Use of National Facilities in Technology Development for Energy and Transportation

Ernie Hall
Chief Scientist
GE Global Research

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GE … a heritage of innovation

Founded in 1892

$180 billion in annual revenues

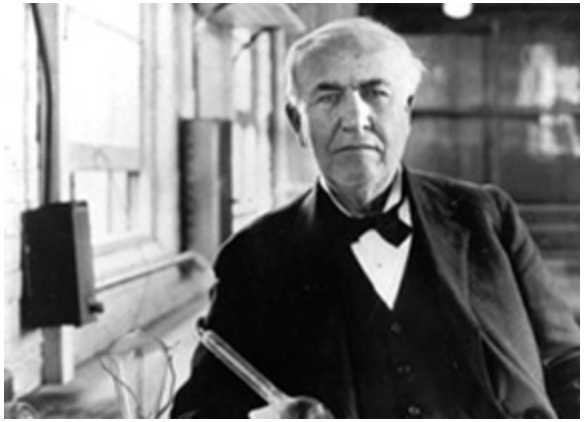
Only company in Dow Jones index originally listed in 1896

300,000 employees worldwide

36,000 technologists

50,000th US patent in 1978

$5.7 billion technology spend (2006)



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Four segments aligned for growth

Infrastructure - Energy	Infrastructure - Technology	GE Capital	NBC Universal
			NBC BEIJING 2008 hulu

Energy
Oil & Gas
Water

Aviation
Transportation
Healthcare
Security, Sensing, Inspection
Lighting, Appliances, Industrial

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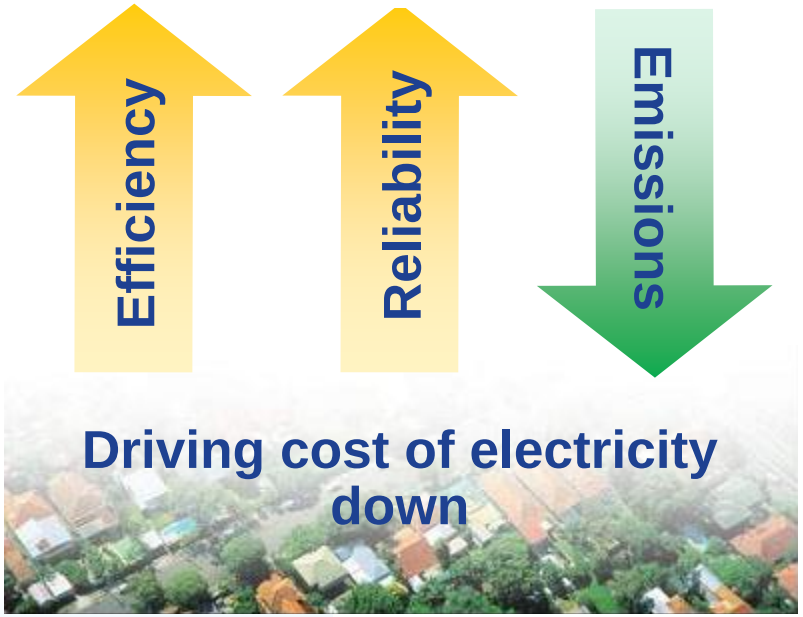
Energy technology objectives

Diverse

Nuclear
Coal
Gas
Wind
Oil
Geothermal
Biomass
Hydro
Solar

+

Efficient



Affordable, reliable & environmentally responsible

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Sustainable Energy

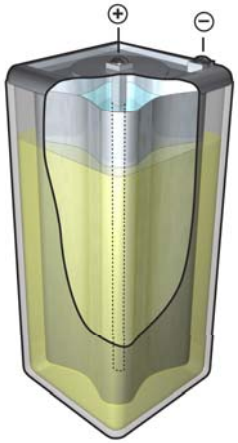
Developing new ways to power an energy-hungry, eco-conscious world

Solar

Win

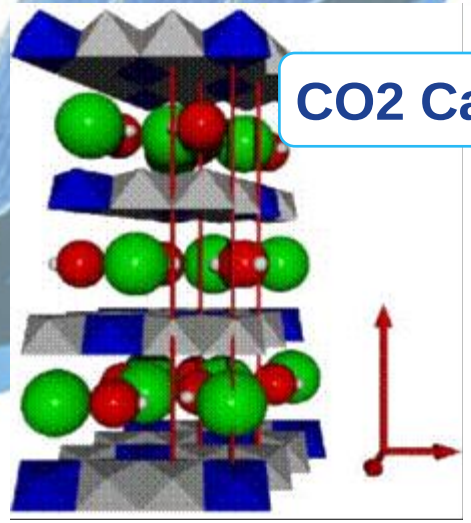
Biofuels

Energy Storage



Cleaner Coal

CO2 Capture



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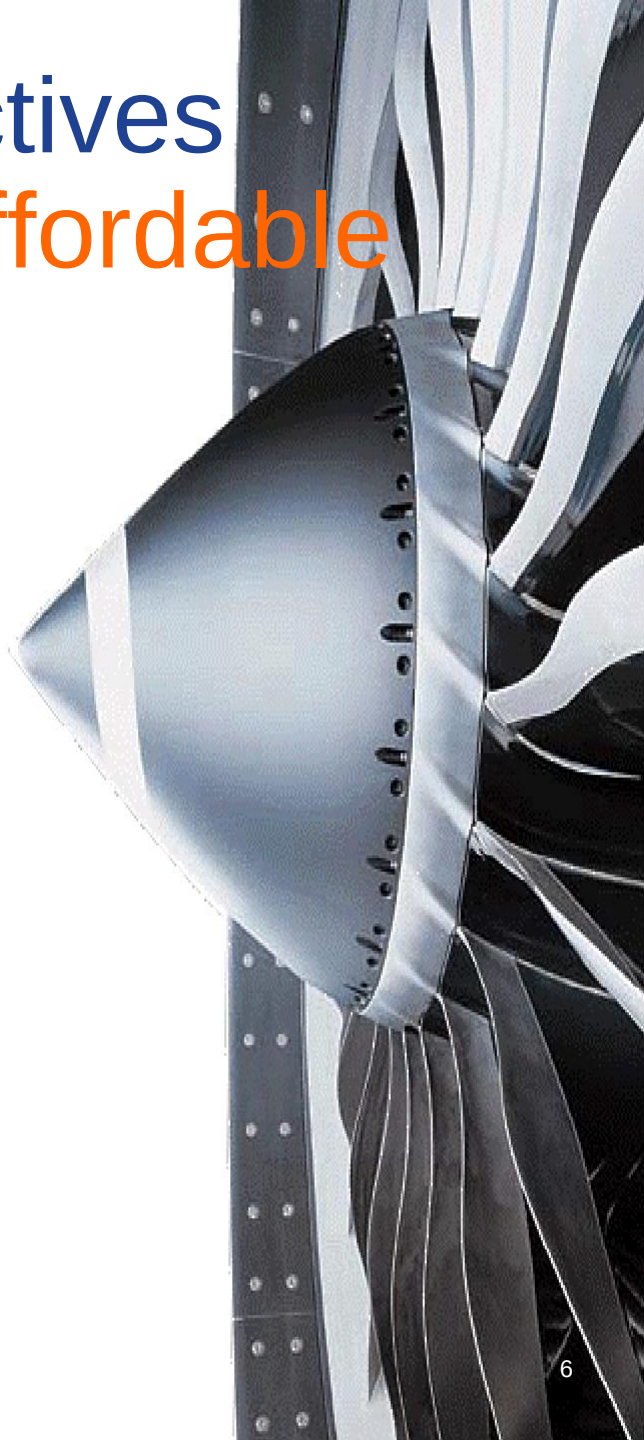
Aviation technology objectives
cleaner, quieter, faster, affordable

Fuel burn	20%
Emissions (NOx)	85%
Noise	55%
Cost of ownership	30%
Reliability	50%



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Hybrid locomotive

Sets new standards in fuel efficiency, environmental performance

Leverages unique GE electro-chemistry for battery… increases power 3x and energy 2x

Provides additional 10% NOx and CO_2 reduction

Improves fuel efficiency 10%

Global Research: market-focused R&D

First US industrial lab

Began 1900 in Schenectady, NY

Founding principle … improve businesses through technology

One of the world's most diverse industrial labs

Cornerstone of GE's commitment to technology

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3,000 technologists strong

Global Research Center
Niskayuna, NY

John F. Welch Technology Center
Bangalore, India

China Technology Center
Shanghai, China

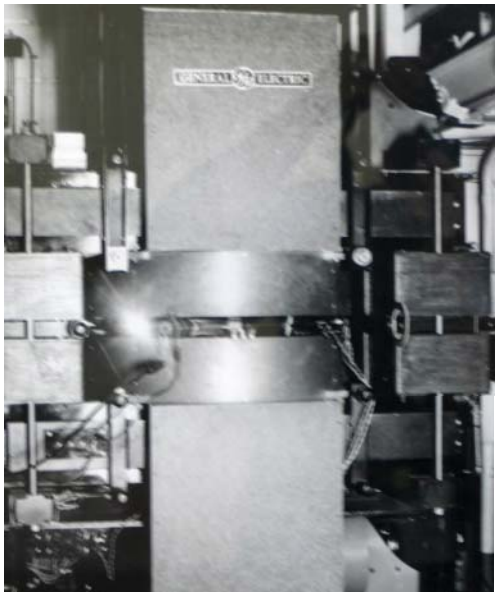
Global Research – Europe
Munich, Germany

A long history of innovative approaches to materials characterization…

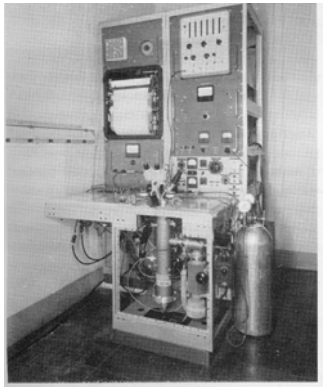
Discovery of synchrotron radiation at GE Research Center (1947)

TEM

X-ray Microscope



General Electric synchrotron accelerator built in 1946



❑ The first operating microcrobe in the U.S., which GE management was persuaded to abandon on the advice of its market analysts.

Electron Microprobe

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Materials characterization using synchrotrons and neutrons

We use a <u>variety</u> of techniques at <u>various</u> national facilities to characterize a <u>wide range</u> of materials

FRM-II (Germany)

NCEM (USA)

NSLS (USA)

NIST (USA)

APS (USA)

SSRF (Shanghai)

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GE usage… “research between basic and applied

- Use model / non-proprietary systems to develop key mechanistic, structure-property correlations
- Use a variety of facilities, beamlines, collaborators optimized for task
- Different access models
- Geographic accessibility plays a role
- Constant pressure on research budgets

Typical GE usage:

- ***High-resolution XRD***
- ***High-pressure/ temperature XRD***
- ***High-energy XRD***
- ***XAFS***
- ***SAXS***
- ***Pair-distribution function (PDF)***
- ***Synchrotron microtomography***
- ***X-ray microscopy***
- ***X-ray microprobe***
- ***Prompt gamma-ray activation analysis***
- ***Neutron diffraction***
- ***Neutron radiography***

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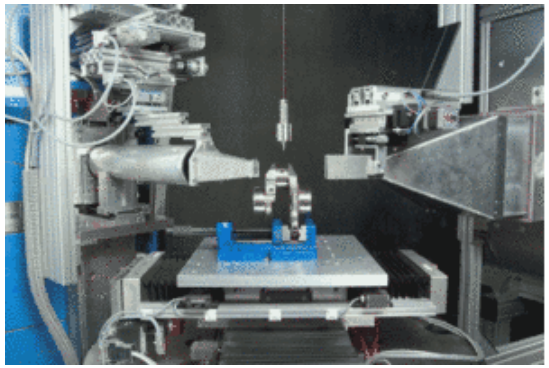
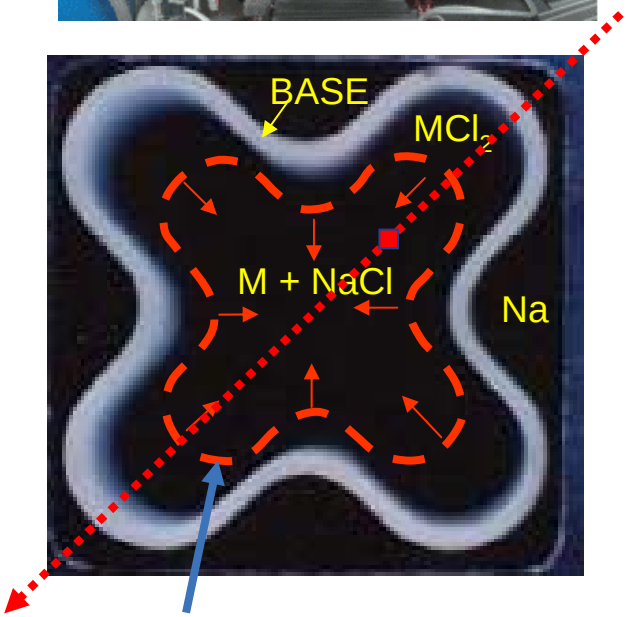
Industrial Needs – are they different?

- Varies by segment: pharma, chemical, semiconductor, energy/infrastructure/materials
- Mixed long and short terms needs
- Less-flexible sample conditions
- In-situ measurements and custom-designed setups
- Quick access and short turnaround time
- Productivity
- Reliable and usable results and solutions
- Spectrum of knowledge/capabilities of users

Neutron diffraction of Na-MCl_2 battery – phase distribution

Stress-Spec, FRM-II



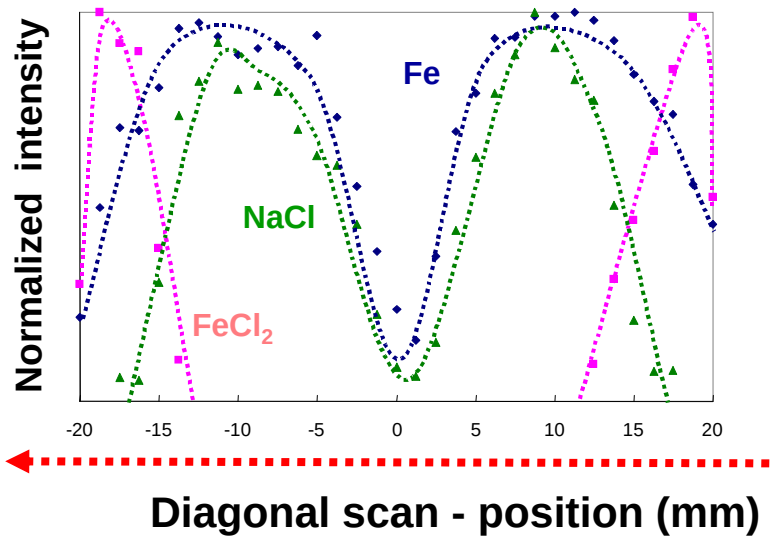


"Reaction front" will move during charge/discharge

charge

$$2NaCl + Fe \rightleftarrows FeCl_2 + 2Na$$

(300°C) discharge



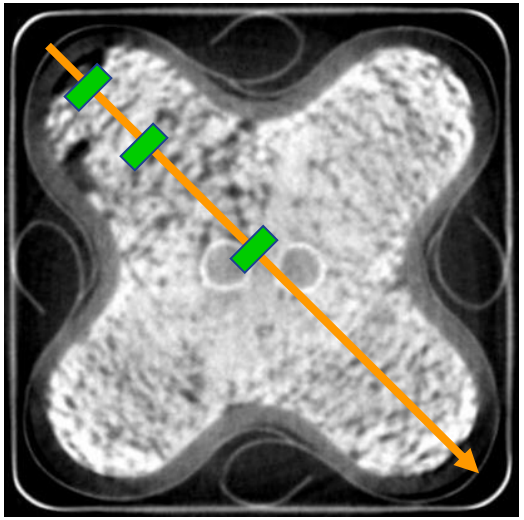
Diagonal scan with neutron beam to reveal the chemistry change in a half-charged battery cell.

Neutron data from a half-charged cell, FRM-II, TUM (Hoffmann, Gilles)

In-situ XRD diffraction from battery cells

X17B NSLS BNL

1) Diagonal scans at end of (dis)charge



2) Single point during (dis)charge

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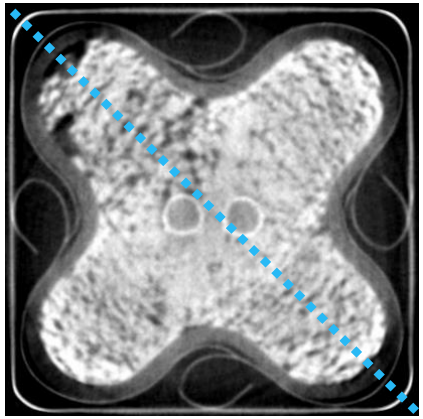
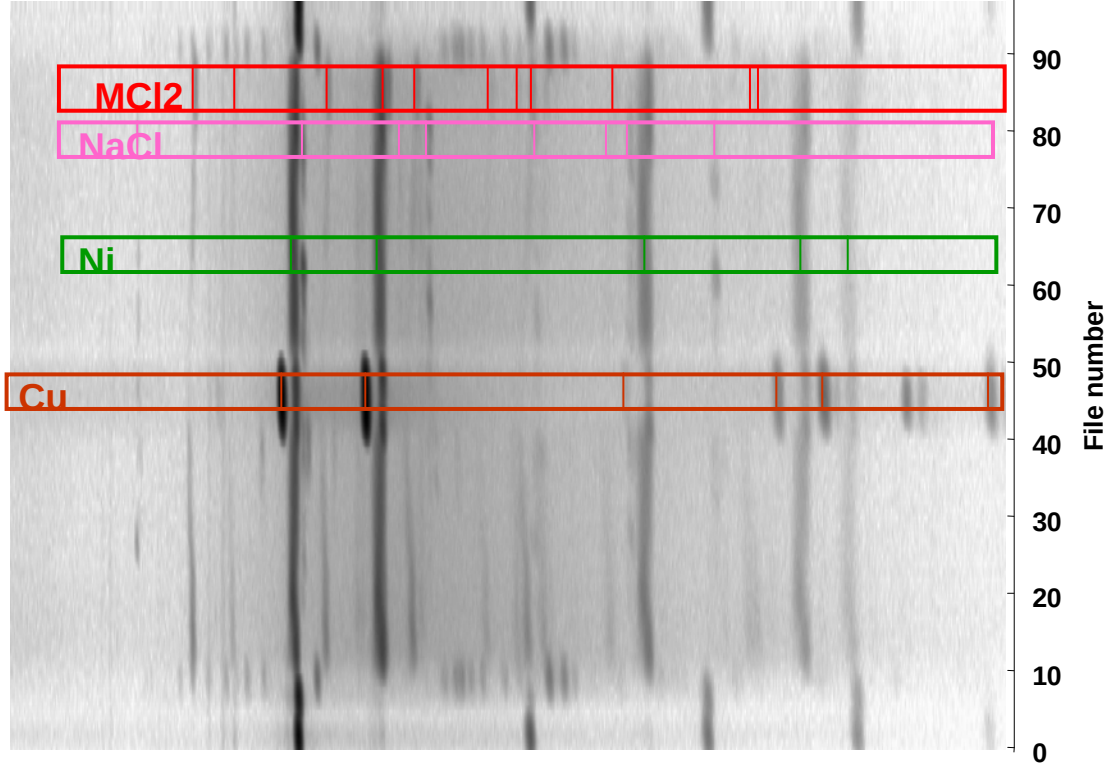
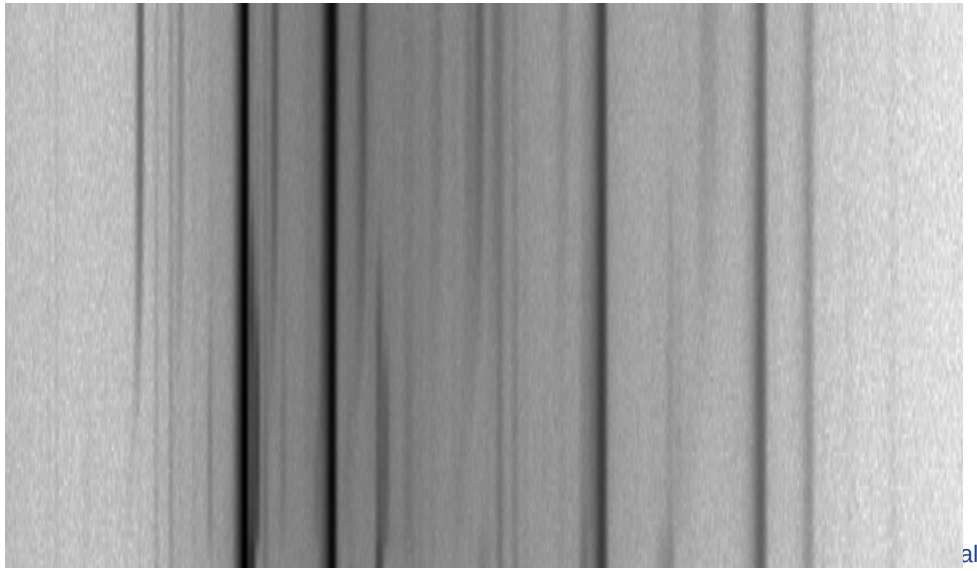


Diagonal scan



In-situ diffraction pattern during charging (beam is fixed to a point inside the cell)

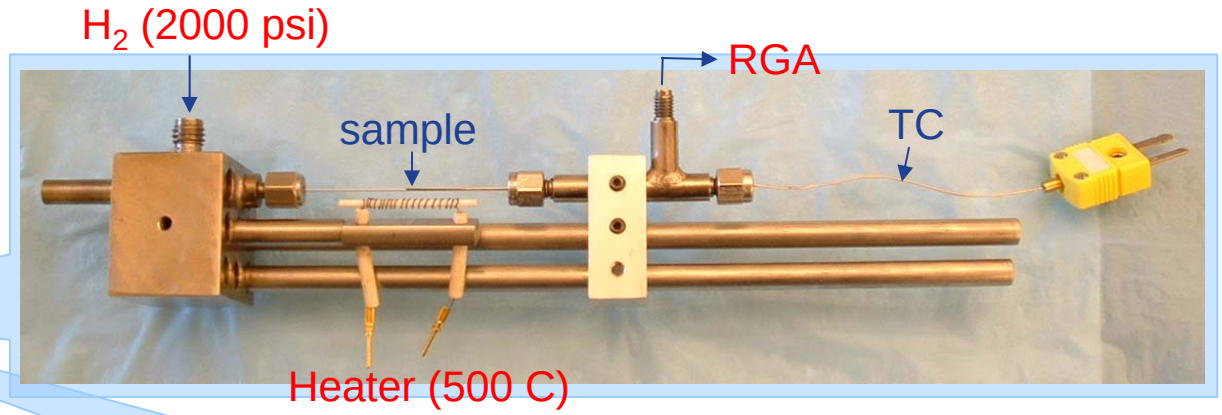
Evolution of MCl2 and disappearance of NaCl with charging

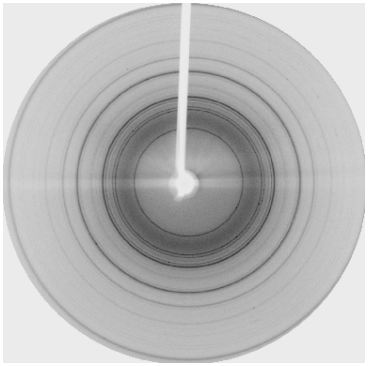


imagination at work Zhong Zhong (BNL), Mark Croft (Rutgers), Job Rijssenbeek (GE-GRC)

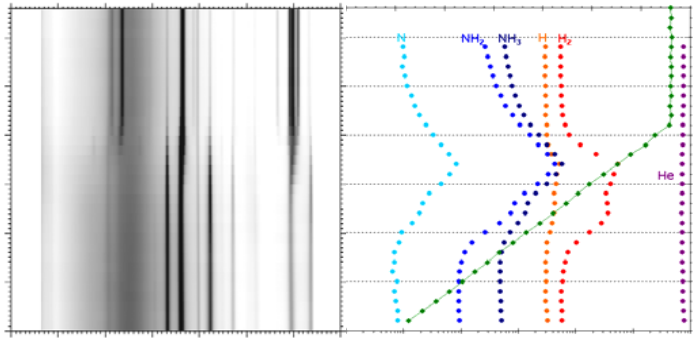
In-situ powder diffraction: hydrogen storage material

X7B, NSLS, USA





2D XRD data



XRD Mass spec

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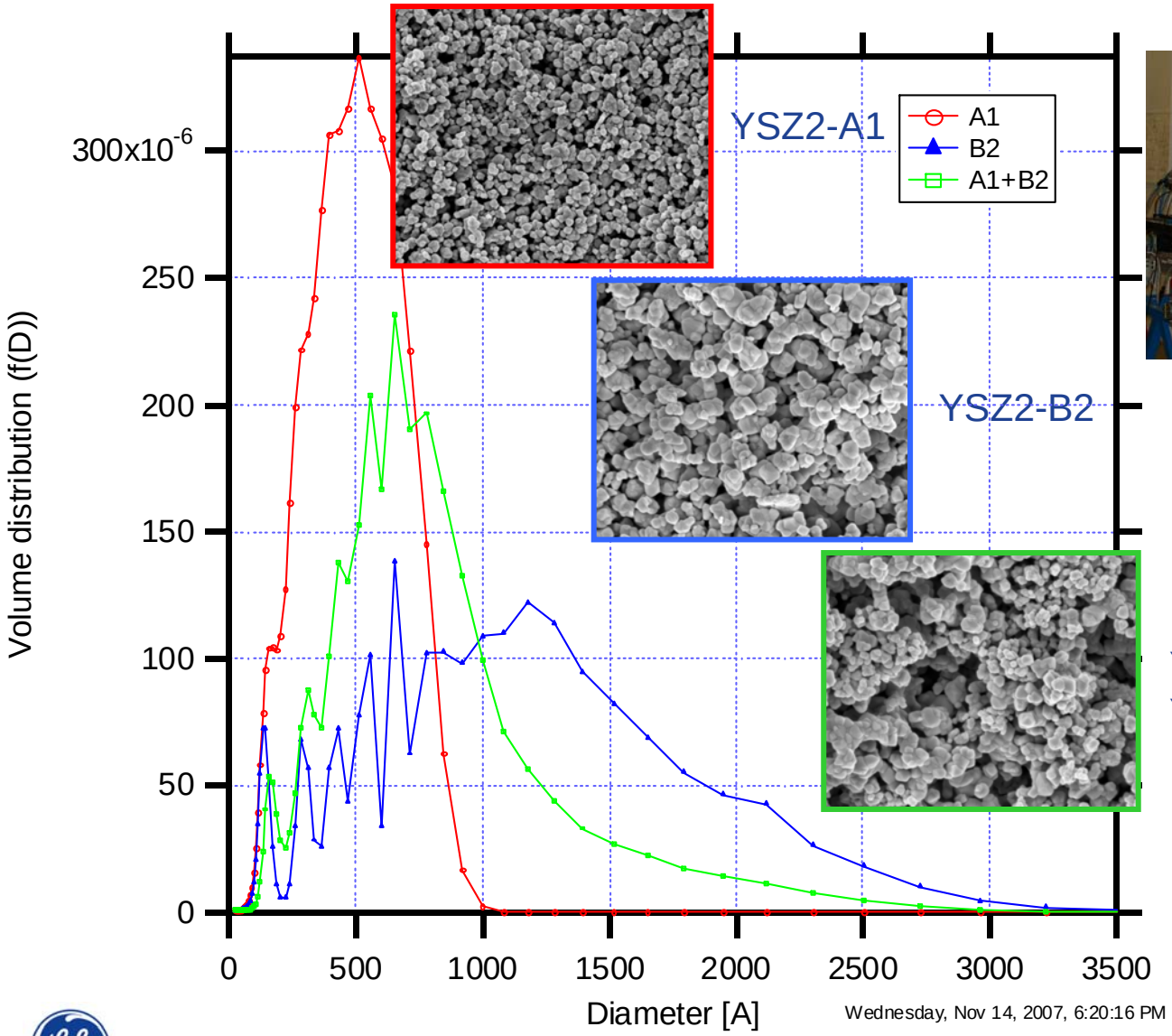
J. Rijssenbeek, G. Soloveichik, J.-C. Zhao (GRC-N), J. Hanson (BNL), J-H Her, P. Stephens (SUNY Stony Brook), Q. Huang, C. Jones, B. Toby (NIST)

Size distribution of nano-oxides by small-angle x-ray scattering



Steve Weigand (APS DND-CAT), Anthony Ku (GE-GRC), Todd Striker (GE-GRC), Pat Willson (GE-GRC), Jim Ruud (GE-GRC)

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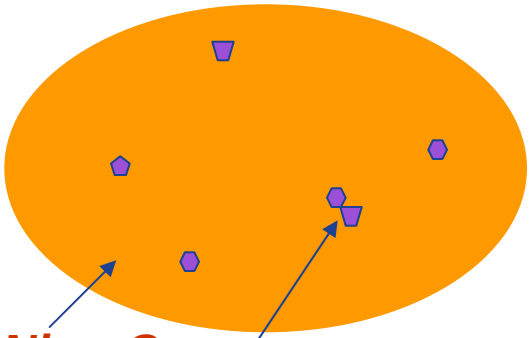
Cast oxide dispersion strengthened (ODS) alloys

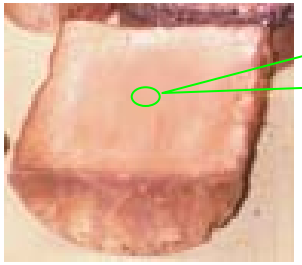
Oxide Dispersion Strengthened A



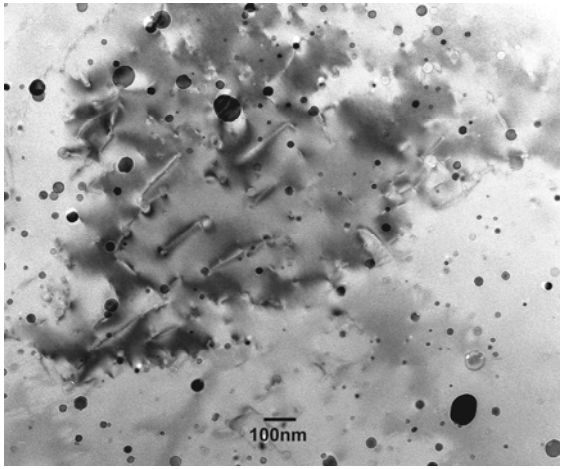
Fe, Ni or Cu

Nano-sized oxide (less than 1 wt%)

Conventional analyses



- *XRD phase analysis*
- *TEM sample: from a tiny area*
- *SAXS sample: thin and small*



TEM micrograph

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Cast oxide dispersion strengthened (ODS) alloys

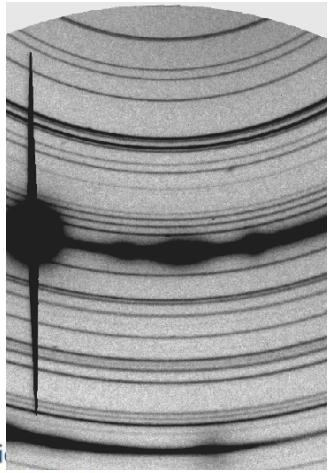
Cross-section of ingot
A few mm thick

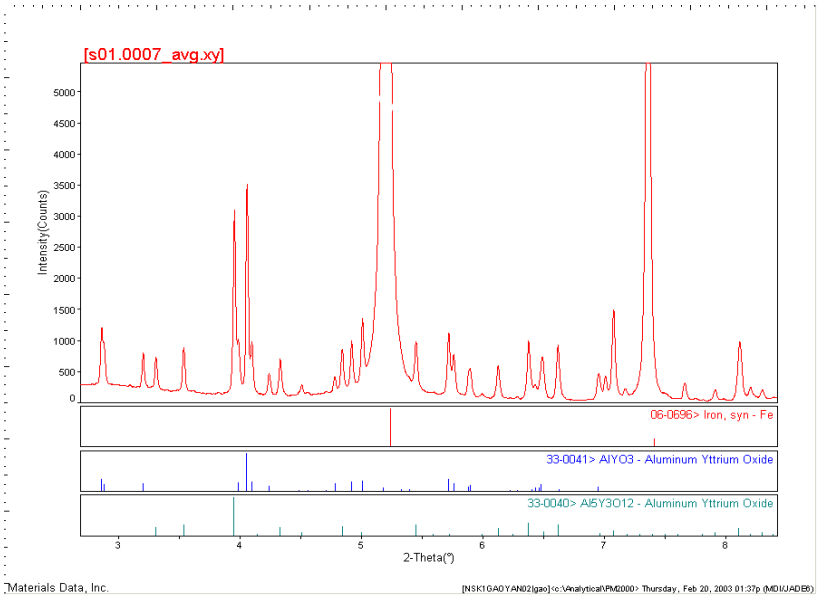
Transmission HE-XRD

- *Phase identification*
- *Oxide dispersion in macro scale*

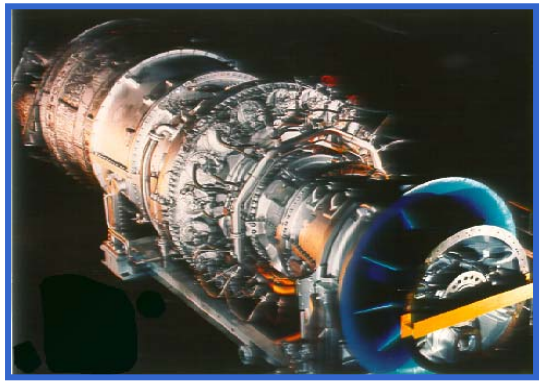
HE-SAXS

- *Oxide dispersion in micro scale*
- *Oxide size and size distribution*





Thermal Barrier Coatings (TBC)

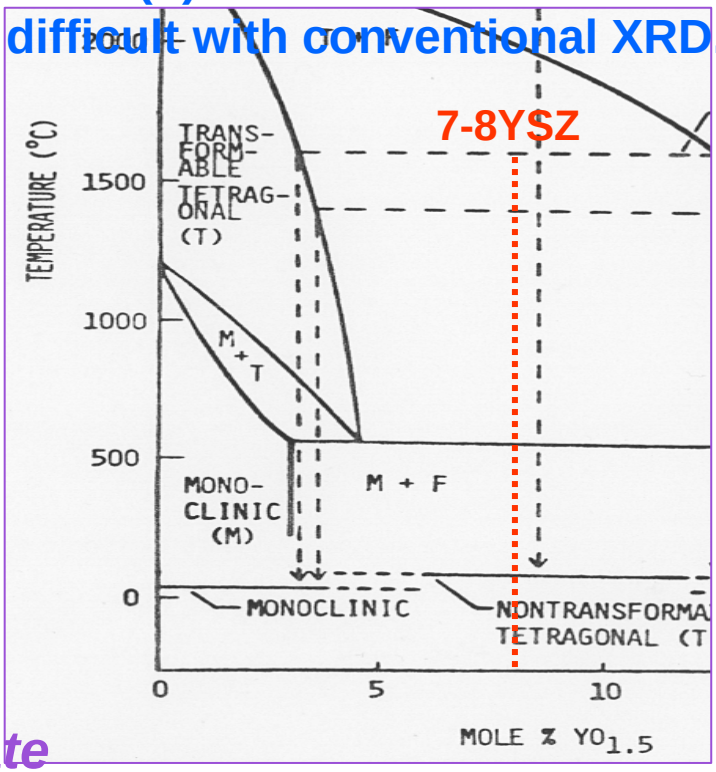


- **Polymorphs: tetragonal, cubic and monoclinic**
- **Separation of tetragonal and cubic peaks**
- **Determination of lattice parameters and c/a': transformable (t) and non-transformable (t')**
- **Texture: difficult with conventional XRD.**

➡ *YSZ*

➡ *Bond coat*

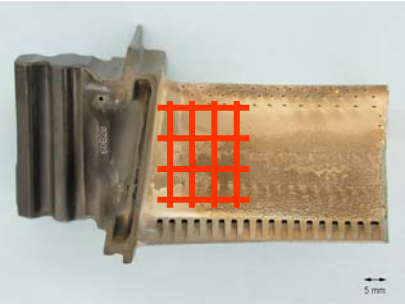
➡ *Superalloy substrate*



Wayne Hasz (GE-GRC), Curt Johnson (GE-GRC), Don Lipkin (GE-

Thermal Barrier Coatings (TBC)

TBC analyses may involve large number of measurements



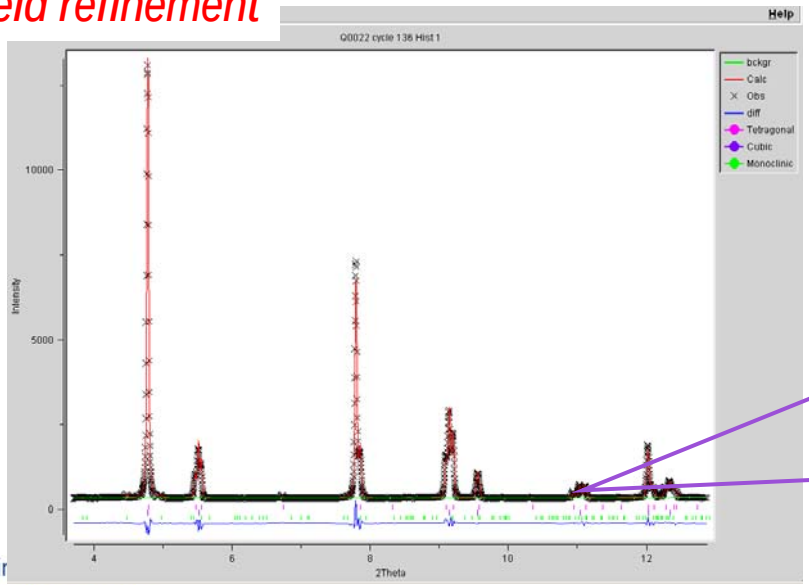
Performance DOE

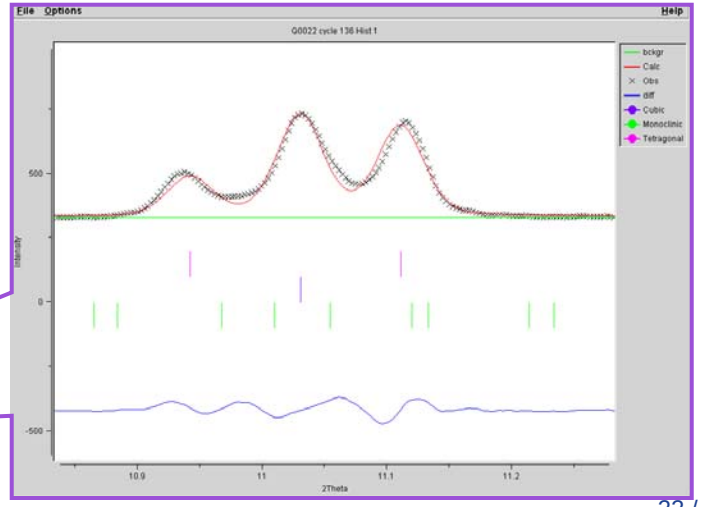
or

	Temperature		
Time	x	x	x
	x	x	x
	x	x	x
	x	x	x
	x	x	x

- *Tetra = 49.9 wt%*
- *Cubic = 47.9 wt%*
- *Mono = 2.2 wt%*
- *Tetra c/a' = 1.0154 → t'*
- *Tetra c/a' → 4.4 mol% $YO_{1.5}$*
- *Tetra c/a' → thermal history*
- *Cubic a → 14.0 mol% $YO_{1.5}$*
- *Peak width → micro-strain*
- *Peak position → macro-strain*

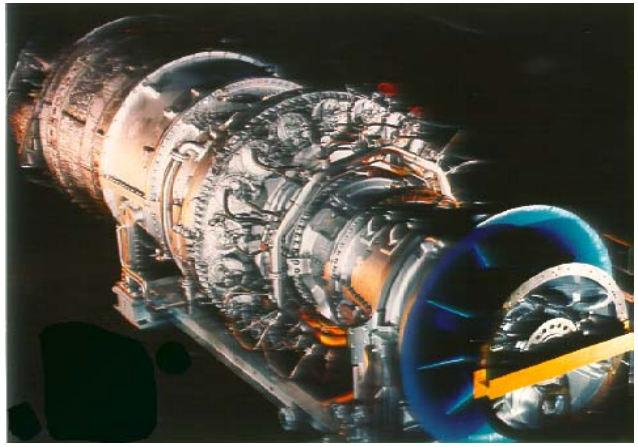
Rietveld refinement

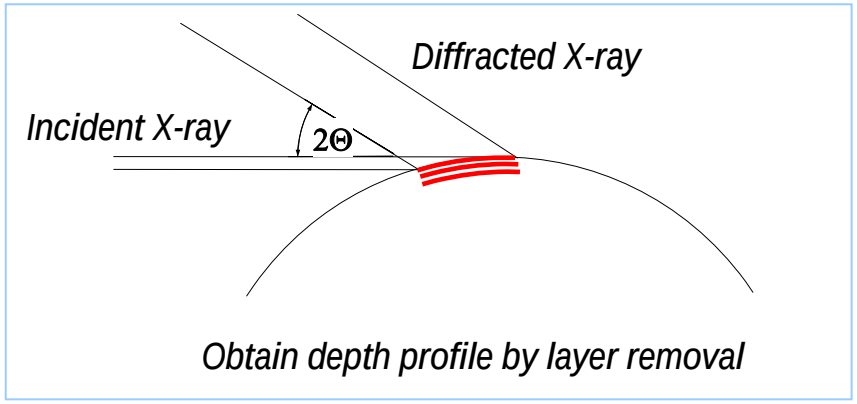


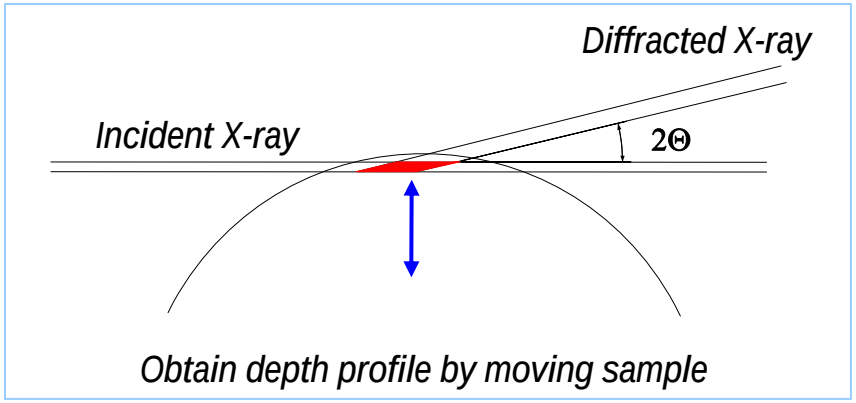


Non-destructive residual stress measurement

Residual stress is a key concern for turbine lifing, and measuring residual stress **accurately** and **non-destructively** is an important industrial need the HE-synchrotron can offer.



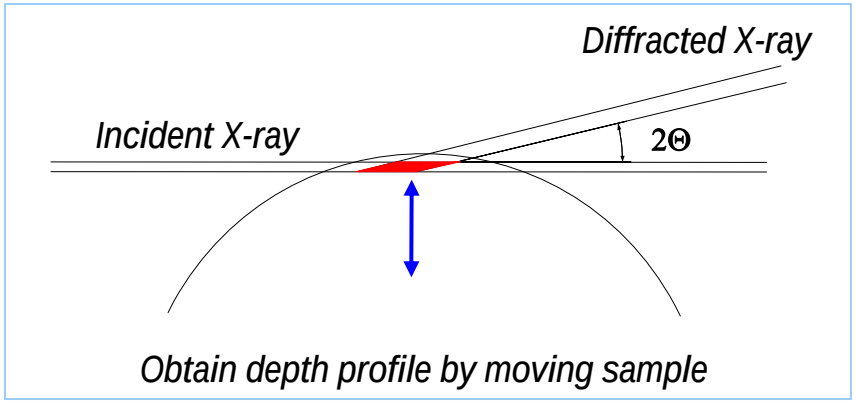


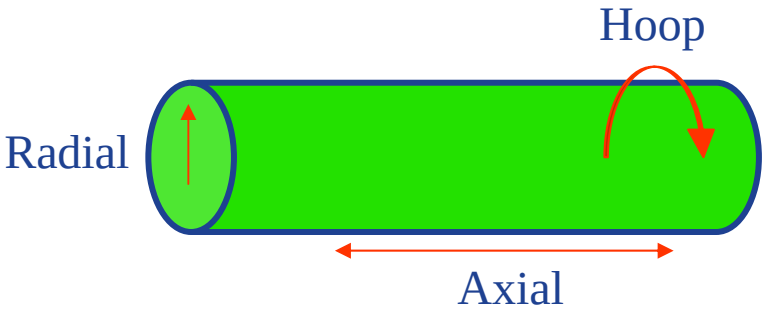


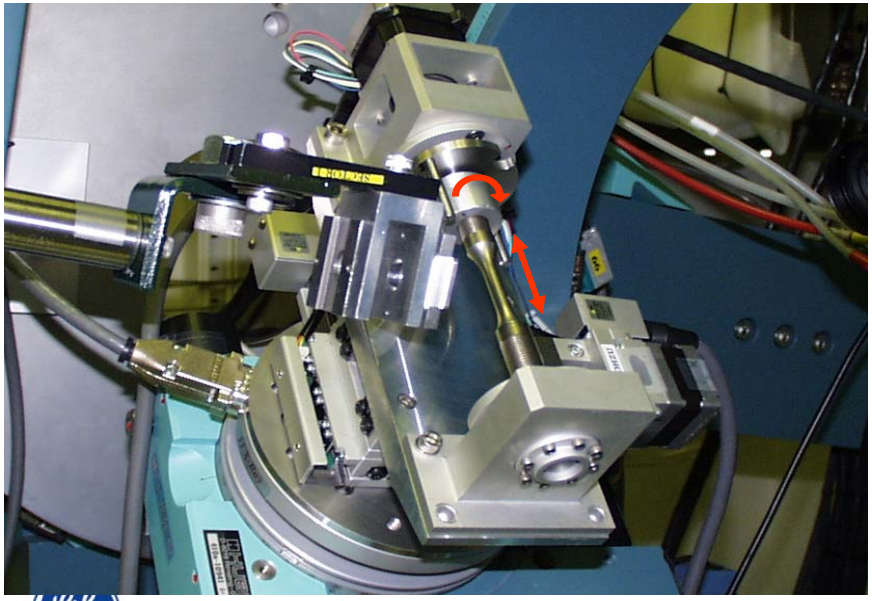
More accurate and sample can be used for further tests or uses

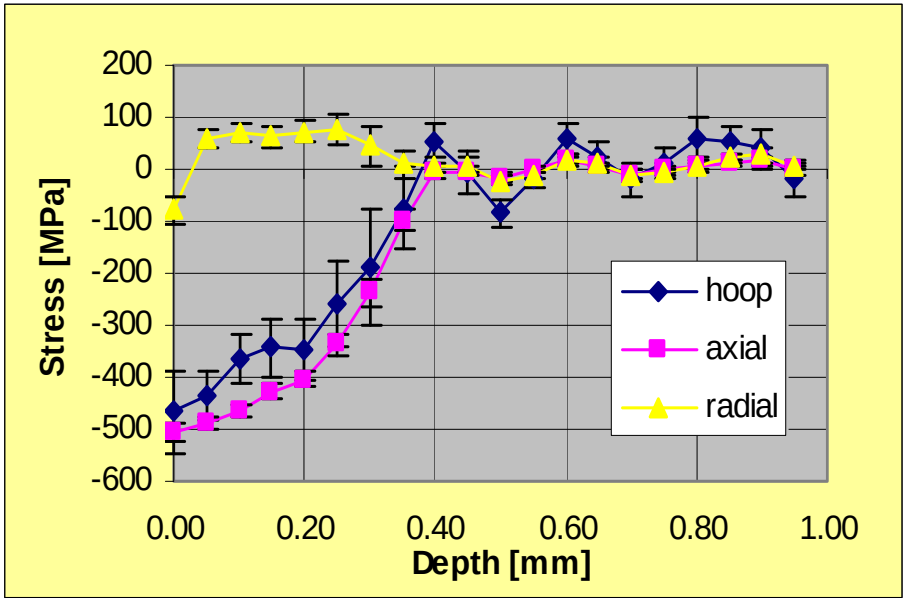
imagination

Non-destructive residual stress analysis



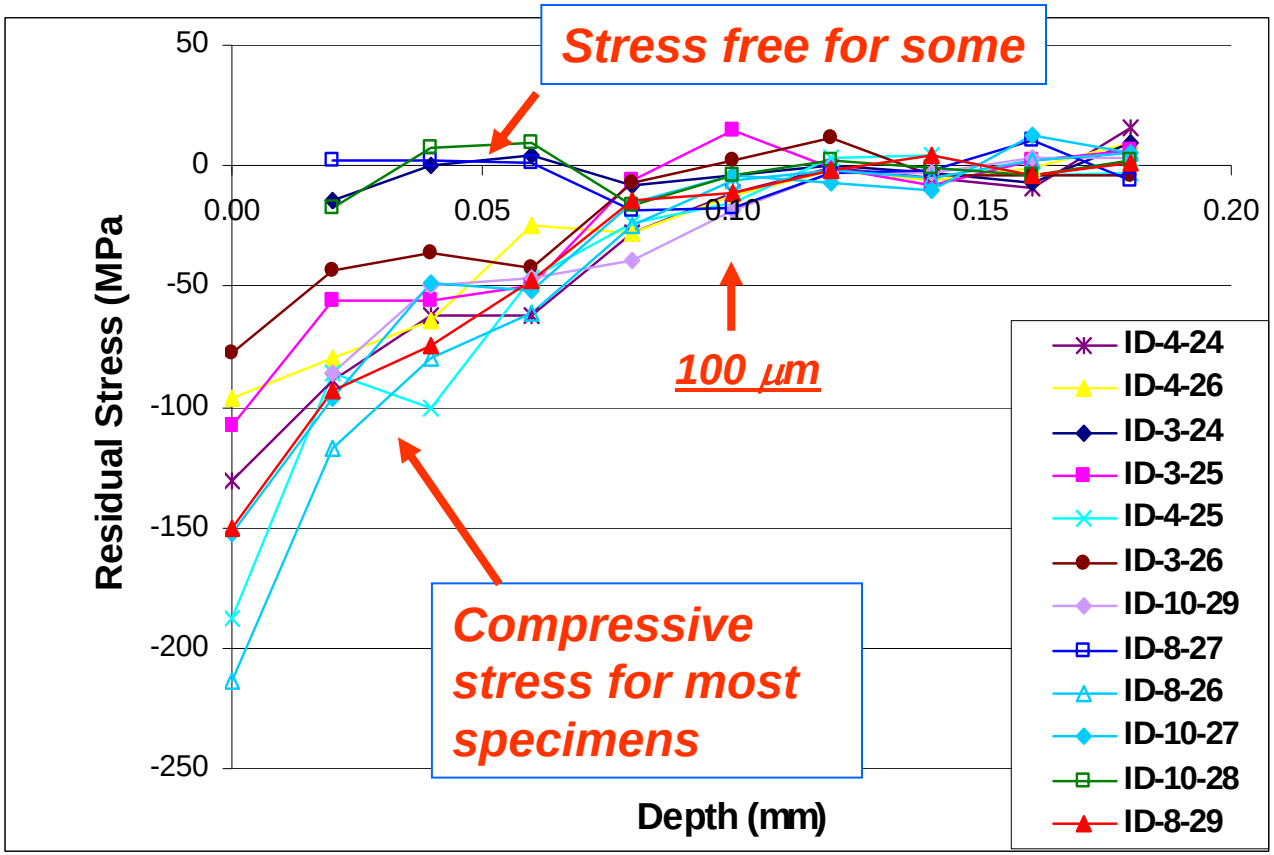






ND residual stress measurement: an industrial case

12 (samples) x 2 (locations) x 10 (steps) = 240 images in 12 hours



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Ulrich Lienert (APS), Bill Carter (GE-GRC), Mike Henry (GE-GRC)

Residual stress measurement

- An analytical tool – not a science, for most cases
- **Scientifically** challenging areas:
  - ✓ 3D x-ray microscope – measuring single grains
  - ✓ Microdiffraction – 3D strain mapping
  - ✓ Non-crystalline materials via PDF method
- **Technically** challenging areas:
  - ✓ Non-destructive strain tensor measurement
  - ✓ Samples with complicated geometry
  - ✓ Large samples
  - ✓ Productivity – many samples

Stewardship of National Facilities – testimony before Congress

- National user facilities are of immense importance to industrial technology development

- Individual companies are not capable of building and maintaining individual facilities

- The relationship with DOE / BES / OS is good, is moving forward, but there are areas for improvement.

An ideal model for industrial access…

- Wide variety of research stations in good working order, staffed by experts, with standardized equipment/software

- Clear and simple website information on modes and mechanisms of industrial access

- Can accommodate research, characterization, process development, problem solving, proprietary studies

- Simple and straightforward proprietary agreements

- Special support for small businesses (students): experts to help design experiments, choose samples, conduct experiments, interpret data; travel money?

On behalf of GE, thank you for all of the support in our past interactions, and moving forward with us into the future

imagination at work

Acknowledgments

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Ralph Gilles (FRM-II)
Michael Hoffmann (FRM-II)
Martin Mühlbauer (FRM-II)
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Mark Croft (Rutgers)
Job Rijssenbeek (GE-GRC)

H-storage:

Jon Hanson (BNL)
Peter Stephens (Stony Brook)
J-H Her (Stony Brook)
Qingzheng Huang (NIST)
Brian Toby (NIST)
Job Rijssenbeek (GE-GRC)
Grigorii Soloveichik (GE-GRC)

SAXS:

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Jim Ruud (GE-GRC)

Residual Stress:

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Bill Carter (GE-GRC)
Mike Henry (GE-GRC)

TBC:

Wayne Hasz (GE-GRC)
Curt Johnson (GE-GRC)
Don Lipkin (GE-GRC)