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Industrial Technology Research Institute

Report on Activities and Measurement Capabilities in Mass and Related Quantities of CMS/ITRI

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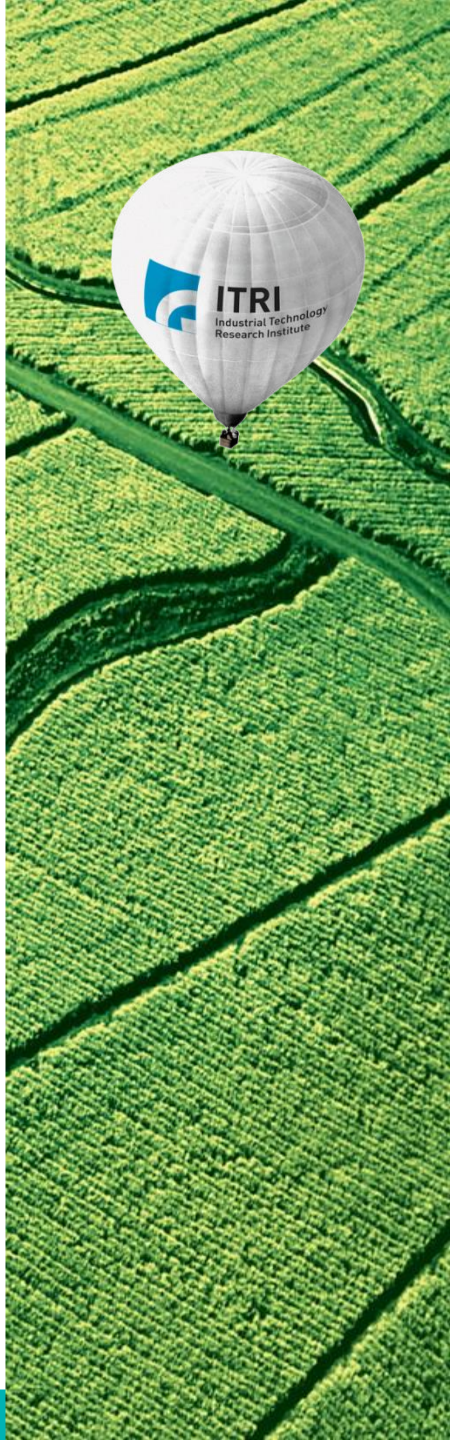
Center for Measurement Standards

18th meeting of the CCM

20-21, May, 2021



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Industrial Technology Research Institute

a nonprofit R&D organization engaging in applied research and technical services

2030 Technology Strategy & Roadmap

Smart Living

Enjoying High Quality
Living & Lifestyle

Quality Health

Keeping Healthcare
Good & Affordable

Sustainable Environment

Creating a Low-Carbon,
Energy-Saving &
Circular Community

Intelligentization Enabling Technologies

for boosting multiple applications

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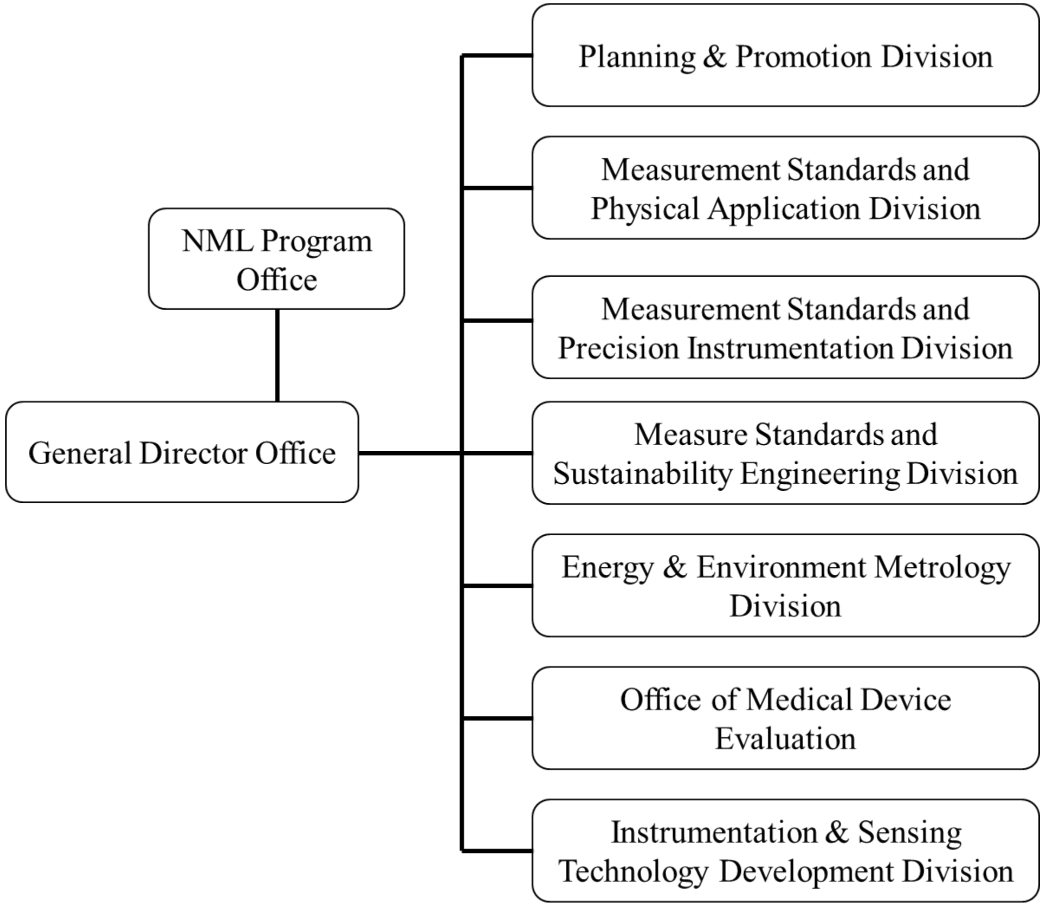


Organization chart of CMS/ITRI

- ITRI's largest linking center
- One of the DIs for Chinese Taipei's participation in CIPM MRA
- National Measurement Laboratory (NML) Project - Establishing and maintaining national measurement standards in area of **AUV, EM, L, M, PR, QM and T**

Center for Measurement Standards

2021 Project Executed by NML

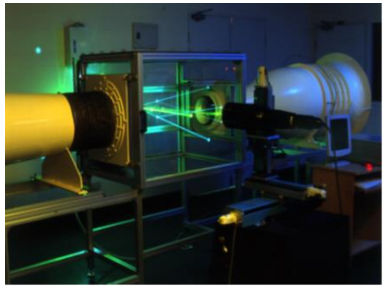
Standards Maintenance and International Equivalence	Industrial Metrology	Development of Legal Metrology Technology	National Metrology Infrastructure Refinement
International Equivalence	Nano-particle Analysis and Standard Technologies	Technical Regulation for Type Approval of Active Electrical Energy Meters	Single Particle ICP Mass Spectrscopy
Industrial Service	Critical Dimension Metrology for Advanced Semiconductor Manufacturing Processes	Pre-research on Battery Metering Mechanism of Electric Scooter	Hydraulic Force Calibration Machine
System Maintenance	Optical Measurement Technology for Lithography Process	Draft Technical Regulation for Initial and Subsequent Verification of Gas-oil Ratio Detectors	Microwave Scattering Parameter and Impedance Measurement
			High Pressure Gas Flow Calibration

Fluid Flow Standards

Standard and calibration system	Measurement range	Type
F01: Large Water Flow Calibration System	(10 to 8000) L/min	Primary standard
F02: Small Water Flow Calibration System	(2 to 700) L/min	Primary standard
F03: Low-Viscosity Oil Flow Calibration System	(60 to 6000) L/min @ 2.6 mm^2/s to 4.8 mm^2/s	Primary standard
F04: High-Viscosity Oil Flow Calibration System	(60 to 6000) L/min @ 37 mm^2/s to 150 mm^2/s	Primary standard
F05: High Pressure Gas Flow Calibration System	(15 to 12000) Sm^3/h	Primary standard
F06: Low Pressure Gas Flow Calibration System - Piston Prover	(0.002 to 24) L/min	Primary standard
F08: Low Pressure Gas Flow Calibration System – (Bell Prover:600 L)	(20 to 1000) L/min	Primary standard
F10: Air Speed Calibration System	(0.5 to 25) m/s	Primary standard
F11: Micro Flow Calibration System	0.1 µL/min to 10 mL/min	Primary standard
F12: Low Pressure Gas Flow Calibration System (PVTt) – PVTt Method	0.01 L/min to 300 L/min	Primary standard


Water Flow and Oil Flow Calibration System

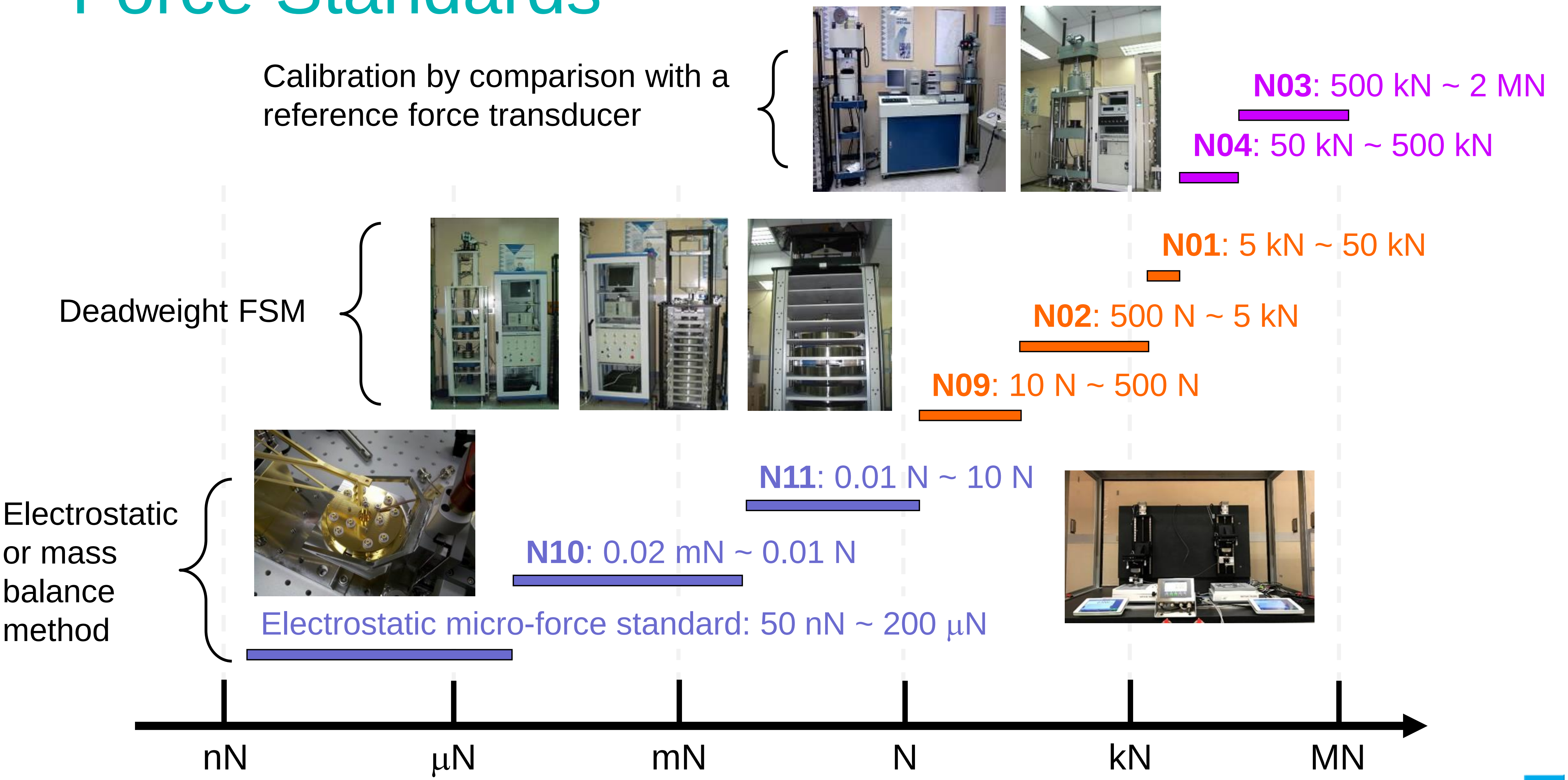

High Pressure Gas System


Air Speed Calibration System


Low Pressure Gas System


Micro Flow Calibration System

Force Standards



Gravimetry Standards

Absolute gravity measurements system

- CMS has two FG5 (#224 and #231) absolute gravimeters as national standard of the acceleration of free fall
- Standard uncertainty is 20 nm/s^2

Relative Gravimeter

- LACOSTE-ROMBERG gravity meters #1184 and #1200
- Standard uncertainty is 100 nm/s^2

Superconducting gravimetry

- High quality continuously recording gravimeters
- Sensitivity of the instrument reaches the level of 10^{-12} nm/s^2

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Hardness Standards

Rockwell Hardness Calibration System
The system provides calibration for hardness with a measurement range of 29.4 N to 1470 N, the uncertainties are as follows,

0.30 HRA
0.40 HRB
0.30 HRC

Vickers Hardness Calibration System
The system provides calibration for hardness with a measurement range of 9.8 N to 294.2 N, the relative uncertainty is 3.0 %.

Micro Vickers Hardness Calibration System
The system provides calibration for hardness with a measurement range of 489.46 mN to 9789.14 mN, the relative uncertainty is 6.7 %.

Nanoindentation Calibration System
The system provides calibration for hardness and reduced modulus with a measurement range of 0.2 mN to 10 mN, the relative uncertainty is 2.4 % and 3.1 %, respectively

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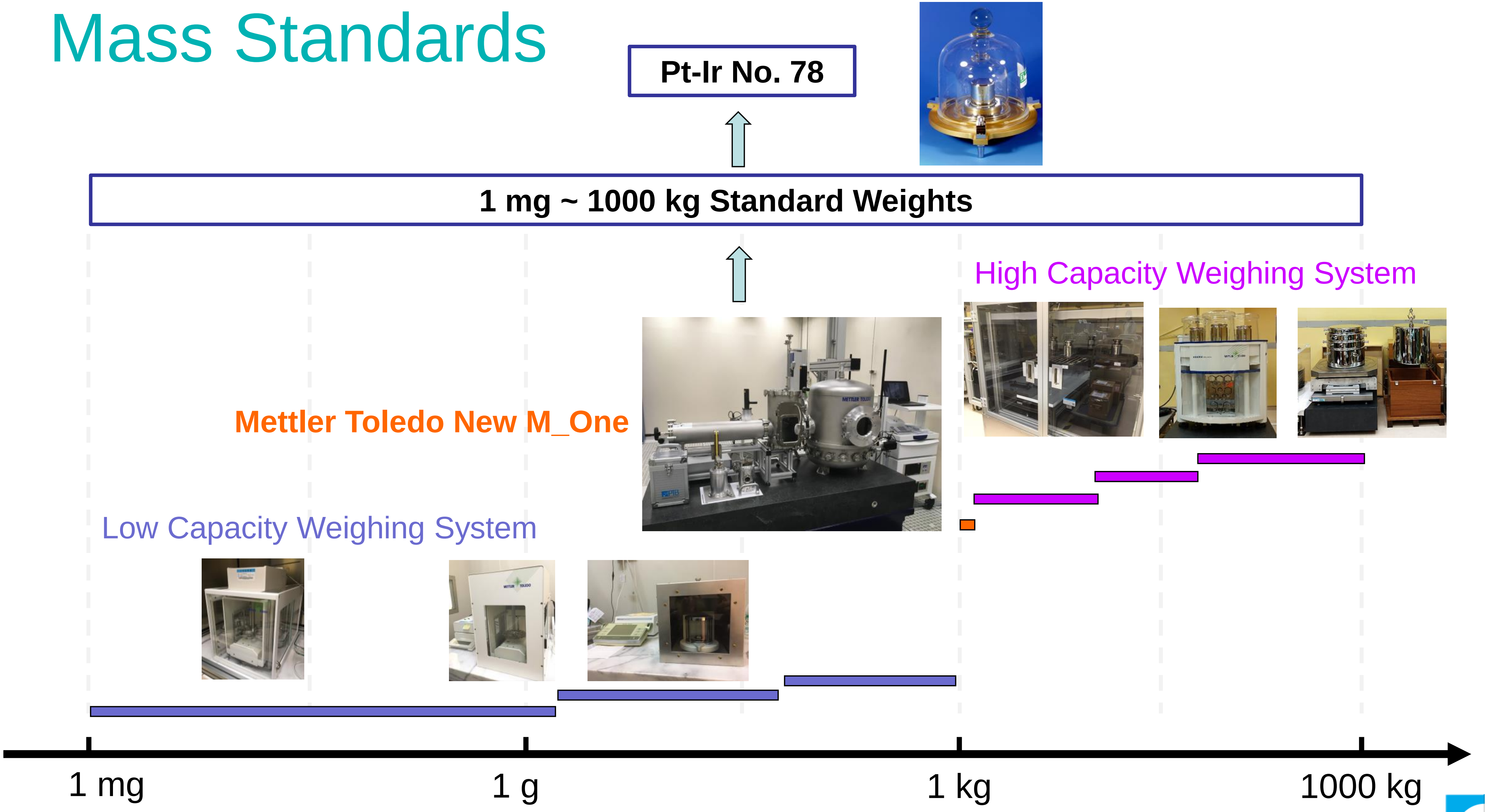
Mass Standards



Pressure Standards

Gas pressure calibration system
The system provides calibration for gas pressure gauges with the measurement range from **1 Pa to 10 kPa** with the uncertainty of **0.25 Pa** and the measurement range from **5 kPa to 7000 kPa** with relative uncertainty of **3.4E-05 to 4.2E-05**.

Hydraulic pressure calibration system
The system provides calibration for liquid pressure gauges with a measurement range from **2.8 MPa to 280 MPa** with the relative uncertainty of **3.3E-05 to 7.4E-05**.

Vacuum Standards

Vacuum Gauge Comparative Calibration System
The system provides calibration for vacuum gauges with a measurement range of **0.1 Pa to 100 kPa**, the relative uncertainty is **1.8 %**.

Dynamic Expansion Vacuum Calibration System
The system provides calibration for vacuum gauges with a measurement range of **5×10^{-6} Pa to 8.6×10^{-3}Pa**, the relative uncertainty is between **4 % to 9 %.**

Research & Development

- New kg realization via XRCD method
- Development of Optical Pressure Standard
- Micro-force/small mass standard
- Natural gas metrological research

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New kg realization via XRCD method

Planck constant *h*

Primary mass standard **(vacuum)**

Vacuum to air transfer

Secondary kg standard **(air)**

Dissemination

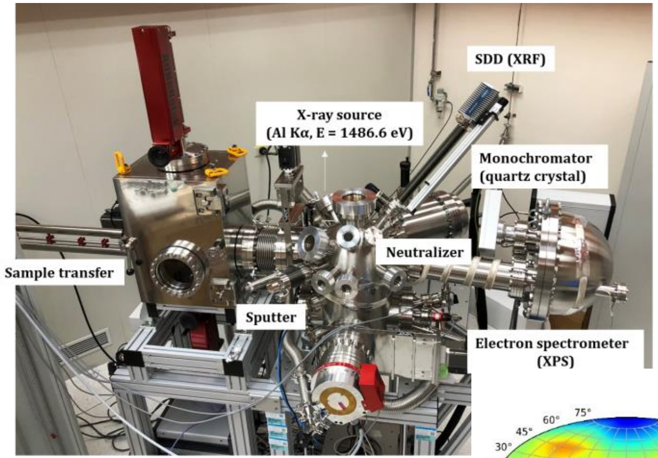
1 mg – 1000 kg

- Evaluate the mass of the Si-sphere *under vacuum*

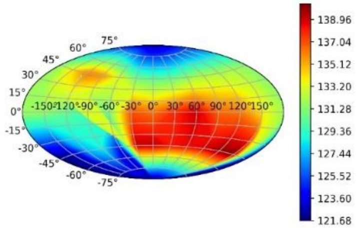
$$m_{sphere} = \underbrace{\frac{8V_{core}}{a^3}\frac{\sum_i x(^i\mathrm{Si})A_r(^i\mathrm{Si})}{A_r(e)}\frac{2hR_\infty}{c\alpha^2} - m_{defect}}_{m_{core}} + m_{SL}$$

Surface layer model of Si-sphere

✓ XRF/XPS surface analysis system for the measurement of m_{SL}



Total mass deposition of oxygen: **36.68 ± 3.37 μg**



✓ Evaluate m_{sphere} *under vacuum* based on m_{SL} and other pre-determined parameters of m_{core}

X_i	x_i	$u(x_i)$	Unit	$c_i(y_j)$	$u_i(y_j)$
M_e	5.485799E-07	1.65E-16	$kg \cdot mol^{-1}$		
Mu	1.000000E-03	3.00E-13	$kg \cdot mol^{-1}$	1000	3.00E-10
$A_r(e)$	5.485799E-04	1.60E-14		1800	2.90E-11
h	6.626070E-34	0.00E+00	$kg \cdot m^2 \cdot s^{-1}$		
R_∞	1.097373E+07	2.10E-05	m^{-1}	9.10E-08	1.90E-12
c	2.997925E+08	0	$m \cdot s^{-1}$		
α	7.297353E-03	1.10E-12		270	3.00E-10
M_{Si}	2.797694E-02	1.40E-10	$kg \cdot mol^{-1}$	36	5.00E-09
V_{core}	4.310555E-04	5.06E-12	m^3	2300	2.20E-08
a	5.430996E-10	1.46E-18	m	5.50E+09	8.10E-09
$m_{deficit}$	1.740E-08	3.98E-09	kg	1	4.00E-09
m_{SL}	6.5840E-08	6.66E-09	kg	1	6.70E-09
m_{sphere}	1.0000783890	1.91E-8	kg		

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New kg realization via XRCD method

Planck constant *h*

Primary mass standard **(vacuum)**

Vacuum to air transfer

Secondary kg standard **(air)**

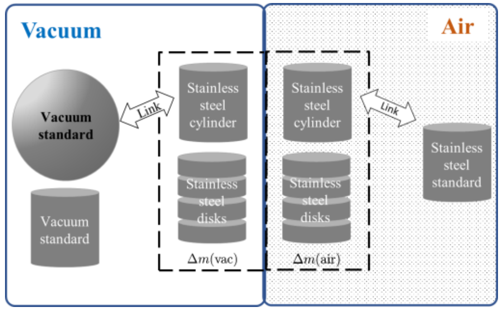
Dissemination

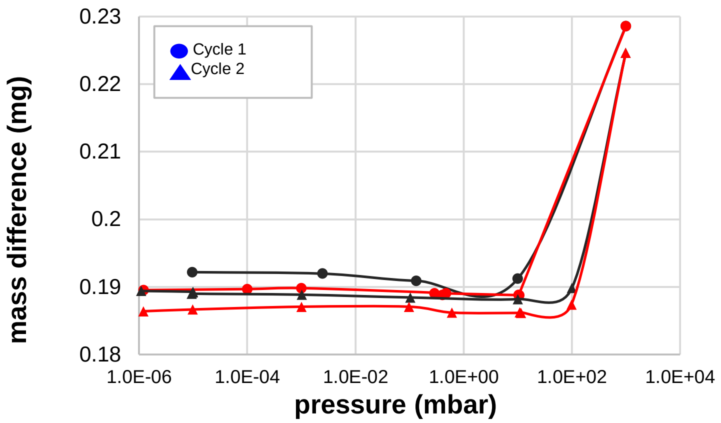
1 mg – 1000 kg

- Vacuum-air transfer the mass from the Si-sphere to the stainless steel kg standard

$$m_{ss,air} = m_{ss,vac} + A_{ss} \cdot s \quad \rightarrow \quad s = \frac{\Delta m_{vac} - \Delta m_{air}}{\Delta A}$$

✓ Sorption coefficient ***s*** estimated by measuring the mass difference of sorption artefacts in air and vacuum with vacuum mass comparator.





Vacuum mass comparator

Sorption artefacts

	Δm_{vac} (mg)	Δm_{air} (mg)	ΔA (cm^2)	s (μg/cm^2)
10 disks	-0.1865	-0.1717	434.4310	0.0342

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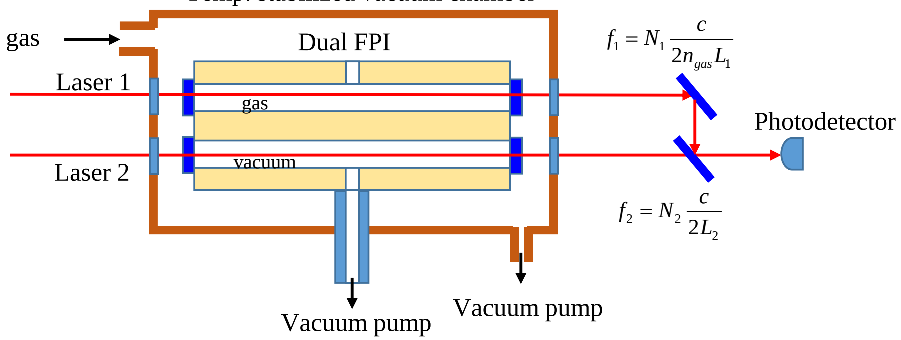
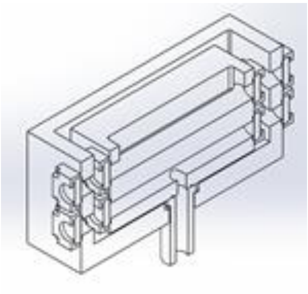
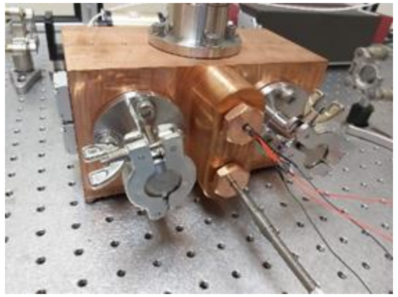
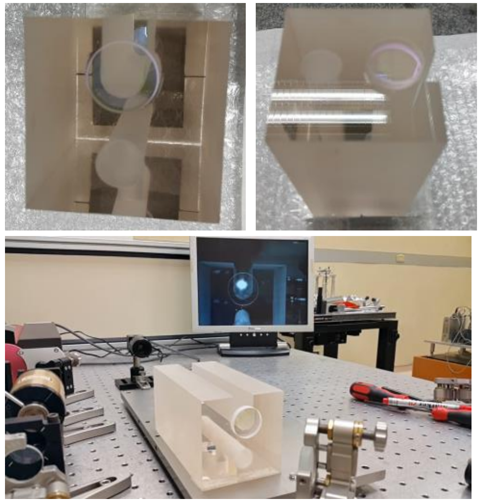
Development of Optical Pressure Standard

Direct SI traceable: $p_{gas} = \rho_{gas}\, k\, T$

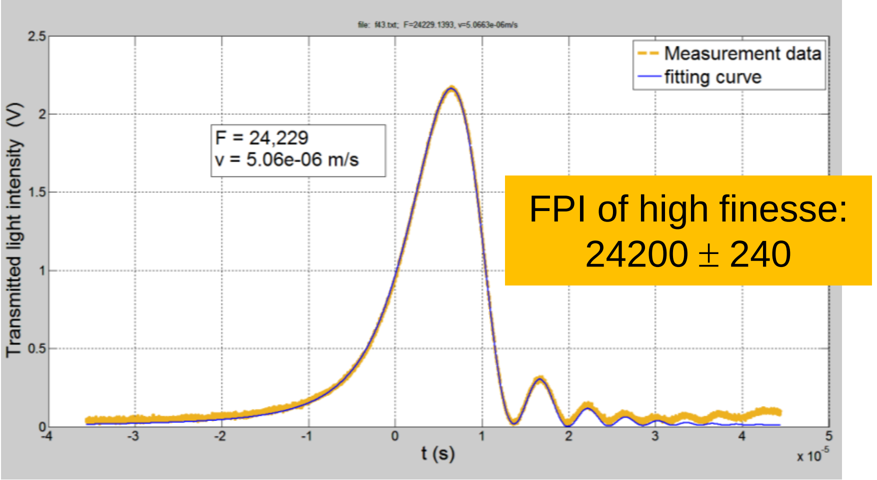




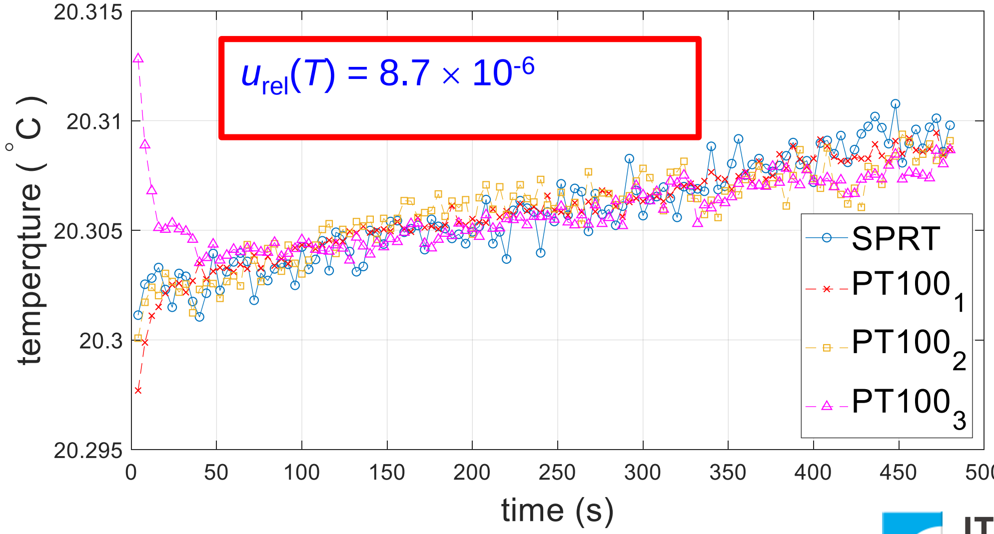




Ring down effect: data & curve fitting



Fabry-Perot Interferometer for refractive index measurement



Temperature drift of copper vacuum chamber

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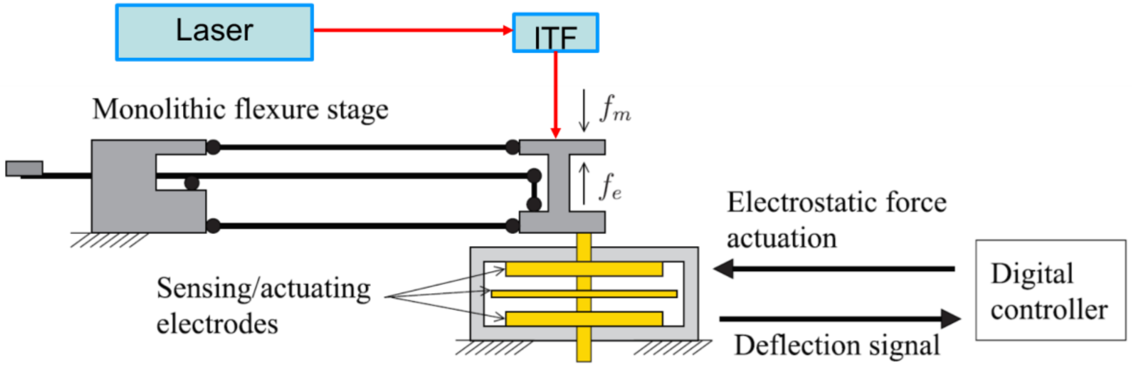
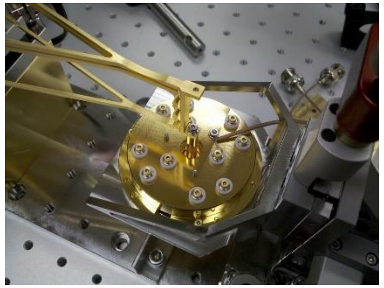
Microforce/small mass Standard

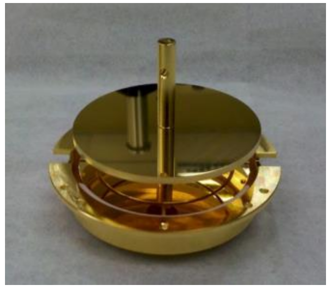
Electrostatic Sensing and Actuating Force Balance

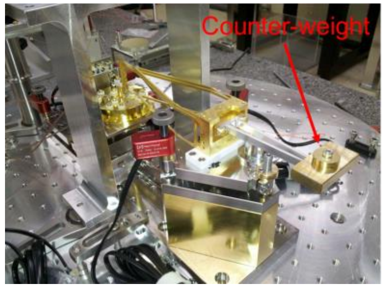
- Range: $\leq 200\ \mu\text{N}$
- Uncertainty: $\sqrt{(4.7 \times 10^{-9})^2 + (1.4 \times 10^{-4} \Delta f_e)^2}$ N

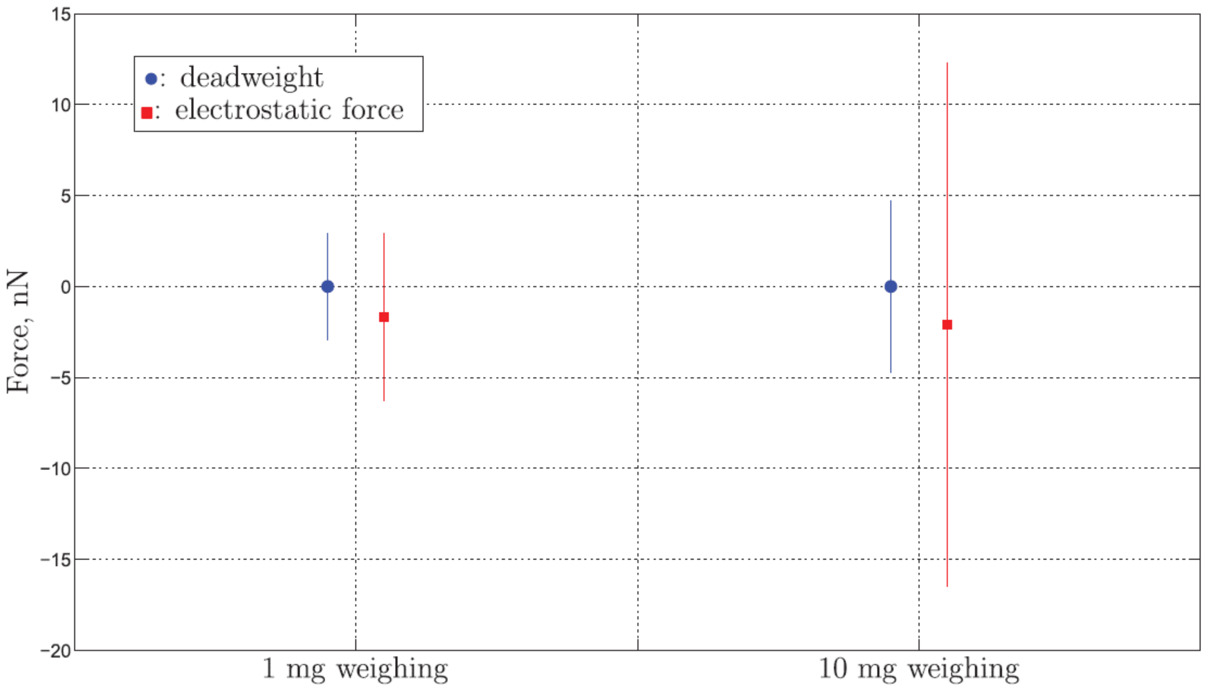


(Differential Capacitive Sensing)

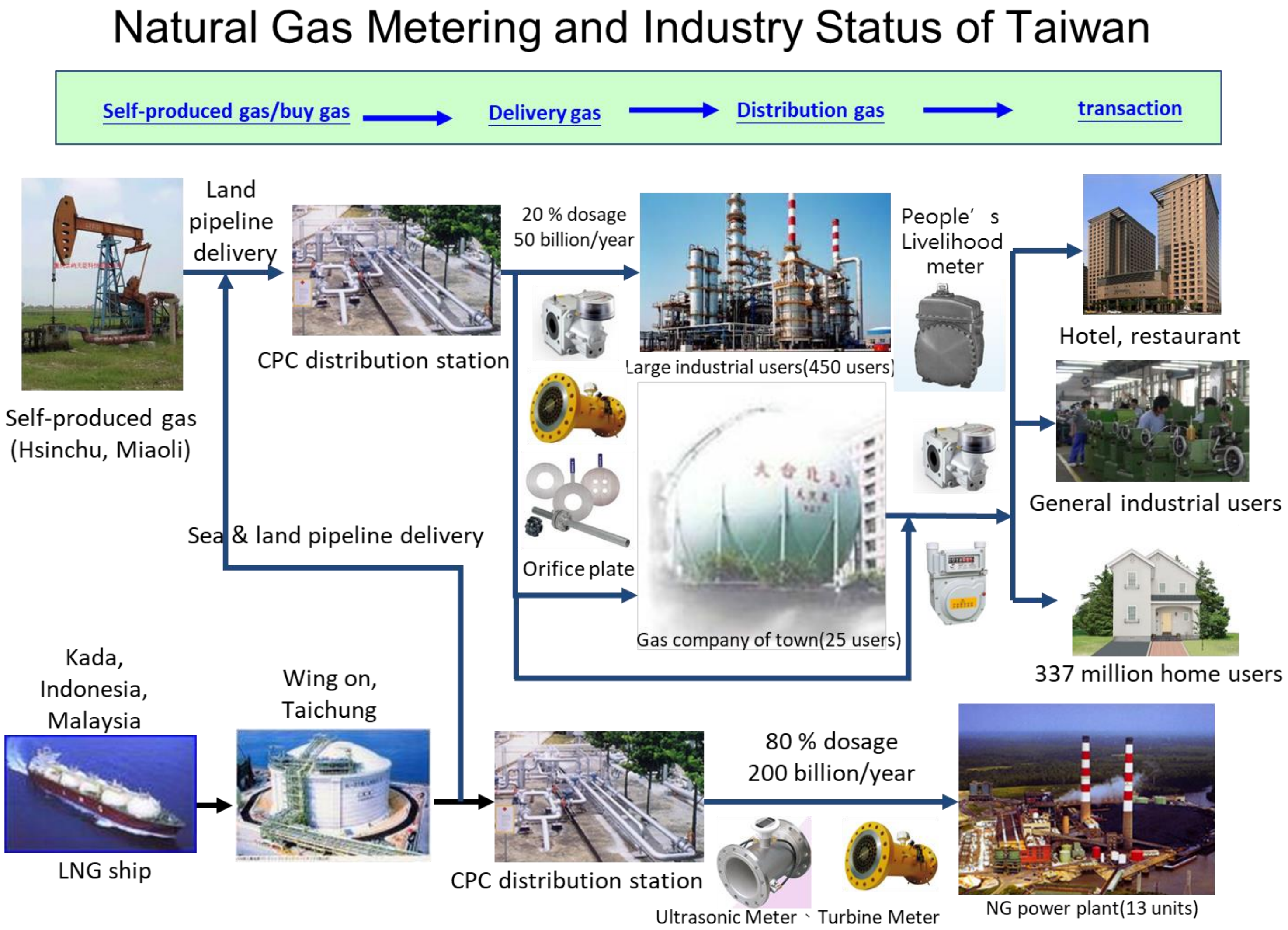








Natural gas metrological research



Participation in International Standardized Committees

- **CCM**
  - Member of CCM-WGM
  - Observer of CCM-WGPV
- **APMP** – Asia Pacific Metrology Programme
  - Full Member since 1992
  - Technical Committee for Mass and Related Quantities: Member, Chair (2019 ~ 2021)
  - Medical Metrology Focus Group: Member, Chair (2015 ~ 2019)
- **APMF** – Asia-Pacific Measurement Forum on Mechanical Quantities
  - International Program Committee Member
  - Hosting Organization (APMF 2013)
- **IMEKO** *TC16* (Pressure and Vacuum Measurement)
  - Member

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Future works

- Commissioning the XRF/XPS surface analysis system
  - XPS is under test and final integration
  - Contribute to the future kg realization comparisons
- Dynamic Measurements
  - Development of dynamic force/torque standard under way
  - Other mechanical quantities under evaluation
- Establishing quantum based optical pressure standard

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