# Optimization of source and shielding for an *in-situ* Doppler broadening positron annihilation spectroscopy instrument

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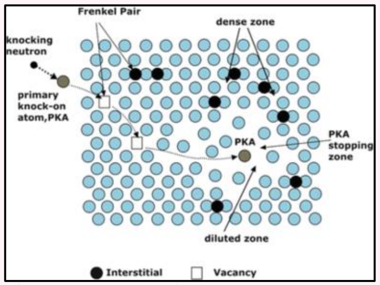
## Background:

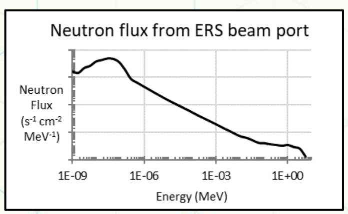
The lifespans of components in nuclear reactors are limited by the damage from fast neutrons, which appears in the form of atomic vacancies and interstitials. Using coincidence Doppler broadening PAS , we can quantify and qualify the change in the defect chemistry during the irradiation process.

**One high-energy neutron can impart a cascade of defects in a material via a displaced primary knock-on atom.[1]**




## Resources:

The East Radiography Station (ERS) at the Neutron Radiography (NRAD) reactor in the INL Material and Fuels Complex (MFC) has a direct view of the reactor core. The available footprint for the PAS spectrometer is 130 x 200 $cm^2$. Calculations were performed using MCNP.

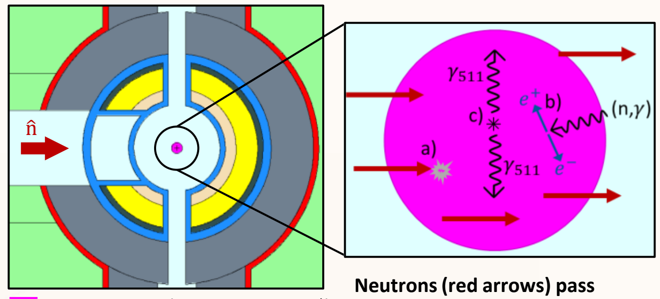



Upon entering the ERS, the neutron and photon beams have an extent of about 20 x 30 $cm^2$. The neutron beam fast-to-thermal ratio is ~15.[2]

**Detailed simulations of the NRAD facility predict neutron and photon fluxes of ~$10^9$ $cm^{-2}$ $s^{-1}$ within the ERS primary beam. Isotropic spray from the west wall contributes an additional 30% of particle intensity.**

## Layout:

The target is positioned within the experimental tank. Layers of materials surround the target to induce neutron thermalization, reflection, and (n,$\gamma$) conversion. Two HPGe detectors view coincidence photons from the target.

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|---|---|
| Target | (316L SS, 1.3 cm Ø) |
| Housing | (6061 Al) |
| (n,$\gamma$) Conv. | ($Gd_2O_3$) |
| Thermalizer | (Polyethylene) |
| Reflector | (Tungsten) |
| $\gamma$-Shielding | (Lead) |
| n-Shielding | (BorAl) |
| n-Shielding | (B-Polyethylene) |

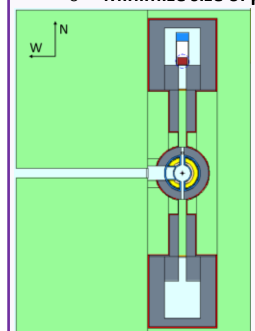
**Neutrons (red arrows) pass through the target; fast neutrons induce atomic dislocations (a). High energy photons from (n,$\gamma$) conversion induce pair-production within the target (b). The resulting positrons quickly annihilate (c) and the Doppler-shifted 511 keV photons are detected by 180° oriented HPGe detectors.**

## Metrics:

- Total input count rate (ICR) on detector: ICR ≤ 500 kHz.
- Fast neutron flux (FNF) on detector: FNF ≤ 2,000 $cm^{-2}$ $s^{-1}$
  - 4 x $10^9$ fast neutrons in 23 days
- Signal rate (S) of coincidences S ≥ 100 Hz
  - 1 x $10^6$ signal events in 2.78 hrs
- Signal-to-Noise (S/N) S/N > 0.1

## Results:

- High energy photon flux in target is maximized with **20.3 cm tank** ($I_\gamma$ = 2.3 x $10^8$ $cm^{-2}$ $s^{-1}$ (E > 1.02 MeV)).
- Keeping fast neutron flux within metric requires careful consideration:
  - **65 cm from target to detector front face.**
  - **Polyethylene plug with 0.64 cm thick titanium plate blocks target-detector line-of-sight.**
  - **Minimize size of primary beam aperture.**




Most particles enter detector through front face. We estimated count rates using a small solid angle model.[3]

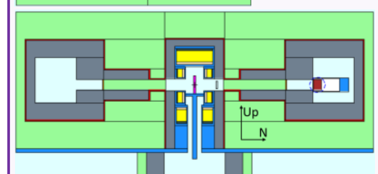
**ICR = 727 kHz**

**FNF = 1,400 $cm^{-2}s^{-1}$**

**S = 430 Hz**

**S/N = 0.18**

These results indicate signal rates will be more than adequate. Solutions for reducing total input count rate are being developed. Simulations of pulse height signals are forthcoming.




## References:

1. *Handbook of Damage Mech.*, G. Voyiadjis, (2015)
2. S. Giegel et al., *NIM:B* **454**, pp 28-39 (2019)
3. J. Livesay et al., *Efficiency of TTAC's ORTEC IDM*, ORNL, 2012