Long-Life, High-Yield D-D Neutron Generator

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

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Long-Life, High-Yield D-D Neutron Generator

Outline

- Plasma Neutron Generators
- RF Plasma Source
- Neutron Yield
  - Current Designs
  - Efficiency
- Research Applications
- Mining Instrument Application
  - Industry Need
- Prototype Test Results
- Conclusion
Long-Life, High-Yield D-D Neutron Generator

**Axial Generator: Function**

- RF Ion Source
- Ti Target
- Electron Shield
- Antenna
- HV
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**RF Plasma Source: Coil Antenna**

- Mechanically and thermally stable and rugged

![Diagram of RF Plasma Source: Coil Antenna]

- Water inlet
- External antenna
- Alumina (Al₂O₃) plasma chamber
- Aluminum or vinyl water jacket
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**Axial Generator DD-108**

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

**Components:**
- RF-Plasma Source
- Secondary electron shroud
- Titanium coated water-cooled target
- High voltage insulator
- Voltage feed-through with coiled water cooling line
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
Long-Life, High-Yield D-D Neutron Generator

**Axial Generator – DD-109**

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

![Diagram of Axial Generator](image)
Long-Life, High-Yield D-D Neutron Generator

**DD-109 Neutron Generator**
Axial Generator DD-110

- Cooling and moderator function integrated

- Ti Target (wedge shaped)
- Slit Iris
- RF-Plasma Chamber
- Water-filled Moderator (also Cools target)
- HVConnector & Insulator
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**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 $\gamma$-ray signature
  - Deconvolution of $\gamma$-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).
Adelphi Technology, Inc.

Periodic Table of Elements for PGAA

[Image of periodic table]

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**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·cm$^{-2}$·s$^{-1}$ in the sample
- Provides the ability to throttle, stop or pulse neutron production on command
- Neutron moderator designed to minimize background noise
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
**Prototype Performance – Calibration**

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

![Nickel Calibration Curve Using PGNAA](image.png)

\[ y = 0.00927x - 0.01488 \]

\[ R^2 = 0.99348 \]
Prototype Performance – Test Samples

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

![Sulfur Graph]

- Calibration Data
- Samples
- DL: 0.50%
- Accuracy: +/-15.0%
Results – Summary

<table>
<thead>
<tr>
<th>Element</th>
<th>Detection Limit: prototype</th>
<th>Detection Limit: target for final instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>0.2% (DGNA)</td>
<td>0.02 % (DGNA)</td>
</tr>
<tr>
<td>Cobalt</td>
<td>0.5%</td>
<td>0.05 %</td>
</tr>
<tr>
<td>Copper</td>
<td>0.6%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.9%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Iron</td>
<td>1.5%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.5%</td>
<td>0.05 %</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.5%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Zinc</td>
<td>3%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Integration time</td>
<td>1,000 s</td>
<td>300 s</td>
</tr>
<tr>
<td>Absolute accuracy</td>
<td>+/- 15%</td>
<td>5%</td>
</tr>
</tbody>
</table>
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.