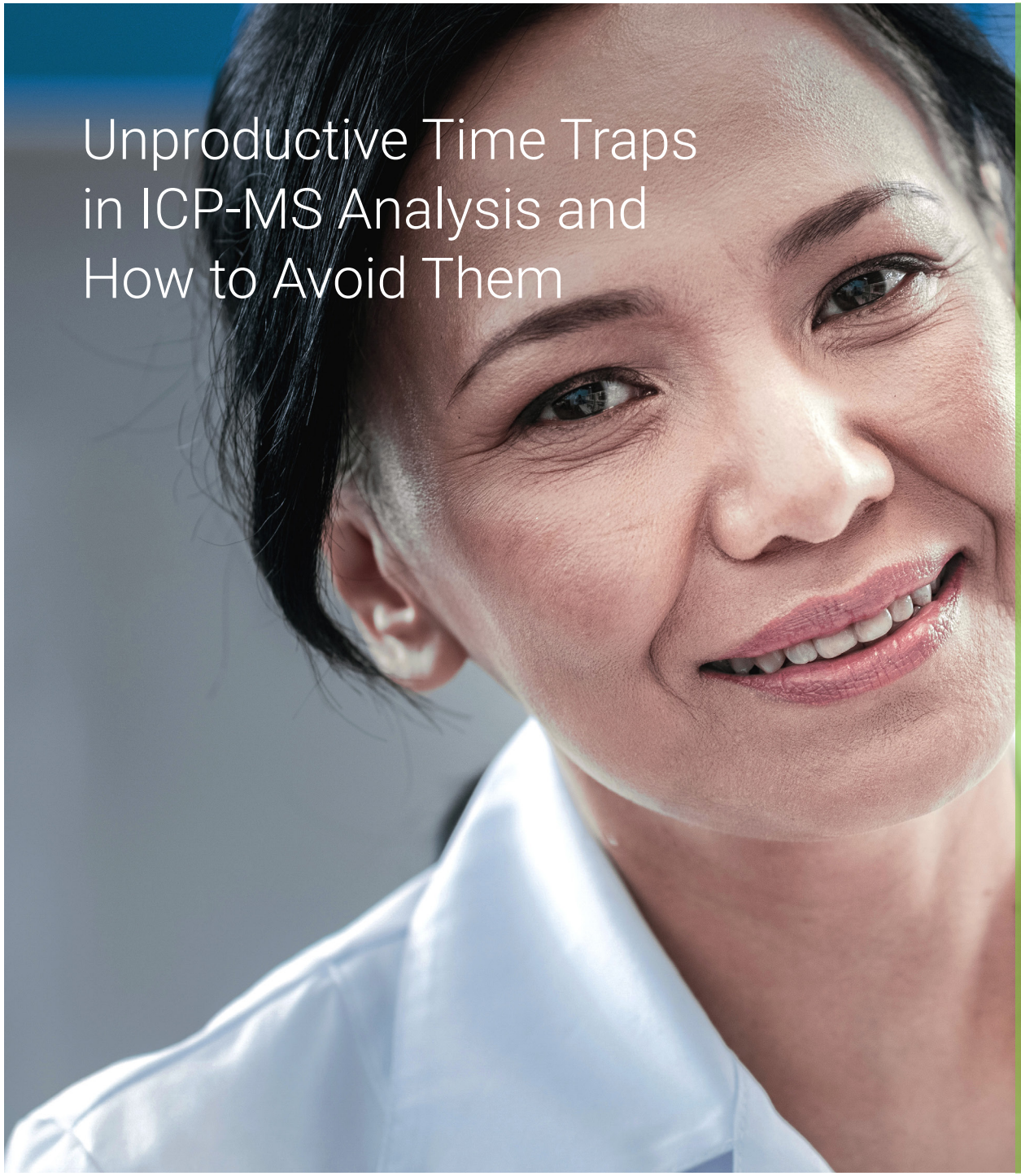
Unproductive Time Traps in ICP-MS Analysis and How to Avoid Them

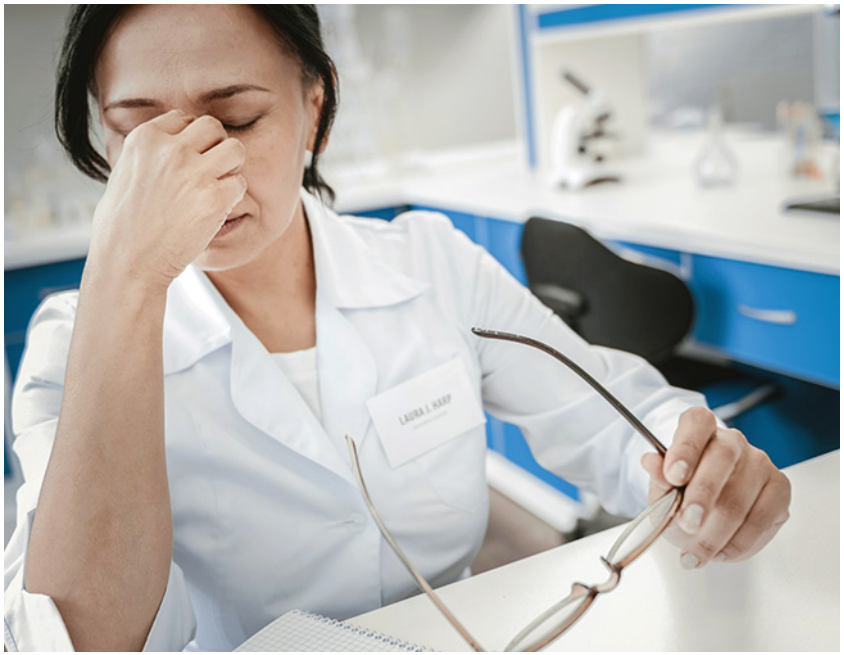


Agilent

Trusted Answers

Time Traps in the ICP-MS Workflow

Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) is a well-established technique for the measurement of trace and major elements in a range of sample types. ICP-MS is used in industries including food, agriculture, environmental, geochemistry and geology, materials and semiconductor, petrochemical, life science, clinical research, and nuclear energy.



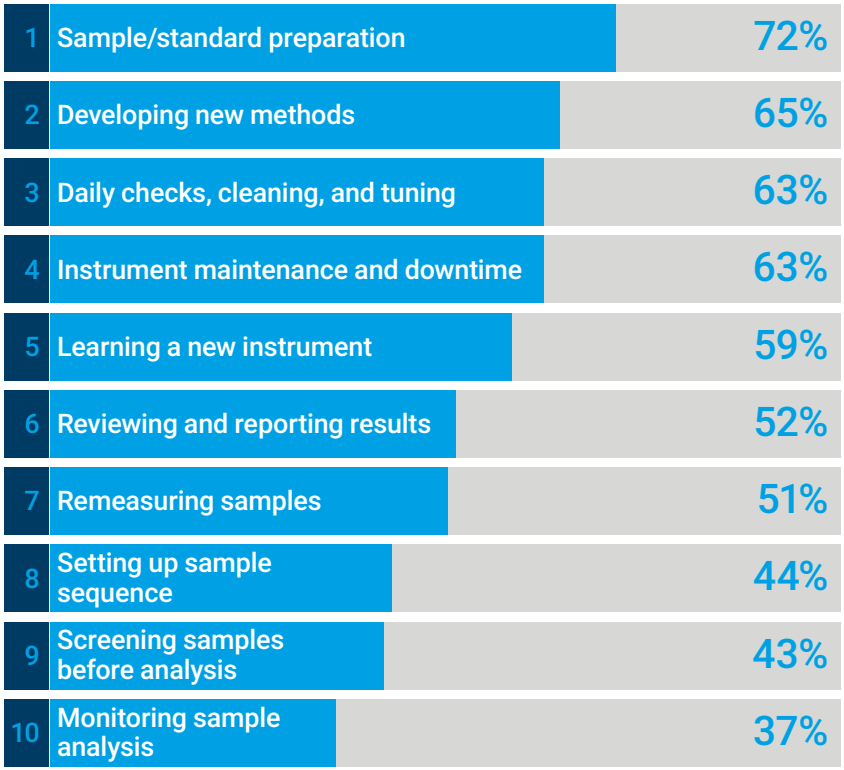
ICP-MS is known for its high sensitivity, matrix tolerance, and ability to measure elements over a wide range of concentrations. Simple spectra and reliable control of interferences make ICP-MS the technique of choice for routine and regulated applications, from drinking water and environmental monitoring to food safety and pharmaceutical manufacturing.

Many laboratories are seeking to switch from another atomic spectroscopic technique to ICP-MS or want to upgrade their ICP-MS to achieve better detection limits and higher sample throughput. Labs new to the technique may perceive ICP-MS as difficult to learn, difficult to use, and expensive to operate and maintain. These perceived difficulties may even discourage some from adopting the technique.

Labs that already use ICP-MS can sometimes struggle with optimizing methods and workflows, but many assume this is an inevitable part of setting up and running an ICP-MS. For labs that have not optimized their ICP-MS methodology, unproductive and often unnecessary activities—time traps—can impact productivity and profitability. These time traps can cost more than just lost time. Employees overburdened by manual method setup, instruments checks, and having to repeat analyses may feel dissatisfied at work and are more likely to make mistakes. Mistakes can lead to reanalysis, impact sample turnaround time, and affect the quality of the results reported. This can put a lab's reputation at risk.

Top time traps

A recent online poll[1] asked lab managers to rank common time traps that have the most impact on their ICP-MS analysis. Here are the results.



You may think these time traps are an unavoidable part of ICP-MS analysis; something you must accept in your daily operation. But there may be a better, more efficient way to perform your analysis. A way that could make your life easier, your employees happier, and your results more reliable.

Like most sophisticated scientific techniques, a degree of knowledge and experience is required to achieve accurate and reproducible results using an ICP-MS. Fortunately, as instruments become more automated, the level of expertise required to perform an analysis is reduced. Modern ICP-MS instruments contain predefined method templates, auto-optimization routines, performance checks, and self diagnostic sensors and monitors. These built-in capabilities replicate the level of expertise that would previously have required an experienced operator.

But it is not only the instrument's capabilities that help. Laboratory processes can be improved by making simple changes to how you do your analyses.

This e-book examines the common time traps that affect routine ICP-MS analysis and offers solutions to minimize their impact or avoid them altogether.

1. Poll conducted in September 2020 by Agilent. A ranking of 100% represents all respondents ranking that time trap as the most significant.

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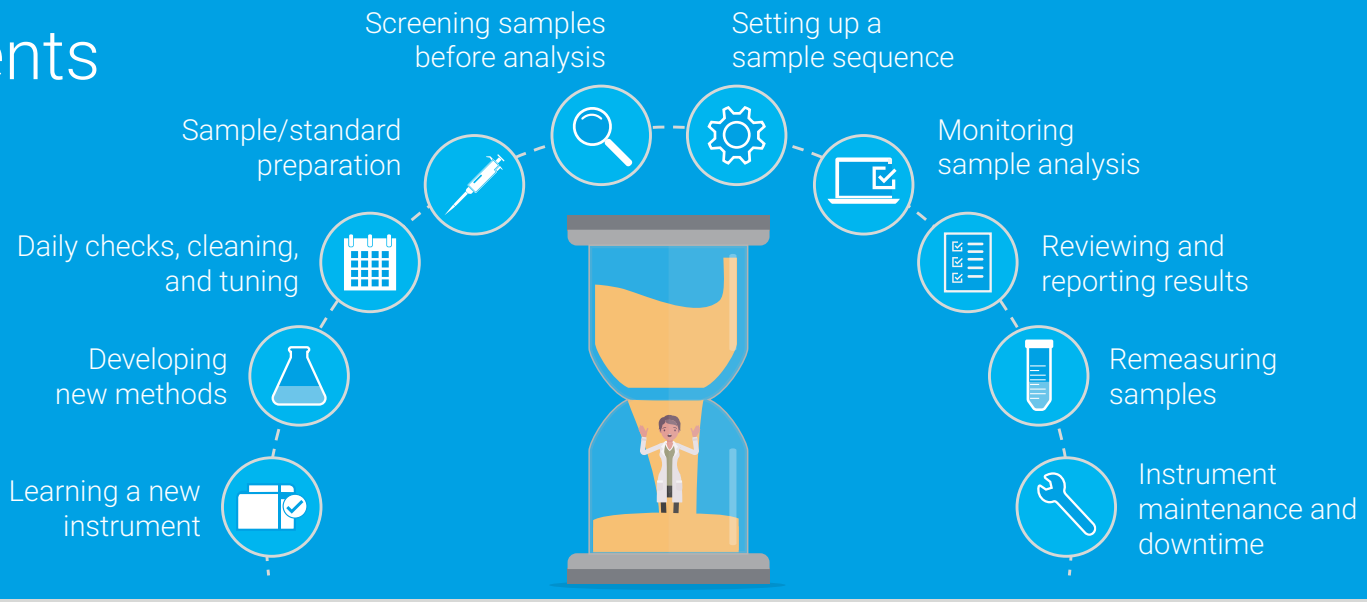

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Learning a new instrument

The time trap

Users who are new to ICP-MS often assume that the technique will be difficult to learn and operate. The same applies to users who are familiar with one brand of ICP-MS and are not sure an alternative brand will be as easy to use. It is true that an ICP-MS, in common with other advanced analytical instruments, requires some time to learn to use effectively. But modern ICP-MS instruments offer software interfaces and workflow solutions that can make the learning process much shorter and simpler.

Some labs will keep running old equipment or they'll replace an aging instrument with another of the same type, just to avoid having to learn something new. Often labs work around the limitations of their old equipment, thinking this is an easier solution than installing a newer instrument. But commercial labs compete for business, and there may be a bigger cost to retaining old equipment that does not perform as well as a newer system installed by a competitor lab. A more capable instrument could offer the ability to run samples that you can't currently measure. It could also improve analytical speed and accuracy and allow your business to expand to support other industries. The most recent ICP-MS systems include features to simply the process of setting up the instrument and transferring existing methods from older equipment.

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The solutions

Asking the right questions when selecting a new instrument

When you are considering the purchase of a new ICP-MS, these tips may be useful:

- Test the instruments using a range of samples that are representative of what you will be running routinely. Don't assume that all instruments have the same capability and don't just rely on published specifications. Real-world performance differences will be most obvious for the most difficult, complex, high matrix samples. So make sure you test performance for your most difficult sample types.

  Ask the vendor to demonstrate the system in a way that matches your lab's workflow. If you routinely run samples "as received"—without extensive method setup—then ask to see your test samples run that way. It will give you crucial insight into how easy the system will be for you to run.

- Think about how your lab operates. Are your routine samples run by nonspecialist shift-chemists, using a method setup by a more experienced analyst? If so, make sure you check whether there is a simplified interface that can be used to ensure that the routine analysis follows the defined workflow.

- Do your analysts manage several instruments/techniques at the same time? Having an instrument interface that can run on a mobile device such as a tablet will allow analysts to monitor a sample run while they are somewhere else. Having clear visual indicators on the screen that communicate the status of the analysis is also important. You don't want to come back to the lab and find that a QC failed an hour ago and now you have to repeat the measurement of many samples.

- During the demonstration, determine what method settings (if any) will need to be changed for different sample types. If your lab runs a range of different sample types, having to adjust multiple method settings each time your sample type changes will be a huge time trap.

- The support and training available from the vendor are also important considerations. Is in-person training available in your lab soon after your instrument is installed? Can you access remote support to help with problems later, or do you have the wait for a service engineer to visit? What is the quality of the support like? Another consideration is ongoing training and education. Check each instrument manufacturer's website to determine what training and education courses they offer, how frequently they run and if they are online and/or in classroom. If they are in classroom, are they near your location?

Accessing free training

'How to' videos are often available on youtube.com or other websites. These are a great source of training and information. For example, Agilent has a suite of ICP-MS videos on Youtube.

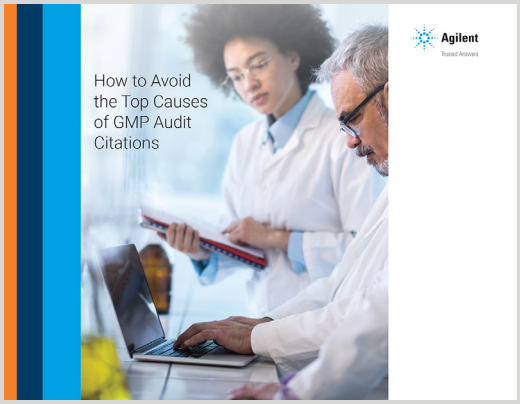
Using all the resources provided with the instrument

Most new instruments are supplied with a wealth of information and tools to make it easy for the new user. The Agilent 7850 instrument, for example, includes videos and 'How-to' guides in an extensive Help and Learning center that is part of the instrument software. There's also an extensive ICP-MS Resource Hub that includes a lot of great information for new and experienced users alike.

Instruments are also often supplied with ready-to-use methods (and/or method development tools) that take the guess work out of method development. These methods predefine most of the method parameters that new users can struggle with, such as isotope selection, internal standard selection, which cell gas mode to use, and what integration time to set, etc. Using a predefined method simplifies and shortens the time to develop new methods, and reduces the likelihood of method setup errors.

Documenting routine workflows using SOPs

Good documentation can really help analysts learn a new instrument quickly. A standard operating procedure (SOP) should include clear, step-by-step instructions with lots of images as well as tips to overcome common problems. Instrument vendors such as Agilent can provide prewritten SOP templates for common ICP-MS analyses that you can use or modify to suit into your company's SOP template. Writing a good ICP-MS analysis SOP from scratch can take weeks, so being able to use an existing template is a huge time saving.



How to write SOPs that work

Written for the pharmaceutical industry, but applicable to all labs that use SOPs, this eBook shows you how to:

- Write an SOP that can easily be read and understood
- Balance compliance needs with creating a useful SOP
- Test your SOPs and ensure consistency

Download the eBook

Developing new methods

The time trap

It can take a long time for a lab to develop, optimize, verify, and document a new ICP-MS method, particularly if they are not familiar with the technique. Performance testing and documenting methods for regulatory compliance adds more work, with the whole process taking several weeks or even months. Where do you start if you are developing a new method or installing a new ICP-MS system that you are not familiar with? How can you reduce the time it takes?

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The solutions

Use proven, existing methods

A new ICP-MS instrument may include predeveloped method templates. The Agilent 7850 is supplied with predeveloped or "preset" methods for many applications including EPA 6020, 200.8, and ISO 17294 for environmental samples, and USP/ICH/ChP methods for pharmaceutical manufacturing. The 7850 also includes general methods with optimum settings for samples with different matrix levels, which you can modify to suit your specific analytes, internal standards, and sample introduction settings. Once any modifications have been applied, the method and parameters and related information such as calibration levels and QC settings can be saved as a 'batch file'. Batch files can be used as a template for subsequent sample batches, saving significantly on setup time. The batch file ensures method settings will be applied consistently, even when a different analyst is running the instrument.

ICP-MS instruments may even be supplied with a method that had been developed specifically for you. If you send samples or take samples with you to a demonstration of the ICP-MS, the vendor's applications chemist may be able to save the method used for the analysis as a template. This template can be provided to you or loaded on to your system during installation, giving you a working method with proven performance for your samples.

If relevant method templates were not supplied with your instrument, you can access published methods on the US EPA, AOAC official methods of analysis and ASTM methods websites. You'll need to fine tune these for the instrument you are using, but they are good starting points. Access online communities, such as the Agilent community (community.agilent.com), to ask questions and learn from others who have created similar methods. Published application notes on instrument vendor websites are another useful source of information. Finally, most instrument vendors can offer a method development consultancy service, which may be a good solution if your samples or methods are particularly unusual.

Defining a new method

Whether you are using an existing or predefined method template or starting from a blank sheet, certain parameters are critical for the long-term success of the analysis. Among the most important are ensuring the method is setup correctly to handle the matrix level of the samples being measured, and to deal with any spectral overlaps.

Matrix tolerance of any ICP-MS is determined by the robustness of the plasma, which you monitor using the CeO/Ce ratio. Make sure that the plasma conditions defined in your method are appropriate to handle the sample types and matrix levels you will be analyzing. Higher matrix samples need more robust (lower CeO/Ce) plasma conditions. Running with lower robustness than required will lead to long-term issues with matrix deposition, shorter maintenance intervals, signal drift, QC failures, and sample reruns.

Verify method performance using standard reference materials

Verifying method performance by analyzing Certified or Standard Reference Materials (CRMs/SRMs) is a good way to determine if your method is producing accurate results. There are many suppliers of these materials, covering a wide range of sample types, so you will most likely be able to find one that is close to the matrix of your samples.

To check the sample preparation as well as the analytical performance, the reference material should go through the same sample preparation process as your samples. The reference material is then added to each sample batch and analyzed in the same way as the unknowns. If your method produces results that match the certified values for each element in the reference material, it is a good indication that your sample preparation is giving good recoveries. Achieving accurate results for the reference material also confirms that your calibration is accurate.

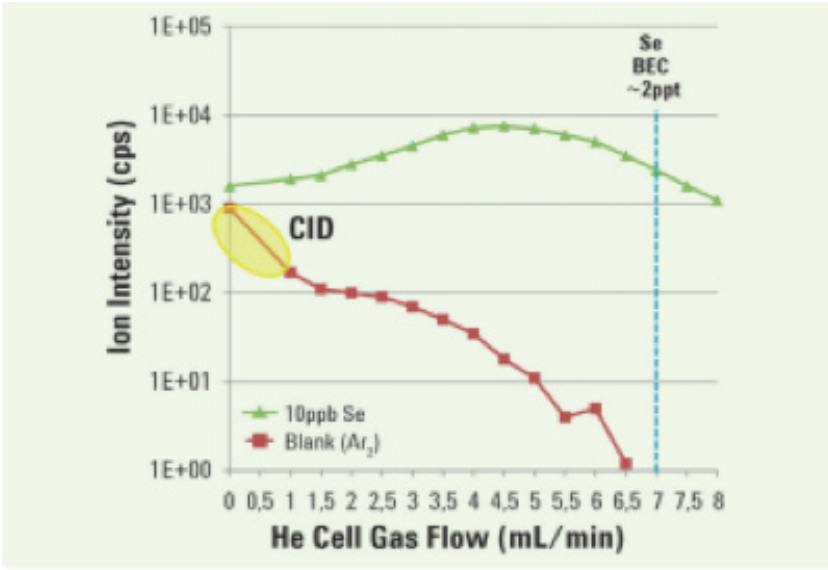
Use helium mode to control polyatomic interferences

Controlling polyatomic interferences is a critical requirement in most ICP-MS methods. Interferences can be problematic in food and environmental applications, where sample matrices are often high, variable and complex. Agilent ICP-MS systems provide a simple and reliable solution to common polyatomic interferences by using a collision/reaction cell (CRC) that is optimized for helium (He) collision mode.

Most collision/reaction cells (CRCs) can be used in either collision or reaction mode, although the cell design may provide better performance for one or the other mode. The mode (collision or reaction) depends on whether an inert gas (such as He) or a reactive gas (such as H_2, O_2, NH_3, etc.) is added to the cell. For routine, multielement analysis, (He) collision mode is much more universal than any reactive cell gas, making He mode much more suitable for multielement analysis and for variable and unknown sample types.

He mode uses kinetic energy discrimination (KED) to filter out polyatomic ions while allowing atomic ions to pass through the cell. KED is a physical process that makes use of the fact that polyatomic (molecular) ions have a larger cross-section than atomic ions of the same mass. As a result, the polyatomic ions collide more frequently with the cell gas and lose more energy, so they can be rejected using a bias voltage at the cell exit. He collision mode is effective for all typical polyatomic ion overlaps, so it works for most elements and it can be applied to a wide range of sample types with complex and unknown matrices. Common, matrix-based polyatomic interferences are removed, allowing access to the preferred isotopes of all typical analytes. He mode also removes the common polyatomic overlaps on secondary, qualifier isotopes. Measuring qualifier isotopes adds a few seconds to the analysis time but enables you to confirm the result reported using the primary isotope. The use of secondary isotopes is even recommended in some regulated methods in the environmental and pharmaceutical industries, where the additional isotopes are used to give confirmatory results.

Using a single helium mode in the CRC saves a lot of time by simplifying method setup, and also reduces the sample-to-sample analysis time. If you use a different cell gas for different analytes, there is a delay while the cell is evacuated and the cell gas is changed. This adds considerable time to the total analysis, compared to using helium for all analytes.



The reduction of Ar_2 interference on Se is a good example of how helium mode can reduce a polyatomic interference. At a helium flow rate of 7 mL/min, Ar_2 is reduced to a level where it makes minimal contribution to the signal of ^{78}Se.

While it is effective for common polyatomic overlaps, He mode cannot resolve isobaric overlaps or doubly-charged interferences. And for ultra-low analyte levels and for unusual overlaps, a reaction gas may provide more effective removal of interferences and so lower detection limits. Reaction mode is not, however, generally applicable to multi element analysis on single quadrupole ICP-MS. On a single quadrupole ICP-MS, reaction gases can create new errors, for example by forming reaction product ions that overlap other analytes.

The ability to control reaction chemistry in the collision/reaction cell is one of the big benefits of a triple quadrupole ICP-MS (ICP-QQQ). ICP-QQQ uses an additional mass selection step (Q1) to control the ions that enter the cell and react, eliminating the overlaps that can affect reaction modes on single quadrupole instruments.

Note: The US EPA does not currently allow the use of cell gases when measuring drinking water using Method 200.8. Cell gases are permitted when measuring other sample types, such as ground and waste waters, where the more complex matrix is likely to lead to the polyatomic interferences which He mode removes.

Correct for doubly charged interferences

Certain, relatively unusual combinations of matrix and analyte levels can give rise to doubly-charged ion interferences that are not removed using He mode. Some elements, including barium (Ba) and Rare Earth Elements (REEs) such as Nd, Sm, and Gd, have relatively low second ionization potentials. This means these elements form a small percentage of doubly charged ions in the plasma. Doubly charged ion interferences are much less problematic than polyatomic ions, but they can affect trace arsenic and selenium analysis when a sample contains a relatively high concentration of REEs.
If your application requires trace As and Se analysis, the contribution from doubly charged REEs can be corrected using 'half-mass correction', which is built into the Agilent ICP-MS MassHunter software. If your samples contain Ba or REEs, using half mass correction on your ICP-MS will improve accuracy and reduce detection limits for As and Se.

Select appropriate internal standards

Agilent 7850 preset methods for specific applications include default internal standards (ISTD) that have been found suitable for typical samples measured in that application. For new sample types and generic methods, the selection of appropriate internal standard elements can help ensure accurate and stable analysis. If the ISTD elements are not specified as part of a regulated method, you can use some simple guidelines to help you choose suitable elements, which should be:

- Absent from your samples
- In the same mass range as the analytes they are correcting
- Similar in ionization potential to the analytes they are correcting
- Chemically compatible with your analyte elements, and chemically stable
- Not likely to be affected by any interferences in your sample types[2]
- Not likely to cause interferences on your analyte elements[2].

It is often not possible to find internal standards that are a perfect match for both the mass and the ionization potential of all the analytes, so often a compromise is needed. Simple sample matrices, such as drinking water, can often be analyzed successfully with just one, mid-mass internal standard. Analytical accuracy and stability in complex and higher matrix samples can often be improved by using several internal standards spread across the mass range and with a range of ionization potentials.

2. On a modern ICP-MS, the last two of these criteria can usually be ignored. Any polyatomic ion overlaps on, or caused by, the ISTD elements should be removed using He cell mode.

Mass-to-charge ratio: 66 Mass-to-charge ratio: 66

The quadrupole mass filters used in ICP-MS instruments separate ions according to their mass-to-charge ratio (*m/z*). Since $^{66}Zn^{+}$ and $^{132}Ba^{2+}$ have the same *m/z* of 66, a quadrupole mass filter is unable to distinguish between them.

Full details of how half mass correction removes doubly charged ion interferences can be found in the Agilent technical overview: "Simplifying Correction of Doubly Charged Ion Interferences with Agilent ICP-MS MassHunter"

An ISTD closely matched for mass gives better correction of mass-based signal drift, while a close match in ionization potential gives better correction for ionization suppression. The relative importance of these factors will depend on your sample types and tuning, especially the plasma robustness. A robust plasma will reduce both signal drift and suppression, so the need for closely matched ISTD elements is reduced.

Once the ISTDs and the analyte-ISTD assignments are defined, they can usually be included in a method and written into the sample batch template for subsequent analyses.

As discussed in 'Use helium mode to control polyatomic interferences', using an ICP-MS with a collision/reaction cell that is optimized for He collision mode can resolve most polyatomic interferences, including those on or caused by the ISTD. Operating the plasma under robust (low CeO) conditions also reduces the formation of polyatomic ions. Using these two approaches as part of your method development gives you more choice in selecting reliable internal standard elements.

A simple way to improve chemical stability

For many years, HNO_3 has been the preferred acid used during preparation of samples for analysis by ICP-MS. The use of HNO_3 alone avoids the polyatomic interferences that can form when other acids such as H_2SO_4 and HCl are used. However, the absence of HCl causes numerous problems with several elements:

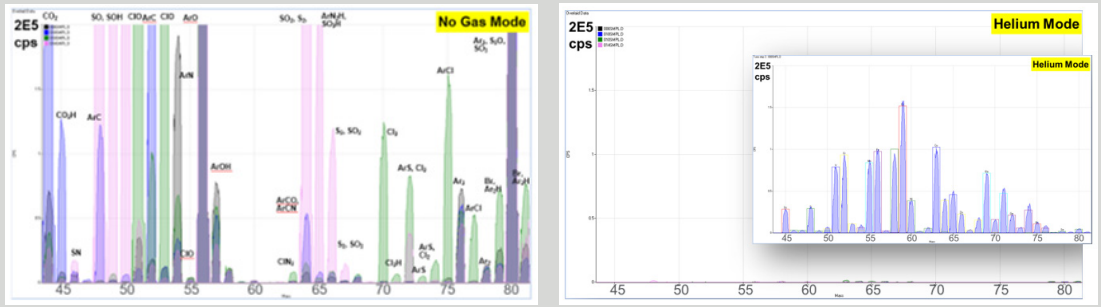
- Poor extraction efficiency during preparation (e.g., Sn in soil extracts).
- Poor stability for many elements (Hg, Sn, Mo, W, Ag, As, Se, PGMs, REEs).
- Poor linearity and stability of many elements in standard solutions due to lack of co-existing ions/ligands.
- Slow wash-in (stabilization) and washout characteristics.

Using an ICP-MS with He collision mode will remove the Cl-based polyatomic ions, allowing you to routinely add HCl to your samples and standards (0.5% minimum). This overcomes the listed problems and is an easy way to simplify sample preparation and method development.

Using collision/reaction mode to deal with polyatomic overlaps

A significant advantage of ICP-MS is its simple spectra. Every naturally occurring element (except In) has at least one isotope (mass) that is free from direct overlap by any other element. These "free" isotopes are usually defined as the preferred isotopes for ICP-MS analysis, even though they are not always the most abundant. In practice, this means that most spectral interferences that affect ICP-MS analysis are due to poly-atomic (molecular) ion overlaps.

Analysts need to be aware that many common polyatomic overlaps are formed from the sample matrix, so interferences vary with sample type and can be difficult to predict. But current ICP-MS instruments can usually deal with polyatomic ions overlaps by using a collision/reaction cell in helium collision mode. The effect of He mode on an array of typical polyatomic ions is illustrated below.



These spectra show the background polyatomic ions formed from several common matrix components, indicated by the color coding: HNO3 (grey), HCl (green), H2SO4 (pink), and isopropyl alcohol (blue). The spectrum on the left shows the intense, matrix-based polyatomic ions present in No Gas mode, while the spectrum on the right shows the same sample measured in helium (He) collision mode. All the polyatomic interferences are reduced to negligible levels in He mode, allowing interference-free analysis. The inset spectrum shows the same mix of matrices spiked with 10 ppb of the first row transition elements, also measured in He mode. Good sensitivity is maintained for all analytes and all isotopes match the theoretical abundance templates.

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Daily checks, cleaning, and tuning

The time trap

Nearly 10% of service calls[3] are due to routine cleaning not having been performed. For some labs, it's clear that improving the scheduling of routine maintenance would help avoid the wasted time of waiting unnecessarily for a service engineer to arrive. There are six areas that analysts should consider for regular cleaning and maintenance on an ICP-MS:

1. The sampling probe and sample uptake tubing
2. The peristaltic pump tubing and pump clamp tension
3. The nebulizer, spray chamber, transfer tube and plasma torch
4. The interface cones
5. The ion lens
6. The vacuum pump oil and air filters

3. Based on Agilent service call data.

The solutions

Avoiding nebulizer problems

A partially blocked nebulizer will cause poor sensitivity, poor precision, and signal drift. The micro-flow nebulizers typically used on ICP-MS systems will not tolerate suspended solids (particulate matter).

To help prevent nebulizer blockages:

- Ensure that samples are digested, filtered, or any suspended particulate material is allowed to settle before analysis
- Rinse for at least 10 minutes with a reagent blank before extinguishing the plasma (this should be configurable in the instrument software)
- Use only lint-free wipes
- Use a nebulizer cleaning tool to back flush the nebulizer with a suitable cleanser. This will dislodge any particle build up and thoroughly clean the nebulizer tip. You can buy one from Agilent using part number G3266-80020

Preventing other glassware problems (spray chamber, transfer tube, and torch)

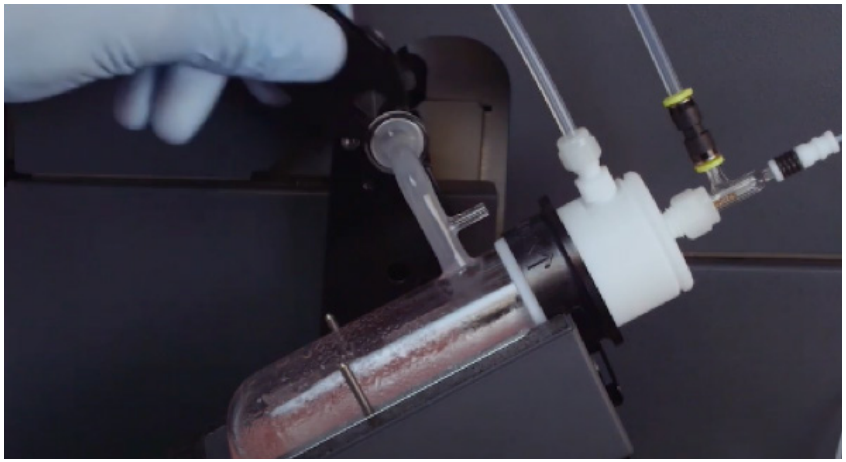
A dirty spray chamber leads to poor precision. Short-term precision can be monitored by from a scheduled Performance Check run before and/or after the analysis, or reviewing the %RSD for the replicates per sample, Medium-term precision can be monitored through the use of a QC solution, although this will only indicate that a problem has occurred, rather than preventing it from happening.

A dirty or contaminated spray chamber leads to poor drainage and uneven aspiration of the aerosol through to the plasma. This issue can be identified by watching how the solution runs down the inside of the spray chamber. The liquid should be running down the spray chamber as a uniform film. If there are droplets running down instead of a film, it shows the spray chamber is dirty.

Samples that contain a lot of organic material such as oils are a particular problem for causing spray chamber contamination. Running samples with high organic content causes variable spray chamber drainage and poor washout. Flushing with clean wash solution for a few minutes at the end of the analysis will flush the spray chamber. Some labs keep a separate set of sample introduction components for use with samples that contain a high level of organic material or high salt matrices. The separate sample introduction components can be installed when needed, preserving the life of the sample introduction system used for more routine samples.

Different types of spray chambers have different washout characteristics, but these should not be considered in isolation. The shorter pathlength and the larger droplet size range of a cyclonic spraychamber[4] means more solution flushes through the spray chamber. This can improve washout, but also increases the matrix loading and the level of oxides formed in the plasma. This leads to a less robust plasma, poorer matrix decomposition, higher interferences, and lower ionization, which may outweigh the washout benefits.

Include glassware cleaning as part of your routine maintenance schedule. If available, it's also useful to run an instrument performance tests at the start and end of each day's analysis. This will allow you to easily monitor system performance to ensure the ICP-MS is passing manufacturer's specification.



Excessive droplet formation inside the spray chamber is one of the signs that the spray chamber may require cleaning.

4. Cyclonic spraychambers are not required for Agilent ICP-MS instruments.

To help analysts to manage their maintenance schedule, the Early Maintenance Feedback (EMF) function of the Agilent ICP-MS software can be used to set alerts to perform routine maintenance tasks such as cleaning the spray chamber. If you are running oils, food samples, or other high matrix samples, you can adjust the EMF timers to suit the required maintenance intervals for your particular sample types. Similarly, if you analyze cleaner samples you can set the timer to a longer interval so you don't waste time performing maintenance necessarily.

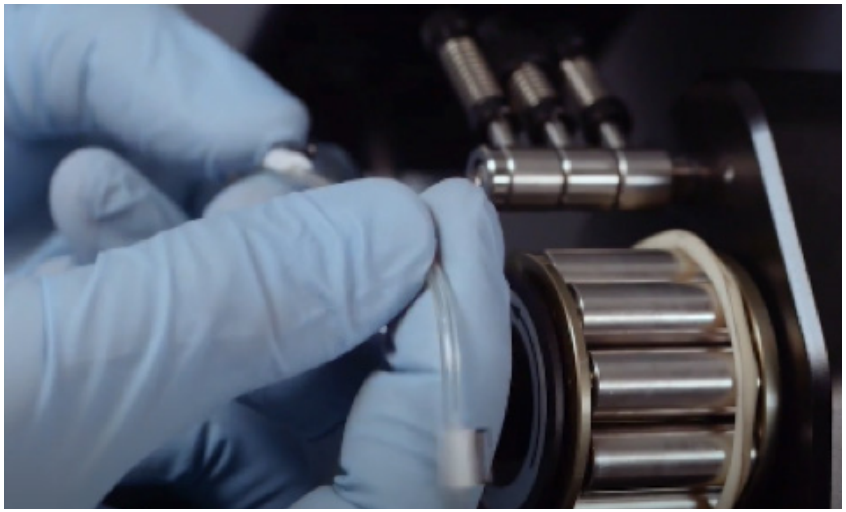
Caring for pump tubing

Pump tubing wear is an underappreciated problem in many labs. Analysts will often leave worn tubing in place, not realizing the impact it has on data quality. Pump tubing that is not replaced when necessary can cause signal instability, drift, and inaccuracies, as well as causing chemical stability issues such as slow wash-in and analyte carryover. Replacing worn tubing is a simple and inexpensive maintenance task, but replacing pump tubing more frequently than necessary increases consumables costs and wastes time.

Leaking connections, incorrect tension, and air bubbles are problems that can occur with poorly maintained uptake and pump tubing. Under pressure analysts may occasionally forget to reclamp the peristaltic pump tubing before starting a sample run , or even install the drain pump tubing the wrong way round.

Worn, leaking, or maladjusted peristaltic pump tubes will cause poor sensitivity and drift during the analysis as the pumping efficiency of the worn tubing changes with use. Both precision and drift can be monitored through QC solutions, but they are often spaced 30-40 minutes apart, so waiting for a failed QC solution to address an issue wastes a lot of time, especially when you need to go back and remeasure samples that had been measured since the last valid QC.

Regular routine maintenance prevents the occurrence of peristaltic pump tube problems. Checking the tube's elasticity, roundness, connection, and tension at the start of each day, or after a certain number of samples, is important—if in doubt about the condition of the tubing, change it. Regular checks reduce the risk of having to remeasure samples due to pump tubing problems. It's also a good idea to precondition new tubing before use.



Regular checks of the peristaltic pump tube for wear, discoloration, flexibility, and roundness, help ensure the sample is delivered to the nebulizer smoothly and consistently, without pulsing.

When installing new tubing, ensure it is stretched evenly over the pump rollers, and don't overtighten the tubing. Adjust the pressure on the tubing to deliver a smooth, even sample flow, and run blank solution through new tubing for a few minutes to clean and condition the inside surface.

Most instruments have a function that rotates the pump at extremely low speed while the instrument is idle, for example after completion of an unattended overnight run. This stops the tubing forming flattened sections where it sits on the pump rollers. Make sure you utilize this function if your ICP-MS isn't being used constantly.

The Early Maintenance Feedback function of the Agilent 7850 ICP-MS can be used to alert the analyst to perform tubing maintenance tasks. For example, an EMF alert can be set up to remind the analyst to check or change the pump tube on a time-based or sample-based frequency. The alert counter can be set to a value to suit the type of sample matrix. If you are analyzing dilute nitric/hydrochloric acid solutions, you could set the counter to alert after 2000–3000 samples. If you are using a higher acid concentration, you might need to set the alert counter to a lower number, for example every 1000 samples.

For non-typical sample types, you should also consider the type of pump tubing you are using. The sample uptake tubing needs to be chemically resistant to the sample matrix, so organic and aqueous solutions usually need different types of pump tubing. PVC works well for most aqueous and acidic matrices, but it is not suitable for use with most organic solvents. PVC degrades quickly when exposed to many organic solvents so that it doesn't pump properly, and may even break down completely. Many labs that analyze organic solvents avoid pump tubing entirely, and use self-aspiration to deliver the sample to the nebulizer. Regularly checking the elasticity of the tubing is an easy monitoring task. As the tubing degrades, it goes hard, stretches, and loses elasticity.

Running a rinse solution through the instrument and unclamping the tubing and disconnecting the pump tubes (so they are no longer stretched over the pump rollers) at the end of the day is good practice if the instrument is not running samples unattended. These actions will prolong the life of pump tubes. If you leave your sample matrix sitting in the tubes overnight, you may get sample leaching into the tubing, causing contamination of the first samples of the next run and faster degradation of the tubing.

Typically, worn pump tubing will cause an increase in the %RSD as well as poor washout and chemical backgrounds. An increase in RSD of the measured signal can be due to several things, but the ICP-MS may be able to alert you to the potential problem by flagging results that exceed a user-set RSD limit. These flags are displayed using outlier conditional formatting (OCF) in the results table of the Agilent 7850, for example. If an alert is triggered, then you have the opportunity to fix the problem before a lot of samples have been completed and have to be remeasured after changing the pump tubing.

Looking after interface cones and ion lens

Matrix deposition on the interface cones and dirty ion lenses can cause low sensitivity, poor long term precision, and elevated background.

Reduced sensitivity and increased backgrounds are apparent from the normal daily instrument performance checks that most labs run. You can quickly visually inspect the cones if performance results indicate there might be a problem. A magnifier is useful to get a close look at the cone surface. Check for matrix build-up at the tip and if there's any damage or enlargement of the orifice.

If you are running high matrix samples, the matrix deposits on the interface cones will happen more quickly. That's one reason why more robust (lower CeO/Ce) plasma conditions are used for higher sample matrices, to ensure that the matrix is decomposed as thoroughly as possible. With high matrix routine analysis, it is advisable to check the cones every 500-1000 samples and, if deposits are apparent remove the cones and sonicate them in water. Dry the cones and reinstall them in the instrument. Note that clean cones benefit from being conditioned to ensure stability of the next run. After cleaning cones or fitting a new set, it is beneficial to condition them again by aspirating a sample matrix such as a mineral water or matrix standard such as EPA ICS for 10 to 15 minutes.

It's a good idea to clean the cones if you are measuring different sample types where a major element in the first sample type is a trace element in the second. In some cases, it can even be beneficial to use separate, dedicated cone sets for very incompatible sample types. This suggestion can be applied to other components of the sample introduction system as well.

Pumps

The frequency you need to change pump oil and oil mist filters will depend on the type of samples you typically measure. Running high matrix samples or using plasma conditions that do not give adequate decomposition of the sample matrix, will result in more frequent pump maintenance being required.

Reducing instrument tuning frequency

A simple way to reduce the need to retune an instrument when running high matrix samples is to use a robust (high energy) plasma. The high energy of the plasma will decompose the matrix so that it isn't deposited on the interface cones, where it could cause signal drift, which in turn drives the need to retune the instrument.

Using instrument self-health checks

Many ICP-MS instruments have sensors and counters to advise you when maintenance tasks are needed. Refer to 'Getting preventative maintenance right'.

Sample/standard preparation

The time trap

The preparation of samples and standards was voted as the top time trap for ICP-MS analysis in the online poll. Analysts often have to prepare samples at multiple dilutions and use different calibration levels to match the expected concentration range of each element. It's no surprise that sample preparation consumes so much time. Preparation errors, screening samples to assess matrix levels, QC failures, and rerunning samples after overrange results create even more work.

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The solutions

Preventing calibration problems

Calibration problems are a common cause of analytical errors. We often see analysts struggling to work out what's wrong with their results, only to realize that it was caused by a simple error during standard preparation. It could be a pipette that is out of calibration, contamination from poorly cleaned equipment, chemical stability issues, or the accidental selection of the wrong stock solution.

Eliminating human error is key to reducing calibration errors, so good training and documentation can go a long way towards ensuring your lab does not suffer from these issues.

Regulatory bodies like the US EPA are driving good analytical practice. Regulated methods have built-in quality control (QC) that aims to prevent or identify calibration errors. For example, many US EPA methods for environmental samples include both an Initial Calibration Verification (ICV) check solution and a Continuing Calibration Verification (CCV) check. These quality control standards—which are prepared from a different source than the calibration stocks—provide an independent check on the validity of the calibration. Modern instruments will typically provide method templates that predefine these types of quality control standards, along with appropriate QC checks and actions, simplifying method setup. These types of quality control measures can also be used to ensure the accuracy of calibrations for nonregulated methods.

Using an instrument that has a wide linear measurement range also helps reduce the time and effort spent setting up calibrations. Having a linear response over a wide concentration range means you can prepare a single uniform calibration set, rather than needing custom calibrations to cater for different levels of major elements in different sample types. You will be able to measure ppb of an element in one sample and then % levels of the same element in the next sample, using the same calibration. This saves an enormous amount of time, compared to having different calibration sets for each set of sample types.

Preventing over range errors

An over range error occurs when a sample reading is beyond the range of the detector, or above the highest calibration standard for the analyte. If the plasma and detector can tolerate high concentration levels, over range errors can be avoided by preparing a high concentration standard for your upper calibration point. With a 10 or 11 orders dynamic range detector, your highest standard can be up to 100s of ppm for elements you expect to be at high levels in your samples. This extended calibration is an insurance policy against a sample analysis results being over range. Preventing such overrange errors avoids the time trap of having to dilute and remeasure samples.

Some analysts routinely prepare multiple dilutions of each sample to ensure that trace and major elements are within the detector range. A less diluted solution is prepared for the analysis of the trace analytes and a more diluted solution is used to measure the majors. The Agilent 7850 is one instrument that can practically eliminate the need for additional dilution of normal ICP-MS sample types by using a Ultra High Matrix Introduction (UHMI) system. UHMI dilutes the sample aerosol as it passes from the spray chamber to the torch, eliminating time-consuming manual dilutions, and avoiding the expense of a conventional liquid autodilutor. With UHMI, the 7850 can tolerate a range of sample matrices containing up to 25% total dissolved solids (TDS), without having to dilute each sample to a target TDS level. The aerosol dilution settings are calibrated and stored, giving a range of preset dilution factors that can be selected as appropriate for the sample type or types you are measuring.

The Agilent Ultra High Matrix Introduction System (UHMI) easily handles tough sample matrices with up to 25% total dissolved solids (TDS). Use of UHMI reduces sample prep time and error and provides better long-term stability for the analysis.

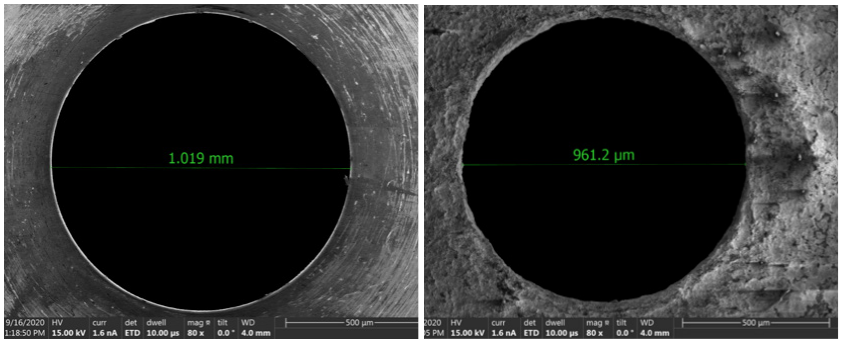
Using an ICP-MS with high matrix tolerance means you can use a standard approach to sample preparation e.g. use an existing ICP-OES sample preparation process for ICP-MS as well. For even greater time saving, an optimized ICP-MS method will often be able to measure all elements at required levels in a single run (majors, traces, hydride elements, and Hg). This removes the need to prepare samples for the different analytical techniques that you might have previously used to measure major elements or the hydrides and mercury. For example, some labs use AAS or ICP-OES to measure elements at high concentrations, and GFAAS or ICP-MS for trace elements. An additional separate technique such as atomic fluorescence may be used for single elements such as Hg that are often thought to be impossible to run on an ICP-MS. Getting all your elemental data from one sample run on one technique represents a huge time saving, reduces errors and contamination, and simplifies lab services, utilities, consumables and even staff training.

Avoiding having to matrix-match standards

When high matrix samples are analyzed by ICP-MS, signal suppression can occur if the energy of the plasma is too low. The plasma must have enough energy to both fully decompose the matrix and ionize the analyte elements. Plasma suppression results in a lower signal (and thus, a lower measured concentration) for analyte elements in high matrix samples.

One approach to address matrix suppression is to try to match the matrix of the calibration standards to that of the samples. There are several problems with this approach, including the fact that the analyst needs to know the sample matrix in advance, which is not always practical in labs running mixed batches of food or environmental samples. Matrix matching standards with an equivalent matrix to your samples is a tedious and time-consuming task and may even require screening of the samples prior to analysis. You can avoid the need for matrix matching by using a more 'robust' plasma. A robust plasma is one that operates at a high energy level. The high energy allows the plasma to both decompose the matrix and still have the energy to generate a consistent level of analyte ions even if the matrix level varies.

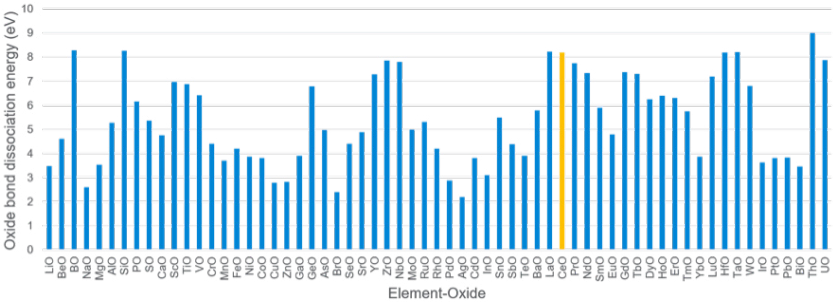
Plasma robustness is also essential for long term stability and matrix tolerance. If the plasma doesn't have enough energy to decompose the matrix, some of the matrix will be deposited on the instrument's interface



These magnified images of the orifice of an ICP-MS sampling cone illustrate the effect of running high matrix samples. The image on the right shows the cone after sample analysis, with matrix deposits causing microscopic changes to the size and shape of the orifice.

cone. The deposits change the shape of the hole in the cone, giving lower sensitivity and more signal drift. The effect is more pronounced for samples that contain a high level of "refractory" (high melting point) minerals such as oxides of Al, Mg, Si, and Ca.

If you often measure high matrix samples or samples of varying matrices, then using an instrument with a robust plasma is essential. The robustness of the ICP-MS plasma is usually monitored using the CeO^+ ratio, measured using the intensity of CeO^+ compared to Ce^+. A low CeO^+ ratio (<1.5%) indicates that the plasma has sufficient energy to dissociate the strongly-bound CeO molecular ion. A plasma with a low CeO ratio gives better decomposition of the matrix and other polyatomic ions, so interferences are lower and high matrix samples can be run for longer with less drift. You also won't have to recalibrate and remeasure samples because your QCs fail due to drift.



If a plasma is robust enough to break the strong Ce-O bond (shown in yellow) then the plasma energy is high enough to dissociate potentially interfering oxide ions. This is why the CeO^+/Ce^+.ratio is used as a measure of plasma robustness.

Avoiding chemical stability problems

Chemical instability can cause analytical problems such as slow wash-in, sample carry-over, unstable internal standards, and non-linear calibrations, amongst other problems. Historically, ICP-MS analysts have frequently had to deal with chemical stability issues. This is due to the combination of ICP-MS being used for the analysis of multiple, sometimes incompatible elements, and analysts striving to avoid creating spectral interferences.

The larger number of analytes measured using ICP-MS, compared to traditional techniques such as GFAAS, means that chemically incompatible elements are often measured together. Early ICP-MS users quickly settled on using only nitric acid for sample digestion and stabilization. Nitric acid (HNO_3) does not contribute any additional spectral interferences in ICP-MS, since H. N, and O are already contributed by water in the sample and the air around the plasma. Other acids such as hydrochloric (HCl) or sulfuric (H_2SO_4) were avoided, as the high levels of Cl and S caused numerous additional polyatomic ion overlaps in the ICP-MS spectrum.

Avoiding HCl has, however, led to its own problems, as many elements are not soluble or stable in nitric acid alone. Agilent ICP-MS instruments now enable the routine addition of HCl for sample/analyte stability, as the Cl-based polyatomic interferences are dealt with effectively using the standard helium mode collision/reaction cell. In fact, helium mode on the Agilent 7850 gives effective and reliable control of all the common matrix-based interferences that are found in typical ICP-MS applications. Note that the US EPA Method 200.8 does not currently allow the use of helium mode when measuring drinking water. It is permitted when measuring other water types, such as ground and waste waters. Drinking water is a relatively simple matrix, so measurement is less affected by the polyatomic interferences which helium mode removes.

Routinely adding HCl to samples for ICP-MS analysis is a quick and easy way to eliminate most chemical stability problems and obtain accurate results. The addition of HCl will even fix the washout problems and stability issues associated with the analysis of mercury. You don't need to prepare a separate sample or run Hg by a separate technique, so overall workflow is much simpler.

Preventing contamination problems

Poor lab practices can lead to contamination problems for any analytical technique, but the contamination may be more apparent at the trace levels analyzed by ICP-MS. If you have used another atomic spectroscopy technique prior to using ICP-MS, you need to be aware of the considerable difference in measurement sensitivity between ICP-MS and say AAS or ICP-OES. Similar considerations apply when migrating methods from a single element technique such as flame AAS or graphite furnace (GF) AAS to a multielement ICP-MS method. Whereas single element standards only need to be certified for the target element concentration, standards for multielement (ICP) analysis also need to be certified as being free from other elements. Mixing multiple AAS standards for ICP-MS analysis can lead to errors due to the presence of other elements as contaminants in the various single element standards.

To maintain low and consistent detection limits, you may have to adjust your approach to rinsing, pipette use, water systems and acid/reagent quality. For example, you may be doing acid digestion in a microwave vessel. If you don't clean the microwave vessel thoroughly between samples, you are going to get carryover that will contaminate the next sample, causing inaccurate results.

Many autosamplers, like the Agilent SPS 4 shown here, can be fitted with a cover to reduce the exposure of your samples to sources of contamination within the lab.

You can detect contamination caused by inadequate cleaning by including a preparation blank with each sample batch. A preparation blank is a blank solution that has been taken through the same sample preparation process as your samples. By setting a QC threshold for the preparation blank, any contamination will be flagged when it is analyzed during the run.

Note that contamination levels should be considered relative to the required reporting limits, not the capability of the analytical technique. ICP-MS can measure most elements at ng/L (ppt) levels. But ppt-level contamination is not relevant or important if you are measuring and reporting analytes at the ppb level or above, as is the case for many common applications.

Contamination can also affect the ICP-MS sample introduction system, causing signal carryover from a previously analyzed sample. An unusually high level of an analyte in one or more samples in the sample batch can lead to contamination of the next sample(s). This carryover effect is particularly noticeable for highly adsorptive or "sticky" elements such as mercury, boron, molybdenum, tungsten, and thallium. These elements stick to the surfaces of the sample introduction system, causing erroneous results in subsequent samples. Using an optimized acid mix for samples and standards can help reduce carryover, for example by including 0.5% hydrochloric acid as well as the usual nitric acid. Similarly, a multi-stage rinse program, where the autosampler probe is rinsed in a basic rinse solution followed by an acid rinse, can help flush sticky elements from the sample introduction.

Automated rinse functions that monitor the signal during the rinse cycle can help prevent cross-contamination. The Agilent 7850 instrument includes an Intelligent Rinse feature that automatically pumps rinse solution until the signal for selected elements drops below a set threshold. Using a switching valve can also help by minimizing exposure of the sample introduction system to a sample matrix.

If you have a completely unknown sample, or one that is an odd color or that smells strange, it is worthwhile performing a semiquantitative acquisition. This will enable you to ascertain what elements are in the sample, and what their approximate concentrations are. The Agilent 7850 has a function called IntelliQuant that performs Quick Scan semiquant analysis on each sample in an unknown batch, adding only 2 seconds to the normal analysis time.

Use an acid dispenser instead of pipettes to reduce the risk of contamination.

You can use the IntelliQuant data to assess whether instrument settings or sample preparation need to be further optimized for subsequent batches of similar samples.

Good laboratory practice can also reduce the risk of contamination from the laboratory environment. Avoid sample contamination from airborne dust by performing all sample preparation and handling in a 'clean bench'. This is usually a fume hood-type bench with a HEPA filtration system. Aim to reduce the number of sample handling steps—such as dilutions—you perform, as each step adds another possible source of contamination.

Reducing any activities that generate dust/particles is also essential, for example by using powder-free nitrile gloves and removing dust-creating equipment (such as printers and water chillers) from the lab.

Here are some key things to consider to reduce the risk of contamination:

- Reagents and laboratory equipment that come into contact with sample solutions can cause contamination. Vials and pipette tips must be metal free (avoid colored pipettes or vials caps, for example).
- NEVER use glass labware for trace element analysis of aqueous or acid samples. Glass contains high levels of many elements that will be extracted into and contaminate your solutions.
- The quality of ultrapure water (UPW) and acids used for sample stabilization or dilution is critical. A lab water purifier that provides a final quality of >18MΩ.cm is recommended, along with ultrapure acids and other reagents.
- Use bottle-top acid dispensers instead of pipettes if you are adding the same acid to a large number of samples.
- Ensure that you are using ICP-MS standards, not AAS standards. ICP-MS standards are certified for lower levels of contaminants, so you won't be introducing other elements in your standard solutions.
- Do not pipette directly from the original standard or acid container. Decant into a clean plastic cup. Do not return unused solution to the original bottle.
- Store your standard solutions correctly and discard any that are out of date.

Reducing transfer steps

Another way to simplify and speed up the preparation of samples is to reduce the number of transfer steps as you move between digestion, dilution, filtration, and analysis.

Some labs do sample digestion in the same tube as they then use in the autosampler. They use a microwave digester or a hot block sample digestion system, transferring the tube that the sample has been digested in straight into autosampler racks for analysis. This eliminates the sample transfer step, reduces the chances of contamination from the additional vessel, and reduced the likelihood of samples being mixed up.

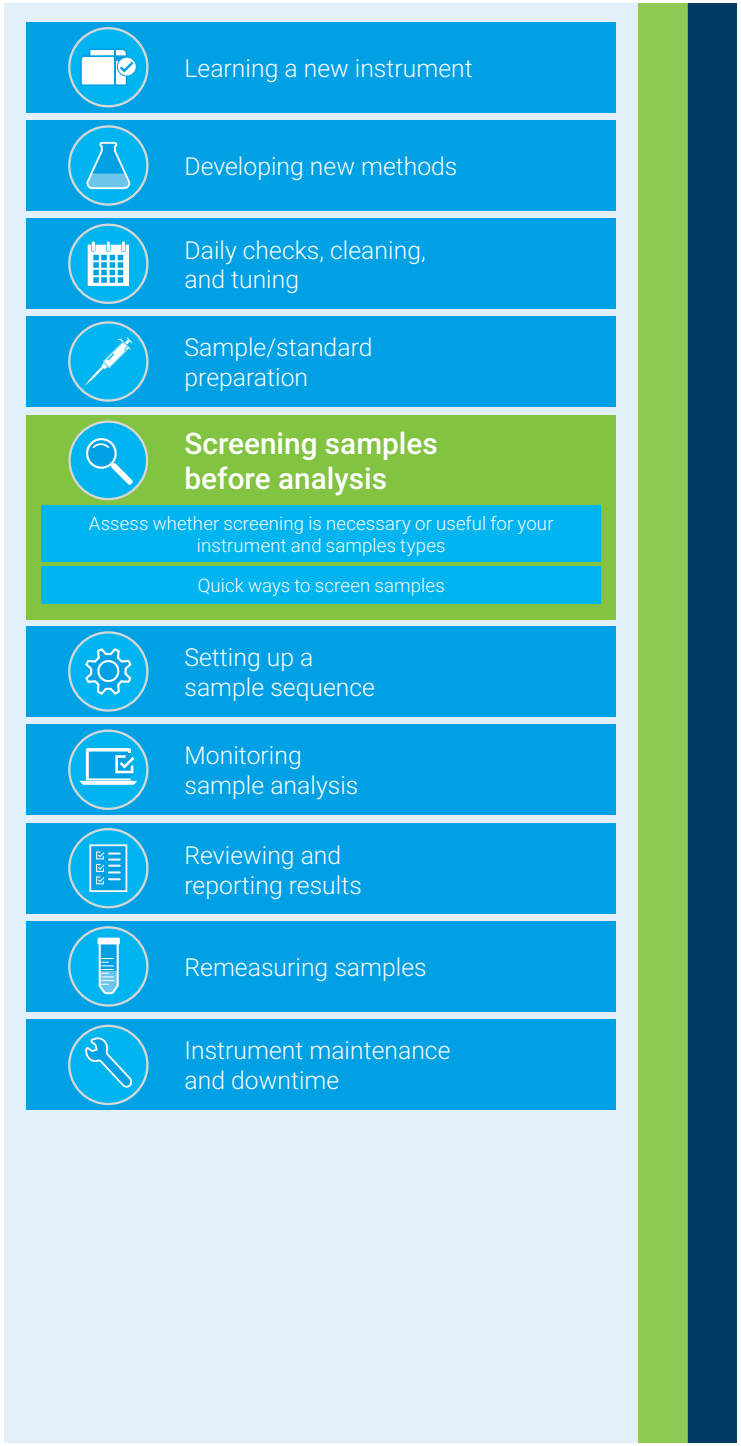
The Agilent FilterMate Filtration System allows you to digest, filter and analyze samples using the same tube. They are compatible with hot block digestion systems, but are not suitable for use in microwave digestion systems.

Screening samples before analysis

The time trap

Contract laboratories or others that receive samples that are of unknown composition may want to screen samples before analysis or when first setting up the method for new sample types. Sample screening, either using a different technique such as ICP-OES, or by running highly diluted samples on the ICP-MS, was once commonplace in new ICP-MS laboratories. In either case, it means running samples twice; either screening representative samples from the batch, or, in the worst case, running every sample twice, a very time-consuming task.

Improvements in ICP-MS matrix tolerance, detector dynamic range, and the ability to resolve most common matrix-based interferences have made routine screening largely redundant in labs that run modern ICP-MS instruments. But users of some ICP-MS systems still rely on screening new sample types to optimize their method setup. The US EPA Method 200.8, which predates many recent ICP-MS developments such as collision/reaction cells, recommends that a semi-quantitative analysis be carried out to screen new or unusual samples for elements at high concentration. Screening can be used to guide sample dilution and can also be used to identify possible issues with sample preparation, or potential sources of interferences that might be addressed by changes to the analytical method. If screening is deemed appropriate, how can labs ensure that it gives the most useful information and has minimal impact on lab productivity?



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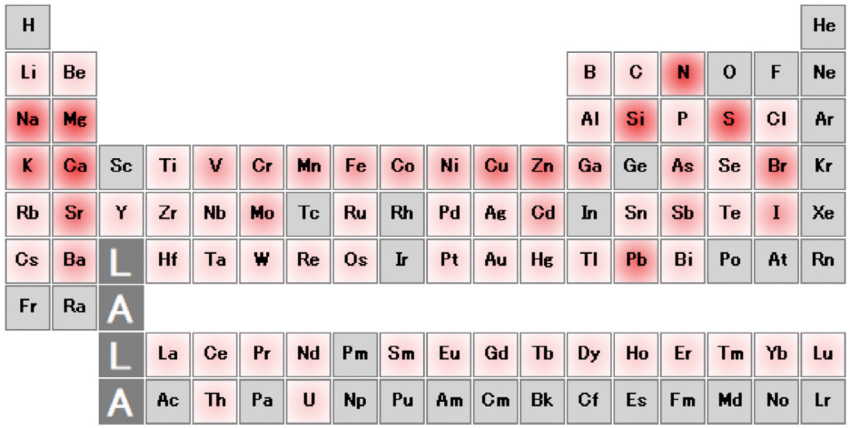
The solutions

Assess whether screening is necessary or useful for your instrument and samples types

The need for screening can be practically eliminated if the ICP-MS can handle the required sample types under standard operating conditions. This typically means having a plasma robust enough to handle the high matrix levels, sufficient dynamic range to measure major elements, and a reliable method to remove common matrix-based interferences. The Agilent 7850, for example, uses a high matrix introduction system with variable aerosol dilution to extend matrix tolerance up to 25% salt. Helium mode in the collision reaction cell will remove most common interferences without requiring sample-specific or element-specific settings (refer to 'Use helium mode to control polyatomic interferences'). Finally, the instrument's wide dynamic range allows it to measure both major and minor elements in the same measurement, so no need to prepare two different dilutions of each sample.

Quick ways to screen samples

Even with an optimized ICP-MS configuration and method, there may be some situations where a lab receives a really unknown or unusual new sample type. In these cases, a fast screening capability can save time by avoiding issues that can arise when unsuitable matrices are accidentally introduced into the instrument. Some ICP-MS instruments include a semiquantitative analysis capability that provides approximate concentrations of all elements in the sample. For example, Agilent ICP-MS instruments include the IntelliQuant function. IntelliQuant collects a full mass Quick Scan acquisition in helium mode, to determine the concentrations of all elements in the sample, as well as the total level of dissolved solids. The IntelliQuant semiquantitative results can be presented as a heat map on a periodic table (as shown below), so you can easily visualize the relative concentrations of each element and compare different samples in the batch.



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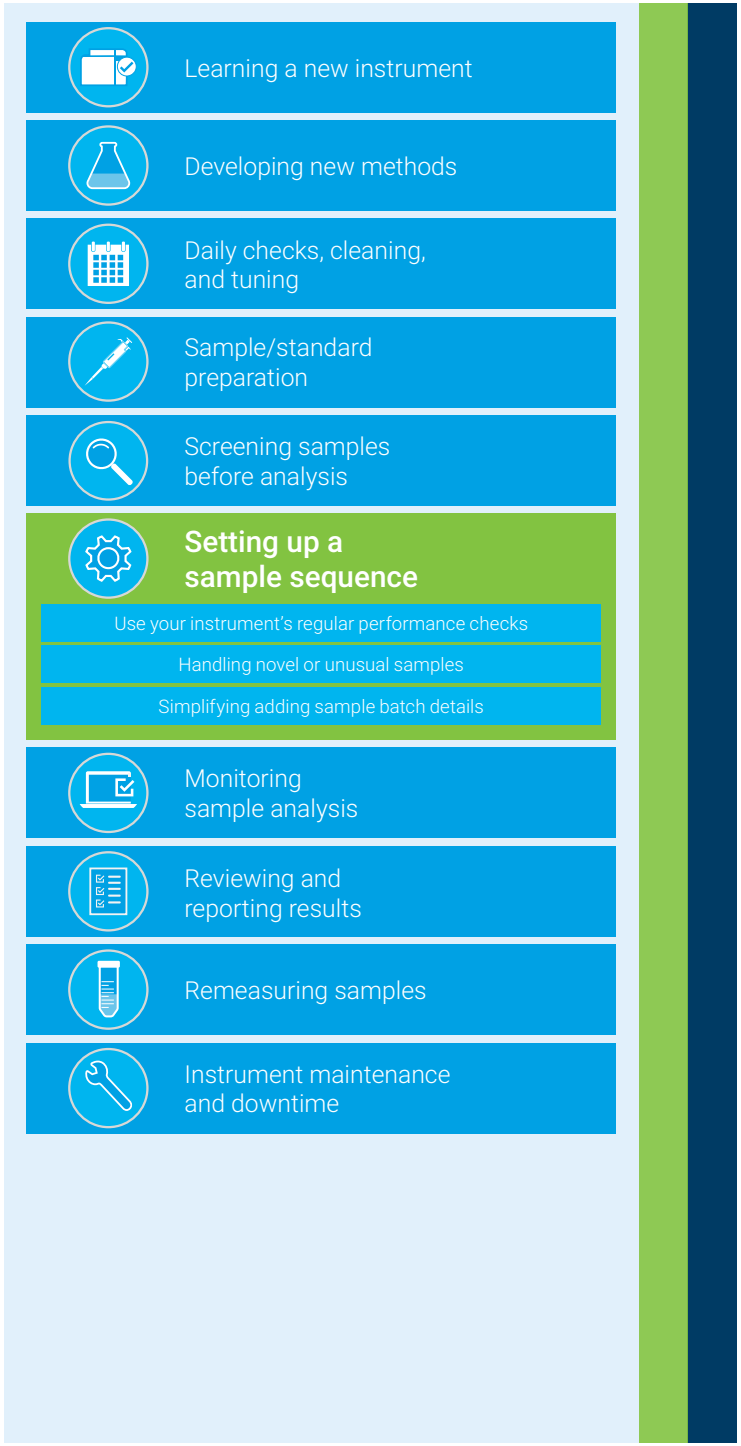
Setting up a sample sequence

The time trap

Setting up a sample sequence consists of:

1. Setting up the instrument and igniting the plasma
2. Assessing instrument performance and correcting any problems
3. Creating or modifying batch details
4. Tuning and calibrating, if required
5. Loading the autosampler
6. Preparing or importing the sample list and defining any required QC solutions

At each of these steps, there are potential time traps and ways to streamline operations.



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The solutions

Use your instrument's regular performance checks

A common delay when setting up the ICP-MS to run the day's first sample batch is when you light the plasma, allow the instrument to warm up, run the normal system checks, and only then find a performance problem that must be fixed before samples can be analyzed. This often requires you to extinguish the plasma and wait for the system to cool down before taking corrective action.

By scheduling a performance check to run automatically at the end of an overnight run, you can identify and fix any problems before you light the plasma at the start of the next day's first batch of samples.

For more information on identifying and fixing common issues, refer to 'Instrument maintenance and downtime' for information.

Handling novel or unusual samples

Depending on the instrument you are using, you may need to adjust method settings if you receive samples that are different to the ones you normally analyze.

Being able to handle unusual samples without needing a lot of changes to standard method settings saves a lot of time, but requires some specific capabilities from the ICP-MS.

- The ICP-MS may need to analyze a range of high matrix samples, so plasma robustness is one important consideration.
- With unknown and variable samples, the major elements may give rise to new and unexpected spectral overlaps, so having a facility such as He collision mode to remove polyatomic ions helps ensure results are accurate.
- Unknown samples may contain higher than expected levels of target analytes, So an ICP-MS with a wide dynamic range can help ensure that valid results are obtained, rather than reporting over-range results that require samples to be rerun.

Simplifying adding sample batch details

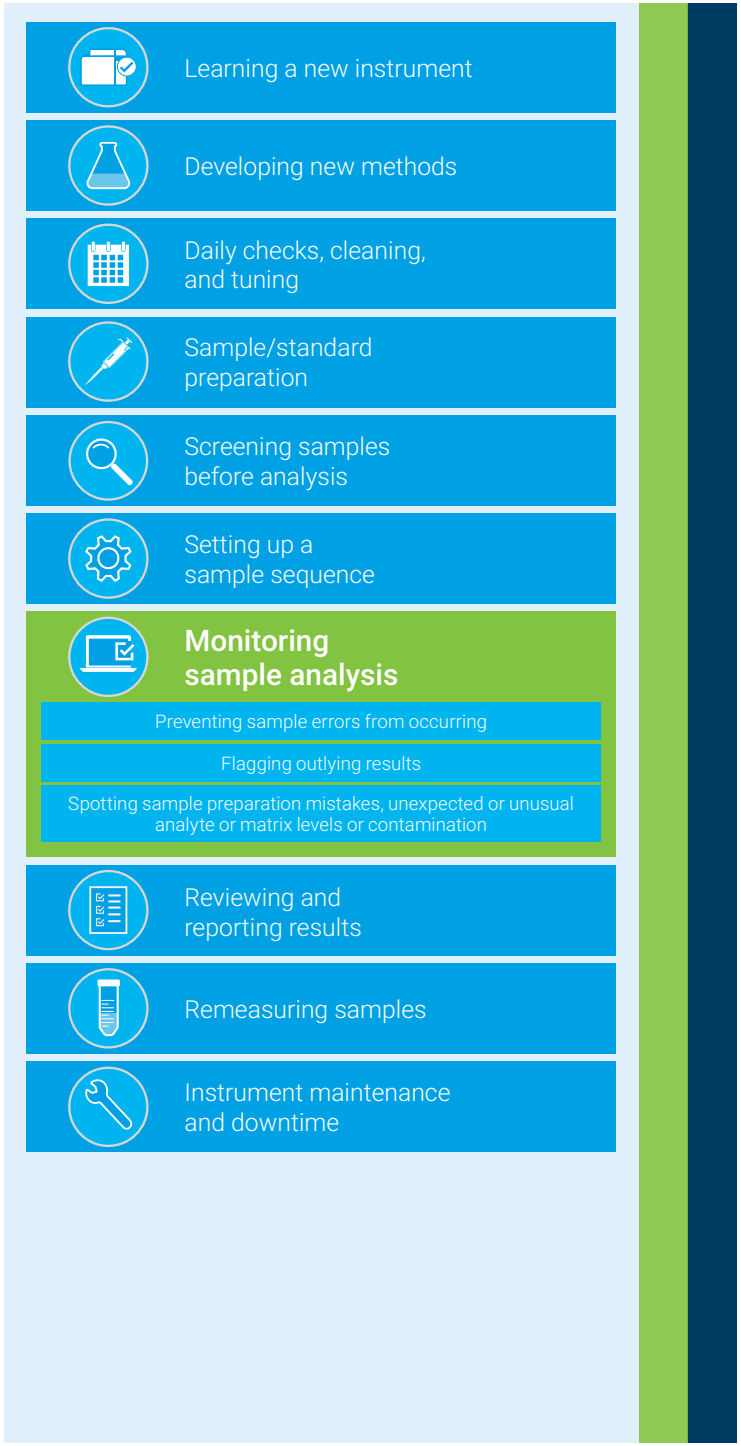
There are several ways that modern ICP-MS instruments can simplify the setup for sample analysis:

- Measuring major and minor elements in one run. You might currently be doing two separate sample batches—one to measure the elements present in high concentrations (the 'majors') and another to measure elements present in low concentrations (the 'minors' and 'traces'). These might even be done using separate techniques. The development of ICP-MS detectors with extremely wide dynamic range has overcome this limitation, so you can now measure all elements in a single sample batch.
- Measuring different elements in different samples in the same sample batch—for example, 20 elements in drinking water samples, 12 elements in soil samples and 8 in waste water samples. With some instruments, you are limited to measuring the same elements in each sample—it's fixed in the method. You would have to setup three different measurements—one for each sample type. Some ICP-MS instruments such as the Agilent 7850 use a 'Sub list' function that lets you select specific groups of analytes to be measured in different samples. By using sublists, you can run all your drinking water, soil and waste water samples in one analytical run and using a single global calibration, but without wasting time collecting data for elements that are only of interest in the other sample types.
- Automatic dilution factor calculation. This is a simple but effective way to save time when setting up a sample list and when entering your calibration standards. By entering or importing the sample weight and volume (which could be created by the prep lab and downloaded from a LIMS) the instrument software will determine both the measured concentration and the reported concentration. If you create calibration standards by serial dilution from a mixed stock, it may be possible for the software to complete the whole standards table for you by applying a multiplier to calculate all the analyte levels, instead of you having to enter the concentration of each element in each standard.
- Importing sample information from a LIMS system saves tedious data entry.
- Functionality that allows you to specify different sample types in a sequence as different sample 'blocks' e.g. a block for calibration standards, another for unknown samples, another for QC and blank solutions etc. These blocks can be run in a specified order and/or at a specified sample number or time trigger. The blocks can be predefined, saved in a template, and reused in each analytical run, so the analyst only needs to update the unknown sample list.

Monitoring sample analysis

The time trap

ICP-MS can generate a lot of data. Sample batches frequently run to 200-300 unknown samples, plus perhaps 10 calibrants and up to 50 QC solutions run throughout the batch. And each sample may have results for 30 or more analytes, plus internal standards, each run in triplicate. With different sample types and major elements potentially giving rise to different errors in each sample, it can be a problem to monitor the run to ensure data quality. The data table can be overwhelming, making reviewing the results as they appear on the screen a daunting task, especially for an inexperienced user. Reviewing this large volume of data can lead to an issue being missed, leading to sample reanalysis to address an issue that could have been resolved easily if it had been noticed during the run.



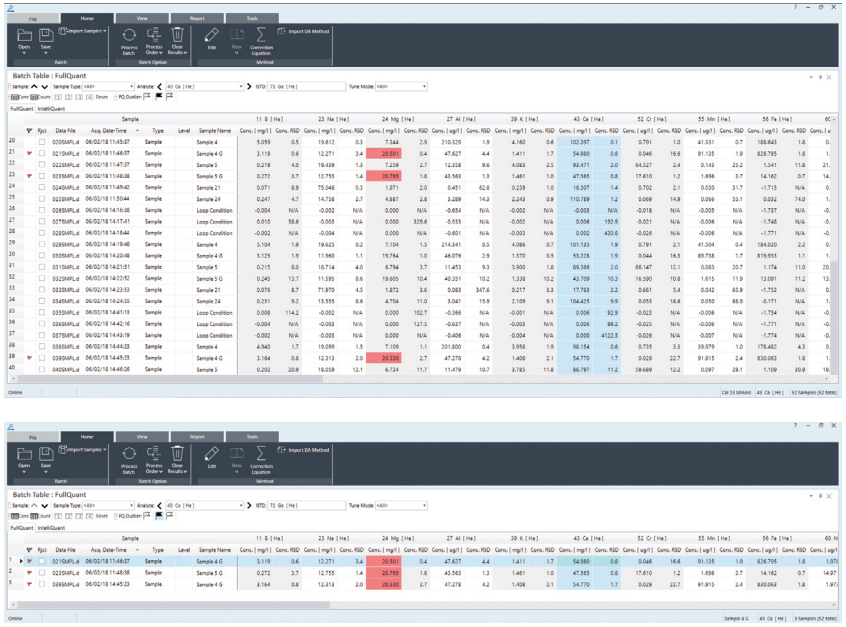
The solutions

Preventing sample errors from occurring

Both the instrument and the method used play a big part in making result monitoring simpler. Refer to 'Creating methods that minimize sample errors'.

Flagging outlying results

Analyst experience and knowledge is beneficial when interpreting ICP-MS results. But there are many functions built into the latest generation of ICP-MS systems that can simply and speed up the task for less experienced analysts. For example, optimized ICP-MS system configurations and methods can eliminate many of the sources of error that users might previously have struggled to identify and correct. Data analysis tools can also help new users with the review process. It's often possible to filter the results as they appear, flagging any that don't meet specified criteria, such as %RSD or failed QC tests. This makes it easy to pick out the problematic results (as shown in the images, following).

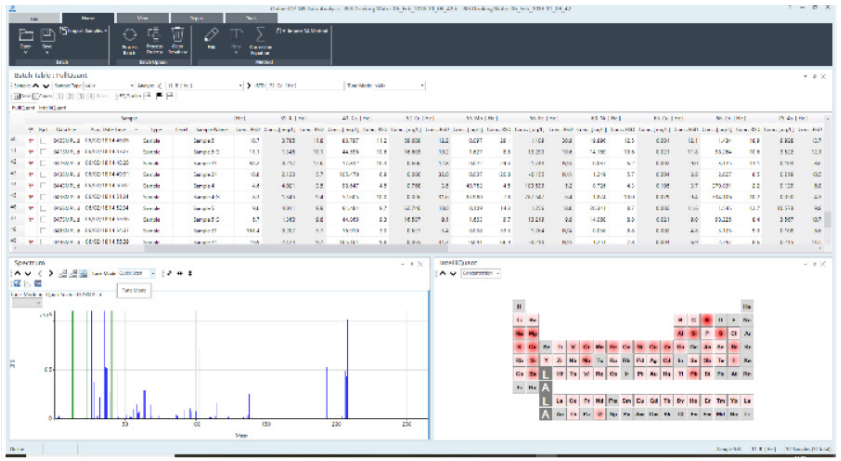


The Agilent MassHunter Outlier Conditional Formatting function flags any sample results that don't meet specified criteria. The red flags highlight the problematic results and you can display only those results on the screen to make it easier to troubleshoot them.

Spotting sample preparation mistakes, unexpected or unusual analyte or matrix levels or contamination

As well as flagging potential errors in the data table, ICP-MS software may include utilities to help the user to identify the cause of the problematic result. If your ICP-MS method has the facility to collect a full mass spectrum of each sample during the analysis this can be used for troubleshooting. For example, a busy analyst may miss a sample vial when adding acids during sample preparation. If Cl is missing from the full mass scan, or present at low level, it's a good indication that the HCl wasn't added to that sample.

More generally, if your lab measures a lot of unknown and variable samples, unexpected matrix components or high level analytes might be present in a particular sample. These unexpected elements can be identified quickly and easily from the full mass spectrum data. In the image below, the quantitative results for each sample are shown in the table at the top of the screen. The full mass Quick Scan spectrum measured for the selected sample line is shown in the bottom left. To the right, the IntelliQuant periodic table view shows the concentration range of all the elements found in the Quick Scan spectrum. These semiquant results can include up to 78 elements, not just the analytes included in the quantitative analysis. This visual presentation allows you to quickly compare samples and identify any unexpected or unusual elements present, whether due to contamination or an abnormal or mislabeled sample matrix.



Reviewing and reporting results

The time trap

As with real-time checking of data during the run, checking row after row of sample results after the analysis is completed is a tedious and error-prone activity. You can easily feel overwhelmed by the number of results presented for a typical multi-element ICP-MS batch. Outliers and false positive or negative results can be missed, and erroneous results reported. Not only is reviewing data a time trap, having to remeasure samples that fail adds to wasted time. Even worse is the potential reputation damage of reporting erroneous results that a customer then queries or uses to make important decisions. But without target values or expected ranges for the analytes in an unknown sample, how do you confirm—to yourself and your client—that the reported results are accurate. Often labs conclude that, to be safe, they need to run samples with unexpected results again, or run them on a second technique to confirm the data. All this takes extra time and effort, and eats into productivity.

The solutions

Creating methods that minimize sample errors

Method development plays a big part in reducing the time spent reviewing results. Data errors can be minimized if the ICP-MS is setup with the robustness to handle the sample matrix and the dynamic range to measure all the analytes. Similarly, spectral overlaps can be controlled using appropriate cell conditions.

By using settings that can address the common causes of unreliable data, ICP-MS analysts can make data review and reporting much faster, easier, and less prone to errors. For example, the helium mode collision cell in the Agilent 7850 instrument minimizes the contribution from polyatomic ions, removes overlaps from unexpected matrix elements, and resolves interferences on internal standards. It also means you don't have to use correction equations to address common polyatomic ion overlaps. Correction equations can often be a source of additional errors as the equation may not account for all interferences that may be present.

Using a function that corrects for interferences from doubly charged ions is also useful, particularly if you are likely to receive samples containing barium or rare earth elements. This can be included in your method so that interferences due to doubly charged ions are automatically corrected in the reported results.

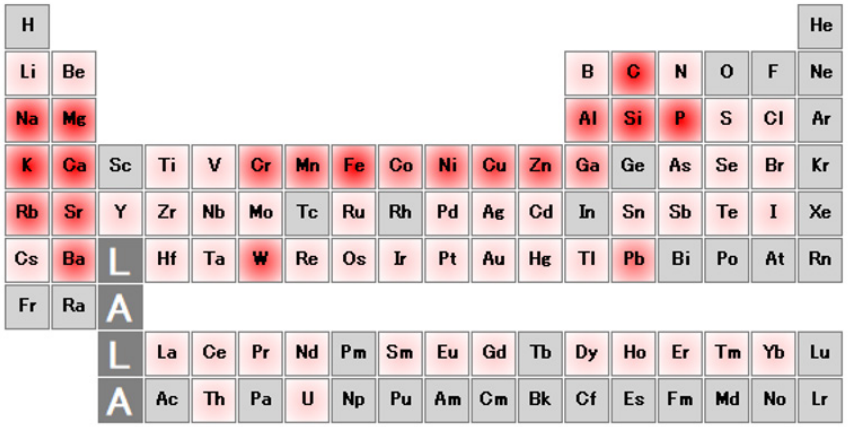
Using secondary qualifier isotopes for your analysis helps with routine data confirmation, giving added confidence in results. The data from secondary isotopes is also a useful backup if there's a query on a result. You can compare the results from both isotopes—if they are the same then it's confirmation the result is accurate.

Using a quick semiquantitative analysis tool, like the 7850's IntelliQuant function, is useful when investigating outlier results or client queries on results. IntelliQuant can check the full elemental composition of a sample, determining the approximate concentration of each element. Unexpected results for a sample can be compared against the IntelliQuant results. The IntelliQuant full mass scan can also be used to confirm the presence of an element by its isotope abundance pattern. This function is illustrated for a dark chocolate sample (as shown on this page), where the presence of the unexpected element tungsten (W) at ppm levels was confirmed by the IntelliQuant isotopic abundance template.

Using software tools for data analysis

Many high volume labs export their data to specialized QC programs to automate their data analysis. ICP-MS instruments often have software functions that allow you to setup limits, outside of which results will be flagged or samples reanalyzed. The Agilent 7850 has an Outlier Conditional Formatting function that filters sample results so only those that fail to meet predefined criteria are displayed. This makes it easy to identify results that require investigation. The function can also be setup to take actions on the failure of a QC sample, ISTD or other solution type.

Many labs use an integrated data system to transfer information between systems in the lab, for example providing sample weights and volumes from the prep lab to the ICP-MS, and reporting results and QC flags from the ICP-MS to a laboratory information management system (LIMS). In terms of reporting, being able to easily export data to a LIMS system or third party reporting package can be a useful way to reduce the burden of generating reports.



Agilent ICP-MS IntelliQuant color intensity heat map shows the relative concentrations of each element. This sample of dark chocolate shows a relatively high concentration of Ca, Cr, Ni, W, and Pb. This data can be reported for elements not included in the calibration standards.

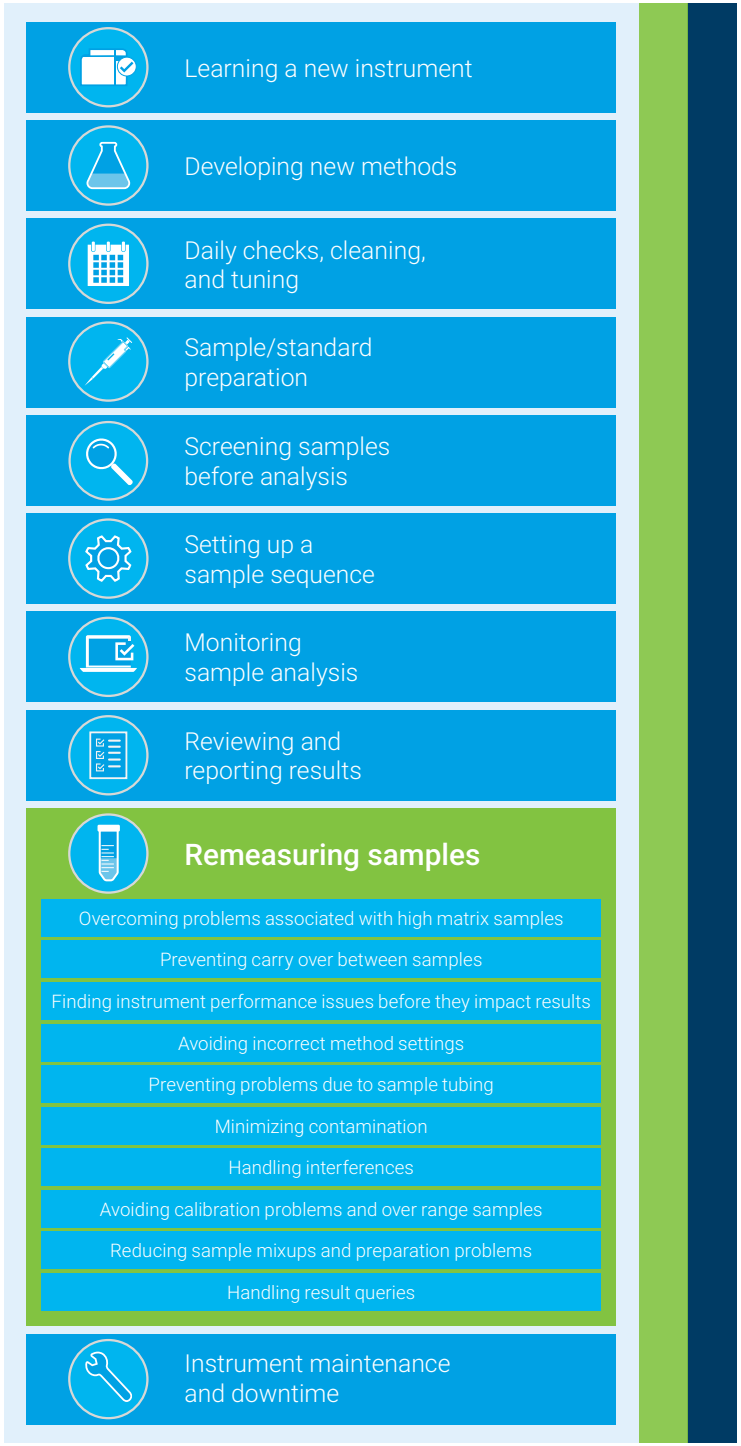
Remeasuring samples

The time trap

Most labs pay close attention to sample throughput and productivity, but fail to consider the cost of having to measure samples more than once.

A QC failure while using a regulated or lab-created method may result in having to rerun the calibration, various QC solutions, a blank, and then repeat the last 10+ samples. For more difficult samples, rerunning samples may require redigestion of the sample, as well as repeating the ICP-MS analysis. This all comes at considerable time cost, with sample remeasurement being a significant, although often underappreciated, burden for ICP-MS labs.

But for many of the causes of sample remeasurement, there are relatively simple ways to avoid the potential time traps and streamline routine ICP-MS operations.



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The solutions

There are many causes of having to measure samples more than once. Here are the common ones and how to avoid or minimize their impact.

Overcoming problems associated with high matrix samples

Extended analysis of samples with high levels of solids can lead to drift caused by the build up of deposits on the interface cones. These deposits can cause poor sensitivity, poor precision, and QC failures. Refer to 'Tips for running high matrix samples'.

Manually diluting high matrix samples is time-consuming, and auto dilutors are expensive and complex; dilutions can also introduce contamination and errors. The Agilent 7850 includes the Ultra High Matrix Introduction (UHMI) system that uses argon gas to dilute the sample aerosol, avoiding the time and cost of conventional liquid dilution. Using UHMI with aerosol dilution means you can directly introduce mixed, high matrix samples containing up to 25% total dissolved solids. UHMI reduces matrix effects and drift, meaning fewer in-run QC failures, less chance of internal standards drifting out of spec, less need to recalibrate and rerun, fewer sample-related (e.g. suppression) problems

Preventing carry over between samples

A surprise high matrix sample in the sample batch can lead to contamination of the next sample due to carry over of highly absorptive or "sticky" elements, such as Hg, B, Mo, W. This contamination can cause an erroneously high result. Stabilizing sample solutions by adding HCl during sample preparation will improve the solubility and stability of many elements, helping to reduce errors due to carryover.

Automated rinse functions that monitor the signal during the rinse cycle can also help prevent cross-contamination. The Agilent 7850 instrument includes an Intelligent Rinse feature that automatically pumps rinse solution until the signal drops below a set threshold.

Finding instrument performance issues before they impact results

Running an automated instrument performance check before starting analysis each day can identify faults with the instrument or utilities (e.g. argon pressure, cooling water flow, exhaust vent operation). These checks, performed during system startup, flag any issues before they can impact analytical performance.

Adding a post-run performance check at the end of the day's sequences gives you a head start, as the results are available before you start the instrument the following day. The post-run performance check allows you to identify and fix issues before you start the instrument, saving time the next day. The Agilent 7850 allows you to schedule a performance check to be run before any sample batch—useful for helping audit the data quality. A post-run performance check can also be scheduled at the end of the analysis queue.

Avoiding incorrect method settings

Instrument method settings can dramatically impact your results. To prevent such situations, analyze a certified reference material (CRM) introduced as a Laboratory Control Sample (LCS) into your sample batch. You should always try to include a CRM with a similar matrix to that of your samples as part of your method development process. You should be able to get good recoveries at the trace levels when you measure the CRM. If you are unable to get good recoveries at trace levels, further optimization of the method will be required.

Using pre-prepared methods and method optimization tools are also helpful ways to get method settings right. Refer to 'Developing new methods' for more information.

Preventing problems due to sample tubing

Worn, leaking, or maladjusted peristaltic pump tubes will cause poor result precision, which may result in having to remeasure samples.

Regular routine maintenance prevents the occurrence of peristaltic pump tube problems. Check the tube's elasticity, roundness, connection and tension at the start of each day, or when your standard operating procedure mandates it. Remember to unclamp the peristaltic pump tubing at the end of each day to preserve its life. These checks can reduce the risk of having to remeasure samples due to pump tubing problems. You'll also avoid wasting time, waiting for new pump tubing to wear in. Refer to 'Caring for pump tubing' for more information.

Again, running automated instrument performance tests at the start of each day's analysis and at the end of a run will determine if result precision is passing manufacturer's specifications.

Minimizing contamination

As ICP-MS is such a sensitive technique, contamination can be a major source of errors, causing sample remeasurement. Refer to 'Preventing contamination problems' for more information.

Handling interferences

Several sources of interferences may cause inaccuracies in the determination of trace elements by ICP-MS[5]. Most modern instruments have various ways of dealing with these. The Agilent 7850, for example, includes a helium cell mode (refer to 'Use helium mode to control polyatomic interferences') that practically eliminates data errors due to polyatomic interferences, meaning there are fewer samples that are affected by matrix-based errors. He collision mode also helps you to confirm data validity by allowing access to qualifier isotopes. Being certain of your results means there's less pressure to rerun samples to check queried data.

Interferences caused by the doubly-charged ions of rare earth elements are negated by a half-mass correction algorithm. Refer to 'Correcting for doubly charged interferences'.

5. Refer to the US EPA Method 200.8 for descriptions of the different types of interferences.

Avoiding calibration problems and over range samples

Non linear calibrations and samples which are beyond the range of the calibration are a common cause of remeasurement.

The dynamic range of the instrument detector will have a large impact on the frequency of this problem. A wide dynamic range enables major elements to be measured under standard method settings (no custom attenuation needed), leading to fewer over-range and out-of-calibration results. Refer to 'Preventing calibration problems' and 'Preventing over range errors' for more information.

Reducing sample mixups and preparation problems

Sample mix-ups shouldn't occur, but lab staff are human and busy humans can make mistakes. A simple error of placing a vial in the wrong position when loading samples into the autosampler rack can lead to errors that may be hard to spot and difficult to correct. Mixing up the racks when loading them onto the autosampler can also occur.

Using a sample barcoding system can help minimize mix-ups. Bar coding a sample test tube at the very start of a sample preparation, then using that same test tube throughout sample preparation, through to analysis can minimize sample mix ups. Using QC solutions and sample duplicates in your run can also help.

Reducing the number of times a sample is transferred from one vessel to another also reduces the risk of mix-ups as well as helping to control contamination. Refer to 'Reducing transfer steps' for more information.

Handling result queries

A result being questioned is another common cause of time wasting sample remeasurement. Sometimes it's possible to avoid the need for remeasurement by confirming the original result using additional data that may be been collected when the sample was measured. Agilent ICP-MS methods can include a full mass Quick Scan spectrum, which can be used to collect a full mass spectrum and calculate a semiquantitative concentration for every element in each sample. For most analytes, secondary isotopes can be used to confirm the result.

IntelliQuant data can also be used to identify errors in sample preparation. For example, a low signal for Cl may indicate that HCl was not added during sample preparation.

The full mass spectrum data can also be useful when investigating site problems. For example, your production facility might start having issues with titanium (Ti). You don't include Ti in your standard sample analyses, but you have the full mass spectrum data from all your sample runs and can use this to see when Ti started becoming elevated. This information can then be used to track down the cause of the problem in production.

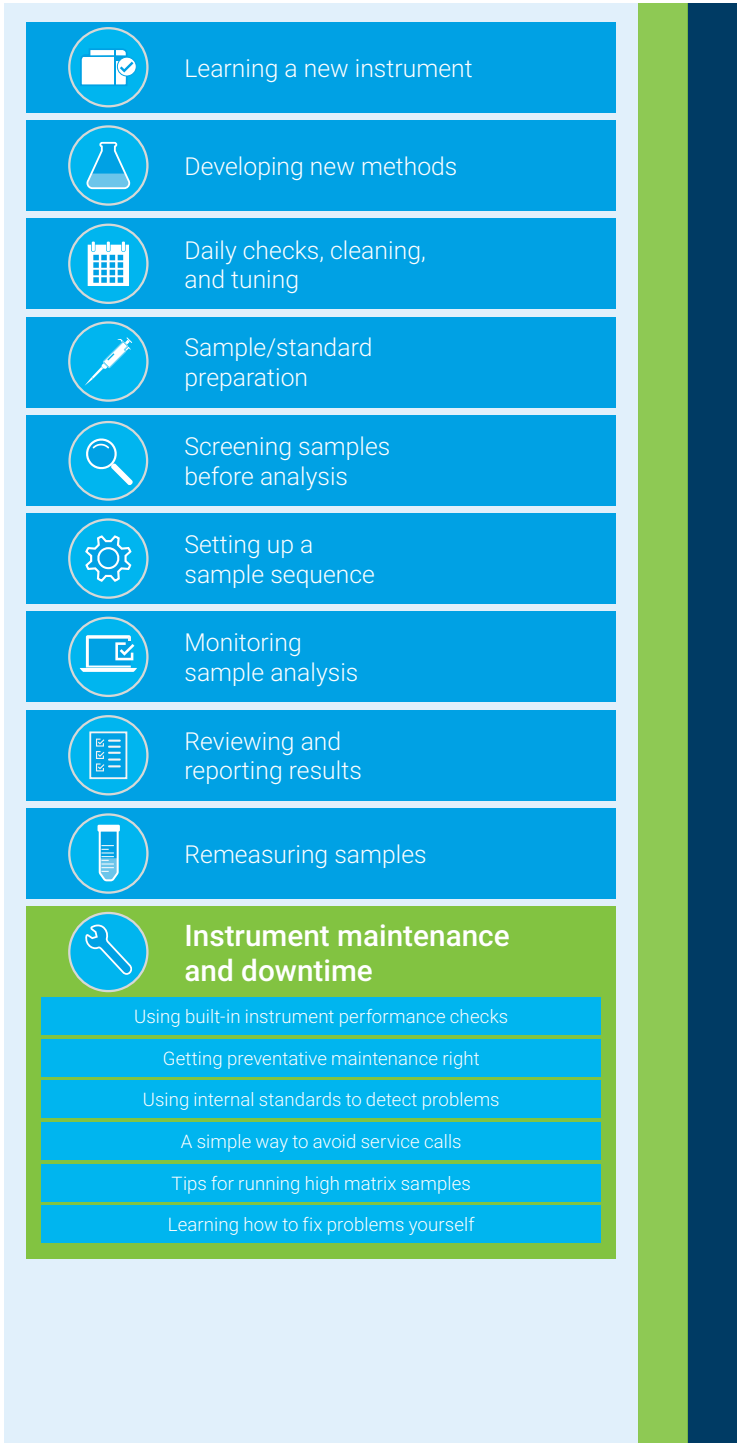
Not familiar with QC solutions?

Don't know your Internal Standard from your Quality Control Sample? The definitions of these terms can be found on page 5 of the US EPA Method 200.8 available here.

Instrument maintenance and downtime

The time trap

It's a common misconception that ICP-MS instruments are difficult, time-consuming, and expensive to maintain. Equally, some users believe that their analytical instruments will keep on running, day in, day out, without any maintenance or attention. It is also common for laboratories to rank instrument downtime as one of their biggest frustrations. And yet, a service engineer will often arrive to find that the instrument just needs cleaning or routine adjustment. These simple tasks could have been performed by the analyst, if only they knew how.



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The solutions

Using built-in instrument performance checks

With high sample workloads and pressure to maximize productivity in commercial laboratories, establishing a regular maintenance schedule can ensure optimum instrument performance and prevent small issues causing downtime during analysis. A good strategy is to run an automated instrument performance check prior to starting analysis each day and at the end of unattended overnight runs. The performance check confirms the status of the instrument before analysis starts. This check reduces the chances of needing to stop the analysis and rerun samples if performance degrades during the day. Most ICP-MS instruments have built in performance tests and may also test utilities such as exhaust vent temperature and gas supply pressure.

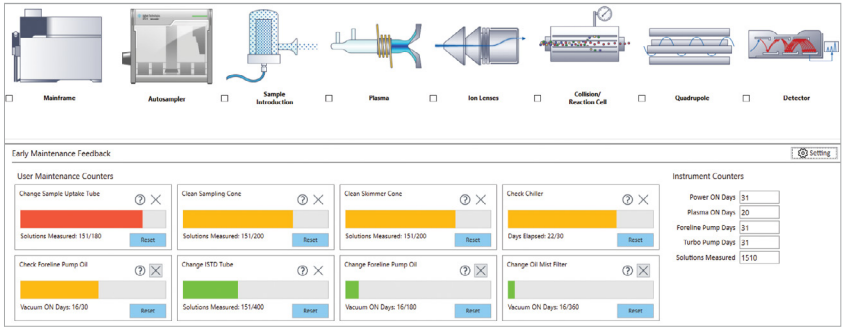
The Agilent 7850 ICP-MS includes the ability to schedule a post-run performance check in the analysis queue, as well as running the typical pre-run checks. The post-run check is particularly useful if you run the instrument overnight. When you return to the lab the next day, the post-run check results will indicate if there's anything that needs to be addressed before you start the next analysis. There's no need to wait for the warm-up time and pre-run check to tell you if maintenance or adjustment is needed.

Getting preventative maintenance right

Many labs include instrument maintenance and cleaning in their daily routine or standard operating procedures. But the timing for these activities might be based on instrument defaults, previous instruments, or what was done for different sample types or on other metals analysis techniques. You may be cleaning interface cones or changing pump tubing far more frequently than you need to, which costs money and wastes time. Conversely, cleaning and maintenance schedules documented in lab procedures may be forgotten or ignored, particularly when the lab is under time pressure. Not performing these tasks can have a big impact on results, which then wastes time because you have to troubleshoot the problem and potentially remeasure samples.

Modern instruments often have built-in self-health checks and other functions to alert you when a maintenance or cleaning activity needs to be done. For example, the 7850 ICP-MS has an Early Maintenance Feedback (EMF) system that allows alerts to be setup to prompt the analyst to perform common preventative maintenance tasks. These alerts can be configured for the lab's requirements and can be based on the number of samples that have been run, the hours of operation, or feedback from a sensor. Just like the recommended service intervals for cars can vary depending on environmental and driving conditions, routine maintenance of an ICP-MS can be varied depending on sample number and type. This gives more accurate scheduling of service intervals and is a better way to maintain instrument performance than if you just rely on elapsed time. The alerts can be adjusted to suit the sample types a lab typically runs. For example, an ICP-MS analyzing clean water samples will need less frequent maintenance than one being used for challenging, high matrix samples such as acid digested soils.

The other great benefit of the EMF function is the fact that it can be used as evidence during an audit. For example, if your lab has a three-week routine maintenance cycle, but during one of those weeks you only ran 50 samples, then the maintenance may have been delayed. If an auditor questions why the maintenance wasn't done, the data from the EMF function can be used to show that the scheduled maintenance wasn't needed because of the reduced sample load. In fact, labs may find they can move away completely from time-based maintenance schedules and get rid of hardcopy ICP maintenance records. The EMF function retains all the data and will do the maintenance scheduling for you. Another useful feature is when maintenance



The 7850 uses early maintenance feedback (EMF) sensors and counters to determine when maintenance is needed, based on operation time or number of samples measured. The traffic light color-coded alerts mean that maintenance tasks—such as changing pump tubing, cleaning the cones, or changing the vacuum pump oil—are never missed, but are also not performed more frequently than necessary.

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monitors are linked to the user guides and video tutorials showing you how to perform the required maintenance task. A great way to save time and ensure maintenance actions are performed correctly.

Using internal standards to detect problems

Most analysts add internal standards (ISTDs) to their ICP-MS samples. But many users don't monitor or check the ISTD signals unless they fail a method QC requirement. If the internal standard signals start to drift this usually indicates a problem within the amount of undissociated matrix reaching the interface cones. Usually, this can be resolved by operating the ICP-MS with more robust plasma conditions (optimize for lower CeO^+ ratio or run with a higher UHMI dilution factor). Alternatively, the EMF counters may indicate that a scheduled maintenance activity was not performed, leading to the signal drift. Internal standard signals can also be used to identify other sample related issues such as matrix or ionization suppression. Again, optimizing for better plasma robustness can reduce or eliminate these problems.

A simple way to avoid service calls

Problems such as slow wash-in, carry over, unstable internal standards and non-linear calibrations often result in a call for service support. Downtime associated with these problems can often be avoided by simply adding at least 0.5% HCl to samples during sample preparation. The addition of HCl will even fix the washout problems and stability issues associated with the analysis of mercury, something most analysts think they can't measure on an ICP-MS. Using helium mode in the collision/reaction cell of the ICP-MS removes any Cl-based interferences that result from the additional of the HCl.

Regular changing of peripump tubing can also reduce issues such as slow wash in or washout, as old pump tubing can acquire a surface coating that increases the adsorption of certain "sticky" elements.

Tips for running high matrix samples

Measuring high matrix samples often results in more frequent cleaning being required. If the plasma is not well optimized, the matrix will not be fully decomposed, leading to deposition on the interface cones.

If high matrix samples are causing you problems, there are a few simple strategies you can use:

- Optimize for better plasma robustness (lower CeO). Robust conditions are the default for Agilent ICP-MS systems, but may not be familiar to new users or users transferring from non-Agilent systems.
- Increase the level of dilution, for example using a higher aerosol dilution factor. Liquid dilution—either manually or using an autodilutor accessory—can also be used, although these approaches can add time and cost.
- Add a switching valve such as the Agilent Integrated Sample Introduction System (ISIS) to reduce the time the sample is being aspirated and increase the rinse time. This change will reduce the overall matrix loading on the interface and so reduce drift and can also provide a significant increase in sample throughput.

If undissolved particulates are the issue, for example leading to frequent nebulizer blockages, you can:

- Filter or centrifuge the samples.
- Set the autosampler probe depth to sample from a greater distance above the base of the tube, to minimize the chance for particles on the bottom of the test tube to be sucked up by the probe.
- Change the type of nebulizer you are using to one with a larger internal diameter sample path that is more resistant to blockage.

The frequency of cleaning you should do depends on the type of samples being run, and the way the system is optimized. If your blanks are low, the sensitivity is high enough, and the stability is good, then you probably don't need to clean the system. Long term results are often better if you don't keep going back to a totally clean system.

Agilent Captiva Syringe Filters

Single use Captiva filters provide high flow rates and loading capacities. They are available in a variety of membrane types and pore sizes, to suit your application. The disk filter fits onto the syringe, allowing the solution to be filtered straight into a sample tube.

Filters recommended for spectroscopy applications:

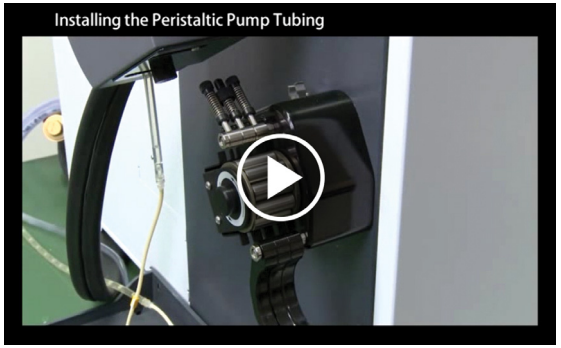
- Captiva Premium, 100/pk PTFE, 0.45um Pore, 15mm dia. (P/N 5190-5085) or 25mm dia. (P/N 5190-5087)
- Captiva Econofilters, 1000/pk PTFE, 0.45um Pore, 13mm dia. (P/N 5190-5266) or 25mm dia. (P/N 5190-5268)

Learning how to fix problems yourself

You can fix many instrument problems—if you know how. In fact, over 40% of ICP-MS service calls[6] could be avoided if the user was able to perform basic troubleshooting and carry out routine cleaning and maintenance by themselves.

New ICP-MS users are typically provided with instructions on routine maintenance tasks but may not realize which of these tasks to prioritize. Some analysts clean the interface cones daily or as the first response to any performance issue. While cone cleaning is unlikely to degrade performance, it does take time and is often unnecessary. Also, there is a period of stabilization after a clean (or new) cone is fitted, where the cone surface is reconditioned by exposure to the sample matrix. During this period, signals can be less stable, so leaving a used cone in place can give faster startup and better stability. It is preferable to perform maintenance when necessary to maintain performance, rather than following a schedule that doesn't take account of the type and number of samples analyzed.

Technical resources such as the online Help, training tutorials, and system documentation provided with an instrument provide guidance on how to maintain performance. The 7850 ICP-MS Help and Learning Center includes many interactive guides and video tutorials on how to do common maintenance tasks to keep your instrument performing well. Being able to diagnose and fix common issues yourself means your instrument will be operational, rather than idle while you wait unnecessarily for a service engineer.



Videos for common tasks are included in the 7850's Help and Learning Center.

6. Based on Agilent service call data.

The Agilent 7850 ICP-MS

Free your ICP-MS analysis from common time traps with the Agilent 7850 ICP-MS. It's the smart way to reduce wasted time so busy staff can can focus on tasks that deliver value. The 7850 instrument can handle samples with up to 25% solids, reducing the dilution time trap. The instrument features a helium (He) mode collision cell and half mass correction that remove both polyatomic and doubly charged ion interferences, making method development simpler and addressing a common cause of time-wasting sample remeasurement.

Learn more at: www.agilent.com/chem/7850icpms

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