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Evaluation Report on PTB Braunschweig and Berlin

Science policy position paper on PTB Braunschweig and Berlin

Contents Page

Annex: Evaluation report on PTB Braunschweig and Berlin

Preliminary remark

The German Federal Government, after it had passed extensive recommendations and thirteen individual evaluations of federal institutions undertaking R&D (research and development) work, in June 2006 asked the Wissenschaftsrat (German Council of Science and Humanities) to evaluate all those institutions not yet evaluated.

At a meeting on December 7, 2006 the Committee on Governmental Research Agencies of the German Council of Science and Humanities decided to carry out the evaluation of the Physikalisch-Technische Bundesanstalt (PTB), Braunschweig and Berlin, during the second half of 2007, and appointed an appropriate team of evaluators. The team included experts who are not members of the German Council. The Council owes them special thanks. The team of evaluators visited PTB from September 25 – 27, 2007 and, based on this visit as well as on information submitted by PTB, prepared the evaluation report presented here.

On March 11, 2008 the Committee on Governmental Research Agencies of the German Council of Science and Humanities formulated the draft of the science policy statement on the basis of this evaluation report.

The German Council of Science and Humanities ratified the status report on May 8, 2008.

A. Characteristics

The Physikalisch-Technische Bundesanstalt (PTB), Braunschweig and Berlin, was founded in 1887 as the first national metrology institute worldwide and named the Physikalisch-Technische Reichsanstalt (PTR). With the federal institutes for Materials Research and Testing (BAM) in Berlin and for Geosciences and Natural Resources (BGR) in Hannover, PTB is one of three legally non-autonomous federal institutions with R&D (Research and Development) responsibilities, subordinate to the Federal Ministry of Economics and Technology (BMWi).[1] Besides the principal PTB site in Braunschweig, there are two further sites in Berlin-Charlottenburg and Berlin-Adlershof.

In the year 2007 the basic revenue of PTB out of the federal budget was a total of 124.5 million Euros (nominal). The staff remuneration budget was 70.3 million Euros; expenditure for consumables and durable equipment was 23.3 million Euros. In 2007 PTB earned an additional income, in the form of fees, of 11.3 million Euros. Out of this income PTB reimbursed the federal budget with about 9.6 million Euros. Moreover, between 2005 and 2007 PTB won 38.4 million Euros grant money, of which about 22.1 million Euros were from federal funds, and some 5.2 million Euros from commercial sources. The financial support by the Deutsche Forschungs-gemeinschaft (DFG: German Research Foundation) was about 2.7 million Euros, that by the EU some 3.0 million Euros.

According to the budget plan, on the reference date of December 31, 2007 PTB had 1346.3 staff positions at its disposal, 338.5 of these were posts for scientific personnel. Of the institutionally funded positions 52.8 were not filled on the reference date, among them 17.0 for scientific personnel. Besides the budgetary posts, on the reference date PTB also had 54.8 third-party funded positions for scientific work and 59.0 positions for postgraduate (PhD) students, created by re-allocation within the budget. All of the third-party funded positions, the reallocated postgraduate positions, as well as 2.0 institutionally funded budget positions for scientific personnel were occupied by temporary personnel. On the reference date a total of 1744 employees were working in PTB, among them 430 scientists, including 75 third-party funded employees.

B. Scope

PTB's task spectrum comprises more than 60 tasks based on laws or decrees, 57 of which are its exclusive responsibility. These include research and development (R&D) in the field of the fundamental units and the most important derived units, besides verification, type approval, and calibrations. Furthermore, PTB develops measurement standards, standard measuring devices and measuring procedures, and represents Germany on international committees and organizations.

The most important duties are set out in the new PTB statutes, drafted in 1996, and comprise:

- Realization, maintenance and dissemination of the units of physics to guarantee national and international uniformity of measures, and the determination of fundamental constants,
- Research and development in all areas of metrology, particularly in precision metrology, and in connection with scientific problems in the fields of physics and technology,
- The determination of the structure and physical properties of materials,
- Promotion of science and the economy by R&D, calibration, testing and certification, consulting and information, as well as

[1] The BAM was assessed by the German Council of Science and Humanities (WR) in 2007, the BGR in 2007, cf.: *Wissenschaftsrat: Stellungnahme zur Bundesanstalt für Materialforschung und -prüfung (BAM)* (in German), Berlin, Drs.7256-06, Nürnberg, May 2006; *Wissenschaftsrat: Stellungnahme zur Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)* (in German), Hannover, Drs 8173-07, Frankfurt a.M., November 2007.

- The transfer of technologies to industry.

To better observe these duties, PTB is organized into the four segments of work: fundamental metrology, metrology for industry, metrology for society, and international affairs.

C. Research and science-based services

PTB provides R&D projects and science-based services which are collectively of very high, in parts of excellent quality. This federal institute may be regarded as belonging scientifically and technologically to the upper international echelons of the leading national metrology institutes (NMI). The institute's R&D projects provide a significant contribution to the further development of metrology. The highly competent and visibly motivated scientific personnel, the excellent research infrastructure, and the effective R&D management constitute the foundation of PTB's remarkable performance profile. Those areas of work, such as chemistry for instance, that have as yet not achieved the high level of scientific competence of the majority of PTB divisions, possess the necessary means to enhance their scientific profile within a foreseeable period.

The high scientific standard of PTB is expressed in the sophisticated research program containing topics that are both relevant and of current importance. PTB's research topics are well coordinated, so ensuring sufficient coherence between the diverse projects. The research topics are initiated on the basis of a convincing research guideline and within the scope of program planning procedures that combine in equal measure the “bottom up” and “top down” processes within PTB, as well as stimuli from the users and addressees of services. Overall the institute succeeds in making profitable use of all its scientific projects, to the advantage of the services it offers, beginning with fundamental metrology research all the way to primarily application-oriented work, and so is able to align the whole spectrum of its work with the state-of-the-art of science and technology.

PTB brings about the necessary transfer of information to users in industry, science and the public through numerous R&D collaborations, through regular publication of research results in prestigious journals, and by effective publicity drives on basic metrological topics. With regard to industry – here primarily small and medium-sized enterprises (SME) – PTB uses strategically selected industry collaborations to encourage a mutual transfer of know-how between the institute and the companies, in the form of technologically advanced product and process development. With regard to the scientific community, PTB's numerous publications in top-ranking journals and the organization of and regular participation in national and international specialist conferences constitute significant contributions to the advancement of metrology. However, in some areas the publication portfolio is limited to scientifically less prominent formats. PTB is able to present itself to the general public through target-group oriented events that reach a wider audience. Generally speaking, however, PTB should apply, in greater measure than hitherto, its high level of scientific and technical expertise, its close collaboration with technologically oriented enterprises, and its strong position within national and international networks to offer policy-makers stronger support on questions of technological development, emphasizing specifically here the recently established *Directorate-General Technology Policy* of the Federal Ministry of Economics and Technology (BMWi). Moreover, science policy advice in future ought not to be restricted to the drafting of legislative or administrative recommendations, but instead be comprehensively understood as a continuous process of technology policy monitoring for politics, economy and society.

On the basis of its highly successful scientific performance profile PTB is a recognized member of the network of leading institutions and organizations in the scientific community, both within metrology and beyond. Besides the traditionally close collaboration of the institute with other NMIs, for example on international committees and within associations, PTB is distinguished by numerous nationally and internationally prominent R&D collaborations with universities and other

establishments. PTB is a cooperative partner in several *Sonderforschungsbereiche* (Collaborative Research Centres) of the DFG (German Research Foundation), and participates in research alliances which were successful in the "Excellence Initiative" by the Federal Republic and its states. As demonstrated by its collaboration with the universities of applied sciences, PTB utilizes the complete spectrum of fundamental and applied research in Germany to carry out the duties of a governmental research agency at a high scientific level.

PTB has introduced important measures to support the scientific training of young scientists. Support of undergraduates, postgraduates and postdocs remains integral to the future of PTB in view of the presently high proportion of older scientific staff, and the anticipated loss of expertise when these reach retirement age in the near future.

PTB is able to maintain the quality of its scientific work with the aid of a comprehensive system of both internal and external procedures, such as, for example, international metrological key comparisons. An important component of the quality control process was the 2002 external evaluation that PTB initiated: the so-called "Weule Committee" added valuable momentum to the future development of the institute. This method of independent external examination of its own work should continue to be applied in future. In contrast, there is room for improvement in strategic support and quality control of PTB's work by the institute's *Kuratorium* (Board of Trustees).

For users and addressees in industry, society and science, the institute offers a remarkable bandwidth of relevant services, some in great demand, that go beyond the strictly defined field of metrology. PTB's work contributes considerably to the creation of economic wealth in Germany, particularly in those areas of great relevance for the future: precision metrology, medicine, electrical engineering, and optics. The services are generally linked to the institute's own R&D work. This not only enables PTB to guarantee the state-of-the-art standard of its services, but above all gives industrial enterprises a distinct competitive edge. This is achieved, for instance, when standards of measurement and experimental processes developed by PTB in collaboration with industrial companies are recognized as universally binding by European and international panels. Moreover, PTB offers an important service to public and private research establishments through its valuable scientific and technical infrastructure, and the extremely competent operation of metrological equipment and large-scale installations. However, within PTB's broad spectrum of services, the significance attached to science policy advice to the federal government could be increased. On the whole the capacity of the institute to advise the BMWi and other departments on pertinent questions of technological evolution is still insufficiently exploited.

D. Organization and management

PTB possesses efficient structural and deployment organizations on the basis of which its *Präsidium* (Presidential Board) has developed an extremely effective research management. Despite the deterioration in recent years of the boundary conditions, it has succeeded in introducing important measures to assure its European and international alignment. PTB's management has profited here from an unusually high (for federal institutions with R&D responsibilities) degree of autonomy. As a result of the much appreciated restraint of the BMWi in controlling PTB, it could plan its work with relative independence without losing sight of the legally mandated duties. This particular model for the organization of governmental research developed in recent years by PTB and BMWi can be regarded as exemplary for similar federal institutions.

The resources of PTB overall are in accordance with the range of responsibilities of the institute. Yet, to secure PTB's internationally leading role for the future, additional resources are needed. In this context the decision of the BMWi to allow PTB to benefit from an increase in R&D funding, realized by the "High-tech Initiative" of the federal government, is to be welcomed. In order to

continue to maintain its very good ranking in the international competition with the USA and Asia, the budget of PTB must specifically be increased.

In the area of personnel development the “job pyramid”, the fixed relative proportions of available positions requiring scientific, technical, and non-skilled qualifications, that currently has been allotted to PTB endangers the long-term scientific excellence of the institution, despite first improvements in the recent past. For instance, in some areas the low proportion of scientific personnel compared to non-scientific personnel does not correspond to the spectrum of duties of the institute. Greater flexibility is therefore necessary concerning the “job pyramid”. By joint appointments with universities PTB has been successful in winning leading scientists for positions in higher management. On the whole, however, the proportion of internally filled management positions is relatively high and the number of female scientists in leading positions too low. In principle the higher management positions of PTB should be publicly advertised. The Presidential Board has introduced convincing mechanisms for personnel development, such as the partially performance-oriented remuneration of scientific personnel. In order to preserve the high motivation of the scientific staff these mechanisms should be strengthened further. On the other hand, despite the numerous permanent responsibilities, in the past as in the present the proportion of institutionally funded temporary-employment positions is too low.

The scientific and technical infrastructure of PTB is very good to excellent. The federal institute possesses internationally competitive, in some cases unique, laboratories and metrological equipment. The infrastructure as a whole is very well organized and in general is available for use by external scientists.

E. Comments and recommendations

True to its great tradition, PTB convincingly does justice to its role as one of the worldwide leading metrological establishments, even in an evolving environment. The spectrum of work comprises challenging R&D tasks and important science-based services of great economic, social and scientific significance. Beyond the more strictly defined field of metrology, the work of the federal institute is of great scientific and commercial value for innovation, for example in medical technology, and electrical engineering and optical industries in Germany. Here, with regard to the broadness of its expertise, its competent scientific staff and infrastructural setup, PTB occupies a unique position, both in the national and to some extent European sense. As a consequence of the long-term character of its responsibilities, as well as the high degree of specialization, on the whole neither universities nor other R&D institutions can take over its current spectrum of work.

The European activities of PTB are exemplary for other federal institutions with R&D responsibilities. The federal institute pursues ground-breaking avenues towards closer collaboration with other European institutions. Under its chairmanship of EURAMET (a registered association) PTB effectively employs its scientific and technical expertise, besides international networking, to take up a leading position in European metrology. At the same time PTB takes care to preserve and further develop on a national scale the metrological competence central to German economy. In this way PTB safeguards existing competitive advantages for German companies. The federal institute ensures the necessary balance between European cooperation and standing out in the international competition.

In view of the high scientific quality of its work, the very good research management and the convincing European strategy, the recommendations of the Science Council refer to specific sections of PTB’s work:

1. Task evolution

   In order to preserve the consistency of the spectrum of activities in the future, PTB should not be

burdened with tasks that run counter to the scientific profile of the institute. Routine tasks such as the testing of firearms, gambling machines or electronic polling devices should be delegated elsewhere.

2. Publications

In some sections of PTB the proportion of publications in peer-reviewed journals could be enhanced (cf. Annex B.II). PTB should desist where possible from publishing so-called "grey literature" in favor of refereed publications.

3. Transfer of expertise and science policy advice

PTB plays an important role for economic development in Germany. The German Council of Science and Humanities recommends that PTB take appropriate steps to more clearly communicate to the executives in economy, politics and society the significance of its R&D work for innovative processes in Germany. It further recommends that PTB leverage its very good or excellent work to engage more strongly in discussions concerning possible key technologies of the future. Policy advice should therefore receive higher priority within PTB's task spectrum. The institute should increasingly undertake tasks of technology policy monitoring for the federal government. For this purpose a suitable coordinating position is required in PTB's presidential office.

4. Quality control

The trustees of PTB should engage more strongly than hitherto in the strategic decision-making of the institute and perform systematic analyses of possible weak areas in the organization of research and deployment. The German Council of Science and Humanities advises the BMWi and PTB to develop an efficient procedure for external review that will allow external evaluation of the institute at five to seven year intervals.

5. Networking

In research collaborations with universities and other R&D establishments PTB should involve its partners in project planning at the earliest possible stage. To enhance the attraction of the institute for visiting scientists PTB needs a separate program for visits by scientists from other establishments. In contrast to the already very good cooperation with experts in the field, PTB should extend its networking to specifically include the general scientific community.

6. Promotion of young scientists

Despite successful measures to promote young scientists, it is recommended that the currently still poor numbers of young scientists of both genders be increased. The proportion of PhD students should be maintained and PTB should increase its participation in graduate colleges. With the initiation of a regular PTB summer school, young scientists of quite diverse disciplines could become interested in and be won over to the topics of metrology.

7. Resources

To improve the financial resources of PTB, the institute should be permitted to retain in total the revenue gained from services. The proportion of revenue for external services should not exceed 12% of its total budget. Overall PTB needs more extensive budget flexibility, preferably by the introduction of a global budget.

8. Staff

To maintain the high performance level of PTB, the German Council of Science and Humanities emphatically recommends that the annual reduction of institute staff be suspended. Furthermore, the "job pyramid" of PTB (the fixed relative proportions of available positions requiring scientific, technical, and non-skilled qualifications) does not correspond to its true task spectrum. By appropriate measures for improved flexibility on the part of the funding body PTB should be enabled to achieve a better ratio between scientific and non-scientific personnel, in keeping with its evolving responsibilities. For the appointment of qualified division and department heads PTB needs versatile means and salaries to win them. This requirement is already in place for the institutions of the Helmholtz association, and has been recommended by the German Council of Science and Humanities for federal institutions with R&D responsibilities.[2] Overall, when filling

[2] cf. *Wissenschaftsrat: Empfehlungen zur Rolle und künftigen Entwicklung der Bundeseinrichtungen mit FuE-Aufgaben* (in German), Köln, 2007, p.147. Executive Summary available in English as "Executive Summary - Recommendations on the Role and Future Development of Governmental Research Agencies with R&D Activities"

leading staff positions PTB should increasingly consider external candidates and in particular female scientists. In this context extra effort is required to support family-friendly structures in PTB.[3] To encourage further study and science education PTB should offer its scientific staff the opportunity for periods of research abroad (sabbaticals). For further flexibility of staff assignments the number of institutionally funded positions for temporary scientific personnel should be increased.

9. Infrastructure

As recommended for federal institutions with R&D responsibilities by the German Council of Science and Humanities, the Presidential Board of PTB should, when making investment decisions for large-scale R&D installations over the limit of 1.5 million Euros, seek the advice of external experts to a greater extent than hitherto.[4] External users should be able to access PTB's Metrology Light Source (MLS) in the Willy Wien Laboratory in Berlin. This should be on condition that PTB in turn, when using the Berlin Synchrotron Radiation Laboratory BESSY II, would be on an equal footing with other users from public scientific institutions.

The German Council of Science and Humanities requests that the BMWi submit a timely report on the implementation of these recommendations, within three years at the latest.

[3] cf. *Wissenschaftsrat: Empfehlungen zur Chancengleichheit von Wissenschaftlerinnen und Wissenschaftlern* (in German), Drs. 8036-07, Berlin, July 2007

[4] cf. *Wissenschaftsrat: Empfehlungen zur Rolle und künftigen Entwicklung der Bundeseinrichtungen mit FuE-Aufgaben* (in German), loc. cit., p.153.

Drs. 8025-07
Cologne, 21 March 2008

Annex

Evaluation Report on the Physikalisch-Technische Bundesanstalt (PTB), Braunschweig and Berlin

Contents Page

Preliminary remark

The evaluation report on the Physikalisch-Technische Bundesanstalt (PTB), Braunschweig and Berlin, presented here is divided into two parts. The status report section was subsequently checked with PTB for factual correctness. The evaluation section presents the assessment of the scientific performance, structures, and organizational characteristics.

A. Status Report

A.I. Evolution and Responsibilities

I.1. Historical evolution

The Physikalisch-Technische Bundesanstalt (PTB), Braunschweig and Berlin, was founded on the joint initiative of Werner von Siemens and Hermann von Helmholtz as the Physikalisch-Technische Reichsanstalt, Berlin-Charlottenburg, in the year 1887, and was the first institute of metrology worldwide. After the relocation of the principal seat to Braunschweig and its renaming in the year 1950, PTB today, together with the Federal Institute for Materials Research and Testing (BAM), Berlin, and the Federal Institute for Geosciences and Natural Resources (BGR), Hannover, is one of the three legally non-autonomous federal agencies with R&D responsibilities subordinate to the BMWi.[5] Besides the principal campus in Braunschweig the institute has two further campuses in Berlin-Charlottenburg and Berlin-Adlershof.

As the national metrology institute of Germany PTB supports the federal state in its primary responsibility of guaranteeing the uniformity of measurement, by providing an internationally recognized powerful metrological infrastructure equally for society, industry and commerce. With this mandate PTB is the only institution of its kind in Germany. At the international level PTB counts itself among the group of leading national metrology institutes, whose members include the National Physical Laboratory (NPL), United Kingdom; the Laboratoire National de Métrologie et d'Essais (LNE) France; the National Institute of Standards and Technology (NIST), USA; and the National Metrology Institute of Japan (NMIJ). On the basis of benchmarking performed in 2002 PTB considers itself, with regard to its size, importance, and scientific and technological capabilities, as internationally in second place behind NIST.

I.2. Responsibilities and areas of work

a) Responsibilities

In accordance with its mission statement “Progress and Reliability in Metrology” the work of PTB is divided into four areas: foundations of metrology, metrology for economy, metrology for society, and international cooperation. Since PTB was established before the creation in 1949 of the Federal Republic of Germany, and by government decree was part of the federal administration, there was no need for a founding mandate or law. The most important of its responsibilities are contained in the revised statues of March 12, 1996 and comprise:

- Realization, maintenance and dissemination of the units of physics to guarantee national and international uniformity of units, and the determination of fundamental constants;
- Research and development in all areas of metrology, particularly in precision metrology and for the solution of scientific problems in physical technology;
- Determination of the structure of materials and their properties;
- Promotion of science and economy by research and development (R&D), calibration, verification and certification, consulting and information; as well as
- Technology transfer to industry.

PTB's spectrum of work contains 63 duties based on laws and legal decrees, of which 57 are under its exclusive authority. These comprise R&D on the base (SI) units and the most important derived

[5] BAM and BGR were evaluated by the German Council of Science and Humanities in 2006 and 2007, respectively, cf. *Wissenschaftsrat: Stellungnahme zur Bundesanstalt für Materialforschung und -prüfung (BAM)* (in German), Berlin, Drs 7256-06, Nürnberg, May 2006; *Wissenschaftsrat: Stellungnahme zur Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)* (in German), Hannover, Drs 8173-07, Frankfurt Main, November 2007.

units, based upon which traceability to appropriate national standards is provided, as well as testing, type approval, and calibration. In addition, PTB develops standards, standard measuring devices and measuring procedures and is represented on numerous national and international panels and in scientific societies. Some special duties are explosion protection testing, control of the reliability of gambling machines and electronic polling devices, or the determination of the metrological characteristics of civil firearms.

In consequence of this broad spectrum of responsibilities, PTB regards its role as a federal establishment with R&D duties as being primarily a support for economy, science and society, and less as a political consultant. According to PTB, for an export-oriented economy a highly developed metrological infrastructure and the provision of metrological know-how in support of new technologies is an equally important prerequisite, as is the international recognition of certificates based on measurement and testing. Accordingly, the metrological research at PTB not only constitutes the basis for the realization of the units and the appropriate graduated scales at the highest level, but it also offers metrological system solutions for accurate and reliable measurements and testing in industry and commerce, by the technical development of standards and standard measuring devices combined with proven measuring procedures.

b) Areas of work

In line with its eight technical divisions, subdivided into a total of 48 departments, the work of PTB is coordinated in the following categories:

- Mechanics and Acoustics
- Electricity
- Chemical Physics and Explosion Protection
- Optics
- Precision Engineering
- Ionizing Radiation
- Temperature and Synchrotron Radiation
- Medical Physics and Metrological Information Technology (IT).

Within the departments work is organized in working groups that are limited to a period of two to five years. PTB also has a division for scientific and technical cross-sectional tasks as well as another for internal central administration and services (cf. Appendix 1).

As a result of the increasing complexity and interdisciplinary character of the task areas, the topic-oriented collaboration in the established European and international metrology structures, as well as the European Metrology Research Program (EMRP) set up in the year 2006, PTB has decided to divide its work in a program-oriented way into the 13 subject areas commonly used in international contexts. The departments in the different divisions are involved in the 13 subject areas to varying degrees (cf. Table 1). The institute is planning to organize the development of its areas of work and also the allocation of resources more strongly according to program in future. At the same time it will retain its medium to long-term divisional and departmental structures, which will result in a matrix organization for PTB.

Table 1: Task categories according to topic and department

Topics	Departments
Acoustics, Ultrasound, Acceleration	1.3 – Kinematics, 1.6 – Sound, 1.7 − Applied Acoustics
Flow	1.4 – Gas Flow, 1.5 – Liquid Flow, 7.6 – Heat
Electricity and Magnetism	2.1 – Direct Current and Low Frequency, 2.2 – High Frequency and Electromagnetic Fields, 2.3 – Electrical Energy Measuring Techniques, 2.4 – Quantum Electronics, 2.5 – Semiconductor Physics and Magnetism, 2.6 – Electrical Quantum Metrology, PSt – Presidential Staff
Ionizing Radiation	6.1 – Radioactivity; Catalogue of Activity Standards, 6.2 – Dosimetry for Radiotherapy, 6.3 – Radiation Protection Dosimetry, 6.4 – Ion accelerators and Reference Radiation Fields, 6.5 – Neutron Radiation, 6.6 – Fundamentals of Dosimetry
Length, Dimensional Metrology	5.1 – Nano- and Micro-Metrology, 5.2 – Length and Angle Metrology, 5.3 – Coordinate Metrology, 5.4 – Interferometry on Material Measures, 5.5 – Scientific Instrumentation, 4.2 – Imaging and Wave Optics, 4.3 – Quantum Optics & Unit of Length
Mass and Derived Quantities	1.1 – Mass, 1.2 – Solid Mechanics, 3.2 – Analytical Measuring Techniques and Pressure, 4.3 - Quantum Optics and Unit of Length, 7.3 – High-Temperature and Vacuum physics
Metrology in Chemistry	3.1 – Metrology in Chemistry, 3.2 – Analytical Measuring Techniques and Pressure, 3.3 – Physicochemical Material Properties
Medical Metrology	8.1 – Medical Metrology, 8.2 – Biosignals, 8.3 – Biomedical Optics
Radiometry and Photometry	4.1 – Photometry and Applied Radiometry, 4.5 – Optical Technologies, 7.1 – Photon Radiometry, 7.2 – Detector Radiometry
Thermometry	7.3 – High-Temperature and Vacuum physics, 7.4 – Temperature, 7.5 – Low-Temperature Thermodynamics and Technology, 7.6 – Heat, 1.7 – Applied Acoustics
Time and Frequency	4.3 – Quantum Optics and Unit of Length, 4.4 – Time and Frequency
Mathematics and Information Technology (IT)	8.4 – Mathematical Modelling and Data Analysis, 8.5 – Metrological Information Technology
Physical Safety Engineering, Explosion Protection	3.4 – Fundamentals of Explosion Protection, 3.5 – Flame Transmission Processes, 3.6 – Intrinsic Safety and Safety of Systems, 3.7 – Prevention of Ignition Sources

Source: PTB

c) Development of areas of work in the last five years

PTB affirms that within the last five years significant changes were undertaken concerning the areas of work, in connection with the evaluation of the institute by the Weule Committee in the year 2002

on the one hand,[6] and the discussion of PTB's "Concept 2016" on the other hand. Following the recommendations of the Weule evaluation, PTB strengthened the fields of metrological information technology and metrology for chemistry by installing independent departments in each of the areas Mathematics and Metrological Information Technology; the resources for chemistry were increased by about 10% between 2002 and 2006. During the period from October 2006 to January 2007, in conjunction with the development of the "Concept 2016", PTB underwent an internal critical assessment of its responsibilities, the consequence being the termination or begin of tasks corresponding to a personnel reallocation involving more than 100 employees. Examples of terminated work are: the ion accumulation experiment for the possible redefinition of the mass unit Kilogram; the development of infrared lasers for radiometry; the testing of analog-to-digital converters. New or intensified work includes, for instance, single electron circuits for the quantum realization of the units Ampere and Farad, quantitative optical bio-analysis and imaging, optical clocks, and dimensional nano-metrology.

For the drafting of the European Metrology Research Program (EMRP), PTB has proposed its own ideas which were then subjected to critical discussions by its European partner institutes (cf. Section III.1.c). Within the framework of the EMRP the European national metrology institutes intend to coordinate their R&D work to exploit synergies and avoid unnecessary duplication. Some crucial points the EMRP will focus on are: the realization of the units via quantum effects, the determination of fundamental constants of importance for the system of units, and the fields of chemistry, medicine, environmental analysis, and energy.

d) Task spectrum of the scientific staff

The work of PTB's scientific staff extends over a broad spectrum of tasks where, as stated by PTB, its own R&D activities averaging 63% make up the major portion, followed by the provision of science-based services for the ministry, third parties, and the public (21%). Then there is approval, testing and certification work decreed by law (15%), and finally of minor importance in PTB at this time (about 1%) is consultant work and the provision of scientific or science-based information for politics.

The relatively large proportion of R&D work in the total task spectrum of the scientific staff at PTB is the result of a long-standing harmonization process with BMWi. This proportion corresponds to that of similar metrology institutes abroad which likewise consider themselves to be metrological R&D establishments offering services, approval, verification, and consultant work. Of PTB's own R&D work roughly 20% is directed at current services, 10% at testing and verification, and just 1% at consulting for politics. The largest part of PTB's R&D work targets future requirements in the form of long-term projects on measuring procedures and traceability that will be a distinct improvement over present methods, or will enable new traceability structures to be established.

A.II. Organization and resources

II.1. Organization

a) Management organization

PTB is directed by the Presidential Board comprising three members, supported by the department "Presidential Staff" which focuses on cross-sectional topics relevant to central management. In addition the triumvirate is assisted in its executive duties by the Directorate (*Direktorenkonferenz*),

[6] cf. *Evaluation der Physikalisch-Technischen Bundesanstalt: Abschlussbericht der Evaluationskommission unter Vorsitz von Prof. Dr. Hartmut Weule* (in German), Universität Karlsruhe, commissioned by the Federal Ministry of Economics and Labour, 2002.

a committee composed of the Presidential Board and the ten heads of divisions. Since 2004 this executive committee has set up seven thematic subcommittees to deal with cross-divisional management tasks.[7]

The Presidential Board of the institute is supported by the trustees of PTB (*Kuratorium*) in the planning and assessment of its tasks. The trustees meet at PTB at least once a year and advise the institute on technical questions of metrology, as well as the BMWi on questions pertaining to PTB. According to the statutes the presidency of the Board of Trustees is filled by the head of the Directorate-General in the BMWi responsible for the supervision of PTB. The status report and discussion of the progress towards the agreed objectives (*Zielvereinbarung*) between PTB and BMWi are a part of the report that the president of PTB presents during the meeting of the trustees. There are 28 members of the Board of Trustees at this time, among them 13 scientists employed in public research institutions and 14 representatives from industry. The trustees can also set up committees, in particular the recruiting committee that nominates new trustees and proposes a candidate for refilling the position of PTB's president.

The appointment of management staff is the result of joint consideration by BMWi, the trustees, and the Presidential Board. The position of president of PTB is generally filled without public recruitment notice after nomination by BMWi and appointment by the President of the Federal Republic. The nomination is preceded by a search for candidates by the recruiting committee of the Board of Trustees, which proposes to BMWi a suitable external candidate. Because of the particular positions of trust they hold, the offices of vice-president and third member of the Presidential Board are customarily filled by internal candidates, as a targeted recruitment. PTB's heads of divisions and departments are chosen following public recruitment notice, partly from external but more often from internal candidates.[8] In the case of the appointment of a head of division the interviews are conducted by an internal selection panel under the chairmanship of the president, and for heads of departments a similar panel acts under the auspices of the relevant head of division. When a joint appointment for PTB is undertaken with a university, a joint selection panel is set up by both institutions.

All candidates for senior positions in PTB are subject to similar qualification requirements. In addition to a university science or engineering degree, a doctorate (PhD) in a pertinent field is expected, as well as continuing scientific achievements and experience in procuring project funding. Candidates should possess experience in working with national and international cooperation partners and committees. All management staff must complete a one year probationary period.

b) Supervision and coordination by BMWi

Together with BAM and BGR, PTB is one of three legally non-autonomous federal agencies with R&D responsibilities within the portfolio of BMWi. Supervision of PTB is a task of the Division "Standardization, conformity assessment, metrology, supervision of PTB and BAM" in the Directorate-General "Technology Policy" of the BMWi; control of the budget, personnel and organizational matters is in the hands of the appropriate divisions in the Directorate-General "Central Administration" of the ministry. Within this framework BMWi determines the objectives of PTB's professional duties, organization and management, scientific and technological cooperation, and the evolution of its resources, laid down in an Agreement on Objectives (*Zielvereinbarung*) valid in general for a period of three years. These objectives are jointly discussed by PTB's Presidential Board and the head of the division in the BMWi responsible for PTB, and according to PTB have always been ratified in consensus.

[7] Subcommittees currently exist dealing with the following topics: Personnel, Investments, IT Infrastructure, Metrological Services, International Collaboration, Quality Management, Research Programs.

[8] If, apart from the function, the budgetary position itself is vacant the opening will be advertised publicly, but internal candidates may apply.

To strengthen the exchange between the ministry and PTB, the institute regularly seconds scientific staff to BMWi – as well as to the Federal Ministry for Economic Cooperation and Development (BMZ) – to support the ministries in their work on matters pertinent to PTB. As a contribution to the coordination among those federal establishments with R&D responsibilities affiliated with BMWi, PTB and BAM have set up a joint working group, composed of some of the scientists responsible, for the harmonization of developments and strategies in the field of explosion protection. Cross-ministerial coordination is performed within the scope of the PTB-led network "Metrology for Chemistry", where, besides the BAM, the Federal Environment Agency (UBA), the Federal Office of Consumer Protection and Food Safety (BVL), and the German Society for Clinical Chemistry and Laboratory Medicine (DGKL) are involved.

Overall both the ministry and the federal institute describe the supervision and coordination of PTB by BMWi as functioning well, since the extensive legal mandate of PTB does not require any particular coordination. Consequently PTB rates highly its flexibility and autonomy in the performance of its duties, particularly since the institute and the ministry are agreed that its flexibility shall be upheld, and where possible even enhanced. Only where the annual budget negotiations with the Federal Ministry of Finance (BMF) are concerned does PTB desire stronger participation.

In addition to the tasks assigned by BMWi, PTB continually receives inquiries and requests from other federal ministries[9] and their subordinate authorities. Added to these are the various federal state ministries and offices. According to PTB those inquiries and requests refer to research, technical services, and drafts for technical aspects in draft regulations. The commissions for technical services mainly concern questions of calibration and the testing of measuring equipment of other authorities. A special case, according to PTB, is the department "Technical Cooperation" which the BMZ regularly commissions to realize technical cooperation projects with developing, threshold and transformation countries. Since February 2006 this commissioning is based on an inter-ministerial agreement between BMZ and PTB.

On the whole, PTB does not see any need for more coordination efforts for its activities since these, as a rule, are based on specific laws.

II.2. Resources

a) Budget

In the year 2006 PTB had available a primary budget of 119.9 million Euros (nominal). Personnel expenditure was 68.1 million Euros, non-personnel administrative expenditures 19.7 million Euros. In 2006 PTB earned revenue from fees of 9.6 million Euros, besides project funds of 13.8 million Euros (cf. Appendix 5). In 2006 50% of the fees above a threshold of 7.5 million Euros could be used by the institute to cover expenses and did not have to be passed on to the federal budget. PTB benefited from the growth in R&D spending under the high-tech strategy of the federal government: in 2006 it gained an additional 3.0 million Euros of R&D funds.[10]

PTB considers its budget to be sufficient on the whole to cover personnel expenditure, durable

[9] These are the Federal Ministries of Labour and Social Affairs (BMAS), of Food, Agriculture and Consumer Protection (BMELV), of Health (BMG), of the Interior (BMI), for the Environment, Nature Conservation and Nuclear Safety (BMU), of Transport, Building and Urban Affairs (BMVBS), and for Economic Cooperation and Development (BMZ)

[10] In contrast, since 2006 there have been effective reductions in non-personnel administrative expenses and increases in personnel costs in connection with the revised pension plan for public employees, managed by *Versorgungsanstalt des Bundes und der Länder* (VBL)

equipment, and consumables as well as building and operating costs. According to its own estimate, some 90% of the expenditure title was flexible. In line with the federal budget code PTB may reciprocally cover most of the items in a main budget group, and 20% of items between different main budget groups. Moreover, up to now the unexpended balance of titles for which enhanced flexibility is in force was available in the subsequent budgetary year and was not subject to budget reductions, provided the BMF could accept that they came about in the course of PTB's technical work. To counterbalance this flexible budget management PTB annually reimburses the federal budget with a so-called "efficiency return" of 5% of the total value of the relevant items included in the flexibility.

PTB regards the structuring and regulations for the execution of its budget, not least due to the introduction in 2000 of cost-benefit calculation (KLR), as overall suitable to allow it to undertake work on topical questions, generally of a short or medium-term nature. The allocation of additional funds during the process of budget negotiation to new, long-term tasks on the other hand requires a process of several years duration and is therefore cumbersome. Moreover, PTB would welcome the consideration of inflation when the costs for personnel, durable equipment and consumables are calculated. Furthermore, PTB aims to be allowed to keep the total income from third-party R&D commissions as well as from licensing fees.

b) Staff

According to the budget plan, on December 31, 2006 PTB had at its disposal 1370.3 staff positions (nominal), of these 334.0 (nominal) were posts for scientific personnel (cf. Appendix 2). Of the institutionally funded positions 54.8 were not filled on the key sampling date, among them 12.0 for scientific personnel.[11] In addition to the direct budgetary positions, PTB also had 51.0 third-party funded positions for scientific staff and 39.0 positions for postgraduate (PhD) students, created by PTB by reallocation within the budget (cf. Appendix 3). All of the third-party funded positions for scientific staff, the reallocated PhD student positions, as well as 6.0 institutionally funded budget positions for scientific staff were occupied by temporary staff. On the key sampling date a total of 1726 employees were working in PTB, among them 418 scientists, including 66 third-party funded employees. The majority of scientific personnel are physicists (80%), followed by electrical engineers (9.3%) and chemists (5.8%).

In line with all federal establishments, PTB, too, has for several years been subject to a dictated reduction in its budgeted positions by at least 1.5% annually.[12] Thus, between 2004 and 2006 a total of 71.0 posts were lost, among them 23.0 scientific positions. PTB was able to compensate for some of these cut-backs by seeking third-party funding. Hence 12.0 of the 14.0 personnel positions which were newly placed at PTB's disposal during this period were assigned without funds and are financed with the aid of third-party funds. In the interval 1993 to 2006 PTB has had to sacrifice a total of 332.0 permanent positions, and in so doing lost 89.0 permanent positions for scientific employees. Despite the corresponding recommendations of the Weule commission and the explicit objective of the federal government to strengthen R&D establishments, according to PTB there is as of yet no end in sight to the compulsory staff reduction.

PTB considers its so-called "job pyramid" (the relative proportion of positions in the four grades of the civil service, as mirrored more or less by the qualification groups from scientist to non-skilled personnel), which is fixed by the personnel budget plan, to be a fundamental problem with respect to its staff evolution. Because of the increasing complexity of laboratory apparatus and more elaborate measuring procedures, the institute in the medium term has a greater need for more highly qualified positions. This requires the "job pyramid" to be adapted in favor of increased numbers of

[11] PTB points out that this situation on the sampling date December 31, 2006 was not representative because of a hiring freeze for the duration of the negotiations around the so-called "Concept 2016" (cf. Section A. II. 1c).

[12] In the year 2007 the reduction quota was about 2%.

positions in the upper and middle grades of the civil service. The disadvantage of attempts in this direction is that any adjustments must be compensated by PTB by an efficiency return and can only be achieved with a time lag via the budget drafting process.

Moreover, PTB is experiencing increasing difficulty in attracting qualified personnel. Notwithstanding the university teaching activities of some of its scientific employees, through which in the past young people could often be won over to working in PTB, recruitment is hampered by the low proportion of natural sciences graduates and the significantly higher wages in industry. This is particularly true for female scientists. PTB is therefore actively engaged in improving the compatibility of family and career by introducing child-care services and telecommuting opportunities, to try to increase the current ratio of 9% female scientists in the institute. PTB reports a measure of success in keeping a balanced age structure. Increased gains in third-party funding and the creation of PhD student positions by budget reallocation has made it possible to increase the proportion of scientific employees under 40 years old to be raised to about 35%. Some 56% of the scientific staff have been working in PTB for less than nine years.

To improve the hiring situation PTB promotes the young scientific generation by focusing on special programs and employment offers for PhD students, students trainees and apprentices, who, as with the graduate program, are usually financed by reallocated institutional funds. In this way young scientists are given the opportunity to work on tasks within the regular operation of the institute. On the sampling day of June 1, 2007 a total of 67 PhD students were working in PTB. In this context, between 2004 and 2006, in cooperation with a university, 35 PTB employees obtained their PhD degrees and two the *Habilitation* degree, the traditional prerequisite qualification for university professorships.

The instrument of temporary employment is used by PTB within the scientific context mainly for qualification of the young generation and for work on third-party funded projects. Within the scope of the "Concept 2016" the proportion of those positions in the budget for scientific staff filled with temporary personnel will be raised to about 9% by 2009. If the number of third-party funded posts remains constant, this means that also in future some 25% of the scientific staff will be employed on a temporary basis. An increase in this proportion of temporary scientific staff is not intended by PTB since the majority of the permanent responsibilities demands special know-how which, as for the operation of the atomic clocks for instance, requires a long initial training period, as well as the experience accumulated over long years of work. Moreover, permanently employed personnel are able to build up long-term relations of mutual trust for cooperation with industrial clients and for work in international committees. And finally, secure permanent positions represent a certain compensation for the lower wages of employees compared to those offered in industry.

c) Infrastructure

PTB owns property in the form of real estate having a total area of 1,042,728 m^2 holding 89 buildings in Braunschweig and Berlin; the main buildings provide a working area of 102,159 m^2. Most of the buildings are built for special metrological tasks requiring a large amount of building service engineering and technical installations. The property is in a good general state of repair according to PTB, and is estimated at a total value of 320 million Euros. The value of the equipment in PTB is about 300 million Euros, where the majority is so-called investment apparatus.[13] The sites in Braunschweig and Berlin-Charlottenburg each have a scientific library at their disposal.

Decisions concerning investment in the scientific infrastructure of PTB above a threshold of 250,000 Euros are discussed in the inter-divisional *Größtgeräte-Direktorenkonferenz* (a one-day conference of the heads of PTB's divisions and of the Presidential Board, discussing all applications

[13] Investment apparatus is that which individually costs more than 5000 Euros and must therefore be financed out of investment budget item.

for such large-scale apparatus). These decisions are made in autumn as part of the annual planning process for next year's work. The concept of large-scale apparatus ranges from costly modernization works to start-up funding for new tasks that influence the direction of PTB's work. Decision-making is assisted by economic considerations and portfolio analyses, so that the measures to be introduced are assessed under a uniform scheme and a uniform list of criteria. The final decision is taken by the president who may, in certain cases, seek complementary opinions from external experts. Positive decisions on investments are jointly agreed upon with the trustees, are then taken up in the draft budget plan. On account of its specific and unique responsibilities, inter-departmental consensus for investment in the R&D infrastructure of PTB has hitherto not been sought.

PTB opens its larger-scale measuring and research facilities to external users. In addition, in the frame of the coordination between European metrology institutes, PTB has pledged a number of "special facilities" for mutual use (e.g., clean room facility, particle accelerators, tunable laser systems for photometry, synchrotron radiation sources). Because of the comprehensive technological character of its buildings, and the closeness of this infrastructure to the key competences of PTB, it has asked for an exemption from the transfer of ownership and maintenance of its property to the *Bundesimmobilienanstalt* (BImA, the federal facility management office) according to §2 section 4 of the BImA founding act.

A.III. Focus of work

PTB characterizes itself as a metrological R&D establishment with responsibilities for services, certification, calibration, testing, and consulting within the authority of the federal government. The majority of its work is based on research. A topic-oriented organization enables the individual divisions to work on all the fields within PTB's responsibility, including the research in and development of their own respective fields. In this way the competence gained from research projects is to the advantage of the services offered, and in return, the choice of research topics is determined by the services, certification, and consulting duties.

III.1. Research and development in PTB

PTB realizes and maintains national standards and standard measuring devices and so guarantees the conformity of the national metrology with the international system of units (SI) to which the Federal Republic of Germany has pledged itself under the Metre Convention. Using its primary standard devices, PTB not only realizes the base units but also their multiples and sub-multiples, as well as interpolation values over a specified range. Since on principle the uncertainty of measurement increases with each subsequent calibration step – and above all in the end ranges of the scale – yet the users demand the highest accuracy in many branches of metrology, it follows for PTB that its measuring facilities oftentimes have to operate reliably at the limits of today's technology. This automatically demands large in-house R&D efforts.

In some areas of R&D work PTB reports that anticipatory research[14] uses up about two thirds of the available R&D resources; in general these are medium-term R&D projects that aim to satisfy a clearly anticipated future need. Moreover, some 10% of PTB's R&D projects are work of a

[14] Anticipatory research "is concerned with research on topics which, in agreement with the ministry, usually [lead] into government-regulated areas and to law-making", or which deal with the "investigation of research fields that anticipate a not yet acute consulting or regulating need of the ministry". Depending on its relevance to current or foreseeable use, anticipatory research not directly concerned with governmental responsibilities or political consulting may take on the character of 'free' fundamental research. cf. *Wissenschaftsrat: Empfehlungen zur Entwicklung der Rahmenbedingungen der Forschung in Ressortforschungseinrichtungen am Beispiel der Forschungsanstalten in der Zuständigkeit des Bundesministeriums für Verbraucherschutz, Ernährung und Landwirtschaft (BMVEL)* (in German), in: *Empfehlungen und Stellungnahmen 2004*, vol. 1, Cologne 2005, pg. 128.

fundamental character and of unknown outcome, as for example the investigation of a possible temporal variation of the fine structure constant. Both anticipatory and fundamental research represent an indispensable element of the R&D work at PTB.

a) Research program

PTB formulates a combined work and research program. This is motivated by its closely interwoven R&D work, legal responsibilities, and expert services. All R&D work is included in the comprehensive work program with its 13 thematic areas (cf. Appendix 6). Within PTB's work program the R&D focal points are: the development of new and improved measuring procedures, the extension of the range of the scales, and the decrease in the uncertainty of measurement for the realization and dissemination of the units. PTB asserts that these focal points have evoked great interest in the scientific community.

The choice of topics is effected on two levels, on the one hand between PTB and BMWi within the scope of a generally three year agreement on objectives (*Zielvereinbarungen*), where the ministry states that it restricts itself to outlining essential economic policy targets, and on the other hand within PTB itself. Here one differentiates between:

- one-year plans, elaborated in work-plan conferences held by the Presidential Board with the heads of divisions and departments,
- one to three-year plans elaborated in the Directorate (*Direktorenkonferenz*), a committee composed of the Presidential Board and the ten heads of divisions, for larger investments and the drafting of the work program by PTB's Subcommittee on Research Programs (*Ausschuss Forschungsprogramme*),
- three and multi-year plans formulated during strategy conferences.

The one-year work-plan conferences take place according to an obligatory schedule, whereby various sessions consider the suggestions from employees, and strategic aspects developed by of the Presidential Board and by the division and department heads, but also client assessment and requests, the assessments of external experts as well as recommendations by the trustees and by advisory boards of relevant external institutions are taken into account. In addition the Presidential Board regularly takes part in internal expert discussion meetings. In contrast, the drafting and evolution of the one to three-year work program takes place in PTB's Subcommittee on Research Programs, consisting of the heads of divisions and the presidential office. Here PTB takes its lead from the customary international classification of topics and the structure of the European Metrology Research Program EMRP (cf. Section A.I.2.). Long-term trends in science, economy, and society and the resultant strategies for PTB are discussed during a strategy conference held about every three years by the Presidential Board and the heads of divisions.

The choice of topics within the European metrology alliance takes on a particular significance. In the case of co-funding by the European Commission according to article 169 of the EU treaty, in the medium term PTB aims to devote about 20% of its R&D expenditure to projects within the scope of the European Metrology Research Program (EMRP). When the EMRP was first formulated in the year 2006 PTB's subcommittee on research programs discussed the research topics that would be suitable for European coordination. Subsequently so-called "roadmaps" for the long-term research strategy were elaborated by the subcommittee in collaboration with the European partners in the ten Technical Committees of EUROMET and the newly founded "focus groups" for life science, biotechnology and mathematics. Based on these roadmaps an editorial team of representatives from four large national metrology institutes (LNE, METAS, NPL, PTB) produced the draft EMRP which was accepted at the first meeting of the EMRP committee in January 2007.

b) The scientific network

According to PTB, the institute is part of a network of research establishments in Germany and abroad working on numerous joint R&D projects. A significant part of this R&D cooperation occurs within a framework of contractual, usually international, joint projects. PTB is currently engaged in 133 international joint projects with an average of ten project partners. At the national level PTB is participating in three DFG Collaborative Research Centres and five other joint projects in which numerous industrial companies are also taking part. Furthermore, PTB participates in bilateral R&D cooperation with other establishments, as the following list shows:

- Bilateral cooperation with 66 German and 47 foreign universities; a total of 194 projects are ongoing, 20 of them regulated by contract.
- Bilateral cooperation with 60 German and 68 foreign non-university research establishments on a total of 168 projects, of which 65 are regulated by contract.
- Bilateral cooperation with 135 German and 13 foreign industrial companies. Of the total of 149 individual projects 104 are being realized on the basis of a contractual agreement.
- Bilateral cooperation with eleven German institutions and one foreign institution within the domain of scientific associations and foundations.

One of the contractual cooperation projects with German universities is with the Technical University (TU) Braunschweig on the mutually maintained Joint Optical Metrology Center (JOMC), another is the participation in the graduate school “Berlin School of Mind & Brain” of the Humboldt University in Berlin which is being funded by the excellence initiative of the Federal Republic and its states. In addition PTB regularly offers external university staff or scientists from non-university research establishments the opportunity for research at PTB. In the last two years, among others, two Humboldt prize winners stayed at PTB as guest researchers.

Besides the research collaborations PTB also participates in university teaching. At the present time 34 scientists of the institute are engaged in teaching for at least two hours per week. Twelve members of PTB staff are adjunct or honorary professors at German universities. As a result of the research and teaching cooperation, in the period 2002 to 2006 three PTB employees left the institute to take up university professorships. Between 2004 and 2006 eight members of PTB staff were elected to editorial boards of scientific journals, among others by “Metrologia”, the foremost international journal in the field of metrology.

To improve its networking, most importantly with university research, PTB has utilized the instrument of joint appointments. Currently (July 2007) PTB is collaborating with the TU Braunschweig for the appointment of a new head for Division 3. Since earlier joint appointments by PTB according to the Berlin or Jülich models were unsuccessful, owing to limitations set for the partner universities by the university law in Lower Saxony, PTB now chose a different procedure. The university and PTB published a joint public recruitment notice for the PTB management position, where the person hired will also be named an adjunct or honorary professor at the cooperating university. A joint PTB and university selection committee makes the initial nominations and carries out the interviews.

c) Networking with the metrology community

In addition to networking with the scientific community, PTB sees itself represented in all of the relevant European and international metrology networks. The institute represents the Federal Republic of Germany in the International Metre Convention (international treaty of 1875); the Bureau International des Poids et Mesures (BIPM) of the Metre Convention is situated in Sèvres. The Comité International des Poids et Mesures (CIPM), the scientific executive committee of the BIPM, is currently chaired by the president of PTB. Moreover, PTB is represented in all ten of the Consultative Committees (CC) of the BIPM; these coordinate the international activities within the

scope of the Metre Convention in the various metrological fields.

Just in the period 2004 to 2006 covered by this report, 36 PTB employees were newly selected to the program committees of regular international specialist conferences, and 83 employees were nominated for the scientific panels of international or European metrological organizations. At the present time PTB employees are working in 257 national and 245 international scientific panels and technical organizations. PTB is also engaged in 278 national and 227 international standardization projects.

The following institutions are counted among the ten most important international cooperation partners by PTB, in the order that approximately mirrors the estimated intensity of the collaboration:

- The National Physical Laboratory, NPL, United Kingdom
- Laboratoire National de Métrologie et d'Essais, LNE, France
- National Institute of Standards and Technology, NIST, USA
- National Metrology Institute of Japan, NMIJ, Japan
- Istituto Nazionale di Ricerca Metrologica, INRiM, Italy
- Bureau International des Poids et Mesures, BIPM, France
- Bundesamt für Metrologie, METAS, Switzerland
- National Institute of Metrology, NIM, China
- Korea Research Institute of Standards and Science, KRISS, South Korea
- Institute for Reference Materials and Measurements, IRMM, Joint Research Centre of the EU.

PTB reports that European activities play a major role in its work. For instance, PTB is a founding member of EUROMET, the community of the European national metrology institutes. EUROMET was founded in 1987 with the aim of achieving the most comprehensive collaboration of the national metrology institutes without infringing upon their individuality. Currently there are 34 member institutes. This institution thus goes beyond the membership of the EU and encompasses practically all of Europe, including Turkey.

According to PTB, since 2005 the European metrology institutes have been working towards the joint European research program for metrology with their own R&D activities. The conceptual content of the research program and the definition of the research focus were set out in the European research project “implementing Metrology in the European Research Area, iMERA” under the auspices of 15 metrology institutes and five ministries.[15] It is supported by the 6th EU Framework Program. In the EMRP present-day important research topics will be taken up in joint projects. The novel approach here is that the national metrological research programs are coordinated autonomously in order to free resources through division of labor. This enables the best scientists to jointly achieve internationally competitive research results on the most urgent questions to date. The program, conceived for a period of seven years (2007-2013) and costing 500 million Euros, will be financed in two equal parts: half out of EU funds and half by the national metrology research programs of the 20 participating countries. A decision has not yet been taken regarding co-funding by the EU according to article 169 of the EU treaty. However, there has already been some success in the form of a 33% co-funding of some of the research topics by an ERA-Net plus measure, beginning 2008 (duration 3 years, 63 million Euros in total).

According to PTB, to operate a joint research program the hitherto rather “informal” structures of European metrology had to be modified. In January 2007 the European metrology association EURAMET (European Association of National Metrology Institutes) was founded as a successor to EUROMET. According to PTB the essential difference between the two is that EURAMET is a Registered Society according to German law and consequently is a legal entity that may conclude a

[15] Besides the BMWi, the Department of Trade and Industry (DTI) United Kingdom, the Office of Standards, Metrology and Testing (UNMS) Slovakia, the Ministry of Economic Affairs (EZ) Netherlands, the Czech Office for Standards, Metrology and Testing (COSMT) Czech Republic

contract and accept and administer European funds. The present chairman is a member of PTB. The federal institute is also represented by its employees in all ten Technical Committees (leading one of them) and the EURAMET secretariat is permanently situated at PTB.

Concurrent with the European and international activities concerning the realization and dissemination of the international system of units, PTB sees itself closely involved in the networks of legal metrology. The institute is a member of the International Organization of Legal Metrology (OIML), in the Presidential Council of which PTB was represented for many years, often as chairperson. PTB reports that its scientific staff regularly occupies senior positions in the technical committees and subcommittees. The same is true of the European organization of legal metrology (European Legal Metrology Cooperation, WELMEC). Here PTB has in recent years made significant contributions to the creation of the EU guideline for measuring instruments (Measuring Instruments Directive, MID), which replaces the hitherto national certification requirements for measuring instruments in regulated areas by European requirements.

d) Publications and the transfer of knowledge

Members of PTB regularly publish the results of their scientific work in prestigious national and international technical journals and present them at technical conferences. In the year 2006 PTB scientists published:

- no monographs (in 2004: 4; in 2005: 1)
- 393 contributions to collected papers (external publishers) (in 2004: 348; in 2005: 346)
- 238 articles in reviewed journals (in 2004: 201; in 2005: 245)
- 76 articles in non-reviewed journals (in 2004: 76; in 2005: 90) and
- 24 contributions to PTB publications (in 2004: 20; in 2005:19).

Also in 2006 PTB employees gave a total of 993 presentations on scientific topics (in 2004: 948; in 2005: 941) and applied for 19 patents or other property rights (in 2004: 12; in 2005: 11). PTB lists the following titles by members of its staff as particularly important for metrology; they resulted in part from cooperation with national and international partners:

- Peik, Ekkehard; Lipphardt, Burghard; Schnatz, Harald; Schneider, Tobias; Tamm, Christian; Karshenboim, Savely G.: Limit on the Present Temporal Variation of the Fine Structure Constant. Phys. Rev. Lett. 93, 170801 (2004).
- Becker, P.; De Bièvre, P.; Fujii, K.; Gläser, M.; Inglis, B.; Lübbig, H.; Mana, G.: Consideration on future redefinitions of the kilogram, the mole and of other units. Metrologia 44, 1 (2006).
- Jurgons R.; Seliger C.; Hilpert A.; Trahms L.; Odenbach S.; Alexiou C.: Drug loaded magnetic nanoparticles for cancer therapy. J. Phys.: Cond. Matter 18, 2893 (2006). (Among the “Top Papers 2006” in the Journal of Physics.)
- Sorokin, A.; Bobashev, S.V. ; Tiedtke, K. ; Richter, M.: Multi-Photon Ionization of Molecular Nitrogen by Femtosecond Soft X-ray FEL Pulses. J. Phys. B: At. Mol. Opt. Phys. 39, L299 (2006). (Among the most frequently cited papers in the Journal of Physics B in 2006.)
- Blumenthal, M. D.; Kästner, B.; Li L.; Giblin, S.; Janssen, J. T. B. M.; Pepper, M.; Anderson, D.; Jones, G.; Ritchie, D. A.: Gigahertz quantized charge pumping. Nature Physics 3, 343 (2007).
- Engert, J.; Fellmuth, B.; Jousten, K.: A new ^{3}He vapour-pressure based temperature scale from 0.65 K to 3.2 K consistent with the PLTS-2000, Metrologia 44, 40 (2007).
- Schumacher, H. W.; Serrano-Guisan S.; Rott K.; Reiss, G.: Ultrafast magnetization dynamics probed by anisotropic magnetoresistance, Appl. Phys. Lett. 90, 042504 (2007).

At the same time PTB itself publishes the following series that are directed at different target groups:

- *PTB News* as a PTB news periodical that is issued three times a year with a circulation of about 8000 copies. According to PTB's assessment *PTB news* has established itself as a means of communication between the scientific working groups of PTB and the rest of the scientific community as well as industrial companies.
- *PTB Mitteilungen* is a quarterly metrological journal and official journal with a circulation of 1200 copies. It is aimed at metrology science readers as well as – in its official section – industrial companies and administrative authorities.
- *PTB Berichte* comprise longer scientific treatises on particular subjects that are unsuitable for publication in scientific journals on account of their length. PTB issues 20 to 30 reports annually with 200 to 500 copies each.
- *PTB Prüfregeln* comprise documentation and guidelines for the testing of measuring instruments and equipment. The series currently extends to 30 volumes and is expanded as the need arises. The testing regulations are directed towards verification authorities as well as industrial testing laboratories.
- *maßstäbe* is a popular science magazine; each issue is devoted to a single scientific subject and with a circulation of 40,000 copies is aimed at the general public, and especially high school and university students.

PTB notes that the publishing activities of the scientific staff are regarded as important success criteria for internal work planning, as well as providing one aspect of performance rating. PTB sees its participation in or organization of scientific meetings and conferences as another important part of know-how transfer, and also for the feedback of its own R&D results into the scientific community. In the years 2004 to 2006 PTB staff gave a total of 2882 presentations at international conferences, of which 239 were invited. In addition, during the report period PTB itself organized 14 national and 27 international conferences. For a further 28 conferences PTB acted as co-organizer, and at another 34 conferences PTB staff served on the scientific committees.

e) Quality management

In order to guarantee the scientific quality of its R&D, the legal tasks and its expert services, PTB has set up a stratified organizational system. The responsibility for quality management in PTB lies with the president, who has charged the PTB quality manager with it for the areas of services and of internal processes. For the assessment of research and development performance, e.g. via the work-plan procedures, the president, as the Research Representative (*Forschungsbeauftragter*), exercises this function himself.

In 1995, for internal quality management PTB has introduced a formalized process that covers all its metrological activities. This process is in accordance with the requirements of ISO/IEC 17025, the principles of ISO 9001:2000, but also the recommendations of the German Research Foundation (DFG), and is regularly evaluated by experts from EUROMET/EURAMET. In addition to the comprehensive procedure mainly mandated by ISO/IEC 17025, the system of quality management includes among other things the assessment of work progress at the annual work-planning meetings. Within the directorate a discussion of results and aims occurs, supported by technical lectures and the cost-benefit calculation which compares figures of merit for performance in research, services and consulting with their respective cost. At these evaluations the opinions of clients and partners are also considered.

To ensure that the methods, theories, and techniques employed are up-to-date, PTB above all resorts to extensive exchange with the scientific community, but also with industrial companies which in many cases possess excellent metrological capabilities. Part of that is the publication of its R&D work in reviewed technical journals, where the peer-review process guarantees an effective check of the work. Moreover the scientific staff have PTB's libraries in Braunschweig and Berlin at their disposal, besides access to electronic publications, to allow them to keep up-to-date with the

specialist literature. In addition PTB employees participate in important national and international technical conferences, usually presenting lectures on their work.

For external control of scientific quality PTB is part of a tight network of international agreements that aims to ensure the quality and accuracy of measurements and services of metrology institutes (the Mutual Recognition Agreement – MRA – of the CIPM). The system is based on the exchange of R&D results, the disclosure of results and measurement capabilities, extensive international comparison measurements, and the checking of the mandatory quality management system following ISO/IEC 17025. In this global structure the association of European metrology institutes EURAMET executes the function of a regional metrology organization (RMO) within which by peer reviews the results of measurement comparisons, as well as the records in the relevant BIPM database of measuring and calibration capabilities and the results of key comparisons are checked. In a second step the results are examined by all the other, non-European, RMOs.

In 2002 PTB was evaluated by an international expert commission (Weule commission).[16] The commission certified that PTB's specialist work and the competence of its staff were predominantly of excellent quality. The interlinking of PTB research activities with the national and international community is very good. However, in view of new developments and the consequential requirements for metrology, the expert commission identified the need for PTB to network more strongly with the scientific system as a whole. This would allow it to keep up with the newly emerging tasks in the fields of foodstuff analysis, forensic science, clinical laboratory medicine, and pharmaceutics. This includes participation in third-party funded research consortia at the national, European and international level.

PTB followed the recommendations of the evaluation commission by extending the network "Metrology in Chemistry" to develop traceability systems for a large number of additional analytes. This was done in collaboration with the partner institutions BAM, Federal Environment Agency, Federal Office of Consumer Protection and Food Safety, and the German Society for Clinical Chemistry and Laboratory Medicine. The new head of the division responsible for chemistry was appointed jointly with the faculty of life sciences in the TU Braunschweig. And by its participation in the Berlin Neuro-Imaging Center and the 7-tesla full-body nuclear magnetic resonance tomography installation, still under construction, PTB has further enhanced its networking with the Berlin universities and other medical research establishments.

f) Competitivity

As reported by PTB, certain competitive elements exist at various levels of its research organization. The resources given to each division contain a proportion which is allocated depending upon the number of third-party funded staff employed there. Furthermore, the number of newly granted third-party funded projects enters the work plan discussions held between the Presidential Board and the technical divisions as one figure of merit. In addition PTB offers bonuses and performance-related salary increases to particularly highly dedicated civil servants.

Success in the competition for third-party funding is of great significance for PTB's R&D work. In the period 2004 to 2006 the institute has been granted third-party funds of some 36.7 million Euros (cf. Appendix 5). The federal government contributed the lion's share during this period with project support of about 21.4 million Euros, followed by industry with approximately 5.2 million Euros. In the scientifically particularly competitive area of EU funding PTB was able to solicit about 3.3 million Euros and from the DFG a further 1.9 million Euros.[17]

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[16] cf. *Evaluation der Physikalisch-Technischen Bundesanstalt: Abschlussbericht der Evaluationskommission* (in German), loc. cit.

[17] Already during the period 2002 to 2004 PTB was among the eight federal establishments with R&D responsibilities to have solicited over 0.5 million Euros from the DFG for R&D resources. In the DFG sponsoring ranking of 2006

By soliciting third-party funds PTB regularly tries to access new areas of research. The institute is generally permitted to compete for third-party funds for research projects that support it in the fulfillment of its legal and constitutional duties. However, according to the third-party funding regulations of PTB, these resources may not put the neutrality and independence of the institute at risk, particularly in those areas with approval and certification tasks. Besides, as stated by PTB, the basic principles of budget transparency and truthfulness set up by the Federal Audit Office forbid that the BMWi sponsor with third-party funds the inherent duties which fall under the executive responsibility of the federal institutions. Moreover, it is out of the question that long-term primary tasks be permanently financed by third-party funds since these tasks presuppose that PTB has established sustained metrological competence and is independent. The European metrology research program EMRP presents a new situation in this context because its very aim is to use EU funds in a coordinated way to sponsor national metrology research programs, and hence the primary duties of PTB. In this matter PTB is in close agreement with the BMWi.

III.2. Science-based services

As the national metrology institute and top-level technical authority PTB offers a broad spectrum of scientific and technical services for society, commerce and the economic sector. Some of the services covered by PTB are subject to fees according to various regulations governing the charges to be levied, as determined by the BMWi and other ministries. The annual income from PTB services is about 10 million Euros which, up to a threshold value of currently 7.5 million Euros, have to be passed on to the federal budget; above that threshold 50% has to be ceded.

a) Types of service

The science-based services, for which PTB is legally responsible, include all the so-called legal metrology activities (approval, testing, certification), the dissemination of units to verification offices and testing centers, as well as special duties, such as, e.g., type approval of gambling machines and polling devices, or the type approval of containers for the transport of explosive goods. The focal point of PTB's services lies with the calibration of measuring instruments which are thereby connected to PTB's national standards (traceability), and the type approval or conformity assessment of measuring instruments with mandatory verification requirement. In addition there is a certain amount of consulting work, particularly in national and international committees such as standardization committees, and also direct technical consulting for clients and R&D cooperation partners with the purpose of technology transfer.

PTB calibration work is subsidiary in that the institute restricts itself to those requests that secure the traceability of accredited calibration laboratories to national standards, or which are not on offer by the laboratories of the German Calibration Service (DKD – initiated in 1977 by PTB and industrial companies). As a result of the division of labor with the DKD PTB notes that its calibration work has an important multiplier function. For instance, in 2006 the DKD calibration laboratories issued over 300,000 calibration certificates, based on 3500 PTB traceability calibrations, which in turn led to far more than 10 million factory calibrations. PTB regards this as a successful model for a “private-public-partnership”.

The introduction of the European measuring instrument directive (MID) caused a change in the legal metrology responsibilities of PTB. PTB was given the function of “designated institute” by the European Commission for conformity assessments of electricity, gas, and water meters, for

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out of 167 non-university R&D establishments PTB took the 19th rank, becoming the most successful federal institution regarding third-party funding. Cf. *DFG: Förderranking 2006. Institutionen – Regionen – Netzwerke. DFG-Bewilligungen und weitere Basisdaten öffentlich geförderter Forschung* (in German), Bonn 2006, Table A-14.

example. Here too the subsidiary principle holds, i.e., PTB performs only those conformity assessments for which, due to their complexity, there is no other provider, or at the manufacturer's specific request.

Another area of PTB science-based services concerns the participation in standardization committees. At the present time PTB employees are engaged in 471 international committees. In 227 cases these are standardization committees, 42 of them are chaired by PTB staff, and in eight others PTB staff members are either deputy chairpersons or secretaries. This committee work is seen by PTB as highly important for German industry and also helps the federal institute to judge metrological demand.

Policy consulting takes up about 1% of PTB's resources, where only the minor part of the expense is concentrated on consulting for the BMWi. Of high significance is consultancy for the European Commission, e.g., in connection with the Measuring Instrument Directive (MID), and for other federal ministries. PTB receives several hundred requests per year from various government departments, but mainly from the BMWi. 40% of the requests concern near-term topics such as metrological facts regarding laws and regulations; a further approximately 40% deal with more complex items such as the wording of technical requirements in draft laws. The remaining approximately 20% concern larger projects, such as consulting for the Federal Office of Civil Aviation on the testing of computer codes for the determination of the radiation dose to which flight personnel may be exposed. Finally, PTB also provides technical opinions for courts of law.

The collaboration on law-making or harmonization processes at the national, EU, and international level is another type of service. This kind of work does not as a rule require much research effort. On the national side the revision of verification laws and directives, including their appendices, takes up most of the time, besides supporting work for the draft of an accreditation law. PTB’s involvement reaches from consulting all the way to the development of measuring procedures to which the verification directive refers, some of them requiring extensive research to develop. Participation in processes at the European level is shaped by the MID and work in the European Cooperation of Legal Metrology (WELMEC). PTB asserts that it strongly supported the decision-making on the MID from the beginning through consulting, for instance by providing preliminary information, by consulting of EU bodies during the process through its membership in the EU Commission working groups, by consulting for the EU Council and the Committee on Economic and Monetary Affairs of the EU parliament. At the international level the work most time-consuming for PTB is devoted to the international organizations for metrology, the International Committee for Weights and Measures, and the International Organization of Legal Metrology.

To promote the further education of its own personnel and of the users and clients of its services, PTB offers a series of seminars on special topics in metrology which is supported by the Helmholtz Fund (a non-profit registered society). Topics covered in seminars include, for example, the European Measuring Instruments Directive, the field of explosion protection, or training of clients in the fields of electrical and optical measuring techniques. In the report period 2004 to 2006 PTB held 49 training seminars which were attended by a total of 2463 external users. Beyond this offer of training for external addressees in Germany, within the scope of technical collaboration PTB is also engaged in the training of personnel in partner institutions in developing, threshold, and transformation countries. The training encompasses topics from the whole spectrum of quality infrastructure (measurement and testing, standardization, quality management, accreditation and certification) and is carried out on behalf of BMZ, EU, or the World Bank.

As a rule PTB offers all its services itself. Only in rare exceptional cases is part of the work that belongs to PTB's responsibilities commissioned to third parties. This outsourcing takes place in those cases when demand exceeds the capacity of the PTB sections responsible, or else when the measuring devices or particular expertise are not available in PTB for this part of the work.

b) Basis in research and quality management

According to PTB, with few exceptions it bases all its services on its own R&D work, that may also

include anticipatory research for long-term service options. As an example, for many years PTB has been developing primary clocks to establish legal time. Since the sixties this has entailed the development of caesium atomic clocks, since the nineties caesium fountains and in recent years optical atomic clocks on the basis of ultra-cold single ions or neutral atoms. According to PTB the precision of these clocks was improved in each decade by about one order of magnitude. Based upon their accuracy and PTB's competence in this field, PTB's atomic clocks contribute the distinctly largest contribution to coordinated universal time. Here numerous applications in industry and the economic sector rely on PTB's time signals distributed by the DCF77 long-wave radio emitter, by the internet, or by telephone.

In consequence of the close interlock of PTB services with its R&D work, quality control of the methods employed in service areas is performed analogously to quality control of R&D areas. However, whereas research performance is assessed solely by the prevalent academic performance criteria, the evaluation of development projects, services and consulting is also affected by whether the appropriate technological objective was reached, or whether the service or consulting was useful to the client. As a rule, the methods and techniques employed in the provision of the services are developed by PTB itself. Moreover, it is the international comparison measurements above all that ensure that PTB offers its services according to the most up-to-date level of science and technology.

In the majority of its legal responsibilities PTB is obliged to follow certain procedures. Conformity assessments within the framework of national or European statutes represent a focal point in this area, for example in consumer protection and fair business practices, or in electromagnetic compatibility and energy measurement technology. PTB reports that the specified methods and processes do not always comply with the up-to-date standard of science and technology and therefore frequently have to be adapted. Again as a result of its competence and its extensive R&D work PTB often plays a decisive part in the continued development of the standard procedures.

To guarantee the quality of its services it is further PTB policy to regularly involve its users and clients. Because of the significance of measuring processes for economy and society, the community of service users is quite diverse. The main clients for services outside the legal field are above all the calibration laboratories of the DKD, as well as industrial companies, mainly small and medium-sized enterprises, that request calibrations which the calibration laboratories are unable to provide. The main users of PTB services are the DKD laboratories and manufacturers of measuring instruments, to which must be added authorities such as verification offices and the ministries. The most important controlling panel for PTB services is the Board of Trustees in which, among others, the industrial representatives act as consultants. Other important panels that provide client feedback are the plenary meeting of the stakeholders in verification, and the Advisory Board and Technical Committees of the DKD.

PTB regularly determines the satisfaction of its clients and users with its services by polling them under the quality management system, which also offers "complaint management". Furthermore, PTB employees receive direct feedback regarding the clients' wishes through their work on standardization and other panels, as well as in industrial associations. By means of the so-called MERA poll in 2003 PTB, by offering an internet-based, interactive questionnaire to 2402 of its clients, determined the priorities and the evaluation of its services. 38% replied and gave PTB the mark 1.2 (as in Germany's school grading system, ranging from 1 (best) to 6 (failed)) for the technical competence, 2.6 for the handling time, and 2.3 for the pricing of its services.

c) Transfer of knowledge

On principle, as its contribution to making knowledge available to science, the economic sector and society, PTB always publishes research results. The results of measurement and calibration services, as well as of consulting are not published, although the results of approval and certification are.

PTB recognizes that an essential component of the transfer of knowledge is its collaboration on development with industrial companies. As of June 1, 2007 PTB was engaged in 149 R&D

cooperation projects with industry, with both stock-exchange listed companies and small and medium-sized enterprises (SME). Moreover, in July 2004 the position of Technology Transfer Representative was created within PTB who, together with the legal advisers, counsels PTB's inventors and assists with patent claims and applications. PTB regards this concentration of inventor counseling, patent application and patent marketing in a single staff position − compared with separate patent exploitation offices − as a more effective path for technology transfer.

In the year 2006 the BMWi initiated a measure to "support small and medium-sized enterprises in the realization of innovations in the fields of measurement, standards, testing and quality control" (*MNPQ-Transfer*) which, according to PTB, has much enhanced the transfer of its know-how to the economic sector. Through collaboration with SMEs, for those R&D results – for example of PTB – with significant economic potential this supporting measure aims to help their timely integration into marketable innovative products, procedures or services, thus contributing to a more effective technology transfer. Prerequisite is that in the companies, which are obliged to provide their own funding, direct proof of the economic advantage be seen. The proposed projects, planned to take from one to three years, are approved by an external, independent jury. The MNPQ funds are awarded in accordance with the projects' rating in competition between BAM, BGR, and PTB. The program is currently endowed with a total of 3 million Euros annually. From the point of view of PTB, these projects offer another possibility for delegating some tasks in a subsidiary manner, allowing private businesses to undertake them.

Besides these initiatives, it is the declared aim of PTB to support spin-off companies. In 2004 two PTB employees established the Etalon AG after the industrial partners of a successfully running R&D project shied away from the associated costs. The firm meanwhile has grown to nine employees. As an initial boost PTB offered the firm work space under the conditions of a technology park for start-up companies (*Gründerzentrum*). However, PTB reports that this intensified technology transfer, although politically desired by the government, ran into certain personnel-related obstacles, mainly in the form of legal restrictions regarding side jobs by public employees. These problems could be solved internally by PTB only in a limited way on account of existing legal restrictions.

A significant element of the transfer of knowledge for PTB are aggressive public-relations activities in order to raise a higher public awareness of the value of metrology and the work of PTB. Besides the usual contacts with the press, this manner of knowledge transfer is above all based on the popular science magazine *maßstäbe* (current circulation 40,000) in which it is exclusively journalists who write in varying styles about science and especially metrology. In this magazine PTB sees an important multiplication tool for the dissemination of metrological topics since it is also employed as instruction material in schools. The magazine was honored in 2005 by *Bild der Wissenschaft* as its choice of "Magazine of the Year" 2005. As well as working with the press, PTB organizes guided tours for over 10,000 visitors annually, open-house days, and other events with great public appeal such as *Die lange Nacht der Zeit* ("the long night of Time") to seek direct contact with the public.

A.IV. Future development

The basic mandate of PTB to carry out research and development in the field of metrology and to offer services based thereupon has remained unchanged for almost 120 years. Yet, as a consequence of new legal specifications, shifting focus and the growing demands on the part of German industry, in addition to new scientific insights and novel technologies, PTB continually renews its orientation of work in central areas. Thus the institute expects that the need for traceable and technologically ever more sophisticated measurements in metrology will continue to increase. This may be observed in the "classical" fields of metrology such as mechanics, electricity, and production metrology, where on the one hand the ranges of the measured quantities are constantly being extended, and on the other hand the demands on measurement precision are growing. Further needs are anticipated in the fields of chemistry, medicine, and the environment.

B. Evaluation

B.I. Responsibilities and scientific significance

The Physikalisch-Technische Bundesanstalt (PTB), Braunschweig and Berlin, counts among the leading metrological establishments in the world. The high scientific quality of its work, the convincing competence of its staff, the very good scientific and technical infrastructure, and important (research) strategy decisions by its directors constitute the basis for the remarkable level of performance of PTB. The reputation of the federal institution reaches beyond the field of metrological traceability of the national to the international standards. Through its research and development (R&D) work and the science-based services, PTB makes an extremely valuable contribution to the application-oriented development of relevant technologies and so plays a significant part in the creation of wealth in Germany.

The spectrum and coherence of work

The spectrum of work of PTB extends over a large bandwidth of challenging science-based duties. These include the support of industry and commerce by safeguarding the units of measurement and the pertaining technical development, the promotion of science by the operation and continual development of a powerful R&D infrastructure, and policy consulting in the form of technology consulting for the federal government. These responsibilities are altogether highly relevant to society since in many areas they touch upon questions of reliability and trustworthiness in legal business and the standardization of technical development.

As the central metrology institute PTB occupies a unique position in Germany in the fulfillment of these duties. Because of the generally long-term character of the R&D work, and the required experience for the operation of precision metrology laboratories, PTB as a federal institution with R&D responsibilities has at its disposal the necessary structural prerequisites for the tasks, in contrast to university institutes in particular. On the international stage, in the appropriate committees and organizations, PTB plays a leading role in the development and evolution of metrological standards. In some individual areas PTB duties partly overlap those of other departmental research institutions. In these cases the institute successfully coordinates its duties with the partner institutions. For instance, PTB together with the Federal Institute for Materials Research and Testing (BAM) has developed a convincing procedure for the sharing of duties in the field of explosion protection. In other fields such as chemical metrology PTB engages in an efficient cooperation with departmental research institutions such as the Federal Environment Agency (UBA), Dessau, and with non-departmental institutes such as the Federal Office of Consumer Protection and Food Safety (BVL), Braunschweig.

For the evolution of its responsibilities in recent years PTB has successfully balanced its concentration on the central tasks on the one hand against the assumption of new tasks on the other, despite the continuing reduction in personnel. With the impetus from the relevant recommendations made by the Weule commission in 2002,[18] the institute carried out a convincing procedure of internal critical assessment of its responsibilities within the scope of the so-called “Concept 2016”. This led to the necessary resources for new work being released by the termination of less relevant projects. In so doing PTB sufficiently ensured the coherence between individual task fields, although the number of scientific staff does not yet correspond to the breadth of the spectrum of work. To preserve this coherence in the long term as well as the high scientific standard of PTB, it is essential that the scientific work of the institute not be rendered more difficult by the assignment of new tasks that run counter to the profile of PTB. Therefore the present responsibility of PTB for gambling machines, firearms, and electronic polling devices as a routine task should be delegated elsewhere.

[18] cf. *Evaluation der Physikalisch-Technischen Bundesanstalt: Abschlussbericht der Evaluationskommission unter Vorsitz von Prof. Dr. Hartmut Weule* (in German), Karlsruhe University, commissioned by the Ministry of Economics and Labour, 2002

Task evolution within the European context

The European activities of PTB represent an important aspect of its task evolution. PTB as a leading member of EURAMET e.V., the association of European metrology institutes, plays a decisive role in the creation of a European network aimed at carrying out new metrological tasks by division of labor, for example in the area of medical metrology. This form of division of labor permits research on new metrological topics to be performed, despite the stagnation or even reduction of the budgets of European national metrology institutes (NMI). PTB should continue to pursue this kind of European division of labor. Nevertheless, PTB took the right decision not to subject those research projects to the European division of labor that are part of a bilateral cooperation with German industrial firms. For example, on the European scale PTB commands a degree of competence in the field of production metrology that is closely linked with the R&D activities of the leading German engineering companies which are otherwise only poorly represented in Europe. To turn this task into a European one would be to jeopardize the technological advantage developed in Germany in this area. Moreover, not least because of language barriers and the different European "cultures" with respect to the delivery of services, the small and medium-sized enterprises (SME) in particular depend on the availability of a competent national partner to contact.

The quality of research and development

The R&D work of PTB as a whole is of very good to excellent quality. In the field of metrological research PTB belongs to the upper international echelons of national metrology institutes and plays a decisive part in the definition of the state-of-the-art in science and engineering. Only in isolated cases, such as the recently established department Metrology in Chemistry, is there a partial need for further scientific improvement, in order to catch up with the altogether high standard of other departments.

Apart from the highly dedicated and greatly motivated scientific staff it is the research program of PTB, which encompasses relevant and topical R&D questions, that is an important basis for the very high quality of the R&D work. The R&D concept convincingly combines anticipatory research, that to a large extent may be regarded as excellent fundamental research, with work on the continued improvement of measuring techniques, as well as with application-oriented development work in the area of calibration. In this way PTB succeeds in providing its services with a very good scientific foundation, by regularly adapting the methods used to the insights gained through its own research, thereby linking them constantly to the state-of-the-art of metrology.

Overall, the evolution of R&D topics in PTB's areas of work is strategically directed. Thanks to transparent and powerful procedures for the creation of these topics PTB is able, on the one hand, to take its lead from the needs of users in economy, politics, and society. On the other hand PTB avoids fragmentation and arbitrariness in its research projects by choosing its research according to clearly defined strategic goals. The federal institute thus embodies an important mediatory function between the users and addressees of its services and the metrological scientific community.

Transfer of knowledge

Based upon its broad spectrum of activities and the high quality of its R&D work, PTB plays a major role in the transfer of metrological know-how to users in economy, science, and the general public. For users in industry and commerce PTB makes an important contribution to the transfer of metrological techniques by strictly taking user requirements as a guidance. PTB is engaged, for example, in important R&D cooperation projects with selected industrial companies. This kind of cooperation is of mutual advantage to both parties: industrial research can be guided towards top metrological research by model projects, thereby profiting from the measuring processes developed in PTB, while PTB gains an insight into the production techniques developed by industrial research as possible future fields of application. Furthermore, this cooperation helps PTB to do work in new fields of technology already at an early stage, as is the case, for instance, with the work on Terahertz Metrology. In the future PTB should continue to take care in its R&D cooperation with industry that the circle of partners remains as open as possible.

For the scientific community PTB regularly transfers its research results through publication in

qualified technical journals, some of which have a high impact factor. PTB thus makes sure that its R&D topics generated from applied fields are taken up in the discussion of top research and at the same time subjects itself to peer review by the community of metrology experts. In some individual areas (cf. section B.II.) the proportion of publications in reviewed journals can still be increased. On the whole, PTB departments should wherever possible avoid the publication of so-called “grey literature” in favor of higher-ranked publications. This equally holds for development work in service areas such as calibration. Moreover, PTB personnel should participate more in international specialist conferences to present their R&D work.

In its publicity work PTB has begun to interest a broader audience in metrological questions. For example, certain activities such as the measurement of time are publicly highly visible and closely tied to PTB work. However, on the whole PTB is as yet insufficiently recognized as an important establishment for technological development in Germany. PTB should take targeted action to publicly present its contribution to development in chosen areas of technology, as is done for example by its sister institute in the United States, NIST, at annual press conferences. Furthermore, PTB should consider whether it can identify and point out, on the basis of its R&D work, relevant future developments in innovative fields. It should be the aim of PTB's public activities to establish public awareness for metrology research as a significant foundation for future technological development.

Quality control

PTB guarantees the quality of its R&D work and its science-based services by applying a series of powerful internal and external processes. PTB’s work is subjected to regular quality control by the scientific community thanks to proven external instruments: the publication in reviewed journals; the competitive soliciting of third-party funding of R&D in the appropriate fields; the participation in national and international conferences. PTB is further closely tied into the international network of national metrology institutes and these mutually check the quality of their R&D work and their services by regularly performing round-robin comparisons. These procedures are complemented by efficient internal quality control measures, where the annual report to and evaluation by the PTB Board of Trustees is of great importance. In this context, PTB’s Board of Trustees, in general acting as a scientific advisory board, should participate more strongly than hitherto in the strategic decision-making of PTB’s directorate and on a regular basis perform analyses of possible weak points in the research organization.

Under the Weule commission of 2002 for the first time PTB in its entirety faced an external evaluation. The results yielded important indicators for the future development of the institute's research strategy. In coordination with the trustees and the BMWi PTB should develop a powerful and efficient process for the regular revision of its work, for instance by being evaluated at seven-year intervals, which should not, however, lead to a disproportionate strain on the institute.

Science-based services

PTB is characterized by a comprehensive portfolio of science-based services for the economy, for science, society, and politics, which are closely linked to its high-quality R&D work in the respective working areas and therefore reflect the current state of science and technology. With regard to the quantity and the quality of its science-based services, the federal institute holds a unique position in Europe. This is particularly true for its calibration services that are highly important for industry and commerce. In this field PTB not only guarantees the scientific quality of the calibrations, but it also actively takes part in the competition predominantly with the European metrology institutes. Here it is able to secure an obvious competitive advantage for the German export industry, for instance by its nomination as a so-called “designated institute” of the EU. Thanks to the increasing participation of the service users in task planning, and a remarkable flexibility in the organization of its processes, PTB is also in a position to quickly adjust to the changing requirements of its clients in industry and commerce.

Beyond its support of industry, with its services PTB also performs an important duty for the scientific system. The institute offers a highly developed and in part internationally unique R&D

infrastructure and ensures the reliable operation of those facilities. The great diversity of its research apparatus such as the caesium clocks, the synchrotron radiation sources, accelerator and cyclotron of the ion beam laboratory, as well as the Berlin magnetically shielded room are very well organized by PTB. By offering its infrastructure to external scientists PTB substantially promotes metrological fundamental research in Germany.

Compared with the services for the economy and science, in the area of policy consulting PTB has some catching up to do. On the whole PTB operates on too narrow a concept of policy consulting, namely in the sense of the specific preparation of new laws. In view of its high scientific and technical profile, the close cooperation with technologically oriented companies, and its well-established European and international network, the institute should leverage its potential far more to more strongly support the BMWi and above all the newly established Directorate-General Technology Policy. The objective should be to exploit the strong specialist expertise of PTB in order to assess development goals in technology policy or to secure early competitive advantages for the German economy by anticipating technological progress. In return the BMWi should ensure that additional personnel is allotted to PTB so that an appropriate coordinator position can be installed in the presidential office of PTB.

B.II. Work focus in the task areas

Mechanical quantities

The R&D work carried out in the departments of the division Mechanical Quantities of PTB is altogether of very good to excellent quality. The scientific projects in the fields of Force, Angular Momentum and Pressure are essentially applied development tasks for the realization and dissemination of the SI units for mass, force, angular momentum, and pressure, which nevertheless have too little impact in terms of publications in reviewed journals or of third-party financed research projects. The R&D activities of PTB are concerned with continued development of efficient testing bays, where the institute plays a leading national as well as international role. In other areas such as the development of new sensors for weighing technology PTB occupies a top international position thanks again to extensive cooperation with industry. Furthermore, in the areas of solid state mechanics and kinematics the institute has opened up an extremely promising research area with enormous innovation potential with dynamical force measurement and with the development of velocity meters. In addition the groups in this field also deliver important and high-quality contributions to research oriented cross-sectional projects such as the Avogadro project. The scientific work of PTB combines very well the basic questions of metrology with aspects of applicability of metrological methods for the economy. For the future development of this sub-field overarching questions should be formulated to better focus the present approaches and know-how. A good point of departure here is the research focus “dynamical measurement of mechanical quantities” already developed.

The R&D and service tasks undertaken in the Acoustics departments are of mostly excellent quality particularly in the fields of ultrasound and building acoustics. In this area PTB manages to strike a balance between its own research, development, and the legally prescribed duties in an appropriate and goal-oriented way. The R&D topics are of great scientific complexity; they are interdisciplinary by nature and are supported by third-party funding by DFG and industry. To free up the necessary resources and time to be able to focus on new areas, routine measurements are contracted out to the DKD and building acoustics testing centers. The scientific staff enjoys a high reputation in the scientific community and their R&D work is regularly presented in specialist publications and at high-ranking conferences; they also participate in the most important technical committees and organizations, usually in senior positions. Moreover, the departments also cooperate closely with universities, particularly with the TU Braunschweig. It should be considered how the departments can be given additional freedom to take up tasks at the European and international level in particular.

Electricity

The scientific work and services of the PTB division Electricity and Magnetism are of very high standard overall and show obvious applicability. In the field of electrical and electromagnetic metrology, both in Germany and by international comparison, the federal institute holds a dominant position which it is expedient to preserve and strengthen.

In the area of fundamental research the internationally outstanding Electrical Quantum Metrology should be mentioned. The scientific staff in this section is at the forefront of the development of novel quantum physical devices with which the quantities voltage, resistance, and current shall be realized (Josephson effect, von-Klitzing effect, single-electron devices). The following are of particular significance: the successful development and validation of the first programmable quantum standard worldwide for voltages up to 10 volt; the long-standing optimization of semiconductor-based quantum Hall structures as resistance standards; the investigation of electrically addressable quantum dot structures for application in single electron pumps, which may in future become a quantum standard for the fundamental SI unit ampere. The results of these R&D tasks are of a convincingly high scientific and technological standard and have been prominently published in leading journals. In comparison with other metrology institutions worldwide PTB has secured the leading position in this field.

The metrology work in the subsection Direct Voltage and Low Frequency is of equally high and convincing scientific quality. The research and development in this field is important for the measurement of the electrical power of time-varying current or voltage consumption as found in industry and particularly in the watt-meters of every household. So the direct socio-economic significance of these activities is immediately evident. The two approaches (thermo-converter and synchronous sampling) for the construction of such meters clearly are based on the most up-to-date science and technology. The scientific staff are contributing substantially to the continued development of these methods, which are secured by patent applications or by technology transfer to external industrial firms.

The work in the area High Frequency Metrology (1MHz – 300 GHz) is also of a comparably high scientific standard. The staff in the respective working group are involved particularly in quantitative vector network analysis in the high-frequency range, for example for the description of the scattering parameters of emitter-receiver-systems and in the field of antenna metrology. Besides being fundamentally important, this work also possesses significant practical value, e.g., for the quality control of instrument landing systems in aeronautics.

Dimensional Metrology

In the field of dimensional metrology PTB, thanks to its very good to excellent R&D work and its closely-meshed scientific networking, belongs to the top echelon of institutes worldwide. Prominent in the work is the collaboration with other metrology institutes and industrial partners. The scientific staff is well-represented in the specialist panels and working committees of national and international associations and organizations.

The work in Production Metrology is characterized by topical questions and a client-centered orientation. Based on close contact with scientific and industrial institutions, PTB employees are involved in the scientific progress in this field. Important applied methods are being researched and measuring procedures developed, particularly in the areas of scanning probe methods for mask metrology in micro-system technology, and for the realization of a traceable nanometer comparator. The work is highly industry oriented and plays an outstanding role in the creation of wealth. In the use of computer tomography for industrial applications PTB holds a unique position in the world. The research work on a laser tracker for high-precision 3D-position measurement has led to the founding of Etalon AG as a spin-off of PTB. Also in future a fair balance in the supporting measures of PTB towards spin-off companies should be sought.

As in nano-metrology, the group Macro-dimensional Metrology in PTB also regularly achieves exceptional F&D results. In its scientific work the working group employs very good analytical methods and is distinguished by remarkable development efforts for research equipment. In

addition, the group is following convincing approaches to the investigation of the use of the internet for calibration tasks. There is, however, room for improvement in integrating the modeling work of the PTB group on "Mathematics, Metrological Information Technology".

Chemical Physics

Work in the field of chemical metrology, in consequence of the recommendations by the Weule commission among other considerations, has been greatly intensified in recent years. In parts the working groups concerned are still in the setup phase. In this area PTB is pursuing the targeted approach of providing for chemical substances the traceability of metrological quantities and a further development of the corresponding metrology at the highest level. The entry of PTB into this developing field of a more complex chemical metrology is expedient and necessary in view of its leading role in physical measuring procedures. The working groups pursue the ambitious goal of developing metrological standards, above all in the areas of health and energy, in order establish European leadership within the framework of the European Metrology Research Program EMRP.

Compared with other areas of PTB and despite a partially good performance in the areas of Clinical Chemistry Laboratory Diagnostics and of Flow and Calorimetry, the division of Chemical Physics—mainly because of inadequate numbers of scientifically qualified personnel—needs further scientific development overall. The proportion of the in-house R&D work is noticeably lower than the average 60% recorded for PTB. With a view to the claim of comprehensive competence in the field of chemical metrology, the currently apparent metrological perspective is far too narrow. The broadness of the field leads to problems in formulating a coherent research plan. The result is that there is only limited interaction of the individual project groups with each other. Finally, the group in some areas lacks sufficient contacts to top-level university research.

PTB with its excellent metrological equipment, and beyond the obligation of legal R&D tasks, is in principle in a position to build up extensive competence in the area of metrological chemistry. This, however, is on condition that the chemistry division is given a noticeable increase in personnel. While "simpler" chemical analytes or macroscopic material data may be accurately treated with the current equipment, for quantitative metrology in the domain of complex materials and chemical functional groups an appropriate capacity still has to be set up. In order to promote efficient cooperation with relevant universities and research institutes it is recommended that the division establish two junior research groups. Internationally recognized leading experts in analytical chemistry and bio-organic chemistry/macro-molecular chemistry should be integrated with at least one junior scientist and two third-party funded PhD students each, in order to gain the necessary expertise and to establish a platform for cooperation and the continued competition for third-party funding.

Optics

Excellent and internationally highly prominent work is done by PTB in the field of optics. The division's personnel is scientifically highly competent and highly specialized; the individual working groups are very well linked with each other. Besides PTB scientists, there are numerous undergraduates and PhD students contributing to the work.

The Radiometric and Photometric research in PTB internationally holds a unique metrological position thanks to considerable investment and competent staff. Most of the work has development character, whereas investigative research only occupies a smaller proportion. However, the development work is highly relevant for German industry, for instance in the area of novel light sources where high economic dynamics is on the horizon. The standardization activities of PTB represent an important contribution to the international acceptance of the standards used in Germany.

Compared with the radiometry and photometry, a more investigative aspect is observed in the PTB work on the topic of Optical Femtosecond Metrology. The working group is the international leader in measuring the nonlinearity of optical components, such as lenses and polarizers, with high sensitivity. The work makes important contributions to technological areas such as optical lithography or chip production in the sub-micrometer range. The group is very well equipped with

instrumentation, such as femtosecond lasers which are very suitable for the measurement of optical nonlinearities. The group performs very good and innovative development work at today's state-of-the-art of science and technology, also with the help of PhD students integrated into the group.

The work sections Time and Frequency in the optics division belong, even in the public eye, to the most visible areas of PTB. On the basis of an excellent infrastructure and scientifically leading staff, the institute performs universally recognized time measurements. In the continued development of both conventional caesium clocks and the future optical clocks PTB stands in the front row of the international metrology institutes. The group closely networks with the scientific community and is very well represented at relevant specialist conferences and in the most important journals.

Ionizing radiation

The division Ionizing Radiation performs metrology for research, medicine, and the public at the highest level. Its core competence comprises the dosimetry for any medical application of ionizing radiation. This is the essential prerequisite for its practical application (e.g., for radiation therapy, X-ray imaging). The setting-up of an early warning system for radiation accidents and the maintenance of measuring installations for radon decay products and high energy X-ray reference radiation fields on the one hand carry a high priority for environmental protection, and on the other hand form the basis for law-making and the preparation of directives. The division liaises closely with the various national and international panels for radiation protection and standardization, and has a decisive influence there because of its expertise. This influence and the elaboration of laws and directives for the application of ionizing radiation are of critical importance to society, and to industry as well. In the area of service tasks and development work the division produces work of excellent quality. Since the majority of its resources are bound up in the work mentioned above, the division is active in research only in a limited way, but nevertheless this is mostly third-party funded. Important and high-quality third-party financed anticipatory research is performed for environmental dosimetry and neutron dosimetry for medical and other applications (e.g., fusion research). The thoron (220Rn) project must be regarded as innovative and of great importance for environmental research and should have a significant effect on future radiation protection directives.

Over a large energy range the division has a unique standing with its neutron dosimetry. The expertise of the division allowed it to develop a transportable neutron dosimeter for the monitoring of flight personnel. The extensive knowledge of neutron dosimetry led to the working group's involvement in fusion reactor control by neutron flow monitoring. The group is worldwide one of the few that have a thorough knowledge of neutron dosimetry, a field regarded as rather difficult, and this is confirmed by the group's high-level publications.

Some improvements could be made in the decisions on the R&D infrastructure. The operation of five accelerators should be made more transparent. Furthermore, external users should increasingly gain access to the laboratories, so that the sophisticated infrastructure is exploited more effectively. The choice of research topics is not always comprehensible. For example, the focus on dosimetry for tomotherapy, when the future significance of hadron therapy is already becoming apparent, ought to be critically discussed. Therefore medical expertise should be consulted more widely when a choice of topics in the medical field is made. While the group is integrated very well in the international metrology network, in some sections of the division there is room for improvement in the cooperation with universities and non-university R&D establishments. Moreover, in accordance with partner universities, the education of the young scientific generation ought to be intensified.

Explosion protection and physical safety technology

The section for explosion protection and physical safety technology in PTB is charged with high-profile development work with the aim to find substantiated quantitative answers to central aspects, while routine work is given in commission to appropriately instructed institutions. To understand and prevent the ignition/explosion of gas mixtures, research-based physical modeling is required and this is convincingly being performed by PTB scientific staff in cooperation with recognized experts in national and foreign universities. The group is also very well linked up with the PTB

section for mathematical modeling.

Also thanks to a very good technical infrastructure, the division has become the internationally leading expert center for explosion protection and physical safety technology. The scientific staff is very well represented at international congresses and publish their R&D results in reviewed journals, in proportion to the amount of fundamentally oriented research undertaken. The research is supported, among others, by adequate third-party funding from industry and DFG. The research plan for the department ensures coherent development of the work, where only those research topics are chosen that cannot be covered by external expertise. Networking with scientific establishments—in particular with comparable work at BAM—is clearly strategically guided so that no unnecessary R&D resources are being spent. The department is overall very well set up for the duties it is charged with and fulfills a very important bridging function to the economy and society. The timely taking-on of new topics and the full integration of PhD students in all areas of the work contribute to the leading position of PTB in this field of work.

Medical physics

The PTB section Medical Metrology is engaged in high-profile early-stage research in a series of R&D projects. The working group performs R&D tasks of primary importance worldwide, particularly in coil construction and characterization, and in so-called parallel transmission. The remaining work can be assessed as good science. The group stays in close contact with the scientific community by attending high-level specialist conferences and is very well linked with the Berlin universities. In sub-areas such as “high frequency energy deposition in humans during magnetic resonance tomography” there is a need for a substantial increase in staff count so that PTB may fulfill its legal obligations in earnest. The department Biomedical Optics has gained a good reputation in the scientific community through long-term R&D projects, and performs good scientific work in this area. On the whole the group is well-integrated in the scientific environment. The process of topic evolution in the group, pertaining to the possible clinical applications of the investigated methods, should be checked critically. Despite the necessary close cooperation with Berlin universities, in the clinical field it is important to ensure that sufficient capacity remains available for fundamental R&D work.

In the department Biosignals PTB is developing magnetic metrology for medicine. The group is working on the basis of legal directives to guarantee the uniformity of metrology for health care. Nevertheless, PTB work in this field can be classified as application-oriented fundamental research since it is closely integrated in associated BMBF projects and the coordinated research programs of DFG. The work performed by the group is overall of very good to excellent quality. Apart from the strong competence of the staff, the foundation for this high scientific standard is, for instance, the internationally outstanding R&D infrastructure in the form of the “Berlin Magnetically Shielded Room”. Here highly precise measurements at very small magnetic fields, as is the case for biosignals, may be carried out. In addition the department, whose work constitutes a core project of the “Berlin Neuro-Imaging Center” (BNIC), upholds a very close and proven cooperation with academic partners such as the Charité and with industrial research. The section is noteworthy for a very high percentage of competitively won third-party funded projects, numerous PhD students who are closely involved in the R&D projects, and lively publication activities in reviewed journals.

The department Mathematical Modelling and Data Analysis was established in 2004 and belongs to PTB’s division of Medical Physics. Nonetheless the section fulfills important science-based service tasks for many of the working groups in PTB. The R&D work of the group aims above all to preserve scientific competence in the development of individual services. The majority of the group's projects are still in the early stages and focus on the application of established modeling methods to new problem areas. The scientific staff realizes the R&D projects in a highly competent manner, but because of the modest time spent on them to date these are not yet visible on the international scene. The establishment of this specialist section is of great importance for its contribution to the infrastructure and to the mathematical foundations of metrology. With regard to personnel resources and networking with other PTB working groups it is advocated that the group be enlarged.

Temperature

The work of the PTB section High Temperature and Vacuum Physics primarily encompasses science-based services according to legal regulations or for the support of industry and science. On the one hand the aim of the work is to develop methods for the reliable and precise measurement of temperature, thereby supporting industrial production in the areas glass and ceramics, and other fields. At lower temperatures, on the other hand, the improvement and development of non-contact measuring methods are in the foreground, which find important applications in the calibration of infrared radiation sources and detectors in vacuum, for example. Thanks to the scientific competence of the staff, overall the work in this section is of good to very good quality. The work is in agreement with the present state of science and technology, and, using traditional methods, is based on time-tested concepts of temperature and radiation. In consequence of PTB's expertise in length measurement, the group can claim a leading national and international role in the evaluation of the effect of mechanical dimensions on temperature measurement. The results of the development work are regularly presented at specialist conferences and thus are subject to evaluation by the scientific community.

A leading role is played by the R&D work in PTB pertaining to the international Boltzmann Project for the accurate determination of the Boltzmann constant, which is one of the outstanding current metrological projects. Based on effective international division of labor, the project concentrates on the application of a certain method to arrive at a final representation of the Boltzmann constant by the year 2011, in competition with other national metrology institutions. The working group located in PTB profits in this international competition from the excellent metrological expertise of the other sections in the institute, and from the close cooperation with research groups outside PTB. This has led to the publication by scientists in the group of one of the most authoritative reports on the project. The scientific staff in this section is highly competent and dedicated. In spite of the classical nature of the project it does entail a large portion of fundamental research which is altogether of excellent quality.

R&D work of very good to excellent quality is also being performed in PTB in the field of Low Temperatures. The R&D projects aim to improve and simplify the measuring procedures for the realization of the international temperature scales, to develop high-precision superconducting sensors (SQUID), and to generate and measure ultra-low temperatures down to the microkelvin range. The working group is very closely linked with other specialist areas in PTB. Thus there is a close cooperation between the development of cryosensors and the biosignals specialist field. On this basis PTB was able to develop precision sensors of greatest accuracy and sensitivity. The low temperature section is very well set up with regard to the suitability of its tasks, the equipment, the structure and internal organization, and shows considerable ability in networking with the scientific system. Yet there is room for improvement in the number of personnel for the microkelvin installation for the generation of ultra-low temperatures, so that the realization of this temperature range may become a future focal point.

Synchrotron radiation

The section synchrotron radiation of PTB has been consistently and constantly developing its metrology for the last 20 years and has attained a top position in this field worldwide. There is intense concentration on research and the specialist, professional know-how of the scientific staff is convincingly extensive. PTB takes up topics in this field such as terahertz metrology and concerns itself with sources and standards ranging from the infra-red to hard X-rays. Together with the quantitative calculability, the broad tuning range makes synchrotron radiation a unique metrological tool. The current discussion in the scientific community on methods and topics is central to the whole section. The development of the synchrotron laboratory (Willy Wien laboratory) allows PTB to carry out front-line fundamental and anticipatory research, so that already in the approach to a new technology generation the institute can work on the measurement and calibration standards that will be required later on.

The research profile of the working group is characterized by a top position worldwide. Reliable measurements of the reflectance of mirrors for extreme ultraviolet radiation (EUV) and of reflection

masks, as well as luminous intensity measurements of the EUV sources being developed are of enormous significance for the development of EUV lithography. The research topics emerge within the group by the continuous development of the metrology with synchrotron radiation. It is manifest here that the decision to develop the Metrology Light Source (MLS) in the Willy Wien laboratory as PTB's own large installation was a groundbreaking one. This affords the group the flexibility it needs for its future development and measurement program, without the restriction to relatively few dedicated beam times. The MLS ought in future to be accessible for external users for part of the time.

The working group maintains manifold contacts and collaborations which are in part internationally highly conspicuous. An example is the early work in cooperation with NASA and ESA on radiation detectors in space probes. At the present time there are close connections with all of the prominent national metrology institutes and with numerous university partners. Internally, too, the group is well-linked up with other PTB sections.

Cross-sectional topics

Within the framework of the international Avogadro project PTB performs R&D work of a universally excellent standard. The purpose of the project is to realize the original kilogram mass unit by traceability to the Avogadro constant. This objective concerns a core task of PTB which is tackled by a cross-sectional team from six PTB divisions in cooperation with various German research institutes and industrial laboratories. Under the leadership of PTB the work is internationally well-connected. The Avogadro project places extreme scientific demands on metrology and can only be successful if an institution specialized in long-term precision measurements, such as PTB, is involved. For specific questions PTB designs new measuring devices since the precision of the available instruments is insufficient. These developments at the same time become the basis for other cooperation projects for measuring the ultra-precise optical systems of industrial partners. Moreover, various topics in the Avogadro project are treated in theses. The results are presented both at international metrology conferences and in reviewed specialist journals.

The work on traceable measurements in the Terahertz Range belongs to the core tasks of PTB and on the one hand demonstrates the ability of PTB to set up new task fields, despite limited personnel resources. On the other hand, the cross-sectional topic makes it clear that new technologies create new metrological questions that must essentially be solved for the further progress of these technologies. Since terahertz technology shows great economic promise, e.g., in the field of security, in medical imaging, and in communications technology, the availability of calibrated measuring procedures is of large economic significance. PTB’s scientific staff working in this field show convincing competence. The most recent technologies are brought to bear on the topics; the knowledge gained is presented in suitable publications. In view of the size and complexity of this task, the allocation of personnel to the terahertz cross-sectional group as well as its instrumentation appear too slight. The planned expansion in conjunction with a European project proposal should definitively be carried forward and reinforced by additional internal measures, which urgently demand a moratorium on the mandatory staff reduction. Furthermore, the assignment of new personnel positions for the expansion of this field in PTB would be extremely helpful and prevent the institute from falling behind in the competition with the USA and Japan.

Using relatively few resources, in the area Technical Collaboration PTB performs far-reaching and very valuable basic metrological work that has a positive effect on the economy of the partner countries and on their relationship with Germany. This department, cooperating with the Federal Ministry for Economic Collaboration and Development (BMZ), counsels developing and threshold countries on questions of metrology. In so doing PTB concentrates in detail on the needs of the international cooperation partners and promotes the collaboration by exchanging personnel. Depending on the technological status the projects range from the provision of basic technologies for metrology and verification, up to mutual research projects. PTB maintains collaborations with the strategically important “anchor states” Brazil, Mexico, South Africa, Thailand, India, and China. In multilateral projects these anchor states act as local multipliers for metrology projects with less-

developed countries in the target area. In this context the cooperation with China should be expanded.

B.III. Organization and Resources

The directorate of PTB has succeeded, despite difficult financial and legal boundary conditions, in aligning the organization and process structures of the institute with the new requirements in the European and international metrology community. It is laudable that PTB enjoys a relatively liberal (for a federal establishment with R&D responsibilities) autonomy in the organization of its internal processes and the definition of its research program. The BMWi restricts itself, as the responsible authority, to ratifying agreements with PTB on the objectives within the scope of which the institute can plan its work relatively independently.

Budget

The financial resources of PTB are adequate overall for the present spectrum of its responsibilities. The federal institute profits from the decision of the BMWi to allow subordinate federal establishments with R&D responsibilities to have a share in the three percent growth of the research institutions under the high-tech strategy of the federal government. However, in spite of this positive development the budget of PTB, as indeed those of the other European metrology establishments, clearly lags behind when compared with its most important international competitor the NIST, USA. The US government has decided to increase the budget of NIST under its "American Competitiveness Initiative" over the next 10 years, and this represents a serious challenge to the currently still very good international rating of PTB. The federal government, in view of the considerable significance of PTB for technological development in Germany, for example in medicine and electrical engineering, should work towards a moratorium on the annual staff reductions in PTB and a distinct increase in PTB's budget. A first important step would be to permit PTB to withhold all of the income gained from service fees, whereby the proportion of the fees in the primary budget in future, too, shall not surpass 12%. If, in addition, a global budget were introduced, the flexibility of PTB budget already achieved could become permanent.

Personnel

PTB has effected a series of important measures to gain greater flexibility in personnel planning. Taken as a whole, however, the personnel structure of PTB, considering the large proportion of employees in the second and third (of four) qualification levels on the civil service scale (with scientists being in the top level), does not correspond to the foreseeable scientific demands on the federal institute. Only on the basis of a sufficient number of qualified scientific staff can PTB uphold its currently high scientific standard in the longer term. In this context the job pyramid[19] of PTB should, through a more generous regulation by the federal budget of the re-allocation of staff positions, be made flexible to the extent that the present ratio should change in favor of scientific personnel within the next ten years. The retirements anticipated for the near future would pave the way for this.

To continue to win qualified senior personnel in the competition with international metrology institutions and with industry, PTB needs to be able in substantiated cases to make attractive salary offers outside of tariff. This concerns above all the offers made in connection with the joint appointments of senior staff for PTB and neighboring universities. The laudable efforts of PTB in this area are clearly impeded by the introduction of the W-salary scale and its related conditions, in particular the regulation of pensions. The federal government should grant PTB the same options in this case as are accorded the Helmholtz Association. To win senior personnel PTB ought in future to concentrate more strongly than hitherto on recruiting external candidates. When recruiting for department or division head positions, PTB should introduce nomination procedures that allow the collaboration of external referees.

In the area of personnel development PTB has introduced a number of effective instruments such as

[19] "Job pyramid": the fixed relative proportions of available positions requiring scientific, technical, and non-skilled qualifications

the partly performance-oriented remuneration of personnel. The institute should extend this type of performance stimulus further in order to support the highly dedicated staff above all in the scientific/technical areas. Moreover, for further education the scientists need to be able to take sabbatical leave to do research unrelated to their tasks. The proportion of female scientists in senior positions in PTB is too low at the present time and should definitely be increased in the medium term by taking appropriate measures, as the German Council of Science and Humanities has recommended.[20] Notwithstanding the greater need in PTB, compared with universities and non-university institutions, for permanent employment jobs so that permanent tasks may be attended to, the proportion of temporary positions for scientific staff should be increased in the medium term.

Infrastructure

The scientific/technical infrastructure presented by PTB is very good to excellent overall and in certain areas, such as the measurement of time, is internationally unequalled. The federal institute with its considerable collection of large-scale installations contributes effectively both nationally and internationally to the promotion of metrology research. The apparatus and laboratories are open for use by external cooperation partners as well, thanks to effective internal organization. In some measure there is room for improvement in the participation of external experts when investment decisions are being made for the R&D infrastructure. For instance, the scientific community was not sufficiently involved in the albeit laudable decision to install a further synchrotron radiation source at Berlin-Adlershof.

B.IV. Scientific cooperation and the promotion of young scientists

Scientific cooperation

On both the national and international level PTB is closely linked with the leading metrology institutes, just as with universities and various non-university R&D institutions of diverse areas of specialization. Within the international framework PTB is able to cooperate with leading metrology institutions because of the high quality of its R&D work, and so to effectively influence the state-of-the-art of metrology research. The cooperation projects of PTB are thereby strategically directed towards the improvement of its own metrology.

In the cooperation with national research institutions the self-concept of PTB as a scientifically independent establishment manifests itself, taking the quality standards for its work in large measure from academic science, upon which principle it offers its services for the economy, society, and politics. The federal institute unequivocally follows the criterion of scientific excellence in its scientific collaborations. Besides four Collaborative Research Centres of DFG, PTB is also engaged in two "Clusters of Excellence" and one graduate school which were successful under the Excellence Initiative of the federal government and its states. Model character for R&D cooperation may be attributed to the offer to undergraduates of technical colleges ("Universities of Applied Sciences") to carry out their thesis research within the scope of PTB projects; these colleges often lack an R&D infrastructure. In this way PTB is able to utilize the broad spectrum of university research, from the top echelons down to the applied research projects in technical colleges, for its departmental research tasks. This has the effect of anchoring metrology research more securely within the scientific system.

Close networking within the scientific region Berlin/Brandenburg is demonstrated by the medical research at the PTB site in Berlin-Charlottenburg. Here PTB has participated in the graduate school "Berlin School of Mind and Brain" and in the "cluster of excellence" "NeuroCure: Towards a better outcome of neurological disorders". This close scientific collaboration of PTB's Medical division with a research region may be regarded as a model for the cooperation in other fields. Hence it is advisable that the collaboration of PTB with the TU Braunschweig be intensified beyond the field of electrical engineering. By expanding its guest scientist program, which also includes the use of

[20] *Wissenschaftsrat: Empfehlungen zur Chancengleichheit von Wissenschaftlerinnen und Wissenschaftlern* (in German), Drs. 8036-07, Berlin, July 2007

its R&D infrastructure, PTB would become decidedly more attractive to potential guest scientists from within the country and abroad.

Promotion of the younger generation

Considering the imbalance in the age structure in some parts of PTB (lower proportion of young employees) and the small number of institutionally funded posts for young scientists (cf. section B.III.), PTB introduced early important measures to support PhD students and young scientists. By re-allocation of permanent positions in the personnel budget to temporary positions for PhD students, as well as resolutely procuring R&D third-party funds to provide qualification positions, PTB is already making an important contribution to the promotion of the younger generation of scientists in the field of metrology. By the direct recruiting (for their thesis work) of undergraduates from technical colleges PTB is also addressing an important target group: the coming generation of scientific/technical employees.

Notwithstanding these noteworthy achievements in the support of the young generation, the recruitment of young scientists as successors for the metrological work of PTB employees who will soon reach retirement age remains an important task for the near future. The present number of PhD students should be retained and increased where possible. In addition to its engagement within the Berlin graduate school, PTB should participate in the work of other graduate colleges and in so doing win excellent scientists for its own work at an early stage. In this context PTB should consider the organization of its own international summer school for metrology topics in Braunschweig, in order to win students from related disciplines for this field. During the preparation of R&D cooperation for PhD theses the institute should include the university supervisors as early as is feasible in the process of finding and developing the experimental topics, so that an equal partnership may be established.

B.V. Conclusion

Thanks to the very high and in parts excellent scientific quality of its work and the extremely good scientific/technical infrastructure, the Physikalisch-Technische Bundesanstalt (PTB), Braunschweig and Berlin, ranks as one of the leading national metrology institutes worldwide. With its research and development work (R&D) and its science-based services, PTB makes a remarkable contribution to the technological development in Germany and with that to the creation of wealth. This is particularly true for high-potential fields of the future, such as medical technology, optics, and electrical engineering. The broad PTB spectrum of work encompasses economically, politically, and socially relevant tasks besides genuinely scientific work. The federal institution occupies a unique position in Germany in performing these tasks that cannot be undertaken in this form or quality by universities or large research establishments. Where duplication of tasks with respect to other R&D institutions may occur, PTB ensures the coordination of its work. Beyond that PTB, by way of effective processes of internal criticism, also ensures complete coherence between its duties and its work. This is particularly seen in the task evolution in European collaborations where PTB plays a noteworthy leading role. For the future evolution of its tasks it is important that PTB shall not be too heavily burdened with non-scientific responsibilities.

The high scientific standard of PTB is based upon its own R&D work of overall very good to excellent quality and, because its methods are often fundamental in character, the work supports the progress of science and technology. The R&D program of the institute comprises relevant, current, and strategically oriented projects that are defined by transparent and efficient procedures and also take account of user interests. Moreover, the quality of its R&D work is regularly controlled by effective internal and external processes. In this context PTB's trustees should take a stronger interest in the research strategy and deficiency analyses.

PTB effects the transfer of its R&D results by diverse cooperation with industrial research and scientific institutions, besides regularly publishing also in reviewed international specialist journals. Altogether PTB must pay attention to questions of neutrality and possible unfair competition in its industrial cooperation, and in its publications it should follow the pertinent format of the scientific

community. In publicity work the significance of PTB for innovative processes in German industrial companies is not yet sufficiently prominent.

Characteristic of PTB's science-based services for industry is the high quality, the clearly user-friendly orientation and the exclusiveness both in the national and, for production metrology, in the European context as well. At the European and in large measure the international level the institute with its metrological expertise provides important competitive advantages for German industry. Besides assisting industry, PTB, by operating its highly-developed R&D infrastructure, also fills an important role for the scientific system. Science policy consulting could be emphasized more in PTB, specifically in the sense of a technology policy consulting for the federal government.

With regard to the organization of the directorate and the planning of its work PTB profits from the relatively generous autonomy granted by the Federal Ministry of Economics and Technology (BMWi). By contrast the budget of the institute with respect to equipment and flexibility does not as a whole comply with the needs of an internationally top-ranking metrological establishment, despite notable progress such as the participation of PTB in the high-tech strategy of the federal government. In the personnel sector PTB needs a moratorium on the annual reduction of staff positions, as well as the possibility of securing 12% of its annual budget by revenue from fees, without suffering a reduction in its primary budget. In order to maintain its extraordinary scientific competence the “job pyramid” of PTB should be made more flexible such that the present ratio can be shifted in favor of scientific staff.

To win more external scientists for senior positions the institute needs to be able to offer attractive extra-tariff remuneration. PTB should also offer separate performance incentives to stimulate dedicated scientific staff in greater measure than hitherto, as well as distinctly increase the proportion of female scientists in senior positions.

The R&D cooperation with universities, non-university R&D establishments, and with metrology institutions is manifold and follows a clearly-defined strategic path. The institute is overall very successful in exploiting to the advantage of its departmental responsibilities the broad spectrum of scientific cooperation, starting with top-level research at universities and non-university establishments down to applied science projects at technical colleges. Here PTB undoubtedly contributes in no small measure to anchoring metrology research all over the scientific system. To improve its chances of winning and supporting young scientists PTB should become more involved in graduate colleges and, by organizing a summer school on metrology topics for example, engage the interest of young scientists of both genders.

Appendices

Annex 1 Organization Chart of the Physikalisch-Technische Bundesanstalt (PTB), Braunschweig and Berlin

		Presidential Board			*Department PSt*	Press and Information Office	As of May 2007	
		President	**Vice-president**	**Member of the Presidential Board**	Presidential Staff			
Division 1 **Mechanics and Acoustics**	*Division 2* **Electricity**	*Division 3* **Chemical Physics and Explosion Protection**	*Division 4* **Optics**	*Division 5* **Precision Engineering**	*Division 6* **Ionizing Radiation**	*Division 7* **Temperature and Synchrotron Radiation**	*Division 8* **Medical Physics and Metrological Information Technology**	*Division Q* **Scientific-technical Cross-sectional Tasks**	*Division Z* **Administrative Services**
Department 1.1 Mass	*Department 2.1* Direct Current and Low Frequency	*Department 3.1* Metrology in Chemistry	*Department 4.1* Photometry and Applied Radiometry	*Department 5.1* Nano- and Micro-Metrology	*Department 6.1* Radioactivity	*Department 7.1* Photon Radiometry	*Department 8.1* Medical Metrology	*Section Q.11* Academic Library	*Section Z.11* Budget
Department 1.2 Solid Mechanics	*Department 2.2* High Frequency and Electro-magnetic Fields	*Department 3.2* Analytical Measuring Techniques & Pressure	*Department 4.2* Imaging and Wave Optics	*Department 5.2* Length and Angle Metrology	*Department 6.2* Dosimetry for Radiotherapy	*Department 7.2* Detector Radiometry	*Department 8.2* Biosignals	*Department Q.2* Theoretical Fundamentals	*Section Z.12* Personnel
Department 1.3 Kinematics	*Department 2.3* Electrical Energy Measuring Techniques	*Department 3.3* Physicochemical Material Properties	*Department 4.3* Quantum Optics and Unit of Length	*Department 5.3* Coordinate Metrology	*Department 6.3* Radiation Protection Dosimetry	*Department 7.3* High-temperature and Vacuum Physics	*Department 8.3* Biomedical Optics	*Department Q.3* Legal Metrology and Technology Transfer	*Section Z.13* Procurement, Legal Matters
Department 1.4 Gas Flow	*Department 2.4* Quantum Electronics	*Department 3.4* Fundamentals of Explosion Protection	*Department 4.4* Time and Frequency	*Department 5.4* Interferometry on Material Measures	*Department 6.4* Ion Accelerators & Reference Radiation Fields	*Department 7.4* Temperature	*Department 8.4* Mathematical Modelling and Data Analysis	*Department Q.4* Information Technology	*Section Z.14* Organization and Controlling
Department 1.5 Liquid Flow	*Department 2.5* Semiconductor Physics and Magnetism	*Department 3.5* Flame Transmission Processes	*Department 4.5* Optical Technologies	*Department 5.5* Scientific Instrumentation	*Department 6.5* Neutron Radiation	*Department 7.5* Low-temp. Thermodynamics & Technology	*Department 8.5* Metrological Information Technology	*Department Q.5* Technical Cooperation	*Section Z.15* Berlin Administration
Department 1.6 Sound	*Department 2.6* Quantum Electrical Metrology	*Department 3.6* Intrinsic Safety and Safety of Systems			*Department 6.6* Fundamentals of Dosimetry	*Department 7.6* Heat		*Section Q.61* Technical Service	*Section Z.16* Internal Services
Department 1.7 Applied Acoustics		*Department 3.7* Prevention of Ignition Sources			*Section 6.71* Operational Radiation Protection	*Department IB.T* Technical-scientific Infrastructure Berlin			*Section Z.17* Training

Appendix 2 Positions Plan of the Physikalisch-Technische Bundesanstalt (PTB)

(as of Dec. 31, 2006)

Position type	Renumeration groups	Total (nominal)	Currently filled
Scientific personnel	B 8	1.0	1.0
	B 4	1.0	1.0
	B 3	6.0	5.0
	B 2/I	33.0	28.0
	B 1	20.0	20.0
	A 15/I a	44.0	40.0
	A 14/I b	165.0	163.0
	A 13/II a	64.0	64.0
Interim total		**334.0**	**322.0**
Non-scientific personnel			
	highest level	58.0	39.5
	second level	345.0	333.0
	other	633.3	621.0
Interim total		**1036.3**	**993.5**
Total		**1370.3** *	**1315.5**

* Budgeted positions and positions according to the 2006 budget plan, corrected for so-called substitution positions for partial retirement

Source: Physikalisch-Technische Bundesanstalt

Appendix 3 Distribution of positions for scientific personnel at Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin

(as of Dec. 31, 2006)

Division/Department	Budgetary positions for scientists			Third-party funded positions for scientists (FTE*)			PhD student positions (incl. annex, third-party etc.)			Total positions or FTE for scientists		
	total	temporary contract	vacant	total	temporary contract	vacant	total	temporary contract	vacant	total	temporary contract	vacant
Directorate	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0	0.0
Division 1	45.0	1.0	2.0	4.0	4.0	0.0	5.0	5.0	0.0	54.0	10.0	2.0
Division 2	45.0	1.0	1.0	6.5	6.5	0.0	3.0	3.0	0.0	54.5	10.5	1.0
Division 3	45.5	1.0	2.0	3.0	3.0	0.0	7.0	7.0	0.0	55.5	11.0	2.0
Division 4	32.0	1.0	1.0	3.0	3.0	0.0	5.0	5.0	0.0	40.0	9.0	1.0
Division 5	36.0	0.0	1.0	13.5	13.5	0.0	3.0	3.0	0.0	52.5	16.5	1.0
Division 6	42.0	0.0	3.0	1.0	1.0	0.0	3.0	3.0	0.0	46.0	4.0	3.0
Division 7	35.0	1.0	0.0	9.0	9.0	0.0	9.0	9.0	0.0	53.0	19.0	0.0
Division 8	41.5	0.0	0.0	10.0	10.0	0.0	3.0	3.0	0.0	54.5	13.0	0.0
Department Q.2	6.0	1.0	2.0	1.0	1.0	0.0	1.0	1.0	0.0	8.0	3.0	2.0
Total	**334.0**	**6.0**	**12.0**	**51.0**	**51.0**	**0.0**	**39.0**	**39.0**	**0.0**	**424.0**	**96.0**	**12.0**

* FTE: full-time equivalents

Appendix 4 Duration of affiliation, age structure, gender and specialization of scientific personnel in the institution

(as of Dec. 31, 2006)

Duration of affiliation	Number	
	male	female
20 years and more	72	3
15 to less than 20 years	100	8
10 to less than 15 years	35	2
5 toless than 10 years	71	7
less than 5 years	102	18

(as of Dec. 31, 2006)

Age	Number	
	male	female
60 years and older	38	1
50 to less than 60 years	92	9
40 to less than 50 years	126	5
30 to less than 40 years	109	15
less than 30 years	15	8

(as of Dec. 31, 2006)

Gender	Number
Male	380
Female	38

(as of Dec. 31, 2006)

Specialization of university degree (most frequent specializations)	Number	
	male	female
Physics	312	26
Electrical Engineering	39	0
Chemistry	14	10
Mechanical Engineering	9	1
Other	6	1

Source: Physikalisch-Technische Bundesanstalt

Appendix 5 Third-parts funds gained by Physikalisch-Technische Bundesanstalt (PTB), Braunschweig and Berlin, in the years 2004 to 2006, sorted by source

Division/Department	Source	Third-party funds in k€ (rounded)			Total
		2004	2005	2006	
Division 1	DFG	148	86	77	311
	Fed. Government	55	-	43	98
	Federal States	-	-	5	5
	EU	33	68	26	127
	Industry	22	127	117	266
	Foundations	-	-	-	-
	Other	201	143	81	425
Total		**458**	**425**	**348**	**1 231**
Division 2	DFG	67	121	79	267
	Fed. Government	141	56	141	338
	Federal States	-	27	111	138
	EU	214	268	152	634
	Industry	232	155	82	469
	Foundations	-	-	-	-
	Other		5	58	63
Total		**654**	**633**	**624**	**1 911**
Division 3	DFG	-	-	40	40
	Fed. Government	140	177	147	464
	Federal States	-	-	2	2
	EU	45	18	38	101
	Industry	169	223	409	801
	Foundations	-	-	-	-
	Other	147	37	48	232
Total		**500**	**455**	**683**	**1 638**
Division 4	DFG	-	-	-	-
	Fed. Government	349	152	53	554
	Federal States	-	-	21	21
	EU	108	30	52	190
	Industry	67	282	162	511
	Foundations	-	-	-	-
	Other	530	130	636	1 296
Total		**1 055**	**593**	**924**	**2 572**
Division 5	DFG	68	267	454	789
	Fed. Government	473	84	454	1 011
	Federal States	33	48	117	198
	EU	1	73	7	81
	Industry	382	235	609	1 226
	Foundations	-	-	-	-
	Other	92	218	168	478
Total		**1 049**	**926**	**1 809**	**3 784**
Division 6	DFG	-	-	3	3
	Fed. Government	142	431	208	781
	Federal States	-	-	-	-
	EU	73	84	20	177
	Industry	63	40	17	120
	Foundations	-	-	-	-
	Other	14	8	35	57
Total		**292**	**562**	**284**	**1 138**

Division/Department	Source	Third-party funds in k€ (rounded)			Total
		2004	2005	2006	
Division 7	DFG	-	-	115	115
	Fed. Government	204	20	-	224
	Federal States	21	134	446	601
	EU	121	189	77	387
	Industry	609	509	481	1 599
	Foundations	30	30	30	90
	Other	136	320	245	701
Total		**1 121**	**1 202**	**1 394**	**3 717**
Division 8	DFG	108	1	129	238
	Fed. Government	714	487	475	1 676
	Federal States	14	17	143	174
	EU	217	117	84	418
	Industry	45	9	112	166
	Foundations	-	-	-	-
	Other	33	248	160	441
Total		**1 131**	**879**	**1 103**	**3 113**
Division Q	DFG	36	29	26	91
	Fed. Government	4 800	5 401	6 000	16 201
	Federal States	-	-	-	-
	EU	333	206	378	917
	Industry	1	-	73	74
	Foundations	-	-	-	-
	Other	12	38	58	108
Total		**5 180**	**5 673**	**6 535**	**17 388**
Department PSt	DFG	-	-	-	-
	Fed. Government	-	-	7	7
	Federal States	-	-	-	-
	EU	23	143	59	225
	Industry	-	-	-	-
	Foundations	-	-	-	-
	Other	-	-	-	-
Total		**23**	**143**	**65**	**231**
Institute total	**DFG**	**426**	**504**	**923**	**1 853**
	Fed. Governm't	**7 018**	**6 807**	**7 527**	**21 352**
	Federal States	**68**	**227**	**845**	**1 140**
	EU	**1 166**	**1 196**	**893**	**3 255**
	Industry	**1 590**	**1 581**	**2 061**	**5 232**
	Foundations	**30**	**30**	**30**	**90**
	Other	**1 164**	**1 146**	**1 489**	**3 799**
Total		**11 463**	**11 491**	**13 769**	**36 723**

Deviations in the totals are due to rounding residuals

Source: Physikalisch-Technische Bundesanstalt

Appendix 6 Current work program of Physikalisch-Technische Bundesanstalt (PTB), Braunschweig and Berlin

Topic area 1: Acoustics. Ultrasound, Acceleration

- Development of standard measuring devices for pressure and acceleration measurement,
- Continued development of optical hydrophones for measurement of sound power and pressure in high intensity ultrasound fields in medical applications,
- Development of methods for the theoretical prognosis and for the experimental measurement of the transmission of sound power in complex structures.

Topic area 2: Flow

- Development of optical standards (Laser-Doppler anemometry) for measurement of flow and velocity in gases (high & low pressure),
- Uniform traceability for the measurement of flow and velocity of liquids independent of their chemical composition,
- Development of measuring procedures for calorific value determination of flowing gases, particularly for eco-fuels (e.g., biofuels, biogases).

Topic area 3: Electricity & Magnetism

- Development of quantum standards for electric current & proof of the consistency of the then completed "quantum metrology triangle" of voltage (Josephson effect), resistance (quantum Hall effect) and current (single electron/Cooper pair transistor),
- Traceability of electrical energy metrology and the alternate/direct transfer to quantum standards,
- Development of position- and time-resolved measuring methods for magnetic quantities, to investigate the magnetization dynamics of storage media.

Topic area 4: Ionizing Radiation

- Development of basic metrology for fusion research, focusing on neutrons, and continued development of dosimetric reference radiation fields, in particular for mono-energetic neutron beams,
- Research on the effect of ionizing radiation in microscopic dimensions (trace structures, nano-dosimetry), focusing on health care,
- Development of dosimetric measuring procedures for novel therapeutic beam sources , e.g., as employed in intensity-modulated radiotherapy (IMRT).

Topic area 5: Length, Dimensional Metrology

- Continued development of dimensional metrology for large complex structures and for nano-technology; development of a primary standard of force in the nN-range,
- Development of improved measuring procedures for the optical shape measurement of surfaces, particularly the so-called free-form surfaces,
- Continued development of interferometric measuring procedures for length and distance, particularly for the determination of the volume of the silicon spheres in the Avogadro project with a relative uncertainty of less than 3×10^{-9}.

Topic area 6: Mass and Derived Quantities

- Expansion of the frequency range of the standard measuring device for dynamic force (up to 1 kHz below 10 kN, up to 100 Hz below 100 kN),
- Development of improved procedures for the determination of the mass of the spheres in the Avogadro project, with a relative uncertainty of measurement less than 1×10^{-8},
- Development of an improved primary standard to realize the measurand pressure for the Boltzmann project with a relative uncertainty of measurement less than 1×10^{-6}.

Topic area 7: Chemical Metrology

- Development of primary measuring procedures for clinical chemistry and element analysis,
- Development of primary measuring procedures for the measurands pH-value and conductance,
- Development of thermo-physical measuring procedures for novel energy sources.

Topic area 8: Metrology for Medicine

- Development of basic metrology for nuclear magnetic resonance spectroscopy (NMR) in high magnetic fields (7T magnetic resonance tomograph at MDC),
- Development of quantitative image producing procedures for medical physics, particularly through the combination of NMR, time-resolved near infra-red spectroscopy and biomagnetism,
- Continued development of optical measuring procedures for cellular and molecular medicine, e.g., for the non-invasive measurement of oxygen saturation.

Topic area 9: Radiometry & Photometry

- Development of photometric & radiometric measuring procedures for novel light sources (LEDs, OLEDs etc.), development of camera-based methods,
- Development of radiometric methods for the far-infrared and the THz range,
- Continued development of metrology using synchrotron radiation, e.g., for EUV-lithography.

Topic area 10: Thermometry

- Development of a special gas thermometer, applicable at the triple point of water, for the new determination of the Boltzmann constant for the re-definition of the temperature unit Kelvin,
- Development of novel temperature fixed points and thermo-elements for the interpolation in between, to expand the international temperature scale to the range between 1100 °C and 3000 °C,
- Extension of radiation thermometry to low temperatures (down to -150 °C); development of radiation thermometric procedures for conditions in space.

Topic area 11: Time & Frequency

- Development of optical clocks based on an ultra-cold Ytterbium ion ($^{171}Yb^{+}$), ultra-cold neutral strontium atoms (Sr lattice clock) or an optical nuclear transition in Thorium for a future re-definition of the second with a relative uncertainty of less than 1×10^{-17},
- Continued development of optical frequency combs for comparison of optical clocks by frequency transmission via telecommunication glass fiber networks.

Topic area 12: Mathematics & Information Technology

- Modeling physical processes of fundamental importance to metrology,
- Development of procedures for data analysis for complex metrology problems,
- Development of procedures for the secure transfer of measurement data and for software validation.

Topic area 13: Physical Safety Technology, Explosion Protection

- Investigation of the propagation and ignition properties of explosive gas mixtures,
- Development of theoretical models and numerical simulation procedures for ignition processes,
- Investigation of the limitation and containment of explosion effects and the technically safe design of instruments and equipment.

Appendix 7 Supporting material provided by Physikalisch-Technische Bundesanstalt (PTB), Braunschweig and Berlin

- Reply of PTB to the questionnaire of the German Council for Science and Humanities
- Work Programme 2007 of Physikalisch-Technische Bundesanstalt
- List of legal duties of PTB
- Statutes of PTB, as given on 12 March 1996
- Organisation chart of PTB
- PTB Annual Report 2006
- *Evaluation der Physikalisch-Technischen Bundesanstalt, Abschlussbericht der Evaluationskommission*, 2002
- European Metrology Research Programme, Outline 2007
- Budget plan of PTB 2007
- List of budgeted positions of the institution
- Distribution of scientific staff positions across the work areas
- Structure of the scientific personnel: duration of affiliation, age, gender, and area of specialization of their university degree
- List and quantitative overview of publications 2004 – 2006, sorted by division
- Third-party funds 2004 – 2006, sorted by funding source
- Overview of national and international conferences organised by PTB in 2004 – 2006
- List of international conferences where scientific personnel of PTB participated with an invited contribution
- List of completed PhD and *Habilitation* degrees of PTB personnel
- List of current members of advisory committees of PTB
- Minutes of the last three meetings of the *Kuratorium* (Board of Trustees) of PTB
- List of institutions with whom PTB is currently collaborating in the area of research and development
- Guiding principles of the Presidential Board of PTB regarding the "Concept 2016"
- Guidelines of PTB regarding strategic planning processes, 2005
- Overview of functions with leadership responsibility assumed by PTB in the CIPM
- List of training programs held at PTB 2004 – 2006

Glossary of the most important abbreviations

BAM	Federal Institute for Materials Research and Testing
BGR	Federal Institute for Geosciences and Natural Resources
BIPM	Bureau International des Poids et Mesures, France
BMAS	Federal Ministry of Labour and Social Affairs
BMBF	Federal Ministry of Education and Research
BMELV	Federal Ministry of Food, Agriculture and Consumer Protection
BMF	Federal Ministry of Finance
BMG	Federal Ministry of Health
BMI	Federal Ministry of the Interior
BMU	Federal Ministry for the Environmental, Nature Conservation and Nuclear Safety
BMVBS	Federal Ministry of Transport, Building and Urban Affairs
BMWi	Federal Ministry of Economics and Technology
BMZ	Federal Ministry for Economic Collaboration and Development
BVL	Federal Office of Consumer Protection and Food Safety
CC	Comité Consultative
CIPM	Comité International des Poids et Mesures
DFG	German Research Foundation
DGKL	German Association for Clinical Chemistry and Laboratory Medicine
DKD	German Calibration Service
EMRP	European Metrology Research Programme
EURAMET	European Association of National Metrology Institutes
EUROMET	European Collaboration in Measurement Standards
iMERA	European research project “implementing Metrology in the European Research Area”
INRIM	Istituto Nazionale di Ricerca Metrologica, Italy
IRMM	Institute for Reference Materials and Measurements, Geel, of the EU Joint Research Centre
KLR	Cost-benefit calculation
SME	Small and medium-sized enterprises
KRISS	Korea Research Institute of Standards and Science, South Korea
LNE	Laboratoire National de Métrologie et d'Essais, France
METAS	Federal Office of Metrology, Switzerland
MID	Measuring Instruments Directive
MNPQ	Measurement, Standardization, Testing, Quality Control
MRA	Mutual Recognition Agreement

NIM	National Institute of Metrology, China
NIST	National Institute of Standards and Technology, USA
NMIJ	National Metrology Institute of Japan
NPL	National Physical Laboratory, United Kingdom
OIML	Organization Internationale de Métrologie Légale
PTR	Physikalisch-Technische Reichsanstalt
RMO	Regional metrology organization
UBA	Federal Environment Agency
SI	Système International d'Unités
WELMEC	European Legal Metrology Cooperation