RUNNING AN ION BEAM ANALYSIS LABORATORY WITH UNDERGRADS: LESSONS FROM YEAR TWO AT HOPE COLLEGE

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Holland, MI, USA

In 2004 a NEC 5-SDH Pelletron, with a standard Aplhatross ion source and a nuclear microprobe, was installed at Hope College. A new facility report was presented last year at SNEAP/HIAT after our first year of operation, and this year we continue to run a vigorous and varied experimental program almost entirely with undergraduate students. We have two faculty members, one technician and 22 undergraduates trained to operate the facility to date, although over a dozen other faculty/senior personnel collaborate with us on individual research projects. We have learned considerably more about reliable Alphatross and microprobe operation in our second year, only some details of which are printed in the operations manuals. We will share our insights into the facility maintenance and operation, and also present a broad spectrum of current research projects undertaken by undergraduates in the past year. These project range from geology, to limnology, to electrochemistry, to biochemistry, to solid state physics and forensic science. In terms of the ion beam analysis techniques available to our students, we are using PIXE, mPIXE, RBS and PESA routinely at the moment, and have been analyzing our results with commercially available software (GUPIXWin and SIMNRA). Because of the interdisciplinary nature of a primarily undergraduate research-intensive college, this IBA facility is ideally suited to the pursuit of imaginative interdisciplinary research that both attracts undergraduates and trains them well in modern data collection and analysis. One area we would like to develop further is establishing collaborations with other IBA facilities.

Questions: (The audio quality for this session was poor)

Jan Klug (Ruhr-Universität Bochum): Have you compared the results of your gel analysis with the standard method of analysing.

Peaslee: There are several things that we start with. One is a non-protein. So we must get 1.00 back because that is how many ions there are in myoglobin and we haven't actually achieved that because we didn't know our biochemistry well enough. Myyoglobin is not well enough bound up in the gel and comes out well before it gets to the accelerator. We have switched to cytochrome-C and we are pretty sure we can reach a standard with a known protein and at the same time we are developing our technique.

Larry Lamm (University of Notre Dame): With your PIXIE stuff you are certainly able to identify the various things you see. Were you able to get any quantitative measurements of those materials?

Peaslee: Yes. We get quantitative numbers, everything within about 10%

Our best operator was taken on as a freshman... It's a licencing to run the accelerator. We have three categories for the radiation safety test. Everybody who works anywhere within the machine must take a radiation safety quiz which means then they can sit and watch sample being run. Then there is the user who is not allowed to operate the machine, but is able to run samples and work on a project. So that person has the second seat. Then there is a trained operator who get trained by me or Paul, and then that student will be allowed to operate the machine as long as there is a second person on the floor. That is fairly strictly adhered to. We have had very few accidents; a vacuum excursion once or twice, but that is about it. It's very hard to operate the system wrong following a written set of instructions.

End of questions:

Running an Ion Beam Facility (NEC 5SDH) for Undergraduates:

Graham F. Peaslee

HOPE COLLEGE

October 19, 2006

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Outline

- Introduction –
  The Hope Ion Beam Analysis Lab
- Research Examples
  Lake sediment chemistry
  Metalloprotein Stoichiometry
- Two Potential Forensic Applications
- What we have learned…

Outline

- Introduction –

What we have…

- Research Examples

How we use it...

- Two Potential Forensic Applications

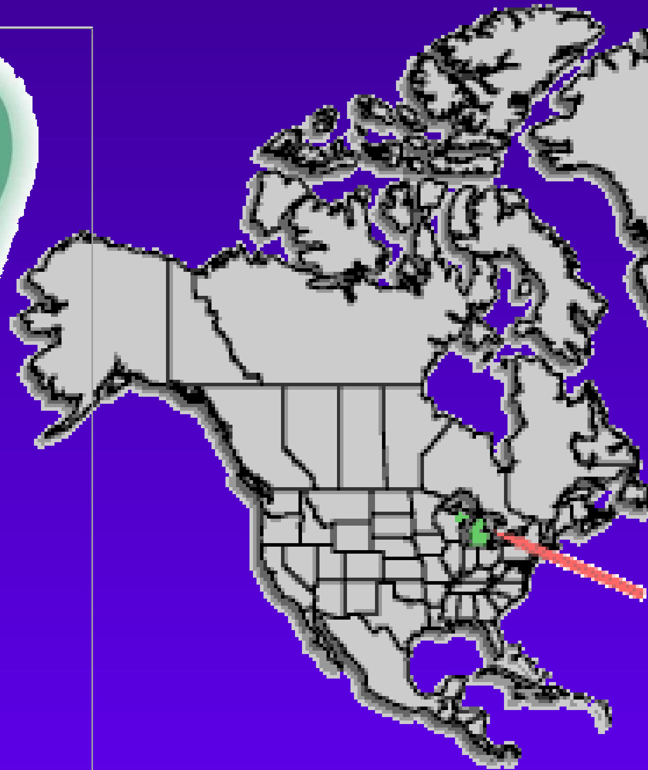
New ideas...

- What we have learned…

Why it matters...

Where is Hope?

3000 undergraduates



Holland, MI

Where is Hope?

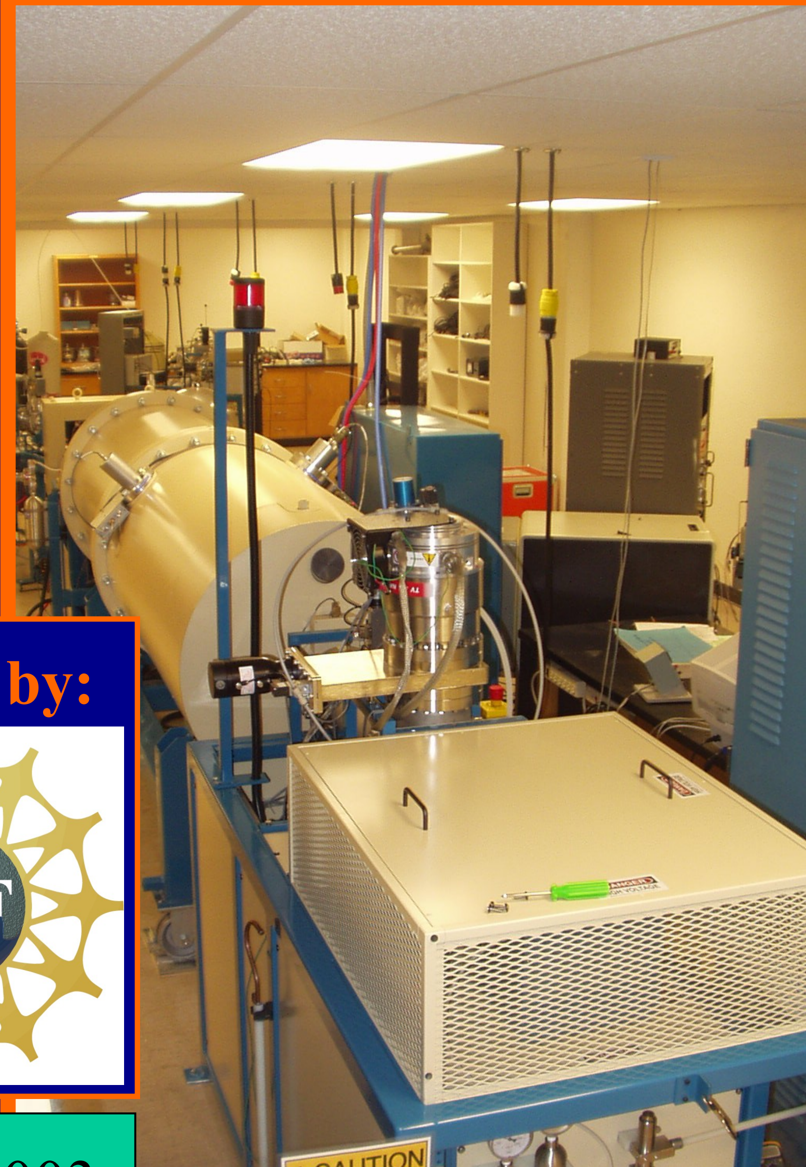
3000 undergraduates

6 REU sites:

- Biology
- Chemistry
- Mathematics
- Computer Science
- Physics & Engineering
- Geological & Environmental Sciences

>170 students last summer…

Hope College Ion Beam Analysis Laboratory

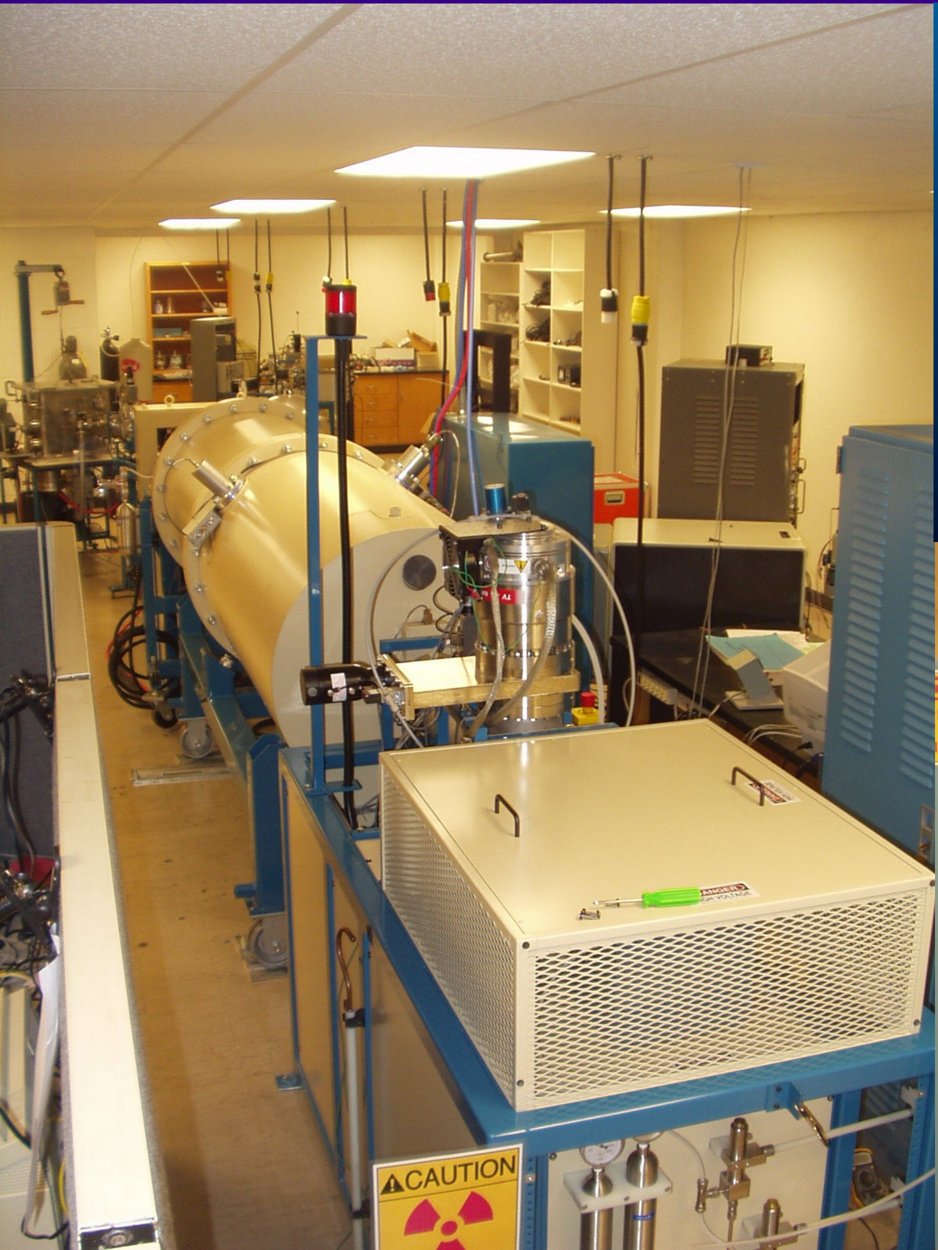


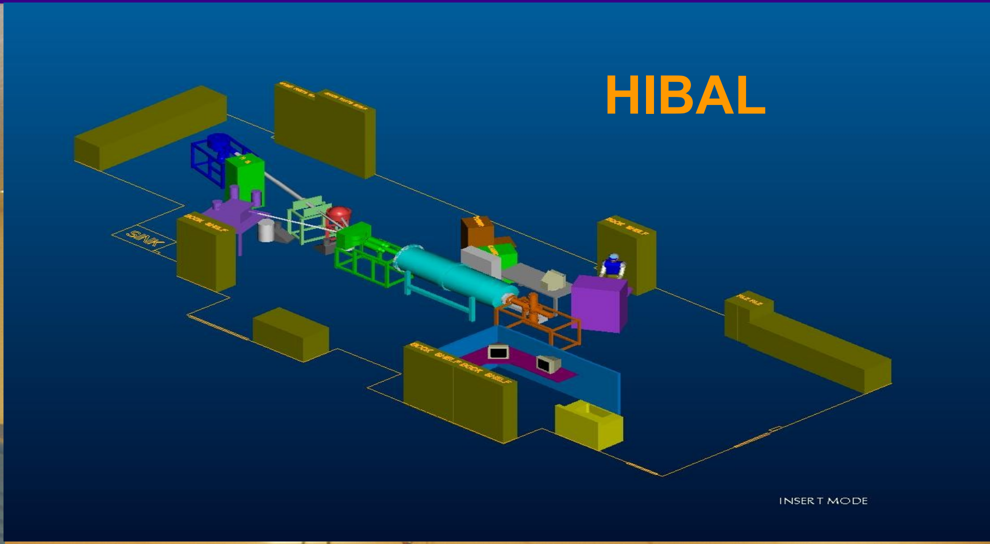
Funded by:

NSF

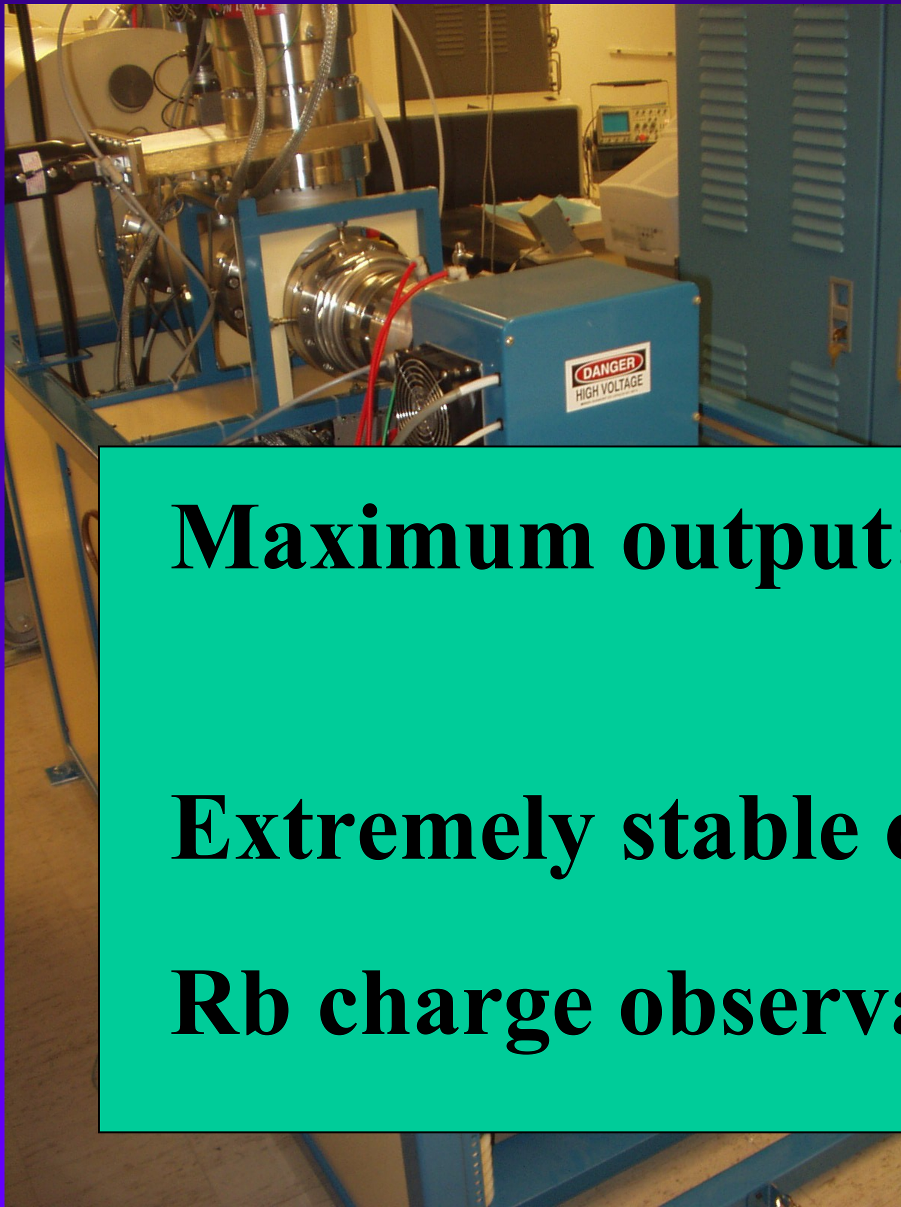
MRI - 2003

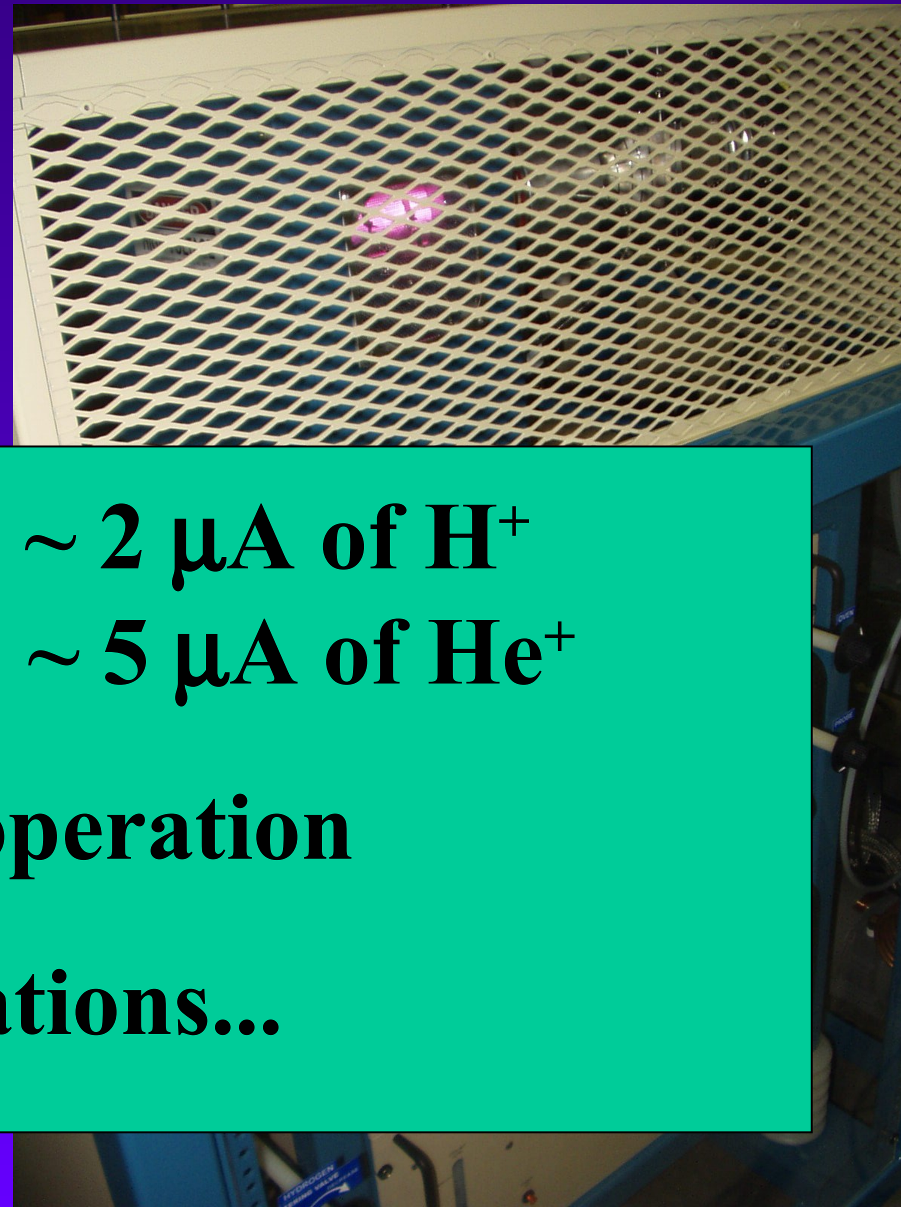
Our Configuration





"Standard" Alphatross Ion Source



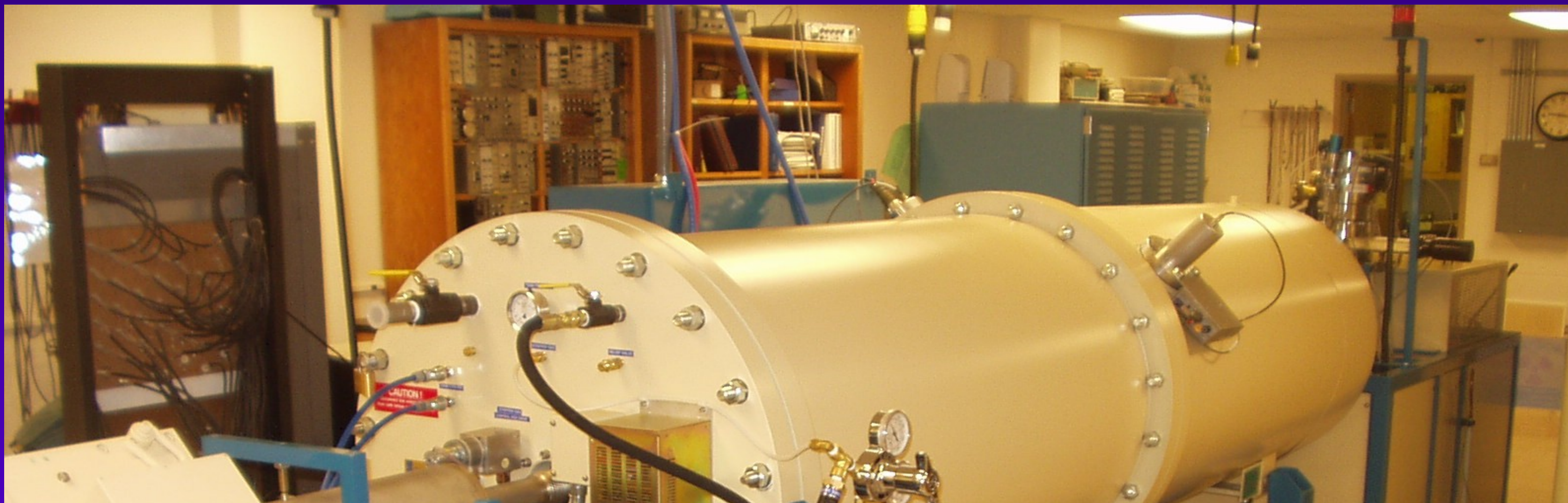


Maximum output: ~ 2 μA of H^+
~ 5 μA of He^+

Extremely stable operation

Rb charge observations...

5-SDH 1.7MV Tank



Split tank design: for installation

1.7 MV; 80 psi SF_6; no sparks…

No required tank openings to date…

Extra lead shielding option…<2mR/hr

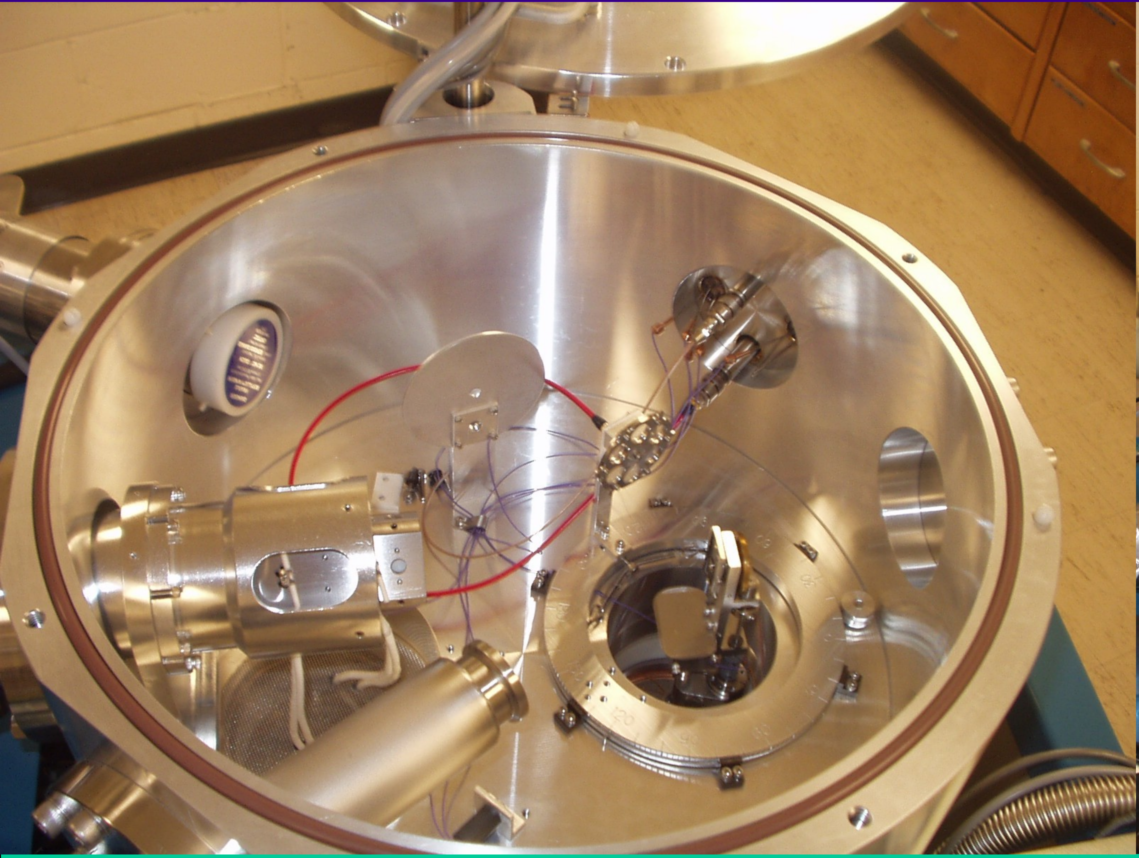
HE Focusing & Analyzing

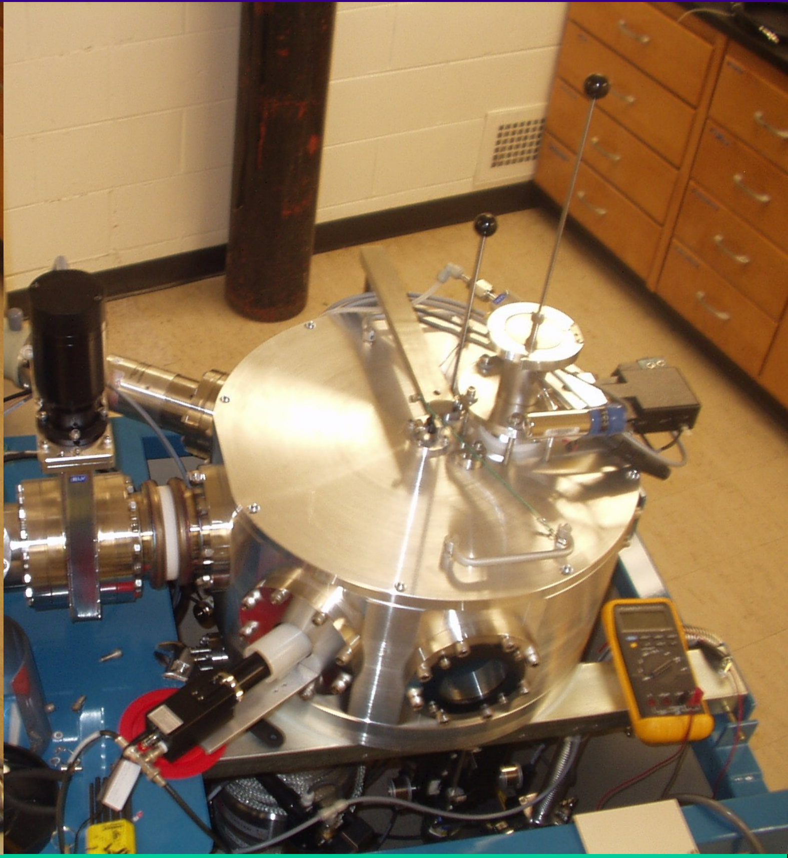
3 Varian 550 Turbo pumps

RC-43 Endstation & Microprobe

NEC microquads (quadrupole quadruplet) Sie & Ryan (1986)

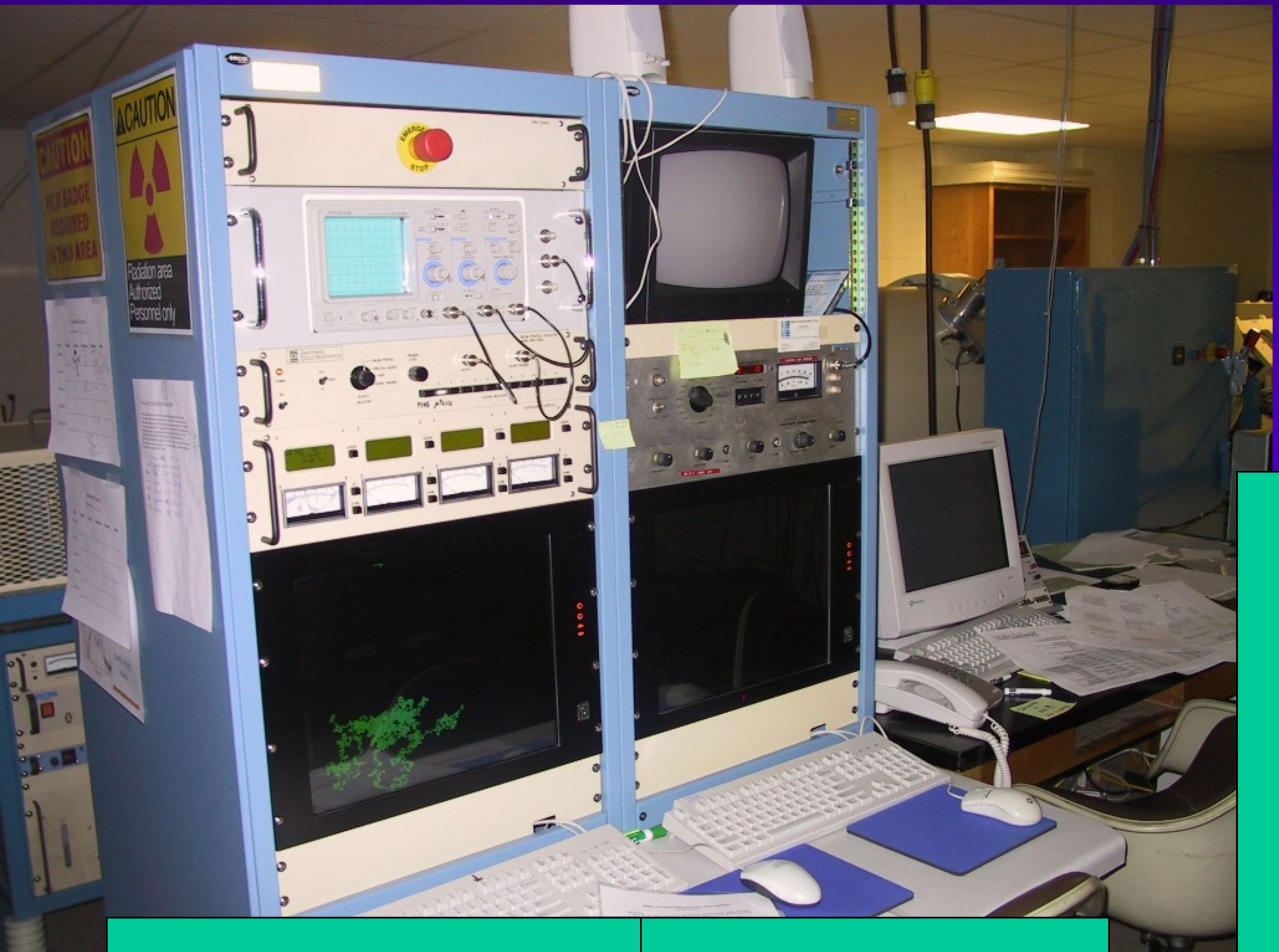
RC-43 Endstation & Microprobe





5-axis goniometer, CCD camera, sample vacuum interlock, separate control console

Control Consoles



Linux
AccelNET

Windows
RC43

Windows

CAMAC/
FPGA
DAQ
control

What have we done so far…

Beam Development & Training

Contaminated sediment PIXE

Paleontology PIXE

Gel Electrophoresis PESA

Sand Dune Mineralogy μPIXE

Electrochemical probe RBS

Solid State Physics RBS

Proprietary RBS

Glass & Paint Forensic PIXE

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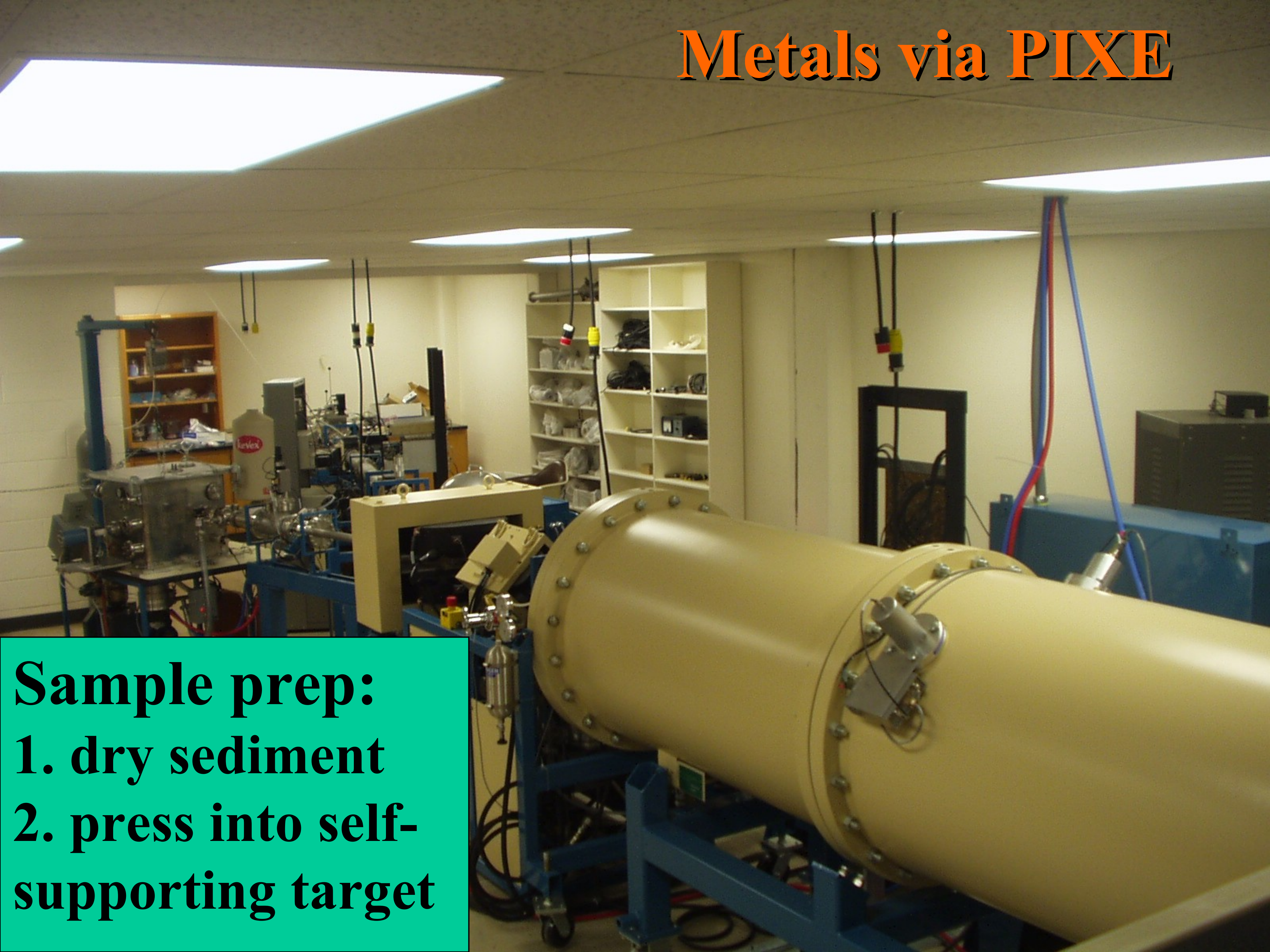
Trace Metal Analysis of Sediment...

Metals via ICP

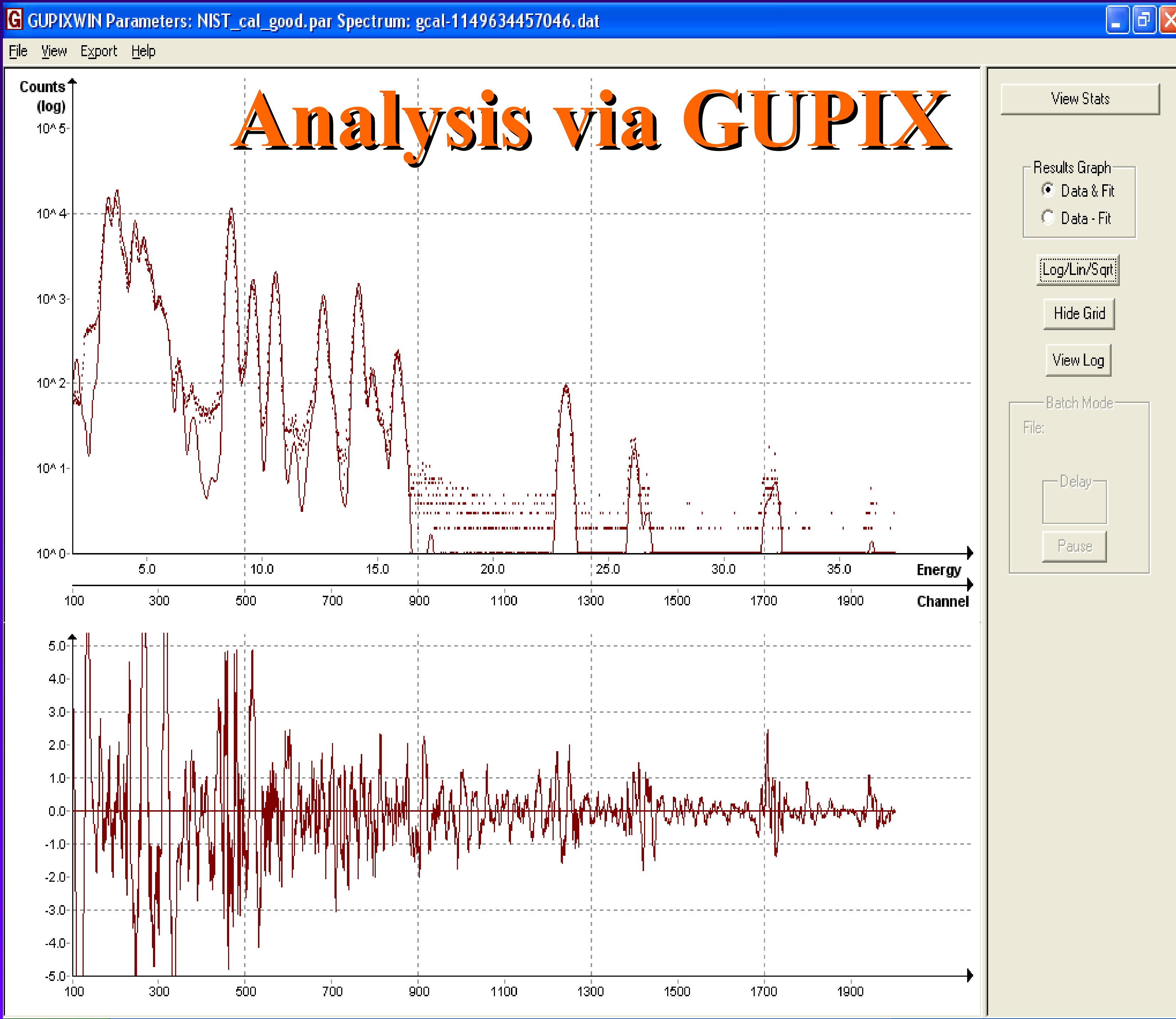
Metals via PIXE



Sample prep:

1. dry sediment
2. press into self-supporting target

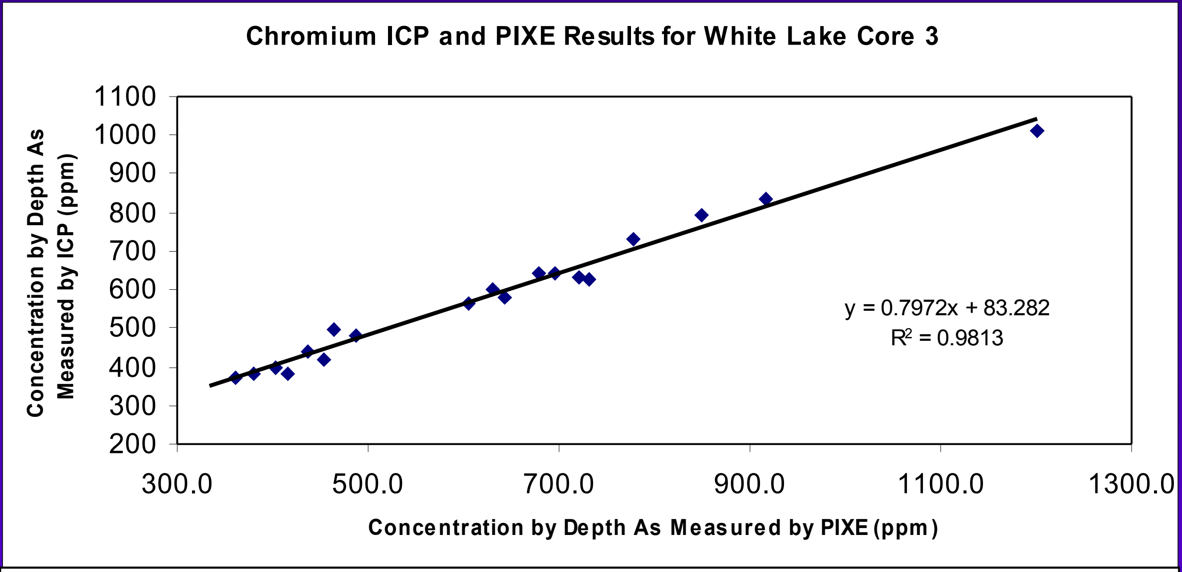
Analysis via GUPIX

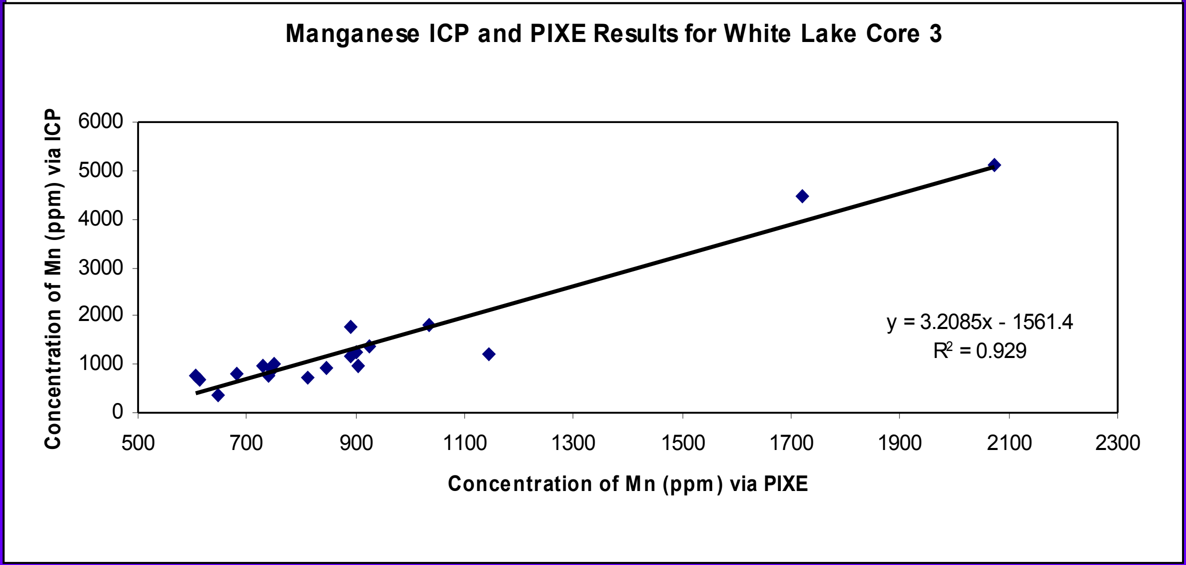


ICP vs. PIXE

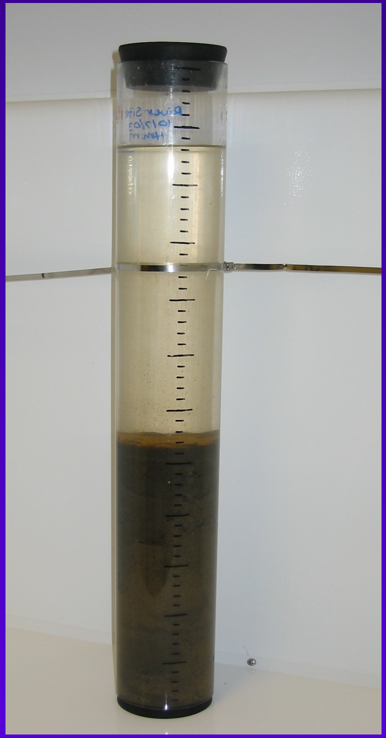
- **White Lake Sediment Core**
  - Quantitative, reproducible, non-destructive
  - Faster by a factor of ~3!

R. Bartlett & N. Hoogeveen



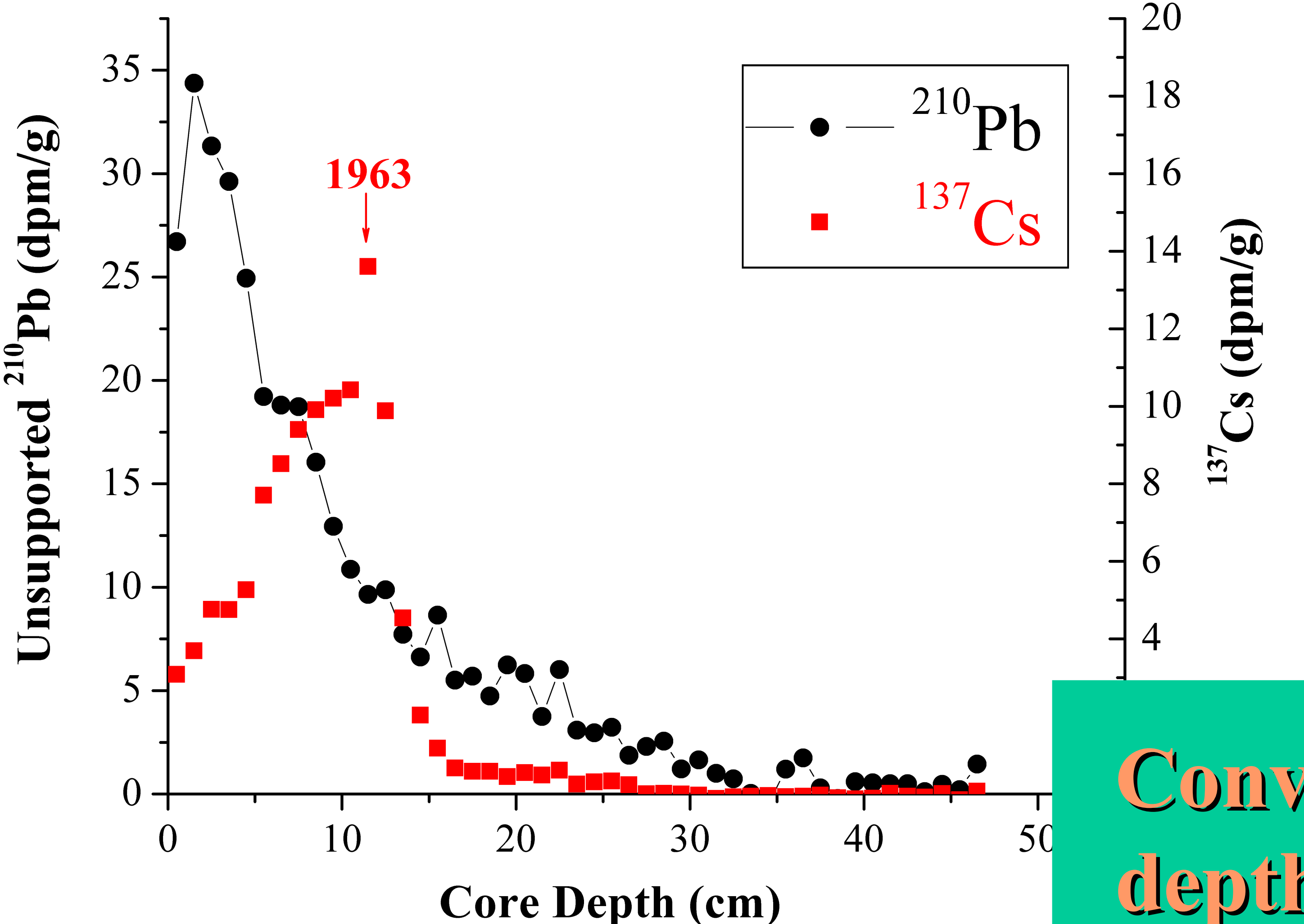


Lake Michigan Sediment



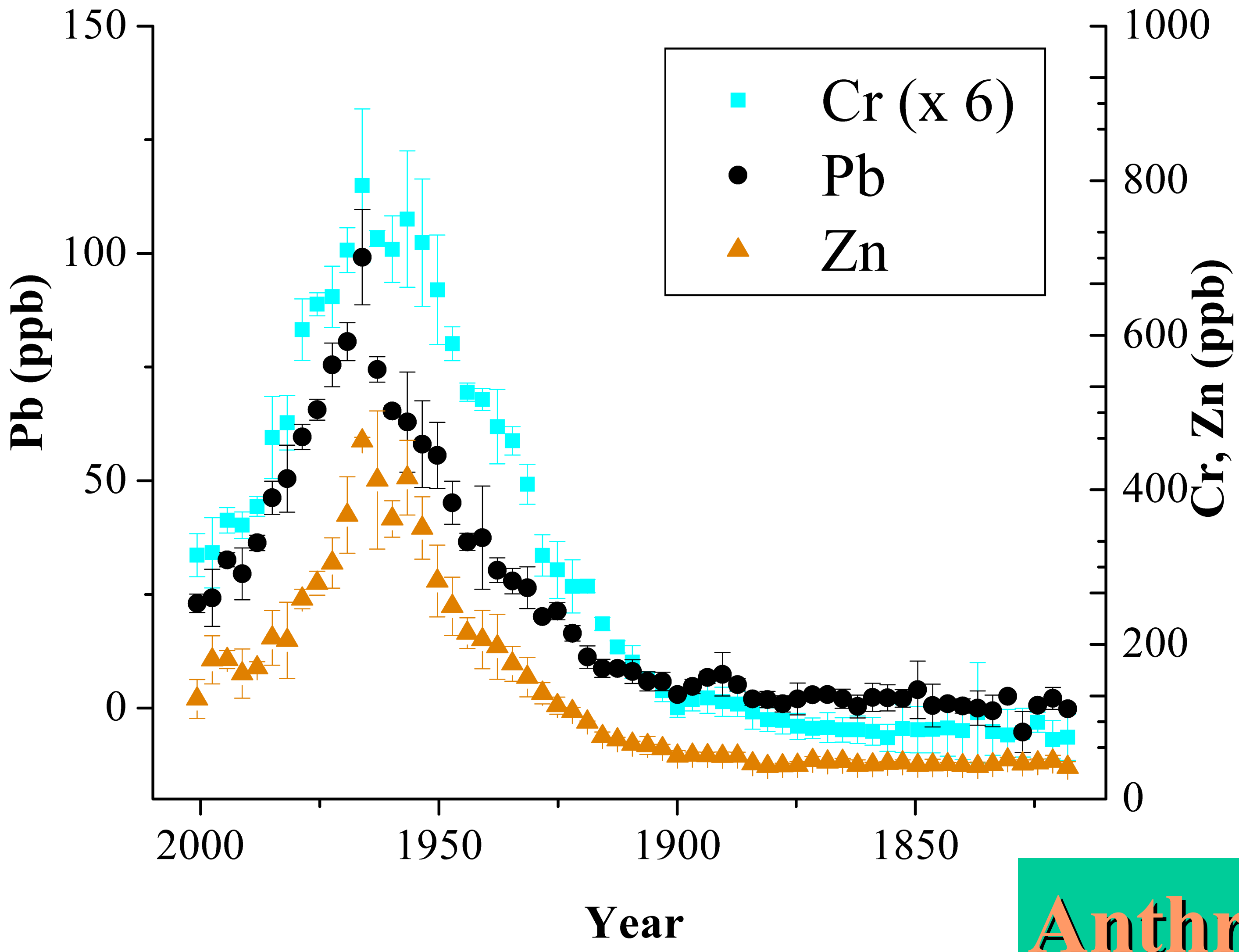
~13 km off Grand Haven
65m depth

Radiodating Lake Cores



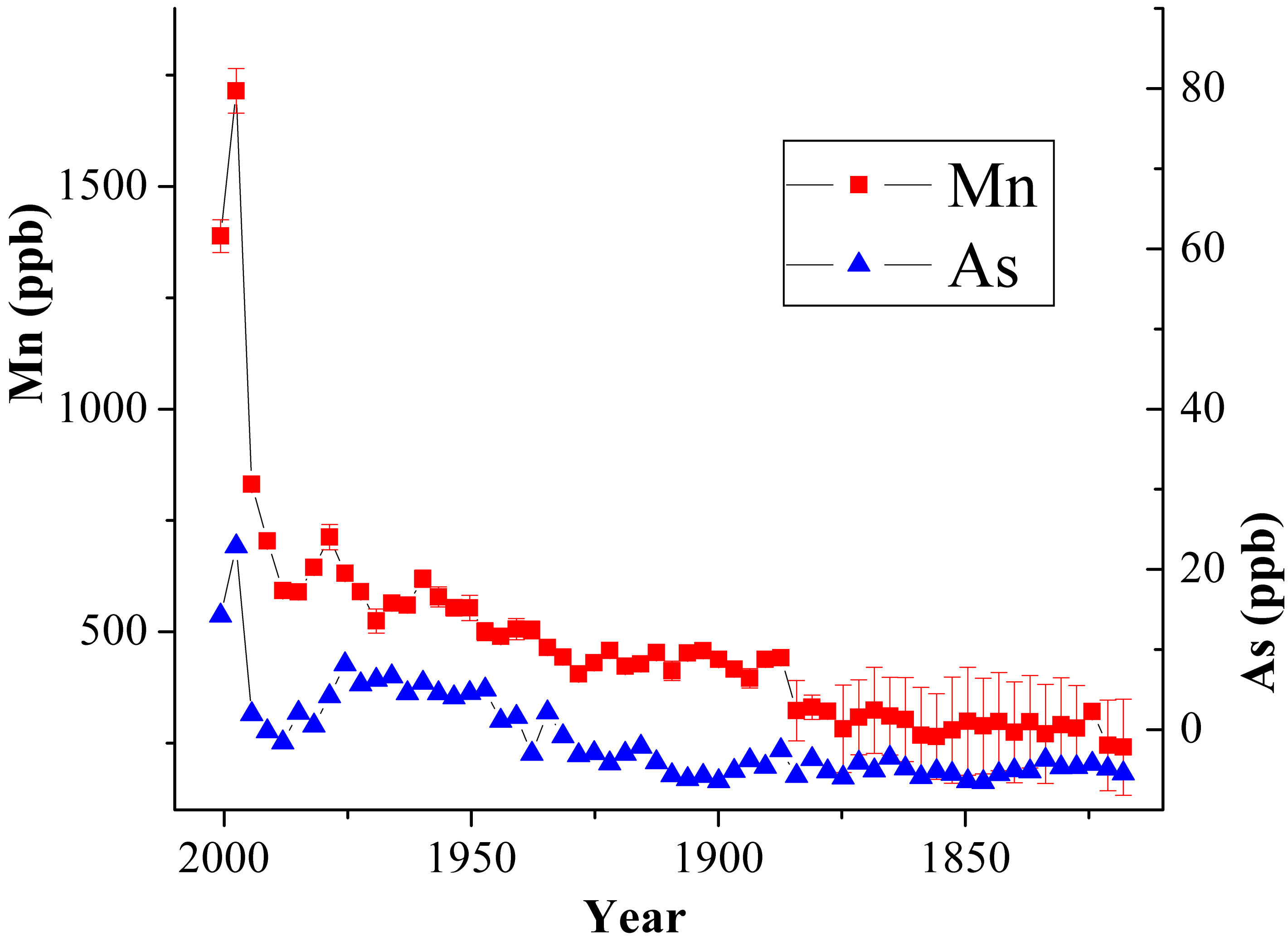
Convert core depth to year

Sediment Chemistry



Anthropogenic

Sediment Chemistry



New?

What have we done so far…

Beam Development & Training

Contaminated sediment PIXE

Paleontology PIXE

Gel Electrophoresis PESA

Sand Dune Mineralogy μPIXE

Electrochemical probe RBS

Solid State Physics RBS

Proprietary RBS

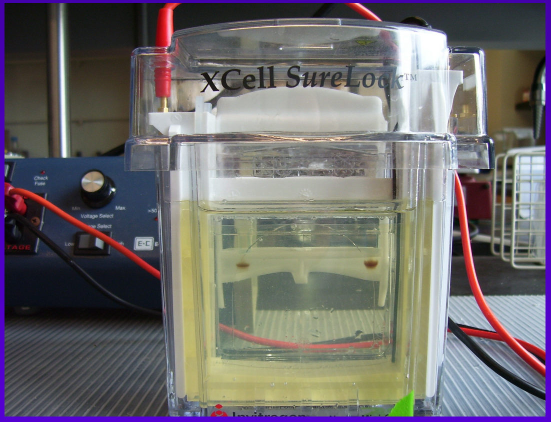
Glass & Paint Forensic PIXE

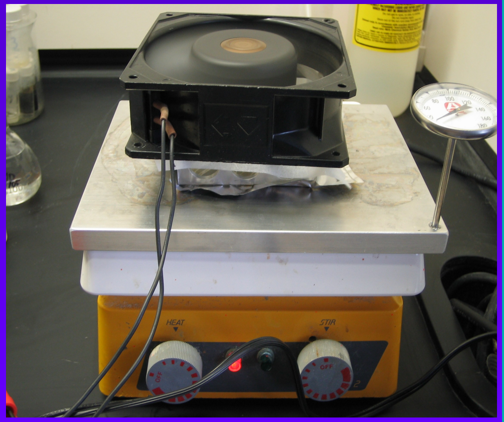
Gel Thickness Determination

Proton Elastic Scattering Analysis (PESA)

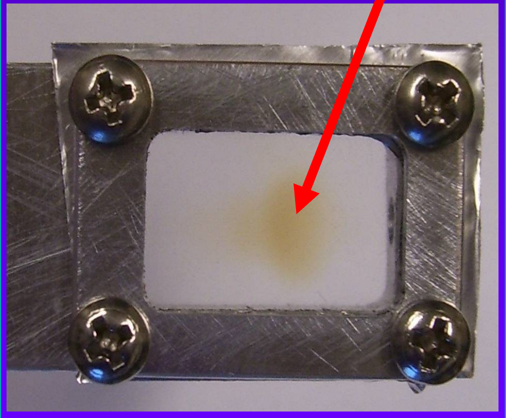
- ΔE is directly proportional to Δx
- SIMNRA allows us to relate energy loss to atoms/cm^2

J.Warner, L.Ellsworth, M.Rycenga, L.Kiessel



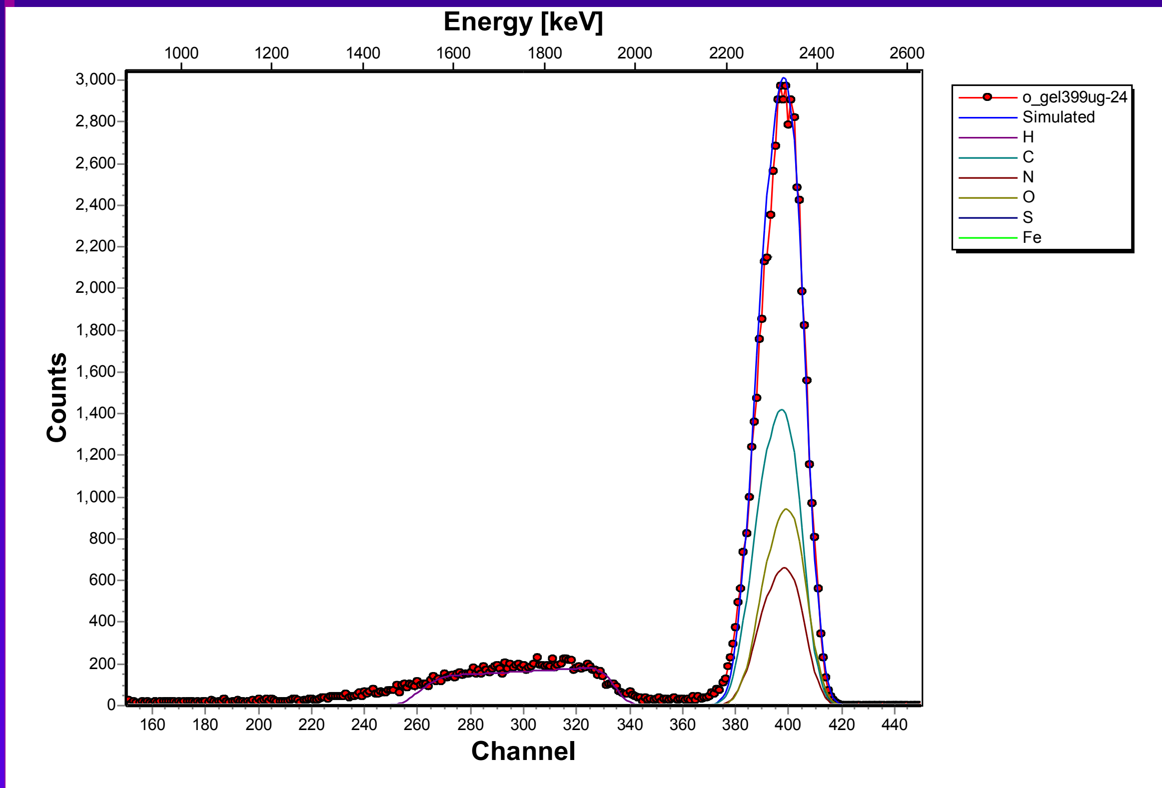


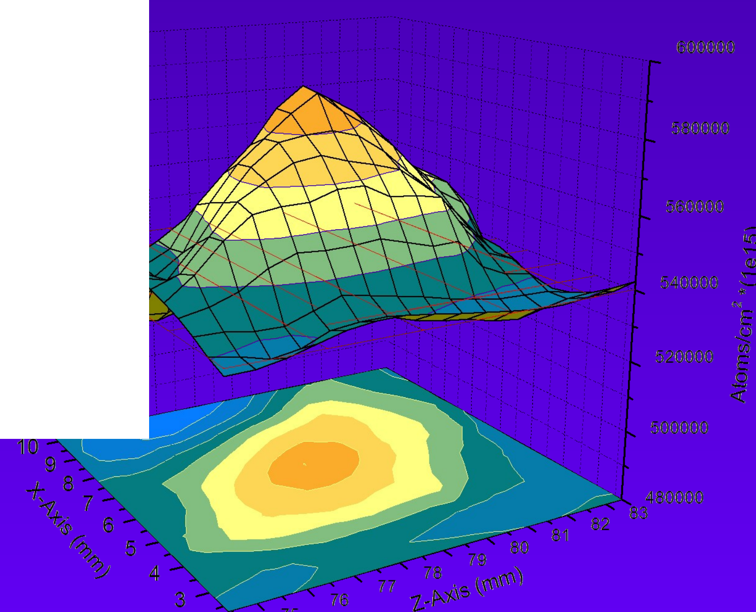
Myoglobin



PESA Analysis

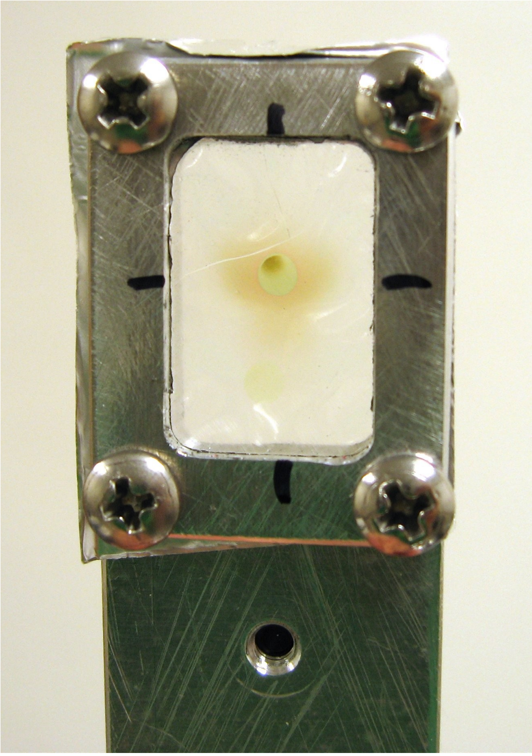
SIMNRA Analysis

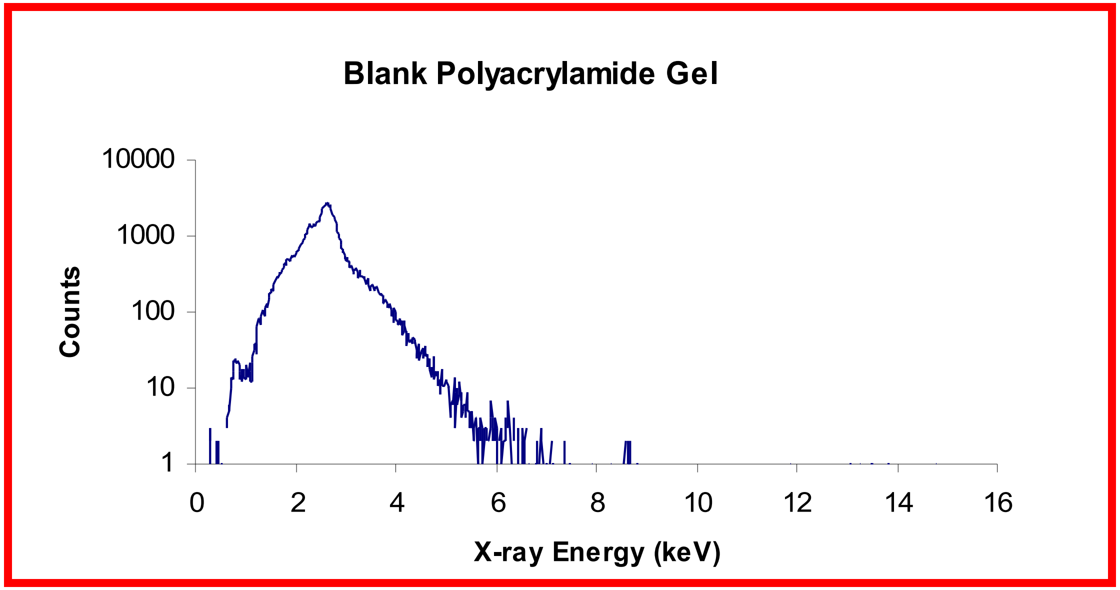


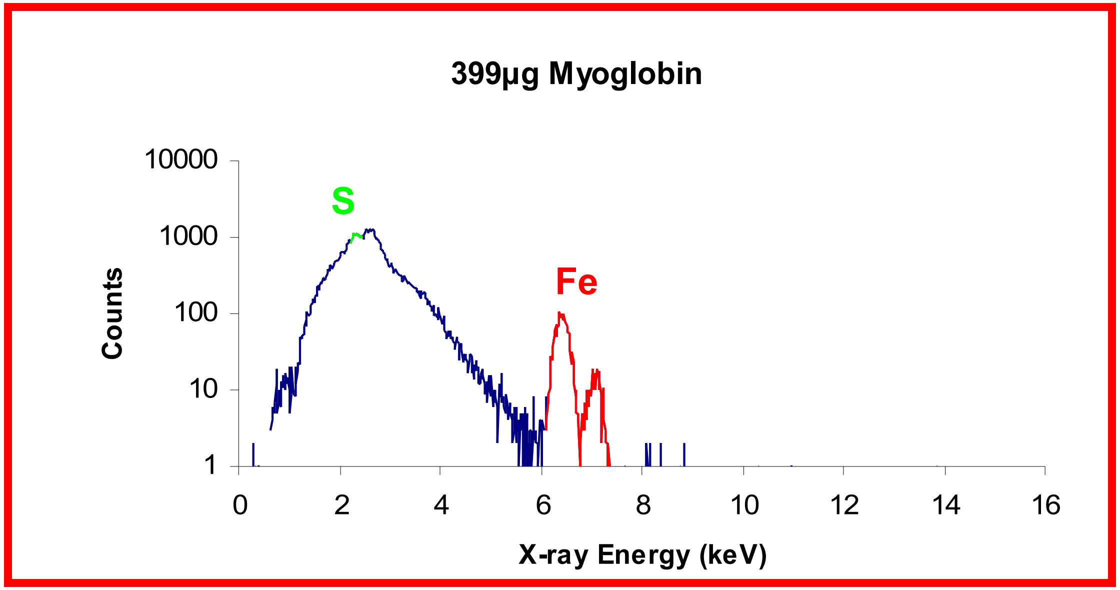


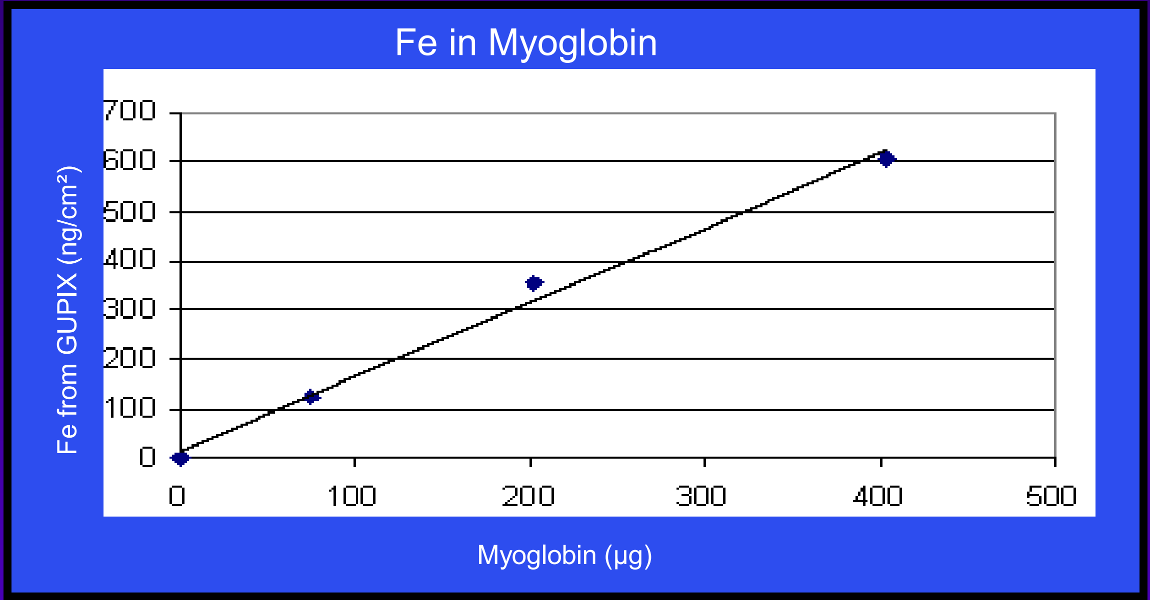
SIMNRA by Matej Mayer
http://www.rzg.mpg.de/~mam/index.html

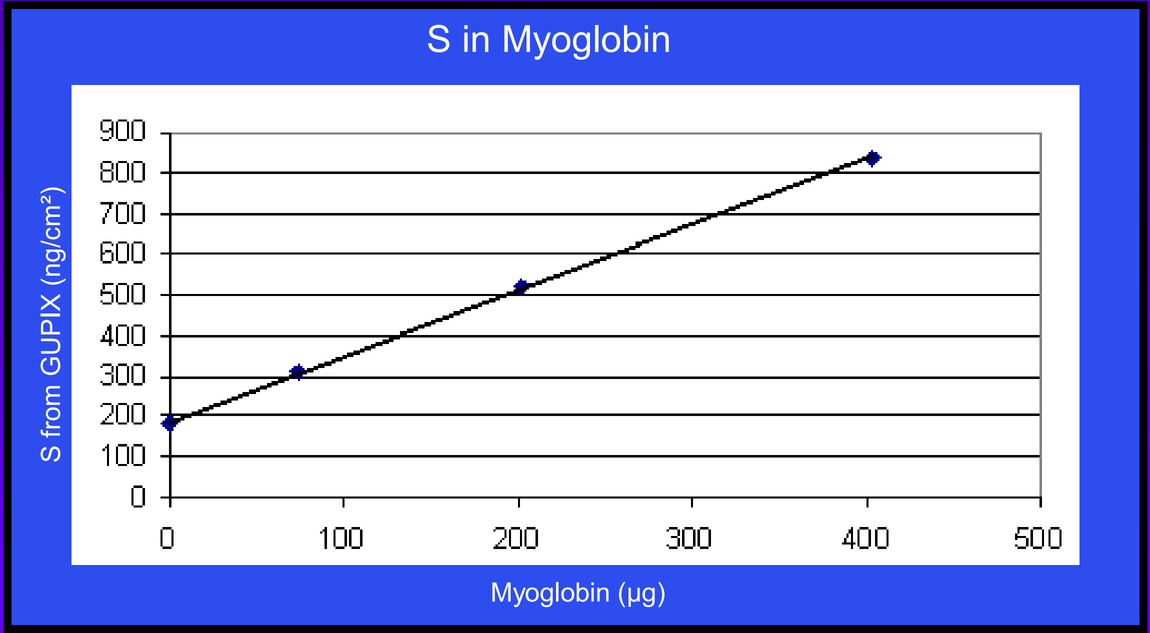
PIXE Analysis








Fe in Myoglobin
Fe from GUPIX (ng/cm²)
700
600
500
400
300
200
100
0
0
100
200
300
400
500
Myoglobin (µg)


S in Myoglobin
S from GUPIX (ng/cm²)
900
800
700
600
500
400
300
200
100
0
0
100
200
300
400
500
Myoglobin (µg)

What have we done so far…

Beam Development & Training

Contaminated sediment PIXE

Paleontology PIXE

Gel Electrophoresis PESA/PIXE

Sand Dune Mineralogy μPIXE

Electrochemical probe RBS

Solid State Physics RBS

Proprietary RBS

Glass & Paint Forensic PIXE

What we are doing next?

Beam Development & Training

Contaminated sediment PIXE

Paleontology PIXE

Gel Electrophoresis PESA/PIXE

Sand Dune Mineralogy mPIXE

Electrochemical probe RBS

Solid State Physics RBS

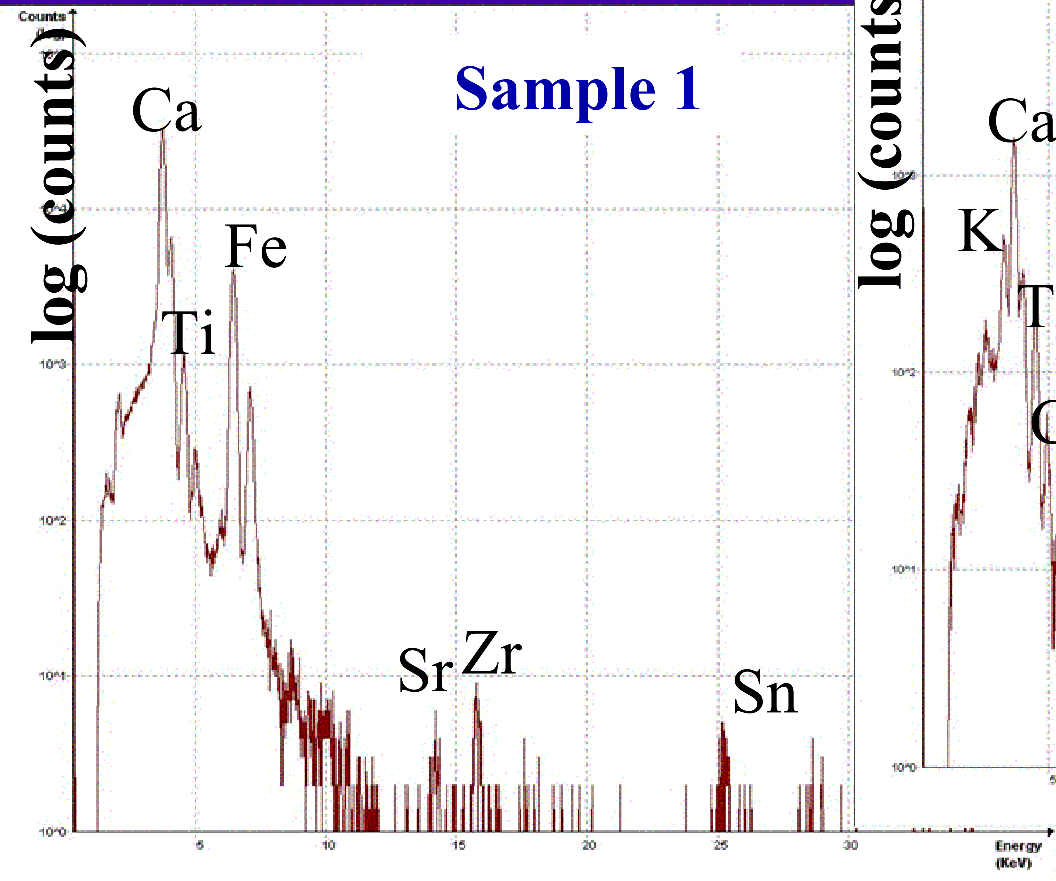
Proprietary RBS

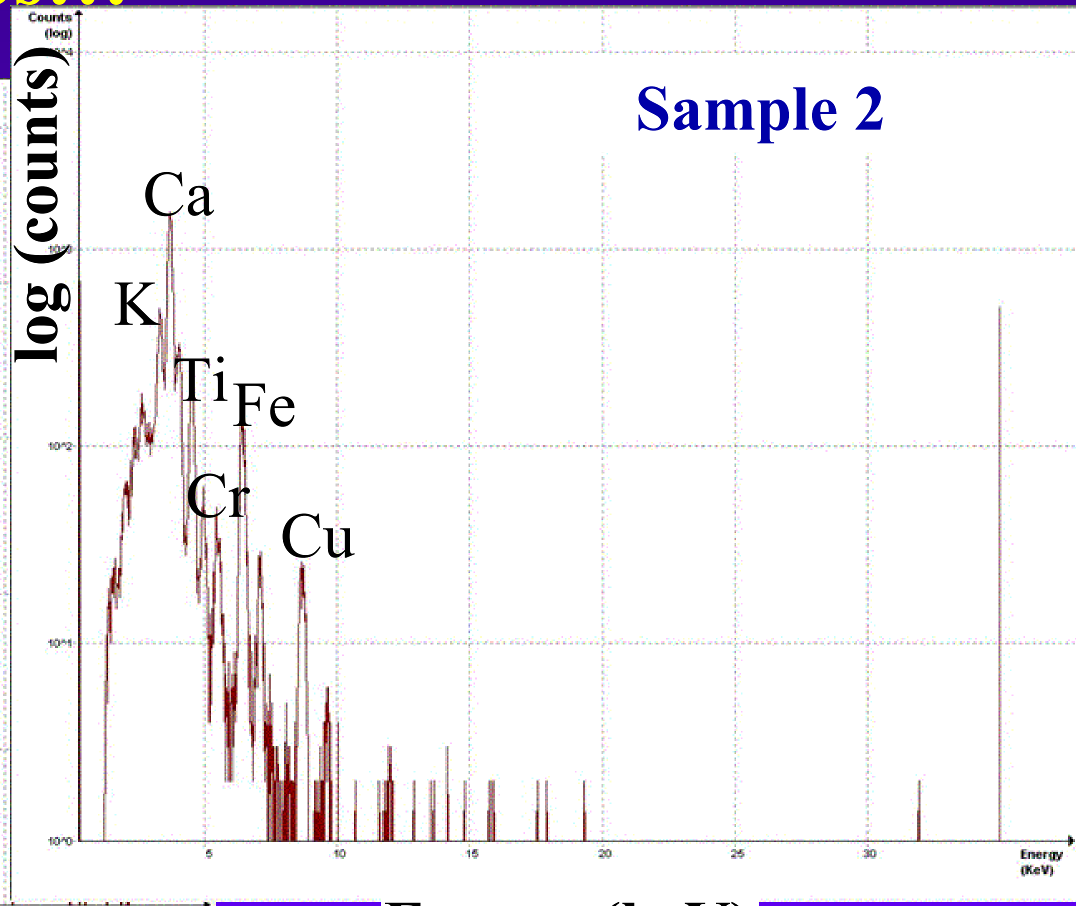
Glass & Paint Forensic PIXE

Two MS Police Glass Samples

Non-destructive (like XRF)

Easy to tell differences…





Two MS Police Glass Samples

Analysis

- **Elements selected for analysis**
- **Elemental ratios used to avoid systematic errors**

	A	B	C	D	E	F	G	H	I
1	Sample:	1\1				Sample:	1\2		
2	Element	ppm	% fit error	±		Element	ppm	% fit error	±
3	19 K K	184.7	37.45	69.17015		19 K K	745.6	15.27	113.8531
4	20 CaK	28784.2	7	2014.894		20 CaK	59848.9	7	4189.423
5	22 TiK	617.1	7	43.197		22 TiK	1263.7	7	88.459
6	25 MnK	43	13.97	6.0071		25 MnK	45.2	14.94	6.75288
7	26 FeK	3111.5	7	217.805		26 FeK	5892.2	7	412.454
8	29 CuK	17.8	38.44	6.84232		29 CuK	14.7	52.42	7.70574
9	38 SrK	37.9	68.24	25.86296		38 SrK	117.4	30.69	36.03006
10	40 ZrK	265.7	23.31	61.93467		40 ZrK	367.1	26.24	96.32704
11									
12	Sample:	2\1				Sample:	2\2		
13	Element	ppm	% fit error	±		Element	ppm	% fit error	±
14	15 P K	83051.2	10.94	9085.801		15 P K	61578.1	13.57	8356.148
15	16 S K	10421.4	7.79	811.8271		16 S K	6646.1	10.04	667.2684
16	17 ClK	1294.6	14.15	183.1859		17 ClK	1576.4	8.79	138.5656
17	19 K K	1600.1	7	112.007		19 K K	1137.4	7	79.618
18	20 CaK	1403	7	98.21		20 CaK	2721.3	7	190.491
19	22 TiK	389.3	7	27.251		22 TiK	268.9	7	18.823
20	26 FeK	202.7	7	14.189		26 FeK	208	7	14.56
21	30 ZnK	120	7.13	8.556		30 ZnK	112	7	7.84

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1								Single Sample Concentration Ratios									
2																	
3	1	19 K K	±	20 CaK	±	22 TiK	±	25 MnK	±	26 FeK	±	29 CuK	±	38 SrK	±	40 ZrK	±
4	19 K K			155.8430	59.3740	3.3411	1.2729	0.2328	0.0931	16.8462	6.4182	0.0964	0.0517	0.2052	0.1597	1.4385	0.6346
5	20 CaK					0.0214	0.0021	0.0015	0.0002	0.1081	0.0107	0.0006	0.0002	0.0013	0.0009	0.0092	0.0022
6	22 TiK							0.0697	0.0109	5.0421	0.4991	0.0288	0.0113	0.0614	0.0421	0.4306	0.1048
7	25 MnK									72.3605	11.3068	0.4140	0.1693	0.8814	0.6139	6.1791	1.6792
8	26 FeK											0.0057	0.0022	0.0122	0.0084	0.0854	0.0208
9	29 CuK													2.1292	1.6676	14.9270	6.7105
10	38 SrK															7.0106	5.0554
11	40 ZrK																

Two MS Police Glass Samples

Sameness is more difficult…

- Z-scores table created for sample comparisons between multiple hits on the same run
- Samples are considered the same if most are within one standard deviation of each other

$$u = \frac{x}{y}$$

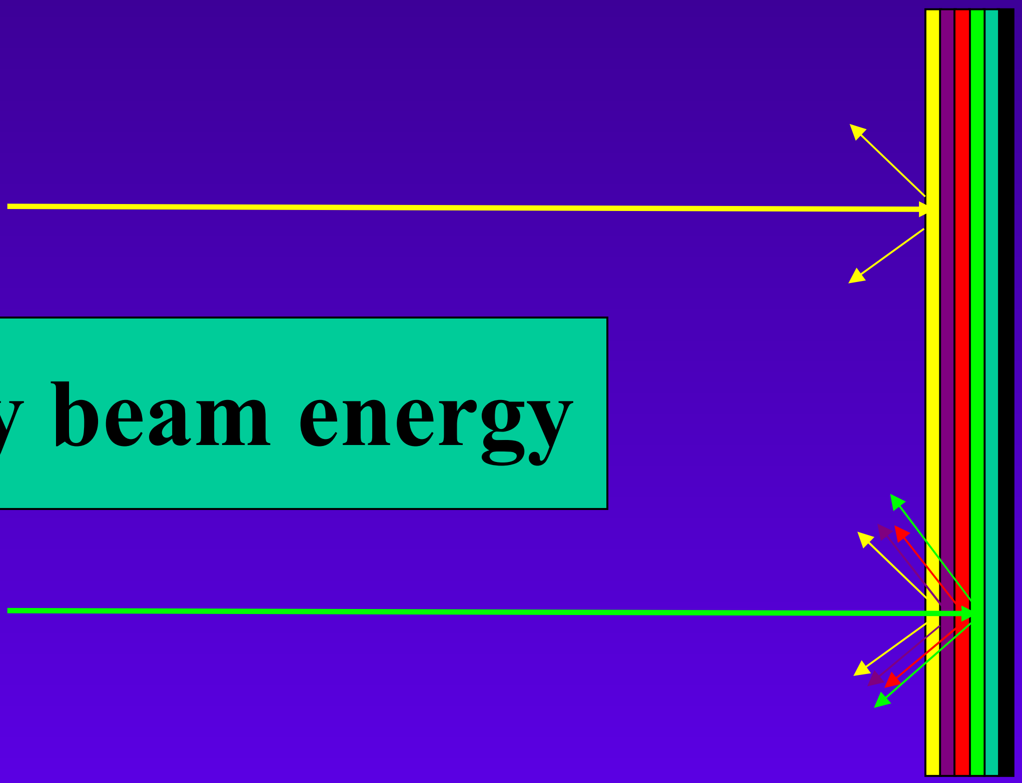
$$\sigma_u = \sqrt{\frac{\sigma_x^2}{y^2} + \frac{x^2}{y^4}\sigma_y^2}$$

$$Z = \frac{u_1 - u_2}{\sqrt{\sigma_{u_1}^2 + \sigma_{u_2}^2}}$$

	A	B	C	D	E	F	G	H	I
1	Z-Score 2 to 3								
2									
3	1.0000	19 K K	20 CaK	22 TiK	25 MnK	26 FeK	29 CuK	38 SrK	40 ZrK
4	19 K K		0.769002	0.746616	1.829465	0.764385	0.466554	0.219785	0.321434
5	20 CaK			0.045597	1.958712	0.009414	0.714969	0.725008	0.266887
6	22 TiK				1.989313	0.036183	0.70818	0.711203	0.247652
7	25 MnK					1.785593	1.066719	1.387458	1.198221
8	26 FeK						0.713569	0.722162	0.262921
9	29 CuK							0.303722	0.51823
10	38 SrK								0.461336
11	40 ZrK								

	A	B	C	D	E	F	G	H	I
1	Z-Score 1 to 3								
2									
3	1.0000	19 K K	20 CaK	22 TiK	25 MnK	26 FeK	29 CuK	38 SrK	40 ZrK
4	19 K K		0.902544	0.938408	1.255223	1.055041	1.5852	0.381213	1.356854
5	20 CaK			0.154356	1.330639	0.675806	1.879663	0.11426	1.482196
6	22 TiK				1.233278	0.522118	1.863207	0.145395	1.427058
7	25 MnK					0.929356	1.576503	0.538594	0.624623
8	26 FeK						1.804761	0.254061	1.233541
9	29 CuK							1.030342	0.870549
10	38 SrK								0.591707
11	40 ZrK								

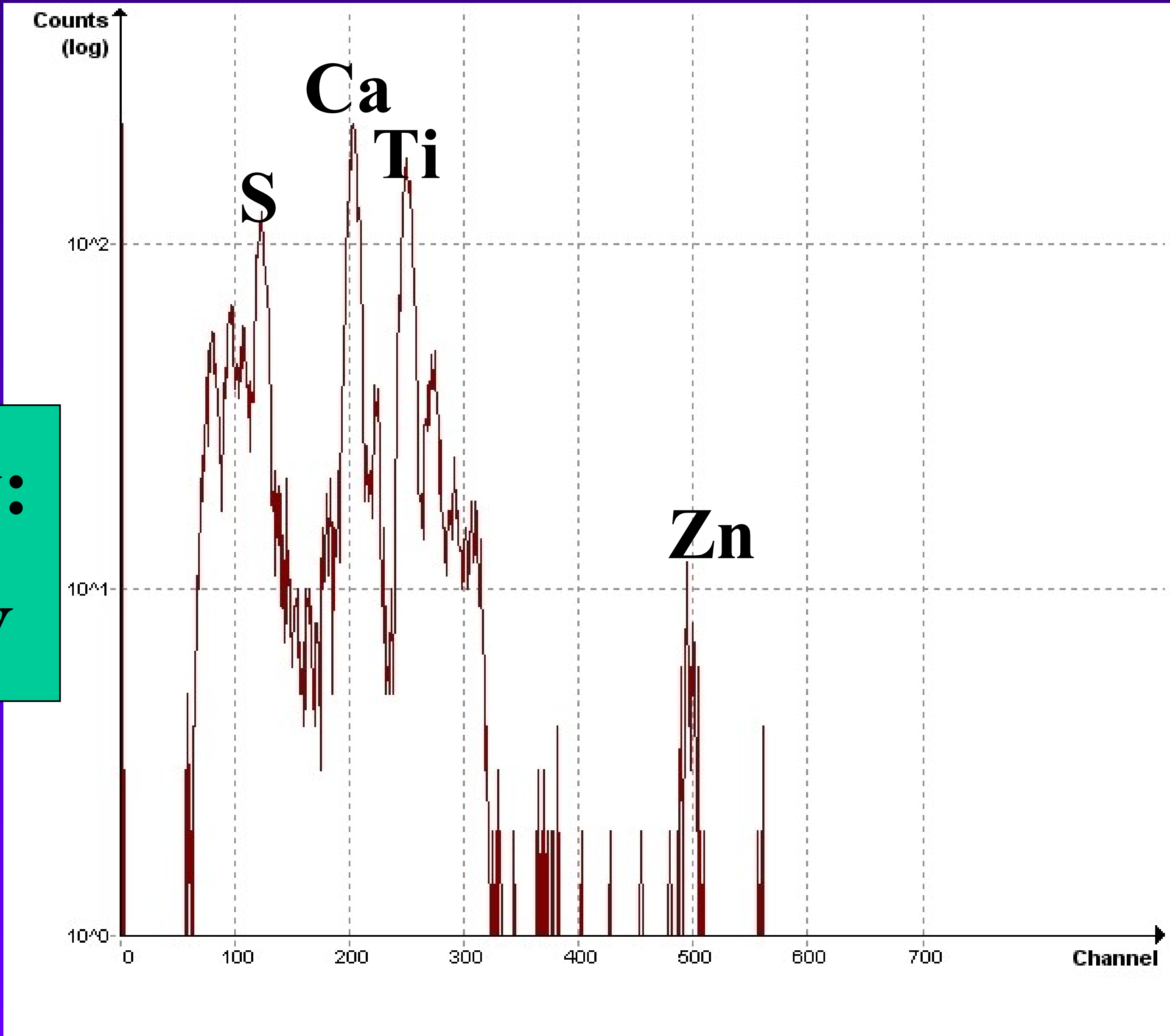
Differential PIXE for Paint Layers



Vary beam energy

"Subtract" spectra

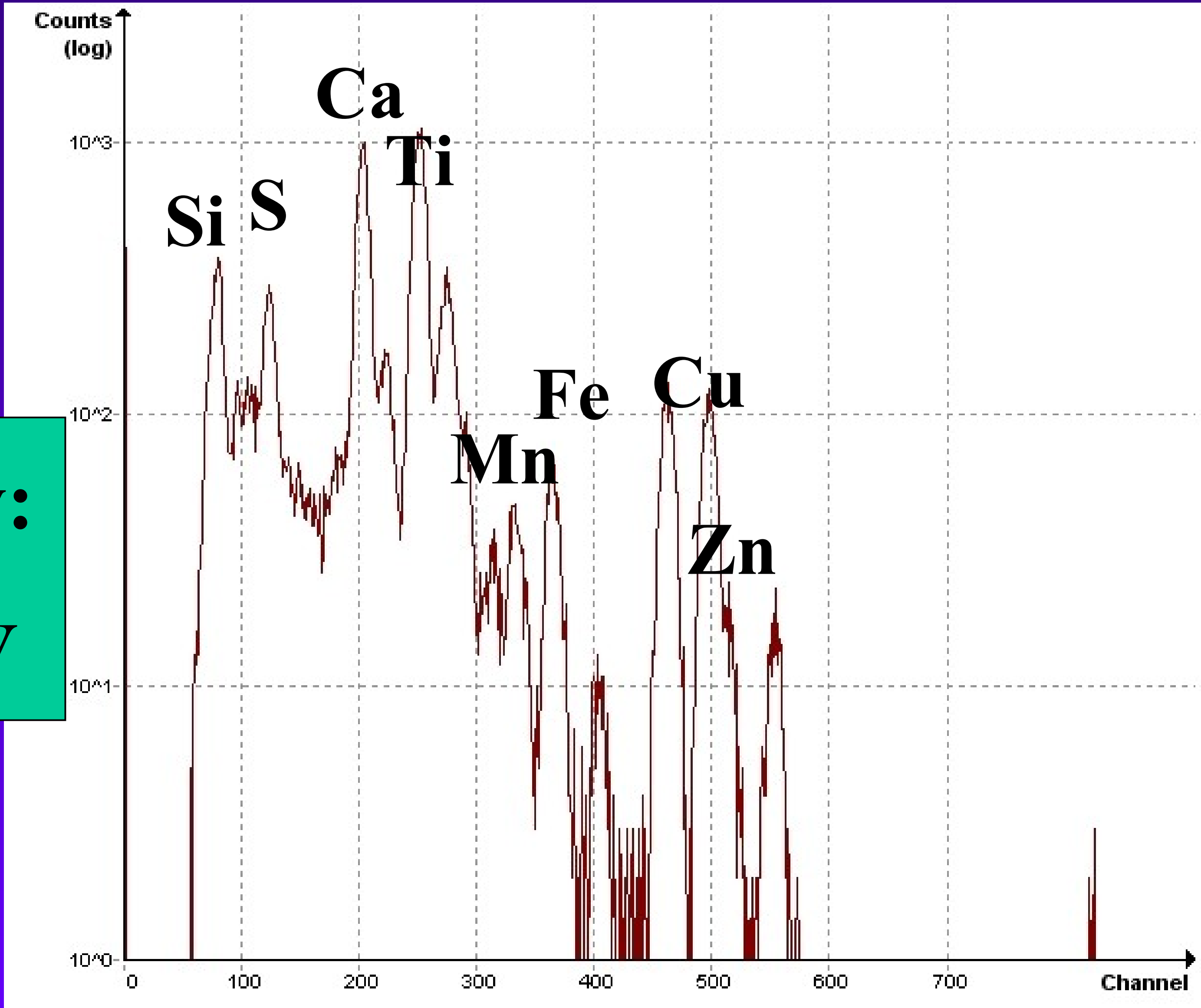
Differential PIXE for Paint Layers



beam energy:

1.0 MeV

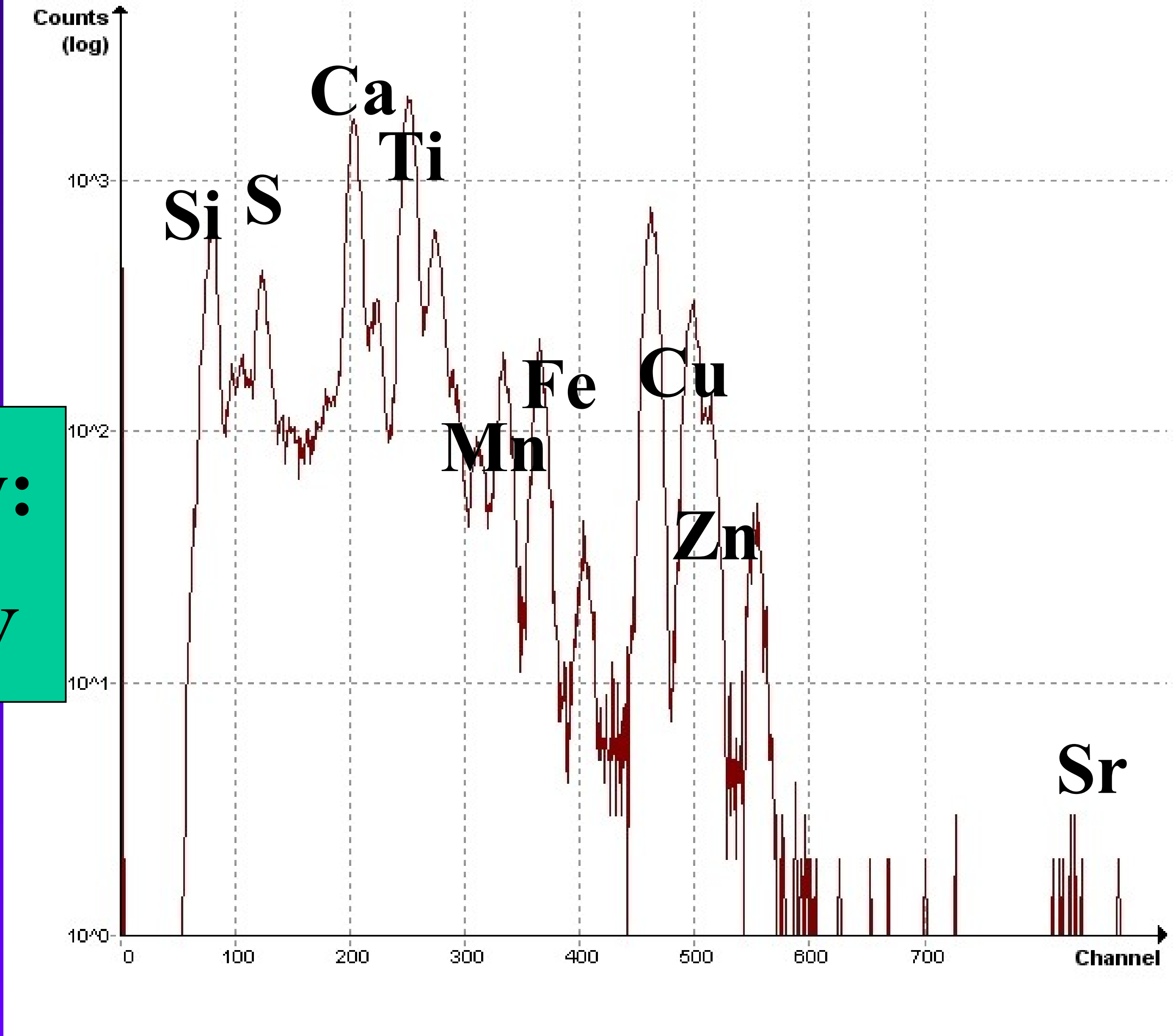
Differential PIXE for Paint Layers



beam energy:

2.3 MeV

Differential PIXE for Paint Layers



beam energy:

3.4 MeV

Some Conclusions?

- **Interesting possibilities**

Non-destructive

Quantitative with good LOD's

Heavier elements than XRF

Ability to control penetration depth

- **Future development**

Sandia's CSIBA…

IBIL...

Some Conclusions?

- **What works:**

Alphatross & accelerator...

Student involvement in every aspect...

Interdisciplinary research draw…

- **Future development**

Forensic science and others...

More networking with other labs...

Acknowledgements

NSF – MRI 0319523 & RUI 0354920 *(Funding)*

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Graham Bench *(LLNL)*, Rick Rediske *(GVSU)*, Tom Guarr *(Gentex)*, Bryce Bergethon *(Huron)*

Recent Students: Andy Huisman, Lee Kiessel, Jill Pinter, Natalie Hoogeveen, Matt Rycenga, Josh Warner, Pat Mears, Maureen Yonovitz, Keiko Kito, Carolina Contreras, Abe Pena, Chris Hall, Derek Padilla, Meghan Winer, Lindsay Ellsworth, Eric Johnson

Craig Marshall – Scitek Australia
Turbos and Blue Smoke – Vacuum Technology talk

(No abstract available for this talk)

Questions: (The audio quality for this session was poor)

Question Inaudible ...

Marshall: It is on the one shaft. I'm told that it is a single shaft that has a turbine blade at the top, ... It will be high speed, I'm thinking at least 40 to 50 thousand. It's new, and I haven't seen one yet.

?????

Marshall: I think it's fair to say that pump design has come a long way. Back in the 50's and 60's, people were very reticent to switch away from diffusion pumps and that continued almost into the 80's. People were saying “ they are going to crash.” But in industrial coating where they are doing CD's and DVD'd, with very quick cycle time, and those chambers are going from atmosphere to 10^{-4} in a few seconds. The pumps are designed to take those shock waves. They are much better than they used to be and part of that is the technology.

?????

Marshall: Now we have a frequency converter that is integral with the pump and you can drive it with a remote power supply but you only need with a modern turbopump, 24 volts to run it and a supply capable of suppling about four amps. So they are a lot easier to use and a lot less prone to failure.

???? (Question concerning vibration)

Marshall: It looks to me as though it has a standard ISO flange mounting. We have a vibration isolator which is a convoluted bellows which is supported by two hooks welded into it and you have some anti-vibration material wrapped around that. When the vacuum goes on, the bellows compressed and that anti-vibration material takes up the vibration and reduces it by a factor of ten.

????: Is it important when you re-assemble a pump that the stator blades be aligned or can they be put back in any way?

Marshall: You can put them back in any position. I usually find that it is good to stagger the blades a bit.

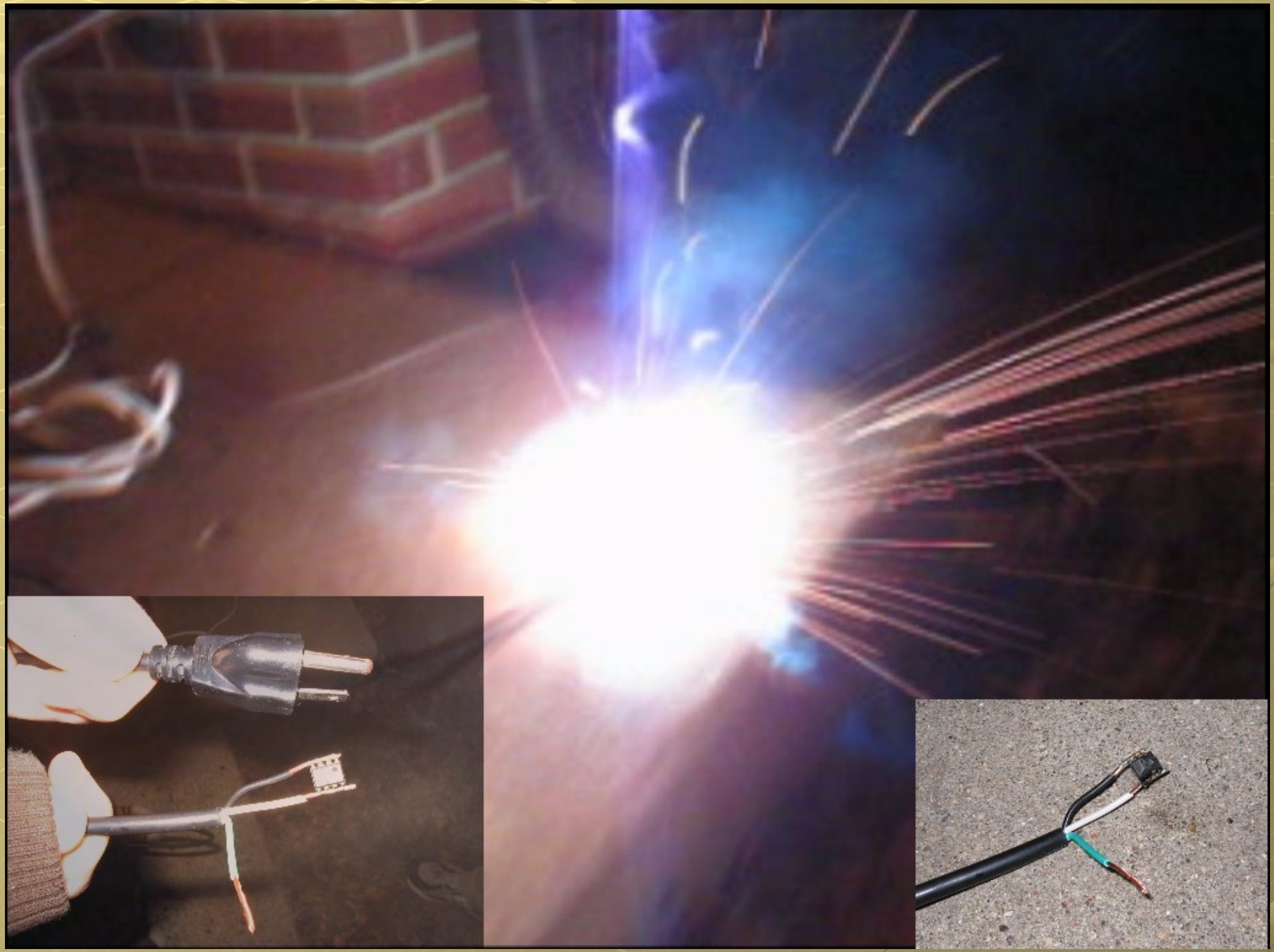
?????

Marshall:At your own peril you can buy bearings from other sources but bearing Pfeiffer use are designed for them. For example, the bearing used in the small pumps has a slight chamfer on it which is matched exactly to the splash nut that is used to transport the lubricant up into the bearing, so I wouldn't try to second guess any aspect of the design.

The other pumps all do their job but to get into the the ultra-high vacuum range, you have to do a lot more to achieve very little and that means spinning the pump at an almost obscene speed, but it works because they have worked out the materials, the blade angles. Everything has been worked out. That is not to say that Pfeiffer pumps can't be used in more workhorse situations, generating 10^{-5}. That has been done very successfully in commercial sputtering machines.

End of Questions

BLUE SMOKE AND TURBOS



Electrical theory of smoke

by Joseph Lucas

Blue smoke makes electrical circuits work.

The smoke itself resides in the micro porosities within conductor or device. We know that this is true because every time blue smoke comes out of the electrical system, it stops working. This can be verified by repeated empirical testing.

Early Smoke Theory

Benjamin Franklin 1706-1790

- believed electricity and magnetism to be one ‘fluid’

Charles De Coulomb 1736-1806

- believed electricity and magnetism to be 2 separate ‘fluids’

Enlightened technicians 1950-

- should believe in blue smoke, an occluded super high pressure gaseous substance,demonstrating ferrofluidic properties within all “conductors”

Major Advantages of understanding Blue Smoke

- Better trouble shooting capabilities –
  Where there’s smoke there’s fire
- Better able to understand where and how power authorities are overcharging us, eg.Power station smoke conversion
- One big disadvantage!

How do Turbos of similar physical size running at significantly different speeds produce similar molecular flow rates?

A Brief history of Turbo Pumps

1913 Gaede invents the first variant of turbo (moving wall similar to today's drag pump)

1915 practical diff pump (Hg) invented

1925 Hollweck improved the Gaede design (double ended cylinders similar to the famous Pfeiffer axial flow pump

1940 Siegbahn improves the disk design

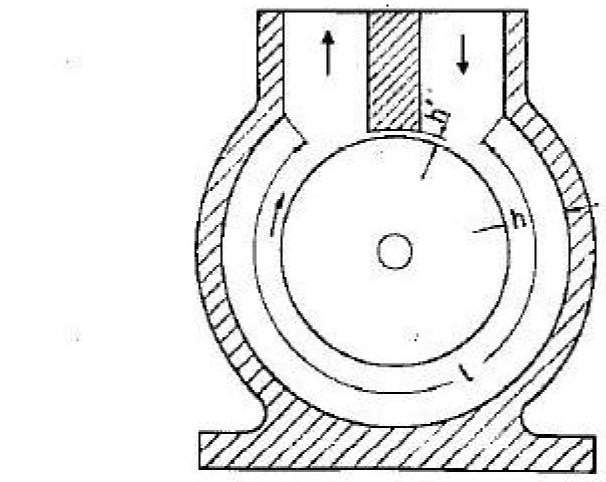


Figure 1. Molecular drag pump (Gaede).

A Brief history of Turbo Pumps
cont'd

1957 Willi Becker/Arthur Pfeiffer invent the double ended TVP(1st commercial variant)

with 3 phase motor and slipping clutch

1960 Same but with improved electrics and frequency converter

1970 Vertical pumps became available

1975-1980 Wide range pumps became available

Mid 1980's -> turbo molecular drag pumps (Gaede + Siegbahn)

Pumping Speed of a single disk

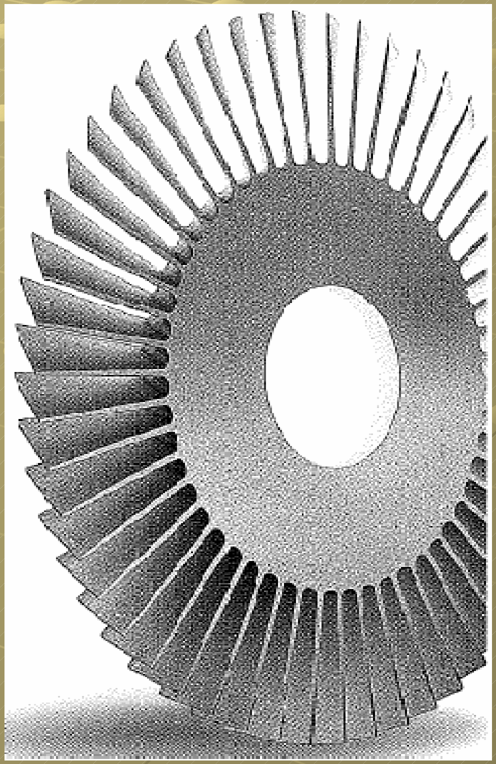
Depends on:

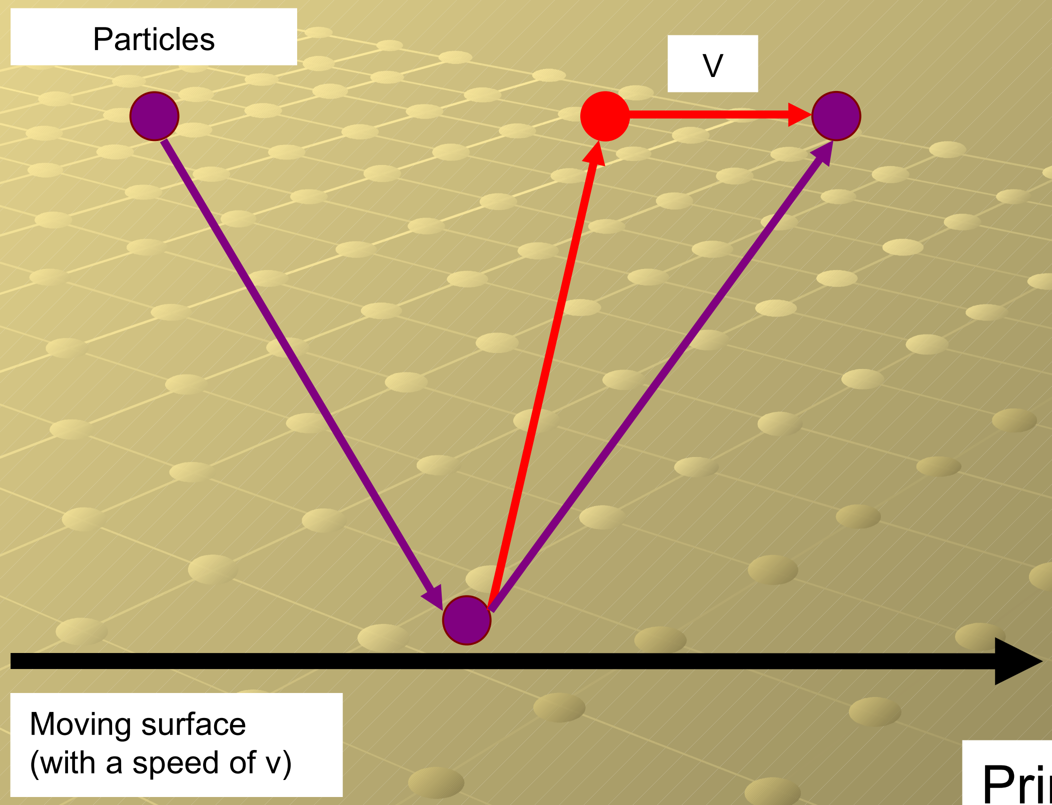
- Outer diameter of the disk
- Outer diameter of the blade base
- Operating frequency

(cycles per sec 26k(
90k)

Σ of all disks

And drag stages





Principle of the Molecular pump

Capturing probability of molecules

Depends on:

- Blade angle
- Gas density
- Optical opacity of disk
- Backscattering effects
  (minor impact on performance)

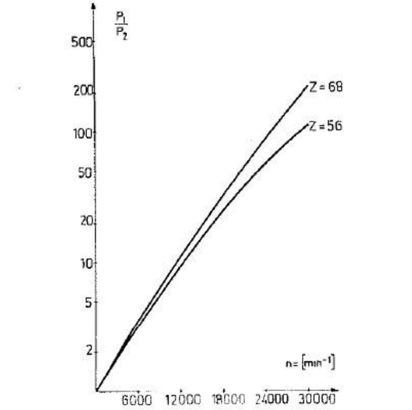


Figure 5. Compression ratio for air of optically opaque and optically not opaque discs (closed and open disc structures).

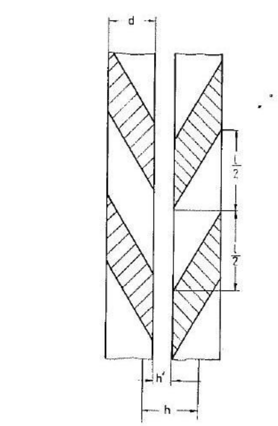


Figure 2. Discs of a turbo-molecular pump (schematic).

Dependence of pumping speed on compression ratio

- Ratio of outlet pressure to inlet pressure
- High compression ratio means better pumping speed for helium and hydrogen, important for UHV
- Compression ratio is different for all gases

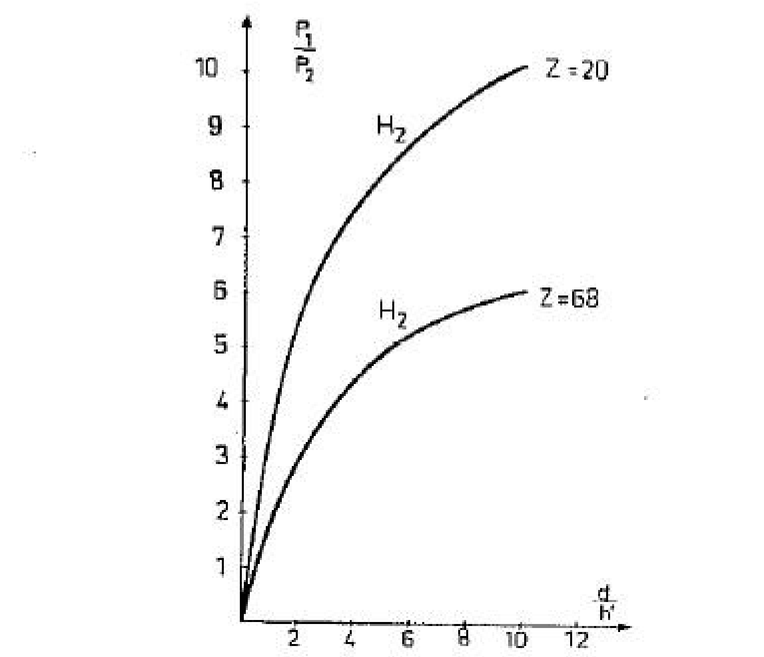
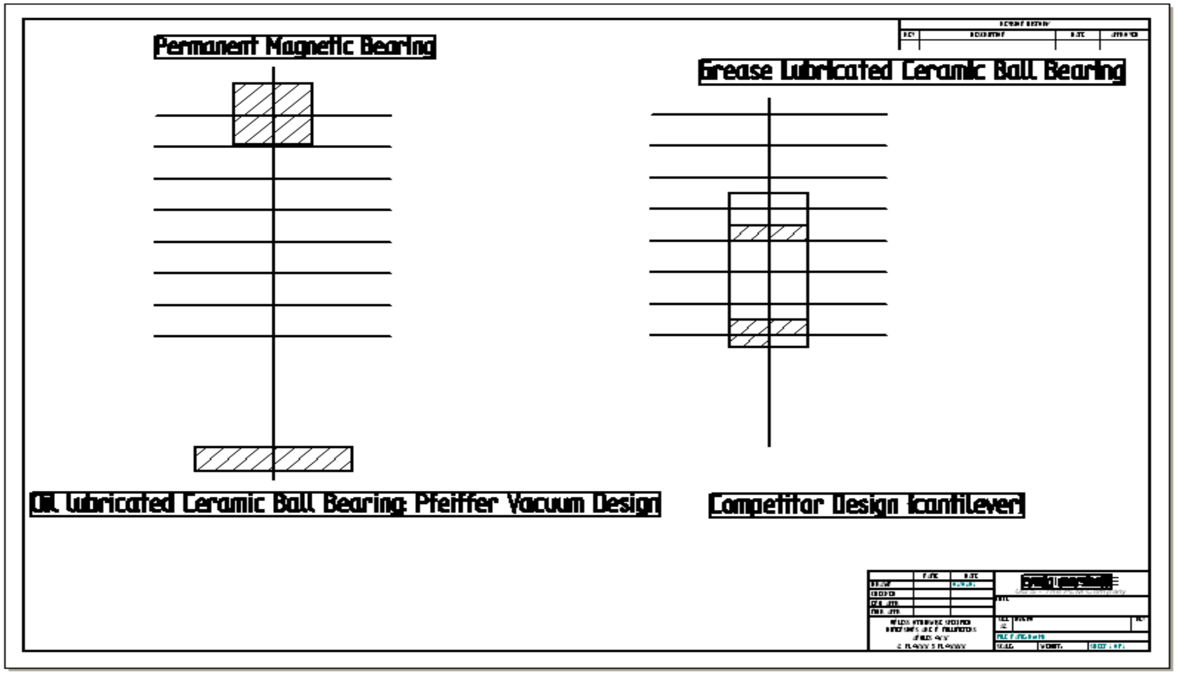


Figure 3. Compression ratio for hydrogen as a function of d/h'.

Cantilever vs equal loadbearing



Summary

Pumps of similar physical size run at different speeds and produce similar flow rates but:

- Compression ratios will be different
- Pumping efficiency will vary
- Ultimate pressures should be comparable
- Wear and tear will be comparable despite vastly different rotation speeds owing to bearing support and design, blade shape and lubrication system

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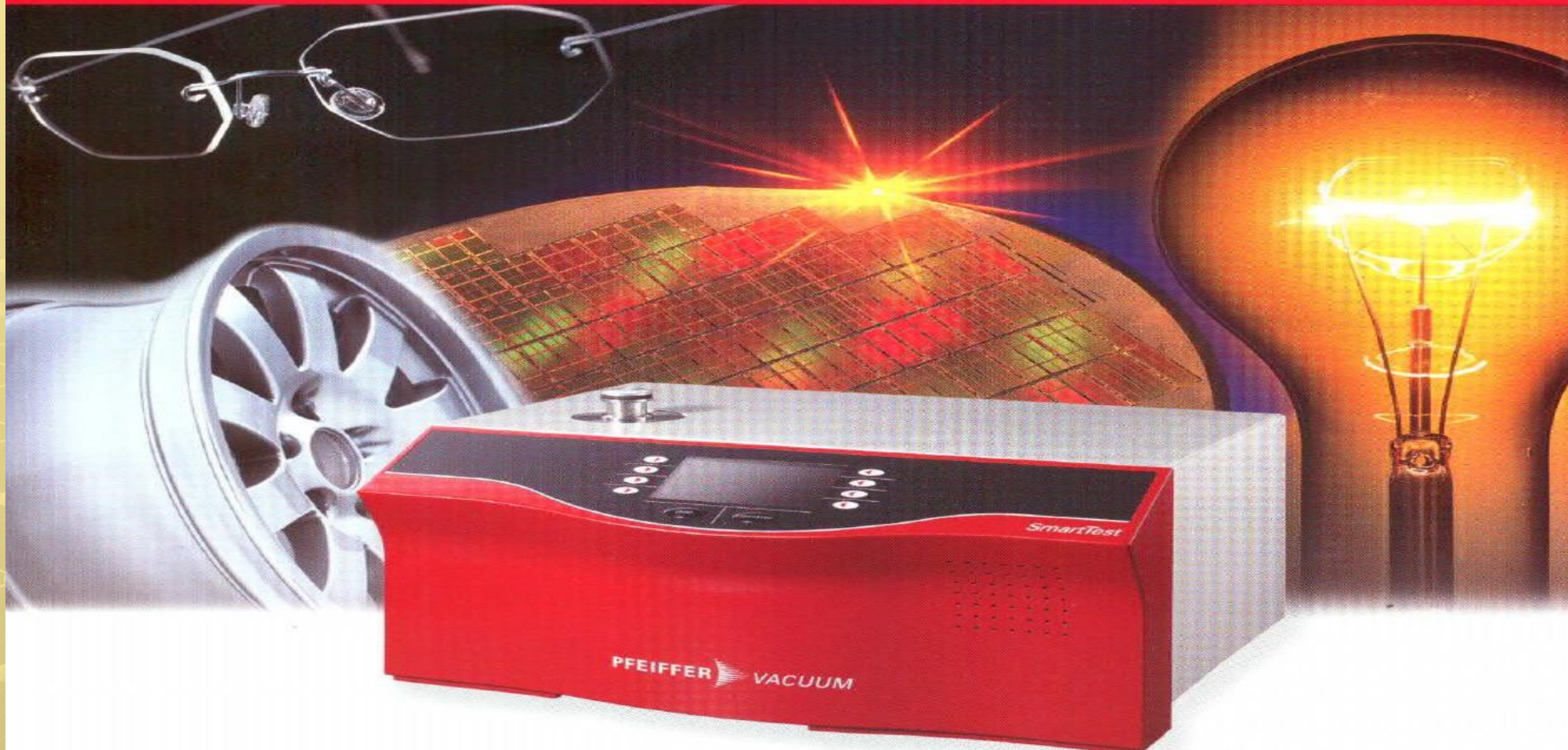

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Modular concept.
Simple operation. Top performance.

PFEIFFER VACUUM

Weather Forecast

- Today’s fire danger will be low, with little sign of blue smoke. By tomorrow evening, an extremely low pressure cell will be forming up in your PFEIFFER turbo

- THANK YOU and GOOD DAY