

ICP-MS, or ICP-AES and AAS?—a comparison

ICP-MS-1
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Introduction

The attractiveness of the inductively coupled plasma atomic emission spectrometer (ICP-AES) has led many analysts to ask whether it is wiser to buy an ICP-AES or to stay with their trusted atomic absorption technique (AAS)¹. More recently, a new technique, inductively coupled plasma mass spectrometry (ICP-MS), has been introduced².

The ICP-MS offers at first sight, albeit at higher cost, the advantages of ICP-AES and the detection limits of graphite furnace atomic absorption spectrometry (GFAAS).

This article will briefly describe these three techniques, and point out the important criteria by which to judge their applicability to your own analytical problems.

For many people with an ICP-AES background, ICP-MS is a plasma, with a mass spectrometer as a detector. Mass spectroscopists would prefer to describe ICP-MS as mass spectrometry with a plasma source. Either way, the technique is capable of giving isotope information. This information can help to overcome many of the "spectral" interference problems that can occur in the mass spectrometer.

Basically, the sample compartments and plasma of ICP-AES and ICP-MS look similar. In ICP-AES, the optical spectrum (approximate range 165-800 nm), is viewed and measured, either sequentially or simultaneously. The simultaneous ICP-AES is faster, but more expensive, than sequential ICP-AES.

The ICP-MS extracts the ions produced in the plasma into an interface consisting of a sampler cone followed by a skimmer cone. This configuration enables the pressure to be reduced differentially from atmospheric pressure down to a final pressure of between 10^{-5} - 10^{-7} Torr. The ions pass through the interface into ion optics, which optimize the ion paths. Neutral species are removed from the beam at this stage, either by the vacuum pumps or by collision with a photon stop. The ions then pass through a mass filter, usually a quadrupole, before

the selected ions reach the detector.

The ICP-MS provides information for each atomic mass unit (amu or Daltons; more accurately, the ratio of the mass of the ion to its charge is displayed, and labelled m/z), in the mass region 3-250 amu. The isotope information can be used in several ways; these include isotope ratio measurements, often used for Pb and U which do not have a constant natural abundance, and analysis of samples having unnatural isotope abundances.

Isotope dilution is a method of spiking the samples with a known concentration of a pure isotope to obtain a very accurate determination of the concentration of the element. A pre-requisite of this technique is that the element of interest must have more than one isotope.

Detection Limits

ICP-MS detection limits are very impressive. Most detection limits are in the 1-10 parts per trillion (ppt) range for solutions. These are as good as, or better than, GFAAS detection limits for most elements in pure water. ICP-MS can also detect many elements that have very poor GFAAS detection limits. ICP-MS has typically two to three orders of magnitude better detection limits than ICP-AES, which has detection limits for most elements in the 1-10 parts per billion (ppb) range. Recently, some ICP-AES spectrometers have shown impressive detection limits in the sub ppb region for selected elements in an optimized part of the spectrum for clean samples.

It should be noted, however, that the comment above about ICP-MS detection limits is for simple solutions having low levels of other dissolved material. For detection limits related to concentrations in the solid, the advantage for ICP-MS can be degraded by up to 50 times, because of the poorer dissolved solids capability. Some common lighter elements, (e.g. S, Ca, Fe, K, Se) have serious interferences in ICP-MS which degrade the detection limits considerably.

Interferences

The three techniques present different types and complexities of interference problems. For this reason, we will look at each technique separately.

ICP-MS interferences

1. Spectral

The spectral interferences in ICP-MS are predictable and number less than 300. Polyatomic and isobaric interferences are found where a species has a similar mass to the analyte, whereby the resolution of the spectrometer (generally around 0.8 amu) will not resolve it, e.g. ^{58}Ni on ^{58}Fe , ^{40}Ar on ^{40}Ca , $^{40}\text{Ar}^{16}\text{O}$ on ^{56}Fe , or ^{40}Ar - Ar on ^{80}Se .

Element correction equations (similar in principle to inter-element correction in ICP-AES) can be used. In many cases alternative isotopes with lower natural abundances may be employed. The use of mixed gases (small percentages of other gases such as nitrogen, added to the main argon gas) can sometimes be effective in reducing interferences.

2. Matrix acids

It should be especially noted that HCl , HClO_4 , H_3PO_4 and H_2SO_4 can cause considerable spectral problems. Polyatomic interferences are caused by Cl^+ , P^+ , S^+ ions in conjunction with other matrix elements like Ar^+ , O^+ , H^+ . Examples are, $^{35}\text{Cl}^{40}\text{Ar}$ on ^{75}As and $^{35}\text{Cl}^{16}\text{O}$ on ^{51}V .

The avoidance of HCl , HClO_4 , H_3PO_4 and H_2SO_4 in ICP-MS is paramount for most analyses. Where this is not possible, separation chromatography (microcolumns) may be used before the sample is introduced into the plasma. This is a method many favour to get rid of the unwanted species, and it also creates an opportunity to preconcentrate at the same time. Other techniques used to overcome these problems are: electrothermal vaporization (ETV), and mixed gases. Another very expensive alternative is a high resolution magnetic sector ICP-MS which can resolve masses less than 0.01 amu apart. This enables many of the spectral interferences to be eliminated.

Solutions for ICP-MS analysis are normally prepared in nitric acid.

3. Doubly charged ions

A doubly charged ion will cause a spectral interference at half the m/z of the singly charged ion, e.g. $^{138}\text{Ba}^{++}$ on $^{69}\text{Ga}^+$ or $^{208}\text{Pb}^{++}$ on $^{104}\text{Ru}^+$. These interferences are few and can be considerably minimized, or effectively eliminated, by optimizing the system before proceeding with the analysis.

4. Matrix effects

Transport effects include spray chamber effects and differences in viscosity between sample solutions and calibration standards. This will change the efficiency of aerosol production from one solution to another. Matrix matching is usually required, although internal standardization can be used as an alternative method. The rapid scanning speed of ICP-MS does give superior results when using an internal standard.

5. Ionization

Ionization effects can be caused by samples containing high concentrations of group I and group II elements. Matrix matching, sample dilution, standard addition, isotope dilution, extraction or separation by chromatography may be necessary.

6. Space charge effects

Space charge effects occur mainly behind the skimmer cone, where the net charge density becomes significantly different from zero. The high ion density leads to interaction between ions present in the ion beam causing preferential loss of the light ions in the presence of heavy ions, e.g. Pb^+ on Li^{+3} . Matrix matching, or careful choice of internal standards across the mass range of analytes, will help to compensate for these effects, although this may prove difficult in practice. Isotope dilution will be effective though expensive, but the simplest and most effective method is to dilute the sample.

ICP-AES interferences

1. Spectral

ICP-AES spectral interferences are more numerous and are more difficult to solve. There are more than 50,000 ICP-AES spectral lines documented, and the matrix can cause considerable problems, which makes a high resolution spectrometer mandatory for the analysis of samples such as steels, chemicals and rocks. Inter-element correction, used extensively in simultaneous ICP-AES, can have only limited success.

The background in ICP-AES may be elevated or structured, requiring an off line background correction. Sophisticated dynamic background correction, if available, is very useful to improve accuracy. Different molecular species such as OH give peaks or bands which can cause analytical problems at low analyte concentrations, degrading the detection limits in real samples.

The background in ICP-MS is so low, typically <20 counts/second, that it doesn't pose a problem. This is a major reason for the superior detection limits of ICP-MS.

2. Matrix effects

Like ICP-MS, ICP-AES can use internal standards to overcome matrix effects such as spray chamber effects and viscosity differences between samples and calibration standards⁴.

3. Ionization

Interference from easily ionizable elements can be minimized by careful choice of individual element conditions⁶ or by adding an ionization buffer, i.e. by adding an excess of a group I element.

GFAAS interferences

The interferences in GFAAS have many sources. They include:

1. Spectral

There are a few spectral interferences in GFAAS when deuterium background correction is used, but these can be eliminated by use of Zeeman GFAAS.

2. Background

For many matrices careful programming of the ash stage is required to minimize the background signal during the atomization. The use of chemical modifiers can be helpful in increasing the allowable ash temperature. For example, a Ni chemical modifier for Se determinations allows ash temperatures of up to 1000 °C before Se loss. The use of Zeeman background correction can give an improvement in accuracy compared with D₂ arc background correction in many GFAAS applications.

3. Vapor phase interferences

These can be caused by the atomization of the analyte into a cooler gas environment. These interferences have been minimized in recent years by isothermal tube design and use of platforms so that the sample is atomized into a hot inert gas environment.

4. Matrix effects

Matrix effects are caused by variable retention of the analyte on the graphite tube, depending on the sample type. The dry and ash stages can have a dramatic effect on the shape of the transient peak. The use of matrix modifiers (e.g. PdCl₂) and hot injection can be quite effective in minimizing these effects; also the use of peak area measurement can be advantageous in some cases⁵.

Ease of use

For routine analyses, ICP-AES has matured in automation to the point where relatively unskilled personnel can use methods created by the ICP-AES specialist. Until recently, ICP-MS was still the domain of the specialist chemist making fine adjustments before performing routine analysis.

The trend to simplicity has been evident since 1993 and will continue in the future. One of the reasons for this is full computer control of parameters stored within a method. Another reason is the use of a multitasking graphical user interface, to show the operator several indicators of data integrity on the same screen. The use of such software also has a very positive effect on method development time. Before this software became available, ICP-MS method development was a highly complex and time-consuming task. GFAAS, although relatively simple for routine analysis, requires considerable skill in setting up the methods.

Total Dissolved Solids (TDS)

Recent ICP-AES spectrometers have been able to analyze routinely up to 10% TDS and even up to 30% for simple salt solutions. Although the analysis of 0.5% TDS for ICP-MS may be possible for a limited timescale, most chemists are happier with 0.2% maximum TDS. This should be borne in mind when the original sample is a solid. The ultimate detection limit for some elements in ICP-MS may not be so impressive when expressed in the solid, compared with ICP-AES. GFAAS can cope with extremely high levels of dissolved solids.

Linear Dynamic Range (LDR)

ICP-MS can have a LDR in excess of 10⁵. Various methods for extending the linear range up to 10⁷ include de-sensitizing one of the ion lenses, use of detector analog mode, or use of a separate Faraday cup as a second detector. These should be used with caution, however, as high matrix component concentrations may cause problems best solved by dilution. For this reason, and because of the problems with high levels of dissolved solids, ICP-MS should be mainly the domain of trace/ultratrace analysis. The exception to this is when using isotope dilution. With this technique very good results have been obtained with high concentrations.

GFAAS has a limited LDR of 10²-10³. It can be used for higher concentrations if a less sensitive line is selected.

Trace to major element analysis may be performed by ICP-AES because of its 10⁵ LDR. ICP-AES is ideal for analysis up to and including percentage levels. For this reason ICP-AES, in addition to ICP-MS or GFAAS, is often needed to fulfil laboratory requirements.

Precision

The short-term precision of ICP-MS is generally 1-3%. This is improved routinely by use of multiple internal standards. The longer term precision (over a period of hours) is still <5% RSD. The use of isotope dilution can give results of very high precision and accuracy, although the cost can be prohibitive for routine analysis.

ICP-AES has generally precisions of 0.3-2% RSD in the short term and again less than 5 % RSD over several hours.

GFAAS, however, will generally have short term precisions of 0.5-5% RSD. Longer term precision is a function of the number of graphite tube firings, rather than time.

Sample throughput

The ICP-MS has an incredible capacity to analyze a vast number of samples for trace elements. Typical analysis time is less than 5 minutes/sample, for the whole suite of required trace elements. For some applications this may only take a couple of minutes. Consulting laboratories find the sample throughput a major advantage.

While the speed of ICP-AES analyses will depend on whether simultaneous or sequential instruments are used, generally this can vary from 2 to 6 minutes per sample. Simultaneous ICP-AES can be faster, typically 2 minutes/sample, but sometimes its accuracy can be compromised by spectral interferences present with some types of samples (e.g. rocks).

The speed of GFAAS is typically 3-4 minutes per element per sample (assuming 2 replicates). Automated overnight runs can be performed, and this will improve throughput of samples.

Total sample throughput can be a major factor favouring ICP-MS in the busy laboratory. The following examples (expressed as solution concentrations), will give a guide:

1. One to three elements/sample, at sub/low ppb concentration will generally be better by GFAAS, assuming the elements of interest can be determined by this technique.
2. 5-20 elements/sample at sub ppm-% levels will generally be better by ICP-AES.
3. 4 or more elements/sample at sub ppb and ppb concentrations will generally be better by ICP-MS, if the number of samples to be analyzed is high.

Unattended operation

ICP-MS, ICP-AES and GFAAS can all operate unattended overnight, because of the modern automated designs and the safety inherent in the use of inert argon gas in these techniques. For highest productivity, overnight operation is mandatory.

Cost of ownership

The running cost of ICP-MS is more than ICP-AES because several components have a limited lifetime and have to be replaced. These include the turbomolecular pumps, the sampler and skimmer cones and the detector. The torch and nebulizer have similar lifetimes for both ICP-AES and ICP-MS techniques. If ICP-AES is chosen instead of ICP-MS the laboratory will probably require GFAAS as well.

Hence, the cost of graphite tubes for the latter has to be taken into account. In all three techniques the cost of argon is a significant budget item, with the ICP techniques requiring more than GFAAS.

Capital cost

This is always a difficult subject to quantify because it will depend on the amount of automation, the accessories and the supplier. In very approximate terms, you can estimate that an ICP-AES will cost twice as much as a GFAAS and 2-3 times less than ICP-MS. It should be noted, however, that the accessories can distort these figures considerably.

Another cost that needs to be taken into account is that ultra trace analysis requires a clean laboratory and ultra pure chemicals. These are not cheap.

Accessories

Being a very rapid sequential method, ICP-MS can utilize transient signals in multi-element mode. This opens the way for a host of accessories.

Electrothermal vaporization, laser ablation, glow discharge and spark ablation can obviate the need to dissolve the sample. Some accessories provide the means of separating the matrix from the sample and/or to pre-concentrate. These include hydride generation, and various forms of chromatography (e.g. HPLC, ion chromatography, microcolumns).

The advantage of separation by chromatography for speciation work has only been fully realized in ICP-MS. This is due to the low concentration levels of interest in environmental, toxicological, medical and food samples.

Although ICP-AES can use some of the above accessories, their cost and their marginal advantages have meant that we have rarely seen many of them routinely used.

Summary

To advise anyone what to buy is always difficult. Look at your present and future needs, and answer the check-list questions in table 1. This should help you to decide.

It should always be remembered that no technique will satisfy all your requirements. The techniques are complementary. There will always be samples where one technique is better suited for the analysis than another.

Table 2 shows a simplified comparison of the three techniques. Table 3 compares detection limits.

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Table 1. Checklist of analytical requirements

1. How many samples/week?
 2. What are the sample types? (steels, rocks, effluents, soils, etc)
 3. What method of dissolution may be employed?
 4. How many and what elements need to be determined?
 5. What are the concentration ranges?
 6. What sample volume is typically available?
 7. What other options/accessories are being considered? Why?
 8. How important is isotope information to you?
 9. How much money is available to purchase or lease costs/month?
 10. What is the cost of ownership and running costs for the techniques to fulfil the requirements?
 11. What skilled operators are available to you?
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Table 2. Simplified comparison of ICP-MS, ICP-AES, GFAAS

	ICP-MS	ICP-AES	Flame AAS	GFAAS
Detection limits	Excellent for most elements	Very good for most elements	Very good for some elements	Excellent for some elements
Sample throughput	all elements 2-6 min/sample	5-30 elements /min/sample	15 seconds/ element/sample	4 mins/element /sample
Linear dynamic range	10 ⁵ (10 ⁸ with range ext'n)	10 ⁵	10 ³	10 ²
Precision				
Short term	1-3%	0.3-2%	0.1-1%	1-5%
Long term (4hrs)	<5%*	<5%*		
	* precision improves with use of internal standards			
Interferences				
Spectral	few	common	almost none	few
Chemical (matrix)	moderate	almost none	many	many
Ionization	minimal	minimal	some	minimal
Mass effects	high on low	NA	NA	NA
Isotopes	yes	no	no	no
Dissolved solids (maximum tolerable concentration)	0.1-0.4%	2-25%	0.5-3%	>20%
No. of elements	>75	>73	>68	>50
Sample usage	low	high	very high	very low
Semi-quantitative analysis	yes	yes	no	no
Isotope analysis	yes	no	no	no
Routine operation	easy	easy	easy	easy
Method development	skill required	skill required	easy	skill required
Unattended operation	yes	yes	no	yes
Combustible gases	no	no	yes	no
Operating cost	high	high	low	medium
Capital cost	very high	high	low	medium/high

Table 3. Detection limit comparison ($\mu\text{g/L}$)

Element	ICP-MS	ICP-AES	Flame AAS	GFAAS
As	<0.050	<20	<500	<1
Al	<0.010	<3	<50	<0.5
Ba	<0.005	<0.2	<50	<1.5
Be	<0.050	<0.5	<5	<0.05
Bi	<0.005	<20	<100	<1
Cd	<0.010	<3	<5	<0.03
Ce	<0.005	<15	<200000	ND
Co	<0.005	<10	<10	<0.5
Cr	<0.005	<10	<10	<0.15
Cu	<0.010	<5	<5	<0.5
Gd	<0.005	<5	<4000	ND
Ho	<0.005	<1	<80	ND
In	<0.010	<30	<80	<0.5
La	<0.005	<0.05	<4000	ND
Li	<0.020	<1	<5	<0.5
Mn	<0.005	<0.5	<5	<0.06
Ni	<0.005	<10	<20	<0.5
Pb	<0.005	<20	<20	<0.5
Se	<0.10	<50	<1000	<1.0
Tl	<0.010	<30	<40	<1.5
U	<0.010	<30	<100000	ND
Y	<0.005	<0.5	<500	ND
Zn	<0.02	<1.0	<2	<0.01

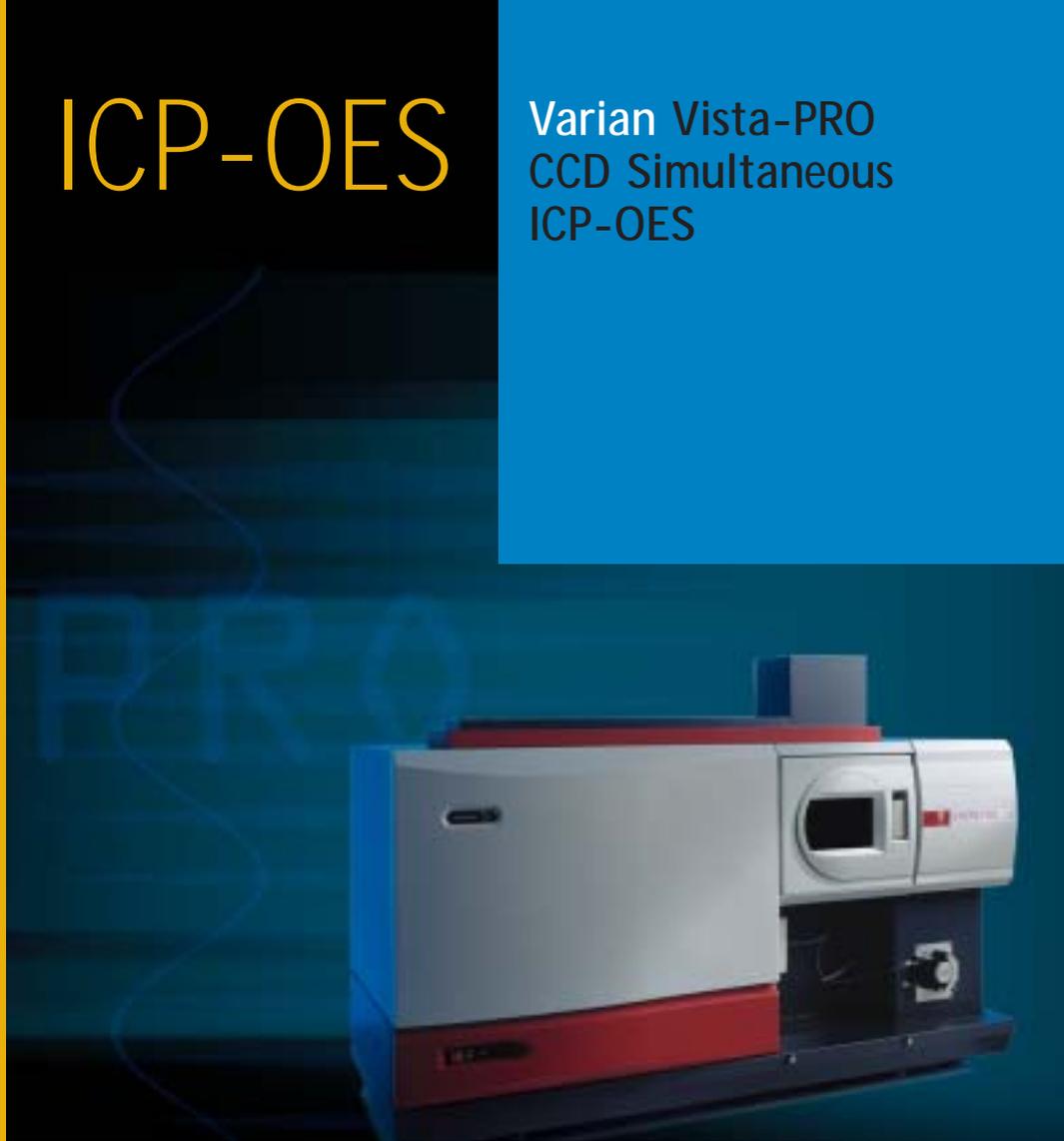
ICP-MS, ICP-AES, Flame AAS: Detection limits (defined on the basis of 3 standard deviations of the blank)

GFAAS: Sensitivity (0.0044 absorbance) measured with 20 μL of sample

ND: Not determined

ICP-OES

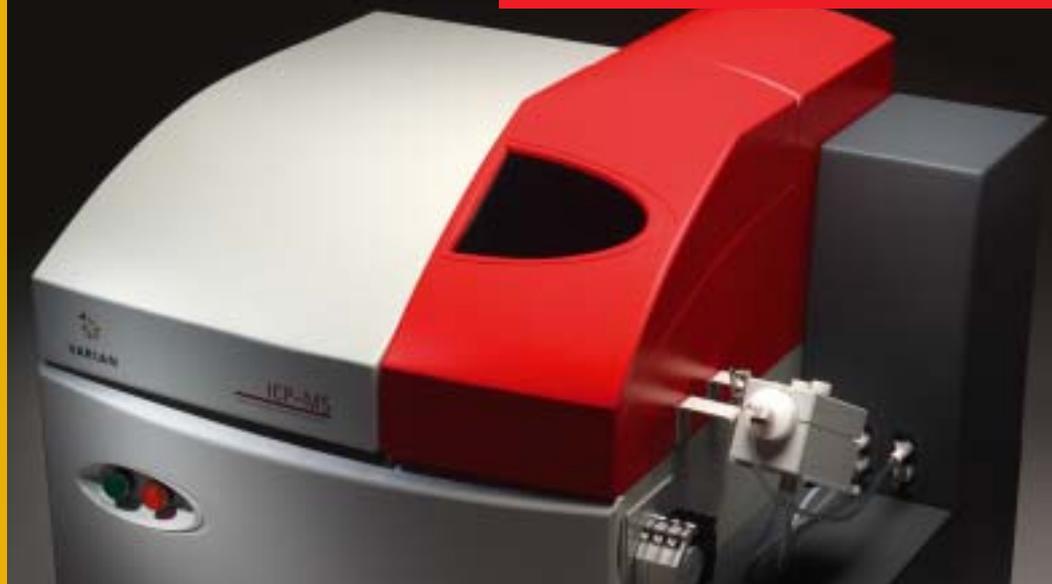
Varian Vista-PRO
CCD Simultaneous
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With greater ease-of-use and the highest sensitivity, Varian sets a new direction in ICP-MS.

The Varian ICP-MS with tunable sensitivity is ideal for environmental, semiconductor, and laser ablation geochemistry applications. With Varian's ICP-MS you can choose workhorse conditions for routine operation at high concentrations and gigahertz performance for the ultimate detection limits.

Varian's unique ion-mirror* reflects analyte ions through 90 degrees while neutrals and photons pass through the hollow structure. This produces the highest signal-to-background ratio available and the lowest detection limits.

The Varian ICP-MS is the world's first ICP-MS with tunable gigahertz sensitivity, providing one thousand million counts per second for every part per million. This sensitivity does not compromise performance, with the formation of oxide and doubly charged interferences remaining very low ($\text{CeO}^+/\text{Ce}^+ < 3\%$, $\text{Ce}^{++}/\text{Ce}^+ < 2\%$).

The all-digital, extended range detector provides nine orders of linear dynamic range without digital to analog cross calibration. This means the detector is more reliable, easier to use and offers linear performance from parts per trillion to hundreds of parts per million.

The ICP-Expert software that controls the Varian ICP-MS provides one step optimization and method development. Standard preparation is easy, as ICP-Expert can instruct you on what solutions to make and how to make them.

To further enhance productivity, we've sped up the slowest part of the analysis – sample introduction. Our new SPS-3 is Varian's fastest ever autosampler, while the diluter further extends linear dynamic range, maximizing productivity for very concentrated samples.

The ICP-MS features an all-Varian manufactured and guaranteed vacuum system, and the hollow ion mirror is virtually maintenance free. Both turbomolecular pumps are easily accessible, with the first pump swinging away to provide access to the ion optics system. For peace of mind, the detector has a one year guarantee.

If you need a competitive edge in performance and technology, Varian's new ICP-MS is better by ninety degrees.

* Patent pending





"The 90 degree reflecting ion optics revolutionizes ICP-MS performance"

When you require high sample throughput and the ultimate in analytical performance, the Varian ICP-MS delivers.

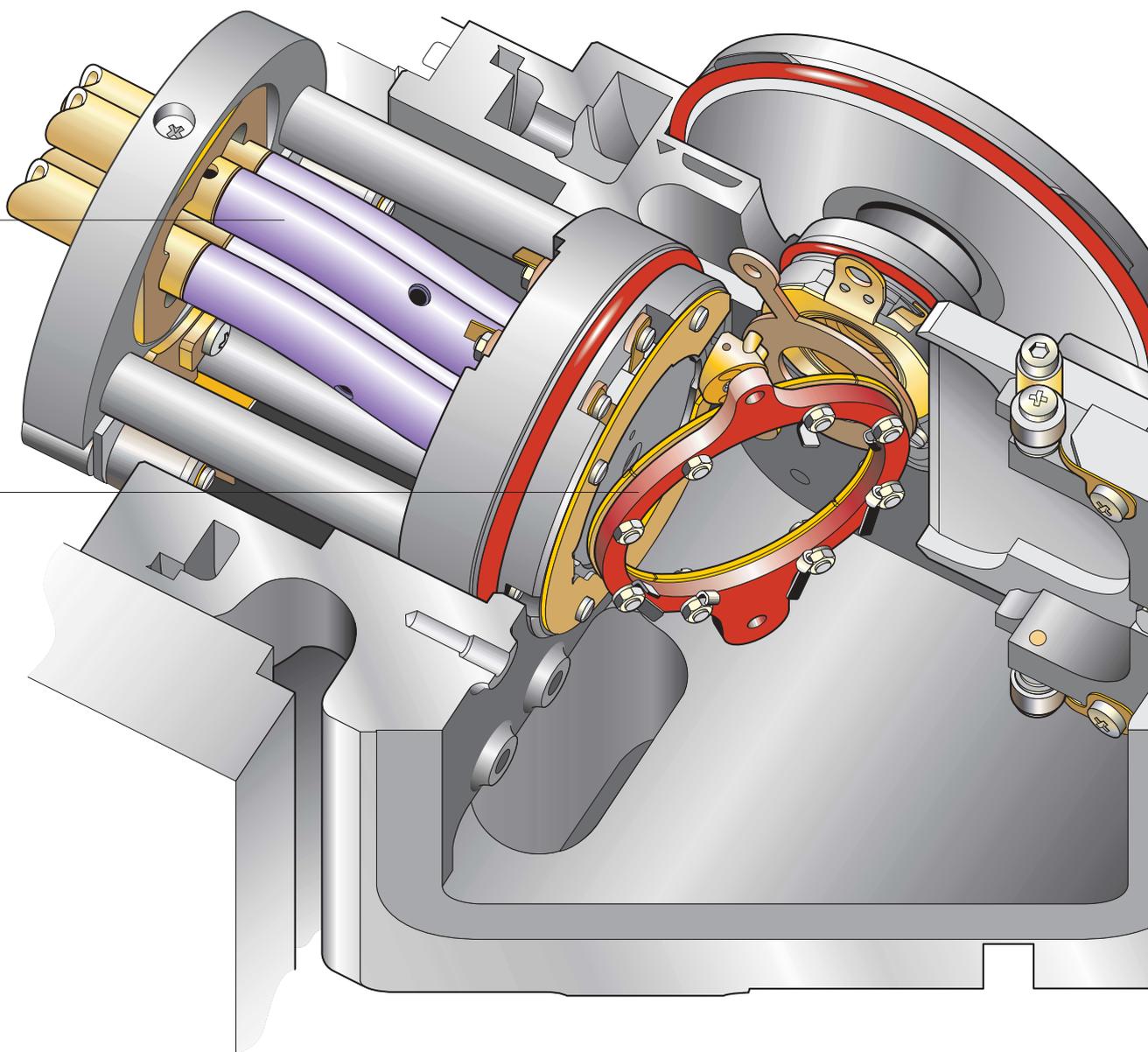
All-Digital Extended Dynamic Range Detector

At last, an all-digital Extended Dynamic Range system that works! Varian's nine orders detector achieves linear performance from ppt to hundreds of ppm without clumsy digital to analog cross calibrations. Ease-of-use, fewer dilutions and a guaranteed one year detector lifetime mean greater productivity and lower running costs for your laboratory.

Low noise quadrupole with curved fringe rods* for ultimate efficiency and low background.

* Patent applied for

Varian's ion mirror reflects the ion beam through 90 degrees, focusing the analyte ions into the quadrupole with the highest possible efficiency. By keeping photons and neutrals away from the mass analyzer, the ion mirror greatly reduces background signal.



Industry benchmark sensitivity, patented Turner Interlaced Coils, and 27MHz plasma combine to deliver the remarkable performance of the Varian ICP-MS.

Isotope/Species	Typical Hot Plasma Performance
⁹ Be	> 50 Million cps/ppm
¹¹⁵ In	> 1000 Million cps/ppm
²³² Th	> 500 Million cps/ppm
CeO ⁺ /Ce ⁺	< 3%

Isotope/Species	Typical Cool Plasma Performance
⁷ Li	> 2000 Million cps/ppm
²³ Na	> 1000 Million cps/ppm
²⁴ Mg	> 500 Million cps/ppm
⁴⁰ Ca	> 100 Million cps/ppm
⁵⁶ Fe	> 100 Million cps/ppm

Solutions for Environmental Speciation

Determining the oxidation state or molecular form of an element requires high sensitivity, accurate separation and rapid measurement. Varian makes elemental and molecular speciation easy with:

- Varian-manufactured ICP-MS and HPLC systems
- Fast 3 MHz quadrupole scanning for superior transient peak resolution and precision
- Gigahertz ICP-MS sensitivity providing better multi-element detection limits and faster scan rates

Real Gigahertz Sensitivity for Semiconductor Applications

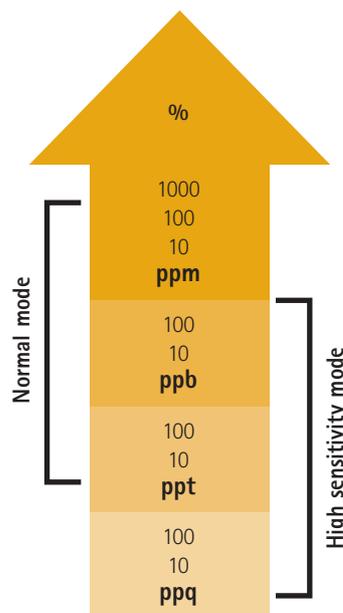
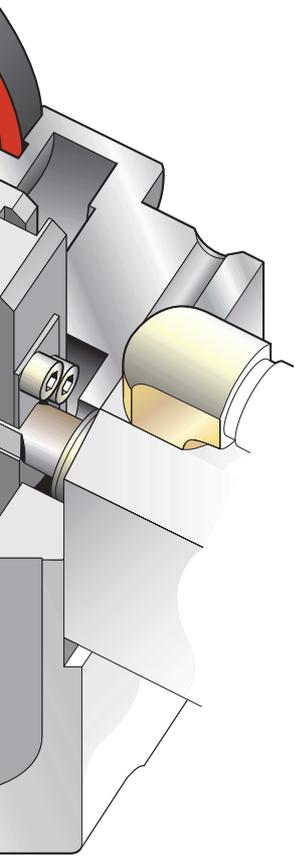
Varian's tunable gigahertz sensitivity sets a new benchmark in elemental detection limits. For semiconductor applications, the push continues to lower acceptance limits of contaminants both in process chemicals and final products. The very low detection limits achievable with the Varian ICP-MS make it ideal for these applications.

Unmatched Sensitivity for Laser Ablation

Varian's ICP-MS takes your laboratory to the leading edge of laser ablation performance with tunable gigahertz sensitivity unmatched by any commercially available quadrupole ICP-MS.

With the Varian ICP-MS you can:

- Use the smallest possible spot sizes for characterizing fluid inclusions or individual crystals, and identifying microscopic features
- Examine the finest details of art pieces, jewelry or artefacts with minimal damage and cost
- Scan for accurate isotope ratios for geochronology, palaeothermometry, marine science and climatology



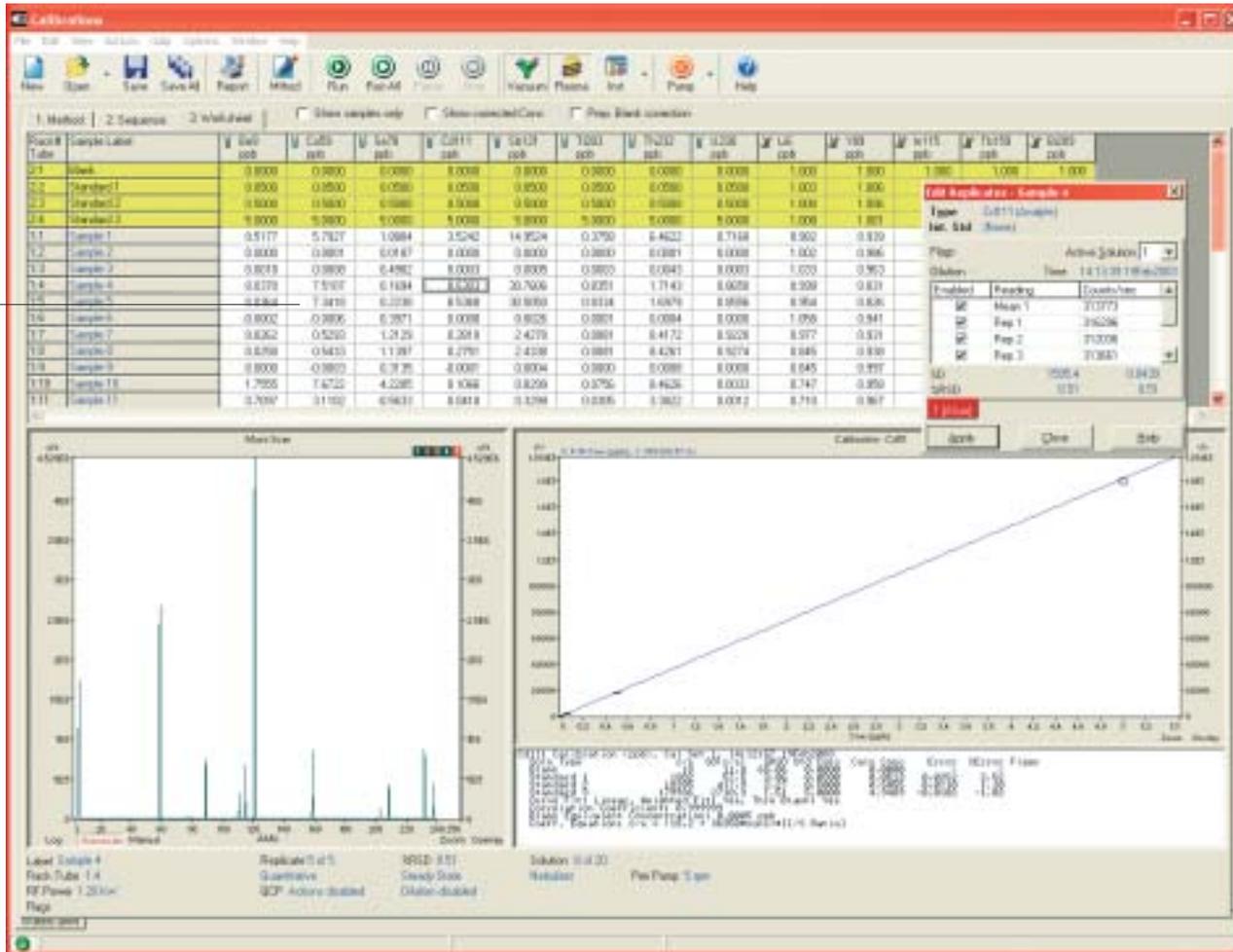
In high sensitivity mode, oxides such as CeO remain at <3% and can be further reduced under normal mode conditions to <1%.

ICP-Expert software for ICP-MS – setting the benchmark for ease-of-use

Varian's ICP-MS software is compatible with Microsoft's Windows® XP and 2000 for optimum connectivity and compatibility with all of your desktop applications.

Each worksheet cell gives all the results you need – including concentrations, intensities, statistics, replicate readings and graphical mass scans.

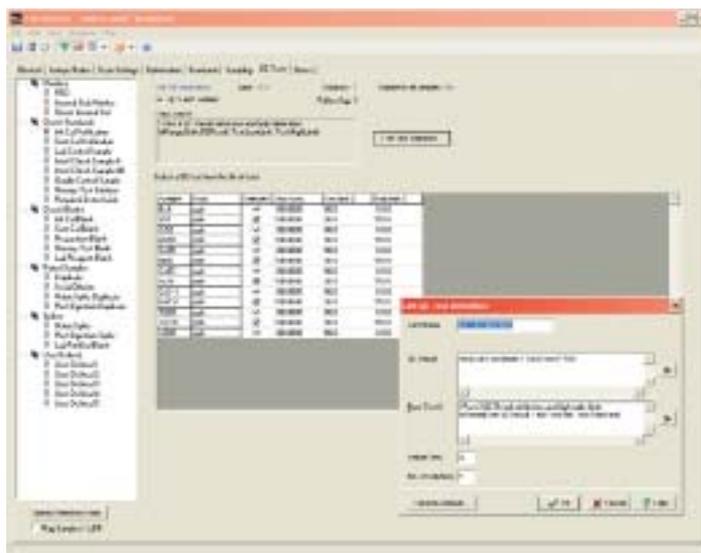
ICP-Expert switches automatically between multiple method condition sets within a single sample, giving optimum performance for specific element suites, without having to rerun samples.



If you thought ICP-MS was difficult to use, think again. Varian redefines ease-of-use with our new web-integrated ICP-MS worksheet software. ICP-Expert features a range of automated options, including setup and initialization routines such as plasma alignment, mass calibration and resolution tests. Varian's AutoMax makes method development easy by automating all ion optics, nebulizer and plasma settings for optimum results.

ICP-Expert includes wizards to guide you through every aspect of the analysis, from method development to analysis setup. The unique standards preparation wizard outlines how to prepare calibration standards, including which pipettes and flasks to use. You can then use Smart Rinse to maximize your sample throughput. Smart Rinse automatically spends less time rinsing samples that don't need it and more time rinsing those that do.

Varian's web-integrated ICP-Expert software directly links you to all of Varian's support resources. You can download the latest methods and application notes and access the latest software upgrades and product announcements. You can also get expert advice from MassNet, our ICP-MS user forum. In fact, with Varian's ICP-Expert software, ICP-MS has never been easier.



Ensuring the quality of your data is simple. Whether you're analyzing a check standard with each batch or a range of blanks, quality controls, spikes and duplicates, ICP-Expert's Quality Control Protocols can be customized to your needs. The software includes compatible methods for US EPA 6020, 200.8 and 1638.



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Safety

It is Varian's policy to manufacture safe products and to meet all legal requirements governing the design, manufacture and sale of safe products. As with all similar products, some or all of the following hazards may be present: high temperatures, high pressure gases, explosive gases, magnetic and radio frequency radiation, UV and visible light and electricity. Each product is designed to protect operators from potential hazards. Varian supplies instructions that describe the correct procedures for the operation and maintenance of each product.

The Varian ICP-MS instrument is designed to be used to determine trace elements.

CE The Varian ICP-MS is certified to comply with the requirements of the EMC and LV directives of the European Union.





Varian 1200L LC/MS. The high performance, affordable triple quadrupole setting new standards for selectivity and sensitivity.

Mass Spectrometry

Our new ICP-MS complements Varian's range of innovative spectrometry products. Varian offers a complete line including benchtop and portable gas chromatographs (GC and Micro-GC), gas chromatograph/mass spectrometer (GC/MS and GC/MS/MS) systems, liquid chromatograph/mass spectrometer (LC/MS and LC/MS/MS) systems, chromatographic columns and supplies, and custom solutions.

Varian MS instruments maximize laboratory efficiency with easy-to-use, reliable products supported by superior customer service.

The Varian 1200LC/MS

- Productivity with the only single quadrupole that can be upgraded to the full selectivity of triple quadrupole MS/MS at any time
- Superior performance with robust and sensitive Atmospheric Pressure Ionizations (API) interface
- Keep pace with changing applications by adding the analytical capabilities of a GC interface for EI, PCI, or NCI

The Varian Saturn 2200 GC/MS

- Sets the industry standard for EI and CI sensitivity
- Add GC and MS options, any or all, as needed
- Highly productive, easy-to use options include gas and liquid CI, MS/MS, and Chromatoprobe for solid samples
- Element-specific GC detectors for complimentary compound identification

Varian Saturn 2200 GC/MS. The world's most versatile GC and flexible MS provides the highest level of performance and easily expands to support any application.



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servicing worldwide markets in:

- Agriculture
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- Biotechnology
- Clinical
- Electronics
- Environmental
- Photonics
- Toxicology
- Pharmaceutical
- Food and Beverage
- Metals and Mining
- Petroleum and Petrochemical



Varian, Inc. is committed to a process of continuous improvement which demands that we understand and then meet or exceed the needs and expectations of our customers—both inside and outside the company—in everything we do.

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Varian's patented VistaChip™ CCD ensures Vista-PRO™ is the world's fastest ICP-OES, measuring 73 elements in just 35 seconds. When combined with a high efficiency RF generator and powerful, easy to use software the Vista-PRO is quite simply the world's best ICP-OES.



Cutting-edge technology for today, and tomorrow

The custom designed VistaChip CCD detector provides unparalleled advances in performance. Combined with a compact, thermally stabilized echelle polychromator, the Varian Vista-PRO gives complete flexibility in wavelength selection to avoid spectral interferences, and increase linear dynamic range.

A built-in wavelength library features 32,000 lines but you can choose any line you like ensuring that you meet your needs now, and in the future.

Measure any sample type

Varian's highly efficient free-running 40 MHz RF generator with Direct Serial Coupling (DISC™), produces a robust plasma that gives you the confidence to analyze any sample type—from brines and fusions to the most volatile organic solvents. The reliable RF generator has no moving parts and is proven in over 1000 instruments worldwide. With fast analysis and short warm-up times, Vista-PRO delivers reliability, low operating costs and greater uptime.

You are the Expert

Vista-PRO's ICP Expert™ software takes the guesswork out of analysis. Manual optimization is eliminated with AutoMax™, providing fast, automated, method optimization. New worksheet features allow you to mathematically combine results for total composition analysis, purity calculations and extend linear dynamic range. Add in SmartRinse™ for faster sample washout, FACT™ on-line spectral deconvolution and Stability Reference Standardization for geochemical and high salt applications, and you are the ICP Expert.



Vista-PRO improves productivity and precision by providing true simultaneous measurement of all elements from parts per billion to percent levels.

Save time and argon costs with simple 'one step' analysis from one plasma view. Unlike dual-view systems, with Vista-PRO, you don't have to measure the sample twice.

From tubings and nebulizers to spectrometers, applications and technical support, Varian offers a complete elemental solution for your laboratory.

Simultaneous high resolution ICP using CCD detection



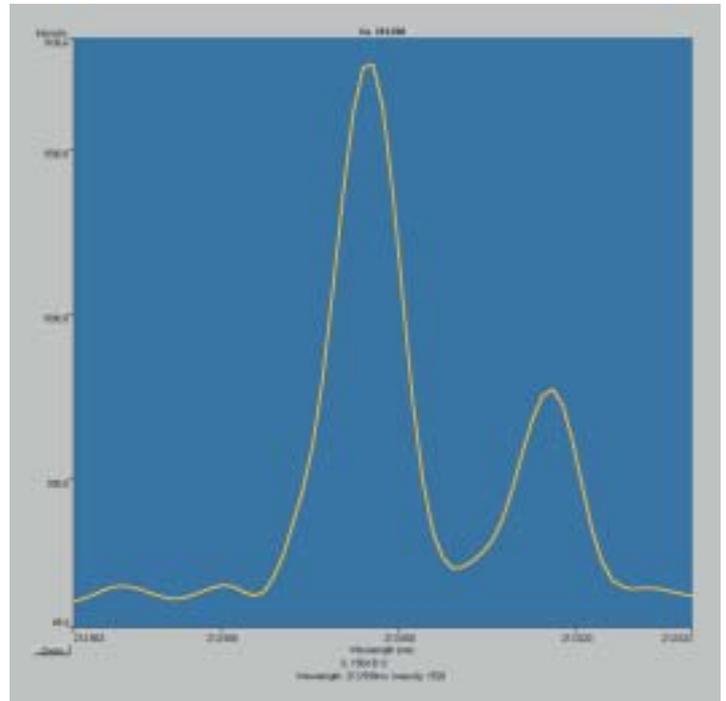
Varian's patented VistaChip CCD detector features unique image mapping (I-MAP™) technology. I-MAP ensures complete coverage of the echelle spectrum by arranging 70,000 pixels in uninterrupted arrays that exactly match the two-dimensional optical image. This provides full wavelength coverage from 167-785 nm.

The VistaChip CCD also features anti-blooming protection on every pixel, ensuring trace analytes can be accurately measured in the presence of high concentrations of other elements.

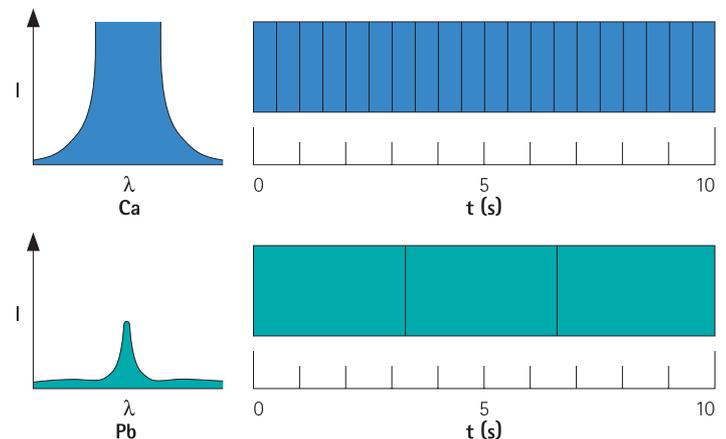
The unparalleled detection limits and linear dynamic range of the Vista-PRO allow one step analysis from a single plasma view.

Only Vista-PRO offers superior dynamic range and detection limits using:

- Adaptive Integration Technology™ (AIT), an intelligent algorithm that prevents overrange signals by adjusting the measurement time simultaneously for each wavelength to achieve the optimum signal-to-noise ratio.
- Triple stage Peltier cooling that provides the ultimate in low noise performance.
- True simultaneous measurement of background signals and internal standards. The VistaChip CCD improves analytical precision by eliminating plasma flicker noise, further lowering detection limits.

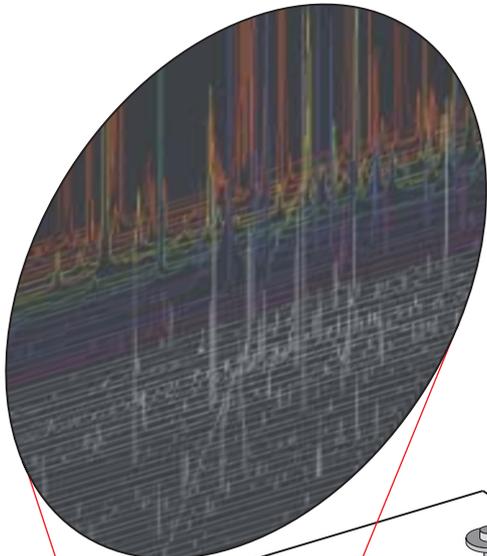


Principles of Adaptive Integration



The high resolution provided by the optical system does not compromise sensitivity as the separation of P 213.618 nm from Cu 213.598 nm shows. (Top)

For a replicate time of 10 seconds, AIT will average lots of short readings for a high intensity line and fewer, longer readings for low intensity lines, providing the optimum signal-to-noise ratio in both cases, simultaneously. (Bottom)



Vista-PRO provides the productivity of simultaneous ICP-OES. All wavelengths are captured in one reading without time consuming scanning.

The patented VistaChip provides anti-blooming protection on every pixel. A 1 megahertz pixel processing speed ensures signal processing is 80 times faster than competitive instruments.

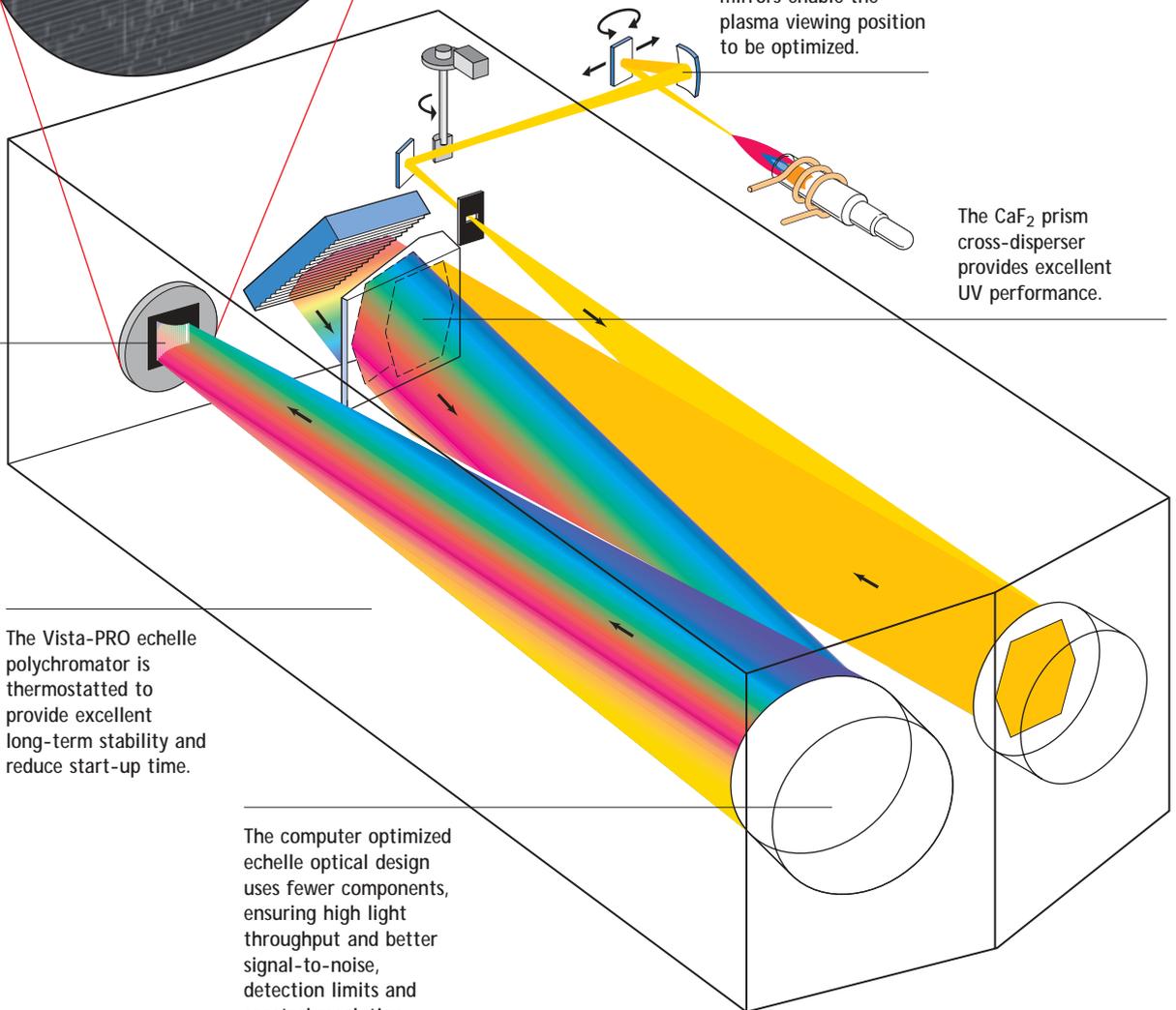
Computer controlled mirrors enable the plasma viewing position to be optimized.

The CaF₂ prism cross-disperser provides excellent UV performance.

The fast operational speed of the VistaChip reduces running expenses, by saving on maintenance and argon costs, as well as providing more accurate sample analyses each day.

The Vista-PRO echelle polychromator is thermostatted to provide excellent long-term stability and reduce start-up time.

The computer optimized echelle optical design uses fewer components, ensuring high light throughput and better signal-to-noise, detection limits and spectral resolution.



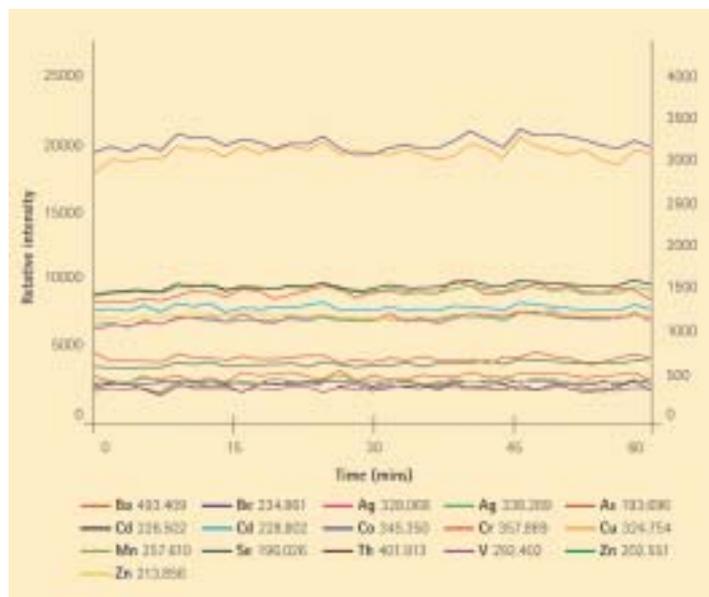


Varian's ICP systems have always provided stable and accurate analytical results, even for the most challenging samples. Utilizing our established high performance RF generator, Vista-PRO continues this tradition of excellence, offering:

- Superior plasma performance from over 75% RF coupling efficiency. Directly analyze organic solvents and samples containing high levels of dissolved salts.
- Excellent long-term stability through the elimination of inefficient secondary matching networks, and reduced waste heat.
- Higher uptime, better reliability and lower service costs, as there are no moving parts.
- The flexibility to easily analyze your full range of sample types. Varian's compact 40 MHz free running design responds quickly to any changes in plasma sample loading.
- Maximized reliability and serviceability, as water-cooling is eliminated.

Difficult samples made easy

No matter what the sample, the Vista-PRO provides excellent long-term stability. To achieve this, Varian created the Direct Serial Coupling (DISC) system that improves the transfer efficiency of RF energy into the plasma by eliminating inefficient secondary matching networks. As a result, the Vista-PRO RF system produces a robust and stable plasma suitable for the direct analysis of samples ranging from organic solvents to industrial wastes and concentrated brines. Unlike crystal locked designs, Vista-PRO's free running RF generator responds instantly to changes in the plasma impedance for superior stability.



The direct aspiration of methanol for an extended period is a test of RF and sample introduction stability. This continuous measurement of a range of elements for over an hour demonstrates the excellent robustness and stability of the Vista-PRO.

Linear dynamic range from parts per billion to percent levels

The revolutionary VistaChip CCD detector provides full wavelength coverage from 167-785 nm. Our unique MultiCal™ feature then automatically assigns each result to the appropriate wavelength for that result. MultiCal extends the linear range of ICP-OES analysis from parts per billion to percentage levels. Unlike dual view systems, Vista-PRO provides this linear dynamic range without having to analyze the sample twice. Vista-PRO provides one-step analysis from a single plasma view.

Automatic results confirmation

One of the greatest challenges in the laboratory is to prove that you have accurate results for unknown samples. Vista-PRO's MultiCal can help by providing automatic on-line results confirmation throughout the analysis. Use MultiCal to simply monitor your results at two or more wavelengths for each element and you have automatic results validation. MultiCal also offers an extra level of data quality control, giving you confidence in the accuracy of your results and confirmation of freedom from interferences. If you are not using MultiCal confirmation today, how can you be sure of the accuracy of your data?

Vertical or horizontal plasma?

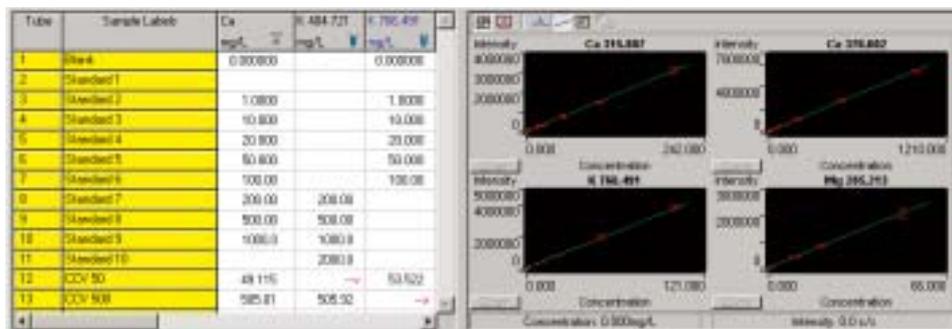
Vista-PRO offers either optimized axially viewed or radially viewed plasma systems. The horizontal, axially viewed plasma is ideal for environmental and research applications that require excellent sensitivity, while MultiCal provides the dynamic range needed from one plasma view. Varian's axially viewed plasma is suitable for the routine analysis of samples with dissolved solids content up to 5% (or up to 25% with Varian's High Solids* torch).

If long term analysis of the most difficult samples is required, the Vista-PRO radially viewed plasma offers the benefits of robust operation with minimal maintenance. The radially viewed plasma is vertically oriented, providing immediate venting of exhaust vapors for reduced injector tube blockage and longer torch life. Vertically oriented, radially viewed plasma systems are the accepted standard in many industries including chemicals manufacture, salt production, wear metals analysis, petrochemical production and precious metals refining. Dual view plasma systems, which feature horizontal torches, cannot match the rugged, high dissolved salts performance of the Vista-PRO radial system.

* patent pending

3 sigma detection limits of Vista-PRO radial and axial radial instruments using 30 s integration time

Element	Wavelength (nm)	3σ Detection Limits (µg/L)	
		Vista-PRO Radial	Vista-PRO Axial
Ag	328.068	1	0.3
Al	167.016	0.9	0.2
As	188.979	5	1.5
Au	267.595	5	1.0
B	249.773	0.6	0.1
Ba	455.403	0.15	0.03
Be	234.861	0.05	0.01
Bi	223.061	6	2
Ca	396.847	0.06	0.01
Cd	214.438	0.6	0.05
Ce	418.660	2	2
Co	238.892	1	0.2
Cr	267.716	0.9	0.15
Cu	327.396	1	0.3
Fe	259.940	0.8	0.1
K	766.490	4	0.3
Li	670.784	1	0.06
Mg	279.553	0.04	0.01
Mn	257.610	0.08	0.03
Mo	202.030	2	0.5
Na	589.592	2	0.15
Ni	231.604	1.4	0.3
P	177.432	5	2
Pb	220.353	5	0.8
S	181.971	10	5
Sb	231.147	5	2
Se	196.026	6	2
Si	251.611	2.2	1.4
Sr	407.771	0.05	0.01
Ti	334.941	0.2	0.1
Tl	190.790	6	2
V	292.402	0.7	0.2
W	207.911	3.5	2
Zn	213.856	0.8	0.2
Zr	343.823	0.9	0.3



The advantages of MultiCal: shown is Ca calibrated using both the 315.887 and 370.602 nm lines with an axial Vista-PRO. The wavelengths are calibrated to 100 mg/L and 1000 mg/L respectively, providing extended linear dynamic range and detection limits from one plasma view.

The accuracy of the results is verified by the Continuing Calibration Verification (CCV) results. The first column combines the results from the two wavelengths to provide the mean final result.

With ICP Expert, you are the Expert



ICP Expert software for the Vista-PRO is the most capable ICP software ever developed. Use its multi-tasking capabilities to reprocess results from yesterday's analyses, whilst collecting results for today's samples. ICP-Expert software is compatible with Microsoft Windows® 98, Windows NT4 and Windows 2000, ensuring it is suitable for any laboratory computing environment.

The intuitive interface of ICP Expert is logically organized for easy navigation and use. With ICP Expert you can become an expert user quickly, with wizards that guide you through common operations and a video help system that shows you how to do everything from setting up a method to changing an accessory.

ICP Expert is compatible with Varian's complete range of ICP spectrometers and features unmatched software capabilities, including:

- Powerful reporting features that enable you to export to spreadsheets for trend analysis and process monitoring, and to HTML formats for web access compatibility.
- Full retrospective editing that allows you to mask replicates or standards, correct standard concentrations, try alternative calibration algorithms and adjust your choice of background correction.
- The capability to mathematically combine results for different elements or wavelengths, and to provide automatic calibration range verification. This facility is ideal for manufacturers of metals, chemicals and pharmaceuticals seeking total composition analysis, purity calculations or elemental ratios.

- Complete units' conversion facilities and element reporting in molecular forms such as KCl or NaCl.

- Stability Reference Standardization (SRS), which provides periodic referencing to a standard reference material for the ultimate in analytical accuracy. SRS is ideal for geochemical and high salt content samples and when internal standard elements cannot be used.

- Extensive Quality Control Protocols (QCP) that can be easily modified to suit your laboratory's QC system.

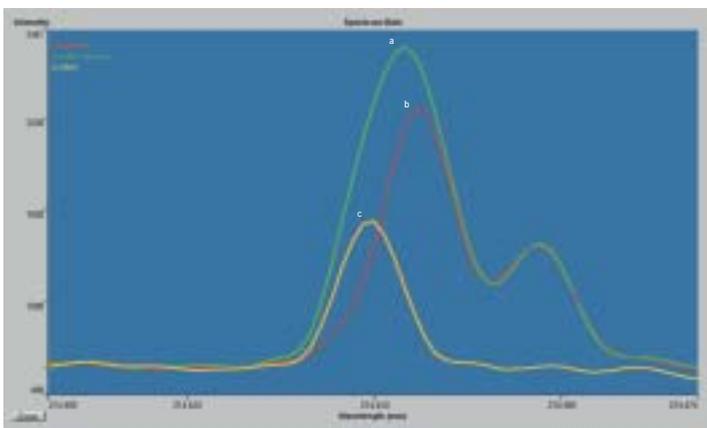
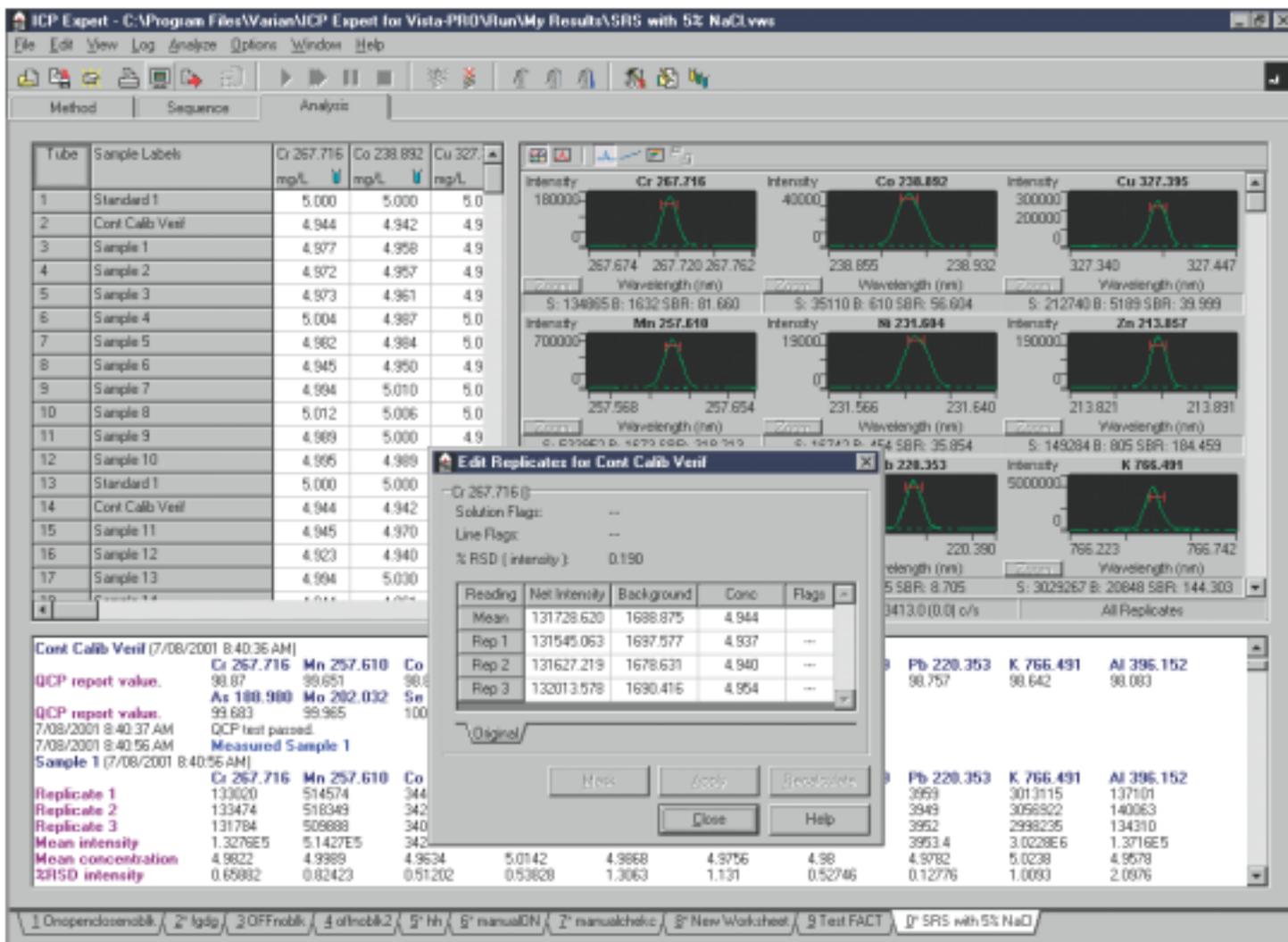
- A unique time resolved signal mode that enables you to couple the Vista-PRO to an HPLC for fast speciation and separation applications.

- Compliance to the US FDA's 21 CFR Part 11 requirements for audit trails, electronic signatures and access privileges (optional software).



Need help?
Join PlasmaNet™,
Varian's online ICP
user email forum.

The ICP Expert online
help includes video
instructions on
hardware setup and
routine maintenance
procedures.



Varian's patented Fast Automated Curve-fitting Technique provides real time spectral deconvolution with no time penalty. FACT improves analytical accuracy by solving spectral interference problems in difficult samples. Best of all, if you suspect a spectral interference in your analysis, you can apply FACT after the analysis has finished.

As shown here FACT easily handles the resolution of the difficult Fe interference on Cd at 214.438 nm. Shown are:

- the unresolved spectrum from a soil sample
- the FACT model of the interference (500 mg/L Fe)
- the FACT deconvolution of the Cd analyte

We take pride in Vista-PRO's performance



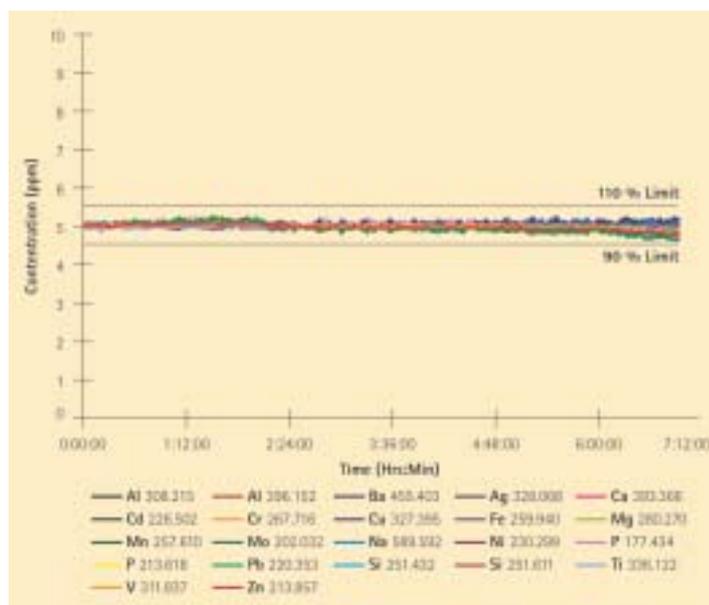
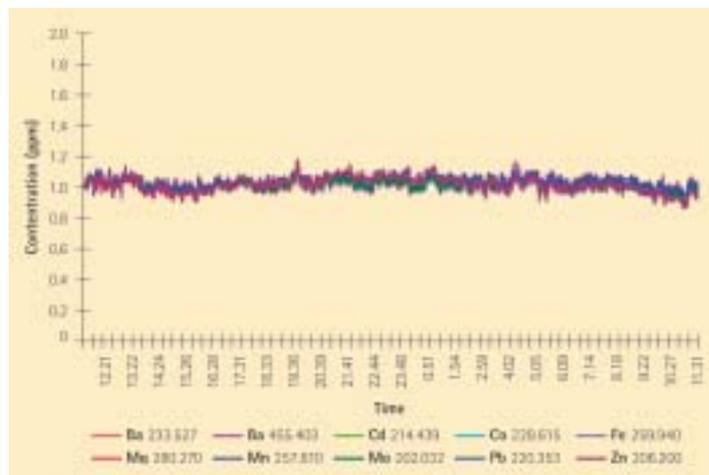
Element	Wavelength (nm)	Measured (µg/L)	Certified (µg/L)
Analysis of NIST SRM 1643c Water			
Ag	328.068	2.3	2.2 ±0.3
As	188.979	83.5	82.1 ±1.2
Ba	233.527	46.6	49.6 ±3.1
Be	265.045	23.1	23.1 ±2.2
Cd	226.502	12.1	12.2 ±1.0
Co	228.616	21.5	23.5 ±0.8
Mn	257.610	35.7	35.1 ±2.2
Mo	202.030	100.0	104.3 ±1.0
Ni	231.604	58.0	60.6 ±7.3
Pb	220.353	32.7	35.3 ±0.9
V	292.402	28.1	31.4 ±2.8

The Vista-PRO axial instrument offers one-step analysis from one plasma view. Soil digest analyses are easily and accurately performed. Varian's MultiCal gives accurate recoveries from parts per billion to sub-percentage levels, such as the excellent recovery for 650 mg/L of Al shown. (Right)

Element	Wavelength (nm)	Measured (mg/L)	Certified (mg/L)
Analysis of Soil Digest			
As	188.979	6.0	6.3
Ba	233.527	6.6	7.0
Cd	214.438	0.2	0.2
Co	228.616	0.07	0.1
Cu	324.754	3.1	3.0
Zn	206.200	68.8	70.0
Fe	260.709	348.0	350.0
Al	257.510	649.0	650.0
K	766.490	221.0	210.0

Today, busy laboratories are expected to be both centres of analytical excellence and profitability. Providing excellent long-term stability and plasma robustness, Varian's Vista-PRO is perfect for achieving these goals. The long-term stability offered by the Vista-PRO results in greater productivity and profits for your laboratory due to less downtime and maintenance costs. The superior stability of the Vista-PRO reduces the need for recalibration, thereby reducing running costs and maximizing the throughput of samples per hour.

With Vista-PRO you can confidently analyze any sample, from the highest dissolved solids to the most volatile organic solvents, simply and accurately.



With Varian's unique high solids torch, the axial Vista-PRO shows excellent stability for the direct aspiration of 25% sodium chloride over 24 hours. (Top)

The stability of elements in kerosene directly aspirated for 8 hours with no internal standardization is shown. (Bottom)

Every analysis presents its own unique challenges. Varian's comprehensive range of sample introduction components allows you to tailor your ICP to achieve the best, most accurate results as quickly as possible.

Varian's sample introduction systems are easy to mix and match for your specific application. For high dissolved solids applications choose our high solids torch with Twister™ spraychamber and Seaspray™ nebulizer. For volatile organic solvents you can rapidly change to our fully or semi-demountable torches with our water-cooled glass spraychamber for optimum performance.

The benefits of Varian's sample introduction systems include:

- A wide choice for ultimate flexibility
- Easy, fast set-up and changeover
- Dedicated systems for unique applications
- Fast delivery

Safety

It is Varian's policy to manufacture safe products and to meet all legal requirements governing the design, manufacture and sale of safe products. As with all similar products, some or all of the following hazards may be present: high temperatures, high pressure gases, explosive gases, magnetic and radio frequency radiation, UV and visible light and electricity. Each product is designed to protect operators from potential hazards. Varian supplies instructions that describe the correct procedures for the operation and maintenance of each product.

The Vista-PRO series Inductively Coupled Plasma Optical Emission Spectrometer is designed to be used to determine the levels of trace and major elements.



Vista-PRO is certified to comply with the requirements of the EMC and LV directives of the European Union.



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Environmental
Photonics
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Food and Beverage
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