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TEXAS
The University of Texas at Austin

UT-NETL PROMPT GAMMA RAY ACTIVATION ANALYSIS FACILITY

NSUF New Facilities Briefing

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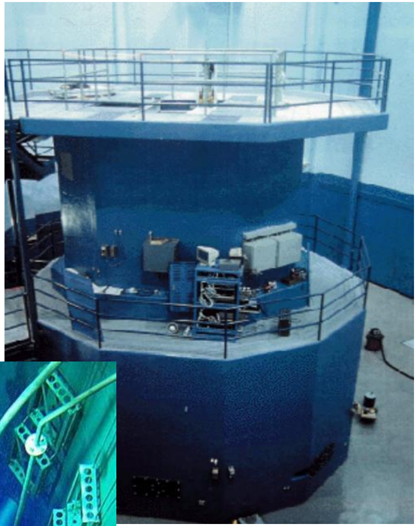
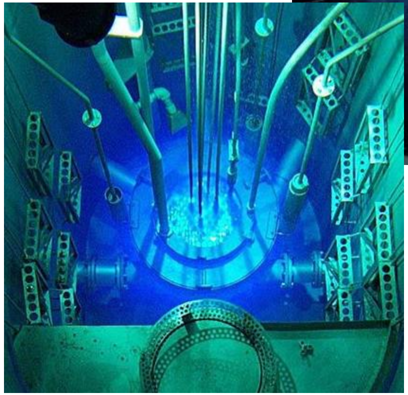
UT-NETL Reactor

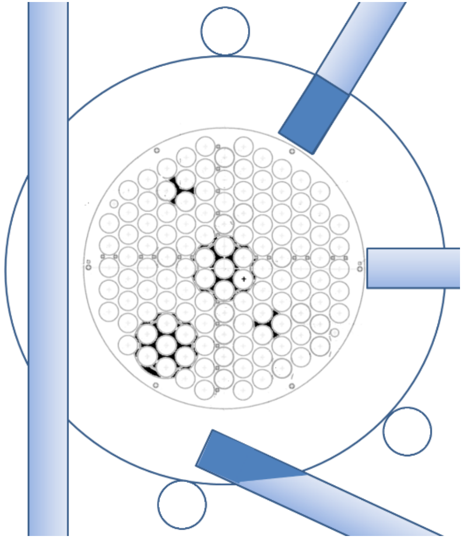
- The University of Texas at Austin - NETL is home to a 1.1 MW TRIGA Mark II reactor with initial criticality in 1992
  - reactor is principally designed as a neutron beam facility and includes a Prompt Gamma-ray Activation Analysis (PGAA) system with a cold neutron source
- NETL includes numerous additional radiation sources:
  - Thermo MP320 14-MeV Neutron Generator ($1x10^8$ n/s with a pulse rate up to 20 kHz)
  - Pu(Be) and Cf-252 Neutron Sources
  - Calibrated α, β, and γ Radiation Sources
    - Including a MultiRad 350 irradiator at 20 Gy/min dose rate





Reactor Facilities

- In-Core Irradiation Facilities
  - Pneumatic Transfer Facility (3×10^{12} n/cm^2-s)
  - 3-Element Irradiator (1×10^{13} n/cm^2-s)
  - 3-Element Irradiator with Cd liner (2×10^{12} n/cm^2-s)
  - 7-Element Irradiator
  - Rotary Specimen Rack (3×10^{12} n/cm^2-s)
  - Central Thimble Facility (3×10^{13} n/cm^2-s)
- Beam Port Facilities
  - Radiation Effects Horizontal Port
  - Cryogenic Gas Irradiation Facility
  - Prompt-Gamma Activation Analysis with Cold Neutron Source
  - Fast Neutron Beam Facility
  - Neutron Radiography



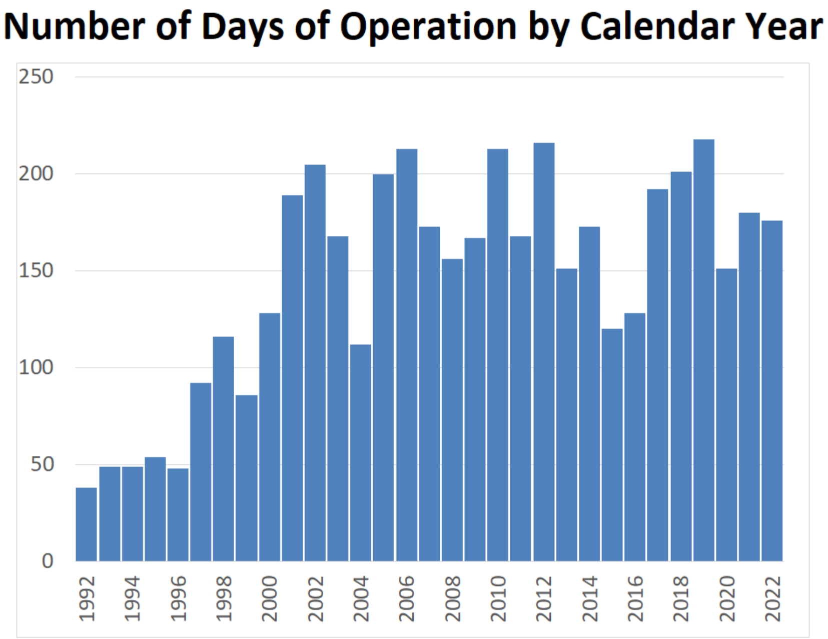
Laboratory Facilities

- Analytical Laboratories
  - NAA Laboratory
  - Radiation Effects and Detector Development Laboratory
  - Gamma-Ray Spectroscopy Laboratory
  - Chemistry and Sample Preparation Laboratory
  - Radioactive Experiment and Radiochemistry Laboratory
  - Hot Cell Laboratory
- Detector Systems
  - Three Compton Suppression γ-Ray Spectroscopy Systems
  - β-γ and γ-γ Coincidence and α-Spectroscopy System
  - HIDEX 300 SL Liquid Scintillation Counter
  - Mirion TLD Reader and Oven
  - Numerous Portable Instruments
- Nuclear and Applied Robotics
  - Develop and deploy advanced robotics in hazardous environments to minimize risk for the human operator



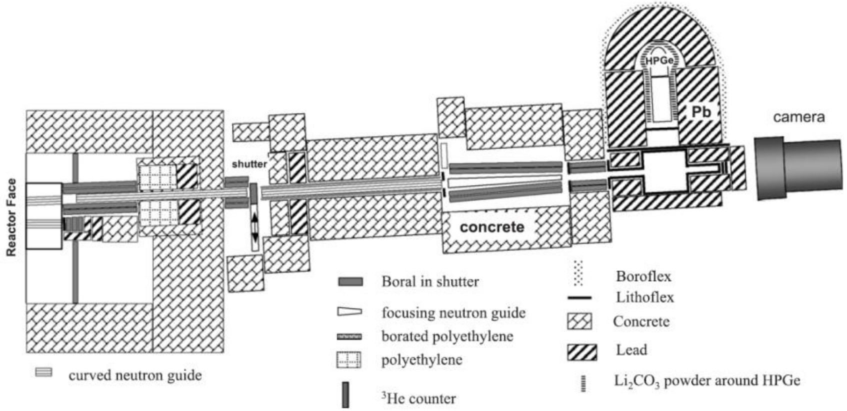

Reactor Utilization

- The NETL Reactor is operated approximately 180 days per year
- This includes operation for
  - education,
  - undergraduate research,
  - graduate research,
  - external research collaborations, and
  - irradiation services
    - Medical and industrial isotope production
    - Detector testing
    - Radiation effects testing



PGAA at the NETL

- PGAA System first operated in 1995
- Significant redesign in 2007
  - Guided-beam cold neutron source
  - High efficiency HPGe
- Complete rebuild of the detector system in 2022
  - Changed sample chamber
  - Added compton suppression HPGe
  - Added neutron shielding around detector
  - Minimized H and other background sources

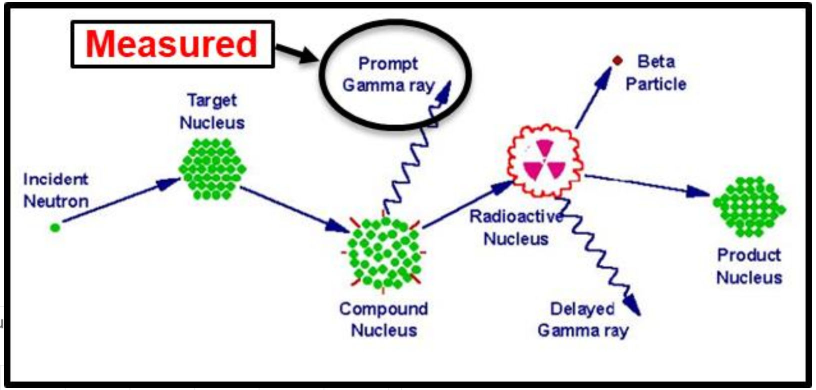


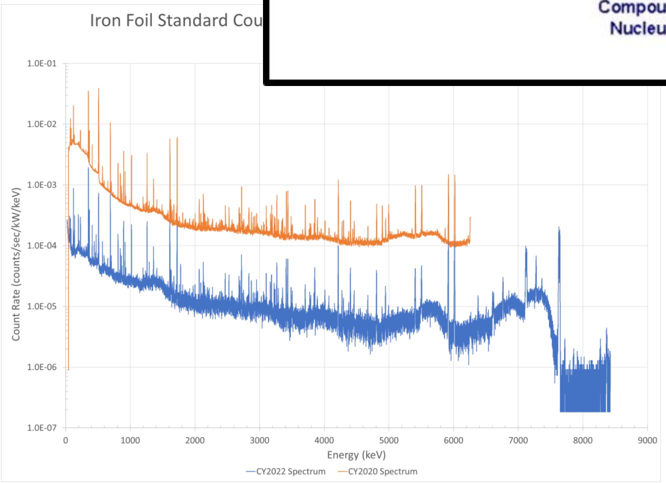
Prompt Gamma Ray Activation Analysis

- Prompt Gamma Activation Analysis (PGAA) is based on the detection of γ-rays emitted after radiative neutron capture reactions

$$ {}^{A}_{Z}X + {}^{1}_{0}n \rightarrow \left[{}^{A+1}_{Z}X\right]^{*} \rightarrow {}^{A+1}_{Z}H + \gamma $$

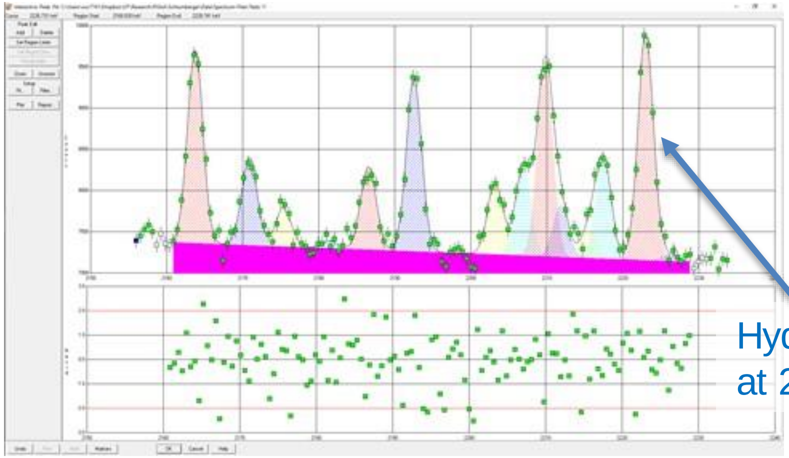
  - Binding energy typically leaves compound nucleus in an excited state
  - Promptly decays by γ-ray emission
- Prompt γ-rays are characteristic to the excited nucleus and can be used to identify the target isotope and concentration

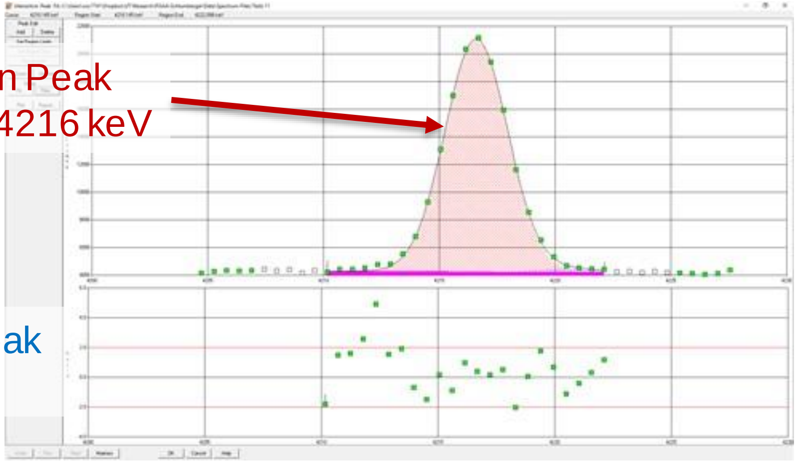




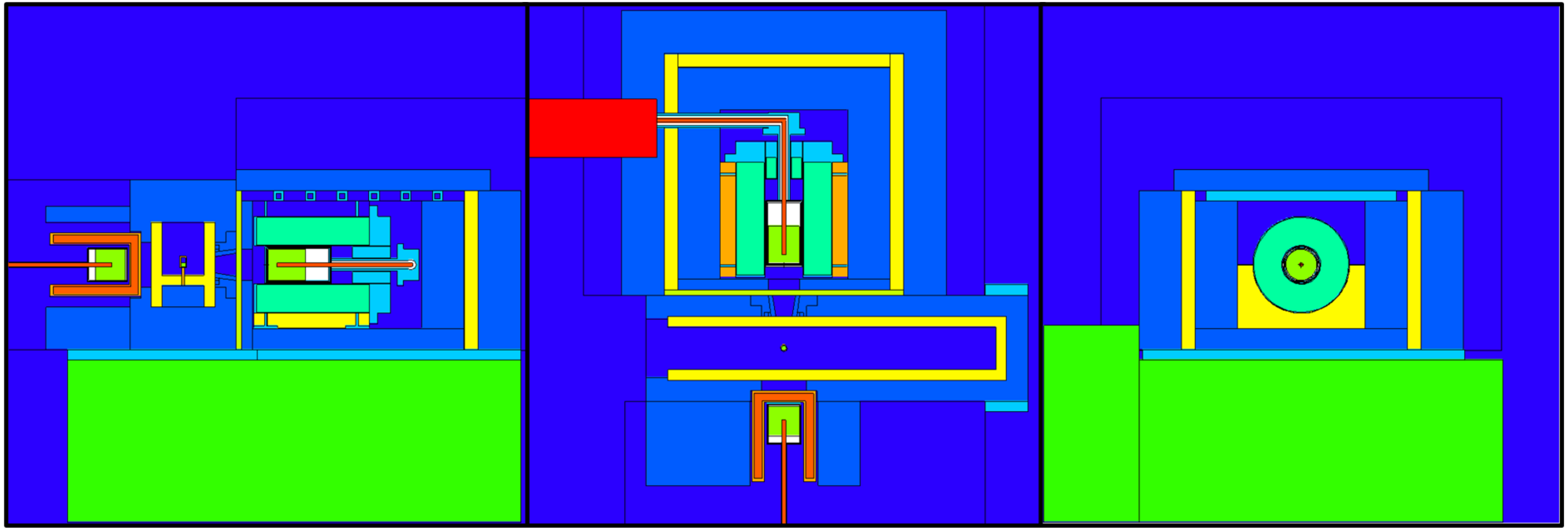
Prompt Gamma-ray Spectrum Analysis

- We have excellent capability in measurement of various elements including **H**, B, Cd, Sm, Gd, Cl, In, Nd, Na, Ti, V, Cr, Mn, Co, Ni, Cu, Ag, Au, Fe, Si, and Hg in bulk samples including steels, semiconductors, fiber composites, and ceramics





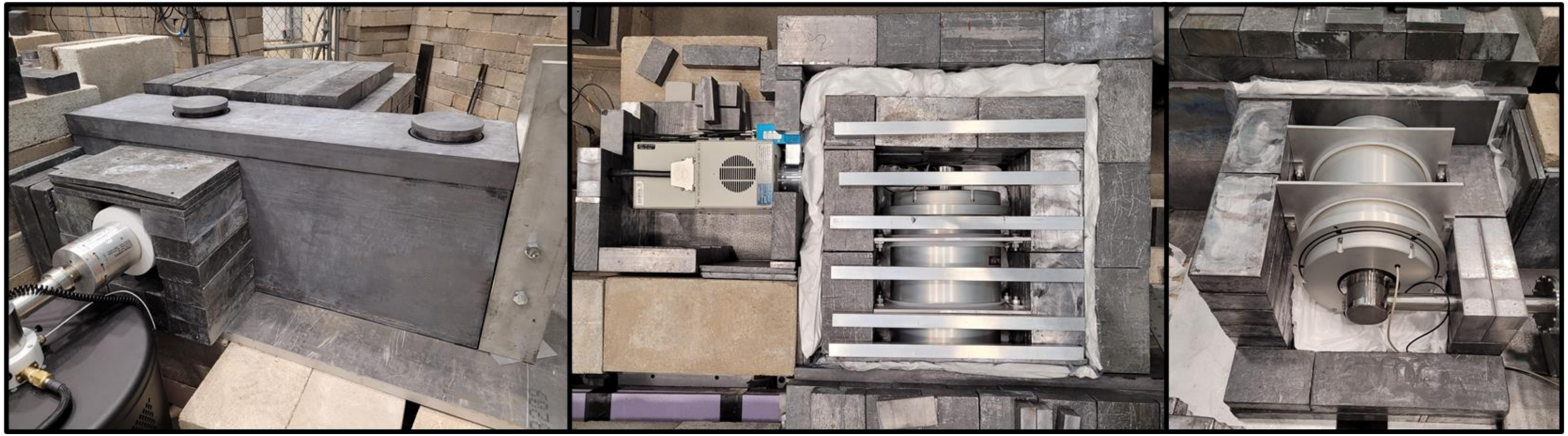
System Design and Simulation



Materials

- Dry Air
- NaI(Tl)
- HPGe
- Li_2CO_3 (natural)
- Li_2CO_3 (enriched)
- PFA
- LiF (enriched)
- Aluminum
- Aluminum and Helium
- Concrete
- Copper
- Vacuum

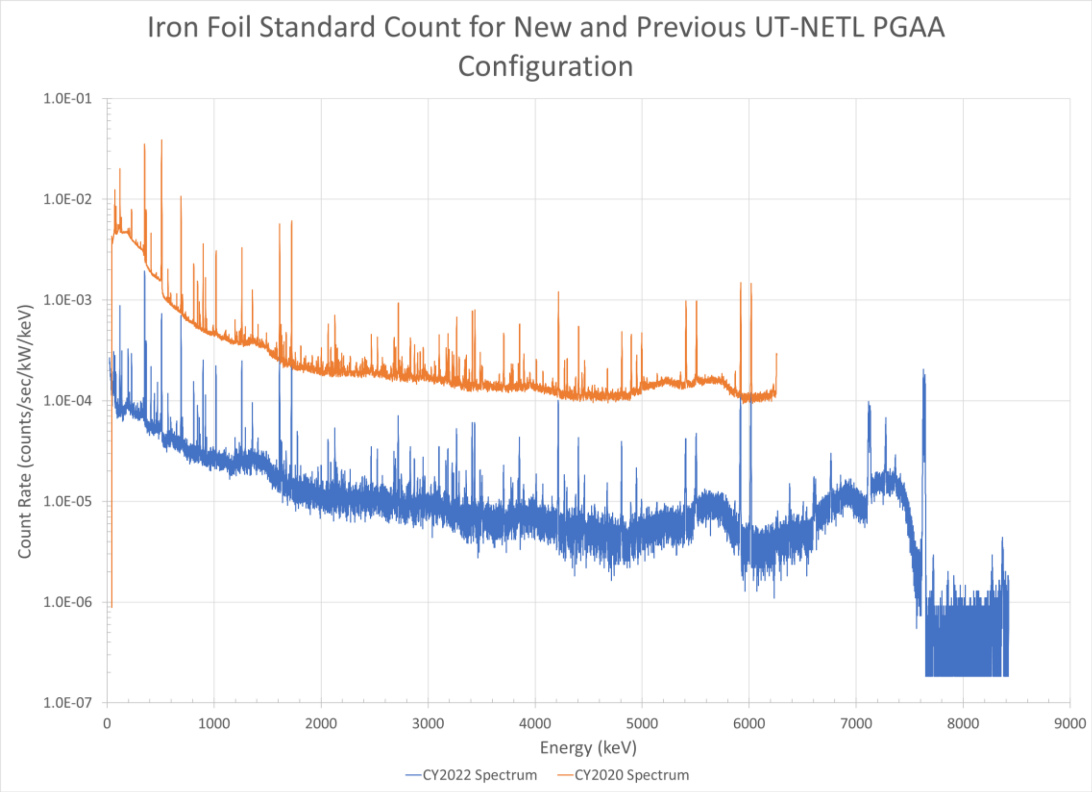
System Characteristics



- Custom cast lead sample chamber purged with He gas
- Compton suppressed HPGe manufactured by Mirion Technologies with cryocooler
- Stereoscopic ORTEC HPGe for self-attenuation correction measurement
- Lithium neutron shielding (minimized shielding materials)
- Neutron beam monitor recording fluence delivered to sample

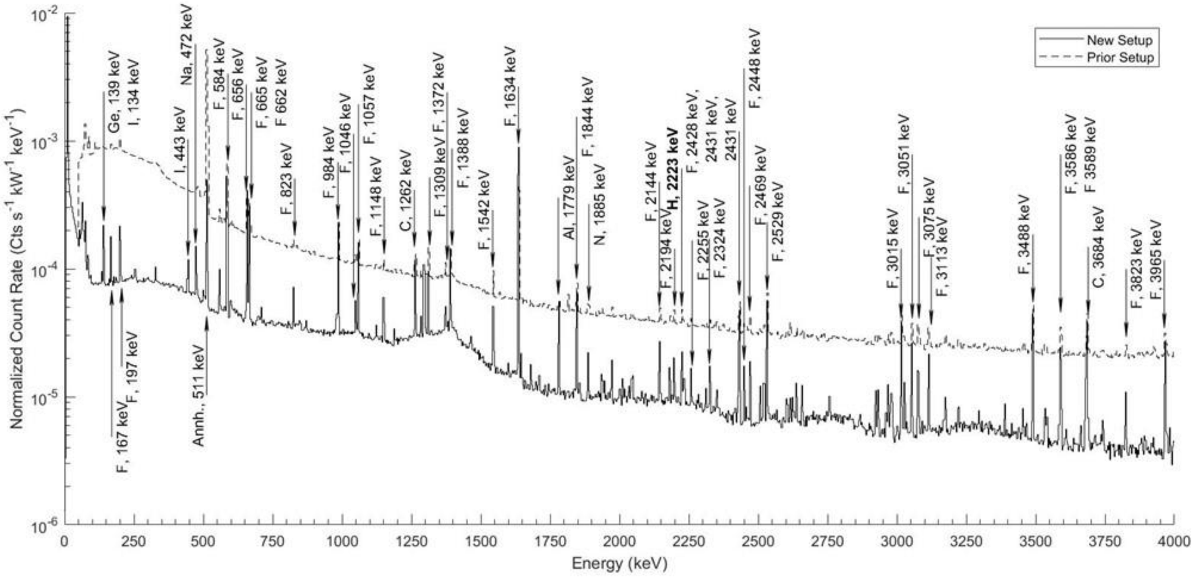
Spectrum Improvement: Iron Foil Standard

- Continuum reduced x10
- Uncertainty in Fe and H peaks reduced by >50%



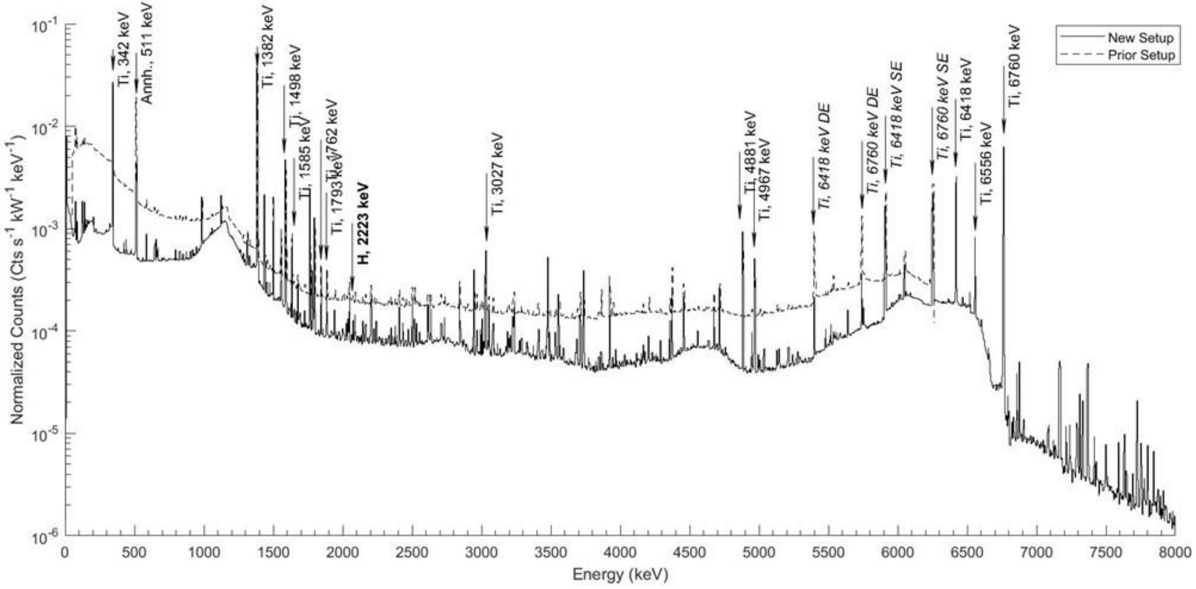
Background Characterization: Empty Vial

- Continuum reduced 70-90%
  - Lead activation minimized
- H background reduced by 50%
- Few unexpected peaks identified

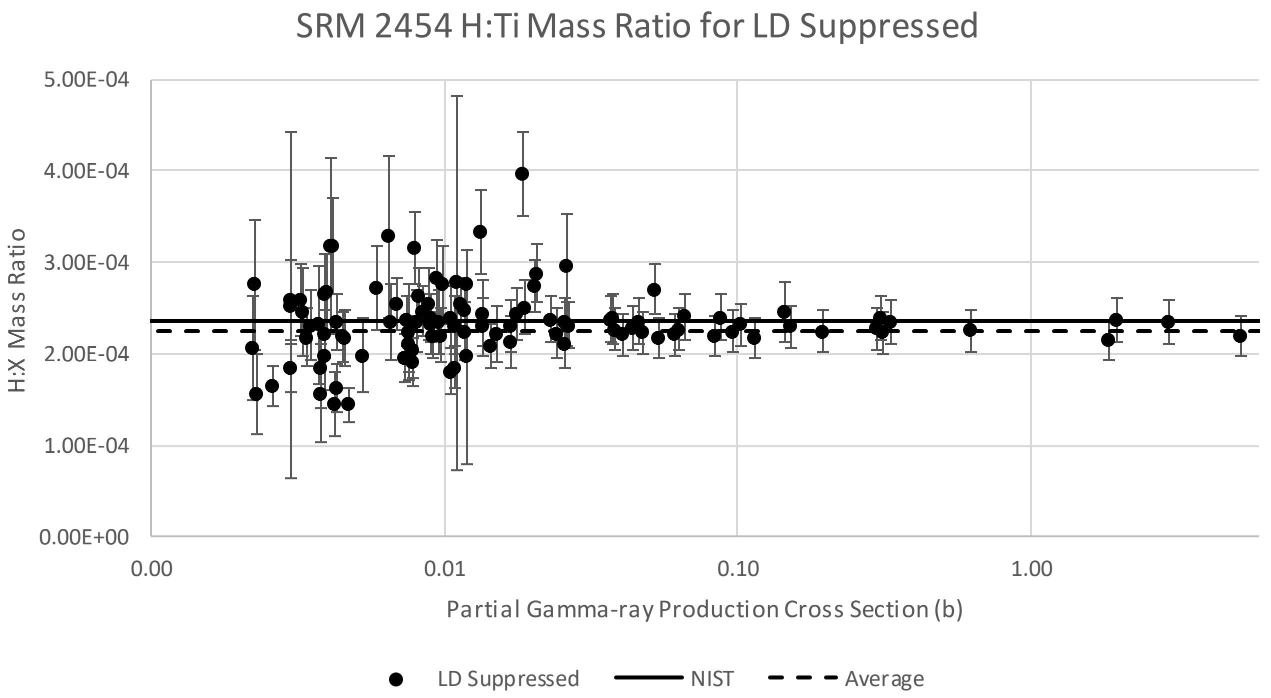


Performance Characterization

- NIST SRM 2454, Hydrogen in Titanium Alloy [3]
- Measured H:Ti mass ratio at 257±8 mg kg^{-1}
  - 31% reduction in uncertainty

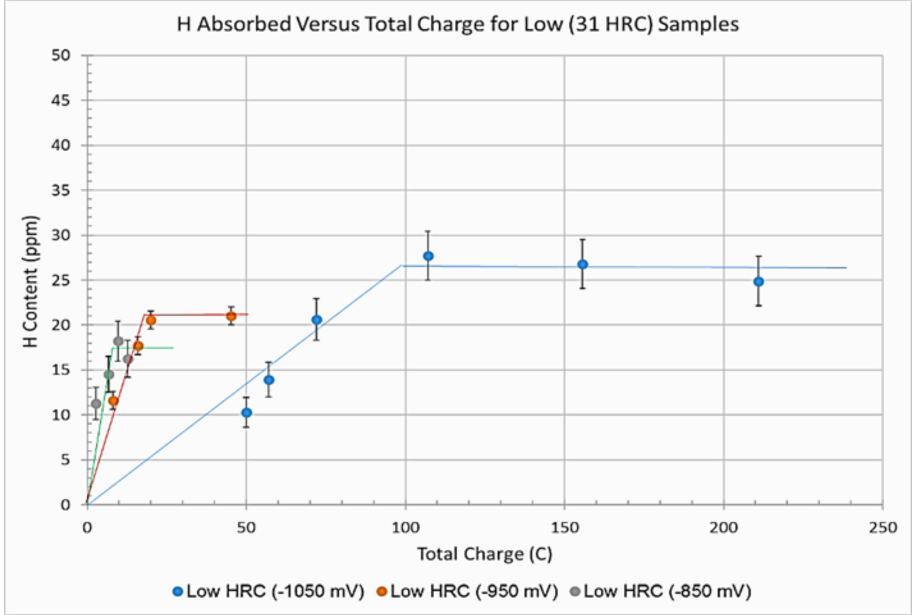


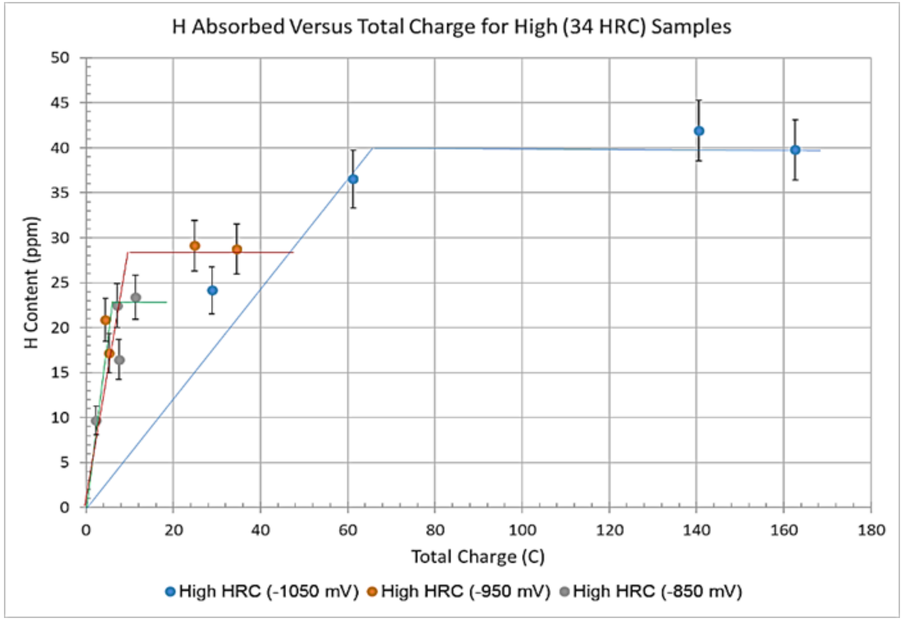
SRM2454 Mass Ratios



NIST* H:Ti Mass Ratio	Weighted Average
237.0 ± 4.7 ppm	229.0 ± 11.0 ppm
*Not a NIST certified value.	

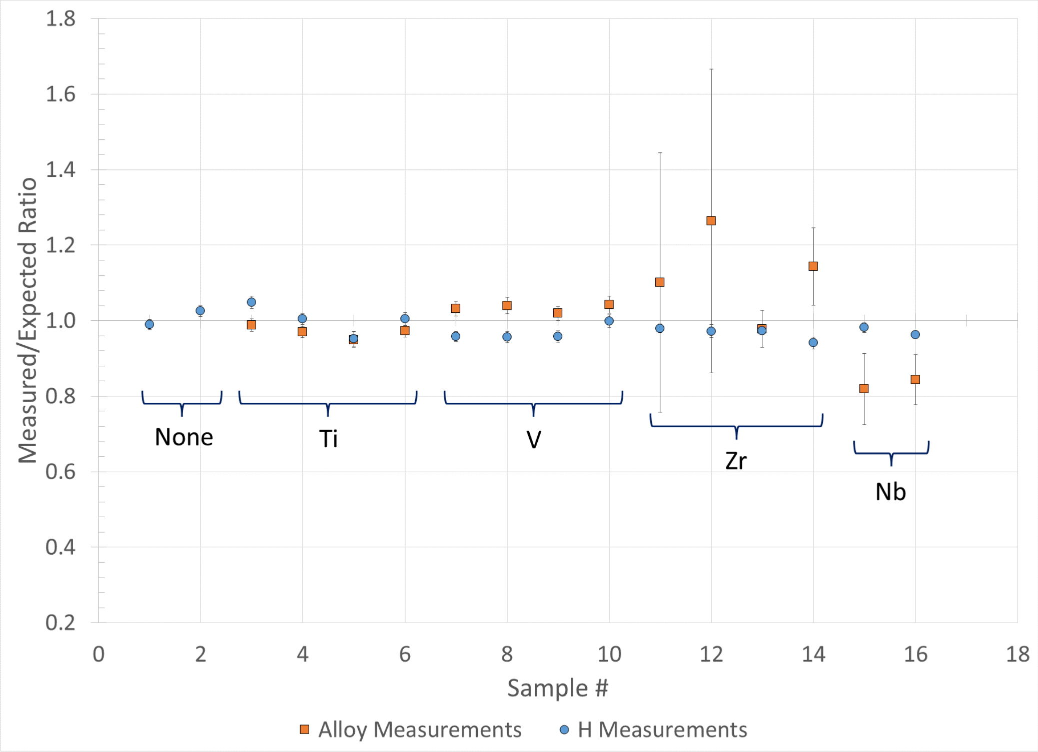
H in Steel: Saturated Hydrogen Absorption as a Function of CP and Hardness





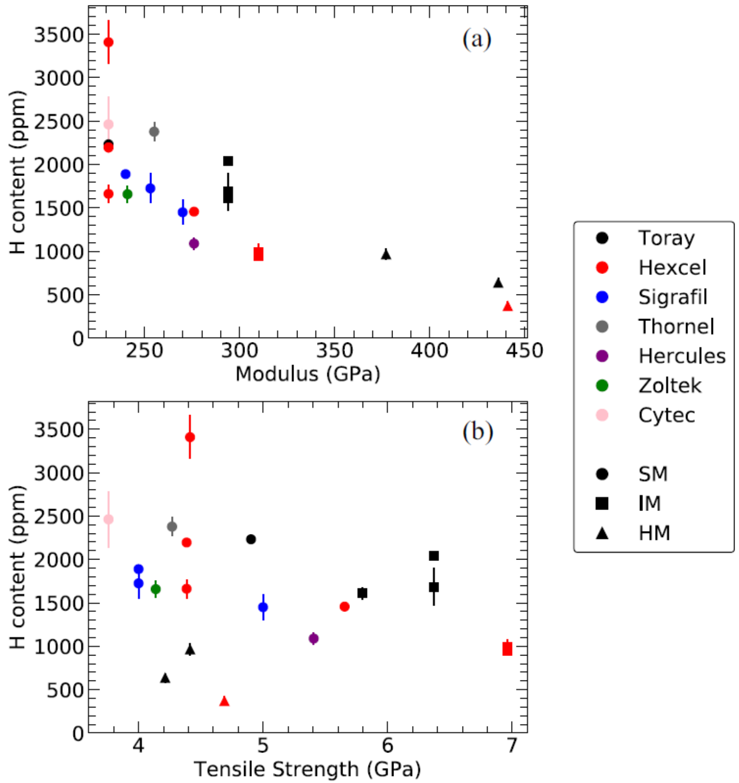
H in Nuclear Fuel Materials

- In collaboration with LANL, we demonstrated PGAA capability to measure H and alloy agent content in a variety of U alloys that could serve as advanced fuel forms
- PGAA capability was excellent for H but varied for some alloying agents (most notably Zr and Nb)



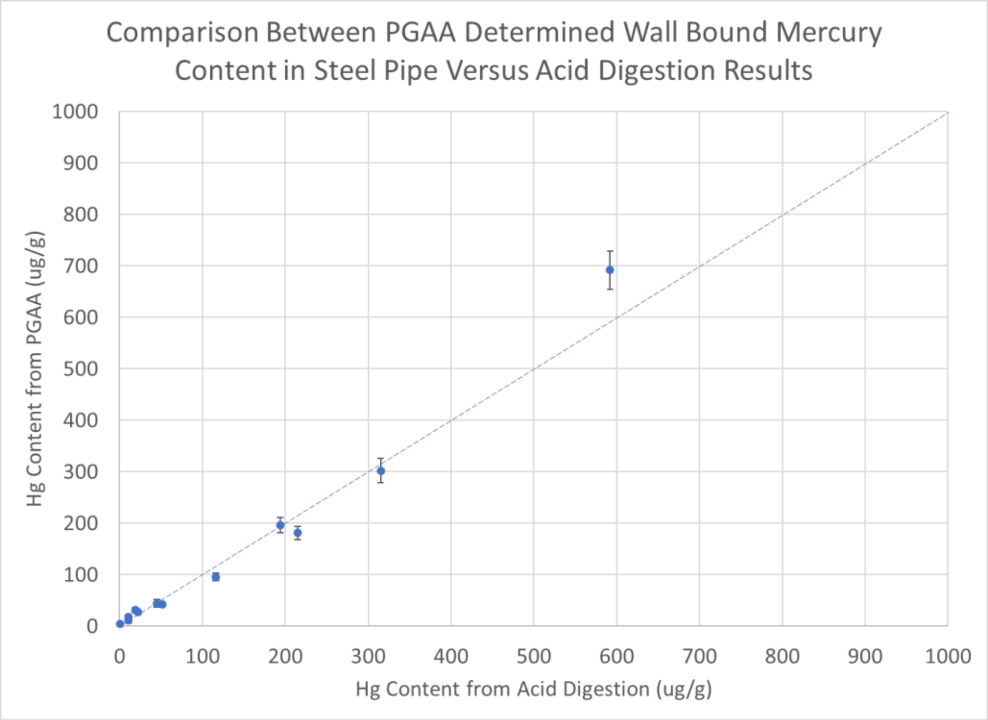
H in Carbon Fibers

- We just recently published a study with collaborators at ORNL looking at the correlation between H content and physical characteristics of carbon fibers used in composites
- This showed a strong correlation between the fiber modulus and H content
  - Likely due to intercalated hydrogen defects



PGAA Measurements of Hg Contamination in Steel Pipes

- Hg can contaminate gas pipelines
- PGAA was used to measure Hg content in ¾” thick steel pipe sections to determine degree of contaminant
- PGAA can measure Hg content to within 3 ppm



^{239}Pu PGAA Gamma Ray Yields

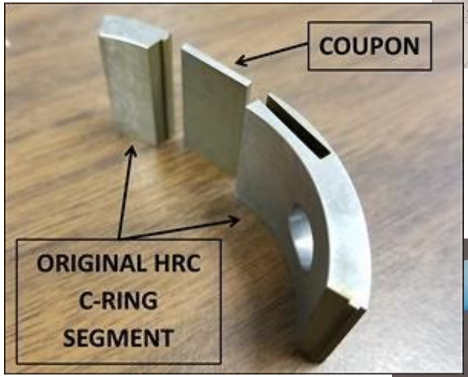
- We recently reported some of the first measurements of prompt gamma lines from ^{239}Pu using a Pu sample electrodeposited on Ni
- The yield for each of the gamma rays was calculated relative to the 2554.1 keV ^{58}Ni peak:

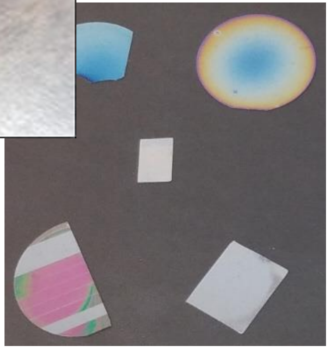
$$Y_{^{239}Pu} = Y_{^{58}Ni} \frac{\varepsilon(E)_{^{58}Ni}}{\varepsilon(E)_{^{239}Pu}} \frac{m_{^{58}Ni}}{m_{^{239}Pu}} \frac{C_{^{239}Pu}}{C_{^{58}Ni}}$$

Energy (keV)	Yield (barns)	Uncertainty (barns)
1427.53	4.98	0.55
1633.03	4.67	0.52
2015.2	2.60	0.34
2032.31	0.93	0.23
2321.65	0.61	0.16
2790.08	0.54	0.15
2944.12	0.64	0.21
3401.32	0.50	0.18
3579.6	1.78	0.36
4294.47	0.94	0.27
4754.15	5.14	0.75
6104.99	40.76	4.44

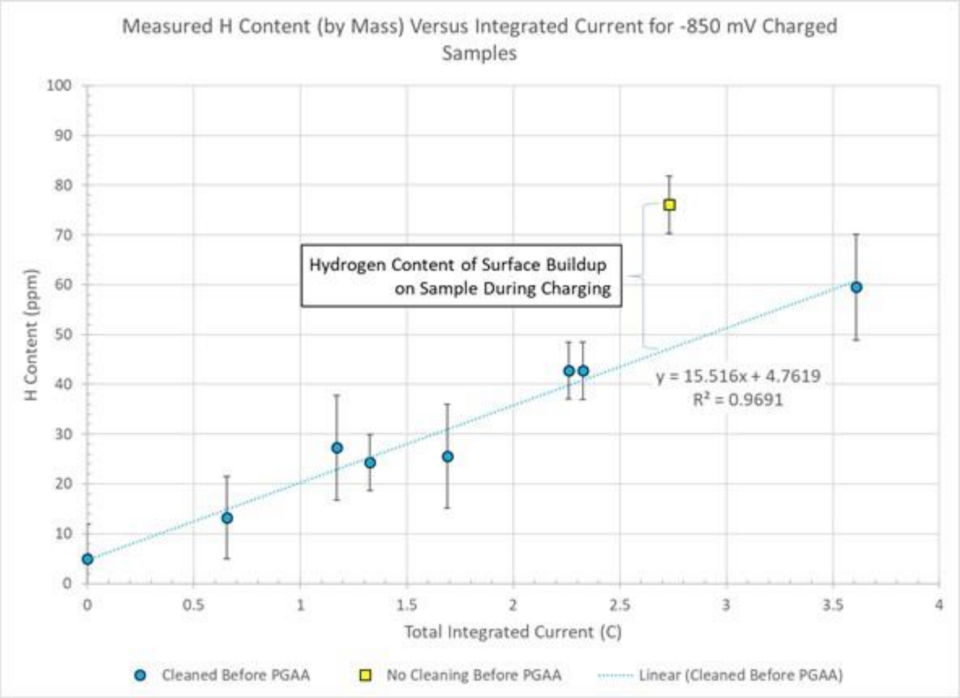
Sample Configurations

- Samples analyzed in the UT-NETL PGAA system are typically in unprocessed and bulk form
  - Such as metal coupons (typically about 1”x0.5”x0.05”)
- Powders, liquids, or loose samples are packaged in PTFE vials or heat sealed in PFA bags
  - Sample chamber is purged with He gas, so reactive sample materials can be analyzed safely
- For H measurements sample cleaning prior to analysis may be important





Example Effect of Surface H Content on Analytical Results



Data Analysis

- Most samples are analyzed relative to a standard
  - Measure unknown
  - Measure standard
  - Use ratio of unknown to standard corrected by neutron fluence delivered to acquire result for unknown
- We prefer to measure samples relative to a matrix element
  - For example, measuring H relative to Fe in a steel coupon
  - Lower overall uncertainties and no need for a standard
- For H, there are very few good standards to use

Conclusions

- The UT-NETL PGAA system has been in operation for over 20 years and has evolved into a highly capable analytical instrument that can provide precise measurements for a variety of elements in bulk samples
- UT-NETL PGAA H background is likely the lowest in the US
- System includes the ability to correct for self-attenuation of neutrons and gamma-rays during irradiation