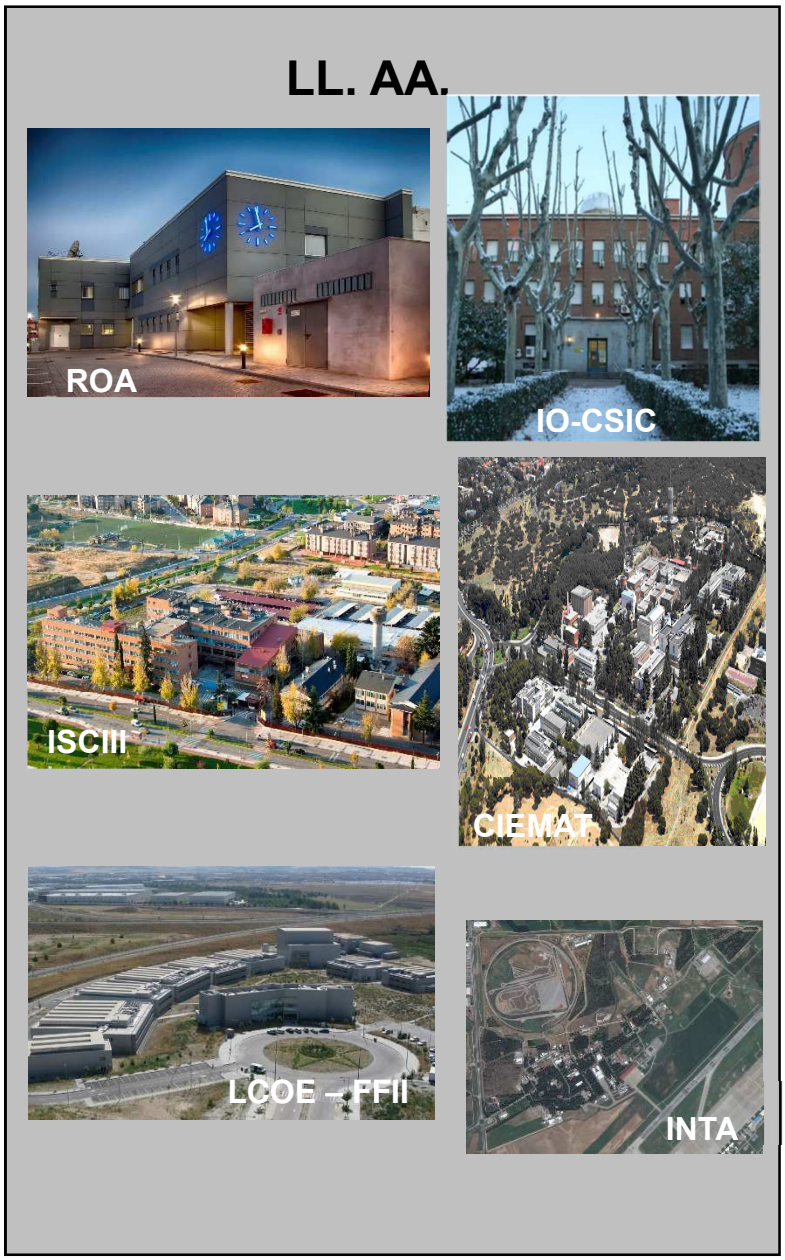
2018

Service Offer on Traceability to SI and support to R&D: CEM & LL.AA.



Comisión de Laboratorios Asociados

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Service Offer on Traceability to SI and support to R&D

NETWORK: Centro Español de Metrología (CEM) & Laboratorios Asociados (LL.AA.)

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Good measurement improves productivity and quality; it underpins consumer confidence and trade, and is vital to Industrial Competitiveness.

" Science starts when measurement begins. Exact science is not possible without measurement." (Mendeleyev)

1.- Introduction

In everyday life, we all depend on reliable measurements which underpin trade, regulation, sustainable manufacture and societal well-being e.g. clean environment, secure energy supply and improved health of citizens. With rapidly advancing science and technologies, the demand for new measurement techniques and measurements of unprecedented accuracy and reliability continues to grow to meet these requirements. As a consequence, there is a clear need for metrology R&D and a network of high level laboratories that can support all this research work. Metrology, the science of measurement, plays a rather hidden role in innovation. It is an indispensable building block in our industrialized and increasingly globalized society. Metrology boosts innovation through exploiting the link between measurement science and technological advance. Advanced measurement capabilities are essential to innovation in every major economic area and at every stage—from discovery to commercialization. Consequently, developing and improving the available measurement capabilities of a country is essential for strengthening and supporting technological innovation and industrial development processes. Metrology is the central nerve in the spine of our high-tech world.

The availability of measuring equipment and the ability to use it effectively are essential if scientists are to be able to objectively document the results they achieve. Reliable and traceable measurement allows the wider scientific community to build better instruments and do better science.

In Spain, Centro Español de Metrologia (CEM) and Associated Laboratories (LL.AA.) constitute a suitable network that provides facilities and knowledge to promote and facilitate collaborative research and development in order to be an effective vehicle for addressing needs for new measurement technologies, many of which will have broad utility. It makes available the measurement capabilities and tools required by science and industry to accelerate innovation.

Excellent science applied in CEM & LL.AA., including frontier research and development, is essential to maintain the leadership of the national metrology infrastructure. This challenge is looking for by building critical mass and rebalancing core science capabilities, maintaining breadth through partnership, attracting star researchers and providing an attractive environment for world-class scientists in the facilities of this network. CEM & LL.AA. provide the core to this challenge, allowing the government to invest in facilities, capability, skills and maintenance that can be used by internal and external researchers.

CEM & LL.AA. is a metrology network made of 7 public and private national institutions that are responsible for developing and maintaining the national measurement standards for one or more quantities and, for that reason, their research activities are performed at the state of the art having some singular facilities. This network is an answer to the new challenges for metrology that aims at a higher level of integration and coordination of science research.

CEM & LL.AA.is a network opened to all players (academia, research institutions and industry, national and abroad) promoting the internationalization of metrology as well as encouraging the search of solutions for addressing the main great global challenge in a multidisciplinary approach. These singular infrastructures support both the public and the private sector to ensure that Spain has the measurement capabilities and tools required by science and industry to accelerate innovation.

The network is a distributed research infrastructure organized inside the Associated Laboratories Commission of the National Metrology Council. It coordinates, develops and optimises research metrology infrastructure owned by the member institutions. The members are:

- Centro Español de Metrología (CEM). Ministerio de Industria Comercio y Turismo
- Instituto Nacional de Técnica Aeroespacial (INTA). Ministerio de Defensa
- Instituto de Óptica "Daza de Valdés" (IO-CSIC). Agencia Estatal Consejo Superior de Investigaciones Científicas (CSIC). Ministerio de Ciencia, Innovación y Universidades.
- Laboratorio de metrología de Radiaciones Ionizantes (LMRI) del Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT). Ministerio de Ciencia, Innovación y Universidades.
- Real Instituto y Observatorio de la Armada (ROA). Ministerio de Defensa
- Instituto de Salud Carlos III. Ministerio de Economía, Industria y Competitividad
- Laboratorio Central Oficial de Electrotecnia (LCOE). Fundación para el Fomento de la Innovación Industrial (FFII)

2.- Objectives

The main goal of this Metrology Network is to open its singular research facilities to the scientific community in a transparent and competitive way that facilitates to facing key societal challenges, such as sustainability of energy, environment and health with new and reliable measurement technologies, promoting, and accelerating technological innovation through metrology. Such facilities which cover a wide spectrum of quantities, equipment and services are thus essential to meet current and future research requirements of scientists, industry, regulators and policy makers alike.

CEM & LL.AA. provide more than 20 000 m^2 of specialized laboratories including facilities of mechanical, optical, electrical, physic-chemical, kinematic and dynamic, photometry, radiometry, radioactivity, dosimetry and neutron quantities. For the operation of these facilities, CEM & LL.AA. have more than180 experts on metrology, with more of 20% of them PhD.

The portfolio of services, described in detail in this document cover from advice and support in technological developments that require measurements with primary metrological traceability, high accuracy and low uncertainty in the

measurement fields covered by the infrastructure (physics, chemistry, biology, ionizing radiation, etc.) to development of standards, and measurement instrumentation adapted to processes or products and support in metrology for access to European R & D & I programs.

In the following lines the facilities and services of each Laboratory are described.

3.- Introduction of Laboratories

3.1.- Centro Español de Metrología (CEM)

Centro Español de Metrología is an Autonomous Body of the General Administration of the State. It is attached to the Ministry of Industry, Trade and Tourism through the General Secretariat of Industry and Small and Medium Enterprise.

The current centre was created by the article 100 of the Law 31/1990, of 27th December, which established the General Budget for the State for 1991. Its Statute was approved later by the Royal Decree 1342/2007 of 11th October.

According to the Article 149 of the Spanish Constitution, the Centro Español de Metrología is the highest technical organization in the metrology field in Spain and represents the State before the International Organizations in charge of Scientific and Legal Metrology.

Since its creation, and along the years, CEM has been consolidated as a national reference in issues regarding standards and scientific metrology.

CEM is one of the original signatories of the Mutual Recognition Arrangement (CIPM-MRA). Nowadays it offers a wide list of Calibration and Measurement Capabilities internationally recognized, that can be consulted in the BIPM data base (http://kcdb.bipm.org/).

One of the CEM key activities is the realization of R&D&i projects for the development of standards and measurement techniques both in European (EMRP/EMPIR European programs) and national levels.

Located in Tres Cantos, near Madrid, CEM covers 80 000 m^2 where 18 000 m^2 are occupied by buildings among which 10 000 m^2 are dedicated to highly specialised laboratories. Its facilities include:

- a central building for general and administrative services,
- an assembly hall with audiovisual aids and capacity for 200 people,
- a permanent exhibition that gathers a collection of standards and materialised measures that were traditionally used in the Spanish provinces before the application of the Decimal Metric System, as well as ancient instruments and metric standards,
- six two-floor buildings with specialised laboratories designed to satisfy the strict requirements for the environmental conditions needed for the physical and chemical realizations of the national standards and of R&D activities,
- auxiliary facilities.

About 100 people work at CEM; and more than 50 % have a high education degree. Among them, 60 % performs technical activities and 40 % works in administrative issues. This staff is complemented with temporary staff for the implementation of R&D projects and granted staff under training.

Predominant education among technical staff includes:

- Mechanical Engineering
- Physics
- Chemistry
- Telecommunication Engineering

CEM has an Integrated Quality System that covers, apart from the requirements of the standards UNE-EN ISO/IEC 17025 and ISO 34, those established in the standards UNE-EN ISO/IEC 17020, UNE-EN ISO/IEC 17021, UNE-EN ISO 45011 and UNE-EN ISO 14001, having obtained the AENOR certification for its Environmental Management System.

This integrated quality system enables CEM to improve their good professional practices and the quality in their services.

3.2.- Instituto Nacional de Técnica Aeroespacial (INTA)

Instituto Nacional de Técnica Aeroespacial is the Public Research Establishment specialized in the aerospace and aeronautical field. It is a commercially oriented autonomous organization of the Ministry of Defence (according to Law 15/2014 of 14th September, 2014), and was founded in May 1942 by Esteban Terradas.

Since its creation, Metrology has been included in its responsibilities by statute and it has played a key role in support of public and private research and industrial laboratories in many fields, acting, de facto, as a national metrology laboratory, until the creation of the *Centro Español de Metrología*, when it formally joins the National Metrology Infrastructure within the *Consejo Superior de Metrología*, designated by the Government as an Associate Laboratory of CEM in the fields of humidity (Royal Decree 346/2001 of 4th April) and radio frequency (Royal Decrees 250/2004 of 6th February and 1587/2009 of 16th October).

Its human Resources consist of around 1.500 Government employees. Among them, more than 1000 are fully involved in R&D activities. A percentage of approximately 50% are University graduates. There are also around 400 external staff, linked to the Institute via technical assistance, management agreements and contracts with private companies.

INTA´s activities are performed on four technological campus in the Madrid Region (Torrejón de Ardoz, La Marañosa, CEHIPAR and LABINGE); Four main testing centres (León (CUADROS), Lugo (ROZAS), Huelva (ARENOSILLO) and Cádiz (TORREGORDA); one space station in MASPALOMAS, Gran Canaria. INTA also

operates three international space stations in Spain (Robledo de Chavela (NASA) and Cebreros and Villafranca del Castillo (ESA). It also has other special facilities in Guadalajara and the airports of Sevilla and Granada. The facilities for metrology in this network are located in the Campus of Torrejón de Ardoz and La Marañosa.

INTA carries out scientific and technical R&D&i activities, providing technological services in the following fields: Space, Aeronautical, Naval, Terrestrial, Security and Defense.

The departments housing the facilities integrated in the metrology network have implemented a Quality Management System that covers, the requirements of the standards UNE-EN ISO/IEC 17025:2005, both for the primary metrology services as well as the calibration and testing activities that research R&D&i projects.

The Metrology and Calibration Centre, dependant of the General Subdirectorate for Coordination and Planning, is responsible for coordination of all metrology activities within the Institute. It is a consolidated metrology and calibration laboratory whose technical competence has been evaluated by national accreditation bodies. It has remained accredited, without interruption, since the first accreditation in April 1972 by the British Calibration Service (BCS), until the current accreditation by the Spanish Accreditation Body, *Entidad Nacional de Acreditación* (ENAC) under the ILAC Mutual Recognition Agreement (ILAC-MRA). It is part of the CIPM Mutual Recognition Arrangement (CIPM-MRA) as a Designated Institute in the fields of designation.

Currently it offers a broad wide range of Calibration and Measurement Capabilities, that for CIPM-MRA services can be consulted in the BIPM data base (https://kcdb.bipm.org/) and for ILAC-MRA services on the ENAC web page (https://www.enac.es/web/enac/entidades-acreditadas/).

The Centre takes part directly in R&D&i projects within the European (EMRP/EMPIR) and indirectly in European, international and national research projects by providing measurements services that are used to guarantee metrological traceability of the results of research performed by other INTA departments and external research establishments.

3.3 Instituto de Óptica "Daza de Valdés" del CSIC (IO-CSIC)

The Highest Research Council (CSIC) is the largest public institution dedicated to research in Spain and the third in Europe. Under the Ministry of Science, Innovation and Universities, through the State Secretariat for Universities, Research, Development and Innovation, its mission is the promotion, coordination, development and dissemination of scientific and technological research, of a multidisciplinary nature, in order to contribute to the advancement of knowledge and to economic, social and cultural development, as well as the training of personnel and the advice of public and private entities in this area.

CSIC is made up of a network of centres and institutes that carry out scientific research independently. Every institute has a director and is organized in

departments that group related research teams. *Instituto de Optica "Daza de Valdés*" (IO-CSIC) is one of those institutes with highly internationally recognized members performing research and technology in Optics and Photonics, contributing significantly to the CSIC mission of creating an impact in science and society (http://www.io.csic.es). Almost from the outset (1950's) IO-CSIC has been investigating in photometry and colorimetry and later in Radiometry, arising from that research the national primary standards in the area of Photometry and Radiometry, which today require highly qualified experimental facilities and equipment, that are metrologically very trustful since the national standards they help to define and maintain are traceable to the international system of units via comparisons organized by the International Committee for Weights and Measures (CIPM) or the regional metrological organizations as EURAMET. These facilities are not only useful to define units and standards but for research projects where measuring changes in the optical radiation field (power spectral distribution, phase, frequency, angular or spatial distributions) is a key point and has to be done with low uncertainty, lower than the standard that can be obtained from the calibrations done by laboratories according to their calibration and measurement capabilities. Examples can be found in areas so different as Astrophysics, space science and technology, remote sensing, Earth observation, medicine and clinical diagnostics, energy efficiency and lighting, optical telecommunications, environment and climate change studies, fundamental physics, material science, defense technologies…

Therefore, IO-CSIC offers a Laboratory known as "*Laboratorio de Fotometría, Radiometría y Fibras Ópticas*" with an extension of 300 m^2, hosting highly specialised laboratories for the measurement of optical radiation.

In addition to the permanent staff running the laboratory (3 PhD responsible for the projects and 2 technicians for doing the technical work), temporary staff for the implementation of R&D projects and granted staff under training are currently present.

3.4.- Ozone National Standard Laboratory (PNO-CNSA)

The Ozone National Standard Laboratory is an investigation infrastructure belonging to the Department of Atmospheric Pollution (ACA) of the National Environmental Health Center (CNSA) of the Carlos III Health Institute (ISCIII) (http://www.isciii.es).

The Carlos III Health Institute is the main Investigation Public Organism (OPI), who finances, manages and executes the biomedical investigation in Spain.

With a trajectory of more than 20 years of investigation in health and life sciences and the provision of reference services, is also the managing body of the Health Strategic Action (AES) in the framework of the I&D&I National Plan.

Ascribed organically to the Ministry of Science, Innovation and Universities (Royal Decree 865/2018) and functionally to this and to the Ministry of Health, Consumer

Affairs and Social Welfare (Royal Decree 1047/2018), it has as main mission the promotion of the generation of the scientific knowledge on health sciences and the drive for innovation in health care and disease prevention.

The CNSA is the scientific and technical organism of the Carlos III Health Institute, focused on the sanitary aspects of the problems arising from environmental pollution. Its primary purpose is the characterization of the potential risk to environmental pollutants to which the population is exposed.

It was created through the Decree 252/1974, of 25th January and later on, attached to the Carlos III Health Institute (Law 14/1986).

Currently more than 100 people of high technical qualification work on the CNSA, and its laboratories have an extension of more than 3000 square meters and equipped with high technology instrumentation. It works under a quality system UNE-EN ISO/IEC 17025 and it's accredited by the Accreditation National Entity (ENAC) for 186 essays, distributed on the different functional units: Atmospheric Pollution, Water Pollution and Environmental Toxicology and Radioprotection.

The eight laboratories (seven for testing and one for calibration) belonging to the CNSA are included on the Madri+d Laboratories and Infrastructures Network.

Also the CNSA has a Quality Program guaranteeing the technical competence for the accredited tests and a Training Unit that supports to the implementation and diffusion of the formative projects of the Center.

FUNCTIONS

- Technical and scientific advice and support in the matters of competence to public and private organisms.
- Services in the field of environment and health
- Research
- Standardization
- Specialized training
- Associate laboratory of *Centro Español de Metrología* (CEM) and holder of the Ozone National Standard (R.D. 250/2004)
- Reference laboratory of the Biological Laboratories Network- RELAB (Order PRE 305/2009)
- National Reference Laboratory for Air Quality (R.D. 102/2011)
- Authorized service by the Nuclear Security Council for extreme personal dosimetry in radioactive facilities.
- Reference laboratory of the OMS-Europe for mercury in hair.

The Atmospheric Pollution Area (ACA) is the Reference National Laboratory (LNR) of Air Quality to have been designated the ISCIII for that purpose in the RD 102/2011 of 28th January and responsible of the Ozone National Standard.

To fulfill the 2nd article of the RD 250/2004 in which the CNSA of the ISCIII is named responsible of the diffusion of the National Standard, the ACA is performing the following activities:

- It participates on the key comparisons of ozone national standards organized by the *Bureau International des Poids et Mesures* (www.bipm.org)
- It organizes calibration intercomparison exercises for ozone analyzers
- It organizes "in situ" ozone intercomparison exercises
- It performs the calibration of the ozone transference standards, both in the air quality survival networks in Spain, as in the national and international calibration laboratories.

The ACA is accredited for 154 essays in ambient air according to the Norm UNE-EN ISO/IEC 17025, that ensures the quality of its services.

3.5.- National ionizing radiation metrology laboratory (LMRI-CIEMAT)

The measurement of ionizing radiations (IRs) is one of the relatively young branches of metrology, when compared with the classical metrology of length, mass and temperature. Given the phenomena that it contains and treats (radioactivity, interactions, types of detection, ...) is more complex than the rest of the metrologies and therefore, its values of uncertainty are much higher in general than the rest of the branches of metrology.

The IRs have beneficial applications for humanity in the areas of medicine, industry, environment, energy, etc. Moreover, it is well aware of the risks of misuse of IRs, which is why it has made it possible to develop and implement a radiological protection system and the development of IIRR metrology.

CIEMAT LMRI is the national reference by Royal Decree, which consists of the following laboratories (radioactive facilities):

- Alpha Standard Lab.
- Liquid scintillation laboratory.
- Laboratory alpha, X and gamma spectrometry.
- Reference laboratory for gamma radiation in levels of environmental protection.
- Reference laboratory for X-rays in protection levels.
- Reference laboratory for gamma radiation at therapy levels (hospitals).
- Reference laboratory for beta radiation.
- Laboratory of Neutron Standards

The CIEMAT LMRI began its activities in radionuclide metrology in 1961, in an intercomparison of a sample of ^{198}Au sponsored at that time by the International Committee on Weights and Measures (CIPM). In 1978, it began its activities in the metrology of dosimetric standards, ^{60}Co energy and levels of therapy, to do so later

in 1983 in protection levels and for gamma and beta beam beams. Later it was recognized as National Laboratory by the Industrial Calibration System (SCI) of the Ministry of Industry and Energy. In 1996 it was declared by Royal Decree 533/96 as depositary of the national standards of activity units, exposure, kerma and absorbed dose and at the same time Laboratory associated to *Centro Español de Metrología* (CEM), acquiring at State level the responsible for maintaining and disseminating such national standards.

The LMRI depends on the General Subdirectorate of Institutional Relations and Knowledge Transfer of CIEMAT, being a national benchmark for establishing, maintaining and disseminating national standards of nuclear physics magnitudes.

The main objectives of the LMRI are:

- Establish, maintain and disseminate on behalf of the Spanish State, according to Royal Decree 533/1996, of March 15 (BOE nº 77, of March 29), the National Standard of SI units of Activity (becquerel), Exposure (coulomb.kg-1), Kerma (gray) and Absorbed Dose in the Order of MOPTMA of April 11, 1996 (BOE 99), as Laboratory Associate to Centro Español de Metrología (CEM) in the field of ionizing radiation.
- To assume national representation in the field of the metrology of ionizing radiations before international organizations, such as the International Committee of Poisons and Mésures (CIPM), Comité Consultatif pour les Rayonnements Ionisants, the International Bureau for Radionuclide Metrology (ICRM), the European Collaboration of National Metrology Institutes (EURAMET) and others.
- Ensure the international traceability of National Standards for ionizing radiation through compliance with the requirements of the Mutual Recognition Arrangement of the National Institutes of Metrology (MRA), promoted by the International Committee of Poisons and Mésures since 1999, establishing a ISO 17025 Quality System and participating in the CIPM / BIPM Key Intercomparisons, the EURAMET Supplements and the BIPM "Système International de Référence" (SIR).

In order to achieve its objectives, the LMRI must ensure, at the same time as international traceability, the coherence of ionizing radiation measurements within the country in all sectors, industry, health or research, and in applications as diverse as calibrations and tests industrial radiation protection, radiation protection, nuclear medicine, radionuclide experimentation techniques, or environmental radiological surveillance.

The LMRI has the following legal provisions and technical acknowledgments:

1) Royal Decree 1952/2000, of 1 December (BOE No. 289, of 2 December), which approves the CIEMAT Statute, establishes among the functions set out in article 3, section f, "The provision of technical, performance of services and issuance of certifications of the measures, tests and

calibrations that are carried out in their laboratories, when they are requested and in the conditions that, in each case, are established".

2) Royal Decree 533/1996, of March 15 (BOE nº 77, of March 29), which declares to the Laboratory of Metrology of Ionizing Radiations of CIEMAT as:
   - Laboratory depositary of the National Standards of measurement of units derived from Activity (from a radionuclide), Exposure (x-rays and g), Kerma and absorbed dose (Article 1).
   - Laboratory Associated with the Spanish Center of Metrology (CEM) in the field of ionizing radiations (Article 2).
   - Responsible, on behalf of the State, for the custody, conservation, maintenance and dissemination of the National Standards of these units, in coordination with the Spanish Metrology Center (article 3), by virtue of the competence conferred on this Organization by section 2 of article 4 of Law 3/1985, of March 18, on Metrology.

   In 2013, LMRI has incorporated a new Laboratory of Neutronic Standards adding a new magnitude: neutronic fluence

3) The national standards of the units derived from the international system of units whose custody, maintenance, conservation and dissemination corresponds to the CIEMAT LMRI are defined in ORDEN ITC / 2581/2006, of July 28 (BOE No. 186 of 5 of August).
4) In its capacity as a laboratory of national standards, signatory, through the CEM, of the Agreement "Mutual recognition of national measurement standards and calibration and measurement certificates issued by national metrology institutes" (MRA), promoted by the International Committee of Poids Mésures (CIPM, 1999) and subscribed by the countries of the Metro Convention.

3.6.- Real Instituto y Observatorio de la Armada (ROA)

The *Real Instituto y Observatorio de la Armada at San Fernando* (ROA) is an Organism that depends on the Spanish Ministry of Defence, under the direct command of the Admiral of General Services, Technical Assistance and Information Systems and Telecommunications.

The ROA was founded in 1753, as a consequence of the participation of Antonio de Ulloa and Jorge Juan in the Campaign promoted by the '*Académie des sciences du Paris*' to measure a degree of the Meridian Circle in the Royal Audience of Quito, currently Ecuador.

Since then, ROA has been serving the Navy and Spain participating in science investigations and taking relevant participation in Astronomical, Geodetic and Geophysical campaigns.

The main activities at ROA cover the following fields: Astrometry, Earth rotation, Seismology, Geophysics, Artificial Satellites, Ephemeris, Celestial Mechanics, Time Scales and Time transfer techniques.

By a Royal Decree (RD 1308/1992), ROA was appointed as Associated Laboratory (Designated Institute) of the *Centro Español de Metrología*, CEM, inside the decentralised scheme of Metrology in Spain.

Time Department is in charge of the development, maintenance and dissemination of the Spanish Time and Frequency Standard.

ROA time laboratory also maintains the official time in Spain with an uncertainty less than 2.5 ns in relation to the coordinated universal time (UTC) and national frequency with a 1 x 10^{-14} relative uncertainty.

3.7.- Laboratorio Central Oficial de Electrotecnia (LCOE)

The LCOE laboratory was created in 1949 by the Ministry of Industry and the Ministry of Education, inside the facilities of Polytechnic Engineering School of the University of Madrid, UPM. In 1992 the LCOE was integrated in the Foundation for the Promotion of the Industrial Innovation FFII.

Currently more than 100 people of high technical qualification work on the LCOE, and its laboratories have an extension of more than 5000 square meters and are equipped with high technology instrumentation. It works under a quality system UNE-EN ISO/IEC 17025 and it's accredited by the National Accreditation Body (ENAC) for many testing and calibration activities, not only in High Voltage.

LCOE, specifically the High Voltage Technological Centre of FFII is a support tool for Industry and for R&D&i in the HV Electrical Engineering Area, in different fields of action. Because of its structure, staff, and facilities, as well as its experience, prestige, accreditations and national and international awards, LCOE is an international reference in High Voltage and Metrology Areas.

The main High Voltage Laboratory, HVL, has two screened testing halls, the High Voltage one, sized 40 m x 25 m x 25 m, and the Medium Voltage one, sized 29 m x 13 m x 12 m, together with a climatic chamber sized 5.5 m x 3 m x 3 m.

The High Voltage hall has a power frequency generator up to 1 MV (50 Hz / 60 Hz), and an impulse generator up to 2.4 MV (lightning impulses) or 1.3 MV (switching impulses). The Medium Voltage hall is divided in five testing areas, where it is possible to perform power frequency tests up to 150 kV, lightning impulse tests up to 400 kV, ratio and phase measurements on instrument transformers, both voltage and current types, high sensitivity partial discharges measurements in the Faraday cage, and performance tests over power transformers, such as short-circuit impedance, looses, temperature rise test, winding resistance measurement, induced overvoltage, and so on. The climatic chamber allows to make performance tests at extreme temperatures, simulating severe ambient conditions between -40 ºC and +60 ºC.

International recognitions and accreditations of LCOE:

- BIPM recognition: LCOE was recognized by the Spanish Metrology Centre (CEM) in 2001 (R.D. 346/2001) as a Laboratory associated with CEM, holder of the Spanish High Voltage standards and ratified by the International Bureau of Weights and Measures (BIPM). The international recognition, as Designated Metrology Institute, DI, enables to the LCOE to issue BIPM Certificates to spread the traceability of high voltage and high current magnitudes and impulses. Currently it offers a broad wide range of Calibration and Measurement Capabilities in high voltage and high current, that for CIPM-MRA services can be consulted in the BIPM data base (https://kcdb.bipm.org/) and for ILAC-MRA services on the ENAC web page (https://www.enac.es/web/enac/entidades-acreditadas/)
- ILAC / ENAC: LCOE is ISO/IEC 17025 accredited by ENAC the Spanish National Accreditation Body which is member of ILAC. Accreditation number ENAC 3/LE130 for testing services and ENAC 1/LC10.001 for calibration services.
- STL: LCOE is member of the Spanish Association of High Power Laboratories (AELP), which is presently an applicant for the membership in the Short Circuit Testing Liaison (STL).

4.- Facilities and Services

Services of calibration and measures are provided for all Laboratories of the metrology network and can be checked in their own website and those internationally recognized in the website of KCDB of BIPM (https://kcdb.bipm.org/).

Other available services are:

- Support for the implementation of a quality management system based on ISO / IEC 17025, in metrology laboratories.
- Support as a technical evaluator of the audit team and for carrying out peer reviews.
- Technological support, conducting studies, seminars or courses in specific areas.
- Training of technical personnel in different metrology fields.
- Support for the organization of comparisons, including technical direction.
- Advice on the definition of metrological capabilities (CMC).
- Advice for establishing balance sheets of uncertainty in different metrological fields

Some facilities and more specific services focus to R&D&i are described in the following lines:

4.1.- CEM

CEM can offer the following facilities and services in the Metrology network framework:

SI Length Unit

Facilities for the practical realization, maintaining and dissemination of the national standard of the SI unit of length, the metre. Singular instruments: Optical synthesizer based on frequency comb technology, referenced to Cs frequency standard, iodine stabilized Helium-Neon lasers and modular systems for optical detection of beat frequency.

Service offered: Metrological characterization of laser sources and interferometric measurement systems:

- to determine the frequency and stability of laser sources used in research, industry, medicine, etc., with the lowest uncertainty,
- to determine the measurement errors of interferometric laser measuring systems (LIMS) when used in long-range measurements in industrial environments (aerospace, avionics, shipbuilding,etc.),
- to characterize the environmental sensors of LIMS and to adjust them for getting the right wavelength emitted in ambient conditions, through its dependence of the air refractive index,
- to get traceable and reliable results in projects, helping to validate departure hypotheses and support scientific publications.

Characterization of materialized standards

Facilities to transfer the SI unit of length to highly accurate materialized standards used as references by metrology laboratories or being integral part of measurement equipment and systems, so conferring metrological traceability. Singular instruments: Gauge block Interferometer and interferometric comparator.

Service offered: Metrological characterization of accurate materialized standards:

- to determine by interferometry the length of very accurate gauge blocks until 100 mm, with the smallest uncertainty,
- capability to measure:
- to determine long materialized standards until 1200 mm, reaching a repeatability of 70 nm and a measurement uncertainty U(k=2) ≥ Q[70; 0.4 L/mm] nm,
- step gauges used for transferring the unit of length to coordinate measuring machines, reaching an uncertainty U (k=2) ≥ Q [90; 0.45 L/mm] nm,
- high precision line scales, optically, by using recognition and image-treatment specific software, with an uncertainty U ≥ Q[70; 0.4 L/mm] nm.

Angular measurements

Development and maintaining of the SI unit of plane angle. Characterization of standards and instruments belonging to lower metrological levels, providing them with the required traceability. Singular instruments: absolute angular generator, automatic goniometer and photoelectric autocollimators.

Service offered: Metrological characterization of Angular Standards and Instruments for angular measurements. Support to characterize standards and measuring devices crucial for other important facilities such as Synchrotron or FEL (free electron laser) where the reliability of their experimental results and the confirmation of departure hypotheses depends on the metrological state of such instrumentation

Coordinate Metrology

Facilities for the characterization of transfer standards and coordinate measuring machines and systems. Development and application of metrological measurement methods in order to get reliable and traceable results from 1D to 3D, tactile and optical measurement systems. Singular instruments: horizontal 1D coordinate measuring machine, high accuracy hybrid (contact and vision) coordinate measuring machine, differential laser interferometer system and high accuracy form measuring machine.

Service offered: Metrological characterization of coordinate measuring systems and their standards. Measurement of complex subsystems with micrometric tolerances and study of their behaviour after submitted to thermal and vibrational cycles. Support to applications requiring embedded subsystems on satellites and aerospace missions.

Surveying and Geodesy

Facilities for the characterization of instruments used in surveying and geodesy (total stations, electronic distance meters, invar rods, levels, etc.) as well as equipment for large volume measurements (laser tracker, laser scanner, etc.). Singular instruments: absolute tracker system, long range interferometric bench, collimator optical bench and standard baseline.

Service offered: metrological characterization of surveying and geodetic instruments used in spatial, avionic and eolic industries, or in surveying and geodesy in order to get traceable and reliable results. To verify Laser Scanner Systems used in automotive or preservation of the historical heritage applications, etc.

Micro and nanometrology

Facilities to get traceable and reliable measurements in micro and nanometrology fields and to characterize standards used for calibrating micro and nanometrology instrumentation (surface quality analysers, microscopes (optical, holographic, SPM), etc.

Singular instruments: interferometric microscope, dual-wavelength digital holographic microscope in reflected light mode, metrological Scanning Probe Microscope (MSPM) and contact profilometers

Service offered: Metrological characterization of accurate standards and instruments used in micro and nanometrology fields

Contact Thermometry

Contact thermometry facilities for the characterization of contact temperature sensors in the temperature range from -190 ºC up to 1600 ºC and fabrication of noble metal thermocouples.

Singular instruments: isothermal enclosures, traceable temperature standards and instrumentation to perform traceable measurements of resistance and electromotive forces in the temperature range from -189 ºC up to 1600 º and the necessary equipment to construct noble metal thermocouples types S, R, B, Au/Pt and Pt/Pd and perform their characterization and calibration.

Service offered: Characterization of temperature sensors and instrumentation for temperature measurements in the range from -190 ºC to 1600 ºC. The characterization service could comprise, among other measurements, determination of sensitivity, repeatability, drift, reproducibility, etc with traceability to national standards. Construction, characterization and calibration of custom made thermocouples types S, R, B, Au/Pt and Pt/Pd.

Preparation of gas mixtures and analysis

Facilities for preparation of gas mixtures by gravimetric method and analysis

Singular instruments: vacuum system with TM pump and heaters (vacuum down to 10-7 hPa) for the cylinders cleaning and a Filling station, GC-TCD-FID, GC-HID-FID, GC-MS and microGC-TCD. It also count on an FTIR with 2 m and 20 m cells, Cavity Ring-Down Spectrometer (CO2/CO/CH4/H2O), specific analyzers: CO (2 levels), CO2, HC, O2, NOx (2 levels), SO2/H2S, 3 samplers and automatic switch to select the specific analyzers.

Service offered: Traceable analysis of gas mixtures with the following compounds: CO, CO2, O2, NO, C3H8, CH4, ethanol, natural gas (up to 7 compounds), etc (other gases should be consulted) for R&D projects.

Radiation Thermometry Facilities

Radiation thermometry facilities for the characterization of radiation temperature sensors in the temperature range from -40 ºC up to 2500 ºC.

Singular instruments: different blackbodies and radiation sources, like liquid baths from -40 ºC to 200 ºC (up to 70 mm source diameter), three zone furnace from 200 ºC to 600 ºC (up to 70 mm source diameter), heat pipes furnaces from 200 °C to 950 °C (up to 30 mm source diameter), three zone furnace from 1000 °C to 1600 °C (up to 20 mm of source diameter) and furnace from 1100 °C to 2500 °C (up to 10 mm of source diameter).

Service offered: Characterization of temperature sensors and instrumentation for temperature measurements in the range from -40 ºC to 2500 ºC. The characterization service could comprise, among other measurements, determination of sensitivity, repeatability, drift, reproducibility, etc with traceability to national standards.

Radiometric Facilities

Radiatiometric facilities for radiance measurements

Singular instruments: blackbody radiation sources and a supercontinuum laser with an AOFT (ranging from 450 nm to 700 nm and 1200-nm to 2000 nm) and a 750 mm monochromator to perform measurements of radiance and spectral response of sensors.

Service offered: radiance measurements corresponding to temperature from 200 ºC to 2500 ºC and wavelengths near 650 nm and 1550 nm. Measurement of the spectral response of sensors from 300 nm to 1600 nm.

Mass and solid density measurements

Facilities that provide the reference for all the mass and density measurements all around our country. The determination of mass value for normalized weights and masses in general can be performed with very small uncertainties (at the state of the art).

Singular instruments: Set of diverse high accurate mass comparators that enables to perform mass measurements from 50 µg to 1000 kg, in some case with resolutions up to 10 ng.

For mass values below 1 kg it is possible to perform measurements in different pressure environments (even in high vacuum conditions) in different gas media.

Service offered: The characterization service could comprise, among other measurements, determination of calibration factors or corrections, sensitivity, repeatability, drift, reproducibility, etc. Determination of volume and density of solids from 2 g up to 50 kg (for solids with mass larger than 1 kg the expected density has to be larger than the density of water).

Force and torque measurements

Facilities that provide the reference for all the force and torque measurements all around our country. Forces and torques can be generated with relative uncertainties as small as 0.001 % for the best cases.

Singular equipment: dead-weight force standard machines with ranges 1 kN, 20 kN and 500 kN, hydraulic force machines with ranges 2 MN and 10 MN, 1 kN•m dead-weight torque standard machine, and comparison torque machines with ranges 20 N•m and 5 kN•m.

Service offered: Characterization of force sensors and instrumentation for force measurements in the range from 1 N to 10 MN. Characterization of torque sensors and instrumentation for torque measurements in the range from 1 N•m to 5 kN•m. The characterization service could comprise, among other measurements, determination of calibration factors or corrections, sensitivity, repeatability, drift, reproducibility, etc.

Pressure and vacuum measurements

Facilities that provide the reference for all the pressure measurements all around our country. It can generate and measure pressure values from 1 µPa up to 1 GPa with very small uncertainties with uncertainty as low as 0.001 % for the best cases.

Singular instruments: dynamic expansion system for high vacuum measurements, static expansion system for low and medium vacuum, laser mercury manobarometer for barometric pressures and pressure multiplier to be able to characterize pressures up to 1 GPa.

Service offered: characterization of pressure and vacuum sensors and instrumentation for pressure and vacuum measurements in the range from 1 µPa to 1 GPa. The characterization service could comprise, among other measurements, determination of calibration factors or corrections, repeatability, drift, reproducibility, etc.

Fundamental metrology and DC resistance Facilities

Quantum Hall resistance standard system laboratories in DC resistance measurements.

Singular instruments and equipment: quantum Hall resistance samples, cryogenic system, sample holder and connexions, superconducting magnet, digital nanovoltmeters, DC current generators, instrumentation and DC resistance reference standards

Service offered: traceability for DC resistance standards and equipment and instrumentation for DC resistance measurements in the range from 1 mΩ up to 10 TΩ with an expanded uncertainty value up to 0.04 μΩ/Ω. The service could comprise, among other measurements, DC resistance reference standards, DC resistance sources and meters with reference to the national DC Quantum resistance standard.

Fundamental metrology and DC voltage Facilities

Quantum programmable Josephson standard system laboratories in DC voltage measurements.

Singular instruments and equipment: programmable and conventional Josephson arrays, bias source, cryogenic system, sample holder and connexions, in order to get a temperature about 4.2 K, faraday chamber, digital nanovoltmeters, microwave synthesizer generators, microwave counters and DC voltage reference standards in order to get an expanded uncertainty value up to 20 nV in DC voltage measurements with reference to the DC voltage national standard.

Service offered: traceability for DC voltage standards and instrumentation for DC voltage measurements in the range from 0.1 mV up to 1 000 V with an expanded uncertainty value up to 20 nV. The service could comprise, among other measurements, DC voltage reference standards, DC voltage and current sources and meters and determination of linearity of digital multimeters with reference to the Quantum DC voltage national standard

Low frequency Quantum standard based on Josephson standard Facilities

Quantum Josephson standard facilities for AC voltage measurements

Singular instruments and equipment: 10 V programmable Josephson array, programmable source, Cryogenic system, sample holder and connexions, instruments control software, microwave guide, nanovoltmeters and instrumentation.

Service offered: traceability for AC voltage and current standards and equipment and instrumentation for AC voltage and current measurements, in the range from 2 mV up to 1 000 V, from 10 Hz to 1 MHz with an expanded uncertainty value from 4 μV/V up to 400 μV/V and from 5 mA up to 100 A, from 10 Hz to 100 kHz with an expanded uncertainty value from 4 μA/A up to 400 μA/A. The service could comprise, among other measurements, AC voltage and current sources and meters with reference to the national AC Quantum standards.

Power and energy measurement facilities

Power and energy measurement laboratories for the characterization of reference power and energy standards

Singular instruments and equipment: power and energy standard by digital sampling, coaxial current shunts and voltage dividers, digital multimeters, power and energy standards, reference standards and transfer standards. The laboratory counts also with high accuracy power analyzers for harmonic measurements.

Service offered: traceability of reference and transfer standards, equipment and instruments for the measurement of power and energy, in the range from 0,5 V up to 600 V and 5 mA up to 100 A with expanded uncertainty values up to 30 x 10-6 with reference to national standards.

I&D in acoustic field

Flexible facilities to characterized acoustic sensors and develop R&D projects

Singular equipment: anechoic chamber to cover the frequency range from 160 Hz to 20 kHz and a plane wave tube to cover the frequency range 31.5 Hz to 250 Hz, with proven acoustic absorption of ≥ 0.75 at 20 Hz.

Service offered: measurement response acoustic in free field with a plane progressive wave incident on the device from a specific direction.

Speedmeter in-situ facility

The reference system is based on piezoelectric wires which are embedded in the roadway and positioned perpendicularly to the direction of travel at perfectly known distances. It calculates the speed of vehicles through the signal received from the piezos, when they are pressured by the passage of vehicles.

Singular equipment: group of piezoelectric wires distributed in a particular provision, and equipment for processing the signal.

Service offered: evaluation procedures for instruments that measure instantaneous and average speeds and accelerations. Characterize systems like speedmeters and speed of special cars with the smallest uncertainties.

Vibration and accelerometers measurements

Reference system for the characterization/calibration of vibration gauges and accelerometers. It can be used for the realization of the different random and sinusoidal tests

Singular equipment: system with 3 exciter corresponding power amplifiers: (5 Hz - 50 kHz vertical, 0 - 200 Hz horizontal; and 0 - 160 Hz vertical) laser vibrometer and associated data acquisition equipment.

Service offered: Characterization of standards and instrumentation like accelerometers, vibration meters and vibration gauges, and signal conditioners with the smallest uncertainties.

4.2.- INTA

Frost/Dew-point temperature measurement and generation facilities

Humidity facilities for the characterization of frost and dew-point hygrometers and other humidity sensors in the frost/dew-point temperature range from -75 ºC up to 95 ºC using air or nitrogen as the carrier gas at pressures up to 1 MPa.

Singular instruments and equipment: Standard humidity generators, precision chilled mirror hygrometers, thermal enclosures, dry oil and CO_2-free air production, heat-regenerated adsorption driers, traceable pressure and temperature standards and instrumentation to perform traceable measurements of electrical quantities (resistance, voltage and current) associated to humidity sensors.

Service offered: Characterization of frost/dew-point hygrometers, sensors and instrumentation for humidity measurements in the range from -75 ºC to 95 ºC. The characterization service could comprise, among other measurements, determination of sensitivity, temperature coefficient of humidity, repeatability, drift, reproducibility, hysteresis, etc with traceability to national standards.

Trace humidity measurement and generation facilities

Trace moisture facilities for the characterization of humidity analyzers and other trace humidity sensors in the range from 50 nmol/mol to 2000 nmol/mol using nitrogen as the carrier gas.

Singular instruments and equipment: Atomspheric pressure ionization mass spectrometer (APIMS), Precision gas blender using critical orifices, Magnetically coupled suspension balance (20 g with 1 µg sensitivity) with temperature control (20 ºC to 150 ºC), Cavity Ringdown Spectroscopy Trace gas analyzer (CRDS), permeation tube trace humidity generators, precision chilled mirror hygrometers, quartz crystal microbalance humidity analyzers, mass flow transfer standards, temperature-controlled recirculation chillers for temperature control of sensors, traceable flow, pressure, temperature standards and instrumentation to perform traceable measurements of resistance, voltage and current associated to trace humidity sensors.

Pure nitrogen production from 6 m^3 liquid nitrogen tank with evaporator and getter-activated gas purifiers for production of zero gas for trace moisture measurements at line pressure up to 1 MPa.

Machining and orbital welding equipment for the construction of gas delivery systems and measurement manifolds for intercomparison of analyzers and sensors.

Service offered: Characterization of trace moisture analyzers, materials, sensors and instrumentation for humidity measurements in the range from 50 nmol/mol to 2000 nmol/mol using nitrogen as the carrier gas. The characterization service could comprise, among other measurements, determination of sensitivity, response time, temperature coefficient, repeatability, drift, reproducibility, hysteresis, etc with traceability to national standards. Construction of gas delivery systems and manifolds in electropolished stainless steel for humidity measurements.

Relative humidity and air temperature measurement and generation facilities

Humidity facilities for the characterization of relative humidity sensors and materials in the relative humidity range from 1 %rh to 98 %rh at temperatures from -40 ºC up to 95 ºC using air or nitrogen as the carrier gas. Measurements can be performed at line pressures up to 1 MPa.

Singular instruments and equipment: Humidity generators, precision chilled mirror hygrometers, thermal enclosures, dry oil and CO_2-free air production, heat-regenerated adsorption driers, pure nitrogen production, getter-activated gas purifiers traceable pressure and temperature standards and instrumentation to perform traceable measurements of electrical quantities (resistance, voltage and current) associated to humidity sensors.

Service offered: Characterization of relative humidity hygrometers, sensors, materials and instrumentation for humidity measurements in the range 1 %rh to 98 %rh at temperatures from -40 ºC up to 95 ºC using air or nitrogen as the carrier gas at line pressures up to 1 MPa.

The characterization service could comprise, among other measurements, determination of sensitivity, temperature coefficient of humidity, temperature coefficient of temperature with respect to relative humidity, repeatability, drift, reproducibility, hysteresis, multi-sensor intercomparison, spatial homogeneity and temporal stability of temperature and relative humidity in climatic and thermal enclosures, etc., with traceability to national standards.

Power measurement facilities

Power measurement facilities for the characterization of low-power sensors, high-power wattmeters and standards in the range from 100 kHz to 40 GHz.

Singular instruments and equipment: Temperature-stabilized thermistor mounts, measuring instruments and automation software, specifically developed by INTA, including measurement uncertainty analysis.

Service offered: Characterization of power sensors, wattmeters in the range from 100 kHz to 40 GHz for Type-N, PC 3.5 mm and PC 2.4 mm connectors.

The characterization service could comprise, among other measurements, determination of calibration factor of power sensors (thermistors, thermocouples and low-power sensors), measurement of power, determination of power sensor linearity, sensitivity, repeatability, reproducibility and provision of traceability for high-power wattmeters.

Attenuation measurement facilities

Attenuation measurement facilities for the characterization of radio frequency attenuators from 0 dB to 110 dB at frequencies from 100 kHz to 50 GHz.

Singular instruments and equipment: Primary WBCO piston attenuator, clean humidity controlled dry compressed air supply, pneumatically damped optical bench, scalar attenuation measurement system, step attenuators, Vector Network Analyzers (VNA), RF generators and sources, precision multimeters.

Service offered: Characterization of RF attenuators with high-value Insertion Losses (as compared with transmission [S] parameters measured with a VNA) from 0 dB to 110 dB at frequencies from 100 kHz to 50 GHz.

The characterization service could comprise, among other measurements, determination of the attenuation of devices such as fixed attenuators, step attenuators and continuously variable attenuators, including repeatability, reproducibility and the provision of metrological traceability.

Impedance measurement facilities

Measurement of Voltage Reflection Coefficient (VRC) of passive devices of one, two or more ports at frequencies from 100 kHz to 50 GHz.

Singular instruments and equipment: Vector Network Analyzers.

Service offered: Characterization of impedance using reflection [S] parameters using a VNA and specialized software at frequencies from 100 kHz to 50 GHz.

The characterization service could comprise, among other measurements, determination of the impedance of devices such as fixed coaxial terminations, sliding loads, mismatch (offset) loads, high-reflection terminations (open and shorts), attenuators, cables, directional devices (directional couplers and directional bridges); Characterization in terms of directivity, coupling factor and isolation of devices such as power splitters, power dividers and the scalar measurement of output VRC of active devices (RF generators or sources).

Electromagnetic noise measurement facilities

Electromagnetic noise measurement facilities for the characterization of noise sources at frequencies from 10 MHz to 26.5 GHz.

Singular instruments and equipment: Reference noise sources, Vector Network Analyzers (100 kHz to 50 GHz), cryogenic temperature maintenance systems for 77 K, pure heat transfer gases and vacuum equipment.

Service offered: Characterization of noise sources and amplifiers in the range from 10 MHz to 26.5 GHz for Type-N and PC 3.5 mm connectors.

The characterization service could comprise, among other measurements, determination of the Excess Noise Ratio (ENR, dB) of solid state noise sources, measurement of amplifier gain and noise figure (NF, dB) and the provision of metrological traceability.

Vector Network Analysis facilities

Facilities of the evaluation of Vector Network Analyzers in the frequency range from 100 kHz to 50 GHz.

Singular instruments and equipment: Three state of the art Vector Network Analyzers, directional couplers, power splitters, RF sources, loads, special cables, automation software, specifically developed by INTA, including uncertainty budget computation and measurement of uncertainty components for full VNA assessment.

Service offered: Characterization of Vector Network Analyzers, RF sources and one-, two- and several-port devices in the frequency range from 100 kHz to 50 GHz. for Type-N, PC 7 mm, PC 3.5 mm and PC 2.4 mm connectors.

The characterization service could comprise, among other measurements, determination of Reflection Coefficient of RF sources; measurement of [S]-parameters (magnitude and phase) of one-, two- and several-port devices; evaluation of directional devices (bridges and couplers); measurement of equivalent Source Match of power splitters; Evaluation of fixed and sliding loads; full characterization of Vector Network Analysers, including measurement of residual errors, directivity, Test Port Match, Linearity, Isolation, Noise, Connector repeatability, Measurement repeatability and Cable repeatability.

Antenna and target radar cross section (RCS) measurement facilities

Facilities of the evaluation of antennas target radar cross section (RCS) in the frequency range from 1 to 40 GHz and characterization of antennas in the range from 200 MHz to 1.3 GHz.

Singular instruments and equipment: Compact test range for antennas and RCS measurements. The INTA Compact Antenna Test Range (CATR) is a

complete turn-key test system for antenna and RCS measurement capabilities. It consists of a single reflector test range, installed inside a 30.5 m x 18 m x 13 m (L x W x H) shielded anechoic chamber. The compact range reflector produces a collimated RF wavefront in a quiet test zone as an emulation of far field conditions. The quiet zone is an elliptical cylinder 5.5 m x 5 m x 6 m (W x H x L) and is usable over a frequency range of 1 GHz to 40 GHz when used with the appropriate RF feeds and subsystem components. The INTA CATR has qualification of class ISO 8 cleanroom area (formerly 100,000), if required. Reference antennae, Spectrum analysers, RF generators, RF feeds and subsystems.

Service offered: Measurement of the main parameters of antennae and RCS measurement.

The characterization service could comprise, among other measurements, the determination of radiation diagrams, gain, return losses, efficiency, etc. RCS measurement, complex target, absorber material, structure-antennae interaction studies, etc. in the frequency range from 1 to 40 GHz. Metrological traceability of the antenna factor and gain of biconic, log-periodic, dipole, horn, spiral and monopole antennas is also available.

4.3.- IO-CSIC

From the experience, and knowledge background of its staff, IO-CSIC can offer the following facilities and services:

Laser radiometry laboratory.

This facility allows characterization of power meters and radiometers with very low uncertainty by comparison against an electrical substitution cryogenic radiometer (ESCR) at specific laser wavelengths. ESCRs are the most accurate radiometers at present. Most relevant national metrology institutes base their radiometric measurements on them, as IO-CSIC does for realizing the primary national standard for radiometric flux (optical radiation power) measurements in Spain.

Service offered: High accuracy spectral responsivity characterization of radiometers. This service can be spectrally extended by using other monochromator based facilities.

Fully absolute BRDF laboratory.

IO-CSIC has designed and built a gonio-spectrophotometer that is singular because can measure the absolute Bidirectional Reflectance Distribution Function (BRDF) of materials in-plane and out of-plane of incidence at any geometry for irradiation and observation, including real retro-reflectance (the only instrument at present able to do that). This facility is the basis for the realization of spectrophotometric quantities and very useful to study and develop new materials

based on nanoparticles and surface effects produced by laser material interactions.

Other remarkable features of this facility are that spatial distribution of BRDF on sample's surface can be studied in the visible range andthe field of view, which is rather uniform, and can be adapted, within a range, to the sample size.

Services offered:

- Bidirectional scattering distribution function of materials including its spatial distribution (visible and NIR).
- Algorithms to represent and analyse BRDF data.

High dynamic range spectrophotometer in clean laminar flow cabinet.

Determination of total transmittance and reflectance (including and excluding specular component) of samples down to 8 orders of magnitude in a clean area with direct traceability to the SI system, from the UV to NIR. Particularly useful for space applications material characterization.

Service offered: Accurate determination of spectrophotometric properties of materials.

Frequency comb laboratory.

High accuracy wavelength calibration in the optical telecommunications wavelength bands (1260 nm – 1640 nm) with direct traceability to SI system by using a self-referenced frequency comb. Characterization of optical clocks.

Non-linear properties characterization of waveguides and materials using a femtosecond laser at 1550 nm.

Services offered:

- High accuracy wavelength calibration and characterization of IR optical clocks.
- Non-linear properties characterization of waveguides and materials using a femtosecond laser at 1550 nm.

Special optical fibre characterization laboratory.

Determination at the state of the art uncertainty of linear and nonlinear optical properties of special optical fibres (micro-structured optical fibres, such as photonic crystal fibres and holey fibres", active fibres, plastic fibres, etc.) with direct traceability to SI system. This includes chromatic dispersion, polarization mode

dispersion, spectral attenuation, and non-linear properties such as Raman and Brillouin absorption and gain.

Services offered:

Linear and nonlinear characterization of the optical properties of special optical fibres.

In addition, and for the different facilities, advice on technological developments that require measurements with primary metrological traceability, high accuracy, development of standards, and measurement instrumentation adapted to processes or products is also offered as service by IO-CSIC.

4.4.- PNO-CNSA

Laboratory of the Ozone National Standard

This facility provides the reference for all the measurements of ozone in ambient air, in a range of 2 nmol/mol to 1000 nmol/mol, allowing traceability to transference standards used as reference, both for ENAC accredited calibration laboratories, and for other organisms who needs to give traceability to their measurements.

Singular instruments: 2 NIST Reference Photometers, that measures by UV photometry the ozone concentrations dynamically generated.

Services offered:

- Characterization of instruments of less metrological levels through the determination of calibration factors or corrections, repeatability, reproducibility, drift, etc, giving them the stablished traceability on the regulations in force.
- Organization of calibration intercomparison exercises for ozone analyzers.

Intercomparison of gases laboratory

This laboratory allows to generate concentrations of different gaseous pollutants by dynamic diffusion of Certified Reference Materials (MRC), giving traceability to the ozone measurements in controlled conditions of humidity, temperature and interferents presence.

Singular instruments: gases generation system (up to 100 l/min), cero air purification system (up to 240 l/min), specific analyzers based on the reference methods for the determination of CO, NOx, O3 and SO2, sample humidification unit and system for measurement of relative humidity, temperature and sample pressure.

Services offered:

- Characterization of instruments for pollutants measurement in the ambient air through the determination of calibration factors or corrections, sensibility,

repeatability, reproducibility, drift, etc, as well as interference studies for I+D projects.
- Organization and performance of “in situ” gases intercomparison exercises.
- Validation of new methods for measurement of atmospheric pollutants to give reliability to the experimental results

Laboratory of automatic analyzers

This laboratory gives reference to all the gaseous pollutants measurements in ambient air, both in the air quality surveillance networks in Spain, as to the long distance cross-border European network for measurement of atmospheric pollutants EMEP/VAG/CAMP (European Monitoring and Evaluation Program/ Global Atmospheric Surveillance/ North Atlantic Atmospheric Pollution Surveillance Program).

Singular instruments: approved type analyzers for the determination of CO, NOx, O3 and SO2, based on the reference methods stablished on the RD 102/2011. Analyzers for the determination of BTX, NH3 and H2S. Gas dilution banks with flowrate mass controllers (up to 6 l/min). Cero air purification system (up to 240 l/min). As well as the needed standards to perform the necessary quality controls.

Services offered: Validation of measurement methods in ambient air and studies of methods equivalence.

4.5.- LMRI-CIEMAT

The National Standards Laboratory for IRs, and in line with similar metrological institutions from other countries in our environment, the LMRI develops the following R & D activities:

- Establishment of new standards and measurement techniques.
- Maintenance and Traceability.
- Dissemination of Units.

Establishment of New Standards and Measurement Techniques

The LMRI develops and establishes the National Standards for ionizing radiation through two specialized radioactive facilities:

- *Radionuclide Metrology (RN) Laboratories*, where appropriate measurement techniques are used to metrologically characterize the radiation disintegration and emission processes, which allow the definition of the National Standards of the magnitude Radionuclide activity for α, β or γ emitters. RN currently carries out studies on liquid scintillation techniques with digital pulse processing, TDCR absolute meter improvement, spectral efficiency calculation in liquid scintillation and dating of geological materials.

- *Laboratories of Dosimetric Patterns (PD)*, where appropriate measurement techniques are used to characterize the processes of interaction of radiation emitted with matter in terms of the energy deposited, allowing the definition of the National Standards of Exposure, Kerma and Absorbed dose, for γ (^{60}Co, ^{137}Cs), X (ISO 4037 10 to 300 kV) or β (^{147}Pm, ^{85}Kr, ^{90}Sr / ^{90}Y) photons. At present PD studies are being developed to extend X-ray qualities to levels of diagnosis and therapy, new standards for flat chambers (use in therapy), automation of calibrations in air and water and development of primary standards.
- *Neutron measurement standards laboratory (LPN)*. The main functions of this laboratory are the following:
  a) Calibrate the neutron detectors in the magnitudes of:
     i. neutron creep,
     ii. environmental and personal dose equivalent and in the fields corresponding to: Cf, Am / Be and Cf moderated by heavy water.
  b) Assign dosage to passive or active dosimeters as reference for the calibration of personal or environmental dosimetry equipment.
  c) Characterize the response of measurement equipment in mixed neutron-gamma fields and perform reliability studies of measurements of personal or environmental neutron dosimetry services in Spain.
  d) Assign controlled neutron irradiation of materials with dosimetric or other interest.
  e) To carry out equipment type approval tests with neutron generating sources and neutron measuring equipment.
  f) Characterize neutron fields in mixed neutron-gamma field installations using neutron spectrometers: medical lenses, cyclotrons for the production of radiopharmaceuticals, industrial installations, etc.
  g) Irradiation of materials in intense neutron fields
  h) Study of new materials for shielding purposes
  i) Radiation damage
- The sources are 185 GBq of ^{241}Am / Be which results in an emission rate of 1.11 · 107 s^{-1}, and a 5 GBq ^{252}Cf source that offers an emission rate of 3.63 · 108 s^{-1} (for 04-12-2012). These sources will allow the calibration of neutron measurement equipment in these fields in the neutron fluence and dosimetric radiometric magnitudes of H * (10) and Hp (10).
- In addition the LPN has two neutron sources of verification of ^{241}Am / Be of 11,1 and 3,5 GBq, as well as another gamma of ^{137}Cs also of 11,1 GBq.

Service offered:

Dissemination of Units

To meet the needs of end users, the LMRI carries out the dissemination of standards and their units by providing services of:

- Equipment calibration:
  - Monitors of radiation protection or pollution, α, β or γ and X-ray (protection).
  - Environmental reference chambers, radiotherapy, nuclear power plants.
  - X-ray quality control equipment and radiation level alarms.
- Radiation reference samples, solid or liquid, with different geometry and support, for the application as tracers or calibration of semiconductor detectors, liquid scintillation counters, radiation monitors and pollution monitors, of various emitter radionuclides α, β, γ, or Cocktails ^{241}Am + ^{57}Co + ^{137}Cs + ^{3}H + ^{89}Sr + ^{90}Sr / ^{90}Y for Nuclear Plant Interlaboratory Exercises or the CSN Network of Environmental Radioactivity Measurement Laboratories, or certification of ^{14}C activity in alcohols and vinegars to establish the value of the official Spanish reference of the Agro-food Arbitration Laboratory of the Ministry of Agriculture.
- Dose assignments γ (^{60}Co, ^{137}Cs), X (ISO 4037 grades from 10 to 300 kV) or β (^{147}Pm, ^{85}Kr, ^{90}Sr / ^{90}Y) to dosimeters or materials (TLD dosimeters, biological materials, etc.).
- Type approval tests according to the Nuclear and Radioactive Installations Regulations, of ionizing radiation generating instruments (apparatus with X-ray tubes, linear accelerators or β or γ sources, for inspection of packages, detection of drugs or explosives, control of filling of containers, particulate ionizers).Calibration of activimeters throughout the national territory (with more than 120 users).
- Traceability Programs of Secondary Laboratories, for those laboratories that prefer to remain traced directly to the LMRI as opposed to the mere accreditation of "a priori" technical competence.

4.6.- ROA

Description of the existing facilities:

On September 15, 2017, it was inaugurated the new ROA Time Laboratory (LHROA). The new building is two stories and basement. The labs occupy approximately 200 of the nearly 860 square meters of the edifice.

The facility has been designed to accommodate new technologies that enables to expand their research and development capacity. The expansion supports the Centre's objectives to shape the future of time and frequency metrology and to

conduct research to the new optical frequency standards. Two rooms, with a surface area of around 50 square meters, have been specially designed for the accommodation of atomic clocks, and the new development of frequency standards, in addition with the high precise measurements of phase noise (near the carrier frequency), and of short term frequency stability (in terms of the Allan Deviation). They are located in the basement and covered by a Faraday cage, in order to avoid the influence of external electromagnetic fields.

All the laboratories are equipped with technical flooring, which provides an elevated structural floor above a solid substrate to the passage of mechanical services, coaxial and fibre optics connections, and wiring that lay underneath.

The building culminates in a walkable roof, with two separated zones, one prepared for geodetic GNSS antennas, and the other focused in TWSTFT VSAT antennas. Both are open-sky visibility and far away from obstacles that could difficult or reduce satellite signals. In the future it would be feasible for the accommodation of some optical antenna for time and frequency transfer by means of optical links.

Services:

Characterization of Clocks and Oscillators

Facilities for the practical realization, maintaining and dissemination of the national standard of the SI unit of time, the second, and the national time scale UTC(ROA). Singular instruments: 5120A High-Performance Phase Noise and Allan Deviation (ADEV) Test Set with Ultra Low Noise Floor, which provides accurate single sideband (SSB) phase noise and ADEV measurements. ROA operates a group of atomic clocks of two complementary types: active MHM-2010 hydrogen masers (two units) and 5071A caesium clocks (five units, and one more located at CEM's Dimensional Laboratory), that provide the national time scale UTC(ROA) and contribute to the generation of the world time system, Coordinated Universal Time (UTC).

Services offered:

Characterization of the accuracy with uncertainties up to 1×10^{-14} (τ = 1 day) and stability with uncertainty up to $1 \times 10^{-13} \times \tau^{-1/2}$ (for $\tau \geq 1$ s). Modeling of the aging and study of the nature of the instability. Diagnosis of the noise sources.

Characterization of the time links based on GNSS systems - Study of systematics delays of GNSS time links

Facilities for the practical realization, maintaining and dissemination of the national time scale. Singular instruments: The traditional and more widely used link for TAI (Time Atomic International scale)/UTC contribution and in general for precise time synchronization, is based on GNSS systems. ROA has several geodetic receivers: one GPS/GLONASS PolaRx3eTR receiver, one multichannel GTR50, two PolaRx4TR and one PolaRx5TR geodetic receivers with multi-constellation capability that includes Galileo, GPS, GLONASS, Beidou and IRNSS and finally

one multichannel GTR51 with access to Galileo, GPS and GLONASS satellite navigation signals. PolaRx5TR currently constitutes the receiver of the IGS station denoted as ROAG. All these receivers work using either of the usual techniques: Precise Point Positioning (PPP) that allows the computation of higher accuracy positions and precise behaviour estimation of the clock used as reference, or the traditional P3, and all in view (AV).

Services offered:

Access to the CGGTTS and RINEX files of geodetic receivers, for the traceability at the nanosecond level with respect to the used time reference UTC(k), or for the precise time synchronization between organizations or institutions that also generate their own files.

Characterization of time links based on TWSTFT systems - Study of systematics delays of TWSTFT time links

Facilities for the practical realization, maintaining and dissemination of the national time scale. Singular instruments: The main link for the contribution of ROA to TAI is based on a TWSTFT Ku-band station. This link is periodically calibrated, making it one of the most accurate time links (with an associated uncertainty less than 1 ns) in the contribution of clocks to the realisation of TAI.

Services offered:

Access to the ITU TWSTFT files, for the traceability at the nanosecond level with respect to the used time reference UTC(k). TWSTFT European network comprises eight Europe and two American laboratories.

Precise time and frequency dissemination via fiber optic link

Facilities for the dissemination of the national time scale. Singular instruments: Two standalone WR-ZEN modules that offer the White Rabbit features, exploiting its redundant connections for a reliable product in timing applications. This system combines ultra-stable reference clock, with low jitter and temperature compensated system, to enhance the synchronization. The ROA WR-ZEN modules can provide precise timing performance with sub-nanosecond accuracy.

Services offered:

Precise time and frequency (T&F) dissemination based on Precise Time Protocol (PTP) - White Rabbit. It allows high performance T&F signals distribution, with high level of requirements regarding to the characteristics of these signals.

Synchronization and tuning of high performance standards: hydrogen maser, caesium and rubidium

Facilities for the practical realization, maintaining and dissemination of the national standard of the SI unit of time. Singular instruments: active hydrogen masers, caesium clocks, OCXO (Oscilloquartz 8607-BGE), time and frequency transfer systems, and two Keysight 34970A data acquisition systems jointly with two SR620 time interval counters, to measure the time offset between each clock and the physical realization of UTC(ROA).

Services offered:

Software and hardware development for the realization of a clocks measurement system. Time synchronization of clocks in ROA facilities and through remote measurements, the latter by means of the common view GNSS technique. Practical implementation of mathematical model for atomic clocks.

Synchronization over the internet using the Network Time Protocol (NTP) protocol

Facilities for the dissemination of the national standard. Singular instruments: own design of NTP servers.

Services offered:

Network time synchronization to UTC(ROA) based on the NTP protocol. ROA has two highest level (stratum-1) and free access servers: *hora.roa.es* and *minute.roa.es*; which continuously attends more than 70M requests of synchronization every day, with an achievable uncertainty of around one millisecond at its best. Time certification systems by means of NTP protocol in symmetric P2P lines. The authentication key configuration for secure NTP communication.

4.7.- LCOE

The main facilities of the High Voltage Laboratory are the following:

- Lightning impulse tests 2000 kV
- Switching Impulse (Wet/Dry) 1500 kV
- Current impulse tests 200 kA
- AC 50/60 Hz Tests
  - Dry 900 kV
  - Wet 800 kV
- DC Tests
  - Dry 200 kV
  - Wet 200 kV
- Partial discharge measurement 500 kV
- RIV 400 kV
- Capacitance and Tan δ 200 kV
- Pollution tests 240 kV

- Short Circuit tests 50/60 Hz 80 kA RMS (208 kA Peak)
- Power Tests 50/60 Hz (2500 MVA) 36 kV, 20 kA
- Environmental tests -40 ºC / +60 ºC

On site testing facilities:

LCOE has different mobile generation and measurement systems to perform off line tests, standing out among them four resonant generators installed in mobile laboratories for PD measurements, with rated voltages from 36 kV to 680 kV, and output currents up to 83 A, allowing to test up to 400 kV insulated cables up to 12 km long, as well as Gas Insulated Switchgear (GIS).

LCOE has also two mobile systems to perform induced overvoltage tests with PD measurements on power transformers: the medium power transformers system up to 120 MVA transformers (enclosed in a 20 feet container), and the high power transformers system up to 700 MVA (mounted on a 13 m long trailer).

LCOE uses state-of-the art technologies for performing on-line PD measurements. Depending on the particular characteristics of the circuit, LCOE uses different type of PD sensors (HF, VHF and UHF), different filtering technologies (measuring frequency, band selection, wavelet filter, etc.) to differentiate the electrical noise from the PD signals, different PD location techniques (reflectometry, GPS, etc.), and different ways for identifying the detected PD sources with the type of fault or cause that origins the PD signals. LCOE offers either periodical or continuous insulation monitoring services, by means of PD measurements on electrical grids, which allows analysing the time evolution of PD patterns and evaluate its critical nature.

LCOE disposes also of tools and measuring equipment to perform transient overvoltages analysis and measurements. Burying of high voltage cables and their connection to GIS substations have created numerous overvoltages problems and insulation failures. LCOE performs specific studies of transients in the high voltage electrical grids, especially on the insulated high voltage cables and their connection to GIS and aerial high voltage lines. The studies are made using the ATP software and other own tools, developed for determining the over-voltages in the screen of the high voltage cables that are connected in different configurations (cross-bonding, single point with or without earth conductor).

The developed tool allows modelling any of the connection ways between the screens of high voltage cables, even if they are bonded to aerial lines and GIS, in order to be able to evaluate the most unfavourable conditions facing different types of fault (fault in the substation, far occurring fault and the siphon effect). This tool has been used by the designers of new insulated lines as well as for the already existing ones. Situations, such as the transition from an aerial to buried line to avoid crossing a highway, or going out from a substation through an insulated cable are practical cases commonly simulated in order to choose the best solution. ATP studies and on site measurement have allowed to model and predict the over-voltages that may appear, in order to control its effect by means of a properly selection of voltage limiters and the earthing of the screens.

LCOE has mobile high voltage standards installed in vehicles, to provide calibration service to independent or manufacturer owned testing labs, as well as to calibrate high voltage and current transformers installed on the electrical substations. The recognition of LCOE by the Spanish authorities as a verifier of electrical measurements entity allows the issue of Initial Verification Certificates for these instrument transformers, when they are going to be used in combination with energy meters.

Summary of on-site facilities:

- Mobile High Voltage Laboratory. Resonant Mobile Generators
  - 260 kV / 83 A, 20 Hz - 300 Hz
  - 680 kV / 3 A, 20 Hz - 300 Hz
  - 36 kV / 17 A, 20 Hz - 300 Hz
- Power Transformer Testing: up to 50 kV / 1000 kVA, 50 Hz - 115 Hz
- Partial discharge measurement and monitoring systems
- Electric power quality measurements

LCOE can offer the following services in the metrology and measurement framework focused on High Voltage measurements, High Power tests and calibration services according to CIPM-MRA that can be consulted in the BIPM data base as well as ISO / IEC 17025 calibration of standards and HV measuring systems or other services as research projects and investigation tests.

Services offered: Special training courses on

- High Voltage regulations and Standards.
- Insulation coordination course.
- Installations and equipment design.
- HVDC electrical grids.
- Metrology and HV measurements procedures and testing.

Services offered:

Measurements and testing on a wide range of HV equipment, according to IEC, ANSI or CENELEC standards:

- High Voltage Test Techniques. IEC 60060 / IEC 60270 / IEEE 4.
- Instrument transformers. IEC 61869 / IEEE C57.13.
- Power transformers. IEC 60076 / IEEE C57.12.
- HV / MV Cables and their accessories. IEC 60840 / IEC 62067 / IEC 60502.
- HV / MV Insulators. IEC 60383 / IEC 61109 / IEC 60137.
- HV / MV Switchgear and control gear. IEC 62271.
- Surge Arresters and protective devices. IEC 60099 / IEC 61643 / UNE 21186.
- Aircraft Industry. EUROCAE ED-105 / RTCA DO-160.
- Live working materials and insulated equipment.

Services offered: Metrology and calibration on a wide range of instruments and HV equipment, including on site calibrations:

- DC Dividers up to 1.0 MV and AC Dividers up to 3.5 MV
- Lightning Impulse Dividers up to 3.0 MV
- Switching Impulse Dividers up to 2.5 MV
- Voltage transformers up to 500 kV
- Current transformers up to 12.6 kA
- Partial discharges instruments and calibrators from 0.1 pC up to 2000 pC
- Low voltage power measurements (transformer loss).
- Capacitance & tan ∂ bridge calibrations.
- Passive standards, resistances, capacities and inductances.
- High resolution standard DMM and standard calibrators. AC-DC transfers.
- Current or voltage transformers and comparators.
- Transformation ratio measuring bridges.
- Capacity and dissipation factor measuring bridges.
- RLC and resistance measuring bridges.
- FRA and SFRA analyzers.
- Power and energy analyzers or flicker and harmonics meters.
- DMM, clamps, electrical safety testers, ohmmeters, ground resistance meters,
- Low voltage testers, residual current devices.
- Tachometers and frequency meters.
- Optic equipment such as luxmeters and luminometers.

Services offered: R&D. Research Development and innovation.

High voltage underground power lines studies:

- Cable sheaths overvoltage studies. Temporal and transient overvoltages.
- Short circuit currents analysis.
- ATP software and LCOE software analysis.
- Selection of sheath voltage limiters.
- Insulation Coordination analysis.

Studies and measurements on Gas Insulated Substations (GIS):

- On-site testing and measurements.
- Very Fast Transients overvoltages studies or measurements.
- Insulation Coordination analysis.
- ATP software modelling.

5.- How to access to the services

CEM & LL.AA. Metrology network is opened to all player (academia, research institutions and industry, national and abroad) promoting the internationalization of metrology as well as encouraging the search of solutions for addressing the main great global challenge in a multidisciplinary approach. In addition, the network offers the training of scientific personnel and technologists, as well as support to research groups and companies for their participation in national and international R & D & i projects.

The Network offers access and use of the infrastructures of the seven belonging Laboratories to public and private sector researchers, both national and international. The access to the facilities must be requested through the different Laboratories and will be able to be accessed under their official or special rates.

The services offered by the seven Laboratories of the Network are accessed by filling out an electronic application. The request can be made in generic form or for a specific Laboratory.

The Network has its access open permanently.

The access to infrastructures could be made in a combined or separate way in two modalities:

- Modality 1
  Processes performed by technologists of one of the seven nodes of the network (Encomienda)

  In this modality, the work proposed by the applicant researcher will be carried out by technicians specialized in the different fields offered. This is the most efficient way of working, since for each team there is a technician with several years of experience in its use. The technicians at all times will inform and advise the applicant about the evolution of the processes. This modality is the way to also access to processes when the complexity of the use of an equipment does not allow that it can be used by the own applicant.

- Modality 2
  Processes made by the applicant researchers themselves (Self-service)

  Some of the processes and equipment available in the network infrastructures can be used by researchers outside the nodes of the network as long as they demonstrate sufficient knowledge to do so. In case this is not so, the external investigator can request a training that allows him/her to successfully pass a pre-qualification process necessary to directly access the use of the equipment requested to carry out his project. This modality makes the function of formative stage for the researcher and later of practical stage in the use of an equipment or technology.

In case the requested action requires the participation of more than one node, they will agree between them and the contact back with the applicant will be carried out in a coordinated way depending on the weight of the participation of each node in the application. In modality 1, all the work will be performed by the technicians of the nodes.

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