

## Report from PTB for CCM 2021

### Part I

#### 1. Main research activities in Mass, Force/Torque, Pressure/Vacuum, Density, Viscosity, Hardness and Fluid Flow

##### Mass

- Participation in the first CCM key comparison of realisations of the kilogram (CCM.M-K8.2019) with two  $^{28}\text{Si}$  spheres (AVO28S8c and Si28kg01a) made from two different crystals as primary mass standards with relative standard uncertainties ( $k = 1$ ) of  $1.6 \times 10^{-8}$  and  $1.4 \times 10^{-8}$ , respectively. One platinum-iridium prototype and one  $^{\text{nat}}\text{Si}$  sphere were used as travelling standards.
- Investigation of the repeatability of a cleaning method for silicon spheres by gravimetric measurements and by XRF/XPS analysis of the surface layers; results show that the repeatability of the cleaning method applied at PTB can be characterised by a standard deviation in the order of two micrograms
- Correction of PTB mass scale in the order of  $+1 \times 10^{-8}$  based on BIPM corrections provided for national prototypes as a result of the recalibration of the BIPM working standards and the introduction of the consensus value (annex on the maintenance of the BIPM mass unit of the “BIPM note on the impact of the beginning of Phase 2 of the kilogram dissemination process on BIPM mass calibrations”), implementation of changes in QM system, update of CMCs and information of customers

##### Force/Torque

- Traceability of probing forces for AFM, stylus instruments, CMM and nanoindenters.
- Development und investigation of methods for traceability of force measurement for continuous and dynamic applications (<https://www.ptb.de/empir2018/comtraforce/home/>).
- Development of methods for traceable mechanical and electrical power measurement for efficiency determination of wind turbines (<https://www.ptb.de/empir2020/windefcy/home/>).
- Development of a torque standard machine with a capacity of  $5 \text{ MN}\cdot\text{m}$  with the possibility of an extension to  $20 \text{ MN}\cdot\text{m}$  in the new competence center for wind energy
- Development of standards and methods for the multi-component calibration of force and torque transducers
- Development and investigation of low force standards for the range from  $1 \text{ N}$  down to  $1 \text{ nN}$
- Development and investigation of low torque standards for the range from  $1 \text{ N}\cdot\text{m}$  down to  $1 \text{ mN}\cdot\text{m}$

##### Pressure/Vacuum

- Pressure realization by fundamental measurement of refractivity
- Development of a new type of ionization vacuum gauge suitable as transfer standard
- Validation of a new high and medium vacuum standard made of aluminum (static expansion system)

- Development of an oil-based interferometric micromanometer with an integrated oil density measurement facility as a primary pressure standard for 2 kPa range of absolute and gauge pressure.
- Characterisation of force-balanced piston gauges as primary pressure standards in the range of 15 kPa based on state-of-the-art dimensional metrology and methods of the rarefied gas dynamics.
- Development of methods and standards for reliable calibration of low gauge pressures and particularly negative gauge pressure based on pressure balance and liquid column manometry.

## **Density**

- Development of a robotic system for the automatic volume and density calibration of a set of weights
- Development of a high-precision hydrostatic system to compare 1 kg spheres manufactured from natural and isotopically enriched silicon
- Development and validation of a liquid density measurement facility for elevated pressures up to 700 bar
- Development and investigation of traceable liquid density measurements under wide conditions (EMPIR 17RPT02 rhoLiq, Establishing traceability for liquid density measurements)

## **Hardness**

- Development of fast measurement techniques for nanomechanical characterization of nanowires used in energy harvesting nanodevices (EMPIR 19ENG05 NanoWires "High throughput metrology for nanowire energy harvesting devices", <https://www.ptb.de/empir2020/nanowires/project/>)
- Automation of Rockwell measurement systems based on measurements at the preload phase (TransMet Project)

## **Fluid-Flow**

### **1. R&D activities**

- Development of a new wind primary Lidar standard for 3D wind vector measurements and measurement heights between 10 m and 300 m with high spatial and time resolution.
- Development of test infrastructure for calibration and testing as well for conformity assessments (type approvals) with gaseous fuels containing hydrogen up to 100%.
- Development of a new primary standard for high-pressure natural gas measurement for operation in a closed loop test rig.
- Development of infrastructure and test regimes for the characterization of flow meters closer to operating conditions
- Research in the use of cavitation nozzles in liquid flow metrology
- Development of transfer setups for bilateral and intercomparisons of flow meters

## 2. Participation in relevant comparisons after/until 2019

| Comparison ID                            | Subfield                   | Number of Participants                   | Pilot            | Status  | Years       |
|--|----------------------------|--|------------------|---|-------------|
| EURAMET.M.D-K1.1                         | Density of silicon spheres | 15 from EURAMET, 1 from APMP (NMIJ/AIST) | PTB              | Completed, final report: Metrologia <b>57</b> (2020) Tech. Suppl. 07028 | 2008-2020   |
| EURAMET EMPIR 17RPT02 rohLiq             | Density of liquids         | 12                                       | IPQ              | In progress   | 2018-2021   |
| EURAMET EMPIR 17RPT02 rohLiq             | Density of liquids         | 12                                       | IPQ              | In progress   | 2018-2021   |
| CCM.D-K5 and EURAMET comparison No. 1440 | Density of liquids         | 15                                       | BEV              | In progress   | 2019-       |
| CCM.D-K5 and EURAMET comparison No. 1440 | Density of liquids         | 15                                       | BEV              | In progress   | 2019-       |
| EURAMET.M.FF-S10                         | Fluid Flow, Gas            | 12                                       | VTT/ MIKES       | published   | 2015-2019   |
| COOMET.M.FF-S9                           | Fluid Flow, Gas            | 6  | VNIIR            | published   | 2019-2020   |
| EURAMET.M.H-S2.a.b                       | Hardness                   | 3  | INRIM            | Measurements completed  | 2018-2019   |
| CCM.H-K3                                 | Hardness                   | 5  | INRIM            | Protocol complete   | 2020        |
| CCQM-P160                                | High purity chemicals      | 8  | PTB              | Completed, report published as Metrologia paper                         | 2014-2020   |
| EURAMET.M.D-K4.2020                      | Hydrometers                | 9  | INRIM            | In progress   | 2020-       |
| EURAMET.M.M-S7                           | Mass standards             | 21                                       | MIRS             | Measurements completed, Draft A in progress                             | 2017 - 2019 |
| CCM.M-K8                                 | Mass standards             | 7  | BIPM             | Completed, Final report: Metrologia 57 (2020) 07030, 21 pages           | 2019 - 2020 |
| EURAMET.M.M-K7                           | Mass standards             | 12                                       | UME              | Measurements in progress  | 2020 -      |
| APMP.M.P-K9                              | Pressure                   | 12                                       | KRISS            | Completed, Final report: Metrologia 57 (2020) 07017, 51 pages           | 2010-2020   |
| EURAMET.M.P-K1.c                         | Pressure                   | 21                                       | FORCE Technology | Completed, Final report: Metrologia 57 (2020) 07022, 43 pages           | 2011-2020   |
| EURAMET.M.P-K1.c                         | Pressure                   | 21                                       | FORCE Technology | Completed, Final report: Metrologia 57 (2020) 07022, 43 pages           | 2011-2020   |
| APMP.M.P-S9                              | Pressure                   | 3  | NIMT             | Completed, Final report: Metrologia 57 (2020) 07012, 18 pages           | 2016-2020   |
| EURAMET.M.P-K15.1                        | Pressure                   | 4  | PTB              | Approved for equivalence  | 2017-2020   |
| CCM.P-K4.2012.1                          | Pressure                   | 2  | NIST             | Protocol complete   | 2019-       |
| EURAMET.M.P-K4.2020                      | Pressure                   | 5  | PTB              | In progress   | 2019-       |
| CCM.P-K16                                | Pressure                   | 9  | CENAM            | In progress   | 2020-2022   |

| <b>Comparison ID</b>                  | <b>Subfield</b> | <b>Number of Participants</b> | <b>Pilot</b> | <b>Status</b>               | <b>Years</b> |
|---------------------------------------|-----------------|-------------------------------|--------------|-----------------------------|--------------|
| CCM.P-K17                             | Pressure        | 9                             | CENAM        | In progress                 | 2020-2022    |
| CCM.P-K18                             | Pressure        | 9                             | CENAM        | In progress                 | 2020-2022    |
| CCM.V-K3                              | Viscosity       | 19                            | NMIJ         | Report in progress, Draft A | 2012-xxx     |
| SIM.M.FF-S9                           | Water flow      | 6                             | PTB/CENAM    | Report in progress, Draft A | 2015-2019    |
| EURAMET Project No. E 1507            | Water flow      | 13                            | CMI          | In progresss                | 2020-2021    |
| EURAMET Project E. 1506 – Pilot study | Water flow      | 8                             | CETIAT       | Report in progress, Draft A | 2020-2021    |

### 3. List of relevant publications since 2019

#### Mass

*D. Knopf, Th. Wiedenhöfer, K. Lehrmann, F. Härtig: A quantum of action on a scale? Dissemination of the quantum based kilogram, Metrologia 56 (2019) 024003*

*Bernd Güttler, Olaf Rienitz, Axel Pramann, The Avogadro Constant for the Definition and Realization of the Mole, Annalen der Physik, 531, 2019, 1800292*

*Bernd Güttler, Horst Bettin, Richard J C Brown, Richard S Davis, Zoltan Mester, Martin J T Milton, Axel Pramann, Olaf Rienitz, Robert D Vocke, Robert I Wielgosz, Amount of substance and the mole in the SI, Metrologia 56 (2019) 1-14 044002, doi.org/10.1088/1681-7575/ab1fae*

*Bernd Güttler, Peter Becker, Horst Bettin, Axel Pramann, Olaf Rienitz, Mol und Avogadro-Konstante, Bunsenmagazin (21) 2019, 121-128*

*Rainer Stosch, Olaf Rienitz, Axel Pramann, Bernd Güttler, Eine neu definierte SI-Einheit für die Chemie – Wie viele Moleküle enthält ein Mol?, Chemie in unserer Zeit, 53 (2019) 256-262, <https://doi.org/10.1002/ciuz.201900014>*

*Axel Pramann, Olaf Rienitz, Bernd Güttler, Die Revision der SI-Einheit Mol: Hintergründe und der Einfluss auf die zukünftige Arbeit des praktischen Chemikers, tm - Technisches Messen, 2019, <https://doi.org/10.1515/teme-2019-0084>*

*Axel Pramann, Olaf Rienitz, The molar mass of a new enriched silicon crystal: maintaining the realization and dissemination of the kilogram and mole in the new SI, Eur. Phys. J. Appl. Phys. 88, 20904 (2019)*

*N. Rogge, S. Lin, C. Rothleitner, and S. Vasilyan, "Excitation frequency dependent deviations during the "velocity mode" of Bl measurements in the Planck-Balance," in Proc. Int. Conf. on 23rd IMEKO TC4 International Symposium, Xi'an, China), 2019.*

*S. Lin, C. Rothleitner, N. Rogge, „Amplitude estimation using three-parameter sine fitting algorithm in the Planck-Balance“, in Proc. Int. Conf. on 23rd IMEKO TC4 International Symposium, Xi'an, China), 2019.*

*S. Lin, C. Rothleitner, N. Rogge, Investigations on the sine fitting algorithm in the Planck-Balance. Proc. of 20. GMA/ITG-Fachtagung Sensoren und Messsysteme 2019, Nürnberg, Germany, 25-26 June 2019, pp. 547-553.*

*H. Bai, N. Rogge, C. Rothleitner, T. Fröhlich. Model based correction of motion deviations in the Planck-Balance, Proc. of 20. GMA/ITG-Fachtagung Sensoren und Messsysteme 2019, Nürnberg, Germany, 25-26 June 2019, pp. 554-560.*

*S. Lin, C. Rothleitner, L. Günther, D. Knopf, F. Härtig, N. Rogge, V. Vasilyan, F. Hilbrunner, T. Fröhlich. The Planck-Balance (PB2) - tracing the mass via electrical quantities, Messunsicherheit - Prüfprozesse 2019. - Düsseldorf: VDI Verlag GmbH, 2019, Seiten 53-65.*

*T. Fröhlich, N. Rogge, S. Vasilyan, F. Hilbrunner, C. Rothleitner, L. Günther, D. Knopf, S. Lin, F. Härtig. The Planck-Balance (PB2) - using a fixed value of the Planck constant to calibrate E2-weights, Messunsicherheit - Prüfprozesse 2019. - Düsseldorf: VDI Verlag GmbH, 2019, Seiten 41-52.*

*C. Rothleitner, H. Bettin, P. Becker, D. Knopf. Kilogramm und Planck-Konstante. Bunsenmagazin. Heft 1/2019. Seiten 13-20.*

Olaf Rienitz, Axel Pramann, *Comparison of the Isotopic Composition of Silicon Crystals Highly Enriched in <sup>28</sup>Si*, *Crystals* 2020, 10(6), 500, <https://doi.org/10.3390/cryst10060500>

Olaf Rienitz, Axel Pramann, Jochen Vogl, Kyoung-Seok Lee, Yong-Hyeon Yim, Dmitriy Malinovskiy, Sarah Hill, Philip Dunn, Heidi Goenaga-Infante, Tongxiang Ren, Jun Wang, Robert D. Vocke Jr., Savelas A. Rabb, Tomohiro Narukawa, Lu Yang, Zoltan Mester, Juris Meija, Dmitri G. Aref'ev, Vladimir Marchin, Alexander G. Sharin, Andrei D. Bulanov, Alexander M. Potapov, Polina A. Otopkova, Rüdiger Kessel, *The comparability of the determination of the molar mass of silicon highly enriched in <sup>28</sup>Si: Results of the CCQM-P160 interlaboratory comparison and additional external measurements*, *Metrologia* 57 (2020) 065028, <https://doi.org/10.1088/1681-7575/abdbbf>

Axel Pramann, Jochen Vogl, Olaf Rienitz, *The Uncertainty Paradox: Molar Mass of Enriched Versus Natural Silicon Used in the XRC Method*, *MAPAN-Journal of Metrology Society of India*, (2020) <https://doi.org/10.1007/s12647-020-00408-y>

Mecke, M.; Borys, M.; Beyer, E.: Investigation of the repeatability of a cleaning method for silicon spheres by gravimetric measurements. *ACTA IMEKO*, Volume 9 (2020), Number 5, 12–16

Beyer, E.; Borys, M.; Mecke, M., Kolbe, M.: Investigation of a cleaning procedure for silicon spheres used in the realization and dissemination of the redefined kilogram via combined spectroscopic and gravimetric measurements. *Int. J. Metrol. Qual. Eng.* 11 (2020) 18

Stock, M.; Conceição, P.; Fang, H.; Bielsa, F.; Kiss, A.; Nielsen, L.; Kim, D.; Kim, M.; Lee, K.-C.; Lee, S.; Seo, M.; Woo, B.-C.; Li, Z.; Wang, J.; Bai, Y.; Xu, J.; Wu, D.; Lu, Y.; Zhang, Z.; He, Q.; Haddad, D.; Schlamming, S.; Newell, D.; Mulhern, E.; Abbott, P.; Kubarych, Z.; Kuramoto, N.; Mizushima, S.; Zhang, L.; Fujita, K.; Davidson, S.; Green, R. G.; Liard, J. O.; Murnaghan, N. F.; Sanchez, C. A.; Wood, B. M.; Bettin, H.; Borys, M.; Mecke, M.; Nicolaus, A.; Peter, A.; Müller, M.; Scholz, F.; Schofeld, A.: Report on the CCM key comparison of kilogram realizations CCM.M-K8.2019. *Metrologia* 57 (2020) 07030

Bettin, H.; Borys, M.; Firlus, M.; Buchner, C.; Zelenka, Z.; Medina, N.; Parlić-Risović, T.; Bezjak, M.; Mitsas, C.; Lefkopoulos, A.; Lenard, E.; Popa, G. F.; Malengo, A.; Madec, T.; Beaudoux, F.; Fuchs, P.; Marti, K.; Wüthrich, C.; Kajastie, H.; Eltawil, A.; Fujii, K.; Kuramoto, N.; Waseda, A.; Perkin, M.; Davidson, S.: EURAMET key comparison 1031 (EURAMET.M.D-K1.1) – solid density comparison. *Metrologia* 57 (2020) 07028

Lehrmann, Katharina; Knopf, Dorothea; Härtig, Frank:  
*Innovative mass standards for the worldwide transfer of the redefined unit kilogram.*  
*Proceedings of euspen's 20th International Conference & Exhibition (2020)*, 1-2,  
<https://www.euspen.eu/knowledge-base/ICE20357.pdf>

Lehrmann, Katharina; Tusch, Rainer; Härtig, Frank:  
*Design of sorption and buoyancy artefacts made of silicon.*  
*Special issue for TC3, TC5, TC16 and TC22 ; in: Acta IMEKO*, 9 (2020), 5, 37-41

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*Mathematic modelling of a new inlay buoyancy artefact.*  
*Special issue for TC3, TC5, TC16 and TC22 ; in: Acta IMEKO*, 9 (2020), 5, 42-46

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Numerische Simulation zur Bestimmung der Messunsicherheit für die Kalibrierung von Massenormalen durch Transferkörper = Numerical simulation for the determination of the measurement uncertainty for the calibration of mass standards by transfer artefact. Technisches Messen, 88 (2021), 2, 90-102*

*N. Rogge, C. Rothleitner, S. Vasilyan, T. Fröhlich. Perspektiven zur direkten Nutzung der Neudefinition des Kilogramm in der Kraftmess- und Wägetechnik. Der Lebensmittelbrief. 2021*

*C. Rothleitner. Wieviel Planck-Konstante steckt in einem Kilogramm? Physik in Unserer Zeit. Wiley. 2021.*

### **Force/Torque:**

*Weidinger, Paula; Foyer, Gisa; Kock, Stefan; Gnauert, Jonas; Kumme, Rolf: Torque calibration in the MN m range under rotation in a nacelle test bench; 20. GMA/ITG Fachtagung Sensoren und Messsysteme 2019 (2019)*

*Weidinger, Paula; Foyer, Gisa; Kock, Stefan; Gnauert, Jonas; Kumme, Rolf: Calibration of torque measurement under constant rotation in a wind turbine test bench; Journal of Sensors and Sensor Systems (2019)*

*Röske, Dirk: Linear regression analysis and the GUM: example of temperature influence on force transfer transducers, Acta IMEKO 9 (2020) 5, 407-413, 2020*

*M. Abdulhakim, Saher R. Hassan, F. Tegtmeier: Practical investigation for the concept of a serial-type build-up force measurement system, Acta IMEKO 9 (2020) 5*

*Geva, K.; Kahmann, H.; Schlegel, C.; et al.: Analysis of the measurement uncertainty of a new measurement flexure calibration set-up, Acta IMEKO 9 (2020) 5*

*Kobusch, M.; Klaus, L.: In-situ dynamic force calibration using impact hammers Acta IMEKO 9 (2020) 5*

*Brüge, A.: On the regression of sensitivity characteristics of torque transducers, Acta IMEKO 9 (2020) 5*

### **Density**

*A. Furtado, J. Pereira, R. Quendera, M. Schiebl, E. Lenard, E. Malejczyk, A. Alic, S. Alisic, J. Rauch, F. Lorenz, A. Bescupschii, A. Ciubara, B. Laky, R. Amsüss, FIRST DENSITY COMPARISON ON*

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H. Bettin, M. Borys, M. Firlus, Ch. Buchner, Z. Zelenka, N. Medina, T. Parlic-Risovic, M. Bezjak, Ch. Mitsas, A. Lefkopoulos, E. Lenard, G. F. Popa, A. Malengo, T. Madec, F. Beaudoux, P. Fuchs, K. Marti, Ch. Wüthrich, H. Kajastie, A. A. Eltawil, K. Fujii, N. Kuramoto, A. Waseda, M. Perkin, S. Davidson, Ü. Y. Akcadag and A. Domostroev: EURAMET key comparison 1031 (EURAMET.M.D-K1.1): Solid density comparison, Metrologia **57** (2020) Techn. Suppl. 07028.

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## Flow

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H.-B. Böckler : **Messrichtigkeit von mechanischen Gasmessgeräten bei Verwendung von unterschiedlichen Gasbeschaffenheiten : Modellgleichung zur Abschätzung der Messabweichung und Korrektur der Messergebnisse** .(PTB-Bericht PTB-MA-101) ; Dissertation, Universität Duisburg-Essen, 2019, XVI, 132 S.

J. v. d. Grinten : **Ein Vergleich von statistischen Tests und Monte-Carlo-Methoden zur Konformitätsbewertung = A comparison of statistical testing and Monte Carlo methods for conformity assessment**. 9. VDI-Fachtagung Messunsicherheit 2019, Messunsicherheit praxisgerecht bestimmen : 4. VDI-Fachtagung Prüfprozesse in der industriellen Praxis 2019 ; (VDI-Berichte: 2365), (2019), 227-240

J. v. d. Grinten, A. Gunnarsson, M. Van der Beek, B. Mickan : **An intercomparison between primary high-pressure gas flow standards with sub-permille uncertainties** . 37th International North Sea Flow Measurement Workshop, 1-10, Norwegian Society for Oil and Gas Measurement.

R. Kramer, T. Dietz : **Ultrasonic flowmeter for flow rates below 100 l/h**. FLOMEKO 2019 - 18th International Flow Measurement Conference: proceedings, 1-5,

H. Müller, A. Taube, H. Hager, E. Sander, R. Mock, J. B. Westenberg, P. Busche, H. Mellinghoff, D. Wüstenberg: **Nationaler DKD-Ringvergleich für Strömungsgeschwindigkeit - Transfornormal: Prandtl-Rohr mit Auswerteeinheit Kalibrierbereich: 5 m/s bis 50 m/s**. (Vergleichsbericht DKD-V 11-1), 25 S., Physikalisch-Technische Bundesanstalt.

H. Müller, I. Care, C. Popov : **CCM.FF-K3.2011.1 CIPM Key Comparison of Air Speed, 0.5 m/s to 40 m/s**.

S. M. Sarge : **Ein skalierbares Kalorimeter für die Bestimmung thermodynamischer, kinetischer und sicherheitstechnischer Kenngrößen elektrochemischer Energiespeicher**. Würzburger Tage 2019 - TA Instruments - Innovative Materialcharakterisierung in Forschung & Technik, 11 S.



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M. Eggert, J. Tamke, C. Gutmuths, S. Oertel, P. Wilhelm, H. Müller, M. Mauder : **Vergleich des bistatischen Doppler-Lidars der PTB und eines Ultraschall-Anemometers zur Messung von Turbulenzspektren = Comparison of turbulence measurements by PTB's high-resolution bistatic Doppler lidar and a CSAT3B sonic anemometer.** Experimentelle Strömungsmechanik : 27. Fachtagung, 3.-5. September 2019, 29.1-29.9, Karlsruhe : Deutsche Gesellschaft für Laser-Anemometrie.

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L. Chunhui, B. Mickan, C. Lishui, C. Wang : **The high pressure sonic nozzle gas flow standard facility in NIM.** FLOMEKO 2019 - 18th International Flow Measurement Conference: proceedings, 1-6

S. Sukhwinder, G. Schmitz, B. Mickan : **Modeling of the Flow Comparator as calibration device for high pressure natural gas flow metering in Modelica.** FLOMEKO 2019 - 18th International Flow Measurement Conference: proceedings, 1-6

B. Mickan : **Discharge coefficients of CFVN predicted for high Reynolds numbers based on Low-Re-calibration.** FLOMEKO 2019 - 18th International Flow Measurement Conference: proceedings, 1-8

S. Oertel, M. Eggert, C. Gutmuths, P. Wilhelm, H. Müller, H. Többen : **Bistatic wind lidar system for traceable wind vector measurements with high spatial and temporal resolution.** FLOMEKO 2019 - 18th International Flow Measurement Conference: proceedings, 1-5

A. Gunnarsson, J. v. d. Grinten, , M. v. d. Beek, B. Mickan : **Primary Piston Prover intercomparison between PTB, VSL and FORCE Technology.** FLOMEKO 2019 - 18th International Flow Measurement Conference: proceedings, 1-5

J. v. d. Grinten, B. Mickan : **Combining three independent traceability chains for high-pressure gas flow in Germany.** FLOMEKO 2019 - 18th International Flow Measurement Conference: proceedings, 1-4

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