# *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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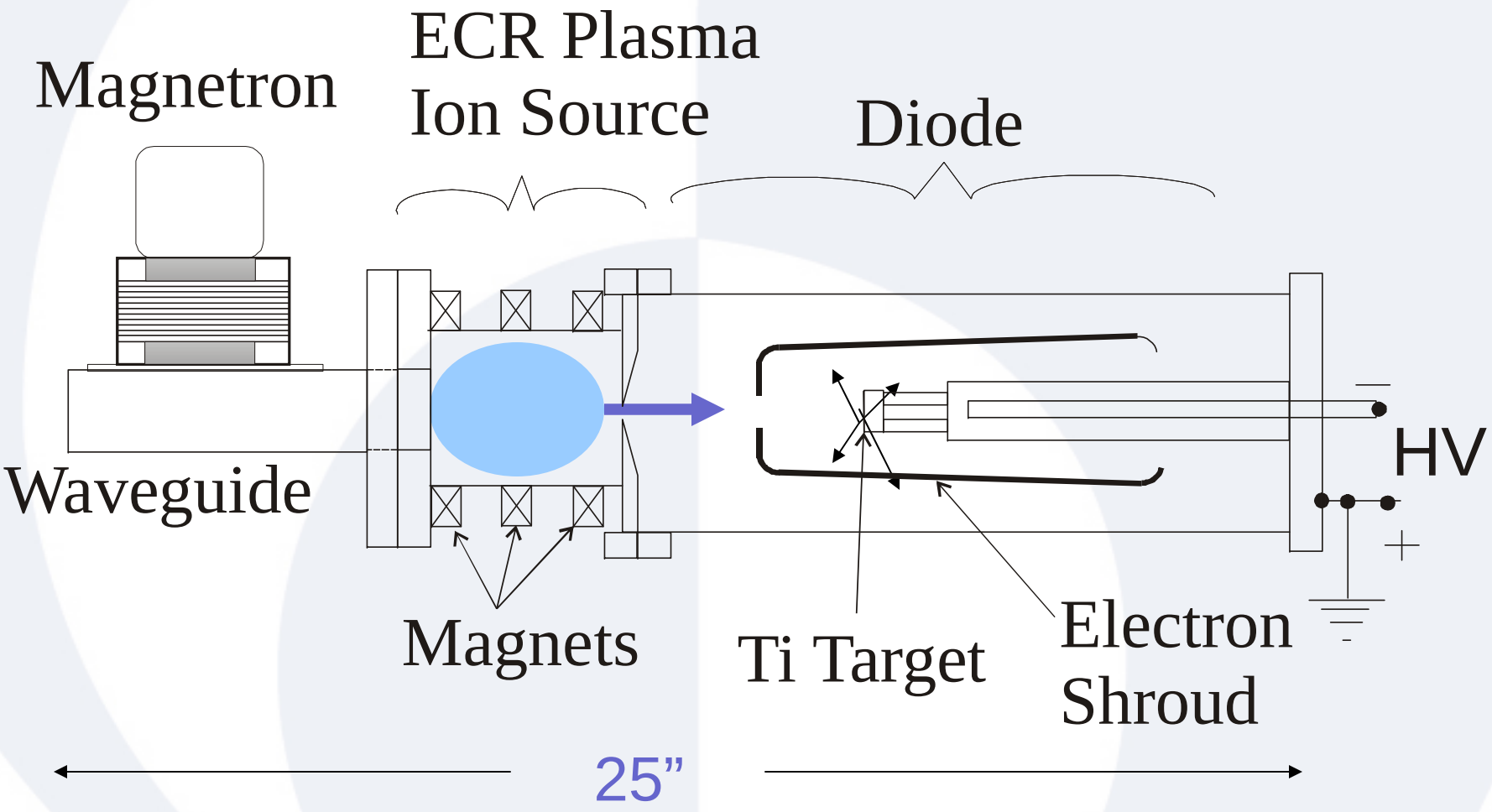
# Adelphi Makes Neutron Generators

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

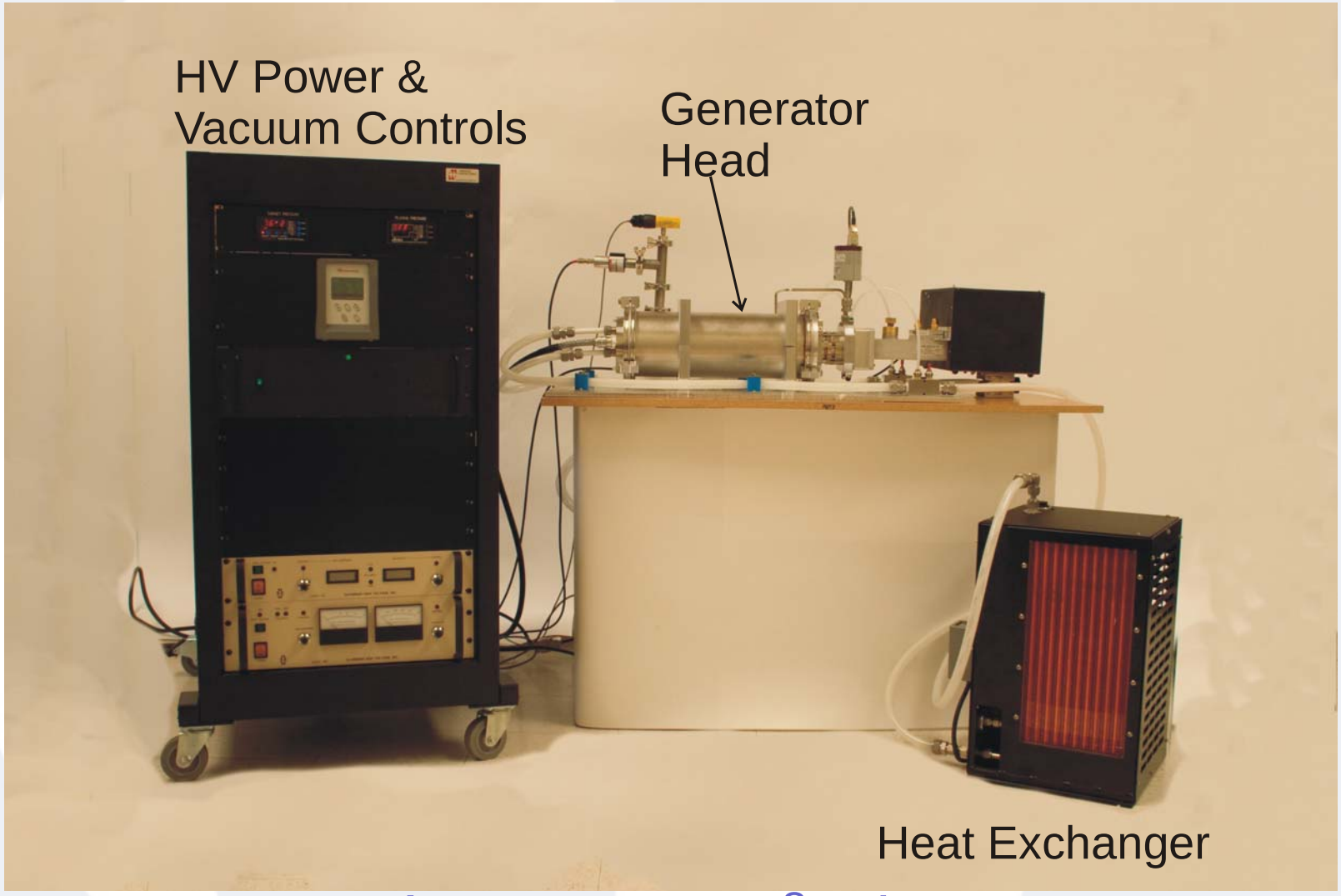
- DD reaction at high neutron yields
- Actively vacuum pumped (uses lecture bottle of Deuterium)
  - Serviceable and long lived
- Sealed versions (DD and DT)
  - Field portable and rugged

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

# ECR-Driven Neutron Generator

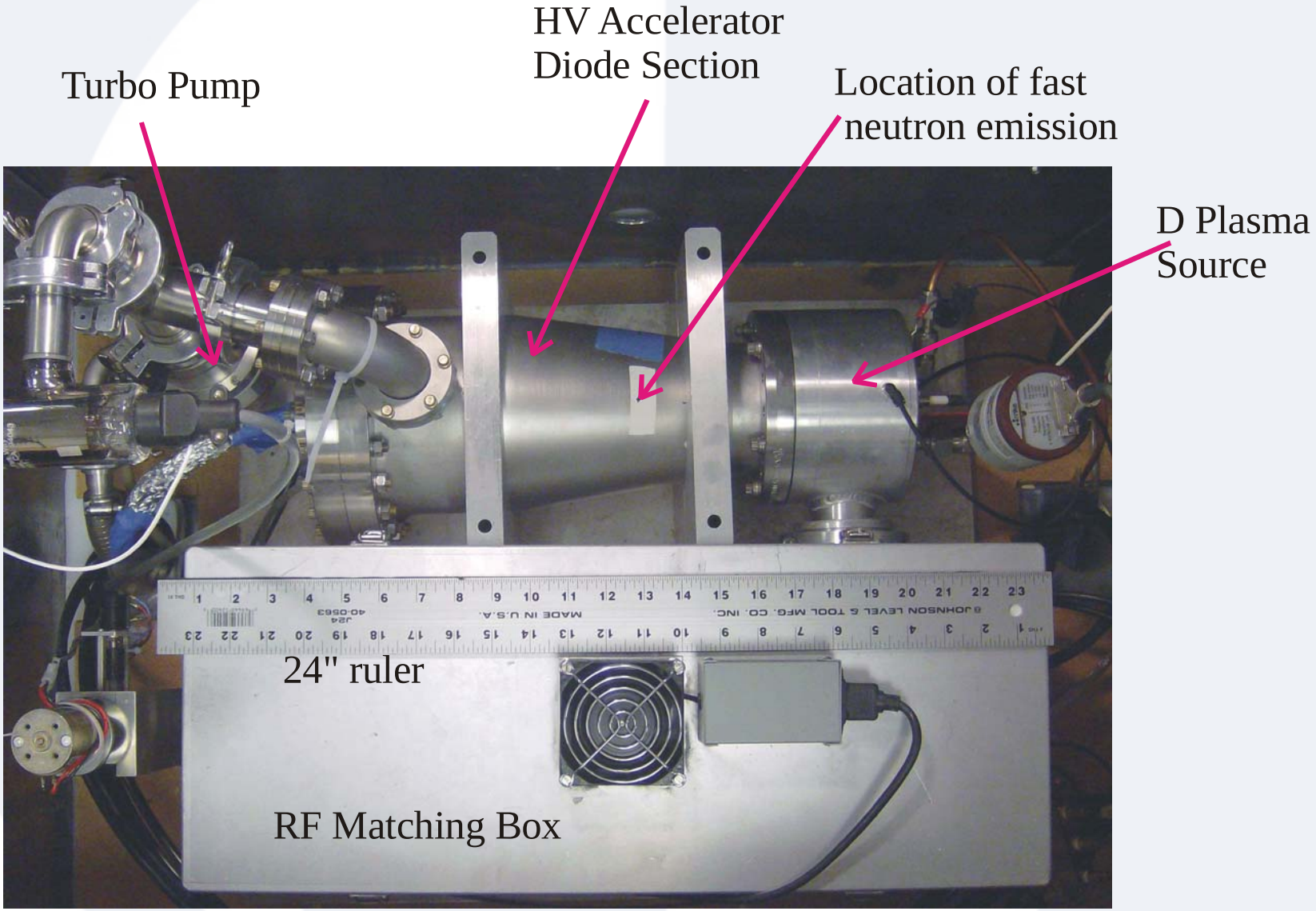


# DD-108 Neutron Generator




Produces 2 x $10^8$ n/s

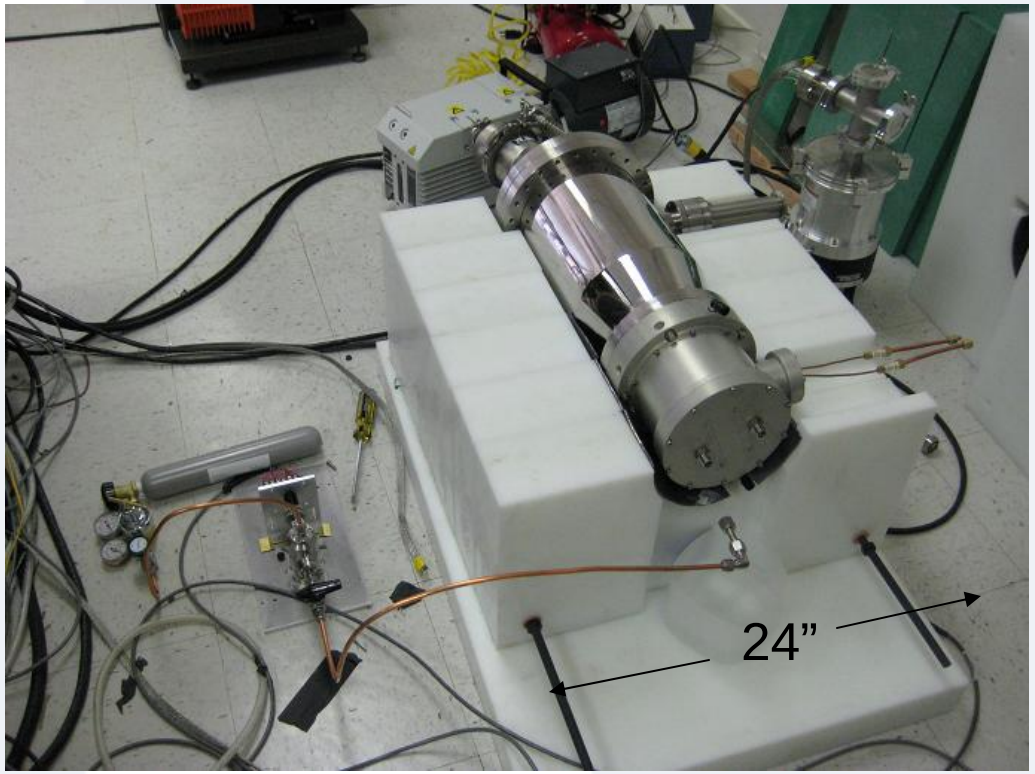
# Old Neutron Generator with RF plasma source



# 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 $\gamma$-ray spectrum to obtain elemental composition
- Applications in mining, oil sands and environmental clean up.

# Important Benefits of STTR

- Transition from RF to Microwave ion source
  - Reduces generator size and weight
    - Compact ECR plasma ion source
  - Higher ion beam currents
  - Lower gas pressures in generator
    - Less arcing of high voltage

# Vacuum System

- Open – Actively pumped using turbo and roughing pump
  - Easy to service generator head
  - Doesn’t require high vacuum techniques
- Closed (Sealed} Getter pump
  - Required for tritium use
  - Required for compact systems like gamma calibrator
  - Reduced lifetime
  - Requires high vacuum practices: bake out head, conflat flanges

# Sealing Generator Head

- Vacuum Practices
  - Used conflat flanges
  - Some brazing of major joints
- Difficult areas
  - Sealing the ion source at the microwave power input
    - Used Alumina window and brazed
  - Permanent Magnets had to be removed

# Gamma Calibrator

## Problem:

- No long-lived gamma-ray calibration sources with energies above 3.5 MeV

## Idea:

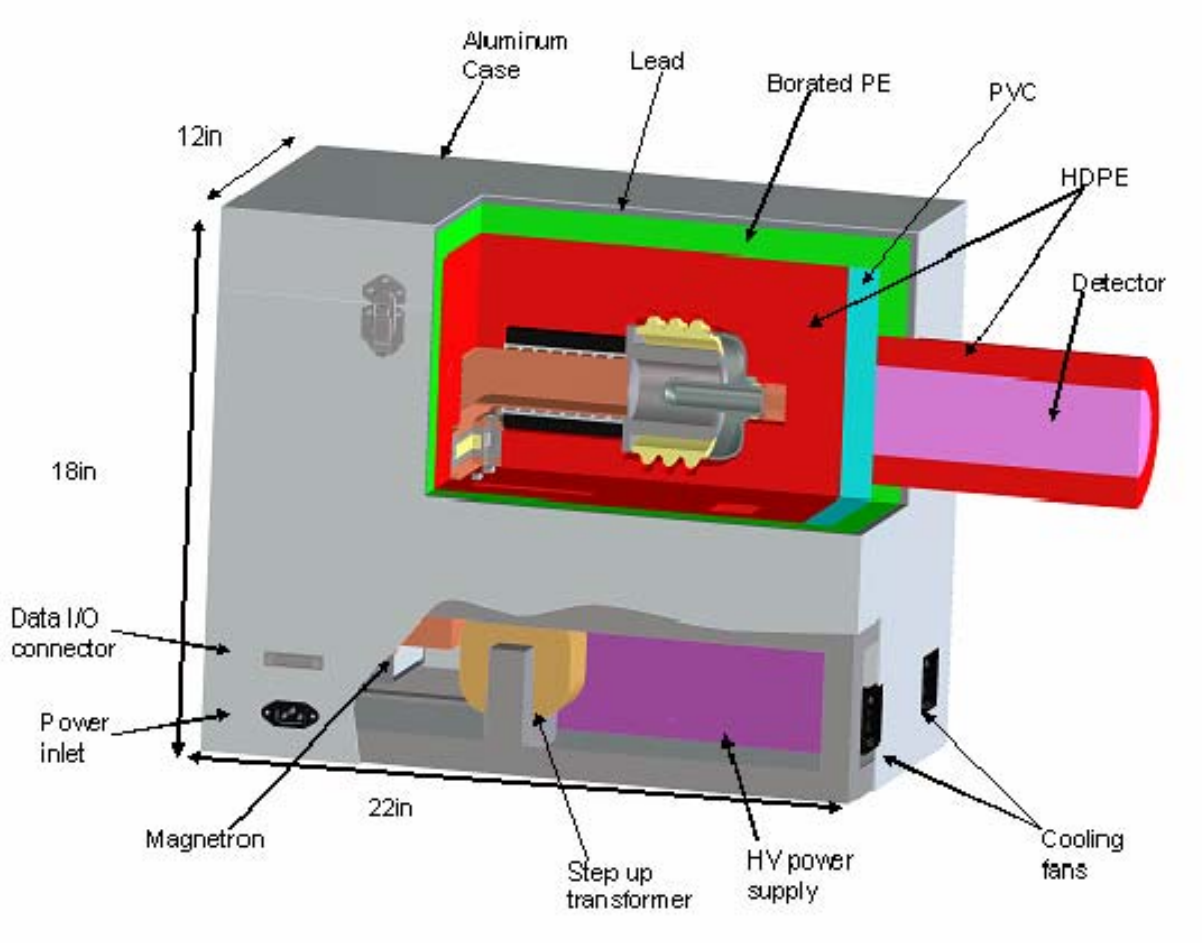
- Produce high energy gamma lines using prompt gamma neutron activation and an inexpensive neutron generator
  - Inexpensive and light weight

# Production of gamma emission

- 2.5 MeV fast neutrons are produced by the DD fusion reaction
  - Using D+ ions striking titanium target
  - 80 kV, 100 μA ion beam
- 2.5 MeV neutrons are thermalized in polyethylene
- Thermal neutrons captured by Cl nuclei in PVC.
  - PVC = Polyvinyl Chloride
- Gamma emission produced by prompt neutron activation
  - Up to 8.6 MeV gammas

# ORIGINAL DESIGN: Gamma Calibrator

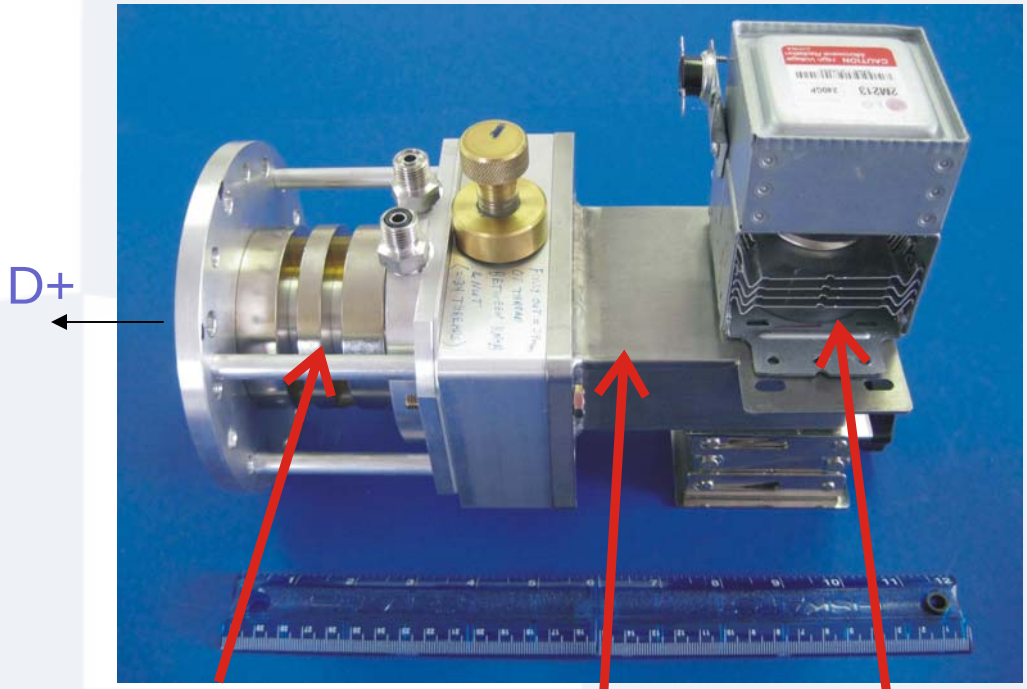
- Neutron Generator enclosed in HDPE moderator with PVC gamma converter.
- Uses inexpensive magnetron
- All supporting components inside.



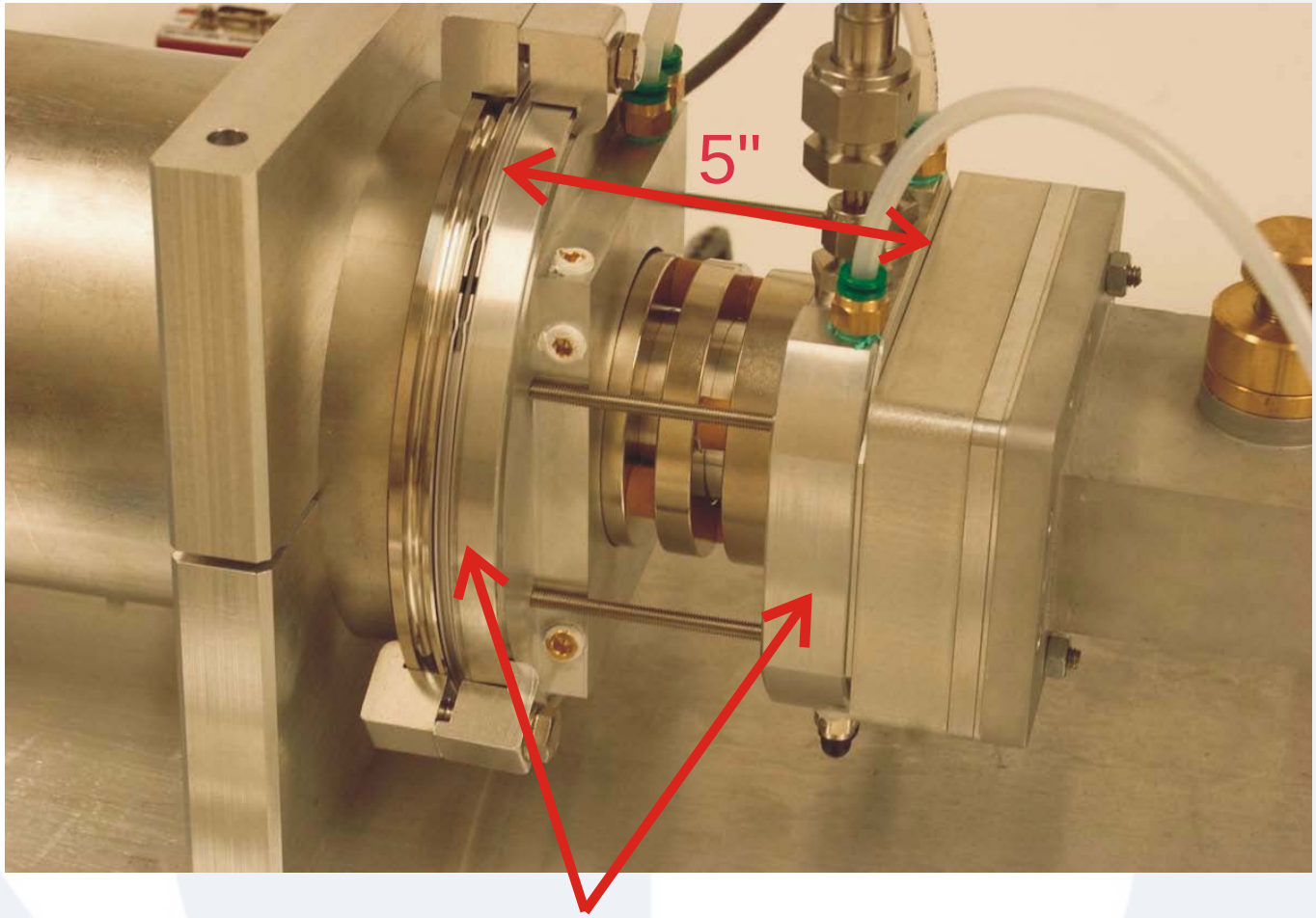
# Compact ECR Source

## ECR = Electron Cyclotron Resonance

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



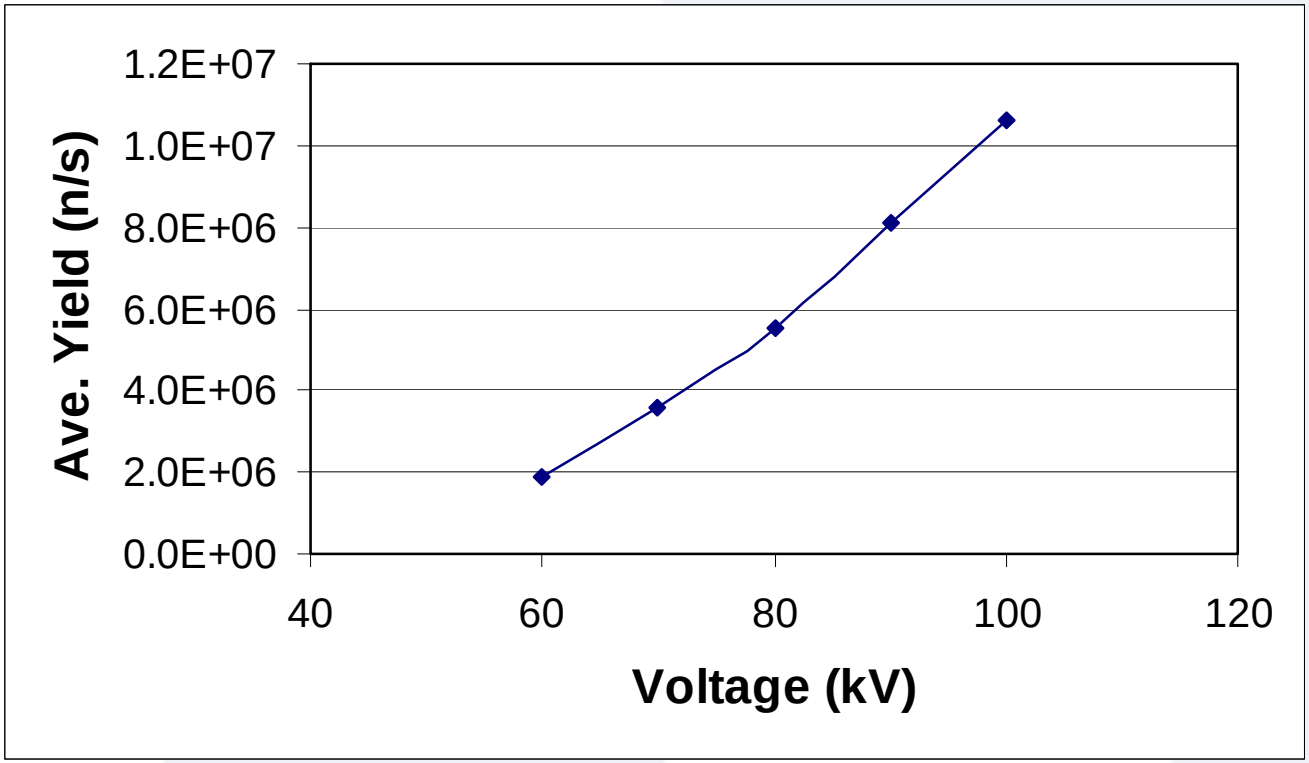
# ECR Plasma Ion Source



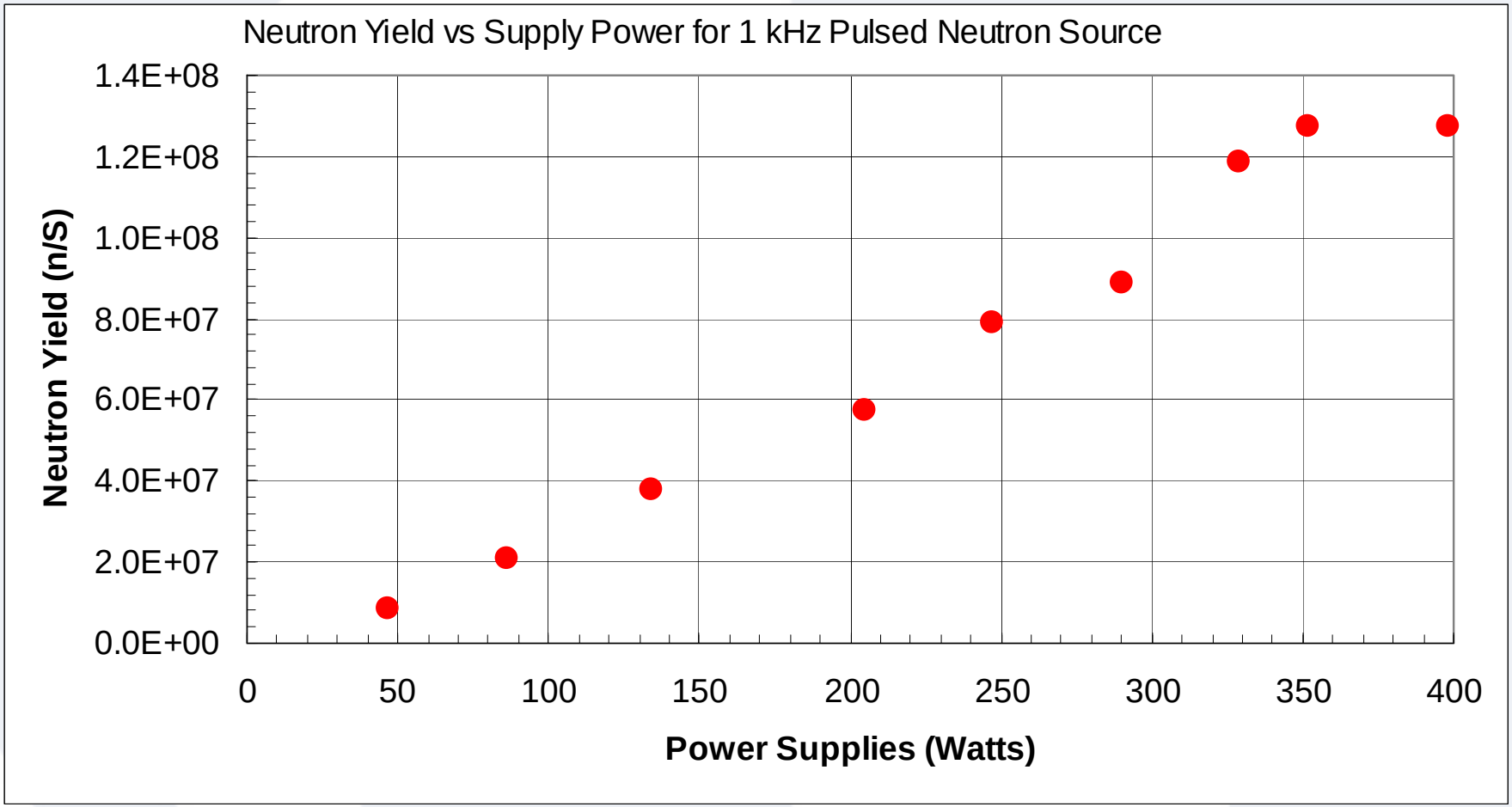

ECR Plasma Ion Source

# Low Power Operation

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

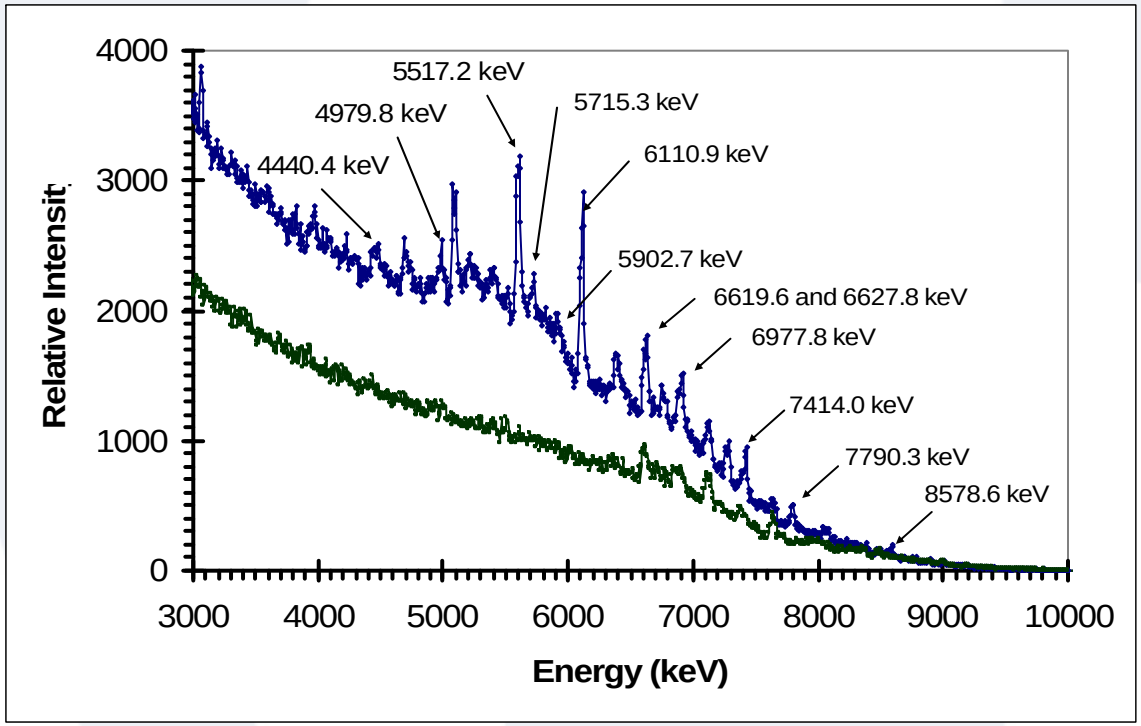


# Measured Neutron Yield vs. Total Average power



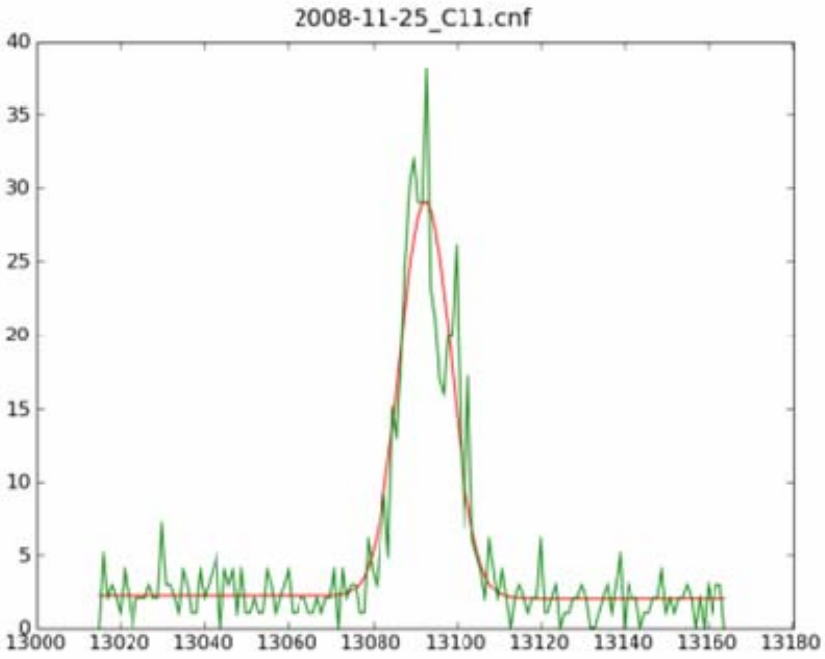

Only 80 watts of acceleration + magnetron pwr. required for 2 x $10^7$ n/s.

# Calibration Lines from PVC (Chlorine)



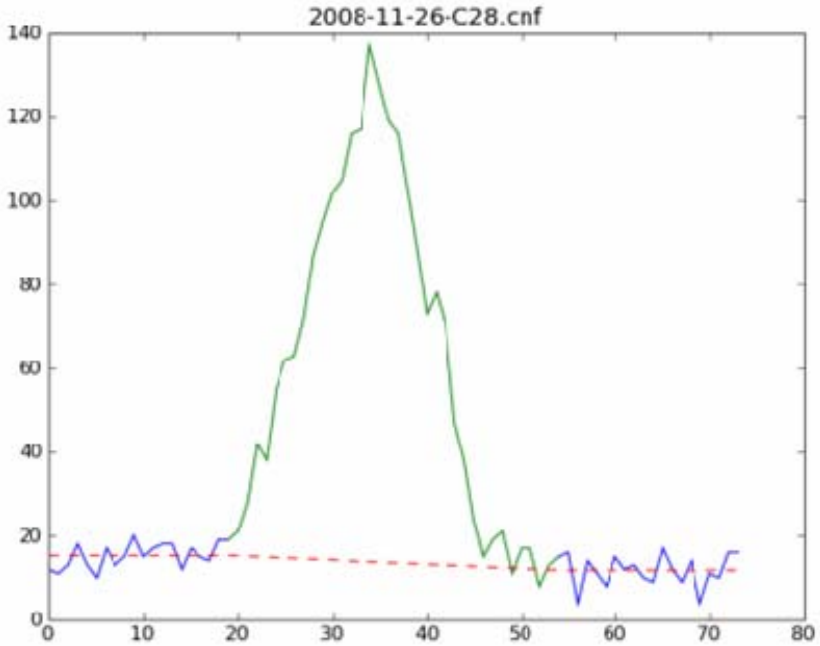

| Energy [MeV] | Expected cts per second | Measured counts per second |
|---|---|---|
| 2.864 | 0.33 | 0.60 |
| 3.062 | 0.19 | 0.26 |
| 4.980 | 0.11 | not observed |
| 5.715 | 0.14 | 1.09 |
| 6.111 | 0.45 | 1.13 |
| 6.620<br>6.628 | 0.25 | 0.44 |
| 7.414 | 0.16 | 0.16 |
| 7.790 | 0.12 | 0.15 |
| 8.579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

# PGNAA Calibration Lines from Ni and Pb




Ni: 8998 keV

Gaussian Fit




Pb: 7368 keV

Background subtraction

# Status of Gamma Calibrator

## Completed:

- First compact ECR plasma ion source using inexpensive magnetron & permanent magnets.
- Prototype ECR-driven neutron generator
- Sealed generator and plasma ion source
- PGNAA calibration spectra measured using DD generators.

## Next:

- Fabricate compact acceleration section integrated with moderator & gamma transducer.
- Demonstrate gamma calibration

# OTHER APPLICATIONS

- Materials Analysis (PGNAA and NAA)
  - Small Laboratory Materials Analyzer
    - Mining and coal analyzer
  - Field portable neutron generator for the detection explosives and special nuclear materials

# 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
- Customer: *Scantech Limited*

# Summary

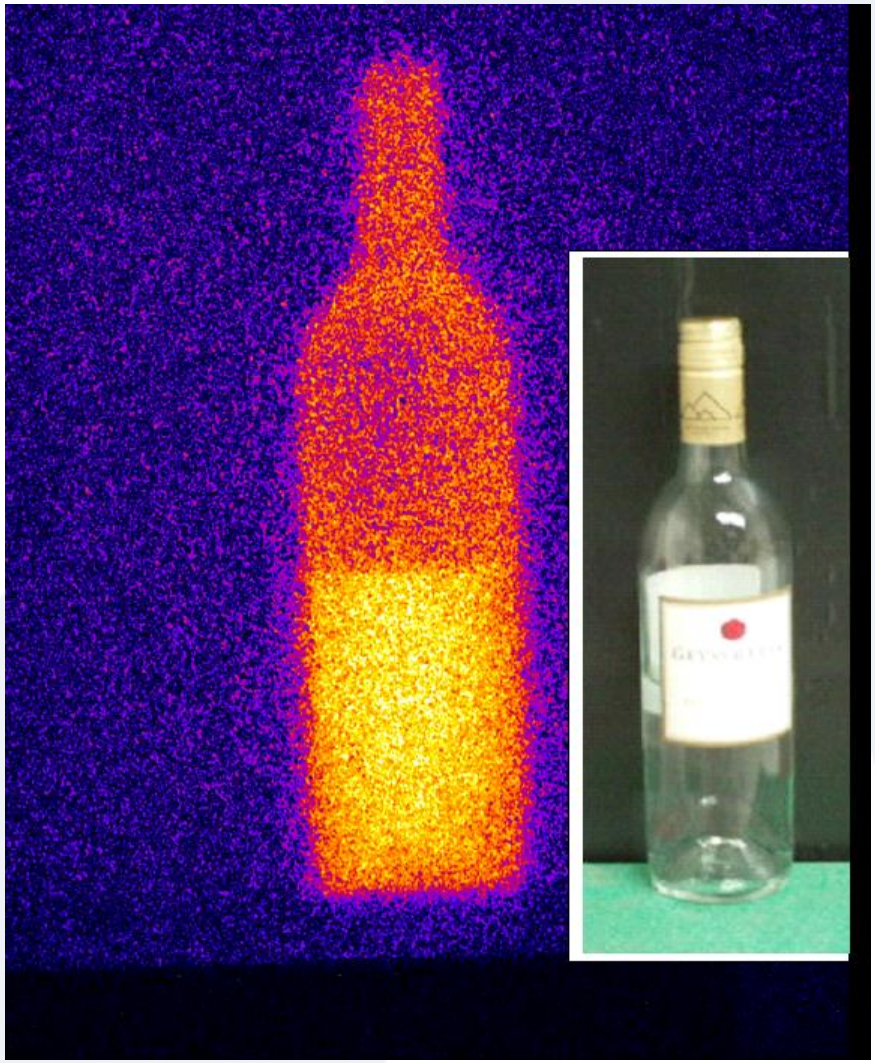
Gamma Calibrator

- 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

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