# Neutron Facilities & Main Acivities at LENA –
## Laboratory of Applied Nuclear Energy of Pavia University

Laboratorio Energia Nucleare Applicata
*Università degli Studi di Pavia*

**Michele PRATA**

Helium Replacement in Italy – 2nd - 3rd December 2013
ENEA Centro Ricerche Frascati

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# University of Pavia

## Universitas Studiorum

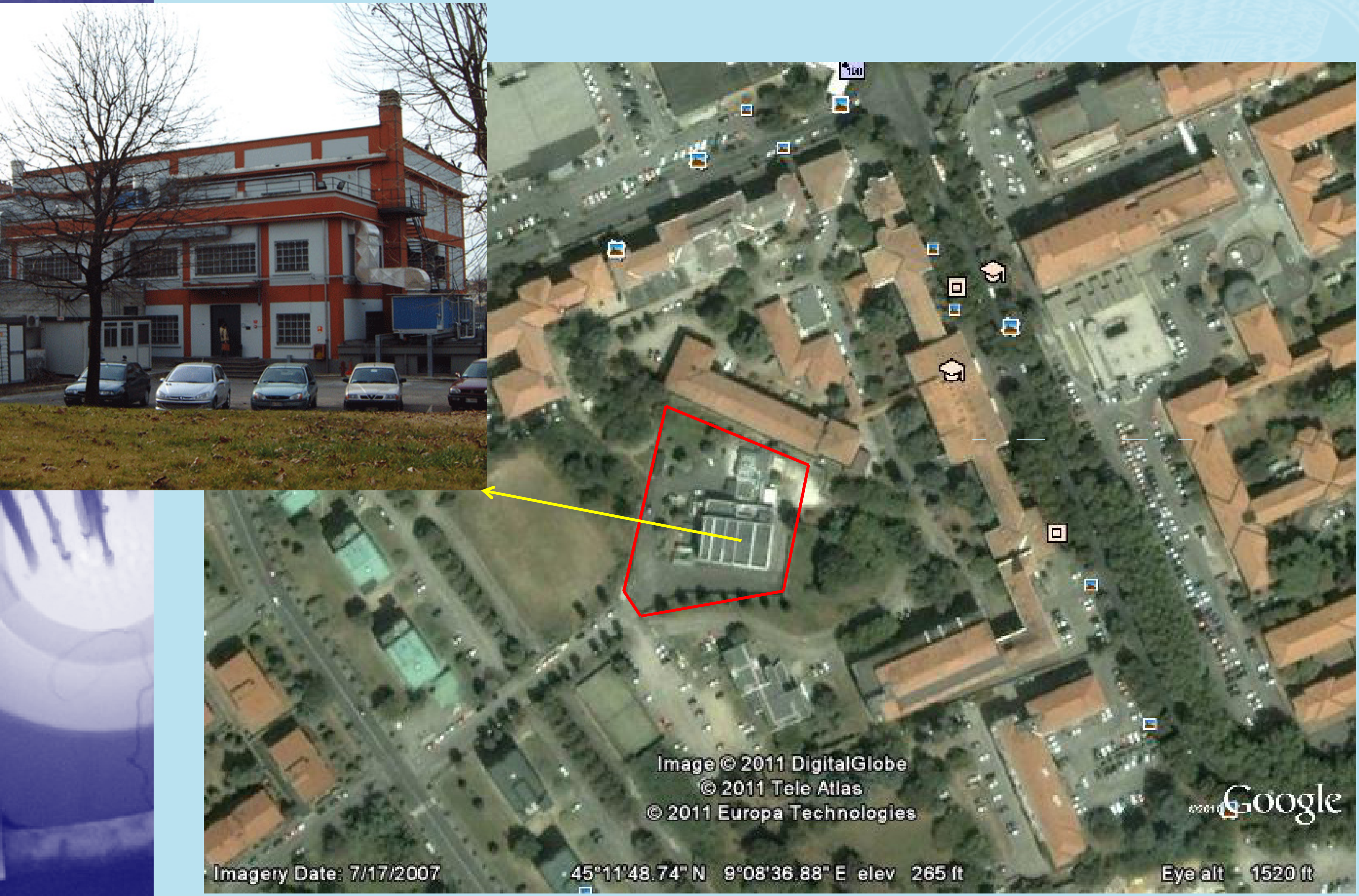
*....since 1361*

- ✓ one of the oldest universities in Europe
- ✓ officially established as a Studium Generale by Emperor Charles IV in **1361**
- ✓ In 2011 celebrated its 650th year

- ✓Alessandro Volta (1745-1827, inventor of the battery)
- ✓Camillo Golgi (1843-1926, physician and pathologist )
- ✓Girolamo Cardano (1501-1576, known for the invention of the “cardan joint” mechanism)
- ✓ Antonio Scarpa (1752-1832, anatomist)
- ✓Carlo Rubbia (physicist, Nobel Prize)

are just a few of a large group of famous professors who taught at the University of Pavia.

# LENA – Interdepartmental Service Center



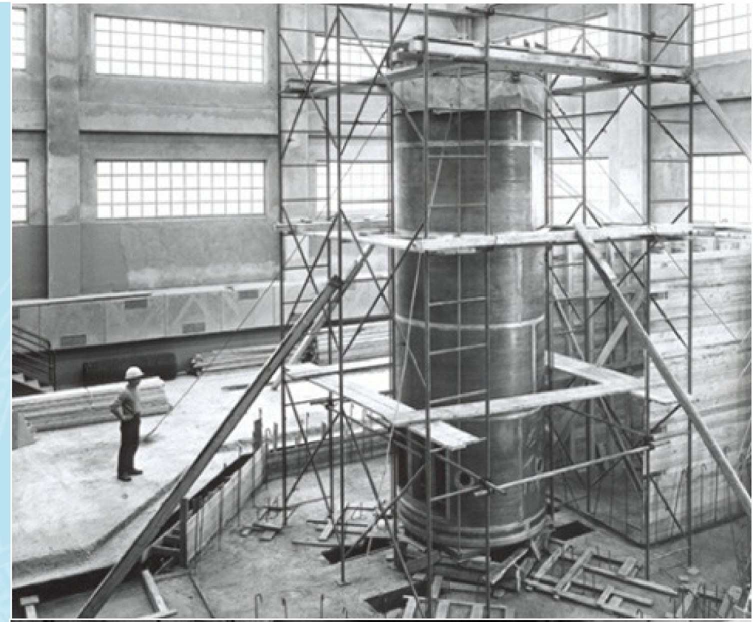
# LENA *from the beginning …*

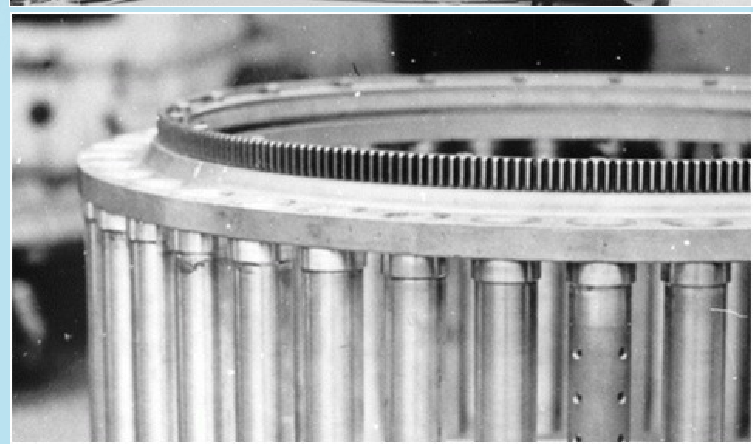
The reactor reached its first criticality on November,15th 1965 and was officially inaugurated on December 16th 1966.

<u>After the first 40 years</u> of operation, an official report of 2005 reported a list of <u>**600 publications**</u> related to research conducted with the reactor in different areas:

- ✓Nuclear Chemistry and Radiochemistry,
- ✓Activation Analysis
- ✓Basic Chemistry
- ✓Nuclear Physics
- ✓Reactor Physics
- ✓Dosimetry

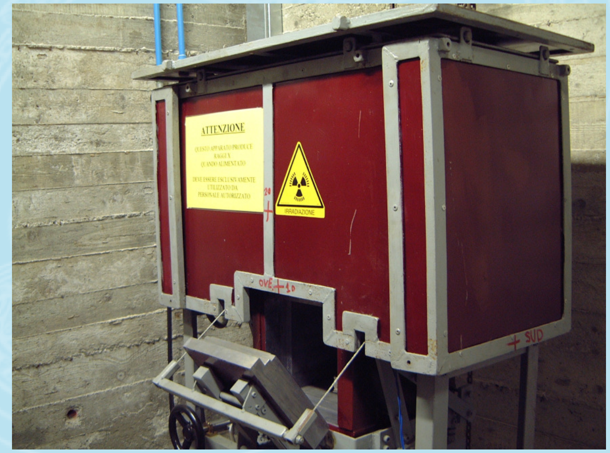
The reactor is still in excellent condition and is used almost daily for research activities.





# Main Facilities

- 250 kW TRIGA Mk II Research Reactor
- X ray industrial generator
  - 250 kV, 12 mA dose rate 15.6 Gy/min
  - 350 kV, 6 mA dose rate 17.5 Gy/min
- Gamma source of $^{60}Co$ (0.26 kGy/h)
- Radiochemistry Laboratory (Class 2)
- Cyclotron IBA Cyclone 18/9
  - 18 MeV protons ($I_{max}$ = 80 μA)
  - 9 MeV deuterons ($I_{max}$ = 40 μA)

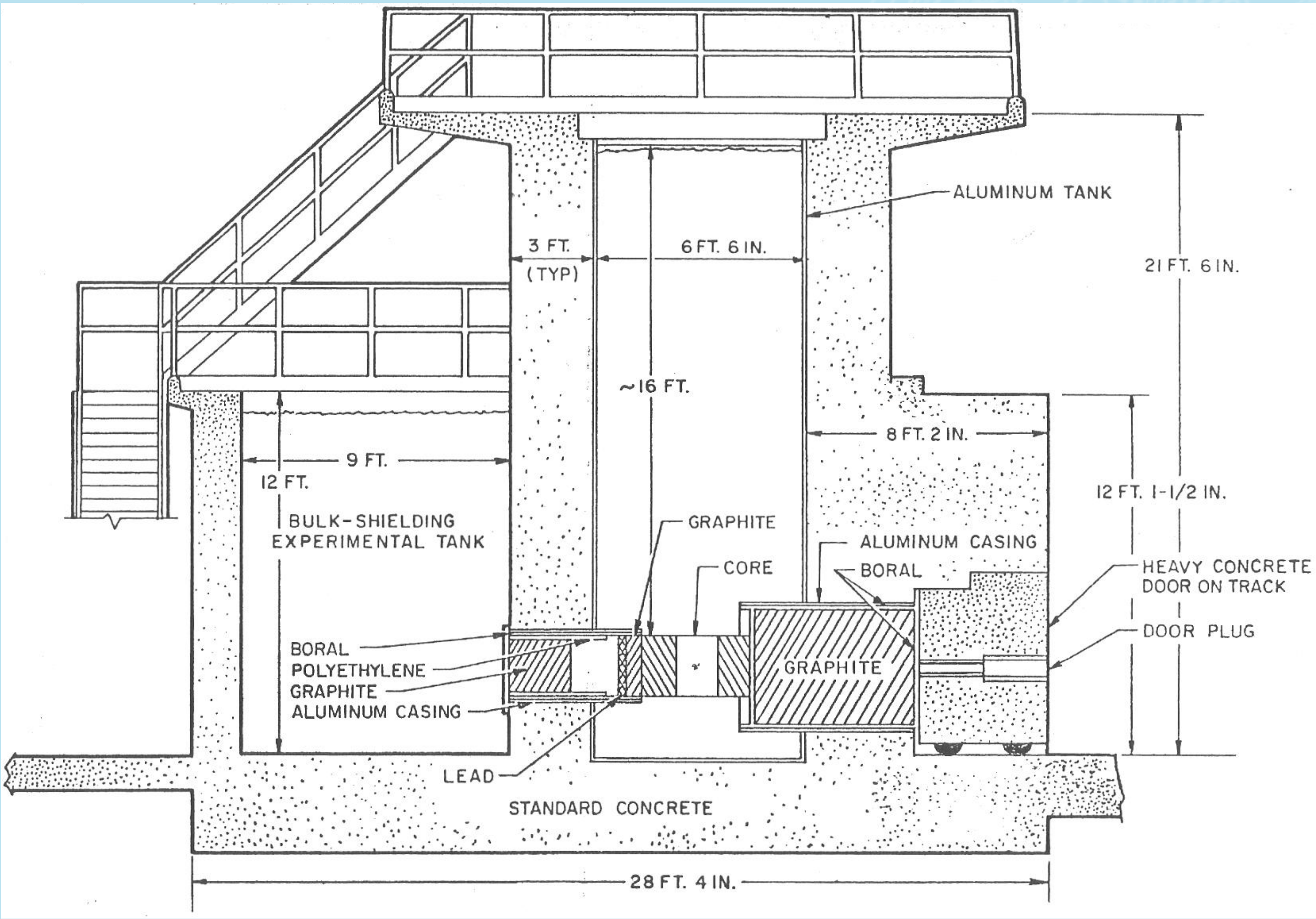



# TRIGA Mark II Nuclear Research Reactor

**TRIGA** (**T**raining, **R**esearch, **I**sotopes production, **G**eneral **A**tomics)

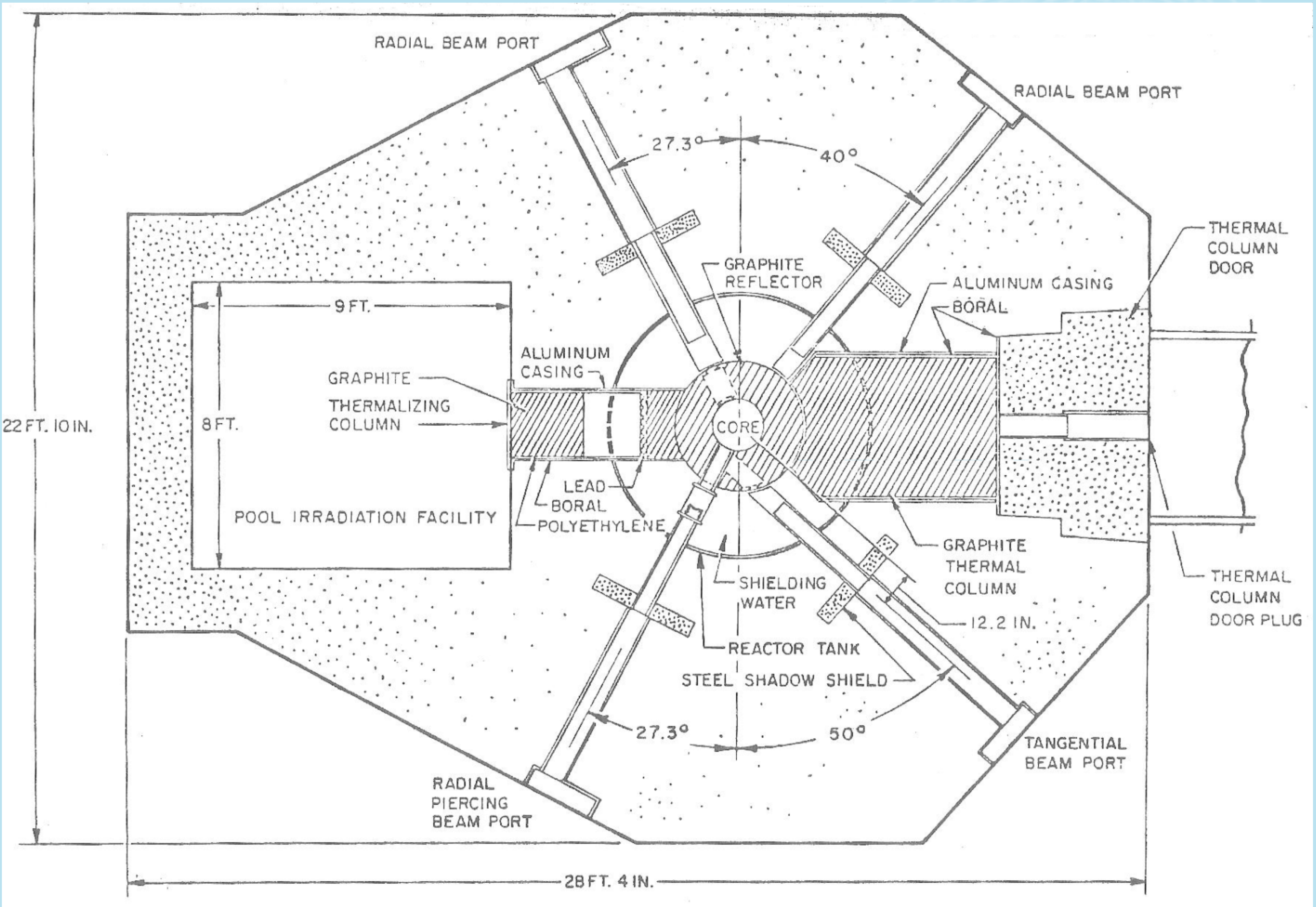
- **250-kW** light-water **Thermal Reactor,** with an annular graphite reflector, cooled by natural convection
- offers many positions of irradiation (facilities) with **"in-core"** neutrons flux **from $10^{12}$ to $10^{13}$ n $cm^{-2}$ $s^{-1}$**
- **6 “out-core” irradiation facilities** with typical neutron flux **from $10^{6}$ to $10^{10}$ n $cm^{-2}$ $s^{-1}$**
- **Fuel:** 20% enriched Uranium
- **Moderator/Cooling:** light water
- **Reflector:** graphite
- **3 control rods**
- **Irradiation:** 400 hours/year

# TRIGA Mark II Nuclear Research Reactor



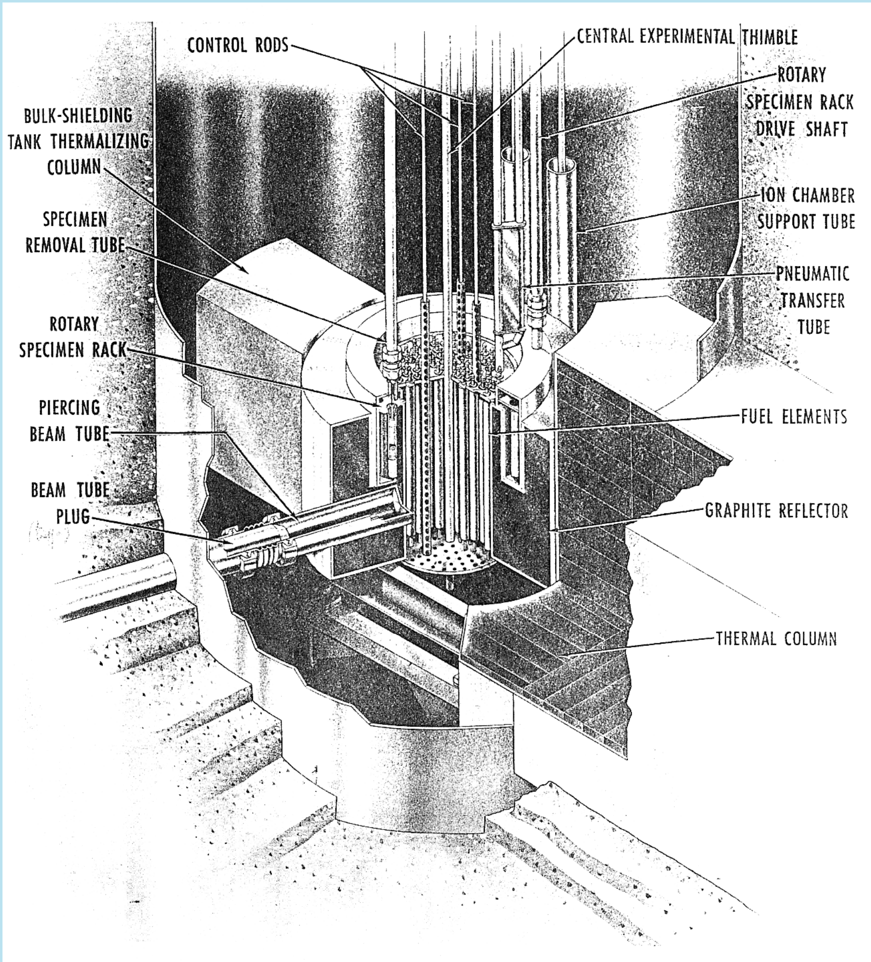

## Reactor side view

# TRIGA Mark II Nuclear Research Reactor



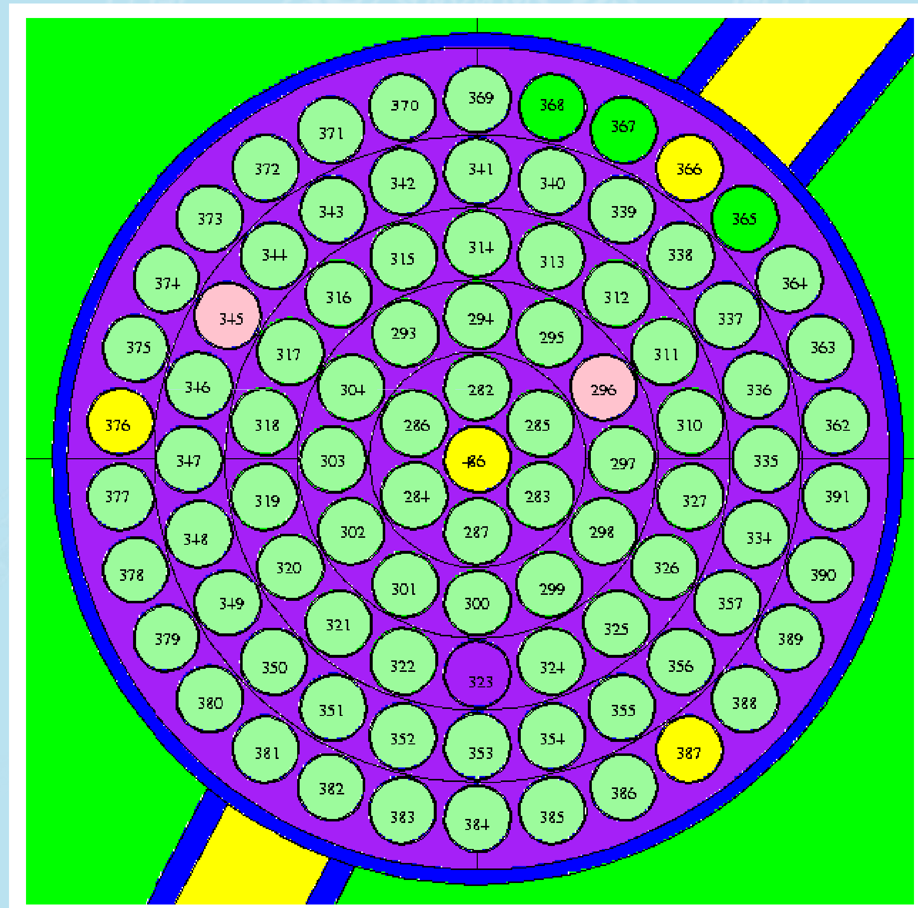

## Reactor top view

# TRIGA Mark II Nuclear Research Reactor



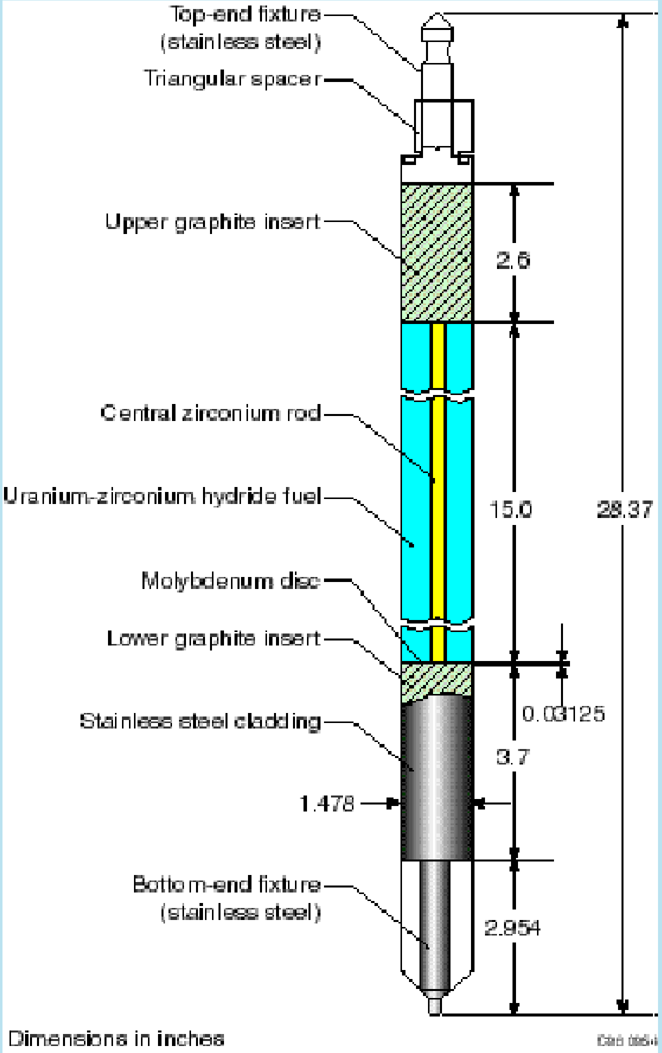

## REACTOR CORE

The core is placed at the bottom of the 6.25-m-high open tank with 2-m diameter.




- Cylindrical configuration
- Lattice of 90 cylindrical elements (September 2013):
  - **80 moderator-fuel elements**
  - **3 control rods** (REGULATING, TRANSIENT and SHIM)
  - **1 Radium-Beryllium source**
  - **2 vertical irradiation facilities** (Central Thimble, Pneumatic Transfer System Thimble *(Rabbit)*)
  - **5 dummies graphite elements** in the external ring (F.ring)

# TRIGA Mark II Nuclear Research Reactor

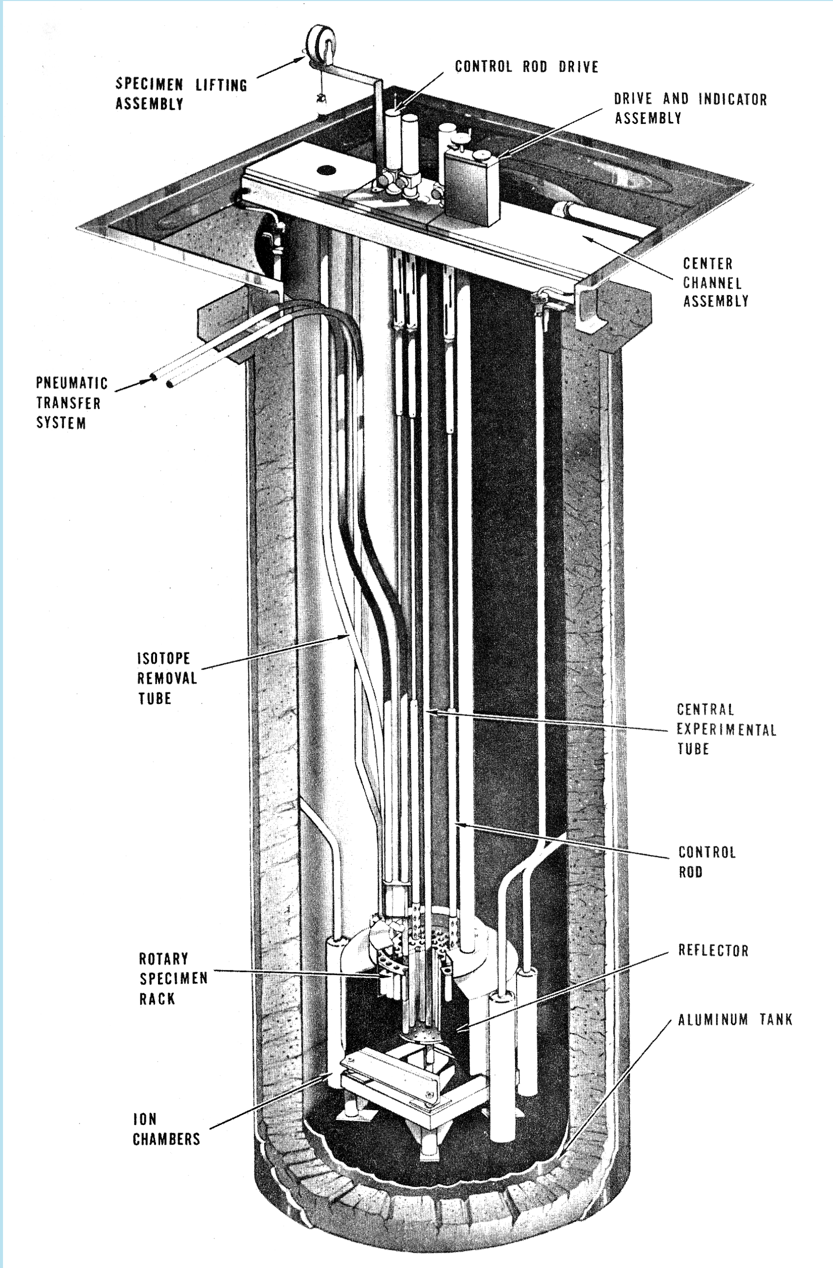



## FUEL ELEMENTS

- Cylindrical rod with **alluminium** or **stainless steel**-clad
- Uranium is **20 wt.% $^{235}$U**
- The fuel is a homogeneous mixture of uranium and zirconium hydride.
- The large **prompt negative temperature coefficient of reactivity** characteristic of UZrH fuel results in safety margins
- An increase in temperature causes a decrease of the thermal neutron population (i.e. decrease of fission probability), ensuring an automatic limitation of the reactor power

| Fuel element composition | Weight % | Weight (gr) |
|---|---|---|
| $^{235}$U | 20% U | 36 |
| $^{238}$U | 80% U | 144 |
| $^{235}$U + $^{238}$U | 8% mixture | 180 |
| ZrH | 92% mixture | 2070 |
| Total | 100% mixture | 2250 |

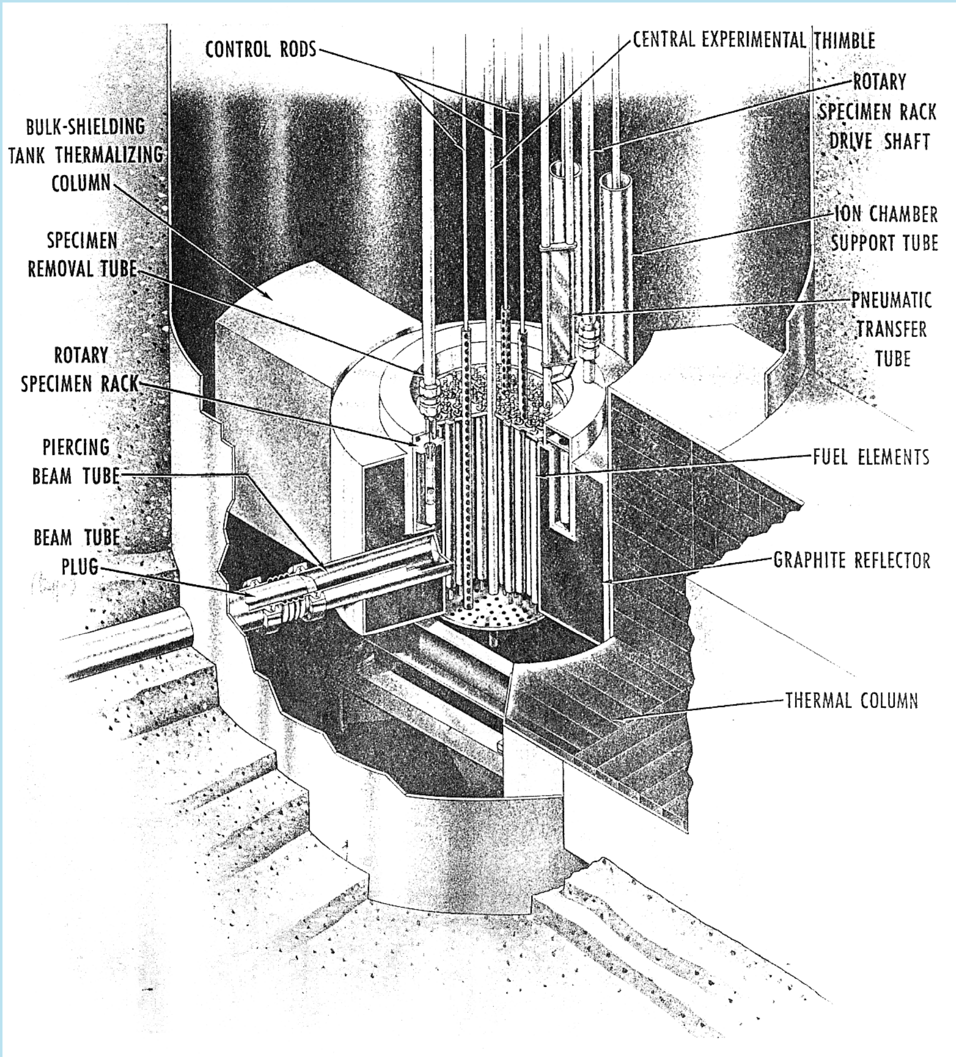
# TRIGA Mark II Nuclear Research Reactor




## CONTROL RODS

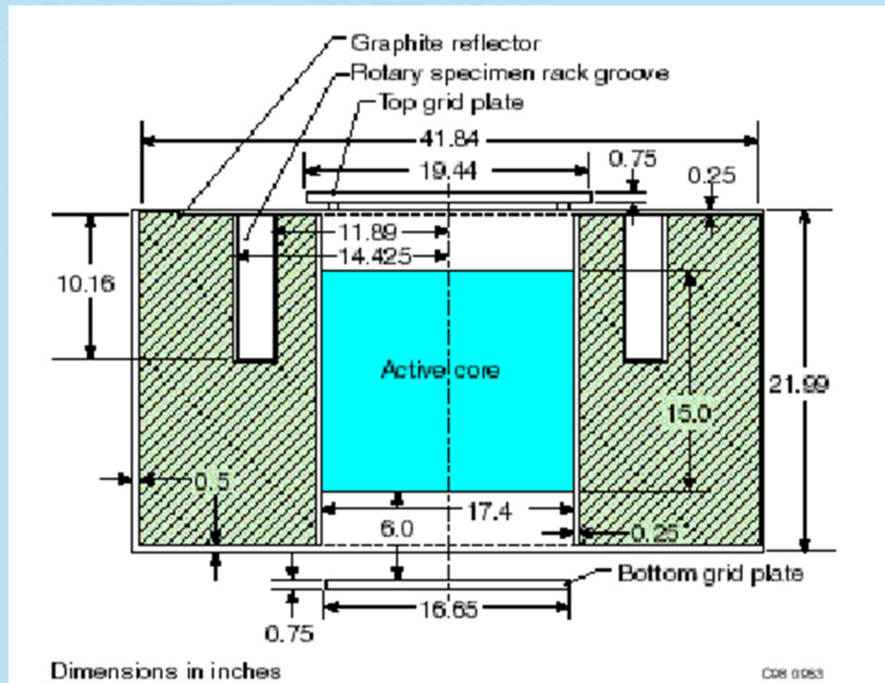
- Three control rods are used in the reactor:
  - regulating (**REG**)
  - shim (**SHIM**),
  - safety (**TRANS**).
- **Composition**: Boron carbide (REG, SHIM) or Borated Graphite (TRANS)
- **Boron** is a typical neutron absorber (thermal neutron cross section 3800 barn)
- Control rods are removed from or inserted into the core in order to **control the neutron flux** — increase or decrease the number of neutrons which will split further uranium atoms. This in turn affects the thermal power of the reactor:
  - The control rods extraction allows the multiplication of the neutron population (**supercritical** reactor, K>1)
  - Inserting control rods in the core means the insertion of negative reactivity (**subcritical** reactor, K<1)

# TRIGA Mark II Nuclear Research Reactor




## Graphite Reflector

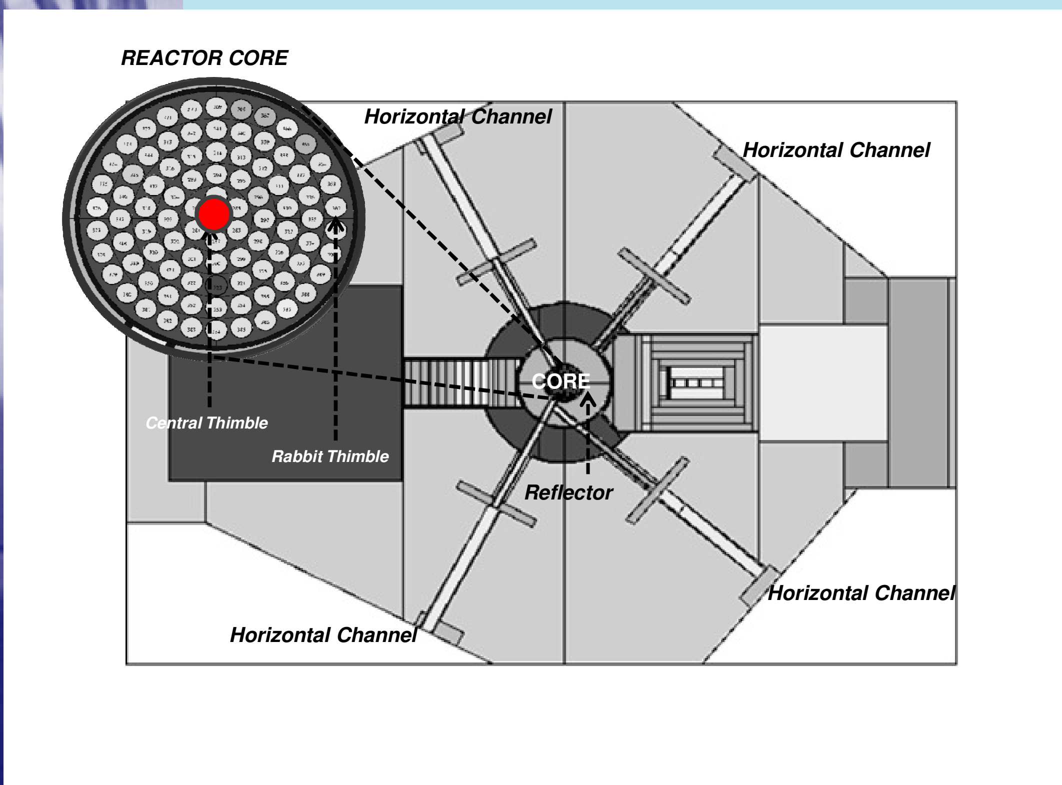
- A graphite reflector enclosed in aluminum casing surrounds the core.
- A annular groove in the upper part of the reflector body is provided to contain a special irradiation facility (rotary specimen rack).
- The rotary specimen rack is made of aluminum and consists of **40 holes** with inner diameter of 38 mm.

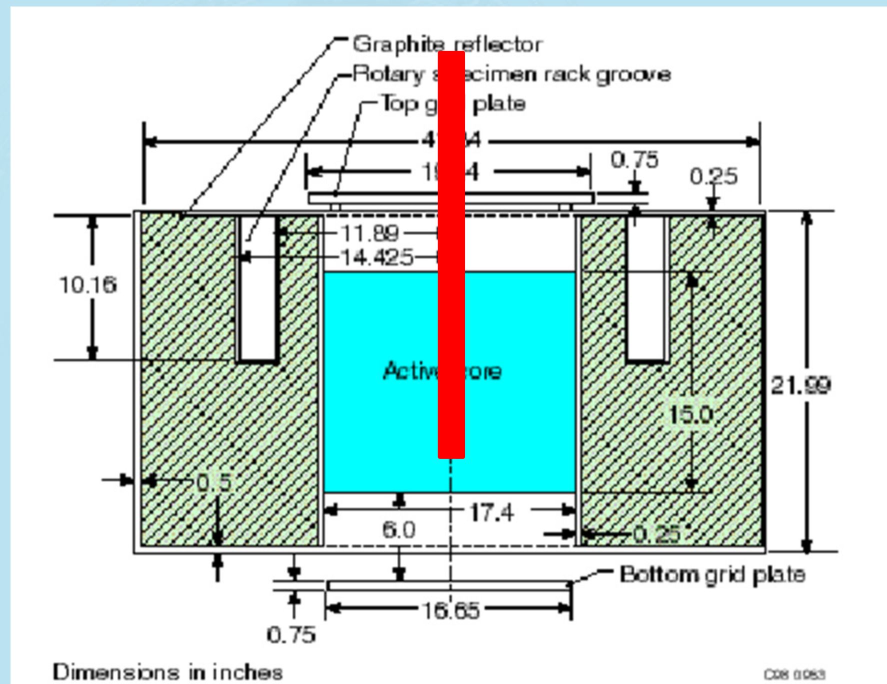


# “In-core” irradiation facilities – Central Thimble

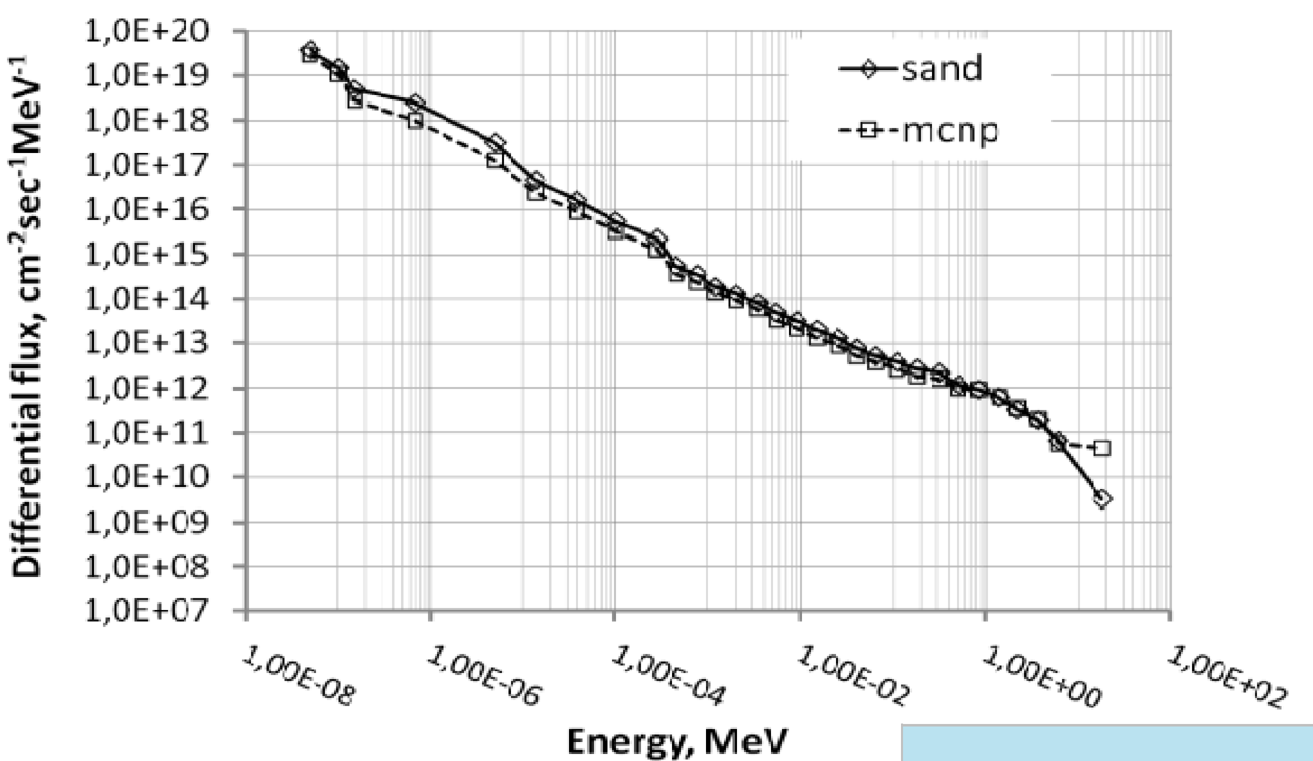
## Central Thimble

- It is positioned along the <u>vertical axis</u> of the “core” cylinder, where the <u>neutron flux is maximum</u>
- It can host up to **3** samples in cylindrical containers *(130 mm-height; 30 mm-diameter made by Polyethylene or Aluminum)*



# “In-core” irradiation facilities – Central Thimble



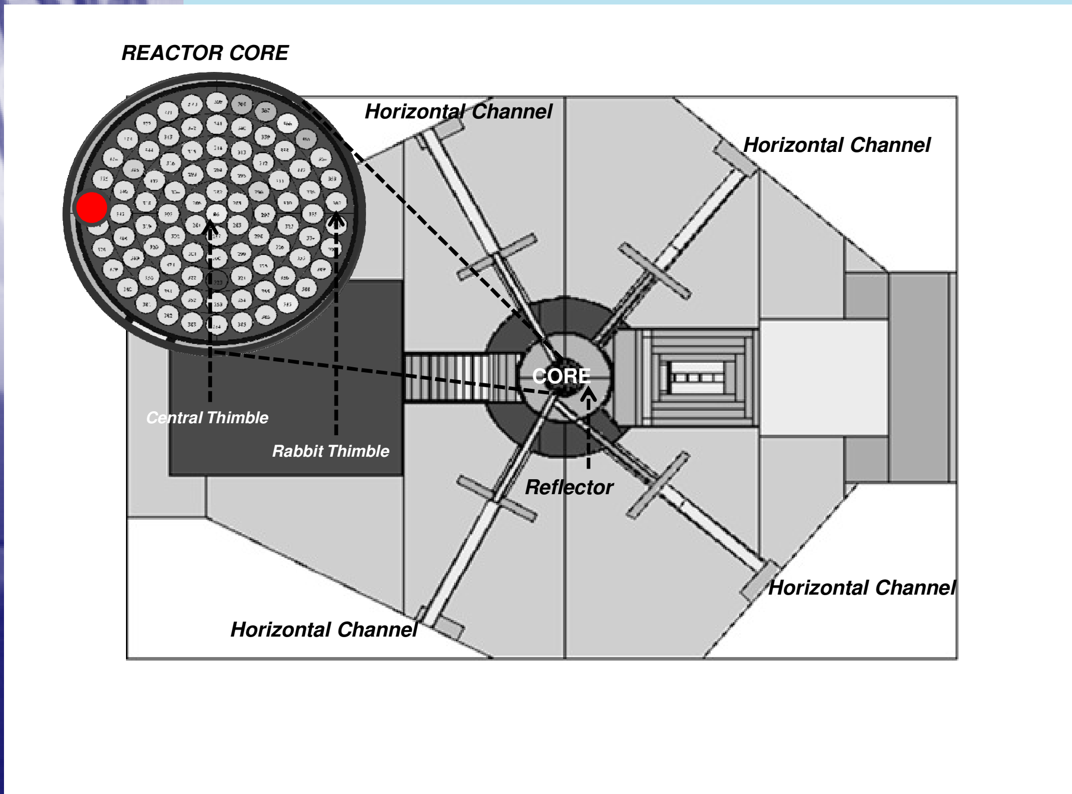

| **Central Thimble** | **Measured Flux (n cm$^{-2}$ s$^{-1}$)** |
|---|---|
| Thermal (E < 0.21 eV) | $(3.00 \pm 0.15)\ 10^{12}$ |
| Epithermal (0.21 eV < E < 9.2 keV) | $(4.64 \pm 0.21)\ 10^{12}$ |
| Fast (E > 9.2 keV) | $(5.89 \pm 0.18)\ 10^{12}$ |
| **Total Flux** | $\mathbf{(1.39 \pm 0.31)\ 10^{13}}$ |

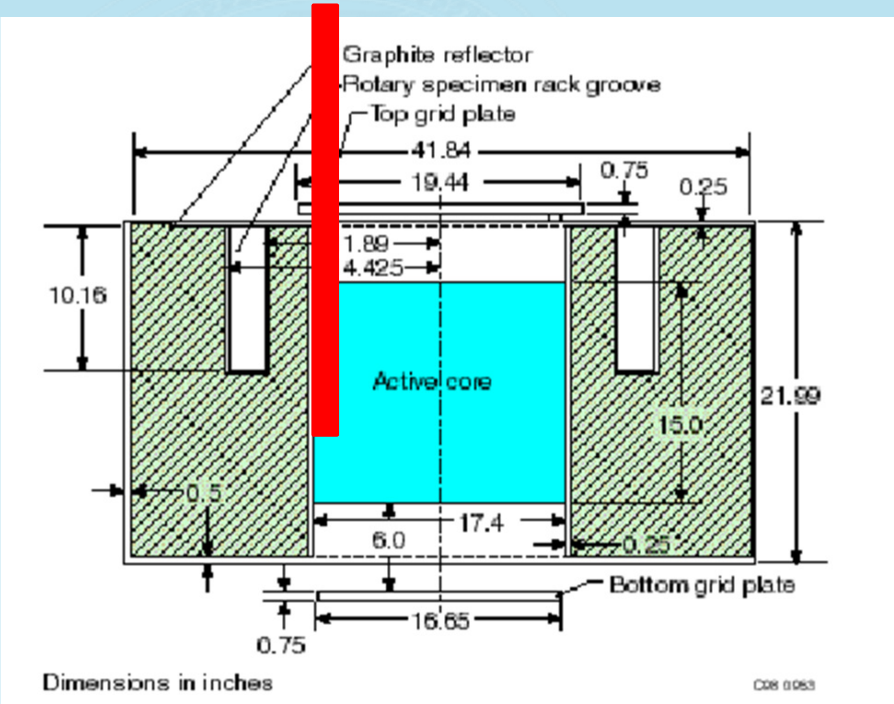
D. Alloni, M. Prata, A. Salvini, A. Ottolenghi
*“Neutron flux characterization of the Pavia TRIGA Mark II Reactor for radiobiological and microdimetric applications”*
submitted to RADIATION PROTECTION DOSIMETRY (2013)

# "In-core" irradiation facilities – Rabbit Thimble

## Pneumatic Transfer System Thimble

- It is positioned along the vertical axis of the "core" cylinder, in the external ring (F-ring)
- A pneumatic transfer system offers the possibility to make short irradiation time in order to detect immediately the short half-life activated radionuclides, by means of HPGe gamma spectrometry installed in Radiochemistry Laboratory.

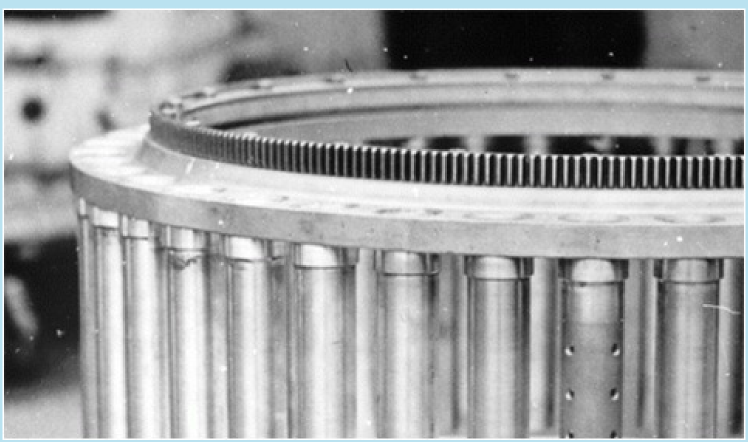


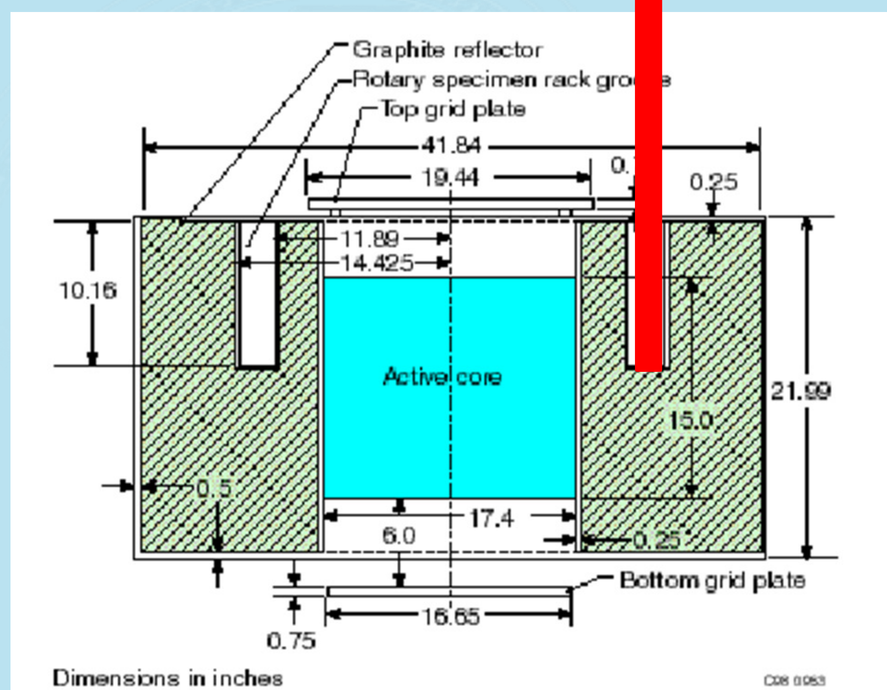



# “In-core” irradiation facilities – Lazy Susan

## Rotary specimen rack

- An annular groove in the upper part of the reflector body is provided to contain a special irradiation facility (**rotary specimen rack**).
- The rotary specimen rack is made of aluminum and consists of **40 holes** with inner diameter of 38 mm.
- It can host up to **80 samples** cylindrical containers *(130mm-height; 30mm-diameter)*

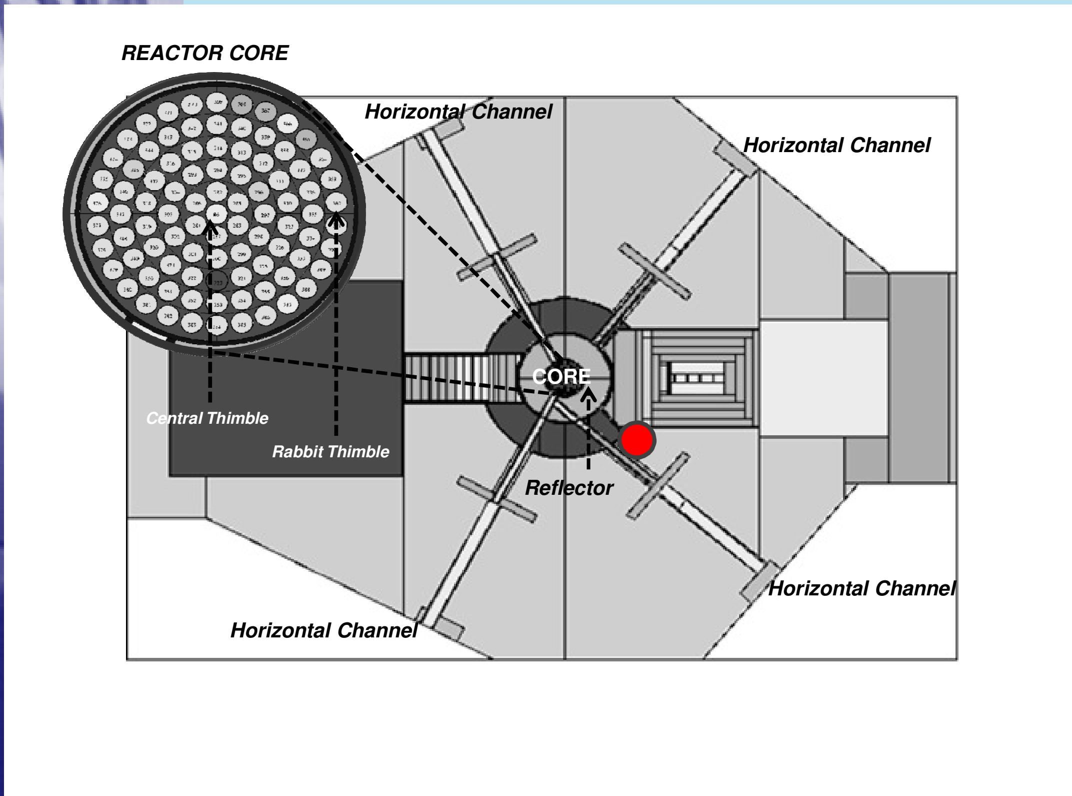


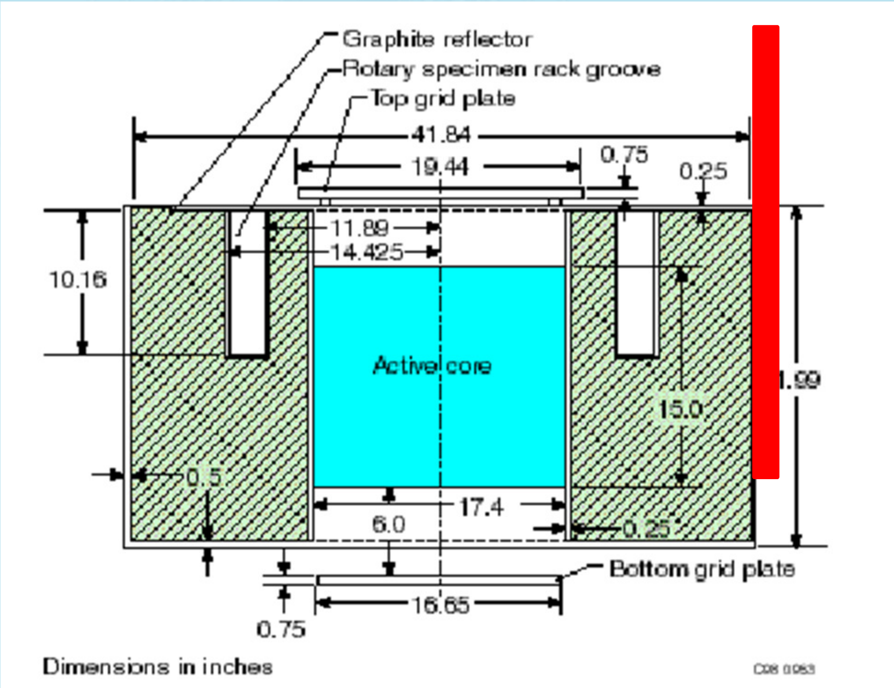


# “In-core” irradiation facilities – Thermal Channel

## Thermal channel

- It has been recently installed, out from the reflector body, an aluminum cylinder (38cm-height; 7cm-diameter) (**Thermal channel**).



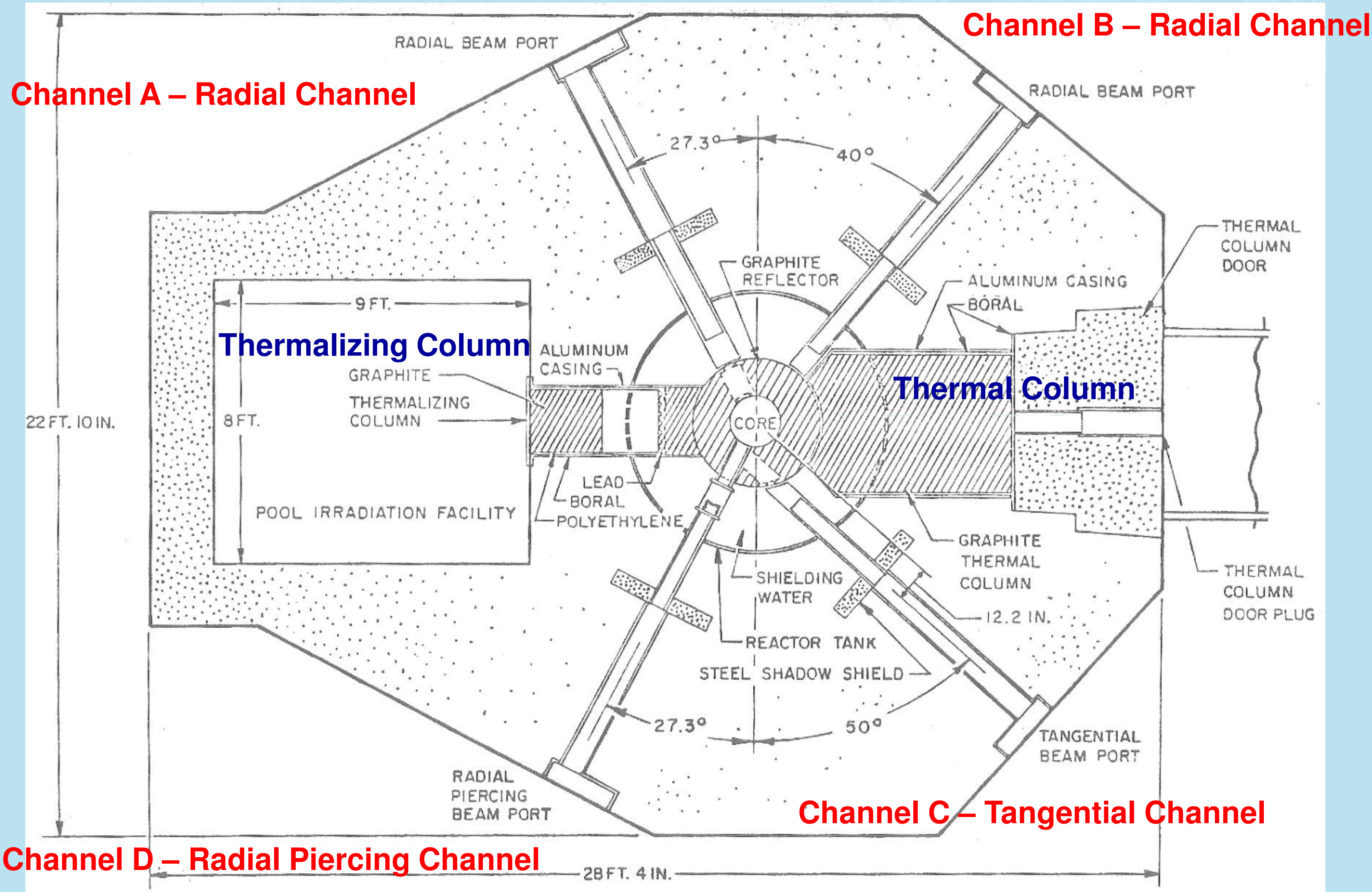
# “In-core” irradiation facilities – Neutron Fluxes

- In order to characterize the irradiation facilities, experimental data on neutron fluxes have been collected analyzing and measuring the induced gamma activity in thin target foils of different materials irradiated in different TRIGA experimental channels.
- The data on the induced gamma activities have been elaborated and finally compared with the spectra obtained with MCNP Monte Carlo simulation.

| Irradiation Facility | Measured Flux (n $cm^{-2}$ $s^{-1}$) | MCNP Flux (n $cm^{-2}$ $s^{-1}$) |
|---|---|---|
| Central Thimble | $(1.75 \pm 0.23)\ 10^{13}$ | $(1.88 \pm 0.02)\ 10^{13}$ |
| Rabbit Channel | $(7.47 \pm 1.01)\ 10^{12}$ | $(8.39 \pm 0.17)\ 10^{12}$ |
| Lazy Susan | $(2.42 \pm 0.25)\ 10^{12}$ | $(2.76 \pm 0.04)\ 10^{12}$ |
| Thermal Channel | $(2.52 \pm 0.36)\ 10^{11}$ | $(5.79 \pm 0.07)\ 10^{11}$ |

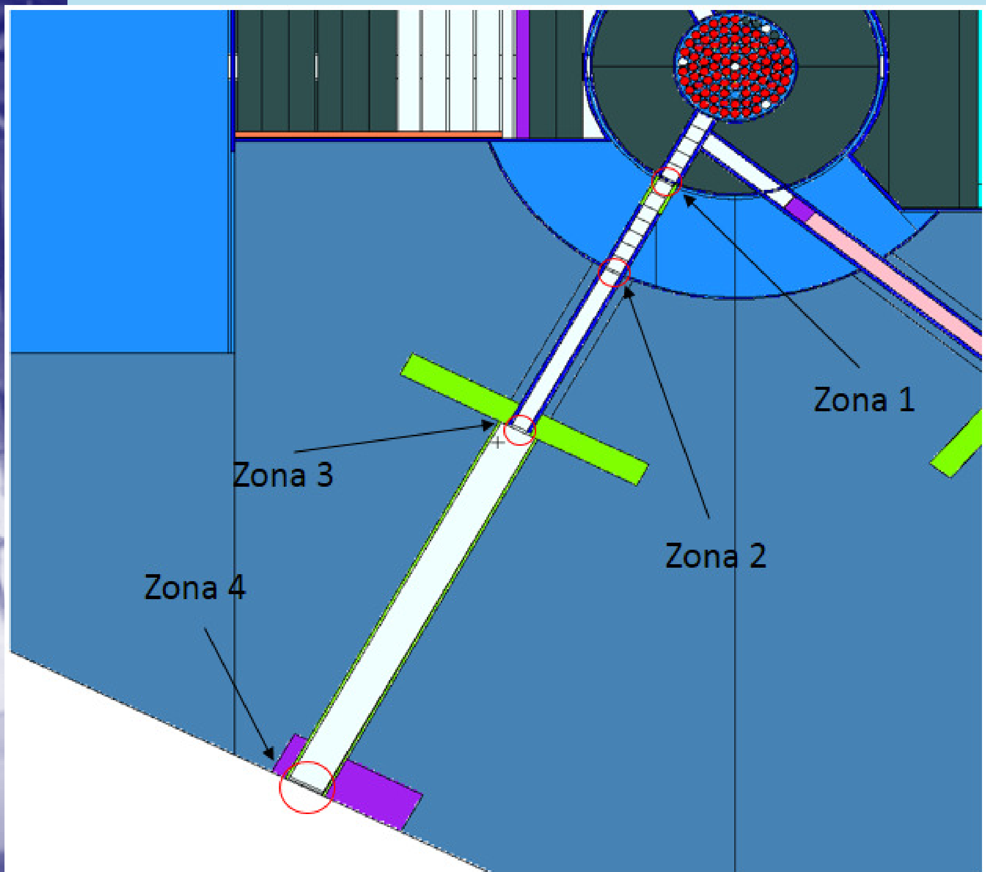
A. Borio di Tigliole, A. Cammi, D. Chiesa, M. Clemenza, S. Manera, M. Nastasi, L. Pattavina, R. Ponciroli, S. Pozzi, M. Prata, E. Previtali, A. Salvini, M. Sisti
“*TRIGA reactor absolute neutron flux measurement using activated isotopes*”
PROGRESS IN NUCLEAR ENERGY Volume **70**, January 2014, Pages 249–255

# “Out-core” irradiation facilities



# “Out-core” irradiation facilities – Channel D

MCNP5 SOURCE




NEUTRON FLUXES n/cm$^2$s

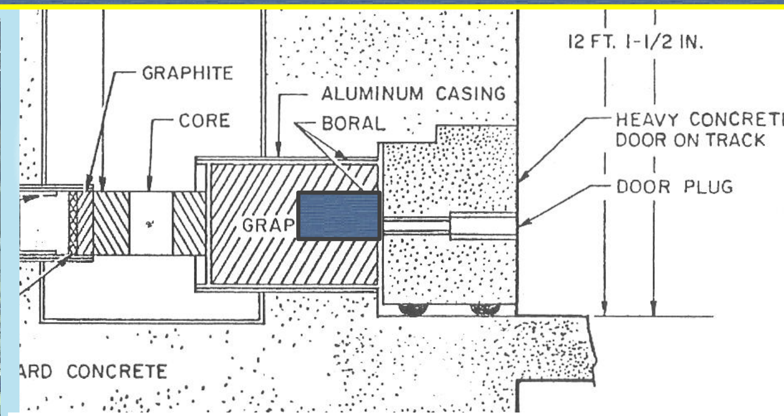
| | Zona 1 | Zona 2 |
|---|---|---|
| Thermal | $6.34 \cdot 10^{11}$ | $7.03 \cdot 10^{10}$ |
| Epithermal | $4.43 \cdot 10^{11}$ | $3.39 \cdot 10^{10}$ |
| Fast | $7.14 \cdot 10^{10}$ | $7.66 \cdot 10^{9}$ |
| Total | $\mathbf{1.14 \cdot 10^{12}}$ | $\mathbf{1.12 \cdot 10^{11}}$ |

| | Zona 3 | Zona 4 |
|---|---|---|
| Thermal | $3.16 \cdot 10^{9}$ | $2.99 \cdot 10^{8}$ |
| Epithermal | $4.53 \cdot 10^{9}$ | $5.65 \cdot 10^{8}$ |
| Fast | $1.38 \cdot 10^{9}$ | $2.36 \cdot 10^{8}$ |
| Total | $\mathbf{9.07 \cdot 10^{9}}$ | $\mathbf{1.10 \cdot 10^{9}}$ |

Luca Reversi
*“Studio computazionale per la realizzazione di un fascio di difrattometria neutronica presso il reattore TRIGA di Pavia”*
Master Degree Thesis – University of Pavia (2013)

# “Out-core” irradiation facilities – Thermal Column

Thermal Column modified for BNCT research & activities




Radial Piercing Channel (Ch. D)

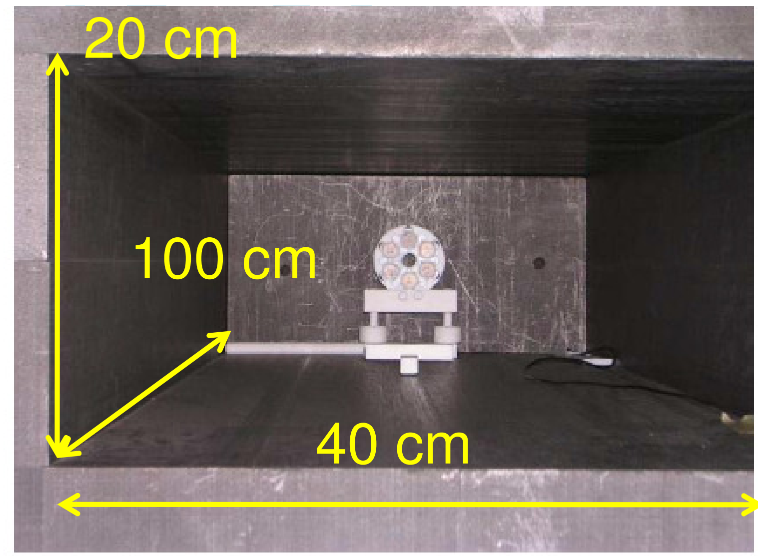
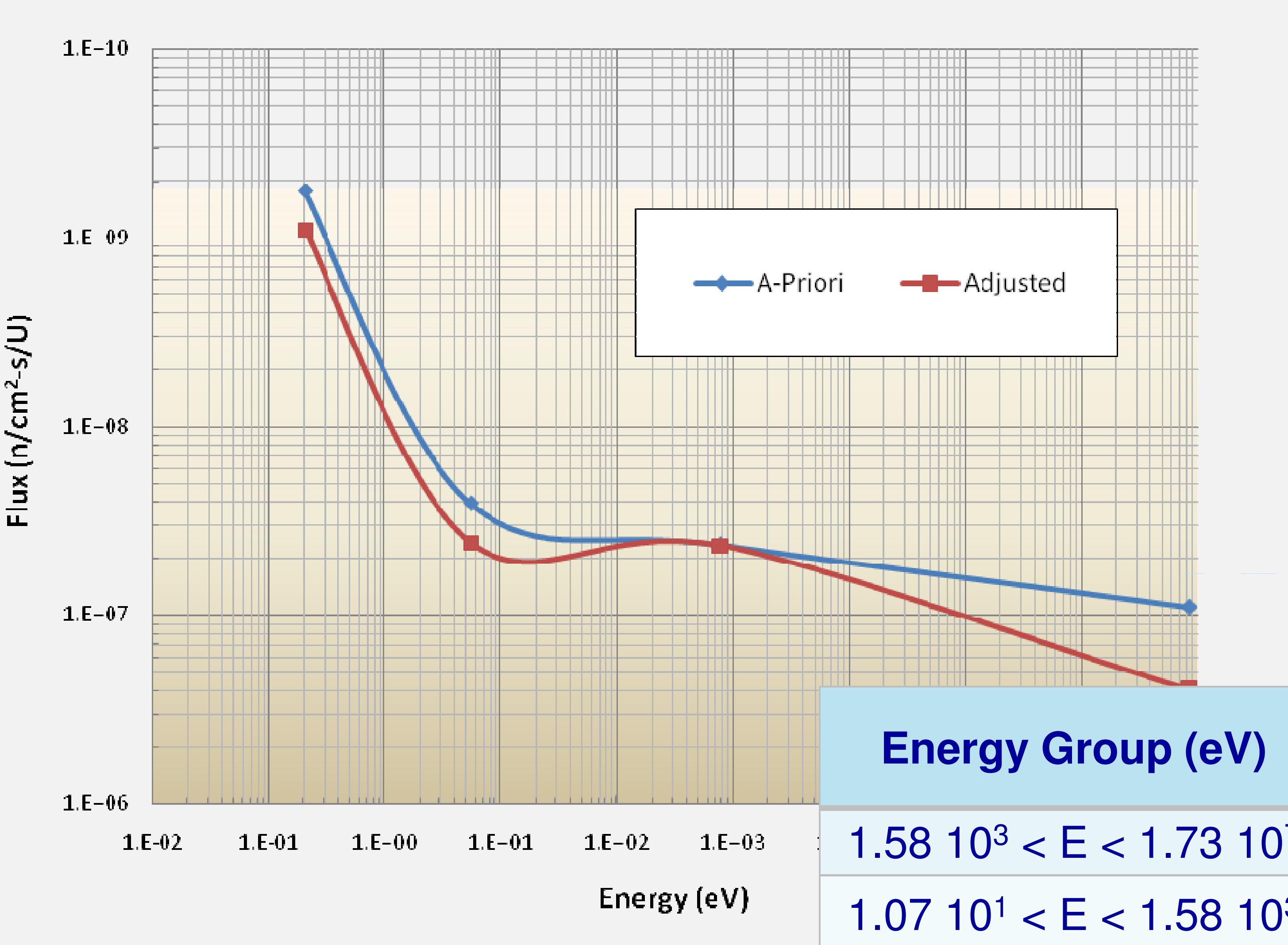



Fig. 2. View upstream into the graphite thermal column, showing positioning of the neutron activation dosimeter foil packages.

# "Out-core" irradiation facilities – Thermal Column

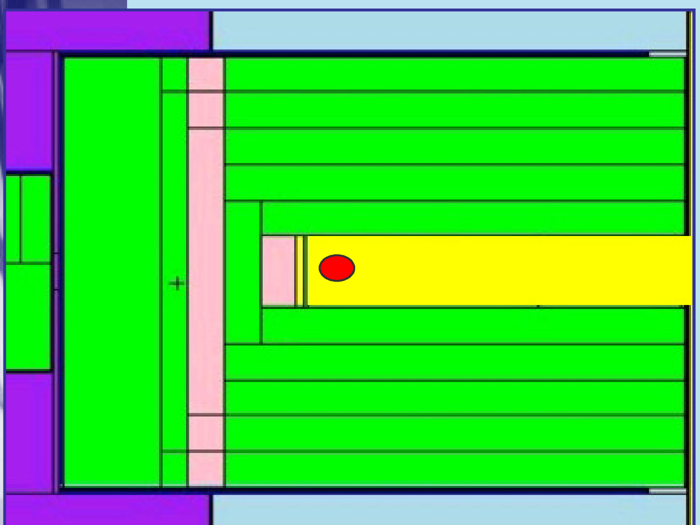



| **Energy Group (eV)** | **Measured Flux ($n\ cm^{-2}\ s^{-1}$)** |
|---|---|
| $1.58\ 10^{3} < E < 1.73\ 10^{7}$ | $4.39\ 10^{7} \pm 9.0\%\ (1\sigma)$ |
| $1.07\ 10^{1} < E < 1.58\ 10^{3}$ | $1.20\ 10^{8} \pm 5.4\%\ (1\sigma)$ |
| $4.14\ 10^{-1} < E < 1.07\ 10^{1}$ | $7.51\ 10^{7} \pm 3.1\%\ (1\sigma)$ |
| $1.00\ 10^{-5} < E < 4.14\ 10^{-1}$ | $1.17\ 10^{10} \pm 2.5\%\ (1\sigma)$ |

N. Protti, S. Bortolussi, M. Prata, P. Bruschi, S. Altieri, D. W. Nigg
*"Neutron Spectrometry for the University of Pavia TRIGA Thermal Neutron Source Facility"*
Transactions of the American Nuclear Society, Vol. **107**, San Diego, California, November 11–15, 2012

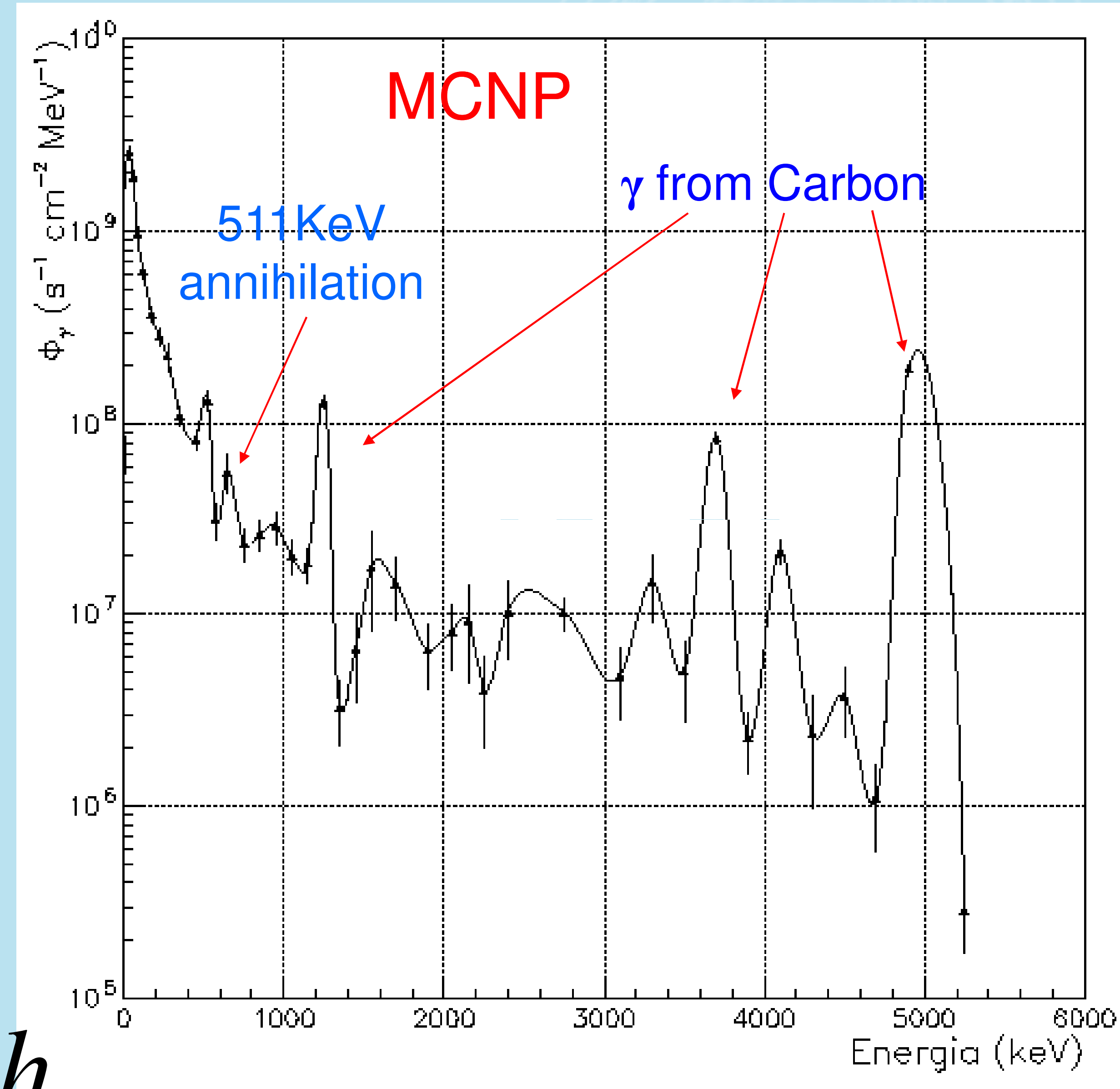
# Thermal Column – The $\gamma$ spectrum in air

Calculated by MCNP
Measured by TLD



Bismuth shields to cut gamma coming from the core

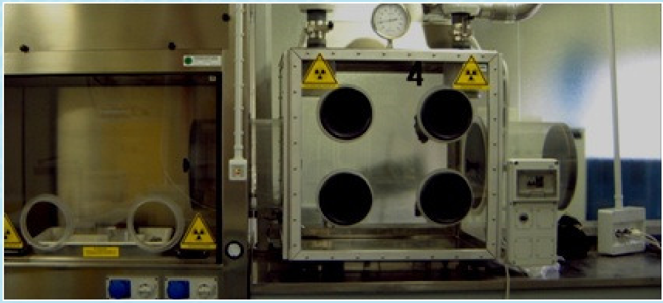
$$\dot{D}_{\gamma} = 8\, Gy / h$$

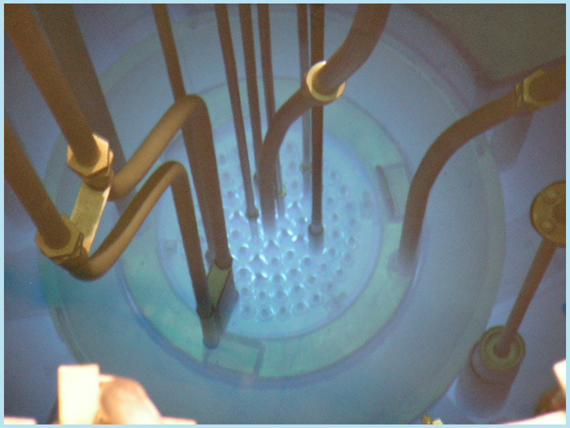


# LENA Research Center

- The research facilities are at the disposal of:
  - ✓ Public  Research Institutions (National and International)
  - ✓ Private Companies
  - ✓ Schools and Universities students
  - ✓ Individual workers

- The reactor is used for many different purposes:
  - ✓ Fundamental Research
  - ✓ Applied Research and Technologic Transfer
  - ✓ Education and Training
  - ✓ Public Information





# LENA *… up today*

operates daily to carry out research activities, such as:

- ✓ Analysis of materials and environmental samples for the determination of **trace elements by Neutron Activation Analysis** (NAA) method
- ✓ Experimental **cancer therapy** based on **BNCT** - Boron Neutron Capture Therapy
- ✓ **Neutrons irradiation of semiconductors** in order to induce a change in their characteristics and their behavior
- ✓ Studies for the **characterization of materials** with respect to their nuclear properties
- ✓ Study of **radiation-induced damage** on electronic components for aerospace applications and for accelerators
- ✓ Production of **radio-labeled pharmaceuticals for medical diagnosis**
- ✓ Study on **Nuclear Reactor Physics** and **Kinetics**
- ✓ Studies on **Nuclear Fuel Partitioning & Transmutation**
- ✓ Analysis of materials and **ancient artifacts** and **geological samples** and determination of their origin

# Thank You
# For Your Attention

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