Contents (Geel, linac)

- Validation of resonance parameters from measurements on CBNM standards (collaboration with JAEA)
- Validation of nuclear data by combining transmission data at GELINA and pile oscillator measurements with pellet samples at MINERVE (collaboration with CEA Cadarache)
- Improve resonance data for Ag (collaboration with CEA Cadarache)
- Improve resonance data for criticality safety (collaboration with ORNL)
NRTA: Transmission station for validation of resonance data
NRTA: CBNM U standards at GELINA

\( \text{U}_3\text{O}_8 \) reference sample

EC NRM 171

\[ \begin{array}{c}
\phi 80 \\
90 \\
20.8 \\
\phi 66 \\
\phi 70 \\
\end{array} \]

- Ultrasonic seal
- Aluminium plug
- U3O8 powder

Counts / (1/\text{ns})

Time-of-flight / \text{ns}

\( C_{\text{out}} \)

\( C_{\text{in}} \)
NRTA: CBNM U standards at GELINA

$\text{U}_3\text{O}_8$ reference sample
EC NRM 171

![Diagram of U$_3$O$_8$ sample container](image)

![Graph showing neutron energy distribution](image)
NRTA: CBNM U standards at GELINA

U₃O₈ reference sample
EC NRM 171

<table>
<thead>
<tr>
<th>U-isotope</th>
<th>Areal number density (at/b)</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>²³⁵U</td>
<td>(5.0326 ± 0.0080) x 10⁻⁴</td>
<td>1.006</td>
</tr>
<tr>
<td>²³⁸U</td>
<td>(1.0628 ± 0.0015) x 10⁻²</td>
<td>0.999</td>
</tr>
</tbody>
</table>

⇒ bias < 1.0 %
NRTA: CBNM Pu standards at GELINA

<table>
<thead>
<tr>
<th>Material</th>
<th>$^{238}\text{Pu}$</th>
<th>$^{239}\text{Pu}$</th>
<th>$^{240}\text{Pu}$</th>
<th>$^{241}\text{Pu}$</th>
<th>$^{242}\text{Pu}$</th>
<th>$^{241}\text{Am}/\text{Pu}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBNM Pu 93</td>
<td>0.0117</td>
<td>93.4392</td>
<td>6.2886</td>
<td>0.2215</td>
<td>0.0390</td>
<td>0.1039</td>
</tr>
<tr>
<td>CBNM Pu 84</td>
<td>0.0706</td>
<td>84.3985</td>
<td>14.1578</td>
<td>1.0197</td>
<td>0.3534</td>
<td>0.2157</td>
</tr>
<tr>
<td>CBNM Pu 70</td>
<td>0.8506</td>
<td>73.4248</td>
<td>18.2445</td>
<td>5.4257</td>
<td>2.0544</td>
<td>1.1624</td>
</tr>
<tr>
<td>CBNM Pu 61</td>
<td>1.2045</td>
<td>62.6562</td>
<td>25.3526</td>
<td>6.6376</td>
<td>4.1491</td>
<td>1.4362</td>
</tr>
</tbody>
</table>
NRTA: CBNM Pu standards at GELINA

Note: $^{241}$Am parameters from latest JEFF 3.2 evaluation

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>$n_{NRTA}$ ± $n_{NRTA}$</th>
<th>$n_{REF}$ ± $n_{REF}$</th>
<th>$n_{NRTA}/n_{REF}$ ± $n_{NRTA}/n_{REF}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{238}$Pu</td>
<td>0.0098 ± 0.0002</td>
<td>0.00950 ± 0.00002</td>
<td>1.031 ± 0.020</td>
</tr>
<tr>
<td>$^{239}$Pu</td>
<td>0.6250 ± 0.0010</td>
<td>0.62602 ± 0.00028</td>
<td>0.999 ± 0.002</td>
</tr>
<tr>
<td>$^{240}$Pu</td>
<td>0.2630 ± 0.0002</td>
<td>0.25272 ± 0.00024</td>
<td>1.039 ± 0.001</td>
</tr>
<tr>
<td>$^{241}$Pu</td>
<td>0.0157 ± 0.0001</td>
<td>0.01549 ± 0.00002</td>
<td>1.016 ± 0.005</td>
</tr>
<tr>
<td>$^{242}$Pu</td>
<td>0.0398 ± 0.0001</td>
<td>0.04149 ± 0.00006</td>
<td>0.960 ± 0.002</td>
</tr>
<tr>
<td>$^{241}$Am</td>
<td>0.0632 ± 0.0001</td>
<td>0.06300 ± 0.00063</td>
<td>1.003 ± 0.001</td>
</tr>
</tbody>
</table>
Comparison GELINA – MINERVE data

**Goal:** Define analytical expressions for homogeneous samples with a complex shape

Transmission experiments at FP 4 (50 m) with different Cu samples (bar and pellets)

- Cu-bar with $L = 10$ mm:
  different orientation ($30^\circ$, $45^\circ$, $90^\circ$) with respect to the direction of neutron beam

- Cu-bars with different dimensions at $90^\circ$
  - 20 mm x 10 mm
  - 20 mm x 5 mm
  - 10 mm x 5 mm

- Cu-cylindrical pellets with different diameter (data analysis in progress)
  - Diameter 5 mm
  - Diameter 10 mm
NRTA measurements on Cu-bar

![Graph showing transmission vs neutron energy](image)
NRTA measurements on Cu-pellet
Validation of Ag resonance parameters

Normalisation from different samples (different thickness) fully consistent within 1%

Resonance parameters can be improved
Nuclear data for criticality safety

- Criticality calculations require improved evaluations for structural materials, nuclear fuel and fission products
- A collaboration between ORNL and JRC has recently produced experimental data for Ca, Ce and V
- New capture and transmission measurements ongoing on $^{nat}$Zr
New experiments as key to high quality neutron multiplicities
Hambsch et al. JRC-Geel

• Motivation
• Experiment on prompt neutron emission of $^{235}$U(n,f)
  • SCINTIA array
  • 3D ionization chamber
  • Results
• VERDI (2E-2v) time-of-flight detector
• Conclusions
Motivation

PFN multiplicity correlations with fragment observables

Based on energy balance in fission

- Detailed modelling (CGMF, Fifrelin, Freya…)
  - successfully reproducing correlations
  - in the case $^{235}\text{U}(n,f)$
    - difficulties: in particular $\nu(TKE)$

\textbf{Lemaire et al. (2005)}

"...a dramatic deviation between calculation and experiment on $\nu$ is observed at low TKE that would indicate the presence of additional opened channels"

\textbf{Kornilov et al. (2007)}

"The incorporation of the SCN emission leads to a much better agreement between theoretical and experimental data for $\nu(TKE)$ in the high energy range. However, the assumption of SCN emission at high TKE should be confirmed with direct experimental data"
Experimental setup

GELINA neutron time-of-flight facility

Twin Ionization Chamber
- Fission fragments
  - Energies
  - Masses - 2E-technique
  - Fission axis orientation

Neutron Detector Array SCINTIA
- 12 (22) x Scintillators
- Prompt fission neutrons
  - Energy (time-of-flight)
Validation of method $^{252}\text{Cf}(sf)$

- Results show consistency with literature data
- Specifically with methods that do not suffer from neutron energy detection threshold
  - (Dushin et al.) Gd-loaded $4\pi$ scintillator tank
Position sensitive ionization chamber

**Orientation of the fission axis in 3D-space is a requirement**

**Twin Ionization Chamber**

- Electron collector replaced by position sensitive electrode
- Charge-division readout
Energy dependence of prompt neutron multiplicity

3D position sensitive ionization chamber

- JRC Geel in-house development
- state-of-the-art
- unique
- technical paper in Nucl. Inst. Meth. A 830
2E-analysis of FF data
Conservation of linear momentum
Correction for PFN emission
TKE dependence of neutron emission

\[ \Delta_{TKE} = \frac{TKE(m^*) - TKE}{E_{sep}} \]

\[ 235U(n_{th},f) \]
Multiplicity vs. Fragment Mass

Shoulders around $A_L=100$ and $A_H=140$

Pronounced minima around $A_L=80$ and $A_H=130$

$E_n \in [0.3 \text{ eV}, 60 \text{ keV}]$
Multiplicity vs. Fragment TKE

Close to linear dependence

\[- \frac{dTKE}{d\bar{\nu}_T} = 12.0 \text{ MeV/n}\]

The slope is much steeper than earlier studies

\[- \frac{dTKE}{d\bar{\nu}_T} = 16.7 - 18.5 \text{ MeV/n}\]

The difference cannot be explained by difference in incident neutron energy

Statistics $\sim 500000$ events
Multiplicty vs. Fragment TKE

- Wide TKE-distributions
- Significant Yield at TKE > $Q_{\text{max}}$
  $\Rightarrow$ Resolution broadening
  - Decreased slope
  - Increased neutron yield at $Q_{\text{max}}$

Tailing of TKE distribution

- Energy degraded scattered fission fragments
- Neutron yield should approach average nubar
  - Drop in nubar at low TKE
  - Present also in our data
VERDI design (2E-2ν detector)

**Energy**
- 2 arrays of 16 Si detectors
- Pairs facing each other
- Each detector 450 mm²

**Time-of-Flight**
- **Start**: Electrons emitted from target detected by Micro Channel Plate (MCP)
- **Stop**: Si detector

- Maximum solid angle coverage (0.5% of $4\pi$) at relatively short flight path (50 cm)
- Excellent energy (0.5%) and timing resolution (150 ps)
- Energy losses only in target backing and silicon detector dead layer
Pre-neutron kinetic energy
Agrees well
Göök $<\text{TKE}> = 184.1$ MeV
VERDI $<\text{TKE}> = 184.1$ MeV
(perfect match)

Post-neutron kinetic energy
Agrees well
Göök $<\text{TKE}> = 181.4$ MeV
VERDI $<\text{TKE}> = 181.1$ MeV
(within 0.2%)
Pre-neutron mass
✓ Agrees well with results obtained with the double-energy technique
✓ Better resolution due to the good timing resolution of the MCPs
✓ more structure around maximum yields

Post-neutron mass
✓ Agrees well with results obtained with the double-energy technique
✓ Small discrepancy around heavy peak
Average neutron multiplicity

- Difference between pre and post mass
  - $\langle n \rangle$ within 2.2% of recommended value (3.759)!
  - Independent method to determine mass-dependent prompt neutron multiplicity data
- Differences around mass symmetry
  - Pointing to an improved post mass resolution
  - $\Delta A \sim 2$ u
- Problems
  - Diffusion of Cf material into backing
  - 250 nm Ni much thicker than our standard PI backings
  - Correction for plasma defects in Si detectors
Conclusions

- Improved modelling require **better and more detailed experimental data especially correlation data** of fission fragments with prompt neutron and γ-ray emission

- Prompt neutron and prompt γ-emission data are **difficult** to measure

- Digital data acquisition and analysis shows **definite advantages**

- The saw-tooth shape of the average number of neutrons emitted per fragment for $^{235}$U **shows more pronounced minima** at $A_H=130$ u and $A_L=80$ u

- The **TKE dependence** of the number of neutrons emitted per fission shows an **inverse slope** $dTKE/d\nu$ ca. 35% weaker than observed in earlier studies. The difference can be explained by improved fission fragment TKE resolution in the present experiment

- The 2E-2ν detector VERDI shows **improved resolution and promising results**, although some issue are still persisting
Prompt fission gamma-ray measurements $^{239}\text{Pu}(n_{\text{th}},f)$

- Prompt fission gamma-rays – reference spectral data and energy dependence
- Physical Review C accepted paper, Gatera et al.
- PhD thesis of Angélique Gatera (JRC Geel)
  - High priority data request from OECD Nuclear Energy Agency
  - Data included in JEFF-3.3T3 and ENDF/B-VIII

![Graph showing prompt fission gamma-ray characteristics from the reaction $^{239}\text{Pu}(n_{\text{th}},f)$]

<table>
<thead>
<tr>
<th>Results</th>
<th>Detector</th>
<th>Diameter × length</th>
<th>$\bar{M}_\gamma$ (per fission)</th>
<th>$\epsilon_\gamma$ (MeV)</th>
<th>$E_{\gamma,\text{tot}}$ (MeV)</th>
<th>Energy range (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>This work</td>
<td>LaBr$_3$:Ce</td>
<td>5.08 × 5.08</td>
<td>7.27 ± 0.11</td>
<td>0.86 ± 0.02</td>
<td>6.06 ± 0.10</td>
<td>0.1 - 7.0</td>
</tr>
<tr>
<td>This work</td>
<td>LaBr$_3$:Ce</td>
<td>5.08 × 5.08</td>
<td>7.35 ± 0.11</td>
<td>0.84 ± 0.02</td>
<td>6.17 ± 0.08</td>
<td>0.1 - 7.0</td>
</tr>
<tr>
<td>This work</td>
<td>LaBr$_3$:Ce</td>
<td>5.08 × 5.08</td>
<td>7.26 ± 0.11</td>
<td>0.88 ± 0.02</td>
<td>6.42 ± 0.10</td>
<td>0.1 - 7.0</td>
</tr>
<tr>
<td>This work</td>
<td>LaBr$_3$:Ce</td>
<td>5.08 × 5.08</td>
<td>7.35 ± 0.12</td>
<td>0.85 ± 0.02</td>
<td>6.27 ± 0.11</td>
<td>0.1 - 7.0</td>
</tr>
<tr>
<td>This work</td>
<td>Averaged spectrum</td>
<td></td>
<td>7.35 ± 0.12</td>
<td>0.85 ± 0.02</td>
<td>6.27 ± 0.11</td>
<td>0.1 - 7.0</td>
</tr>
</tbody>
</table>

TABLE II. Detailed contributions to the total uncertainties of prompt fission $\gamma$-ray characteristics given in Tab. I. The two first lines show absolute contributions to the total uncertainties and the three last lines detail relative contributions to the systematics.

<table>
<thead>
<tr>
<th>Type of uncertainty</th>
<th>$\bar{M}_\gamma$ (MeV)</th>
<th>$\epsilon_\gamma$ (MeV)</th>
<th>$E_{\gamma,\text{tot}}$ (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistical (fission, simulation, $\gamma$-ray)</td>
<td>0.004</td>
<td>0.002</td>
<td>0.018</td>
</tr>
<tr>
<td>Systematics</td>
<td>0.109</td>
<td>0.017</td>
<td>0.083</td>
</tr>
<tr>
<td>(i) Simulation (setup, cross section)</td>
<td>84.2 %</td>
<td>76.4 %</td>
<td>70.5 %</td>
</tr>
<tr>
<td>(ii) Energy calibration</td>
<td>-</td>
<td>1.6 %</td>
<td>2.2 %</td>
</tr>
<tr>
<td>(iii) Fitting detector response</td>
<td>15.8 %</td>
<td>22.0 %</td>
<td>27.3 %</td>
</tr>
</tbody>
</table>
Energy dependence of prompt fission gamma-ray characteristics

PFGS characteristics from 240Pu(sf) and 242Pu(sf); First experimental data ever: Physical Review C 93, 054603 (2016)

Data to IAEA Nuclear Data section for inclusion in EXFOR data base

Data to LANL T2 Theory Division to benchmark de-excitation code CGMF

PFGS characteristics from 239Pu(n, f) at \( <En> = 1.7 \text{ MeV} \): measurement performed within CHANDA TAA at the LICORNE directional fast neutron beam (IPN Orsay, FR)

Scientific support provided to a PhD thesis at the Université Sud de Paris. 235U(n,f) PFGS at resolved resonance-neutron energies measured and data analysis on-going
Measurements performed at n_TOF

- fission
- capture
- char. par.
Measurement of nubar(A,E) and PFNS for $^{235}\text{U}$ and $^{237}\text{Np}$ at IRMM

A. Al Adili$^1$, A. Göök$^2$, K. Jansson$^1$, F.-J. Hambsch$^2$, S. Oberstedt$^2$, V. Rakopoulos$^1$, A. Solders$^1$, D. Tarrio$^1$, S. Pomp$^1$

$^1$Uppsala University, Sweden  $^2$JRC-IRMM, Belgium

**Aim:** Measure nubar and PFNS as function of energy and mass for various targets

**Method:** Frisch-Grid Ionization Chamber + neutron detectors from SCINTIA setup

**Data:** First measurements with thermalized neutrons from IRMM Van De Graaff. New run at higher energy (5.5 MeV) accepted by EUFRAT.

**Setup with FGIC, 2 neutron detectors, moderator and shielding**

**Test result for $^{252}\text{Cf}$:**
- nubar(A) and nubar vs TKE
- Red: this exp.
- Black: A. Göök et al.

See A. Al-Adili et al., ND2016 conference proceedings.
Measuring FF properties with the VERDI (2E-2v) spectrometer at GELINA

K. Jansson1, S. Oberstedt2, M.-O. Fregeau2,3, A. Al Adili1, C. Gustavsson1, F.-J. Hambsch2, D. Tarrio1, S. Pomp1, et al.

1Uppsala University, Sweden 2JRC-IRMM, Belgium 3GANIL, France

Aim: Develop VERDI and measure FF properties via the 2E-2v method.
Method: VERDI spectrometer at GELINA facility.
Status: Proof of principle using both arms (individual timing information). Test case: Cf(sf).

In black: preiim. Results for $^{252}$Cf(sf)
In red: data from A. Göök et al.

Two arms with one MCP and 16 Si each

See K. Jansson et al., ND2016
Medley@NFS:
Light-ion production, fission fragment angular distribution and fission cross section measurements relative to elastic np scattering

D. Tarrío, A.V. Prokofiev, S. Pomp, C. Gustavsson, K. Jansson, E. Andersson Sundén

Aims: (1) Light-ion production studies from various targets.

21 shifts for $^{12}$C(n,lcp) accepted by PAC in the first call for NFS

(2) Simultaneous measurement of cross sections for H(n,n), $^{235}$U(n,f), and $^{238}$U(n,f) over the energy range of the future “white” neutron beam at NFS.

Goal: For standard cross section: High-quality data (uncertainties below 2%)

The existing Medley setup is being upgraded with PPACs to allow neutron ToF measurements. A gas system for the chamber is operational. The targets are under development within the CHANDA project.

The beam time at NFS for accepted experiment is expected in early 2018.
Measuring neutron-induced independent fission yields and isomeric ratios at IGISOL + JYFLTRAP

M. Lantz, A. Mattera, V. Rakopoulos, A. Solders, A. Al Adili, S. Pomp, A. Prokofiev, and the JYFL IGISOL team

Goal: Obtain high quality data for better understanding of the fission process and for better use of resources in present and future nuclear systems.

Performed:
- First direct measurement of Isomeric Yield Ratios by direct ion counting in (p,f)
- Several isomeric pairs in $^{238}$U(p,f) and Th(p,f) measured for the first time.
- Dec 2016: first data on $^{238}$U(n,f)
  - Based on gamma spectroscopy
  - Mass region 129-133
  - Manuscript in progress

Next steps:
- More IYR also for (n,f), go for JYFLTRAP
- Implement Phase imaging technique -> mass resolving power corresponding to <50 keV is reachable. Test this for (p,f).

A. Al Adili et al., EPJA (2015) 51:59
V. Rakopoulos et al., proceedings ND2016
A. Solders et al., proceedings ND2016
A. Mattera et al., EPJA (2017) submitted

30 MeV protons
Characterization of Be(p,xn) neutron field with activation plates.
Total flux of fast neutrons (>1 MeV) of 2-3 x $10^{12}$ n/sr/s can be achieved.
Measuring $^6$Li (n,α) at IRMM with the GELINA white spectrum neutron source

K. Jansson¹, A. Al Adili¹, C. Gustavsson¹, F.-J. Hambsch², S. Oberstedt², D. Tarrio¹, S. Pomp¹, et al.

¹Uppsala University, Sweden  ²JRC-IRMM, Belgium

**Aim:** Measure $^6$Li(n,α) cross section up to several MeV for extension of neutron standard

**Method:** Twin Frisch-Grid Ionization Chamber (with P-10) at GELINA facility using LiF targets and U-235 as reference; digital DAQ

**STILL PRELIMINARY**

syst. uncertainties? background issues?

See K. Jansson et al., ND2016

Part of the PhD project of Kaj Jansson  kaj.jansson@physics.uu.se
Study of $(n, xn \gamma)$ reactions
Status and prospects of the EEDIN collaboration

Greg Henning, Maëlle Kerveno, Philippe Dessagne, Eliot Party
(CNRS/IPHC – Université de Strasbourg)
Marc Dupuis, Stéphane Hilaire, Pascal Romain
(CEA/DAM – Bruyères le Châtel)
Cyrille de Saint-Jean, Pierre Leconte, David Bernard
(CEA/DEN- Cadarache)

$^{238}\text{U}(n, xn \gamma)$ cross sections – preliminary
Band 2

635.3 keV
1⁰ → 2⁺_{bgs}

680.2 keV
1⁰ → 0⁺_{bgs}

583.55 keV
3⁻ → 4⁺_{bgs}

686.99 keV
3⁻ → 2⁺_{bgs}

519.46 keV
5⁻ → 6⁺_{bgs}

678.3 keV
5⁻ → 4⁺_{bgs}

Band 3

905.5 keV
2⁻ → 2⁺_{bgs}

218.1 keV
2⁻ → 3⁻_{b2}

270.1 keV
2⁻ → 1⁻_{b2}

Band 6

1060.3 keV
3⁺_{b6} → 2⁺_{bgs}

957.8 keV
3⁺ → 4⁺_{bgs}

1084 keV
5⁺_{b6} → 4⁺_{bgs}

2⁻_{b9} → 2⁺_{bgs}
Calculations and integral experiments

Calculations – by CEA/DAM

Microscopic approach in the entrance channel greatly impacts the spin distribution and fixes discrepancies for high spins ground state rotational band transitions. Also looking into gamma-strength and level density impact. From other isotopes (W), the number of discrete levels used in calculations also plays a role.

Perspectives: $^{233}\text{U}$

Experiment

Upgraded GRAPhEME setup
(5 planar HPGe detectors + 36 pixels)
Target: 8.3 grams of $^{233}\text{U}$ (~3 Gbq)

2500 hours of dat recorded, and still going...
Absolute cross section measurements of neutron-induced fission of $^{242}$Pu from 1 to 2.5 MeV

C. Matei, F. Belloni, J. Heyse, A. J. M. Plompen, and D. J. Thomas
Phys. Rev. C 95, 024606 – Published 14 February 2017
ELI-NP/IFIN-HH, JRC-Geel, NPL

<table>
<thead>
<tr>
<th>Production method</th>
<th>Molecular plating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical composition</td>
<td>$\text{Pu(OH)}_4$</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>29.95±0.03</td>
</tr>
<tr>
<td>Activity (MBq)</td>
<td>0.0915±0.0003</td>
</tr>
<tr>
<td>Mass ($\mu$g)</td>
<td>625±5</td>
</tr>
<tr>
<td>Areal density ($\mu$g/cm$^2$)</td>
<td>88.7±0.8</td>
</tr>
<tr>
<td>Isotopic purity</td>
<td>99.96518(45)%</td>
</tr>
</tbody>
</table>

TABLE II. Summary of evaluated and experimental data on the spontaneous fission half-life of $^{242}$Pu.

<table>
<thead>
<tr>
<th>Evaluation/Experiment</th>
<th>$T_{1/2}^{SF}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holden (2000) [17]</td>
<td>$(6.77\pm0.07)\times10^{10}$</td>
</tr>
<tr>
<td>Chechev (2005) [18]</td>
<td>$(6.79\pm0.09)\times10^{10}$</td>
</tr>
<tr>
<td>Salvador-Casteleira (2013) [16]</td>
<td>$(6.74\pm0.08)\times10^{10}$</td>
</tr>
<tr>
<td>This experiment</td>
<td>$(6.72\pm0.09)\times10^{10}$</td>
</tr>
</tbody>
</table>

TABLE III. Calculated neutron fluences with standard uncertainties, neutron beam attenuation, and target scattering correction at the chosen neutron energies.
Backward-forward reaction asymmetry of neutron elastic scattering on deuterium

JRC-Geel, HZDR (expt at HZDR)

99.999% $^2$H/H; Raghu Rao, AECL, 40 kCD
Neutron scattering data (Pirovano)

New setup developed.
Data in preparation for n+C and n+Fe (2-5 MeV).
Measurement of the 477.6-keV γ -ray production cross section following inelastic neutron scattering by $^7$Li

With IFIN-HH and U. Bucharest

Papers in preparation on GAINS data for
- $^{57}\text{Fe}(n,n'g)$
- $^{48}\text{Ti}(n,n'g)$ + minor isotopes

$^{48}\text{Ti}(n,n'g)$ data contributed to standards project IAEA, as was case for $^7\text{Li}(n,n'g)$.

With IRSN and IFIN-HH new experimental data taken for $^{54}\text{Fe}(n,n'g)$. 
(n,tot) on $^{16}$O

- Neutron transmission through liquid oxygen, $E_n=20-35$ MeV
- Monoenergetic peak decrease measured using TOF selection
The fission fragment separator ‘Lohengrin’ @ the high-flux reactor of the Institute Laue Langevin in Grenoble (France)
Collaboration between LPSC / ILL / CEA

Example: $^{239}\text{Pu}(n_{\text{th}}, f)$

- Mass range covered: [126-150]

\[ \sum_{126}^{150} Y_{\text{Loh}} = 96.69\% \]

- Strong reduction of the uncertainties compared to JEFF-3.1.1 library: below 5% between [126-146]
Ternary fission yield from $^{241}\text{Pu}(\text{n}_{\text{th}}, f)$ reaction

Serot, Heyse, Wagemans

Ternary particles: important source of tritium production in nuclear reactors and in used fuel elements:

- Direct contribution from $^3\text{H}$ ternary particles
- Indirect contribution from $^6\text{He}$ ternary particles

Measurement performed at the Budapest Research Reactor

Olivier SEROT, CEA-Cadarache, France
Jan HEYSE, Andre MOENS, EC-JRC-Geel, Belgium
Tamas BELGYA, Zoltan KIS, Centre for Energy Research, Budapest, Hungary

$6\text{He}/B = (4.48 \pm 0.30) \times 10^{-5}$
STATUS OF THE UO2 MEASUREMENTS AT ILL FROM ROOM TO 900 K

G. Noguere, J.P. Scotta, A. Filhol, J. Ollivier, E. Farhi, Y. Calzavarra

16-18 May 2017
Experimental programs

2010
⇒ Light and heavy water in IN5 and IN4 at ILL in cold operating conditions
• D2O: 250 K (ice), 295 K, 296 K, 325 K

2015
⇒ Light and heavy water in IN6 and IN4 at ILL in hot operating conditions
• T = 300 - 540 K and P=1 - 600 bar

2016
⇒ Measurement of the double-differential neutron cross section of U in UO2 in IN6 and IN4 from room temperature to Hot Full Power conditions
• T = 294 K, 600 K et 900 K

Objectives of the experimental program
• Experimental validation of the new NCSU evaluation
• Comparison MCNP/TRIPOLI calculations
• Recommendation of effective températures for PWR calculations
### Spectrometer IN4

<table>
<thead>
<tr>
<th>Sample</th>
<th>Neutron energy</th>
<th>Temperature</th>
<th>Time</th>
<th>Run</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UO2</strong></td>
<td>111.9 meV (0.855 Å)</td>
<td>290.15 K (17°C)</td>
<td>12h</td>
<td>88121-88144</td>
</tr>
<tr>
<td></td>
<td>111.9 meV (0.855 Å)</td>
<td>591.15 K (318°C)</td>
<td>12h31min</td>
<td>88146-88171</td>
</tr>
<tr>
<td></td>
<td>111.9 meV (0.855 Å)</td>
<td>901.8 K (628.65°C)</td>
<td>12h</td>
<td>88174-88197</td>
</tr>
<tr>
<td></td>
<td>66.4 meV (1.11 Å)</td>
<td>902.15 K (629°C)</td>
<td>7h46min</td>
<td>88198-88213</td>
</tr>
<tr>
<td></td>
<td>111.9 meV (0.855 Å)</td>
<td>296.15 K (23°C)</td>
<td>3h57min</td>
<td>88257-88264</td>
</tr>
<tr>
<td></td>
<td>66.4 meV (1.11 Å)</td>
<td>296.15 K (23°C)</td>
<td>2h46min</td>
<td>88265-88270</td>
</tr>
<tr>
<td><strong>Vanadium</strong></td>
<td>66.4 meV (1.11 Å)</td>
<td>288.18 K (15°C)</td>
<td>1h30min</td>
<td>88396-88398</td>
</tr>
<tr>
<td></td>
<td>111.9 meV (0.855 Å)</td>
<td>287.15 K (14°C)</td>
<td>4h02min</td>
<td>88399-88407</td>
</tr>
<tr>
<td><strong>Dummy</strong></td>
<td>111.9 meV (0.855 Å)</td>
<td>290.15 K (17°C)</td>
<td>6h</td>
<td>88468-88479</td>
</tr>
<tr>
<td></td>
<td>111.9 meV (0.855 Å)</td>
<td>598.15 K (326°C)</td>
<td>6h</td>
<td>88482-88493</td>
</tr>
<tr>
<td></td>
<td>111.9 meV (0.855 Å)</td>
<td>905.15 K (632°C)</td>
<td>6h</td>
<td>88496-88507</td>
</tr>
<tr>
<td></td>
<td>66.4 meV (1.11 Å)</td>
<td>905.15 K (632°C)</td>
<td>3h</td>
<td>88508-88513</td>
</tr>
<tr>
<td></td>
<td>66.4 meV (1.11 Å)</td>
<td>306.15 K→297.15 K (33°C→24°C)</td>
<td>4h58min</td>
<td>88542-88551</td>
</tr>
</tbody>
</table>

**Two energies**
- 66 meV
- 112 meV

**Three temperatures**
- T=300 K
- T=600 K
- T=900 K
## Spectrometer IN6

<table>
<thead>
<tr>
<th>Sample</th>
<th>Neutron energy</th>
<th>Temperature</th>
<th>Time</th>
<th>Run</th>
</tr>
</thead>
<tbody>
<tr>
<td>UO2</td>
<td>3 meV (5,12 A)</td>
<td>336.15K→324.15K (63°C→51°C)</td>
<td>20h</td>
<td>189008 - 189048</td>
</tr>
<tr>
<td></td>
<td>3 meV (5,12 A)</td>
<td>584.15K (311°C)</td>
<td>7h</td>
<td>189049-189062</td>
</tr>
<tr>
<td></td>
<td>3 meV (5,12 A)</td>
<td>888.15K (615°C)</td>
<td>6h</td>
<td>189064-189075</td>
</tr>
<tr>
<td></td>
<td>3 meV (5,12 A)</td>
<td>306.15K→302.15K (33°C→29°C)</td>
<td>12h30min</td>
<td>189233-189257</td>
</tr>
<tr>
<td></td>
<td>3 meV (5,12 A)</td>
<td>587.15K (314°C)</td>
<td>6h30min</td>
<td>189259-189271</td>
</tr>
<tr>
<td></td>
<td>3 meV (5,12 A)</td>
<td>890.15K (614°C)</td>
<td>12h30min</td>
<td>189272-189296</td>
</tr>
<tr>
<td>Vanadium</td>
<td>3 meV (5,12 A)</td>
<td>304.55K (31.4°C)</td>
<td>2h30min</td>
<td>189094-189098</td>
</tr>
<tr>
<td>Dummy</td>
<td>3 meV (5,12 A)</td>
<td>302.68K (29.53°C)</td>
<td>18h</td>
<td>189101-189136</td>
</tr>
<tr>
<td></td>
<td>3 meV (5,12 A)</td>
<td>594.15K (321°C)</td>
<td>15h</td>
<td>189138-189167</td>
</tr>
<tr>
<td></td>
<td>3 meV (5,12 A)</td>
<td>598K (324.85°C)</td>
<td>18h</td>
<td>189169-189204</td>
</tr>
</tbody>
</table>

**Energy**: 3 meV

**Three temperatures**
- T=300 K
- T=600 K
- T=900 K
⇒ simple comparison with ddxs calculated with the $S(\alpha, \beta)$ established by NCSU
Experimental density of states of UO2


Neutron-weighted phonon density of states of UO2 (J. Pang)

Density of states of UO2 extracted from the IN6 data by J. Ollivier, ILL
Measurement of the double-differential neutron cross section of U in UO₂ up to 2000 K

- Main problem ⇒ sealed tubes are needed
- Strong efforts from JRC-Karlsruhe (R. Caciuffo) and ILL (A. Filhol) to find a solution ⇒ laser welding (Nb or Mo tubes)

Any suggestions are welcome!
INTEGRAAL @GELINA
for inelastic scattering validation
JEF/DOC-1824

From EXCALIBUR
Experiment in CALIBAN on Uranium 238

to INTEGRAAL
Integral Transmission Experiment in Gelina Relying on Activation Analysis

CEA/DEN/DER/SPRC/LEPh
Pierre Leconte, David Bernard, Pascal Archier
CEA/DEN/DER/SPEX/LPE
Benoit Geslot
JRC GEEL
Arjan Plompen, Markus Nyman, Francesca Belloni

JEFF - NEEDS Workshop, OECD Conference Center, April 24-25, 2017.
Starting point: use of different disks of depleted U available at JRC Geel to build a slab of thickness ~15 cm x 20 cm Ø

Use of various dosimeters with energy thresholds ranging from thermal to 9 MeV

Measurement of the integral transmission coefficient:

\[
T(x) = \frac{R(x)}{R(0)}
\]

\( R(x) = \) microscopic activation rate on the dosimeter placed behind a Uranium thickness of \( x \)

<table>
<thead>
<tr>
<th>Dosimeter</th>
<th>Threshold reaction</th>
<th>E50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au</td>
<td>( ^{197}\text{Au}(n,\gamma)^{198}\text{Au} )</td>
<td>Thermal</td>
</tr>
<tr>
<td>Ni</td>
<td>( ^{58}\text{Ni}(n,p)^{58}(g+m)^{59}\text{Co} )</td>
<td>4.20</td>
</tr>
<tr>
<td>Fe</td>
<td>( ^{54}\text{Fe}(n,p)^{54}\text{Mn} )</td>
<td>4.28</td>
</tr>
<tr>
<td></td>
<td>( ^{56}\text{Fe}(n,p)^{56}\text{Mn} )</td>
<td>7.58</td>
</tr>
<tr>
<td></td>
<td>( ^{56}\text{Fe}(n,\gamma)^{59}\text{Fe} )</td>
<td>Thermal</td>
</tr>
<tr>
<td>Rh</td>
<td>( ^{103}\text{Rh}(n,n'g)^{103}\text{mRh} )</td>
<td>2.38</td>
</tr>
<tr>
<td>Co</td>
<td>( ^{59}\text{Co}(n,p)^{59}\text{Fe} )</td>
<td>5.76</td>
</tr>
<tr>
<td></td>
<td>( ^{59}\text{Co}(n,\gamma)^{60}\text{Co} )</td>
<td>Thermal</td>
</tr>
<tr>
<td></td>
<td>( ^{59}\text{Co}(n,p)^{56}\text{Mn} )</td>
<td>8.36</td>
</tr>
<tr>
<td>Al</td>
<td>( ^{27}\text{Al}(n,a)^{24}\text{Na} )</td>
<td>8.66</td>
</tr>
<tr>
<td>Mg</td>
<td>( ^{24}\text{Mg}(n,p)^{24}\text{Na} )</td>
<td>8.26</td>
</tr>
<tr>
<td>Ti</td>
<td>( ^{46}\text{Ti}(n,p)^{46}\text{Sc} )</td>
<td>6.08</td>
</tr>
<tr>
<td></td>
<td>( ^{47}\text{Ti}(n,p)^{47}\text{Sc} )</td>
<td>3.82</td>
</tr>
<tr>
<td></td>
<td>( ^{48}\text{Ti}(n,p)^{48}\text{Sc} )</td>
<td>8.35</td>
</tr>
<tr>
<td>In</td>
<td>( ^{115}\text{In}(n,n'g)^{115}\text{mIn} )</td>
<td>2.67</td>
</tr>
<tr>
<td>U</td>
<td>( ^{238}\text{U}(n,f)PF )</td>
<td>2.78</td>
</tr>
</tbody>
</table>
THE INTEGRAAL EXPERIMENT IN GELINA
Individual uranium disks (~20kg each)
### Sensitivity study of the integral transmission rate $T(x)$ to microscopic cross sections

- **Linear increase with $^{238}$U thickness up to 12cm**
- **Worse at 15cm due to room return effect**

<table>
<thead>
<tr>
<th>Threshold reaction</th>
<th>E50%</th>
<th>$x$ (cm)</th>
<th>Integral transmission coefficient $T(x)$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Geometry with concrete walls</td>
<td>Geometry without concrete walls</td>
</tr>
<tr>
<td>$^{115}$In(n,n')</td>
<td>2.7</td>
<td>3</td>
<td>0.620 ± 0.017</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>0.350 ± 0.011</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9</td>
<td>0.192 ± 0.017</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12</td>
<td>0.105 ± 0.015</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>0.073 ± 0.004</td>
</tr>
<tr>
<td>$^{54}$Fe(n,p)</td>
<td>4.3</td>
<td>3</td>
<td>0.600 ± 0.025</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>0.339 ± 0.016</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9</td>
<td>0.196 ± 0.012</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12</td>
<td>0.105 ± 0.008</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>0.063 ± 0.006</td>
</tr>
<tr>
<td>$^{24}$Mg(n,p)</td>
<td>8.3</td>
<td>3</td>
<td>0.617 ± 0.051</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>0.338 ± 0.031</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9</td>
<td>0.213 ± 0.029</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12</td>
<td>0.115 ± 0.018</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>0.051 ± 0.011</td>
</tr>
</tbody>
</table>

### A tricky issue: the room return effect

- Only significant for low threshold reactions and deep penetrations

THE INTEGRAAL EXPERIMENT IN GELINA
Ready for neutrons

Any good experiment has some tape!
Integral Transmission Rate $T(x)$ – threshold neutron reactions

The INTEGRAAL EXPERIMENT IN GELINA
Post-irradiation $\gamma$-spectrometry measurements

Integral Transmission Rate $T(x)$

Uranium thickness (cm)

- $^{103}\text{Rh}(n,n'g)^{103}\text{mRh}$
- $^{115}\text{In}(n,n'g)^{115}\text{mIn}$
- $^{58}\text{Ni}(n,p)^{58}(g+m)^{\text{Co}}$
- $^{27}\text{Al}(n,a)^{24}\text{Na}$
- $^{47}\text{Ti}(n,p)^{47}\text{Sc}$
- $^{56}\text{Fe}(n,p)^{56}\text{Mn}$
- $^{54}\text{Fe}(n,p)^{54}\text{Mn}$
- $^{24}\text{Mg}(n,p)^{24}\text{Na}$
- $^{59}\text{Co}(n,a)^{56}\text{Mn}$
- $^{235+238}\text{U}(n,f)^{\text{PF}}$
- $^{46}\text{Ti}(n,p)^{46}\text{Sc}$
- $^{48}\text{Ti}(n,p)^{48}\text{Sc}$
The GELINA facility has the potential to provide new high quality integral transmission experiments for ND improvements

First tests realized in GELINA have shown promising results for $^{238}\text{U}$

The Monte-Carlo analysis is going to start next months so... suspense!
The **CANDELLE project**

Neutron calibration of lithium-enriched thermo-luminescent dosimeters @ PEREN for gamma-heating measurements

**CEA, DEN/CAD/DER/SPEX**

**LPSC, UGA, CNRS/IN2P3**
ZEPHYR

Zero-power Experimental Physics Reactor – A new critical facility @ CEA Cadarache

Project status and associated R&D

CEA, DEN/CAD/DER/SPEx

www.cea.fr
SPECTRAL Project
Spectrométrie Neutronique Rapide Large Bande
JEF/DOC-1821

L. Dioni¹, R. Jacqmin², V. Gressier³, P. Leconte², B. Perot⁴, C. Carasco⁴, V. Lacoste³, M. Aiche⁵, L. Mathieu⁵, B. Stout¹

¹Institut Fresnel (Aix-Marseille Université), ²CEA-CAD/DER, ³IRSN-CAD, ⁴CEA-CAD/DTN, ⁵CENBG Bordeaux

JEFF/NEEDS
Paris, 24-25/04/2017
Summary

- SPECTRAL project: develop a neutron spectrometer system based on a combination of measurement techniques for the spectral characterization of intermediate-to-fast energy neutron spectra (together with gammas)
- Main initial motivation = new measurements + extended use of MASURCA after the current refurbishment work
- Project has triggered interest among various groups and for different applications
- Organic scintillators are good candidates for the measurement of the neutron spectrum above about 1 MeV
- Solution-grown stilbene has a wider energy domain but lacks experimental data, need for a full characterization of the detector response
- The SPECTRAL plans in 2017 are to test the stilbene in various neutron fields
FALSTAFF@SPIRAL2/NFS

FALSTAFF SPECTROMETER
Status of development

L. Thulliez, A. Chietera, E. Berthoumieux, D. Doré, A. Letourneau

In collaboration with S. Oberstedt (IRMM)

Other fundings
NEEDS
SEVENTH FRAMEWORK PROGRAMME

CEA/DEN, P2IO
www.cern.fr
On-going activities

Tests of new SED-MWPC detectors

Frisch Grid change

Voltage on the anode to increase the field

New Acquisition system for position signals

Equipment of the new reaction chamber

D. Doré, CEA/Saclay
EXPERIMENTAL PROGRAMME ON NUCLEAR DATA AT ILL: From Lohengrin to FIPPS spectrometers

FY Collaboration:
Kessedjian G. ¹, Julien-Laferriere S. ¹, Chebboubi A. ¹, Serot O. ², Sage C. ¹, Méplan O. ¹, Bernard D. ², Litaize O. ², Blanc A. ³, Faust H. ³, Mutti P.³, Köster U. ³, Letourneau A. ⁴, Materna T.⁴, Rapala M.⁴

FIPPS collaboration:
G. Kessedjian¹, A. Blanc³, A. Chebboubi¹,², H. Faust³, E. Froidefond¹, M. Jentschel³, U. Köster³, C. Michelagnoli³, P. Mutti³, E. Ruiz-Martinez³, G. Simpson¹

¹ LPSC, Université Grenoble-Alpes, CNRS/IN2P3, F-38026 Grenoble Cedex, France
² CEA, DEN, DER, SPRC, LEPPh, Cadarache center, F-13108 Saint Paul lez Durance, France
³ Institut Laue-Langevin, F-38042 Grenoble Cedex 9, France
⁴ CEA, DSM, IRFU, SPhN, LEARN, Saclay center, F-91191 Gif-sur-Yvette, France
Recent results and perspectives using PPACs for fission measurements

L. Audouin, D. Ramos, Y. Chen, C. Le Naour
IPN Orsay
L. Tassan-Got
CERN

JEFF-NEEDS joint workshop - 24/04/2017

Parallel Plate Avalanche Counters:
- 2 segmented cathodes + 1 anode
- 3 mm gap, 5 mbar C₃F₈
- 20x20 cm² active area

- FF-detection in coincidence
- FF-position measurement
- Compact & transparent configuration
- 10 ns FWHM time-response

- α-background rejection
- Fission point tracking
- 9-targets setup
- En up to 1 GeV (EAR-1)

Emitting point on the target

European Commission
Measurements relevant for JEFF from experiments with the LICORNE neutron source

JEF/DOC-1815

J.N. Wilson, M. Lebois and L. Qi

IPN Orsay
- Good alpha-fission fragment discrimination: <2%
- Good Time resolution: <1ns
- Efficiency: ~100%
- 360mg $^{238}$U in 72 deposits
Measured Spectrum: $g(x)$
$^{238}\text{U}(n,f) @ 4.6\text{MeV}$

- Average: 6.29±0.69 MeV
- Average: 7.37±0.49 /fission
- Average: 0.85±0.11 /fission

- Average: 6.06±0.60 MeV
- Average: 7.25±0.42 /fission
- Average: 0.84±0.10 MeV

12 June 2017    L. QI    IPNO
Total absorption measurements for reactor applications (Algora et al.)

**Goal:** to obtain beta decay data free from the Pandemonium effect that can improve the predictions for the decay heat and the neutrino spectrum from reactors

**Technique:** total absorption spectroscopy

**Experiments:** performed at IGISOL (Jyväskylä), that provides radioactive beams of very high isotopic purity (trap assisted experiments)

**Spokespersons:** A. Algora, J. L. Tain, M. Fallot

\[ d = R(B) \cdot f \]
“Recently” performed measurements

VTAS run (November 2009)
Measurement of beta delayed neutron emitters cases of high priority for decay heat. The idea was to measure the same nuclides using different techniques and different setups (TAS, Pn, neutron spectrum meas.). In this run we also measured some cases of interest for neutrino physics. All analyses finished, some results are already published and the rest in preparation for publication. BaF2 TAS detector

DTAS run (December 2014)
Primary goal: measurement of nuclei of high interest for the prediction of the neutrino spectrum in reactors. Priority list defined by the Nantes group. NaI detector DTAS developed for DESPEC (FAIR).
The main reasons are the chemical insensitivity (ion guide technique), high purity by means of purification of the beam using the JYFLTRAP and acceptable yields!
Beta delayed neutron emitters, example: $^{87}\text{Br}$

$R(B) \cdot f_{\text{final}}$

$S_n$

$^{87}\text{Br}$

$Q_{\beta}$


J. L. Tain et al., PRL 115, 062502
Beta delayed neutron emitters, example: $^{88}$Br

J. L. Tain et al., PRL 115, 062502
Impact of the studied (bdn) cases

E. Valencia, JL Tain, A. Algora et al, PRC 95, 024320 (2017)

<table>
<thead>
<tr>
<th>Isotope</th>
<th>$E_\gamma$(keV)</th>
<th>$E_\beta$(keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ENSDF</td>
<td>TAGS</td>
</tr>
<tr>
<td>$^{87}\text{Br}$</td>
<td>3009</td>
<td>$3938^{+40}_{-67}$</td>
</tr>
<tr>
<td>$^{88}\text{Br}$</td>
<td>2892</td>
<td>$4609^{+78}_{-67}$</td>
</tr>
<tr>
<td>$^{94}\text{Rb}$</td>
<td>1729</td>
<td>$4063^{+62}_{-66}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Isotope</th>
<th>$\bar{E}_\beta$(keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{87}\text{Br}$</td>
<td>$1170^{+32}_{-19}$</td>
</tr>
<tr>
<td>$^{88}\text{Br}$</td>
<td>$1706^{+32}_{-38}$</td>
</tr>
<tr>
<td>$^{94}\text{Rb}$</td>
<td>$2450^{+32}_{-30}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Isotope</th>
<th>$P_\gamma$ (%)</th>
<th>$P_n$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{87}\text{Br}$</td>
<td>$3.50^{+49}_{-40}$</td>
<td>2.60(4)</td>
</tr>
<tr>
<td>$^{88}\text{Br}$</td>
<td>$1.59^{+27}_{-22}$</td>
<td>6.4(6)</td>
</tr>
<tr>
<td>$^{94}\text{Rb}$</td>
<td>$0.53^{+33}_{-22}$</td>
<td>10.18(24)</td>
</tr>
</tbody>
</table>

Astrophysics implications discussed in Tain et al. PRL 115, 062502
Impact of $^{91}$Rb case

<table>
<thead>
<tr>
<th></th>
<th>$E_\gamma$ [keV]</th>
<th>$E_\beta$ [keV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present result</td>
<td>2787(29)</td>
<td>1330(22)</td>
</tr>
<tr>
<td>Greenwood et al.</td>
<td>2885.2$^a$</td>
<td>1282.0$^a$</td>
</tr>
<tr>
<td>ENDF/B-VI.8</td>
<td>2340(140)</td>
<td>1561(25)</td>
</tr>
<tr>
<td>JEFF-3.1.1</td>
<td>2706(27)</td>
<td>1368(13)</td>
</tr>
<tr>
<td>JENDL/FPD-2011</td>
<td>2340(50)</td>
<td>1610(190)</td>
</tr>
<tr>
<td>Rudstam et al.</td>
<td>2335(33)</td>
<td>1560(30)</td>
</tr>
</tbody>
</table>

$^a$ No error evaluation was performed

$^{91}$Rb is a particular case. It was used as a normalization point in Rudstam measurements of the mean gamma energies assuming that it does not suffer from Pandemonium. We showed (in agreement with earlier measurements by Greenwood, that it suffered from Pandemonium. So Rudstam mean gamma energies data require re-normalization.
Greenwood vs Rudstam  
(orig. pointed out by O. Bersillon)

There are systematic differences between the mean gamma energies obtained by Rudstam and Greenwood (for the cases measured by both, in red our new TAS data compared with Rudstam). Mean value of the differences -360 keV.

The mean value of the differences is reduced after the renormalization of Rudstam data induced by our new measurement of the decay of 91Rb. The discrepancy between the two data sets does not disappear completely. (new mean value -180 keV).

S. Rice, A. Algora, J. L. Tain et al, submitted to PRC
92Rb: star case, nuclear data matters

TABLE I. Main contributors to a standard PWR antineutrino energy spectrum computed with the MURE code coupled with the list of nuclear data given in Ref. [12], assuming that they have been emitted by $^{235}$U (52%), $^{239}$Pu (33%), $^{241}$Pu (6%), and $^{238}$U (8.7%) for a 450 day irradiation time and using the summation method described in Ref. [12].

<table>
<thead>
<tr>
<th></th>
<th>4–5 MeV</th>
<th>5–6 MeV</th>
<th>6–7 MeV</th>
<th>7–8 MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{92}$Rb</td>
<td>4.74%</td>
<td>11.49%</td>
<td>24.27%</td>
<td>37.98%</td>
</tr>
<tr>
<td>$^{96}$Y</td>
<td>5.56%</td>
<td>10.75%</td>
<td>14.10%</td>
<td>...</td>
</tr>
<tr>
<td>$^{142}$Cs</td>
<td>3.35%</td>
<td>6.02%</td>
<td>7.93%</td>
<td>3.52%</td>
</tr>
<tr>
<td>$^{100}$Nb</td>
<td>5.52%</td>
<td>6.03%</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$^{93}$Rb</td>
<td>2.34%</td>
<td>4.17%</td>
<td>6.78%</td>
<td>4.21%</td>
</tr>
<tr>
<td>$^{98m}$Y</td>
<td>2.43%</td>
<td>3.16%</td>
<td>4.57%</td>
<td>4.95%</td>
</tr>
<tr>
<td>$^{135}$Te</td>
<td>4.01%</td>
<td>3.58%</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$^{104m}$Nb</td>
<td>0.72%</td>
<td>1.82%</td>
<td>4.15%</td>
<td>7.76%</td>
</tr>
<tr>
<td>$^{90}$Rb</td>
<td>1.90%</td>
<td>2.59%</td>
<td>1.40%</td>
<td>...</td>
</tr>
<tr>
<td>$^{95}$Sr</td>
<td>2.65%</td>
<td>2.96%</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$^{94}$Rb</td>
<td>1.32%</td>
<td>2.06%</td>
<td>2.84%</td>
<td>3.96%</td>
</tr>
</tbody>
</table>

Gs to gs feeding
Evolution

$^{94}(+6−20)(<2000)$
Olson et al.

$^{51(18)}\%(<2012)$
NDS 2000

$^{95.2(7)}\%(2012)$
NDS 2012
G. Lhersonneau
(PRC74 (2006)017308)

New experiment ???

Table from Zakari-Issoufou et al.
PRL 115.102503(2015)
92Rb: star case

\[ ^{92}\text{Rb}: \]

- TAS Experiment \( \beta \)-tagged
- ENSDF (High resolution)

Gs to gs feeding Evolution

- Olson et al.
  - 94(\(+6−20\)\(<2000\))
  - 51(18)\%\(<2012\)
- G. Lhersonneau
  - 95.2(7)\%\(2012\)
- NDS 2012
- TAS result
  - 87.5(2.5)\%\(2015\)

Zakari-Issoufou et al.
PRL 115.102503(2015)
92Rb: star case

Zakari-Issoufou et al.  
PRL 115.102503(2015)
Another application: prediction of the neutrino spectrum from reactors for non-proliferation

<table>
<thead>
<tr>
<th></th>
<th>235U</th>
<th>239Pu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Released E per fission</td>
<td>201.7 MeV</td>
<td>210.0 MeV</td>
</tr>
<tr>
<td>Mean neutrino E</td>
<td>2.94 MeV</td>
<td>2.84 MeV</td>
</tr>
<tr>
<td>Neutrinos/fission &gt;1.8 MeV</td>
<td>1.92</td>
<td>1.45</td>
</tr>
<tr>
<td>Aver. Int. cross section</td>
<td>$3.2 \times 10^{-43}$ cm$^2$</td>
<td>$2.8 \times 10^{-43}$ cm$^2$</td>
</tr>
</tbody>
</table>

\[ \nu + p \rightarrow e^+ + n \] (threshold 1.8 MeV)

- Relevance for non-proliferation studies (working group of the IAEA). Neutrino flux can not be shielded. Study to determine fuel composition and power monitoring. Non-intrusive and remote method.

- Recently performed experiment to study some Rb, Sr, Y, Nb, I and Cs (IGISOL, trap assisted TAS) (Fallot, Tain, Algora), analysis by V. Guadilla.
Collaboration

Univ. of Jyvaskyla, Finland
CIEMAT, Spain
UPC, Spain
Subatech, France
Univ. of Surrey, UK
MTA ATOMKI, Hungary
PNPI, Russia
LPC, France
IFIC, Spain
GSI, Germany

Special thanks to the students working in the project:
D. Jordan (not an student anymore)
Discussions with and slides from: J. L. Tain, V. Guadilla are acknowledged
Integral Benchmark Experiments on a Large Copper Block using GELINA accelerator to validate $^{nat}Cu$ neutron inelastic scattering cross sections from different neutron cross section databases

Presented by: M. Pillon
ENEA C.R. Frascati, via E. Fermi, 45
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mario.pillon@enea.it
Target in shielded position when not operating
MCNP calculation model

Copper block

GELINA target

Measuring positions
Calculation/Experiment comparison

Neutron transport calculation has been performed using MCNP6. The source neutron spectrum and the neutron yield normalization factor used were that obtained by STAYSL-PNNL unfolding. Three neutron transport libraries have been compared: FENDL3.1; JEFF33T2 and ENDF 7.1.

The experimental results are not well reproduced at great depth.
The epithermal neutrons from the source and the neutrons from room return are probably not well simulated.
JEFF-33_T2 gives the better results (slightly)
This was the first time that GELINA photo-neutron generator was used to perform a benchmark transmission experiments. A $^{nat}$Cu block 60x60x60 cm$^3$ was irradiated and the neutron activation from threshold reactions measured at different depth inside the block has been compared to MCNP6 calculations. The results from three cross section databases have been compared. The C/E results, taking into account all the sources of uncertainties, are satisfactory, no large differences are observed among the result obtained using the three cross section databases but JEFF-3.3_T2 seems to slightly better predict the results.

**Acknowledgments**

This work was supported by the European Commission within the FP7 EUFRAT program.
First simultaneous measurement of fission and gamma-emission probabilities for the understanding of the surrogate-reaction method

Jurado et al.

$3\text{He} + 238\text{U} \rightarrow 4\text{He} + 237\text{U} \leftrightarrow n + 236\text{U}$

Fission is much less sensitive to the entrance channel than gamma-decay!
Comparison with statistical-model calculations

\[ P_{\text{surro, decay}} (E^*) = \sum_{J^\pi} P_{\text{surro}}^{\text{form}} (E^*, J^\pi) \cdot G_{\text{decay}} (E^*, J^\pi) \]

Preliminary DWBA calculations by I. Thompson, J. E. Escher, UCRL-TR-225984 (2006)

Preliminary calculations based on extended R-Matrix theory by O. Bouland. Parameters tuned with neutron-induced cross sections.

Good reproduction of our data! This means that we can proceed the other way around and use surrogate data to tune model parameters in order to infer n-induced cross sections.
Heavy-ion storage rings

The Experimental Storage Ring (ESR) at GSI

- Beam cooling $\rightarrow$ Excellent beam-energy resolution of few hundreds keV at 10 A MeV, beam size 1 mm!!
- In-ring gas-jet targets (H2, D2, 3He, 4He) with $10^{14}$/cm$^2$. Effective target thickness increased by $\sim10^6$ due to revolution frequency!
- Pure beams, pure targets (no contaminants, no backing)!
- Pure isomeric beams!

Challenge: Detectors in Ultra-High Vacuum ($10^{-11}$ mbar)
First reaction cross-section measurement at the ESR!
Decay-probability measurements in inverse kinematics inside a storage ring

All open decay-channel probabilities can be measured simultaneously with high efficiency for very short-lived nuclei! Measurements possible in the next few years.
Research Centre Rez, Czech Republic

Neutron Spectra Measurement and Calculations using Data Library JEFF-4.0T1 in Iron Benchmark Assemblies

(used files: JEFF-4.0T1, calculated in 27.2.2017)

Laboratory report No. 20170227, version 1

B. Jansky,1,* J. Rejchrt,1, A. I. Blokhin, 2

1 Department of Neutron Physics, Research Centre, Rez, Czech Republic
2 Nuclear Safety Institute, Russian Academy of Sciences, Moscow, Russia
2. Methodology of calculation and measurement

2.1. Benchmark assemblies

The spherical shape of assemblies (Fe, Ni, H₂O, D₂O, …) and spherical neutron source is used for calculation because this geometry represents the simplest one-dimensional (1D) task. As a matter of fact, the assembly is a 3D object.
3. Neutron spectrometry

**Tab.A. Detectors used with neutron spectrometers**

<table>
<thead>
<tr>
<th>Detector type</th>
<th>Type</th>
<th>Pressure</th>
<th>Dimension</th>
<th>Energy range [MeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportional Counter filled by Hydrogen (HPD)</td>
<td>NOK145</td>
<td>100 kPa</td>
<td>Ø 40 mm</td>
<td>0.01-0.3</td>
</tr>
<tr>
<td></td>
<td>NOK445</td>
<td>400 kPa</td>
<td></td>
<td>0.2-0.8</td>
</tr>
<tr>
<td></td>
<td>NOK1045</td>
<td>1000 kPa</td>
<td></td>
<td>0.5-1.3</td>
</tr>
<tr>
<td>Energy range [MeV]</td>
<td>Fe assemblies</td>
<td>C/E comparison, integral values [1], JEFF-4.T0</td>
<td>dependence C/E on the Fe thickness</td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------</td>
<td>------------------------------------------------</td>
<td>-----------------------------------</td>
<td></td>
</tr>
<tr>
<td>from to</td>
<td>U[%]</td>
<td>FE20,R100</td>
<td>U[%]</td>
<td>FE30,R100</td>
</tr>
<tr>
<td>0.1 1.3</td>
<td>0.65</td>
<td>1.135</td>
<td>0.53</td>
<td>1.13</td>
</tr>
<tr>
<td>0.1 0.2</td>
<td>2.85</td>
<td>1.139</td>
<td>1.90</td>
<td>1.153</td>
</tr>
<tr>
<td>0.2 0.4</td>
<td>1.96</td>
<td>1.174</td>
<td>1.41</td>
<td>1.167</td>
</tr>
<tr>
<td>0.4 0.8</td>
<td>0.75</td>
<td>1.191</td>
<td>0.64</td>
<td>1.144</td>
</tr>
<tr>
<td>0.8 1.0</td>
<td>1.35</td>
<td>1.128</td>
<td>1.29</td>
<td>1.098</td>
</tr>
<tr>
<td>1.0 1.3</td>
<td>1.31</td>
<td>0.980</td>
<td>1.25</td>
<td>0.904</td>
</tr>
</tbody>
</table>

- C/E > 1.10
- C/E > 1.15
- C/E < 0.95
- C/E < 0.90