Starna Certified Reference Materials for UV, Visible and NIR Spectrophotometry

A User Guide

Why do we need Reference Materials?
Ultraviolet and Visible spectrophotometry is one of the most widely used techniques in analytical chemistry, capable of producing accurate and precise results. Procedures using the technique are found in analytical, clinical and research laboratories, and find extensive use in Quality Assurance. Many laboratories, especially in pharmaceuticals, the life sciences and contract analysis, operate in regulated environments or within accreditation schemes that require evidence of the quality and reliability of the results produced. In these situations it is essential to check instrument performance on a regular basis against reference materials having known characteristics that will provide that evidence.

Starna Certified Reference Materials (CRMs) have been developed to give analytical chemists a convenient and dependable way of ensuring that their UV, Visible and Near Infra-Red (NIR) instruments are performing to the requirements of their analytical methods. These materials are manufactured and calibrated under strictly controlled conditions that conform to all the relevant international standards.

Starna has played a leading role in the development of CRMs for spectrophotometry for many years, in collaboration with international regulatory bodies and instrument manufacturers.

In this guide, we discuss the regulatory background behind the use of CRMs in UV, Visible and NIR spectrophotometry, and the significance of the various instrument parameters that can be qualified by their use.
Quality Assurance in the Analytical Laboratory

National and International Quality Conventions

Many analytical measurements are performed within a regulated environment. This is especially so in the pharmaceutical industry, where health and environmental safety data are required for the registration of a wide range of products and product registration is usually sought in more than one country. Within the OECD, adherence by a laboratory in one member state to the principles of Good Laboratory Practice (GLP) ensures that test data generated in that laboratory will be acceptable in other member states. There are other good practice conventions such as GMP (Good Manufacturing Practice) that may impact upon a laboratory’s activities. Adherence to guidelines is usually enforced by national agencies such as the Food and Drug Administration (FDA) in the USA or the Medicines and Healthcare products Regulatory Agency (MHRA) in the UK. Test methods for pharmaceutical analysis and performance criteria for instruments used in them are published in national and international pharmacopoeias such as EP, JP and USP. Laboratories working in these environments will be required to demonstrate that their instrumentation is working to an appropriate specification and is fit for purpose.

Validation and Qualification

These terms are used frequently and sometimes interchangeably, which can lead to confusion. In this document, validation relates to the overall measurement process and methodology for a given analysis, whereas qualification relates to the instrument and proving its performance.

Analytical Instrument Qualification (AIQ)

Instrument qualification is not a single continuous process, but instead results from several discrete activities. For convenience, these activities can be grouped into four phases: design qualification (DQ), installation qualification (IQ), operational qualification (OQ), and performance qualification (PQ). Some AIQ activities cover more than one qualification phase, and analysts potentially could perform them during more than one of the phases. However, in many instances there is need for specific order to the AIQ activities; for example, installation qualification must occur first in order to initiate other qualification activities.

Laboratory Accreditation

In industrial Quality Assurance or in contract analysis, results can have commercial or legal significance. To underwrite the quality of their work many laboratories obtain accreditation to ISO/IEC 17025 by bodies that are members of the International Laboratory Accreditation Cooperation (ILAC). ILAC was first established to facilitate trade by securing international acceptance of accredited test and calibration results. Accreditation is performed by national certification bodies such as the United Kingdom Accreditation Service (UKAS) or the American Association for Lab Accreditation (A2LA) and National Voluntary Laboratory Accreditation Program (NVLAP) in the USA. Again, accredited laboratories will have to demonstrate that their instruments are performing appropriately for the analyses for which the laboratory is accredited.

In many industries, standardised test procedures, such as those formulated by ASTM International, are widely used, and these will often specify the performance requirements of the instrumentation employed.

Even if not working in any of these environments, it is obviously desirable to be able to demonstrate that instruments are working to specification and fit for purpose.

This process is known as Instrumental Equipment Qualification.
IQ - Installation Qualification: is the documented collection of activities necessary to establish that an instrument is delivered as designed and specified, and is properly installed in the selected and that this environment is suitable for the instrument. IQ applies to an instrument that is new or was pre-owned, or to any instrument that exists on site but has not been previously qualified. Relevant parts of IQ would also apply to a qualified instrument that has been transported to another location or is being reinstalled for other reasons, such as prolonged storage.

OQ - Operational Qualification: After a successful IQ, the instrument is ready for OQ testing. Operational qualification (OQ) is the documented collection of activities necessary to demonstrate that an instrument will function according to its operational specification testing in the selected environment.

PQ - Performance Qualification: Performance qualification (PQ) is the documented collection of activities necessary to demonstrate that an instrument consistently performs according to the specifications defined by the user, and is appropriate for the intended use. After IQ and OQ have been performed, the instrument’s continued suitability for its intended use is demonstrated through performance qualification.

Clearly, in a routine situation, only PQ may need to be performed on a regular basis, and OQ less frequently, for example after maintenance or repair operations have been carried out on the instrument.

It should be remembered that AIQ does not prove that the analytical results generated by the spectrophotometer are correct! AIQ demonstrates that the instrument itself is working appropriately; many other factors like sampling procedures, reagent quality and sample handling contribute to the final result.

Qualification of the instrument will assist the instrument user in making several important judgements:

- Is the instrument performing to its manufacturer’s specifications?
- Does it meet the requirements of the quality environment of the laboratory, e.g. a Pharmacopoeia?
- Is it performing suitably for the determination to be carried out?

While the pharmacopoeias and other standards may give generic recommendations for instrument performance, for a specific test the required performance characteristics may be different and are usually given in the monograph for the test method. Furthermore they can change over time, so claims by instrument manufacturers that a spectrophotometer is e.g. “pharmacopoeia compliant” should be treated with caution.

In a regulated environment, the onus of proof is on the user to justify and prove, by the qualification of the system, that
the instrument is ‘fit for purpose’ and capable of providing the required accuracy and precision of data.

Why do we need Reference Materials?

To confirm the performance of an analytical instrument, it will be necessary to calibrate or test its performance against standards having known properties, and virtually all the quality schemes mentioned will require that any materials used to qualify an instrument can themselves be shown to be traceable to Nationally or Internationally recognised standards. Such standards are referred to as Certified Reference Materials and must themselves be manufactured and calibrated under closely controlled conditions.

What is a CRM?

As defined by ISO/REMCO (the International Standards Organisation Committee on Reference Materials), a CRM is a “Reference material, characterised by a metrologically valid procedure for one or more specified properties, accompanied by a certificate that provides the value of the specified property, its associated uncertainty, and a statement of metrological traceability.”

Traceability

Traceability is a key concept in calibration and validation processes and is defined in ISO/IEC Guide 99:2007 International Vocabulary of Metrology (VIM) - as the “property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty”

Starna CRM’s are certified using a number of reference spectrophotometers, all qualified using Standard Reference Materials certified by the National Institute of Standards and Technology (NIST) in the USA, or against primary physical references such as elemental emission lines. These standards are universally recognised, and are noted on the certificates that accompany all Starna CRM’s.

International agreements between National Metrology Institutes (NMIs) at a high level by the Bureau International des Poids & Mesures (BIPM) mean that measurements made against traceable references in one country will be accepted in any other country within the agreement.

CRMs - The Manufacturing Environment

Historically, producers of CRM’s have used either ISO/IEC 17025 or ISO Guide 34 to control their production processes but in 2004 ILAC, the International Laboratory Accreditation Co-operation, ruled that to be a Reference Material Producer, manufacturers should be accredited to both these standards simultaneously. There is considerable overlap between the two standards, but essentially ISO/IEC 17025 is mainly concerned with the technical and management competences required to operate a testing and calibration laboratory, whereas ISO Guide 34 is more concerned with the supplier’s organisational and production control systems. It also requires suppliers to operate a customer support and technical advice service. Any company accredited to these standards will be subject to regular inspections by the national accrediting body.

On 26 October 2012 at the 16th ILAC General Assembly in Rio De Janeiro, Brazil, the following resolution was adopted: “As ISO Guide 34:2009 includes normative references to ISO/IEC 17025 and ISO 15189; the General Assembly resolves that accreditation of reference material producers is conducted in accordance with ISO Guide 34:2009 alone”.

In practice, the normative reference to ISO/IEC 17025 still requires the use of all appropriate and relevant sections of this standard, for the manufacture and production of a Certified Reference Material (CRM). By definition, measured value assignments can only be effectively produced in an ISO/IEC 17025 controlled environment.

Liquid and Vapour Reference Materials

In the 1950s, the founders of Optiglass (the forerunner of Starna) developed and perfected the technique of fully fusing glass and silica cell component parts by heat alone, without distortion of optical surfaces. This major advance transformed the design and production of spectrophotometer cells and associated products. It also allows the permanent sealing, by heat alone, of filled cells containing liquid or vapour phase reference materials, even when those materials are volatile or highly flammable. The use of this technique contributes to the long-term stability of Starna reference materials and the unique lifetime guarantee that applies to all Starna CRM’s. The potential hazards associated with handling volatile and toxic materials such as benzene are also largely eliminated.

Starna was the first CRM producer to be awarded accreditation to both Standards by UKAS, the UK Accreditation Service.
Instrumental Parameters in UV, Visible and NIR Spectrophotometry

Instrument parameters checked as part of Operational Qualification (OQ) and Performance Qualification (PQ) of a UV-Visible spectrophotometer include:

- Photometric accuracy
- Photometric linearity
- Photometric precision
- Wavelength calibration
- Stray light
- Resolution/Bandwidth

These can all be checked using Starna Certified Reference Materials. The following notes briefly describe the various Reference Materials available from Starna for OQ and PQ. Table 1 (p10) shows those Reference Materials accepted by various standardisation bodies for compliance, and Fig 6 (p 11) is a visual guide to the selection of references for different wavelength ranges and parameters.

### Photometric Accuracy, Linearity and Precision

These parameters, also referred to as Absorbance Accuracy etc., describe the quantitative accuracy of the instrument, and as such are probably the most frequently checked. They test not only the optical performance of the instrument but also the quantitative accuracy of its electronic measuring system. It should be noted that deficiencies in any of the foregoing optical parameters could lead to errors in photometric accuracy.

International and national regulatory bodies variously recognise two reference materials for determining the accuracy and linearity of an instrument’s absorbance scale. Potassium dichromate dissolved in dilute perchloric acid is recommended for use in the ultra-violet region. When prepared in 0.001 M perchloric acid, potassium dichromate gives a spectral scan containing characteristic peaks at 257 nm and 350 nm, and troughs at 235 nm and 313 nm. Starna Potassium Dichromate references are available in a range of concentrations: 20, 40, 60, 80, 100, 140, 160, 180, 200, 240 and 600 mg/l and 0.001 M perchloric acid blank, in UV quartz cells that have been permanently sealed by heat fusion. Absorbance values are certified at 235, 257, 313, 350 nm (20 to 240 mg/l), and 430 nm (600 mg/l). Typical absorbance values available range from approximately 0.1 A to 3 A depending on the concentration and wavelength used.

These references can be supplied individually or in any combination.

Starna Neutral Density glass filters are recommended for the visible region (440 nm to 635 nm) Schott NG-type glasses have been used for over thirty years for the validation of the absorbance scale and linearity of spectrophotometers in the visible region. When manufactured to a specific thickness, filters with a range of transmission and absorbance values can be produced. The spectral scan of these materials is essentially flat. Starna ND filters are usually supplied in sets of three filters of varying transmission together with an empty aluminium holder, to be used as a blank. Absorbance and Transmittance values are certified at 440, 465, 546.1, 590 and 635 nm and the full range of filters covers nominal values from 0.03 A to 3.5 A.

For those working outside these wavelength limits, including in the Near Infra Red, more Reference Materials are available from Starna. While not prescribed for Pharmacopoeia compliance, they are widely recognised as absorbance references. These include nicotinic acid solutions for the far UV (210 to 260 nm), Starna Metal-on-Quartz filters (250 to 635 nm) and Starna Green Broadband Qualification References (250 to 650 nm) for instruments with wider bandwidths up to 20 nm, which can also be used as wavelength references. Metal on Quartz filters optimised for the NIR are also available and can be calibrated at wavelengths up to 2500 nm.
Quality Assurance in the Analytical Laboratory

Wavelength Calibration

Accurate wavelength calibration is fundamental to good analytical results by UV/Visible/NIR spectrophotometry. Most methods involve measurements at absorption maxima in the spectrum of the substance being measured, so clearly if the wavelength calibration of the instrument is incorrect, errors can be introduced. The sharper the absorption band being measured, the greater the error is likely to be. The absorption bands encountered in Visible spectrophotometry are often quite broad, so minor wavelength errors may not seem too important at first sight, particularly if analytical standards are being used to calibrate the analysis. It is likely, however, that when wavelength errors exist, problems will be encountered when comparing results between laboratories and certainly when extinction coefficients are being determined or used to derive concentration values. Calibration at the exact wavelength required for measurement may not be possible as no standard may be available, but wavelength calibration should certainly be checked at more than one wavelength, ideally bracketing the wavelength to be used for analysis. In some UV instruments, the facility exists to use an emission line (or sometimes two) from the installed Deuterium lamp to check the wavelength calibration. In principle these are the best possible standards as they are fundamental atomic lines, but only two usable lines are available, both in the visible region at 486.0 and 656.1 nm. Even if both are used, they could not be said to qualify the UV range of the instrument.

A variety of Wavelength CRMs is available from Starna to cover wavelengths from the far UV to the NIR. Solutions and solid filters containing rare earth elements are particularly useful, as these elements have sharp absorption bands in the UV, visible and NIR regions of the spectrum. The most popular is holmium oxide, either incorporated into a solid filter or as holmium oxide solvated in perchloric acid and sealed by heat fusion into a quartz cell. The solution offers 14 certified peaks from 240 to 650 nm and the filter 11, from 270 to 640 nm. "Didymium", a mixture of neodymium and praseodymium, is also popular and can be presented as a filter (11 peaks from 430 to 890 nm) or as a solution reference (14 peaks from 290 to 870 nm). Samarium Perchlorate is particularly useful for wavelengths from 230 to 560 nm, as it has 14 sharp peaks in this widely used region of the spectrum. For the Far UV, a special Rare Earth reference cell has been developed having 5 certified peaks between 200 nm and 300 nm. Starna’s NIR reference has 13 certified peak values between 950 nm and 2550 nm. As noted above, Starna Green is a convenient reference material for qualifying instruments with wider bandwidth, and has certified wavelength values at 257, 416 and 630 nm.

Stray Light

Stray light, also called Stray Radiant Energy or Power, is any light reaching the detector that is outside the SBW selected for analysis by the monochromator. It can be due to optical imperfections or stray reflections within the monochromator itself or to light leaks or other effects in the rest of the optical system. As the detector cannot discriminate between the analytical wavelength and the stray light, the stray light contributes to the detector signal and introduces an error in the measured absorption.

The stray light is not absorbed even at high concentrations of the absorbing species, so its effect is a negative deviation from the linear relationship between concentration and absorbance (the Beer-Lambert law) on which most quantitative determinations are based. (Fig. 2).

The usual way of assessing stray light is to measure, at the desired analytical wavelength, a sample that totally absorbs the radiation at that wavelength, but transmits at all other wavelengths. Any light detected by the instrument is then stray light. Practically, the usual method is to use cut-off filters or solutions that cut off all light near the analytical wavelength. The test for stray light is important even if the spectrophotometer is not used in the far UV, because it is an excellent indication of the overall performance of the instrument optics, grating, and deuterium lamp.

There are two methods of measuring stray light that are recognised by regulatory authorities. In the traditional method, the ASTM 387 Specified Wavelength Method, liquid filters with sharp transitional (cut-off) spectra are measured against a water blank. This method is approved by most Pharmacopoeias. A range of solutions is available to assess stray light at different wavelengths (Fig. 3).
The alternative method, known as the Filter Ratio or Meilene method, has been adopted by the US Pharmacopeia (Chapter <657>, May 2015). The same solutions are used, but in this case the test solution, in a 10mm cell, is scanned against a 5 mm cell containing the same solution. The resulting spectrum is in the form of a peak. The peak wavelength may shift slightly depending on the optical characteristics of the instrument, but the absorbance level at the peak is a measure of the stray light. Fig 4 shows spectra of a potassium chloride solution run on three different instruments. The USP states that the absorbance value at the peak should be greater than 0.7A, so in this case all three instruments meet the specification.

Resolution

Resolution is the ability of the instrument to discriminate between two adjacent absorbance bands. This is usually described in terms of the Spectral Band Width (SBW) of the instrument, which describes the range of wavelengths coming from the exit slit of the instrument’s monochromator. As SBW increases, the measured peak absorption decreases and spectral detail is reduced and eventually obscured completely (Fig.5).

Clearly, the smaller the SBW, the more accurately the instrument will measure the true absorbance of the absorption band. Sensitivity to the analyte will also improve. For the instrument the SBW is defined as the width, at half the maximum intensity, of the band of light leaving the monochromator, see Fig 6.

Fig.6 Spectral Band Width - definition

The accuracy of the measured absorbance will depend on the ratio of the SBW to the natural bandwidth (NBW) of the absorbing substance. The NBW is the width of the sample absorption band at half the absorption maximum. As a general rule, for satisfactory measurement the SBW of the instrument should be 10% or less of the NBW of the absorption peak being measured.

This might suggest that a narrow SBW should always be used, but this invariably means the use of narrow slit widths. Narrow slits will also reduce the energy throughput and hence may adversely affect the signal-to-noise ratio and hence the precision of the measurement. As SBW can have a significant effect on analytical performance it is usually specified in the analytical method. The SBW of an instrument is usually quoted in the manufacturer’s specification, but may need to be verified by testing against a suitable Reference Material, particularly if repairs or maintenance have been performed on the instrument’s optical system.

The most widely used reference for qualifying the bandwidth of a spectrophotometer is a solution of 0.020% toluene in hexane. This is supplied in a permanently heat-sealed quartz cell, with a hexane blank. Another approach is the Starna benzene vapour reference. This contains 0.01ml of benzene, which at room temperature is in the vapour state, sealed into a UV quartz cell. At spectral bandwidths less than 1 nm, the benzene vapour spectrum has characteristic features that may or may not be displayed, dependent on the SBW of the spectrophotometer. Note that benzene vapour will not work well with photodiode array spectrophotometers as these instruments do not measure a continuum and the peaks may not be resolved well enough to be useable. A toluene in methanol reference is also available for instrument resolution validation when using derivative spectroscopy.

Starna Certified Reference Materials for UV, Visible and NIR Spectrophotometry - A User Guide
Quality Assurance in the Analytical Laboratory

Starna Reference Materials - Certification

Descriptions of all the Starna Reference Materials described in this Guide will be found in the Starna catalogue “Certified Reference Materials for UV and Visible Spectroscopy” that accompanies this Guide. Actual certified measurement values are given in the certificates supplied with each material. These certificates are now supplied in USB format so that they can be printed on demand and the digitized information can be easily integrated with the laboratory’s IT system.

Information provided on the certificate includes:
- Certificate Date
- Certificate Number
- Expiration Date
- The serial numbers of the individual cells or filters that make up the set and of the set itself
- These data are on all pages of the certificate to assist with traceability
- A description of the reference material
- The certified measurement values together with the “uncertainties” in these values due to the calibrating instrument and the analytical processes involved in the calibration.
- Details of the qualification of the calibrating instrument including the references used.
- The method used to generate the certified values on the certificate.
- Instructions for use

Duration of certificate: The certificate is valid for a maximum period of two years from the date of issue or sooner if specified by the user’s own protocols. After this period the Reference Material should be re-certified.

Re-certification Procedure: All Starna Reference Materials can be re-certified at the Starna calibration laboratory, normally within 5 days of receipt. Starna can also undertake the certification of other suppliers’ Reference Materials.

Guidance on the care and storage of reference materials.

Instrument Dependencies: any characteristics of the instrument being tested that could affect the measured result, such as SBW.
Selection of Reference Materials

The following table gives an indication of the reference materials accepted for qualification measurements by a number of national and international regulatory authorities.

<table>
<thead>
<tr>
<th>Parameter Tested</th>
<th>Wavelength Region</th>
<th>EP</th>
<th>DAB</th>
<th>USP</th>
<th>ASTM</th>
<th>TGA</th>
<th>BP</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photometric Accuracy</td>
<td>UV</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Potassium Dichromate solution</td>
</tr>
<tr>
<td></td>
<td>Visible</td>
<td>●</td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Potassium Dichromate solution</td>
</tr>
<tr>
<td></td>
<td>Visible</td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Neutral Density Glass filters</td>
</tr>
<tr>
<td>Wavelength Calibration</td>
<td>UV/Visible</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Holmium Oxide solution</td>
</tr>
<tr>
<td></td>
<td>UV/Visible</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Holmium Oxide glass filter</td>
</tr>
<tr>
<td></td>
<td>Visible</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Didymium Glass filter</td>
</tr>
<tr>
<td></td>
<td>Visible</td>
<td>●</td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Didymium Oxide solution</td>
</tr>
<tr>
<td></td>
<td>Far UV</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Rare Earth Oxide solution</td>
</tr>
<tr>
<td></td>
<td>UV/Visible</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Samarium Oxide solution</td>
</tr>
<tr>
<td></td>
<td>UV/Visible</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Toluene in Hexane</td>
</tr>
<tr>
<td>Stray light</td>
<td>UV/Visible</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Stray Light Cut-off filters</td>
</tr>
<tr>
<td>Resolution/ Bandwidth</td>
<td>UV/Visible</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Toluene in Hexane</td>
</tr>
<tr>
<td></td>
<td>UV</td>
<td>●</td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Benzene Vapour</td>
</tr>
</tbody>
</table>

Table 1 – Qualification References

**Key:**

EP (Ph.Eur.): European Pharmacopoeia  
DAB: Deutsches Arzneibuch (German Pharmacopoeia)  
USP: United States Pharmacopoeia  
ASTM: American Society for Testing and Materials  
TGA: Therapeutic Goods Administration (Australia)  
BP: British Pharmacopoeia
Other Reference Materials available from Starna suitable for the qualification of UV–visible spectrophotometers include:

<table>
<thead>
<tr>
<th>Parameter tested</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photometric Accuracy from 250 nm to NIR</td>
<td>Metal-on-Quartz filters</td>
</tr>
<tr>
<td>Photometric Accuracy in far UV</td>
<td>Nicotinic Acid solution</td>
</tr>
<tr>
<td>Photometric Accuracy and Wavelength in UV, Visible and Near IR, instruments with SBW &gt;3 nm</td>
<td>Starna Green Reference</td>
</tr>
<tr>
<td>UV &amp; Visible Wavelength</td>
<td>Didymium solution</td>
</tr>
<tr>
<td>Near IR Wavelength</td>
<td>“Near IR Solution”</td>
</tr>
<tr>
<td>UV, Visible and NIR Wavelength &amp; Absorbance, Instruments with SBW &gt;3 nm</td>
<td>Starna Green Reference</td>
</tr>
</tbody>
</table>

Starna Reference Materials are also available for the qualification of spectrofluorometers and well-plate readers and as Nucleic Acid and Drug Stability references.

Certain reference materials are available in convenient sets for particular applications.

**Useable Ranges of Reference Materials**

![Useable Ranges of Reference Materials](image_url)

**Fig. 6 Usable ranges of reference materials**