Transport System for Large objects at Ljubljana JSI TRIGA Reactor (part of WP15.5)

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TRIGA Mark II Reactor

- 1st criticality:
  - 31st May, 1966
- $P_{\text{max}}$
  - 250 kW (steady state)
  - 1 GW (pulse)
- Fuel
  - UZrH (12 wt. % U)
  - enrichment = 20 %
~91.44 cm (typ)

274.32 cm

365.76 cm.

6 ft. 6 in.

~ 487.68 cm

21 ft. 6 in.

8 ft. 2 in.

12 ft. 1.5 in.

Naris

AIDA2020, Bologna, 25/4/2018

M.Mikuž: JSI Irradiation Channel
New irradiation facility

- Steel shadow shield
- Aluminum casing
- Boral
- Polyethylene

Air
Graphite

243.84 cm Thermalizing column

Pool Irradiation Facility

274.32 cm

33.5°

35°

655.32 cm

690.88 cm

Piercing thruport 32.436 cm

Piercing thruport 101.60 cm

Radial piercing beam port

Aluminum casing

Boral

Lead

Shielding water

Reactor tank

Graphite thermal column

Core

Thermal column door

Thermal column door plug
TRIGA Irradiation Channels

Thermal Column

Reactor Vessel

Tangential Channel (TangCh)

Elevated Piercing Port (EPP)

Radial Beam Port (RBP)

Thermal Column Port (ThCol Port)

Radial Piercing Port (RPP)

Graphite Reflector

Reactor Core

Thermalizing Column

Dry Cell
Cherenkov in Action
Goal

- Develop and install a large sample irradiation (2R < 15 cm) facility in the tangential channel of the JSI TRIGA reactor
Transport system for neutron irradiation of large objects at JSI:

- In the framework of the AIDA-2020 project, Work Package 15 - Upgrade of beam and irradiation test infrastructure, a new irradiation device / transport system which will enable the irradiation of larger samples, up to 12 cm in diameter, has been installed in the Tangential Channel of the JSI TRIGA reactor in Ljubljana, Slovenia. This report documents the design and installation of the irradiation device / transport system.
3-d Modelling
Chronology

• Extraction of cold neutron source used in the past for neutron diffractometry
• Decontamination and inspection of channel interior

• Documentation required to obtain the authorization for the installation of the irradiation device from TRIGA Reactor Safety Committee and Slovenian Nuclear Safety Administration

• Authorization granted in August 2016
• Channel completed in October 2016
TRIGA reactor Tangential channel fitted with irradiation device

Detailed View

Neutron shield - borated polyethylene
Curved passage through neutron and gamma shield (8 cm × 1 cm)

Lead shield
Polyethylene sample holder
Aluminium liner

Outer channel segment
Diam: 20.3 cm

144.2 cm
229.3 cm
248.2 cm
385.2 cm
367 cm (distance to concrete plug at the opposite end)

Inner channel segment
Diam: 15.4 cm

Junction

Outer part, diameter = 20.3 cm
Inner part diameter = 15.4 cm

Junctions
Insertion Tube

- Aluminium liner with 14.6 cm inside diameter
- Protection of internal components
- Facilitates insertion and withdrawal of samples
Sample Support Structure

- Sample support structure made from PE100
- Support jig for sample should be custom made!
- Allows routing of cables to the sample
Shielding Plug

- Neutron shield made from borated polyethylene
- Gamma dose rate at surface of Pb ≈ mSv/h
- Concrete bricks
Plug Insertion

Neutron shield - removable curved insert

Tangential Channel port

Passage through neutron and gamma shield - cables / coolant lines can be fed through easily
Channel Closed
Channel Characteristics

• Inner diameter: 14 cm

• Neutron flux characterisation:

• Predicted neutron flux: $1.3 \times 10^{12}$ n/cm$^2$s
  – Thermal (E<0.625 eV): 58 %
  – Epithermal (0.625 eV < E < 100 keV): 25 %
  – Fast ( E > 100 keV): 17 % -> $2.3 \times 10^{11}$ n/cm$^2$s

• $1 \times 10^{15}$ $n_{eq}$/cm$^2$ in 1 ½ hours
Neutron Spectra

- Central channel (CC)
- Radial piercing port (RPP)
- Radial beam port (RBP)
- Tangential channel (TangCh)
- Thermalizing column (ThCol)

Neutron energy [MeV]

Lethargy spectrum (from F4 tally)

Thermal, Epi-thermal, Fast

Tangential channel
Predicted Fluxes

- Thermal neutrons <0.625 eV
- Epithermal neutrons 0.625 eV – 0.1 MeV
- Fast neutrons > 0.1 MeV

<table>
<thead>
<tr>
<th></th>
<th>$\Phi_{th}(10^{12}\text{cm}^{-2}\text{s}^{-1})$</th>
<th>$\Phi_{epi}(10^{12}\text{cm}^{-2}\text{s}^{-1})$</th>
<th>$\Phi_{fast}(10^{12}\text{cm}^{-2}\text{s}^{-1})$</th>
<th>$\Phi_{tot}(10^{12}\text{cm}^{-2}\text{s}^{-1})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>small channel (F19)</td>
<td>3.66</td>
<td>1.86</td>
<td>1.81</td>
<td>7.32</td>
</tr>
<tr>
<td>large channel (TIC)</td>
<td>4.46</td>
<td>3.45</td>
<td>3.85</td>
<td>11.7</td>
</tr>
<tr>
<td>Tang. Ch.</td>
<td>0.75</td>
<td>0.33</td>
<td>0.23</td>
<td>1.31</td>
</tr>
</tbody>
</table>

Agreement with measurements in small channel within 10 %
Flux Along Channel

Tangential Channel

Distances from channel midpoint:
- 5cm
- 15cm
- 25cm
- 35cm
- 45cm

Lethargy spectrum (rel. units)

Neutron Energy [MeV]
Neutron Flux Measurement

Al-0.1% Au foil

Au197(n,g) RR = 2.01E-12 s⁻¹ (unc.: 2.7%)
Flux @ 2.5 kW = 2.65E10 n cm⁻² s⁻¹
Flux @ 250 kW = 2.65E12 n cm⁻² s⁻¹

5 cm

Au197(n,g) RR = 2.03E-12 s⁻¹ (unc.: 2.7%)
Flux @ 2.5 kW = 2.67E10 n cm⁻² s⁻¹
Flux @ 250 kW = 2.67E12 n cm⁻² s⁻¹

5 cm

Au197(n,g) RR = 1.94E-12 s⁻¹ (unc.: 2.7%)
Flux @ 2.5 kW = 2.56E10 n cm⁻² s⁻¹
Flux @ 250 kW = 2.56E12 n cm⁻² s⁻¹

10 cm

Al-0.1% Au foil + PIN diode

Peak position - highest measured gamma flux
Neutron Flux

• Flux measured by Au 197(n,γ)
  – measures (mostly) thermal flux
  – scaled by simulated spectrum to total flux

• Au - measured total flux 2.67e12 n/cm²s
  – uniformity < 10 % on 10 cm x 10 cm

• PIN - measured NIEL flux 3.9e11 n/cm²s
  – NIEL hardness factor for total spectrum 0.146
  – hardness factor for $E_n > 0.1$ MeV: 0.83

• Twice the predicted value!
Gamma Flux

- Measured gamma flux profile
- Dose rate several 10 kGy/h
- Resulting in several kGy for $10^{14} \text{n}_{\text{eq}} \text{cm}^{-2}$
1st Irradiations

- ATLAS - silicon wafers (DESY)
  - thermo-mechanical studies (2e15 n/cm²)
- Atlas Tile calorimeter upgrade
  - shaper/digitizer card (8e12 n/cm²)
More Kids on the Block

• CMS calorimeter upgrade – Si sensors
  – hexagonal sensor coming from an 6” wafer with the dimensions of 12.6 x 13.6 cm (and a thickness of 320micron)
  – 18 sensors, 2 pieces each of 3 types and 3 fluences (2*3*3)
  – up to 1e15 n/cm²

• ATLAS full sensor QA
  – square sensors out of 6” wafers
  – up to 2e15 n/cm²
Summary

• New irradiation facility at JSI reactor installed and commissioned
  – measurements indicate 2x predicted flux wrt. core simulation predictions
• Allows irradiation of ~12 x 20 cm samples
  – services possible
• $10^{15} \, n_{eq} \, cm^{-2}$ in less than one hour
• First customers served, more in the pipeline
  – limited AU still available