Rapport BIPM-86/17

The BIPM Ionizing Radiation Section (1960-1985)

by A. ALLISY

Bureau International des Poids et Mesures, F-92310 Sèvres

1. The basic rôle of the BIPM Ionizing Radiation Section

Following a proposal made by the Comité International des Poids et Mesures (CIPM) and endorsed by the XIth Conférence Générale des Poids et Mesures (CGPM, 1960, Resolution 1), the Bureau International des Poids et Mesures (BIPM) has been entrusted to establish an Ionizing Radiation Section to work on the unification of standards of measurement of ionizing radiations and the corresponding units. This has been accomplished by the establishment and maintenance of reference standards in the field of ionizing radiations to which all other measurements should be traceable. Long-term stability, continuity and international dependence are essential for achieving this goal.

This objective is achieved with the active participation of the national laboratories equipped with their own absolute standards, to the benefit both of themselves and of those countries whose laboratories are not so equipped. This role is essential for reasons which have often been stressed at the various CGPM meetings, but which it seems important to recall in the context of the work of the BIPM Ionizing Radiation Section.

Comparisons of absolute determinations of radioactivity, absorbed dose and particle fluence (the three major quantities of interest), as performed in the national laboratories, remain the most efficient way of developing scientific metrology in this field. However, such occasional comparisons are not alone sufficient; they must be supplemented by a permanent system of reference standards providing the basis for comparisons which may be made upon request at any time. Therefore, a centre has been established at BIPM with reference standards to which many measurements, performed in different countries of the world, can become traceable. Without doubt, such an organisation represents an optimum from the economic and scientific points of view since it is capable of meeting requests from all Member States of the Metre Convention. The BIPM ionizing radiation laboratory is regarded as the focal point of measurements in this field and it is recognized as such for its reliability as a result of more than 20 years of unceasing efforts. The accuracy of the BIPM reference standards is demonstrated in Figure 1, where one can see the position of the BIPM measurements with respect to the corresponding averages of the measurements of all participants in the international comparisons. The respective uncertainties are also given.

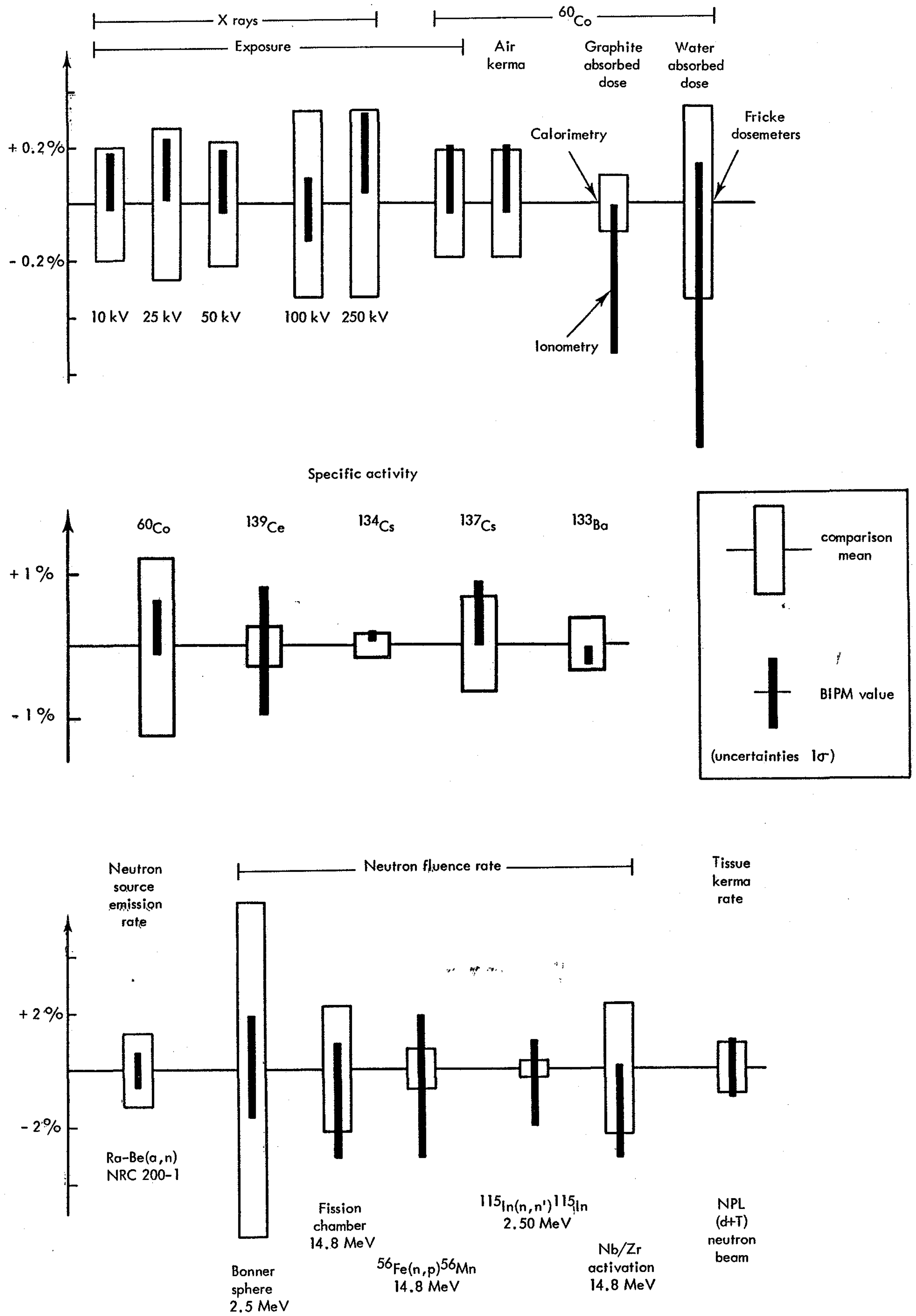


Figure 1 - Status of the BIPM long-term references

It would not have been possible to obtain this degree of success without the contribution of the national laboratories. However, the BIPM contribution is essential in that it would be unrealistic to expect these laboratories to undertake the whole programme. Indeed, the Member States have already financed BIPM to provide this service. Furthermore, the necessary long-term availability of reference standards at national laboratories is not guaranteed. Their existence can be disturbed by economic decisions, such as reductions or changes of programmes.

2. Research work in the BIPM Ionizing Radiation Section

The BIPM is not primarily a research institution, and its resources in terms of personnel and equipment are very limited. Indeed, the Member States of the Metre Convention would not be expected to support a pure research laboratory at international level. Consequently, the section must be very selective in its choice of research projects in support of its objectives, and the decisions are made in the light of advice given by the experts of the Comité Consultatif pour les Etalons de Mesure des Rayonnements Ionisants (CCEMRI) and the needs of the scientific community.

The main objective is to improve the accuracy of measurements of ionizing radiations, and the knowledge of the relevant physical constants. Ways in which this can be achieved include, for example,

- the introduction of more sophisticated instrumentation and techniques, both for absolute standards and for transfer instruments used in international comparisons,
- the use of different methods of measurement of a given physical quantity, the development of new methods, and the search for new ideas,
- the theoretical and experimental study of corrections to be applied to measurements,
- the improvement of methods of data handling and analysis.

The scientists of the BIPM Ionizing Radiation Section have demonstrated that a small but dedicated team can make important contributions in all these fields, as is shown in the following short survey of the most important results achieved.

Those interested in more details should consult the review article "BIPM activities in the field of Ionizing Radiations", by A. Allisy, Rapport BIPM-83/7 (1983), 22 p.

2.1. X- and γ-ray measurements

International reference standards of exposure and absorbed dose have been established, necessitating the construction of standard ionization chambers, and theoretical and experimental determinations of correction factors.

It was therefore necessary to study the effects which give rise to the corrections, in particular those of ion recombination, ambient humidity (influence on ionization current), and perturbation of absorbed dose due to the presence of the measurement cavity in a graphite mass.

The last study has enabled the realization of an ionometric absorbed dose standard which has been compared with four national calorimetric standards. No significant difference has been observed (see Fig. 1). From this comparison, a value of W (average energy required to produce an ion pair) for air has been obtained. Another W value, which is in good agreement with the first, has been deduced from activity and exposure measurements.

Overall, this work makes an important contribution not only to the dosimetry of photons but also of neutrons, as the calibrations of the neutron chambers with ^{60}Co γ rays allow a determination of both gamma and neutron components of the neutron fields.

2.2. Activity measurements

Theoretical and experimental studies are performed at BIPM in order to improve known methods and to suggest novel ones. Examples involve studies of source preparation, improvement in the mass determination and, in particular, a number of studies on the precise evaluation of experimental counting losses, the knowledge of which is vital at high count rates. A method devised by BIPM for the accurate measurement of dead times has become current laboratory practice.

A new method for measuring activities, called "selective sampling" and developed at BIPM, which does not rely on coincidences, has proved to be a most valuable alternative approach, especially at high count rates, and is being introduced at several national laboratories. It should be stressed that this discovery is by far the most fundamental and original achievement of BIPM in the last 30 years.

2.3. Neutron measurements

Two neutron fields, with energies of 2.5 MeV and 14.65 MeV, have been calibrated in terms of fluence rate by the associated particle method with an accuracy of 1.5 %. This result has been confirmed at 2.5 MeV by means of a stilbene scintillator associated with a neutron-gamma discriminator. In addition, the 14.65 MeV neutron field has been calibrated in terms of tissue kerma in free air by the ionization chamber method as well as by the fluence method. A good agreement has been obtained between these two independent methods (a difference of only 0.8 % was found).

The development of the circulation technique for calibrating the standard neutron source Ra-Be(γ,n) allows an accurate measurement of the ratio of thermal neutron absorption cross sections for hydrogen and manganese (σ_H/σ_{Mn}). Consequently, an uncertainty of only 0.13 % in the neutron emission rate determinations is introduced, instead of the previous value of 0.45 %.

In collaboration with IRK (Austria) a precise absolute measurement of the $^{27}Al(n,\alpha)^{24}Na$ cross section for 14.65 MeV neutrons has been performed. It should be noted that this reaction is one of those considered as neutron cross section standards, and it may be useful as a fluence monitor in fusion reactor studies.

3. Personnel and budget of the BIPM Ionizing Radiation Section

Figure 2 shows the number of staff paid by BIPM who have actually worked for the section during the past 20 years, excluding secretary and mechanic.

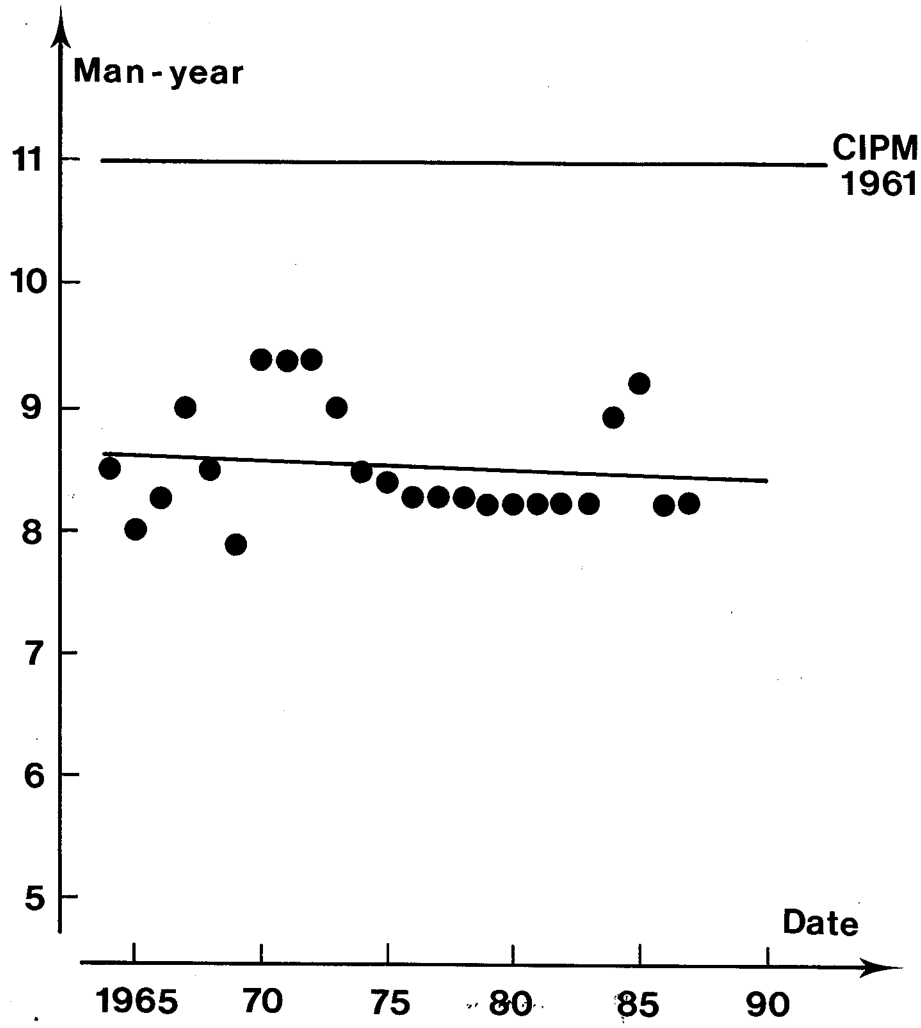


Figure 2 - Man-years effectively spent for ionizing radiation work. BIPM employees, excluding secretary and mechanic.

The strength of the Ionizing Radiation Section, which is shown as a function of time in Fig. 2, has never reached the number of 13 permanent staff (including secretary and mechanic) decided in 1961 by the CIPM after consulting the experts of CCEMRI, and approved by the Twelfth CGPM (1964, Resolution 1). At the creation of the section it was expected that its personnel would represent about 26 % of the BIPM total personnel. In 1985 the actual proportion is 17 %.

Figure 3 shows the number of man-years contributed to the work of the Ionizing Radiation Section by personnel not paid by BIPM. It includes both technicians (43 %), and experienced scientists (57 %), and represents more than 116 man-years from 1965 to 1985. Undoubtedly, these personnel have made a significant contribution to the results achieved by BIPM in the field of ionizing radiations. The decrease in the number of non-BIPM person-years available to the Section is due to the departure of some technicians, two of whom have been recruited by BIPM, and who now devote only a very small fraction of their time to the Section.

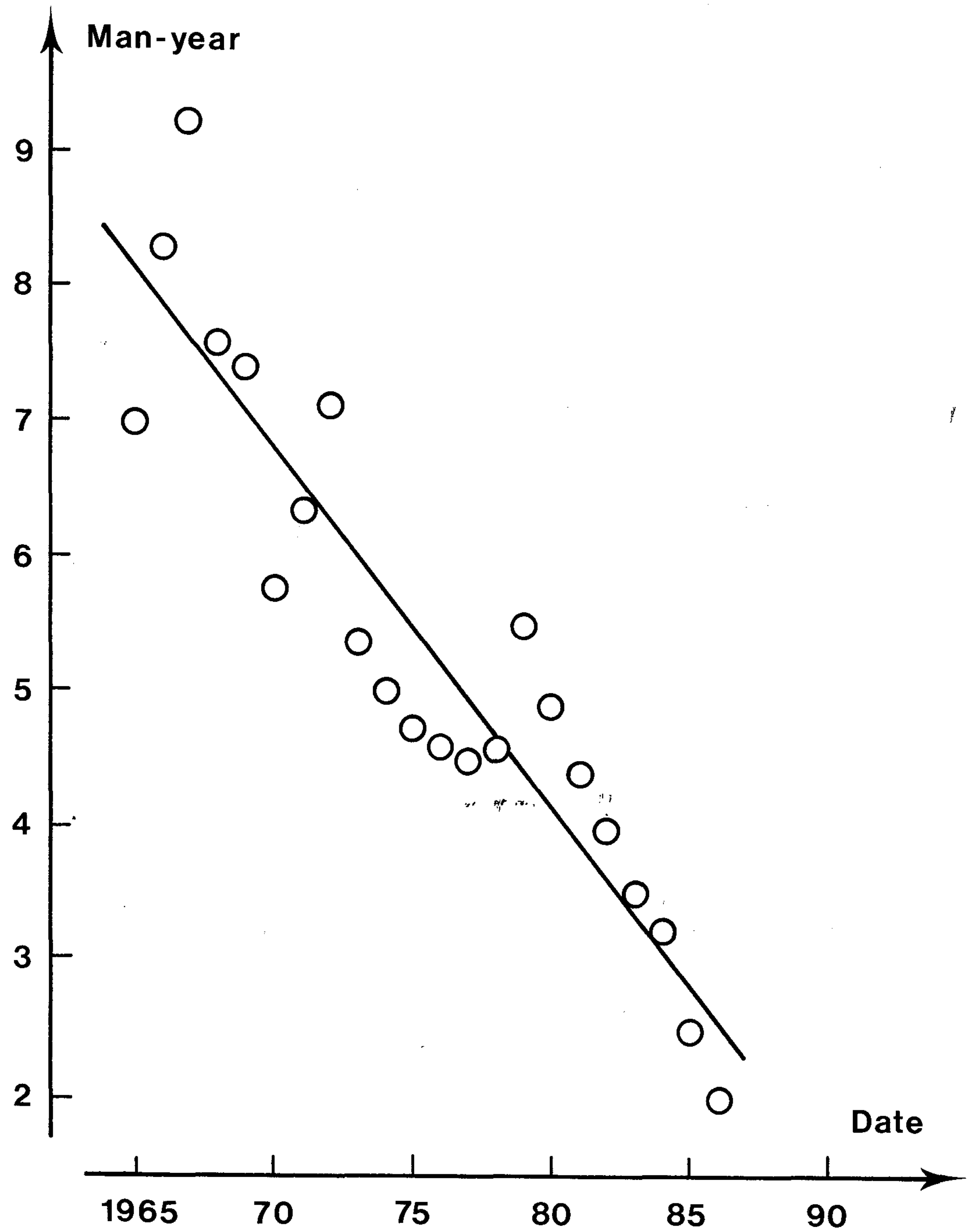


Figure 3 - Man-years effectively spent for ionizing radiation work. Personnel not paid by BIPM.

The future projection of staff levels is shown in table 1. It shows clearly that even if all persons who retire during this period are replaced by new recruitment, there will still be a reduction of over 25 % in the staff of the Ionizing Radiation Section due to the loss of the valuable contribution of the guest workers. Serious consideration should be given to the possibility of recruiting additional BIPM staff (in accordance with the CGPM directives which allocated a total of 11 BIPM staff members) to replace at least some of the guest workers. The final column of table 1 is to be considered as the bare minimum with which the Ionizing Radiation Section could continue to be viable.

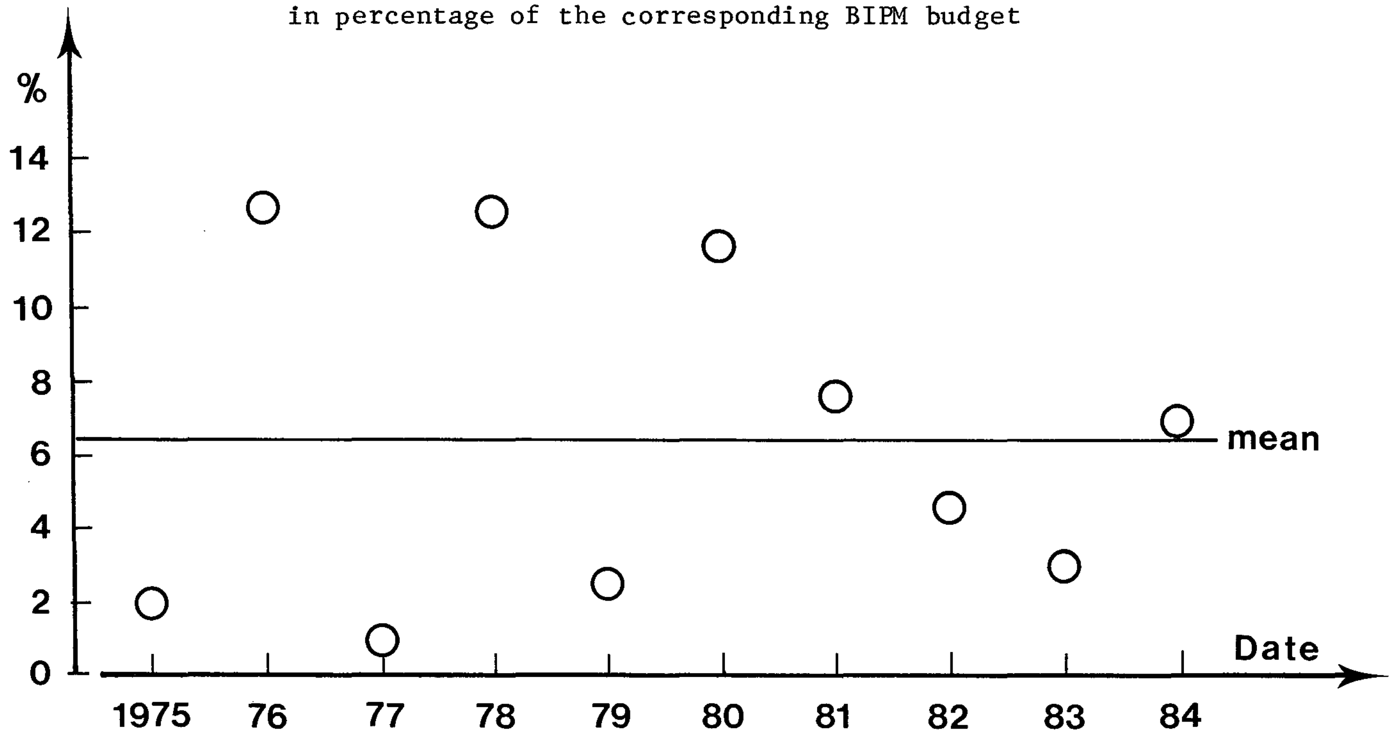
Table 1 - Future staff projection

		1985	1986	1987	1989
BIPM paid staff	Scientist	3.5	3.5 (3.25)*	3.5 (3.25)	4
	Research Fellow	1	0	0	0
	Metrologist	1	1	1	1
	Technician	3.75	3.75	3.75	3.75
	Total	9.25	8.25 (8)	8.25 (8)	8.75
	Guest workers	2.5	2	1	0
Total, including Guest workers		11.75	10.25 (10)	9.25 (9)	8.75

* Values in parentheses are valid if A. Allisy reduces his time from 50 % to 25 %.

Figure 4 shows the actual expenditure of the Ionizing Radiation Section over the years 1975 to 1984, both for capital expenditure on equipment and on laboratory running costs. These sums are expressed as a percentage of the corresponding BIPM budget (excluding the cost of the library, the computer and the mechanics). In each case the average is about 6 %, a value which is considerably below that which would be calculated on a pro-rata basis for the personnel of the section.

Laboratory equipment (Ionizing Radiation Section)
in percentage of the corresponding BIPM budget



Laboratory running costs (Ionizing Radiation Section)
in percentage of the corresponding BIPM budget

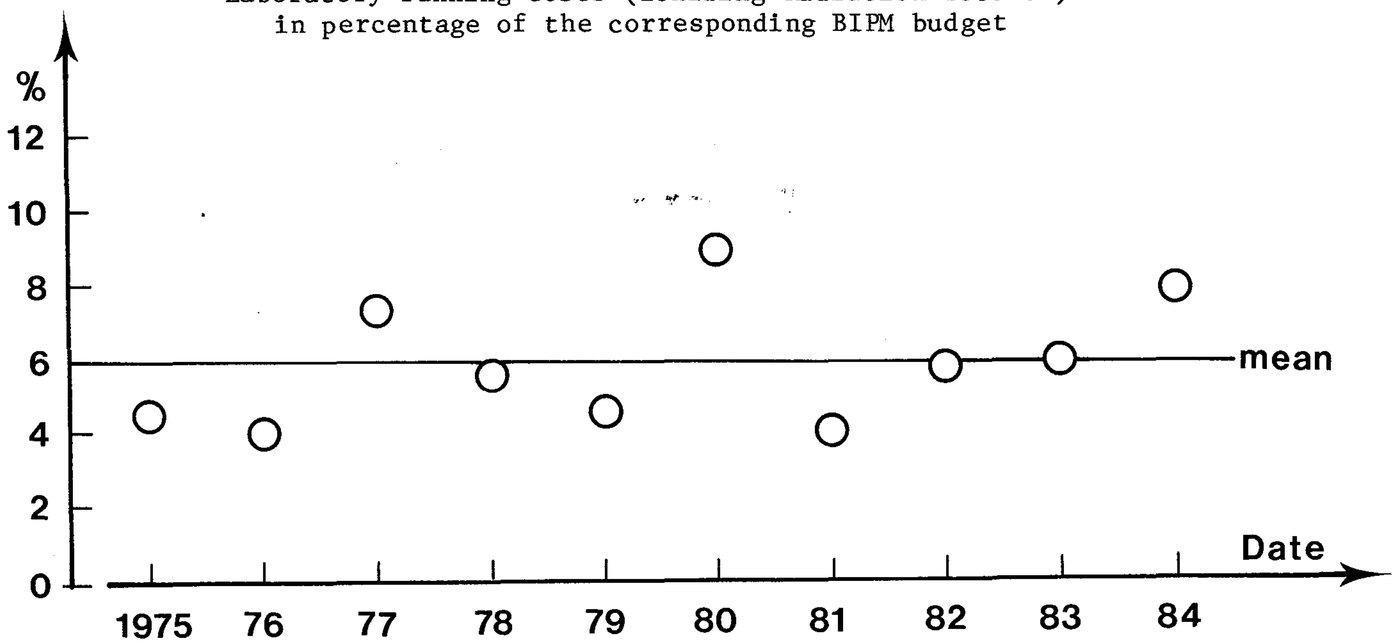


Figure 4 - Actual expenditure of the Ionizing Radiation Section
over the years 1975 to 1984

4. Future programme of the Ionizing Radiation Section

The establishment of reference standards for the measurement of ionizing radiations has become a fundamental rôle of BIPM, resulting from the directives of the CGPM (1960). Such references have long-term stability and continuity and are internationally independent.

The programme which is described below has been drawn up after careful consideration of the present status of the reference system at BIPM, the needs of the Member States, and the resources available to the Ionizing Radiation Section.

The present status is the result of all the work which has been carried out by the Section since its inception in 1961, a description of which is presented in Appendix 2, and Figure 1.

The needs of the Member States have been discussed in detail at the 1985 meetings of Sections I, II and III of CCEMRI (*see* Appendix 1, Recommendations to CIPM).

This programme is established assuming that there will be no major diminution of the BIPM resources available to the Section in the near future.

In order to promote international comparisons of radiation measurements the BIPM has established a system of interdependent reference standards, the accuracy of which has been demonstrated by international comparisons with the major national laboratories. The reference standards are maintained permanently at BIPM and are available on demand for the benefit of member countries who wish to compare their measurements internationally. They may take the form of standard instruments such as ionization chambers, or they may comprise standard techniques such as $4\pi\beta$-γ coincidence measurements of activity, or a combination of both. Likewise, they may consist of facilities for the calibration of samples remitted to BIPM or they may consist of artifacts which may be despatched for use at other laboratories.

4.1. X- and γ-radiation measurements

Reference standards for the measurement of absorbed dose, X and γ rays, and electrons are important for radiotherapy and for radiation protection. The accuracy which can be achieved in radiotherapy centres is not yet adequate, particularly in those countries which have no primary standards of their own. This is to a great extent due to the loss of accuracy in the process of dissemination. The main need therefore is to improve the accuracy of the transfer methods.

The requests for establishing links with the BIPM reference standards are increasing. Consequently, the International Atomic Energy Agency (IAEA) has set up, jointly with the World Health Organization (WHO), a network of Secondary Standard Dosimetry Laboratories (in about 50 countries) and has decided, on the one hand, to develop and improve intercomparisons within the network, and, on the other hand, to ensure that the measurements are traceable to BIPM.

There is also a need to establish a standard for the measurement of absorbed dose at a specific depth in water to simulate measurements at depth in tissue.

For radiation protection it is necessary to extend the reference system so that it is compatible with the new quantities, ambient dose equivalent and directional dose equivalent, as defined by the International Commission on Radiation Units and Measurements (ICRU).

4.1.1. Maintenance and improvement of reference standards

a) Exposure

The reference standards for exposure are two complementary free-air chambers for X rays and a graphite cavity chamber for ^{60}Co gamma rays. Countries which have no primary standards of their own may send secondary standard instruments to BIPM for calibration against the BIPM standard chambers.

b) Kerma in air

The reference standards for kerma in air are the reference standards for exposure supplemented by conversion factors to derive kerma from exposure. The values determined at BIPM for these factors have been agreed by Section I of CCEMRI and their use recommended.

c) Absorbed dose in graphite

Absorbed dose in graphite has been measured both by the BIPM graphite cavity chamber with its associated conversion factors, and by four national calorimetric standards. The reference for absorbed dose in graphite is the weighted mean of these determinations.

d) Absorbed dose in water

Absorbed dose in water is at present calculated from measurements of absorbed dose in graphite.

A reference standard for absorbed dose to water will be established by the construction of a standard cavity ionization chamber adapted for operation in water, and the experimental and theoretical determinations of the conversion factors needed to derive absorbed dose in water from ionometric measurements.

e) Ambient and directional dose equivalent

These quantities will be realised by determination of the correction factors needed to derive these quantities from measurements of exposure and kerma.

4.1.2. Establishment of transfer standards

As the IAEA is already active in arranging international comparisons in this field it is not necessary for BIPM to duplicate this work. The BIPM contribution consists of the calibrations relative to the reference standards described under 4.1.1. above. For example, in order to ensure traceability to BIPM, passive dosemeters (e.g. Fricke or TLD) distributed for intercomparisons organised by national or international laboratories will be calibrated in the BIPM water phantom.

4.1.3. International comparisons

a) Primary standards

The BIPM will continue to participate in future intercomparisons of primary standards for exposure, kerma in air and absorbed dose.

b) Fricke chemical dosimetry systems

An intercomparison of absorbed dose measurement by Fricke dosimetry is to be arranged. Samples will be sent to BIPM for irradiation in the BIPM water phantom, and returned to participants for processing.

4.2. Activity measurements

Accurate activity measurements are needed in many different fields of application, such as medicine and pharmaceutics, biology, reactor techniques, nuclear science, materials testing and environmental protection (waste management). The number of these applications is steadily increasing, as is the demand for higher precision. Thus the International reference system for the measurement of γ-ray-emitting nuclides (SIR) already renders an important service for a large number of γ-ray-emitting nuclides, and its extension to important other nuclides, which are difficult to measure, is often demanded.

Absolute measurements, on which the reference system relies, make use of sophisticated techniques which have to be improved and adapted to individual nuclides, due to the great variety of their decay modes.

For the predictable future all the available evidence points to a further increase and diversification of the applications. As an example one may quote the ever-expanding use of radioactivity in medical diagnostics and therapy. The corresponding metrological requirements present a technical challenge which can only be matched by considerable new efforts.

4.2.1. Maintenance and improvement of reference standards

These demands lead to a programme with efforts in the following fields:

a) Improvements to the SIR, using calibrated samples supplied by the national laboratories.

b) Establishment of an ionization chamber for low-energy photons as an extension of SIR; study of corrections and determination of efficiency functions.

c) Construction of a pressurized proportional counter for activity measurements by the coincidence and the selective sampling methods.

d) Installation of a well-type NaI(Tl) detector in order to improve efficiency in γ-ray measurements and for decay scheme studies.

e) Installation of a second set of $4\pi\beta$-γ coincidence equipment for verification of estimates of type B uncertainties.

f) Measurement of radionuclidic impurities.

g) Standardization of radionuclides such as ^{75}Si and ^{85}Sr for which standard techniques are insufficient due to the complexity of their decay schemes.

h) Measurement with a Ge-Li detector of samples which have been activated by neutron irradiation. This is a contribution to the programme of establishment of transfer standards for neutron fluence (See section 4.3.2.b below).

i) Multiparametric extrapolation by computer discrimination as a faster and more effective method of the traditional β-particle efficiency extrapolation technique.

j) The study of dead-time effects in the counting of activity. This includes calculation of the corrections to activity measurements due to the effect of the first dead time, the study of the model of a generalised dead time, and evaluation of the perturbations caused by the latter in observed counting statistics.

4.2.2. Transfer methods

a) International comparisons

International comparisons are achieved by having a single laboratory prepare an appropriate number of ampoules containing liquid samples of the same size and specific activity for dispatch to all participants simultaneously.

b) Dissemination of the SIR system

The preparation and supply of calibrated solid sources of radionuclides is a service to the Member States which is available from BIPM at any time on demand.

4.2.3. International comparisons

International comparisons of specific radionuclides as selected by CCEMRI Section II are arranged from time to time. BIPM organises these comparisons as well as participating in them, and analysing the results.

4.3. Neutron measurements

There is no doubt that the demand for more accurate neutron reaction data, which imply more accurate fluence measurements, will continue for many years, in order to meet the needs of reactor design, particularly for the fast-breeder and fusion programmes. Similarly, in the fields of radiobiology and radiotherapy there is still a need for more accurate data, with a trend towards the higher neutron energies envisaged for future therapy centres. For radiation protection there is a clear need for better field instrumentation.

4.3.1. Maintenance and improvement of reference standards

Accurate neutron measurements are required for medical purposes (dosimetry for radiation protection and radiotherapy), for industry and research, and for the calibration of transfer instruments for inter-laboratory calibrations. In order to promote international comparisons of neutron source emission rate, neutron fluence, neutron kerma and neutron dose equivalent the BIPM has established a system of reference standards in these fields.

Neutron metrology is a young and still developing science, in which the international consistency of measurements is in the process of being established, in contrast to the situation prevailing in other fields such as those of mass, length, and time. The accuracies so far attained in metrological laboratories are not yet adequate for the requirements in industry, health protection, and biomedical applications.

a) Neutron emission rate from portable radioactive sources

At the present time the most accurate and most convenient method for the calibration of neutron source emission rates is the manganese bath technique. The BIPM system can be used to calibrate sources with widely differing neutron spectra and with emission rates between 10^4 and 10^8 s^{-1} to an accuracy of between 0.5 % and 1.5 % depending on the neutron spectrum. Neutron sources may be sent to BIPM for calibration.

b) Mono-energetic fast neutron fluence

Although radioactive neutron sources have many uses and advantages, their intensity is limited and they are not mono-energetic. Instruments for neutron detection are designed to have energy response functions for specific purposes. For example, they may be energy independent or they may have a response which follows dose equivalent as a function of neutron energy. In order to check the energy response of these instruments, it is necessary to provide calibration fields of mono-energetic fast neutrons. The most widely used neutron energies are 14.8 MeV and 2.5 MeV because they can be provided at low cost. These neutron energies are available with the BIPM accelerator, which can provide fluence rates of up to 1.2×10^6 cm^{-2} s^{-1} and 3×10^4 cm^{-2} s^{-1} for 14.8 MeV and 2.5 MeV respectively, at a distance of 10 cm from the target. The accuracy of the certification of the neutron fluence rate is 1.5 %. Instruments may be sent to BIPM for calibration in these fields.

c) Neutron kerma

Neutron kerma is important in neutron dosimetry both for radiobiology, radiotherapy and for radiation protection. A tissue-equivalent plastic cavity ionization chamber with the associated tissue-equivalent gas flow system has been established as a reference standard for the measurement of neutron kerma. After calibration in a standardized photon beam and with the appropriate conversion factors, the chamber measures kerma. Alternatively, the chamber may be calibrated in a standardized neutron fluence, and the kerma calculated from internationally-agreed fluence to kerma conversion factors. In order to discriminate between the photon and neutron contributions to the total kerma, an energy-compensated Geiger-Müller counter and a magnesium-argon gas flow cavity ionization chamber are available. Instruments may be submitted to BIPM for calibration. However, the small cyclotrons (up to 15 MeV) are not producing the expected benefit in neutron radiotherapy. The tendency in the future will be towards higher energies.

d) Neutron dose equivalent

Instruments may be calibrated in terms of neutron dose equivalent by exposure in a standardized neutron fluence and the use of internationally agreed fluence to dose-equivalent conversion factors.

The possibility to measure dose equivalent at a prescribed depth in a tissue-equivalent phantom by means of a tissue-equivalent proportional counter is under consideration.

4.3.2. Maintenance and improvement of transfer standards

a) Neutron sources

The BIPM standard Ra-Be(α,n), Ra-Be(γ,n), and Am-Be(α,n) neutron sources are available as transfer standards for the measurement of neutron source emission rates.

b) Neutron fluence

Neutron fluence measurements at agreed energies can be compared either by neutron activation methods or with the use of transfer instruments. Both of these methods have been featured in previous international comparisons. The most serious problem in either case is the presence of neutrons scattered by the environment.

- Activation methods.- The aim is to select, for each neutron energy, a nuclear reaction which has the suitable combination of reaction cross section, cross-section variation with neutron energy, and the spectrum of γ-ray emission and the half-life of the induced activity, to enable samples of the chosen material to be dispatched by BIPM to the participating laboratories for activation by neutrons, and then returned to BIPM for activation measurements. The procedure absolves the laboratory from the responsibility of making absolute measurements of radioactivity.

For measurements of thermal neutron fluence, the $^{197}Au(n,\gamma)$ reaction is suitable, provided that the intensity of the fluence to be compared is sufficiently high and that the samples can be returned to BIPM within a day or two.

The most suitable reactions for neutron energies in the range from 14 to 15 MeV are $^{93}Nb(n,2n)^{92}Nb^{m}$ and $^{90}Zr(n,2n)^{89}Zr^{g+m}$. This combination has the advantage that the neutron fluence can be obtained from the induced Nb activity, and the precise neutron energy can be obtained from the ratio of the two activities.

A Working Group of CCEMRI Section III is investigating neutron reactions which would be suitable at other neutron energies.

- Transfer instruments.- The most suitable instrument is the simple moderating sphere containing a thermal neutron detector at the centre. By making measurements at short separation distances, the detection efficiency of the instrument and the scattering corrections can be derived by a least-squares fitting procedure. The instrument is suitable for all neutron energies. If two or three different sized spheres are used, the average neutron energy can be deduced. By working at short distances from the target where the fluence is greater, the measurements at each energy can be completed in a few hours.

  Work is planned, in collaboration with the CCEMRI Section III programme, to investigate the suitability of this transfer method.

c) Neutron kerma

At the conclusion of the intercomparison described above under 4.3.1.c the equipment will be permanently available as a transfer standard for the comparison of neutron kerma in tissue equivalent plastic.

4.3.3. BIPM participation in international comparisons

a) Neutron sources

A report has been prepared on the results of measurements of a ^{252}Cf spontaneous fission neutron source by fourteen laboratories.

No further neutron source comparisons are contemplated for the time being.

b) Mono-energetic neutron fluence

- The results of the comparison at 14.8 MeV neutron energy with the In(n,n') reaction as transfer method are under review.

- The comparison at several neutron energies with a fission chamber as transfer instrument is still in progress.

No further intercomparisons of mono-energetic neutron fluence are contemplated for the time being.

c) Neutron kerma

A comparison of kerma in tissue-equivalent plastic (in air) at 14.8 MeV neutron energy is in progress. This comparison, organized by BIPM, is achieved by circulating, to each participant in turn, the tissue-equivalent cavity ionization chamber and its associated photon detectors, as described in section 4.3.1.c. There are at present eleven laboratories who wish to participate. The reference equipment will continue to be available at BIPM on a permanent basis on demand for the benefit of countries which enter the field later on.

5. Conclusions

The main objective of this report is to provide information, for the Bureau and the other members of the Comité International des Poids et Mesures, as a basis for the discussion of the long-term plan for the future activities of BIPM. If this report is to fulfil this rôle effectively, it is essential that it be objective and that it reflect not only the views of BIPM, but also those of the Member States of the Convention du Mètre.

The discussions with our colleagues in the Sections of CCEMRI have led us to modify certain aspects of the proposed programme and have highlighted some views which are shared by both large and small laboratories. These points can be summarized as follows:

- Due weight should be given to the fact that radiation metrology is a young and still developing science in which the international consistency of measurements is in the process of being established, and that accuracies required in industry, for health protection and biomedical applications have not yet been achieved.

- The BIPM must maintain and improve the reference standards which have been established for the measurement of ionizing radiations, and guarantee their permanence. This is important both from a scientific and from a legal point of view.

- The BIPM must conserve the results of international comparisons, in some cases by means of simple and precise instruments.

- The BIPM must have at its disposal highly qualified staff who are capable of helping junior laboratories.

- Although research is not the principal aim of the BIPM, it is an important factor in maintaining the scientific expertise of the staff. Some of the research carried out in the Ionizing Radiation Section is very much appreciated, but a reduction, particularly in the field of X and γ radiation, would be possible.

- The demand for the services provided by the Ionizing Radiation Section (reference standards, intercomparisons, calibrations, and the training of young scientists in the fields of X- and γ-radiation measurements, radioactivity measurements, and neutrons measurements), is well established. The abolition of any field of activity from amongst those explicitly proposed by the CIPM and approved by the CGPM (1964, Resolution 1) is a major decision which can have serious long-term consequences. Such an action would be detrimental to the radiation metrology of certain Member States, and could have severe repercussions on the reputation of BIPM. It is therefore important for the future of BIPM not to make a decision too hastily.

- General scientific services in the field of the expression and treatment of uncertainties have been provided by a staff member of the Ionizing Radiation Section and the ensuing BIPM recommendation is in the process of being generally adopted.

- The establishment of the existing capabilities in the field of ionizing radiations has taken more than ten years of effort, and extra staff beyond those available at BIPM. The suppression of one, or several, of the fields can be decided quickly, but it is obvious that this would represent an irreversible process, because one can never again expect to reproduce the exceptionally favourable conditions which have prevailed during the establishment of the Ionizing Radiation Section at BIPM.

The arguments developed in this report reflect an averaged consensus of the scientific community. Taking them into account, together with the proposed programme of work as reviewed by the Sections of CCEMRI, and in view of the limited resources of BIPM, we have reached the following conclusion:

> If the Ionizing Radiation Section does not comprise at least 4 physicists, 1 metrologist and 3.5 technicians, it will be necessary to abandon one of the fields of activity: either the measurements of radioactivity, the neutron measurements, or the measurements of X and γ radiation.

In accordance with this conclusion, A. Allisy proposes to reduce the time he devotes to BIPM from 50 % to 25 %, starting with January 1986. From the same date, one of the guest workers of the Section (Mme Boutillon) will work exclusively for ICRU. Another guest worker (Mlle Niatel) will retire during the following two years. Finally, the third guest worker (Mme Perroche) will be able, with the agreement of her supervisor, to continue to work for BIPM until the departure of A. Allisy. At that time it should be possible for her either to join the staff of BIPM, or to be replaced by another physicist specialized in the field of X-ray measurements.

In conclusion it should be stressed that, since the reputation of BIPM is founded on the range and the quality of the services which it provides for Member States, it would be unwise to make any serious changes to them unless the countries concerned are kept fully informed and are in agreement. This would entail a thorough study of the present and future programmes of all Sections of BIPM.

APPENDIX 1

Recommendations of Sections I, II and III of CCEMRI

(English versions only)

RECOMMENDATION
of Section I (Rayons X et γ, électrons)
of Comité Consultatif pour les Etalons de Mesure des Rayonnements Ionisants
presented to the Comité International des Poids et Mesures

Recommendation R(I)-1 (1985)

Considering

- that the establishment of reference measurement standards for X, γ and electron radiation and the intercomparison of national primary standards is a fundamental role of BIPM, conforming to the directives of the Conférence Générale des Poids et Mesures,

- that some member countries of the Metre Convention have deliberately chosen to establish and maintain secondary standards as their national standards, assuming that they could have direct access to the primary standards of BIPM,

- that the IAEA/WHO international network of Secondary Standard Dosimetry Laboratories, which serves a large number of countries that develop measurement capabilities in the field of ionizing radiations, is directly linked to the BIPM,

- that the standards of exposure, kerma and absorbed dose established at BIPM are of considerable metrological interest because they are the only ones directly compared with the majority of national primary standards,

And taking into account

- the increasing concern in matters of human health and personal protection, and the introduction of related legal regulations in many countries,

Section I recommends

- that the system of standards for ionizing radiations established at BIPM should be maintained and developed in accordance with needs,

- that the staff of BIPM should be adequate to perform the necessary tasks.

RECOMMENDATION
of Section I (Rayons X et γ, électrons)
of Comité Consultatif pour les Etalons de Mesure des Rayonnements Ionisants
presented to the Comité International des Poids et Mesures

Recommendation R(I)-2 (1985)

Considering

- that the International Commission on Radiation Units and Measurements has recommended new quantities for use in radiation protection (ICRU 39),

- that increased accuracy will be required in future measurements of radiation for protection purposes, and

- that linking such measurements to the unique existing system of exposure and air kerma standards at the BIPM is necessary to help ensure a world-wide coherence,

Section I recommends

- that the BIPM determine factors for deriving ambient dose equivalent from exposure and air kerma for the beam qualities of the existing system.

RECOMMENDATION
of Section I (Rayons X et γ, électrons)
of Comité Consultatif pour les Etalons de Mesure des Rayonnements Ionisants
presented to the Comité International des Poids et Mesures

Recommendation R(I)-3 (1985)

Considering the necessity to assure the uniformity of measurements of absorbed dose to water, and traceability to the unique international reference system at BIPM,

Section I recommends

- that national and international laboratories, when organizing the distribution of passive dosemeters, e.g. Fricke or TLD, also send to BIPM from the batch of dosemeters a sample to be irradiated at a reference point in the BIPM water phantom, where the absorbed dose to water is known,

- that the measured value of the absorbed dose delivered in the BIPM phantom should be communicated to BIPM; subsequently Section I of CCEMRI should discuss the accumulated results.

This procedure, instituted for absorbed dose values up to 200 grays, is not intended to replace high precision comparisons of absorbed dose standards effected by direct comparison of standards, or by the use of transfer ionization chambers.

RECOMMENDATION
of Section II (Mesure des radionucléides)
of Comité Consultatif pour les Etalons de Mesure des Rayonnements Ionisants
presented to the Comité International des Poids et Mesures

Recommendation R(II)-1 (1985)

Considering

- that the establishment and maintenance of the worldwide unification of radioactivity measurements is a fundamental task of BIPM, in conformity with the decisions taken by the XIth Conférence Générale des Poids et Mesures,

- that the constantly increasing use of radionuclides in very different fields calls for stringent traceability to international references and improvement of the accuracy of activity measurements all over the world,

- that BIPM, by virtue of its generally accepted independence, is the only organization capable of assuming the role of a permanent focal point in the field of measurements of radioactivity,

- that BIPM must take an active part in the application and development of new measurement techniques, especially if these permit the achievement of improved accuracy,

- that radioactivity standards are needed for many radionuclides and, because they decay, must constantly be renewed,

- that the equipment and staff of BIPM are extremely useful to many countries which are developing laboratories for radioactivity measurements, because they can rely on BIPM primary standards and on expertise of BIPM scientists,

Section II recommends

- that BIPM should continue to organize international comparisons of selected radionuclides,

- that the International reference system for activity measurements of γ-ray-emitting nuclides should be maintained, for no other continuing mechanism exists, and extended to include lower energy radiations,

- that the study of theoretical and practical aspects of accurate measurements of radionuclides should continue to be given full attention,

- that the present staff should be considered as less than the minimum personnel needed at BIPM for accomplishing the increasing tasks in the field of radioactivity.

RECOMMENDATION
of Section III (Neutron measurements)
of Comité Consultatif pour les Etalons de Mesure des Rayonnements Ionisants
presented to the Comité International des Poids et Mesures

Recommendation R(III)-1 (1985)

Considering that neutron metrology is a young and still developing science in which the international consistency of measurements is in the process of being established,

Considering the progress achieved in establishing this consistency thanks to the joint efforts made by CCEMRI and the neutron laboratory of BIPM,

Considering that some member countries of the Metre Convention have deliberately chosen to establish and maintain secondary standards as their national standards, assuming that they could have direct access to the primary standards of BIPM,

Considering that in the field of neutron measurements the accuracies required in industry, for health protection and biomedical applications are close to those presently achievable in metrological laboratories,

Considering that some of these measurements are needed to implement the legal basis for radiation protection regulations and that traceability to national standards is usually required,

Section III recommends

- that the international references for neutron measurements existing at BIPM be maintained and improved,
- that the necessary steps be taken with regards to personnel and equipment, so that the neutron laboratory at BIPM can study and improve the simple, yet precise, transfer instruments which have already been tested within the framework of international comparisons,
- that these instruments be maintained at BIPM with guaranteed stability, in order to allow the establishment of a coherent system of neutron measurements to which experienced laboratories as well as those entering this field can be linked.

APPENDIX 2

Historical review

The present status of the reference standards is founded on a combination of absolute measurements, relative measurements, and international comparisons with national laboratories which have well established reputation in the various subdivisions in the field of radiation metrology. It will be noted in the following pages that there has been a steady and significant improvement in worldwide agreement in all of these subdivisions over the years since the inception of the Ionizing Radiation Section. BIPM has contributed significantly to this improvement, not only by its own metrology but also by the stimulation it provides for international collaboration.

In the following sections of this appendix the improvement is illustrated usually by reference to standard deviations or spreads of results in various international comparisons. In some cases it is interesting also to include figures for global agreement pertaining in earlier years. (For more details see also Rapport BIPM-83/7).

1. X- and γ-ray measurements

Table 2 (p. 24) shows the cumulative number of intercomparisons of absorbed dose and exposure which have taken place over the years, publications, and scientific visitors who have come for intercomparisons or for training.

Table 3 gives the current uncertainty of measurements of X and γ rays.

Table 3 - Uncertainty of BIPM measurements (1 σ) in %

	X rays	^{60}Co γ radiation
Exposure	0.10 to 0.14	0.24
Air kerma	0.17 to 0.20	0.17
Graphite absorbed dose		0.26

Table 2 - X- and γ-ray comparisons

Year	before 1975	75	76	77	78	79	80	81	82	83	84	85
Cumulative numbers of:												
- Comparisons of exposure and absorbed dose	16	26	27	31	32	37	39	39	45	48	49	52
- Calibrations of exposure and absorbed dose	22	27	33	37	39	51	61	71	80	92	97	108

These comparisons and calibrations involve 21 countries.

(For X and γ rays the word "comparison" means a bilateral comparison between a national laboratory and the BIPM. These comparisons can take place at any time).

Publications of the X- and γ-ray group

31 external publications and 6 Rapports BIPM.

Visiting scientists 46 people from 22 countries have spent 65 periods at BIPM for training or for intercomparisons, the duration of the visits ranging from one week to two years.

It will be recalled that three physicists from the Institut National de la Santé et de la Recherche Médicale, Paris, have been working at BIPM since 1964, and most of the work of the X- and γ-ray group during this period has been carried out by them.

2. Radionuclide measurements

A summary is given of international comparisons and other work carried out in the years since 1961.

2.1. International comparisons of radioactivity

From the 'Handbook 62' (ICRU, 1956) it appears that there were only six laboratories in the world equiped for the measurement of radioactivity. Frequent intercomparisons were necessary, and an accuracy of 2 % seemed possible, compared with the required 1 %.

The 'Handbook 86' (ICRU, 1963) shows that, during the period from 1955 to 1958, nine international comparisons took place, with on the average four participants. The results showed a dispersion of between 1 and 5 % depending on the difficulties of the measurements of particular nuclides. Between 1959 and 1961 there were twelve intercomparisons with, on the average, ten participants. Some of these intercomparisons were organized by BIPM or IAEA. The dispersion of the results ranged from 1.3 to 19 %.

a) Intercomparisons arranged by BIPM

Years	Number of comparisons	Number of participants	Total dispersion (%)
1961-1965	9	15 to 25	3 to 18
1967-1984	6	19 to 24	0.7 to 3.0

b) International system of reference (SIR)

Year	1975/76	77	78	79	80	81	82	83	84
Cumulative numbers of:									
- different radionuclides	14	22	31	35	39	41	43	46	46
- number of laboratories	11	13	18	18	19	21	22	23	25
- number of results	28	70	116	151	195	221	243	271	288
- number of ampoules measured	49	119	185	230	289	325	351	391	413

2.2. Distribution of thin, solid, calibrated sources and calibrated solutions

In 1971 a questionnaire was distributed to 34 national and international laboratories to assess the demand for calibrated sources.

- 19 laboratories replied,
- 15 laboratories desired to receive solid sources,
- 11 laboratories desired to receive calibrated solutions.

As a result of this, BIPM dispatched 99 calibrated sources (^{60}Co and ^{54}Mn) before September 1972, and 58 sources between 1972 and 1975.

In summary, to date, BIPM has sent about two hundred calibrated sources of fourteen different radionuclides to sixteen laboratories.

2.3. Visits of staff of other laboratories

Eighteen people from thirteen laboratories of different countries have visited BIPM for intercomparisons and for training for periods between five days and two years.

2.4. Publications

Thirty one reports on intercomparisons have been published, as well as eighteen special reports, one hundred and twenty-three reports on counting statistics and eighteen on measurements of α-particle energies.

3. Neutron measurements

A comprehensive list of neutron calibrations and international comparisons in which BIPM took part appears in table 4 (p. 27).

3.1. Neutron source emission rate

The first international comparison of neutron source emission rates took place in 1951. There were six participants, and the total spread of results was 25 % with a standard deviation of 10 %. Table 5 shows the improvement in these figures which has been achieved to date. The first BIPM-sponsored intercomparison was reported in 1966.

Table 5 - Comparisons of neutron source emission rate

	1951	1954	1960	1966	1985	
Number of participants	6	8	10	11	14	
Total spread of results (%)	25	10.6	3.8	3.7	3.26*	2.2**
Standard deviation (%)	10	3.2	1.3	1.3	0.81*	0.56**

* Results as submitted by participants.

** Results normalised to standard reference data and unified corrections.

Table 4 - BIPM participation in comparisons of neutron measurements

Year	Measurement	Calibrations or comparisons
1964	Emission rate of the standard source Ra-Be(α,n) NRC n° 200-1	International comparison (1962-1965) with 11 participants: BIPM, AEET, BCMN, CENS, ETL, IKO, IMM, NBS, NPL, NRC and SRE.
1968	Emission rate of the standard source Ra-Be(α,n), SNRC (Israël)	BIPM calibration.
1968	Emission rate of the standard source Ra-Be(α,n), CEN Saclay	BIPM calibration.
1969	Emission rate of the secondary standard source Ra-Be(γ,n) n° 2C-NPL	BIPM-NPL bilateral comparison.
1970	Emission rate of the secondary standard source Ra-Be(γ,n) n° 2-NBS	BIPM-NBS bilateral comparison.
1973	Neutron fluence rate at 2.50 MeV	International comparison (1973-1978) with 8 participants: BIPM, BCMN, CEN, ETL, IMM, NPL, NRC and PTB (Bonner spheres). A physicist of BIPM assisted with the measurements at the participants' laboratories.
1976	Neutron fluence rate at 14.8 MeV	International comparison (1973-1978) with 7 participants: BIPM, BCMN, CEN, ETL, IMM, NPL and PTB (fission chamber). A physicist of BIPM assisted with the measurements at the participants' laboratories.
1976	Neutron fluence rate at 14.8 MeV	International comparison (1973-1978) with 5 participants: BIPM, BCMN, ETL, IMM and NPL (^{56}Fe(n,p)^{56}Mn).
1978	Neutron fluence rate at 14.65 MeV at BIPM	- BIPM-IRK bilateral comparison (Al activation). - Determination of the ^{27}Al(n,α)^{24}Na cross section.
1978	Emission rate of the source ^{252}Cf n° SR144-NBS	International comparison (1978-1984) with 14 participants: BIPM, ASMW, BARC, BLC, ENEA, ETL, IAEB, IMM, INEL, LMRI, NBS, NPL, PTB and VGKRI.
1979 (January and June), 1981 and 82	Measurement of the efficiency of the sulphur detectors of SCPRI (France) for 14.65 MeV neutrons	BIPM calibration.

.../...

Table 4 (cont'd)

Year	Measurement	Calibrations or comparisons
1980 (January and June)	Efficiency of the fission chambers of CEN Cadarache for neutrons of 14.65 MeV	BIPM calibration.
1981	- Fluence rate of neutrons of 14.65 MeV at BIPM - Mean energy of neutrons	BIPM-NPL bilateral comparison (Nb/Zr activation).
1981	- Fluence rate of neutrons of 14.8 MeV - Mean energy of neutrons	International comparison with 9 participants: BIPM, BARC, BCMN, ETL, IAEB, IRK, NBS, NPL and PTB (Nb/Zr activation).
1981	Fluence rate of neutrons at 2.50 MeV	International comparison with 10 participants: BIPM, BARC, BCMN, ETL, IAEB, IMM, IRK, NBS, NPL and PTB $\left({}^{115}In(n,n'){}^{115}In^m\right)$.
1983	Efficiency of the fission chambers of CEN Cadarache and CEN-FAR for 14.65 MeV neutrons	BIPM calibration.
1983	Kerma rate for neutrons of 14.50 MeV, NPL	International comparison with 7 participants: BIPM, ENDIP, MRC, NBS, NPL, PTB and WGH.
1983	Kerma rate for neutrons of 14.65 MeV, BIPM	International comparison ENDIP-2 with 18 participants (travelling team GSF-TNO making measurements in the participants' laboratories).
1984	Fluence rate of neutrons of 14.8 MeV	International comparison (1983-1987) with 9 participants: BIPM, AERE, BARC, BCMN, ETL, IRK, NBS, NPL and PTB (fission chambers).

Publications: 10 publications and 5 Rapports BIPM.

3.2. Neutron fluence rate

- The first international comparison was organised by the BIPM over the period from December 1973 to February 1978 with nine participants. The fluence was measured with an accuracy of 2 to 3.5 %.
- The second series of fluence rate comparisons started in 1981 and is expected to continue until 1986. Some comparisons are already completed and analysed. In these measurements the neutron fluence was measured with an accuracy of 1 to 2.7 %.
- In general, a better agreement in fluence measurements is obtained when the transfer instrument does not respond to scattered neutrons.

3.3. Neutron kerma (or absorbed dose) rate

The results of two large scale international comparisons of neutron dosimetry are summarized in the following table. The results of these comparisons show some unacceptable discrepancies. Both demonstrated the need for the standardization of experimental techniques and dosimetry systems, as well as basic physical parameters.

	INDI (ICRU)	ENDIP (CEC)
Date	1973	1975
Number of participants	14	20
Deviation from the mean (for most results) (%)	5	5
Standard deviation (%)	7 to 8	7 to 8

The third neutron dosimetry intercomparison took place at NPL in 1983 with seven participants. All groups used tissue-equivalent (TE) ionization chambers associated with a GM counter or with a Mg/Ar chamber. The results of the comparison show a standard deviation of 1 to 2.5 % for the TE + GM system and a standard deviation of 3 to 4 % for the TE + Mg/Ar system.

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