claimed advantages of a new microprocessor-based total organic carbon analyzer introduced at the show by Beckman Instruments Inc. The $8000 instrument can provide analyses of water and waste-water samples in as little as 2 minutes. The microprocessor controls calibration and linearization of the analyzer, zeroes the instrument, and processes the data to put it in a readily usable format.

Microprocessors also play a major role in three new instruments introduced by Princeton Applied Research Corporation (PARC). The first of these is a polarographic analyzer that is used in conjunction with a conventional dropping mercury electrode (or with PARC's new static mercury drop electrode) for electrochemical analyses. All setup, scan, data reduction, calculation, and symbolization steps are controlled by the microprocessor. PARC claims that the combination of the analyzer and the new static mercury drop electrode, a system that sells for $14,500, provides the most favorable signal-to-noise ratio available in any commercial polarographic instrument.

The second new PARC instrument is a microprocessor-based variation of the photoacoustic spectrometer introduced by PARC just last year. At $35,000, the new spectrometer costs about $5000 more than last year's model, but the company argues that the increased versatility more than makes up for the price increase. The third new instrument is the company's model 350 corrosion measurement system for electrochemical analysis of intact metal sheets. This is the first commercial instrument to incorporate a battery of techniques to calculate the potential corrosion rate of the metal. It costs $13,750.

Not only the interiors of instruments have been changed by the advent of microprocessors. The Touchtone keyboard that once was the mark of the microprocessor is beginning to be replaced by heat-sensitive electronic switches that nestle snugly behind a flush faceplate. In some cases, the effect is not unlike that of a child's toy with pretend switches lithographed onto a metal surface. The electronic switches are really an improvement, however, because there are no metal contacts to corrode, wear, or be short-circuited by dirt and foreign objects. Typical examples of this new type of instrument design are the R90 thermal analysis programmer and the model 850 high performance liquid chromatography (HPLC) system introduced at the meeting by the DuPont Company. Instruments produced by PARC, Varian, and a few other companies also display this new look.


Fig. 1. The DuPont model 850 HPLC features heat-sensitive switches and a flush control panel.

There seems little doubt that the advent of the microprocessor is generally beneficial. In the first place, microprocessor instruments are easier to operate, so that they can be operated by technicians rather than Ph.D.'s once a program is stored inside. Their results are more reproducible, and often better, than those of a conventional instrument. Perhaps most important, they collect and reduce data so that manual manipulation is virtually eliminated.

Some scientists, however, have expressed concern that the microprocessor can act as a buffer between the experiment and the experimenter, allowing faulty data to go undetected. Instruments that manipulate data extensively before printing out results—using curve-smoothing procedures, for example—have the potential to produce results that look acceptable even when the raw data are not. Similarly, a poorly written program for subtraction of backgrounds may produce the same result when subtracting 1 unit from 10 as when subtracting 99,991 from 100,000, even though the result in the second case is meaningless. This problem can be accentuated as the instrument ages and performance deteriorates.

This situation is rare, although one instrument company executive concedes that there are some instruments on the market in which microprocessors have been used to disguise fundamental defects. Many manufacturers, though, go to great lengths to avoid such problems by incorporating circuitry to check for them. Microprocessor-equipped instruments manufactured by Perkin-Elmer Corporation, among others, continually check results and performance of components to ensure that they are within preestablished parameters; when they are not, an error light is flashed.

Nonetheless, with the rapid proliferation of microprocessors, the buyer should be aware of the potential problems, particularly in the bottom-of-the-line models. In many cases, it seems likely that the instrument that has been redesigned completely to incorporate an integral microprocessor may be a safer buy than one to which a microprocessor has been attached as an afterthought or a gimmick.—THOMAS H. MAUGH II

Elemental Analysis: Plasmas Revive Emission Spectroscopy

It may be a mouthful, but inductively coupled plasma-atomic emission spectroscopy, ICP for short, performs more than well enough to make up for its long-winded title. ICP is a 9-year-old technique for elemental analysis that can, in available commercial instruments, quantitatively determine the concentrations of up to 48 elements simultaneously in solids, liquids, and gases with detection limits of 1 part per billion or less for many elements. Computerized ICP spectrometers can deliver a publication quality analysis in 1 minute from the introduction of the sample to printout. And the wide dynamic range of ICP instruments means that concentrations of principal constituents and trace elements can be obtained at the same time without the need for costly and time-consuming dilution or concentration procedures.

Although ICP's have been shown at the Pittsburgh Conference since 1974, the introduction of several new instruments and the prominent display given them this year indicates that manufacturers are girding for a big push. Several observers noted that the technique has been demonstrated to provide reliable analyses of a wide variety of samples and

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is ready to take its place as a mainstay in the elemental analysis field. In addition, atomic emission spectroscopy, which has been partially eclipsed by the rise of atomic absorption spectroscopy in the past decade, is regaining some of its lost appeal because of the replacement of conventional flame, arc, or spark sources by the plasma. The existence of three newsletters devoted to ICP attests to its popularity.

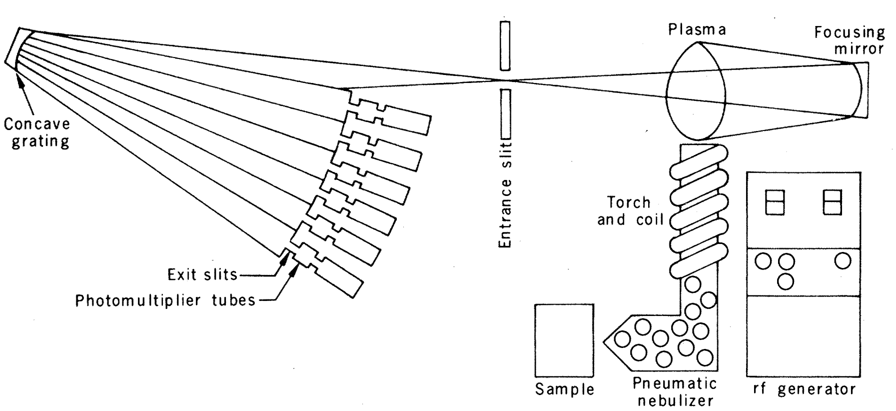

Fig. 1. Diagram of an ICP direct-reading spectrometer capable of simultaneously determining the concentrations of several elements. [Source: Jarrell-Ash Division]

The history of ICP goes back to the early 1960's. Among the first to report on the feasibility of using a plasma as the excitation source in atomic emission spectroscopy were groups headed by Stanley Greenfield of Albright and Wilson, Ltd., Oldbury, England, and Velmer Fassel of the Ames Laboratory at Iowa State University. The earliest results were not encouraging as detection limits were well above the parts per million range. Gradual improvements have, however, resulted in lowering detection limits by approximately one order of magnitude every 2 years. As progress was made in performance, interest in ICP increased. According to Fassel, there are about 175 ICP's capable of multielement analysis in the world. This number may not seem especially impressive, but the technique is still very new and such instruments sell for about $100,000. Thus, a substantial investment has already been made in them.

Although its price tag may appear to be considerable, the sensitivity and high speed of analysis of ICP makes the investment an economical one. At the University of Minnesota, St. Paul, for example, Robert Munter heads an analytical laboratory that is responsible for determining the composition of various soil, water, and plant tissue samples brought to the laboratory by researchers from the university and other nonprofit or government organizations. About half of the samples come from soil scientists and the other half from researchers monitoring environmental pollutants. In the past, the laboratory relied on a spark atomic emission spectrograph, an atomic absorption spectrometer, and a variety of other instruments to carry out this task.

The Minnesotans use spark atomic emission only for qualitative survey analysis because of its poor sensitivity. Atomic absorption is a sequential, one-element-at-a-time technique and is time- and sample-consuming when more than a half dozen elements are to be determined. In addition, certain elements with a tendency to chemically react in the flame used to vaporize samples cannot be analyzed well by atomic absorption, and a wet chemistry technique is required. According to Munter, analysis of 15 or so elements by these methods costs the researcher about $25 per sample. With ICP, all the elements can be done at once and the labor cost for 15 or more elements is essentially the same as that for one. The laboratory charges a nominal fee of $1 per sample, which goes into a fund to be used to buy a replacement instrument in the future. Since the laboratory can supply analyses at the rate of 150 samples per day and expects to service about 25,000 samples this year, 4 years should be sufficient to accomplish this purpose. If the previous charge of $25 were retained, the ICP could pay for itself in 2 months.

The speed and sensitivity of ICP can also mean the difference between doing and not doing an analysis. An eye-catching example of such a situation is provided by a mineral prospecting technique developed by Barringer Research Limited, Rexdale, Ontario. Called Airtrace, the technique involves the collection of airborne particulates over a wide geographical area followed by elemental analysis of the particles collected. The aim is to find areas over which anomalous concentrations of so-called pathfinder elements exist in the air. Pathfinder elements are associated with particular minerals. Mercury, for example, is often associated with gold.

Particulates are collected by scooping up particles from the air with a device called an aerodyne, which is mounted on an aircraft that flies a particular pattern over the area of interest. The aerodyne deposits the particles on a tape, to which they adhere, and at intervals the tape is advanced. The tape is "played back" in the laboratory. During this process, a powerful infrared laser vaporizes the particles, and the vapor is carried into an ICP by a stream of argon gas. Each laser pulse produces a vapor cloud containing about 15 micrograms of material, which is analyzed for about 20 elements. A computer generates a map of elemental concentrations for the geographical area covered during the sampling. Since the sampling area may be several hundred square miles, a rapid analytical technique is essential.

According to Frank Abercrombie of Barringer Research, Airtrace has successfully passed tests in which the locations of known mineral deposits were to be determined, and proprietary studies for clients are well under way. Abercrombie adds that the same technique can and has been applied to the problem of monitoring airborne pollutants.

An additional advantage of ICP is that it can analyze a variety of sample types with a minimum of sample preparation. Petroleum research at Phillips Petroleum Company, Bartlesville, Oklahoma, provides an example of ICP's ability to analyze organic as well as aqueous solutions. Aqueous solutions are by far the most commonly analyzed liquid samples and the easiest. For oil analysis, however, an organic solvent such as xylene is required.

Like a number of other oil companies, Phillips has been interested in recycling motor oil for reuse. The problem is to find an economical process that will rid the oil of numerous impurities that accumulate in it during its lifetime. To a certain extent the procedure followed is a trial-and-error one, in which the composition of the purified oil is determined and changes are made in the recycling process on the basis of the results of the analysis. According to John Runnels of Phillips, analysis of 25 to 30 elements by a combination of atomic absorption spectroscopy and wet chemical procedures would take up to 5 days per sample. With an ICP, however, the test for impurities can be accomplished in a few minutes, thus drastically speeding up the development of the recycling process. Under a joint Phillips–state government program, Phillips now has a pilot plant operating in North Carolina that was developed in this way.

Numerous other examples of the range of sample types analyzable by ICP exist. The materials include metals and alloys, minerals and refractory oxides, whole blood and serum, oils and organic compounds, soils, effluents, mineral acids, and rare earths. Observers say that monitoring environmental pollutants, determining contamination during food processing, and clinical analysis could all become major applications of ICP in the near future. A potential large industrial use is in wear metal analysis, a procedure in which wearing of metal parts in machinery is detected from the concentration of metal in lubricating oil.

As an atomic emission technique, ICP

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A New Meaning for the Term "Service Call"

One overlooked aspect of the microprocessor/minicomputer revolution in analytical instruments is that these components can facilitate servicing of the instruments. When all aspects of instrument operation are controlled by the electronic brain, then remote operation of the instrument—and remote servicing—by factory technicians becomes possible. This development can bring a new meaning to the term "service call."

One example of this approach is provided by the DuPont Company's DP-1, a gas chromatograph–mass spectrometer-data system with an integrated minicomputer that controls data collection and instrument operation. Through the use of a relatively inexpensive (about $1000) device known as a Modem, the DP-1 can be linked to any telephone receiver and operated from a remote location. If the instrument is not operating correctly, the owner or user can call a toll-free number at DuPont and place the telephone handset in the Modem; a technician at the factory can then operate the instrument and diagnose the problem in much the same manner as if he were physically present at the instrument site. Dan Carroll of DuPont estimates that as many as 90 percent of all electronic malfunctions can be diagnosed in this manner. Mechanical malfunctions, however, can be diagnosed only if they affect the electronics in some specific manner. In many cases, the malfunction can be repaired by the owner without further involvement of the technician. If a service call is required, the technician will know what the problem is and what parts may be required. The Finnigan Company has offered a similar service for about 3 years but, like DuPont, has only begun to publicize it this year.

The advantages to the instrument user are obvious: The amount of time the instrument is out of service can be reduced dramatically (particularly if the instrument is located at a site distant from a service center) and the cost of service is reduced. There are advantages for the manufacturer also. The cost of operating a service organization is astronomical, Carroll says, and anything that reduces that cost is beneficial to the company. The service also increases customer confidence in the equipment and the company, he adds.

Carroll thinks that most companies will be providing this type of service for large-ticket items within 5 to 10 years, both to reduce costs and to meet competition. It is not yet clear, however, whether it will be feasible to extend the service to lower-cost instruments. For many of these, the cost of the Modem would represent a substantial fraction of the initial purchase price—although the cost of Modems may decline as more are produced. Even for the less expensive instruments, though, microprocessors can reduce service requirements. Many microprocessor-equipped instruments manufactured, for example, by Perkin-Elmer Corporation incorporate programming that leads the user through a series of diagnostic steps to determine which part of the instrument is malfunctioning. Many types of problems can then be repaired without the delay and expense associated with a conventional service call.

—T.H.M.

A New, Rapid Method for Fourier Transforms

The Fast Fourier Transform (FFT) is a strong contender for the mathematical technique most commonly implemented on computers. Developed in 1965 by James Cooley of IBM and John Tukey of Princeton University, the FFT provides a way to calculate discrete Fourier transforms rapidly. It has thereby revolutionized the analysis of data in a number of fields, such as molecular spectroscopy, seismology, and signal processing for speech analysis, radar, and sonar.

Now, however, Shmuel Winograd of IBM has found a new way to compute discrete Fourier transforms rapidly. Although Winograd's method seems unlikely to knock the FFT from its perch as one of the mathematical techniques most often used, it may replace the FFT on certain special-purpose computers, such as those built around microprocessors.

The discrete Fourier transform is a mathematical technique that separates a complex signal into the frequencies that make it up. For example, a spoken word is recorded as a combination of sound frequencies. When these frequencies are separated, "voice prints" of individuals can be identified. Similarly, specific molecules are characterized by the energies of their electrons and the vibrations and rotations of their component atoms. These energies may give rise to spectral lines with very closely spaced or even overlapping frequencies, which may then be separated by the discrete Fourier transform.

The idea of analyzing spectral data with discrete Fourier transforms is an old one, but such analyses were computationally impractical before the FFT was developed. The problem is that the obvious way to compute a discrete Fourier transform of n data points requires n^2 additions and n^2 multiplications. In practice, n is often about 1000. Thus about 1 million multiplications and 1 million additions are required.

The FFT is based on theoretical developments leading to special tricks that allow investigators to combine some of the operations necessary to compute discrete Fourier transforms. Cooley and Tukey showed that, if n is a power of 2, the number of necessary additions and multiplications is only $\log_2 n$. Thus, if n is about 1000, the number of additions and multiplications can be reduced 100-fold. This meant that discrete Fourier transforms could be implemented on computers without being prohibitively expensive.

Winograd's new method of computing discrete Fourier transforms also relies on special tricks, but the method is totally different from the FFT. For example, rather than requiring n (the number of bears many resemblances to conventional arc, spark, or flame atomic emission. The elements to be analyzed are excited to numerous high-energy quantum states by an excitation source. The intensity of the light given off as these atoms decay to lower-energy states is then proportional to the concentration of the elements in the sample. One difference between ICP and other emission techniques comes in the selection of the emission lines to be monitored. A particular species will generally emit light at several wavelengths. The chosen wavelength depends on which spectral line has the strongest emission relative to the underlying background and noise. Since the excitation conditions in the plasma are different from those in arcs, sparks, and flames, the optimum spectral line can be different as well.

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data points) to be a power of 2, Winograd requires it to be a product of relatively prime numbers—that is, numbers such as 7, 8, and 9 that have no common factors. He finds that he can perform discrete Fourier transforms with only about 1/5 of the multiplications required by the FFT. Moreover, he has shown that, at least when *n* is a prime, the number of required multiplications cannot be further reduced. Winograd reports that his method and the FFT require about the same number of additions.

With such a drastic reduction in the number of multiplications, it seems logical that Winograd's method should replace the FFT. The problem is that the time required for multiplication and addition is only part of the picture. Time is also required for what computer scientists call "overhead"—loading data into the computer, storing it, and moving it around. James McClellan of the Massachusetts Institute of Technology (MIT) is among those who have found that Winograd's method requires more overhead than the FFT—and this increased overhead affects the feasibility of the method.

McClellan points out that multiplication is very rapid on today's general-purpose computers, such as the IBM 360 or the PDP 11. On these computers, the FFT is still faster than Winograd's method. On the other hand, McClellan and his student Hamid Nawab, find that Winograd's method is faster than the FFT on special-purpose computers, such as microprocessors, on which multiplication is very slow.

Since Winograd's method may be a viable alternative to the FFT for some users, Charles Rader of MIT's Lincoln Laboratories is beginning to work on computer hardware to implement it. Thomas Parks of Rice University developed a slightly different way of implementing Winograd's method that further improves its performances on special-purpose, but not on general-purpose, computers. Parks says he has received a number of inquiries about his work from such instrument companies as Tektronix. Representatives of these companies, however, say they are still in the preliminary stages of investigating Winograd's method.

It is Rader's opinion that it will take another year or two for the relative merits of the methods to be sorted out. Even if Winograd's method does not replace the FFT, it is based on what Rader calls "a bag of tricks" that should prove useful to those investigating signal processing.

—G.B.K.

NSF to Fund Regional Instrumentation Facilities

The rapid increase in instrument capabilities demonstrated at the Pittsburgh Conference in recent years is a blessing to scientists because it extends the range of experiments that can be performed and the speed with which they can be carried out. It is, however, a mixed blessing. Increases in sophistication lead to a rapid obsolescence of existing equipment. They generally also lead to increases in cost, and many types of instruments, including nuclear magnetic resonance (NMR) spectrometers, mass spectrometers, and x-ray diffractometers, are being priced out of the reach of individual investigators. More and more, it is becoming apparent that these large ticket items must be shared among a number of investigators.

One step in this direction, now being initiated by the National Science Foundation (NSF), is the establishment of regional instrumentation facilities. NSF has allocated about $3 million during fiscal 1978 for the establishment of five or six such centers. The new laboratories will be designed to ensure that state of the art instruments are available to those who need them and that highly qualified personnel will be on hand to operate and maintain the instruments and, if necessary, to help in the interpretation of data. Ideally, says the program's director, Tom Farrar, the funds will be used to augment existing centers where expertise already exists.

A unique feature of the NSF program is that industrial scientists, particularly those from small companies, will be encouraged to use the facilities. In this manner, NSF hopes to achieve the twin goals of promoting basic research in industry and fostering more cooperation between university and industrial scientists. Preference will thus be given to applications that demonstrate industrial interest.

The idea of sharing instruments is, of course, not new. The Department of Energy (DOE and its predecessor agencies), for example, has for many years provided academic scientists with access to instruments and opportunities for research collaboration. DOE will, in effect, extend this program by making a financial contribution to the NSF project for at least the first year and by participating in proposal selection. The National Institutes of Health (NIH) has an ongoing program, similar to that proposed by NSF, to support facilities for scientists engaged in biomedical research; at these facilities, however, priority for use of the instruments is given to NIH-supported scientists. NIH will join the NSF program in an advisory role and will also assist in proposal selection.

One example of what such a facility might be like is the 360-megahertz NMR spectrometer facility opened at the University of Pennsylvania at the end of January. This NIH-supported regional facility is meant to extend high-resolution NMR techniques to biological specimens. The $440,000 spectrometer is particularly useful for studying nuclei, such as phosphorous-31, carbon-13, and fluorine-19, that can be incorporated into living systems. Use of the instrument is available to anyone whose research is publicly funded; the cost is $10 per hour, in line with the policies of both NIH and NSF to keep user costs low. A similar NMR facility has been in operation at Stanford University for 3 years.

The first grants under the new NSF system are expected to be awarded in September.—T.H.M.

The real difference between ICP and other atomic emission or atomic absorption techniques is the plasma. For one thing, the plasma is at a temperature between 6,000° and 10,000°K, which is much hotter than arcs or flames, so that almost all of a sample is vaporized and excited and little if any is subject to chemical reactions between elements that occur at lower temperatures. The inert argon atmosphere further inhibits interfering reactions. Also, the spatial structure of the plasma is such that a large amount of light associated with the plasma itself (background) occurs at a different height above the torch than the atomic emission, so that a large signal-to-noise ratio is possible. Finally, no electrodes are required, so a common source of contamination in some other techniques is absent in ICP. A future benefit, according to Ramon Barnes of the University of Massachusetts, is that computer techniques exist for studying the plasma in detail, something which cannot yet be done with flames. As a result, it may be possible one day to tailor ICP to take full advantage of the plasma.

Argon gas is the raw material for the plasma. The gas flows through a cylindrical quartz "torch," the end of which sits inside an induction coil. A radio-frequency (rf) electric current in the coil induces a magnetic field of the same frequency around the coil. Any charged particles in the neighborhood are rapidly accelerated and quickly "heat up" the argon by way of collisions. The heated argon becomes the plasma, which consists of argon ions and free electrons. These charged particles then cause the plasma to be self-sustaining as long as the rf power is supplied. Charged particles to "seed" the plasma formation are provided by a tesla coil, an electrical discharge device which ionizes particles near it.

A second stream of argon carries the sample in the form of an aerosol upward through the center of the torch. The aerosol is vaporized in the hot plasma, which is in the form of a cylinder surrounding the aerosol. The discovery, in 1969, of a way to achieve this confinement geometry was a crucial step in making ICP a sensitive technique. The most convenient form of sample for aerosol formation is a liquid, and all commercial ICP's are designed for analysis of liquid samples. The liquid is forced through a device called a nebulizer to form the aerosol. (One manufacturer offers an accessory to nebulize solid samples.)

At the Pittsburgh Conference, four companies (Applied Research Laboratories, Sunland, California; Jarrell Ash Division of Fisher Scientific Company, Waltham, Massachusetts; J-Y Optical Systems Division of Instruments SA, Inc., Metuchen, New Jersey; and Labtest Equipment Company, Los Angeles, California) exhibited simultaneous multielement ICP's. (In Europe, ICP's are made by M.B.L.E., a subsidiary of Philips Analytical, Eindhoven, the Netherlands, and by Kontron GMBH, Munich.) Spectrometers for multielement analysis are called direct readers because they disperse the incident light toward fixed optical slits, each with its own photodetector, located on the circular focal curve of a concave grating. The location of the slits is determined by the wavelengths that are selected for analysis. Selection of the wavelengths and hence of the elements to be analyzed is made when the instrument is ordered. It is possible, but not at all trivial, to change wavelengths after delivery.

Direct readers can analyze 1 to 48 elements simultaneously, but manufacturers say that the most commonly ordered number of elements is about 30. All of these machines are equipped with micro- or minicomputers. Thus, they can automatically calculate background corrections, interferences from elements with nearby spectral lines, and calibration curves from standard samples. They can also monitor and control overall instrument operation. With a printer and an accessory carousel that can hold 50 or more samples, it is almost possible to just push a button and come back later in the day to find a complete analysis printed out ready for publication. The cost of such instruments ranges from $60,000 for a bare-bones ICP that detects a single element to $120,000 for an accessory-laden, 48-element direct reader.

Because of the high cost of such instruments compared to that of automated atomic absorption spectrometers and because many researchers need some development experience to determine the elements, spectral lines, and analytical procedures they want, manufacturers are introducing less expensive ICP's. Rather than incorporating direct-reading spectrometers, these instruments are built around conventional scanning spectrometers with a single exit slit and photodetector. The resulting cost ($20,000 to $35,000) is comparable to that of automated atomic absorption machines (ranging from about $17,000 to $34,000, depending on options), but the simultaneous multielement capability is lost. Some observers say that future ICP's may incorporate both modes of operation.

For analysts who already have spectrometers and would like to try their hand at ICP, Plasma-Therm, Inc., Kresson, New Jersey, manufactures plasma generating units. The plasma is an exceptionally tricky animal, and it is seldom worthwhile for analysts to spend their time building their own source. In fact, many of the ICP manufacturers obtain their plasma sources from Plasma-Therm. The company sells automated plasma generating systems, including the torch, for $8,700 to $16,900, depending on the rf power rating. One of the still unsettled questions in ICP is what the optimum power level should be. Greenfield and his associates in England, for example, use a higher rf power (in conjunction with an argon-nitrogen plasma) than do most U.S. researchers.

Spectrogram Corporation, North Haven, Connecticut, offers an ICP retrofitting service. According to John Johnson of Spectrogram, the company has found much interest among owners of old direct-reading atomic emission spectrometers or spectrographs built with arc or spark sources who want to convert their instruments to ICP's.

Finally, inductively coupled plasmas are not the only kind. One company, Spectrametrics, Inc., Andover, Massachusetts, exhibited both simultaneous multielement and scanning sequential plasma spectrometers built around d-c plasmas. A big advantage of the d-c plasma is cost, with price ranges of $25,000 to $51,000 and $16,000 to $19,000 for the two classes of spectrometers, respectively. Spectrametrics also uses a different type of optical system than the ICP manufacturers. Researchers still argue about the relative advantages of the different types of plasmas. Most, however, would probably agree with a recent assessment by P. W. J. M. Boumans of the Philips Research Laboratory that ICP's "have won the battle against alternative excitation sources."

As a technique barely out of its infancy, ICP clearly has not reached its potential performance limits. The new ultrasonic nebulizers now being made by Plasma-Therm which can lower detection limits by a factor of 10, nebulization techniques for solid samples (a device is available from Applied Research Laboratories), and the possibility of combining computerized scanning spectrometers with photodetectors similar to television cameras in order to simultaneously achieve low cost and multielement analytical capability are some developments that could make ICP an even more desirable analytical technique than it is now.—ARTHUR L. ROBINSON