. 4)

What is meant

Fundamental	National measurement standards (for example, for physical equipment and methods in the case of metrology in chemistry) are the basis of all metrology activities in the country, be they market-related or required by legislation or regulation. Therefore, it is good practice to provide them with authoritative standing within the country's legal system.
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How can it be demonstrated?

National measurement standards should be given standing in principle within the country's legal system in terms of a Metrology Act or a similar law. Thereafter, once a specific national measurement standard is established and its metrological quantities defined, its existence should be made known publicly through a government gazette or similar publication in a way that uniquely identifies the specific instrument. Legally, the national measurement standards should be designated the highest-accuracy instruments of the country's legal metrology system and the links to the international system of measurements.

Existing information/reporting/monitoring

- Metrology Act, decree, regulation, or a similar law
- Formal agreement between the NMI and the government
- Official government journal or gazette or similar publication

4.2.6 Governance (building block no. 5)

What is meant

Fundamental	The NMI should have a board or council in charge of strategy approval and overall fiduciary responsibilities, whether the board or council is appointed by a relevant minister, general meeting, or shareholders.
Major	Good governance models suggest that the members of the board or council should be individuals with specific knowledge regarding metrology and market realities.

How can it be demonstrated?

The actual composition of the council or board must be considered. The number of members, as well as the balance between private sector members, public servants, and even academia, is important. The more-progressive NMIs have more private sector representatives than public servants on their councils or boards. Council or board members should be appointed in their individual capacities and not as representatives of business or industry associations or specific public institutions.

The members of a council or board, however appointed, should be selected for their knowledge, experience, or qualifications relating to the NMI's functions, particularly including local and international metrology and technical infrastructure matters, as well as business management and finance. The council or board should include 12–15 members. Depending on the custom and practice of the country, good governance principles suggest that the CEO of the NMI should be a full member of the council or board. Whatever the case, the CEO should only be an ordinary member of the council or board (that is, not allowed to hold the position of chair or vice-chair) to ensure proper oversight of the NMI by the council or board.

The council or board should have the mandate or authority to (a) approve the business strategies of the NMI, (b) appoint the CEO and consider his or her performance, (c) oversee the financial integrity of the NMI, (d) approve the budget and monitor performance of the NMI against the budget, and (e) approve the NMI's organizational structure.

Existing information/reporting/monitoring

- Metrology Act, decree, regulation, or similar law
- NMI council or board policy papers
- NMI's website and annual reports
- Government regulations regarding public entities
- NMI council or board committee structures

4.2.7 Financial sustainability (building block no. 6)

What is meant

Fundamental	The finances for the NMI can be provided from government sources, from financial support from industry and other stakeholders, and from income generated by metrological services. Whatever the source of funding, there should be assurances that it would be adequate also in the medium to long term.
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How can it be demonstrated?

Most NMIs are largely dependent on government funding because they provide a service for the public good for which a specific paying customer cannot be identified. This funding would broadly include the budget for new laboratories

or the upgrading of older ones and the budget to maintain the laboratory's capacity and recognition costs (for example, memberships, active participation in regional and international activities, intercomparisons, training, environmental controls, and so on).

The NMI will also gain some income for metrological services, such as calibrations, provision of reference materials, consultancy to calibration laboratories, training of metrologists, running proficiency testing schemes, and the like. The NMI's finances should not become totally dependent on services rendered because this may lead to an undue focus on income-generating activities with a concomitant neglect of its fundamental responsibilities, or it may lead to unfair competition with private sector calibration laboratories.

The NMI's overall financial situation of the past three to five years would be a good indication of its financial sustainability. The situation regarding both government funding and income from services rendered should show a positive trend over the years under review. The demand for the NMI's primary metrological services would be a further indicator that should show a positive trend. A formal government commitment to support the NMI in carrying out its responsibilities regarding the establishment and maintenance of national measurement standards, as well as specific financial support for its international and regional liaison activities, are positive indicators of the NMI's financial sustainability.

Existing information/reporting/monitoring

- National quality policy
- Annual government budget allocations
- Annual reports of the NMI
- Monthly and annual financial statements of the NMI

4.3 PILLAR 2: ADMINISTRATION AND INFRASTRUCTURE

4.3.1 Benchmark and significance

Form follows function, and the NMI's organizational structure should be conducive to providing the full complement of metrology services effectively and efficiently according to the needs of its stakeholders. Good governance principles require the NMI to have a proper management executive, and the subject fields of metrology indicate that the NMI should have divisions dedicated to the development and maintenance of national standards in these fields, as well as the wherewithal to serve the calibration environment in the public and private sector and society, ably supported by the necessary corporate services, such as finance, human resources, training, and facility services.

Much more so than for standardization and accreditation, facilities are a vital factor in the success or otherwise of metrology. Without laboratory space and environmental controls appropriate for the specific metrology fields and the accuracy levels the NMI is engaged in, calibration and measurement capabilities (CMCs) cannot be established and metrology services to the country are compromised.

4.3.2 Chief executive officer (building block no. 7)

What is meant

Major	The chief executive officer (here referred to as the CEO, whatever the actual title) is responsible for leading the development and execution of the NMI's long-term strategy with a view to fulfilling its reason for existence. The CEO acts as a direct liaison between the board or council and management of the NMI and communicates to the board or council on behalf of NMI management. The CEO—rather than the chair of the board or council—is the public face of the NMI.
Minor	Depending on the legislation, custom, and practice relevant to the NMI, the CEO may be appointed by the relevant minister or the board or council. Recent tendencies suggest that the CEO should be appointed for a limited period only, typically five years. He or she can be reappointed if relevant key performance indicators are more than fulfilled.

How can it be demonstrated?

There is no standardized list of the major functions and responsibilities carried out by an NMI's CEO, but the following list includes the typical functions:

- Supports operations and administration of the board or council by advising and informing its members, interfacing between board or council and NMI staff, and supporting the board or council's evaluation of management executives
- Oversees the design, marketing, promotion, delivery, and quality of metrology-related programs, products, and services
- Recommends the annual budget for board or council approval and prudently manages the NMI's resources within those budget guidelines according to current laws and regulations
- Effectively manages the human resources of the NMI according to authorized personnel policies and procedures that fully conform with current laws and regulations
- Ensures that the NMI and its mission, programs, products, and services are consistently presented using strong, positive images to relevant stakeholders
- Oversees fundraising planning and implementation, including identifying resource requirements, researching funding sources, and establishing strategies to approach funders
- Represents the NMI regionally and internationally
- Identifies and proposes the development of new areas in the NMI

Existing information/reporting/monitoring

- Relevant legislation (Metrology Act or similar law)
- Official ministerial decisions
- Board or council decisions and minutes
- Official CEO job description
- Agreed-upon CEO key performance indicators

4.3.3 Organizational structure (building block no. 8)

What is meant

Major	Metrology consists of a number of major subject fields in two major groups: physical metrology, and chemical and biological metrology. It therefore follows that an NMI's organizational structure should have divisions that optimally support these groups and their subject fields.
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How can it be demonstrated?

Physical metrology has long dominated the metrology world. The physical metrology subject fields are therefore fairly well developed, and the best accuracy levels are extremely high—that is, at the forefront of technology. Typical subject fields include (a) mass and related quantities; (b) electricity and magnetism; (c) length; (d) time and frequency; (e) thermometry; (f) photometry and radiometry; (g) flow; and (h) acoustics, ultrasound, and vibration (see module 4 of the QI Toolkit).

Metrology in chemistry and biology has risen to prominence over the past two decades as international travel has become commonplace, as has the cross-border transporting of livestock and agricultural products. Just as important are issues like new industrial development (for example, biotechnology, nanomaterials, and so on), as well as those that impinge on quality of life (for example, health care, the environment, food quality, and so on). In all of these matters, chemical and biological measurements play a vital role. The chemical and biological subject fields are still developing, but the following can already be identified: (a) certified reference materials, (b) reference measurement methods, (c) organic chemistry, (d) inorganic chemistry, (e) cell and nucleic analysis, (f) microbial analysis, (g) protein analysis, and (h) electrochemical analysis. These fields will develop further as chemical and biological metrology matures.

Each of the metrology fields is technology-intensive. The NMI's organizational structure should take cognizance of these realities and should support the technologies in question. Other areas or issues to consider in the organizational structure include the following:

- Service delivery regarding calibration, intercomparisons, metrology advice, and certified reference materials
- Support functions, such as human resources and finance
- The NMI's training and development responsibility for the common good relating to the country's metrology infrastructure, such as calibration and high-technology research laboratories
- The major importance of a technical division that can ensure the maintenance of environmental controls and measurement equipment
- The increasing importance of a technical division as the NMI moves from the *advanced* to the *mature* level (see table 4.1) for the development of new high-technology, high-accuracy measuring equipment.

Existing information/reporting/monitoring

- Approved organizational structure
- Board or council decisions
- Ministerial decisions
- Financial system documentation

4.3.4 Management and personnel (building block no. 9)

What is meant

Major	The science of measurement is a people-based activity operating within a high-level technical environment. The management and personnel must therefore have the appropriate skill sets assured by appropriate training, qualifications, and experience. These would include management and technical knowledge as required by the various activities within the metrology fields.
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How can it be demonstrated?

In the first place, the NMI should operate with an organizational structure approved by either the board or council or the relevant minister. For each of the positions, the skill set (qualifications, training, and experience) should be clearly and formally stated. The ratio between technical and administrative staff is a good indicator of efficacy, with a good guideline being that administrative staff make up no more than 20 percent of the total.

Second, there should be few staff vacancies on either the management or technical levels; more than 95 percent of those positions should remain filled. Anything less indicates that the NMI cannot operate effectively or efficiently. Staffing challenges often include a lack of skilled people in the country, but even more so, inadequate remuneration resulting in the departure of trained staff for more lucrative offers elsewhere.

Existing information/reporting/monitoring

- Approved organizational structure
- Actual staffing levels
- Staff turnover figures

4.3.5 Premises (building block no. 10)

What is meant

Fundamental	Metrology is a highly technical endeavor. Each of the metrology fields has specific requirements regarding the laboratory space it needs to operate with the required accuracy.
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How can it be demonstrated?

Each of the metrology fields has specific requirements regarding the laboratory space within which it can operate with the required accuracy. These requirements include environmental controls, such as temperature and humidity, lighting levels, and many more. Freedom from vibrations may indicate premises far removed from heavy traffic lanes, train lines, or airport flight paths. Requirements may also include controlled access to the laboratories.

The requirements also depend on the level of measurement accuracy needed—requirements are far too numerous and technology-specific to list here. The requirements must be obtained from experts in each of the metrology fields and in accordance with the accuracy requirements demanded by the country.

Some equipment submitted for calibration is large and heavy, such as weights for calibrating weighbridges, and ease of access for such equipment must be considered. Appropriate office space for staff outside of the laboratories also needs to be provided, as well as meeting rooms for individual customer discussions and meetings of metrology technical committees.

Existing information/reporting/monitoring

- Consideration of the NMI premises in relation to design, environmental controls, access, and maintenance
- Review of laboratories and environmental controls
- Review of office space and meeting rooms
- Technical requirements as advised by experts in specific metrology fields

4.3.6 Equipment (building block no. 11)**What is meant**

Fundamental	The NMI is the custodian of the national measuring standard, in principle the one with the highest accuracy level in the country and traceable to the International System of Units (SI). The type of equipment and its accuracy class are fundamental aspects that need to be aligned with the country's demonstrable needs.
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How can it be demonstrated?

The national measurement standard for a specific metrology entity should in theory be the one with the highest accuracy in the country, and its accuracy class should be related to the demands of the users with the highest level of technology. It is therefore important that the NMI understand and know the demands of the stakeholders (see table 4.1). With this knowledge, the type and accuracy class of equipment to serve as the national measurement standard can be obtained.

The national measurement standard could be established from the definition of the measurement unit, in which case intercomparisons with similar measurement standards of other NMIs would be indicated to ensure the standard's degree of conformance to the SI definition. This is a technologically advanced and costly option. For many economies, the purchase of a high-level measurement standard, traceably calibrated to a primary standard of an advanced NMI, would be fine.

Thereafter, the NMI will also require a variety of reference standards that can be used to calibrate given measuring equipment at high accuracy levels. The reference standards should be traceably calibrated to the national measurement standards. For each type of measuring equipment, appropriate maintenance measures need to be in place.

The maturity level of the NMI (see table 4.1) will have a marked influence on the type and accuracy class of the measuring equipment used. The spectrum is extreme and is not listed here; expert knowledge for each metrology field will need to be obtained to provide a meaningful evaluation. Such an evaluation is important owing to the high cost of equipment.

Existing information/reporting/monitoring

- Consideration of the NMI's metrology fields of activity
- Demonstrable metrology needs of the country
- Review of national measurement standards
- Review of working reference measurement standards
- Review of maintenance measures for all measuring equipment
- Calibration certificates of national measurement standards (if applicable)

4.3.7 Quality system documentation (building block no. 12)

What is meant

Major	In presenting its CMCs or applying for accreditation, the NMI must demonstrate its compliance with an approved quality system. The quality system must be formalized in quality system documentation.
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How can it be demonstrated?

In establishing its calibration and measurement capabilities (CMCs), the NMI will have to ensure that its workflow is optimized. Good practice suggests that this workflow be formalized in quality system documentation. If the NMI is still at the *basic* maturity level (see table 4.1)—that is, just starting—then this is important, because its recognition will hinge on being accredited to ISO/IEC 17025 (“General Requirements for the Competence of Testing and Calibration Laboratories”) rather than being accepted internationally through declaring its CMCs.

Accreditation to ISO/IEC 17025 presupposes a quality management system, the implementation of which is facilitated by complete quality system documentation. Even for *mature* NMIs, formalizing their workflow in proper quality system documentation is essential to have their CMCs recognized (see table 4.1). The NMI’s credentials as a technically competent organization have to be earned, and it is a long journey before the International Bureau of Weights and Measures (BIPM) will accept the NMI’s declared CMCs.

Existing information/reporting/monitoring

- Consideration of the NMI’s formal quality system and its compliance with known international standards, such as ISO/IEC 17025
- Accreditation certificate or CMCs in the Key Comparison Database (KCDB) of the International Committee for Weights and Measures (CIPM) Mutual Recognition Arrangement (MRA), which is maintained by the BIPM

4.4 PILLAR 3: SERVICE DELIVERY AND TECHNICAL COMPETENCY

4.4.1 Benchmark and significance

ISO/IEC 17025 is generally used for the evaluation of calibration laboratories for accreditation. Although the standard was not specifically developed for NMIs, the journey for a newly established NMI to be internationally recognized seldom bypasses accreditation to ISO/IEC 17025 as a first step (see table 4.1). Once the NMI has reached the *advanced* maturity level, accreditation could be replaced by admission to the International Committee for Weights and Measures (CIPM) Mutual Recognition Arrangement (CIPM MRA) combined with the declared and approved CMCs.

The CIPM MRA is the framework through which NMIs demonstrate the international equivalence of their measurement standards and the calibration and measurement certificates they issue. The outcomes of the CIPM MRA are the internationally recognized (peer-reviewed and approved) CMCs of the participating institutes. Approved CMCs and supporting technical data are publicly available from the CIPM MRA database, the KCDB.

4.4.2 Metrologists (building block no. 13)

What is meant

Fundamental	Metrology is a highly technical endeavor. The people practicing metrology have to be highly trained and experienced to do justice to the technological level required. The more advanced the NMI, the more highly trained and skilled the practitioners need to be.
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How can it be demonstrated?

Metrologists come from various disciplines, including physics, engineering, chemistry, biology, and many more. Over and above the basic education at a university or technical college, important elements in developing metrologists include further training and gaining experience in advanced NMIs of high-income countries. Ultimately, once the NMI moves into the *advanced* maturity level (table 4.1), research activities will foster even greater expertise, and the expertise of relevant metrologists will be acknowledged by their peers.

For a newly established NMI, employing metrologists who take more of a practical approach than a theoretical one may be an effective way to start. The same applies to the personnel responsible for the maintenance of measuring equipment or environmental controls. Ultimately, proficiency in engineering design (mechanical, electronic, electrical, or chemical) may be required to design and manufacture measuring equipment at the highest technological level. Most measuring equipment relies heavily on electronics; hence, electronic specialists and technicians are important members of the NMI.

Existing information/reporting/monitoring

- Approved organizational structure
- Formal job descriptions
- Personnel records regarding education, training, and experience
- Annual training plans and concomitant records

4.4.3 Interlaboratory and key comparisons (building block no. 14)

What is meant

Fundamental	Interlaboratory or key comparisons provide information regarding the NMI's ability to deliver accurate measurement results. They are important for accreditation and are the foundation of establishing the CMCs.
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How can it be demonstrated?

Participation in interlaboratory comparisons provides independent verification of an NMI's measurement capability and shows a commitment to maintenance and improvement of performance. For an NMI at the *basic* maturity level (see table 4.1), such participation is a prerequisite for accreditation. At this level, the interlaboratory comparisons can still be a low-key affair, overseen by an *advanced* or *mature* NMI acting as lead laboratory and involving a smaller number of NMIs.

Once the establishment of CMCs is being contemplated, interlaboratory comparisons move to a higher level, as defined by the BIPM, and are known as key comparisons. The BIPM key comparisons are of two types (see section 4.11.1 in module 4 of the QI Toolkit):

- *CIPM key comparisons*, of international scope, are carried out by those participants having the highest skills in the measurement involved and are

restricted to laboratories of BIPM member states. The CIPM key comparisons deliver the “reference value” for the chosen key quantity.

- *Regional metrology organization (RMO) key comparisons*, of regional scope, are organized at the scale of a region (though they may include additional participants from other regions) and are open to laboratories of BIPM member states, as well as BIPM associates. These key comparisons deliver complementary information without changing the reference value.

The key comparisons underpin the development of the CMCs, which are stated in terms of a measured unit and its uncertainty and may include advice about the instrumentation used.

Existing information/reporting/monitoring

- Key Comparison Database (KCDB) of the CIPM MRA maintained by the BIPM
- Interlaboratory comparison reports of the NMI
- Results of key comparisons of RMOs
- Results of key comparisons of the BIPM and Consultative Committees of the CIPM

4.4.4 Calibration and measurement capability (CMC) (building block no. 15)

What is meant

Fundamental	International recognition of the NMI can be achieved through the CIPM MRA, which is underpinned by the listing of the CMCs in the KCDB maintained by the BIPM for General Conference on Weights and Measures (CGPM) members and associate members.
Major	Alternatively, the NMI can achieve a measure of international recognition through accreditation to ISO/IEC 17025 should listing of its CMCs not yet be feasible.

How can it be demonstrated?

The outcomes of the CIPM MRA are the internationally recognized (peer-reviewed and approved) CMCs of the participating NMIs. Approved CMCs are publicly available in the CIPM MRA database, the KCDB. The fundamental elements that lead to the approval of an NMI’s CMCs include the following:

- Country status as a signatory of the Metre Convention or as an associate member and economy of the CGPM
- Participation by the NMI in reviewed and approved scientific comparisons
- Operation by the NMI of an appropriate and approved quality management system
- International peer review (regional and interregional) of claimed calibration and measurement capabilities

The last three elements are normally organized through a BIPM-recognized RMO. For an NMI that cannot yet participate in the establishment of CMCs, accreditation to ISO/IEC 17025 could be a way to gain a measure of international recognition in the meantime. The accreditation organization, however, needs to be an internationally recognized one.

Existing information/reporting/monitoring

- Key Comparison Database (KCDB) of the CIPM MRA maintained by the BIPM
- Accreditation records of the relevant accreditation body

4.4.5 Calibration service (building block no. 16)**What is meant**

Major	The metrological values of the national measurement standards need to be diffused to industry, society, and authorities. This is achieved through the traceability chain of calibration, starting with the NMI.
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How can it be demonstrated?

A traceability chain is an unbroken chain of comparisons to make it certain that a measurement result is related to references at a higher level, ending in the final level of the national measurement standard. The basic tool in ensuring this traceability is measuring standard calibration, from the national measurement standard through reference standards to industrial standards and their measurements.

In a low- or middle-income economy, with the NMI still at the *basic* maturity level (see table 4.1), the NMI provides such a calibration service to industry. As the economy develops and the NMI with it, this function should be taken up by calibration laboratories, in both the public and private sectors, whose reference and working standards are traceably calibrated to the national measurement standard by the NMI; that is, the NMI calibrates the working standards. In fact, the NMI should promote and support the creation of such secondary metrology laboratories, which is a challenge if the NMI's income is too dependent on calibration services.

Ultimately, the NMI is the pinnacle of a whole system of metrology and calibration laboratories providing the relevant calibration services to industry, authorities, and society. The accreditation of such service providers to ISO/IEC 17025 is an important element in preserving the confidence in the national metrology system.

Existing information/reporting/monitoring

- Network of calibration laboratories
- Calibration laboratory associations
- Accreditation records of calibration laboratories
- Records of the accreditation organization regarding calibration laboratories
- Collaboration between the NMI, calibration laboratories, and technical working groups

4.5 PILLAR 4: EXTERNAL RELATIONS AND RECOGNITION**4.5.1 Benchmark and significance**

International recognition of the country's CMCs and their listing in the KCDB maintained by the BIPM are of paramount importance for the country's metrology system. Such recognition has to be obtained through RMOs. The NMI's liaison with RMOs is therefore an important fundamental necessity; liaison with international organizations can follow thereafter. The recognition based on

CMCs, however, is only possible for signatories to the Metre Convention or for associate members and economies of the CGPM under the Metre Convention. Otherwise, accreditation is currently the only way to achieve a measure of international recognition.

4.5.2 Training system (building block no. 17)

What is meant

Major	Trained and skilled metrologists are a vital component of an effective and efficient national metrology system. Training mechanisms provided by the NMI to develop such metrologists are important.
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How can it be demonstrated?

In parallel with the high demands on the technical side, high demands are placed on appropriately educated, trained, and experienced metrologists and technical staff. The NMI must therefore provide for the training of its own staff, a requirement that increases with the development of a whole calibration laboratory network. Initial training programs can be initiated by technical cooperation programs but eventually must be provided by the NMI in collaboration with tertiary technical education institutions.

Issues that should be considered in training programs include the following:

- Higher-level training of specialist metrologists at NMIs that have higher-level metrology in place
- New developments and new metrology sectors the NMI is getting involved in
- Training programs for metrologists of secondary laboratories

Existing information/reporting/monitoring

- Training programs
- Training records

4.5.3 Liaison with regional organizations (building block no. 18)

What is meant

Fundamental	International recognition of the technical capability of an NMI, and hence of a country, is gained through RMOs recognized by the BIPM or through accreditation. Active membership of the NMI in the relevant RMO is therefore an imperative.
Major	If the country is a member of a regional construct, then the NMI will be required to participate actively in regional metrology activities if these are part of the regional agreements. This means also participating in technical committees at the regional level.
Major	Membership in an RMO affords NMI staff the opportunity to learn from other member NMIs and through participation in working groups of the RMO.

How can it be demonstrated?

International recognition of an NMI, and hence of the country, is based on the declaration of its CMCs and their inclusion in the KCDB kept by the BIPM. The regional key comparisons on which the determinations of CMCs are based are arranged through RMOs recognized by the BIPM, and RMOs also carry out other actions to enhance the mutual confidence and validity of calibration and measurement certificates issued by participating NMIs. (*Note: For NMIs of countries that are not yet signatories to the Metre Convention or associate*

members and economies of the CGPM under the Metre Convention, this route is not possible, but they may gain a measure of recognition through accreditation.)

It is therefore of paramount importance that the NMI be an active member of the relevant RMO when contemplating membership in international metrology organizations (see building block no. 19). Unfortunately, not all countries are covered yet by recognized RMOs, and NMIs in such countries find it difficult to gain international recognition. In such cases, the country should make every endeavor to have an RMO established and recognized by the BIPM in its region.

At the time of writing (January 2019), six RMOs are recognized within the framework of the CIPM MRA:¹

- Intra-Africa Metrology System (AFRIMETS)
- Asia Pacific Metrology Programme (APMP)
- Euro-Asian Cooperation of National Metrological Institutions (COOMET)
- European Association of Metrology Institutes (EURAMET)
- Gulf Association for Metrology (GULFMET)
- Inter-American Metrology System (SIM)

Existing information/reporting/monitoring

- Membership of the NMI in the recognized RMOs
- Reports of the NMI's participation in RMO activities
- Regional trade agreement membership status of the country
- Relevant regional treaties, protocols, agreements, or legislation
- Annual reports of the NMI
- NMI internal reports of RMO meetings attended

4.5.4 Liaison with international organizations (building block no. 19)

What is meant

Major	The two relevant international metrology organizations would be the BIPM and the International Organization of Legal Metrology (OIML). Hence, once the NMI moves from a basic to an advanced level (see table 4.1), the NMI should pursue membership in both organizations if its responsibilities include legal metrology.
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How can it be demonstrated?

The BIPM is the international intergovernmental organization set up by the Metre Convention through which member states act together on matters related to measurement science and measurement standards. Membership can be at two levels, depending on whether the country has signed the Metre Convention (established in 1875), under which the current International System of Units (SI) was established in 1960. If the country is a signatory, then the country is a member (and the NMI can represent it); if not, then the country can become an associate member.

As a signatory, the country participates actively in the various committees under the Metre Convention, starting with the CGPM, which is the highest policy-making organ under the Metre Convention, meeting every four years. The CIPM consists of 18 representatives from the CGPM, and it oversees the BIPM, provides for the chairs of technical committees, and is responsible for cooperation with other international QI organizations. A number of consultative committees accountable to the CIPM have been established, dealing with

specific metrology issues. Participation in the CGPM should be a given for the country (there is also an annual NMI directors' meeting); however, only specific individuals are invited to the CIPM. And active participation in the consultative committees will depend on the metrology policy or strategy of the country.

As an associate member and economy, an NMI can participate in the CIPM MRA. This allows the country to register its CMCs on the KCDB managed by the BIPM, thereby achieving international recognition for its metrology capabilities.

The OIML is discussed in section 11: Legal Metrology.

Existing information/reporting/monitoring

- Metrology strategy and its implementation plans
- BIPM membership data
- BIPM technical committee data
- Annual reports of the NMI
- Business plans and minutes of the NMI technical and mirror committees
- Formal communication records of the NMI with the BIPM and OIML

4.5.5 Coordination within the QI (building block no. 20)

What is meant

Major	Coordination among the fundamental QI organizations (the NSB, NMI, and national accreditation body [NAB]) is important to ensure that their responsibilities and activities provide a unified basis for the calibration and conformity assessment service providers and the market surveillance activities of regulatory authorities. The same applies to the legal metrology organizations.
Minor	NMI staff should participate actively in NSB, NAB, and legal metrology technical committees and ensure there is an exchange of information and liaison between the NMI, NAB, and legal metrology regarding the metrology needs of accredited entities.

How can it be demonstrated?

Coordination within the QI is important, especially among the NSB, the NMI, and the NAB, as the three pinnacle QI organizations. The coordination—to ensure that there are no overlaps or gaps in their service delivery or activities—can be realized formally or informally. If the NSB, NMI, and NAB are governmental organizations, then their line ministries are in a good position to ensure such coordination, especially to ensure that the three are implementing the quality policy measures. Otherwise, a quality council or similar construct would be able to do the same. A third alternative is for the CEOs to have a formal coordination meeting at regular intervals. A technical regulation coordination office (whatever its name) coordinates the activities of the regulatory authorities with the QI regarding the development and implementation of technical regulations, ensuring that costly overlaps and gaps in service delivery are kept to a minimum.

NMI staff should participate in standardization technical committees, act as technical evaluators for the accreditation body, and participate in the technical committee dealing with metrology questions of the accreditation body. Furthermore, an exchange should be fostered between metrologists and the accreditation body regarding the traceability and intercomparison needs that are identified through the existing accredited calibration, clinical, and testing laboratories.

Existing information/reporting/monitoring

- Line ministry policies, pronouncements, and documentation
- Quality council (or similar body) documentation and minutes of meetings
- Technical regulation coordination office mandate and pronouncements
- NSB and NAB technical committee membership
- NAB assessment team membership
- Liaison meeting reports and minutes

4.5.6 Designated institutes (DIs) (building block no. 21)**What is meant**

Major	It is not always only the NMI that establishes and maintains national measurement standards in the country. Designated institutes (DIs) might also be involved. This is often the case for technologies that are not covered by the NMI, such as nuclear technology, metrology in chemistry, and so on. The NMI recognizes such entities and ensures that they comply with the relevant requirements.
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How can it be demonstrated?

In many countries, the NMI shares its responsibilities with one or more designated institutes (DIs), which, like the NMI, operate at the top of the national metrology system. DIs play a crucial role in complementing the NMI's fields of activity at the national reference level and bring expertise in metrological areas not covered by the NMI, thus using the available national resources efficiently. Typical areas would be nuclear technology-related metrology, metrology in chemistry, and the like.

Institutes should only be designated if they have appropriate metrological experience and scientific expertise *and* meet all of the following conditions:

- Hold (or will hold) and maintain national measurement standards
- Will deliver metrological traceability through the provision of calibration services or reference materials in a well-defined metrology area and on an equal basis to all customers
- Will act similarly to the NMI within a limited and well-defined area of metrology, as well as understand and accept the obligations of participation in the CIPM MRA
- Will be appropriately resourced and sufficiently stable for their role within the national measurement system and as DIs within the CIPM MRA

The designation must be done by the authorized body of the state, that is (a) the responsible ministry or authority within the government, or (b) the NMI, if authorized to do so by its government.

Performance of the DI with respect to the CIPM MRA should be monitored by the NMI.

Existing information/reporting/monitoring

- NMI legislation
- Formal procedures for designating institutes
- Official designation documentation of DIs
- BIPM records of the NMIs and DIs
- Work programs of the NMI and DIs
- Annual reports of the NMI

4.5.7 Stakeholder engagement (building block no. 22)

What is meant

Fundamental | Stakeholders play an important role in determining choices regarding the establishment of national measurement standards and their accuracy levels. The NMI must identify its stakeholders, communicate clearly with them, and gain their support and participation in the development and implementation of national metrology standards, as well as the resulting national metrology system that diffuses these standards into industry, authorities, and society through calibration chains.

How can it be demonstrated?

The NMI should map its stakeholder environment, including sectors such as

- *Governance*, such as QI organization boards or councils, regulatory authorities, the NMI line ministry and other ministries, and so on;
- *Beneficiaries*, such as industry, laboratories, business, society, consumers, academia, and so on; and
- *Influencers*, such as business associations, media, nongovernmental organizations (NGOs), trade unions, and so on.

Thereafter, the NMI should follow a deliberate and continuous approach to stakeholder engagement that is properly planned, conveys a clear message, and asks stakeholders their opinions and then acts upon them. This approach would be in the form of a formal communication plan or a similar strategy.

The governance of the NMI is vested in its board or council, but these should be individuals with specific strengths rather than a collection of representatives from stakeholder groups (see building block no. 5). Hence, it is useful for the NMI to establish a metrology forum or a similar meeting in which all stakeholders can participate freely and whereby the NMI can gain an understanding of the needs of its broader stakeholder groups. In addition, it is important for senior NMI management to commit energy and time to building high-level relationships that engender trust and to seeking out networking opportunities and even joint research projects with industry and academia.

Existing information/reporting/monitoring

- Metrology strategy and its implementation
- Communication strategy or plan and its implementation
- Minutes of a metrology forum or similar open stakeholder meeting
- Key performance indicators of senior management
- Stakeholder mapping results

NOTE

1. The list of the recognized RMOs can be found on the BIPM website: <https://www.bipm.org/en/worldwide-metrology/regional/>.

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