Development of Time-tagged Neutron Source for Imaging with Enhanced Spatial Resolution

Qing Ji, Bernhard Ludewigt, and Thomas Schenkel

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Detection of alpha particles allows the neutrons to be tagged – Time – Direction

• Improvement needed
  – Higher spatial resolution
  – Higher intensity

• Both transmission imaging and induced fission imaging methods will be greatly enhanced.

• Applications
  – Nuclear safeguards
  – Homeland security
  – Treaty verification
  – Other similar applications

\[ D + T \rightarrow ^4\text{He} \ (3.5 \text{ MeV}) + n \ (14 \text{ MeV}) \]
Tagged Neutron Source for API Inspection Systems
Proliferation Detection and Nuclear Safeguards Application

Transmission imaging
- Eliminating the scattering component extends the range of transmission imaging to roughly 8 times the neutron attenuation length.

Induced fission imaging
- Spatial resolution important
- Dummy and HEU rodlets visible with 1 mm spot size, but not with 3-5 mm size of current system.
  (Simulated results)

• simulations by Paul Hausladen, ORNL

Needed: Higher spatial resolution, higher intensity for faster measurement
**Imaging Resolution**

- Contributions to angular uncertainty:
  - Geometry: beam spot size on target, distance to alpha detector
  - Position resolution of alpha detector (ideally << spot size)
  - Multiple-scattering of alpha particle in target
  - Kinematics of D-T reaction (in one dimension)
Approach

• Goals
  – Reduce the size of the beam spot on the neutron production target to 1 mm in diameter
    ▪ a several-fold increase in directional resolution
  – Increase the maximum attainable neutron yield (~ $10^9$ neutrons/sec)
    ▪ approximately one order of magnitude over existing sources.

• Technical approaches
  – Microwave-driven ion source
    ▪ Produces sufficient beam current density
    ▪ High atomic fraction
    ▪ Operates at low gas pressure
  – To achieve small beam spot size on target
    ▪ No active beam focusing
    ▪ Use extraction aperture of high aspect ratio
  – Alpha detector with rel. high position resolution (pixel size < beam spot size)
  – Source on HV, target on ground
    ▪ to avoid electron acceleration into alpha detector
Permanent-magnet Microwave-driven Ion Source

![Diagram of the ion source with annotations: Al₂O₃ window, Gas inlet, Ion source chamber (Ø 4 cm × 5 cm), and Permanent magnets.]

- **Deuterium Beam**
  - Microwave Power: 330W
  - Extraction aperture: 2mm-dia

- **High Current Density**

- **High Atomic Fraction**
  - H⁺ (92.6%)
  - H₂⁺ (6.0%)
  - H₃⁺ (1.4%)

- **Beam Current > 100 µA from 0.6mm Aperture**

- **Graphs:**
  - Beam Intensity vs. B Field
  - Beam on Target vs. Acceleration Voltage
  - Ion Beam Current vs. Source Pressure
Beam Optics Optimization

Extraction Gap of 30 mm

Longer Channel length → Smaller Diameter

Graphs showing the relationship between extraction gap and plasma electrode channel length.
Achieving 1-mm Beam Spot Size

- No active focusing element
  - Longer channel of the ion source extraction aperture
- Small extraction aperture
  - 0.6 mm in diameter
- Ion optics simulation to guide system design
  - Various code
    - IGUN
    - PBGun
    - WARP

90 kV ~ 1 mm
Sealed-tube Operation of Ion Source Successfully Tested

• the DT neutron yield is ~100x higher than the DD neutron yield at ~80 keV

• we test with DD to avoid T contamination issues

Note:
Power refers to the input power of the magnetron head, the efficiency of microwave output is ~ 60-70%. Target was not cooled, which may have affect the neutron production by reducing D retention.
Design for compact implementation

- HV insulator
- Alpha detector
- Ion source
- Target

20 cm
A compact microwave-driven ion source is capable of delivering over 100 $\mu$A of beam current (sufficient to produce $10^9$ n/s) onto a 1 mm spot size.

The API system with a microwave-driven neutron generator will offer improved imaging resolution and faster analysis times.

Applications include characterization of fissile material configurations, detection of concealed nuclear materials, contraband etc.