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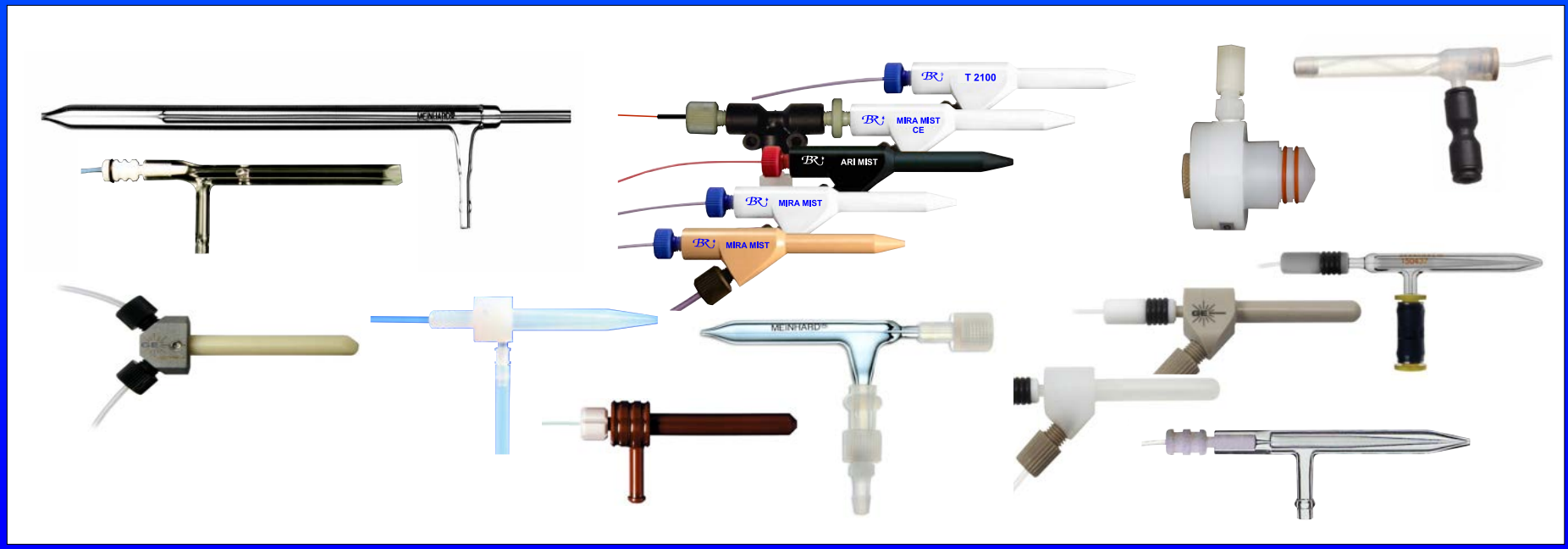
A brief history of ICP & ICP/MS Nebulizers



Presented by John A. Burgener

Pneumatic nebulizers have always been, and are still the main sample introduction method for ICP and ICP/MS.

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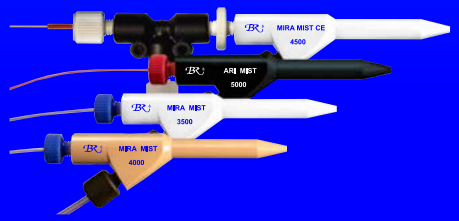
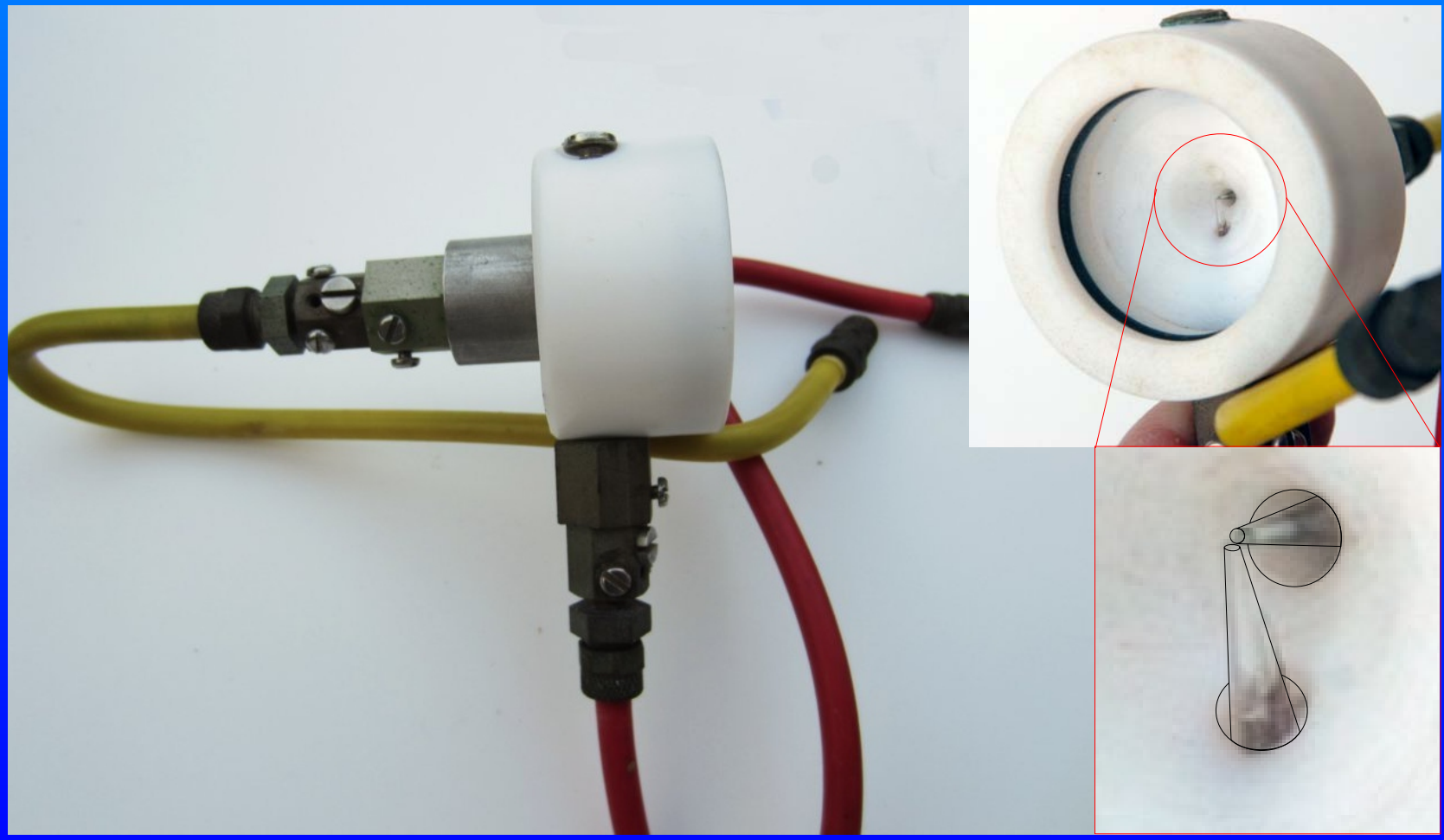


In the beginning, there was the "Adjustable Cross Flow"



They were difficult to adjust, easily broken and easily plugged from salting or particles.

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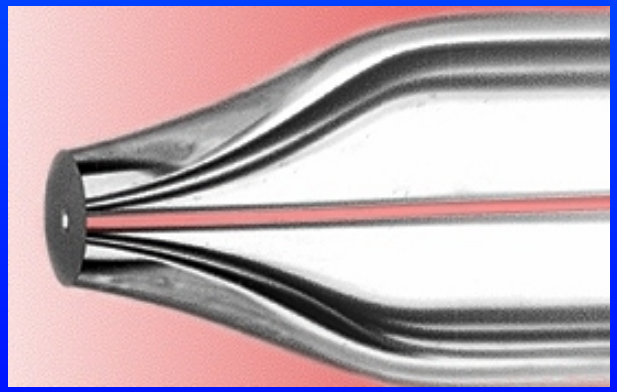
This was soon followed by the Meinhard Concentric, 1974



Meinhard Type T nebulizer
Serial # 4250
Made approx. 1978

Simple, elegant design.

Similar to modern Concentrics.

But salted and plugged easily.

John A. Burgener
Burgener Research Inc.

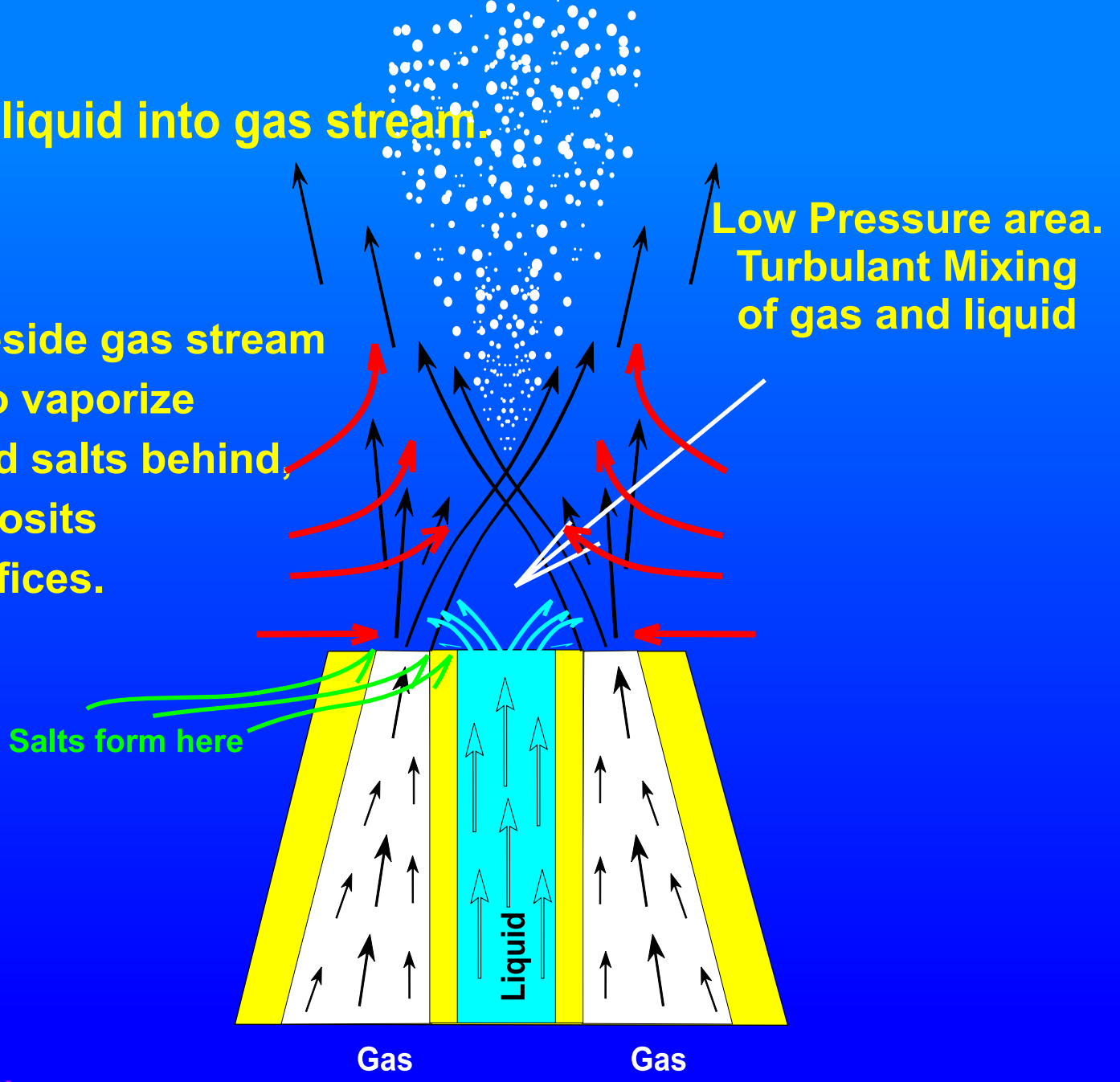
1947: My father started Technical Service Laboratories

1974: TSL received the second ICP made by JA
an Atom comp 950 - Arc/Spark instrument
with an ICP source replacing the arc spark box.

1977: I was asked by my father to help get the ICP running.
The objective was to run Whole Rock analysis.
Whole Rock solutions were 3% $LiBO_4$
ALL nebulizers salted in hours or minutes.
The Adjustable Cross Flow was the first one we used.
Meinhard's concentric salted too fast - minutes.
The cross flow salted in hours,
and plugged too easily.

Induction pulls liquid into gas stream.

Low pressure beside gas stream causes liquids to vaporize leaving dissolved salts behind, causing salt deposits that plug gas orifices.



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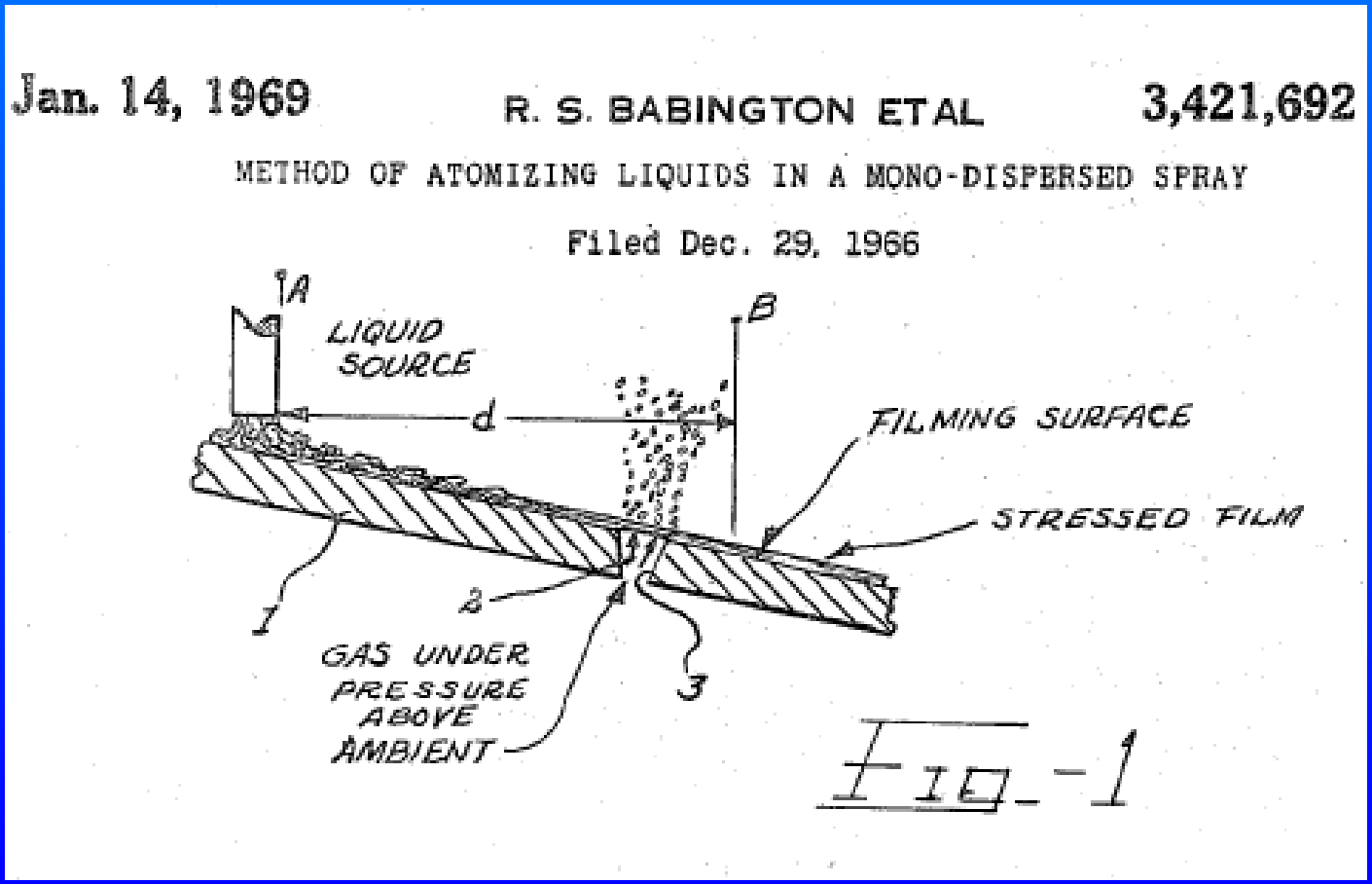
Burgener Research Inc.

Concentrics and Cross flows plug easily. To minimize plugging, Babington designs were developed.



High Solids resistant, but very inefficient.
Only a little part of the liquid passed near the orifice.

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1978 Babington V Groove by Suddendorf and Boyer

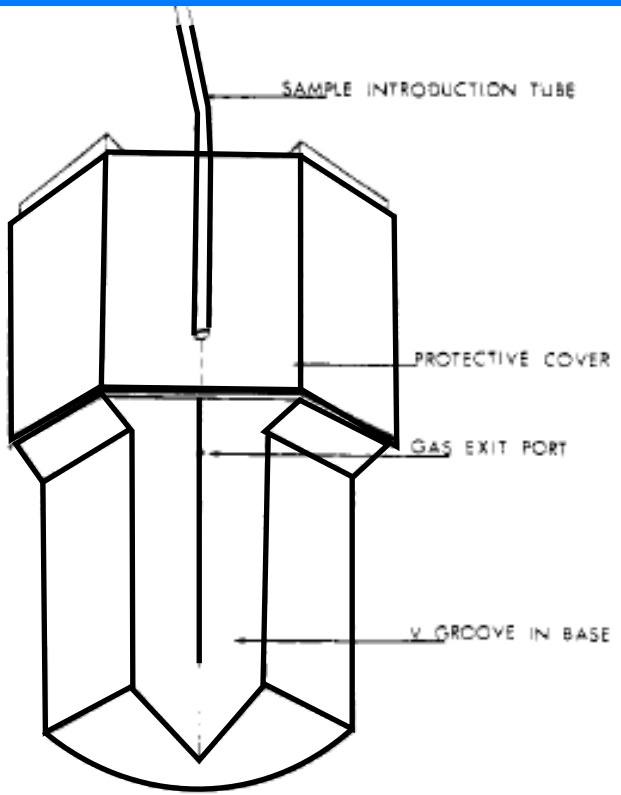

Figure 1. Construction of nebulizer base. Aerosol is produced when the liquid stream flowing down the V groove is ruptured by gas coming from the gas exit port

High Solids resistant, adjustable.
Not commercially introduced.

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Burgener Research Inc.

1980 Babington Pillar and Post by Garbarino and Taylor

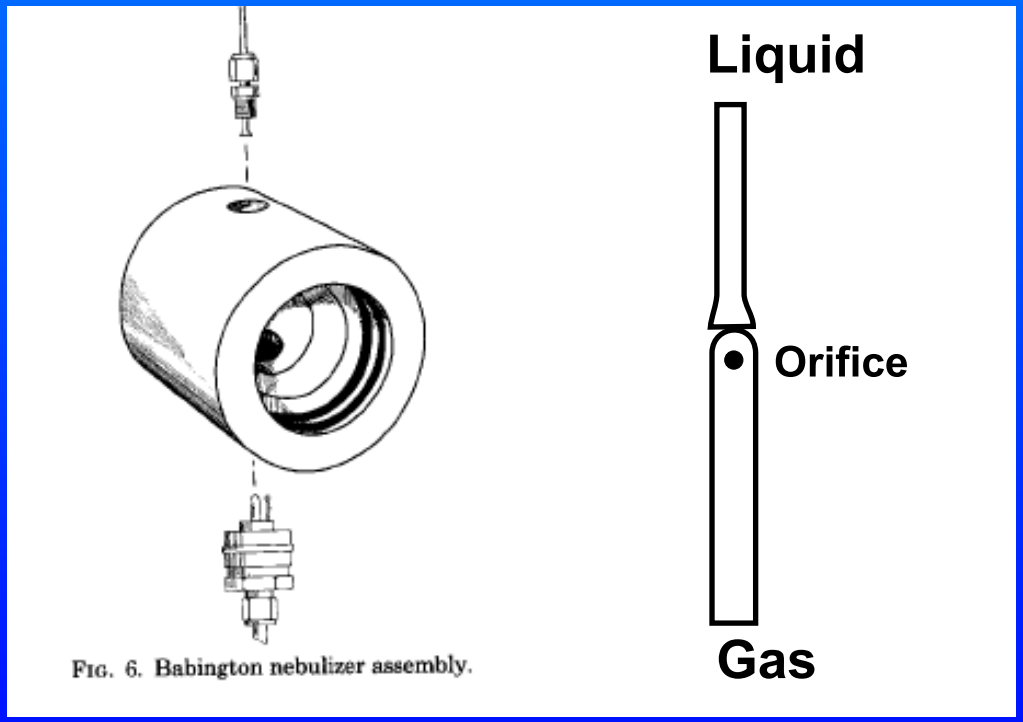

FIG. 6. Babington nebulizer assembly.

High Solids resistant, but very inefficient.
Only a little part of the liquid passed near the orifice.

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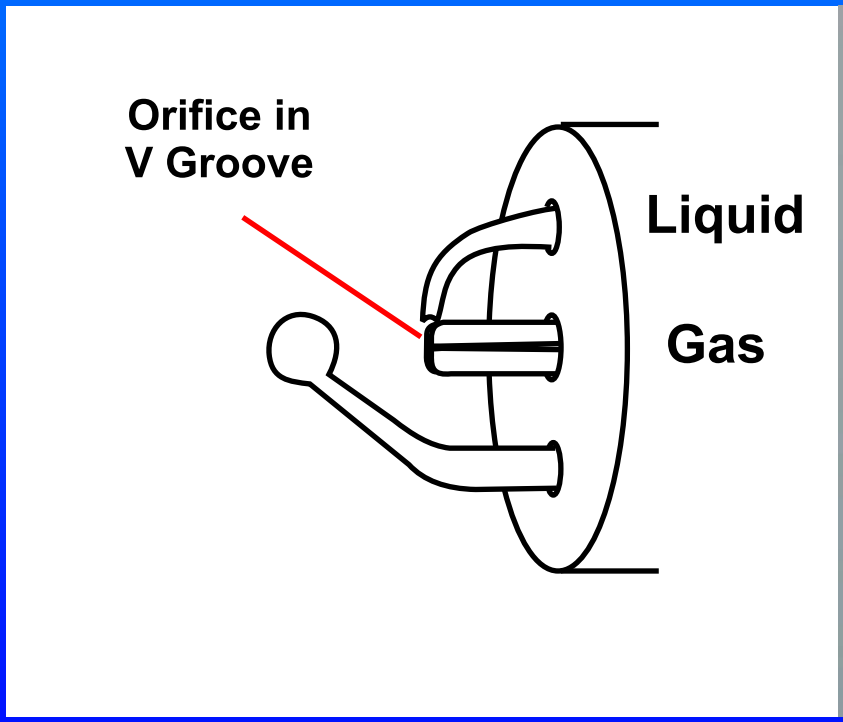
Burgener Research Inc.

~ 1982 GMK Nebulizer
Glass Babington V Groove



Handled particles well, but
gas orifice plugged if running high salts.

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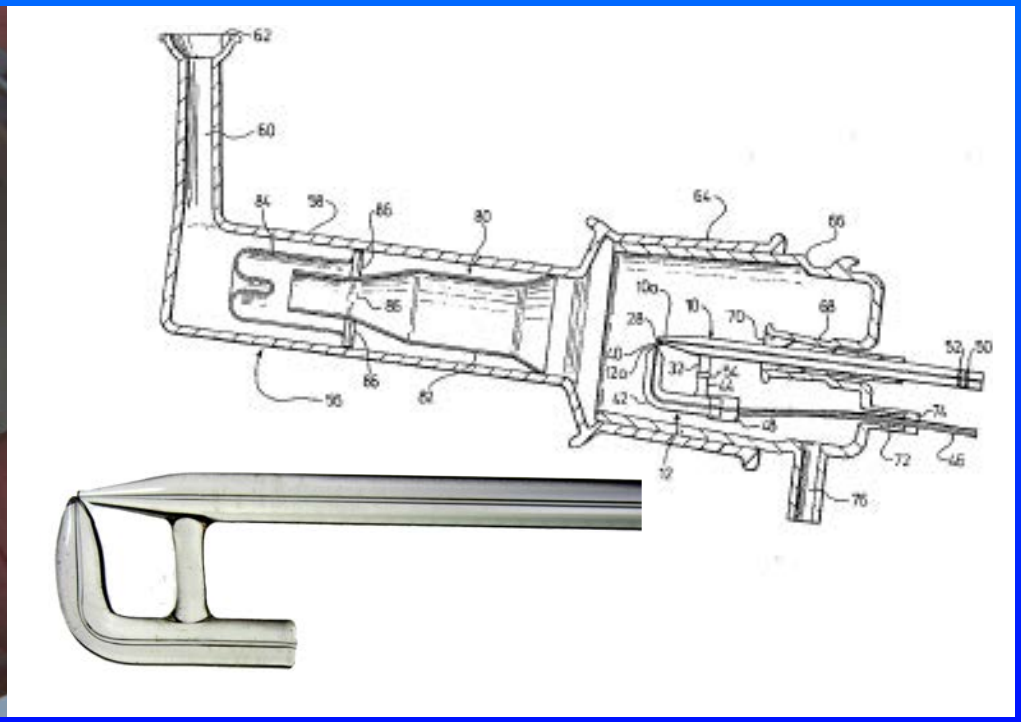
1982 - Meddings' MAK Nebulizer
A Fixed Cross Flow.
Significant improvement over previous ones.



Handled high salts better than most.
More stable, no adjustments.
But still easy to plug with particles.

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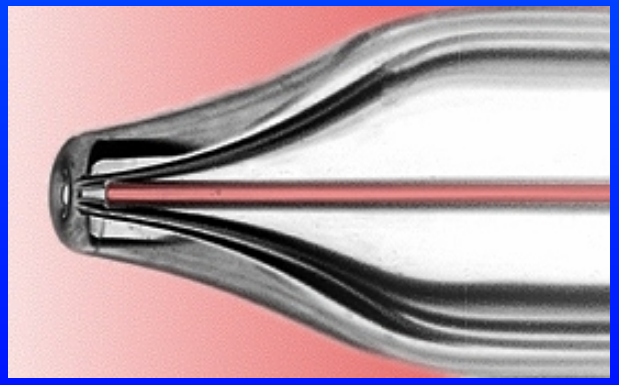
1983 Meinhard introduces the C Type Nebulzer



Lapped edges reduced salting,
but still salted on our solutions.

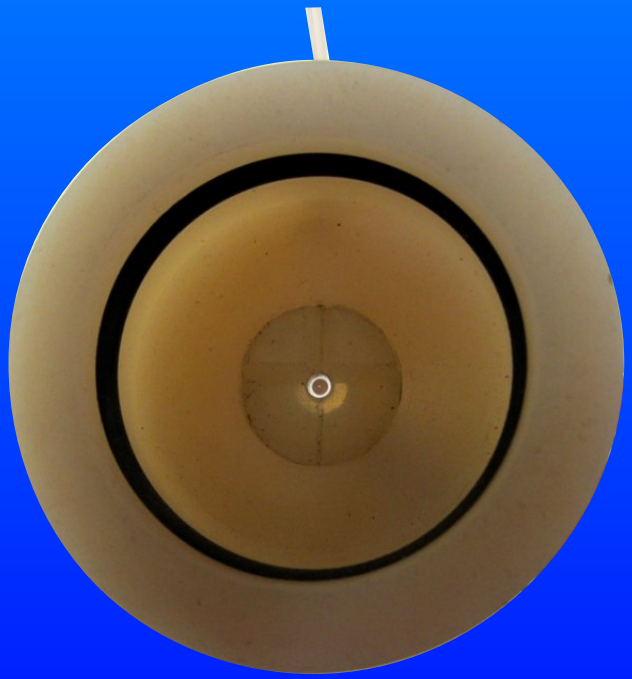
John A. Burgener
Burgener Research Inc.

1983 Precision Glassblowing
began making glassware and nebulizers

Similar to Meinhard's A Type
and still salted on our solutions.

John A. Burgener
Burgener Research Inc.

~ 1983 Jarrell Ash (Thermo) Sapphire V Groove Nebulizer



Handled particles well, but
Sapphire gas orifice would still salt rapidly.
And Sapphire bead would often fall out.

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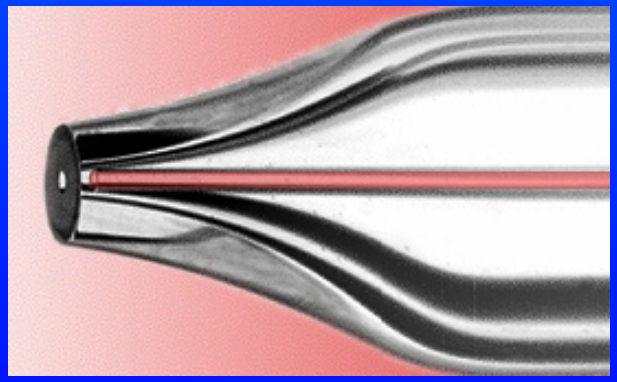
1984 Meinhard introduces the K Type Nebulzer



Recessed inner capillary significantly reduced salting, but still salted on our solutions.

John A. Burgener
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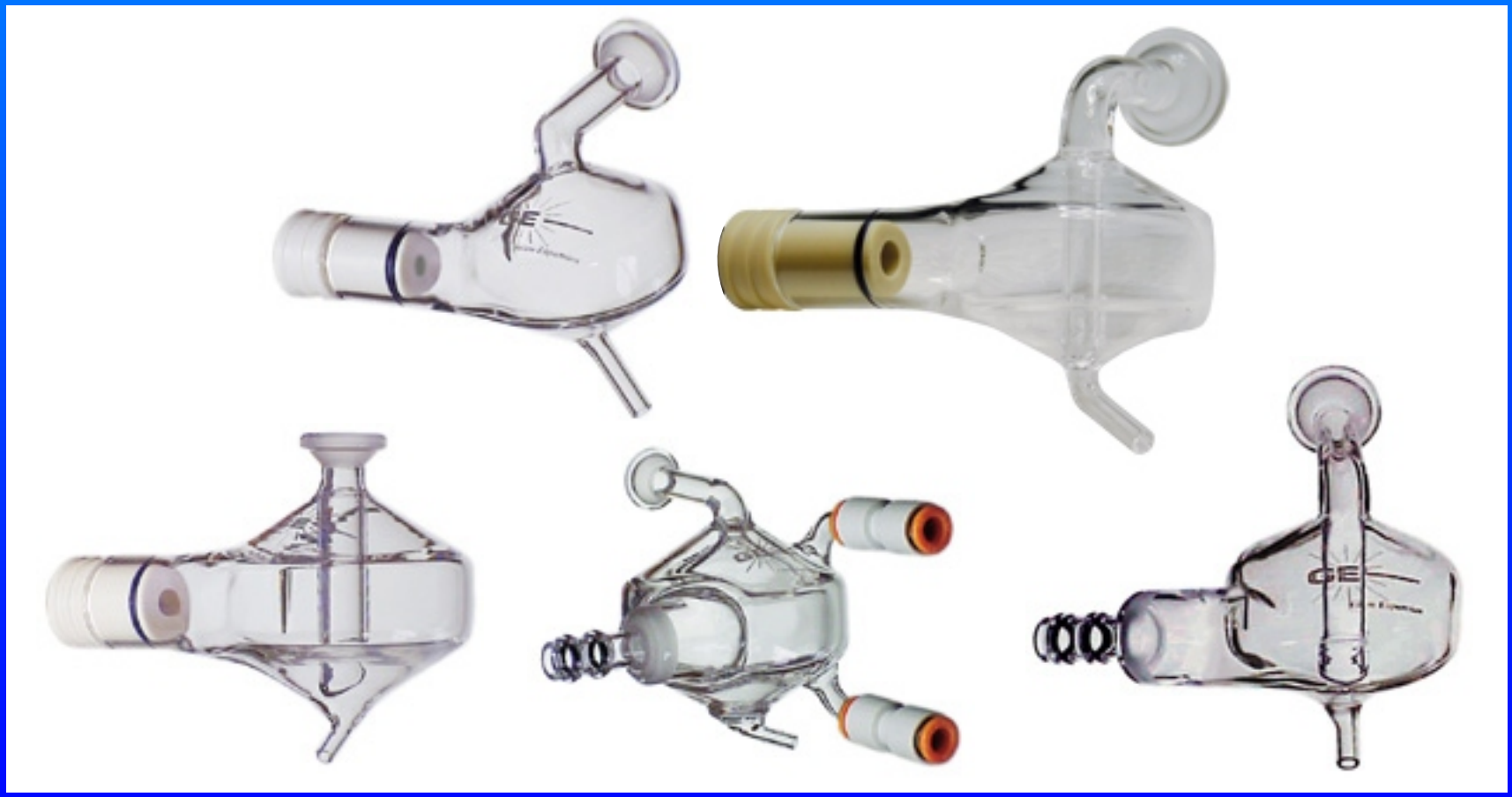
~1984 Glass Expansion
began making ICP glassware



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Burgener Research Inc.

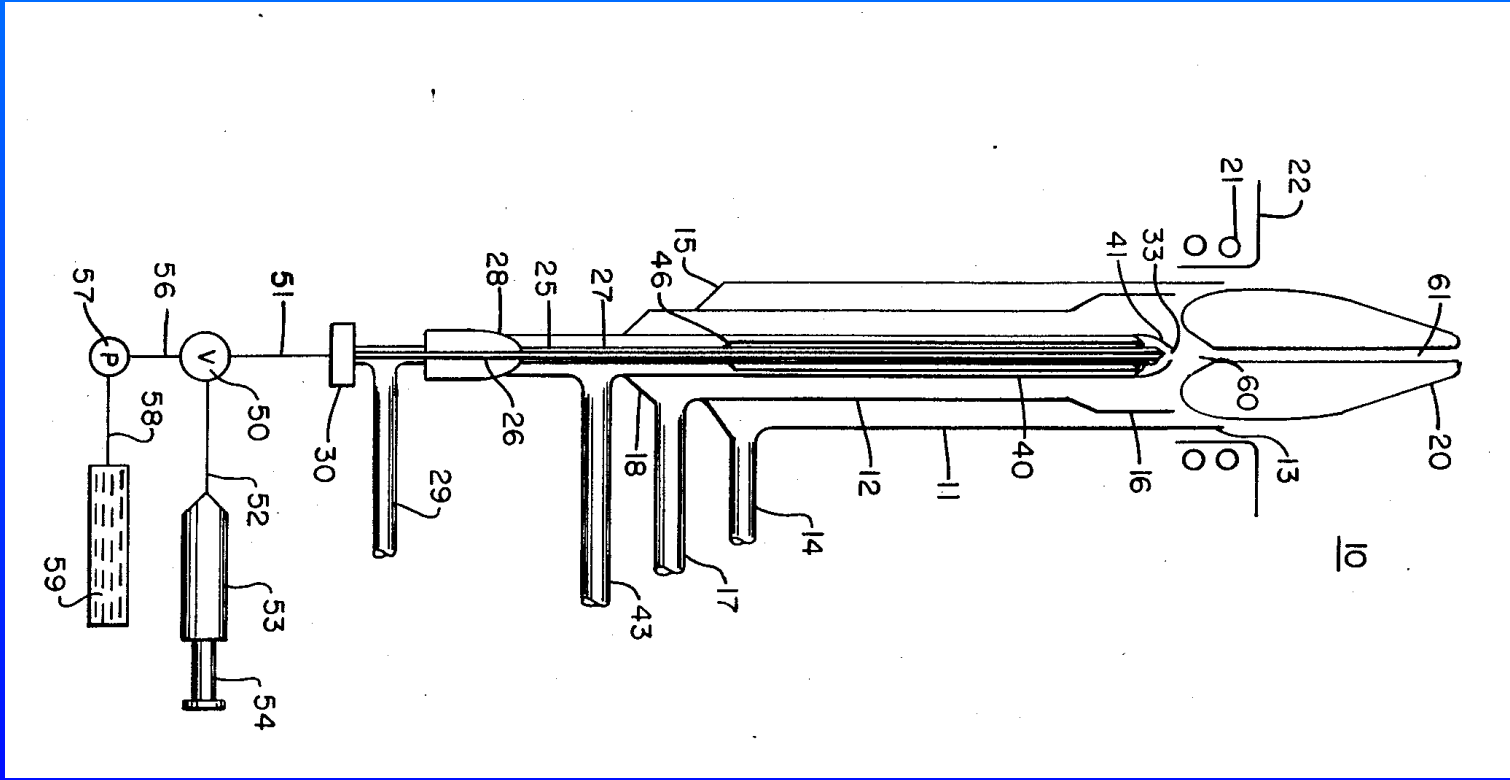
1984-85 The Burgener - Legere Nebulizer
First commercial Teflon Nebulizer.
V Groove with no adjustable parts.

Handled high salts,
More stable, no adjustments,
Not pluged with particles.
Very difficult to make - about a week each.
RAN FOR MONTHS WITHOUT SALTING!

John A. Burgener
Burgener Research Inc.

1986 Fassel, Rice, Lawrence: MicroNebulizer for Direct Injection

(US Patent # 4,575,609)



One of the first micro-nebulizers could not handle salts was not useful for most samples.

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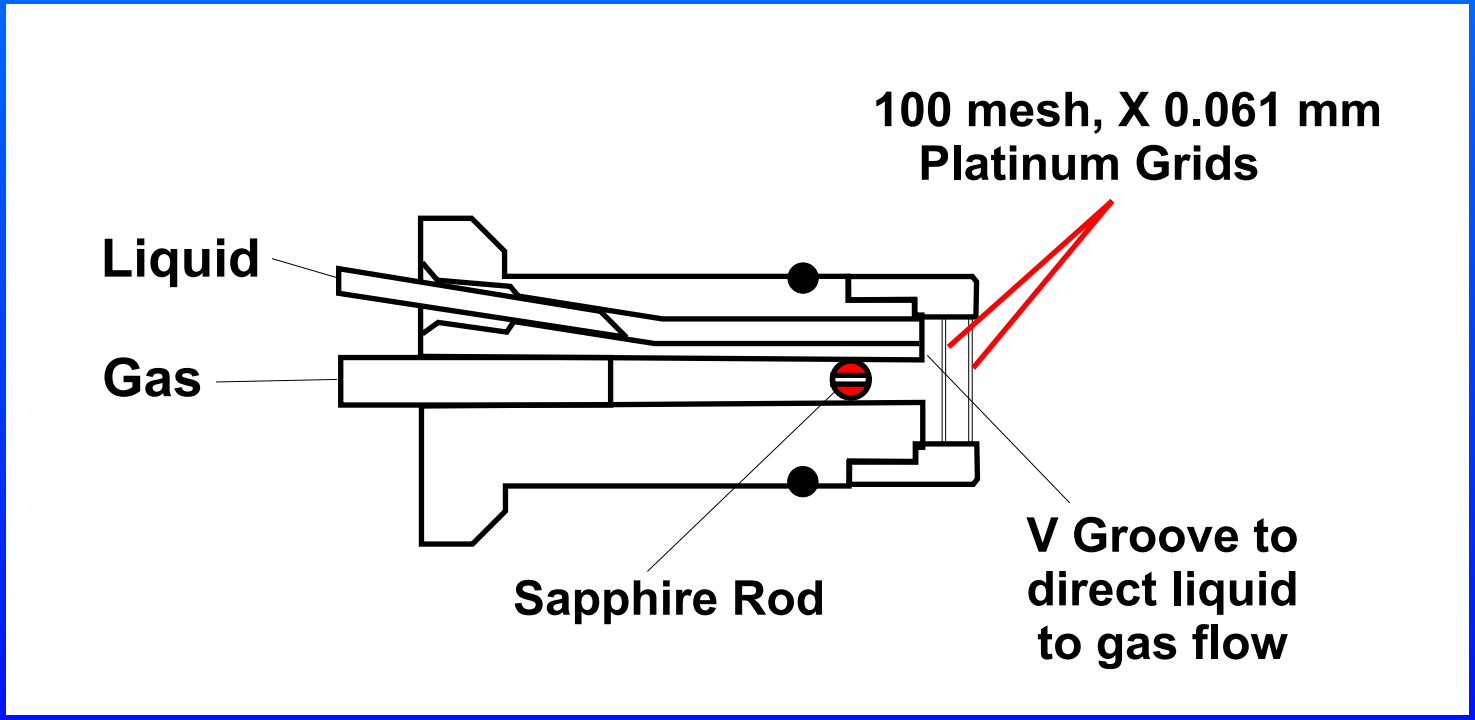
1986 Hildebrand Grid Nebulizer



Excellent Sensitivity
Difficult to clean
Long washout times

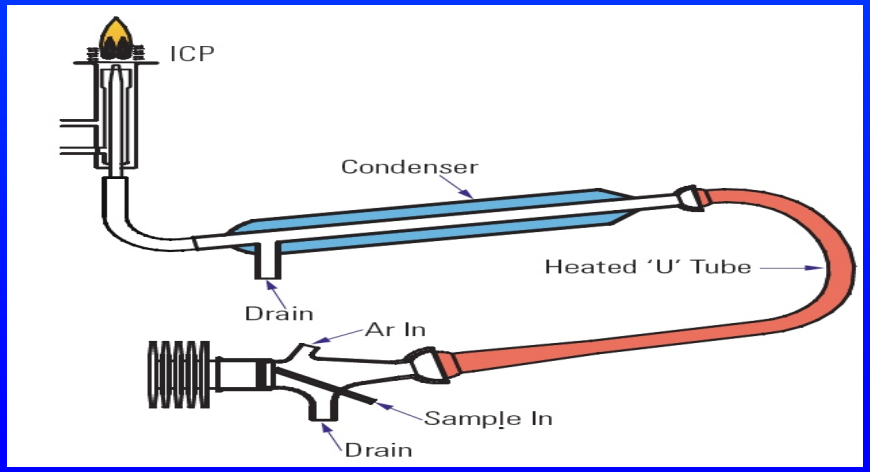
Late 1980s or early 1990s Perkin Elmer Gem Tip Cross flow

Excellent general purpose nebulizer for the analysis of strong mineral acids (including HF) and samples with less than 5% dissolved solids.
Up to 20% NaCl can be aspirated by the nebulizer for 1 hour without clogging.
Uses chemically resistant GemTips made of sapphire and ruby in a Ryton end cap for maximum resistance.

1988 CETAC Ultrasonic Nebulizers
USN 5000, 6000

Efficiency approaches 30%, Sensitivity improves ~10x
Droplet size < 5 microns.
Potentially heavy solvent load so Desolvation essential.
Peltier cooling essential.
Membrane separator available and usually essential.
Desolvation interferences occur (eg., As III vs. As IV)

Does not handle high solids well.
Long washout times required due to desolvators.



Evaluation of an Ultrasonic Nebulizer Using Perkin-Elmer Sequential ICP Instrumentation - Robert Thomas, Cindy Anderau - Atomic Spectroscopy, 10 (2), 71 (!989). This paper describes the capabilities of the first commercially available ultrasonic nebulizer, the CETAC USN-5000 with two of Perkin Elmer's ICP optical emission spectrometers, the Plasma 40 and Plasma II. Various criteria were evaluated including detection limit, precision and memory test. The conclusion of the work was that the early design of this product showed great promise but required some improvements to be accepted and used as a truly routine analytical tool.

Late 1980s: Cyclonic Chambers Arrive

The early chambers were variations on AA chambers.
Most were large straight tubes with baffles.
The Scott Double Pass became the most successful of these.
Most nebulizers were designed to fit 35 mm OD front ends of chambers.

In the late 1980s cyclonic chambers became popular.
introduced by Glass Expansion

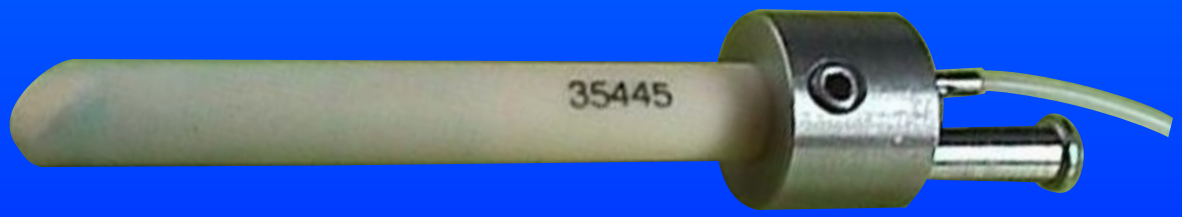
With 2X the sensitivity, and ½ the washout time,
most labs switched to cyclonic chambers.

At first, only concentrics fit.

So nebulizers were re-designed to fit the GE standard 6mm
cyclonic chamber nebulizer fittings.

1987 Glass Expansion's first Nebulizer: The VeeSpray

a ceramic V groove Nebulizer



Material: alumina ceramic
High TDS tolerance: typically up to 30%
High tolerance to particulates: typically up to 300 μ m
Must be pumped - does not self aspirate
Operates best between 1.5 and 2.5mL/min

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Burgener Research Inc.

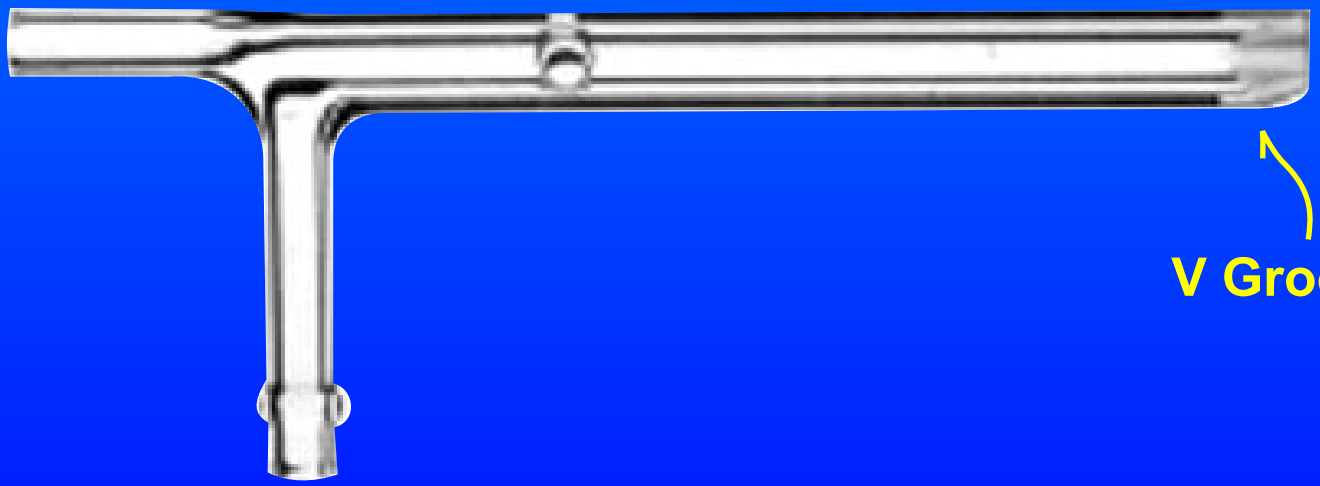
1989 Glass Expansion's first Concentric The Conikal

Machined inner capillary instead of glass blown.

John A. Burgener
Burgener Research Inc.

1989 Noordermeer Glass V Groove

Sample



V Groove

Gas

Good to Excellent Sensitivity
Orifice can salt.

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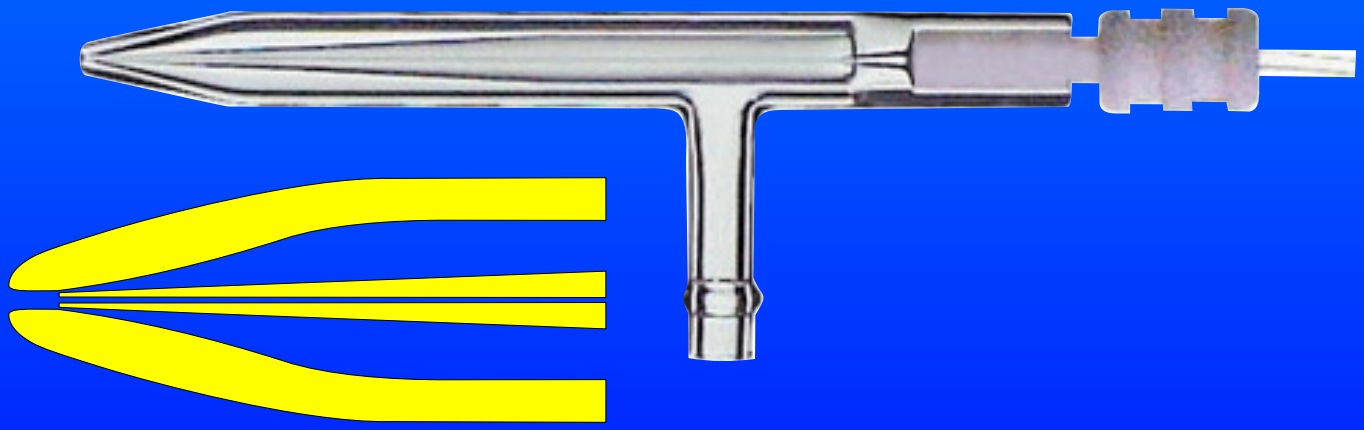
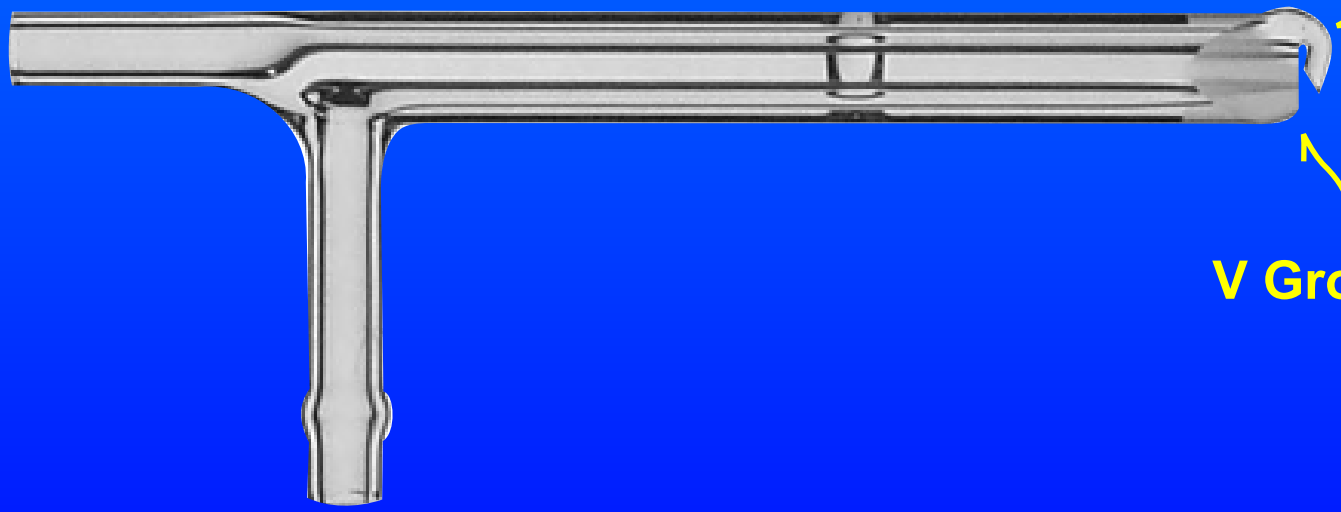
Burgener Research Inc.

1992 Glass Expansion
began making the non salting Sea Spray



Tip of inner capillary is recessed more than with Meinhard K
Nose body extended to create a self cleaning area inside the tip
Can handle 20% salts without blocking
Had improved sample line attachment for easy fitting
and minimal dead volume.

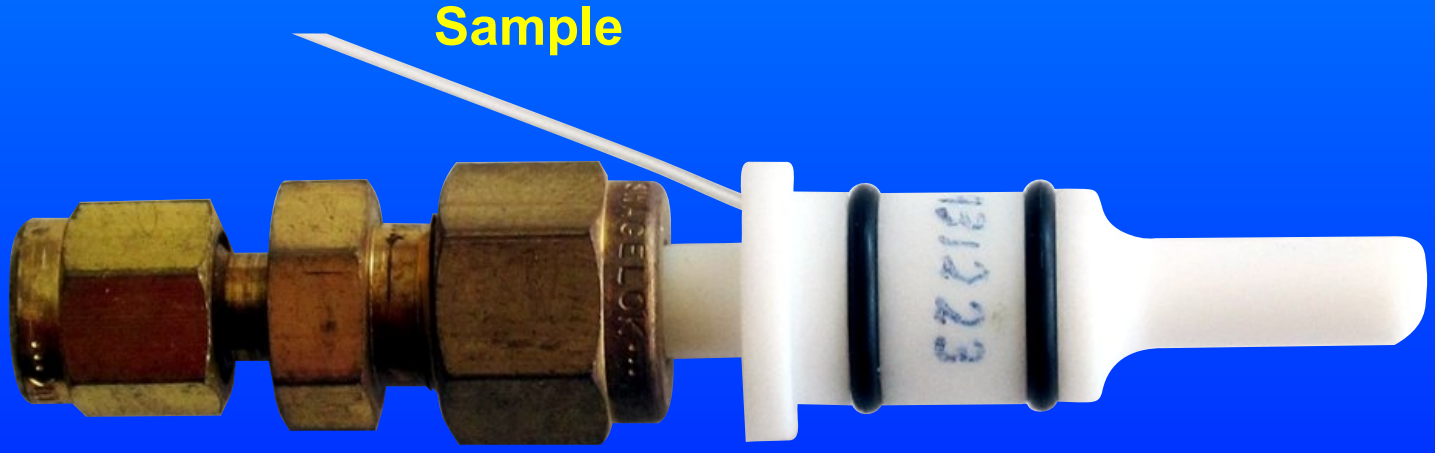
1993 Modified Lichte Glass V Groove



Good to Excellent Sensitivity
Orifice can salt.
Overloads many ICP torches.

John A. Burgener
Burgener Research Inc.

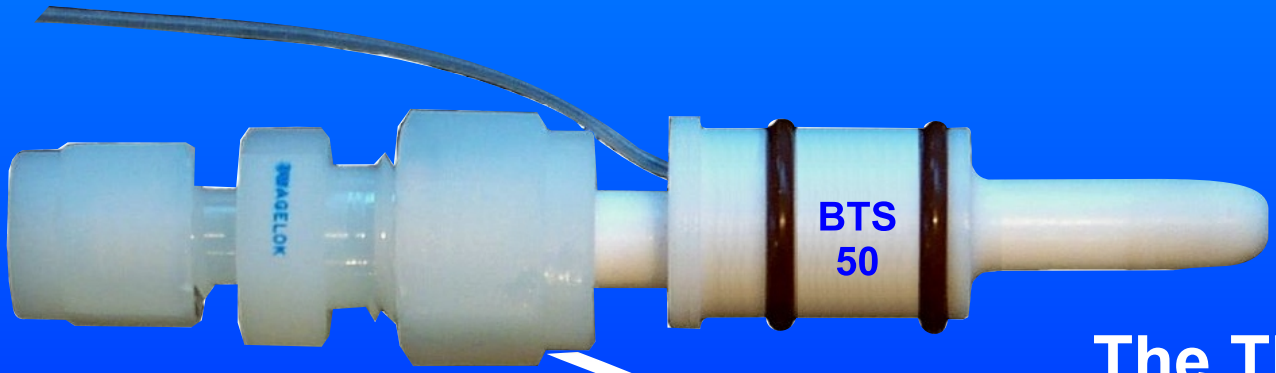
1993 BTF - The first Burgener Parallel Path



Good to Excellent Sensitivity
Non salting design:
can run 100% saturated solutions.
Lasts for months without washing.
Difficult to make - about 2 days each.
Not as sensitive as a concentric.

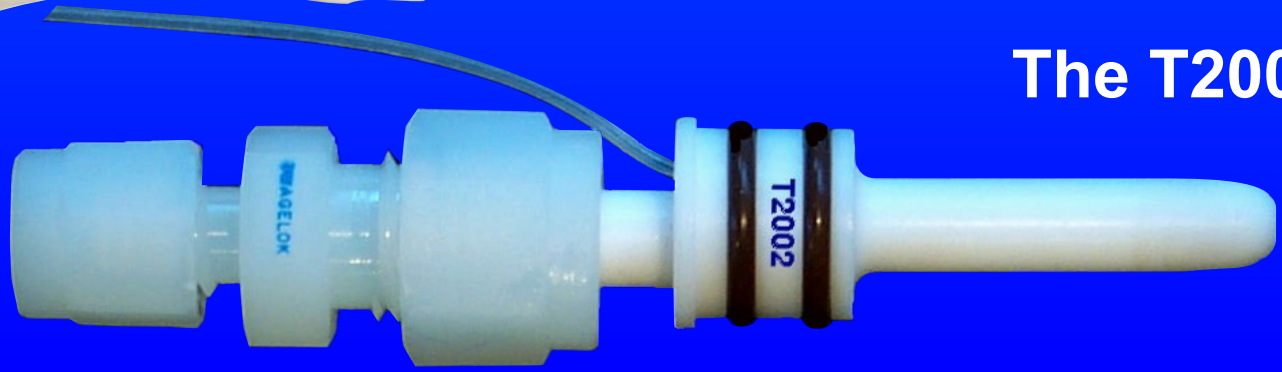
John A. Burgener
Burgener Research Inc.

The Main Burgener Parallel Path Nebulizers
1994 - 1995



The BTS 50

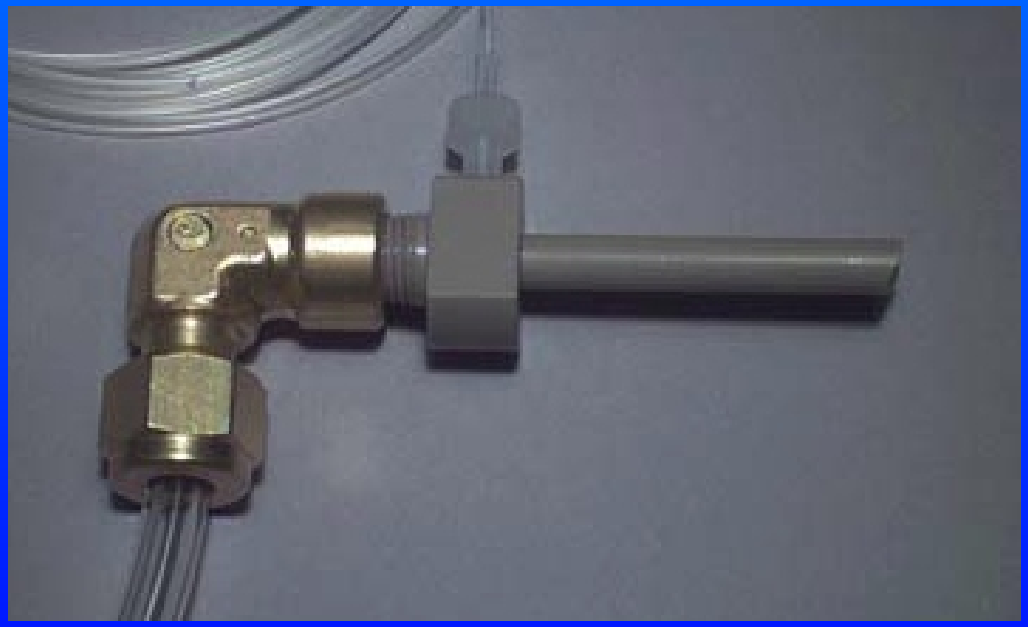
The Thermo Trace



The T2002

Less Difficult to make - about 1 day each.
Eventually we reduced it to about 4 hours each.

Mid 1990s: Perkin Elmer Miniature V Groove
The Gem Cone
Last V groove design I am aware of



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Burgener Research Inc.

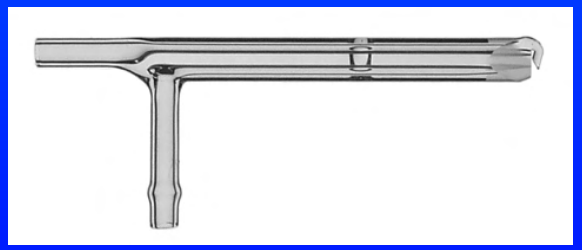
V groove designs still commercially available:

As of 2013

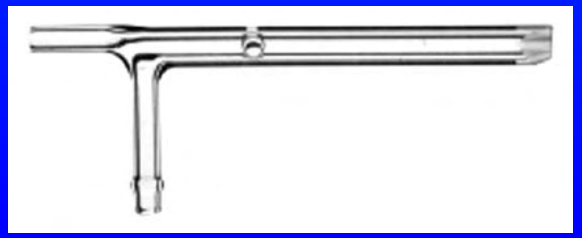
Glass Expansion VeeSpray

Perkin Elmer Gemcone

Precision Glassblowing Modified Lichte



Precision Glassblowing Noordermeer



They all suffer from salting, and are no longer significant in the market. They have generally been replaced by newer, better designs.

Cross Flow nebulizers also declined in use.

Partly in response to the cyclonic chambers.
They are not as good as concentrics in sensitivity and stability.
They are less easy to salt and plug as a concentric, but it is still easy.

But they are inexpensive to make.
So most manufacturers have at least one model available.

And some new ones have been introduced in the last 10 years:

Savillex: X-Flow
PFA Cross Flow Nebulizer

SCP: Ultem Mini Cross Flow
designed for cyclonic chambers

John A. Burgener
Burgener Research Inc.

The arrival of the ICP / MS

In the late 1980s and early 1990s,
ICP / MS became useful lab instruments.

Previously they were mainly used by
R&D institutions and universities.

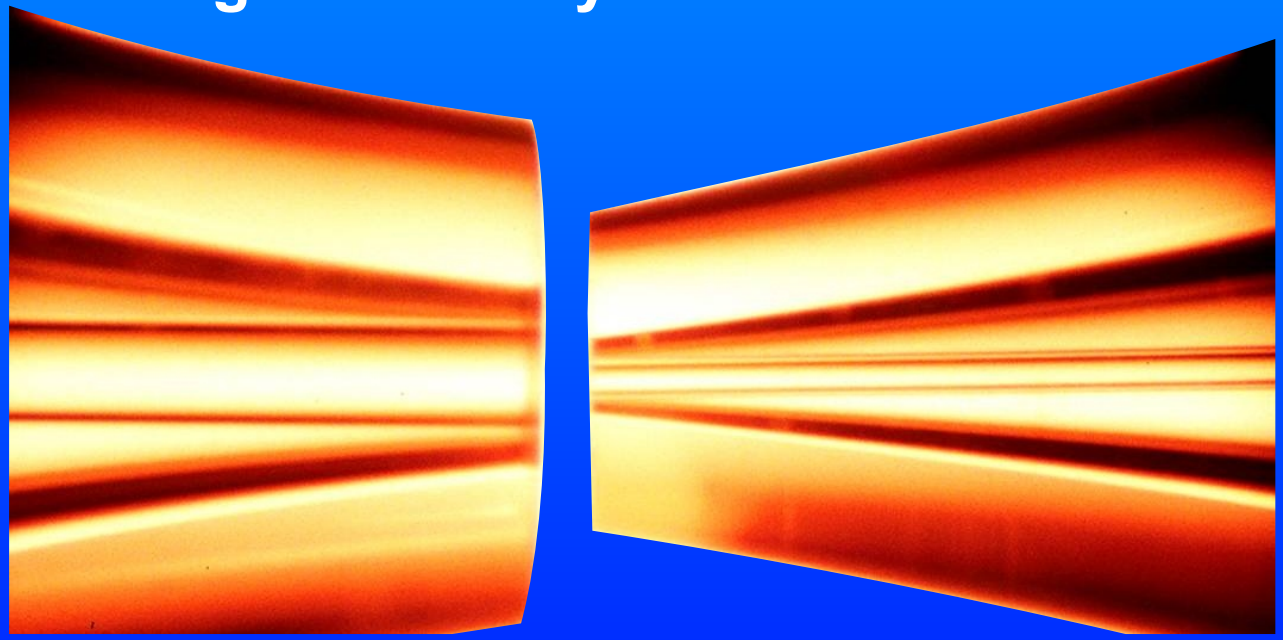
With Agilent and Perkin Elmer / Sciex
ICP /MS became common instruments by the mid 1990s.

Nebulizers running 2 ml/min sent too much sample to the Mass Spec.

Concentrics were able to run much lower flow rates,
and still provide excellent stability and sensitivity.

The development of micro nebulizers began.

MEINHARD HEN:
High Efficiency Nebulizer ~ 1993



	TR-30	HEN-170
Sample Capillary:	220-320 µm	70-110 µm
Gas orifice ID:	350-450 µm	150-200 µm
Pressure at 1 L/min:	25-40 psi	150-180 psi
Normal operating pressure:	15-25 psi	25-60 psi

Very Low Flow capable
Very easily plugged and salted

Burgener Nebulizers
Showed the advantages of Teflon

The Non Salting nature of Teflon Gas Orifices was desirable in all designs.

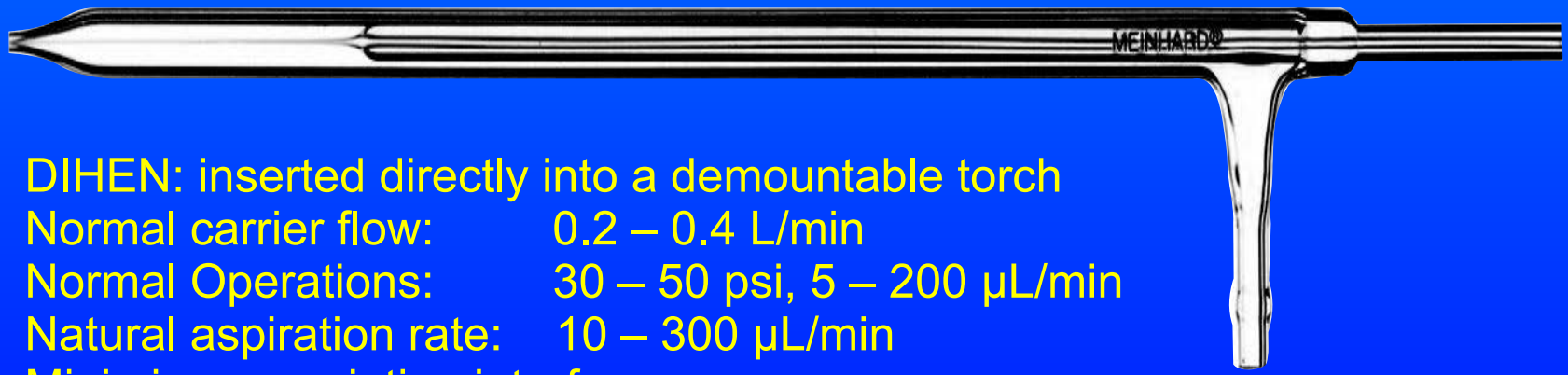
1997 Cetac Microconcentric Nebulizer

The MCN 100 was probably the first Teflon Concentric. It was also the first non-Burgener Nebulizer commercially available that was 100% Teflon.

MCN 100 and Aspire
50, 100, 200, or 400 µL/min

John A. Burgener
Burgener Research Inc.

1997 Direct Injection High Effeciency Nebulizer
Meinhard's DIHEN



DIHEN: inserted directly into a demountable torch
Normal carrier flow: 0.2 – 0.4 L/min
Normal Operations: 30 – 50 psi, 5 – 200 µL/min
Natural aspiration rate: 10 – 300 µL/min
Minimizes speciation interferences
Easily introduce highly volatile solvents
Essentially 100% transport
Design and test pressure: 90, 120, 150, or 170 psi @ 1 L/min

John A. Burgener
Burgener Research Inc.

A. Montaser, J. A. McLean, and Jerold M. Kacsir,
A Novel Direct Injection High Efficiency Nebulizer for Atomic Spectroscopy, 1997
Patent Applications filed December 28, 1998
U.S. Patent No. 6,166,379, December 26, 2000.

1997 Direct Injection High Effeciency Nebulizer
Meinhard's DIHEN

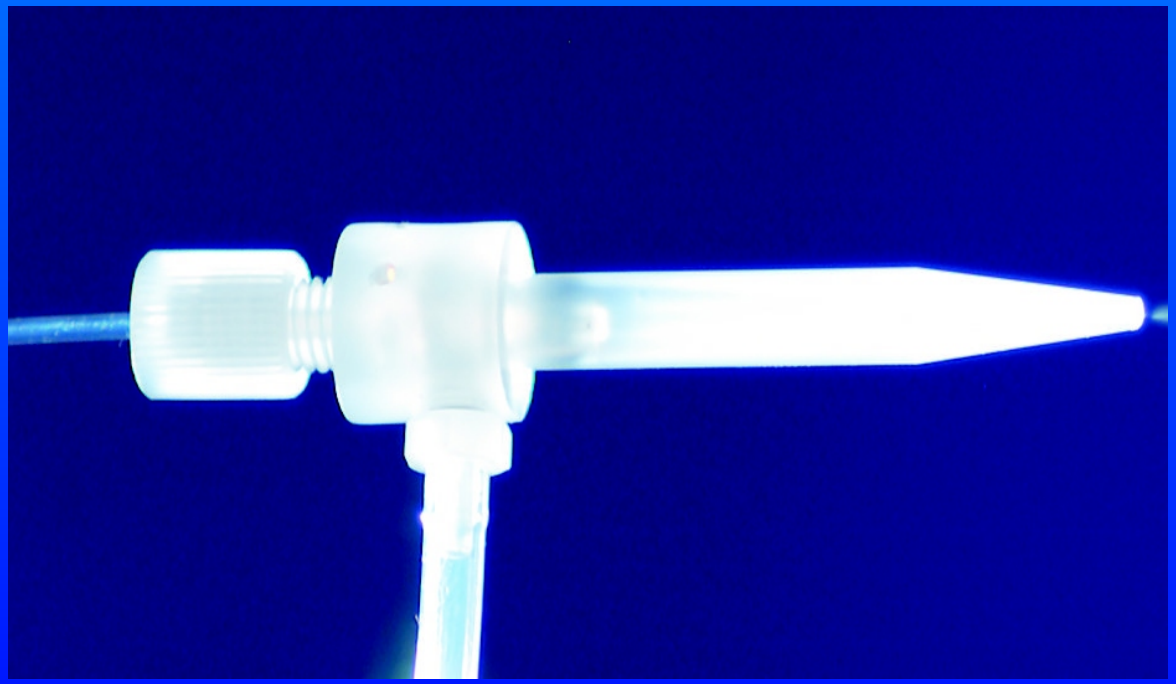
Good Concept,
But droplets do not have time to vaporize.
droplets arrive in plasma as droplets.

Other designs will provide greater sensitivity and stability by NOT being close to the plasma.

John A. Burgener
Burgener Research Inc.

A. Montaser, J. A. McLean, and Jerold M. Kacsir,
A Novel Direct Injection High Efficiency Nebulizer for Atomic Spectroscopy, 1997
Patent Applications filed December 28, 1998
U.S. Patent No. 6,166,379, December 26, 2000.
Note: 1997 - J E Meinhard Produces the 50,000th Nebulizer!

1999 Elemental Sciences
introduced their PFA Concentric Nebulizers



20, 50, 100, or 400 µL/min

1999 Burgener Introduces the Micro 1

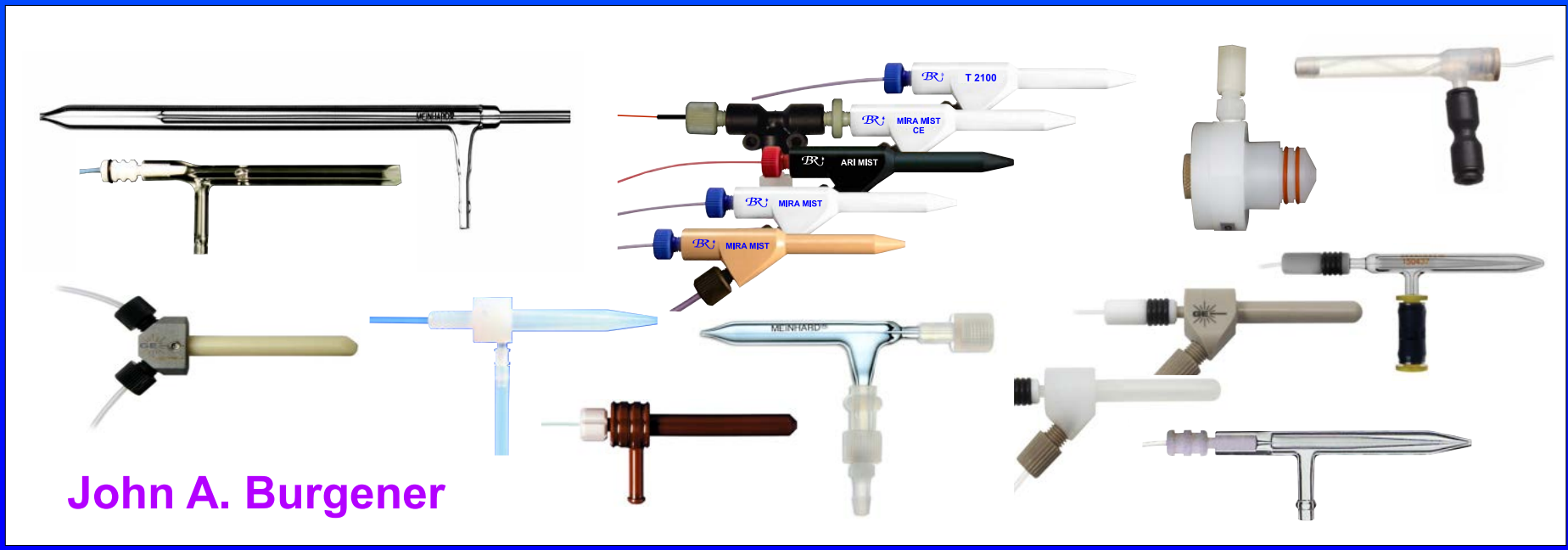
Designed to run low flows, 50 to 1,500 µl/min
New method of construction - New body design.
Still based on the original Parallel Path method.

John A. Burgener
Burgener Research Inc.

Burgener Research Inc.

What's New in Nebulizers

PART 2: Since the year 2000



John A. Burgener

2000 Burgener Micro 3

Improved Body design over Micro 1,
still original Parallel Path Method
Still aiming at low flow
50 - 1500 ul/min range
Looks like a Mira Mist but very different.

John A. Burgener
Burgener Research Inc.

More changes in PFA Concentrics then in Glass Concentrics

Elemental Scientific: Many models including micro PFA nebulizers
Glass Expansion: Opal Mist Nebulizer
Cetac: Aspire, MCN 100 Micro Concentrics
Savillex: C Flow

Many micro designs, and standard flows
But nothing essentially unique or exciting since 2000

Models range from a few microliters/minute to about 1 ml/min

ESI produces many variations on PFA Neb.

PFA MicroFlow Nebulizers

- PFA-20 20-35 µL/min
- PFA-50 45-65 µL/min
- PFA-75 65-96 µL/min
- PFA-100 90-150 µL/min
- PFA-200 150-250 µL/min
- PFA-400 300-400 µL/min

PFA-ST Nebulizers

- 0.15 mm i.d. 20µL/min
- 0.20 mm i.d. 50µL/min
- 0.25 mm i.d. 100µL/min
  - pumped 0.1 to 1.0mL/min
- 0.30 mm i.d. 200µL/min
- 0.50 mm i.d. 400µL/min
  - pumped 0.5 to 3.0mL/min
- 0.80 mm i.d. 700µL/min

PFA-HS: High dissolved solids, 300µm ID

PFA-LS: laser ablation applications, 20µL/min produces an aerosol at low gas flow rates: 0.2—0.3 L/min

PFA-LC: HPLC Interface for micro and standard flow
Low internal volume, 150µm ID

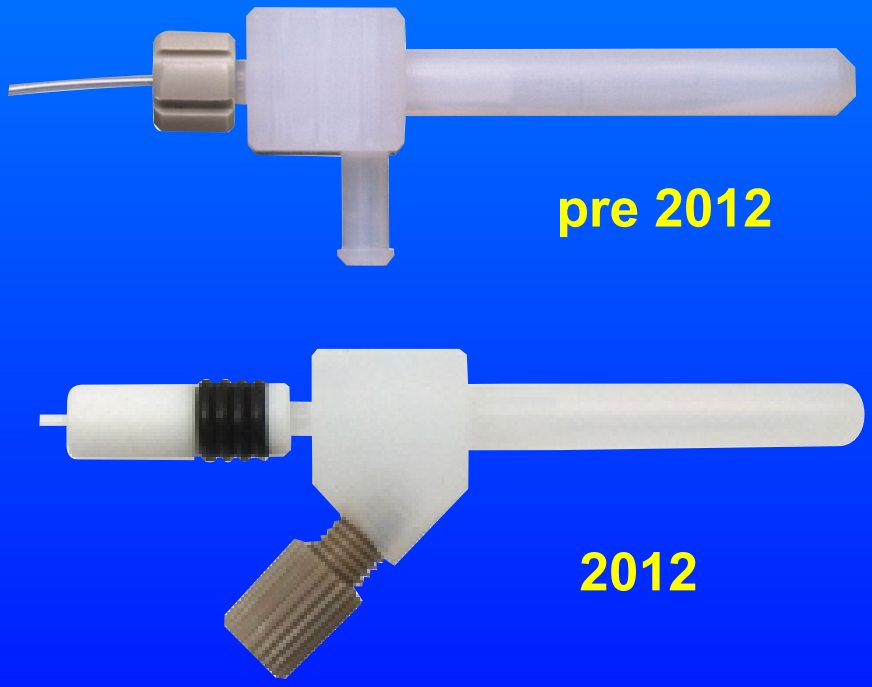
PFA-Q: internal quartz capillary, for applications where the analyte has memory issues with plastic such as Iodine

PolyPro-ST Nebulizers

- 0.15 mm i.d. 20µL/min
- 0.20 mm i.d. 50µL/min
- 0.25 mm i.d. 100µL/min
  - pumped 0.1 to 1.0mL/min
- 0.30 mm i.d. 200µL/min
- 0.50 mm i.d. 400µL/min
  - pumped 0.5 to 3.0mL/min
- 0.80 mm i.d. 700µL/min
  - pumped up to 5.0mL/min

John A. Burgener
Burgener Research Inc.

2012 Glass Expansion changes Opal Mist



Better sample line attachment
More secure gas line attachment
Less contaminating gas line attachment

John A. Burgener
Burgener Research Inc.

2005 Savillex C-Flow and X-Flow

John A. Burgener
Burgener Research Inc.

Refinements in Glass Concentrics

Most manufacturers have continuously improved their designs

John A. Burgener
Burgener Research Inc.

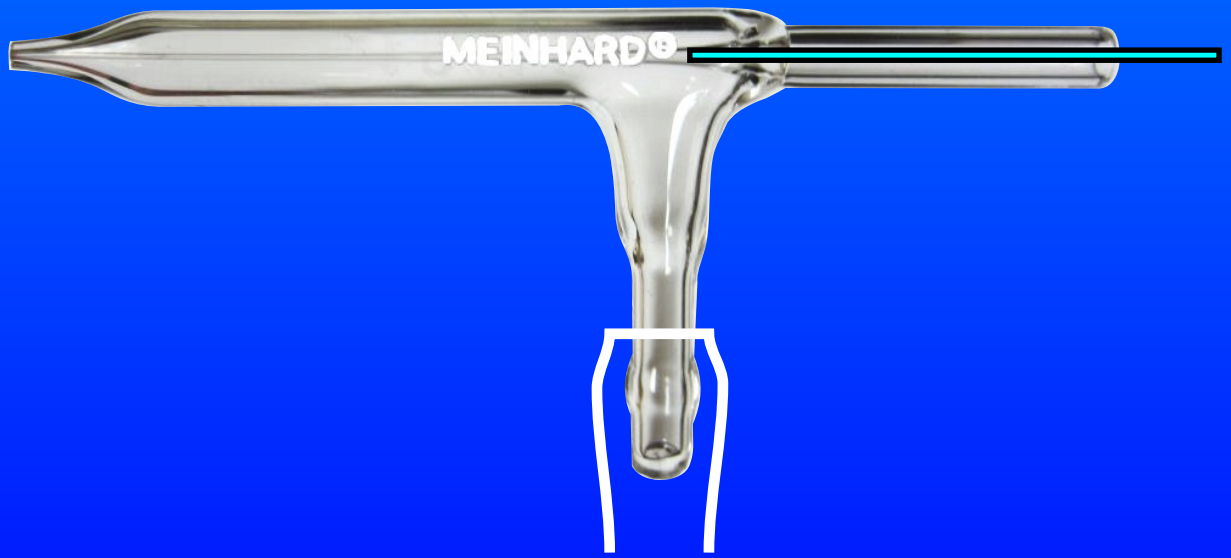
1980 & 90s Meinhard Concentric

Back end was much larger
than inside central capillary.
Led to plugging inside capillary,
And poor sample line connections.

John A. Burgener
Burgener Research Inc.

1980 & 90s Meinhard Concentric

Sample line was pressed into place
Held partly by suction of nebulizer
and partly by the capillary sticking in place
and partly by luck.

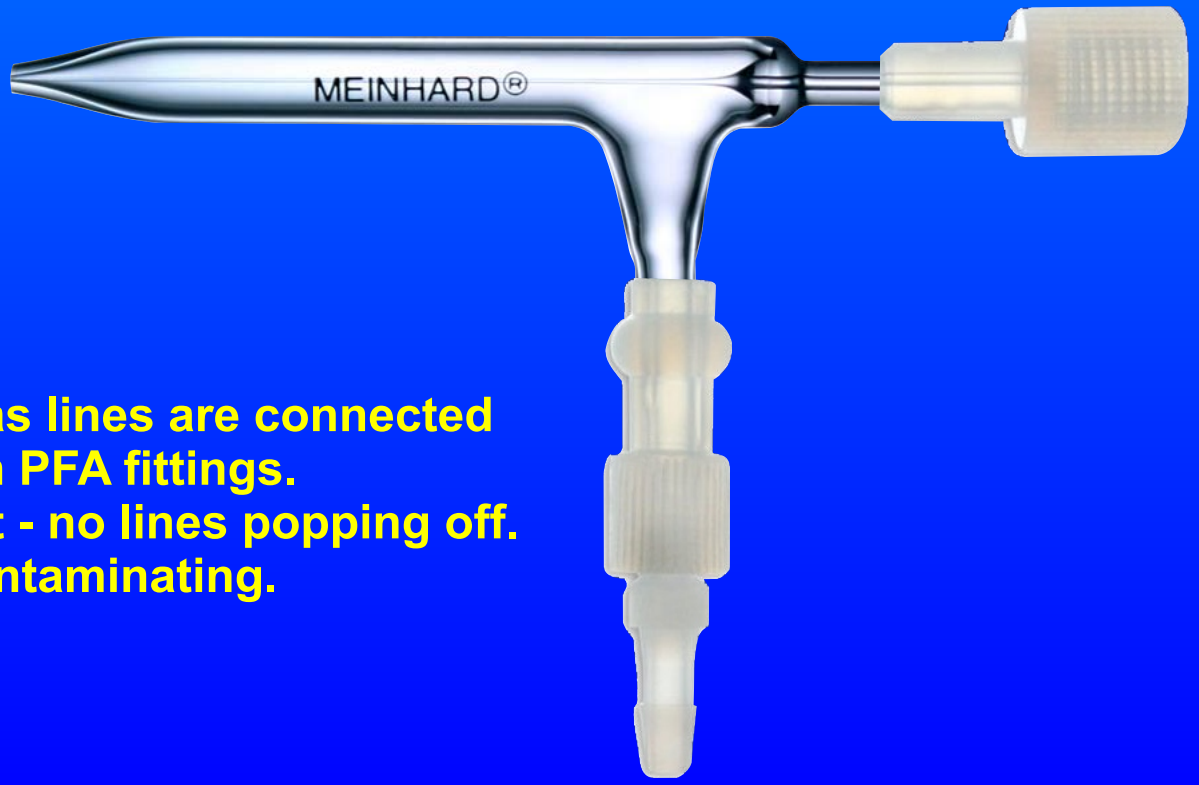


Gas lines were Tygon tubing pushed over the barb.
they regularly popped off if the pressure was 40+ psi

John A. Burgener
Burgener Research Inc.

Modern Meinhard Concentric

Back end is only a bit larger
than inside central capillary.
Minimizes plugging inside capillary.
New Sample line fittings:
Secure, easy to attach to LC or pump.

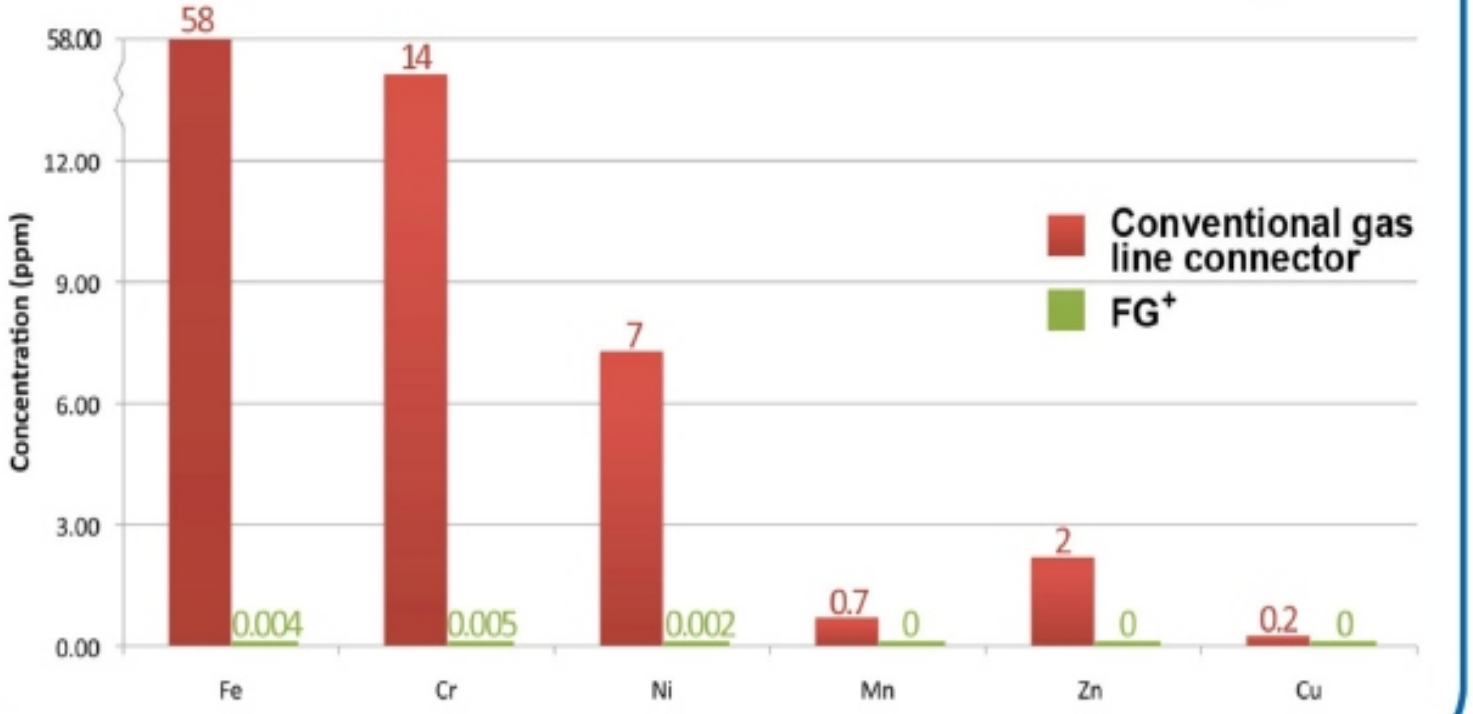


New Gas lines are connected
with PFA fittings.
Tight fit - no lines popping off.
Non contaminating.

John A. Burgener
Burgener Research Inc.

MEINHARD®

Comparison of Trace Metals Leached from Nebulizer Gas Fitting



Conventional gas line connector

PFA FG+ quick connect gas line

1990s Glass Expansion

Sample line was held with Teflon fitting.

Gas lines were Tygon tubing pushed over the barb.
they regularly popped off if the pressure was 40+ psi

John A. Burgener
Burgener Research Inc.

2012 Glass Expansion

Machined inner capillary “Vitricone design”
Constant ID for whole length:
plugging mainly occurs at connection.

Gas lines are connected
with secure fittings with O ring seals.
Tight fit - no lines popping off.

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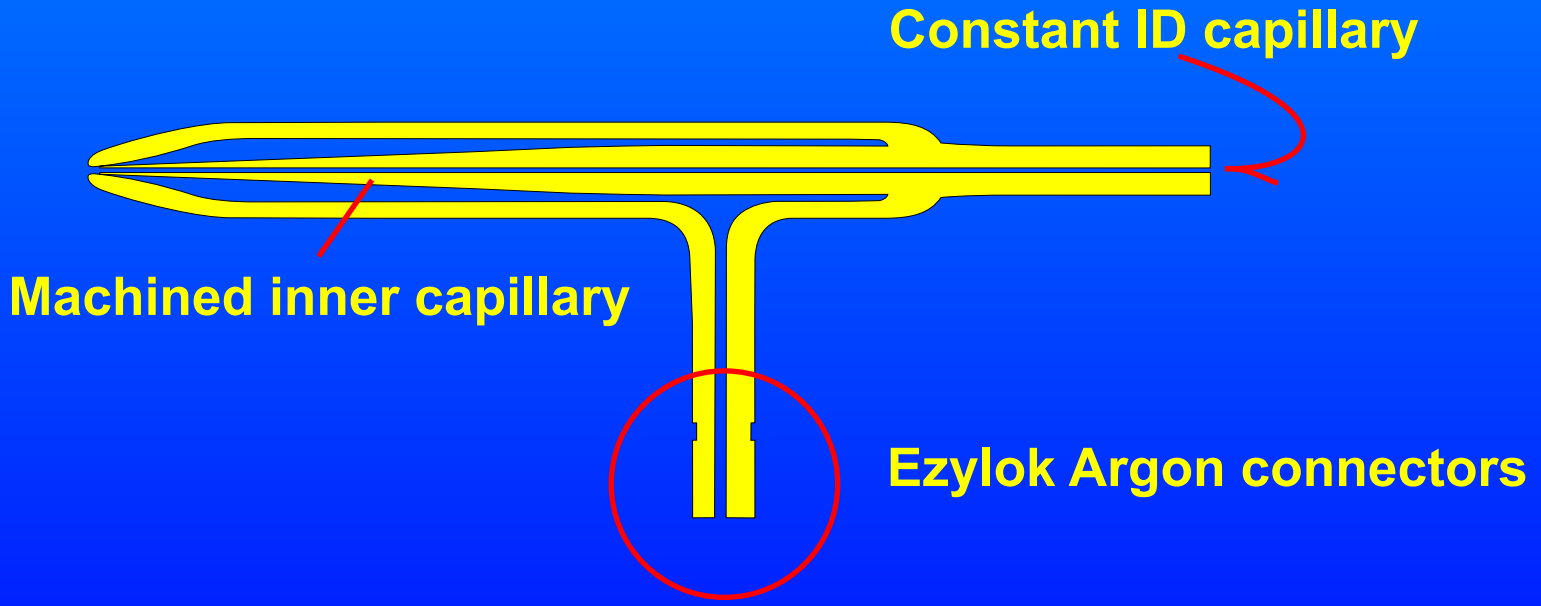
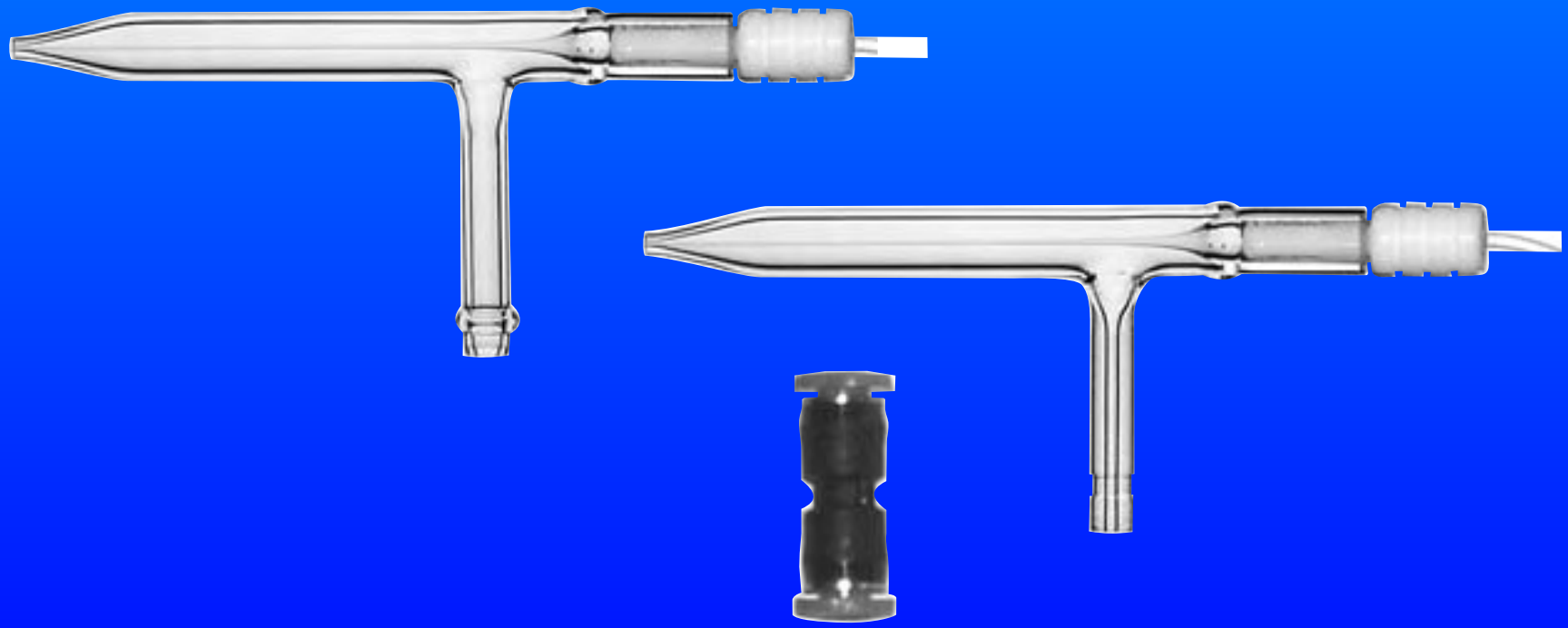
Burgener Research Inc.

2012 Glass Expansion



Machined inner capillary "Vitricone design"
Constant ID for whole length:
plugging mainly occurs at back of nebulizers
First Glass Concentric design that matches
Burgener or ESI's PFA constant ID
More secure gas line attachments.

2012 Precision Glassblowing



Optional Tygon tubing or Ezylok gas line fitting.
Wide range of models
Design a mix of Meinhard and GE features

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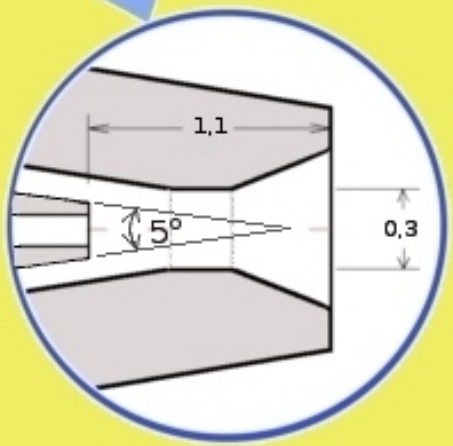
Burgener Research Inc.

2004 Epond's Tyfoon Concentrics

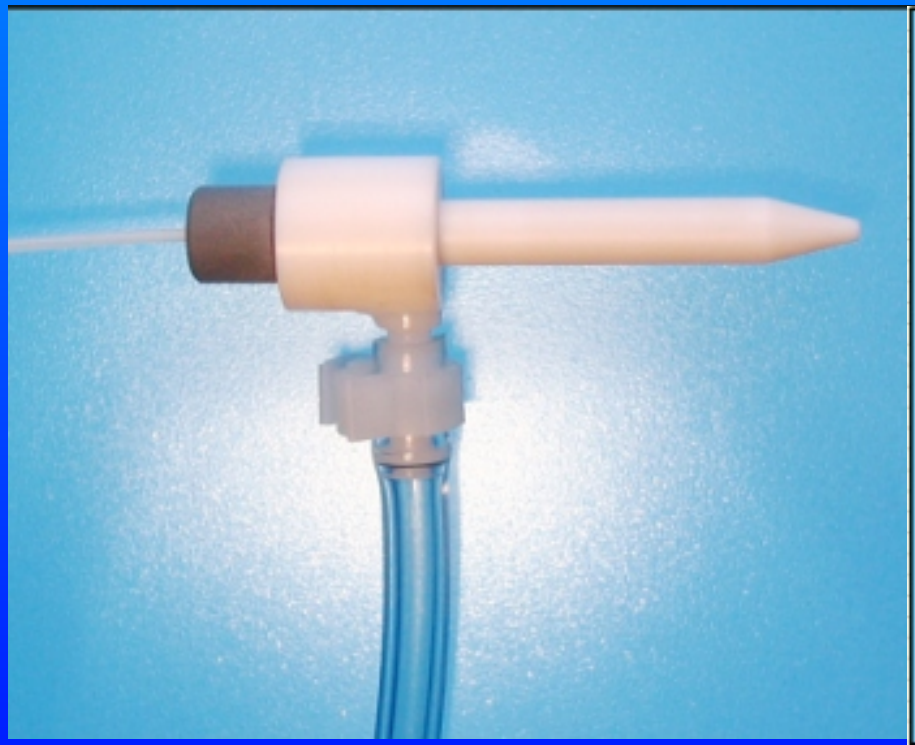
the EPOND 'Tyfoon'

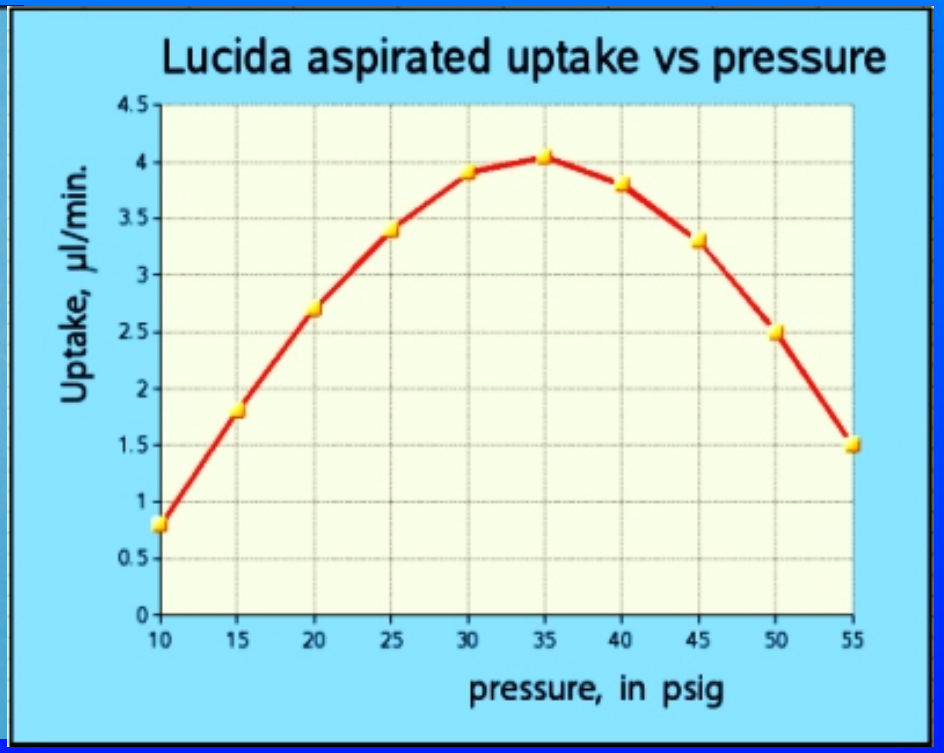
- *higher efficiency*
- *higher sensitivity*
- *higher salt tolerance*



They have a Laval-type nozzle at the tip of the nebulizer,
Gives a more complete nebulization at higher sample flow rates.
Available in glass, quartz and PTFE.

Epond's Lucida: 1 µl/min Microconcentric





The Lucida is unique
in that its natural aspirated uptake is below 10 µl/min.
It can run from 1 to 50 µl/min.

John A. Burgener
Burgener Research Inc.

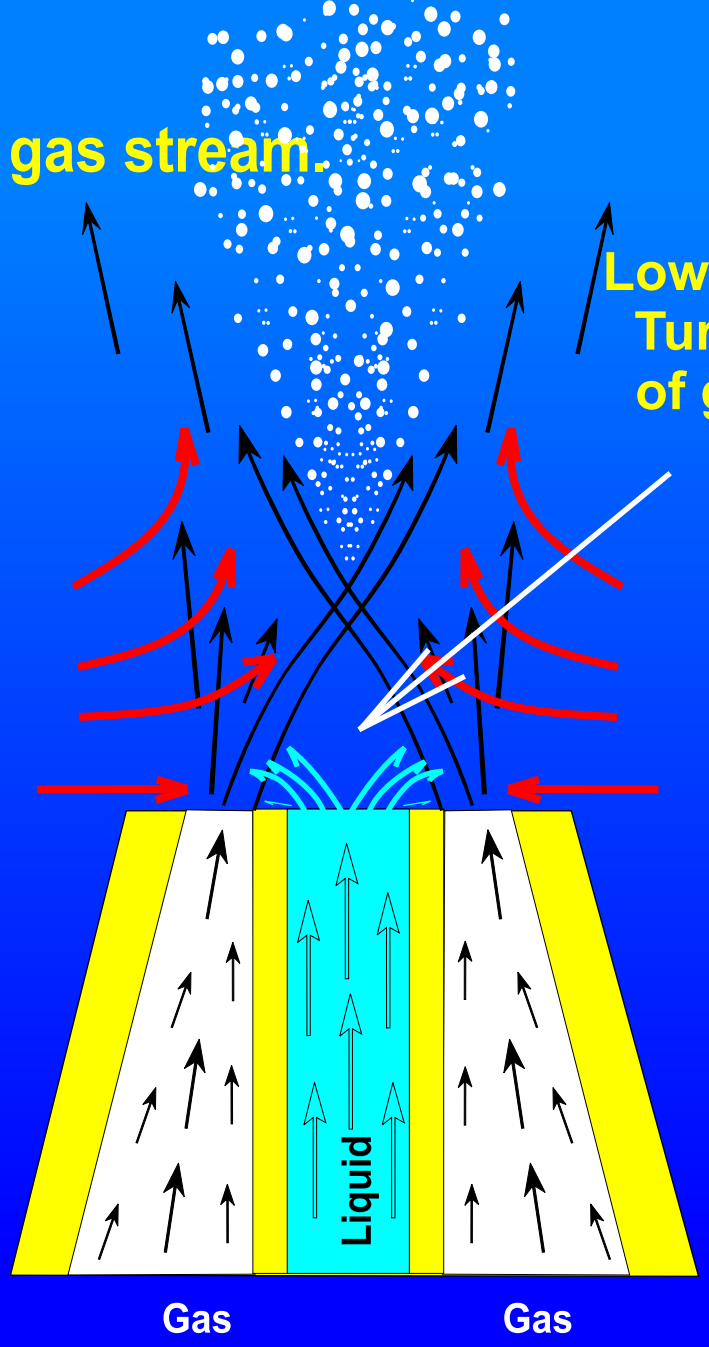
Until 2001, all pneumatic nebulizers used induction.

Gas moving out of an orifice moves in a reasonably straight line.
There is little sideways motion.
Molecules beside the gas stream are not pushed away,
so they move towards the gas stream as though there was a vacuum.

As molecules move into the gas stream,
they are impacted by the gas stream and
move away with the gas stream.

Induction pulls liquid into gas stream.

Concentric
Cross flow
Babington V Groove
Original Parallel Path
All use induction



John A. Burgener
Burgener Research Inc.

New concepts in nebulizers since 2000:

Burgener Enhanced Parallel Path Method

Evolved from Parallel Path

OneNeb Flow Blurring

Evolved from Concentric

Pizeoelectric Vibrating Mesh

Evolved from Ultra sonic

John A. Burgener

Burgener Research Inc.

New concepts in nebulizers since 2000:

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Evolved from Concentric

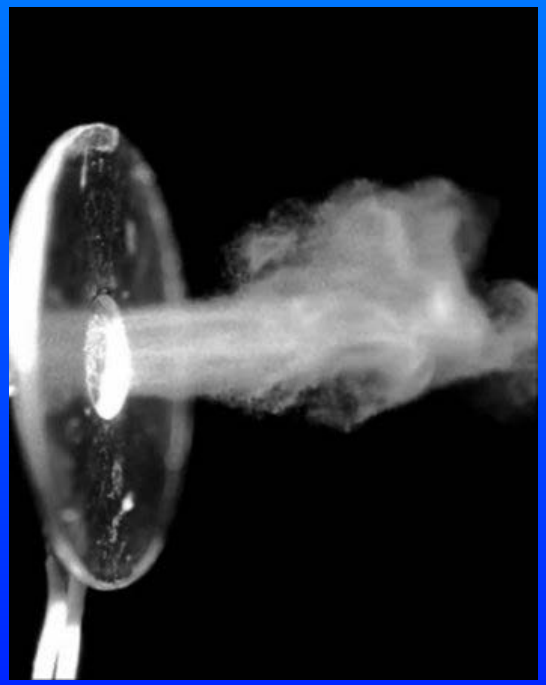
Pizeoelectric Vibrating Mesh

Evolved from Ultra sonic

ALL OF THESE ARE NEW CONCEPTS IN NEBULIZATION
NOT JUST ENHANCEMENTS OF PREVIOUS DESIGNS
AND NONE OF THESE USE INDUCTION

John A. Burgener
Burgener Research Inc.

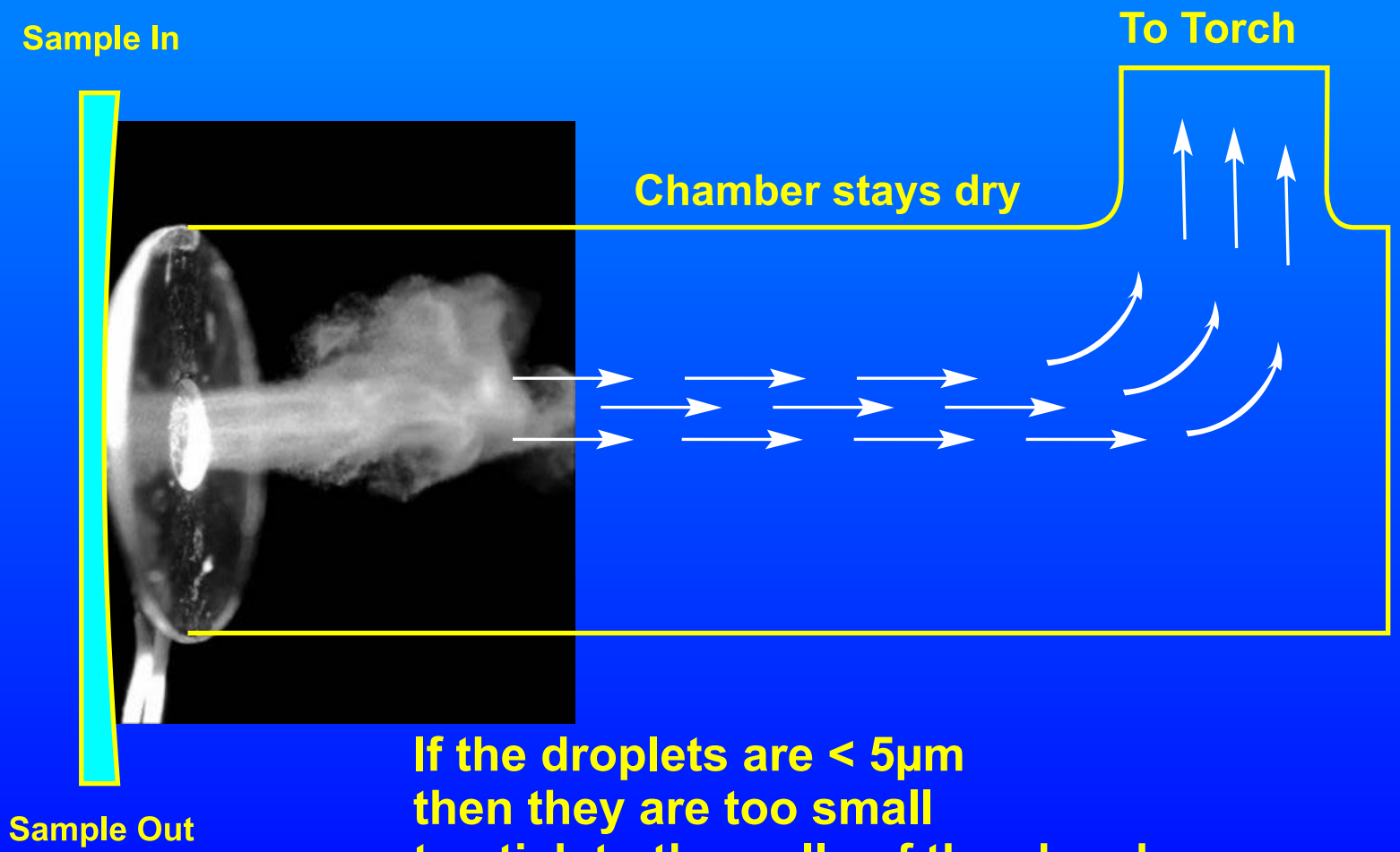
Pizeoelectric Vibrating Mesh



A variation on Ultrasonics
The vibrating membrane has micro holes in it
The sample enters from the back and is pushed out the holes as the membrane vibrates.
Makes a fine mist with droplet size set by hole size.
Requires NO GAS FLOW

John A. Burgener
Burgener Research Inc.

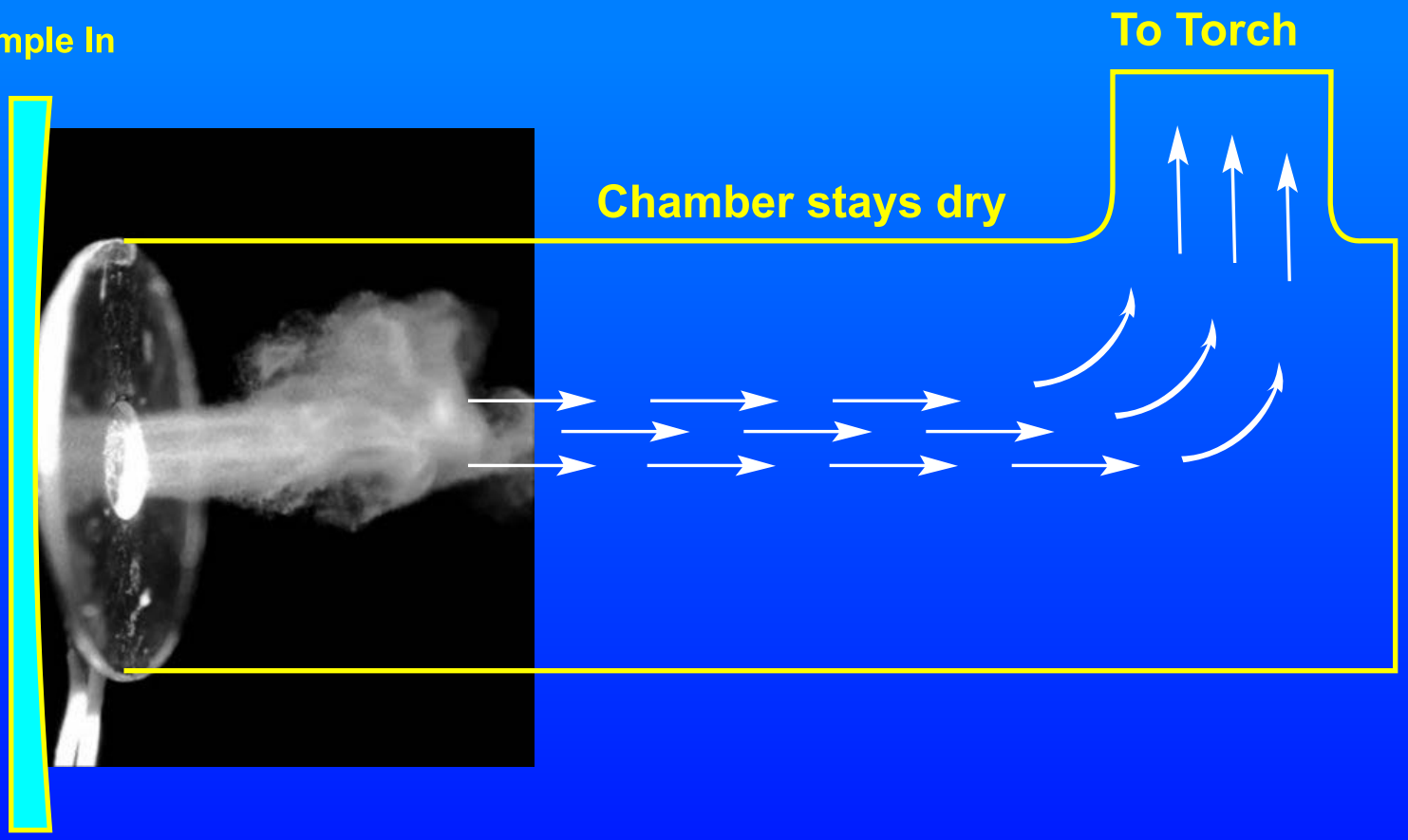
Pizeoelectric Vibrating Mesh



If the droplets are < 5µm
then they are too small
to stick to the walls of the chamber.
the chamber remains dry, and
90-100% of the sample goes to the torch.
With no gas flow required,
very low Argon flows are possible.

John A. Burgener
Burgener Research Inc.

Pizeoelectric Vibrating Mesh



Advantages:

Droplet size set by hole size. All droplets same size.

If running < 15 µl/min then

100% vaporizes and goes to the torch.

Very low flow Argon - same as Laser ablation.

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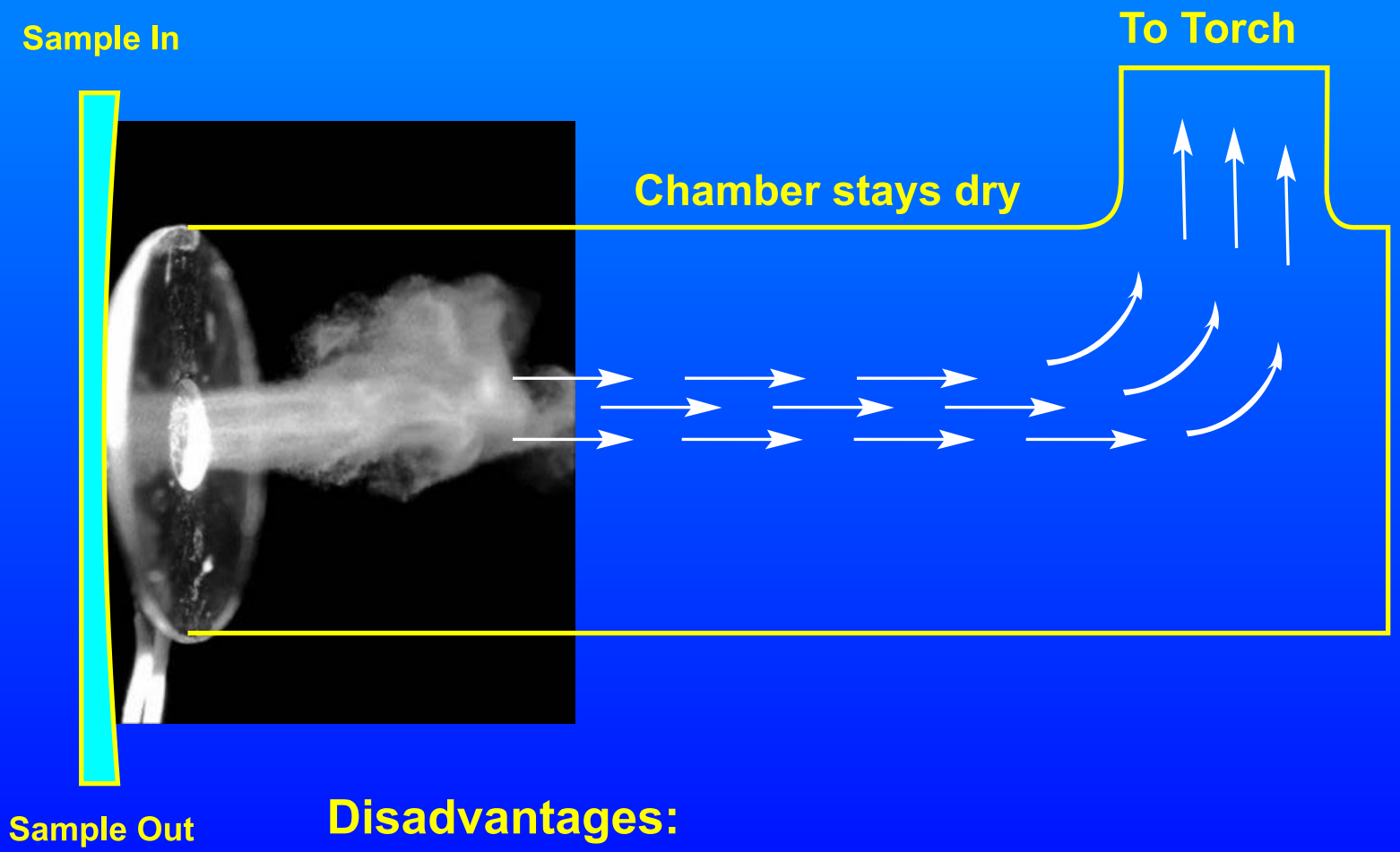
Burgener Research Inc.

Pizeoelectric Vibrating Mesh



Disadvantages:

If running > 40 µl/min, torch is overloaded, requiring use of desolvator.

Volume behind membrane > sample aspirated.

Holes < 5 µm are easy to plug.

Holes < 5 µm are easy to salt.

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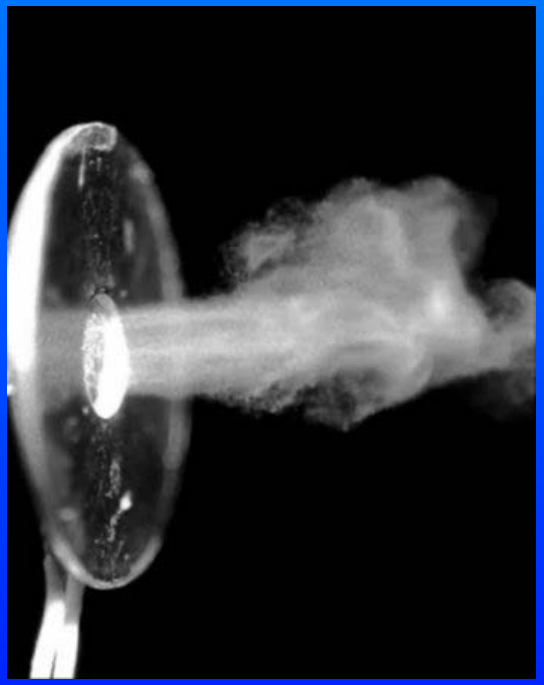
Burgener Research Inc.

Pizeoelectric Vibrating Mesh Summary



Likely for ICP/MS applications only.

Will be a niche usage for applications:

needing minimal sample sent to torch.

having lots of sample to send to nebulizer.

clean solutions only.

low salts only.

John A. Burgener
Burgener Research Inc.

Main New nebulizers since 2000:

Burgener Enhanced Parallel Path Method

OneNeb Flow Blurring

Pizeoelectric Vibrating Mesh

ALL OF THESE ARE NEW CONCEPTS IN NEBULIZATION
NOT JUST VARIATIONS ON PREVIOUS DESIGNS

John A. Burgener
Burgener Research Inc.

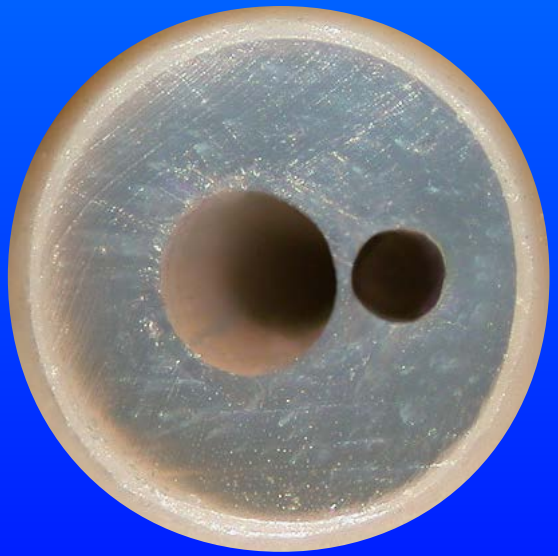
2001 Burgener Mira Mist

Looks like a Micro 3 but very different.

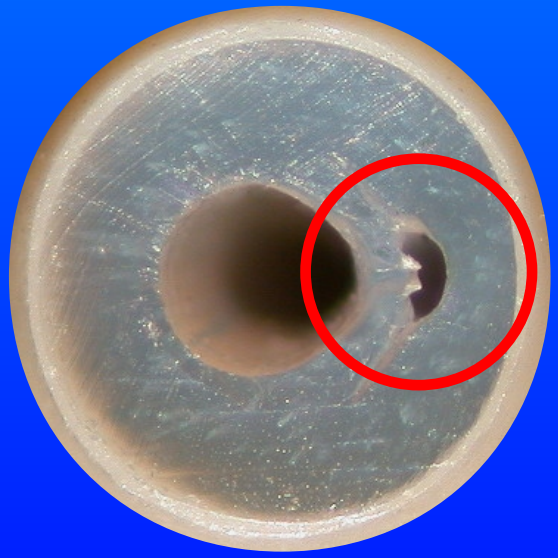
John A. Burgener
Burgener Research Inc.

2001 Burgener Mira Mist

Micro 3
Parallel Path Design



Mira Mist
Enhanced
Parallel Path Design



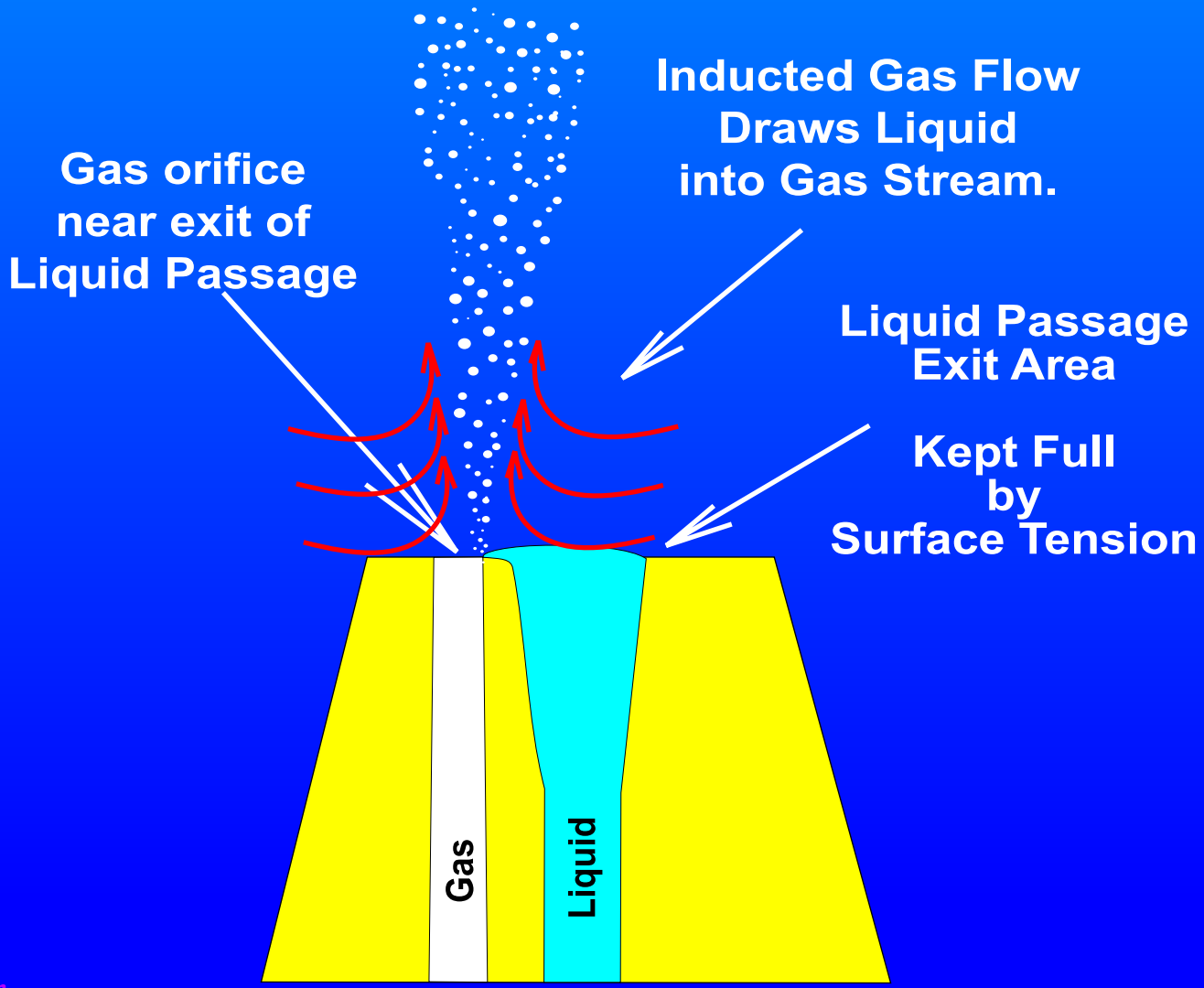
Dramatically different gas orifice
Dramatically different interaction between gas and liquid

John A. Burgener
Burgener Research Inc.

Close-up of the Tip of a Burgener Nebulizer.

The Parallel Path Method

Induction pulls liquid into gas stream.



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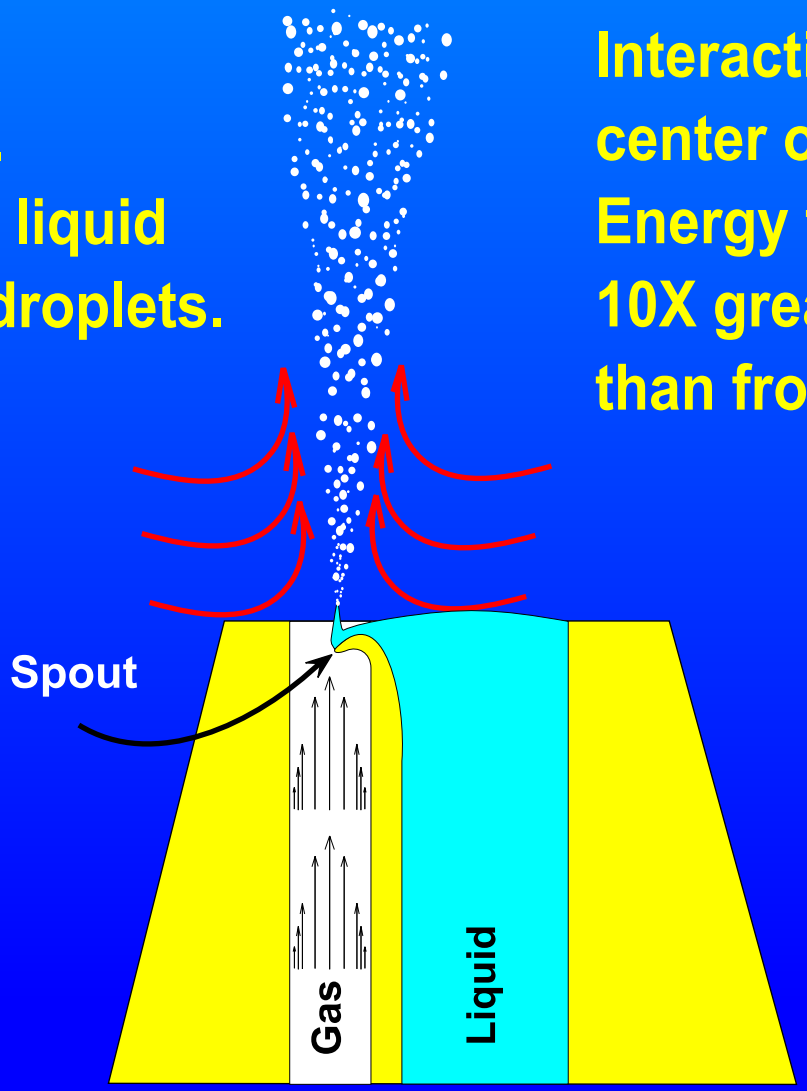
Enhanced Parallel Path Method

Surface tension
pulls liquid into spout.
Gas molecules impact liquid
breaking it into small droplets.



Interaction is at
center of gas stream,
Energy transfer is
10X greater
than from edge.

John A. Burgener
Burgener Research Inc.

Enhanced Parallel Path Method

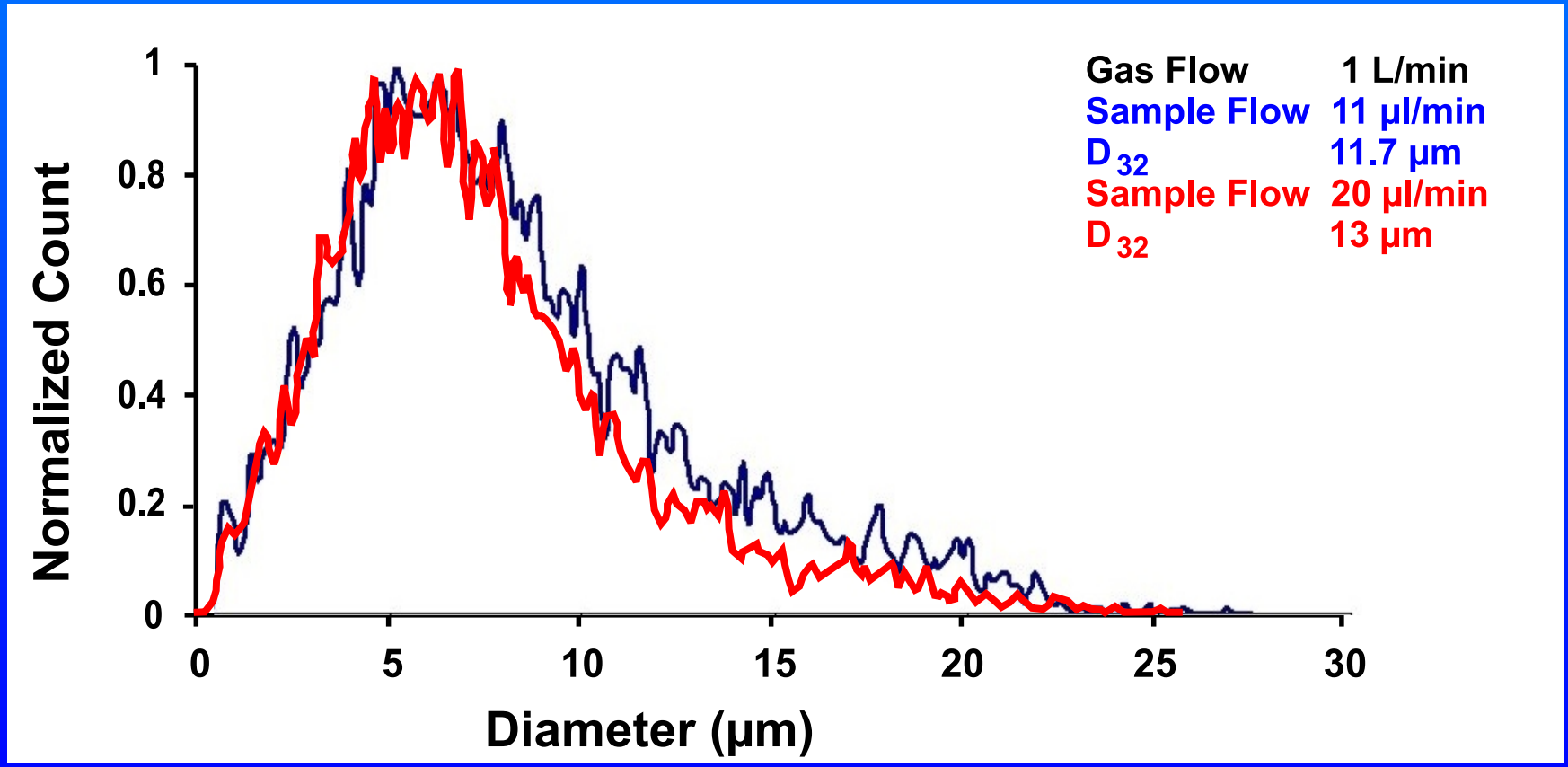
The Enhanced Method does not use gravity or induction. As such, it has zero back pressure and zero suction, and operates equally well in any orientation.

The liquid interacts with the gas stream in the central portion of the gas stream. Gas streams in capillaries have velocity gradients across the diameter of the capillary, with the slowest gas moving at the edges of the capillary and the fastest at the center. The central gas flow is 3 to 10 times as fast as the gas at the edge of the stream. If the central portion of the gas stream can impact the liquid, then the gas impacts the liquid with much more energy. Energy is related to the square of the velocity, so 3 to 10 times the speed is 9 to 100 times the energy. With such an increase in energy transfer from the gas to the liquid, the liquid is broken up into much smaller droplets. This produces a mist with average droplet sizes much smaller than any other method for the same gas flow and pressures.

Mira Mist Nebulizer Characteristics:

Normalized Size distribution for aerosol from Mira Mist

on pure water, the most difficult liquid for a Mira Mist.



John A. Burgener
Burgener Research Inc.

Data from Akbar Montaser,
George Washington University

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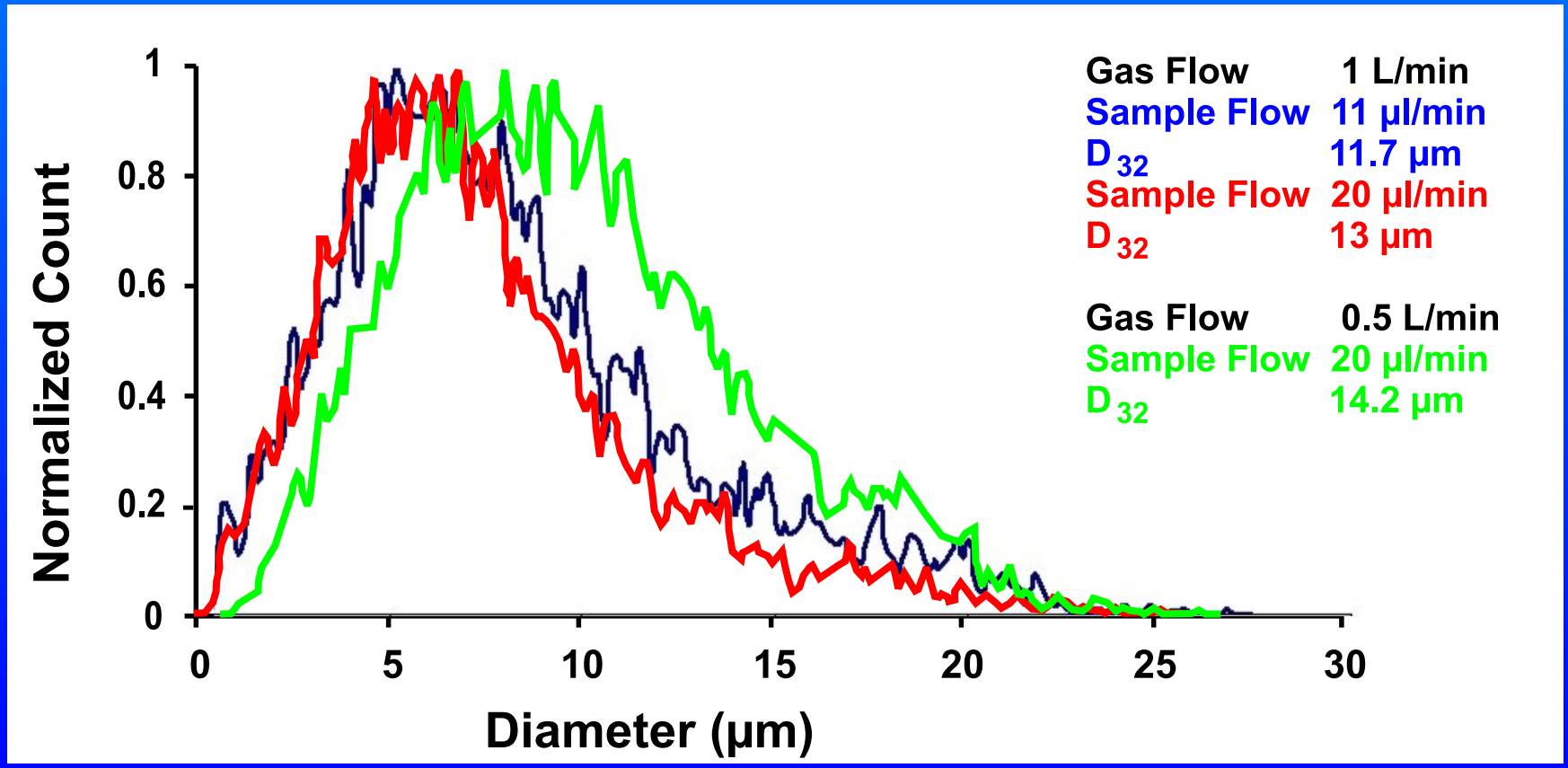

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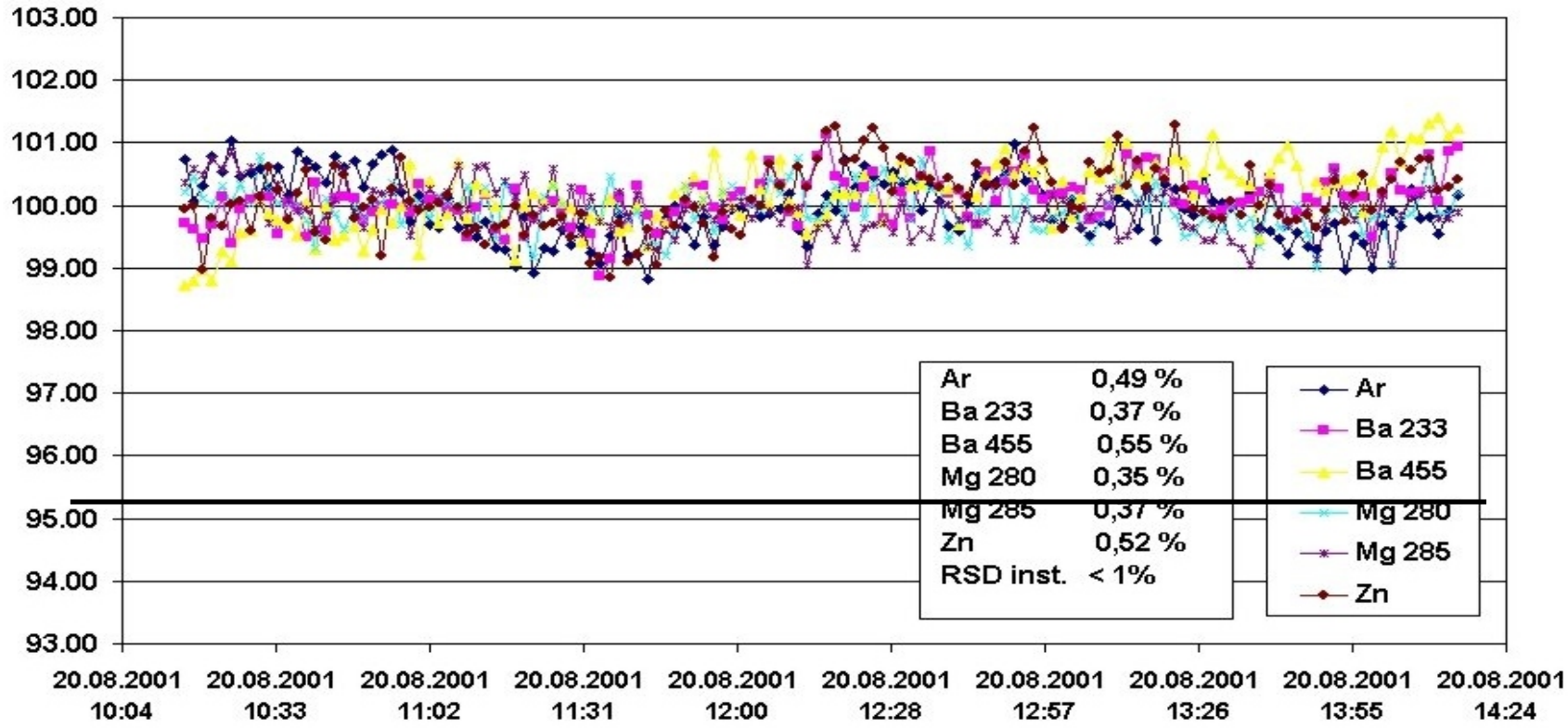
Burgener Research Inc.

Data from Akbar Montaser,
George Washington University

High Stability

Mira Mist Stability Plot

< 1% RSD for 3% NaCl over a 4 hour period



John A. Burgener
Burgener Research Inc.

Data from Jobin Yvon, France

ENHANCED PARALLEL PATH NEBULIZERS for ICP & ICP / MS 2012 Product line

BETTER THAN THE BEST CONCENTRIC

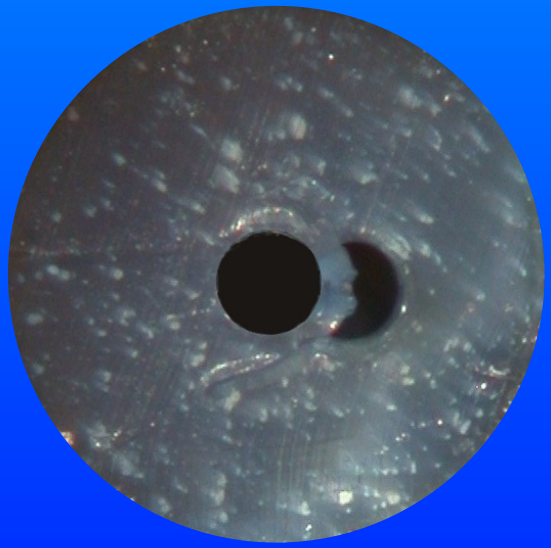
Excellent Sensitivity and Precision with Little or No Drifting, Salting, Plugging, or Maintenance.

3 MONTH SATISFACTION GUARANTEE

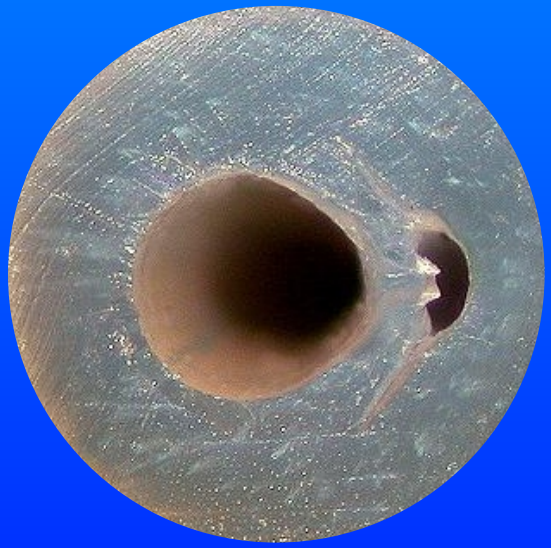
Burgener Research

Comparisons of sample passages

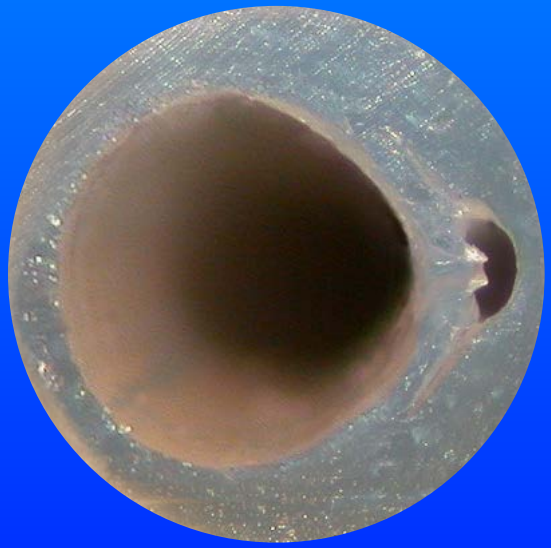
ARI MIST
225 µm



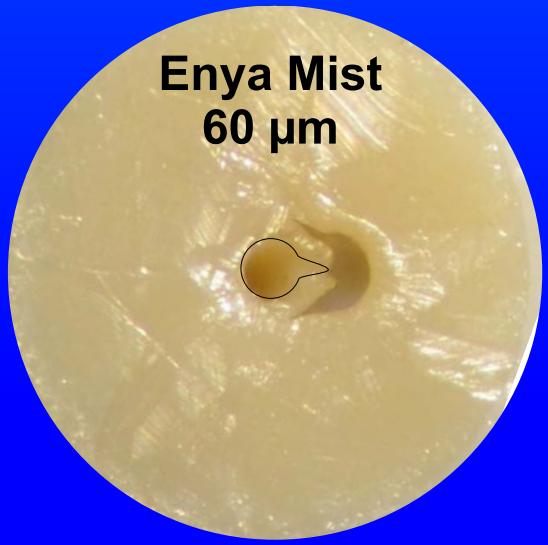
MIRA MIST
500 µm



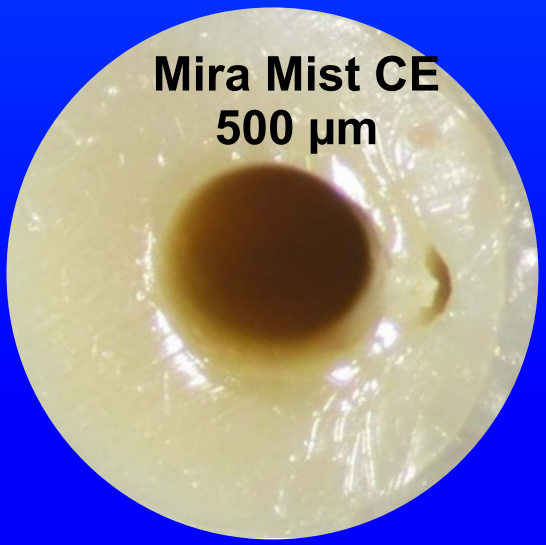
T2100
760 µm



Enya Mist
60 µm



Mira Mist CE
500 µm



Glass Concentric
200 µm

Enhanced Parallel Path Summary

Ideal nebulizers for almost all uses:

Excellent stability and sensitivity.
Handle high to saturated salts.
Handle large particles.
Micro flow and macro flow.
Non contaminating fittings and materials.
Rugged: provides exceptionally long life.

Main New nebulizers since 2000:

Burgener Enhanced Parallel Path Method

OneNeb Flow Blurring

Pizeoelectric Vibrating Mesh

ALL OF THESE ARE NEW CONCEPTS IN NEBULIZATION
NOT JUST VARIATIONS ON PREVIOUS DESIGNS

John A. Burgener
Burgener Research Inc.

Presentation

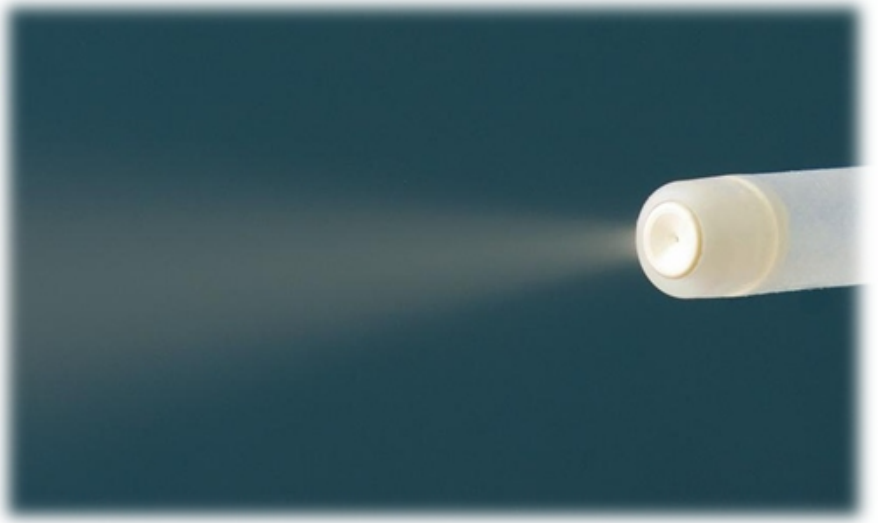
Our product

OneNeb is a new pneumatic nebulizer specially designed for use in liquid sample introduction systems for analytical atomic spectrometry techniques based on inductively coupled plasma (ICP-OES and ICP-MS).

The nebulization mechanism used is based on **Flow Blurring®** technology which is patented by the Spanish company **Ingeniatrics**.

For Challenging Applications
– *OneNeb Nebulizer*

- Robust PFA and PEEK construction
  - Inert - resistant to strong acids such as HF
  - Resistant to breakage
  - Molded plastic design provides improved nebulizer to nebulizer reproducibility
- Constant diameter narrow bore tubing through to nebulizer tip
  - Ideal for high solids/particulates
  - Improved tolerance to high TDS samples
- Narrow aerosol size distribution provides improved precision
- Handles a wide flow range from 0.1 to 2 mL/min.
  - No sensitivity loss at low flow rates



Principle of Operation – Inert OneNeb Nebulizer

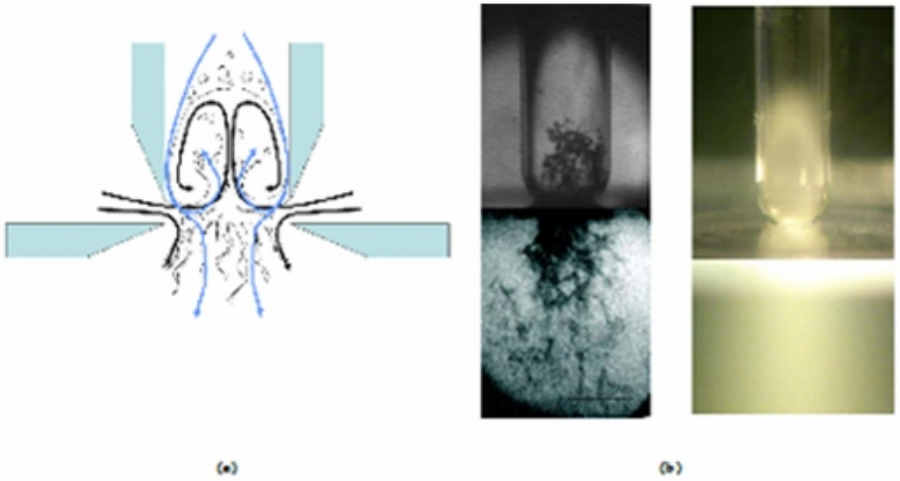
Tip geometry dimensioned to allow carrier gas to mix with the sample

Turbulent mixing of liquid and gas occurs

- Produces aerosol with a narrow size distribution range

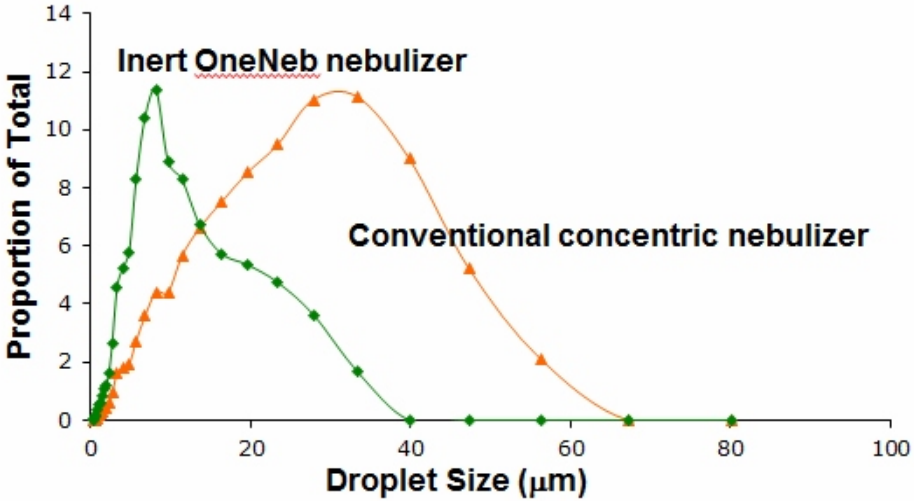
Droplets mixed into gas flow

No area of low pressure



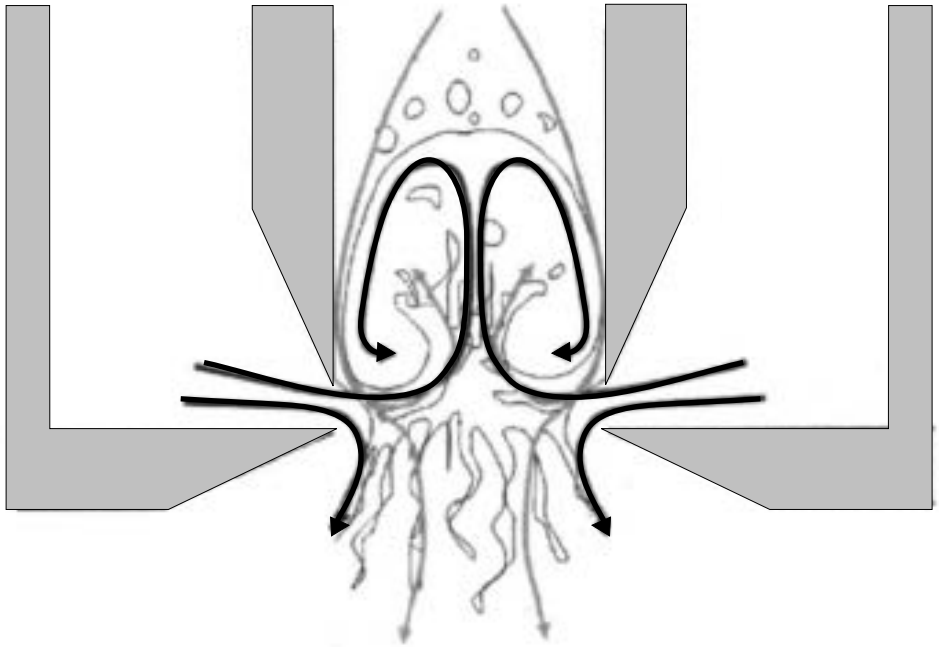
Unique Flow Blurring action increases nebulization efficiency

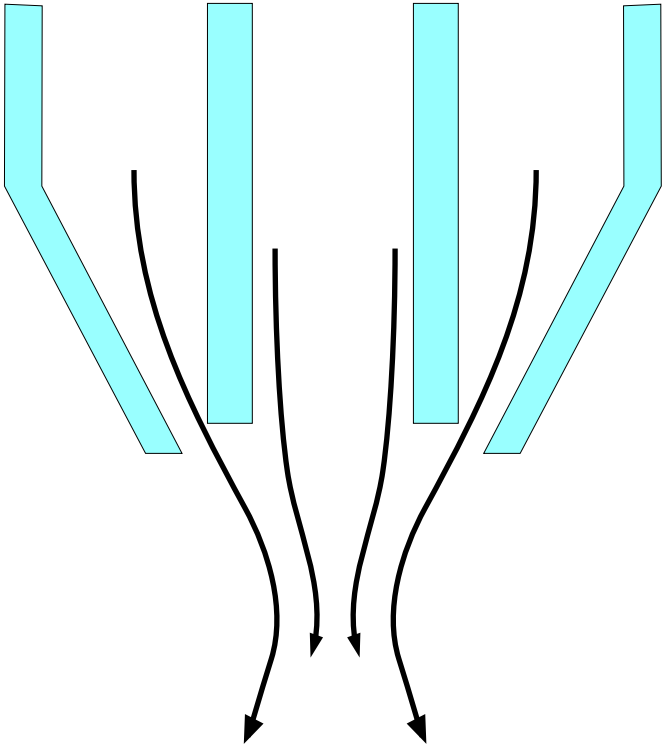
- Greater efficiency than conventional concentric nebulizer
- Improved sensitivity



Flow Blurring
This is NOT using induction !

Concentric

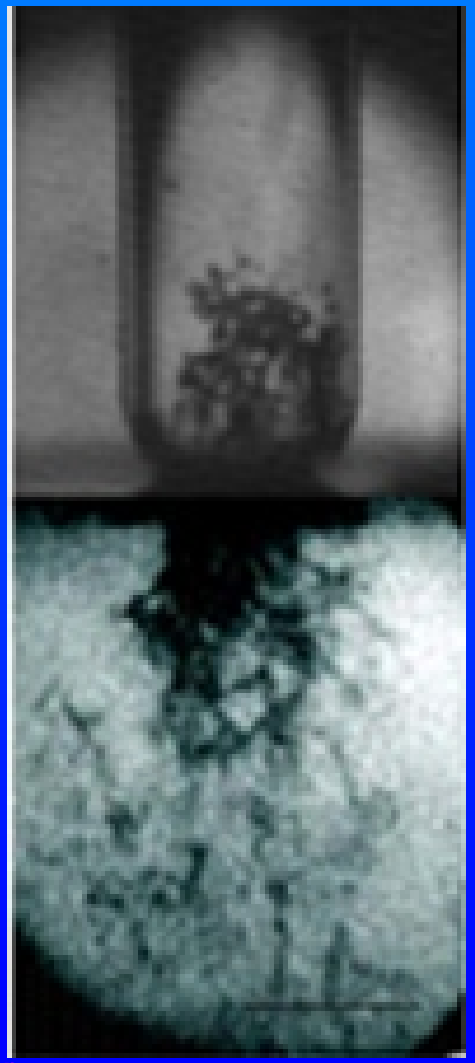




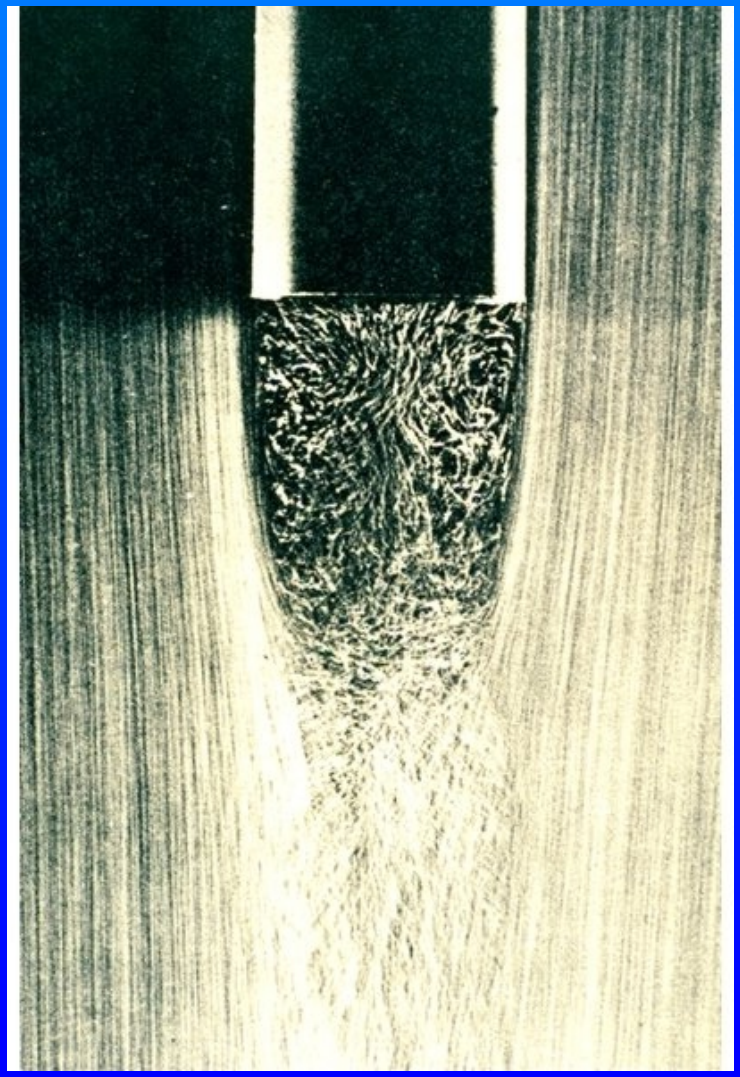
John A. Burgener
Burgener Research Inc.

Close Up Photos

Flow Blurring



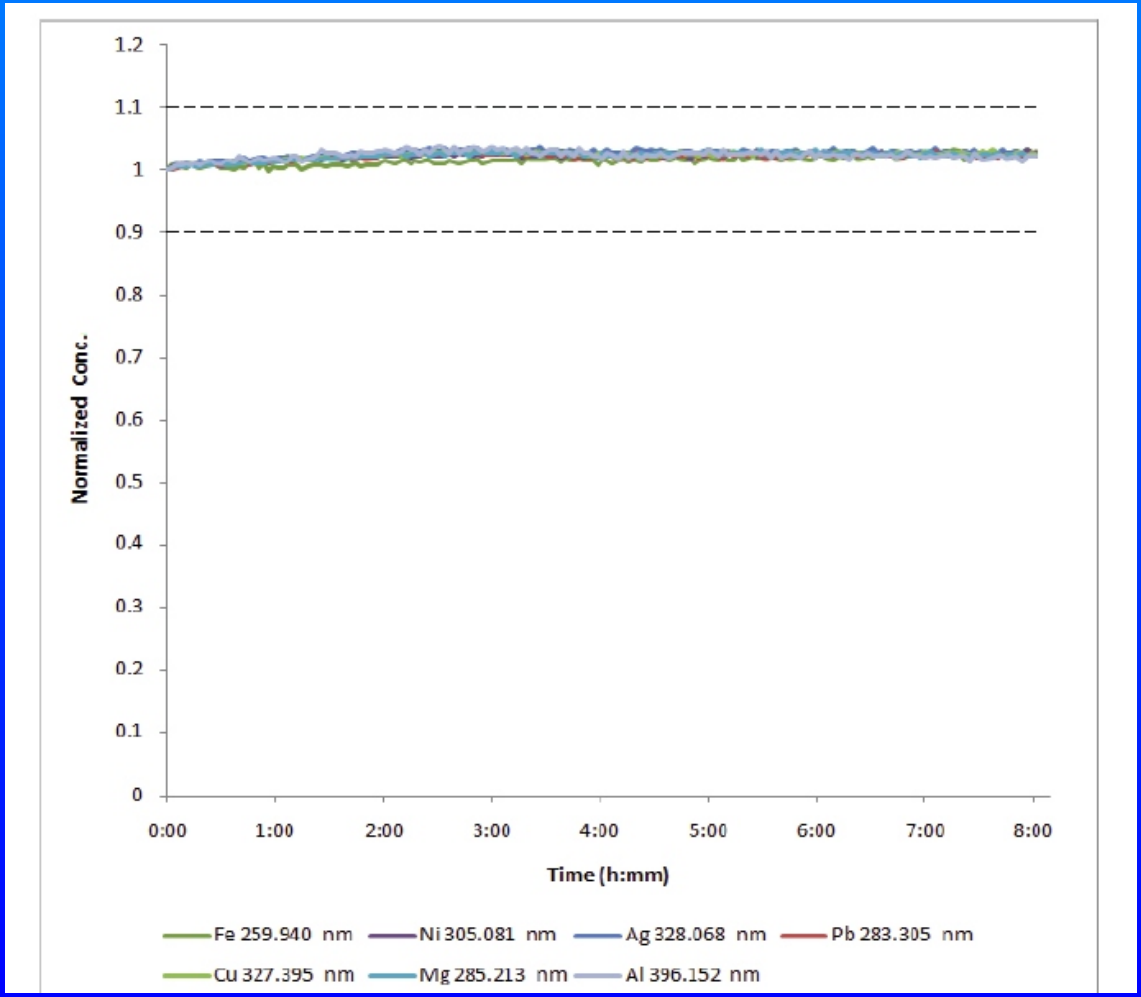
Glass Concentric



John A. Burgener
Burgener Research Inc.

Concentric Photo courtesy of Geoff Coleman, MEINHARD®

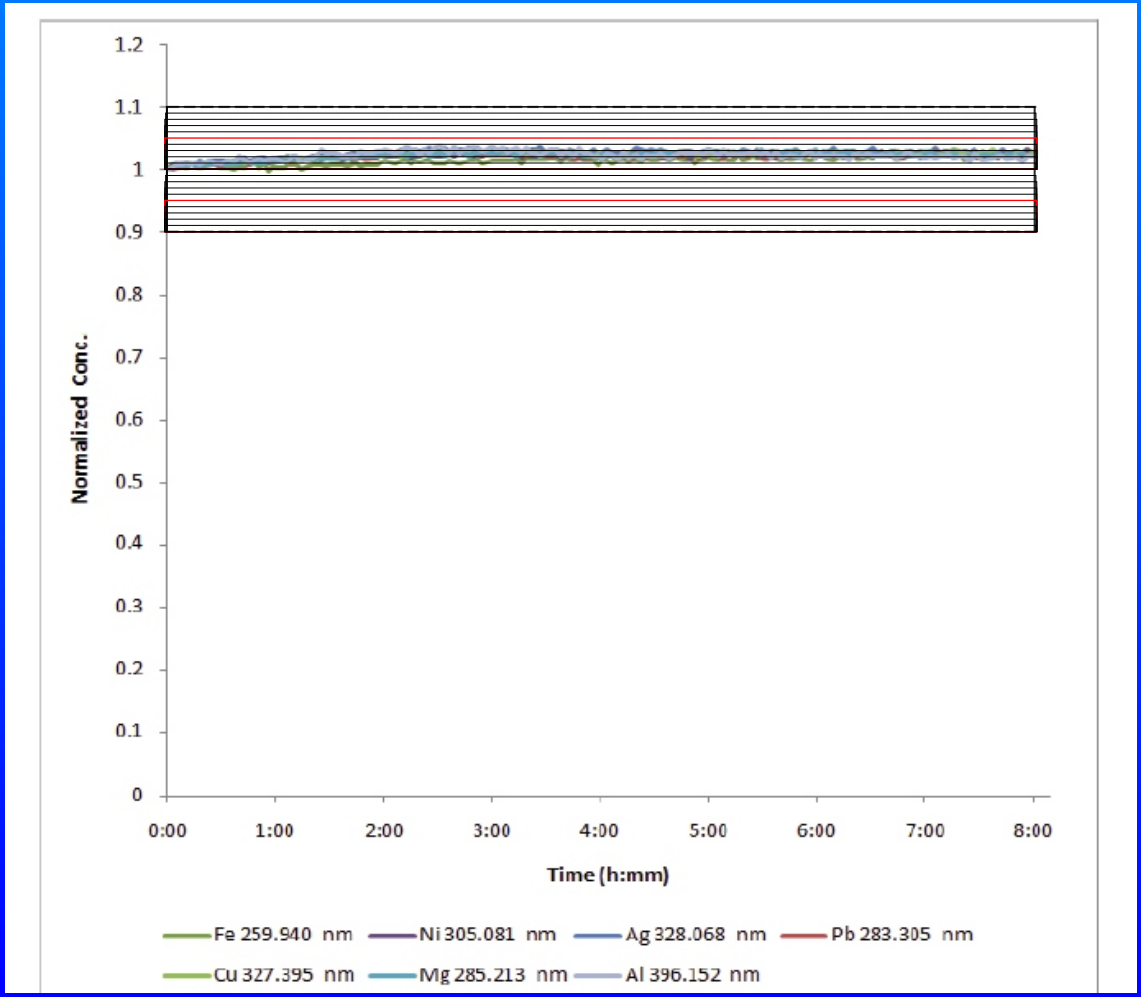
OneNeb Normalized Stability Plot
for 10 ppm S21+K solution over an 8 hour period



Agilent Application note:
"Analysis of wear metals and contaminants in engine oils using the 4100 MP-AES"

Authors:
Phil Lowenstern and Elizabeth Reisman
Agilent Technologies, Melbourne, Australia

OneNeb Normalized Stability Plot
for 10 ppm S21+K solution over an 8 hour period



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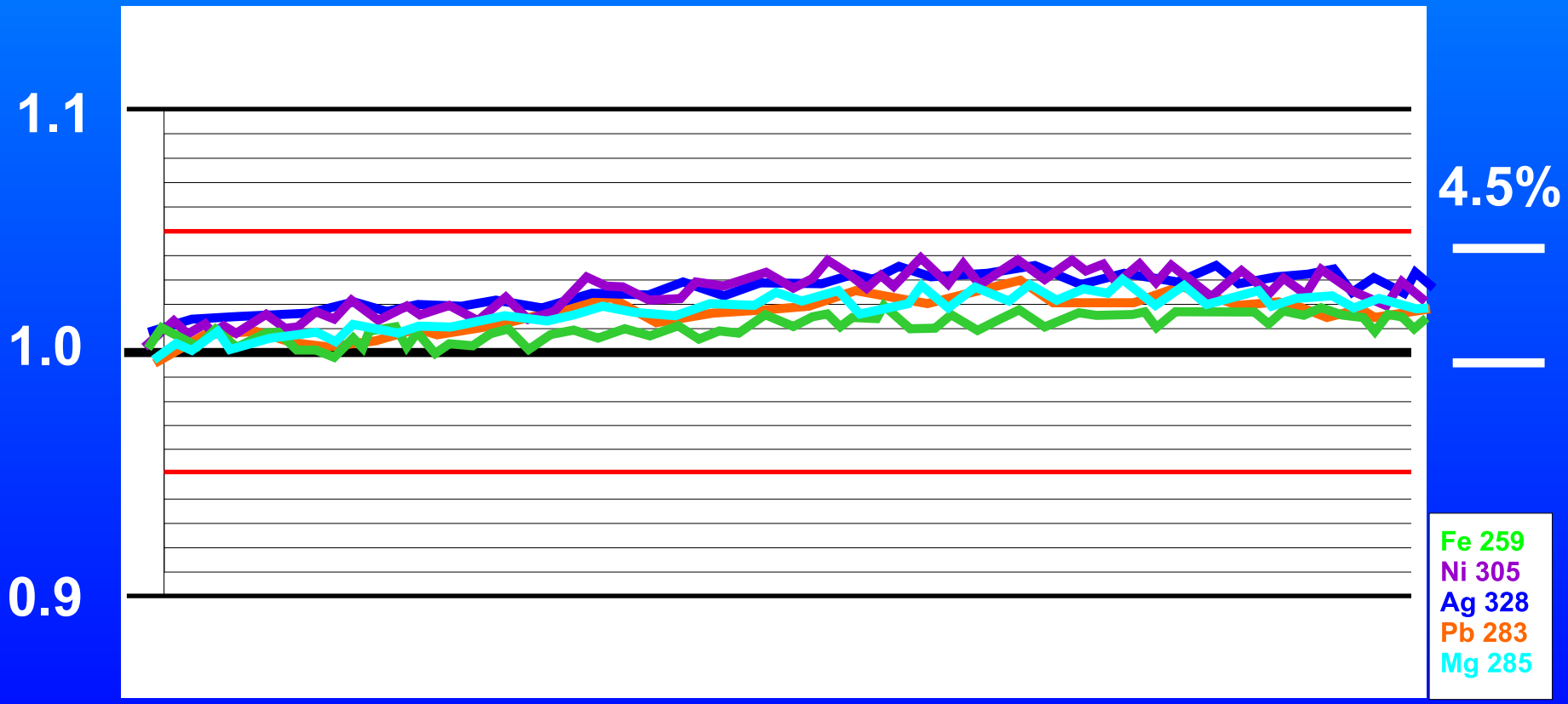
Authors:
Phil Lowenstern and Elizabeth Reisman
Agilent Technologies, Melbourne, Australia

OneNeb Normalized Stability Plot

for 10 ppm S21+K solution over a 4 hour period

(This is half of the previous data, so 4 hours not 8.)



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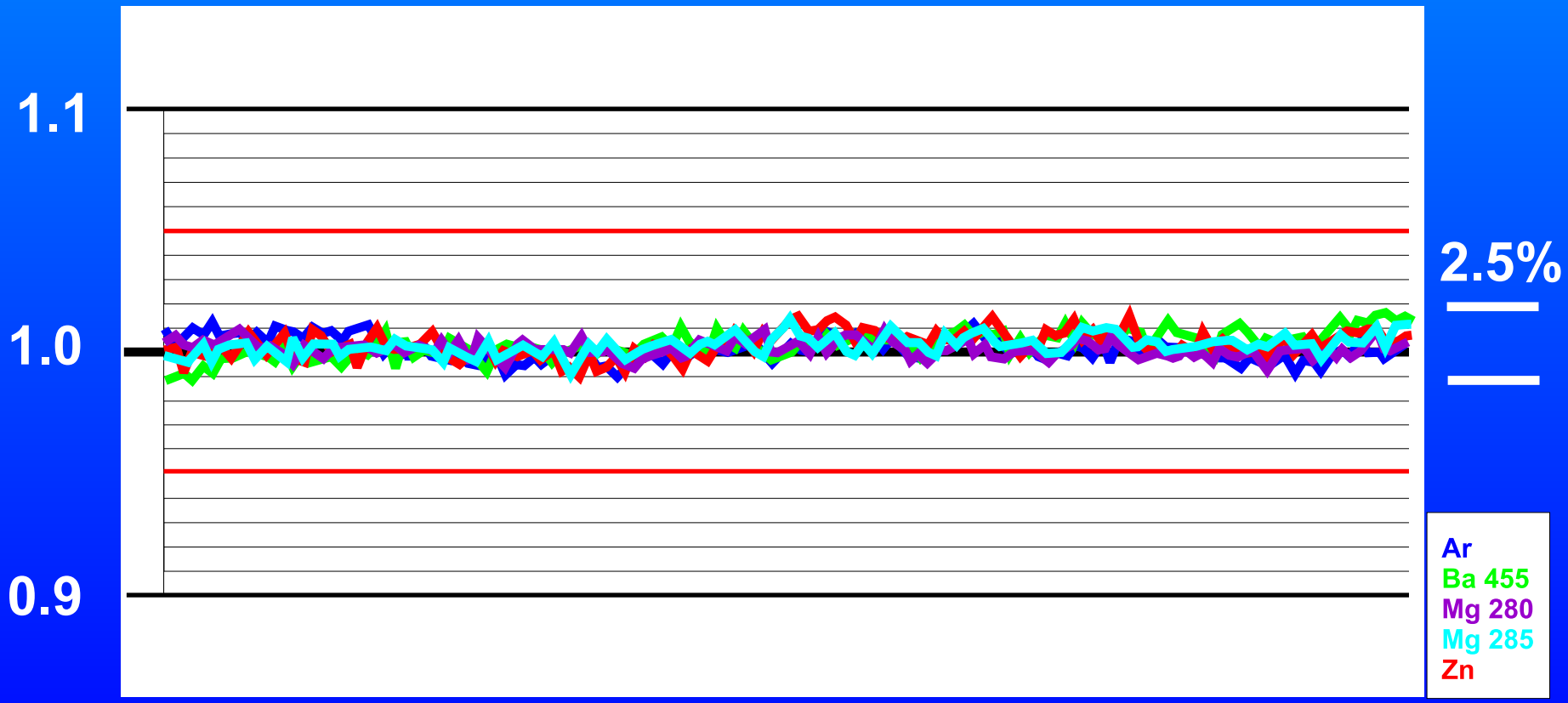
Authors:
Phil Lowenstern and Elizabeth Reisman
Agilent Technologies, Melbourne, Australia

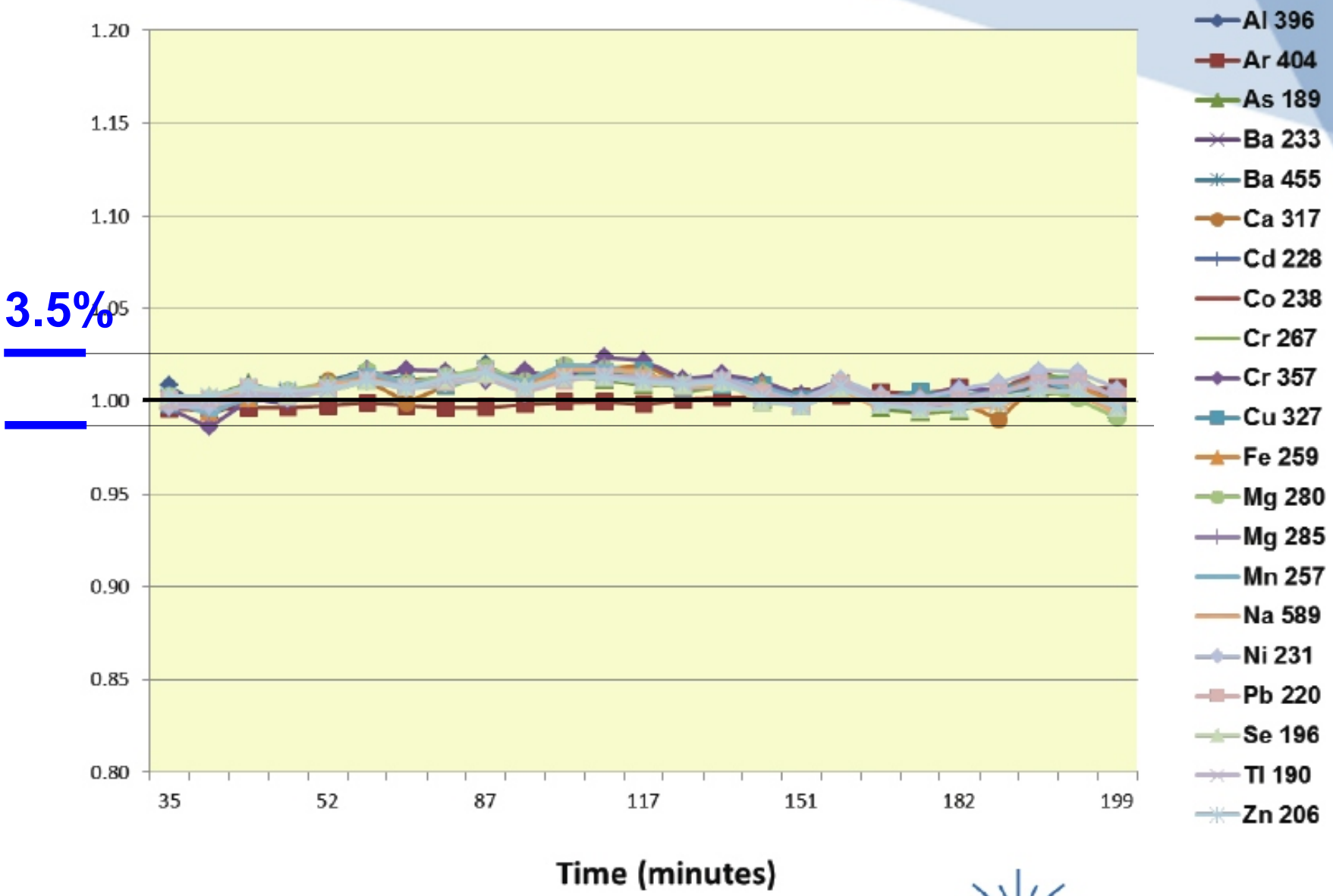
Mira Mist Normalized Stability Plot
for 3% NaCl over a 4 hour period



JY Stability Test 2001

John A. Burgener
Burgener Research Inc.

DuraMist Long-term Stability



GLASS EXPANSION
Quality By Design

OneNeb Review

New Concept, claims to have smaller droplets.

Pro:

High Precision, Low Detection Limits,

Because it has no low pressure zone, it should not salt.

Handles High Salts, Wide range of flow rates.

As with any micro nebulizer,

for < 50 ul/min can deliver nearly 100% to torch.

Con:

Small sample capillary - particles will plug

Rubber in Gas line fitting

- will cause some contaminations

Back Pressure can blow off sample lines

Smaller droplets will drown torches

unless running low flow or using a desolvator.

Claims of perfection seem to be based on

comparisons with non-optimized other nebulizers.

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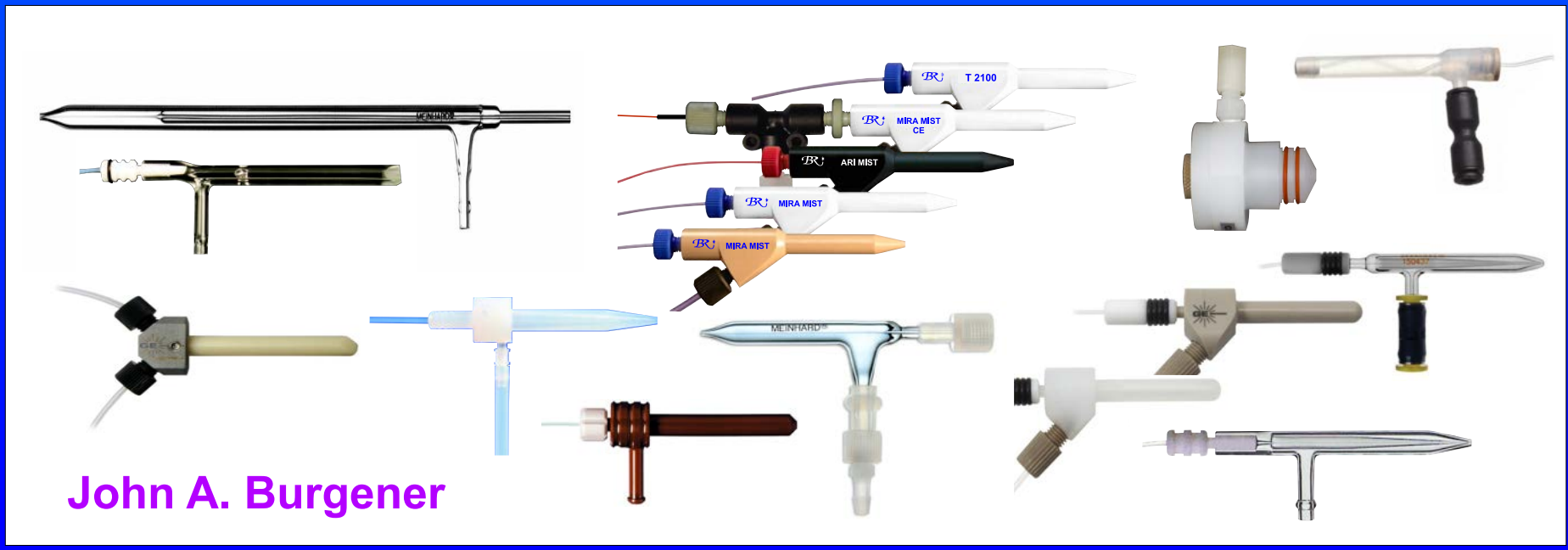
What's New in Nebulizers

PART 3: Some comments on Micro Nebulizers



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The main Micro Nebulizers available today

Microconcentric Nebulizers:

- **Aspire – CETAC (TFE, PFA)**
- **CEI-100 – CETAC**
- **MicroMist – Glass Expansion (glass)**
- **MicroFlow – Elemental Scientific (PFA)**
- **HEN – Meinhard (glass, quartz)**
- **Lucida, Zefyr, Boreal – Epond (PTFE)**

Non-Concentric Nebulizers:

- **Mira Mist CE, Ari Mist, Enya Mist, PFA 250 – Burgener**
- **OneNeb – Ingeniatrics**

Enya Mist: 0.2 - 50 µl/min @ 45 psi
Ari Mist: 5 - 1500 µl/min @ 45 psi
PFA 250: 50 - 1500 µl/min@45 psi
Mira Mist CE: 1 - 2500 µl/min @ 80 - 90 psi
Lucida: 1 - 40 µl/min @ 35 psi
Zefyr: 5 - 100 µl/min @ 35 psi

Boreal: 50 - 700 µl/min @ 35 psi
OneNeb: 10 - 2000 µl/min @ 40 psi
MicroMist: 100 – 500 µl/min @ 30 - 60 psi
MicroFlow: 20 – 700 µl/min @ 60 – 70 psi
High Efficiency Nebulizer: 30 – 300 µl/min @ 90 – 170 psi
Microconcentric Nebulizer: 100 – 500 µl/min @ 60 – 90 psi

Advantages of Micro and Nano flows

1 L of dry Argon can absorb 15 µl of water.

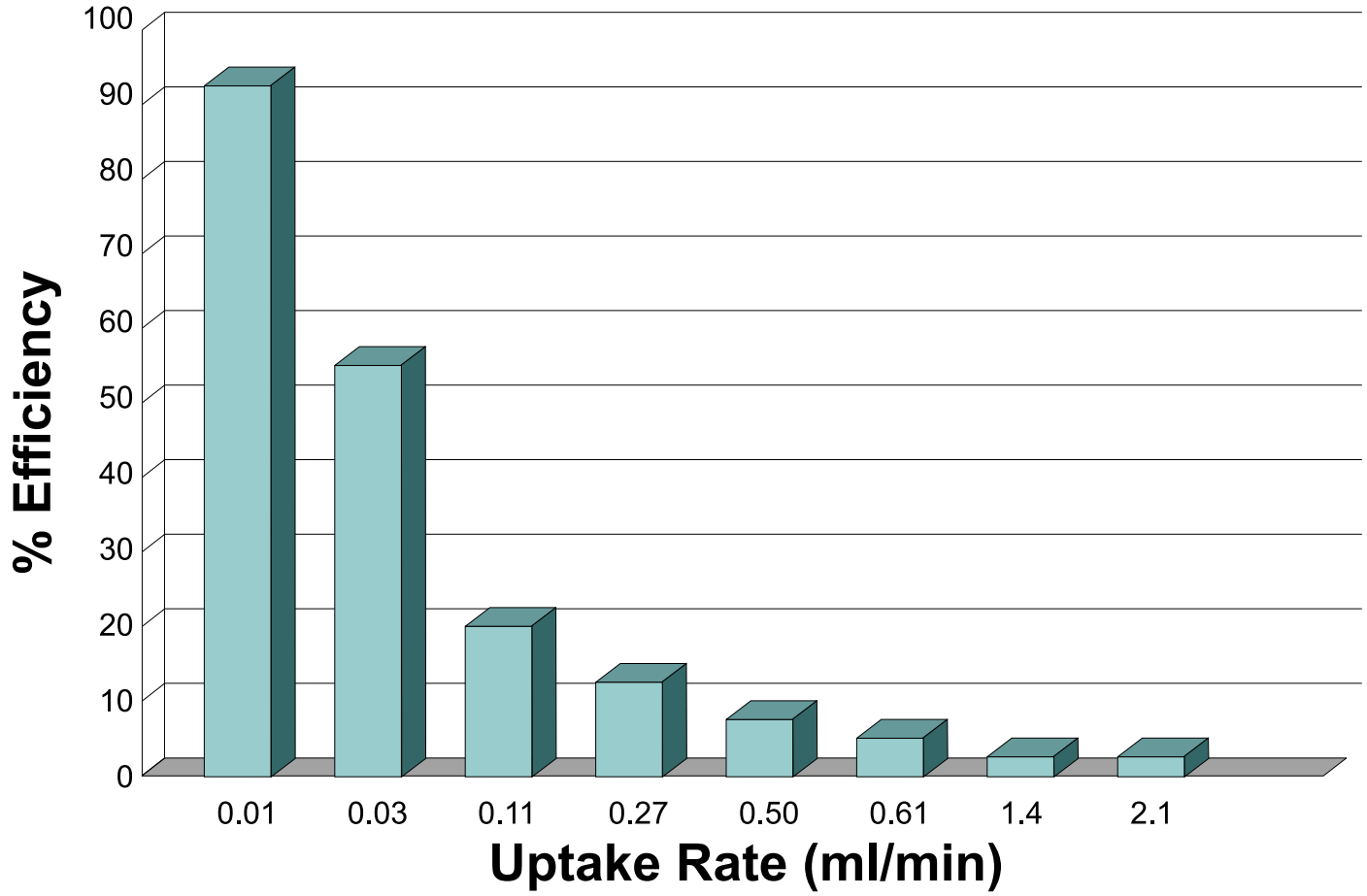
Running less than 15 µl/min enables:

(conditional on droplet sizes being < 10 µm and enough time allowed for vaporization or heating / desolvation being added)

- ALL of the sample vaporizes and goes to torch.
- The chamber stays dry
- Washout times drop from minutes to milliseconds.
- Torch stability improves.
- Speciation effects dramatically reduced.
- ICP/MS interferences drop dramatically.
- MS cones/skimmers last much longer.
- HPLC, µHPLC and CE can have ALL sample to torch.
- Micro samples can be run over a long period of time.
- Organic solvents can be run without effecting the plasma.

Transport Efficiency vs. Uptake

Chart assumes droplets have average sizes < 10 µm



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Data from Geoff Coleman, Meinhard

Disadvantages of Micro Nebulizers?

Micro Concentrics usually have micro capillaries.

Micro particles can plug them.

Micro salts can plug them.

Micro damage can break them.

Advantages of Dry Samples

Torches can handle 40 - 60 µl/min of sample

The variation probably relates to how much sample has vaporized.

With Desolvation, Heating, Cooling,

some of the water can be removed.

With the sample all vaporized,

one gains the same benefits of low flow.

With High Efficiency Nebulizers, TOO MUCH sample

will arrive at the torch unless water is removed.

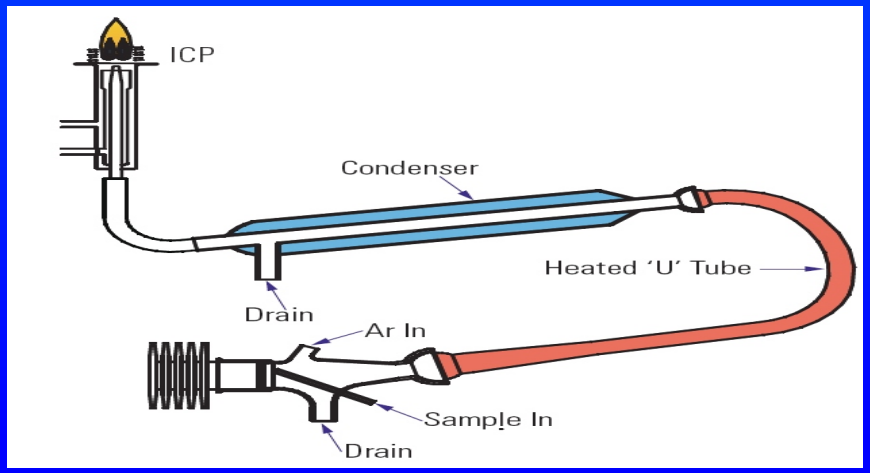
More than 40-60 µl/min water will quench / kill the plasma.

If you can dry 1 ml/min, the signal is 25X better than 40 µl/min.

Since 1988 Cetac Ultrasonic Nebulizers have used Desolvators

Efficiency approaches 30%, Sensitivity improves ~10x
Droplet size < 5 microns.
Potentially heavy solvent load so Desolvation essential.
Peltier cooling essential.
Membrane separator available and usually essential.
Desolvation interferences occur (eg., As III vs. As IV)

Does not handle high solids well.
Long washout times required due to desolvators.



Evaluation of an Ultrasonic Nebulizer Using Perkin-Elmer Sequential ICP Instrumentation - Robert Thomas, Cindy Anderau - Atomic Spectroscopy, 10 (2), 71 (!989). This paper describes the capabilities of the first commercially available ultrasonic nebulizer, the CETAC USN-5000 with two of Perkin Elmer's ICP optical emission spectrometers, the Plasma 40 and Plasma II. Various criteria were evaluated including detection limit, precision and memory test. The conclusion of the work was that the early design of this product showed great promise but required some improvements to be accepted and used as a truly routine analytical tool.

Desolvation Accessories

Now available for most nebulizers, not just Ultra Sonic

Sensitivity improves ~10x
Uses any 6 mm nebulizer
and cyclonic spray chamber

Desolvation interferences problematic
High solids still problematic

Available in HF-resistant versions
Available with membrane desolvation

Aridus II from CETAC
Apex from Elemental Scientific

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Spray Chamber Temperature Control

Sensitivity improves
Uses any 6 mm nebulizer
and cyclonic spray chamber

Reduces solvent loading
Reduces oxide interferences in ICP/MS

Available in HF-resistant versions

PC3 from Elemental Scientific
IsoMist from Glass Expansion

Disadvantages of Micro Nebulizers?

Micro Concentrics usually have micro capillaries.

Micro particles can plug them.

Micro salts can plug them.

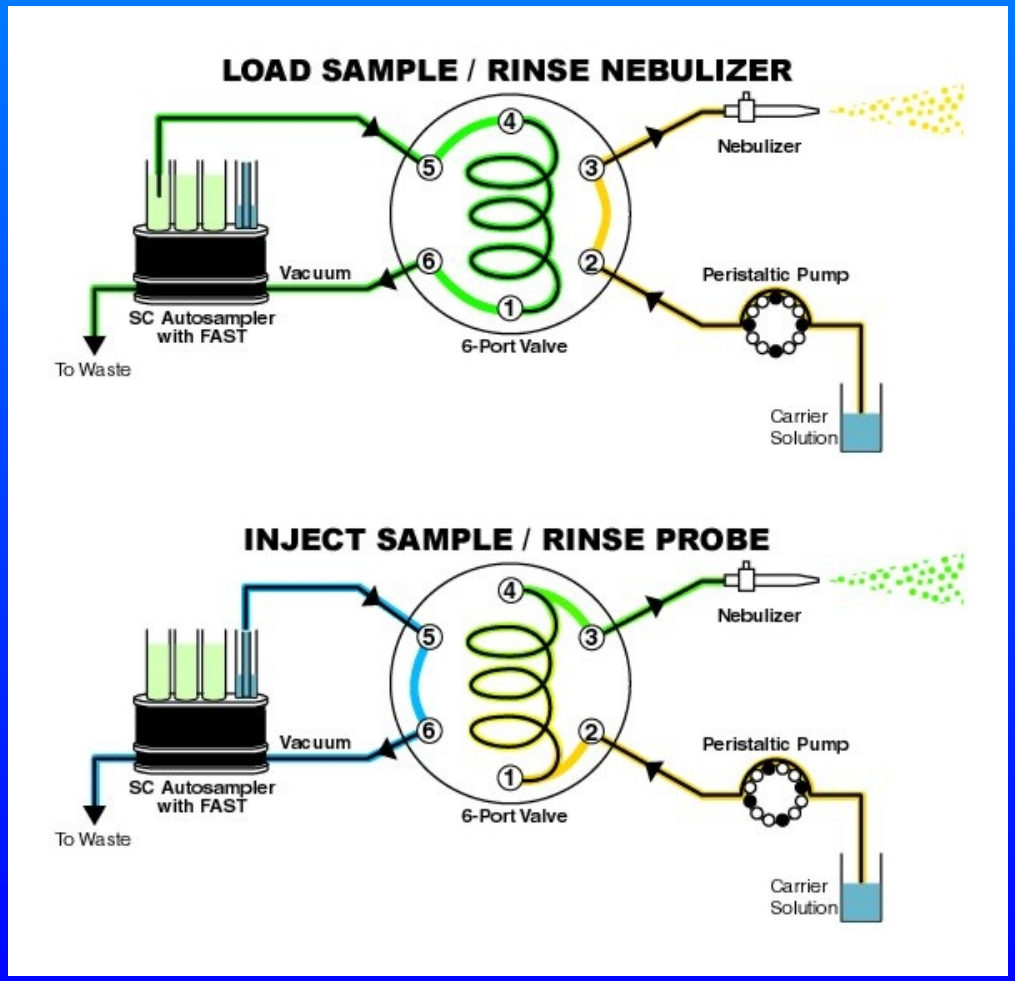
Micro damage can break them.

Micro Flow takes Macro time

to get from sample to nebulizer.

Flow Injection

Allows rapid sample turnaround for micro flows.



Low liquid flow rates mean very low sample throughput

Flow injection / fast rinse Makes low flow practical. Sample is quickly sucked up by vacum, then slowly sent to nebulizer.

Available from CETAC, ESI, GE

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Split Flow

Allows rapid sample turnaround for micro flows.

ENYA MIST - 0.2 to 50 µl/min
SPLIT FLOW CAPABILITY

Input 500 µl/min

Max flow of 50 µl/min
Desired flow 10 µl/min

Output to drain
490 *µl/min*

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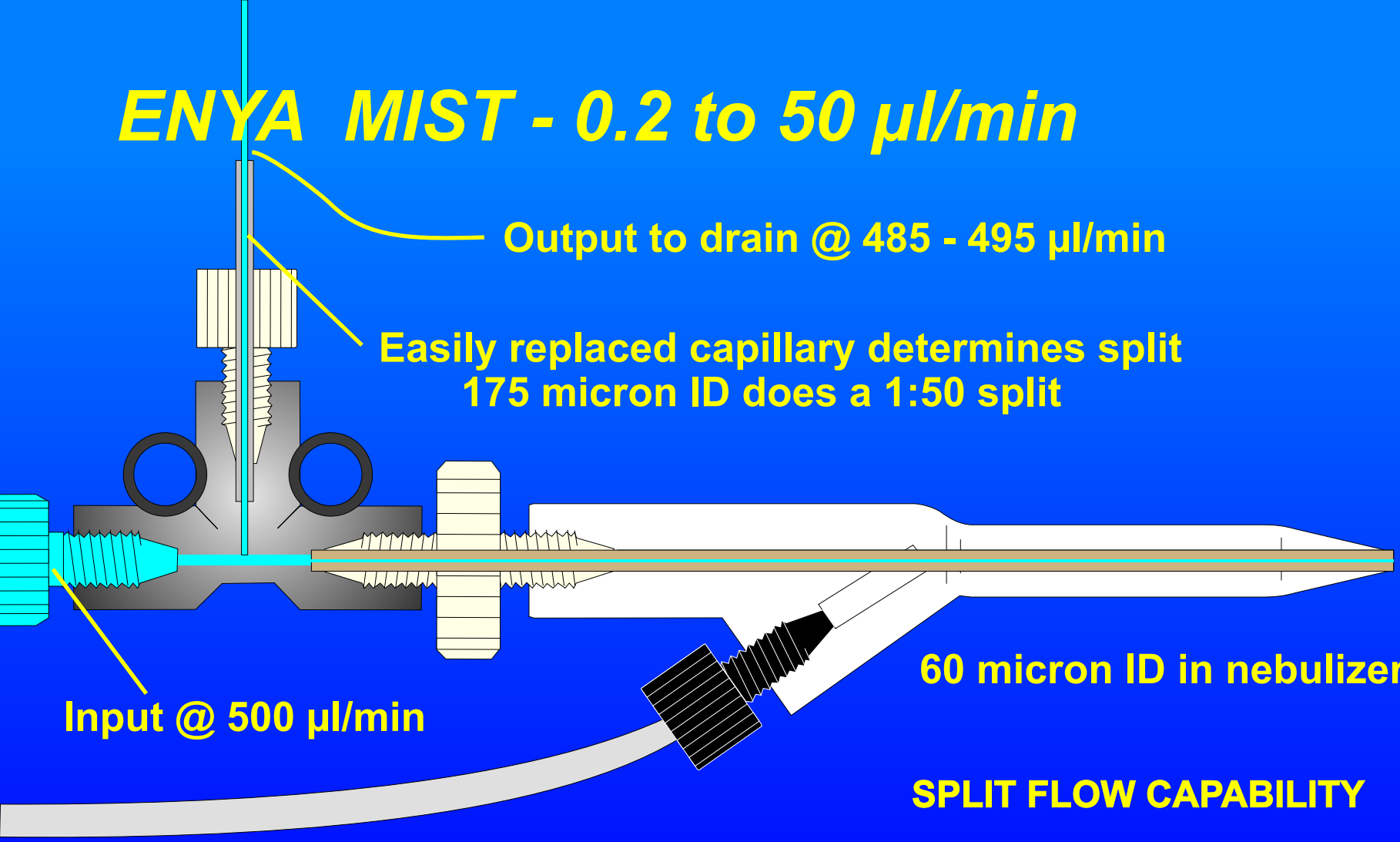
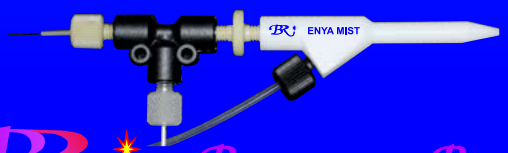
ENYA MIST - 0.2 to 50 µl/min



SPLIT FLOW CAPABILITY

Similar configuration to Mira Mist CE



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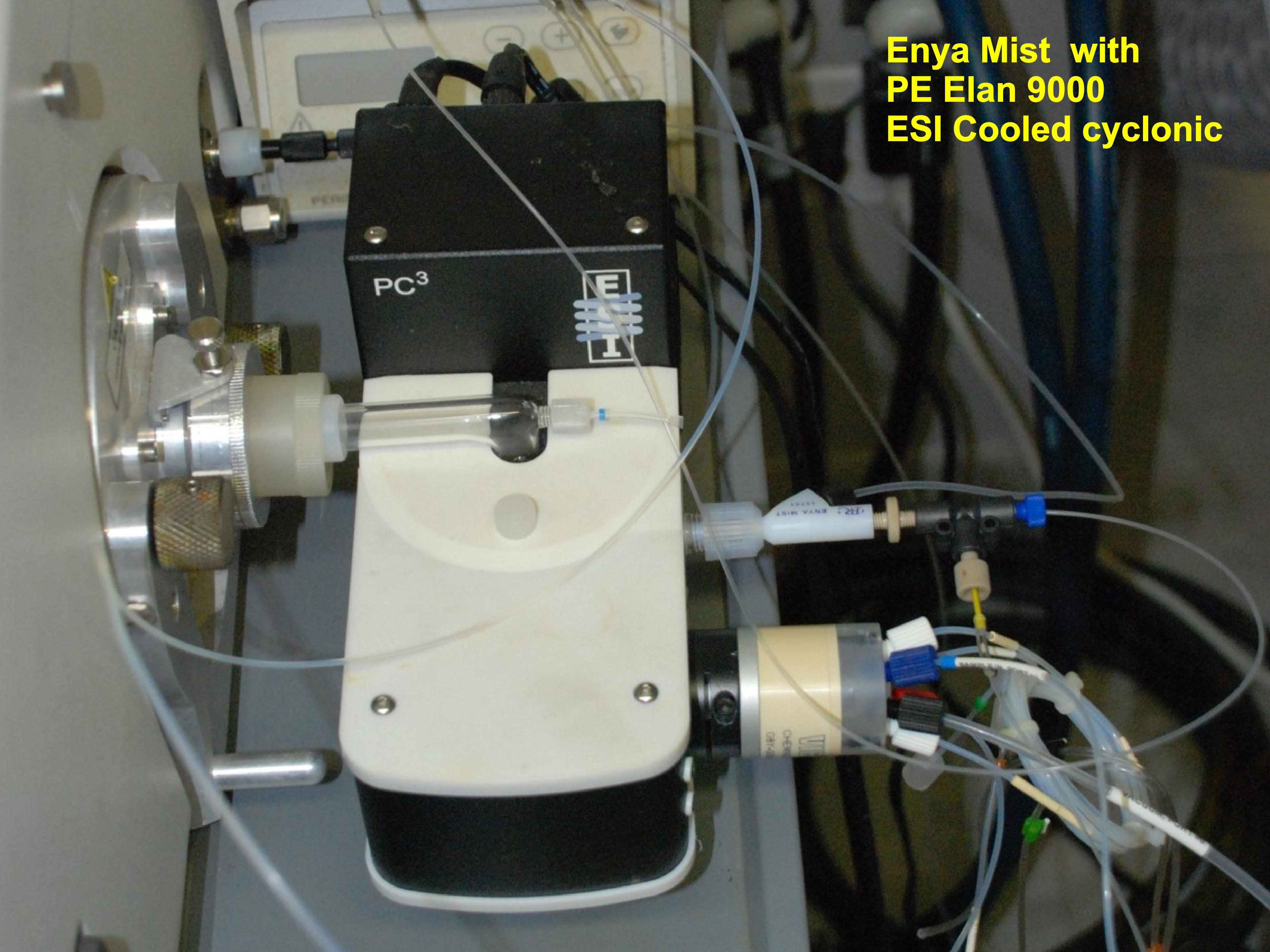


Enya Mist with
PE Elan 9000
ESI Cooled cyclonic

Disadvantages of Micro Nebulizers?

Micro Concentrics usually have micro capillaries.

Micro particles can plug them.

Micro salts can plug them.

Micro damage can break them.

Micro Flow takes Macro time

to get from sample to nebulizer.

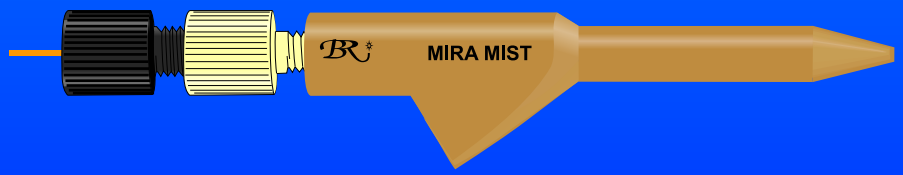
Long narrow capillaries cause signal broading

when connected to LC / CE

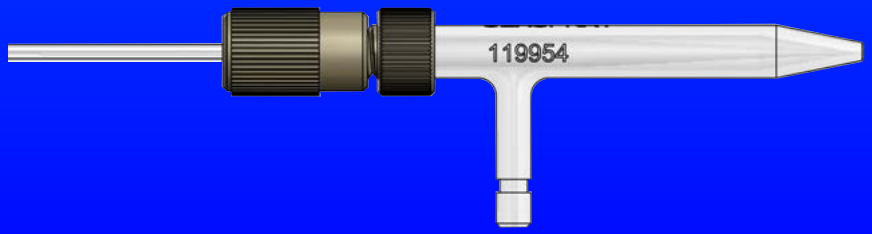
LC, HPLC Connections

readily available from most manufacturers

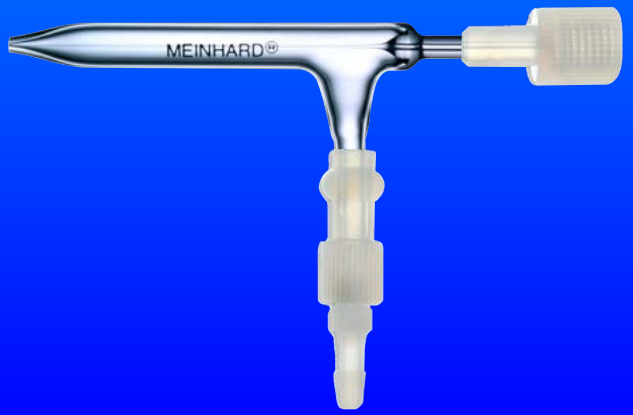
Mira Mist LC interface

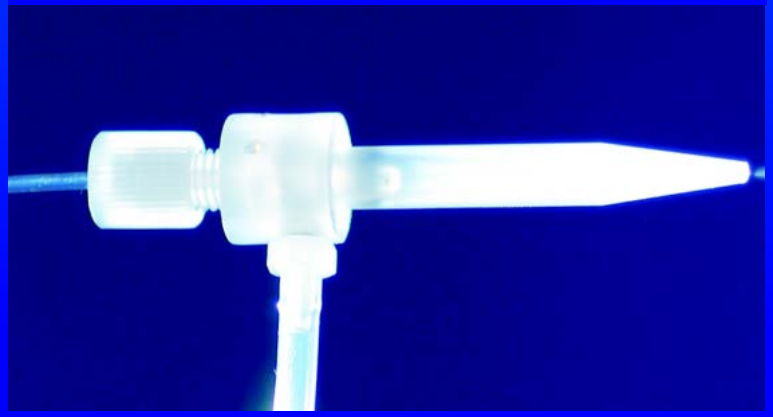


Glass Expansion LC interface



Meinhard and ESI standard fittings attach to LC





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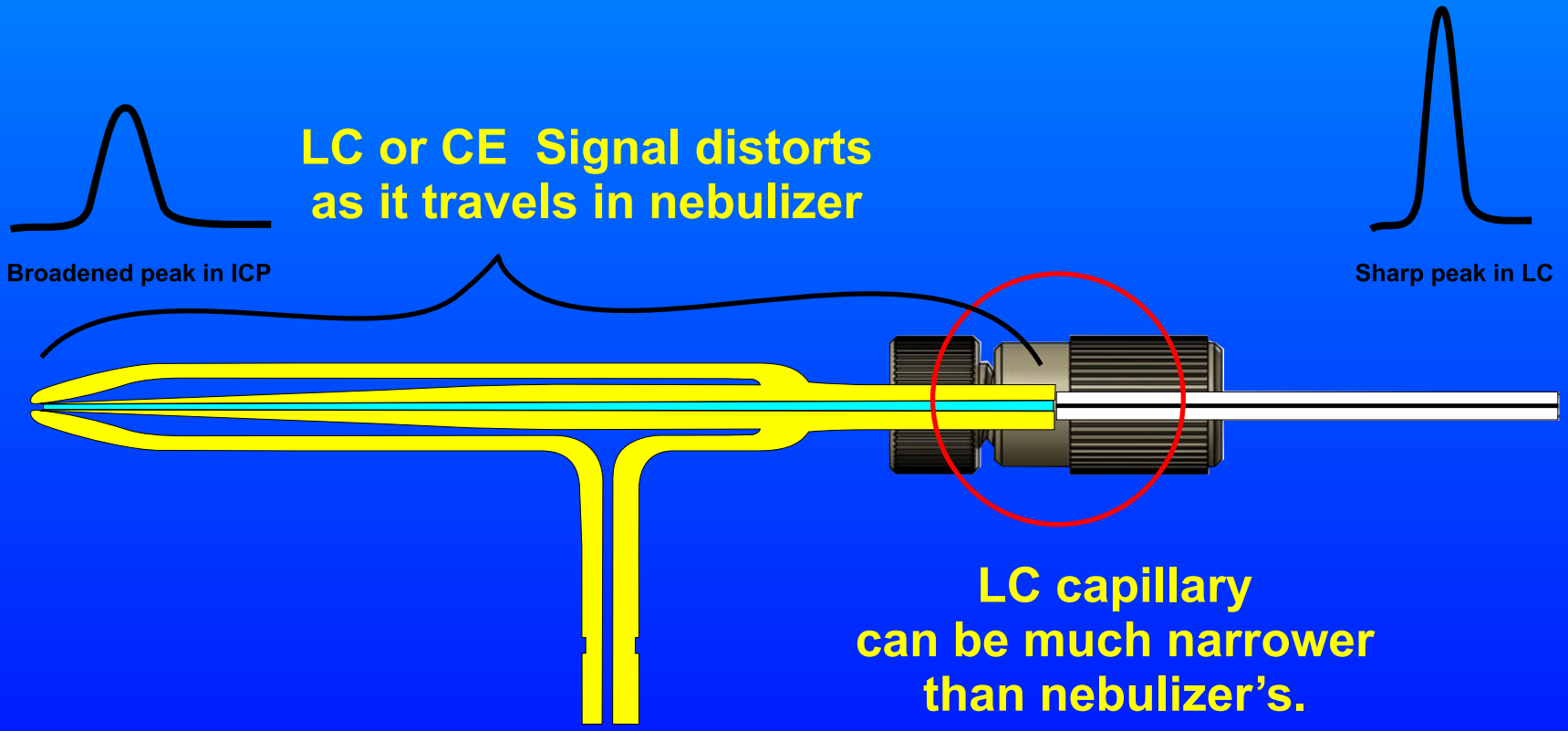
Signal Broadening Problem



LC capillary can be much narrower than nebulizer's.

CE Capillaries are much smaller.

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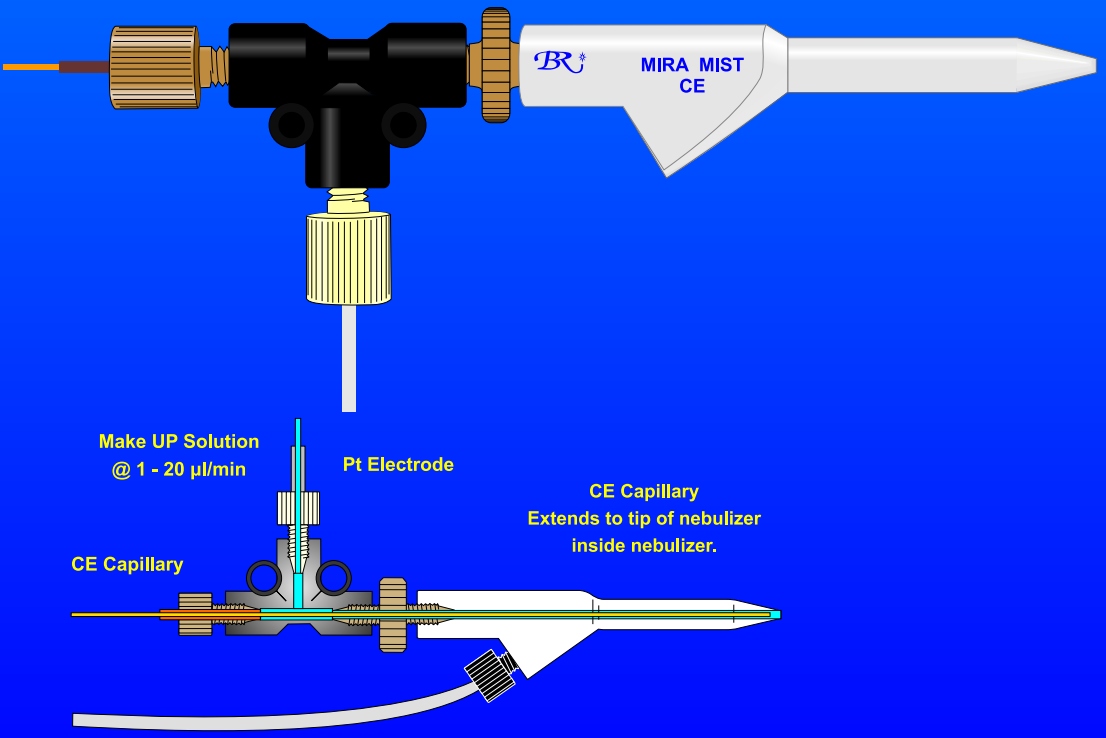
CE Interfaces
Only available from Burgener and Cetac

Mira Mist CE interface



CE Capillary extends to tip: No signal broading

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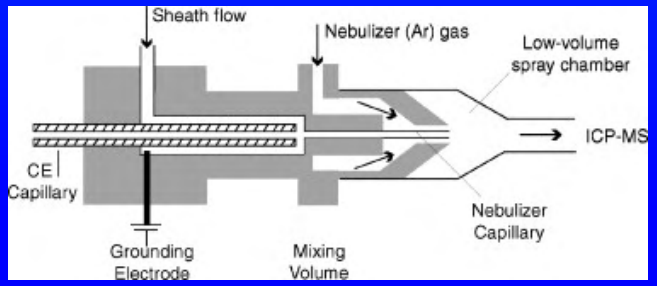
Cetac CEI 100



Short length micro concentric: minimal signal broading

Mira Mist CE: Interface for ICP/MS, CE & LC

Convenient Nano Sample Introduction

2 µl/min to 2,500 µl/min

ICP/MS Interface for CE and LC
0.002 to 2.5 ml/min sample flow rates.
80+ psi for 1 L/min

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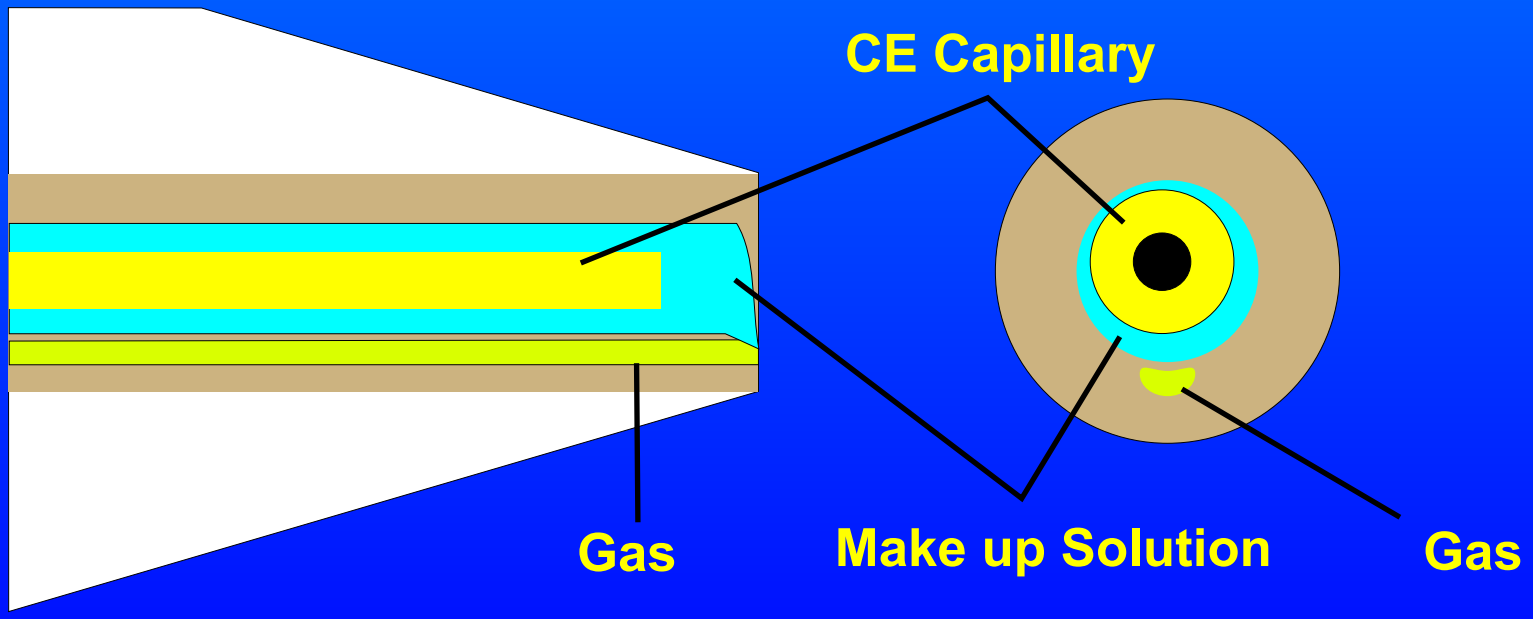
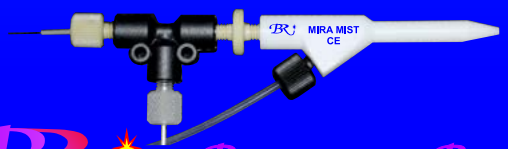
Ideal Nebulizer for CE and LC interfacing to ICP/MS

The CE or LC capillary runs through the nebulizer body to the tip, enabling "instant" flow from the CE/LC capillary to the gas stream. There is no loss of signal as there is with nebulizers interfacing at the back of the nebulizer. The Mira Mist CE has zero suction or back pressure, so there is no interference with the flow from the CE or LC, just 100% transfer, instantly.





Detail of tip of Mira Mist CE

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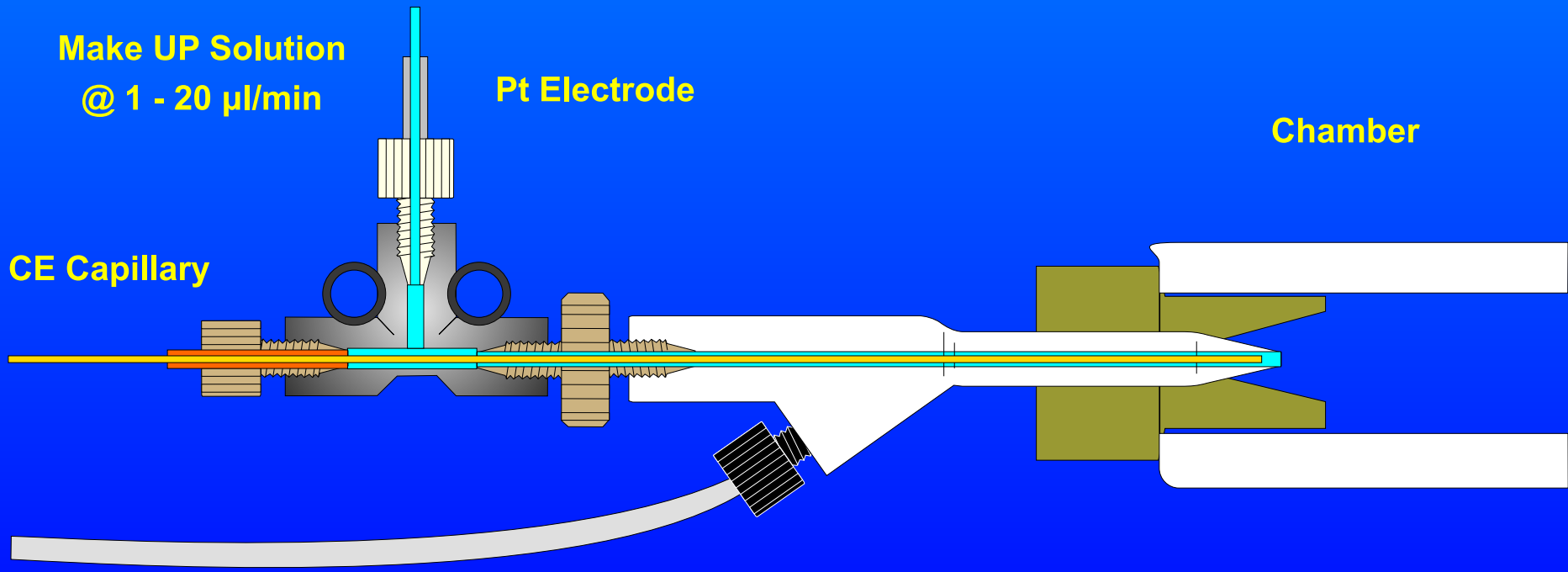
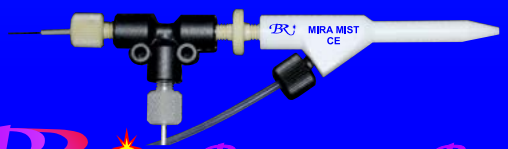
Mira Mist CE
A workable Routine CE - ICP/MS interface and Nano Sample Introduction Method





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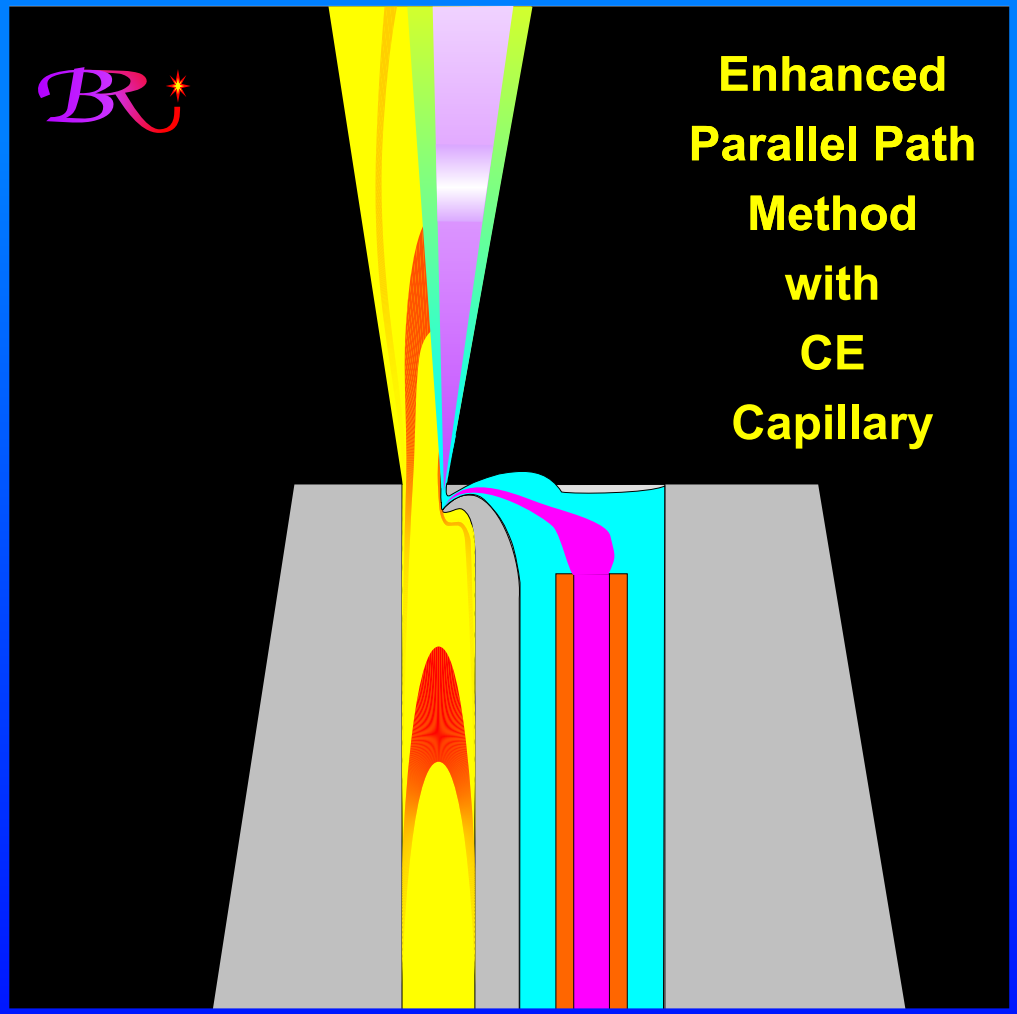
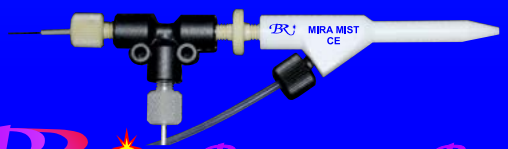
Atomization is independent of sample flow.

As long as the make up solution covers the CE capillary, it maintains good electrical contact and the CE sample is washed directly to the gas orifice.

Close Up of Tip of Mira Mist CE





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Other approach to μHPLC interfacing

Signal broading occurs when
the sample passes from a tiny capillary
into a wider capillary

Solution: Make a nebulizer with a similar size capillary.

The ENYA MIST: 60 µm ID

ENYA = Irish name meaning “Little Fire”.
The Enya Mist is designed to send
very little mist into the plasma (fire).

200 nl to 50 µl/min Micro Flow Nebulizer
For nano HPLC interfacing
And for Split Flow applications

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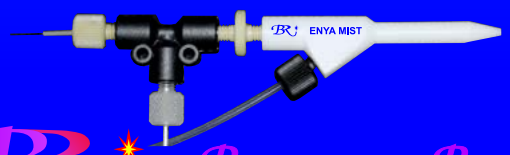
Standard sizes of micro-HPLC columns

(From G &T Septech)

Column ID (mm)	Column Category	Flow Rate Range (µL/min)	Optimum Flow Rate (µL/min)	Analyte Capacity	Bed volume 15 cm column (µL)
1.0	microbore	20 - 200	35	~10 µg	120
0.5	capillary	5 - 50	8	~2.5 µg	30
0.3	capillary	2 - 20	3	~1 µg	10
0.1	nano	0.25 - 2.5	0.5	~100 ng	2
0.075	nano	0.1 - 1	0.3	~25 ng	0.7

All micro and nano HPLC flow ranges covered by Enya Mist



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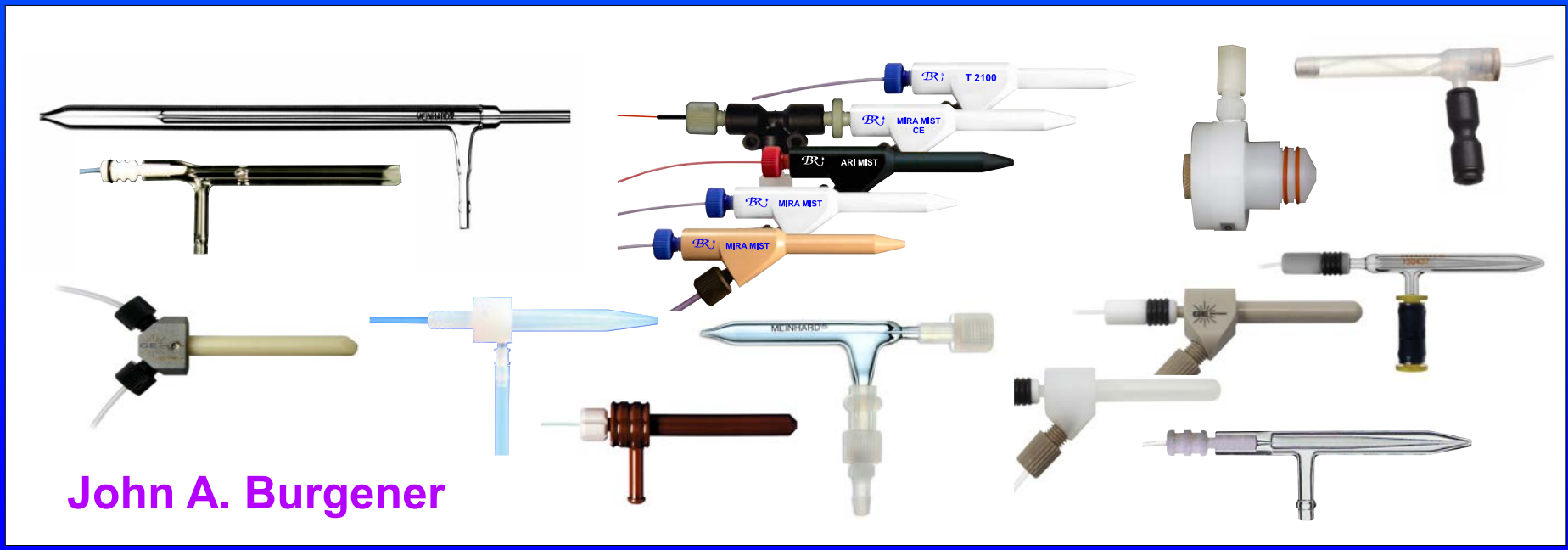
What's New in Nebulizers

PART 4: New 2013 nebulizers from Burgener

The End is very near.



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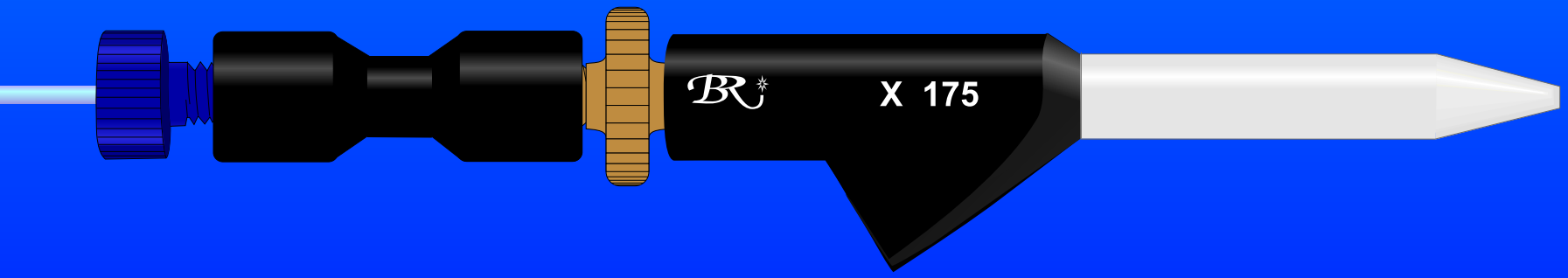
The newest Burgener Nebulizers (2013)

The X 175

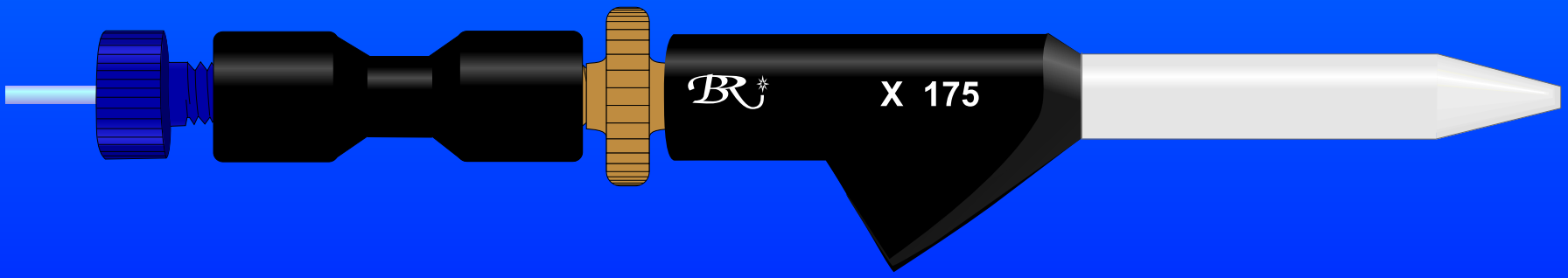


Made in the same style as the Mira Mist CE
Greater stability at low flows than the Ari Mist

Wetted surfaces are Peek or PTFE
The body is strong PEEK.

Runs from 50 µl/min to 1 ml/min
175 micron sample line ID.

The newest Burgener Nebulizers (2013)



The X series can be made in any size internal capillary, from 60 - 760 micron ID

Which matches the main product line Enya Mist to T2100
But runs at higher gas pressures, lower gas flows, and greater stability.

They are expected to mainly be made in the Ari Mist range of 100 - 250 micron ID.

The newest Burgener Nebulizers (2013)

The PFA 250

All wetted surfaces are PFA.
The body is strong PEEK.

Runs from 50 µl/min to 1.5 ml/min
250 micron sample line ID

The newest Burgener Nebulizers (2013)

The PFA 250

1/16” PFA capillary
extends to the
tip of the nebulizer

All PFA in chamber

All wetted surfaces are PFA.
The body is strong PEEK.

Runs from 50 µl/min to 1.5 ml/min
250 micron sample line ID

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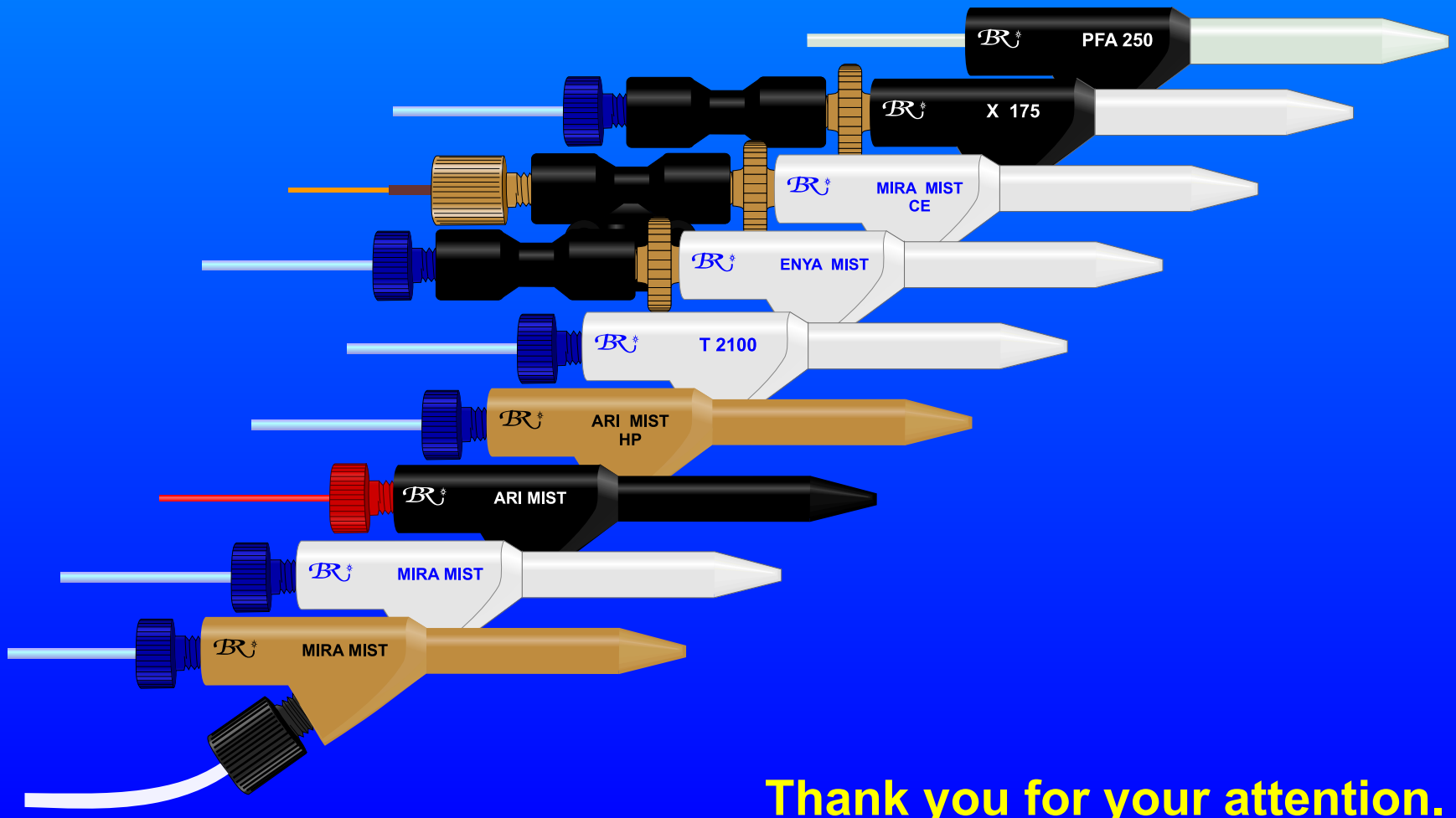

Thank you for your attention.