3 SECTION 3: RECOMMENDATIONS FOR THE IMPLEMENTATION OF THE QMS

This section will provide you recommendations for the implementation of the Quality Management System in your XRF laboratory. Further, Section 4 will supply the templates of QM documentation that you can adapt to your specifics.

Considering the activities typically performed in XRF Analytical Laboratories, we propose you a QMS structure following a combination of the recommendations from ISO/IEC 17025:2005 and ISO 9001:2000 guides.

3.1 MAIN ACTIONS FOR QMS IMPLEMENTATION

According to the ISO 9001:2000 recommendations, for the implementation of the QMS, your organization shall:

- Identify the scope of its QMS, as well as the normative references it complies with.
- Identify the processes needed for its quality management system and their application.
- Determine the sequence and interaction of such processes.
- Establish criteria and methods needed to ensure that the operation and the control of such processes are effective.
- Ensure the availability of resources and information necessary to support the operation and monitoring of these processes.
- Monitor, measure and analyze the results of these processes.
- Implement actions aimed to achieve the planned results and to seek continual improvement of the system.

3.2 DEFINING THE SCOPE OF THE QMS

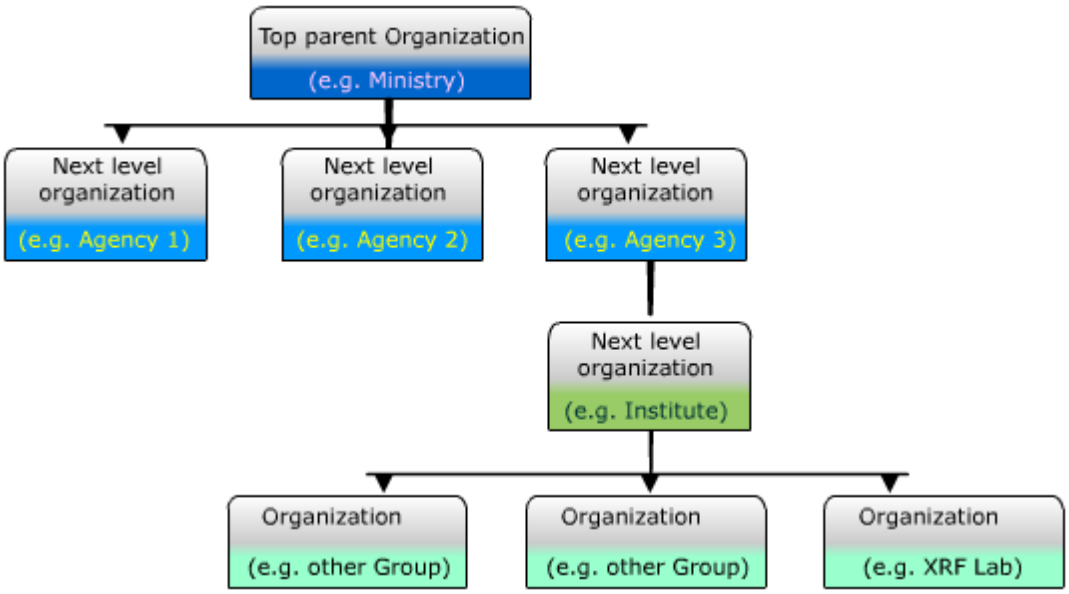
The scope of the Quality Management System is the provision of some of the following services:

- the repair and maintenance of electronic equipment,
- the electrical calibration of testing equipment and nuclear instruments,
- the design and development of interfaces/adaptors for scientific equipment and instruments not available commercially

IT IS ADVISABLE THAT YOU DECLARE IN YOUR QUALITY MANUAL EXPLICITLY THAT THE IMPLEMENTATION OF YOUR SYSTEM HAS BEEN PERFORMED T HROUGH A DOPTING GENERAL PROCEDURES TO ENSURE CONSISTENCY IN OVERALL SYSTEM OPERATION.

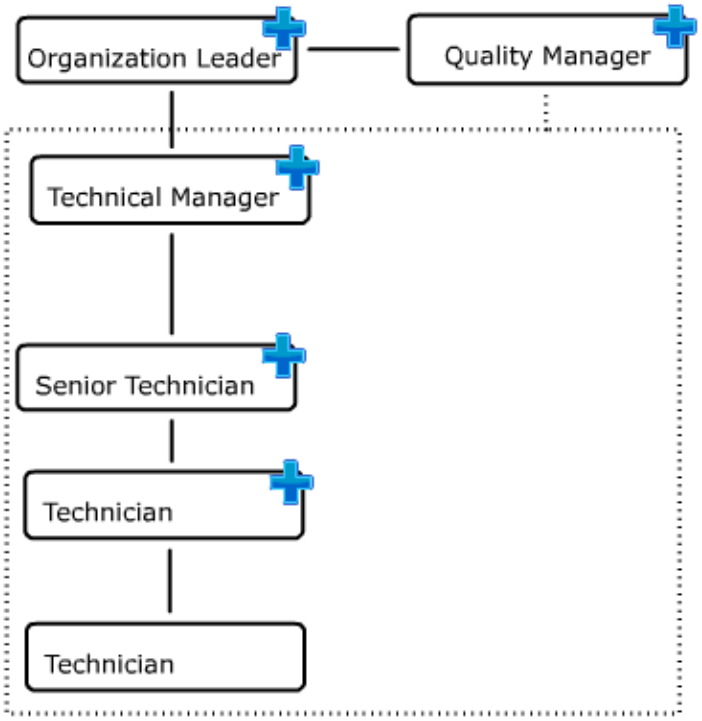
3.3 DEFINING THE ORGANIZATIONAL STRUCTURE

A relation of the authorities and subordination chain from the highest levels of the parent organization (if any) must be described and stated. A typical structure diagram for a public organization could be:



3.3.1 DEFINING THE ORGANIZATIONAL RESPONSIBILITIES

The responsibilities and authorities of the members of the organization in relation to the Quality Management System shall be defined. A typical structure could be:



3.4 DEFINING THE MISSION STATEMENT

The organization mission shall be clearly declared. If the organization is subordinated to a parent organization, the mission shall be declared as to comprise from general (parent organization) to the particular (organization) mission statement.

As an example, the mission of the Nuclear Spectroscopy and Application Laboratory (NSAL) of the IAEA Laboratories is provided:

"The IAEA is seeking to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world. The Agency shall encourage and assist research and make provisions for materials, services, equipment and facilities to meet the needs of its Member States. The Agency shall establish, apply and administer international safeguards designed to ensure, within its abilities, that special fissionable and other materials, services, facilities, equipment and information are only used for peaceful purposes. Within this context, the Mission of the Agency's Laboratories at Seibersdorf and Vienna is:

In the field of international safeguards: to provide analytical data and services, in support of Agency inspections, which ensure the credibility of the operation of international safeguards and the monitoring in compliance with the signatories of the Safeguards Agreements to the commitments made to the Agency and the International Community;

In the field of nuclear science, technologies and their applications: through technology transfer, services and research, to contribute to the implementation of the Agency's programmes on sustainable development by the effective use of nuclear sciences in monitoring of the environment, food and agriculture, human health, industry, physical and chemical sciences, and the management of water resources.

The Nuclear Spectroscopy and Application Laboratory (NSAL) in Seibersdorf, Austria, is part of the Physics Section, which belongs to the IAEA Division of Physical and Chemical Sciences (NAPC) of the Department of Nuclear Applications (NA). The main tasks carried out by the NSAL are focused on provision of training in XRF analysis, direct technical support to the laboratories in Member States, cooperation through bilateral agreements with other XRF groups, extension of the applicability range and improvements in accuracy, and precision of the XRF techniques. The NSAL provides also routine analytical services to other Units of the IAEA Laboratories, supports development of compact / portable XRF spectrometers and data analysis software / hardware for XRF systems. The Laboratory directly cooperates with other research / developer groups and users of X-ray spectrometric methods in the Agency Member States."

3.5 Defining the Quality policy

A typical declaration of the Quality Policy might be:

"It is the policy of the ORGANIZATION that its service support achieves a level of quality in execution and delivery of results that is commensurate with the requirements of its quality system. The ORGANIZATION will endeavour to carry out test and/or calibrations and provide results that are at a quality level consistent with the international requirements.

To achieve this, the ORGANIZATION will establish a Quality System in compliance with the ISO/IEC 17025:2005 and the ISO 9001 international standards. The Organization Leader will ensure that all the members of the staff will be acquainted with the Quality System and the implemented procedures. The members of the ORGANIZATION will perform their work as to fulfil the requirements of the Quality Policy and will remain free of any kind of commitments or motivations other than those explicitly declared by the (PARENT, if any) ORGANIZATION."

3.6 Quality objectives and quality commitment

Typical Quality objectives might be:

A. To ensure that the management of the ORGANIZATION and the service support provided to its customers are maintained and performed in accordance with the principles of a QMS established in compliance with ISO/IEC 17025:2005.

B. To ensure that the tests and/or calibration are made following validated procedures and that the provided calibration results are traceable to SI units and comply to ISO/IEC 17025:2005;

C. To ensure that all staff members involved in activities within the scope of the quality management system are aware of the quality policy, its documentation and implementation, and continuously evaluate opportunities for improving the group's performance;

D. To provide the ORGANIZATION personnel with a stimulating and rewarding environment; and

E. To achieve these objectives in a safe, efficient and effective manner.

NOTICE THAT OBJECTIVES A) AND B) CAN BE DEFINED DEPENDING ON THE SPECIFICS OF YOUR WORK. ON THE CONTRARY OBJECTIVES C) TO E) ARE OF OBLIGATORY INCLUSION!

3.6.1 Declaring the Quality commitment

The declaration can be enunciated as:

The ORGANIZATION is committed to achieve the above enunciated objectives through the implementation of a QMS structured to address, as applicable, the criteria given in international standards of the ISO/IEC 17025:2005, the ISO 9001 and other relevant international standards and guides. The QMS shall be further developed to meet international best practice in activities carried out.

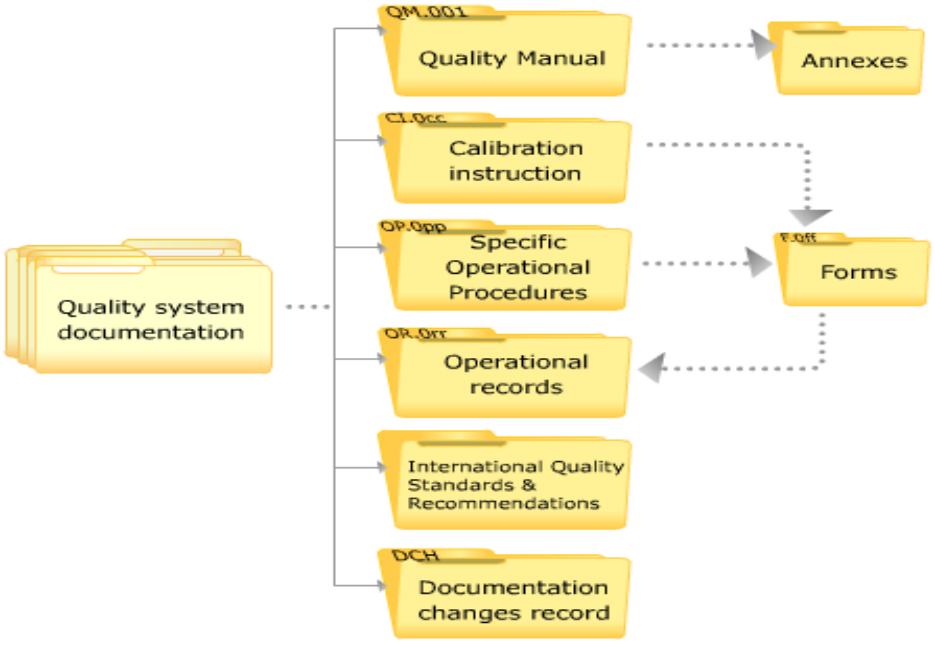
The ORGANIZATION management at all hierarchical levels, hereby represented by the Organization Leader, is fully committed to endorsing the quality policy, to achieving the quality objectives and to implementing the QMS. Overall responsibility for the implementation of the QMS resides with the Organization Leader supported by a proper quality organizational structure.

3.7 Structure of the QMS

The Quality Management System shall include the following key elements:

- A Quality Manual.
- A system for keeping documented and validated calibration instructions, well documented operational procedures and corresponding records.
- Instrumentation that is periodically calibrated and checked to ensure traceability of the calibration results and the quality of the maintenance/repair services.
- A clear and comprehensive statement of uncertainty in the measured quantities and in the reported values resulting from the electrical calibrations.

3.8 Structure of the QMS documentation



NOTICE THAT DOCUMENTATION MUST BE UNAMBIGUOUSLY AND CLEARLY CODED FOR PROPER IDENTIFICATION.

3.9 The Quality Manual

The Quality Manual shall relate:

- the scope of the Quality Management System.
- the statements of quality commitment, quality policy and quality objectives.
- a list of responsibilities and authorities in regard to QMS.
- the different procedures established for quality management, or a reference to them.
  The latter allows to prepare a less voluminous QM.
- the interaction between the processes of the QMS.

3.9.1 The Quality Manual structure

It is advisable to arrange the contents of the Quality Manual following the contents outline of the chosen ISO Standard to comply with (ISO 9001:2000 or ISO/IEC 17025:2005).

The ISO/IEC 17025:2005 outline provides a thorough and easy readable drawing-up. The addition of some sections to this outline is a practical choice to ensure compliance to both standards in an easy way.

There are two approaches in outlining the Quality Manual structure:

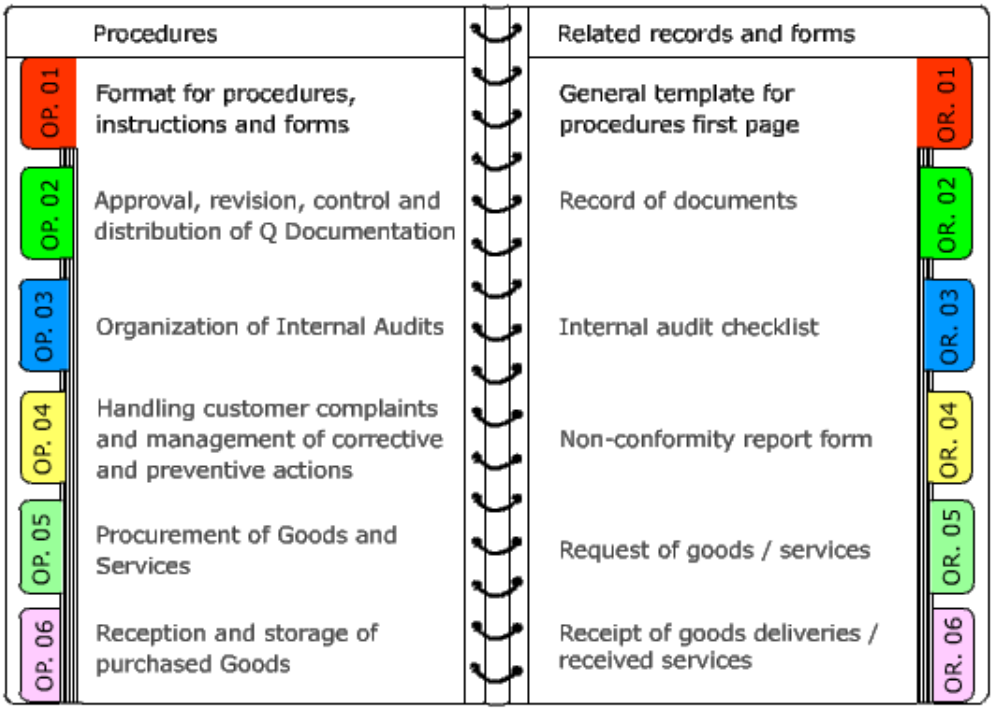
1) an extensive Manual, containing detailed description of most of the processes and;

2) a more succinct Manual, providing references to operational procedures describing in turn the processes.

A template of QM is provided in Section 4 for your consideration.

3.10 A master list of general operational procedures

The following table comprises a list of procedures that are needed to ensure the harmonic functioning of the quality management system and to establish the inter-relation between some of its components:



3.10.1 Format for procedures, instructions and forms

The reasons for establishing a standard format are:

- It is beneficial to the user who learns to look for information in set places.
- It acts as a check list for the person who prepares the procedure or instruction.
- It makes the use of different forms related to the Quality Management System more transparent and allows the use of cross references.
- To maintain the standard format and to minimize the hazard for requirements to be overlooked.
- To make clear the status of a current document (approval date and current version).

3.10.2 Approval, revision, control and distribution of Quality Documentation

This procedure establishes the authorities for the approval, dissemination, revision and changes in the quality documentation. In principle, the documentation must be prepared by the technical staff responsible for the process to which the given procedure or document is related with. Major revision shall be performed by the Technical Manager or the Quality Manager, as appropriate.

> For example: Procedures and records related to workflow control and IQC must be reviewed by the QM, whereas technical procedures must be reviewed by the Technical Manager.

All the documentation must be approved by the top manager of the organization.

ORIGINALS OF THE QUALITY DOCUMENTATION MUST BE KEPT IN A SAFE PLACE. AUTHORISED COPIES OF PROCEDURES SHALL BE AVAILABLE IN THE WORKPLACES FOR THE USE OF THE STAFF INVOLVED IN EACH PARTICULAR PROCEDURE.

3.10.3 INTERNAL AUDITS

This procedure shall describe the basic internal audit practices, and provide guidelines for establishing, planning, carrying out and documenting internal audits. Responsibilities, time frame, and operations to be taken as part of the audit shall be defined, as well as the outputs of the audits and their interrelation with management actions.

The Quality Manager shall control the accomplishment of the plan of audits and to participate in all of the activities related with the audits. The Technical Manager and the top management shall design the remediation plans and to make them effective in realization.

3.10.4 NONCONFORMITIES

The laboratory shall have a policy and procedures that shall be implemented when any aspect of its management system and testing and/or calibration work, or the results of this work, do not conform to its own procedures or the agreed requirements of the customer.

The purpose of this procedure is to allow a proper response to the customer's complains, to provide the evidence on corrective and preventive actions undertaken and to allow management review and related process and quality system improvements.

Top management is responsible for ensuring that the causes of the complaints are thoroughly investigated, proper actions planned and realized in due time.

ANY POTENTIAL NONCONFORMITY REVEALED BY ANY MEMBER OF THE STAFF SHALL BE TREATED AS A COMPLAINT.

3.10.5 OUTSOURCING

When an XRF laboratory subcontracts work, this work shall be placed with a competent subcontractor (the subcontractor must complies with ISO/IEC 17025:2005 for the work in question).

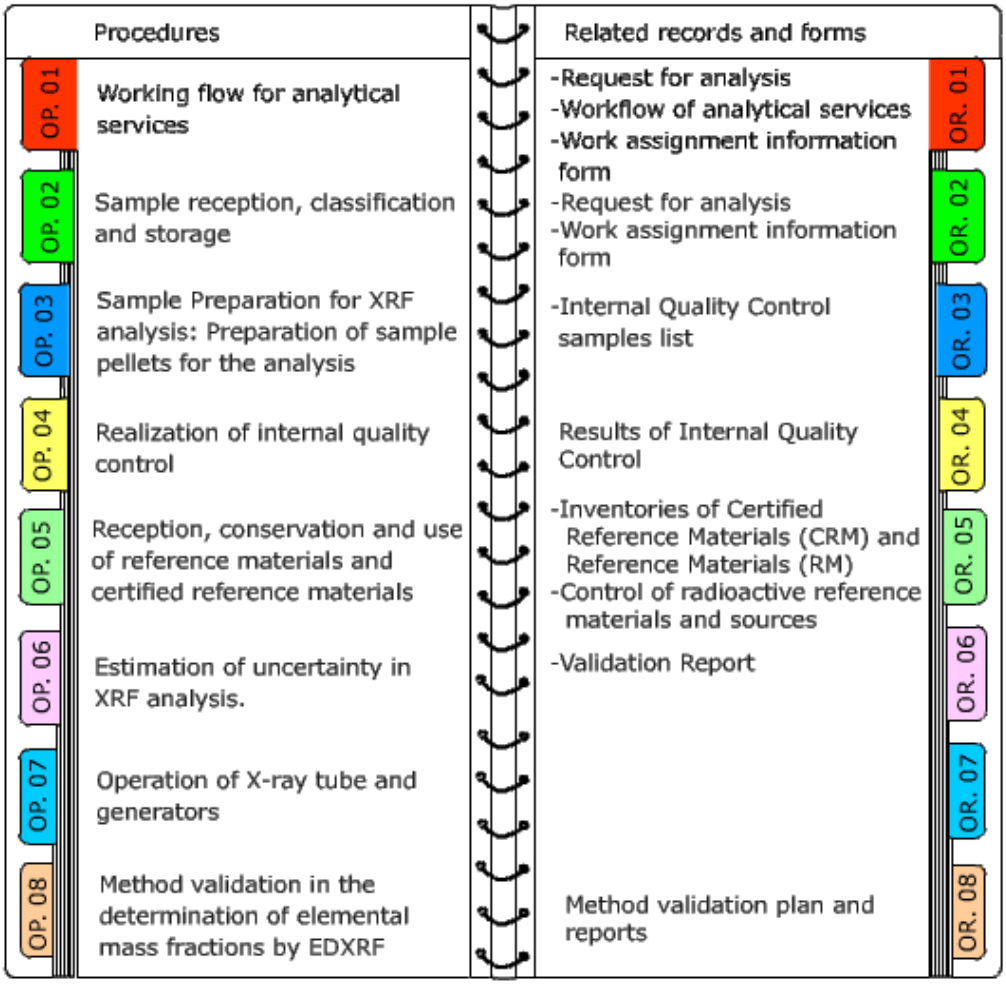
The laboratory shall advise the customer of the arrangement in writing and, when appropriate, gain the approval of the customer, preferably in writing.

The laboratory is responsible to the customer for the subcontractor’s work, except in the case where the customer or a regulatory authority specifies which subcontractor is to be used.

The laboratory shall maintain a register of all subcontractors that it uses for tests and/or calibrations.

3.11 SPECIFIC OPERATIONAL PROCEDURES FOR EDXRF PRACTICE

The following pad illustrates some of the procedures related to the specific case of EDXRF practice:



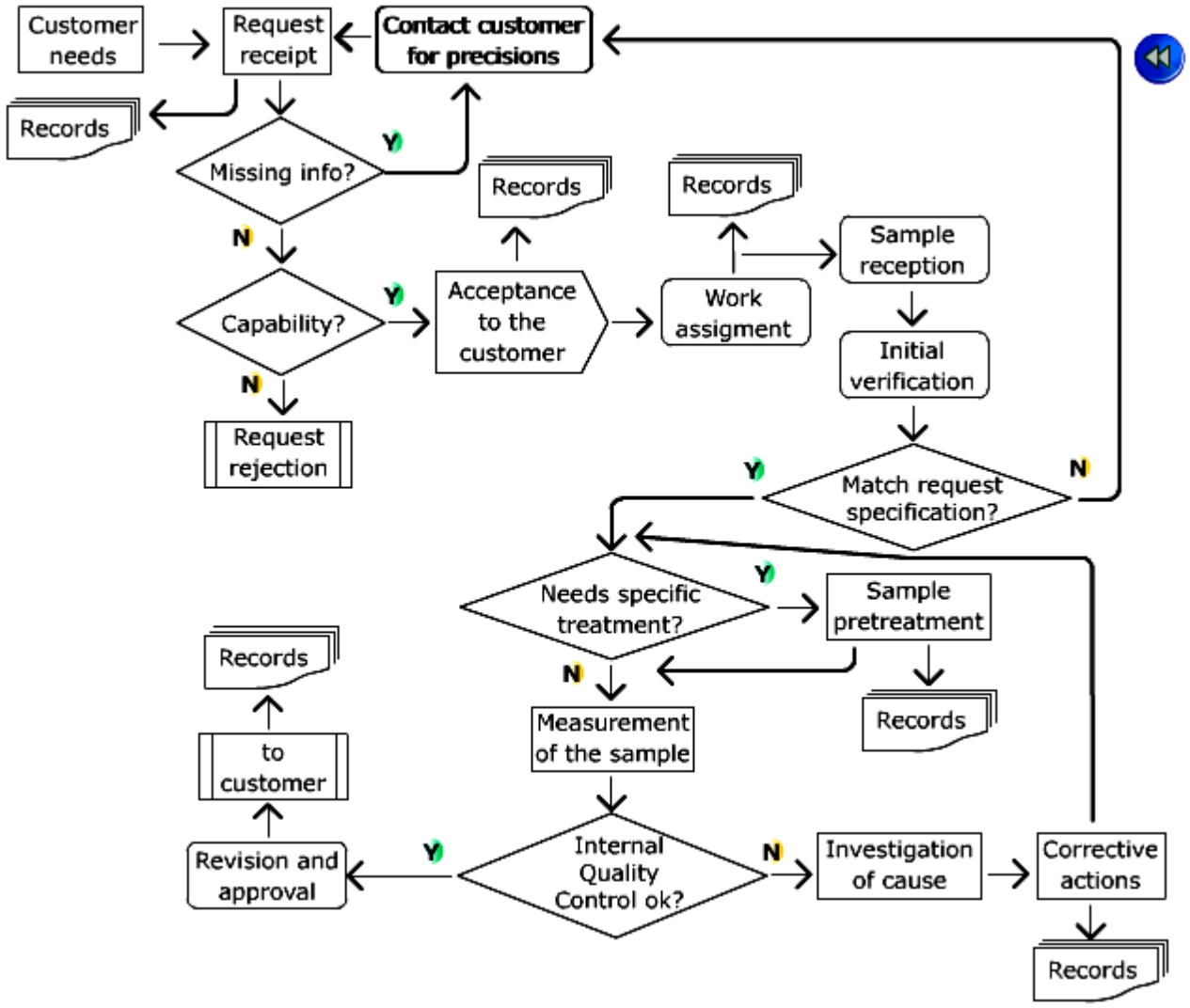
3.11.1 Definition of working assignments and monitoring the service flow

Due to the wide range of applications for XRF techniques, changes in any a-priori defined requirement for analytical services should occur in order to solve challenges. Keeping a constant communication with the customer is the only way to pursue agreement in regard to any modifications or changes arising from unexpected findings. Be always sure that:

- the laboratory has the capability to perform the modified task.
- an agreement is reached with the customer before to proceed.

ON A LONG TERM, IT IS ALWAYS PREFERABLE TO REFUSE A SERVICE REQUEST, RATHER THAN TO FAIL TO CUSTOMER EXPECTATIONS.

3.11.2 A GENERAL WORKFLOW CHART



3.11.3 EDXRF ANALYTICAL INSTRUCTIONS

Your QMS will incorporate as many analytical instructions as new procedures will be implemented and validated. Due to the great versatility of the XRF technique, it is expected that with time the field of applications will be wider. Some examples of analytical instructions might be:

- Mineral resources: Determination of ore grade in copper minerals by XRF analysis. Fundamental Parameters Method
- Steel alloys: Classification of stainless steels by XRF analysis. Normalized Fundamental Parameters Method.
- Food products: Determination of essential elements in cereals by XRF analysis. Emission-Transmission method.
- Water quality: Heavy metal determination in drinking water by TXRF.
- Archaeometry: Identification of pigments in paintings by micro-XRF.

3.11.4 Internal Quality Control practice

The laboratory shall have quality control procedures for monitoring the validity of tests undertaken. The resulting data shall be recorded in such a way that trends are detectable and, where practicable, statistical techniques shall be applied to the reviewing of the results.

Quality control data shall be analysed and, where they are found to be outside pre-defined criteria, planned action shall be taken to correct the problem and to prevent incorrect results from being reported.

The control encompasses the analytical process starting with the sample entering the laboratory and ending with the analytical report. The most important tools in XRF quality control are the analysis of duplicate samples and the use of control charts. Blind duplicates are included in the analysis to monitor the precision, whereas reference materials are analyzed as control samples to monitor in control charts the long term stability in method performance. The results of each run (group of samples analyzed within a request for service) are then accepted or rejected if both IQC requirements are met.

When a quality control program is established, it is essential to have in mind the requirement on the analytical results and for what purposes the analytical results are produced (the concept of fit for purpose).

From the requirement on the analytical results the analyst sets up the control program:

- type of quality control sample,
- type of quality control chart,
- control limits (simple, warning and action limits),
- control frequency,
- amount of duplicates and control samples for each run.

3.11.4.1 Control samples

Control samples are reference materials with a matrix composition close to that of the analyzed samples, and which elemental mass fractions are close to the expected ones in the unknown samples. They should also be stable over time, and be available in sufficient amount as to be used for years. The control samples should go through the whole measurement procedure.

Samples fulfilling all these requirements are not always available. Therefore there are several choices of control samples:

- Certified Reference Material which elemental mass fractions are known with inaccuracies less than those resulting from the intended analytical method are the ideal choice
- Test routine sample characterized by alternate analytical methods (in-house material)
- Reference material, standard solution or in-house material
- Reference materials, standard solutions or spiked materials

Blank samples shall be analyzed for assessment of instrumental blanks or contaminations. Blank samples must be selected or prepared with a matrix similar to that of the unknowns, but with mass fraction of the elements of interest below the detection limits.

3.11.4.2 Principles of Quality Control Charting

Control charting is a powerful and a simple tool for the daily quality control of routine analytical work. Statistical control pursues to verify the stability of operation. For such verification the laboratory analyzes control samples together with the routine samples in every analytical run. The results of the analyses of control samples can be interpreted following different ways, including the use of control charts.

Though there are several types of control charts, these two are the most important used for the internal quality control in XRF laboratories:

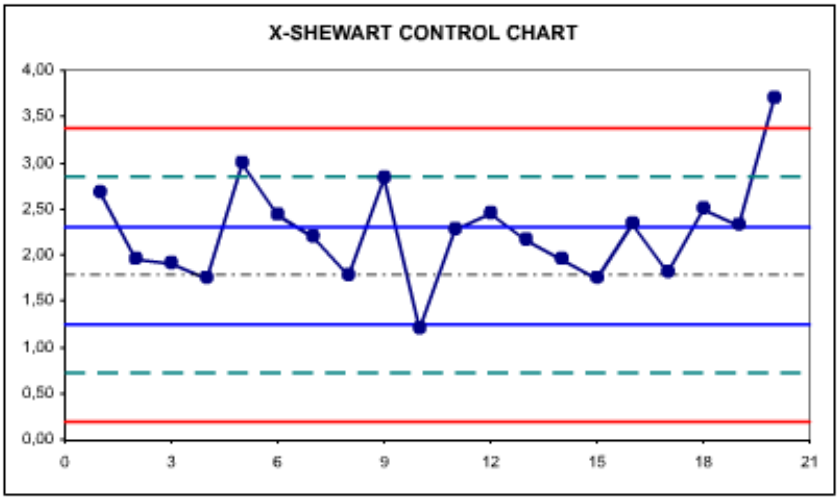
- X-charts
- Range-charts

3.11.4.3 X-Charts

An X-chart has a central line, upper and lower warning limits and upper and lower action limits.

One of the oldest and simplest types of control chart is the X-chart, which is based on the distribution of the control values around a true or expected value. It can be used to monitor the combination of systematic and random effects for control values, based on single results or on a mean of multiple analyses. Using a reference material as control sample, the bias may be monitored by comparing the mean control value over time with the reference value.

X-charts are used to monitor if a bias arise in the results of analysis of a control materials, thus serving to prove whether the method performance remains under stable operation. It is worth to notice that the latter is valid for any sample matrix and elemental concentration order similar to those of the control sample. If a run comprises different types of matrices or different concentration ranges, it is advisable to include more than a control sample on each run.



3.11.4.3.1 SETTING THE CONTROL LIMITS AND THE CENTRAL LINE IN X-CHART

The control limits can be set based on method performance – **statistical control limits** or according to the requirement on *within-laboratory reproducibility* – **target control limits**.

Statistical control limits	Target control limits
The control limits are calculated from the historical results obtained during the analysis of the control sample. For at least 12 analysis carried out during a certain time period, e.g. a month, the standard deviation (*s*) of the results is calculated. This population of results must be free of out-of-control results. Warning limits shall be set at +2s and – 2s. Action limits shall be set at +3s and – 3s. **Note**: The statistical control limits are constantly updated with the more recent results under statistical control.	The control limits are set based on the requirement on the analytical quality. The standard deviation for the control chart, s, is estimated from the requirement on reproducibility. Warning limits shall be set at +2s and – 2s. Action limits shall be set at +3s and – 3s.

The central line in the control chart can be the calculated mean value of the control values or a reference value for the control sample. In most cases a mean central line is used.

Mean central line	Reference central line
The mean value is estimated from control values obtained during a longer time. The central line is set to this mean value.	The control sample is a reference material or a well-characterised material. The central line is set to the assigned (reference or certified) value.

3.11.4.4 RANGE CHARTS

Control Chart of the Range of Duplicates are used to control if the precision of the method remains within the boundaries evaluated during the method validation. The difference between duplicate results is compared to the target uncertainty of the results.

The uncertainty of the range (absolute difference) of replicate values $R = |x1 - x2|$ can be assessed as

$$\sigma(R) = \sqrt{\sigma^2(X_1) + \sigma^2(X_2)} = \sqrt{2}\ \sigma(\bar{X})$$

If the values of the replicate results can be considered as part of a Gaussian probability distribution, then in only 5 % of the cases the differences will exceed

$$2\sqrt{2}\ \sigma(X)$$

and in only 0.3 % of the cases will exceed

$$3\sqrt{2}\ \sigma(X)$$

As in XRF the precision of the results is mainly conditioned by the counting statistics, the precision of the results improves with the increase in the concentration of the element. There are two possible scenarios for a run of analysis: the concentration of the element is similar in all the samples, or the concentration spans within a broad range.

Case 1: The results of duplicate analysis of a control material having the concentration of the element similar to those expected in the unknown samples can serve to assess if the precision correspond to the expected value.

Case 2: Samples contain the element in a broad range of concentration, and therefore the precision of the results changes in a relatively broad range. The quality control manager must request a second run of analysis, this time including duplicates of some of the analyzed samples, as to cover the range of concentrations found during the initial analysis.

Examples of these two charts are provided next.

3.11.4.4.1 RANGE CHART FOR A NARROW CONCENTRATION RANGE IN THE SAMPLES

It is possible to control the precision of the results by performing duplicate analysis of the selected control sample. A range quality control chart (R_{mean}) can be used to monitor the results of the analysis. The R_{mean} -chart is set up by analyzing a series of 15 to 20 duplicates and calculating the range (absolute value of the difference). The mean range can then be calculated and plotted on the R_{mean} -chart as shown in the Figure 1. The method proposed by Youden and Steiner [Statistical Manual of the Association of the Official analytical Chemists, Washington DC, 1975] is based in the assumption that 50 % of the ranges should greater than a value corresponding to 0.845 R_{mean}, only 5 % greater than 2.456 R_{mean} (95 % limit) and only 1 % greater than 3.27 R_{mean} (99 % limit).

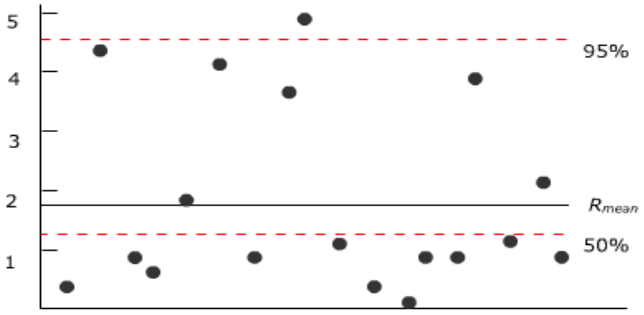


Figure 1: Typical R_{mean} -quality control chart

If 5 or more consecutive points are above the 50 % limit then the analysis is moving out of control and corrective action is needed. Occasionally points will lie above the 95 % limit (about 1 in every 20 points) but points falling above the 99 % limit indicate the need for corrective action. If too many zero values occur it is likely that the results have been rounded to a digit not representing the meaningful precision.

The range value on the R_{mean} -chart can be used to calculate the standard deviation of the analyses by using the equation:

$$S^2 = \frac{\sum R^2}{2N}$$

where *S* is the standard deviation, *R* are the ranges and *N* is the number of samples run in duplicate.

3.11.4.4.2 RANGE CHART FOR A BROAD CONCENTRATION RANGE IN THE SAMPLES

If the results of a given run of analysis cover a wide concentration range, the quality control manager can request a second run. In this run, duplicates of the samples analyzed are submitted to analysis. The values of the ranges are the compared with the expected uncertainty for each concentration of the element. It is understood that the uncertainty has been established during method validation for different concentration levels.

No range shall exceed the action limit calculated as

$$AL = 3\sqrt{2}\ u(X)$$

and only 5 % of the ranges can exceed the warning limit calculated as

$$WL = 2\sqrt{2}\ u(X)$$

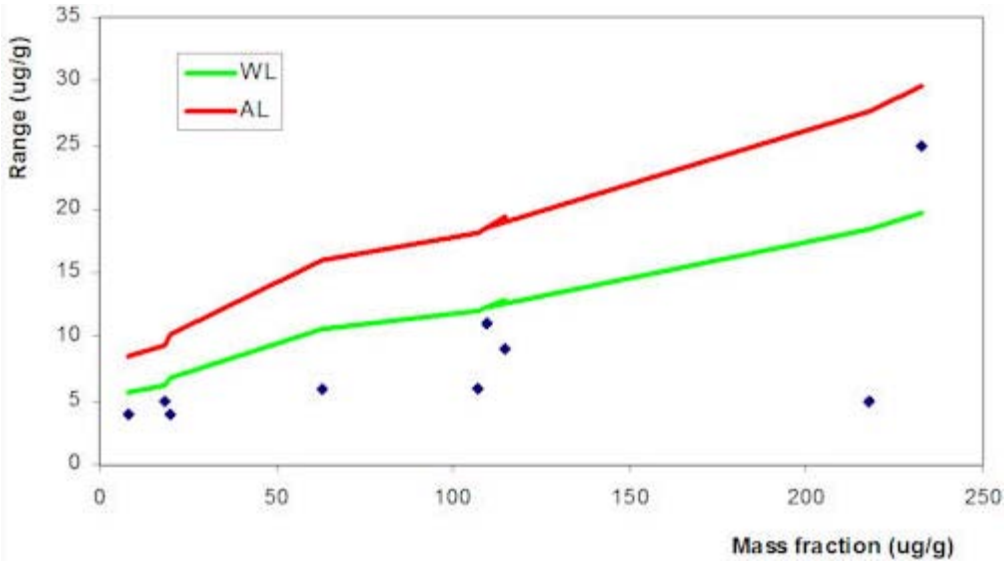


Figure 2: Range chart for results spanning over a concentration interval.

3.11.4.5 VERIFICATION OF TRUENESS AND PRECISION OF THE ANALYTICAL METHOD USING THE IAEA APPROACH

As part of the internal quality control of the analytical method, the measurement of a Certified Reference Material (CRM) serves to investigate if the obtained measurement result is or is not significantly biased in relation with the reported reference value. For evaluating the bias, a validated trueness and precision test (the IAEA approach) can be applied.

For trueness evaluation, the results are considered "Acceptable" if:

$A_1 \leq A_2$

where:

$A_1 = |V_{ref} - V_{lab}|$

$A_2 = 2.58 \sqrt{(u^2_{ref} + u^2_{lab})}$

V_{ref} *- reference value of CRM*

V_{lab} *- value obtained in laboratory*

$u^2_{ref,lab}$ *- standard combined uncertainties associated to* V_{ref} *and* V_{lab}

For evaluation of precision, the results are considered "Aceptable" if:

$P \leq ALP$

where:

$$P = \sqrt{\frac{u^2_{ref}}{V^2_{ref}} + \frac{u^2_{lab}}{V^2_{lab}}}$$

ALP: Acceptable Limit of Precision, set for each analyte as a function of its concentration level and ease of determination.

A result must obtain an "Acceptable" score in both criteria to be assigned the final score of "Acceptable".

3.11.5 UNCERTAINTY ESTIMATION

What is uncertainty of measurement?

- Any measurement result is characterised by imperfections.
- There will always be an uncertainty about the value of a result: Result = Value ± Uncertainty.
- It is a quantitative indication of the quality of the result.
- It is the quantification of the doubt associated with a measurement result.
- It gives an answer to the question: How well does the result represent the value of the quantity being measured?
- There is an uncertainty even when correction factors have been applied, because there is an uncertainty on these factors.

The uncertainty of measurement is due to:

- Trueness: the closeness of agreement between the average value obtained from a large series of test results and the accepted reference value (true value).
- Precision: the closeness of agreement between independent test results obtained under stipulated conditions.

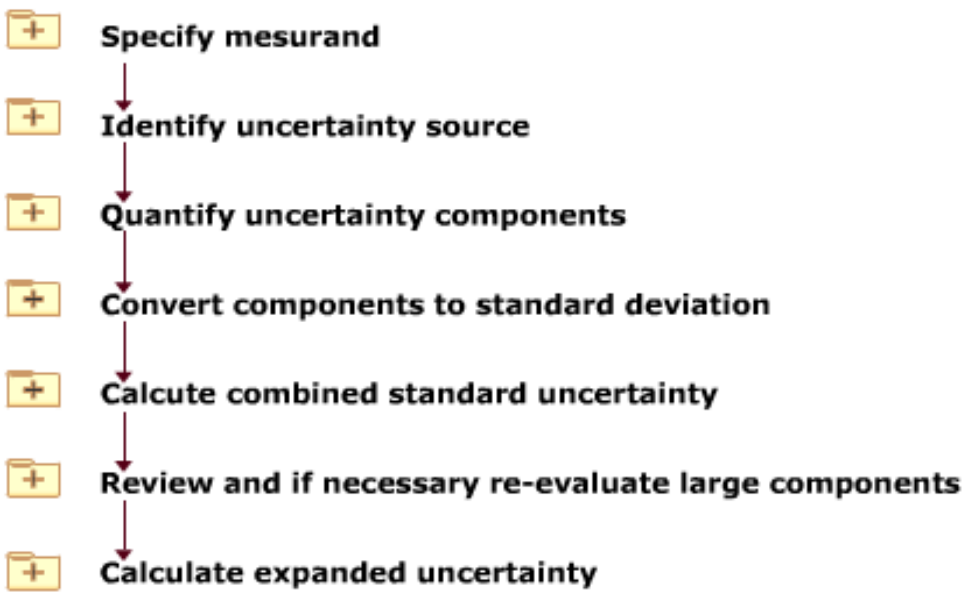
3.11.5.1 MAIN SOURCES CONTRIBUTING TO UNCERTAINTY IN XRF ANALYSIS

The major contributions to uncertainty of the results in XRF analysis are often the following:

- Uncertainty due to counting statistics: Owing to the statistical nature of the measured signal, the standard deviation of the peak area N can be assumed as $\sqrt{N}$. In the case of spectrum fitting, the uncertainty due to the quality of peak fit must be accounted as well. This source becomes one of the largest in the case of low counting statistics.
- When using Certified Reference Materials for the calibration of the model, the uncertainty of the calibration is affected by the uncertainty of the certified values of the CRMs.
- Depending on the procedure followed to estimate the effective sample attenuation, the uncertainty of the attenuation correction can be significant.

Other sources must be carefully evaluated in each analytical procedure.

3.11.5.2 GUM APPROACH FOR UNCERTAINTY CALCULATION



3.11.5.3 THE KRAGTEN SPREADSHEET APPROACH FOR UNCERTAINTY CALCULATION

This is a numerical method, suggested by Kragten which makes effective use of spreadsheet software to provide a combined standard uncertainty from input standard uncertainties and a known measurement model.

Spreadsheet software can be used to simplify the calculations of partial differentials. In this sense, the procedure takes advantage of an approximate numerical method of differentiation, and requires knowledge only of the calculation used to derive the final result (including any necessary correction factors or influences) and of the numerical values of the parameters and their uncertainties. The description here follows that of Kragten.

In the expression for $u(y(x_1, x_2...x_n))$

$$\sqrt{\sum_{i=1}^{n}\left(\frac{\partial y}{\partial x_i}\,u(x_i)\right)^2 + \sum_{\substack{i,k=1\\ i\neq k}}^{n}\left(\frac{\partial y}{\partial x_i}\,\frac{\partial y}{\partial x_k}\,u(x_i,x_k)\right)}$$

provided that either $y(x_1, x_2...x_n)$ is linear in x_i or $u(x_i)$ is small compared to x_i, the partial differentials $(\partial y/\partial x_i)$ can be approximated by:

$$\frac{\partial y}{\partial x_i} = \frac{y\,(x_i + u\,(x_i)) - y\,(x_i)}{u\,(x_i)}$$

Multiplying by $u(x_i)$ to obtain the uncertainty $u(y,x_i)$ in y due to the uncertainty in x_i gives

$$u\,(y,X_i) \approx \; y\,(x_1, x_2,\ldots x_i + u\,(x_i)) - y\,(x_1, x_2,\ldots x_i)$$

Thus $u(y,x_i)$ is just the difference between the values of y calculated for $[x_i+u(x_i)]$ and x_i respectively.

The assumption of linearity or small values of $u(x_i)/x_i$ will not be closely met in all cases. Nonetheless, the method does provide acceptable accuracy for practical purposes when considered against the necessary approximations made in estimating the values of $u(x_i)$.

A step by step sample animation is provided in the course.

3.11.6 VALIDATION

Confirmation by examination and provision of objective evidence that the particular requirements for a specific intended use are fulfilled.

Validation may include procedures for:

- sampling
- handling
- transportation.

All influences of changes which are made in the validated methods should be documented and a new validation should be carried out. Validation is always a balance between costs, risks and technical possibilities

3.11.6.1 METHOD VALIDATION

Techniques for the determination of the performance of a method:

- calibration using reference standards or materials
- comparison of results achieved with other validated methods
- interlaboratory comparisons
- systematic assessment of the factors influencing the result
- assessment of the uncertainty based on scientific understanding of the theoretical principles of the method and practical experience

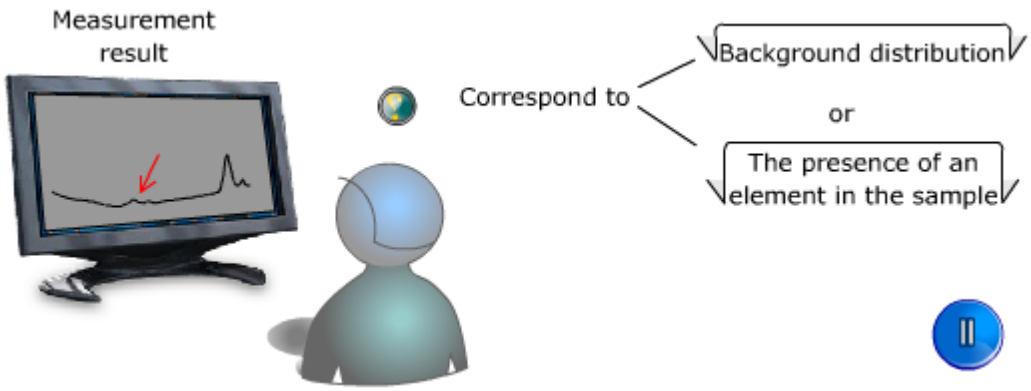
The range and accuracy of the values obtainable from validated methods should include:

- uncertainty of the results
- detection limit
- selectivity of the method
- linearity
- limit of repeatability and/or reproducibility
- robustness against external influences and/or
- cross-sensivity against interference from the matrix as assessed for the intended use, shall be relevant to the clients' needs.

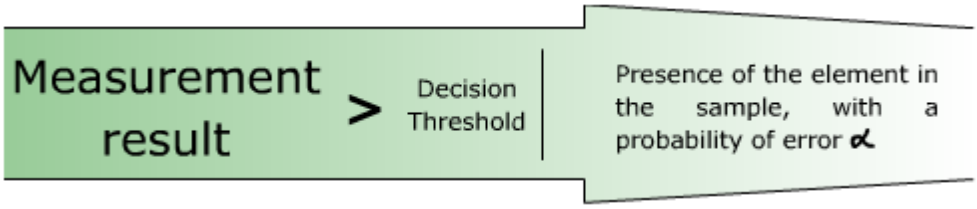
There are many cases in which the range and uncertainty of the values can only be given in a simplified way due to lack of information.

3.11.6.2 CHARACTERISTIC LIMITS. DECISION THRESHOLD

It is a characteristic limit that helps one to decide if the element is present or not in the analyzed sample.

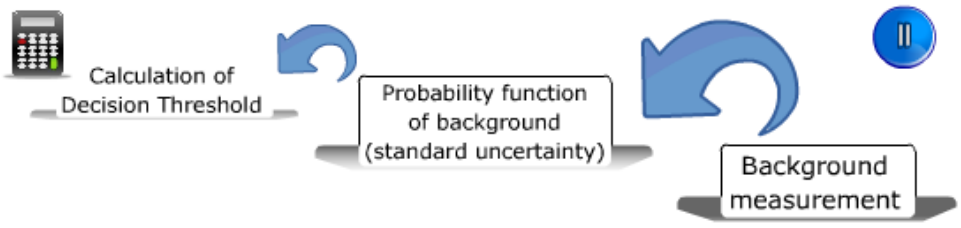


When the measurement result is higher than the Decision Threshold, it is possible to affirm that the element is present in the analyzed sample. There exists, however, an established probability α (usually of 5 %) of finding background measurements above the Decision Threshold, where background comprise blank signal, interferences and continuum:



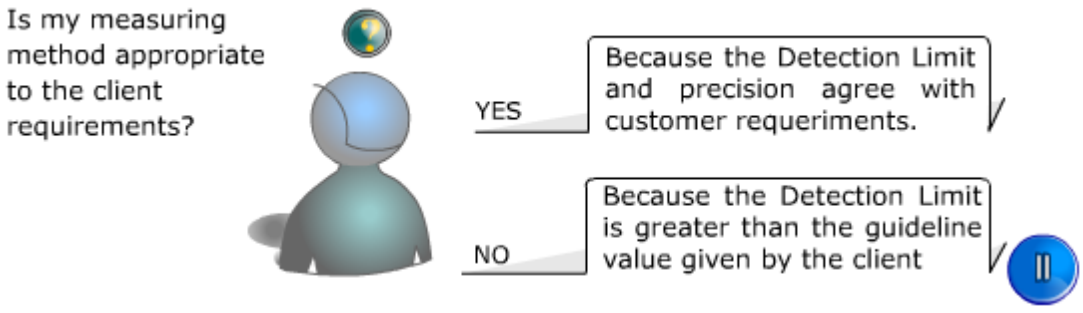
The Decision Threshold is generally expressed in number of counts. When converting from number of counts to concentration of the element in the analyzed sample, the Decision Threshold determines the "minimum concentration of that element that the analytical technique is capable to detect".

For the calculation of the Decision Threshold, the only required data is the probability function of background (standard uncertainty of background) obtained from the measurement of background.



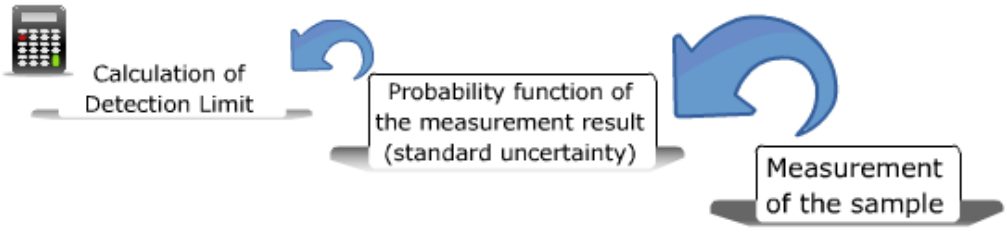
3.11.6.3 Characteristic Limits. Detection limits

The Detection Limit allows a decision to be made as to wether the measuring method satisfies certain requirements and is consequently suitable for the given purpose of measurement. It must always be compared with the guideline value given by the client.



The Detection Limit is the characteristic limit that responds to the following question: what would be the real concentration (of an element in the analyzed sample) that would give a measurement result below the Decision Threshold with an established probability β (usually of 5 %).

The calculation of the Detection Limit requires the knowledge of the probability function of the measurement result (standard uncertainty of the measurement result). Validation shall include:



3.11.6.4 NOISE SIGNAL IN XRF AND DETECTION LIMIT ESTIMATION

In EDXRF practice, detection limit for an element i is customarily calculated by using a signal corresponding to 3 times the standard deviation of the noise signal and the measuring time tmeas. Depending in the theoretical model, other parameters are used to calculate the weight fractions or the mass per unit of area. In the case of analyzing 'thin' samples the detection limits can be calculated as:

$$DL[g/cm^2] = 3\sqrt{N}\,/t_{meas}\,S_i$$

where S_i ($s^{-1}cm^2g^{-1}$) is the instrumental sensitivity for element *i*.

In the case of analyzing samples of intermediate or infinite thickness the detection limits can be calculated as:

$$DL[w/w] = 3\sqrt{N}\,/t_{meas}\,A_i\,S_i$$

where Ai ($g\ cm^{-2}$) is the attenuation correction, which depends on sample effective attenuation coefficient and on sample aerial density.

The main contributions to noise signal *N* in XRF spectra comes from:

- the continuum under the peak (N_{cont}),
- a peak observed in a measurement performed for a blank sample (with a net peak area N_{blank}),
- a peak observed in the absence of sample (instrumental background, net peak area N_{bkg}),
- a spectral interference (net peak area N_{SI}).

As the probability distribution of the results of a series of measurements for any of these signals can be considered as close to a Poisson distribution, the value of $\sqrt{N}$ must be estimated in the more general case as:

$$\sqrt{N} = \sqrt{N_{cont} + N_{blank} + N_{bkg} + N_{si}}$$