Neutrons, nuclear energy and the role of level densities and strength functions: *May LICORNE be of any help?*

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MEASURE OF THE ANGULAR MOMENTUM DEPENDENCE OF Mo $\gamma$ STRENGTH FUNCTION

![Graph showing data points and trend lines for angular momentum dependence.](image)

Data sources:
- $(^3\text{He},^3\text{He})^{94}\text{Mo}$, Oslo data, renorm. (2013)
- $^{94}\text{Mo} \gamma (\gamma,x)$, Beil et al. (1974)
- $^{94}\text{Mo} \gamma (\gamma,n)$, Utsunomiya et al. (2013)
- $^{94}\text{Mo} (\gamma,\gamma')$, Rusev et al. (2009)
- $^{94}\text{Mo} (\gamma,\gamma')$, Romig et al. (2013)
- $\sigma_{\text{max}}$, Romig et al. (2013)

Variables:
- $f(E_\gamma)$ in MeV$^{-3}$
- $E_\gamma$ in MeV
Provides information on radiative strength functions and level densities

- Cascades originate from above the binding energy for fast neutrons, so unique probe of the continuum above $S_n$
- LICORNE neutron energy well defined
- 1.5 MeV produce the highest and broadest spin distribution
- MINIBALL provide high efficiency & good resolution required for the TSC technique
Typically over 99% of neutrons “wasted”

Wasted neutrons contribute to the room background

Placement of gamma detectors impossible without heavy shielding
**NEUTRON PRODUCTION IN INVERSE KINEMATICS**

- **Lithium Inverse Cinematiques ORsay NEutron source**
- p($^7$Li,$^7$Be)n reaction in inverse kinematics
- Focused source of fast neutrons between 0.5 and 4 MeV
THE NEUTRON BEAM CHARACTERISTICS: ENERGY RANGE, FLUX, ...

Lithium \( ^7\)Li H target

100 nA \( ^7\)Li 13-17 MeV

\( p^{(11}B,^{11}C)n \) Kinematics

Neutron Energy (MeV)

Lab. Cone Angle (degrees)

Neutron Energy (MeV)

Lab. Cone Angle (degrees)
DEVELOPMENT OF A GAS TARGET FOR LICORNE
(commissioning performed nov. 2014)

Parasitic fusion evaporation reaction of $^7\text{Li}$ on $^{12}\text{C}$

Need to change the PP target → Gas target

Elements with $Z > 73$ required in the beam path
Hydrogen gas cells

H₂ pressure and flow control system

Development of a kinematically focused neutron source with the p(^7Li,n)^7Be inverse reaction
**EXOTIC NUCLEI PRODUCTION & STUDY WITH FISSION**

### Spontaneous Fission

\[ ^{252}\text{Cf}(\text{SF}), \ ^{248}\text{Cm}(\text{SF}) \]

(Gammasphere, Euroball)

### Thermal neutron induced fission

\[ ^{235}\text{U}(n,f) \rightarrow ^{241}\text{Pu}(n,f) \]

(EXILL Exogam@ILL)

\[ n + ^{235}\text{U} \rightarrow ^{252}\text{Cf} \]

\[ \text{En} \sim 0.025\text{eV} \]

- Study of exotic nuclei at the moment of their formation
- **COLD** fission: no excessive evaporation of neutrons
- Relatively high spin states are accessible

### Fast neutron induced fission

\[ ^{238}\text{U}(n,f), \ ^{232}\text{Th}(n,f) \]

(LICORNE, IPN Orsay)

\[ n + ^{238}\text{U} \rightarrow \text{En} \sim 1.5\text{MeV} \]
MINORCA + LICORNE EXPERIMENTAL SETUP
MINORCA + LICORNE EXPERIMENTAL SETUP
All Ge Time Spectrum

Prompt peak

400 ns

Time (ns)
ONLINE TO PRELIMINARY RESULTS

2 prompt $\gamma$ selection

<table>
<thead>
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<th>TS_diff_vs_gamma</th>
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<tbody>
<tr>
<td>Entries</td>
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<tr>
<td>Mean x</td>
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<td>Mean y</td>
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<td>RMS x</td>
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<td>RMS y</td>
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Energy (keV)

Time (ns)
PROMPT-PROMPT GAMMA SPECTRUM

Counts

Energy (keV)

Gate (814 keV $^{96}\text{Sr}\ 2^+$)

$^{96}\text{Sr}$ +8n
PROMPT-PROMPT GAMMA SPECTRUM

Counts

Energy (keV)

Gate (814 keV ⁹⁶Sr ²⁺)
EXOTIC NUCLEI PRODUCTION & STUDY WITH FISSION

2 prompt $\gamma$ selection

1 delayed $\gamma$ selection
Delayed Time Gate: 100-350 ns

\[ T_{1/2} \sim 170 \text{ ns} \]
Identified: $^{130,132,134,135}\text{Te}$, $^{132}\text{Sn}$, $^{136}\text{Xe}$

10 candidates not yet identified

$^{130}\text{Te} \rightarrow ^{106}\text{Zr}$

$^{107}\text{Zr}$ not known

**Delayed Time Gate: 100-350 ns**

**Gamma Energy (keV)**

- $^{133}\text{I}$ 170 ns
- $^{132}\text{Te}$ 145 ns
- $^{135}\text{Te}$ 500 ns
- $^{136}\text{Xe}$ 2.95 us
- $^{138}\text{Ba}$ 0.8 us
Gate on delayed $^{134}$Te 170 ns isomer (1278 keV)

Graph showing gamma energy spectra with labeled peaks for $^{134}$Te, $^{102}$Zr, and $^{104}$Zr.
**v-ball**

A hybrid LaBr$_3$-Ge array for fast timing spectroscopic studies at the IPN Orsay

- Detectors: ~20 Ge (Gamma pool + loan pool Orsay) and/or others (max ~64) Minimum 36 LaBr3 guaranteed by FATIMA collaboration (max ~50)

- Mechanics: Use/fusion of existing mechanical structure(s) whenever possible

- Electronics: Needs investment in dedicated digital DAQ (fast timing + high energy resolution)

- Time Frame: First experiments mid-to-late 2016

- Campaign Duration: ~6 Months

- Workshop(s) to be held in 2015 to discuss physics cases
The Future: FATIMA for DESPEC

- **FATIMA** = **FAst TIMing Array** = State of the art gamma-ray detection array for precision measurements of nuclear structure in the most exotic and rare nuclei. Part of the ~ £8M STFC NUSTAR project grant (runs 2012-16).
  - Good energy resolution (better than 3% at 1 MeV).
  - Good detection efficiency (between than 5% Full-energy peak at 1 MeV).
  - Excellent timing qualities (approaching 100 picoseconds).

- Use to measure lifetimes of excited nuclear states & provide precision tests of theories of nuclear structure, uses a fully-digitised Data Acquisition System.

- Collaboration with NPL (Radioactivity group) through NMO project on ‘Nuclear Data’ (Judge, Jerome, Regan et al.) on parallel development of NPL-based array for use in traceable radioactive standards and traceability to the Bq.
Coupling 24 JUROGAM Clovers and 33 FATIMA LaBr₃

- Access to short lived isomers (<100 ns)
- Detailed spectroscopy of very neutron rich nuclei
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Thank you
AVAILABLE FLUXES

LICORNE fluxes: $E = 13.25$ MeV, Cell = 2 cm

$n/s/cm^2 \times 10^3$

-5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10

0 1 2 3 4 5 6 7 8 9 10

x (cm)
z (cm)