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Hydrogen Isotope Permeation and Trapping in Additively Manufactured Stainless Steel

Richard Karnesky, Paul Chao, Dean Buchenauer
Sandia National Laboratories, Livermore CA

Tritium Focus Group, PNNL
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- Customers, permeation process, capabilities
- Examples of diatomic gas-driven permeation
  - W for fusion, AM steel
- Atomic driven permeation through aluminide barriers
- Current efforts

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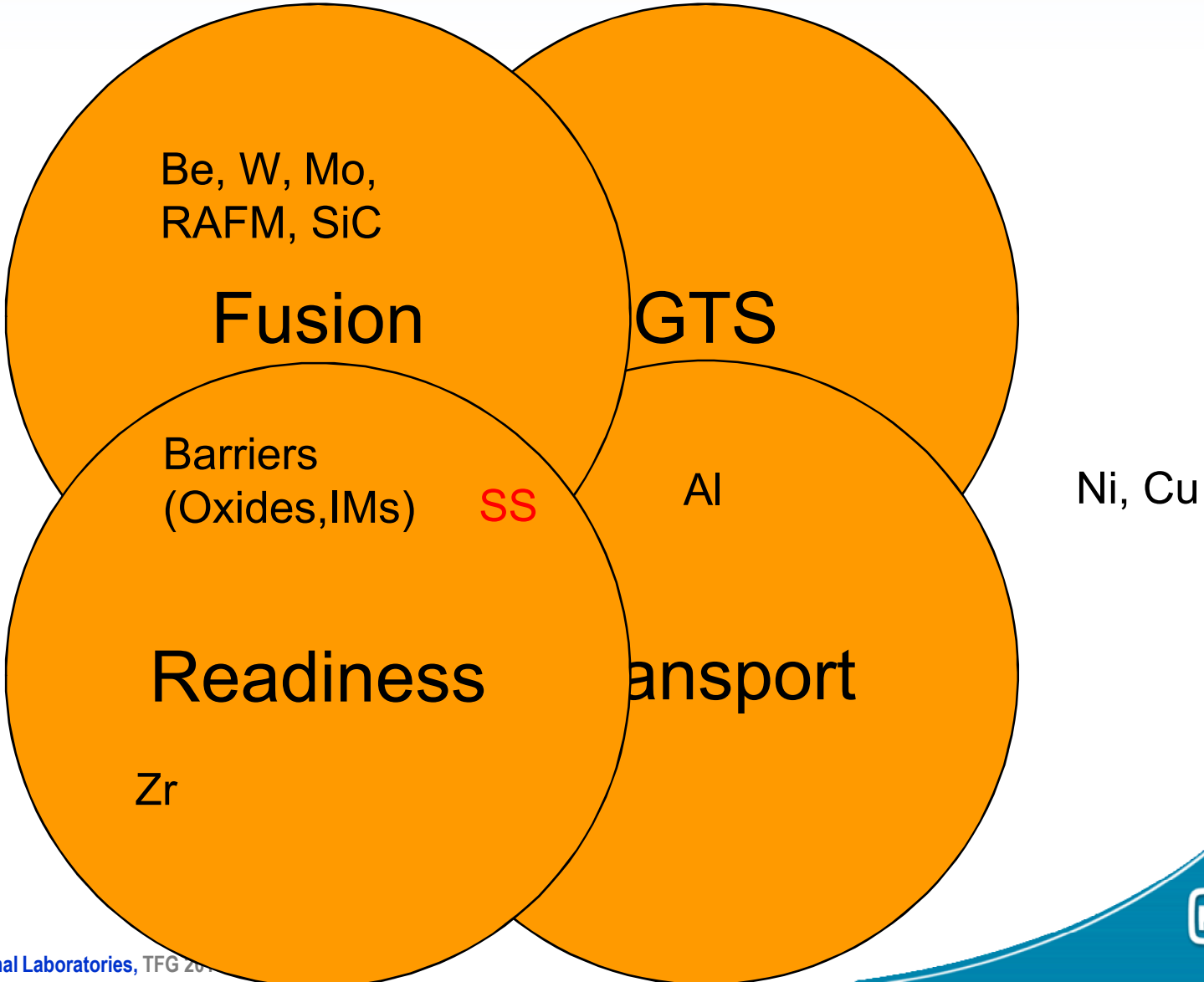
Stainless Steel is Used by Many Hydrogen Customers



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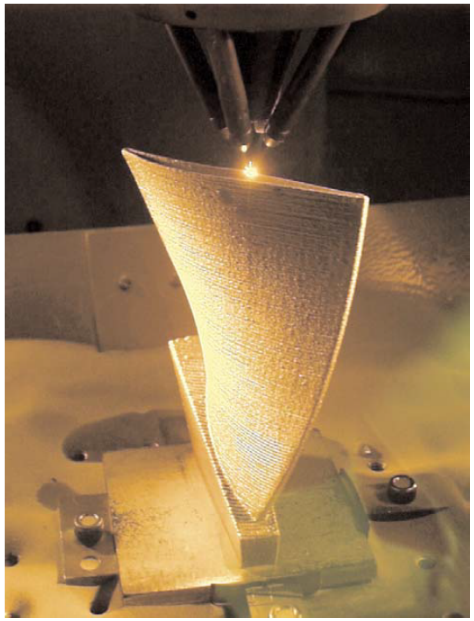
Additively Manufactured 304/316 Steel Processes

- DED/LENS (Direct Energy Deposition/Laser Engineered Net Shaping)
- PBF (Powder Bed Fusion)



Blade made from LENS

SAND2002-3539W; *Laser Engineered Net Shaping*; David Gill

Varying Cooling Rates

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Dislocation Density

Powder Characteristics

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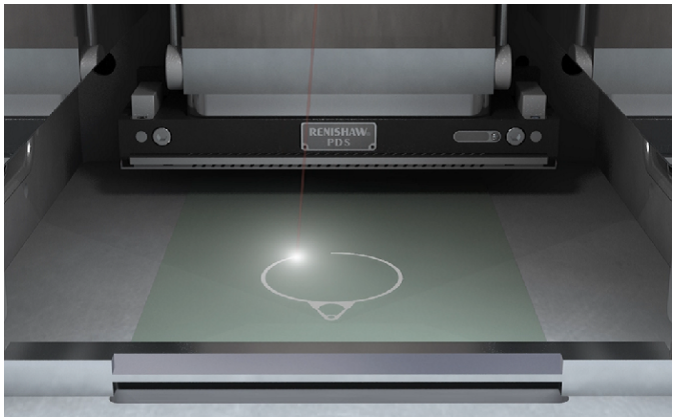
Interstitial Nitrogen



PBF on Renishaw

http://www.renishaw.com/en

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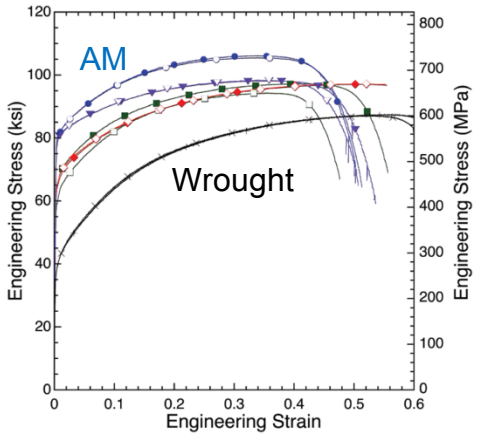
Motivation: Strength, Shaping, Repair

Balch et al. (2016)



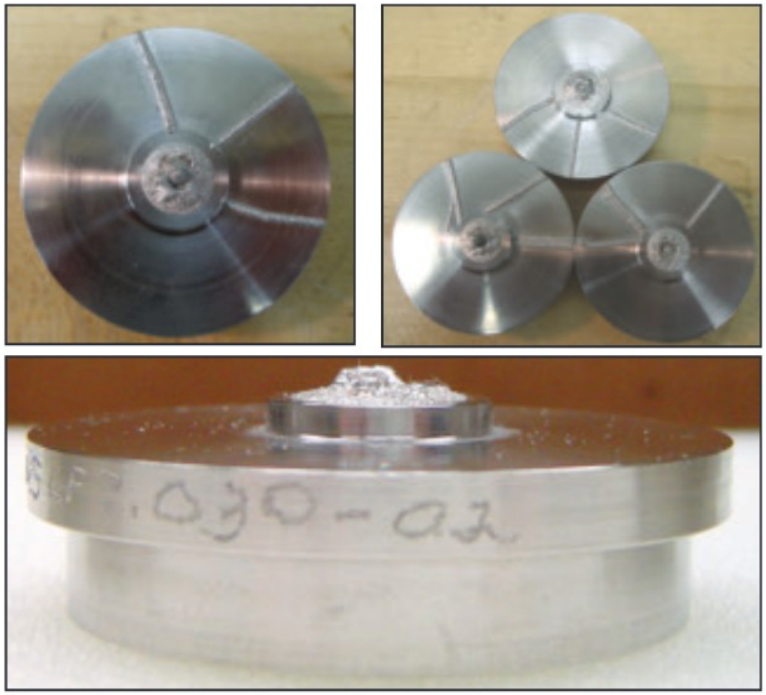


Fig. 6 — Bore and radial repaired scratches on the surface of the weld bases.

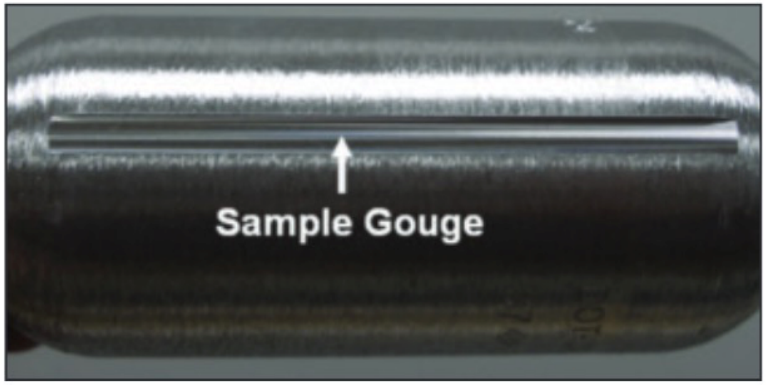
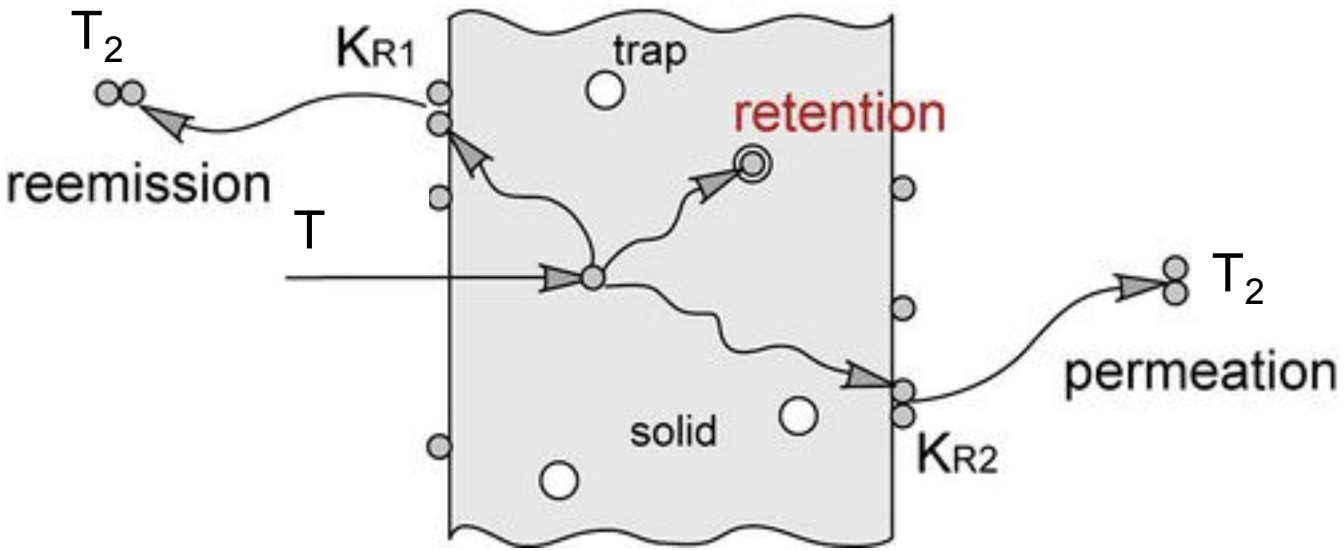


Fig. 7 — Sample gouge in sample gas bottle. Gouges were 0.125 in. wide and either 0.010 or 0.020 in. deep.

Looked at five different builds

ID	Powder	Process	Geometry	Ferrite
LENS1	316	LENS-0.325 kW	Wall	1.1
LENS2	316L	LENS-0.5 kW	Plate	0.3
LENS3	304L	LENS	Wall	0.9
DLPD	304L	DLPD-3.8kW	Plate	2.7
PBF	304L	PBF	Plate	<0.2

Schematic of T permeation, trapping



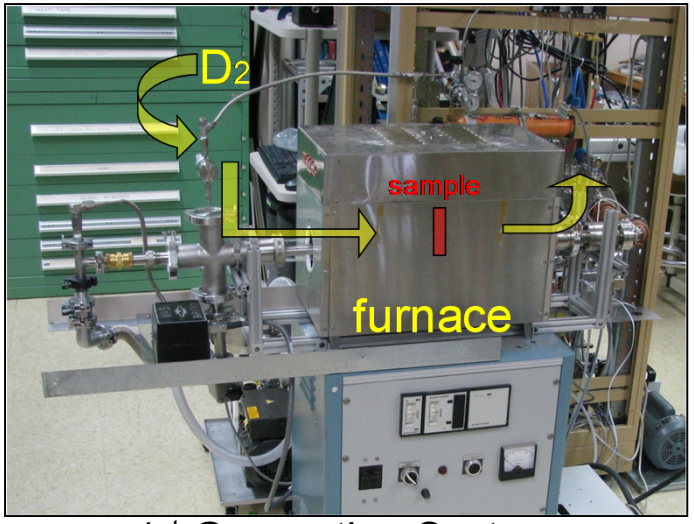
Most materials exhibit diffusion-limited permeation at sufficient pressures
Recombination is often neglected because it is fast
(e.g. K_R ~ 1e-16 cm^4/s for Ni)

After Mayer

Permeation Experiments at Sandia California

- **Deuterium gas driven permeation capabilities presently in use at SNL**
  - 1st generation (150 < T < 500 ° C) used stainless steel construction (VCR seals), evacuated quartz outer tube to reduce D_2 bypass, and low flow to prevent surface contamination

Materials studied: stainless steels, steel alloys, welds, aluminum alloys, nickel, AM steel



1st Generation System

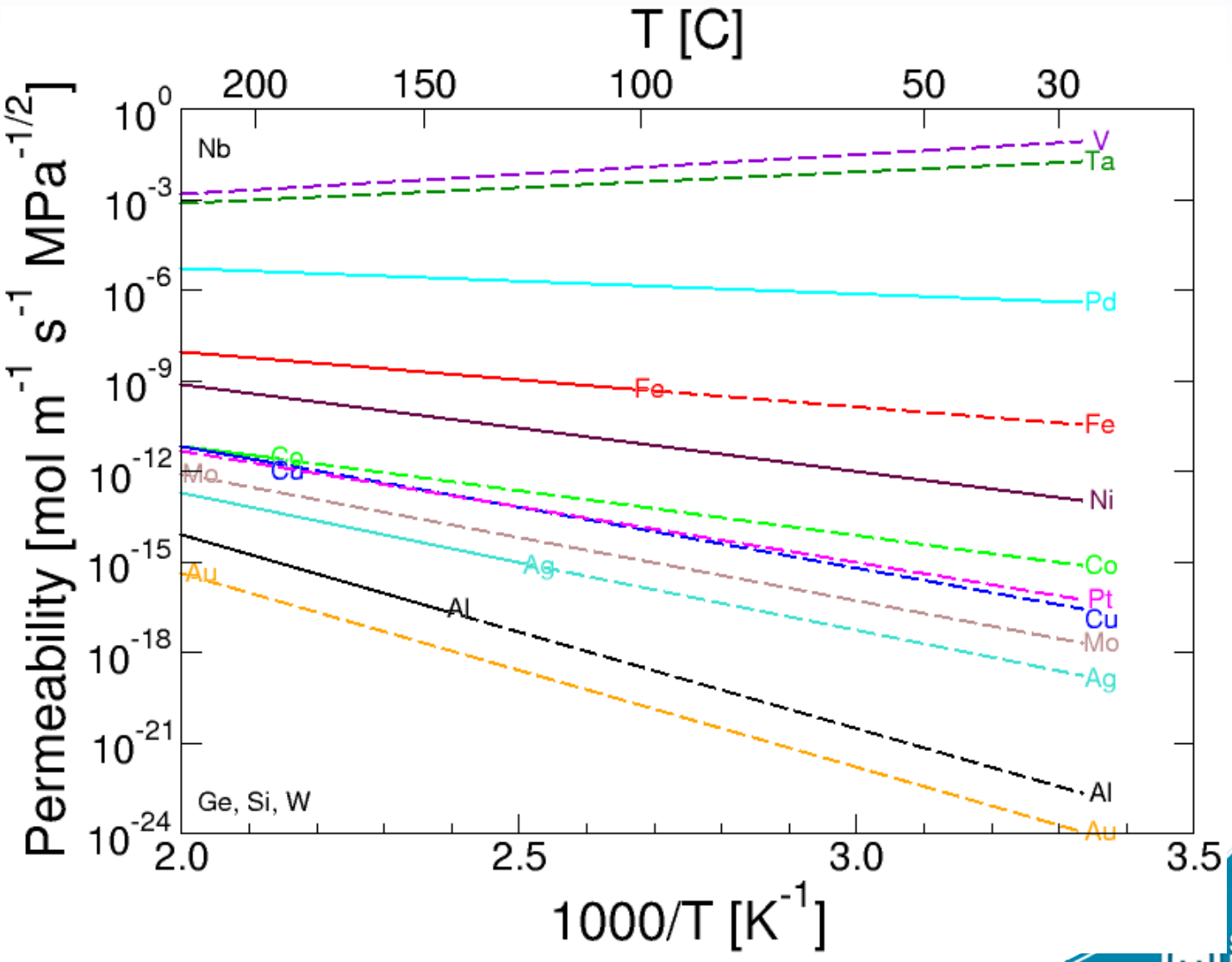
  - 2nd generation (50 < T < 1150 ° C) uses Al_2O_3 construction and soft, pressure loaded seals for brittle specimens (funded by "Work For Others" program to measure SiC permeation barriers for fusion blankets)

Materials studied: stainless steels, SiC, tungsten

$P_{SiC} < 10^{-12}$ mol H^2 m^{-1} s^{-1} $MPa^{-0.5}$

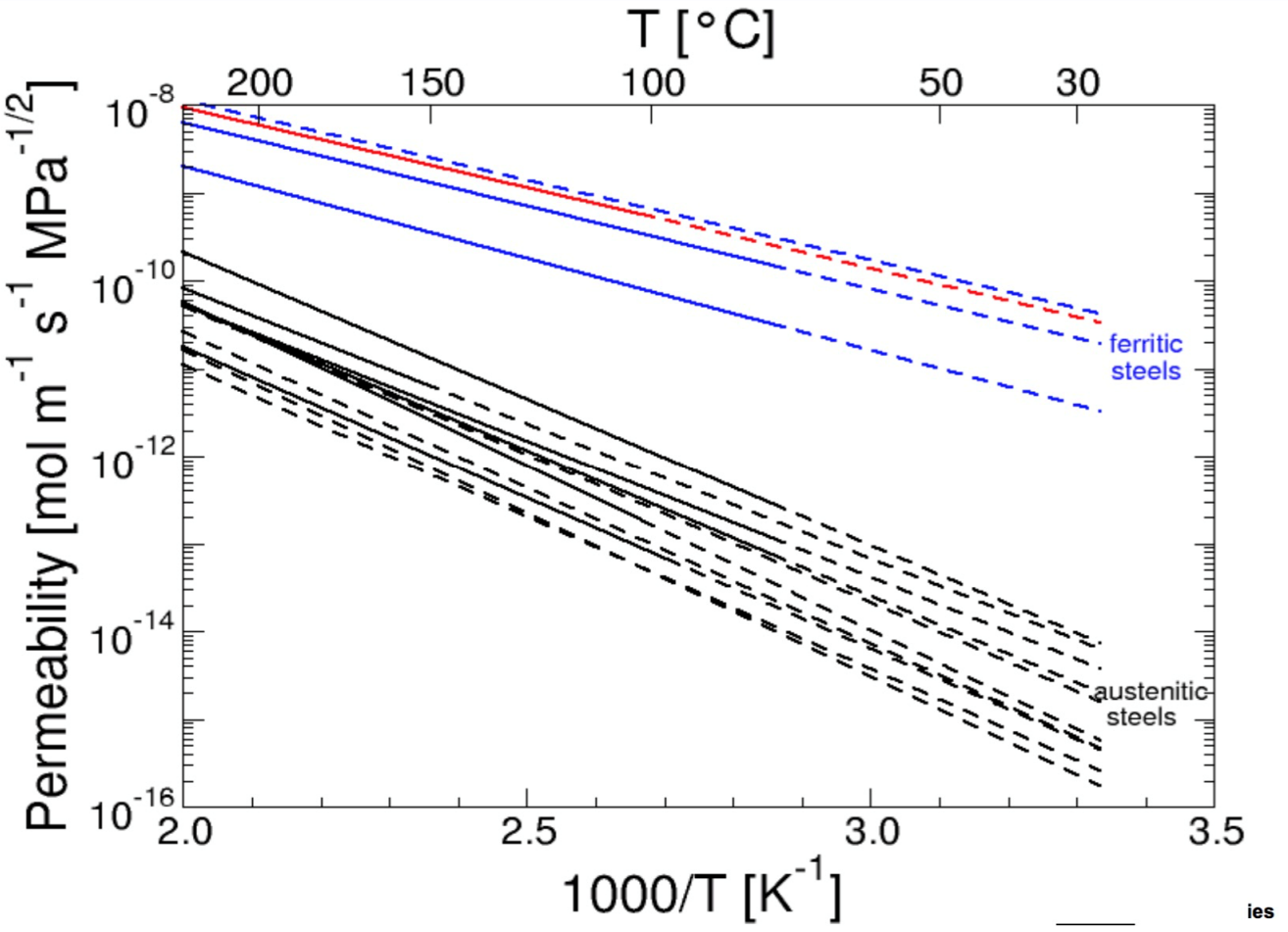
2nd Generation System

Permeability of metals

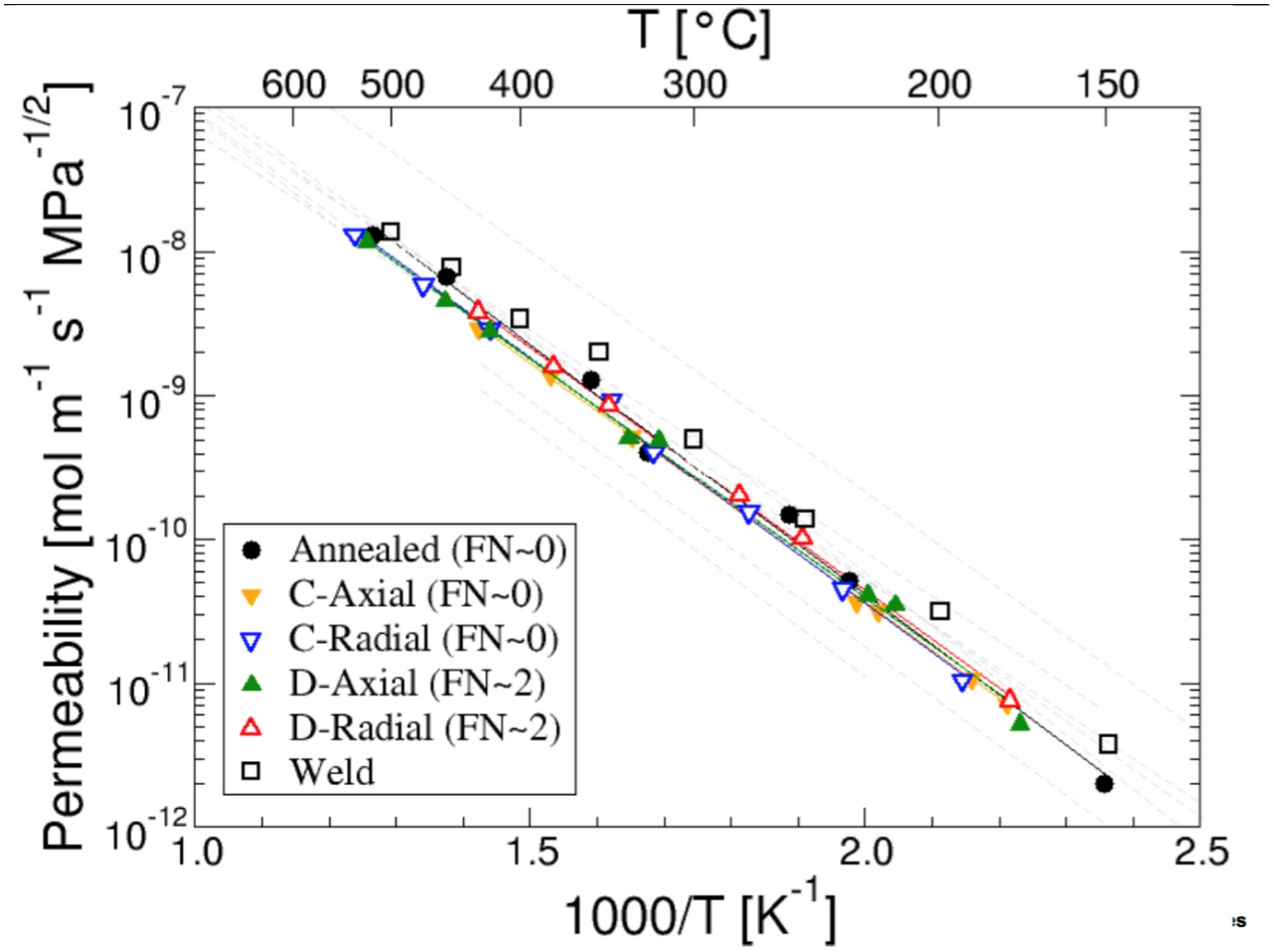


Causey, Karnesky, San Marchi, "Tritium Barriers and Tritium Diffusion in Fusion Reactors" 2012

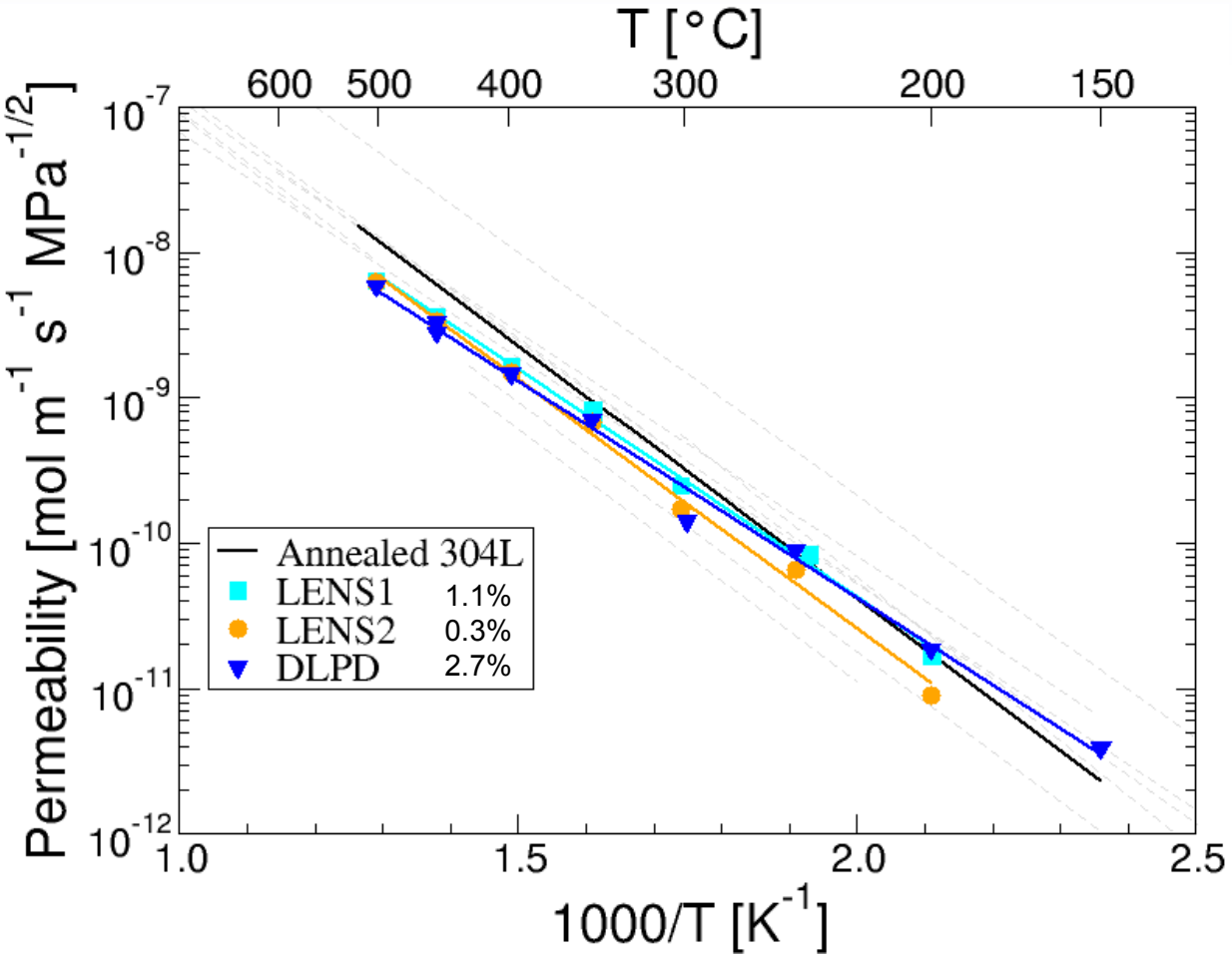
Ferritic steels are much more permeable than austenitic steels



But modest ferrite additions don't increase permeability



And AM steels have similar permeabilities, regardless of ferrite content



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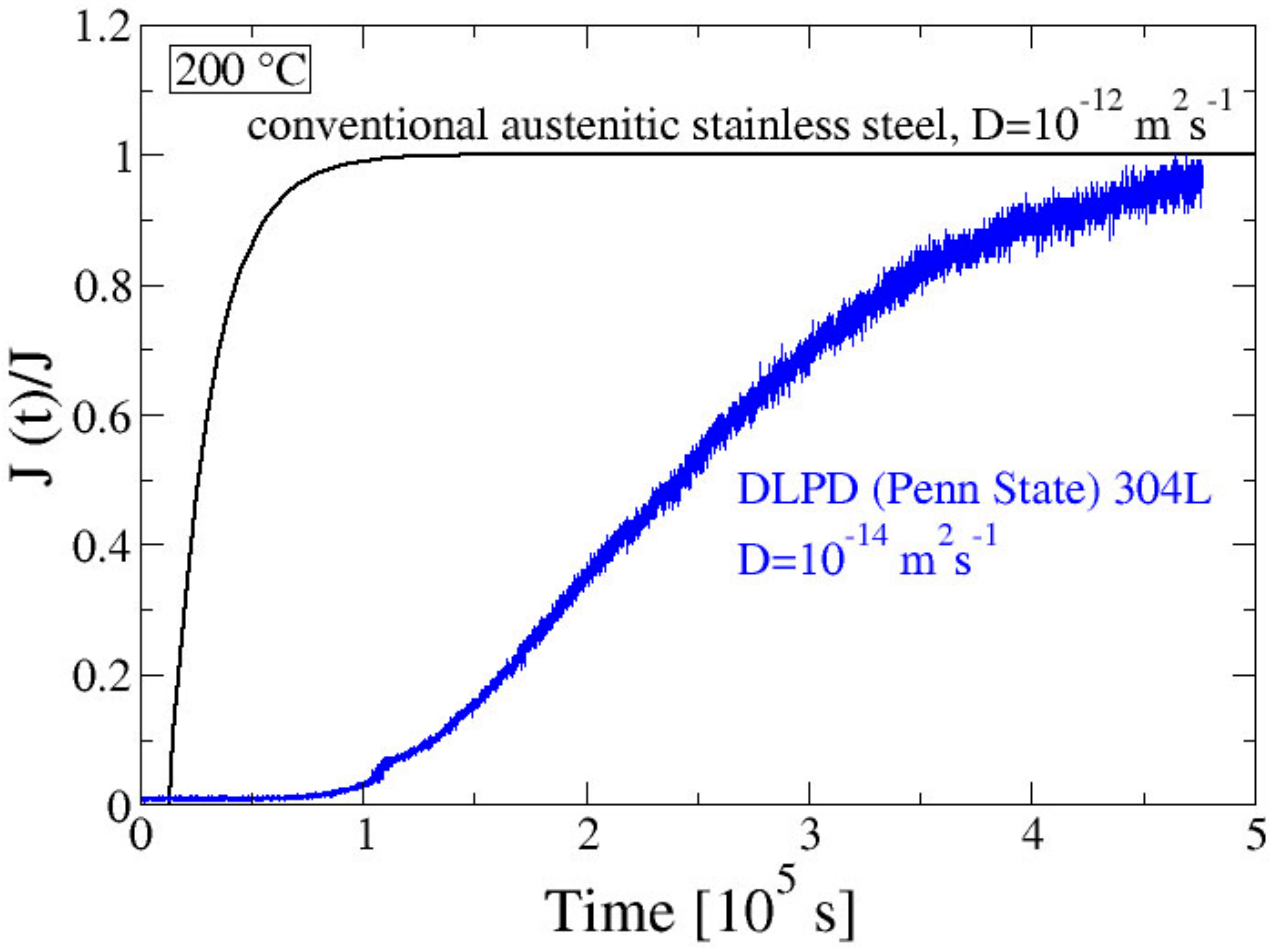
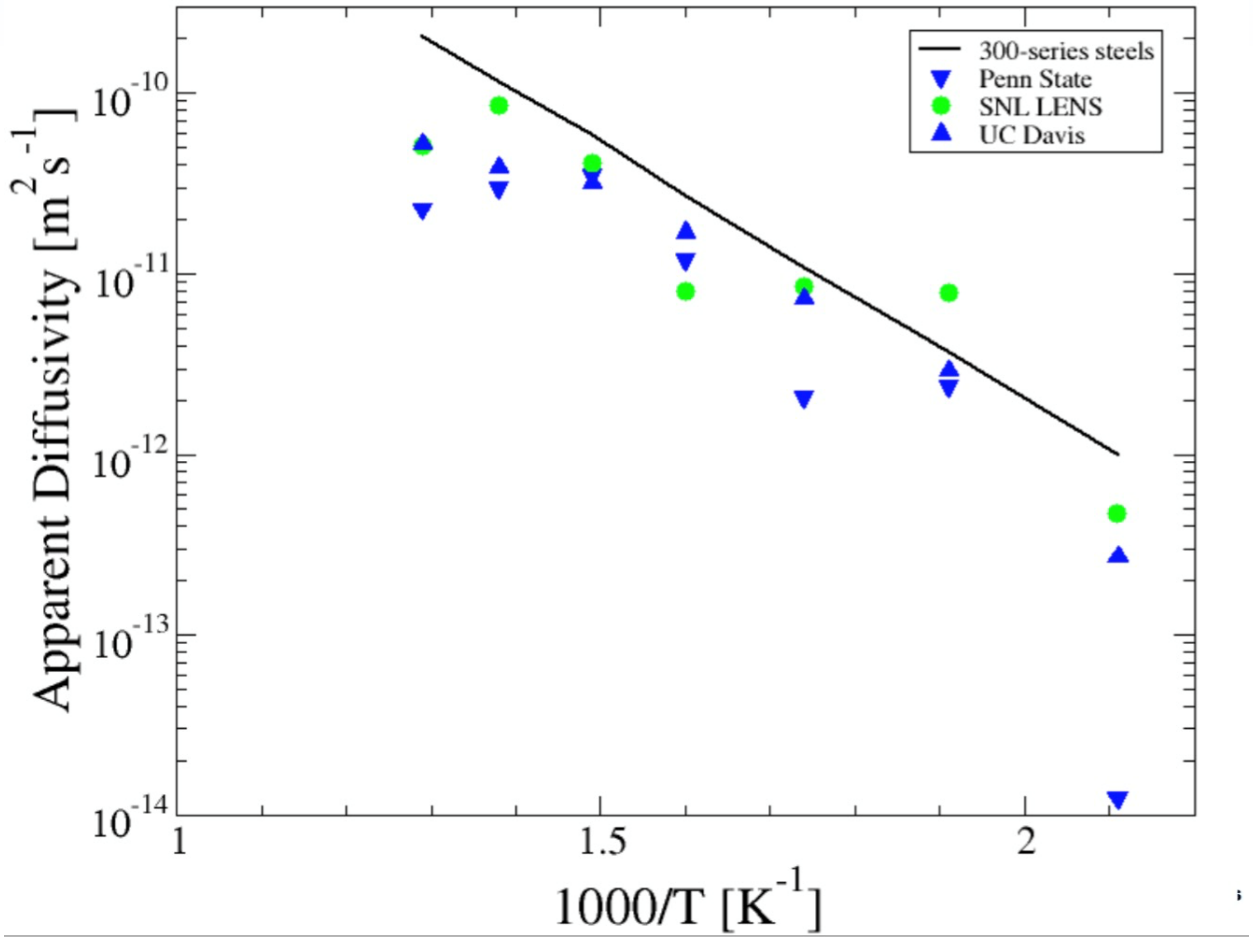
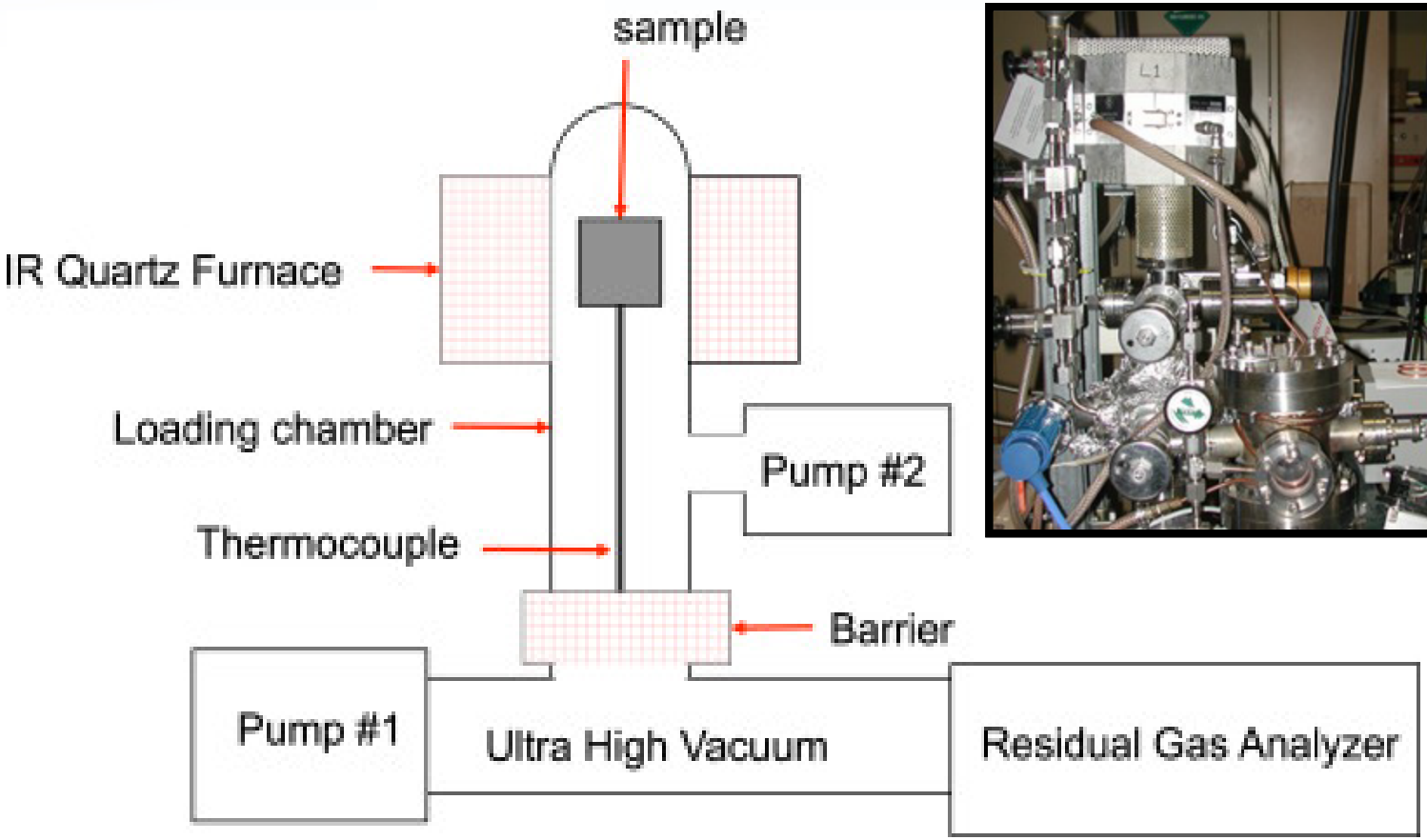
But slow transients suggest trapping



Low apparent D, even at high T

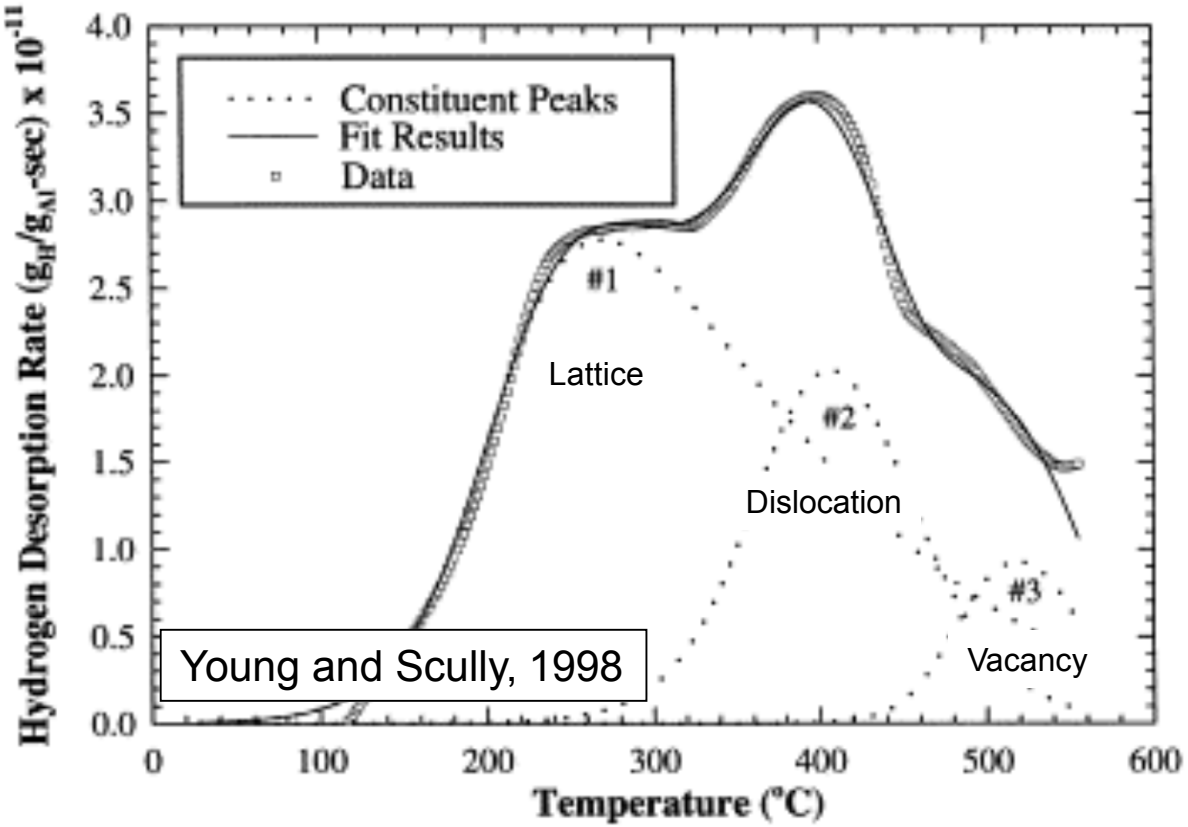


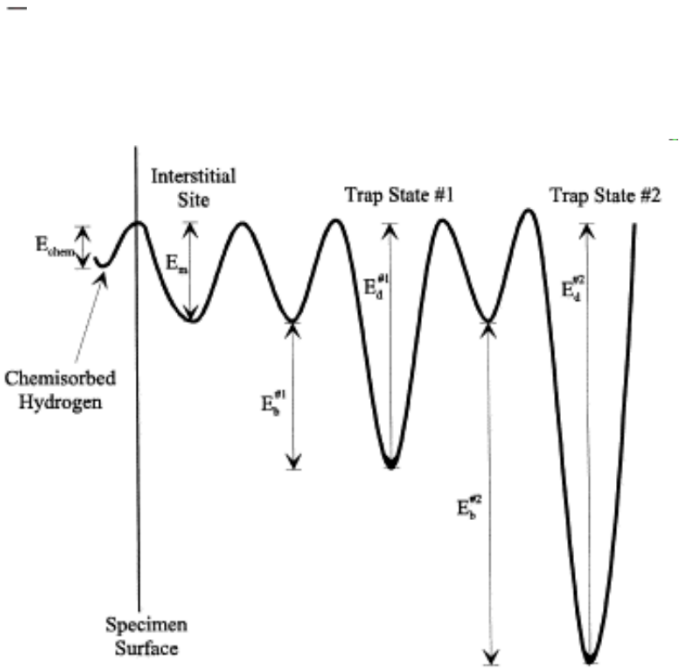
Thermal Desorption Spectroscopy



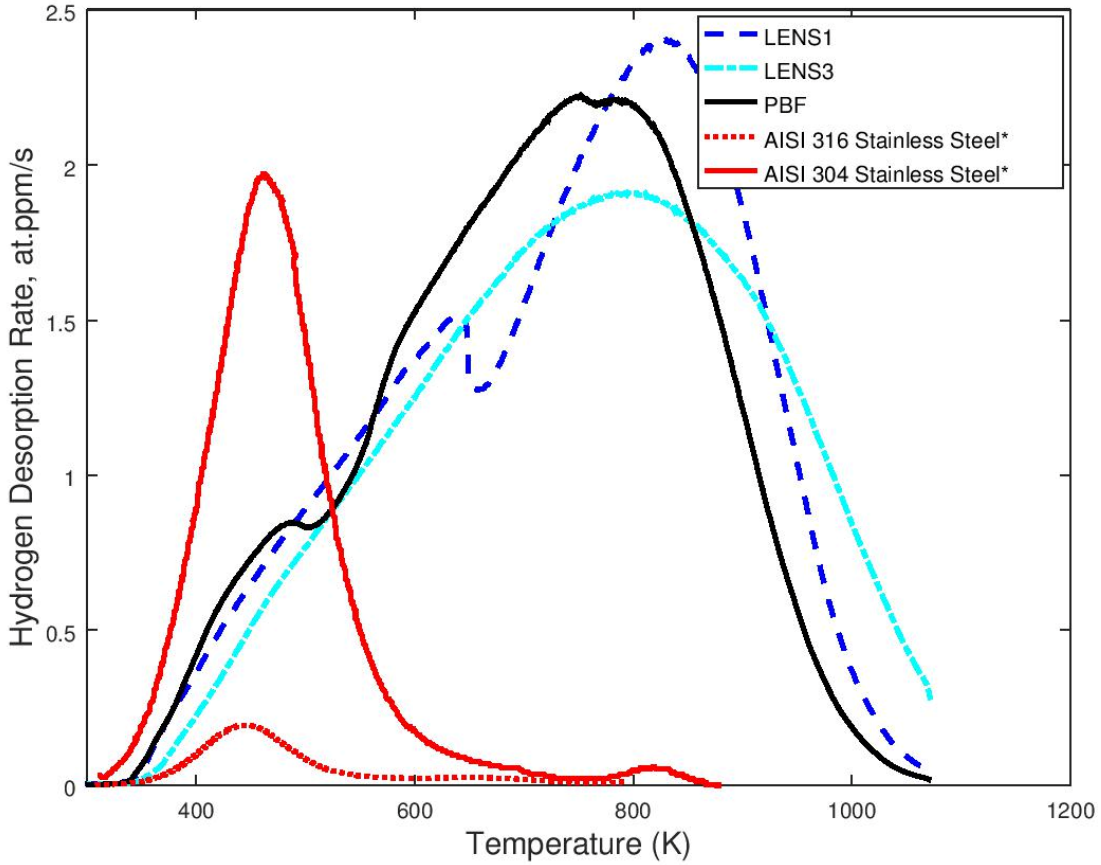
Chao, Paul, and Richard A. Karnesky. "Hydrogen Isotope Trapping in Al–Cu Binary Alloys." *Materials Science and Engineering: A* 658 (2016): 422-28.

Schematic of trapping





AM shows higher energy traps



AM steels have slightly greater amounts of H

ID	Hydrogen isotope content [wt. ppm]*
Conventional [8]	140
LENS1	160±30
LENS3	150±20
DLPD	140±20
PBF	170±20

Summary

- **Permeation of AM is within a factor of 2 of conventional, despite ferrite levels of up to 2.7%**
- **Greater retention/trapping in AM**
  - Dislocations?