An Inexpensive Compact Neutron Generator for Gamma Calibration and other Applications

DOE STTR GRANT: DE-FG02-07ER86294: "Gamma Calibration Source"

STTR with LBNL

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Adelphi Makes Neutron Generators

(thanks to DOE STTR's with LBNL and DNDO SBIR)

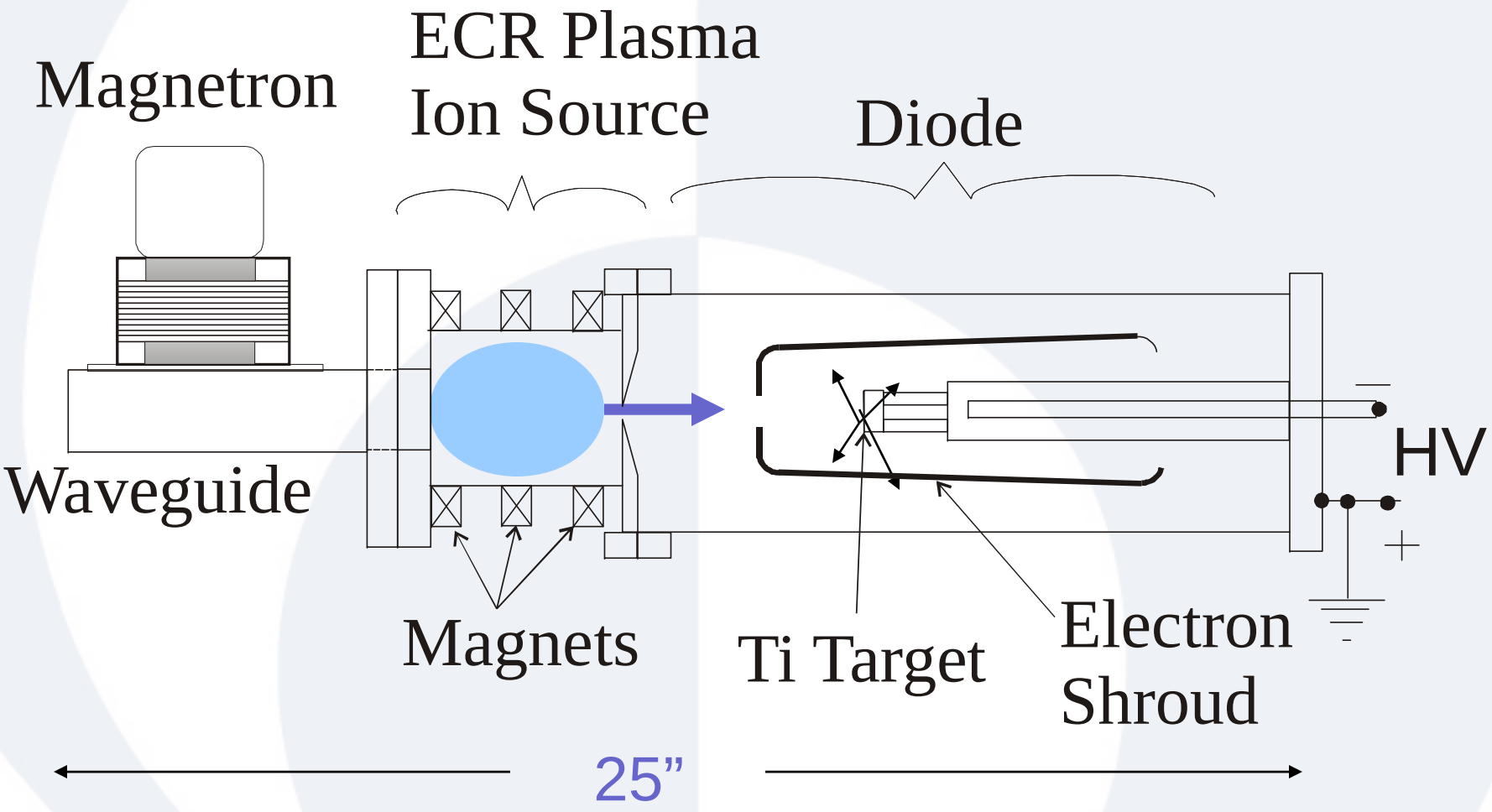
- DD reaction at high neutron yields
- Actively vacuum pumped (uses lecture bottle of Deuterium)
  - Serviceable and long lived
- Sealed versions (DD and DT)
  - Field portable and rugged

Model Number	Fusion Reaction	Yield (n/sec)	Status	Price
DD-108	DD (2.5 MeV)	~ 10^8	4 fabricated	$98K
DD-109	DD	2 x 10^9	2 sold	$158K
DD-110	DD	8 x 10^9	1 sold	$316K
DT-111	DT	10^{11} (expected)	1 sold KSU (2-3 months)	$280K

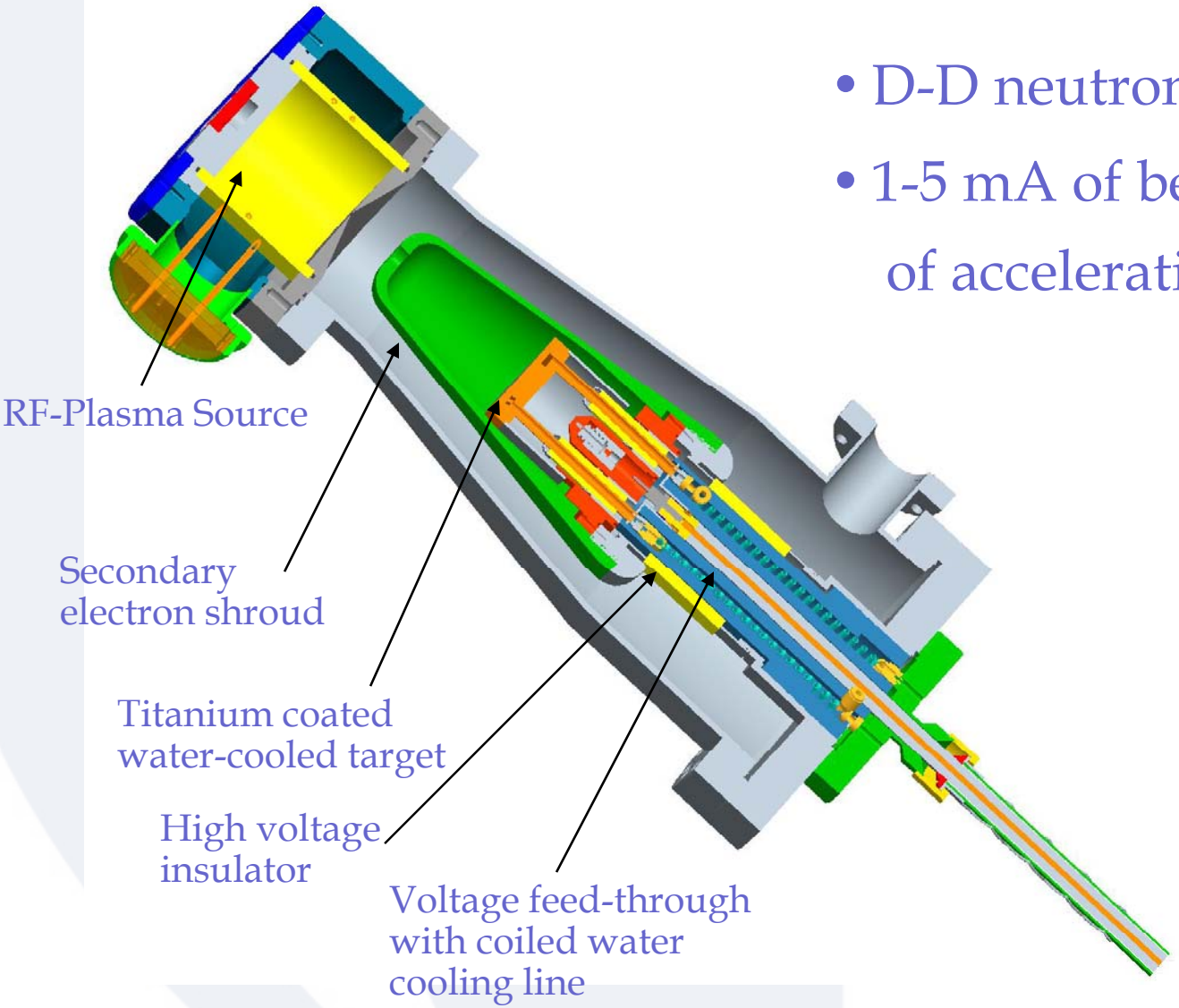
Plasma Ion Sources

- Plasma ion sources fabricated by Adelphi & LBNL
  - 13.45 MHz RF Plasma Ion sources
    - Helical and Spiral Antenna coupling
  - Electron Cyclotron Resonance (ECR) Plasma Ion Sources
    - Segmented Magnet: Large diameter, high current
    - Annular Permanent Magnets: small diameter
- Atomic Species (D+) good in all cases (>90%).
- Long Lived (unlike Penning Diode)

ECR-Driven Neutron Generator



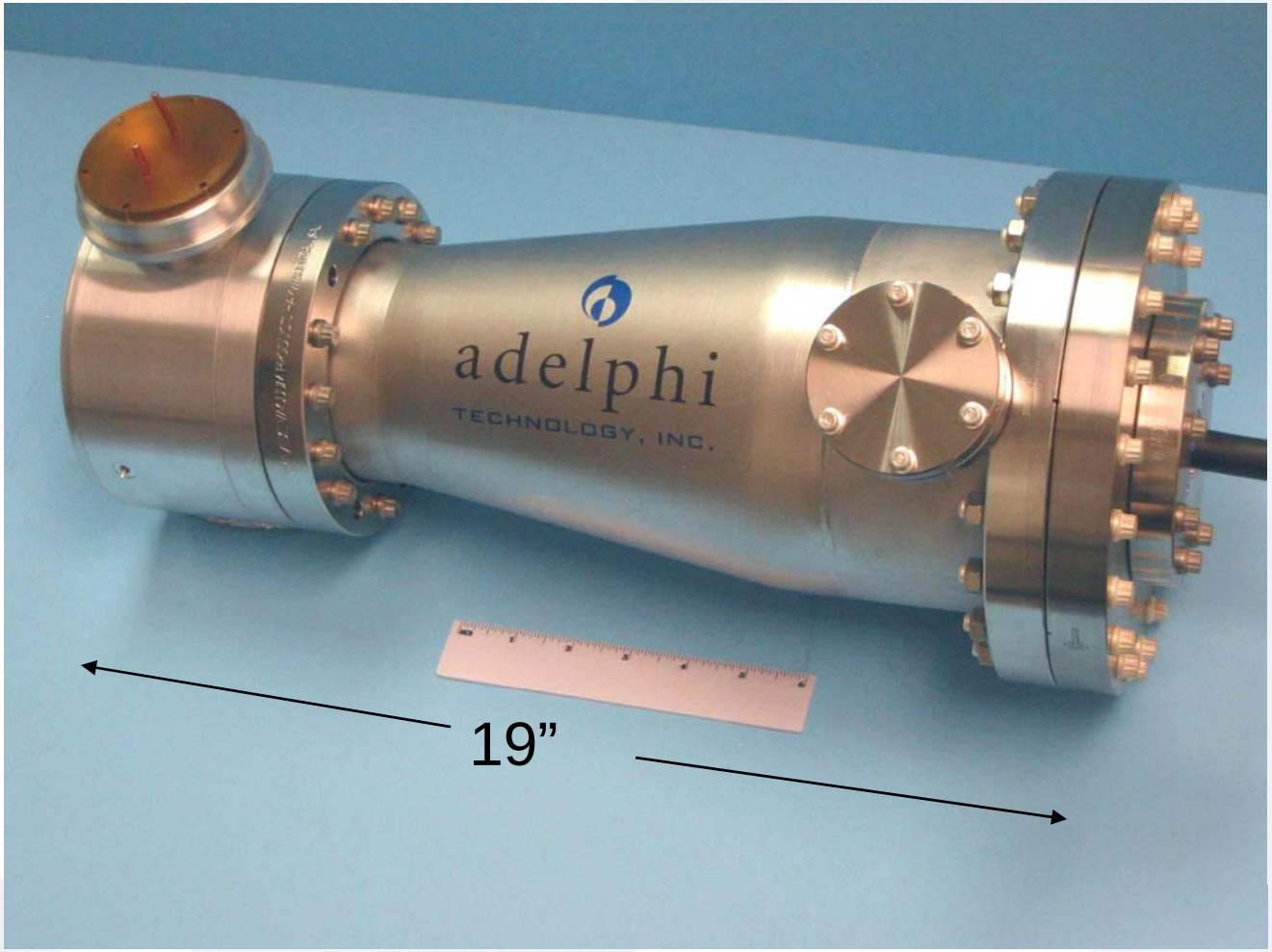
Axial Generator DD-108



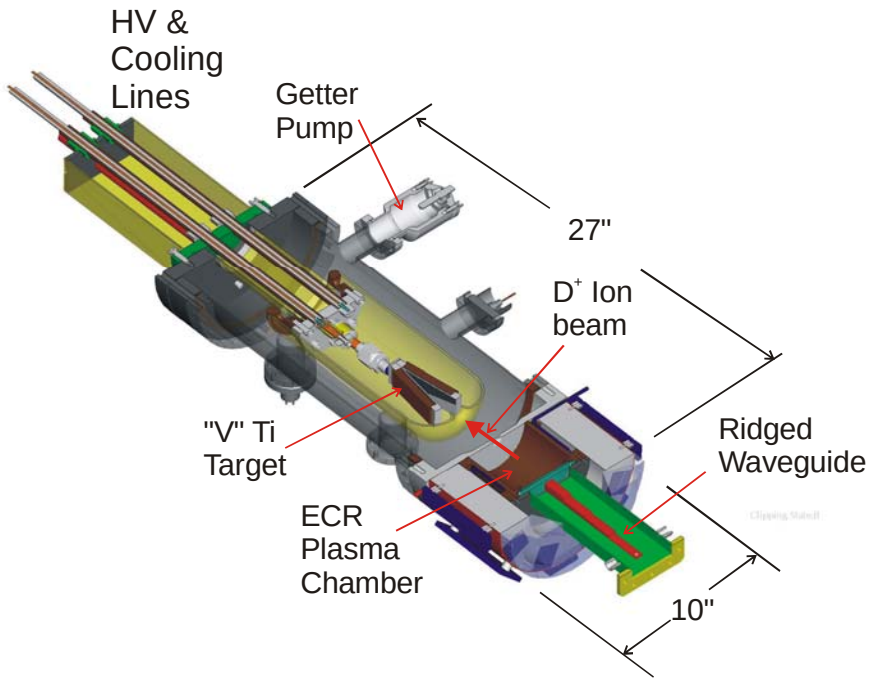
- D-D neutron yield of 10^8 n/sec
- 1-5 mA of beam current & 100 kV of acceleration voltage

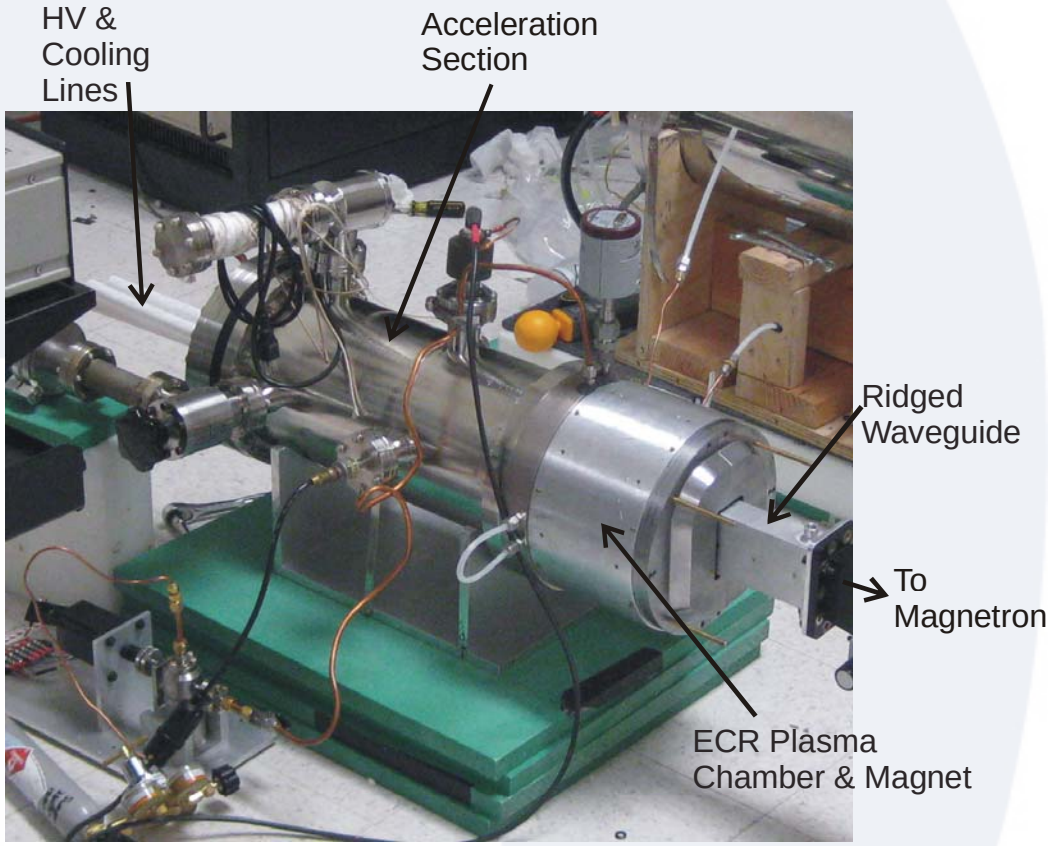
Model DD-109 Generator with RF Plasma Ion Source

Measured Yield 10^8 n/s



Model DD-109 Neutron Generator using ECR Source





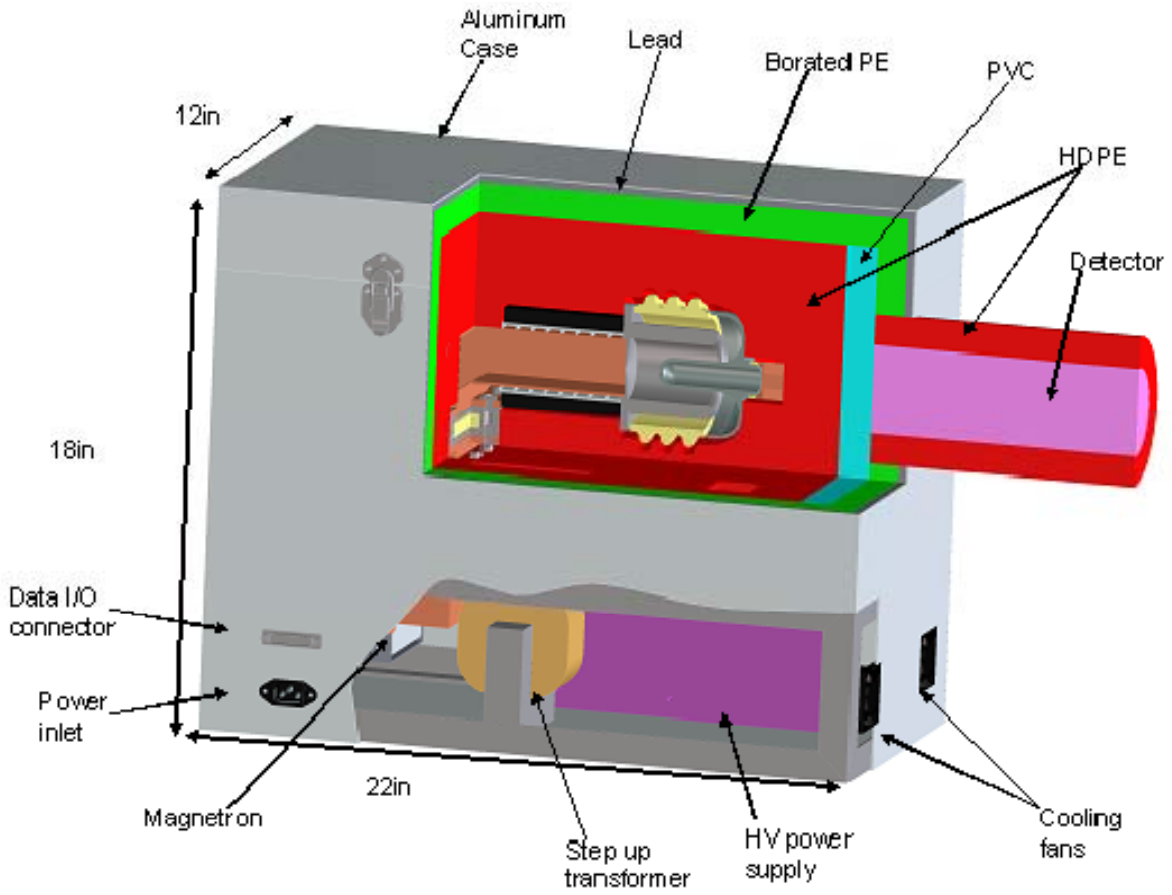
Operating at 10 mA, 120 kV, 1.5 x 10^9 n/s

Gamma Calibrator

- Need:
  - No long-lived gamma-ray calibration sources with energies above 3.5 MeV
- Idea:
  - Produce high energy gamma lines using PGNAA and inexpensive neutron generator
  - Use inexpensive components from consumer electronics

ORIGINAL DESIGN: Gamma Calibrator

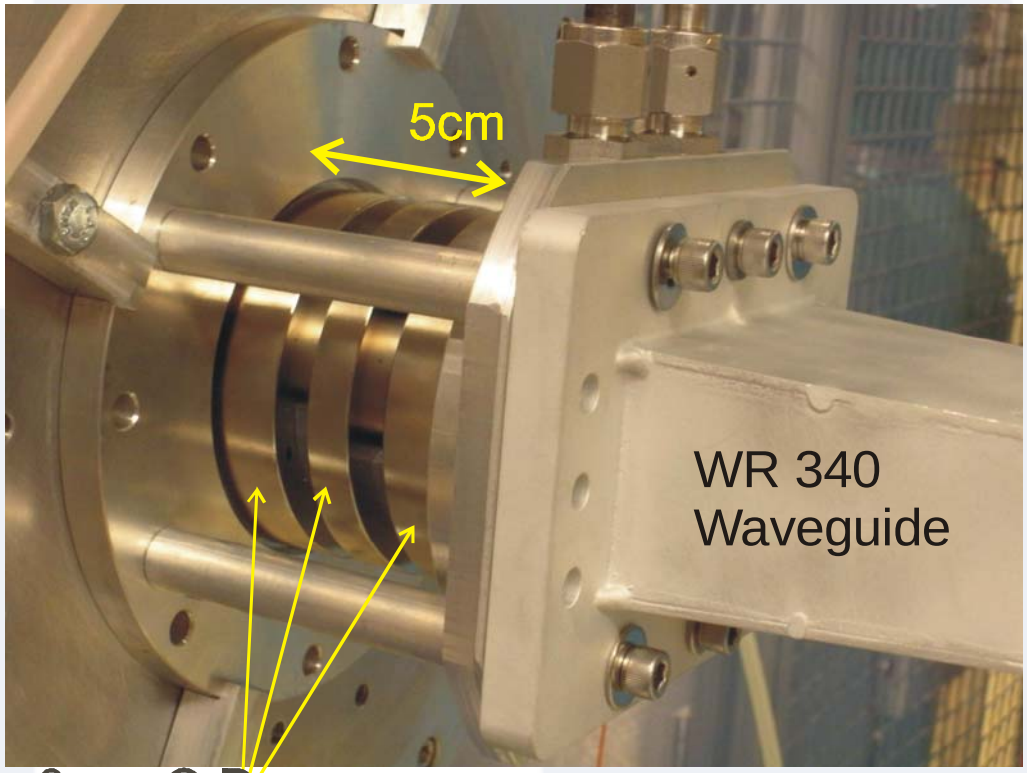
- Neutron Generator enclosed in HDPE moderator with PVC gamma converter.
- Uses inexpensive “microwave oven” magnetron
- All supporting components inside.



Design size:12” x 18” x 22”

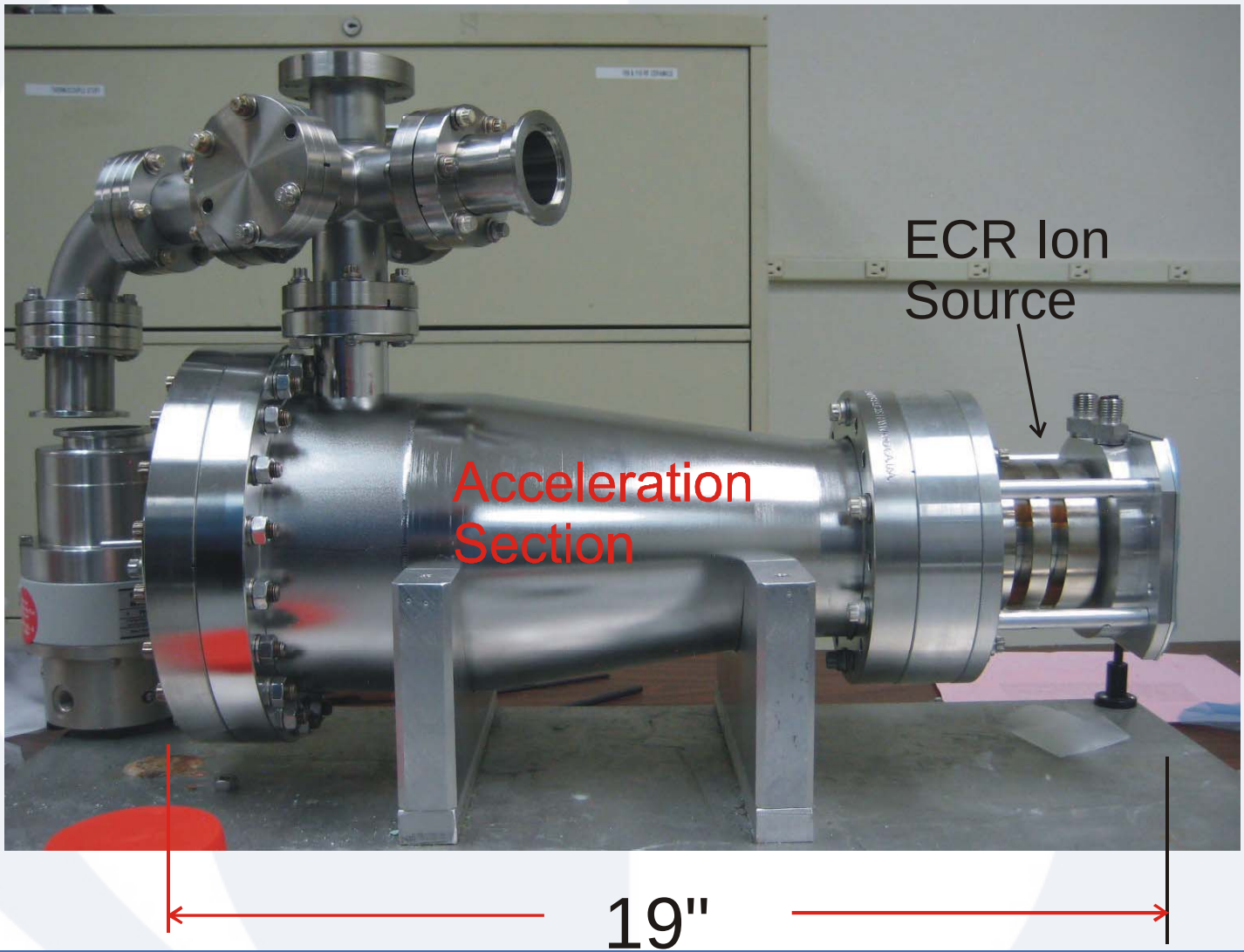
Compact ECR Source

- Meas. Atomic Species (D^+): 92%
- Measured ion current: 1-2 mA
- Uses inexpensive magnetron & COTS annular permanent magnets



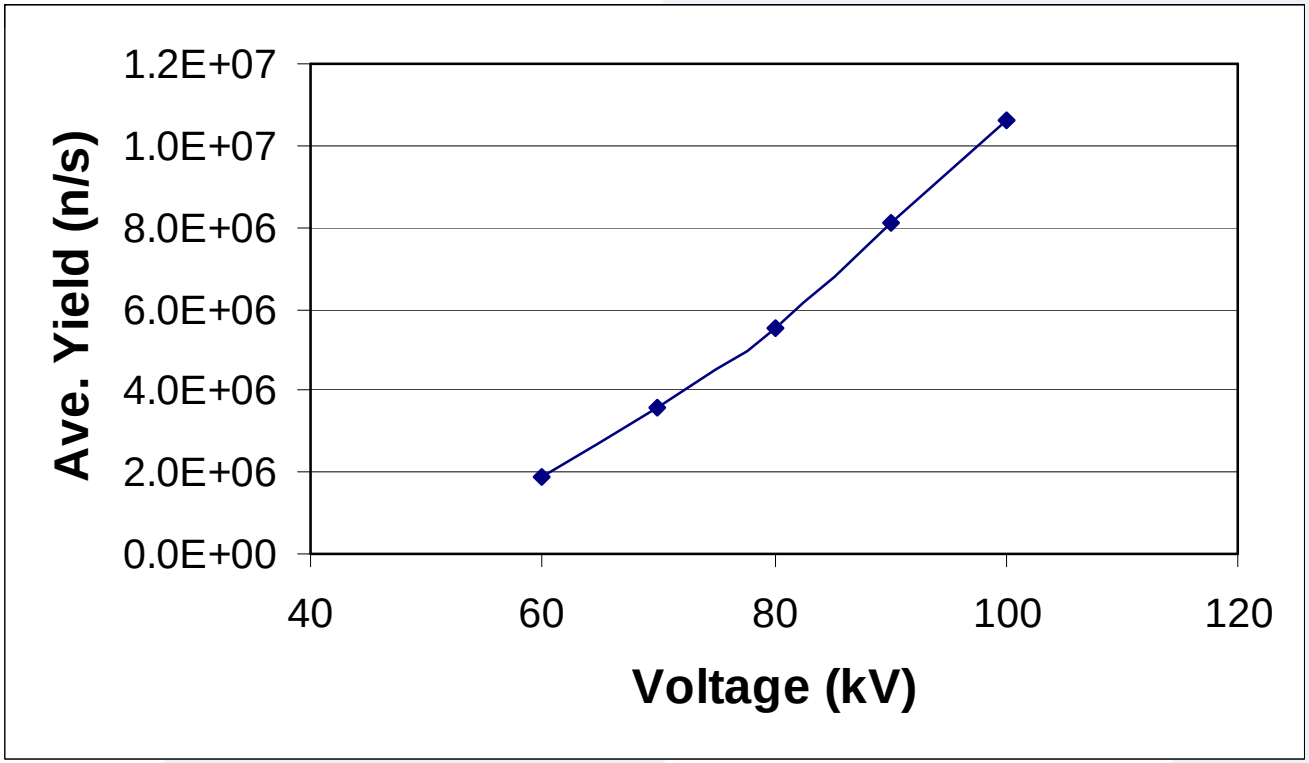
Neutron Generator using Compact ECR Ion Source

Prototype using DD-108 accelerator section: measure yield 7 x 10^7 n/s

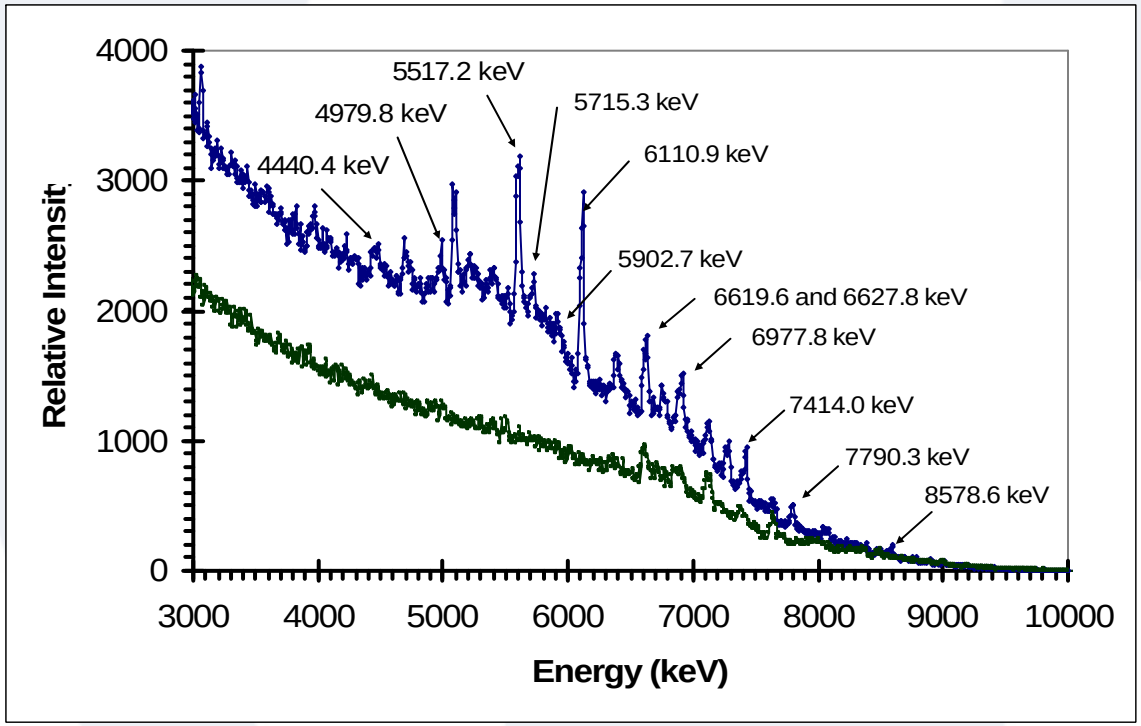


Low Power Operation

- We want low Power operation = Field portable
- Measured: Magnetron Ave power: 117 W (2 ms, 167 pps, 33% duty factor)

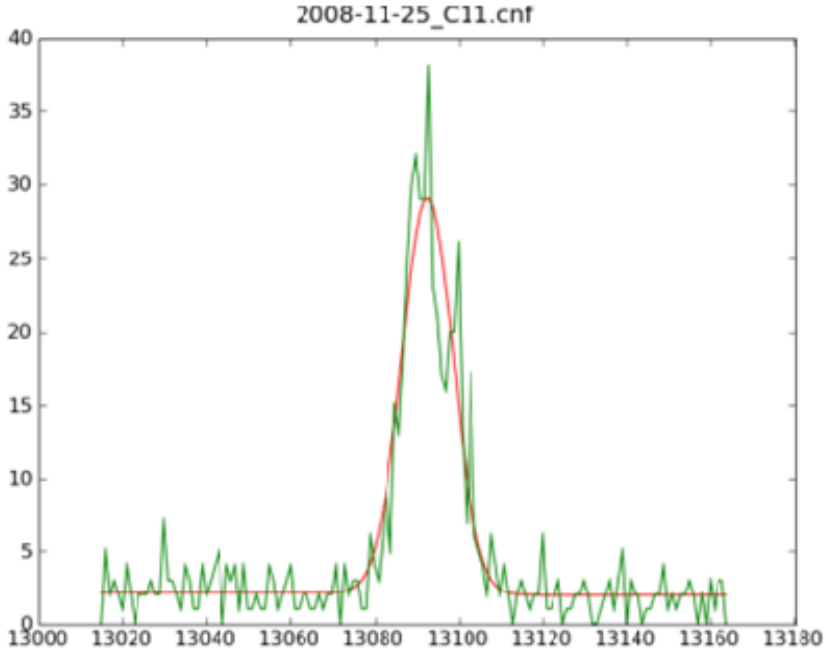


Calibration Lines from PVC (Chlorine)



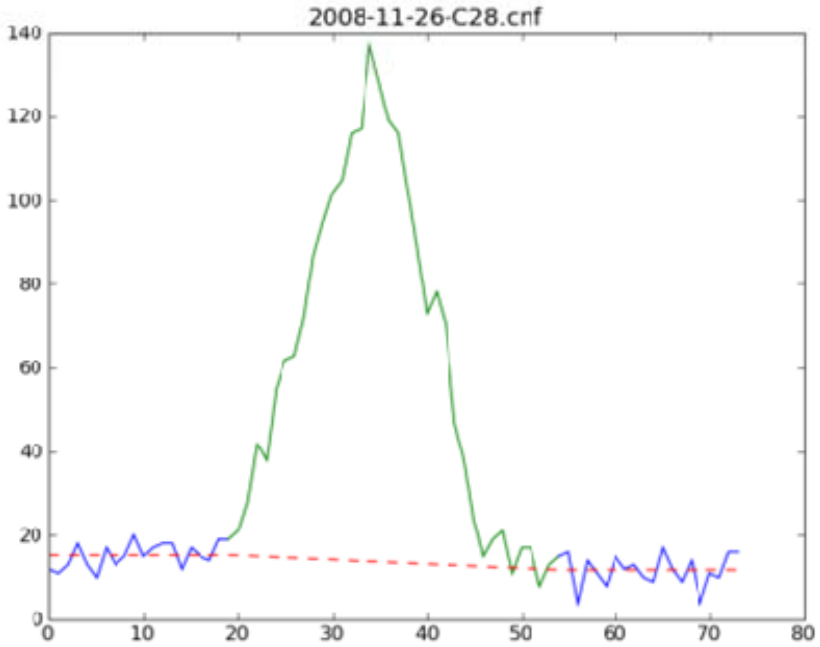
Energy [MeV]	Expected cts per second	Measured counts per second
2.864	0.33	0.60
3.062	0.19	0.26
4.980	0.11	not observed
5.715	0.14	1.09
6.111	0.45	1.13
6.620 6.628	0.25	0.44
7.414	0.16	0.16
7.790	0.12	0.15
8.579	0.034	0.031

PGNAA Calibration Lines from Ni and Pb



Ni: 8998 keV

Gaussian Fit



Pb: 7368 keV

Background subtraction

HELIOCENTRIC TECHNOLOGIES

Status of Gamma Calibrator

Completed:

- First compact ECR plasma ion source using inexpensive “microwave oven” magnetron & permanent magnets working.
- Prototype ECR-driven neutron generator working.
- PGNAA calibration spectra measured using DD generators.

Next:

- Fabricate compact acceleration section integrated with moderator & gamma transducer.
- Demonstrate gamma calibration
- Determine safety of device.

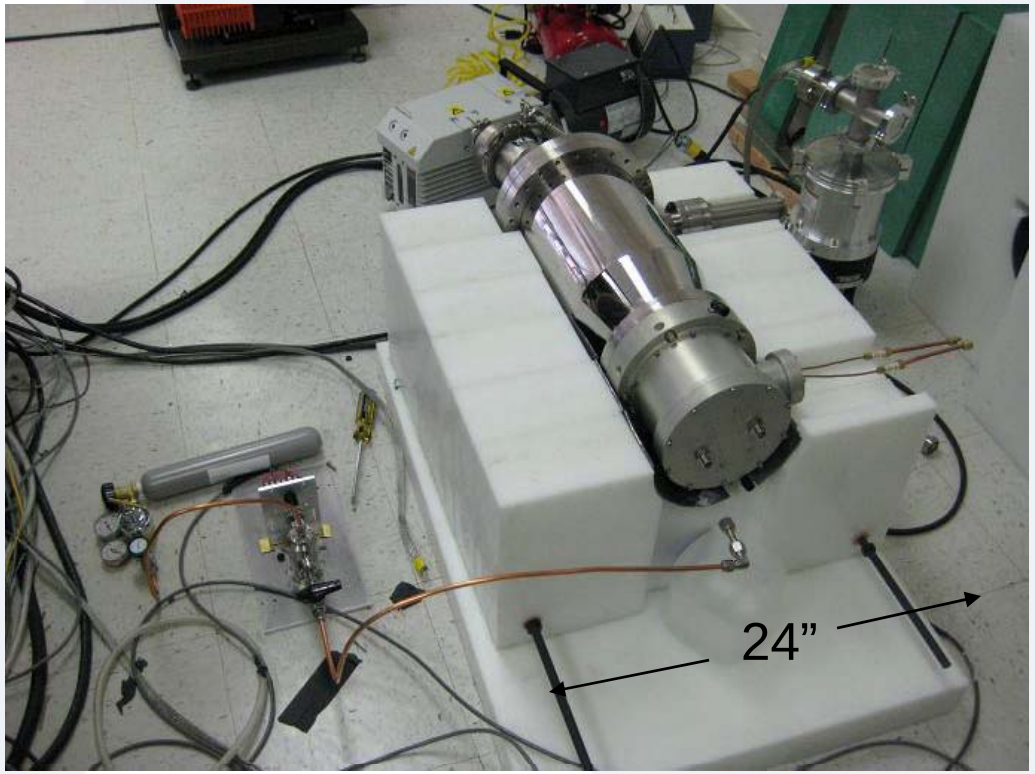
OTHER APPLICATIONS

- Materials Analysis using PGNAA and NAA
- Small Laboratory Materials Analyzer
  - What if you didn't need a reactor?
- Mining and coal analyzer
  - Replace ^{252}Cf

Laboratory Neutron Source

Model DD-110

Model DD-109



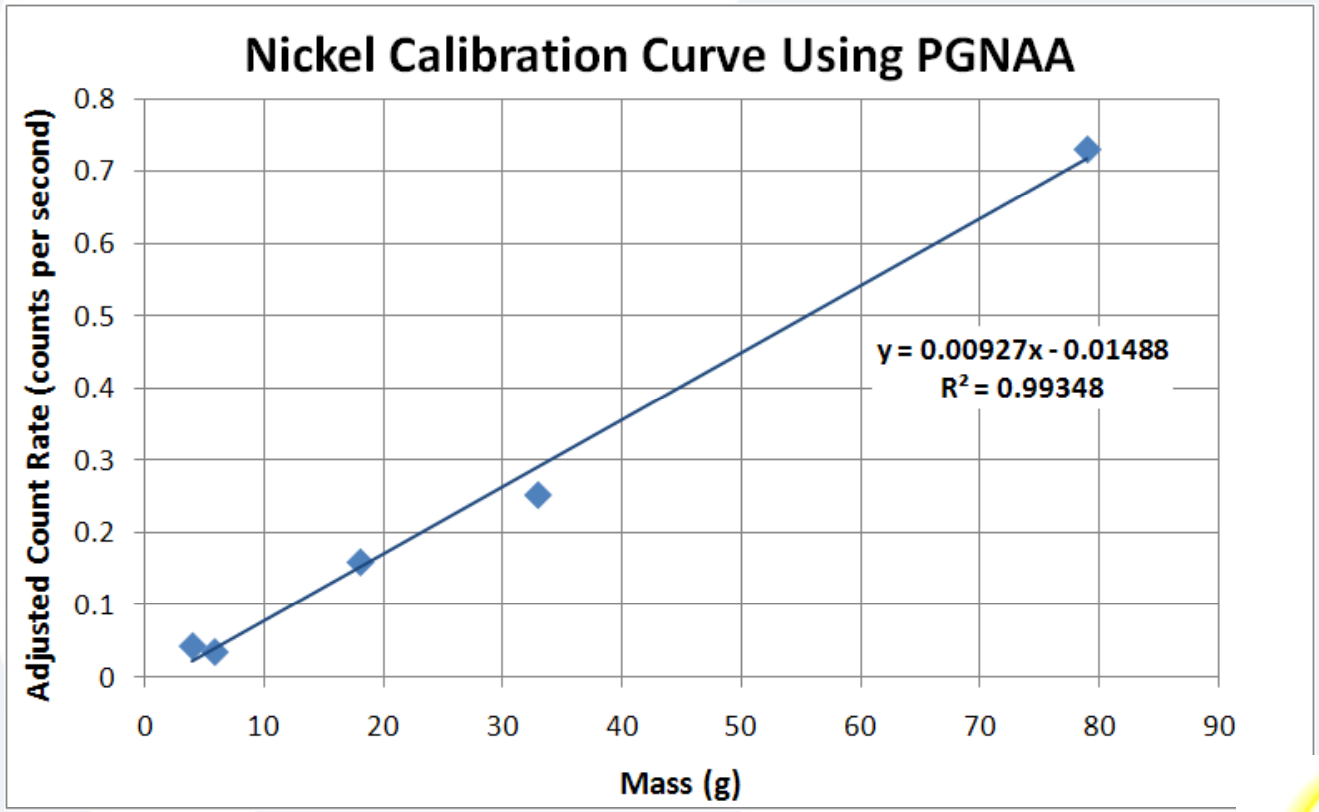
- Easily and inexpensively moderated and shielded
- Easily serviced and long lived
- Do PGNAA and NAA with HPGe detector

Prototype Mining On-Site Analyzer (Heliocentric at Adelphi)

- Trace-Element Prompt Gamma Neutron Activation Analysis (PGNAA):
  - Deep penetration radiation performs bulk analysis
  - Deconvolve γ-ray spectrum to obtain elemental composition
- Applications in mining, oil sands and environmental clean up.

Prototype Performance – Calibration

- Pure elements were used to calibrate
- Detection limits for 1000 sec measurements



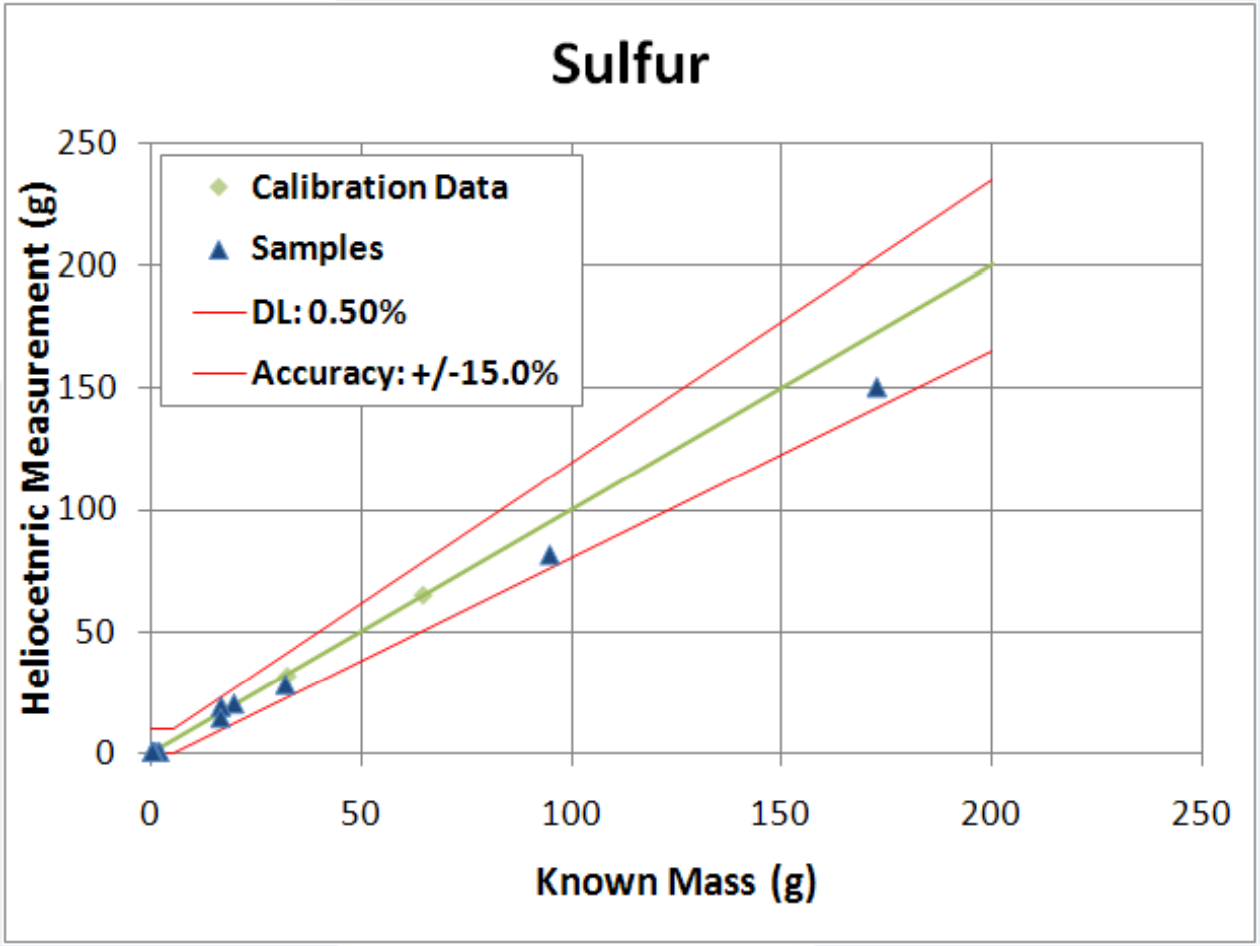
Prototype Performance – Test Samples

- Customers provide samples for measurement
- Samples previously measured by alternate methods
- PGNAA measurements were compared customer
- Measurements to assess the instrument's accuracy

Customer samples have a variety of physical properties

Prototype Performance – Accuracy

- Graphs are generated for each element to assess the instrument's accuracy



HELIOCENTRIC TECHNOLOGIES

Other Elements – Summary (Heliocentric)

Element		Detection Limit: prototype	Detection Limit: target for final instrument
Aluminum	Al	**0.2% (DGNA)**	0.02 % (DGNA)
Cobalt	Co	**0.5%**	0.05 %
Copper	Cu	**0.6%**	0.1 %
Chromium	Cr	**0.9%**	0.1%
Iron	Fe	**1.5%**	0.1%
Nickel	Ni	**0.5%**	0.05 %
Sulfur	S	**0.5%**	0.1 %
Zinc	Zn	**3%**	0.2 %
Integration time	t	**1,000 s**	300 s
Absolute accuracy	+/-	**15%**	5%

On-line Coal Analyzer

This R&D permits the following application:

- Replace ^{252}Cf with compact ECR-driven DD neutron generator
- Generator to fit existing coal analyzer
- Identification of previously undetected pollutants
  - Pulsing of generator should improve sensitivity by 10 X.
- long lifetime and field serviceable
- Target Customers: *Scantech Limited and Sabia Inc*

Summary

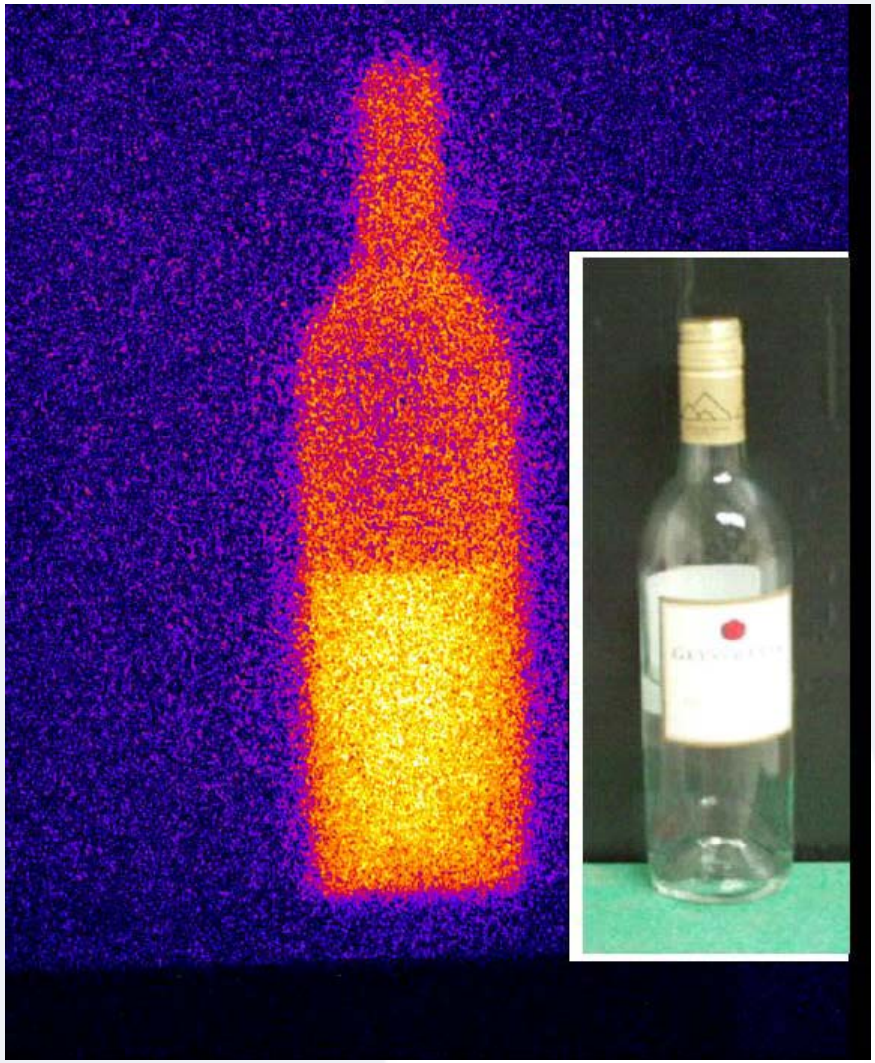
Gamma Calibrator

- Prototype Compact Neutron Generator Fabricated
  - Compact ECR source using inexpensive components
  - More than meets required neutron yield
- Demonstrated use as calibration source
- Need to produce Beta Prototype gamma source (6 months)

Materials Analysis

- Demonstrated use for PGNAA and DGAA for materials analysis
  - Mining (Heliocentric) and coal analysis applications
- Fast and Thermal Neutron Laboratory Source Available NOW

END



Fast Neutron Radiograph of California's Finest, using DD-109