ENEEP Member: Jožef Stefan Institute

Synthesis of implementation workflow and conditions for novel activities

February 2024

Contents

1. Administrative procedure

The administrative procedure in place at the JSI for the implementation of new experimental activities at the JSI TRIGA reactor is based on activity-specific work orders.

A work order is prepared in which the proposed activity is described in detail, including the motivation, review of the past experience, relevant technical information (blueprints, critical dimensions, experimental conditions, etc.), required experimental equipment and required training for personnel for the implementation itself and for subsequent activities. In the work order it is required to define the estimated production of additional radioactive waste due to the new experimental activity.

In the work order, the implementation procedure is described and subdivided into specific phases. For each phase, the phase supervisor and the personnel involved are stated, as well as any specific operating limits or conditions.

The administrative procedure is initiated on the following conditions:

- Submission of all required documentation pertaining to the implementation, prepared in accordance with JSI quality assurance (QA) requirements and the legislation.
- Work-order specific procedure for inspection and handling of possibly contaminated components.
- Radioactive waste treatment and disposal.

The work order undergoes a review procedure, outlined in the flowchart displayed in Figure 1.

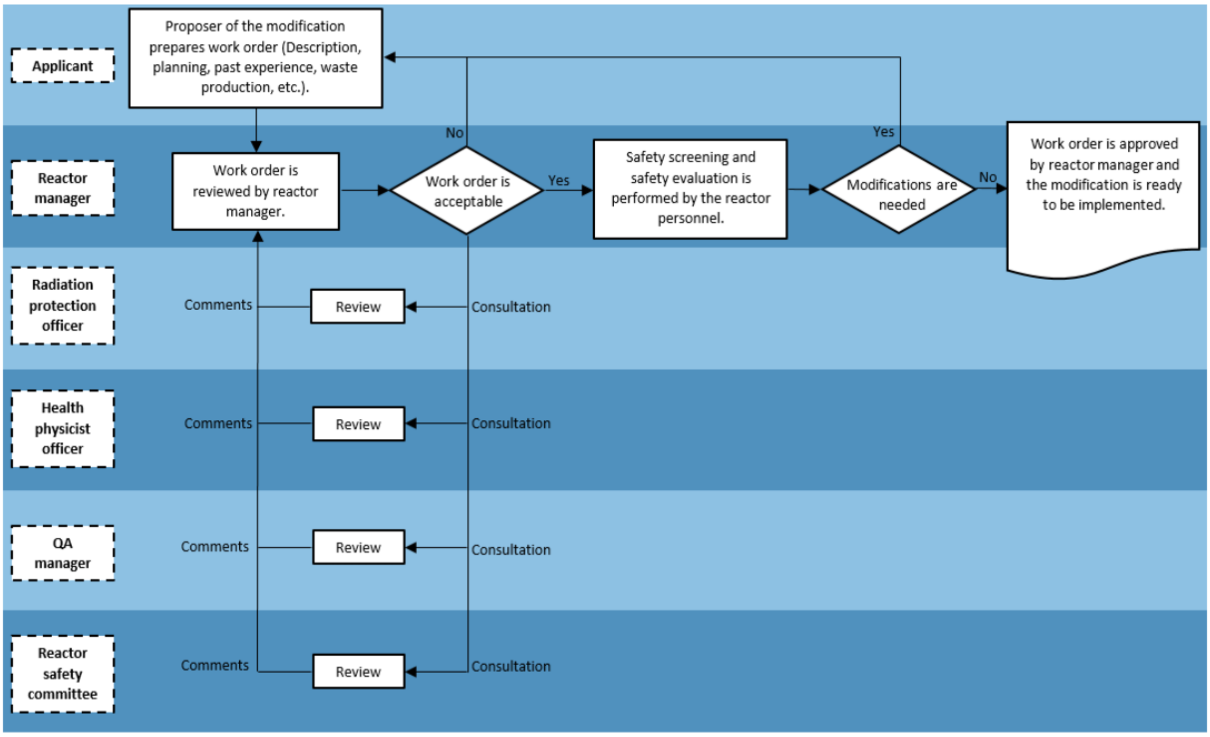


Figure 1: Work order review procedure in place at the JSI.

The implementation is authorized on the basis of the acceptance of the work order and a positive safety screening result. The implementation is documented phase by phase.

2. Operating limits and conditions for irradiations

2.1. Reactivity limits

- The maximum allowable reactivity effect of an irradiated sample is 0.25 $.
- The maximum allowable static reactivity effect of a single experiment is 2.5 $.
- The maximum allowable dynamic reactivity effect of a single experiment is limited to 1.0 $.
- The maximum allowable static reactivity effect of all installed experiments is 3.0 $.

2.2. Maximum allowed dose rates for sample irradiations

The dose rate at a distance of 1 m away from the bare sample should not exceed 10 mSv/h.

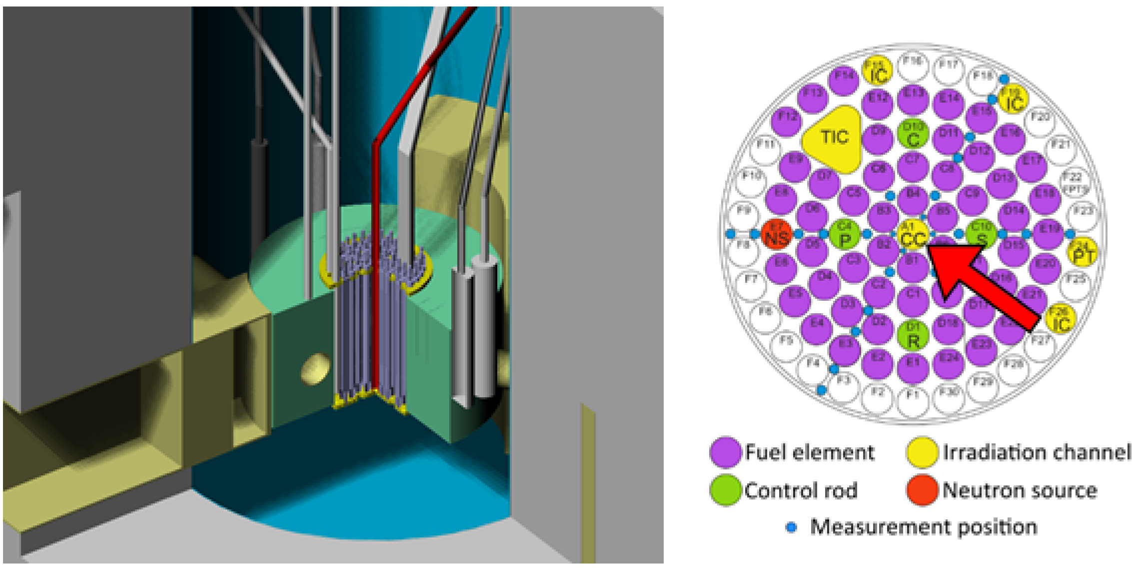
2.3. Limitations on materials

- Materials that are corrosive to the reactor components, react violently with water, are potentially explosive, and fissile materials in liquid form, can be irradiated only under gas-tight encapsulation.
- Every experiment containing fissile material (^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu) has to be supervised. The maximum allowable quantity of fissile material is limited to 30 mg, unless it is proven that in case of failure, the doses received by the operating staff do not exceed the yearly limit set by national legislation.
- Explosive materials like gun powder, nitro-glycerine, TNT etc. are limited to 25 mg. Irradiations can be carried out using special capsules proven to withstand detonation.
- Material quantities are limited. In case of radioactivity release into the reactor hall, the doses received by the operating staff must not exceed the yearly limit set by national legislation.

3. Technical data

The JSI TRIGA reactor features several irradiation facilities / environments. This section presents the most important characteristics, i.e. the thermal, epithermal, fast, total, and 1 MeV silicon equivalent neutron flux levels at full reactor power (250 kW), the facility dimensions and other relevant features.

3.1. Central Channel



(a) (b)

Figure 2: (a) 3D representation of the Central Channel in the JSI TRIGA reactor (in red). (b) Core configuration with the position of the Central Channel indicated.

Table 1: Neutron flux data in central channel

Energy Range	Neutron Flux [$cm^{-2}s^{-1}$]
Thermal (< 0.625 eV)	$5.11 \cdot 10^{12}$
Epithermal (0.625 – 10^5 eV)	$6.50 \cdot 10^{12}$
Fast ($> 10^5$ eV)	$7.59 \cdot 10^{12}$
Total	$1.92 \cdot 10^{13}$
1 MeV equivalent	$5.5 \cdot 10^{12}$

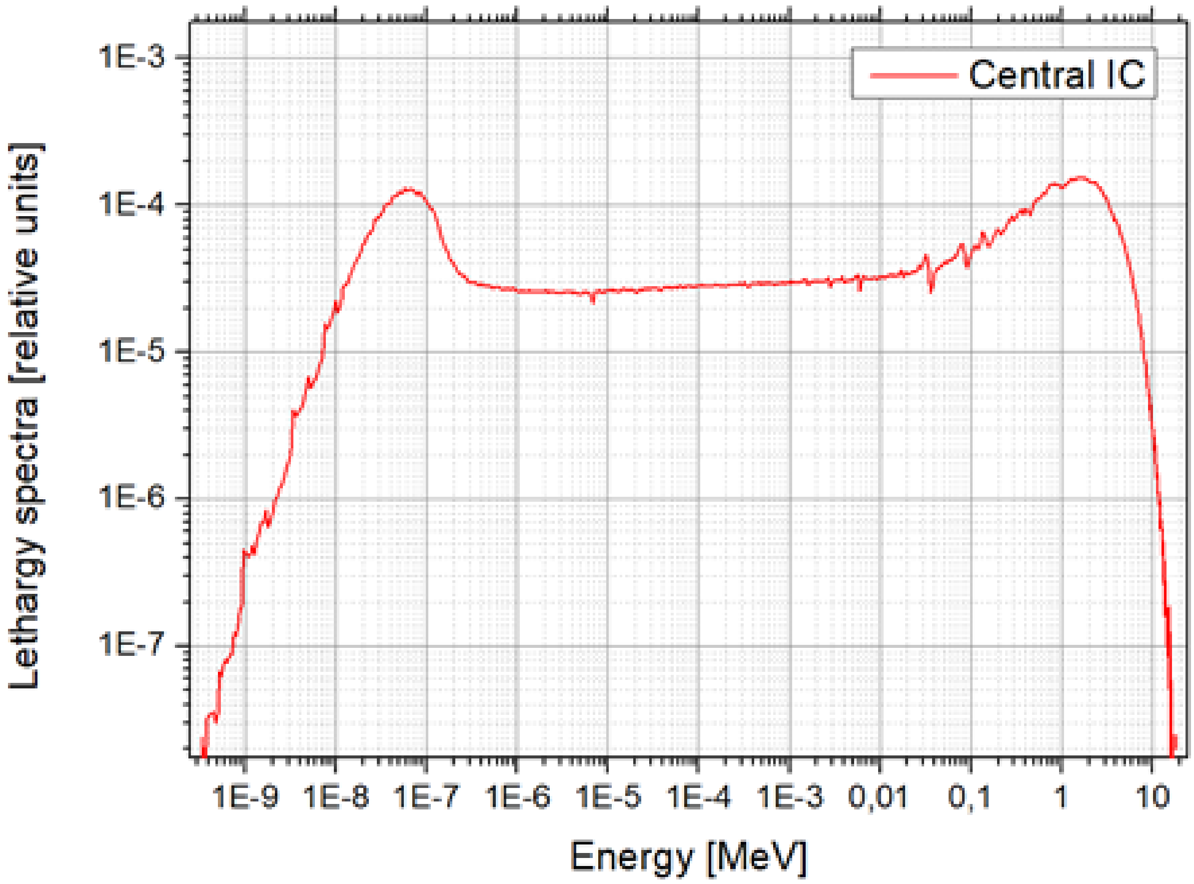
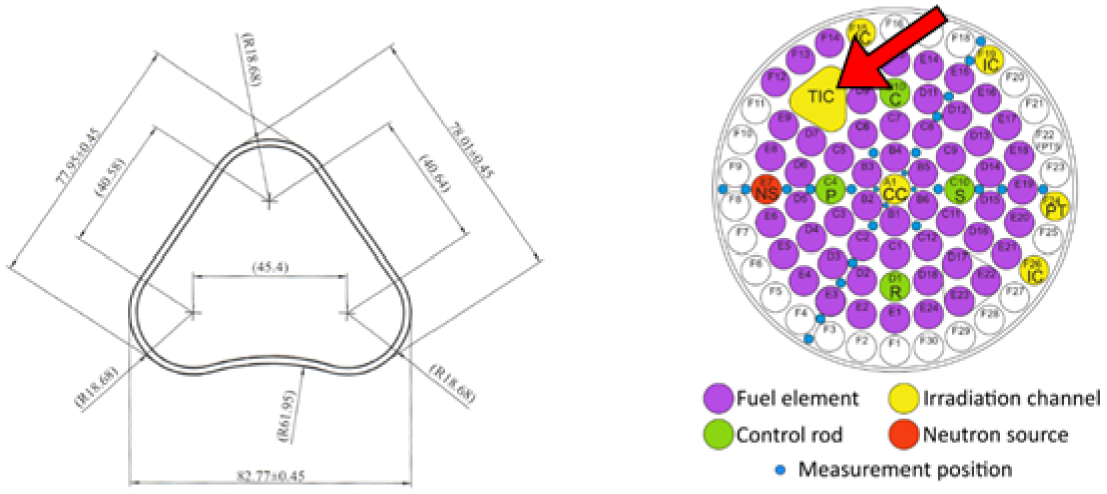


Figure 3: Neutron spectrum in the central channel.

Features:

- dry tube, can be replaced by flooded tube,
- 3 cm in diameter, 20 cm high,
- possibility for on-line measurements.

3.2. Triangular Channel



(a) (b)

Figure 4: (a) Diagram of the Triangular Channel section (dimensions stated in mm). (b) Core configuration with the position of the Triangular Channel indicated.

Table 2: Neutron flux data in triangular channel

Energy Range	Neutron Flux [cm^{-2}s^{-1}]
Thermal (< 0.625 eV)	$4.5 \cdot 10^{12}$
Epithermal (0.625 – 10^5 eV)	$3.5 \cdot 10^{12}$
Fast (> 10^5 eV)	$3.8 \cdot 10^{12}$
Total	$1.2 \cdot 10^{13}$
1 MeV equivalent	$3.57 \cdot 10^{12}$

Features:

- dry tube,
- maximal diameter $\sim$ 5 cm, 20 cm in height.
- occupies three fuel element positions in the reactor core,
- possibility for on-line measurements.

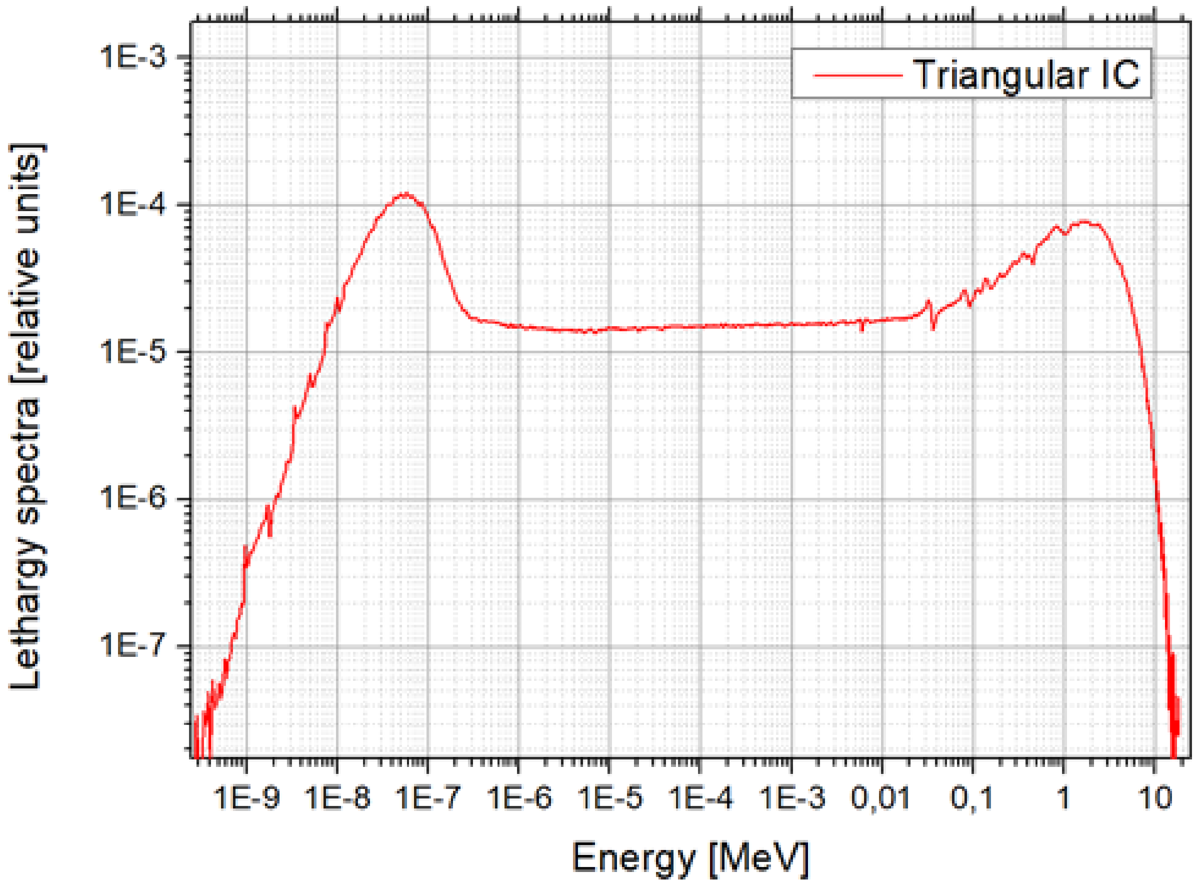
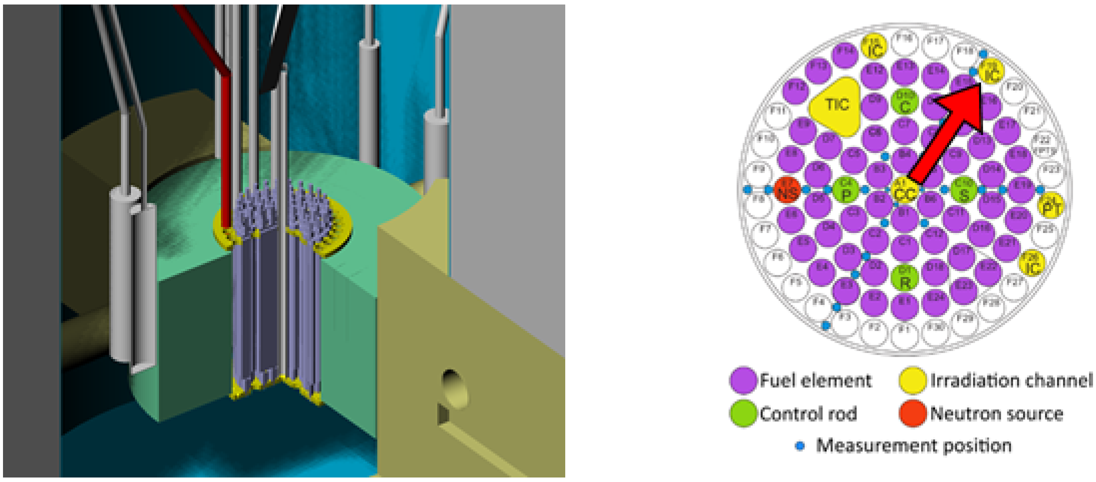


Figure 5: Neutron spectrum in the triangular channel.

3.3. F-19 Channel



(a) (b)

Figure 6: (a) 3D representation of the F-19 Channel in the JSI TRIGA reactor (in red). (b) Core configuration with the position of the F19 Channel indicated.

Table 3: Neutron flux data in F-19 channel

Energy Range	Neutron Flux [$cm^{-2}s^{-1}$]
Thermal (< 0.625 eV)	$3.66 \cdot 10^{12}$
Epithermal (0.625 – 10^5 eV)	$1.86 \cdot 10^{12}$
Fast (> 10^5 eV)	$1.81 \cdot 10^{12}$
Total	$7.33 \cdot 10^{12}$
1 MeV equivalent	$1.54 \cdot 10^{12}$

Features:

- dry tube,
- 3 cm in diameter, 20 cm in height,
- possibility for on-line measurements.

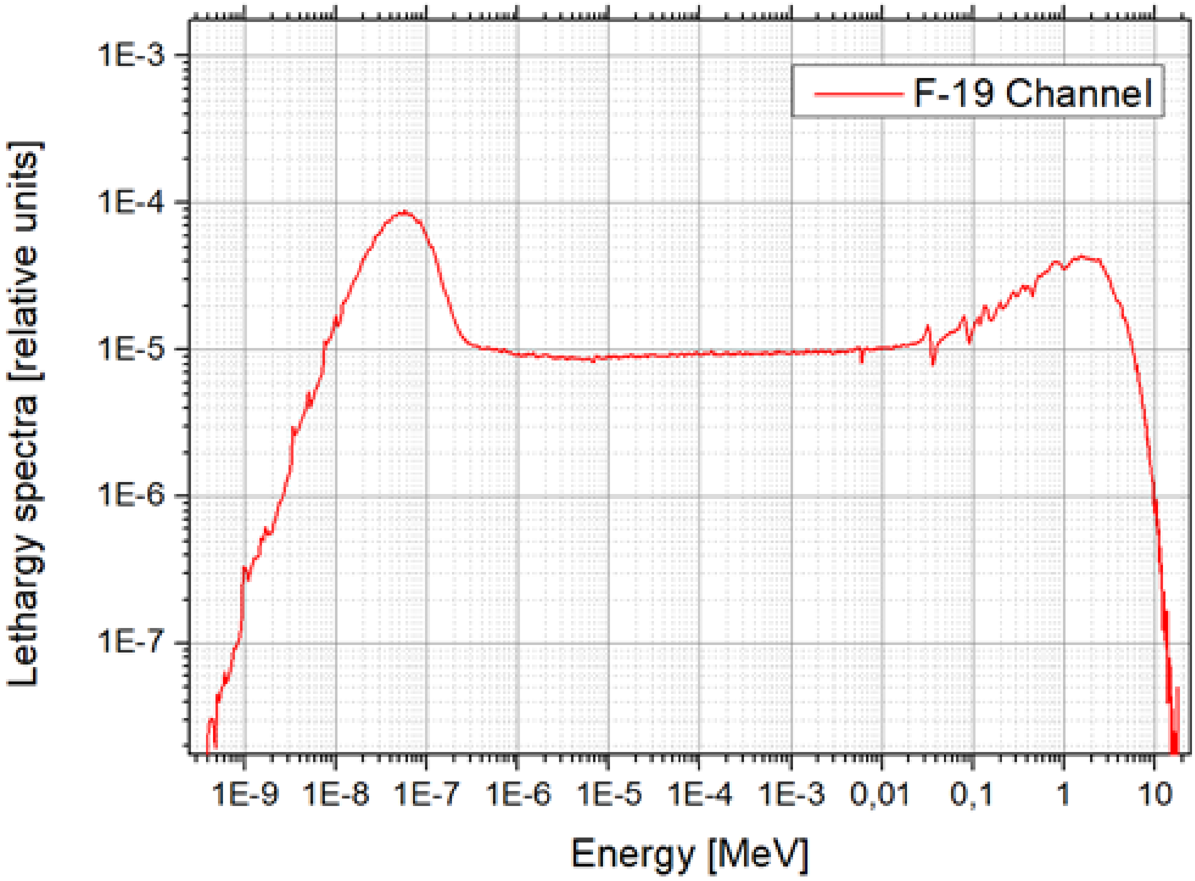
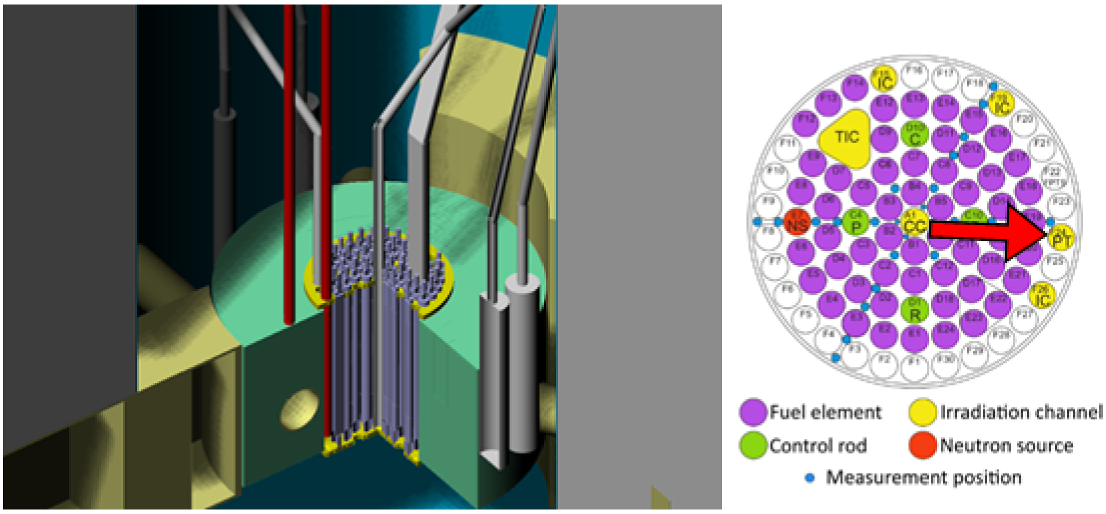


Figure 7: Neutron spectrum in the F-19 channel.

3.4. F-24 Pheumatic Transfer System



(a) **(b)**

Figure 8: (a) 3D representation of the F-24 Pneumatic Transfer System in the JSI TRIGA reactor (in red). (b) Core configuration with the position of the F-24 Pneumatic Transfer System indicated.

Table 4: Neutron flux data in F-24 channel

Energy Range	Neutron Flux [$cm^{-2}s^{-1}$]
Thermal (< 0.625 eV)	$3.29 \cdot 10^{12}$
Epithermal (0.625 – 10^5 eV)	$1.84 \cdot 10^{12}$
Fast ($> 10^5$ eV)	$1.81 \cdot 10^{12}$
Total	$6.94 \cdot 10^{12}$

Features:

- dry tube equipped with pneumatic transfer system. Samples are inserted and retrieved in the reactor basement or in the radiochemistry laboratory,
- 2 cm in diameter, 5 cm in height,
- maximal irradiation time: 3 h.

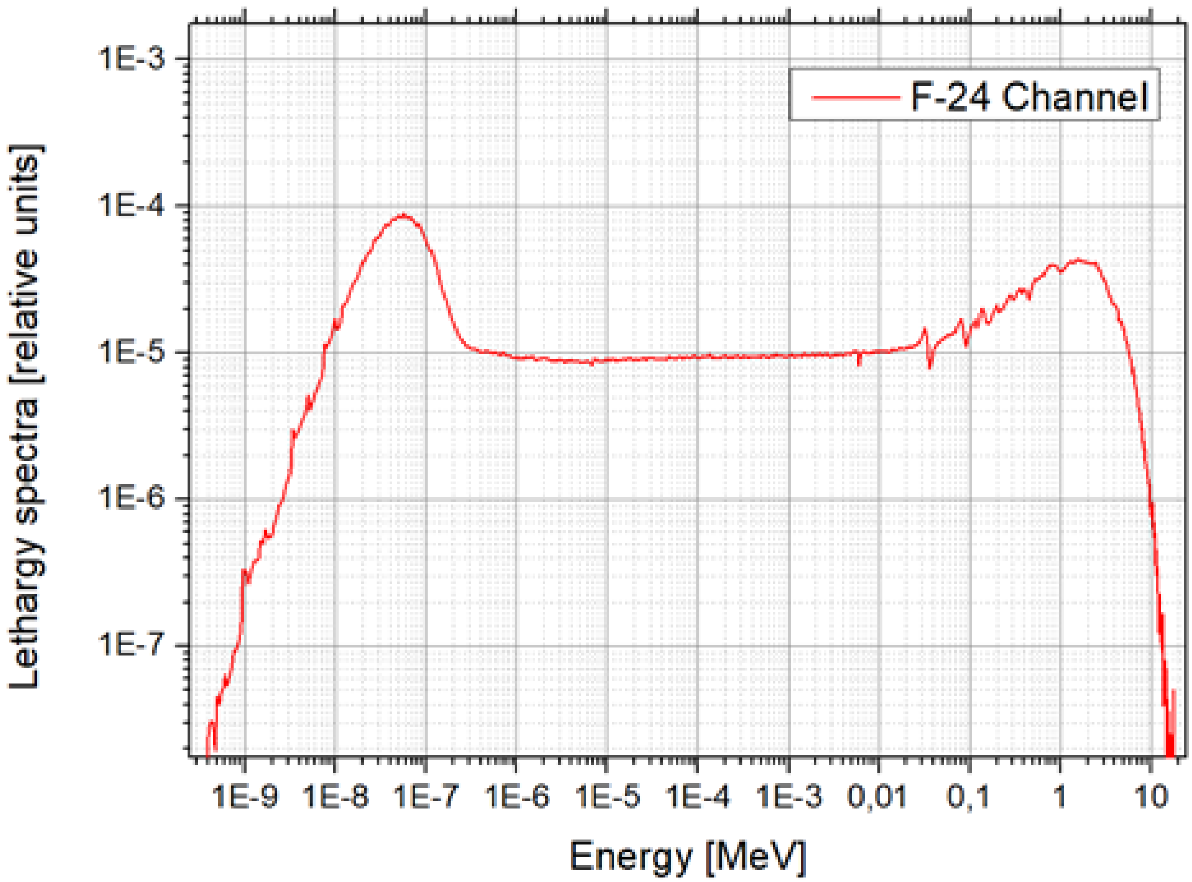


Figure 9: Neutron spectrum in the F-24 channel.

3.5. Carousel

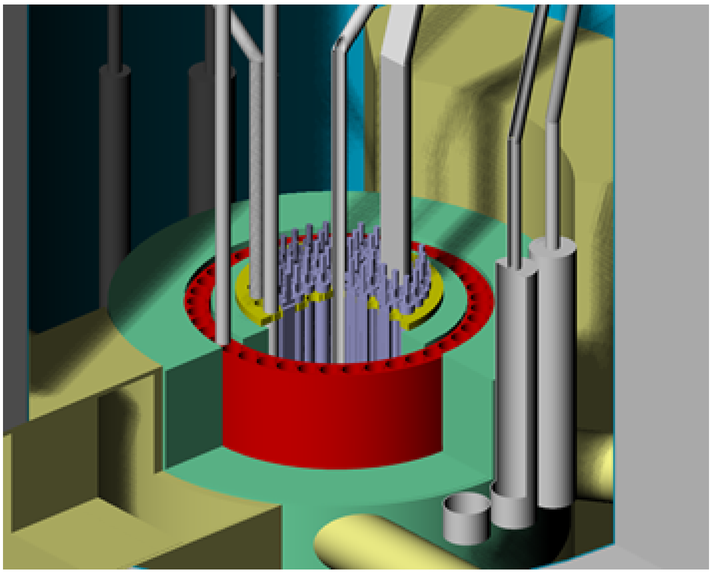


Figure 10: 3D representation of the Carousel in the JSI TRIGA reactor (in red).

Table 5: Neutron flux data in carousel

Energy Range	Neutron Flux [cm^{-2}s^{-1}]
Thermal (< 0.625 eV)	$1.26 \cdot 10^{12}$
Epithermal (0.625 – 10^5 eV)	$5.24 \cdot 10^{11}$
Fast (> 10^5 eV)	$3.03 \cdot 10^{11}$
Total	$2.09 \cdot 10^{12}$

Features:

- 40 irradiation locations,
- can be rotated around the core during irradiation,
- pneumatic transfer system can send samples to the hot cell after irradiation.

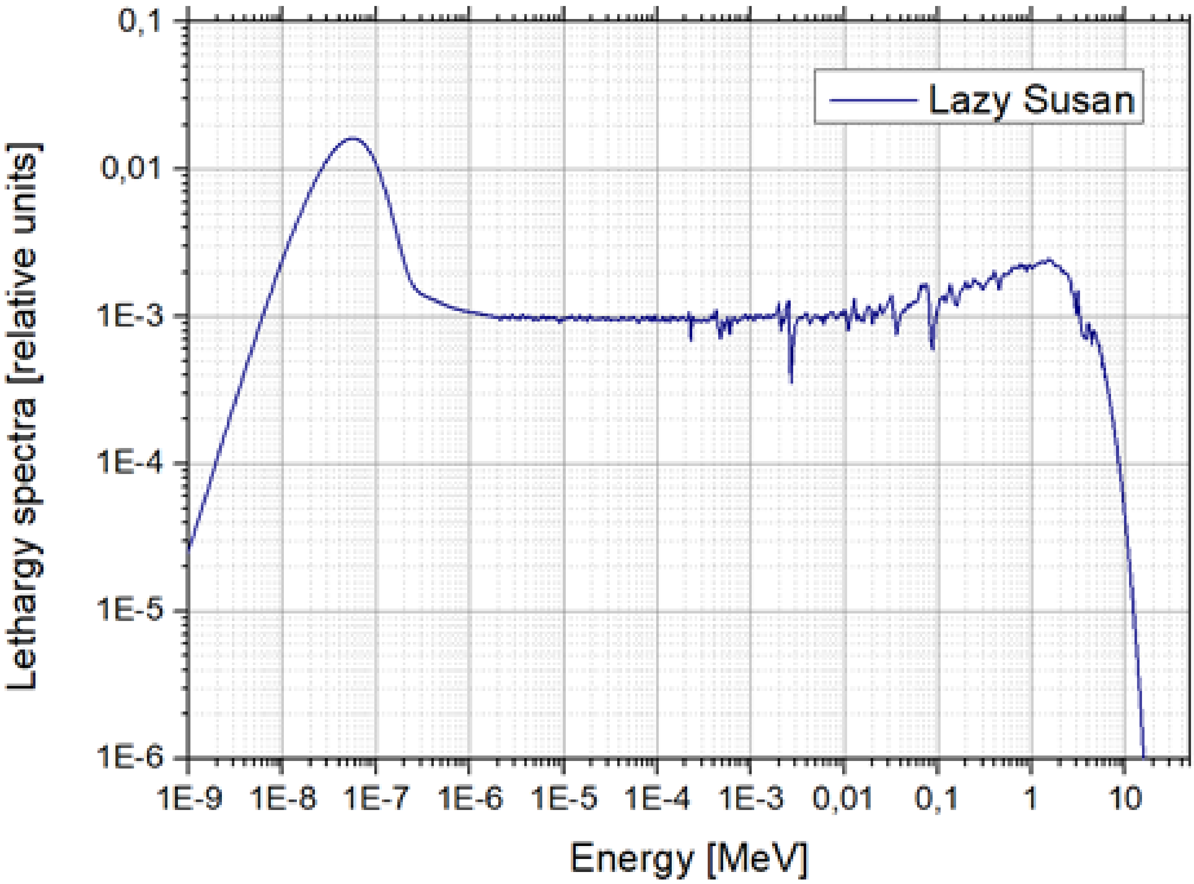


Figure 11: Neutron spectrum in the carousel.

3.6. Standard irradiation capsules

Figure 12: Aluminium capsule

Diameter	2.3 cm
Height	8.0 cm
Material	Aluminium
Irradiation channels	Central Channel F-19 Channel Carousel

Figure 13: Plastic tube

Diameter	1.9 cm
Height	10.5 cm
Material	PET
Irradiation channels	Central Channel F-19 Channel

Figure 14: Pneumatic Transfer System capsule

Diameter	2.0 cm
Height	5.5 cm
Material	PET
Irradiation channel	F-24

3.7. Dry Chamber

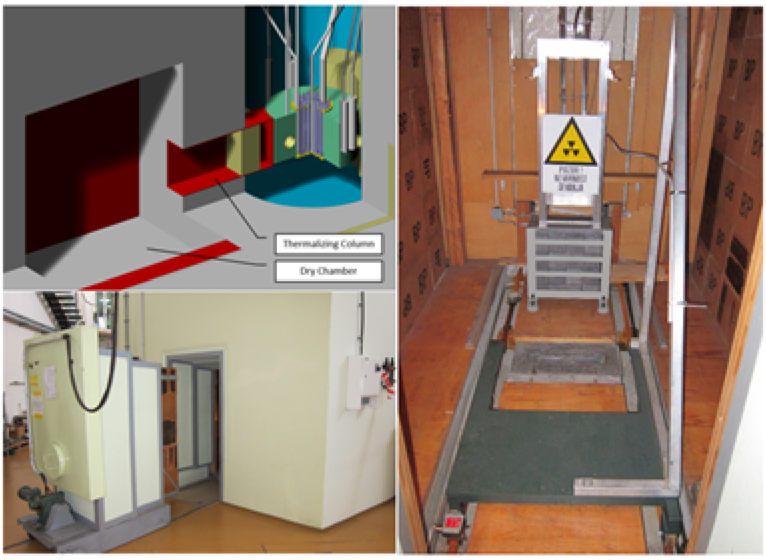


Figure 15: Top left: 3D representation of the Dry Chamber in the JSI TRIGA reactor (in red). Bottom left and right (respectively): photographs of the entrance to the Dry Chamber from the reactor hall and the Dry Chamber interior.

Table 6: Neutron flux data in dry chamber

Energy Range	Neutron Flux [cm^{-2}s^{-1}] no fission plate	Neutron Flux [cm^{-2}s^{-1}] fission plate installed
Thermal (< 0.625 eV)	$8.8 \cdot 10^7$	$8.3 \cdot 10^7$
Epithermal (0.625 – 10^5 eV)	$2.6 \cdot 10^7$	$2.9 \cdot 10^7$
Fast (> 10^5 eV)	$1.7 \cdot 10^7$	$9.5 \cdot 10^7$
Total	$1.3 \cdot 10^8$	$2.1 \cdot 10^8$

Features:

- possibility of irradiation of larger objects,
- neutron beam cross section of approximately 60 cm $\times$ 60 cm,
- possibility of using a U-235 fission plate enabling the introduction of a fission spectrum component to the neutron field,
- a special trolley can be used to introduce samples inside the thermalizing column, a graphite column connecting the Dry Chamber and the reactor core),
- smaller samples can be inserted using a rail connecting the Dry Chamber to the reactor platform,
- possibility for on-line measurements.

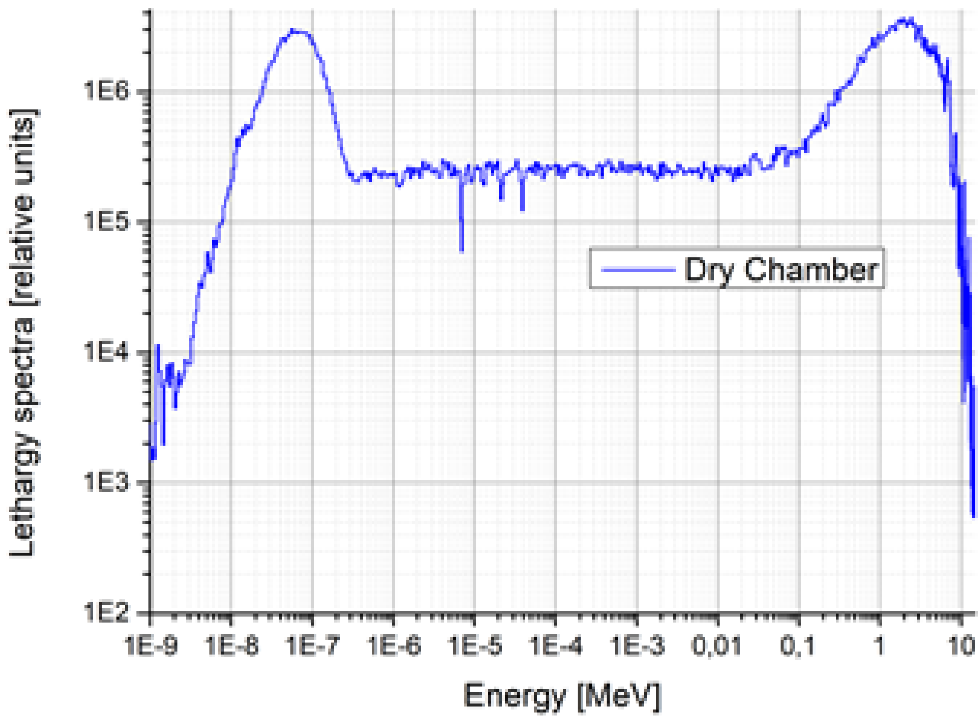
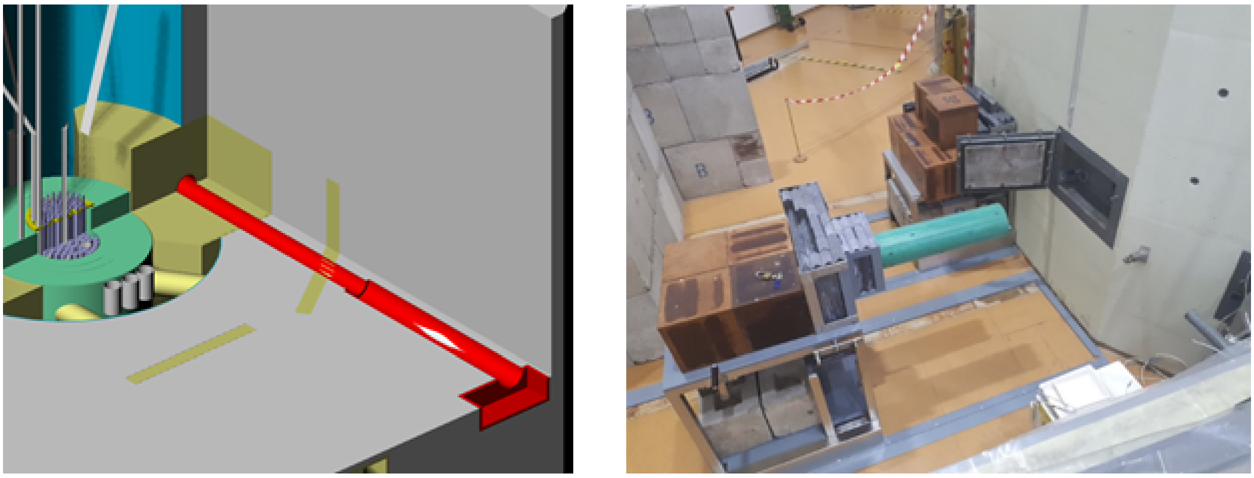


Figure 16: Neutron spectrum in the dry chamber.

3.8. Beam Port No. 5



(a) (b)

Figure 17: (a) 3D representation of the Beam Port No. 5 in the JSI TRIGA reactor (in red). (b) Photograph of the Beam Port No. 5 including a specifically designed neutron and gamma shield enabling sample irradiations.

Table 7: Neutron flux data in beam port No. 5

Energy Range	Neutron Flux [cm^{-2}s^{-1}]
Thermal (< 0.625 eV)	$4.99 \cdot 10^{10}$
Epithermal (0.625 – 10^5 eV)	$1.45 \cdot 10^{9}$
Fast (> 10^5 eV)	$3.23 \cdot 10^{8}$
1 MeV equivalent	$3.00 \cdot 10^{8}$
Total	$5.17 \cdot 10^{10}$

Features:

- special mechanism installed that allows irradiation of samples,
- special holder designed for the samples; 14 cm in diameter, 75 cm in length,
- possibility for on-line measurements.

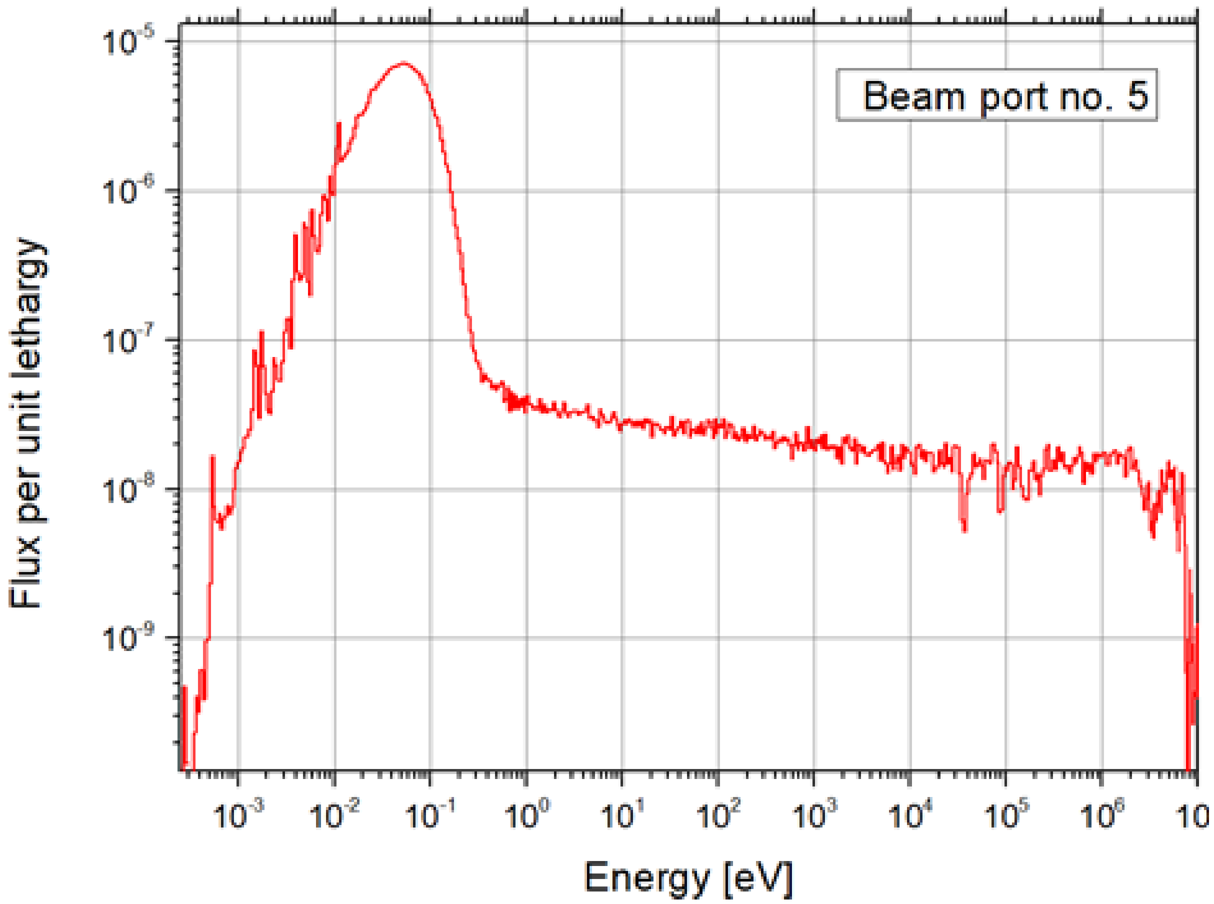


Figure 18: Neutron spectrum in the beam port No. 5.

3.9. Beam Port No. 6

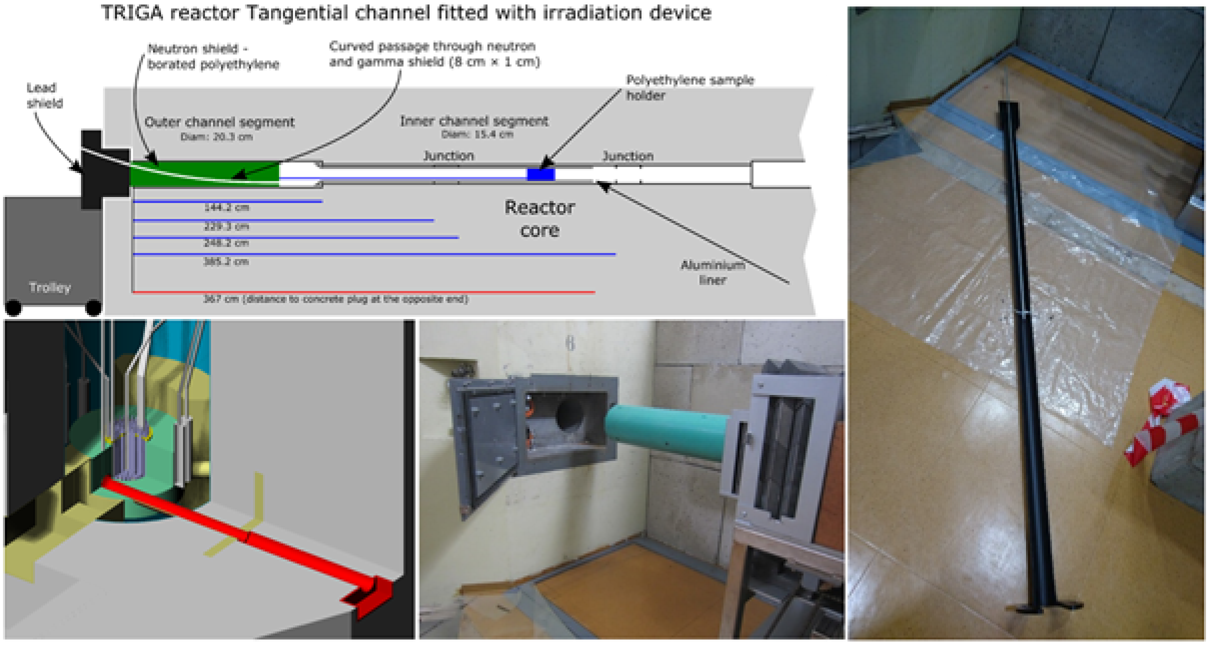


Figure 19: Left (top and bottom): Schematic and 3D representations of the Beam Port No. 6 in the JSI TRIGA reactor. Bottom middle and right (respectively): Photographs of the Beam Port No. 5 entrance, and a sample holder for sample irradiation.

Table 8: Neutron flux data in beam port No. 6

Energy Range	Neutron Flux [cm^{-2}s^{-1}]
Thermal (< 0.625 eV)	$7.54 \cdot 10^{11}$
Epithermal (0.625 – 10^5 eV)	$3.25 \cdot 10^{11}$
Fast (> 10^5 eV)	$2.260 \cdot 10^{11}$
Total	$1.305 \cdot 10^{12}$
1 MeV equivalent	$3.9 \cdot 10^{11}$

Features:

- special mechanism installed that allows irradiation of samples,
- special holder designed for the samples; 14 cm in diameter, 25 cm in length,
- possibility for on-line measurements.

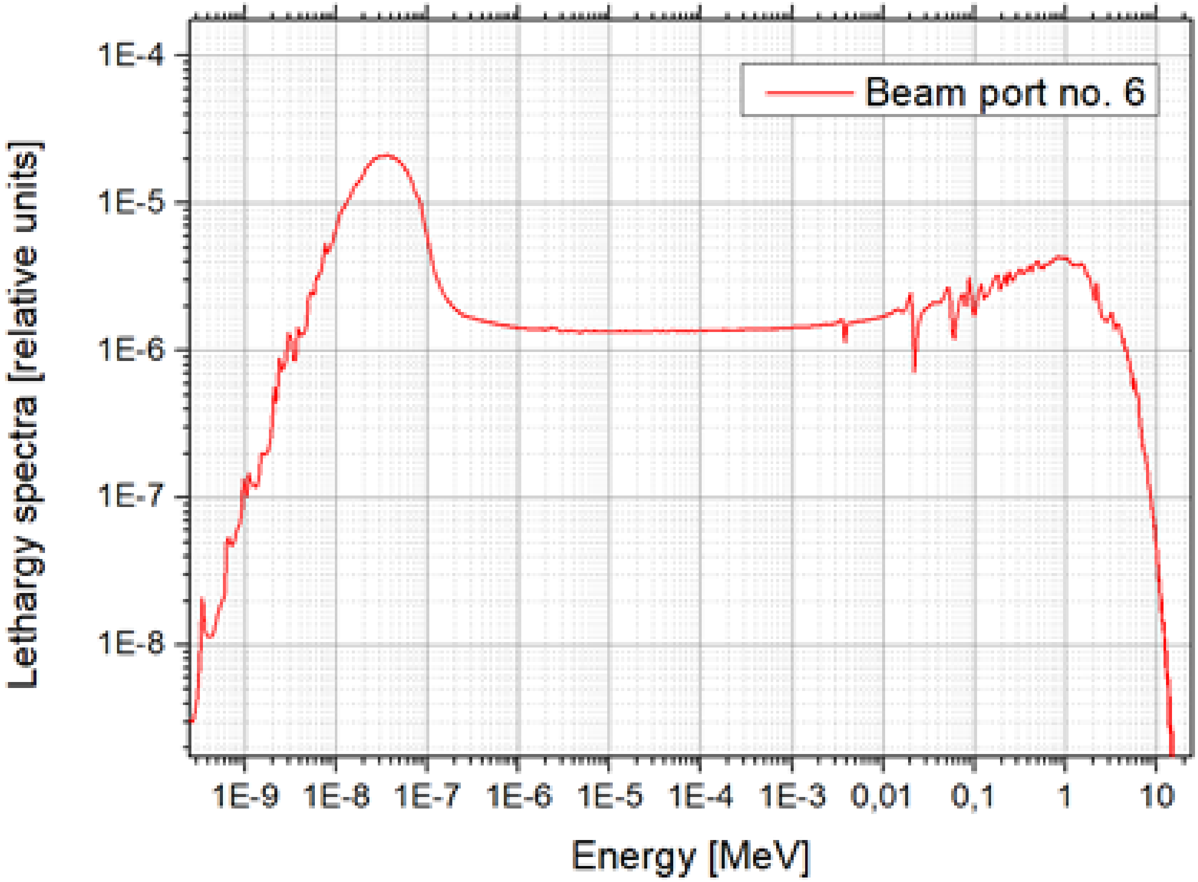


Figure 20: Neutron spectrum in the beam port No. 6.

3.10. Thermal Column

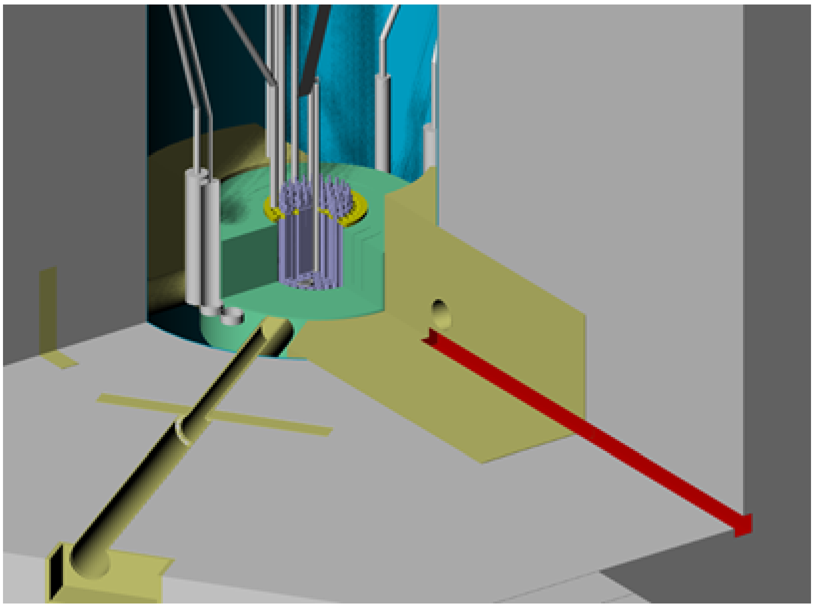


Figure 21: 3D representation of the Thermal Column in the JSI TRIGA reactor (in red).

Table 9: Neutron flux data in thermal column

Energy Range	Neutron Flux [cm^{-2}s^{-1}]
Thermal (< 0.625 eV)	$1.94 \cdot 10^9$
Epithermal (0.625 – 10^5 eV)	$3.53 \cdot 10^8$
Fast (> 10^5 eV)	$1.615 \cdot 10^8$
Total	$2.454 \cdot 10^9$

Features:

- highly thermalized neutron spectrum,
- additional D_2O filled capsules can be installed to improve neutron thermalization,
- square, 10 cm × 10 cm cross section.

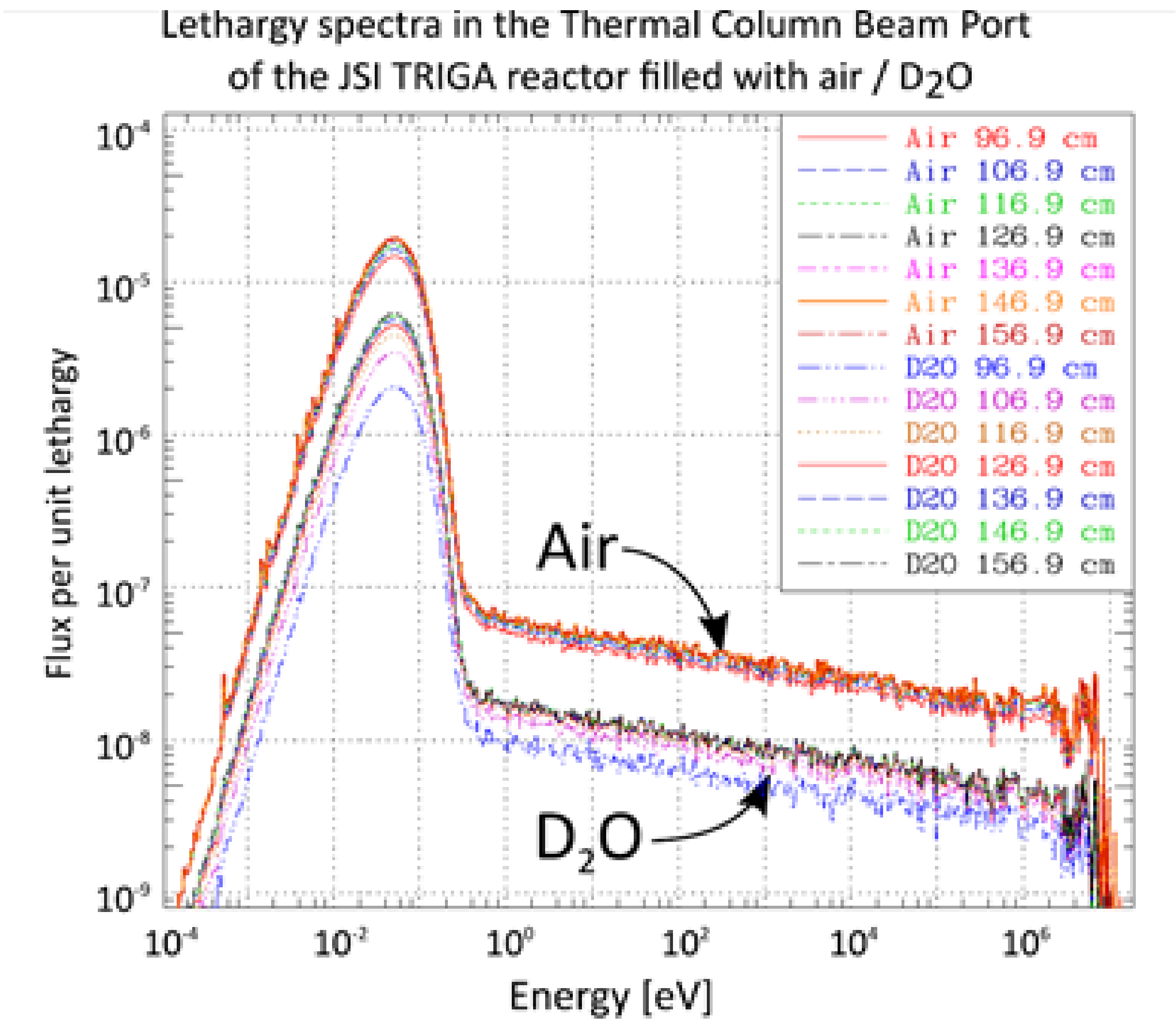


Figure 22: Neutron spectrum in the thermal column.