

PALLADIUM, GOLD AND POTASSIUM IN SILICA CATALYST BY ICP-AES

UOP Method 916-93

SCOPE

This method is for determining palladium, gold and potassium in fresh silica catalyst by Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES). The method is suitable for the concentration ranges of 0.2 to 1 mass-% palladium, 0.1 to 0.5 mass-% gold and 1 to 5 mass-% potassium. Catalysts containing more than 1% alumina cannot be analyzed by this method.

OUTLINE OF METHOD

A representative sample of fresh whole pill catalyst is obtained and ground according to UOP Method 918. A portion of the ground sample is fumed with hydrofluoric and sulfuric acids and the residue is dissolved in hydrochloric and nitric acids. Scandium is added as an internal standard. The sample solution is aspirated into a computer controlled ICP-AES along with a matrix-matched standard. Concentrations are determined by comparison of the sample emission ratios to the computer-generated standard calibration curves. Results are reported on a volatile-free basis at 700°C, following duplicate loss on ignition (LOI) determinations by UOP Method 909.

APPARATUS

References to catalog numbers and suppliers are included as a convenience to the method user. Other suppliers may be used.

Balance, electronic, readability 0.1-mg, 200-g capacity

Balance, electronic, top-loading, readability 0.01-g, 2100-g capacity

Beaker, borosilicate glass, 400-mL

Beakers, Teflon (TFE), 250-mL, Fisher Scientific, Cat. No. 02-593-5B

Bottle, narrow mouth, round, amber glass, 237-mL, with molded plastic conical polyethylene lined cap, Fisher Scientific, Cat. No. 03-320-6C

Bottle, polyethylene, right-to-know safety wash, distilled water, 500-mL, Fisher Scientific, Cat. No. 03-409-11E

IT IS THE USER'S RESPONSIBILITY TO ESTABLISH APPROPRIATE PRECAUTIONARY PRACTICES AND TO DETERMINE THE APPLICABILITY OF REGULATORY LIMITATIONS PRIOR TO USE. EFFECTIVE HEALTH AND SAFETY PRACTICES ARE TO BE FOLLOWED WHEN UTILIZING THIS PROCEDURE. FAILURE TO UTILIZE THIS PROCEDURE IN THE MANNER PRESCRIBED HEREIN CAN BE HAZARDOUS. MATERIAL SAFETY DATA SHEETS (MSDS) OR EXPERIMENTAL MATERIAL SAFETY DATA SHEETS (EMSDS) FOR ALL OF THE MATERIALS USED IN THIS PROCEDURE SHOULD BE REVIEWED FOR SELECTION OF THE APPROPRIATE PERSONAL PROTECTION EQUIPMENT (PPE).

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Buret, weighing, 10-mL, Kimble No. 17200-F10, Scientific Products, Cat. No. B9366-10

Cylinder, graduated, borosilicate glass, Class A, 1000-mL, Fisher Scientific, Cat. No. 08-553D

Cylinder, graduated, polypropylene, 25-mL, Fisher Scientific, Cat. No. 08-572-6B

Flask, Kjeldahl, 100-mL, Fisher Scientific, Cat. No. 10-110C

Flasks, volumetric, Class A, 100- and 1000-mL, Fisher Scientific, Cat. Nos. 10-210-5C and -5G, respectively

Funnel, filter, 58° angle bowl, short stem, 75-mm diameter, Fisher Scientific, Cat. No. 10-322E

Hot plate-stirrer, digital, Dataplate, 9-positions, Scientific Products, Cat. No. H2185-6

Inductively Coupled Plasma-Atomic Emission Spectrometer, computer controlled, having a bandpass of 0.010 nm (FWHM) or better, and covering the wavelength range specified in Table 1. The instrument must have the ability to use internal standards and perform background corrections, and must measure the internal standard response concurrently with each element response. A Perkin-Elmer Plasma 2000 spectrometer with a corrosion resistant sample introduction system, or its equivalent, is required.

Petri dish, Fisher Scientific, Cat. No. 08-747F

Pipetter, motorized, digital, Rainin, Cat. No. EP-10mL, with portable power pack, Cat. No. 6100-080, rapid charge stand, Cat. No. 6101-049 and pipet tips, Cat. No. RC-10mL

Pipetter, repeater, 5-, 10- and 25-mL, Fisher Scientific, Cat. Nos. 13-683-10B, -10C and -10F, respectively

Regulator, argon, two-stage, high purity, Matheson Gas Products, Model 3104-580

Regulator, nitrogen, two-stage, high purity, Matheson Gas Products, Model 3104-580

Scoop, weighing, 20-g capacity, nickel alloy, Fisher Scientific, Cat. No. 01-914-38

Spatula, Scoopula, 150-mm, Fisher Scientific, Cat. No. 14-357

Stirring bars, magnetic, borosilicate glass, 6-mm OD x 21-mm, and 9.55-mm OD x 25.4-mm, Scientific Products, Cat. Nos. S8313-31 and -33, respectively

Stirring bars, magnetic, Teflon, 38-mm, Fisher Scientific, Cat. No. 14-511-64

Thermometer, surface, with temperature probe, Omega Engineering, Cat. Nos. HH81 and 88108K, respectively

Tongs, beaker

Watch glass, Pyro-quartz, triple-rib, 90-mm diameter, rim to center (curvature) height approximately 25 mm, Pyromatics, Cat. No. PI-7206

REAGENTS AND MATERIALS

All reagents shall conform to the specifications established by the Committee on Analytical Reagents of the American Chemical Society, when such specifications are available, unless otherwise specified. References to water mean deionized or distilled water, except where noted.

References to catalog numbers and suppliers are included as a convenience to the method user. Other suppliers may be used.

Acetone, 99.5% minimum purity

Argon, 99.995% minimum purity, ICP feed gas

Gold wire, 0.25-mm diameter, high purity, 99.998%, Aesar, Cat. No. 10967

Hydrochloric acid, concentrated, 37%

Hydrochloric acid, 1:1. Add 500 mL of concentrated hydrochloric acid, measured in a graduated cylinder, to an equal volume of water in a volumetric flask and mix.

Hydrofluoric acid, concentrated, 48-51%

Hydrogen peroxide, concentrated, 30%

Nitric acid, concentrated, 70%

Nitrogen, 99.99% minimum purity, water/oil free, ICP optics purge gas

Palladium wire, 0.25-mm diameter, high purity, 99.997%, Aesar, Cat. No. 10962

Potassium standard, custom grade standard, 10-mg/mL, Inorganic Ventures, Inc., Cat. No. CGK10-5. The relative density information on the label is needed for preparation of the Reference Standard on a mass basis.

Scandium standard, custom grade standard, 1000- μ g/mL, Inorganic Ventures, Inc., Cat. No. CGSC1-5

Sulfuric acid, concentrated, 98%

Sulfuric acid, 1:1. Carefully, and with ice-cooling, pour 500 mL of concentrated sulfuric acid into 500 mL of water, mix and allow to cool. The mixture may be stored indefinitely in a well stoppered bottle or flask.

PROCEDURE

All subsequent steps involving handling and heating of concentrated acids or acid solutions must be performed in a fume hood.

Preparation of Calibration Standards

Palladium Standard Solution (1-mg/g)

1. Weigh 1.0 g of 99.997% palladium wire to the nearest 0.1 mg.
2. Transfer the palladium wire into a 100-mL Kjeldahl flask and add a small borosilicate glass magnetic stir bar.
3. Add 25 mL of hydrochloric acid and 10 mL of nitric acid to the flask. Place the flask in a 400-mL beaker.
 - Treatment of the palladium is conducted at ambient temperature until evolution of chlorine has subsided.
 - If allowed to sit overnight, the palladium may dissolve without heating.
4. Place the flask and beaker on a stirring hot plate and heat to a gentle boil while stirring slowly.
5. Maintain the solution volume at approximately 30 mL by the dropwise addition of concentrated nitric and hydrochloric acid in a ratio of 2 to 5, respectively, until the palladium wire dissolves.
 - Caution must be exercised during the addition of the acids to avoid spattering of the palladium solution.

6. Evaporate the acid solution slowly to approximately 20 mL by gentle boiling.
7. Add 30 mL of water and 20 mL of hydrochloric acid to the solution. Swirl to mix.
8. Remove the flask and beaker from the hot plate and allow them to cool to ambient temperature.
9. Tare a one-liter volumetric flask to the nearest 0.01 g and transfer the palladium solution quantitatively with water to the flask.
10. Add 30 mL of concentrated hydrochloric acid to the solution.
11. Dilute with water to a mass that will produce a palladium concentration of exactly 1.000 mg palladium per gram of solution, weighed to the nearest 0.01 g.
 - The final mass of the palladium solution is equal to the mass of the palladium wire multiplied by 1000. For example, if 1.0034 g of palladium wire were dissolved, the final mass of the palladium solution would be 1003.40 g.
12. Mix the solution thoroughly by shaking.
13. Subdivide the palladium standard solution without dilution, into separate 237-mL (or smaller) amber glass bottles and seal with polyethylene lined caps.
 - The stability of the solution in an unopened bottle is not known. The working standard in use, will deteriorate with time and cannot be used for longer than 4 weeks.

Gold Standard Solution (1-mg/g)

1. Weigh 1.0 g of 99.998% gold wire to the nearest 0.1 mg.
2. Transfer the gold wire into a 100-mL Kjeldahl flask and add a small borosilicate glass magnetic stir bar.
3. Add 25 mL of hydrochloric acid and 10 mL of nitric acid to the flask. Place the flask in a 400-mL beaker.
 - Treatment of the gold is conducted at ambient temperature until evolution of chlorine has subsided.
4. Place the flask and beaker on a stirring hot plate and heat to a gentle boil while stirring slowly.
5. Maintain the solution volume at approximately 30 mL by the dropwise addition of concentrated nitric and hydrochloric acid in a ratio of 2 to 5, respectively, until the gold wire dissolves.
 - Caution must be exercised during the addition of the acids to avoid spattering of the gold solution.
6. Evaporate the acid solution slowly to approximately 20 mL by gentle boiling.
7. Add 30 mL of water and 20 mL of hydrochloric acid to the solution. Swirl to mix.
8. Remove the flask and beaker from the hot plate and allow them to cool to ambient temperature.
9. Tare a one-liter volumetric flask to the nearest 0.01 g and transfer the gold solution quantitatively with water to the flask.
10. Add 30 mL of concentrated hydrochloric acid to the solution.
11. Dilute with water to a mass that will produce a gold concentration of exactly 1.000 mg gold per gram of solution, weighed to the nearest 0.01 g.

- The final mass of the gold solution is equal to the mass of the gold wire multiplied by 1000. For example, if 1.0034 g of gold wire were dissolved, the final mass of the gold solution would be 1003.40 g.
12. Mix the solution thoroughly by shaking.
 13. Subdivide the gold standard solution without dilution, into separate 237-mL (or smaller) amber glass bottles, seal with polyethylene lined caps and store in a dark place.
 - The stability of the solution in an unopened bottle is not known. The working standard in use, will deteriorate with time and cannot be used for longer than 4 weeks.

Potassium-Palladium-Gold reference Standard Solution

The Reference Standard must be prepared fresh daily, and should closely match the catalyst sample solution composition. In addition, the acid content and scandium (internal standard) levels must be matched between samples and standards. In the example below, the Reference Standard is prepared to contain approximately 600 μg K/mL, 100 μg Pd/mL, 50 μg Au/mL and 50 μg Sc/mL (the latter as an internal standard) as follows:

1. Pour 6 mL of 10-mg/mL potassium standard into a weighing buret.
2. Tare the weighing buret on the analytical balance to read zero.
3. Carefully transfer and drain the entire solution into a 100-mL volumetric flask.
4. Place the empty weighing buret on the analytical balance and record the differential mass to the nearest 0.1 mg.
 - The solution mass will be read as a minus value on the balance.
5. Clean the weighing buret with water, rinse it with acetone and blow-dry with a stream of nitrogen in preparation for the next addition.
6. Repeat Steps 2 to 5, weighing out and transferring into the same flask 10 mL of the 1-mg/g palladium standard.
7. Repeat Steps 2 to 5, weighing out and transferring into the same flask, 5 mL of the 1-mg/g gold standard.
8. Rinse the neck of the 100-mL volumetric flask with a little water, then add 20 mL of 1:1 sulfuric acid from a repeater pipet and swirl.
9. Add 20 mL of 1:1 HCl from a repeater pipet, rinse with water and swirl.
 - Stopper the flask and set it aside until the samples are also ready for the internal standard addition. It is imperative that this addition be made simultaneously and with the same pipet.
10. Add 5 mL of 1000- μg /mL scandium standard solution (see **NOTE**) as an internal standard using the Rainin pipetter.
11. Rinse the neck of the flask with water, fill to the mark and thoroughly mix. Store the Reference Standard in the dark until needed.
12. See **CALCULATIONS** to determine the exact concentrations of palladium, gold and potassium in the Reference Standard.

Sample Preparation of Whole Pill Catalyst

1. Obtain and grind a representative sample of whole pill catalyst utilizing UOP Method 918.
2. Shake the ground sample randomly by hand for 5 minutes to avoid errors caused by stratification due to settling of the ground sample in the bottle, then proceed immediately with Step 3.
 - Once this step is complete, the homogenous powder must not be agitated until after the sample is taken.
3. On a top loading balance, weigh out approximately 10-15 g of a thoroughly homogenized, powdered sample into the bottom of a petri dish and gently tap it so as to create a thin layer of sample. Partially cover the sample with the top of the petri dish and allow to air-equilibrate overnight with the ambient laboratory air.
 - Due to the hygroscopic properties of silica catalyst samples, an initial air equilibration of the sample prior to analysis will result in improved precision.
4. Scoop approximately 2.0-2.1 g of the ground air-equilibrated catalyst into a weighing scoop.
5. Tare the weighing scoop with sample on the analytical balance to read zero.
6. Transfer the catalyst sample carefully, to avoid dust loss, into the bottom of a 250-mL Teflon beaker.
7. Place the empty weighing scoop onto the analytical balance and record the differential mass to the nearest 0.1 mg.
 - The sample mass will be read as a minus value on the balance.
8. Obtain duplicate LOIs of the air equilibrated sample according to UOP Method 909.
 - Samples for LOI must be taken at the same time the sample is weighed for the potassium, palladium and gold determination.
 - The two LOI's are to be calculated to three significant figures and the results must agree within 5% relative standard deviation or the analysis, beginning with Step 4, must be repeated.
 - The palladium will be in the form of PdO at 700°C, introducing an insignificant positive analytical error of 0.0007%.
9. Place a Teflon enclosed, magnetic stirring bar into each Teflon beaker and cover with a quartz watch glass.
 - The ribbed quartz watch glass was designed to allow SiF₄ gases to freely escape while preventing spray and spatter losses during digestion. Unlike the tight cover Teflon watch glasses, sample digestion can also be observed. Due to HF attack on the quartz watch glass, reducing its thickness, eventual replacement after 10 or more uses is necessary. Alternatively, a transparent ribbed plastic watch glass may be used if and when it becomes available commercially.
10. Add 20 mL of 1:1 sulfuric acid to each sample through the spout of the covered Teflon beaker and gently hand swirl until all the powder is wetted.
11. Add 25 mL of hydrofluoric acid through the spout from a graduated polypropylene measuring cylinder and gently swirl.
 - Appropriate safety precautions must be taken when handling hydrofluoric acid.
12. Add 10 mL of concentrated hydrochloric acid and then add 5 mL of concentrated nitric acid through the spout of the beaker using a repeater pipet and gently swirl.

13. Place the covered beaker on the stirrer hot plate and while slowly stirring, gradually increase the heat to a gentle boil.
 - The stirring speed is crucial; too slow causes bumping; too fast causes sample spatter.
14. Continue boiling and stirring until the mixture begins to fume, in approximately 60 minutes.
 - Careful control of the hot plate temperature setting is necessary to avoid overheating, buckling or melting the Teflon beakers. The maximum permissible temperature as measured with a digital surface thermometer, should not exceed $270 \pm 10^{\circ}\text{C}$ for Teflon.
 - Heating to sulfuric acid fumes will eliminate all silicon as the tetrafluoride and any residual HF from the solution. DO NOT EXCESSIVELY FUME THE SAMPLES! Doing so will make it difficult to matrix match the standards with respect to acid level.
 - The sample is fumed for no longer than five minutes and the residual concentrated sulfuric acid volume will be approximately 10 mL after fuming. At this point, precipitation of purplish-brown Pd and Au may occur, but this precipitate will be redissolved later.
 - If liquid droplets are observed where the watch glass contacts the rim of the beaker, rotate and reposition the watch glass. If white silica gel is observed on the beaker rim, the analysis must be started over.
15. Allow the acid slurry to cool until warm to the touch. Carefully add several mL of water through the spout of the covered beaker while stirring and then rinse down the beaker walls and watch glass with water to a maximum volume of 50 mL.
 - Care should be exercised on adding water to concentrated acid.
16. Add 10 mL of concentrated hydrochloric acid and 5 mL of concentrated nitric acid through the spout of the covered beaker using a repeater pipet.
17. Stir and reheat the beaker to a gentle reflux, boil and evaporate for about 15 minutes until all precipitates have redissolved to form about 50 mL of a clear, yellow solution. Remove the beaker from the hot plate and allow it to cool to the touch.
18. Transfer the solution quantitatively into a 100-mL volumetric flask through a filter funnel, using water to rinse the watch glass and Teflon beaker walls.
 - The total volume at this point must not exceed approximately 90 mL to permit addition of the internal standard.
 - Stopper the flask and set it aside until the Reference Standard is also ready for the internal standard addition. It is imperative that this addition is made simultaneously and with the same pipet.
19. Add 5 mL of 1000- $\mu\text{g/mL}$ scandium standard solution (see **NOTE**) as an internal standard using The Rainin pipetter.
20. Rinse the neck of the flask with water, fill to the mark and thoroughly mix.
 - A faint turbidity visible at this point has proven to be an insoluble complex mineral. This turbidity can be ignored.

ICP-AES— Instrumental Analysis

Set up the ICP-AES instrument in accordance with the instrument manufacturer's guidelines, allowing at least 30 minutes for equilibration after plasma ignition prior to starting the analysis. Table 1 lists recommended wavelengths for the elemental determinations. Other wavelengths may be used if it can be shown that method precision is not adversely affected (see **PRECISION**). If the recommended spectrometer is used, Myers-Tracy signal compensation must be used. Use of a corrosion resistant sample introduction

system is recommended. Set the instrument to read the Reference Standard, blank (if required) and samples five times each, with the average of the five replicates reported.

1. Standardize the instrument by aspirating the blank (if required), followed by the Reference Standard. Allow sufficient wash-out time between aspirations.
 - A calibration blank is not required if the spectrometer specified in *APPARATUS* is used. The instrument software will use zero for the blank. If another instrument is used, check with the manufacturer to determine if a calibration blank is required.
 - Wash-out times are dependent on instrument conditions such as pump rate, and on the concentration levels being measured, and can vary between 30 and 120 seconds.
2. Aspirate the samples, after first entering the dilution into the computer. Allow sufficient wash-out time between aspirations.
3. Aspirate the Reference Standard, treating it as a sample with no dilution, as a calibration check after every *third* sample, then recalibrate the instrument with the Reference Standard solution, before continuing with the next three samples.
 - Any calibration checks and the final standard reading should return the concentrations of the K, Pd and Au in the Reference Standard within $\pm 0.5\%$ relative for all three elements. If not, recalibrate and reaspirate the samples.

Table 1
Instrument Parameters for the Perkin-Elmer Plasma 2000

	Element		
	Pd	Au	K
Wavelength, nm	340.458	242.795	766.490
Mono Select	A	A	B
Plasma Power, W	1400	1400	1400
Viewing Height, mm	15	15	15
Signal Comp.	Yes	Yes	Yes
PMT Gain, V	600	600	700
Survey Window, nm	0.070	0.080	0.080
Peak Window, nm	0.025	0.025	0.025
Sampling Time, m sec	200	150	250
Background Correction	Manual	Auto	Manual
Corr. Interval, nm	-0.030	—	+0.035
Filter Wheel	Auto	Auto	Manual/Open

CALCULATIONS

Calculate the exact concentrations of palladium, gold and potassium in the Reference Standard to four significant figures as follows:

$$K, \mu\text{g/mL} = \frac{1000 AB}{100D} \quad (1)$$

$$\text{Pd or Au, } \mu\text{g/mL} = \frac{1000 AB}{100} \quad (2)$$

where:

- A** = the net-mass of potassium, gold or palladium standard transferred to the 100-mL volumetric flask, g
- B** = potassium standard concentration in mg/mL or palladium/gold standard concentration in mg/g
- D** = relative density of potassium standard (given on manufacturer's label)
- 100** = volume of Reference Standard, mL
- 1000** = conversion of mg to μg

If the dilution for the sample is entered into the instrument computer, the concentrations of the elements in the original sample, on an as-received (AR) basis are calculated by the computer. Report the results to three significant figures.

If the LOI determination is completed prior to the instrumental analysis, the sample mass can be corrected to a volatile-free basis, and that value entered into the instrument computer will yield elemental concentrations on a volatile-free basis. If the LOI determination is completed after the instrumental analysis, calculate the concentration of potassium, palladium and gold in the original sample to three significant figures on a volatile-free (VF) basis as follows:

$$\text{Element, mass-\% VF} = \frac{100C}{100_A - L} \quad (3)$$

where:

- C** = concentration of element in original sample, mass-% AR, from instrument printout
- L** = LOI at 700°C as determined by UOP Method 909, mass-%
- 100** = factor to calculate mass-%
- 100_A** = factor to convert to mass-% residue after ignition

NOTE

The choice of an internal standard is dictated by the instrument requirements and the composition of the samples to be analyzed. Some instruments require a specific element (i.e., scandium). Other elements that are commonly used include yttrium, bismuth and rhodium. The requirement is that the internal standard element not be present in the sample at levels above a few mass-ppm. A full discussion of internal standardization is not possible here. If the spectrometer listed in *APPARATUS* is used, Sc is required as the internal standard.

The concentration of the internal standard to be used is dependent on instrument response, wavelength and the concentrations of other elements being ratioed to the internal standard. Use the instrument manufacturer's recommendations, or a compromise concentration of approximately 50 mass-ppm of either Sc or Y, which is mid-range in concentration versus the other elements being determined by this method.

Concerning the use of internal standards: a sequential ICP-AES instrument measures element emission intensities in step-wise fashion, moving from one element wavelength to the next. If the internal standard is also read in this way, there will be a time interval between the reading of the internal standard intensity and the subsequent element intensities. During this interval, instrument drift can occur that will lead to error in the analysis. To avoid this, this method specifies use of a sequential instrument that reads the internal

standard emission intensity at the same time each element intensity is read; this compensates for any drift in the instrument. In the case of a simultaneous instrument, the internal standard is read concurrently with all elements of interest, therefore, drift is not a factor. An additional benefit of an internal standard in either case is to compensate for slight differences in matrix conditions between the samples and standards, that can arise from inadvertent small variations in levels of matrix components such as the acids (these generally cause slight viscosity and/or nebulization differences).

PRECISION

Repeatability

Based on two tests performed by each of two analysts, on each of two days (8 tests) in one laboratory, the within-laboratory estimated standard deviations (esd) were calculated at the concentrations shown in Table 2. Two tests performed in one laboratory by different analysts, on different days, should not differ by more than the allowable differences shown (95% probability).

Table 2

	Concentration, mass-%	Within-Lab esd, mass-%	Allowable Difference, mass-%
K	3.04	0.0125	0.04
Pd	0.554	0.0014	0.006
Au	0.248	0.0010	0.003

Reproducibility

There is insufficient data to calculate reproducibility of the test at this time.

TIME FOR ANALYSIS

The elapsed time for one sample analysis with grinding and air equilibration is approximately 30 hours. The labor requirement is 3 hours.

REFERENCES

UOP Method 909, "Loss on Ignition of Catalyst at 700°C"

UOP Method 918, "Collection and Grinding of Adsorbents and Catalysts for Analysis"

SUGGESTED SUPPLIERS

Aesar Grove/Johnson Matthey, 892 Lafayette Rd., P.O. Box 1087, Seabrook, NH 03874-1087 (508-521-6300)

Fisher Scientific, 711 Forbes Ave., Pittsburgh, PA 15219 (412-562-8300)

Inorganic Ventures, Inc., 195 LeHigh Ave., Suite 4, Lakewood, NJ 08701 (201-901-1900)

Matheson Gas Products, P.O. Box 96, Joliet, IL 60434 (815-727-4848)

Omega Engineering, Inc., One Omega Dr., P.O. Box 4047, Stamford, CT 06907 (203-359-1660)

Perkin-Elmer Corp., 761 Main Ave., Norwalk CT 06859-0156 (203-762-4747)

Pyromatics, Inc., P.O. Box 764, Willoughby, OH 44094 (216-951-3985)

Rainin Instrument Co., Inc., Mack Road, Woburn, MA 01801 (617-935-3050)

Scientific Products Division, Baxter Diagnostics Inc., 1430 Waukegan Road, McGaw Park, IL 60085-6787 (708-689-8410)