Long-Lifetime High-Yield Neutron Generators using the DD reaction and application of PGNAA

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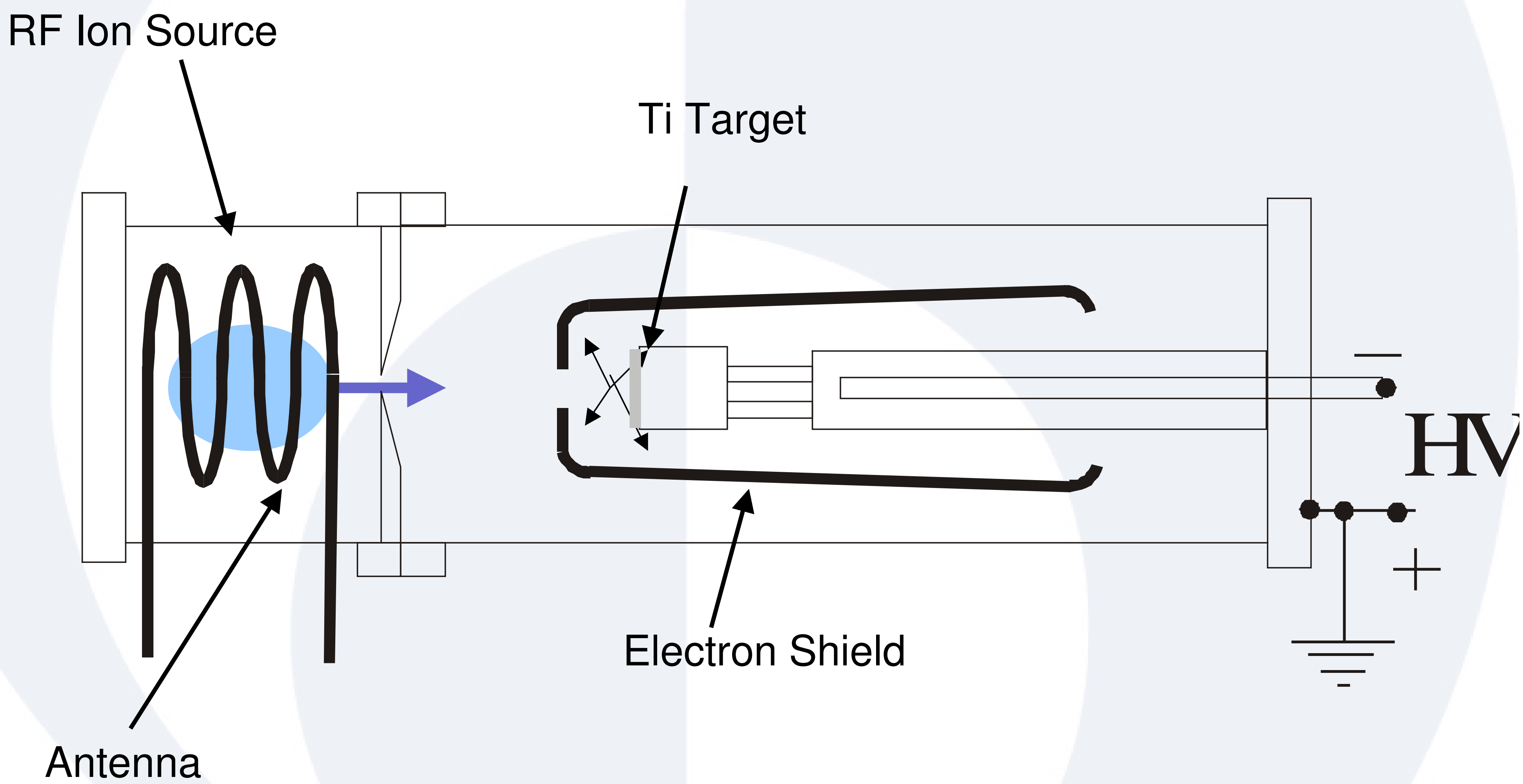
HELIOCENTRIC TECHNOLOGIES

Outline

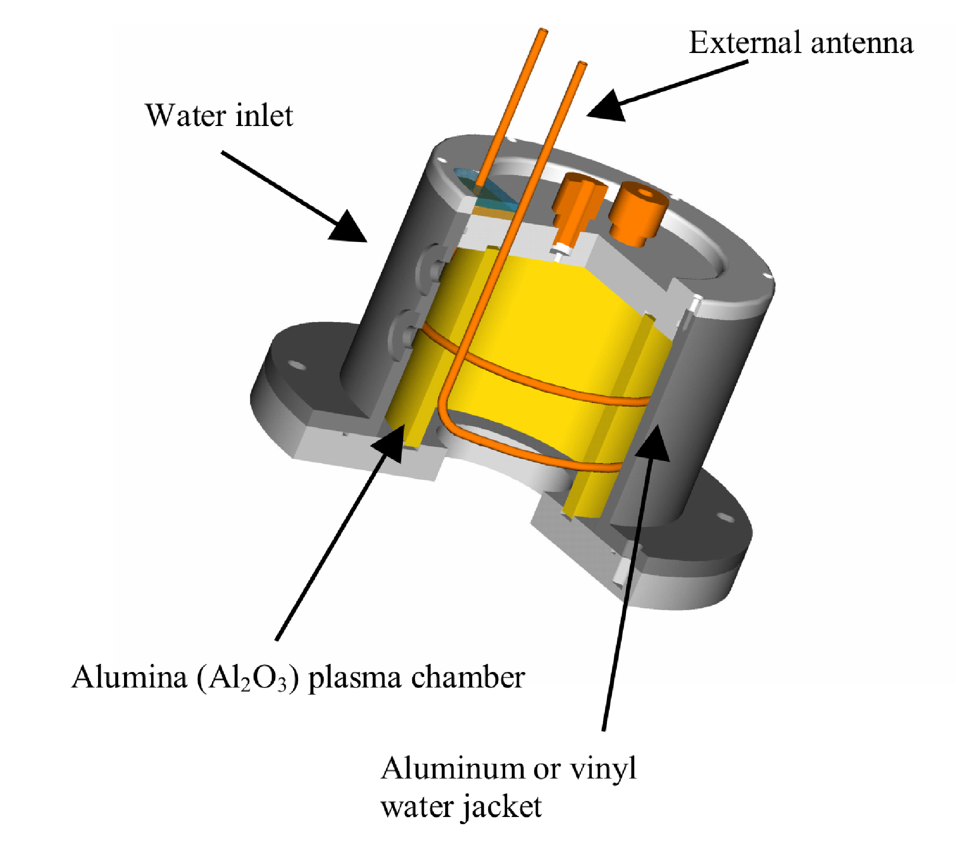
- Plasma Neutron Generators
- RF Plasma Source
- Neutron Yield
  - Current Designs
  - Efficiency
- Research Applications
- Mining Instrument Application
  - Industry Need
- Prototype Test Results
- Conclusion

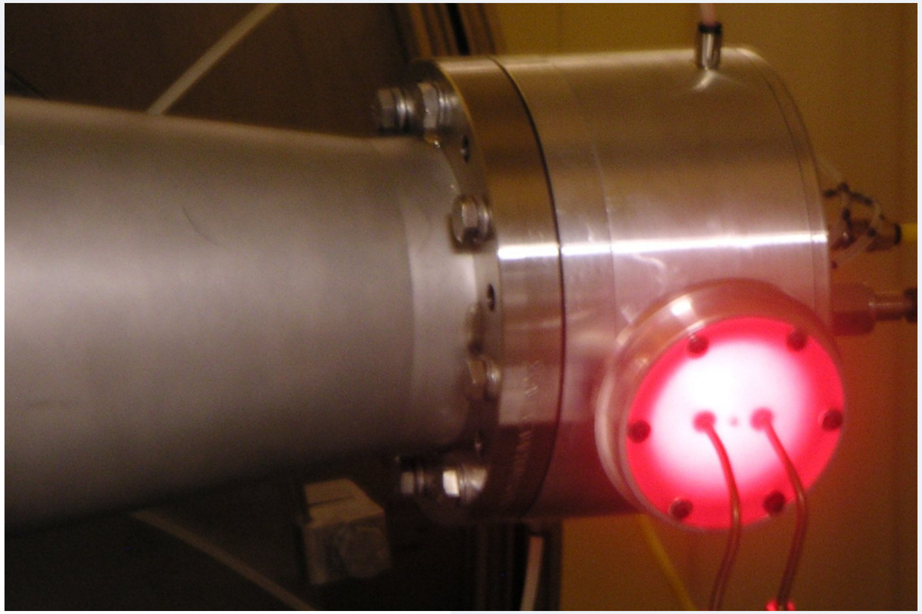
Axial Generator: Function



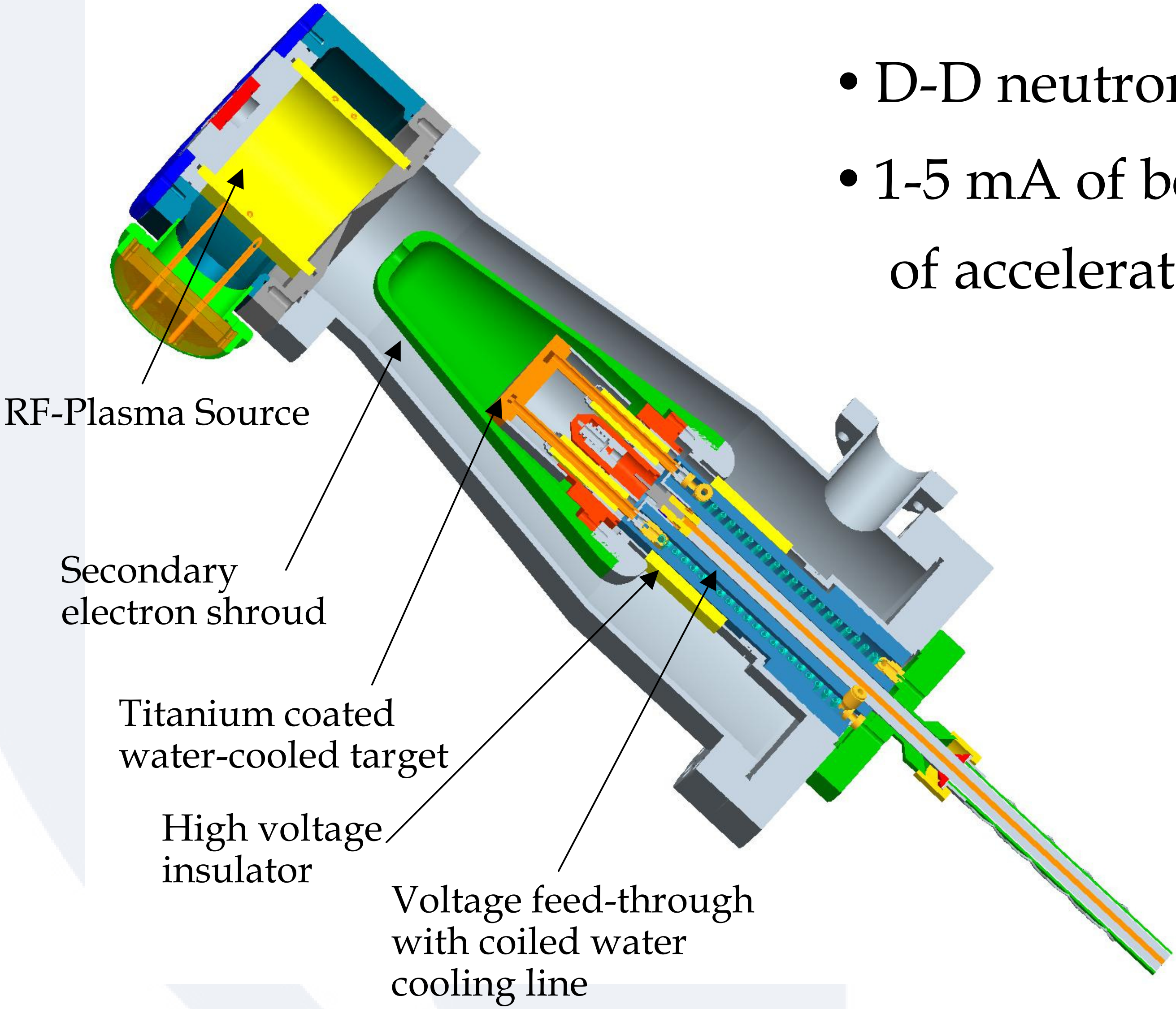
RF Plasma Source: Coil Antenna

- Mechanically and thermally stable and rugged





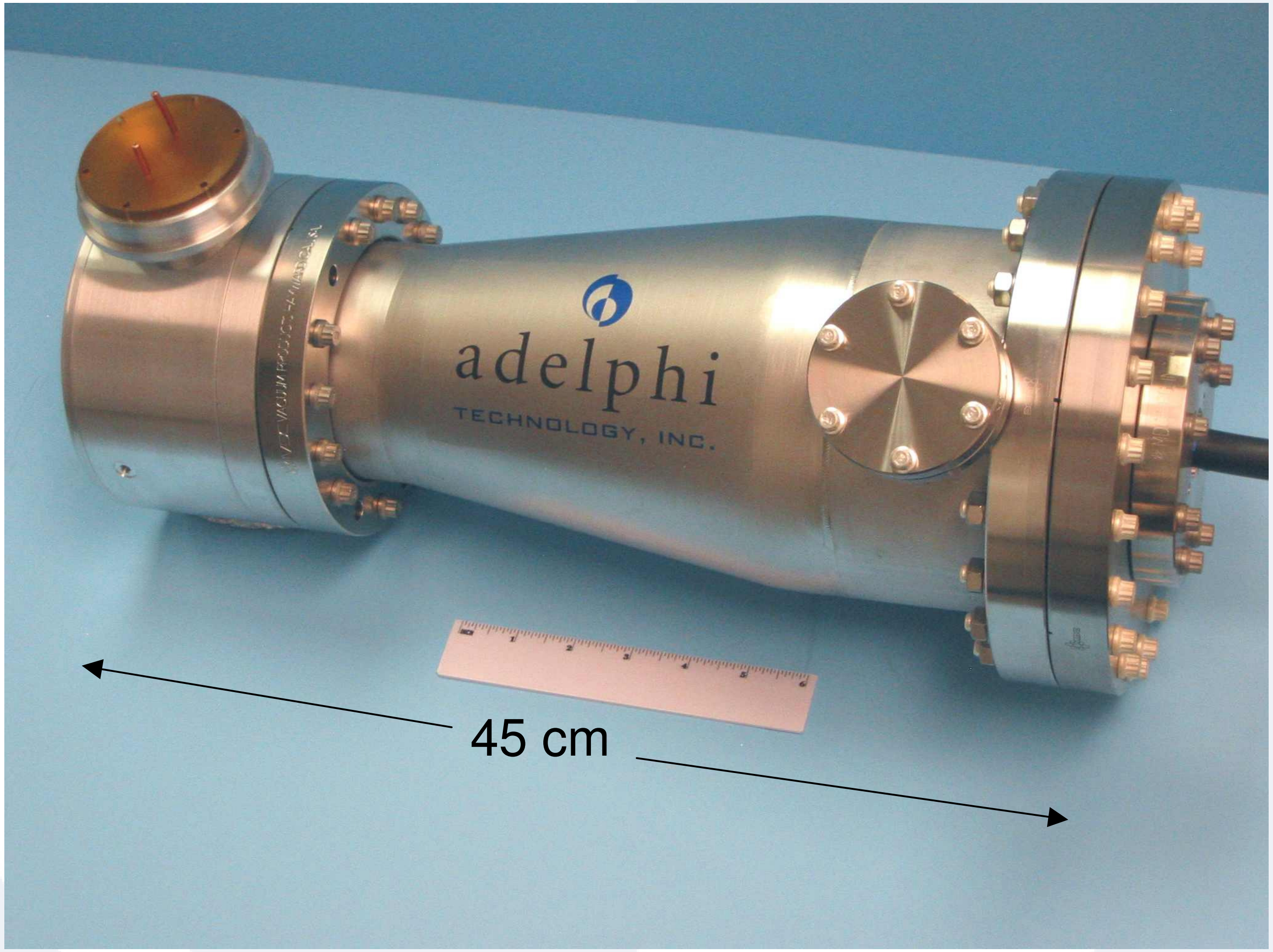
Axial Generator DD-108



- D-D neutron yield of 10^8 n/sec
- 1-5 mA of beam current & 80 kV of acceleration voltage

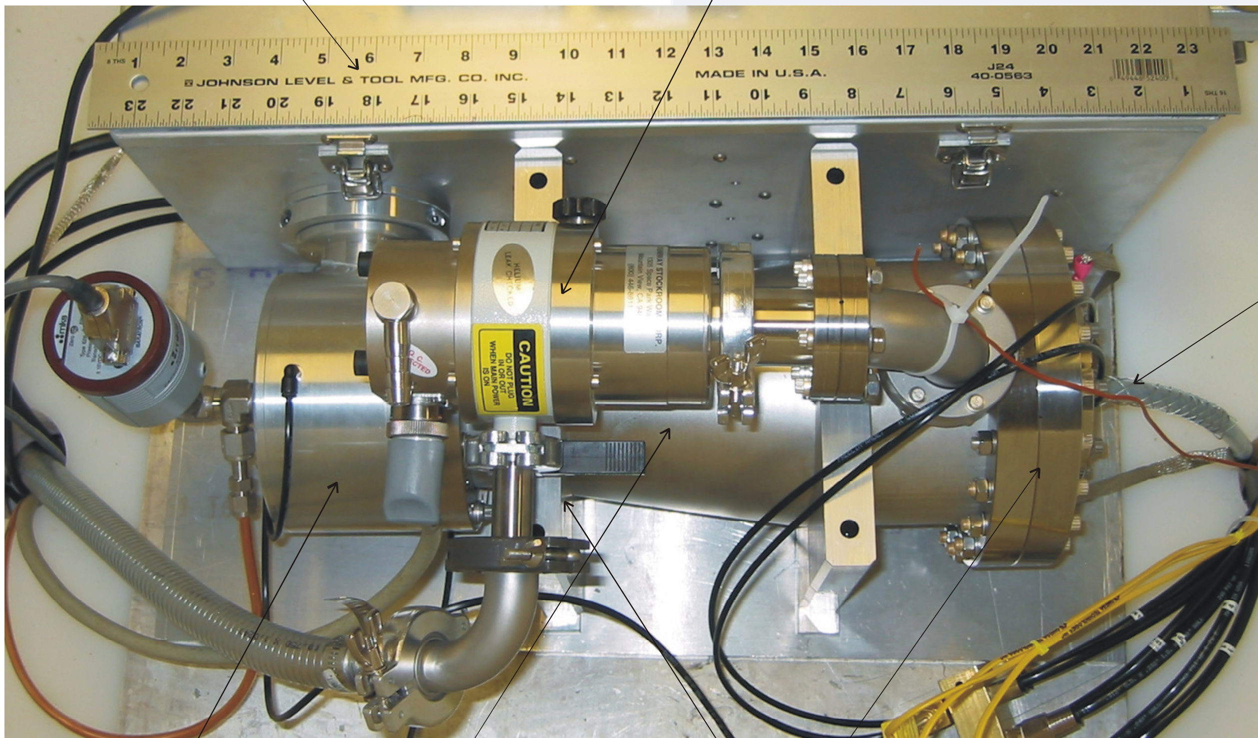
Axial Generator DD-108

- DD-108: Output measured at 10^8 n/s



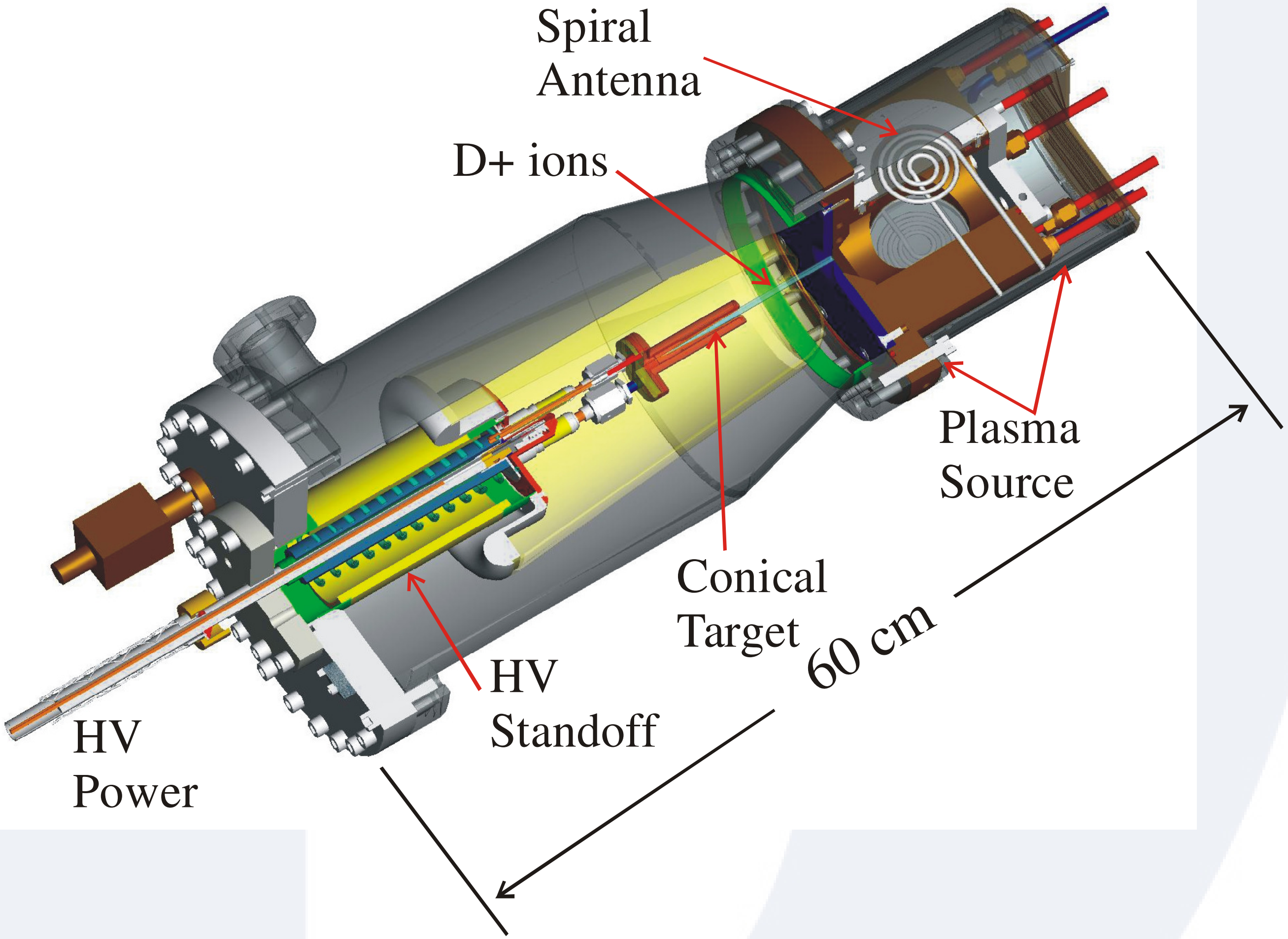
Axial Generator DD-108: Installed

- Ancillary equipment: RF matching, pumps, meters, D2 supply, cooling

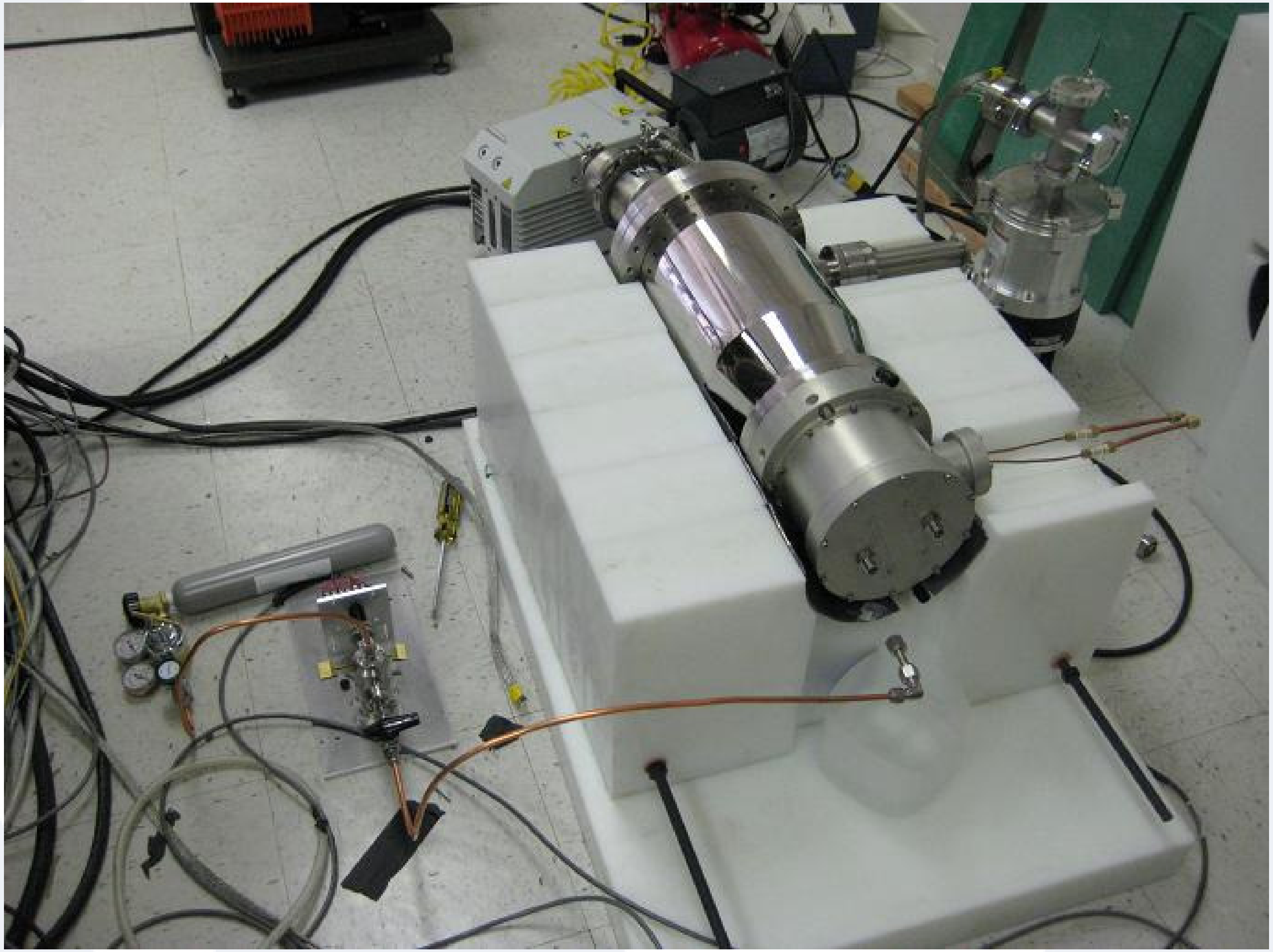


Axial Generator – DD-109

- Small apparent spot size
  - high brightness fast neutron source
- Yield 10^9 n/sec

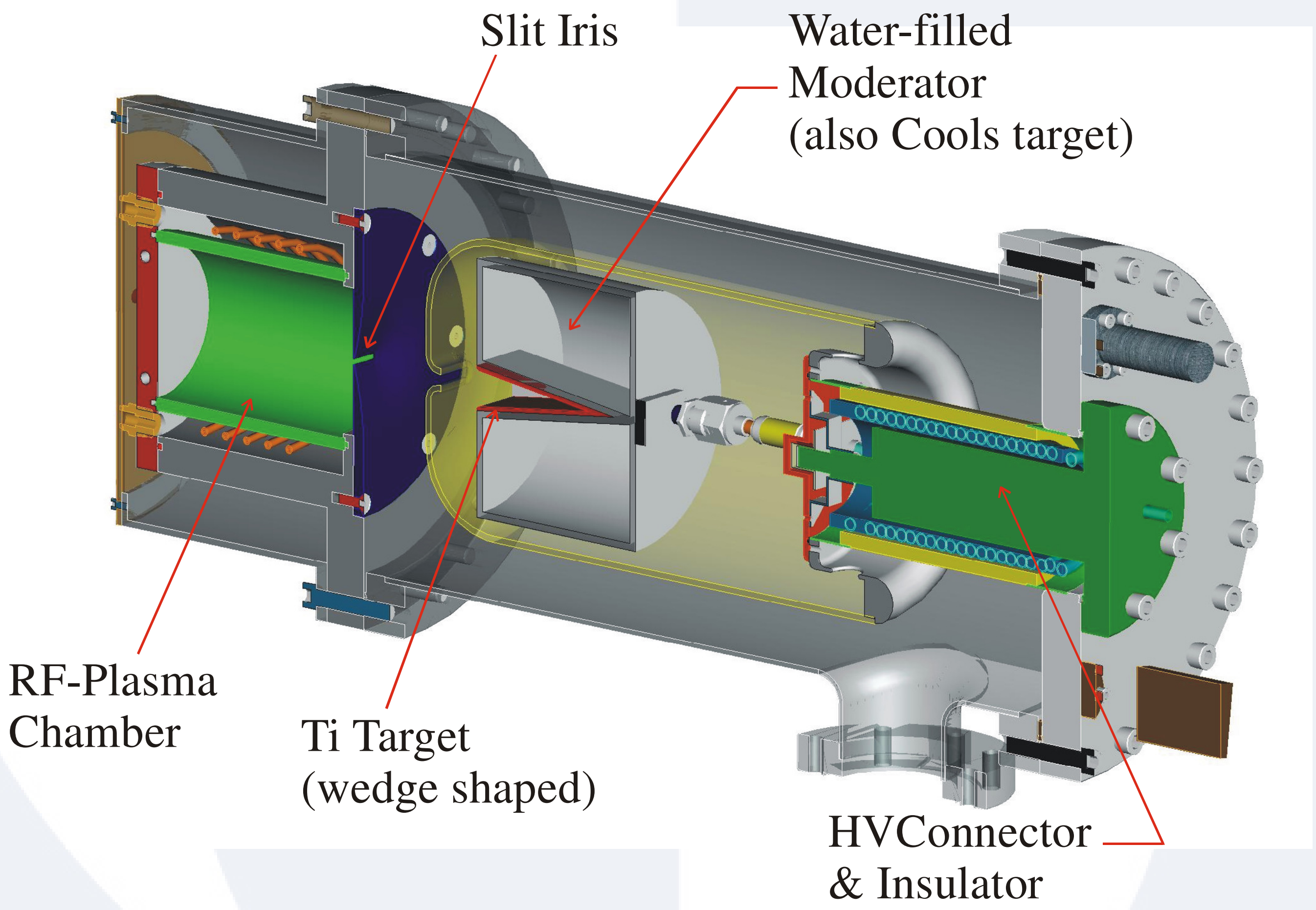


DD-109 Neutron Generator



Axial Generator DD-110

- Cooling and moderator function integrated

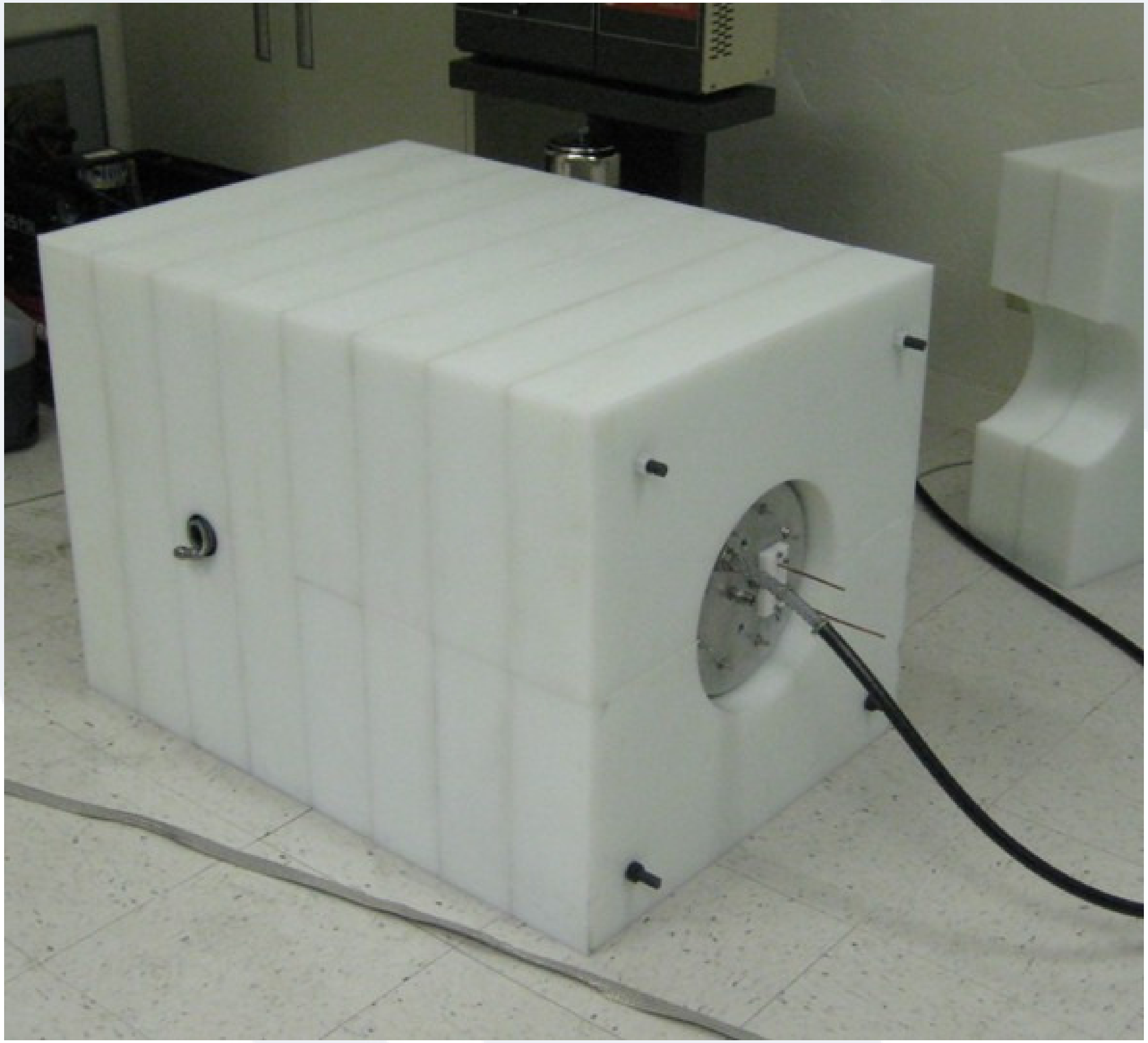


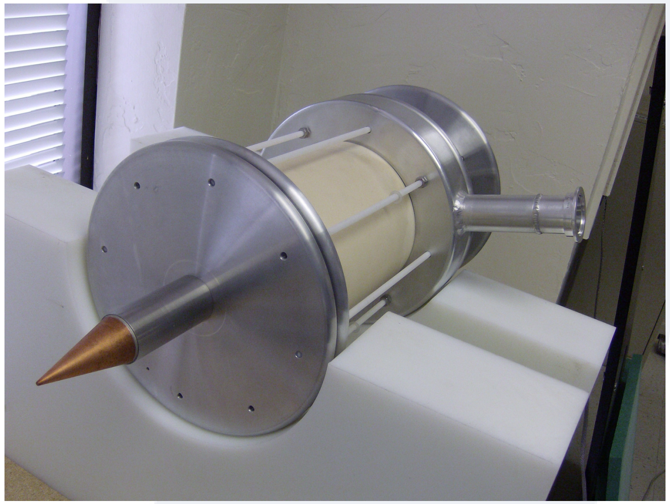
DD-110 Neutron Generator

Integrated Thermal Neutron Sources

- We want maximum thermal neutron flux for PGAA and NAA
- F. A. Sanchez Analysis 2006 (Sect. 7, IAEA report)
  - Minimized distance to moderator
  - Minimizes moderator material used
- Adelphi Solution
  - Use axial fast neutron source
  - Integrate fast neutron source to moderator
    - Use moderator as part of generator structure

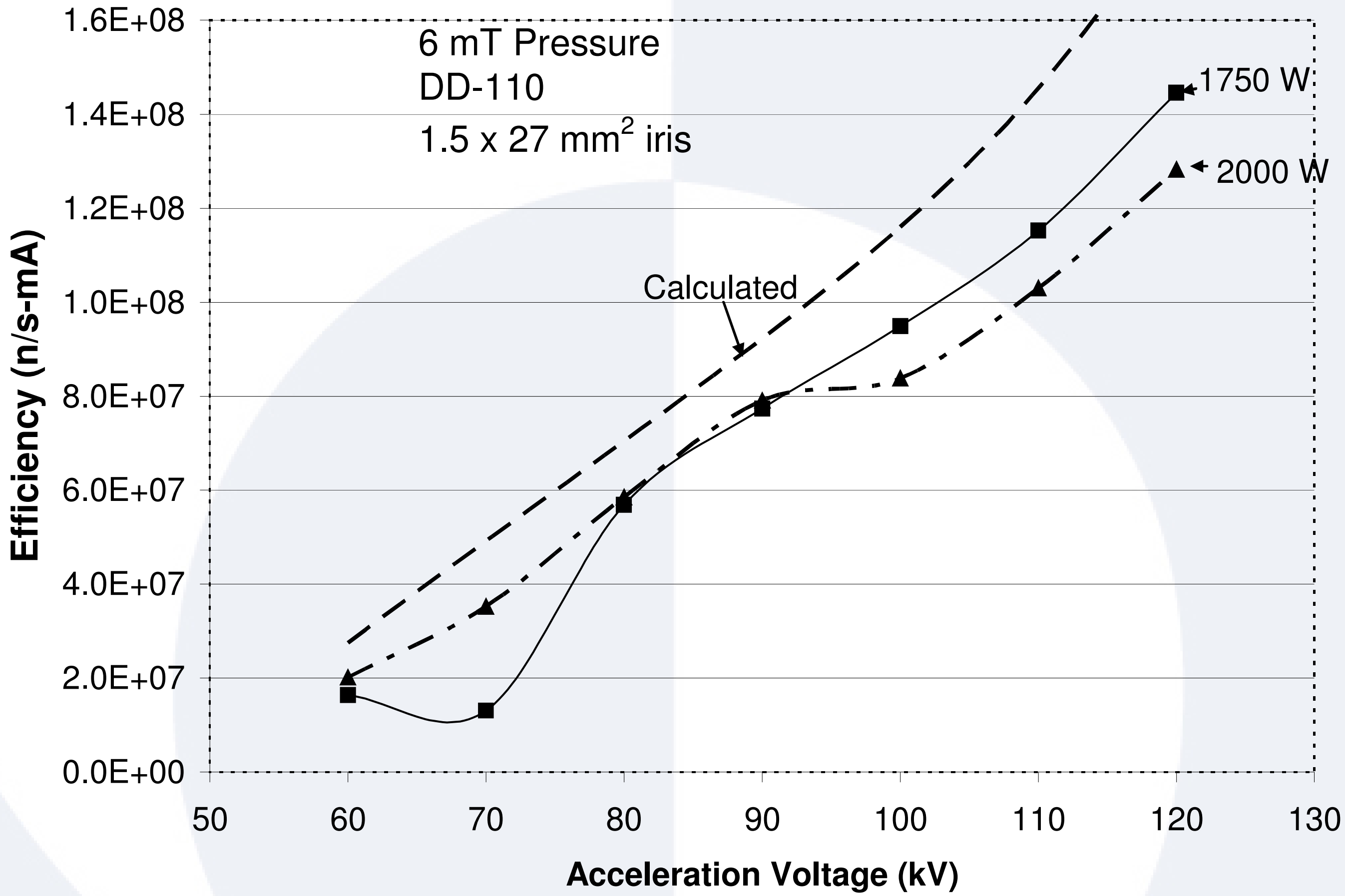
"Thermal" Generator DD-108T





Neutron Yield Efficiency

- The efficiency of neutron production per mA of beam current as a function of accelerator voltage for two RF plasma powers.

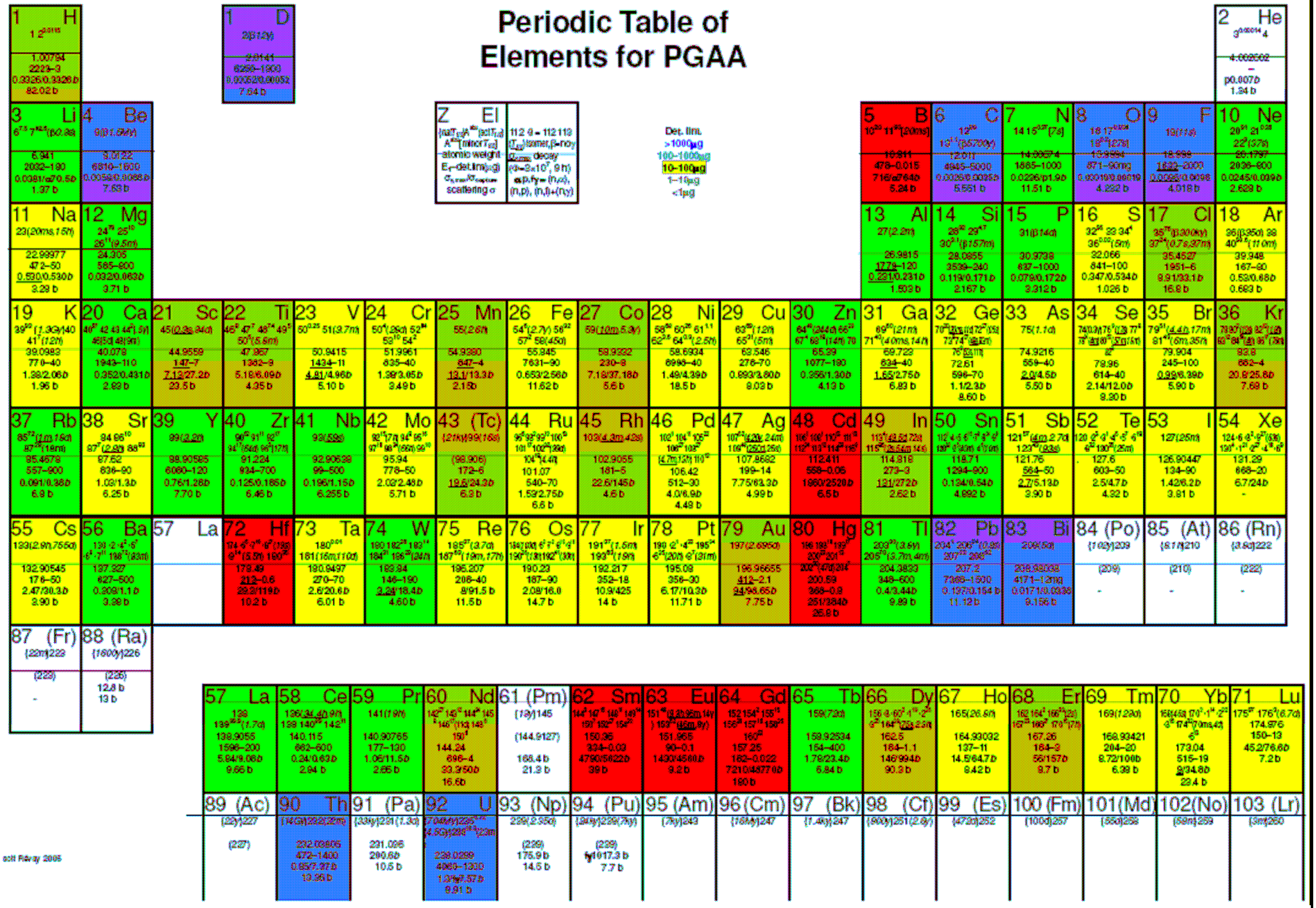


Research Applications

- Neutron Radiography
- SNM Detection
  - Delayed Neutron Response
    - Timed Neutron (Differential Die-Away Technique)
    - Neutron Spectroscopy
  - Delayed Gamma Ray Response
    - Timed Gammas
    - Gamma Spectroscopy
- Explosive Detection
  - Associated Particle and other 2-D Imaging
  - Gamma Ray Compton Camera
  - Fast Neutron Transmission Spectroscopy
  - Fast Neutron Scattering

Industrial Research - Spectroscopy

- Trace-Element Prompt Gamma Neutron Activation Analysis (PGNAA):
  - Deep penetration radiation performs bulk analysis
    - no sample prep. required
  - Elements capture neutrons and re-emit unique γ-ray signature
  - Deconvolution of γ-ray spectrum to obtain elemental composition
  - Neutrons emitted by an electric neutron generator
    - Safe
    - On-off switchable (non radioactive);
- Platform technology:
  - Can measure the content of any sample in any state
- Applications in clean mining (tailings), oil sands and Clean Tech (clean soil).

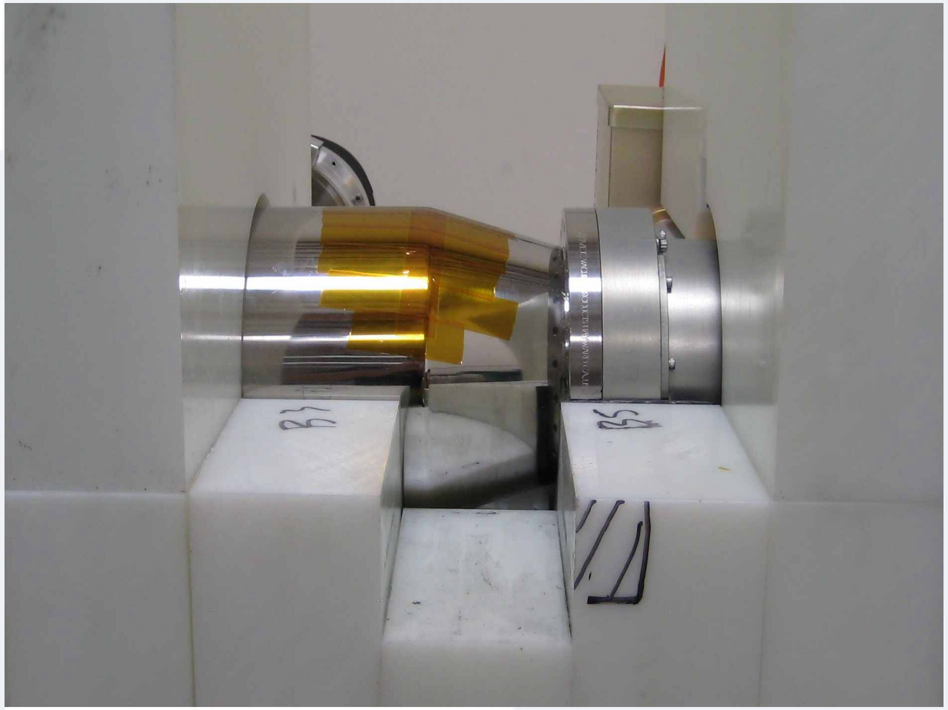

Periodic Table of Elements for PGAA
Z El
atomic weight
Det. lim.
>1000μg
100–1000μg
10–100μg
1–10μg
<1μg
1 H
1 D
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 (Tc)
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
57 La
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 (Po)
85 (At)
86 (Rn)
87 (Fr)
88 (Ra)
57 La
58 Ce
59 Pr
60 Nd
61 (Pm)
62 Sm
63 Eu
64 Gd
65 Tb
66 Dy
67 Ho
68 Er
69 Tm
70 Yb
71 Lu
89 (Ac)
90 Th
91 (Pa)
92 U
93 (Np)
94 (Pu)
95 (Am)
96 (Cm)
97 (Bk)
98 (Cf)
99 (Es)
100 (Fm)
101 (Md)
102 (No)
103 (Lr)
Révay 2005

Base Metal Mining Proposed Solution

- Real-time results while mining enables
  - On-the-spot ore/waste determination
    - Huge penalty of processing waste instead of ore
      - up to ~$3M loss per day (hauling, dilution, etc.)
      - Better smelter returns
    - Particularly relevant for deep underground or large open pit mines
  - Additional benefits
    - In-situ assessment of deleterious elements and environmental contaminants
    - Immediate mill to mine reconciliation/billing
- Optimization of advanced drilling campaigns
  - Optimize resource discovery with finite drill time
    - Very useful for delineation drilling
    - Particularly relevant in the case of "deposits open at depth"
    - Saves on drill commissioning/decommissioning costs (~$100K+)

D-D Neutron Generator & Moderator

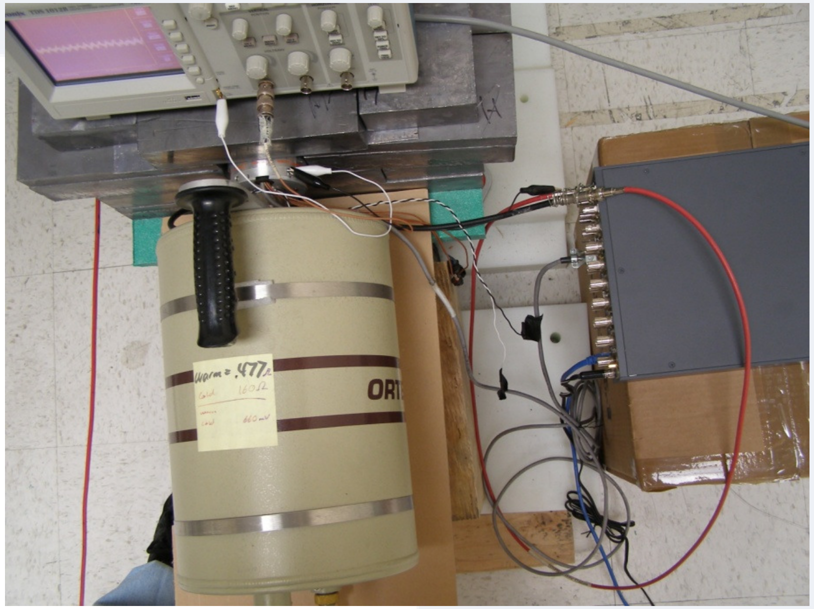
- Yields 10^9 n/s isotropic at 2.45 MeV (mono-energetic)
- Approximately 10^5 $n \cdot cm^{-2} \cdot s^{-1}$ in the sample
- Provides the ability to throttle, stop or pulse neutron production on command
- Neutron moderator designed to minimize background noise



Neutron Generator encased in moderator

Detector and Electronics

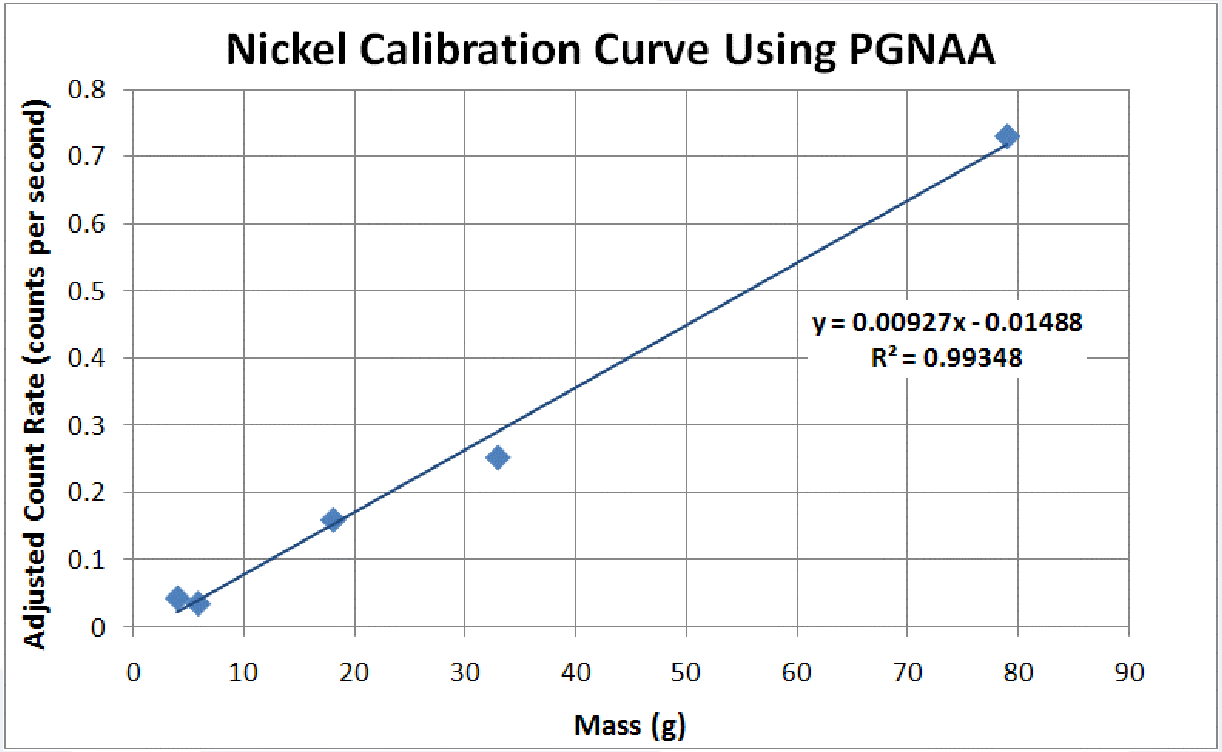
- Detector is coaxial HPGe (~100 cm3 volume)
- Digital Multi-Channel Analyzer (MCA) for signal processing
- Post-Processing
- Algorithms interpret the test spectrum into an elemental composition



Detector and electronics

Prototype Performance – Calibration

- Pure elements are used to calibrate the instrument
- Detection limits for 1000 second measurements are established using the calibration measurements



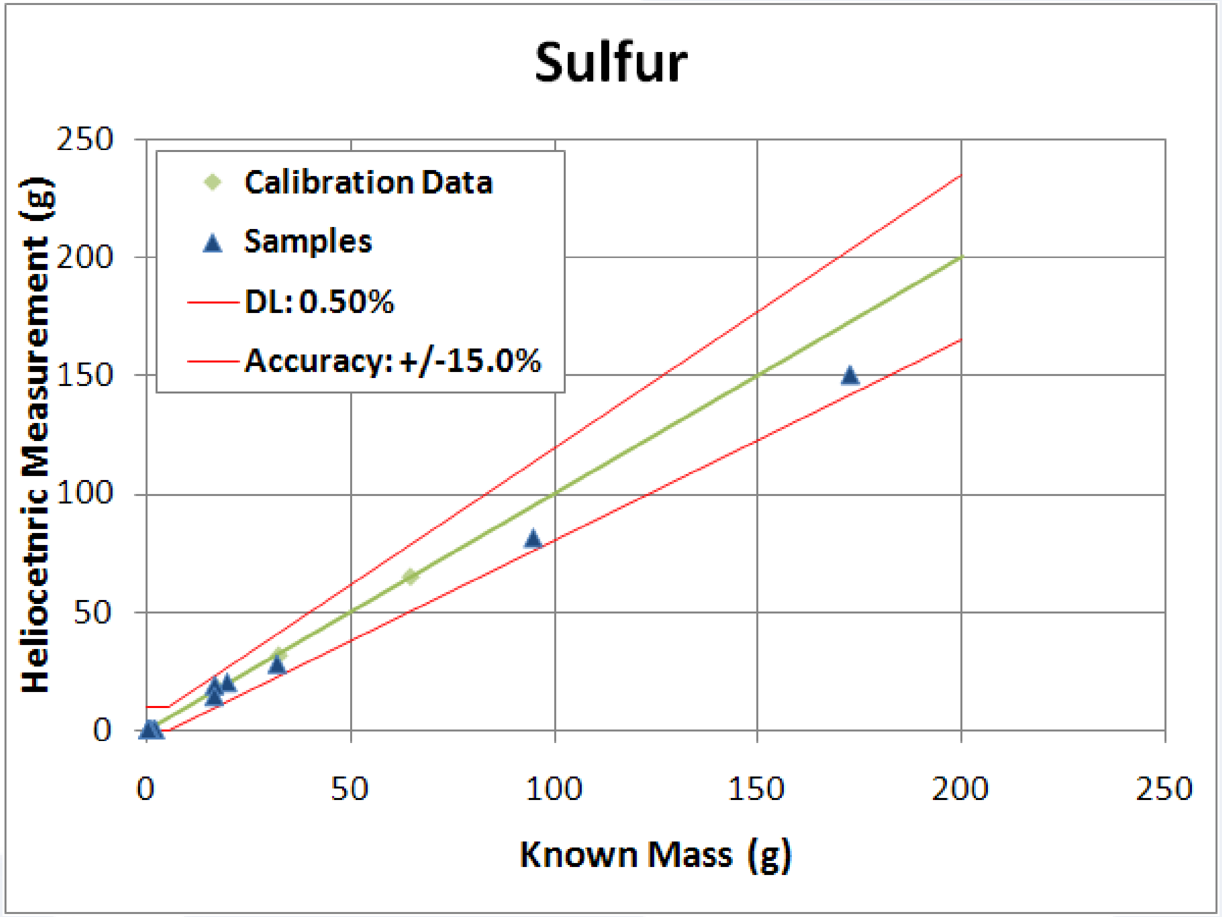
Prototype Performance – Test Samples

- Customers provide samples for measurement
- Samples previously measured by alternate methods
- PGNA measurements are 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



Results – Summary

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%

Conclusions

- The Prototype Elemental Analyzer has achieved its target performance level
  - +/- 15% measurement accuracy
  - Detection limits of 0.5% to 1.5% for 1 kg samples
- Performance is consistent for a range of customer samples with varying physical properties
- Prototype performance scaling for the final instrument is on schedule.

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