Food Chemistry 43 (1992) 307–313
Analytical Methods Section

Use of reference materials in trace element analysis of foodstuffs

Rita Cornelis

Laboratory of Analytical Chemistry, University of Gent, Proeftuinstraat 86, B-9000 Gent, Belgium

The best way to maintain quality assurance of the trace element concentrations in foodstuffs is to perform concurrent analysis of suitable reference materials certified for the trace elements of interest. A wide range of such products, certified on the authority of a number of international and national organizations, is already available. This paper describes the key role and the shortcomings of existing reference materials. CRMs fulfil various purposes: they are useful tools for method development and allow verification of the accuracy of the measurement system and calibration by comparison of the observed result with the certified value. RMs are also necessary for daily quality control and for checking the precision of the performance (Griepink, 1990; Wolf, 1985; McKenzie & Smythe, 1988). Long-term stability of food CRMs may be questionable in many cases, depending on the storage conditions (humidity, temperature) and the nature of the product. This problem will be even more pronounced for the envisaged case of CRMs certified for particular species.

1 INTRODUCTION

Analysis results of trace elements in nutrients are produced on a large scale to estimate the dietary intake of nutritive and toxic elements and to decide on the acceptance or rejection of foodstuffs. Obviously data for such purposes must be accurate; if not, the consequences could be serious for public health or for economic reasons.

Existing analytical techniques in the hands of skilled analysts can produce reliable results, but the complex nature of foodstuffs may create many difficulties. A growing population of analysts does routine work, using advanced, automated, computer-controlled instrumentation. No time is scheduled in their working day to develop a critical approach and make detailed studies of a given trace element in each type of nutrient. The fat content between various food types may vary within wide limits and so can the concentration of the minerals Ca, Mg, P, etc. An adequate sample treatment and measurement of major and trace elements has to take into account possible matrix interferences which are specific to each product. An historical example is the analysis of Cr in NBS SRM 1577 Bovine Liver, which was subsequently certified. The results published for Cr in this matrix prior to certification varied between 0·0499 and 1·923 μg/g. However, when it was certified by NBS the value observed was 0·088 (±0·012) μg/g (Versieck, 1984).

An effective and economical way to control the accuracy of the results consists of analyzing reference materials (RM). A reference material is defined by the International Organization for Standardization (ISO) as a material one or more properties of which are sufficiently well established to be used for calibration of an apparatus, the assessment of a measurement method, or for assigning values to materials (ISO, 1981). A certified reference material is a RM one or more of whose property values are certified by a technically valid procedure, accompanied by, or traceable to, a certificate or other document which is issued by a certifying body (ISO, 1981).

Ideally, a CRM should have a matrix similar to the sample to be analyzed and be certified for concentrations of the trace elements as they occur in field samples. Conclusions at one level may not be applicable at other levels. CRMs allow the investigation of possible systematic errors and can therefore lead to their elimination. There is an impressive choice of RMs and CRMs for foodstuffs, inventoried in various publications and catalogues (Toro *et al.*, 1990; BCR, 1990; NIST, 1990). An overview of the different types of RMs and CRMs is given in Table 1. A specific CRM for each particular problem will probably never be available. The choice of a RM should then be guided not only by the concentration of the particular analyte,

Table 1. Survey of the 54 different types of RMs and CRMs for trace element analysis in foodstuffs (Toro *et al.*, 1990)

Type	Reference materials		Certified reference materials	
Dairy	Milk powders	ACR/CL-MP	Milk powders	NIST-SRM-1549
		IAEA-A-11	Skim milk	BCR-CRM-150
		IAEA-153	Powders	BCR-CRM-151
				BCR-CRM-063
Animal tissues	Bone	IAEA-H-5	Bovine liver	NIST-SRM-1577a
	Pork muscle	ARC/CL-AM		BCR-CRM-185
	Bovine liver	CZIM-liver	Bovine muscle	BCR-CRM-184
			Pig kidney	BCR-CRM-186
Marine animals	Albacore tuna	NIST-RM-50	Mussel tissue	BCR-CRM-278
	Copepoda	IAEA-MA-A-1/TM	Oyster tissue	NIST-SRM-1566
	Dogfish liver	NRCC-DOLT-1		
	Dogfish muscle	NRCC-DORM-1		
	Fish	EPA-FISH		
	Fish flesh	IAEA-MA-A-2/TM		
	Lobster hepatopancreas	NRCC-TORT-1		
Aquatic plants			Aquatic plants	BCR-CRM-060
				BCR-CRM-061
			Chlorella	NIES-CRM-03
			Sargasso	NIES-CRM-09
			Sea lettuce, *Ulva lactuca*	BCR-CRM-279
Flours and cereals	Corn kernel	NIST-RM-8413	Brown bread	BCR-CRM-191
	Corn stalk	NIST-RM-8412	Rice flours	NIES-CRM-10A
	Wheat flour	ARC/CL-WF		NIES-CRM-10B
	Rye flour	IAEA-V-08		NIES-CRM-10C
				NIST-SRM-1568
			Wheat flour	NIST-SRM-1576a
			Wholemeal flour	BCR-CRM-189
Terrestrial plants	Cotton cellulose	IAEA-V-09	Citrus leaves	NIST-SRM-1572
	Hay powder	IAEA-V-10	Hay powder	BCR-CRM-129
	Kale	Bowen's kale	Olive leaves	BCR-CRM-062
			Pine needles	NIST-SRM-1575
			Rye grass	BCR-CRM-281
			Tea leaves	NIES-CRM-07
Other materials	Mixed diet	NIST-RM-8431a	Brewers' yeast	NIST-SRM-1569
	Potato powder	ARC/CL-PP	Single cell proteins	BCR-CRM-273
	Total diet	ARC/CL-TD		BCR-CRM-274

ARC: Agricultural Research Centre, Jokioinen, Finland.
BCR: Community Bureau of Reference, CEC, Brussels, Belgium.
Bowen: Dr H. J. M. Bowen, Dorset, United Kingdom.
CZIM: Nuclear Research Institute, Rez/Prague, Czechoslovakia.
EPA: US Environmental Protection Agency, Cincinnati, USA.
IAEA: International Atomic Energy Agency, Vienna, Austria.
NIES: National Institute for Environmental Studies, Ibaraki, Japan.
NIST: National Institute of Standards and Technology, Gaithersburg, USA.
NRCC: National Research Council Canada, Ottawa, Canada.

but also by the similarity in concentration of the major elements and the matrix. Wolf and Ihnat (1985) and Wolf (1989) made a very interesting estimate of similarity of 163 foodstuffs and 13 reference materials based on the concentrations of the elements Ca, Cu, Fe, K, Mg, Mn, Na and Zn. The statistical treatment of those data with the principal component method gives rise to seven groups of products (dairy, meat, bakery, vegetables, fruit, sugars and sweets, fats and oils), as can be seen in Fig. 1. RMs of single products (liver, oyster, single cell protein, etc.) are presented on the plot as single points. Mixed diets are located somewhere in the middle. A comparable chemometrics approach using principal component and graphical procedures has been used by Meglen (1990) to examine the multivariate suitability of current RMs in matching the concentration ranges and matrices of various food analyses. Such findings are very useful to consult when embarking on a new type of analysis and deciding on the best CRM match.

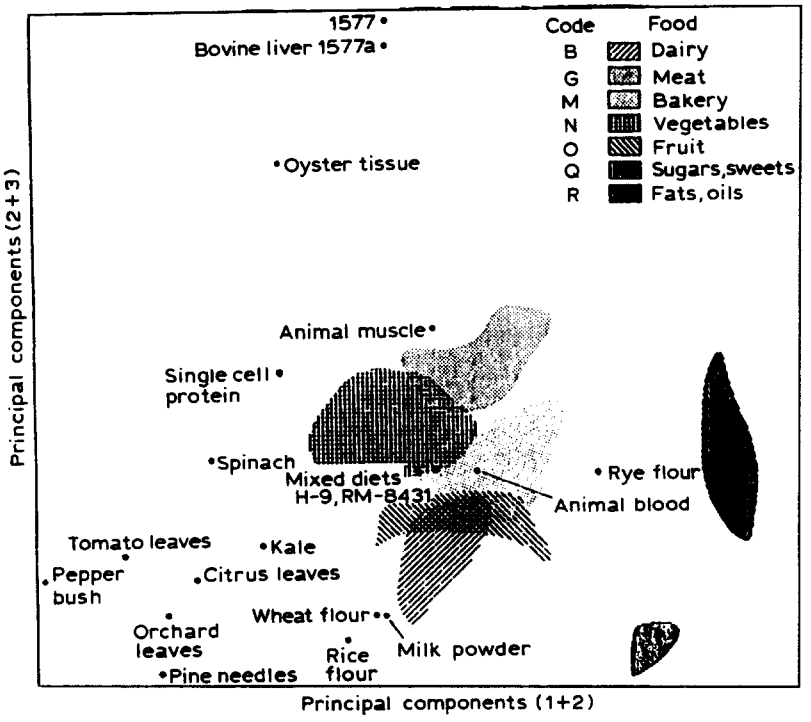

Fig. 1. Statistical treatment of 163 foodstuffs and 13 RMs by principal components using the inorganic elements Ca, Cu, Fe, K, Mg, Mn, Na and Zn (Wolf & Ihnat, 1985; Wolf, 1989).

It makes sense to confirm the accuracy of the analysis with two or three CRMs to bracket the actual sample, thereby confirming that the performance of the system was stable with time.

2 OBSERVATIONS ON THE USE OF REFERENCE MATERIALS

The important steps leading to the determination of concentration of the analyte encompass presampling, sampling, sample manipulation, analytical method development, measurement, calibration and evaluation. The latter also includes quality assurance and quality control of the overall process. Contamination control is a factor which shows up during all stages (Ihnat, 1988*a*).

The analysis of reference materials does not contribute to the accuracy of the presampling steps, neither does it help to verify the validity of the sampling and the representative character of the sample analyzed. There is some potential to control these first steps in so far that if the RM contains endogenous levels of an analyte, it may provide a mechanism to monitor, in some fashion, presampling factors as well. From the sampling manipulation onwards, the analysis of reference materials becomes meaningful.

CRMs are also very useful for the production and evaluation of other reference materials.

It would be inappropriate to use CRMs as 'blind' unknown check samples in quality control programs, since there are only a few CRMs within a given area of expertise, and they are thus easily recognized and may therefore not satisfy the intended purpose. Moreover, CRMs should never be used for both calibration purposes and as blind unknown check samples in the same measurement procedure (Steger, 1987).

2.1 Control of sample manipulation

Sample manipulation encompasses storage, weighing, decomposition, chemical separation of the analyte and control of the blank. The general idea is that if losses and/or additions are made during those steps, similar shortcomings will show up when handling the reference material. For these reasons, it is of paramount importance that the appropriate RM is chosen, i.e. a good matrix match (identical is best) and one that contains a concentration of the analyte similar to that of the sample to be analyzed and in the same chemical form.

Sample size of foodstuffs and CRMs

Virtually all foodstuffs and therefore food CRMs certified for trace element contents are heterogeneous, requiring a minimum weight to be taken to avoid sampling errors (for the CRMs it is specified on the certificate). Although mixed at the time of manufacture, the product may separate on standing owing to the great spread in grain size and thus should be thoroughly mixed before use.

Adjustment of the use of a RM according to its intrinsic inhomogeneity

CRMs are usually considered homogeneous for a certain sample size (usually a few hundred milligrams).

Some methods operate on a much reduced sample intake, in the milligram and submilligram range. Since the degree of inhomogeneity detectable in a CRM is dependent on the repeatability of the method of measurement, it is possible that a user, in applying a method capable of much smaller intakes with a comparable repeatability, could detect inhomogeneity in that CRM. This may be observed in the analytical data obtained by Kurfürst *et al.* (1984) and Kurfürst (1991) for Pb in bovine muscle sample BCR CRM 184. They applied automatic solid sampling analysis by electrothermal atomic absorption spectrometry on large series of replicates of powdered samples. The results showed that the distribution of Pb significantly deviates from normal; it is asymmetric and several maxima are even observed. Such a distribution is a consequence of a small fraction of calcareous particles, or nuggets, with a 300 times higher Pb content than that in the tissue. Figure 2 shows the histogram of 360 replicate Pb determinations in BCR CRM 184 Bovine Muscle. The mean of the subsample mass was 0·55 mg (range: 0·3–0·85 mg). The mean value (±s.d.) of the Pb content was 0·236 (±0·168) μg/g (n = 360), but calculation according to the nugget model using the Poisson distribution gave 0·233 (±0·130) μg/g, versus a certified value of 0·239 (±0·011) μg/g (mean ± 95% confidence interval).

The solid sampling method is heavily dependent on CRMs for its calibration. According to Kurfürst, only CRMs where the analyte is homogeneously distributed are useful.

Kurfürst (1991) calculated that the expected relative s.d. for a 200-mg sample of BCR CRM 184 Bovine Muscle, taking into account the nugget effect, is 2·9%. This is close to the overall s.d. given on the certificate, which accounts for the inherent inhomogeneity in the statistical parameters for the certified Pb content. Suppose, however, that a user applies a method with a better repeatability of measurement (e.g. ≤1%), on a 200-mg sample size. In such a case the user may also detect the inhomogeneity in that CRM. The scientific basis for using the particular CRM to give a true assessment of the user's method must then be questioned (Steger, 1987).

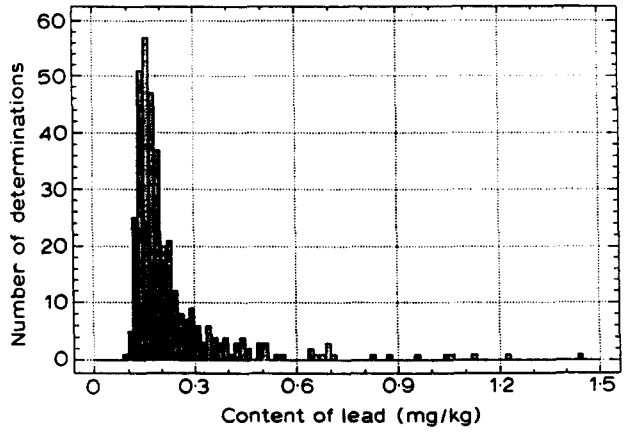

Fig. 2. Histogram of 360 replicate Pb determinations in BCR CRM 184 Bovine Muscle by solid sampling GFAAS on 0·55 mg subsample masses (Kurfürst, 1991).

Drying and moisture determination

Most, if not all existing nutrient reference materials with certified values for major and trace elements appear to be powders. The influence of the drying of a fresh product cannot be controlled by the analysis of a CRM.

The CRMs contain a small amount of residual moisture (≤10%), which is usually determined on an independent sample, at a temperature and a duration described by the manufacturer. Possible losses of volatile As, Se, Hg, etc. compounds and the risk of contamination necessitate the use of an independent sample for moisture determination.

Standardization of drying procedures of various foodstuffs exists up to a certain extent, but would benefit from a very precise protocol stipulating the exact geometry, temperature, duration, etc., of the drying conditions.

2.2 Control of sample treatment

Analysis of CRMs is useful in detecting many sources of error during decomposition, such as losses due to volatilization, e.g. in dry ashing and wet acid digestion, incomplete destruction of the matrix, recovery and analysis of insoluble residue, contamination from ashing aids and acids, contamination and losses of vessels, errors in dilution schemes and so on.

This may be illustrated by the attempt to analyze nitrogen in BCR CRM Single Cell Protein 273 by the aid of proton activation analysis via the nuclear reaction ^{14}N (p,n,) ^{14}O and measurement of the oxygen radioisotope (Vercoutere, 1989). The initial data yielded a mean value (±s.d.) of 110·13 (±2·93) mg/g N, about 10% lower than the certified value of 121·6 (±0·8) mg/g. This loss of nitrogen could be pinned down to volatilisation of part of the radioactive oxygen. Due to 'hot atom chemistry' the ^{14}O undergoes recoil out of the protein during the Szillard Chalmers process. It recombines with other atoms to form O_2 or perhaps CO_2, which escapes from the sample holder. This shortcoming was remedied by designing an airtight sample holder. The results then amounted to 119·06 (±1·31) mg/g, which agrees with the certificate value.

Chemical separations need to be verified for their yield, due to hazards of the procedure such as alteration of oxidation state, incomplete separation (e.g. extraction, elution, etc.), contamination from reagents, contamination and losses to vessels and possible contamination through the laboratory environment.

A recent example of the use of CRMs to verify the chemical yield of As determinations in biological

materials has been documented by Woittiez & Geusebroek (1990). They used radiochemical neutron activation analysis (RNAA), based on a hydride separation, to study the hydride generation atomic absorption spectrometry of As, which has proved to be very difficult especially below a level of about 30 ng/g. No blank value was detected with the RNAA method, because any contamination which may occur after irradiation will consist of natural, non-radioactive isotopes and so cannot be detected. The chemical yield was determined by spiking the irradiated samples with an As radioisotope, different from the one produced during neutron activation. Woittiez and Geusebroek observed that the recovery of As by hydride generation was never complete, nor reproducible. For As in the NIST SRM 1577a Bovine Liver, the overall yield was typically 98%, with large differences between individual determinations (range from 90·6 to 104·3% (n = 11)). This implies that each separation should be followed by a yield determination, which is not practical with hydride AAS measurements.

2.3 Control of measurement and calibration

Good measurements essentially rely on the selection of a proper technique, on instrument optimization, reliable performance characteristics, knowledge of possible physical and chemical interference, appropriate background correction, etc. (Ihnat, 1988*b*).

Calibration forms another crucial part of the analytical procedure. The use of CRMs for establishing calibration functions is applied in some laboratories and is a first prerequisite with some analytical techniques (X-ray analysis, solid sampling atomic absorption spectrometry). This mode of use should not generally be recommended, because it is expensive and the valuable stock of CRMs will be consumed too quickly. Additionally the uncertainties resulting from material inhomogeneity and measurement imprecisions and biases are greater than those of pure element or pure compound assays. Griepink (1990) rules out the use of CRMs as calibrants in trace analysis in all cases where the uncertainty in the certified values is considerably higher than the uncertainty of the analysis.

All analytical steps, from the weighing, through sample manipulation and measurement are collectively monitored by analysis of a CRM. CRMs provide traceability, i.e. the measurement is achieved by an unbroken chain of calibrants connecting the measurement process to fundamental units. The proper use of CRMs ensures both proper calibration and acceptable utilization of methodology.

2.4 Evaluation of the data

Data handling and interpretation of the results obtained for the CRMs have to be in accordance with the guidelines given on the certificate.

In simple terms, the concentrations obtained for the analyte of the CRM are acceptable when the value characterised by its 95% confidence interval, calculated from the standard deviation, number of analyses and Student's t-test, is consistent within the confidence interval of the CRM as given in the certificate. If there is disagreement it can be said that the analytical methodology is biased. Then steps have to be taken to identify and eliminate the sources of bias, though it may be impossible to eliminate all error or even to know if this has been achieved. It is also much easier to repeat a measurement in the same run than to reproduce it over a period of time.

Figure 3 shows the series of values which led to the certification of I in haypowder BCR-CRM-129. It also visualizes the criteria against which the individual analytical data will be tested (Cornelis *et al.*, 1990).

2.5 Quality assurance and quality control

The general principles of quality assurance and quality control of chemical measurements have been authoritatively described by Taylor (1985, 1987). Only a few details of these important issues can be discussed here.

Taylor (1987) offers the following definitions:

'Quality assurance': a system of activities whose purpose is to provide to the producer or user of a product or a service the assurance that it meets defined standards of quality with a stated level of confidence.

'Quality control': the overall system of activities whose purpose is to control the quality of a product or service so that it meets the needs of users. The aim is to provide quality that is satisfactory, adequate, dependable, and economic.

'Quality assessment': the overall system of activities whose purpose is to provide assurance that the overall quality control job is being done effectively. It involves a continuing evaluation of the products and of the performer of the production system.

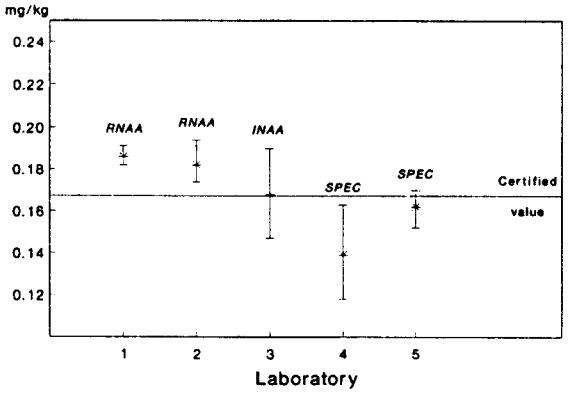

Fig. 3. Values and techniques used for the determination of iodine in hay powder BCR-CRM-129, certified for 0·167 (±0·024) mg/kg (Cornelis *et al.*, 1990).

Brown (1991) cites quality assurance and quality control as two distinct but related features of laboratory performance in a slightly different terminology:

'Quality assurance': refers to systems of external requirements placed upon laboratories by governmental agencies or private accreditation organisations. For analyses of trace elements in biological materials, these requirements may be regulatory in nature or voluntary, depending upon the matrix, the legal context and other factors.

'Quality control': refers to internal activities undertaken by laboratories to assure that their results are reliable. Quality control procedures may or may not be required by quality assurance systems.

CRMs and RMs play a key role in evaluating these qualifications (Elkins, 1985) and allow the control of laboratory performance. Good laboratories appear to have developed an analytical methodology ensuring quality assurance through years of experience. Other laboratories appear less well controlled. Table 2 shows the analytical data for Cd, Pb and Hg in the BCR Olive Leaves CRM 062, produced by four laboratories over a four-year interval. Laboratories A, B, and C are very well controlled, whereas D has to improve a lot (Marchandise, 1985).

Two very important operational terms to describe the quality of the data are *precision* and *accuracy*. Whereas *precision* describes the variability of the individual results of replicate measurements, *accuracy* denotes the closeness of a measured value to the true value. The actual error of the analysis result is usually unknown so that limits of error can only be inferred from the precision. Nearly all measurements will carry a certain degree of *bias*, i.e. the mean differs from the true or accepted value of the property measured due to some systematic error inherent in the method.

CRMs are very useful to control short-term and long-term repeatability, but this may also be done with internal RMs. The data can then be plotted sequentially in a SHEWHART control chart on which warning limits and action limits are defined. The results are considered to be out of control if: (1) the action line is exceeded; (2) the same warning line is exceeded twice in succession; (3) eleven successive measurements are on the same side of the line representing the mean value (Griepink, 1990).

Table 2. Concentrations of Cd, Pb and Hg in Olive Leaves BCR CRM 062, at three years' interval before the certification was issued (Marchandise, 1985)

Laboratory	Cd		Pb		Hg	
	1979	1982	1979	1982	1979	1982
A	0·106	0·106	25·2	25·7	0·250	0·334
B	0·114	0·118	25·5	26·9	0·289	0·254
C	0·161	0·114	29·4	27·4	0·288	0·296
D	2·17	0·12	63·0	5·3	0·306	0·830
Certified mean (±C.I.)	0·10 (±0·02)		25·0 (±1·5)		0·28 (±0·02)	

The terms accurate, inaccurate, precise and imprecise are relative to the end use of the data. A measurement process capable of reproducing the same value within 10% would be considered to be precise in ultra-trace analysis but very imprecise, in fact useless, for major constituent analysis. Likewise, a bias of 5% (relative) would be considered insignificant in the former case and unacceptable in the latter case (Taylor, 1987). The subjective nature of judgements may be illustrated with the results for Pb in the single cell protein SCP BCR CRM 274, certified for 44 (±10) ng/g (22·7%) for the mean ± 95% C.I. (Griepink, 1987). This relatively high C.I. was acceptable for such a difficult trace element as Pb at those low concentrations. The major element N, in the SCP BCR CRM 273, was certified for 121·6 (±0·8) mg/g (0·66%), a degree of precision needed for adequate use of N data (Griepink, 1985).

When a laboratory obtains a result which is close enough to that of the certified value, then accuracy and traceability are established. When there is disagreement, then the user of the CRM is warned about the bias. Needless to say it would be very unwise to apply a correction factor (Marchandise, 1985).

It is essential to harmonize measurements on a national and international level. Up to now, when intercomparisons have been made, the results invariably have shown differences larger than the tolerances allowed by the standard specifications. The use of CRMs may help to remedy this fundamental shortcoming.

3 FUTURE REQUIREMENTS

Wolf and Ihnat (1985) state that approximately 80% of 160 commonly consumed foodstuffs in the USA had no corresponding CRMs as far as inorganic composition is concerned. An extended choice of CRMs and a broader scope of certified elements would be most useful.

More attention is now focused on speciation, but because existing RMs are dried powders and the species were probably altered during drying and storage, it is unlikely that they will serve for this purpose. The production of RMs which contain endogenous species of the analytes may be most difficult and knowing that the analytical methodology to define and quantify the species is still in its infancy, it may be a long time before uniformity is achieved in the type of species which will be identified and quantified.

REFERENCES

BCR reference materials (Community Bureau of Reference) (1990). Commission of the European Communities, Directorate General for Science, Research and Development, B-1049 Brussels.

Brown, S. S. (1991). Quality assurance: achievements, problems, prospects. In *Trace Elements in Health and Disease*, ed. A. Aitio, A. Aro, J. Järvisalo & H. Vainio. The Royal Society of Chemistry, Cambridge.

Cornelis, R., Dyg, S., Griepink, B. & Dams, R. (1990). Participation in BCR-certifications by the laboratory of Analytical Chemistry, Institute for Nuclear Sciences, University of Gent, Belgium, *Fres. J. Anal. Chem.*, **338**, 414–18.

Elkins, E. R. (1985). Quality assurance and check sample program in the food industry. In *Biological reference materials: availability, uses, and need for validation of nutrient measurement*, ed. W. R. Wolf. John Wiley & Sons, New York, Chichester, Brisbane, Toronto, Singapore, pp. 229–37.

Griepink, B. (1985). *BCR information: The certification of the contents (mass fractions) of calcium, potassium, iron, phosphorus and nitrogen in a single cell protein (CRM 273).* EUR 10365 EN, CEC, Brussels, Luxembourg.

Griepink, B. (1987). *BCR information: The certification of the contents (mass fractions) of arsenic, cadmium, copper, cobalt, manganese, lead, selenium and zinc in a single cell protein (CRM 274).* EUR 11001 EN, CEC, Brussels, Luxembourg.

Griepink, B. (1990). The role of CRMs in measurement systems, *Fres. J. Anal. Chem.*, **338**, 360–2.

Ihnat, M. (1988*a*). Pick a number—Analytical data reliability and biological reference materials. *Sci. Tot. Environm.*, **71**, 85–103.

Ihnat, M. (1988*b*). Biological reference materials for quality control. In *Quantitative Trace Analysis of Biological Materials*, ed. H. A. McKenzie & L. E. Smythe. Elsevier, Amsterdam, New York, Oxford, pp. 331–51.

ISO Guide 30 (1981) (revision Dec. 1990 ISO/REMCO N 212). *Terms and definitions used in connection with reference materials.* UDC 53.089.68: 001.4. International Organization for Standardization, Geneva.

Kurfürst, U., Grobecker, H. H. & Stoeppler, M. (1984). Homogeneity studies in biological reference and control materials with solid sampling and direct Zeeman-AAS. In *Trace Element Analytical Chemistry in Medicine and Biology*, Vol. 3, ed. P. Brätter & P. Schramel. Walter de Gruyter, Berlin, New York, pp. 591–601.

Kurfürst, U. (1991). Statistical treatment of ETA-AAS solid sampling data of heterogeneous samples. *Pure Appl. Chem.*, **63**, 1205–11.

Marchandise, H. (1985). *New reference materials. Improvement of methods of measurements.* Commission of the European Communities, Community Bureau of Reference, EUR 9921 EN, Luxembourg.

McKenzie, H. A. and Smythe, L. E. (eds) (1988). Part 7. Reference materials, sample preparation and individual sample types. In *Quantitative Trace Analysis of Biological Materials.* Elsevier, Amsterdam, New York, Oxford, pp. 329–418.

Meglen, R. R. (1990). Analytical problem-solving, reference materials, and multivariate quality control: a chemometrics approach. *Fres. J. Anal. Chem.*, **338**, 363–7.

NIST (National Institute of Standards and Technology) (1990). *Standard Reference Material Catalog.* NIST Special Publication 260, US Department of Commerce, US Government Printing Office, Washington.

Steger, H. F. (1987). *'Proper use' and 'mis-use' of CRMs.* ISO/REMCO 159.

Taylor, J. K. (1985). *Standard reference materials: handbook for SRM users.* NBS Special Publication 260-100, US Government Printing Office, Washington.

Taylor, J. K. (1987). *Quality Assurance of Chemical Measurements.* Lewis Publishers Inc., Michigan.

Toro, E. C., Parr, R. M. & Clements, S. A. (1990). *Biological and environmental reference materials for trace elements, nuclides and organic microcontaminants, A survey.* International Atomic Energy Agency, IAEA/128 (Rev. 1), Vienna.

Vercoutere, K. (1989). *Analysis and evaluation of the 'Single Cell Protein' as a certified reference material for major and trace elements.* Doctoral Thesis, University of Gent, Belgium.

Versieck, J. (1984). Trace element analysis—a plea for accuracy. *Trace Elements in Med.*, **1**, 2–12.

Woittiez, J. R. W. & Geusebroek, M. (1990). Aspects of accuracy and precision in the determination of As and Sb in biological materials by neutron activation analysis. *Biol. Trace Element Res.*, **26**, **27**, 561–9.

Wolf, W. R. (1985). *Biological reference materials: availability, uses, and need for validation of nutrient measurement.* John Wiley & Sons, New York, Chichester, Brisbane, Toronto, Singapore.

Wolf, W. R. (1989). Personal communication.

Wolf, W. R. & Ihnat, M. (1985). Evaluation of available certified biological reference materials for inorganic nutrient analysis. In *Biological reference materials: availability, uses, and need for validation of nutrient measurement*, ed. W. R. Wolf. John Wiley & Sons, New York, Chichester, Brisbane, Toronto, Singapore, pp. 89–105.