An overview of facilities for measuring prompt neutron-induced gamma-rays

(Or: How to make frenemies and confuse lots of people)

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Workshop for Applied Nuclear Data Activities
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A comparison of (some) neutron sources around the world (a.k.a., the too-busy slide that gets me hate mail)

**Flux (n/cm²/s)**

- **10⁶**
- **10⁵**
- **10⁴**
- **10³**
- **10²**

**Energy (MeV)**

- **0.1**
- **1**
- **10**
- **100**
- **1000**

**Sources**

- **WNR (30 deg)**
- **RPI**
- **nELBE**
- **Kentucky (2m)**
- **LBNL TTDB (5m)**
- **LBNL TTDB Faux DT**
- **Gelina (90 deg @ 30m)**
- **Ohio U. 7MeV ¹³C(d,n)**
- **TUNL (2.875m)**
- **TUNL (18.2 MeV DD)**

**FLUX (n/cm²/s)**

- **1**
- **10**
- **10²**
- **10³**
- **10⁴**
- **10⁵**
- **10⁶**
- **10⁷**

**Sources (bar graph)**

- **WNR (15m)**
- **RPI (30m)**
- **nELBE (6.18m)**
- **Kentucky (2m)**
- **LBNL TTDB (5m)**
- **LBNL TTDB Faux DT**
- **Gelina (30m)**
- **Ohio U. (5m)**
- **TUNL (2.875m)**
- **TUNL (18.2 MeV DD)**
LANSCE (Los Alamos National Lab)  
(Spallation neutron source)

Notable capabilities:
- Many beam lines
- GENESIS partner (Chi-nu)
- Reaction/fission studies
- Activation/decay
- Neutron imaging
- Isotope production
- …

Neutron Source(s): 800 MeV Spallation

<table>
<thead>
<tr>
<th>Beam spectrum:</th>
<th>(up to 800 MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target distances</td>
<td>8m - 90m</td>
</tr>
<tr>
<td>n Flux (n/cm²/s)</td>
<td>$1 \times 10^{6-9} + (?)$</td>
</tr>
<tr>
<td>$\gamma$-ray detectors</td>
<td>DANCE, HPGe…</td>
</tr>
</tbody>
</table>
Gaerttner Linear Accelerator Laboratory (RPI) (Electron LINAC, photoneutron source)

Notable capabilities:
- Multiple stations
- $e^- \rightarrow Ta \rightarrow \text{brem} \rightarrow (\gamma,n)$
- Nuclear data
- Rad damage
- Radioisotopes
- LSDS

Neutron Source(s): Photonuclear

Beam current: $8 \mu$A (60 MeV e’s)

Target distances 15m - 250m

n Flux (n/cm$^2$/s) $3.5 \times 10^4$ (30m)

$\gamma$-ray detectors NaI, BaF$_3$, C$_6$D$_6$
nELBE (Helmholtz-Zentrum Dresden-Rossendorf) (Electron LINAC, photonuclear source)

Notable capabilities:
- $e^- \rightarrow Pb_{liq} \rightarrow \text{brem} \rightarrow (\gamma,n)$
- Very short pulse (5ps!)
- Close match to fission spectrum
- Fission, capture, inelastic studies
- $^{56}\text{Fe}(n,n'\gamma)$ including $\gamma(\Omega)$

### Neutron Source(s):
- Photonuclear

<table>
<thead>
<tr>
<th>Beam current:</th>
<th>1 mA (40 MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target distances</td>
<td>6.18m</td>
</tr>
<tr>
<td>$n$ Flux $(n/cm^2/s)$</td>
<td>$4 \times 10^4$ (6.18m)</td>
</tr>
<tr>
<td>$\gamma$-ray detectors</td>
<td>HPGe, LaBr$_3$, BaF$_2$</td>
</tr>
</tbody>
</table>
UKAL – University of Kentucky Accelerator Laboratory (7 MV Van de Graaff Accelerator)

**Notable capabilities:**
- Monoenergetic beams (0.1-23 MeV)
- Spectroscopy
- Scattering studies
- $\gamma$-ray production cross sections ($0\nu\beta\beta$)

**Neutron Source(s):** D(d,n), T(p,n)

**Beam current:** 1-2 $\mu$A (<7 MeV)

**Target distances:** 4cm - 2m

**n Flux (n/cm$^2$/s):** $2\times10^3$ (2m)

**$\gamma$-ray detectors:** HPGe, BGO

Notable capabilities:

- Monoenergetic n (25 keV - 20.5 MeV)
- Low-background experimental area
- Fission yields ($Y_{Nb}$ vs. $E_n$)
- Cross sections
- Activation/decay ($^{169}Tm(n,3n)$)
- Rabbit system (~seconds)

**Neutron Source(s):** DD, DT, pT, $^7Li(p,n)$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam current</td>
<td>1-2 $\mu$A</td>
</tr>
<tr>
<td>Target distances</td>
<td>2.15m, 4.27m…</td>
</tr>
<tr>
<td>n Flux (n/cm$^2$/s)</td>
<td>2x10$^4$ (2.875m)</td>
</tr>
<tr>
<td>$\gamma$-ray detectors</td>
<td>BEGe, HPGe, NaI, CeBr$_3$, LaBr$_3$</td>
</tr>
</tbody>
</table>

Bhatia et. al., NIM A 757 (2014) 7–19
Edwards Accelerator Laboratory – Ohio University (4.5 MV Tandem accelerator)

**Notable capabilities:**
- Swinger arm (0°-155°)
- Beam pulser/buncher (tunable pulse frequency—eliminates wrap-around)
- Long, collimated time-of-flight cave
- Solid/Gas targets
- Monoenergetic+

<table>
<thead>
<tr>
<th>Neutron Source(s):</th>
<th>DD, DT, pT, X(d,n)…</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam current:</td>
<td>5-10 µA</td>
</tr>
<tr>
<td>Target distances</td>
<td>4-30m</td>
</tr>
<tr>
<td>n Flux (n/cm²/s)</td>
<td>1x10⁵ (5 m)</td>
</tr>
<tr>
<td>γ-ray detectors</td>
<td>HPGe, NaI, BGO, LaBr₃</td>
</tr>
</tbody>
</table>

Meisel et. al., Physics Procedia 90, 448-454 (2017)
Gelina – Geel Electron LINear Accelerator (70-140 MeV electron linac, photonuclear/fission)

**Notable capabilities:**

- $e^{-} \rightarrow U \rightarrow \text{brem} \rightarrow (\gamma, n)$
- Water tanks (above/below) to produce low-E neutrons
- Eighteen flight paths
- Long (200m) flight paths
- LONG irradiations (1000’s hours)

**Neutron Source(s):** Photonuclear/fission

- Beam current: 70 µA (avg)
- Target distances: 8-400m
- n Flux (n/cm²/s): $2 \times 10^4$ (30 m)
- $\gamma$-ray detectors: HPGe
GENESIS – 88-inch cyclotron @ Lawrence Berkeley Nat’l Lab (K140 cyclotron)

**Notable capabilities:**
- $\gamma$-tagged inelastic cross sections ($d^3\sigma/dE_n dE_{En'}d\Omega$)
- 22+ EJ309 neutron scintillators
- High flux (>10^{11} n/cm^2/s in Cave 0)
- Tunable spectrum/beam size (<20cm)
- FLUFFY (<1s rabbit system)
- Radioisotope production cross sections

<table>
<thead>
<tr>
<th>Neutron Source(s):</th>
<th>Deuteron breakup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam current:</td>
<td>10 $\mu$A (14-55 MeV)</td>
</tr>
<tr>
<td>Target distances</td>
<td>5-10m</td>
</tr>
<tr>
<td>n Flux (n/cm^2/s)</td>
<td>1x10^{6} (5 m)</td>
</tr>
<tr>
<td>$\gamma$-ray detectors</td>
<td>HPGe, LaBr_3, LEPS</td>
</tr>
</tbody>
</table>

UC Fee NPI@NIF grant launches UCB/LLNL collaboration: 2012

Branching out: 2014

Realizing we need to take group photos more often: 2018

This vast variety of neutron capabilities at LBNL are the result of many dozens of students’ and postdocs’ efforts through a very successful collaboration (BANG) between LBNL, LLNL, and UCB over the past eight years.