

CHAPTER 2 QUALITY ASSURANCE AND QUALITY CONTROL IN RESEARCH DEVELOPMENT

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ABSTRACT

It is now internationally recognised that for any laboratory to produce reliable data it must implement an appropriate programme of quality assurance procedures. It must, as a minimum

- a. ensure it is using methods which have been validated as fit for the purpose before use by the laboratory. These methods should be fully documented, staff should be trained and control mechanisms should be present to ensure that the procedures are under statistical control
- b. ensure that it has implemented appropriate internal quality control measures ensure that the data produced and reported are of known quality and uncertainty
- c. participate in proficiency testing schemes.

There is ample literature available on the principles and requirements of quality control, quality assurance and associated aspects of certification, accreditation, proficiency testing and statistics and chemometry. This paper supports a course on the implementation of quality assurance and the development of quality systems in everyday practice : How to do it, the pitfalls and what can make all good intentions fail in practice.

Examples and suggestions are given which come from the author's experience and it is important to keep in mind that the suggestions are by no means a panacea : as will be frequently emphasized in the course, 'copying' someone else's ideas often leads to disasters since only the lay-out is copied and a top-down advise will be experienced in a negative way at the laboratory, whereas it in fact requires a development bottom-up for maximum consensus.

1 INTRODUCTION

The impact of chemical measurements to the quality of life, the environment and the economy may be large. Laboratories, even the ones which consider themselves as ‘highly experienced’ should be aware that results of analysis do not reflect realistically the correct levels. Analytical laboratories are dealing with

The quest for lower and lower concentration levels. This is partly stimulated by the development of methods of analysis and more sophisticated equipment capable of reaching very low (interference free) detection limits. However, at such levels new and unknown sources of error may occur, e.g., due to contamination or loss of measurand, matrix interferences and spectral interferences.

New types of samples may involve new and unknown sources of error in sampling, sample processing and matrix interferences in the analysis itself.

More sophisticated equipment is available but fewer people are really knowledgeable about the physico/chemical principles of the method itself and the mathematics in the calculation of the data. As a result, the equipment is almost operated as a ‘black box’.

The use of smaller test portions (like for laser ablation ICP-MS and solid state AAS) may result in higher contamination risk and problems of representativeness.

Assessment, monitoring, accounting for and preferably elimination of sources of error can be attained by implementing quality assurance and management. Bottom-up implementation is a must to develop the required awareness to the different attitude and culture that is nowadays expected by customers. Thus, a laboratory may prepare itself for the task of full documentation of all its quality assurance activities into a quality manual, thus complying with the new order for chemical analysis to make data internationally acceptable by comparability. And here is another potential source of errors: *the wrong interpretation of quality control and quality assurance concepts.*

Analytical laboratories are therefore confronted with an increasing pressure to give objective evidence of their technical competence and of the reliability of results and performance and to seek formal certification or accreditation. This pressure may be evoked by the laboratory’s customers (e.g., industry, but also national bodies) but may also result from scientific considerations, e.g., when striving to operate as a national reference laboratory for metrology in chemical measurements. Method validation, uncertainty evaluation, use of primary standards and certified reference materials, participation in laboratory intercomparison rounds and proficiency testing all serve to control and to demonstrate the quality of the measurement results. Compared to e.g. 30 years ago we now have available more stable equipment, computers and access to more reference materials for method validation and calibration. Numerous papers have been published on sources of error, and on quality control and quality assurance practices. To accomplish mutual (international) acceptance of such evidence several protocols have been developed for quality assurance activities. The most widely recognized and used in chemical measurements and testing fall in three groups and are applied according to a laboratory’s needs. The groups are (i) the ISO-Guide 9000:2000, (ii) the ISO/IEC 17025:1999 and (iii) the OECD Guidelines for Good Laboratory Practice and its national and sectoral equivalents.

To comply with such requirements, the laboratory has to develop itself a quality system describing its quality assurance activities and the management thereof. Top-management may translate this into the need for a project resulting in a ‘quality manual’ and ‘accreditation’. One of the common mistakes is that the project leader starts with writing a quality manual, derived from the lists of requirements in the protocols mentioned in the above or from related guidance documents [1,2] in an attempt not to spend too much time and to continue laboratories’ normal activities. The laboratories’

employees are suddenly overwhelmed with this manual, new vocabulary, a new organizational and managerial structure, with a long list of (or demands for) standard operating procedures and requests for bookkeeping and other paperwork. Irritation and frustration will develop faster than the quality system.

Many laboratory managers and their superiors realize insufficiently that a quality system may only be self-sustainable and cost-effective when all employees bottom-up support it. Since a quality system and its management often imply a drastic change of the everyday culture at the laboratory and attitude to work, sufficient time is needed for awareness building. Time, patience and lots of tact are required to guide a process in which traditions have to be left which were built-up over many years, in which people have to understand that cross-checking is not a matter of mistrust but a need to prevent repetition of work. The employees need time to experience the benefits of full trackability, and to decide on harmonization of operations. And they need time to become aware that there may be also internal considerations to improve the laboratory's performance, e.g., because of the current high degree of repetition of work. Development of a quality system is initially a slow process: awareness building easily may require many months. A quality culture has to develop. A realistic plan for implementation has to be made; a plan that can count on everyone's support and commitment. The final goal, e.g. formal recognition of the quality system by certification or accreditation, should be seen as the end-point of this project.

The real objective of the entire operation is still to improve the reliability of the analytical and managerial performance of the laboratory and to be able to give objective evidence on this. The international protocols provide guidance in this. If it all has been accomplished, the quality system may be summarized and described in a quality manual.

So, the first questions and tasks to start with should be:

“What is known about

- the reliability, trackability and traceability of our results
- what are our sources of error
- how can we monitor them and
- how can we take them into account or ultimately eliminate them and

and how can improvement be attained?”

Once these questions have been answered and the underlying matter is understood, quality control measures can be taken and quality assurance may be designed-in in the laboratory's activities. Unfortunately, the terms ‘quality control’ and ‘quality assurance’ are frequently not correctly interpreted, and even abused. As an example, it sometimes occurs that the analysis of a sample of a reference material is considered to be the laboratory's ‘quality assurance’.¹

¹ Both terms are well defined in the document ISO 8402 (1994) ‘Quality Vocabulary’ [3] :

- *Quality Control* : The operational techniques and activities that are used to fulfill requirements of quality. Quality control procedures (see also [4]) relate to ensuring the quality of specific samples or batches of samples and include : Analysis of reference materials, blind samples, blanks, spiked samples, duplicates and other control samples.
- *Quality Assurance* : All those planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality. Quality assurance describes the overall measures that a laboratory uses to ensure the quality of its operations. Typical items are e.g.: Quality control, suitable equipment, trained and skilled staff, documented and validated methods, requirements to calibration, standards and reference materials, traceability, proficiency testing, non-conformance management, internal audits, statistical analysis.
- The quality assurance activities should be embedded in a managerial quality system.

Quality assurance on its own is not sufficient to ensure the proper and efficient operation of an analytical laboratory, nor is a documented quality system. What is needed is a different attitude to work: a quality culture has to be developed.

2 THE QUALITY CULTURE

Each laboratory has its own culture. This culture is the set of written and unwritten rules, it is what the laboratory expects from its employees and which behavior it encourages. Developing a quality system with underlying documentation may change the written rules. It is much more difficult to change also the unwritten rules and to create a quality culture.

Why is so difficult to adapt the lifestyle of a quality culture? One of the reasons might be that the impact of poor chemical analysis is less tangible and dramatic than, e.g., poor clinical analysis that may be of immediate effect to human life and health. Certainly, there are many examples of the importance of good chemical analysis. However, many laboratories are dealing with customers that do not want a statement of uncertainty in their reports, or openly admit to be interested only in gross trends of values rather than their accuracy. The customers do not stimulate these laboratories to attain a higher degree of accuracy and better comparability of their results. In the quality systems of these field laboratories non-conformances affecting throughput will get a higher priority to be solved than non-conformances affecting the degree of accuracy.

A more general reason is that the awareness building on this different attitude to work has not been done properly and in fact has been underestimated. And managers anticipate insufficiently that it will take a lot of time before people are willing to leave their traditional style of working.

The difficulty with implementing quality assurance principles is that the traditional style of working, built-up over many years has largely to be left. It may be compared with implantation of an artificial object in a human body. There is always the risk of rejection; the same with the quality system: it is a strange and threatening object in a safe environment. Whenever a new idea or style of working is suggested, the process of rejection is initiated. Initially, employees fear the quality system since they are afraid to lose their current status and control. Often they face only a call upon compliance, more responsibilities and consequences of the quality assurance rather than that an outlook is given to the benefits and to authorization and powers that should be linked to these responsibilities. The quality system is then considered as a nuisance rather than as a management tool for better efficiency and effectiveness of work. Consequently, the laboratory will minimize its compliance with the requirements and postpone the introduction of measures that face resistance.

Development of a quality culture starts with the assessment of the driving forces. There may be external considerations such as

- The request from customers. These may be clients of commercial services, but also funding organizations like national science foundations.
- Demonstration of analytical quality (accuracy, uncertainty, traceability) in international collaborations.
- Legal and regulatory considerations. The licence of the organization –and perhaps the positions of the employees- may be at stake if the laboratory does not comply with the international quality assurance standards.

However, much more important is to assess if there are internal driving forces, resulting from existing deficiencies. Examples of such internal considerations are:

- Reduction of repetition of work
- Reduction of miscommunication
- Improvement of the trackability of operations
- Improvement of planning of work
- Objective evidence on the quality of work
- To support the change from a monopoly position to market oriented activities
- To differentiate from competitors

Internal driving forces are much more powerful than the external ones since they stem from day-to-day deficiencies and irritations. Too much internal focus is also not good because there is a profound risk that the laboratory will spend a lot of time to improve on something that is of little or no value to its customers. The project leader has to guide the process of identifying the current deficiencies in the laboratory. It is not a matter of just making an inventory of the problems; the main task is to challenge the employees to suggest ways to improvement. In the beginning mainly technical problems will be listed but the employees should also be challenged to discuss organizational problems. Examples are the existence of single points-of-failure, disharmony in organization of work, filing etc., insufficient and incomplete documentation, appearance of laboratories and offices.

3 GETTING STARTED

Changing an attitude to work does not start with what sometimes is proposed such as “quality circles”, “motivation”, “declarations from the top” and so on [4]. It starts by demonstrating that a small ‘quality change’ has a positive impact on people’s daily life at the laboratory. Simple improvements can be introduced without the need of already drafting standard operating procedures:

Sources of error. A list should be made of all potential sources of error, all that might affect the final result in ,e.g., sampling, sample preparation, calibration, instrumentation, analysis and interpretation. Not just the cases which have happened before, but also those which may occur from a fundamental chemical or physical point-of-view. This requires input of all experienced and knowledgeable employees. The list should be completed with

- Checkpoints / opportunities for monitoring these sources of error on their possible occurrence (e.g., via the use of control samples and blanks with every run). As an example, a user lists with balances e.g. is a pro-active quality assurance to alert people on potential contamination due to previous usage.
- Critical variables (e.g., temperature, humidity, spectrometer resolution). Here, control charts can be rather useful for inspection of trends.

Fitness for the purpose. In many laboratories some fitness test before the use of equipment (spectrometers, balances, pipettes) already occurs. However, because of absence of a full insight into sources of error and critical variables, not always the correct parameters are assessed. Equally so, the frequency of such tests may be reconsidered as their evaluation. Sometimes it is necessary to check or calibrate equipment and tools before every individual use, as with, e.g., pipettes.

Assessment of the quality of chemicals, reagents, stock solutions and control samples also contributes to an elimination of sources of error. It may be combined with a thorough check of the quality of chemicals, reagents and standards, including the self-made solutions. Often it has to be acknowledged that the quality is doubtful because of absence of trackability of purity, procurement, storage and use in the past and/or since

expiration dates have long been passed. If control charts have been maintained, some standards may still be usable for day-to-day monitoring but have to be considered invalid for method validation. Purity and stoichiometry are important and have to be demonstrable; stock solutions may have a different concentration due to evaporation or precipitation; sometimes the uncertainty is not listed on the label or the raw data on the preparation are not available. All solutions and control samples should carry an expiration date. Chemicals for reagents and calibration should be stored separately, if possible.

Record keeping of the use of equipment, chemicals, control samples etc. contributes to the tracking of, e.g., -unintentional- wrong uses thereof and/or sources of cross-contamination. Forms can be introduced for many aspects of work, from sample receipt to registration of settings of equipment.

Laboratory organization. (i) Use of an unambiguous coding system for samples, files, documents. The coding system should be set-up in such a way that no two samples or files will carry the same code, and it should be transparent to everyone in the laboratory. Related to this is the need for sample and sub-sample custody.

(ii) Centralized storage of all documentation, manuals, registers, certificates, schemes. Also considering the ordering of all samples and remainders thereof in one place. It all contributes to a reduction of confusion 'where to find things' and opportunities to take over each others work when needed. This can also be the onset for a smarter system of centralized storage of all related information rather than to have it scattered over many laboratory journals and logbooks, and in personal archives or filing systems.

(iii) Independent control of self-made calculations. Such an extra check may rapidly be explained as a mistrust on a persons' capabilities. Still, a few minutes may prevent many hours/weeks/months of bad performance. As an example, not so many people are able to judge, by looking at the results and raw data only, if a standard deviation has correctly been calculated. Related to this is an independent check of transposed data, e.g., when reporting on customer's sheets.

(iv) Participation in laboratory intercomparisons. It will contribute to the laboratory's own assessment of potential sources of error in day-to-day routine operations if these samples can be processed as 'blind' samples rather than that extra care is given to them.

All of these activities do not require much preparation, complicated actions or much debate. Sometimes a laboratory may be surprised to see how many QC/QA items are already operational though they may not have been recognized as such [4]. Relatively little paperwork is involved; there is no need (yet) to draft standard operating procedures. It will result in an improved reliability of results and a first big improvement on the trackability of it all. Employees may become more motivated by the actions undertaken since the majority of the actions is directly applicable to the analytical task and the problems they perhaps may have been facing for quite a while. It is the onset of a systematic inspection of sources of errors, to account them for when the final result is evaluated and to develop actions to eliminate them, eventually. It may contribute to deeper awareness building, required for the further quality assurance and management activities that can subsequently be implemented. A general clean-up of the premises also contributes to the perception that a new lifestyle has started.

Care should be taken not to overload employees with too much motivation. There are too many banners and slogans like 'meeting the customers needs' in daily life, banks, stores and restaurants. People have learnt to distrust them.

The project leader has to challenge the people to suggest ways to improvement, simply because there are more employees than managers. If only the managers are supposed to think about how to improve work, then only a small fraction of the

organization's brainpower is being utilized. It is time to start delegating tasks. Many employees feel disempowered because they are not given the authority for implementation. True leadership shows if, when the work is done, the people will say, "... We have done it ourselves!...".

4 FURTHER STEPS

When awareness on the principles of quality assurance grows and is accepted -both technically and emotionally- more 'sophisticated' measures can be considered. Still, a lot of tact is required from the person who coordinates all activities. It should be made clear to everyone that nobody is blamed or condemned on his old style of working but that new requirements have developed outside the laboratory which imply this different attitude.

It will become clear that the various quality assurance activities are related to one another, and that the laboratories' way of operation, the communications between people and the decisions to be made at checkpoints need to be attuned. Often, this is referred to as 'quality ' management and at this point the laboratory may have reached a level of awareness in which formal documentation is not perceived anymore as 'bureaucracy'. It is strongly recommended to inspect now the related chapters of the relevant international standards to achieve in an early stage compliance with these requirements.

Some of the quality assurance/quality management principles now to be implemented are (in random order and certainly not complete):

Quantification of criteria. Quantified criteria are needed to pass a checkpoint. It is not an easy task to quantify the common 'knowing' or 'feeling' that a result is 'good' (or not), but it should be done to make decisions reproducible, trackable and unambiguous. In defining criteria the laboratory should be well aware of its mission and the consequences to its operationally if its own criteria cannot be fulfilled. It may sometimes happen that a laboratory has to weaken its criteria, thereby perhaps sacrificing some accuracy and uncertainty in turn for continuity in operations. Quantification of criteria (and documentation thereof, see below) contributes to a preservation of the laboratories' expertise and can be of great value in the training of future employees.

Control charts. Once criteria have been established, graphical control charts can be developed as a powerful tool for monitoring trends and finding sources of error [5,6]. In many laboratories variables are just registered in endless lists in log-books whereas simply plotting them may reveal unanticipated information.

Traceability. Another reason for non-comparability of analytical results is due the fact that the link between measurement and the SI units is incomplete by lacking, insufficient or incompetent calibrations. For each step also the uncertainty must be evaluated. In chemical measurements the traceability chain can be broken each time a sample is physically or chemically modified. Various suggestions (e.g. [7]) have been given to establish traceability in chemical measurements.

Validation of methods. Method Validation [8] is an essential part of good laboratory practice and is a requirement of ISO/IEC 17025 for in-house methods. Because most tests are not standard methods, the lab should demonstrate that the method is "fit for purpose" before introducing the test in routine. "Fit for purpose" means, that the method meets requirements of the client or generally accepted criteria at an international level (e.g. the levels of the minimum detectable amount).

From this external viewpoint, the most important parameter are:

- Repeatability

- Within-laboratory reproducibility
- Laboratory bias / accuracy
- Between laboratory reproducibility

Other, less statistical criteria are:

- selectivity and specificity
- decision limit, detection limit, quantitation limit, rate of non-detection, rate of false detection
- background, blank and cross-contamination
- matrix effects

Evaluation of the uncertainty budget. Incomparability and therefore no mutual acceptance of data results also from non-harmonized reporting of the uncertainty of data. Quite frequently one can observe the number behind the “±” sign represents the repeatability of the measurement rather than that the uncertainty on basis of the contributions of every individual step or component in the analysis. To improve this situation a discussion has been started on reporting the uncertainty in measurement based on concepts, differently from what has been traditional in many laboratories for a long time. This has resulted in a new guidance document [9]. It is worthwhile to study this new concept and, since international acceptance and harmonization on this concept may soon be expected, to apply it in the operations. It contributes to an insight which components have the highest contribution to the overall uncertainty and may therefore require extra inspection, or may perhaps be improved by ,e.g., better equipment.

Harmonization and development of standard operating procedures. Many laboratory managers experience difficulties with their employees on this issue. Often each of the employees has developed his own way to carry out a given task. But when there are several employees, there may be a manifold of potential mistakes and it will be a waste of time and money to develop procedures for each of them, including their checkpoints and criteria. It emphasizes the need for harmonize procedures for as many as possible operations within the laboratory. Consensus on the harmonization may be accomplished by having the procedures drafted by the employees who carry-out the work; staff may later inspect them if the sequence of actions is logical and if the checkpoints and criteria are sufficient.

Authorization of reports. Gross errors in reportings to interlaboratory intercomparisons indicate that in some laboratories results are apparently released without final cross-checks. If this occurs in intercomparisons -which, typically, are often carried-out with extra care and attention- it may indicate that a worrying situation might occur with day-to-day routine analyses. Extra checks and formal authorization will contribute to a higher level of reliability and the laboratory’s credibility with its customers.

5 NON-CONFORMANCES

Of course, a quality culture does not imply that a laboratory or its employees will not make mistakes. Each and every person within the laboratory constantly strives to give the best possible service at every moment, and when a problem occurs or an error is made, they will correct it as quickly as possible. This requires non-conformance management.

The employees have to learn to register things that go differently from the expected, peculiar observations, malfunctioning of equipment, forced and unforced deviations from normal working and so on. This has to be followed by a systematic and documented cause analysis, ultimately resulting in corrective or even pro-active actions

to prevent the measurement result being affected again. Suggestions for these actions should come in the first place from the people involved. If non-conformance management and cause analysis is introduced at an early stage of implementing the quality system, there is a high probability that it will become an active tool for further improvement.

However, this requires that the project leader should create an atmosphere in which the question ‘Who did it?’ is replaced by ‘What can we do to prevent it happening again?’. Admitting that a mistake has been made is a big cultural and social change for almost everyone, from the work-floor to the top-management. It is important to generate an understanding that cross-checking each other’s work is not a matter of mistrust but a tool to discover mistakes timely so that repetition of work can be prevented. This is one of the most important steps in the introduction of the quality culture. The project leader should refrain from too much top-down pressure but at the same time demonstrate understanding and commitment to the requirements of the international standard.

Eventually, if the quality culture develops, the non-conformance registrations should be periodically reviewed and categorized so that a “Pareto” analysis can be carried out [10]. On basis of the observations, management goals for the next period can be established, like reduction by 20 % of non-conformances in a given category.

6 SELF-SUSTAINABILITY

The success of the quality assurance activities may become somehow tangible, e.g., by less repetition of (parts of the) analyses, trackability of operations and/or reduction of miscommunications. Benefits of the newly introduced quality management on, e.g., equipment and reporting may be one of the driving forces to further re-organization, extension and implementation of other types of quality management, such as training of personnel, qualifications and authorizations; non-conformance management; appointment and training of a quality manager.

By now the laboratory develops itself a level of self-sustainability with respect to its quality system and quality culture. The quality manager may start to compile all relevant documentation, and to write the quality manual. Even more advanced aspects of quality management may be considered to be beneficial, such as a management review, internal improvement targets and quality indicators and external inspection or auditing.

7 COSTS

A system for quality assurance and its management does not require resources during its development only. It is often underestimated or even overlooked by laboratory managers that, once operational, maintenance of a quality system and further development will require continuous expenses and request for human resources, such as (i) a higher consumption of control samples and reference materials, (ii) fees for intercomparisons and proficiency testing, (iii) the need for externally conducted (re)calibration of reference standards, balances etc. and (iv) time for preventive tests and checks; for corrective actions and for internal audits and maintenance of documentation

The benefits of the quality system are often less tangible in terms of ‘in-pocket money’. However, the laboratory may experience that fewer parts of the work have to be repeated and that less time is needed to find documentation and to ‘reconstruct’ an analysis when something afterwards is suspected to be wrong. And since its reliability can now be demonstrated, it may find more opportunities for externally funded research and analyses.

8 ACCREDITATION; OR NOT ?

In a contractual situation it becomes rather impractical when the customer has to inspect personally the laboratory's "objective evidence" on the quality of the results. In many cases the customer does not have the technical and scientific ability to do so. Here lies the difficulty in (international) mutual acceptance and trustworthiness of laboratories. Laboratory accreditation is one of the internationally accepted keys to take away this mistrust [11]. National accreditation bodies have been formed which verify the technical competence of a laboratory to carry out specific tests and which verify if the laboratory's quality system is in compliance with the ISO/IEC 17025.

Laboratory accreditation may involve relatively high costs, not just for the first audit but also, once accredited, for the annual inspection audits and the (every 3-4 years) audit resulting in continuation of the accreditation. The question therefore may be raised if these costs are justifiable and if accreditation is really necessary. However, it is very well possible that the customers demand that the laboratory demonstrates its technical competence by formal accreditation; or perhaps the customers foresee that international developments as in trade mean that such a demand will become inevitable.

Accredited laboratories have found that formal accreditation appears to be a stimulus for the employees since it increases the status and respect of the laboratory; employees are proud of 'their' quality system. The annual inspection audit by the accreditation body sometimes serves as a 'guard-dog' when facing declining discipline with commitment to the quality system.

9 QUALITY MANAGEMENT IN NON-ROUTINE ACTIVITIES: RESEARCH AND DEVELOPMENT

Research and development is carried out in almost every laboratory, even if routine services are the main activity. In-house developed methods or changes in equipment configuration are typical examples thereof. Many components of a quality system for routine operations may suit research and development as well. However, it has often been noticed that in academic and research establishments some skepticism exists about the value of quality management for scientific goals. It is feared that a too formal quality management approach would restrict scientific freedom and progress, and would increase bureaucracy. Some scientists interpret their academic freedom as freedom to non-commitment, which may have far-reaching negative consequences for trackability and assurance of the other operations in the laboratory. It was previously mentioned in this paper that their solution consists of two styles of working, viz. one according to the quality system for routine work, and one with less rules and regulations for research work. But the same equipment, reagents, laboratory tools etc. are then being used in both styles of working, making trackability of operations almost impossible and as such the cause analysis of non-conformances. Such an approach is detrimental to the development of the quality culture and thus for sustainable improvement of the analytical performance.

Research and development activities are built upon a laboratory's infrastructure. This infrastructure comprises the premises, workbenches, equipment, laboratory tools, chemicals and reagents, etc. Most of the components of this infrastructure are operated and/or managed by standard operating procedures. As an example, fitness tests of equipment, chemicals, reagents should be done irrespective of a routine or a research application. Registration of the use of equipment and tools is equally important and does not do any harm to the conduct of research. Labelling of bottles, but also files and samples as well as registration of observations should be done in the same way for all

applications. New researchers should also be trained in the proper use of the laboratory's infrastructure. Proper planning is often neglected but of increasing importance with the growing number of projects externally funded, and the requested pre-defined milestones and deliverables. The main difference between research and routine is that often the protocols can not exactly be defined in advance, for instance because the protocol itself is subject of research, or because the response of equipment under different settings is being studied.

The EURACHEM guide [12] offers guidelines for quality assurance of such activities, based upon the principles of project management. In short, it is recommended to draft an action plan with details on the requirements regarding time, equipment, materials, human resources etc.

Quality management of research and development activities is not complicated and maybe even easier to accomplish than quality management of routine activities. The biggest effort lies, as may be expected, again in changing the attitude of the employees. It stresses the need for creating a quality culture amongst all employees and to obtain top-down support for this.

It is remarkable and in fact even unacceptable that, in general, universities are so reluctant to introduce quality assurance management in the education of students at (chemical) laboratories and in e.g. M.Sc. and Ph.D. research programs. This hampers the future generation to get practical education in thinking and working in a quality culture, whereas the gap widens between the practice at the universities on one hand and the chemical laboratories in trade, industry and with those active in metrology networks on the other hand. This situation may be threatening for sustainable growth in metrology in chemical measurement. However, it is encouraging to see that in some countries (e.g., Australia, Brazil, Germany) quality assurance and basic principles of metrology are nowadays (again) introduced in the curriculum of the chemical faculties at universities.

10 PLANNING

Planning is difficult in non-routine analysis and scientific research. In the past, insufficient planning caused problems such as repetition of analysis because of incomplete specifications and, consequently, exceeding deadlines.

Now all analyses, both for routine and research activities require an analysis plan with details on the requirements with regard to time, equipment, materials, human resources etc. The plan specifies:

- Analysis organization : who will carry-out the analysis, the supervisor; requirements in additional training of (supporting) personnel
- Codes of the analysis and the samples. This includes also requirements for the identification of samples if supplied by external customers.
- Specification of the analysis : date, method, deadline, accuracy, precision, equipment, facilities needed, analysis protocol to be selected
- Additional materials : reagents, standards, reference materials, amount of analytical portion, etc. The plan should have an indication on availability, procurement term, costs.
- Specification of the samples : sub-sampling and preparation of the test portion, storage conditions, information on receipt and remainders of samples
- Analysis methodology. Identification if the method is applied frequently or incidentally

Planning schedules are in place for the use of the equipment and irradiation facilities, and for human resources. The planning schedules cover a 6 month period.

Planning of human resources is needed to assure not only that the analysis will be done on time but also to ensure that qualified persons are available when reports have to be authorized.

Similarly, detailed plans are made for the research projects. These plans include not only a description of the hypotheses to be tested, but also

- Requirements regarding equipment, consumables, human resources (assistance) with a timeframe using a Gantt-chart
- Documentation and registrations to be maintained
- Requirements in internal training (see above) and external training
- Progress report schedule, milestones, decision points, go/no-go criteria
- Scientific publications, contributions to conferences
- (Scheme of) expenses and overall coverage

The practical aspects of planning in research and development are specifically addressed in the EURACHEM guide. Detailed planning does not violate scientific creativity or opportunities to deviate from the original pathway. If the need for a deviation may arise, the reason for the change and the consequences of the new path are all documented, and the new planning is formally approved before re-start. In relevant cases it is specified in the plan if also approval of external partners is required.

The clear advantage of this extensive planning is that support, equipment and tools will be available when needed, and that there is no misunderstanding about the goals and expectations of the research. It contributes to a better professional image.

11 PITFALLS IN DEVELOPING A QUALITY SYSTEM

Drafting a quality manual and subsequently seeking bottom-up support for implementing all required measures is one reason why realization of a quality system may take longer than desired, or even may fail. But when following another approach, it is important to be aware of additional problems that may jeopardize the entire operation :

Wrong motivations. When a laboratory has not identified its own deficiencies, its own motive to change and to improve the style of working, a situation may easily develop in which the reason for all changes is considered to be only “because the outside world says so...”. The program for quality assurance and its management will not be supported whole-heartedly by the employees.

No support from the top. Development of a system for quality assurance, and eventually, a quality system fit for accreditation requires time, and additional resources. Typically, approximately an average 15 % of a persons time may be required in the development stage (e.g., 2 years [13]). The laboratory is facing a difficult task if these human and other resources are not acceptable for the organization -for instance because the normal ‘production’ cannot be reduced- or when they are not made available.

Improper awareness building stage. Insufficient time for awareness building and too much pressure from the top will have a reverse effect to the motivation and cooperation of the employees to develop the quality system bottom-up. Even when under such conditions a quality system will be developed, the laboratory manager may face great difficulties in the employees’ discipline to comply with the requirements of such a quality system.

No realistic time frame. Often the plans for realizing a quality system are far too optimistic. As a consequence, support from the top may end before the program has been completed, and only a few of its total possibly ineffective- quality assurance activities may remain.

No commitment by the staff. A program for quality assurance fails when the laboratory

management considers itself 'too busy' to get involved or when the strict rules are dropped at the first crisis as a 'nice to have'; for quick and dirty work as an alternative.

There are, however, also indications that accredited laboratories, in spite of mandatory method validation, evaluation of measurement uncertainty and participation in proficiency testing- do not perform significantly better than testing laboratories that have not been accredited. This is a worrying situation especially since in many countries field laboratories with operational quality assurance systems often are invited to participate in the development of new reference materials.

Apparently in practice the quality assurance is often insufficiently effective in spite of all technical developments, tools and documented knowledge. Time has come to question what other measures are needed to really improve and assure analytical quality.

Even though there are opportunities for improvement via fundamental and technical innovations, it is still generally accepted that a measurement result is '...as good as the person who made the measurement...'. It should therefore be anticipated that perhaps the weakest link is being underestimated in the implementation of quality assurance: the people performing the measurements. There are many routes by which people have an impact on (the quality of) the analytical measurement, but the following three aspects are important to consider in the light of the here identified problematic issue since they may be typical for the situation at present:

- Whereas 30 or more years ago analytical measurements were done by people who developed the method and equipment themselves, the current generation may be using the currently available equipment as a 'black box', with the emphasis on throughput and sensitivity rather than on analytical quality and e.g. specificity. It cannot be excluded that in many cases analytical measurements are carried out with insufficient understanding of the basic operation principles of modern analytical equipment, the software and the potential sources of error and interference. Automation of equipment and measurements has reduced the burden of the measurement to the analyst, and has resulted in less care for doing things 'right', the first time. Remarkably, time for repetition of measurements is often willingly created rather than that time is invested in careful preparation, planning and conduct of a measurement.
- The educational system is partly based on the principle that students should learn from their mistakes. The same situation occurs in analytical laboratories where newcomers have to build up experience with the technique(s). To some extent it is justifiable to learn from mistakes if these are related to wrong hypotheses; it is unacceptable if mistakes result from carelessness and ignorance on failures that are common knowledge to others, but that have never explicitly been communicated. However, much of the laboratory's experience –especially when it comes to troubleshooting and potential sources of error- has seldom been properly documented. Mistakes and failures are almost never published in literature or textbooks. If senior scientists leave for retirement or for another job, a lot of this common knowledge vanishes and people may have to start all over again, 're-inventing the wheel'.
- Introducing quality control and quality assurance requires not just an acceptance of these principles and their consequences. It requires more than organizing and working by the rules. Moreover, the style of working in a quality environment is different from what most academics experience during their studies. Thus, young academics with leadership responsibilities may face a gap between their interpretation of the quality assurance principles, and the call from practice. As a consequence, compliance with quality assurance requirements is often not supported by commitment.

12 CONCLUSIONS

There are several reasons why introduction of quality management principles in scientific research and non-routine analysis should be taken seriously:

- In some countries, governments, and funding organizations have decided to evaluate regularly the performance and quality of the public research institutions.
- In some countries, governments and industry subsidize research only at institutes with operational quality management systems. There are already indications that university laboratories are losing opportunities for external funding because of the absence of a culture inspired by quality assurance and management
- Research, and its results, should be trackable and comparable

Some of the benefits will be directly tangible: one or a few well-designed experiments may replace a large number of measurements; non-routine analysis is reported within the time-frame agreed upon (like routine analysis), progress in instrumentation development projects is faster, with easy trackability of experimental conditions due to extensive documentation.

Several analytical laboratories are currently developing their quality systems to become better eligible for services to beneficiaries. In this developing process it might be worthwhile to see if this culture can also be extended to the organization and conduct of the scientific research. After all, this part may still be the more challenging part of everyday activities.

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