Present at the Creation:
The 50-Year Evolution of Environmental Instrumentation and Monitoring

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Phenomenex, Inc.

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Introduction

- **The *50-year* evolution? What was I thinking?**
  - An impossible task
  - How can you cover such a topic in 45 minutes?
- **I decided to focus on my personal half-century journey**
  - What I did
  - What I saw
  - What I learned
- **Hopefully, I can share some useful knowledge and insights**
- **Content warning!**
  - This presentation is going to be more philosophical than technical
  - Don’t worry: lots of good technical stuff coming over the next three weeks

My Theme and Questions

- **Where were we 50 years ago?**
  - What tools did we have?
  - What did we know?
  - What didn't we know?
- **And, through the next five decades:**
  - What events and forces drove the environmental monitoring?
  - What knowledge was gained?
  - And, where are we now?
- **Can this history tell us anything about what's coming next?**
- **What does this mean for you and your professional journey?**
  - What about <u>your</u> "50 Years"?

Prologue: My Journey Began in Iowa ……

PhD in Analytical Chemistry, Iowa State University, 1969

My Thesis

SULFOXIDES AS SOLVENT EXTRACTION REAGENTS FOR THE

ANALYTICAL SEPARATION OF METAL IONS

by

David Colin Kennedy

An Abstract of

A Dissertation Submitted to the

Graduate Faculty in Partial Fulfillment of

The Requirements for the Degree of

DOCTOR OF PHILOSOPHY

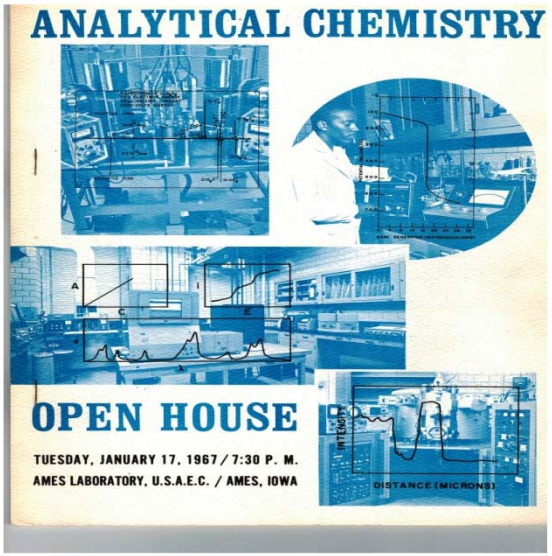
My Lab in Grad School

(Things were much simpler then)

Actually, It Wasn't *Quite* that Primitive

We had really cool 1960s Analytical Gear

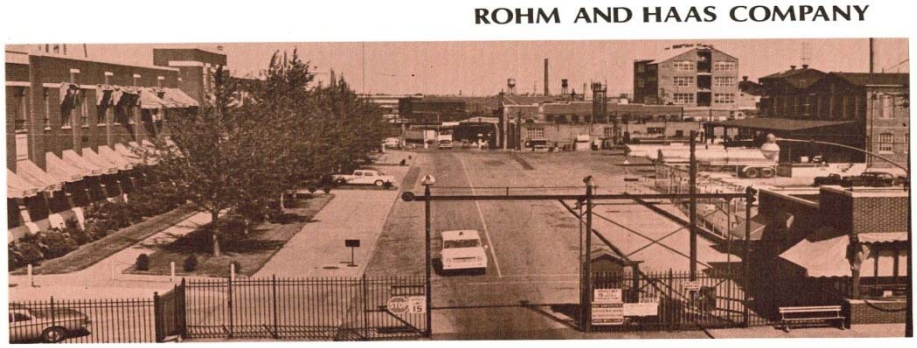
(Mostly with vacuum tubes)



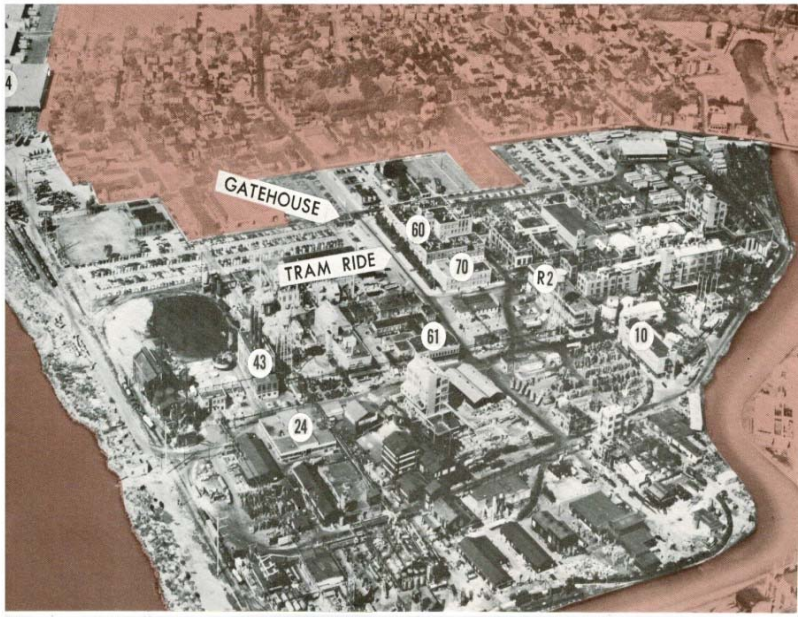
And properly Geeky Chemists

But, also a noticeable lack of Diversity

Then, my First Professional Job: Rohm and Haas Company Bridesburg Plant, Philadelphia, PA. May, 1969



- **Group Leader: Ion Exchange Product Development**
  - New ion exchange Resins
  - New Polymeric Adsorbents (XAD)
- **Applications for**
  - High purity water (for semiconductors)
  - Uranium purification (Cold War specialty)
  - Pharmaceutical processing (Premarin)
- **Environmental Applications?**
  - Those weren't an actual Thing yet
  - (But you could see it and smell it)



But Then, Something Dramatic Happened!

- **June, 1969: The Cuyahoga River Fire in Cleveland, Ohio shocked and galvanized the nation**

This event forced the public to focus on how bad environmental pollution really was

- **It helped to crystallize the Political Will that launched the modern environmental legislative movement**

So, How Bad Was It Back Then?

- It's hard to imagine how bad industrial pollution was back in the day

Hazardous Waste

Source Emissions

Wastewater

- Things have improved a lot in the last 50 years –
- Thanks to **Environmental Legislation** - --beginning in the 1970s

The 1970s: The First Environmental Decade

EPA was established on December 2, 1970 and several critical Legislative Drivers followed during the decade

CAA 1970

CWA 1972

CDWA 1974

RCRA 1976

These Legislative Landmarks created an major industry

And, thus did the "Environment" became a Business Opportunity

The "Environmental Business" also Caught Me Up

- **June, 1970: Rohm and Haas created a new business unit**
  - I was chosen to run the new Pollution Control Development Lab
  - Product and process development (not analytical chemistry)
  - Team of polymer chemists and chemical engineers
  - Ion exchange and adsorption treatment processes for water and air pollution
- **Developed treatment processes for:**
  - **Lead in gasoline**
  - **Dyes in wastewater**
  - **DDT in wastewater**
  - **Very interesting stuff**
    - But, I really missed analytical chemistry

Then, in November of 1973……..

- I spied a tiny ad in C & E News

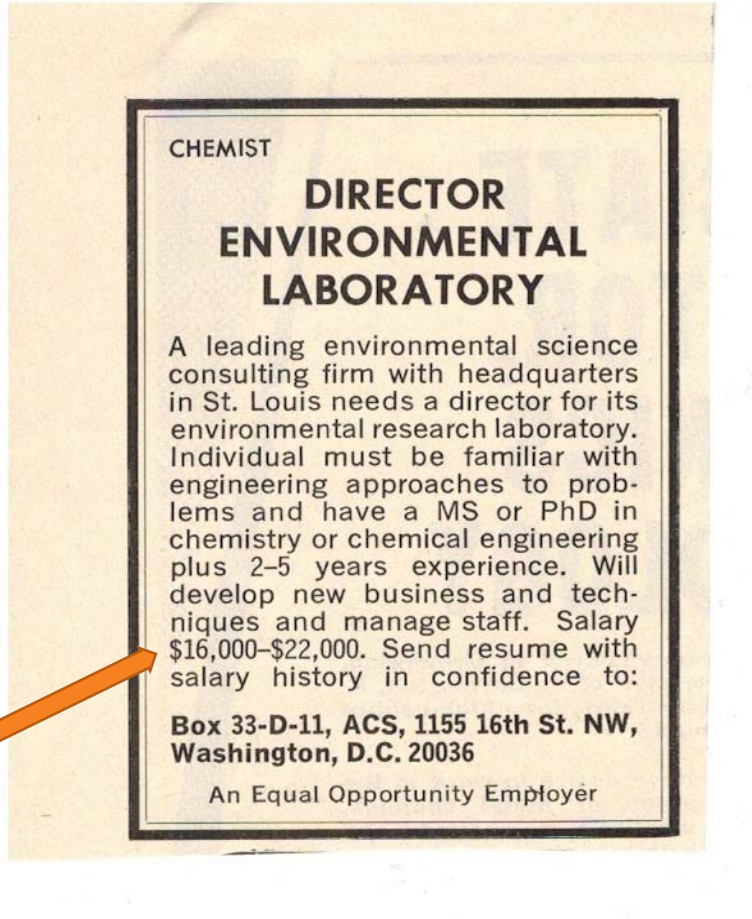
- RETA, a consulting firm in St. Louis, MO wanted a someone to direct a new environmental research laboratory!

- They really meant a "Commercial Environmental Testing Laboratory", but in 1973 that wasn't a thing yet

- First I was intrigued; then I was hooked

So, off to St. Louis I went……

(Check out that salary!)



CHEMIST

DIRECTOR ENVIRONMENTAL LABORATORY

A leading environmental science consulting firm with headquarters in St. Louis needs a director for its environmental research laboratory. Individual must be familiar with engineering approaches to problems and have a MS or PhD in chemistry or chemical engineering plus 2–5 years experience. Will develop new business and techniques and manage staff. Salary $16,000–$22,000. Send resume with salary history in confidence to:

Box 33-D-11, ACS, 1155 16th St. NW, Washington, D.C. 20036

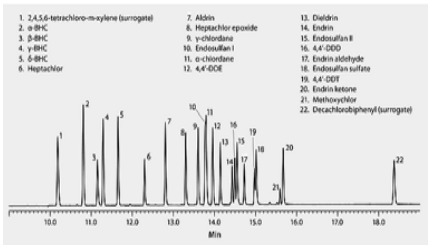
An Equal Opportunity Employer

As RETA Laboratory Director

- **Our business focus**
  - Industrial wastewater treatment
  - Environmental assessment
  - Water quality testing
- **My beginning Tool Box**
  - Wet chemistry for BOD, COD, SS, pH
  - Spectrophotometry for anions
  - Flame AA for metals
- **We quickly added**
  - A gas chromatograph with FID
  - Graphite Furnace AA for refractory metals.
- **Some major differences from today**
  - Very low **productivity**
  - Poorly designed quality systems
  - Little standard analytical methodology (with a lot of improvising)
  - Analytical services were billed on time and materials, not unit prices!
    (Just like a Lawyer!)

Through the Growing 1970s……..

- **New environmental legislation increased testing demand**
- **Environmental projects become more complex**
  - We helped develop the EPA 600 series methods
  - Advanced wastewater treatment processes
  - Industrial source testing and regional air quality



- **Business growth was good**
  - Added multiple GC systems and detectors
  - Extensive metal analysis capabilities
  - Built out a new laboratory building

- **GCMS was starting to get attention**
  - But in 1979, I couldn't justify the cost

The Blazing 1980s!

- **December, 1980 CERCLA (Superfund) became law**
  - Stimulating explosive growth in laboratory testing
- **Continued to grow the RETA laboratory**
  - Added our first GCMS for priority pollutant testing
  - HPLC for explosives and munitions
- **Then, dioxin happened**
  - Extensive TCCD contamination discovered in Eastern Missouri
  - December, 1982: the Times Beach disaster (we found it first)
  - Expanded our GCMS capability for rapid turnaround site investigation
- **In 1986, founded a new environmental laboratory company**
  - Designed and built a new 27,000 sq ft laboratory facility
  - Focused on on dioxin, military waste, radiochemistry
  - Business was booming
- **But, there were clouds on the horizon in the late 1980s**
  - High demand for laboratory services began to create industry overcapacity
  - Fixed unit pricing set the stage for intense price competition
  - Weak quality systems created the potential for data fraud

The 1990s Testing Market Collapse – and a Career Transition

- **In 1990, joined Pace Laboratories to help grow the national network**
- **Between 1990 and 1995, Pace grew rapidly**
  - Multiple lab acquisitions across the country
  - Sales increased from $20M to $80M
- **But, by 1995 testing industry overcapacity was causing chaos**
  - Intense price competition lead to widespread lab closures and bankruptcies
  - Pace was forced to downsize and I left the company in late 1995
  - (However, Pace successfully reorganized in 1996 and went on to become the market leading company we see today)
- **In late 1996 I received a call from a headhunter**
  - Tekmar Dohrmann (now Teledyne Tekmar) was looking for a new CEO
  - I knew the company as an environmental lab customer (P&T, Headspace,TOC & TOX)
  - I had no experience in manufacturing, but I was offered the job anyway
- **So, in early 1997 I began an entirely different environmental career**

Segue: Life on the *Other* Side of the Cash Register

- **Major transition**
  - From operating environmental laboratories (instrument-buying customer)
  - To designing, manufacturing and selling instrumentation (environmental lab vendor)
  - A big shift in thinking and doing
- **Fortunately, there is a unifying principle**
  - Both labs and vendors should want the same thing:
  - Namely, to make the laboratory very successful
  - However, getting together on this is harder than you might think
- **"Instrument Companies" had a historical blind spot:**
  - Falling in love with your technology and the marvelous things it can do
  - Assuming that you know exactly what the customer needs and wants
  - Becoming frustrated when your customers fail to see what's "good for them"
- **As a former customer, I was determined to bridge that gap**
  - How to identify and serve customers on their terms
- **Grew Tekmar globally through the rest of the 90s**

The Remainder of the 2000s

- **Operated Tekmar Dohrmann from 1997 - 2003**
- **In 2003, the company was sold to Teledyne Technologies**
  - And became today's Teledyne Tekmar
  - I continued on as VP and General Manager
- **In 2005, I was transferred to run Teledyne Isco in Lincoln, NE**
  - Much larger company with a diverse environmental product base
    - Wastewater samplers
    - Open channel flow meters
    - Liquid chromatography instruments : primarily flash chromatography
  - Focus on environmental monitoring and pharmaceutical R&D
- **Grew the company globally through the rest of the 2000s**
  - But, at the end of 2009, I had to retire from Teledyne Technologies
- **But, I wanted to "stay in the business", so I started looking for my fourth environmental career.**

Finally - the 2010s (Stay awake! We're almost home)

- **So, in early 2010, I joined Phenomenex**
  - As Environmental Business Development Manager
  - It's a Marketing position: what do our customers really need?
- **Phenomenex is a laboratory consumables company**
  - HPLC and GC columns, sample preparation (SPE/QuEChERs) and accessories
  - Technical innovations: core shell morphology, new LC and GC phases, sample prep
  - Continual new product and application advances
- **The consumables business: quite different from instrumentation**
  - Selling consumable laboratory supplies, not capital equipment
  - Must support all instrumentation platforms, not just your own box
  - Goal of creating superior applications and work flows
- **It's been a great place to work and interact with lab customers**
  - I'm glad to offer my experience and perspective and try not to bore people too much

That's the End of the Historical Documentary

Now, let's take a deep breath and
try to extract some broader meaning……..

What Was Learned?

- **I had the advantage of a highly varied environmental career**
- **Four separate careers, actually:**
  - Pollution control process development
  - Environmental testing laboratory operation
  - Environmental laboratory instrument manufacturing
  - Environmental laboratory consumables development
- **I'm going to try extract a few nuggets from all this activity**
  - To create some perspective on the last half-century
  - And maybe some sense of what to expect in the next
- **But, first, lets briefly recap the incredible advance of analytical measurement technology**

50 Years of Growth in Measurement Technology

1970s UV/Vis, GC/FID

FAA

1980s GFAA, GC/MS

GC/ECD

1990s HPLC, ICP/OES

LIMS

2000s LC/MS, ICP/MS

UHPLC

2010s LC-MS/MS

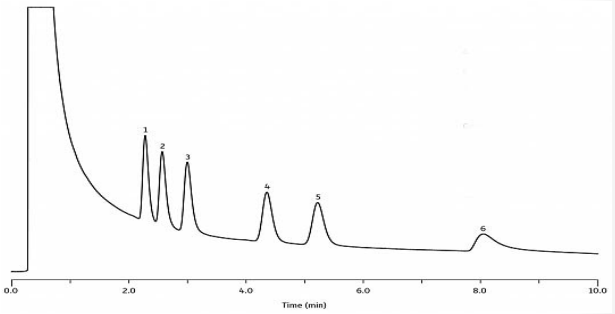
GC-MS/MS

and even No-LC-MS/MS

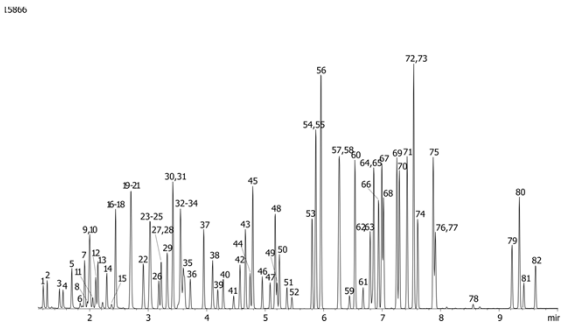
And, growth wasn't just limited to instrumentation…….

Incredible Advances in Chromatography

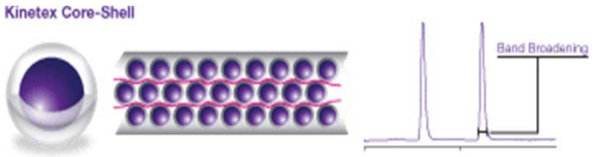
1970s Packed Column GC "Humpo-gram"

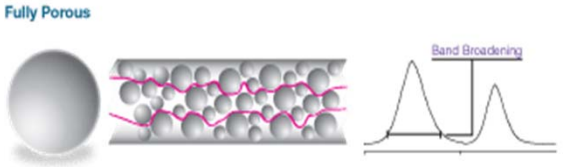


Capillary GC

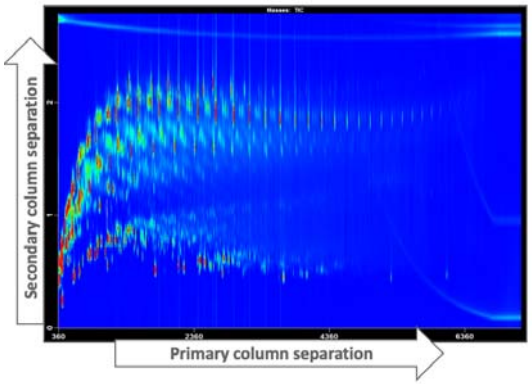


Core Shell LC & UHPLC

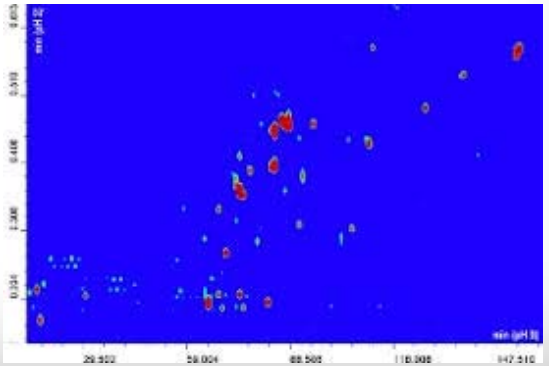




GC x GC

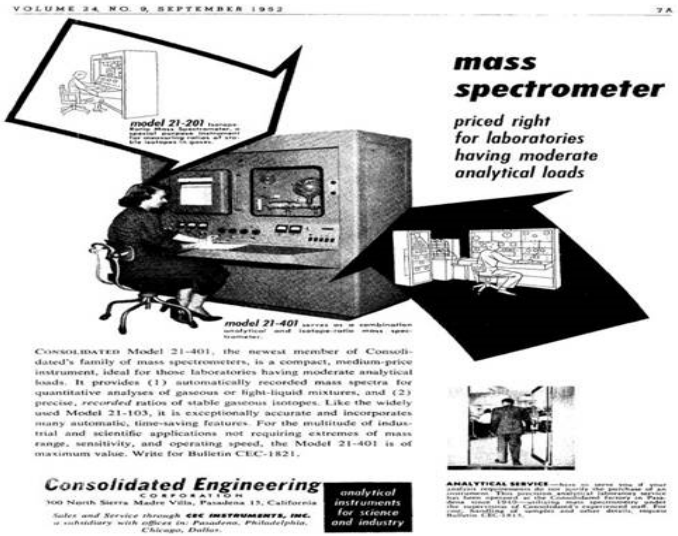


LC x LC



And, Beyond Incredible Gains in Mass Analysis

Your Grandmother's
mid-century mass spectrometer



Has evolved into

A 2020 MS/MS with acoustic sample introduction:
3 samples/second

Is This as Far as We can Go?

Does anyone think we have reached the end of technical progress?

And, what Environmental Progress Came out of all These Technology Advances?

I’m going to select just 4 examples

1. Huge Environmental Testing Productivity Gains

Analytical Principle: Vis-Spectrophotometry

System integration: None; all functions independent

Informatics: Pen and ink, slide rule, telephone

Automation: Chemist

***1970 Price**: $300.00*

***Productivity**: 1X*

Analytical principle: ICP-Mass spectrometry

System integration: Integrated analysis, data processing, communication

Informatics: Acquisition software, LIMS, LAN communication, cloud data storage

Automation: Technician + autosampler

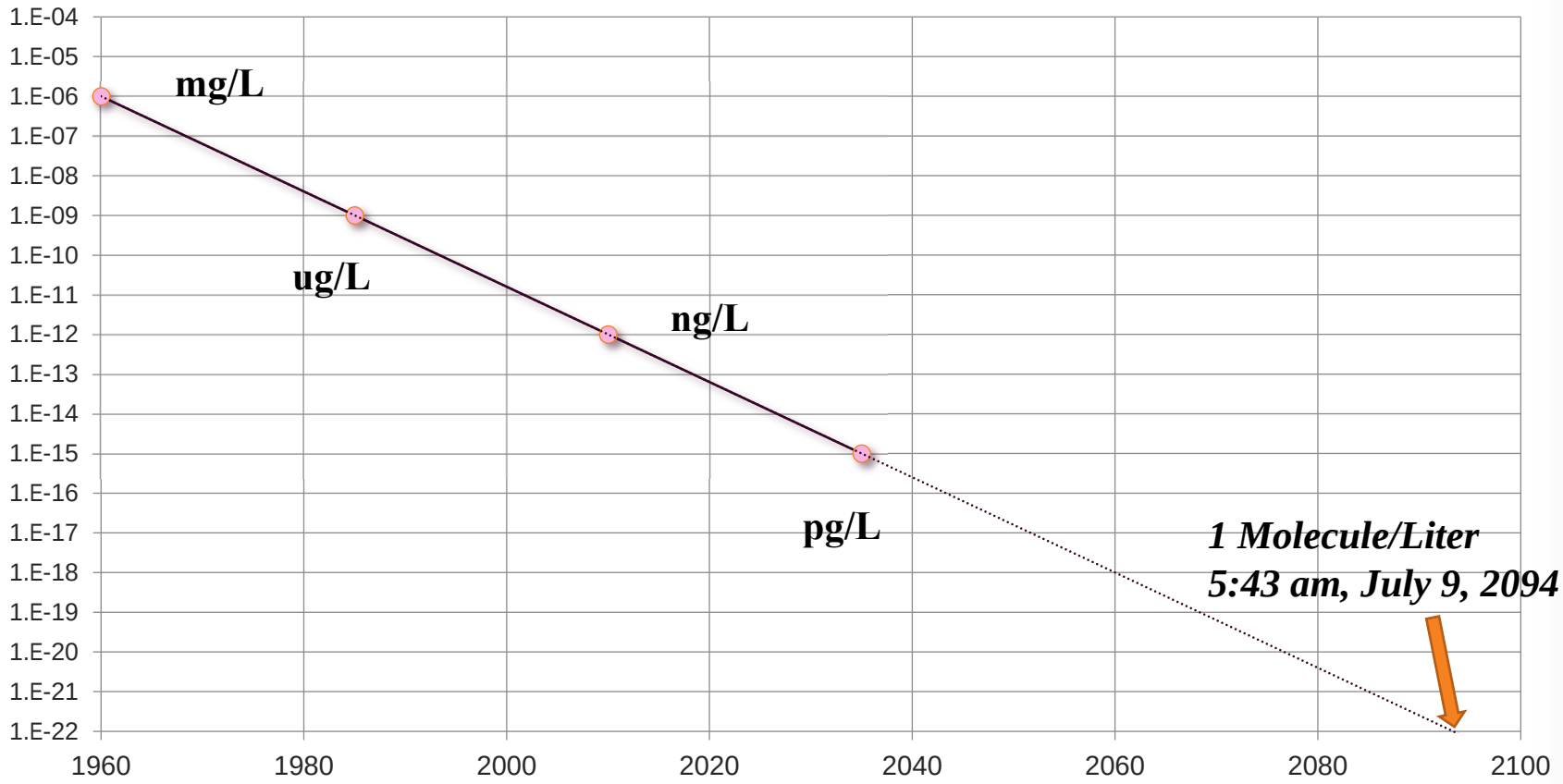
***Price** $175,000 ($26,000 in 1970dollars)*

***Productivity**: 10,000X (115X gain/$ capital)*

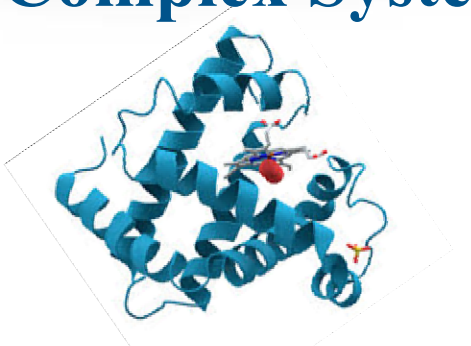
(>1000X gain/$ labor)

2. Lower, Lower and Even Lower Detection Limits

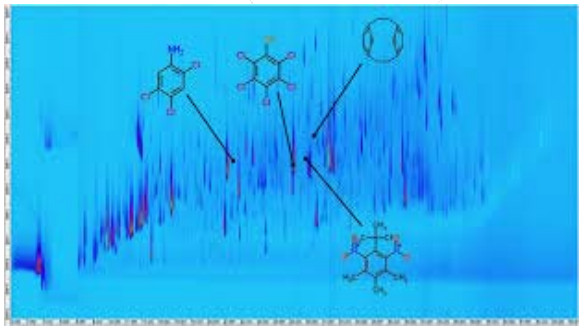
A Short History of Detection Limits *(Courtesy of Andy Eaton)*



3.The Ability to Better Understand Complex Systems

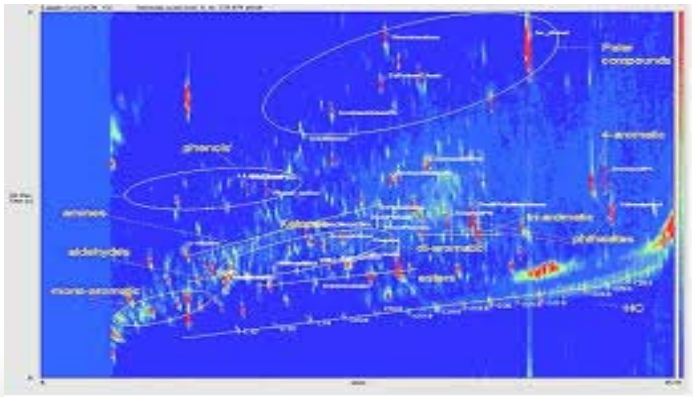


- **Many health effects strongly correlate to molecular structure**
  - **Very low levels of biologically active molecules can cause extreme effects**



- **The environmental world is <u>extremely</u> complex and messy at the pg/L level**

- **Accurately measure low levels of specific molecules in complex matrices**



➢ **Understand and mitigate adverse environmental and health effects**

4. Discovery of "New" Environmental Problems

- **As analytical technology has advanced through the decades……**
- With better tools, new environmental problems have continually emerged

Pre-1970. BOD vs. COD: ***Biodegradable vs. refractory contaminants (surrogates)***

1970s. GC-ECD: ***Chlorinated pesticides, herbicides & PCBs elucidated***

1980s. GC-MS: ***VOA and SVOA pollutants identified and monitored***

1990s. LC-MS: ***Hydrophilic pollutants (PPCPs)identified and monitored***

2000s. LC-MS/MS: ***The widespread distribution of PFAS recognized***

2010s. GC-MS/MS: ***Wider identification of Persistent Organic Pollutants (POPs)***

- **New environmental problems just keep popping up out of nowhere.**

  Why is that?

Based upon these Trends

What Can We Expect over the Next 50 Years?

Obviously, more of the same –

But what, specifically?

So, What About Those Next 50 Years?

- I politely but firmly decline to answer that question
- I've tried to do it several times before at NEMC
  - After a couple of years of progress, you just look silly

- It's going to be <u>your</u> job to determine that future
  - By moving the great environmental discovery and monitoring enterprise forward

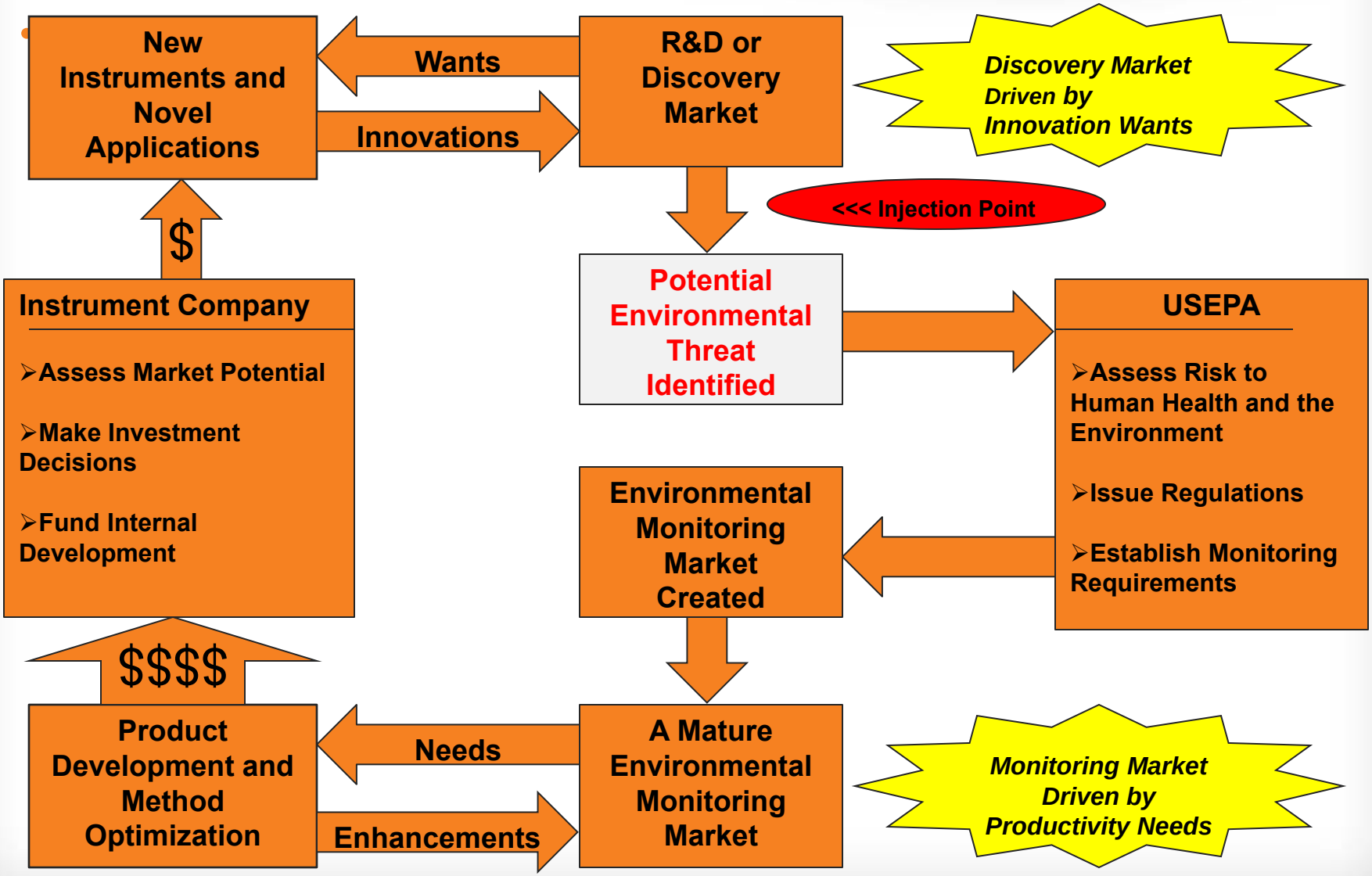
- However, I will offer you three important things that I've learned from my 50 years in environmental monitoring

Maybe this will help you figure it out……

1. The Cycle of Environmental Innovation

- **Technology advances have allowed us to discover so much more about our environment**
- Where did all this incredible innovation come from?
- Did it just "happen"? Was it "inevitable"?
- **It turns out, there is a dynamic relationship between:**
  - Government – Laws and regulations
  - R&D – Innovation and discovery
  - The monitoring Market - Widespread application of testing
- **And, this interaction is cyclical and self-sustaining**
- **I once gave an entire presentation about this phenomenon**
  - The following is a visual depiction of this cycle of innovation

1. The Cycle of Environmental Innovation



1. The Cycle of Innovation – The Important Parts

- **Innovative R&D instrumentation are the "injection point"**
  - They establish the existence of "*New*" environmental threats
  - (That were actually there for 50 years, but we didn't know it - like PFAS)
- **Government laws and regulations are the cycle drivers**
  - They arise out of societal threat concerns and political movements
  - They are mandates for widespread investigation and remedial action
  - They create the large, routine environmental monitoring market
- **Mass monitoring generates profits for the testing industry**
  - Which allows the industry to invest heavily in R&D
- **This sustains a healthy R&D enterprise**
  - To creates innovative new R&D instrumentation and uncover new threats
  - And so forth……..
- **This dynamic cycle has existed for the past 50 years**
  - And it should continue for the next 50 years (So please don't mess it up!)

2. Learn to Listen to the Dog who Doesn't Bark

- **"The Adventure of Silver Blaze" is my favorite Sherlock Holmes story**
- **A famous race horse disappears from its stable. First, Holmes and Watson are brought in to investigate; then a Scotland Yard Detective shows up.**
- **Dialogue**
  - Detective: "Is there any other point that you would wish to call to my attention?"
  - Holmes: "*To the curious incident of the dog in the night time.*"
  - Detective: "The dog did nothing in the night time."
  - Holmes: "*That was the curious incident*."

  (Deduction: Since the dog guarding the stable didn't bark, the thief must have been an insider)
- **The Lesson? *The absence of evidence is often evidence itself***
- **What does this have to do with environmental monitoring?**
  - This is a metaphor for having missed something that is very obvious in retrospect
  - Another way of saying: "You don't know what you don't know"

2. Learn to Listen to the Dog who Doesn't Bark

- **So, over the past 50 years:**
  - How many people were ingesting pharmaceuticals and then going to the bathroom? Where did we (including me) think that stuff was going?
  - How many tons of PFAS were widely dispersed in air base fire suppression foams? And, where did we think that stuff was going?
- **Sure, it took time for modern analytical tools to evolve to provide the hard *evidence*, but that just proves the point**
  - That we weren't seeing these compounds in the environment was evidence in itself
  - They should be out there; we should be seeing them; but we aren't
  - And, the fact that we didn't see them should have been deeply troubling.
- **So, going forward, my advice for you:**
  - We all have blind spots
  - Don't fall in love with your current box of analytical tools
  - ➢ Strive to think more deeply about what we are *not* seeing
- **There are still plenty of non-barking dogs out there**
  - Let's try to find the next ones sooner than we did in the past

3. The Value of Greater Diversity and Inclusivity

- **So, remember that picture of my grad school research group?**
  - We all loved chemistry
  - We all had successful careers
  - But it wasn't a very diverse group
  - Certainly not compared to today

- **It makes me wonder**
  - If the profession had been more inclusive then…….
  - How many other women and minorities might have participated in the environmental enterprise?
  - What additional contributions could they have made over the last 50 years?
- **STEM participation is much more diverse today**
  - I've observed a higher level of energy and focus
  - I've experienced the benefit of broader perspective and varied experience
- **I think this has also been a significant historical development factor**
  - It's helped accelerate the growth of environmental innovation and discovery
  - It's making the "Cycle of Innovation" work more productively
- **So, let's make sure that this trend continues**

In Conclusion: About those Next 50 Years?

- **It's up to you to figure it out**
  - So, good luck with that
  - Please let me know how things work out
  - I'll leave you my forwarding address
- **My sincere belief:**
  - You are all very fortunate to be living in these exciting times
  - Be thankful to be a part of this great scientific/societal adventure
- **And now, go bravely forward into the next 50 years!**
  - Or, at least just enjoy the rest of the show over the next three weeks!

QUESTIONS?