

Guidelines for CIPM key comparisons

(Appendix F to the "Mutual recognition of national measurements standards and of measurement certificates issued by national metrology institutes" (MRA))

1 March 1999

1. Introduction

The procedures used by Consultative Committees for selecting, conducting and evaluating key comparisons, including the detailed technical protocols and periodicity of the comparisons, are designed to ensure that:

- the comparisons test all the principal techniques in the field;
- the results are clear and unequivocal;
- the results are robust;
- the results are easy to compare with those of corresponding comparisons carried out by regional metrology organizations;
- overall, the comparisons are sufficient in range and frequency to demonstrate and maintain equivalence between the participating laboratories.

This note lays out the broad guidelines to be followed in conducting key comparisons. It is supplemented by the detailed technical protocols written for the individual key comparisons, and, if necessary, by additional guidelines prepared by Consultative Committees and applying to particular areas of work.

During key comparisons, it is important that up-to-date information on the progress of the comparison be readily available. This implies that the participants and the president and executive secretary of the Consultative Committee be regularly informed by the pilot institute as to the status of each comparison. It is the task of the executive secretaries at the BIPM to maintain, for consultation, a central record of the status of key comparisons.

In some Consultative Committees, there exist permanent Working Groups or Sections that have responsibilities covering broad areas of work. Examples are the Pressure, Force and Mass Working Groups of the CCM, the three Sections of the CCRI or the GTRF of the CCEM. In these cases, the chairmen of the Working Groups or Sections have particular responsibilities in coordinating the key comparisons in these fields and pilot laboratories should take care to keep them informed.

Note that formally, most members of Consultative Committees are national metrology institutes but at meetings they are represented by designated delegates. Between meetings of the Consultative Committees it is understood that the member institutes continue to be represented by the delegate at the last meeting. In the event that this delegate is no longer available it is the responsibility of the member institute to inform the Executive Secretary of the Consultative Committee of the name of his or her replacement.

2. Types of key comparison

There are two broad types of key comparison: in the first are those comparisons for which the standard or realization of a unit to be compared is assumed to have long-term stability, (typical of these are the quantum-based standards but there are also some others); in the second category are those for which long-term stability cannot be assumed. The procedures

for conducting the comparisons and, in some cases, for evaluating the results may differ in the two cases.

Comparisons of quantum-based and other stable standards are normally carried out bilaterally and on a continuing basis at the convenience of the participating institute. Typical of these comparisons are the laser frequency comparisons, the Josephson voltage comparisons and the quantum-Hall resistance comparisons carried out by the BIPM. Typical comparisons of other stable standards would be BIPM comparisons of ionizing radiation dosimetry standards. The procedures used at the BIPM in carrying out this type of ongoing comparison are described in a separate note entitled *Procedures used in ongoing key comparisons carried out by the BIPM*.

Other comparisons, in which the standards are not assumed to have long-term stability, make up the majority of the key comparisons and are carried out under a strict time schedule. This enables all the participating institutes to make their measurements within a fixed period of time. These comparisons require travelling standards having good short-term stability and stability during transport. Much of the detail in what follows applies mainly to this type of comparison.

A special case is the regular calculation of the time scales TAI and UTC by the BIPM. These are based on the results of a continuing series of clock comparisons carried out and interpreted following guidelines agreed by the CCTF. Equivalence of national time scales throughout the world is assured by the universal adoption of the UTC system. Nothing in these Guidelines alters those arrangements.

3. Responsibilities for choosing key comparisons

The Consultative Committees are responsible for choosing the key comparisons. In each field a set of key comparisons is identified which covers a range of standards so as to test the principal techniques in the field.

On the basis of the results of the key comparisons, statements of equivalence can be made covering a wide range of measurements using these techniques, not just the measurements directly tested by a key comparison. The periodicity of the comparisons is set to ensure continuity of the equivalence without overloading the participating laboratories.

The procedure for choosing and updating the list of key comparisons is the following:

- The Consultative Committee appoints a small working group, which may be one of its permanent Working Groups (see paragraph 1 above), to draw up a list of proposed key comparisons and their periodicity, or to propose modifications to an existing list.
- At a meeting of the Consultative Committee the working group proposal is discussed and a list adopted. This list appears in Appendix D and the key comparison data base of the MRA, is published in the report of the meeting, and appears in the BIPM Directory of Consultative Committees and elsewhere as required.

In deciding on the list of key comparisons, the Consultative Committee takes into account views expressed by the Regional Metrology Organizations (RMOs). These views can be expressed by the RMO to the Director of the BIPM or through RMO members who are members of the Consultative Committee.

4. Initiating a key comparison

Key comparisons are initiated at a meeting of the Consultative Committee.

- The Consultative Committee at each of its meetings examines the needs for comparisons and decides which ones from the list of key comparisons should be initiated at this meeting. In deciding this the committee takes into account, among other things, the views of regional metrology organizations. For each comparison, a pilot institute is identified to take the main responsibility for running the CIPM key comparison.
- In drawing up the provisional list of participants and an approximate timetable, the Consultative Committee ensures that an adequate number of participants from each of the main RMOs take part so that corresponding regional comparisons are properly linked to the CIPM comparison.
- In some CIPM key comparisons the number of participants is limited for technical reasons.
- Two or three institutes from the provisional list are nominated by the Consultative Committee to help the pilot institute in drawing up the technical protocol and timetable for the comparison.
- The timetable of this and any other comparisons decided by the Consultative Committee is discussed to ensure that the work load of the whole set is not too great for the participating and pilot institutes, and that the results will be available for the next meeting, normally in three (or occasionally two) years time. For this the total circulation time of the standards must be fixed and should exceed 18 months only in exceptional circumstances.

5. Organization of a key comparison

The organization of a key comparison is the responsibility of the pilot institute helped by the two or three nominated participants. The first task of this small group is to draw up the detailed technical protocol for the comparison (see Section 6 below) and its dispatch, inviting participation as defined by the Consultative Committee (see paragraph 6 of the MRA). In those Committees having permanent Working Groups or Sections responsible for specific areas of activity (see paragraph 1 above) the draft protocol must be sent to the chairman of the relevant Working Group or Section. The invitation to participate is sent directly to the delegates of member institutes present at the last meeting of the Consultative Committee, plus absent members. Copies of the invitation and the draft protocol are also sent to the BIPM executive secretary of the Consultative Committee. For rules on eligibility for participation in Consultative Committee key comparisons see the Note at the end of these Guidelines and paragraph 6 of the MRA.

The main points decided by the small group headed by the pilot institute are the following:

- the list of participants with full details of mailing and electronic addresses;
- the travelling standard or standards to be used in the comparison;
- whether or not a pilot comparison or any other preliminary work needs to be carried out among a restricted number of participants to verify the performance of the travelling standard;
- the pattern of the full scale comparison; this ranges from the simple circulation of a single travelling standard around all the participants to the sending of an individual travelling standard directly to each participant from the pilot institute, or from each participant to the pilot institute or some combination of these;
- the starting date, detailed timetable, means of transport and itinerary to be followed by each travelling standard; this starting date is subsequently referred to as the starting date for the comparison;
- the procedure in the case of failure of a travelling standard;
- the procedure in the case of an unexpected delay at a participant institute;
- the customs documents to accompany the travelling standards, either ATA Carnet or some other for those participants not qualifying for the ATA scheme.

6. The technical protocol for a key comparison

The pilot institute together with two or three nominated participants draws up the detailed technical protocol. The technical protocol is an important part of the comparison and specifies in detail the procedure to be followed for the comparison.

It is important to remember, however, that the purpose of a key comparison is to compare the standards as realized in the participating institutes, not to require each participant to adopt precisely the same conditions of realization. The protocol should, therefore, specify the procedures necessary for the comparison, but not the procedures used for the realization of the standards being compared.

Among the points treated in the protocol are the following:

- Detailed description of the devices: make, type, serial number, size, weight, packaging etc. and technical data needed for their operation.
- Advice on handling the travelling standard, including unpacking and subsequent packing and shipping to the next participant; this should include a complete list of the content of the package including handbooks etc. and the weight and size of the whole package.
- Actions to be taken on receipt of the standards in a participating institute.
- Any tests to be carried out before measurement.
- The conditions of use of the travelling standard during measurement.
- Instructions for reporting the results.
- A list of the principal components of the uncertainty budget to be evaluated by each participant, and any necessary advice on how uncertainties are estimated (this is based on the principles laid out in the Guide to the Expression of Uncertainty in Measurement, published by ISO). In addition to the principal components of the uncertainty, common to all of the participants, individual institutes may add any others they consider appropriate. Uncertainties are evaluated at a level of one standard uncertainty and information must be given on the number of effective degrees of freedom, required for a proper estimate of the level of confidence.
- The traceability to the SI of each standard participating in the comparison.
- A timetable for the communication of the results to the pilot institute. Early communication helps to reveal problems with the travelling standard during the comparison.
- Financial aspects of the comparison, noting that in general each participating institute is responsible for its own costs for the measurements, transportation and any customs charges as well as any damage that may occur within its country. Overall costs of the organization of the comparison including the supply of the transfer devices are normally born by the pilot institute.
- Insurance of transfer devices is decided by agreement among the participants taking account of the responsibility of each participant for any damage within its country.

7. Circulation of the transfer standards and customs formalities

The pilot institute is responsible for organizing the circulation and transport of the standards and ensuring that the participants make proper arrangements for local customs formalities.

The equipment must be handled with care, i.e., only by qualified metrology personnel. It is desirable and in some cases essential that the transfer instruments be hand-carried. If this is not deemed essential certain precautions must, nevertheless, be taken. As goods are usually delivered to a shipping department in an institute a warning note should be attached to the package indicating that the package should be opened only by laboratory personnel.

The participating institutes are responsible for the transport to the next institute according to the circulation scheme. The method of transport as defined in the instructions shall be respected.

- Before dispatching the package, each participant must inform the next participant and the pilot institute, giving transportation details.
- If an ATA carnet is used, it must be used properly. Upon each movement of the package the person organizing the transit must ensure that the carnet is presented to customs on leaving the country, and upon its arrival in the country of destination. When the package is sent unaccompanied the carnet must be included with the other forwarding documents so that the handling agent can obtain customs clearance. In no case should the carnet be packed with the device in the package. In some cases it is possible to attach the carnet to the package.
- After arrival of the package, the participating institute shall inform the pilot institute of this by completing and returning a form which is included in the package. Immediately after receipt, the participating institute shall check for any damage of the standards, in particular scratches and rust, and report this to the pilot institute.
- If a delay occurs the pilot institute shall inform the participants and revise - if necessary - the time schedule, or skip one country and put it at the end of the circulation.

8. Reporting the results of a comparison

The participating institutes must report the results of a comparison to the pilot institute as soon as possible and at the latest six weeks after the measurements are completed. The measurement results together with the uncertainties and any additional information required should be reported in the format given in the instructions as part of the protocol, usually by completing the standard forms annexed to the instructions.

9. Preparation of the report on a key comparison

The pilot institute is responsible for the preparation of a report on the comparison. The report passes through a number of stages before publication, and these are referred to here as drafts A and B.

The first draft, draft A, is prepared as soon as all the results have been received from the participants. It includes the results transmitted by the participants, identified by name. It is confidential to the participants.

The second draft, draft B, is subsequently prepared for the Consultative Committee and includes an Appendix containing proposals for a reference value and degrees of equivalence. The working group on key comparisons is normally charged with examining draft B prior to its distribution to all members of the Consultative Committee, to ensure that it meets all the requirements set by the Consultative Committee. In the case of those Consultative Committees having permanent Working Groups dealing with specific areas of activity (see paragraph 1), the Consultative Committee may ask these Working Groups to undertake the functions of the key comparison working group.

In more detail, the procedure is as follows:

- During the comparison, as the results are received by the pilot institute, they are kept confidential by the pilot institute until all the participants have completed their measurements and all the results have been received, or until the date limit for receipt of results has passed.
- A result from a participant is not considered complete without an associated uncertainty, and is not included in the draft report unless it is accompanied by an uncertainty supported by a complete uncertainty budget. Uncertainties are drawn up following the guidance given in the technical protocol.
- If, on examination of the complete set of results, the pilot institute finds results that appear to be anomalous, the corresponding institutes are invited to check their results for numerical errors but without being informed as to the magnitude or sign of the apparent

anomaly. If no numerical error is found the result stands and the complete set of results is sent to all participants. Note that once all participants have been informed of the results, individual values and uncertainties may be changed or removed, or the complete comparison abandoned, only with the agreement of all participants and on the basis of a clear failure of the travelling standard or some other phenomenon that renders the comparison or part of it invalid.

- An institute that considers its result unrepresentative of its standards may request a subsequent separate bilateral comparison with the pilot institute or one of the participants. This should take place as soon as possible after the completion of the comparison in progress. The subsequent bilateral comparison is considered as a new and distinct comparison (see paragraph 10).
- Draft A of the report is sent as soon as possible after completion of the comparison to all the participants for comment, with a reasonable deadline for replies. The date at which this draft is sent to the participants is taken to be the end date for the comparison and is subsequently referred to as such.
- If any controversial or contradictory comments are received by the pilot institute, they are circulated to all participants and discussion continues until a consensus is reached.
- Draft A is considered as confidential to the participants. Copies are not given to non-participants, and graphs or other parts of the draft are not used in oral presentations at an outside Conference without the specific agreement of all the participants.
- On receipt of final comments from participants, the second draft, draft B, is prepared which includes an Appendix containing proposals for a reference value and degrees of equivalence for transmission to the Consultative Committee working group on key comparisons as a preliminary to sending it to all members of the Consultative Committee. In calculating the key comparison reference value, the pilot institute will use the method considered most appropriate for the particular comparison, subject to confirmation by the participants and, in due course, the key comparison working group and the Consultative Committee.
- Draft B, which supersedes draft A, is not considered confidential, and may be the subject of a publication with the exception of the Appendix containing proposals for the reference value and degrees of equivalence. The entry of the results, including the degrees of equivalence, into Appendix B of the MRA and the key comparison data base must wait until draft B has been approved by the Consultative Committee when it becomes the Final Report. The approval by the Consultative Committee may be given by correspondence on the recommendation of the working group on key comparisons. Each Consultative Committee will set its own procedures for approving the results of key comparisons in the most efficient and timely way possible. (see paragraph 11 below on publication).
- The key comparison reference value and its uncertainty, normally that proposed by the pilot institute, is approved by the Consultative Committee on the recommendation of its working group on key comparisons.
- After deciding the key comparison reference value and its uncertainty, the deviation from the reference value and the uncertainty of the deviation are deduced for each of the individual results.
- In the event that there is disagreement concerning the results or the interpretation of the results of a key comparison, and the disagreement cannot be resolved by the participants, by the key comparison working group or by the Consultative Committee, the matter is referred to the CIPM for decision.

10. Bilateral key comparisons

A bilateral key comparison, referred to in paragraphs T.8 and T.9 of the MRA and in paragraph 9 above, may be carried out by two institutes meeting the following conditions:

- (a) one of them must have already participated in the relevant CIPM or RMO key comparison; this institute acts as pilot for the bilateral comparison which must use the same or similar protocol as for the key comparison;
- (b) the other must be an NMI that meets the requirements for participation in a key comparison given in paragraph 6 of the MRA.

A bilateral comparison must be carried out following the parts of these Guidelines that are appropriate for bilateral comparisons.

The executive secretary of the appropriate Consultative Committee must be informed of a bilateral comparison before it takes place.

The BIPM ongoing key comparisons, often being a continuing series of bilateral comparisons, are treated separately, see paragraph 2 above.

11. Publication of the results of a key comparison and entry into Appendix B of the MRA and the key comparison data base.

For all key comparisons, the Final Report approved by the Consultative Committee forms the basis for the entry of results into Appendix B of the MRA and the key comparison data base. Publication of the results in draft B, with the exception of the Appendix containing the proposed reference value and degrees of equivalence, may take place as soon as draft B is agreed by the participants.

There are different forms in which the results of a key comparison may be published, depending on the wider significance of the information. The main publication channels are the following:

- publication of an extended paper in *Metrologia* or some other journal;
- publication in a shortened form in *Metrologia* or some other journal;
- publication in a Conference Proceedings following presentation at a Conference;
- publication of the Final Report *in extenso* as a BIPM Report.

A combination of more than one of these channels is possible.

In addition to these, a summary of the results is published in the International Reports section of *Metrologia*. The summary of the results is also entered into Appendix B of the MRA and into the key comparison data base. The summary also includes a reference to a more extended publication in which details of the comparison can be found. The summary is not published before full publication.

12. Supplementary comparisons

Supplementary comparisons whose results are intended to be included in Appendix B.3 must be carried out following these guidelines.

Appendix 1

Note on eligibility for participation in a CIPM or RMO key comparison

The following is an extract from the agreement on mutual recognition of national measurement standards and calibration certificates issued by national metrology institutes:

6. Participation in key and supplementary comparisons

- 6.1 Participation in a CIPM key comparison is open to laboratories having the highest technical competence and experience, normally the member laboratories of the appropriate Consultative Committee. Those laboratories that are not members of a Consultative Committee and not NMIs must be nominated by the designated national metrology institute referred to in paragraph 1.4. as being responsible for the relevant national measurement standards. In choosing participants, the Consultative Committees must take proper account of regional representation. The number of laboratories participating in CIPM key comparisons may be restricted for technical reasons.
- 6.2 Participation in key comparisons organized by an RMO is open to all RMO members and to other institutes that meet the rules of the regional organization (including institutes invited from outside the region) and that have technical competence appropriate to the particular comparison.
- 6.3 Participation in RMO supplementary comparisons is open to those institutes meeting the requirements specified in paragraph 6.2.