The high power target for LENOS Project at Laboratori Nazionali di Legnaro of INFN-LNL

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**LEgnaro NeutrOn Source**

- **Neutron Irradiation Facility.** RFQ/Cyclotron.
- **Time-of-Flight Facility.** CN accelerator

**Main characteristic:**
Based on a method for the production of different neutron spectra which avoid the use of moderators.

**Applications:**
- Nuclear Astrophysics.
- Validation of Evaluated Data.
- Nuclear data.
- Medical physics applications.
- Radiation damage tests (SEE).
- Material science physics (neutron imaging).
Our main motivation: Astrophysics

Nucleosynthesis of elements beyond Fe (B=8.8 MeV/A) are produced in stars by successive (n,γ) and β-decays.

The stellar velocity neutron spectrum is a Maxwell-Boltzmann distribution. Depending on the stellar site and the evolutionary stage of the star the most important kT are 8, 30 or 90keV, being 30 keV the standard temperature of reference. (*)

\[ \frac{dN_A(t)}{dt} = N_{A-1}(t) \cdot n_n(t) \langle \sigma \cdot v \rangle_{A-1} - N_A(t) \cdot n_n(t) \langle \sigma \cdot v \rangle_A \cdot \lambda(t) N_A(t) \]

\[ MACS \equiv \langle \sigma \rangle = \frac{\langle \sigma \cdot v \rangle_A}{V_T} \rightarrow MACS (\text{Maxwellian Averaged Cross Section}) \]

[*] Z. Y. Bao et al., ADNDT 76, 70 (2000).
Neutron integral experiments play a central role in validation of evaluated nuclear data [1][2][3].

Evaluated spectrum averaged cross-section in Maxwellian spectrum are being used for the validation of evaluated reactor dosimetry files [4].

For instance, experimental MACS can be used for the validation of nuclear data libraries in the 10-120 keV range that is important in the description of fast neutron systems (e.g. Gen-IV nuclear reactors).

The integral measurements with our method at CNA (and LNL) are of interest for the IAEA and it has been mentioned as one of the Actions in few IAEA Reports:


LENOS’ method concept

In order to produce a MB neutron energy spectra or other desired spectra, we developed a new method:

Shaping the proton beam to shape the neutron beam energy spectra to a desired distribution

This method avoid the use of moderators and improve the neutron flux at sample position. (*)

[*] P.F. Mastinu et al., NIM A, 601 (2009) 333-338
Example of production of stellar or maxwellian neutron spectra. Low power accelerator.

Setup for low power, CN at LNL-INFN. (7 MV Van Der Graaf accelerator)

- Proton energy shaper: Al or Pb foil (70-125 um)
- Li metal target
- Low mass water cooled target
- Tunable proton energy
- Tunable viewing angle

Since minor corrections are needed, MACS can be directly measured by neutron activation. Our first measurement was the MACS of $^{181}$Ta$(n,\gamma)$ at $kT=30$ keV. (*)

Expected Neutron Flux = $5 \cdot 10^{10}$ n/s·cm$^2$

We decide to shape the proton beam by using the energy straggling and stopping power of charge particles when interact with a thin foil of material. General method: **multilayer energy shaper**.

**LENOS foil material requirements**:
Low atomic number and low density, high melting point, high emissivity, high thermal conductivity, high tensile strength.

→ **GRAPHITE foil**

For lower power we can use a monolayer Aluminium foil.

\[ P = 2 \times 80 \text{ kW for 50mA} \text{ ANSYS, Inc} \]
Graphite disk 70 μm thickness. Power to be dissipated about 50 kW, Mainly by radiation. Working temperature <2000°C
Construction material Al Ergal alloy
LENOS Layout: Energy Shaper (3/3)

Prototype almost completed
In order to dissipate so high specific power (about 3 kW/cm²) a new generation of heat cooling device have to be implemented and developed.

The target must satisfy some constrains:
• Low mass (to avoid neutron backscattering and reduce radioactivity )
• Small thickness, in order to maximize the neutron flux (keeping the measuring sample in touch with the neutron producing surface) and reduce neutron spectra perturbation
• Low cost and easy to fabricate procedure, in order to replace the target often even during a measurements

Microchannels + liquid metal cooling medium
Cu Backing:
13 micro channels
14 mm long
0.45 mm diameter
0.95 mm spacing
0.5 wall thickness
6.4 mm in-out diam tube
Different GaInSn eutectic alloys are commercially available with different thermophysical properties:

- Conservative calculations show that $\sim 3.5$ kW/cm$^2$ could be dissipated. $T_{\text{Li}} < 152$ °C. Melting point of Lithium is 182°C.

- Li (30μm) on a backing of Cu (1.5mm).

- Microchannels, GALINSTAN (gallium, indium e stannum $\text{Ga}_{68}\text{In}_{21}\text{Sn}_{11}$), alloy at $T=15$ °C.
LENOS: Lithium target. ANSYS results (4/7)

**Water cooled**

**Pressure**

- $P_{in} = 2.7$ bar
- $\Delta P = 2.7$ bar

**Velocity**

- $\mu$-channel fluid velocity = 15 m/s

**Temperature**

- Li 40 μm
- Mass flow = 160 l/h
- Inlet fluid temperature = 15°C
- Beam Power = 1000 W
- Flat beam profile

- Melting point Li = 182°C

- $T_{max}$ = 25°C

- $T_{max}$ = 114°C
SnInGa alloy cooled

Pressure

\[ P_{in} = 2.5 \text{bar} \]
\[ \Delta P = 2.5 \text{ bar} \]

Velocity

\[ \mu\text{-channel fluid velocity} = 5 \text{ m/s} \]

Temperature

Li 40 \text{ \( \mu \)m}

\[ T_{max} = 46 \text{ C} \]

Mass flow = 55 l/h

Inlet fluid temperature = 15°C

beam Power = 1000W

Flat beam profile

Melting point Li = 182°C

LENOS: Lithium target. ANSYS results (5/7)
**LENOS: Lithium target. Comparison (6/7)**

### Analytical

Good agreement for water, less for liquid metal

### ANSYS

<table>
<thead>
<tr>
<th>WATER</th>
<th>GALINSTAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>parameters</td>
<td>description</td>
</tr>
<tr>
<td>$c_p$ [J/(kg K)]</td>
<td>fluid specific heat</td>
</tr>
<tr>
<td>$k_h$ [W/m K]</td>
<td>fluid thermal conductivity</td>
</tr>
<tr>
<td>$X_c$ [W/m K]</td>
<td>target thermal conductivity</td>
</tr>
<tr>
<td>$v_s$ [Pa s]</td>
<td>fluid viscosity dynamic</td>
</tr>
<tr>
<td>$p$ [kg/m$^3$]</td>
<td>fluid density</td>
</tr>
<tr>
<td>$d$ [mm]</td>
<td>diameter of the microchannels</td>
</tr>
<tr>
<td>Pr</td>
<td>Prandtl number</td>
</tr>
<tr>
<td>$Re$</td>
<td>Reynolds number</td>
</tr>
<tr>
<td>Nu</td>
<td>Nusselt number</td>
</tr>
<tr>
<td>$q$ [W/m$^2$ K]</td>
<td>convection coefficient</td>
</tr>
<tr>
<td>$T_{in}$ [K]</td>
<td>fluid average temperature</td>
</tr>
<tr>
<td>$n$</td>
<td>number of microchannels</td>
</tr>
<tr>
<td>$q$ [W/m$^2$]</td>
<td>beam specific thermal power</td>
</tr>
<tr>
<td>$q$ [W/m$^2$]</td>
<td>beam specific thermal power</td>
</tr>
<tr>
<td>$T_{in}$ [K]</td>
<td>temperature on beam surface</td>
</tr>
<tr>
<td>$Q_{in}$ [W/m$^2$]</td>
<td>fluid inlet temperature</td>
</tr>
<tr>
<td>$Q_{in}$ [W/m$^2$]</td>
<td>fluid volumetric flow</td>
</tr>
<tr>
<td>$Q_{in}$ [W/m$^2$]</td>
<td>fluid outlet temperature</td>
</tr>
<tr>
<td>$Q_{in}$ [W/m$^2$]</td>
<td>lithium thickness [m]</td>
</tr>
<tr>
<td>$T_{in}$ [K]</td>
<td>126.7277128</td>
</tr>
<tr>
<td>$t_s$ [W/m K]</td>
<td>gold thermal conductivity</td>
</tr>
</tbody>
</table>

**Diagram:**

- **Water**
- **Liquid metal**
- **Extrapolation**

The diagram illustrates the lithium temperature variation with specific power, comparing water and liquid metal behavior and an extrapolation line.
But...

- Micro-channels are not small «tubes»
- CFX package has problems also to reproduce the fluidodynamics inside the microchannels, even the velocity-pressure drop relation
- Internal characteristics of the channels hard to measure
- So we (tried) moved fast to hardware tests
- We have continuously developed our target in order to improve the performances: the new developments are PATENT PENDING by INFN and will be ready soon.
Many targets have been successfully manufactured at LNL.

Indium has been used as a threshold thermometer.

Preliminary Tests done depositing a thin Indium layer instead of Lithium.
- Melting point of Indium: 157°C.
- Thermal conductivity of Indium: 81.6 W/(m·K).
- Thermal conductivity of Lithium: 84.7 W/(m·K).

**TIG test:**
- Measured power transfer: 3.4 kW
- Not reached the Indium melting point

**Oxyd-acethilene test:**
- Measured power transfer: 1.5 kW
- Not reached the Indium melting point
Lithium target testing: e-Beam

**Target** (copper backing) was irradiated by electron beam in $10^{-4}$ mbar

$I = 0.74$ A, $V = 60$ kV, $P = \eta V \cdot I = 0.44$ kW

Maximum transferred Power 13 kW/cm²

Temperature mapped with thermocamera. Transferred power measured by the water temperature and mass flow. Beam spot 0.5 and 1.2 cm diameter

Lithium target testing- E-Beam

Large uncertainty in surface temperature determination due to uncertainty in the emissivity. Estimated value $0.23 < \varepsilon < 0.84$

Linear rise. At least one point for normalization is needed.
Lithium Target Assembly final version in CF

- 1 m long beam pipe in CF
- Water cooled collimator
- Cold trap
- ZnSe window for temperature mapping
- CF LTA
LENOS facility TOF: CN 7 MV Van der Graaf.

Pulsed beam:
- 3 MHz rf pulsing system on the high voltage terminal.
- 1 ns pulse width.
- Only 3 MHz operating: no adequate for neutron TOF measurement in the energy range of interest.

We have developed, installed and testing a switching system able to provide 1 ns pulse at 1 MHz, 625 kHz. (*) low Rep rate available now for TOF measurements at CN accelerator of LNL.

Among the several radionuclides of copper, $^{64}\text{Cu}$ is the most commonly used for basic science investigations and clinical PET, and its production and use have now been reported in the United States, Europe, and Japan. Several companies, including MDSNordion (Canada), ACOM (Italy), Trace Life Sciences (United States), IBA Molecular (United States and Europe), and IsoTrace (United States) are supplying $^{64}\text{Cu}$ for use in preparation of radiopharmaceuticals.

- PET
- CANCER RADIOTHERAPY

$^{62}\text{Zn}/^{62}\text{Cu}$ generator can be used instead of the more common $^{18}\text{F}$ for PET. Problems related to the time distribution of the short lived (109.8 min) $^{18}\text{F}$ can be reduced. It can also be used instead of $^{99m}\text{Tc}$.

- PET
LARAMED: $^{64}$Cu/$^{62}$Zn tandem production, single target

$E_p = 35$ MeV, $300$ uA

When an high heat removal performance are needed, more than one row of micro-channels can be implemented.

Proton energy distribution impinging on Ni

Sublimation effects not taken into account

Beam spot size 1.2 cm
Total power to be dissipated 10.2 kW
LARAMED: \(^{64}\text{Cu}/^{62}\text{Zn}\) tandem production, single

Mass flow=160l/h → fluid velocity on pipes=15m/s water inlet temperature=15°C
Total dissipated power=105kW

On fluid

On Cu surface: \(T_{\text{max}}=860\) C

On Au surface: \(T_{\text{max}}=920\) C

On Ni surface: \(T_{\text{max}}=1000\) C

On target
LARAMED: $^{64}\text{Cu}/^{62}\text{Zn}$ tandem production, two targets

$^1\text{Cu}$

$E_p=35$ MeV, 300 uA

Fluid: water
Mass flow=160 l/h

$^1\text{Cu}$ 2 mm
P = 6042 W

$^2\text{Ni}$ 0.52 mm
P = 3258 W

$^2\text{Cu}$ 1.5 mm
P = 550 W

$^2\text{Au}$ 1.5 mm
P = 650 W

$^2\text{Ni}, 530\text{C}$

$^2\text{Au}, 450\text{C}$

$^2\text{Cu}, 410\text{C}$

$T_{\text{max(Fluido)}}=45$ C
THANK YOU FOR YOUR ATTENTION!
And see you in Legnaro

Union of Compact Accelerator driven Neutron Source

Laboratori Nazionali di Legnaro
What would be LENOS?

- Neutron facility (irradiation, ? TOF ? )
- Based on a method for the production of different neutron spectra which avoid the use of moderators
  - Nuclear Astrophysics.
  - Validation of Evaluated Data for energy and non-energy applications.
  - Medical physics applications.
  - Radiation damage tests (SEE)
  - Material science physics (neutron imaging)