Experimental activities in Europe

San Diego, CA     13 May 2003
Peter Rullhusen

Experimental facilities

Experimental facilities for neutron data measurements in the European Union and Candidate Countries

1. Low energies < 20 MeV

<table>
<thead>
<tr>
<th>City</th>
<th>Institution</th>
<th>Facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Athens</td>
<td>INP Demokritos</td>
<td>tandem</td>
</tr>
<tr>
<td>Bordeaux</td>
<td>CNRS/ IN2P3/ CENBG</td>
<td>VdG</td>
</tr>
<tr>
<td>Braunschweig</td>
<td>PTB</td>
<td>cyclotron, VdG</td>
</tr>
<tr>
<td>Bruyères-le-Chatel</td>
<td>CEA/ DAM</td>
<td>VdG</td>
</tr>
<tr>
<td>Bucharest</td>
<td>INPE</td>
<td>cyclotron, VdG</td>
</tr>
<tr>
<td>Budapest</td>
<td>KFKI</td>
<td>reactor, VdG</td>
</tr>
<tr>
<td>Debrecen</td>
<td>ATOMKI</td>
<td>various</td>
</tr>
<tr>
<td>Dresden/ Rossendorf</td>
<td>TUD/ FZR</td>
<td>(d,l), ELBE</td>
</tr>
<tr>
<td>Geel</td>
<td>IRMM</td>
<td>GELINA, VdG</td>
</tr>
<tr>
<td>Geneva</td>
<td>CERN/ n-TOF</td>
<td>spallation source</td>
</tr>
<tr>
<td>Grenoble</td>
<td>ILL</td>
<td>reactor</td>
</tr>
<tr>
<td>Karlsruhe</td>
<td>FZK</td>
<td>VdG</td>
</tr>
<tr>
<td>Orsay</td>
<td>CNRS/ IN2P3/ IPN</td>
<td>tandem</td>
</tr>
<tr>
<td>Padova/ Legnaro</td>
<td>INFN</td>
<td>various</td>
</tr>
<tr>
<td>Studsvik</td>
<td>NFL, Univ. Uppsala</td>
<td>reactor</td>
</tr>
</tbody>
</table>

peter.rullhusen@irmm.jrc.be
Experimental facilities

Experimental facilities for neutron data measurements in the European Union and Candidate Countries

2. Intermediate and high energies > 20 MeV

<table>
<thead>
<tr>
<th>Location</th>
<th>Facility</th>
<th>Source Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Darmstadt</td>
<td>GSI</td>
<td>RHIC: inverse kinematics</td>
</tr>
<tr>
<td>Geneva</td>
<td>CERN/ n-TOF</td>
<td>spallation source</td>
</tr>
<tr>
<td>Groningen</td>
<td>KVI</td>
<td>cyclotron</td>
</tr>
<tr>
<td>Jülich</td>
<td>FZJ/ COSY</td>
<td>p synchrotron</td>
</tr>
<tr>
<td>Louvain-la-Neuve</td>
<td>UCL</td>
<td>cyclotron</td>
</tr>
<tr>
<td>Uppsala</td>
<td>TSL</td>
<td>cyclotron</td>
</tr>
</tbody>
</table>

Experiment Target Status & Notes

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Target</th>
<th>Allocated</th>
<th>Used</th>
<th>Status &amp; Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOF-02</td>
<td>Varii 1.2</td>
<td>1.2</td>
<td>1.28</td>
<td>DONE</td>
</tr>
<tr>
<td>TOF-03</td>
<td>151Sm 0.4</td>
<td>0.4</td>
<td>0.52</td>
<td>DONE (Mg to be done in 2003)</td>
</tr>
<tr>
<td>TOF-05</td>
<td>204Pb 0.3</td>
<td>0.3</td>
<td>0.68</td>
<td>DONE</td>
</tr>
<tr>
<td>TOF-05</td>
<td>206Pb 0.4</td>
<td>0.4</td>
<td>0.41</td>
<td>DONE</td>
</tr>
<tr>
<td>TOF-05</td>
<td>207Pb 0.4</td>
<td>0.4</td>
<td>0.40</td>
<td>DONE</td>
</tr>
<tr>
<td>TOF-05</td>
<td>208Pb 0.6</td>
<td>0.6</td>
<td>0.86</td>
<td>DONE</td>
</tr>
<tr>
<td>TOF-05</td>
<td>209Bi 0.6</td>
<td>0.6</td>
<td>0.62</td>
<td>DONE</td>
</tr>
<tr>
<td>TOTAL</td>
<td>3.9</td>
<td>4.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOF-07</td>
<td>232Th 0.8</td>
<td>0.8</td>
<td>0.83</td>
<td>DONE (234U and 236U to be done in 2003)</td>
</tr>
<tr>
<td>TOTAL CAPTURE</td>
<td>4.7</td>
<td>5.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOF-06</td>
<td>232Th, 234U, 235U, 236U</td>
<td>2.3</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>TOTAL FISSION</td>
<td>2.3</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRAND TOTAL 2002</td>
<td>7</td>
<td>6.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Plan: capture in 2003

<table>
<thead>
<tr>
<th>Experiment WP-Target</th>
<th>Number of Protons</th>
<th>Approval status</th>
<th>Detector</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capture Cross section of non-fissionable isotopes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n_TOF-03</td>
<td>11</td>
<td>Approved</td>
<td>C6D6</td>
<td></td>
</tr>
<tr>
<td>n_TOF-04</td>
<td></td>
<td>Approved</td>
<td>C6D6</td>
<td></td>
</tr>
<tr>
<td>n_TOF-0X</td>
<td></td>
<td>Approved</td>
<td>C6D6</td>
<td></td>
</tr>
<tr>
<td>Total Number of Protons</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Notes
- The 79Se sample for capture measurement with C6D6 detector is not available.
- The 231Pa sample can be measured by activation (smaller quantity required).

### Plan: fission in 2003

<table>
<thead>
<tr>
<th>Experiment WP-Target</th>
<th>Number of Protons</th>
<th>Mass (mg)</th>
<th>Approval status</th>
<th>Detector</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fission Cross section of ThFC isotopes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n_TOF-06</td>
<td>14</td>
<td>1.1</td>
<td>Approved</td>
<td>PPAC/FIC</td>
<td></td>
</tr>
<tr>
<td>n_TOF-02</td>
<td>14</td>
<td>1.5</td>
<td>Approved</td>
<td>PPAC/FIC</td>
<td></td>
</tr>
<tr>
<td>Total Number of Protons</td>
<td>7.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Notes
- Sample impossible to locate. Measurement probably undoable.
the n_TOF BaF$_2$ array

F. Käppeler, FZK

total-absorption calorimeter TAC

Plan: capture in 2004

Capture Cross section of TRU isotopes

<table>
<thead>
<tr>
<th>Experiment</th>
<th>WP</th>
<th>Target</th>
<th>Number of Protons (10$^{18}$)</th>
<th>Approval status</th>
<th>Detector Campaign</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>n_TOF-07</td>
<td>233U</td>
<td>1</td>
<td>Approved</td>
<td>TAC</td>
<td>2004</td>
<td></td>
</tr>
<tr>
<td>n_TOF-07</td>
<td>237Np</td>
<td>2.5</td>
<td>Pending</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n_TOF-07</td>
<td>240Pu</td>
<td>2.5</td>
<td>Pending</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n_TOF-07</td>
<td>242Pu</td>
<td>2.5</td>
<td>Pending</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n_TOF-07</td>
<td>241Am</td>
<td>1</td>
<td>Approved</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n_TOF-07</td>
<td>243Am</td>
<td>1</td>
<td>Approved</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n_TOF-07</td>
<td>245Cm</td>
<td>3</td>
<td>Approved</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total Number of Protons: 13.5

Deliverables: Missing: Notes:

n_TOF-ND-ADS

alberto.mengoni@cern.ch

peter.rullhusen@jmm.jrc.be
Neutron data for waste transmutation and innovative concepts

- Transmutation studies
- ADS systems
- Th-U fuel cycle

Basic Nuclear Physics and Standards

- Standard cross-sections
- Theory
- Applications

European Research Area and Enlargement:

- Competence building and training:
  - fellows, visiting scientists, national detached experts
- Access to Large-scale facilities: GELINA and VdG

Transmutation: collab. with n-TOF, CEA
Integrated Project in FP6

MA burning: $^{237}$Np $\sigma_{\text{tot}}$
LLFP: $^{99}$Tc, $^{129}$I $(n,\gamma)$, $\sigma_{\text{tot}}$

ADS:
- Pb, Bi: $(n,n'\gamma)$, $(n,\gamma)$ and $\sigma_{\text{tot}}$
- struct. mat.: $(n,xp)$, $(n,x\alpha)$, $(n,\alpha p)$, $(n,n'\gamma)$

Basic Physics and Standards:

- $^1$B $(n,\alpha)$, $^{238}$U $(n,f)$, $^{239}$Pu $(n,f)$,
- $^{251}$Cf $(n,f)$, $^{252}$Cf (s.f.)

Theory:
- fission (Multi-Modal fission)
- LCP (optical model)

Doppler broadening

applications:
- NRCA (n-resonance capture analysis)
IRMM: $^{237}$Np($n,\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\gamma\g
**IRMM: $^{206}$Pb(n,γ)\)**

P. Schillebeeckx, A. Borella:

$^{206}$Pb(n,γ) : C$_6$D$_6$ measurements at 60 m

![Graph showing response vs. energy for $^{206}$Pb(n,γ) measurements](image)

**IRMM: $^{58}$Ni(n,n'γ)\)**

A. Plompen, L. Olah (HU), C. Borcea, L. Mihailescu (RO)

Gamma-ray production cross section for 1454 keV

![Graph showing gamma-ray production cross section for $^{58}$Ni(n,n'γ)](image)
IRMM: $^{58}\text{Ni}(n,n'\gamma)$

A. Plompen, L. Olah (HU), C. Borcea, L. Mihailescu (RO)

gamma-ray production cross section for 1454 keV

![Graph showing gamma-ray production cross section for 1454 keV]
IRMM: Th-U Fuel Cycle

$^{233}\text{Pa}(n,f)$ results Jan.-Feb. 03

F.-J. Hambsch, S. Oberstedt, F. Tovesson (Uppsala)

- Measured energies: 1.2, 1.4, 3.8 MeV (analysed) + 1.5, 3, 6, 7.5 MeV (ongoing)
- Results very preliminary
- Still missing: Separate $^{233}\text{U}$ measurements for back-ground corrections
- Plans: Evaluation of results together with CC-scientists during summer 2003

IRMM: neutron data standards

$^{10}\text{B}(n,\alpha)$ - prelim. results

G. Giorginis, V. Khriatchkov (Obninsk)
IRMM: applications

collab. with Univ. Delft and Ntl. Museum of Antiquities, Leiden
P. Schillebeeckx, P. Siegler, H. Postma, M. Blaauw (Delft)

neutron resonance capture analysis NRCA

Comparison GELINA ↔ n-TOF

non-radioactive targets: $^{206}$Pb(n,γ), raw data
IRMM: P. Schillebeeckx, A. Borella; n-TOF: F. Gunsing (CEA)
Comparison GELINA ↔ n-TOF

Resolution function: $^{206}\text{Pb}(n,\gamma)$
calc: C. Coceva, A. Brusegan

![Graph showing neutron energy and capture yield comparison between GELINA and n-TOF.]
Under construction:
- High intensity neutron beam 20-180 MeV
- Factor 5-10 higher intensity than today
- First beam early 2004

Standard equipment:
- MEDLEY (n,light ion)
- SCANDAL (n,n), (n,xn'), (n,xp)

Detector: planar HPGe (1.5 cm in depth) placed at 12 cm from the target
Sample: - natW (0.5 mm thick) - 232Th (0.3 mm thick) placed at 3.28 m from the neutron source

natW(n,xn) @ Louvain-la-Neuve

Detector: planar HPGe (1.5 cm in depth) placed at 12 cm from the target
Sample: - natW (0.5 mm thick) - 232Th (0.3 mm thick) placed at 3.28 m from the neutron source
**IReS Strasbourg**

Gérard Rudolf

\[ \text{nat}^\text{Pb}(n,n'\gamma) \] @ IRMM

2 weeks beam time in march

- 200 m flight path from neutron source
- natPb sample
- clover detector
  - four closely packed coaxial HPGe crystals
  - each crystal has its own preamp
- digital acquisition
  - home made 14 bit 60 MS/s digitizers

Test with a clover detectors
- in most cases \( \gamma \)-flash is seen only by a part of the detector
- better photopeak efficiency in "add back" mode

---

**The PTB TOF-facility**

R. Nolte

- neutron production: D(d,n)
- \( D_2 \) gas target (30.5 mm, 2 bar)
- neutron energies: 8 MeV - 15 MeV
- flight path: 12 m
- NE213 detectors:
  - \( 4'' \times 1'' \) (D1)
  - \( 10'' \times 2'' \) (D2-D5)
  - \( 1.5'' \times 1.5'' \) (M)
- CV 28° Cyclotron
  - protons: 2.5 MeV - 21 MeV
  - deuterons: 3 MeV - 14 MeV
- repetition frequency: \( \approx 1 \text{ MHz} \)
- time resolution: \( \approx 2 \text{ ns} \)
Neutron sources at PTB

R. Nolte

PTB cyclotron: no Ti(T) target (contamination)
solution for low energies: $^{15}\text{N}(p,n)$

---

Nuclear data activities at PTB

R. Nolte

- 8 MeV - 15 MeV
  - TOF facility with D(d,n) neutron source
  - focused on the fusion program
  - neutron scattering: DX and DDX for elemental samples
  - activation cross sections
- 30 MeV - 200 MeV
  - UCL and iTL (former NAC) facilities
  - fluence measurement techniques, beam characterization
  - fission cross sections relative to n-p scattering
Neutronics mock-up of the ITER shielding system (first wall, blanket, vacuum vessel, TF coils)

flux spectrum at deep positions:
continuous component (photo-neutron source) + 14 MeV peak (D-T generator)
advantage of up to five orders of magnitude

d-beam I

$E_d = 300$ keV on T target
a) continuously, 10 mA?
   source strength $10^{12}$ s$^{-1}$
b) pulsed, 10µs … 100µs, 1 mA
   repetition rate: 1 Hz … 1 kHz

d-beam II

$E_d = 300$ keV on T target
pulse width 1 … 1.5 ns
repetition rate: 1 MHz, 2 MHz, and 5 MHz

e-beam

$E_e = 20$ MeV / 40 MeV
rotary W/Ta target
~ $7 \cdot 10^{13}$ s$^{-1}$ photo-neutrons
Fig. 11. Two-dimensional plot of the isotopic cross sections for fission/fragments obtained in GSI: $^{238}$U + p reactions at 1 GeV/nucleon incident stable isotopes. Colors correspond to increasing areas according to the logarithmic scale indicated.

Fig. 12. Comparison of measured isotopic distribution with predictions in relation to the deformed $^{238}$U core. The GSI reaction, by LAHET [2], is shown by crosses. Experimental data are also indicated.

K.H. Schmidt

The ADOPT cluster:
Advanced Options for Partitioning and Transmutation

EU Framework Program 5

The ADOPT cluster:
Advanced Options for Partitioning and Transmutation

PARTITION
PYROSEP
PARTNEW
CAMEPART

FUETRA
CONFIRM
THORIUM
FUTURE

TRANSFORMATION: DESIGN
PDS-XADS

BASTRA
MUSE
N$_{\text{TOF-MAX}}$

TESTRA
SPIRE
TECLA
MEGAPIE-TEST
ASCHLIM
EU Framework Program 6

Thematic Call in the area of
“Euratom Research and Training programme on Nuclear Energy”

Management of radioactive waste (90 M€)

Main objectives:
Research to contribute to a broadly agreed approach to waste management and disposal; exploration of the technical and economic potential of concepts able to make better use of fissile material and generate less waste.

Research areas:

- **Geological disposal**
  - improvement of fundamental knowledge, developing and testing technologies (key physical, chemical and biological processes, interaction with barriers, long-term stability, etc.)
  - new and improved tools (models for performance and safety assessment, development of alternative measures of performance and better governance)

- **Partitioning and transmutation and other concepts**
  - Partitioning and transmutation
  - Concepts to produce less waste