Commissioning of the New Spallation Target for the n_TOF facility at CERN

Outline
- n_TOF operation until 2004
- New target construction
- Commissioning of the new target
- Facility Upgrade
- Measurements programme

AccApp2009 Vienna 4-8 May 2009
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**Concept of n_TOF**

** ADS Developments:**
- Nuclear Waste Transmutation
- Medical Isotopes Production
- Cleaner Energy Production
- Boron Neutron Capture Therapy [BNCT]

**Require the complete and precise knowledge of neutron cross sections**

**Idea:**
- Knowledge acquired from TARC (PS-211)
- PS of CERN \([26 \text{ GeV/c, } 3 \times 10^{13} \text{ pr}\)]
- Spallation target \(\text{Pb}\), to produce neutrons
  \([1 \text{ proton } 24 \text{ GeV/c} \Rightarrow \sim 700 \text{ neutrons}]\)
- Long flight path \(\sim 200 \text{ m}\)

CERN/ET/Int. Note 97-19
http://proj-ntof.web.cern.ch/proj-nTOF
(A Google-view of) The n_TOF facility at CERN

- **n_TOF** flight path: 185 m
- Proton Beam: 20 GeV/c, $7 \times 10^{12}$ ppp
- Pb Spallation Target
- Neutron Beam: 10$^\circ$ prod. angle
- Pb Spallation Target
- Booster: 1.4 GeV
- Linac: 50 MeV
- PS: 20 GeV
**n_TOF beam characteristics**

- Wide energy range
- High instantaneous neutron flux
- High resolution
- Low ambient background
- Low repetition frequency
- Favorable duty cycle for radioactive samples.

The neutron fluence in EAR-1

<table>
<thead>
<tr>
<th>Energy range</th>
<th>Uncollimated</th>
<th>Capture mode</th>
<th>Fission mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[n/pulse/cm²]</td>
<td>[n/pulse]</td>
<td>[n/pulse]</td>
</tr>
<tr>
<td>&lt; 1 eV</td>
<td>2.0E+05</td>
<td>3.1E+05</td>
<td>2.8E+05</td>
</tr>
<tr>
<td>1 eV - 10 eV</td>
<td>2.7E+04</td>
<td>4.5E+04</td>
<td>2.9E+05</td>
</tr>
<tr>
<td>10 eV - 100 eV</td>
<td>2.9E+04</td>
<td>4.7E+04</td>
<td>3.1E+05</td>
</tr>
<tr>
<td>100 eV - 1000 eV</td>
<td>3.0E+04</td>
<td>5.1E+04</td>
<td>3.3E+05</td>
</tr>
<tr>
<td>1 eV - 1 keV</td>
<td>8.6E+04</td>
<td>1.4E+05</td>
<td>9.3E+05</td>
</tr>
<tr>
<td>1 keV - 10 keV</td>
<td>3.2E+04</td>
<td>5.4E+04</td>
<td>3.6E+05</td>
</tr>
<tr>
<td>10 keV - 100 keV</td>
<td>3.9E+04</td>
<td>7.1E+04</td>
<td>4.7E+05</td>
</tr>
<tr>
<td>100 keV - 1000 keV</td>
<td>1.1E+05</td>
<td>2.3E+05</td>
<td>1.5E+06</td>
</tr>
<tr>
<td>1 keV - 1 MeV</td>
<td>1.8E+05</td>
<td>3.5E+05</td>
<td>2.3E+06</td>
</tr>
<tr>
<td>1 MeV - 10 MeV</td>
<td>8.3E+04</td>
<td>2.4E+05</td>
<td>1.7E+06</td>
</tr>
<tr>
<td>10 MeV - 100 MeV</td>
<td>2.8E+04</td>
<td>7.2E+04</td>
<td>5.1E+05</td>
</tr>
<tr>
<td>&gt; 100 MeV</td>
<td>4.4E+04</td>
<td>1.2E+05</td>
<td>5.6E+05</td>
</tr>
<tr>
<td>1 MeV - &gt; 100 MeV</td>
<td>1.6E+05</td>
<td>4.4E+05</td>
<td>2.7E+06</td>
</tr>
<tr>
<td>Total</td>
<td>6.2E+05</td>
<td>1.2E+06</td>
<td>8.0E+06</td>
</tr>
</tbody>
</table>

Note: 1 pulse is 7E+12 protons. Collimated fluence (fission and capture modes) is integrated over the beam surface.
CERN n_TOF overview
Commissioned in 2001-2002
### Capture

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Mass Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{151}$Sm</td>
<td></td>
</tr>
<tr>
<td>$^{204,206,207,208}$Pb, $^{209}$Bi</td>
<td></td>
</tr>
<tr>
<td>$^{232}$Th</td>
<td></td>
</tr>
<tr>
<td>$^{24,25,26}$Mg</td>
<td></td>
</tr>
<tr>
<td>$^{90,91,92,94,96}$Zr, $^{93}$Zr</td>
<td></td>
</tr>
<tr>
<td>$^{139}$La</td>
<td></td>
</tr>
<tr>
<td>$^{186,187,188}$Os</td>
<td></td>
</tr>
<tr>
<td>$^{233,234}$U</td>
<td></td>
</tr>
<tr>
<td>$^{237}$Np, $^{240}$Pu, $^{243}$Am</td>
<td></td>
</tr>
</tbody>
</table>

### Fission

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Mass Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{233,234,235,236,238}$U</td>
<td></td>
</tr>
<tr>
<td>$^{232}$Th</td>
<td></td>
</tr>
<tr>
<td>$^{209}$Bi</td>
<td></td>
</tr>
<tr>
<td>$^{237}$Np</td>
<td></td>
</tr>
<tr>
<td>$^{241,243}$Am, $^{245}$Cm</td>
<td></td>
</tr>
</tbody>
</table>

### n_TOF experiments 2002-4

- **Measurements of neutron cross sections relevant for Nuclear Waste Transmutation and related Nuclear Technologies**
  - Th/U fuel cycle (capture & fission)
  - Transmutation of MA (capture & fission)
  - Transmutation of FP (capture)

- **Cross sections relevant for Nuclear Astrophysics**
  - s-process: branching
  - s-process: presolar grains

- **Neutrons as probes for fundamental Nuclear Physics**
  - Nuclear level density & n-nucleus interaction
### SC/RP: Cooling circuit activation in 2004

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Activity concentration 11.11.2003 (Bq g⁻¹)</th>
<th>Activity concentration 12.10.2004 (Bq g⁻¹)</th>
<th>Activity concentration 16.11.2004 (Bq g⁻¹)</th>
<th>Ratio Nov. 2004/Nov. 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>⁷Be</td>
<td>99.6</td>
<td>84.4</td>
<td>74</td>
<td>0.74</td>
</tr>
<tr>
<td>⁶⁵Zn</td>
<td>4.49 10⁻²</td>
<td>1.63</td>
<td>6.6</td>
<td>147</td>
</tr>
<tr>
<td>⁸⁸Y</td>
<td>2.88 10⁻²</td>
<td>4.51</td>
<td>18</td>
<td>625</td>
</tr>
<tr>
<td>¹⁷²Hf/Lu</td>
<td>3.6 10⁻²</td>
<td>6.44</td>
<td>23</td>
<td>639</td>
</tr>
<tr>
<td>¹⁸³Re</td>
<td>7.27 10⁻²</td>
<td>8.83</td>
<td>73</td>
<td>1004</td>
</tr>
<tr>
<td>¹⁸³Os</td>
<td>3.46 10⁻²</td>
<td>25.9</td>
<td>120</td>
<td>3468</td>
</tr>
<tr>
<td>¹⁹⁵Au</td>
<td>9.02 10⁻²</td>
<td>59.0</td>
<td>360</td>
<td>3991</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Exemption Limit $L_E$ (Bq g⁻¹) or (Bq)</th>
<th>Activity concentration $\alpha$ 16.11.2004 (Bq g⁻¹)</th>
<th>Multiple of $L_E$</th>
<th>Total activity $A$ in 700 l</th>
<th>Multiple of 100 $L_E$</th>
</tr>
</thead>
<tbody>
<tr>
<td>⁷Be</td>
<td>400</td>
<td>74</td>
<td>0.19</td>
<td>51800</td>
<td>1.3</td>
</tr>
<tr>
<td>⁶⁵Zn</td>
<td>3</td>
<td>6.6</td>
<td>2.2</td>
<td>4620</td>
<td>15.4</td>
</tr>
<tr>
<td>⁸⁸Y</td>
<td>8</td>
<td>18</td>
<td>2.25</td>
<td>12600</td>
<td>15.75</td>
</tr>
<tr>
<td>¹⁷²Hf/Lu</td>
<td>8</td>
<td>23</td>
<td>2.88</td>
<td>16100</td>
<td>20.13</td>
</tr>
<tr>
<td>¹⁸³Re</td>
<td>10</td>
<td>73</td>
<td>7.3</td>
<td>51100</td>
<td>51.1</td>
</tr>
<tr>
<td>¹⁸³Os</td>
<td>20</td>
<td>120</td>
<td>6</td>
<td>84000</td>
<td>42</td>
</tr>
<tr>
<td>¹⁹⁵Au</td>
<td>40</td>
<td>360</td>
<td>9</td>
<td>252000</td>
<td>63</td>
</tr>
</tbody>
</table>

**Total Exemption Limit 100 $L_E$**
Target Interventions

- Target removal was performed at the 27.09.2007
- Target visual inspection & photography
- Pit & pool inspection (web camera)
- First dose rate measurements of the target and pit
- Measurement of hole at the beam impact location
- Samples taken from the target to be analyzed
- FLUKA simulations of the target activation, as well as detailed maps for pit and pool
- Target surface inspection using a dedicated custom-built (and developed) laser system
- Detailed dose rate measurement of the target and pit (November 2007)
- Extensive study of the target corrosion mechanism
New Target: Conceptual Design

Lead
Ø=60 cm
L= 40 cm

Moderator (4cm thick)

Cooling Water (1cm thick)

Existing Pool

Neutron Exit Window

Lead Core

Lead Support

Anti Creep Support

Vessel Body

Proton Entrance Window

New Pressurized Vessel

Existing Retention Vessel

protons
**Cooling Capacity:** 7kW  
**Water flow:** 8 m³/h at 1.5 bars  
**Temperature:** 18°C  
**Instrumentation:** O₂, pH, Conductivity  
**Retention basin:** 1000 l

**Target Area is continuously flushed out**  
**Filter:** ^7^Be  
**Flush:** <150 m³/h  
**Volume:** 1200 m³  
**Dose to public:** < 1µSv for 1.6×10⁻³⁹ p
2008 Short Commissioning of the new Target

Exceptional authorization from CERN SC/RP to start in 2008 with a reduced cooling circuit and no ventilation.

Conditions:
- The specific activity should not exceed 1% of the exemption limit LE for the concentration (Bq/kg)
- The absolute activity released per month (Bq) should not exceed the exemption limit
- The above are calculated based on the past experience and the corrosion/erosion test performed at CERN
- Start: Monday 3 Nov 2008
- Stop: 13 Nov 2008
- Duration: 10 days
- Total number of protons: $2 \times 10^{17}$ pot (1% of a year's beam)
- Max. Power accepted: ~3kW
- Super cycle: 40s – 48s
 Beam characteristics

- Most of the time was spent on tuning the beam and detectors
- We’ve got the authorization to run with 300 pulses of high intensity
**Neutron Fluence**

**Preliminary results**

obtained with:  
Micromegas detector and  
Fission Ionization Chamber (FIC) detector

- Uncertainty of the $^{10}$B mass
- Rather poor statistics
- Bad alignment of the collimator  
  $\phi = 1.8$ cm  
(cf. AT/OC–02 presentation)
The n_TOF-Ph2 experiments (1)

<table>
<thead>
<tr>
<th>Capture measurements</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mo, Ru, Pd stable isotopes</td>
<td>r-process residuals calculation isotopic patterns in SiC grains</td>
</tr>
<tr>
<td>Fe, Ni, Zn, and Se (stable isotopes) ( ^{79}\text{Se} )</td>
<td>s-process nucleosynthesis in massive stars accurate nuclear data needs for structural materials</td>
</tr>
<tr>
<td>A≈150 (isotopes varii)</td>
<td>s-process branching points long-lived fission products</td>
</tr>
<tr>
<td>( ^{234,236}\text{U}, ^{231,233}\text{Pa} )</td>
<td>Th/U nuclear fuel cycle</td>
</tr>
<tr>
<td>( ^{235,238}\text{U} )</td>
<td>standards, conventional U/Pu fuel cycle</td>
</tr>
<tr>
<td>( ^{239,240,242}\text{Pu}, ^{241,243}\text{Am}, ^{245}\text{Cm} )</td>
<td>incineration of minor actinides</td>
</tr>
</tbody>
</table>

(*) approved by CERN Scientific Committee (planned for execution in 2009)
### The n_TOF-Ph2 experiments (2)

#### Fission measurements

<table>
<thead>
<tr>
<th>MA</th>
<th>ADS, high-burnup, GEN-IV reactors</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{235}\text{U}(n,f)$ with $p(n,p')$</td>
<td>new $^{235}\text{U}(n,f)$ cross section standard</td>
</tr>
<tr>
<td>$^{234}\text{U}(n,f)$</td>
<td>study of vibrational resonances at the fission barrier</td>
</tr>
</tbody>
</table>

#### Other measurements

| $^{147}\text{Sm}(n,\alpha), \ 67\text{Zn}(n,\alpha), \ 99\text{Ru}(n,\alpha)$, $^{58}\text{Ni}(n,p)$, other $(n,lcp)$ | p-process studies  
gas production in structural materials |
| Al, V, Cr, Zr, Th, $^{238}\text{U}(n,lcp)$ | structural and fuel material for ADS  
and other advanced nuclear reactors |
| He, Ne, Ar, Xe | low-energy nuclear recoils  
(development of gas detectors for dark matter research) |
| $n+D_2$ | neutron-neutron scattering length |

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The n_TOF Collaboration  
n_TOF-Ph2
Accepted Proposals

CERN-INTC-2006-012:
  The role of Fe and Ni for s-process nucleosynthesis in the early Universe and for innovative nuclear technologies
  Number of protons approved: $1.8 \times 10^{19}$

CERN-INTC-2006-006:
  Proposed study of the neutron-neutron interaction at the CERN n_TOF facility.
  Number of protons accepted: $0.2 \times 10^{19}$

CERN-INTC-2006-016:
  Angular distributions in the neutron-induced fission of actinides. Number of protons approved: $0.15 \times 10^{19}$

CERN-INTC-2008-035:
  n_TOF: New target commissioning and beam characterization.
  Number of protons accepted: $2.45 \times 10^{18}$ (start 18 of May 2008)
Conclusions

- Experience gained from the previous target help on the construction of the new target
- Short commissioning in Nov’08, Showed values consistent with simulations
- Work on progress and finished before 18 of May 2009
  - Cooling system
  - Ventilation of primary area
  - Air tight the technical gallery
  - Alignment of proton beam line and neutron line
- Measurements:
  - 4 Accepted proposals, 2 of them will be performed in 2009
    - Beam Request: $\sim 2.5 \times 10^{19}$ p
  - Expected constant use of $2.0 \times 10^{19}$ p/year
- Future:
  - Borated water
  - Heavy water
  - Disposal of old target