Neutron Radiography of Composites using a High-Flux, Compact, Neutron Generator

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PNL Introduction

- Small business in Madison, WI with ~45 employees
- PNL has developed high yield, gas target neutron generator
- Highest neutron yield outside of a nuclear reactor.
- Fundamental technology combines high current DC ion source, high voltage electrostatic accelerator, and gaseous or solid deuterium or tritium target
- Multiple fielded systems; others under construction
Theory of Neutron Production

- Neutrons produced via nuclear fusion reaction
  - D + D $\rightarrow$ He-3 + n (2.5 MeV)
  - D + T $\rightarrow$ He-4 + n (14.1 MeV)

- Higher accelerator energy and beam current result in higher neutron yield

- D-T reaction provides more neutrons but requires tritium
Applications

Isotope Production

Explosives and SNM Detection

Semiconductor Processing

Radiation Effects Testing

Neutron Radiography
Neutron Radiography

- Complementary imaging technique to X-rays and other NDI modalities

- Neutrons interact with atomic nucleus, not electron cloud
  - Cross section determined by nucleus composition, not material density
  - Excellent at imaging low-density materials
  - Certain materials have very high cross sections (e.g. Gd)

- Use is presently limited due to lack of available neutron sources
  - Reactors are sparse, hard to access, expensive, and logistically difficult
  - Off the shelf neutron generators are too weak to produce images in practical time periods
PNL is just beginning to explore entry into the commercial NDT market; looking for early adopters
- Munitions, Turbine blades, Composite wing structures, Batteries/Fuel Cells, Helicopter blades, etc.

Access to neutrons limited to only a few reactor/national lab sites

PNL is exploring both service models and capital equipment sales

![Propellant Invisible](image1)
![Propellant Visible](image2)

![X-Ray](image3)
![Neutron](image4)
Neutron Radiography Of Composites

- Detecting abnormalities invisible to other NDT methods

Neutron image of 6.4 mm thick laminated composite material with hidden 25.4 mm diameter circular holes.


- Additive Manufacturing

Siemens 3D metal printed turbine blades.

Impossible Objects composite-based additive manufactured carbon fiber airfoil.
Neutron Source Overview

Moderator assembly would not be necessary for fast neutrons

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Radiography Unit
Collimation

- L/D changes with distance to imaging plane and collimator aperture
- Resolution changes with L/D and distance between specimen and imaging plane
- Neutron flux at imaging plane changes with L and D
- Constant trade-off between spatial resolution and imaging time
- PNL system has the ability to vary spatial resolution on the fly.
Neutron Moderation

- Moderate 2.45 MeV neutrons to thermal energies (<0.3 eV)
- Choice of moderating material and configuration is very important
- Graphite is good, heavy water is best

Current in-use systems: heavy water moderator with concrete, boron and lead shielding
Detectors

- PNL is currently evaluating film and digital options
- Emphasis is on maximizing efficiency without too much degradation in contrast and resolution
- Options under evaluation include:
  - Conversion screens with film
  - CR plates
  - Solid state digital detectors
  - CCD cameras
  - Microchannel plates
- Multiple viable options; evaluation still underway
- Lithium and Gd Scientilators are being explored
ASTM Beam Purity Indicator

- Boron plugs easily visible
- Left plug more resolute
- Lead plugs not seen – low gamma
- Cd wires easily visible
- Left wire more resolute
Summary

- PNL has developed high yield, gas and solid target neutron generator for several different applications
- PNL’s solutions allows for more accessible, cost effect and convenient neutron imaging.
- Significant progress has been made on miniaturization, portability, and commercialization
- For some customers, this will offer an in-house alternative to reactor-based neutron radiography
Thank You!

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