Neutron Imaging Camera

Georgia A. de Nolfo
NASA/GSFC
Georgia.a.denolfo@nasa.gov
301-286-1512
NIC Development Team

**NASA/GSFC**
- Stan Hunter, PI
- Seunghee Son
- Georgia de Nolfo
- Jason Link
- Mike Dion

**NSWC/CD**
- Noel Guardala
- Mary Jo Bieberick
- Jack Price
- Pat Winters
- Joe Curran

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Neutron Imaging Camera

- Basis of NIC technology is 3-D tracking of charged particles in a gaseous medium.
  - Comprised of a Time Projection Chamber (TPC) with 2-D Micro-well readout (MWD).
- Unique technology; distinct from traditional methods for neutron imaging.
- Versatile Applications
  - Passive and active standoff interrogation
  - Space/Solar physics
  - Neutron, gamma, & charged particle detection
Methods of Neutron Imaging

• As with gamma-ray imaging, neutron imaging relies on the detection of secondary products of neutron interactions in matter.

• Take advantage of interactions with large cross sections:
  - Inelastic: $^3\text{He}(n,p)^3\text{H}$
  - Elastic: $(n,p)$

• Use measured quantities from secondary tracks (arrival time, $(x,y,z),\vec{p},E$) to reconstruct initial direction & energy of neutron.
Neutron Interactions

- **$^3\text{He}(n,p)^3\text{H}$**
  - Track p & $^3\text{H}$
  - Vertex identification allows for reconstruction of initial neutron momentum vector

- Elastic (n,p) scatter
  - Track single & multiple scatter protons
  - Use $p_p$ to reconstruct initial neutron momentum vector

- Key to NIC technology is measuring secondary by-product momentum vectors.
NIC Advantage for (n,p) tracking

- Measure proton energy, $E_{p1}$ & $E_{p2}$
  + Interaction locations, $L_1$ & $L_2$
  - 1 scatter $\rightarrow$ neutron detection
  - 2 scatters $\rightarrow 2\pi$ sr location, $E_n > E_{p1} + E_{p2}$
- Momenta of scattered protons $\rightarrow$ Energy and direction of neutron

\[
\cos \varphi_2 = \vec{P}_{p2} \cdot \vec{P}_{n'}
\]
\[
E_{n'} = \frac{E_{p2}}{\cos^2 \varphi_2}
\]
\[
\vec{P}_{n'} = \sqrt{2m_nE_{n'}} (\vec{L}_2 - \vec{L}_1)
\]
\[
\vec{P}_n = \vec{P}_{p1} + \vec{P}_{n'}
\]
\[
E_n = \frac{(\vec{P}_n \cdot \vec{P}_n)}{2m_n}
\]

*Increase in sensitivity, background reduction, and angular resolution, omnidirectional

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NIC/3-DTI Theory of Operation

- **Ionization chamber**: Large-volume time projection chamber (TPC)
- **Proportional counter**: 2-D gas micro-well detector (MWD) readout
  - Low density, homogenous medium (low energy particle tracking)
  - 100 % active detector volume (no scattering in passive material)
Successful NIC Demonstration

$^3$He based NIC

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Neutron Imaging

• Imaged 1 MeV neutrons at the NSWC PIAF
• Neutron momentum reconstructed from p, T fragments
• Angular resolution $\theta_{68}=\sim 8$ deg

➢ We are looking at alternatives to $^3$He including $H_2$ & Methane-based NIC

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MWD Construction

MWDs are “double sided flex circuit boards” with orthogonal (2-D) traces on top & bottom.

Micro-wells are holes, machined through substrate concentric with openings in cathodes.

- Well Pitch: 400μm (16 mil)
- Well Diam: 200μm (8 mil)
- Well Depth: 200μm (8 mil)
- Cathode Gap: 50μm (2 mil)
  goal 12μm (0.5 mil)

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MWD Fabrication

- Laser micro-machining facility is fully functional
- Machining sections of $10 \times 10 \text{ cm}^2$ substrate area to optimize technique
  - Many aspects of fabrication effect MWD performance (gas gain)
    - Laser ablation technique
    - Surface cleaning
    - Well diameter wrt to cathode hole diameter
    - Well aspect ratio
- 1 Day turn-around
  - Rapid testing of techniques
GSFC MWD Performance

- 2nd gen GSFC MWDs
- Gain measurement
  - Collimated $^{55}$Fe source, P-10 at 1 atm
- Max gain limited by breakdown

- Works with CH$_4$
  - $V_{AC}$ higher
  - CH$_4$+CS$_2$ tests soon

Typical $^{55}$Fe Spectrum

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GARFIELD Simulations

- Model various gas mixtures and well geometries to optimize MWD performance and fabrication
- Results indicate strong dependence on well shape

P-10 at 760 torr, $V_{\text{Bias}}=700V$
400V drift potential
Histograms from 500 Monte-Carlo electrons drifted from a line 200 mm above the center of the well
30x30 cm$^2$ NIC Development

- Produce 30x30 cm$^2$ NIC for field testing by early 2010.

- 30 cm MWD with 10 cm electronics
  - 1/3 resolution readout (512 channels)
    - Gang 3 electrodes to one FEE channel
  - Snapshot and semi-streaming data mode

- 30 cm MWD with 30 cm electronics
  - 1/2 resolution readout (768 channels)
    - Every other electrode read out, limited by number of ASICs
  - Streaming data mode

- Full resolution readout (1536 channels)
  - Additional ASICs, not before Jan 2010
GEANT4 Simulations

- Simulate (n,p) double scatter events within NIC
  - Assume NIC is filled with CH\textsubscript{4}
  - Neutron beam:
    - Point source or uniform illumination
    - Mono-energetic or representative of a radioactive source, e.g. \isotope[252]{Cf}
  - Track all single & double scatter events

- Generate simulated events for image reconstruction software development

- Reconstruct image plane using simulated events
  - Add instrument response
NIC Efficiency Estimate

30 cm NIC, 3 MeV neutrons

- Probability of interaction \( \sim 0.5\% \)
- \(^3\)He at 3 atm
  - Single interaction, PSF: \( \theta_{68} = \sim 5^\circ \)
- CH\(_4\) at 5 atm
  - Double scatter, PSF: \( \theta_{68} = \sim 2^\circ \)

- Imaging reduces contribution of the background
- Improves sensitivity
NIC Sensitivity

- Evaluate NIC sensitivity to 20 microCi $^{252}$Cf source.
- Consider Omnidirectional NIC (all four sides of square 30x30x30 cm$^2$ active volume).
  - Compute cosmic ray background intensity accounting for zenith dependence (Moser et al. 2005).
  - Assume 25 square degree resolution within field of view, resulting in ~1100 pixels over entire field of view
  - Assume NIC properly identifies every interacting neutron and choose only proton tracks that are fully contained with NIC
- Determine the integration time versus source location such that NIC identifies a source with a 1/1000 probability for false positive.

* Trade Study underway to optimize NIC Sensitivity
NIC Field Testing

• NIC 30 cm prototype completed in early 2010
  - MWD Optimization (GARFIELD and empirical studies)
  - Gas studies for methane-based NIC
  - NIC design optimization based on GEANT4 simulations

• GSFC Field Tests
  - D-T generator
  - 10 mCi $^{252}$Cf source

• NSWC Field Tests
  - D-T generator field tests
  - NSWC/PIAF tests

• ONR funding to investigate active and passive integration of NIC on Naval platforms