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The TAPIRO Fast Neutron Source Reactor: neutronic characterization and Monte Carlo simulations

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The TAPIRO Fast Neutron Source Reactor:

neutronic characterization and Monte Carlo simulations

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The Agency's activities are performed in the following four areas:

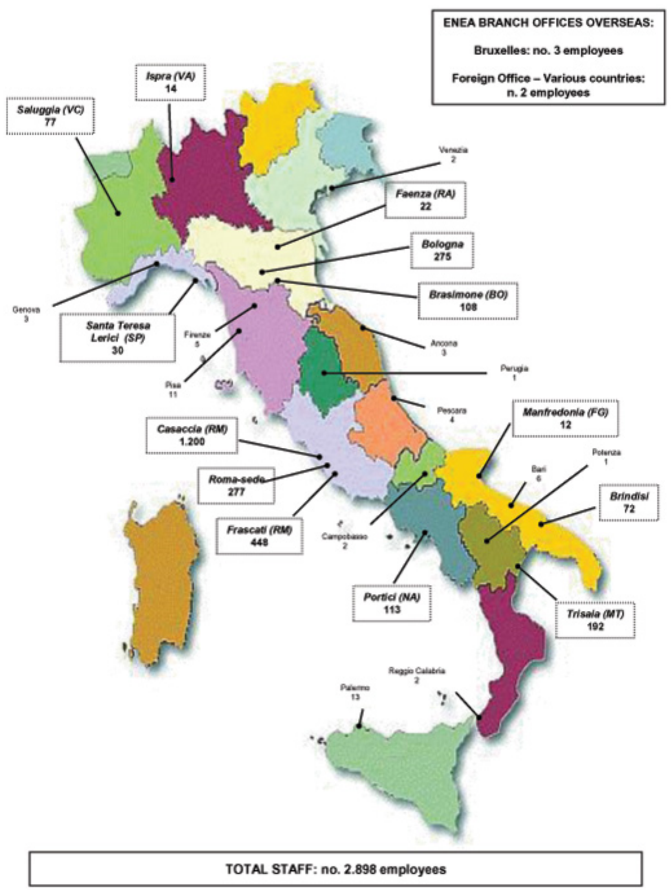
Clean Energy: photovoltaic technologies; biomass technologies; solar thermal technologies, energy efficiency, etc ...

Environmental Technologies: climate studies and modeling, characterization and protection of the environment and territory, air quality, building materials, etc ...

Technologies for the Future: Robotics, biomedicine, nuclear fusion, etc …

Nuclear energy control: ENEA is responsible by law for the scientific and technological aspects of nuclear energy; it encourages and performs basic and applied research, including the creation of prototypes and product industrialization related to nuclear technologies and applications.

GEOGRAPHICAL ALLOCATION OF STAFF AT 30.6.2009



ENEA Research Centres

More than 12 Research Centres spread on the Italian territory.

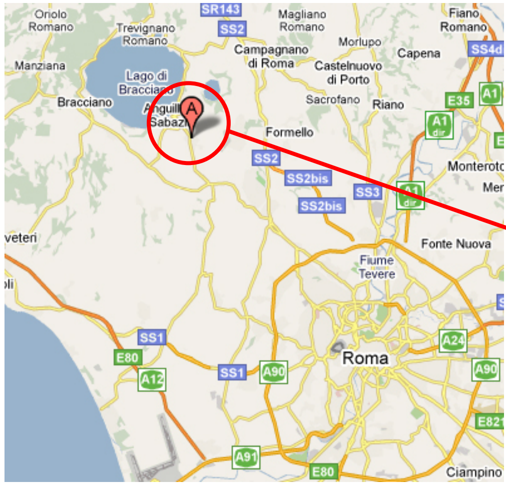
About 2900 employees.

The **Casaccia Centre** is the biggest ENEA Research centre:

- extension of 90 hectares
- 1200 employees

- **TAPIRO reactor**
  - core/reflector/biological shielding
  - How the TAPIRO reactor is monitored?
  - How the TAPIRO reactor is controlled?
  - TAPIRO irradiation facilities
  - Activities
  - Staff
- **TAPIRO neutronic characterization**
  - Integral Control Rod Worth
  - Flux spatial distribution
  - Effective delayed neutron fraction (β_{eff})
- **Monte Carlo simulations**
  - Monte Carlo technique
  - MCNP/MCNPX codes
  - TAPIRO MCNPX model
  - MCNPX results
- **Experimental and Simulations results comparison**
- **Conclusions**

C.R. Casaccia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Ciampino


TAPIRO


TRIGA
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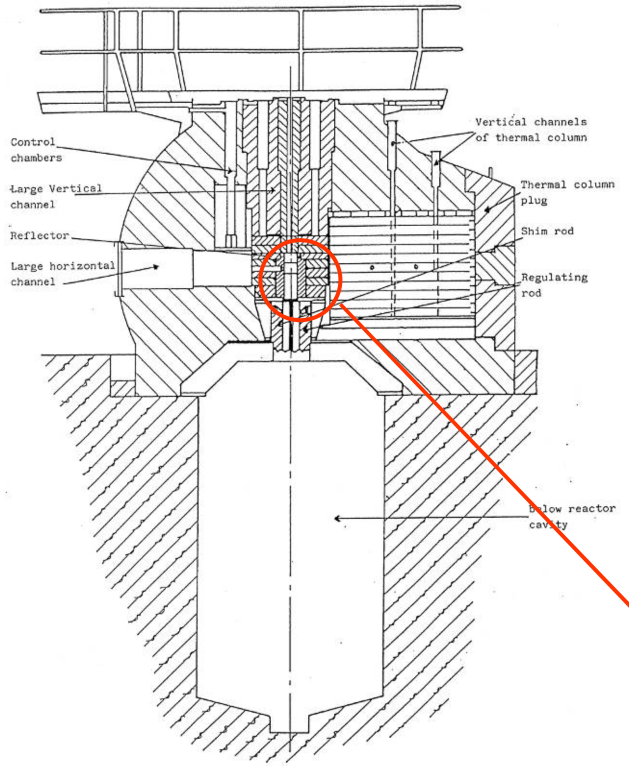
TAPIRO (TAratura Pila Rapida Potenza 0)

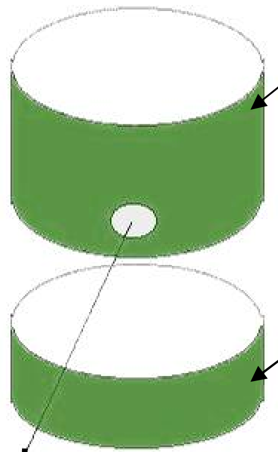
Short description:

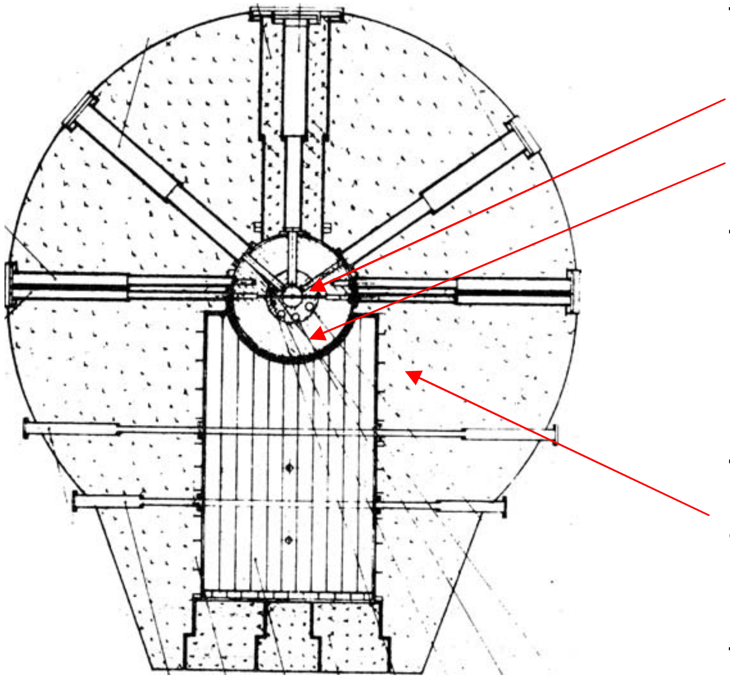
- fast neutron source;
- high enriched Uranium-235 ;
- copper reflected;
- located at the ENEA C.R. Casaccia, near Rome;
- support the experimental program on fast reactor;
- the reactor started up in 1971.



TAPIRO core characteristics:

- cylindrical core of 6.29 cm radius and 10.87 cm height;
- the fuel is a metal alloy (U 98.5 % Mo 1.5 %);
- high enriched Uranium-235 (93.5%);
- the critical mass is 21.46 kg;
- the nominal power is 5 kW thermal;
- the maximum neutron flux is $4 \cdot 10^{12}$ n/cm^2/s;
- cooled by means of helium circulating (P>50W).





Reflector

The copper outer reflector (cylindrical form) is divided in two concentric zones:

- the inner zone up to 17.4 cm radius;
- outer zone up to 40.0 cm radius.

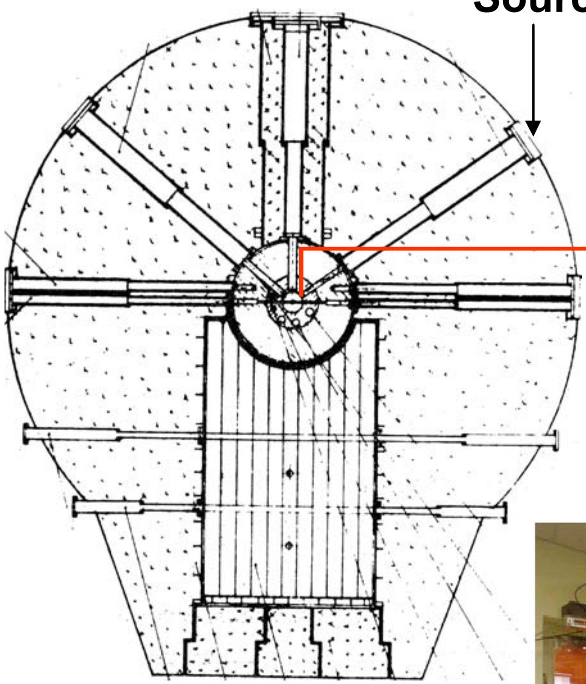
The external height is 72 cm.

Biological shielding

The reactor is surrounded by a borate concrete shield about 170 cm thick.

It guarantees a dose rate lower than 20 μSv/h at 5 kW in the reactor hall

How the reactor is monitored?



Neutron flux

2 ionization chambers

2 compensated ionization chambers

Core temperature

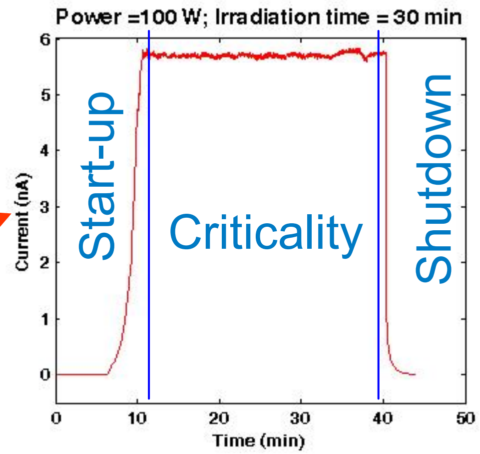
3 thermocouples in different positions of the core

Cooling system monitoring

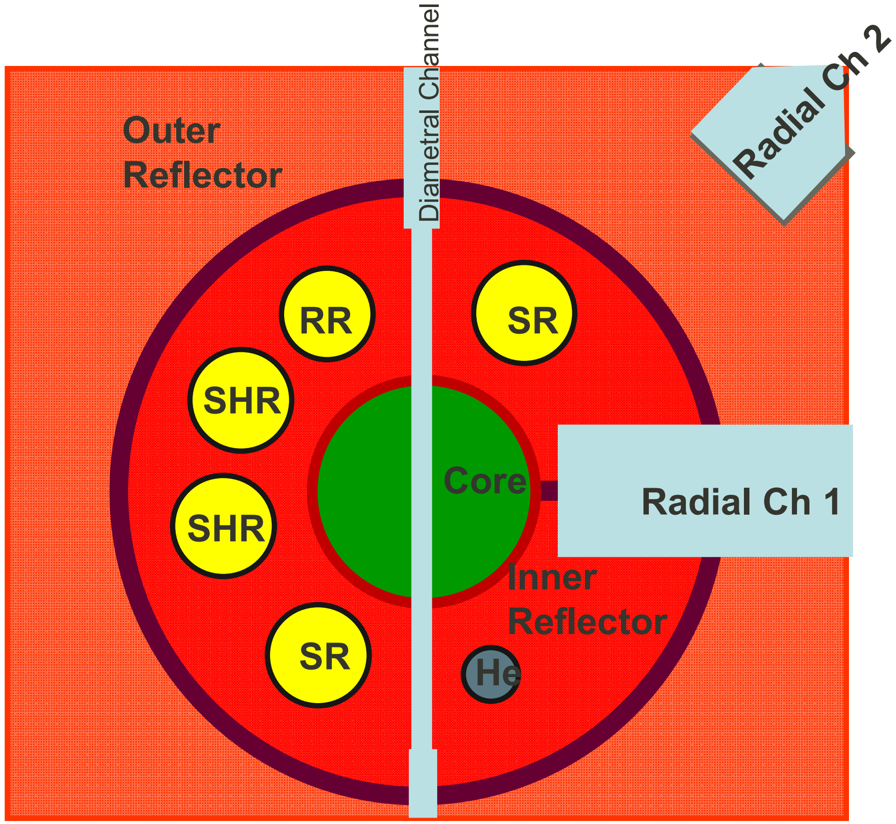
Helium temperature, flow speed, pressure

Reactor Room gamma exposition monitoring

4 Geiger-Muller detector



How the reactor is controlled?



Control rods

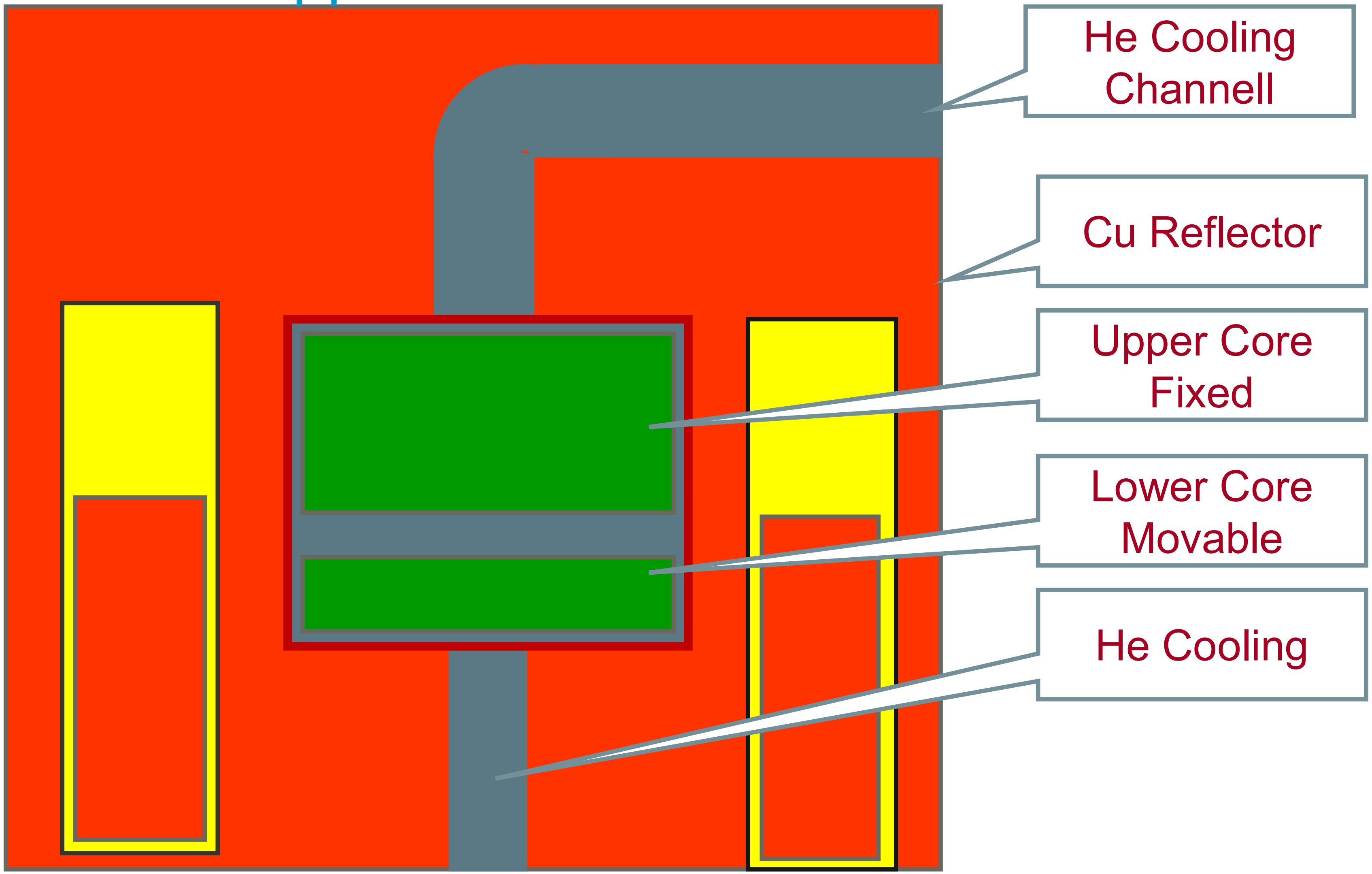
5 control rod made of Copper with a driving distance of 150 mm

2 Shim rods (SHR) - used for coarse control and/or to remove reactivity in relatively large amounts.

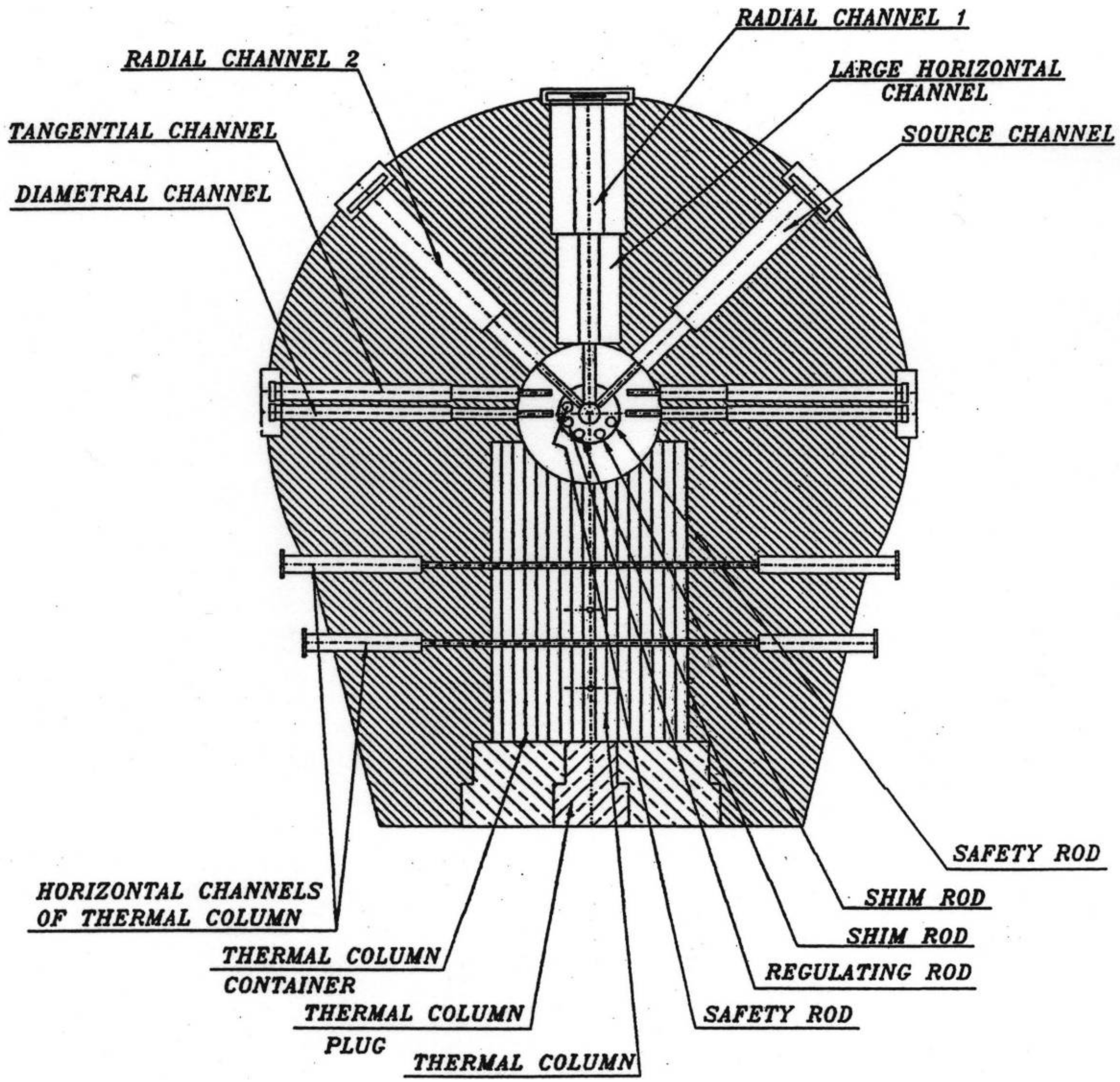
1 Regulating rods (RR)- used for fine adjustments and to maintain desired power or temperature.

2 Safety rods (SR)- provide a means for very fast shutdown in the event of an unsafe condition.

Start-up procedure

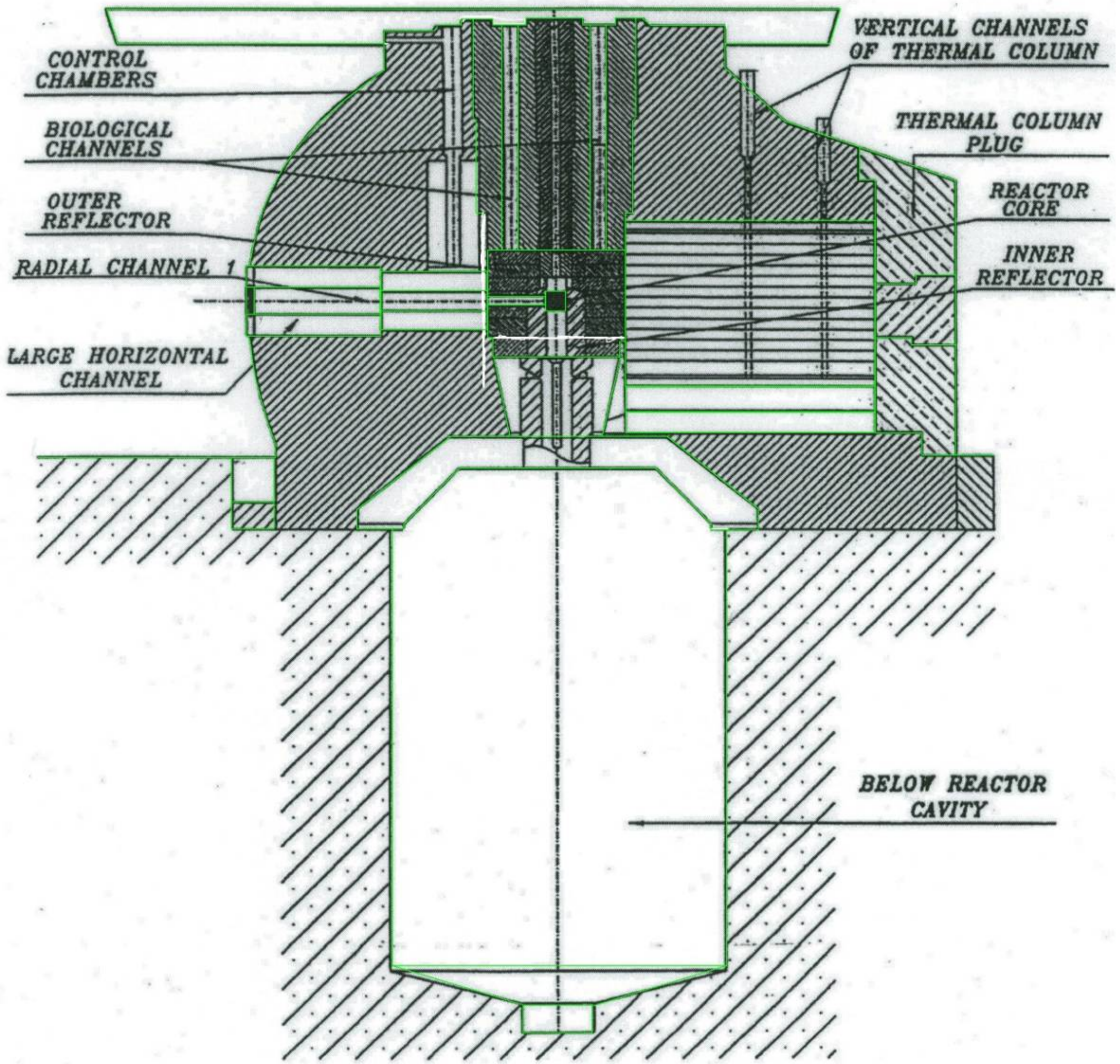


Irradiation facilities #1



TAPIRO Description

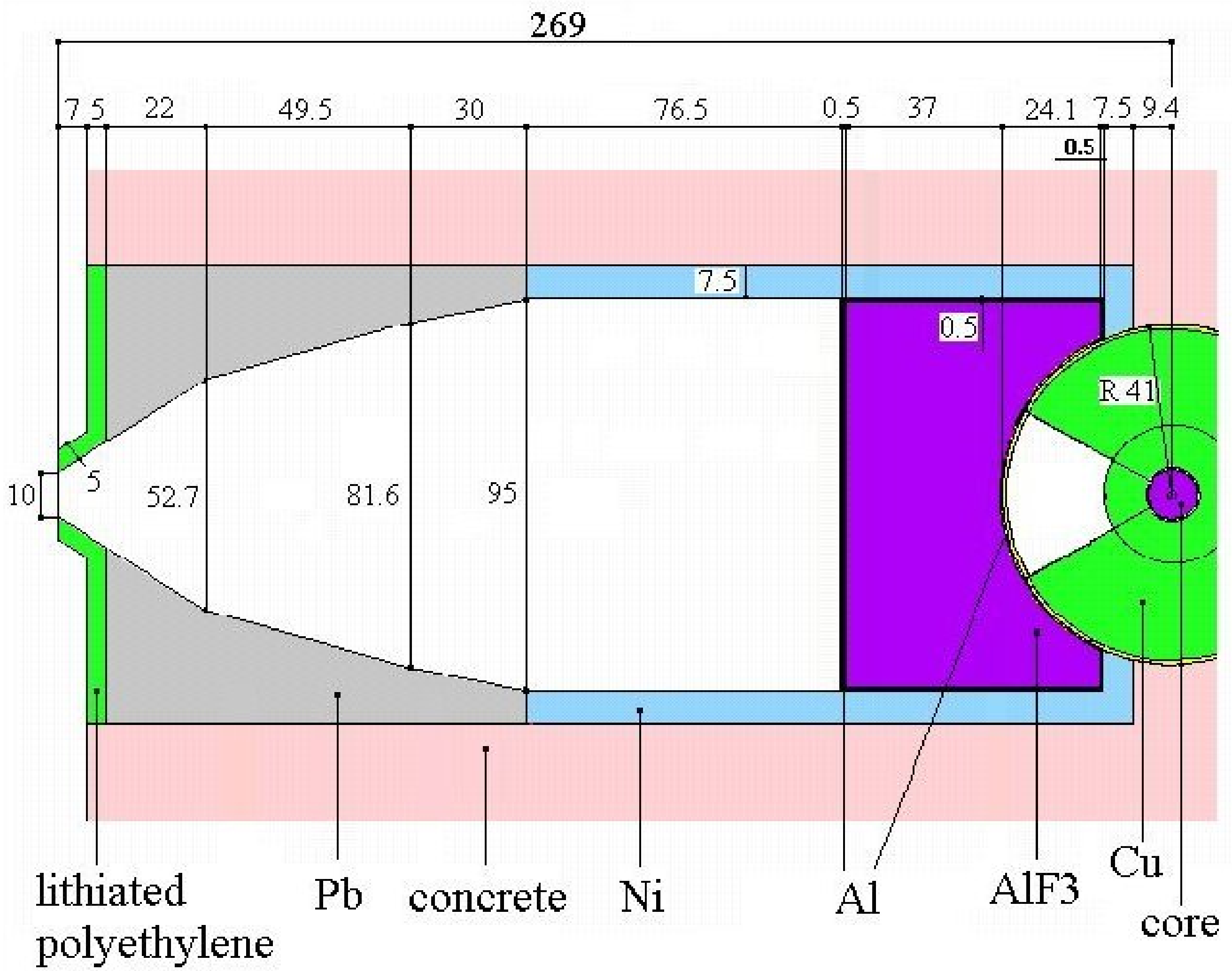
Irradiation facilities #2



Past activities

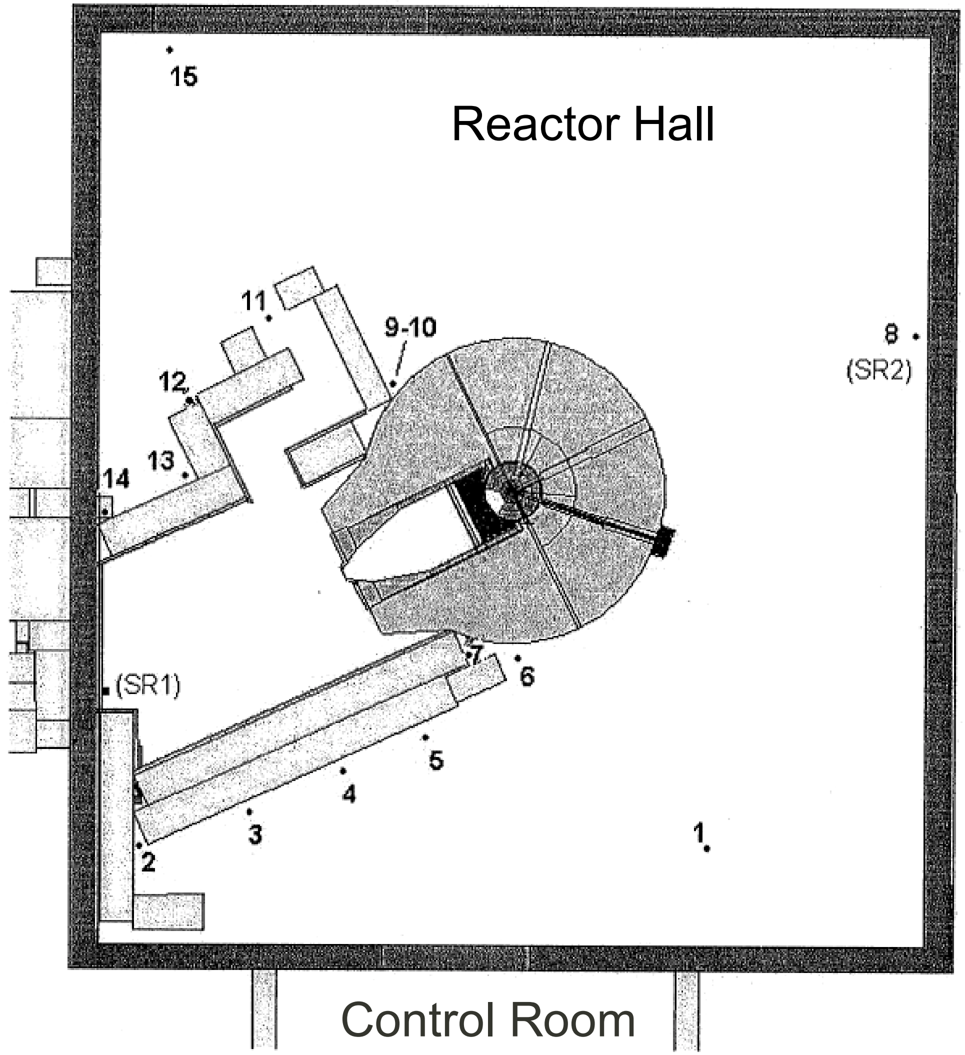
- Fast reactor shielding experiments;
- Fission yields evaluation from hard fast reactor core spectrum to degraded reflector spectra;
- in vivo cells irradiation;
- neutron dose effects on rats and other small animal;
- BNCT (Boron Neutron Capture Therapy).

Last activity (EPIMED)



TAPIRO Description

Last activity



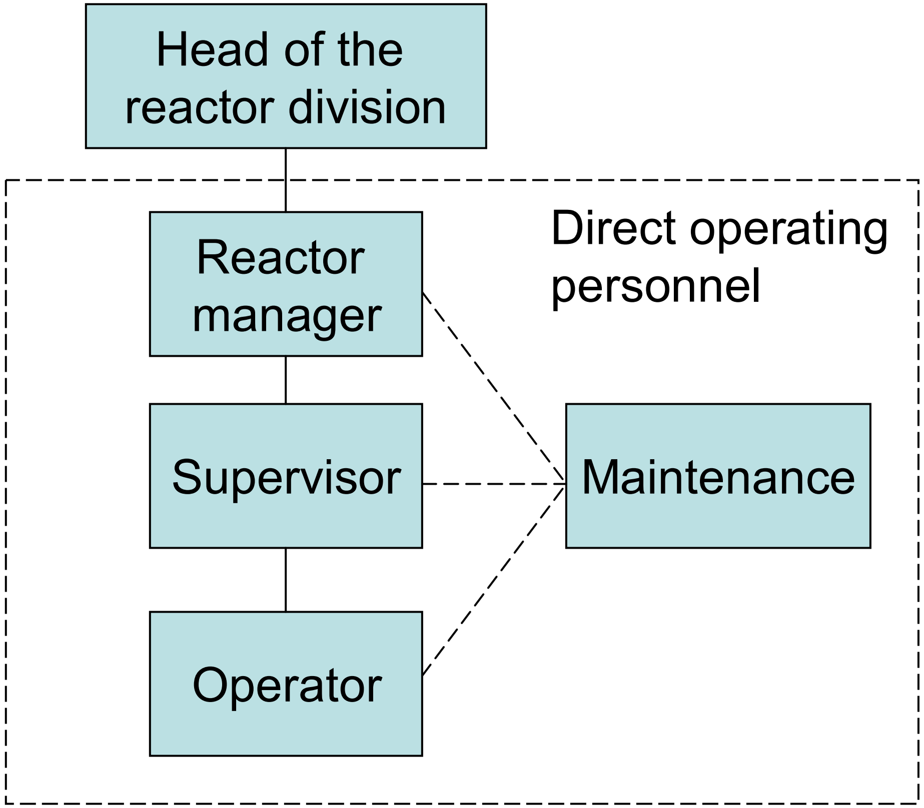
Planned activities …

- Dismantling the EPIMED facility;
- neutronic characterization;
- revision of Monte Carlo model of the reactor;
- support the experimental program about the generation IV reactor (HTGR);
- BNCT (Boron Neutron Capture Therapy) on cells and small animals.

Possible activities …

- New neutron Detectors tests;
- cooperate with Universities and Research Centers for the next Generation of Nuclear Experts;
- dedicated integral experiments and modeling to validate evaluated nuclear data libraries
- dedicated irradiation experiment for incineration/transmutation studies.

Staff


Head of the reactor division
Direct operating personnel
Reactor manager
Supervisor
Maintenance
Operator

Why we need neutronic characterization?

- New core and reflector configuration;
- to validate Monte Carlo model of the reactor;
- Compare the new findings with the old data.

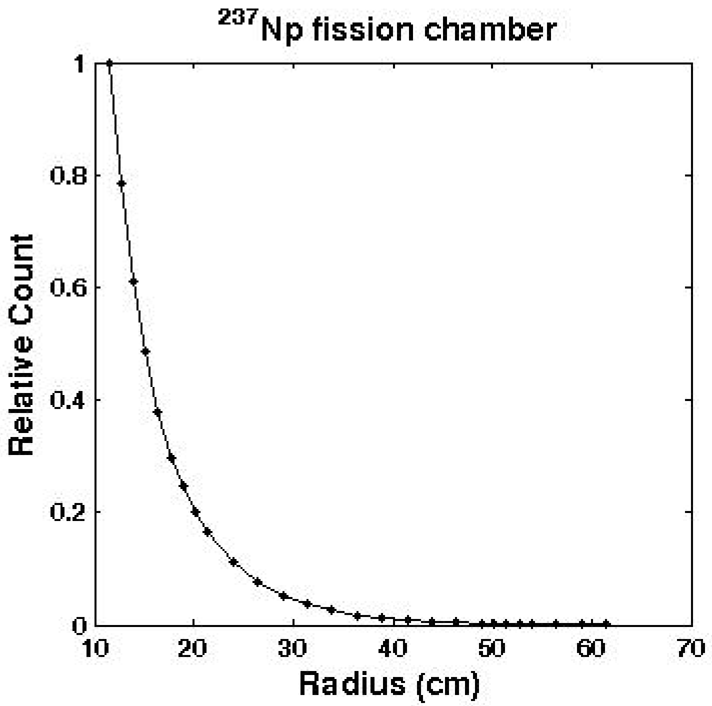
Old data #1

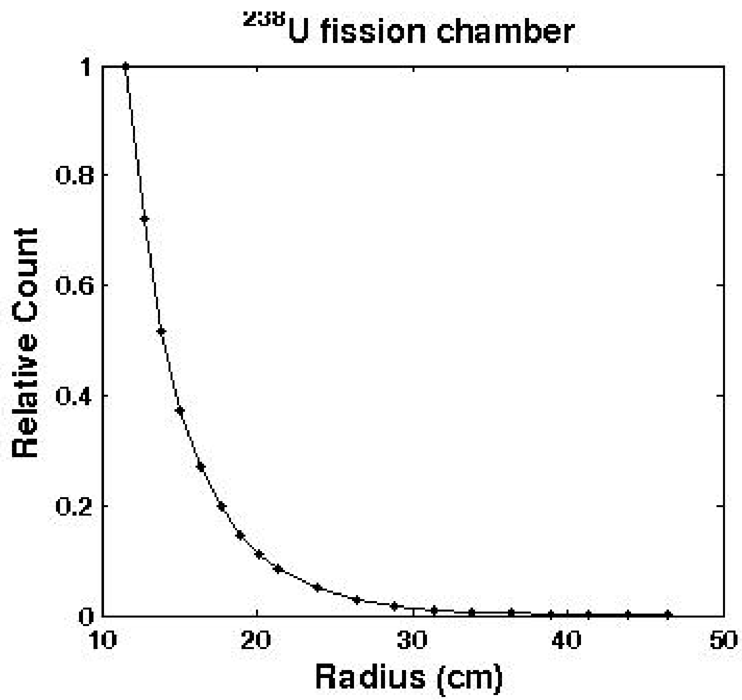
An extensive neutronic characterization of the TAPIRO source reactor was performed in 1984

- Large array of equivalent fission flux and reaction rate measurements was performed.
- Measurement of core centre fuel rating.
- Assessment of perturbations by voids related to TAPIRO shim rods, regulation rod, helium channel and source channel (reaction rate traverses in diametral and radial channels for two shim rod insertion levels: 197AU(n,g), 63Cu(n,g), 235U(n,f), 237Np(n,f) and 58Ni(n,p) reactions).
- Transport theory analysis of TAPIRO.

Old data #2 …

(Radial channel 1)





New measurements

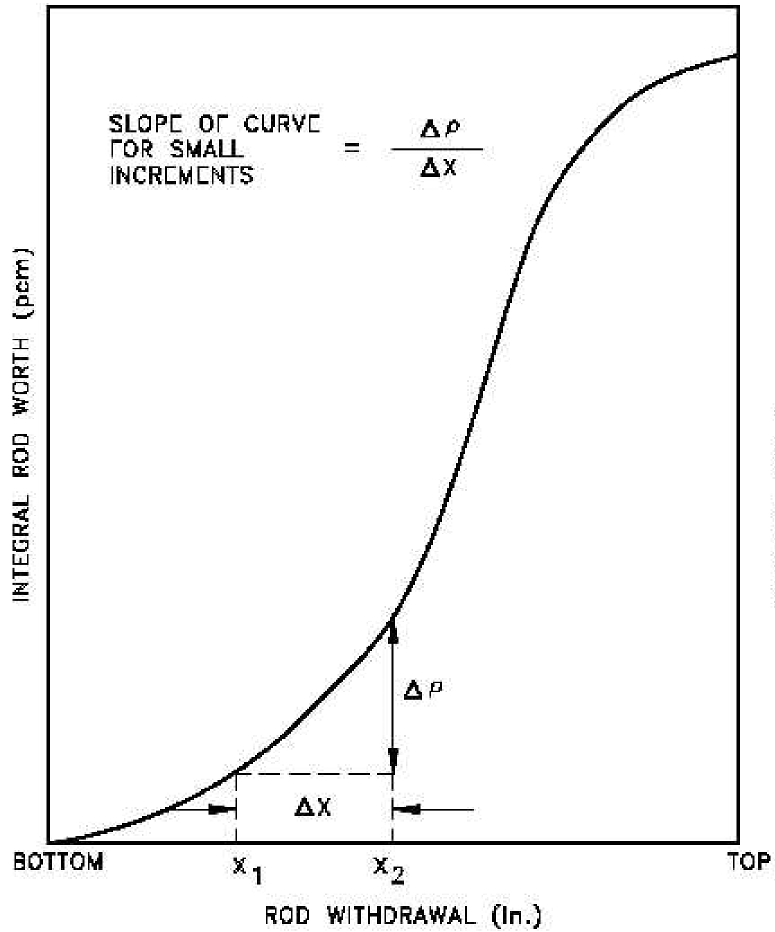
- **Integral Control Rod Worth**
- **Flux spatial distribution**
- **Effective delayed neutron fraction (β_{eff})**
- **External dose rate**

Integral Control Rod Worth /experimental set-up

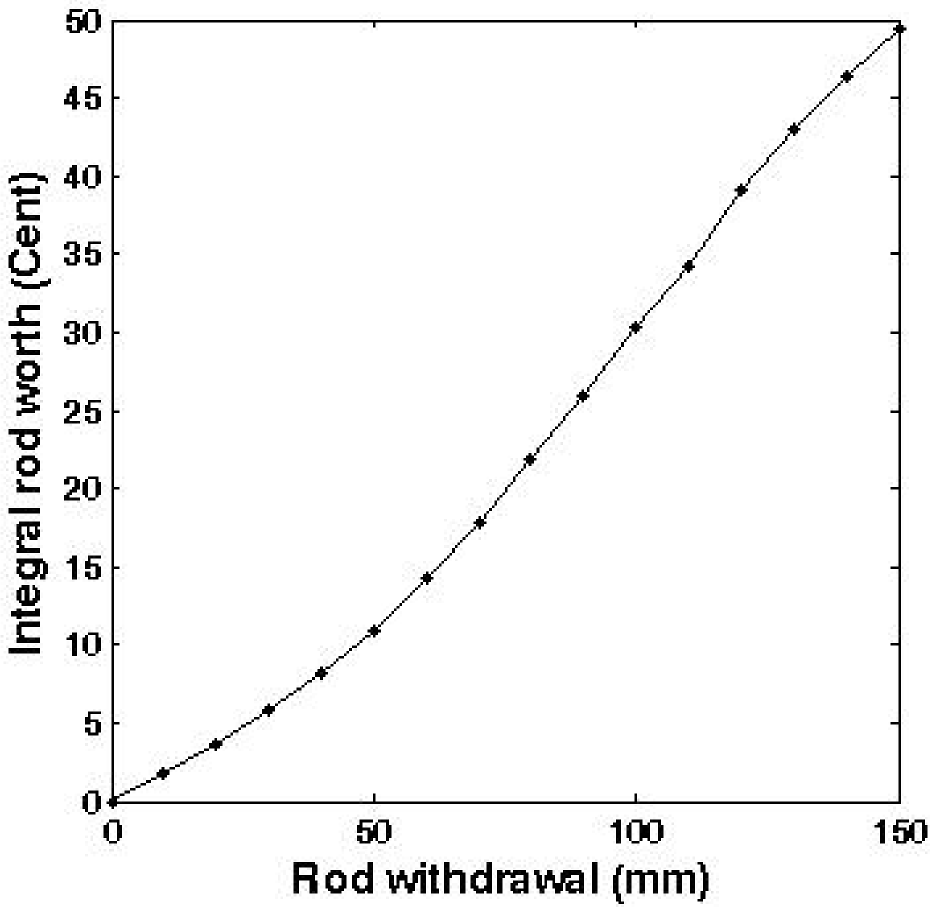
- **Make the reactor super-critical by inserting the Regulation rod;**
- **Power and neutron flux are proportional**
- **Measuring of the doubling time (DT)**

  Time such that $P_2=2 \cdot P_1$ or $\varphi_2=2 \cdot \varphi_1$

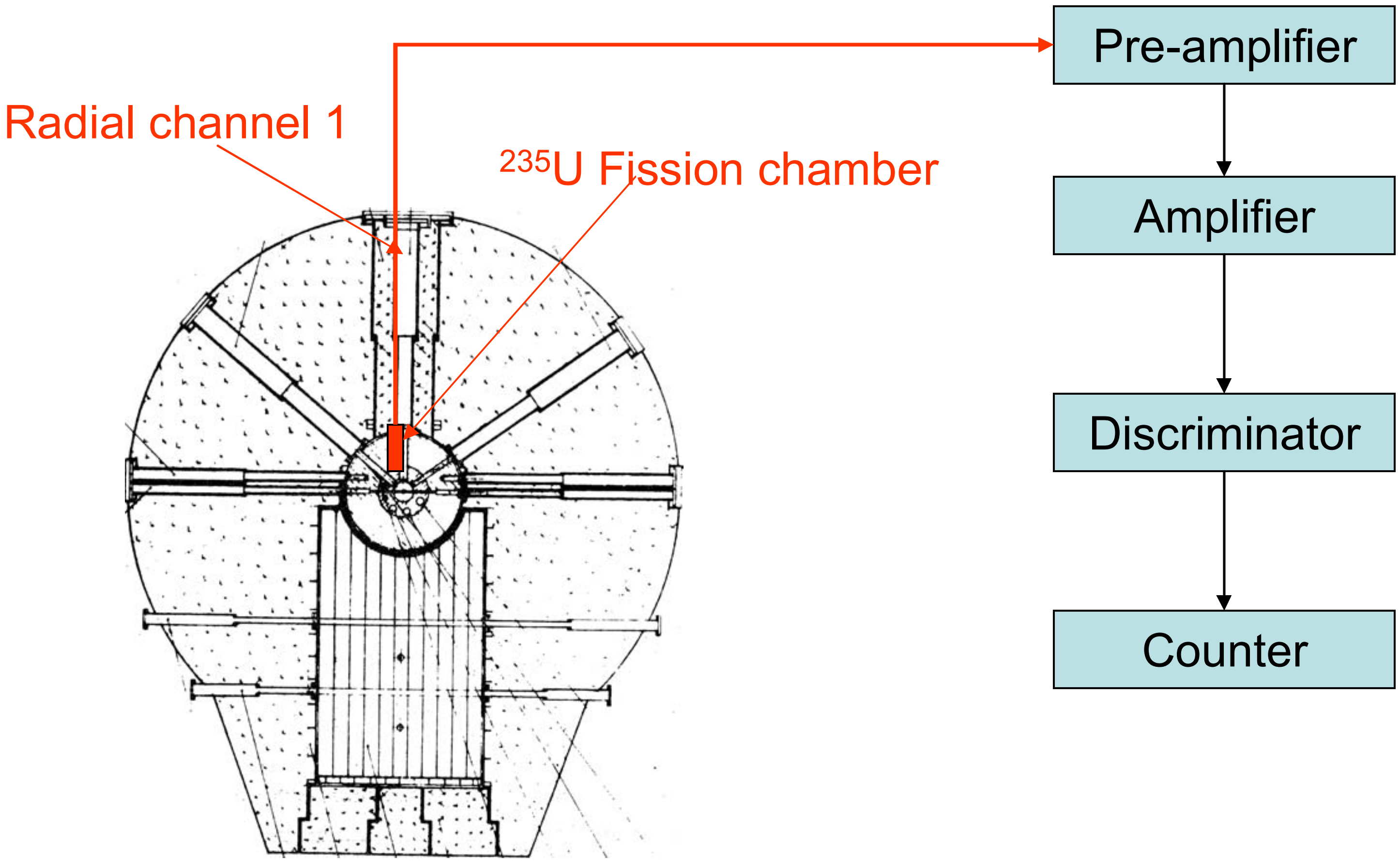
- **determining the stable reactor period $T=DT/\log(2)$**
- **determining the reactivity from the in-hour equation**



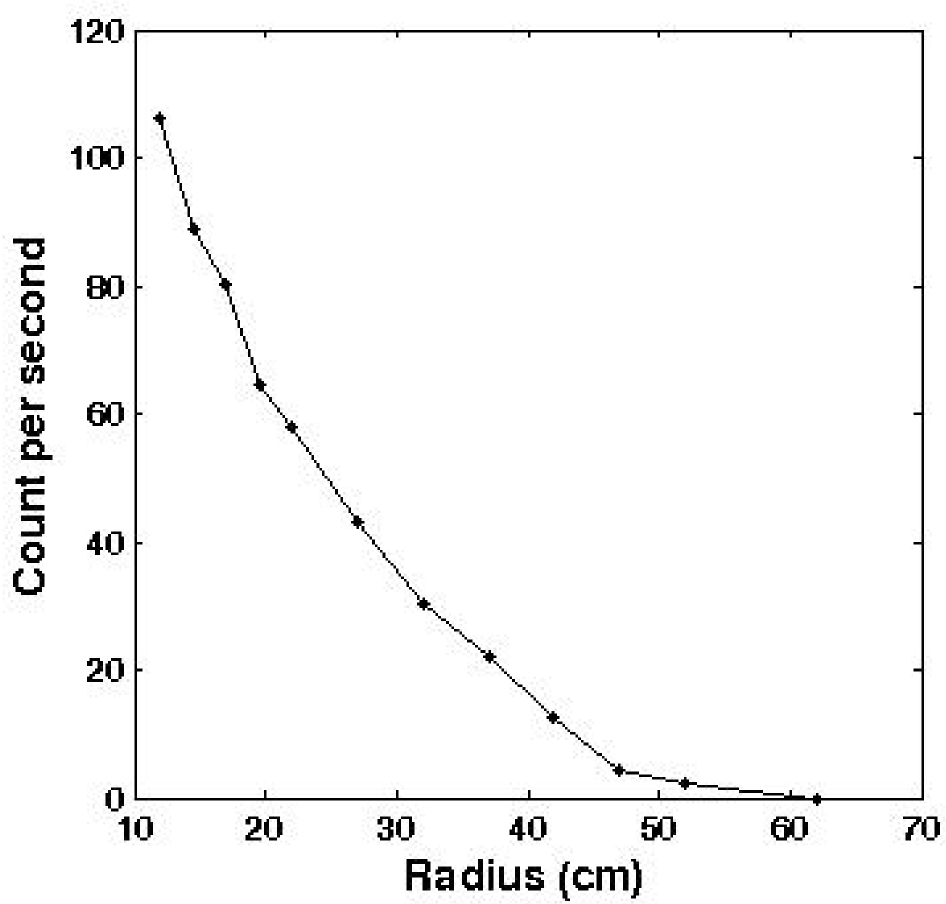
Integral Control Rod Worth/findings



Flux spatial distribution in Radial channel 1/experimental set-up



Flux spatial distribution/findings



Monte Carlo technique #1 (definition)

A technique which obtains a probabilistic approximation to the solution of a problem by using statistical sampling techniques.

Monte Carlo technique #2 (history)

Random methods of computation and experimentation can be traced back to the earliest pioneers of probability theory.

Physicists at Los Alamos Scientific laboratory were investigating radiation shielding and the distance that neutrons would likely travel through various materials.

John von Neumann and Stanislaw Ulam suggested that the problem be solved by modeling the experiment on a computer using chance. Von Neumann chose the name "Monte Carlo“ that is a reference to the Monte Carlo Casino in Monaco

Monte Carlo methods were central to the simulations required for the Manhattan project, though were severely limited by the computational tools at the time.

Only after electronic computers were first built (from 1945 on) that Monte Carlo methods began to be studied in depth

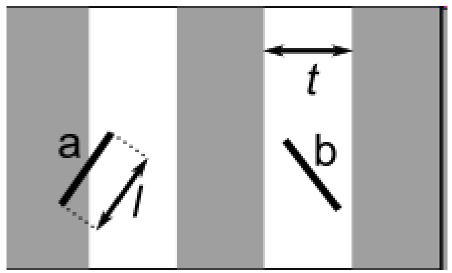
Monte Carlo technique #3 (history)

Example: **Buffon's needle** (18th century)

Suppose we have a floor made of parallel strips of wood, each the same width, and we drop a needle onto the floor. What is the probability that the needle will lie across a line between two strips?

the probability that the needle will cross a line:

$$P = \frac{2 \cdot l}{t \cdot \pi}$$



Suppose we drop n needles and find that h of those needles are crossing lines, then we can estimate the probability to be:

$$P_{est} = \frac{h}{n}$$

Note: $\pi_{est} = \frac{2 \cdot l \cdot n}{t \cdot h}$

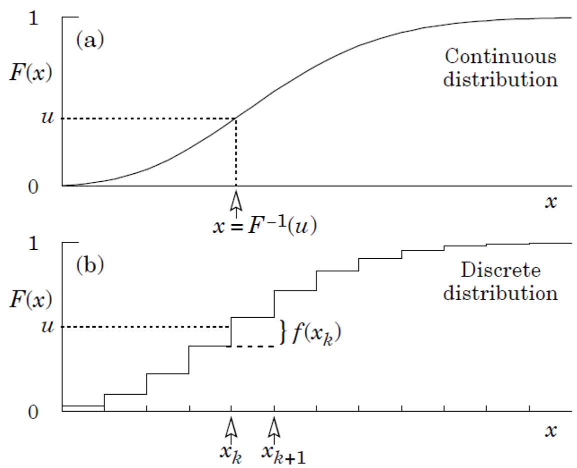
Monte Carlo technique #3 (description)

f(x) probability density →

Step 1) Uniform distribution u in [0,1)
Step 2) Sampling of distribution f(x)
- Inverse transform method $x=F^{-1}(u)$
- Acceptance-rejection method
- ….

→ x

Inverse transform method



Monte Carlo technique #4 (applications)

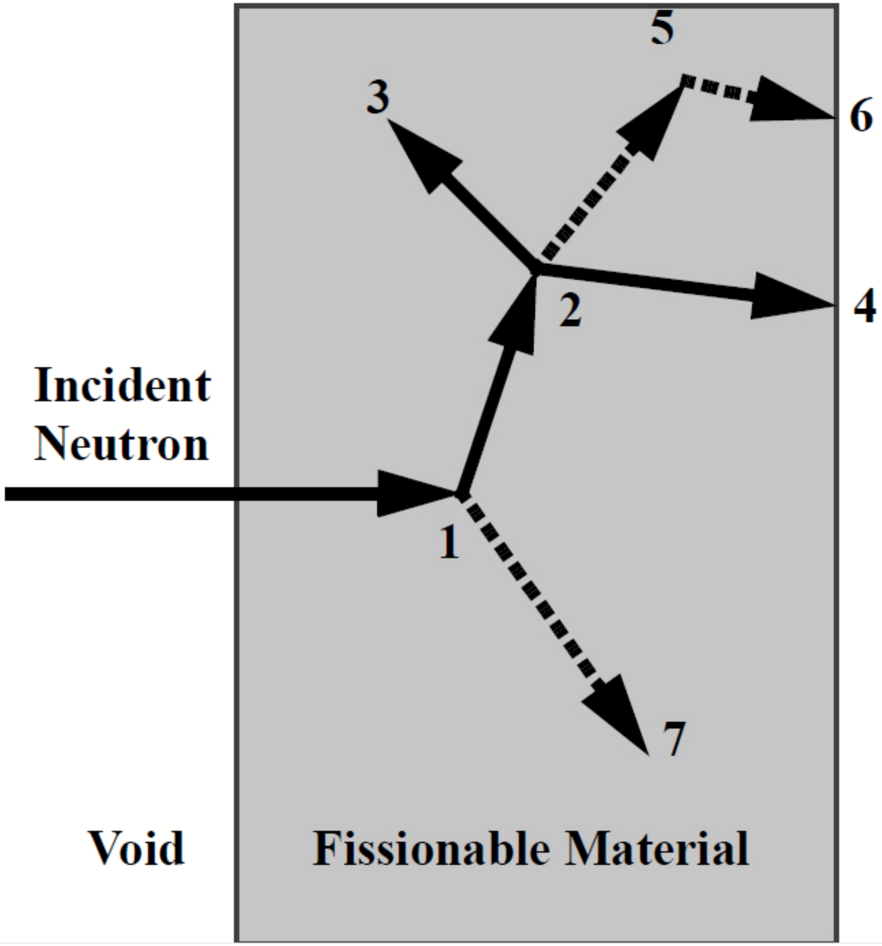
The methods is used in

- Random Number Generations
- Nuclear Reactor Design
- Traffic Flow
- Oil-Well explorations
- Economics
- Environmental – air pollution
- Medical application
- Simulation of galactic formation
- Quantum chromodynamics
- etc …

Monte Carlo technique #5 (particles transportation)

Event Log

1. Neutron scatter, photon production
2. Fission, photon production
3. Neutron capture
4. Neutron leakage
5. Photon scatter
6. Photon leakage
7. Photon capture



MCNP/MCNPX #1 (description)

MCNP is a general-purpose Monte Carlo N–Particle designed to simulate the transportation of neutrons, gamma rays and electrons.

MCNPX

- Is a extension of MCNP code.
- It is able to deal with many particle types over broad ranges of energies.
- MCNPX is fully three-dimensional and time dependent.
- It utilizes the latest nuclear cross section libraries and uses physics models
- MCNPX is used for nuclear medicine, accelerator applications, nuclear criticality, and much more.

The MCNP and MCNPX are Codes undergoing continuous development at Los Alamos National Laboratory and have periodic new releases.

MCNP/MCNPX #2 (history)

1963. First Los Alamos general-purpose particle transport Monte Carlo code: MCS It could run the MCS code to solve modest problems.

1965. MCN could solve the problem of neutrons interacting with matter in a three-dimensional geometry and used physics data stored in separate.

1973. MCN was merged with MCG a Monte Carlo gamma code that treated higher energy photons.

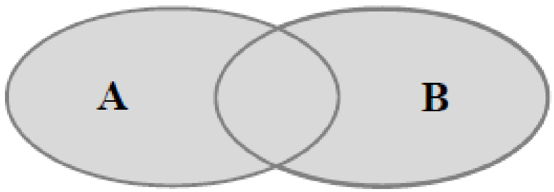
1977 MCNG was merged with MCP a Monte Carlo Photon code with detailed physics treatment down to 1 keV, to accurately model neutron-photon interactions. It name was MCNP

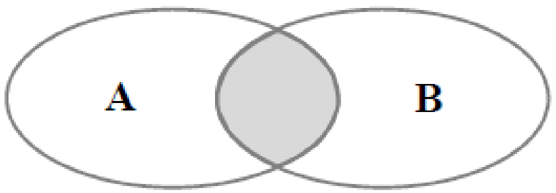
MCNP included the present generalized tally structure, automatic calculation of volumes, and a Monte Carlo eigenvalue algorithm to determine k_{eff} for nuclear criticality (KCODE).

MCNP/MCNPX input #1 …

MCNP is a 3-D combinatorial geometry code

The cells are defined by the intersections, unions, and complements of the regions bounded by the surfaces.





MCNP/MCNPX input #2 …

- Define the surfaces that bounded the cells (first- and second-degree surfaces and fourth-degree elliptical tori).
- The cells are defined by the intersections, unions, and complements of the regions bounded by the surfaces.
- Material definition (cross section library).
- Particles Transport strategy (number of particles, models, tallies, variance reduction technique, etc ..).

MCNP/MCNPX input #3

Structure of the MCNP input file

One Line Problem Title Card

Cell Cards [*Block 1*]

blank line delimiter

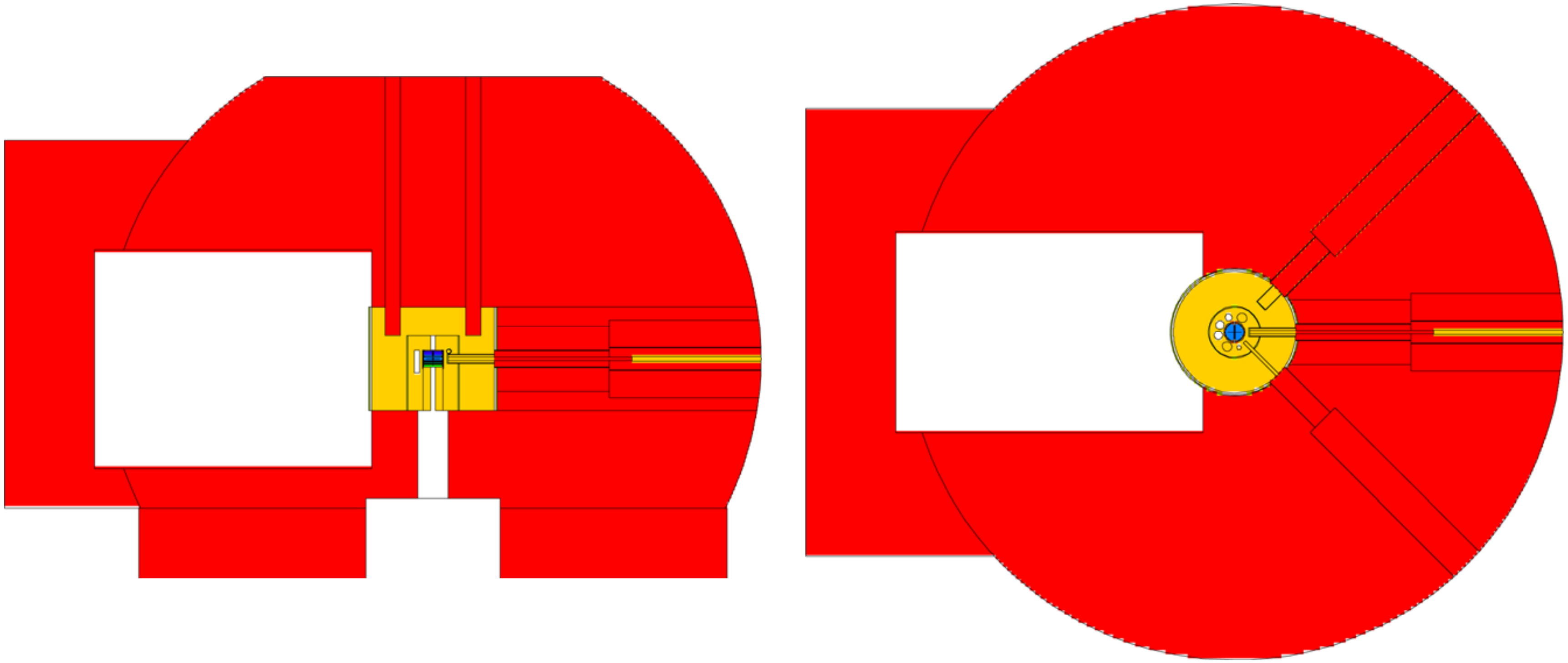
Surface Cards [*Block 2*]

blank line delimiter

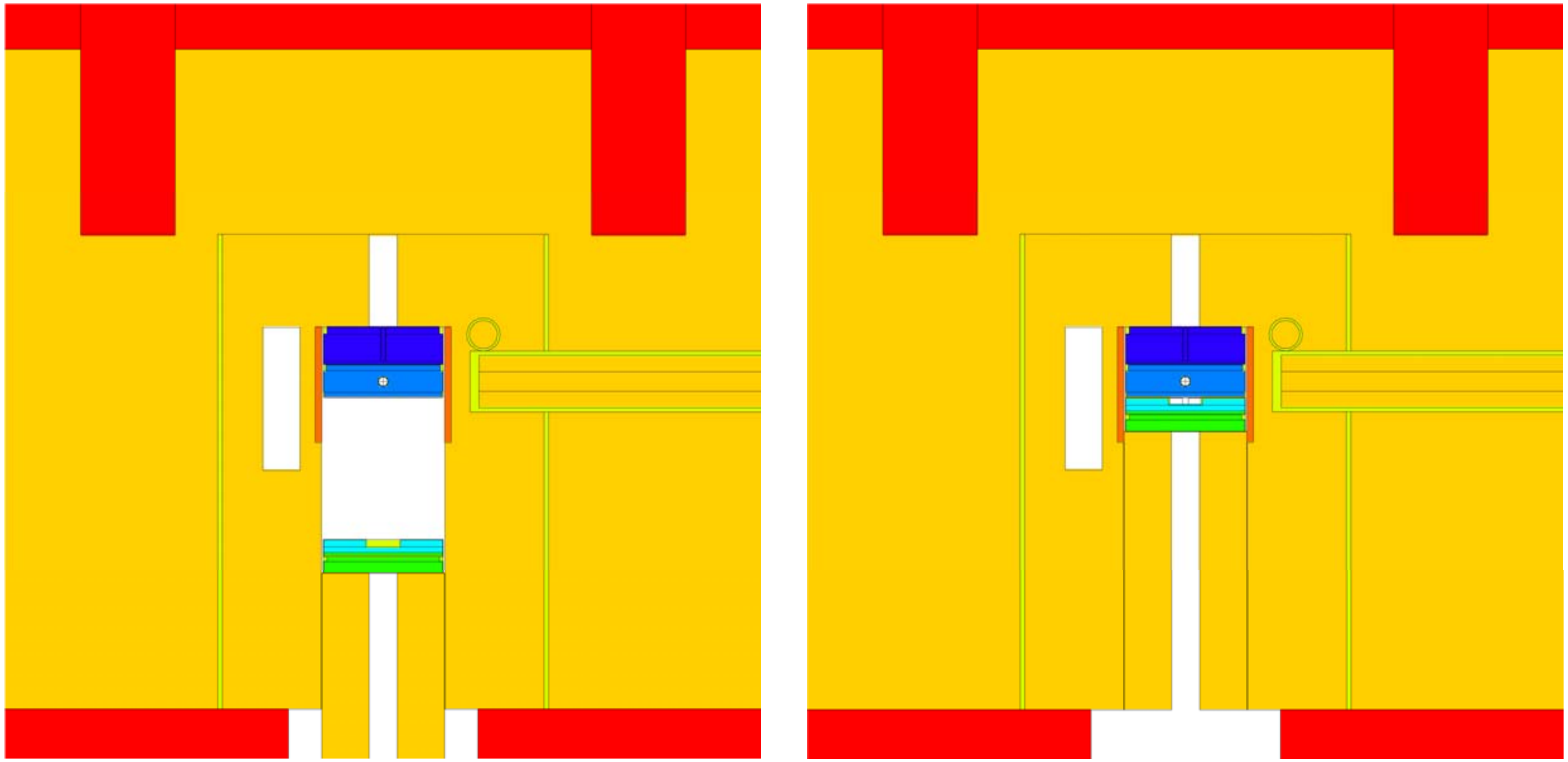
Data Cards [*Block 3*]

*blank line terminator {*optional*}*

MCNP/MCNPX TAPIRO #1 (plot) …

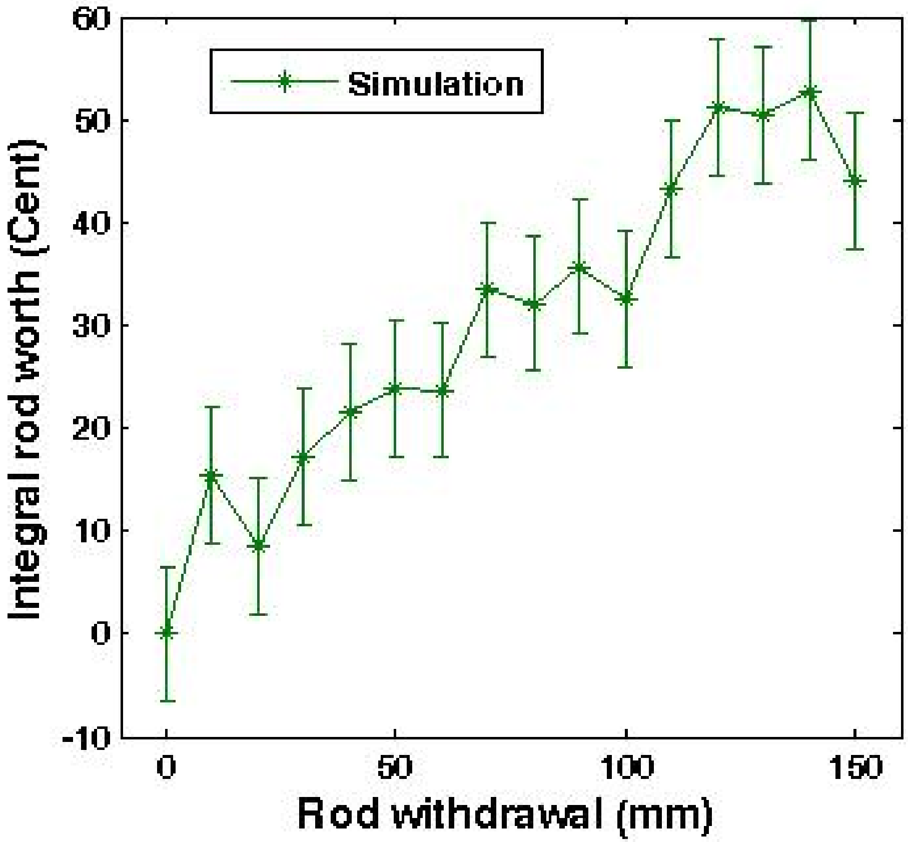


MCNP/MCNPX TAPIRO #2 (plot)



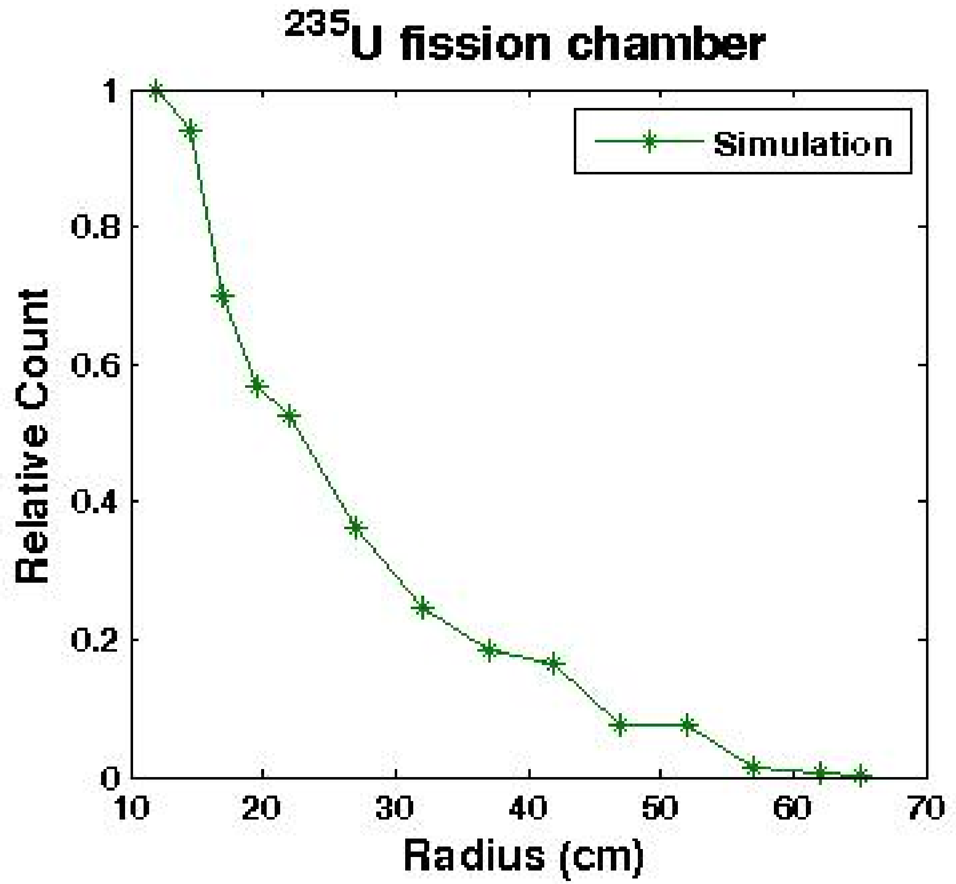
MCNP/MCNPX TAPIRO simulation results #1

(Integral Control Rod Worth)



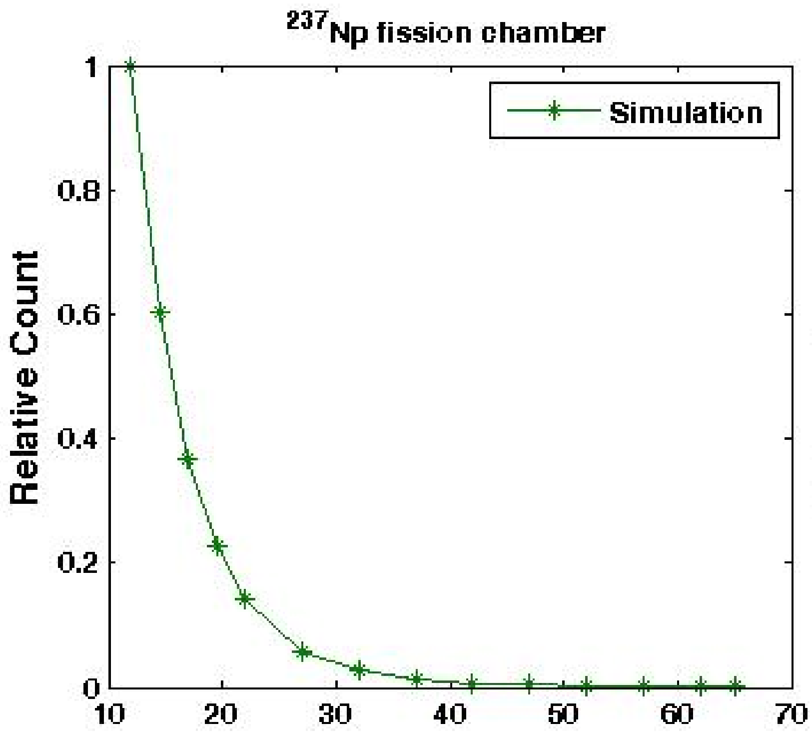
MCNP/MCNPX TAPIRO simulation results #2

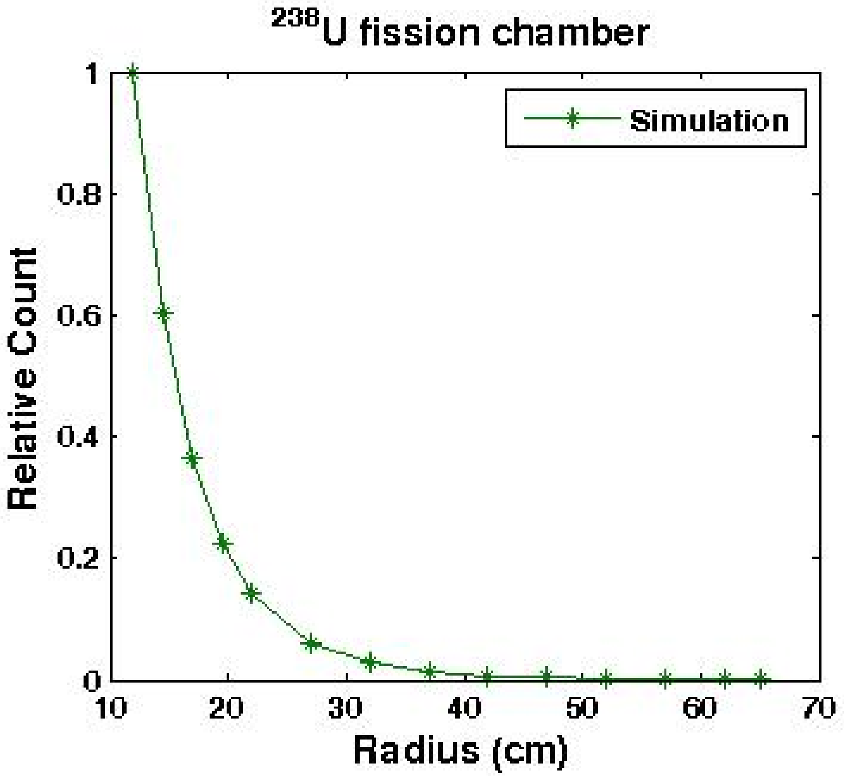
(Fission rate traverse)



MCNP/MCNPX TAPIRO simulation results #3

(Fission rate traverse)





MCNP/MCNPX TAPIRO simulation results #3

(effective delayed neutron fraction)

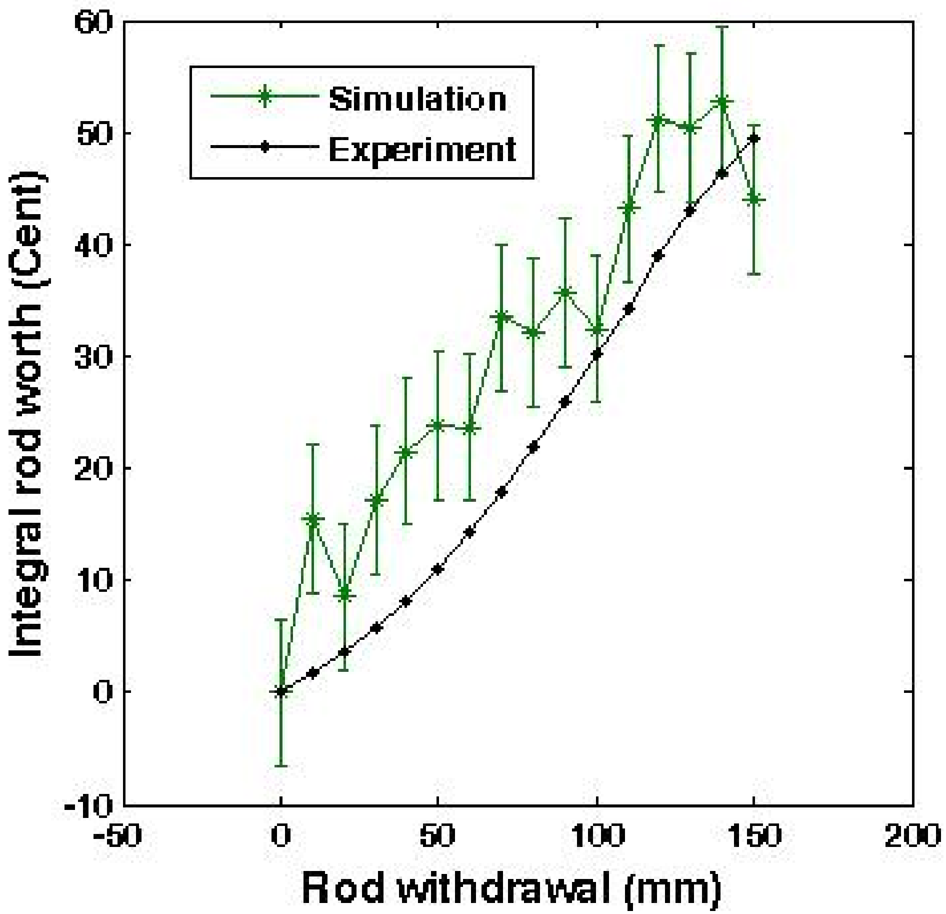
$\beta_{eff} \cong 1 - k_p/k$

k_p = prompt multiplication factor

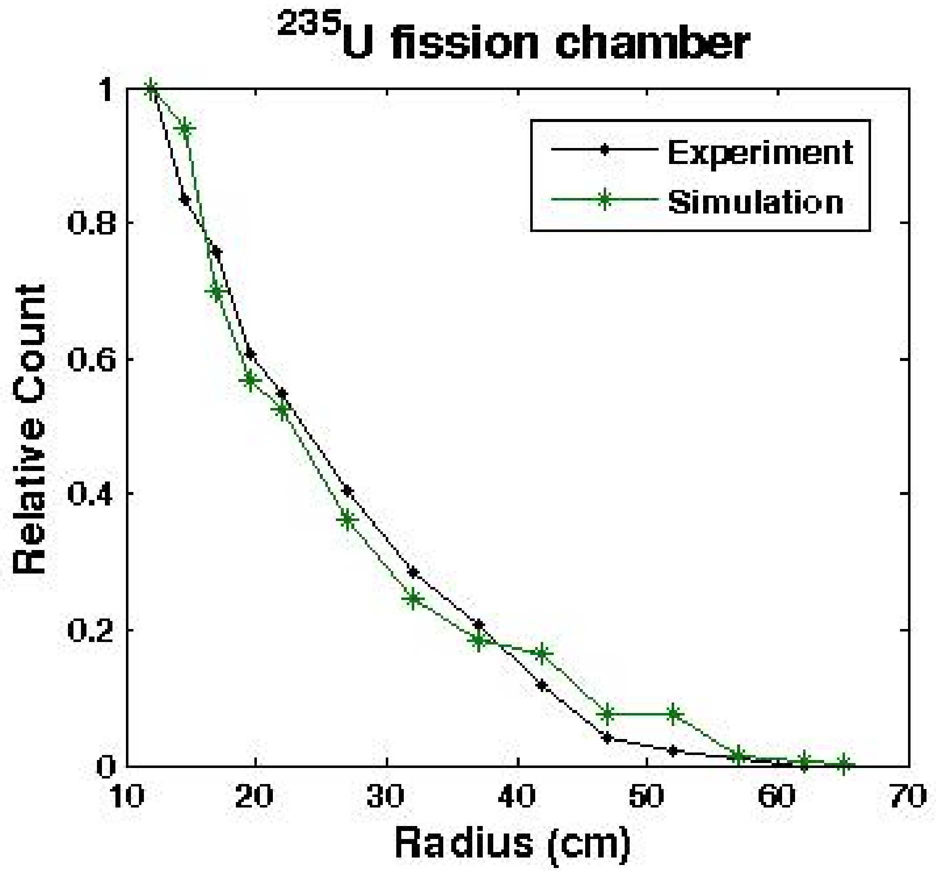
k = total multiplication factor

Old data	MC simulation
660 pcm	621±20 pcm

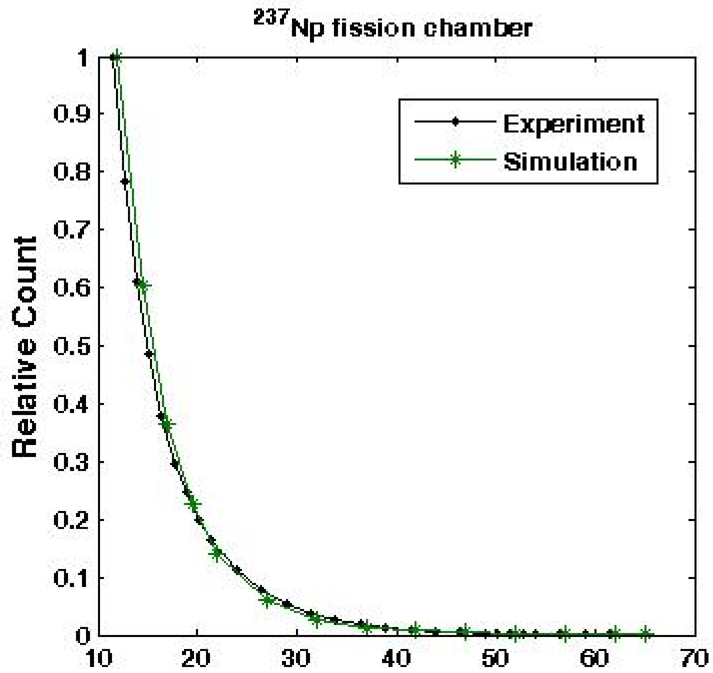
Integral Control Rod Worth Exp/Sim comparison

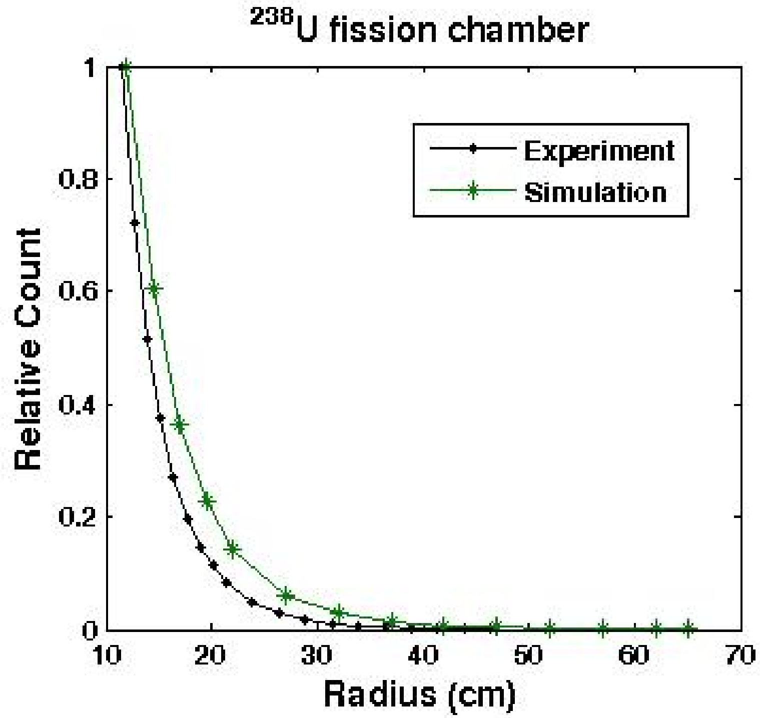


Flux spatial distribution (Radial channel 1) Exp/Sim comparison



Flux spatial distribution (Radial channel 1) Exp/Sim comparison





Conclusions

Simulation results agree with the old date (^{237}Np and ^{238}U fission rate). The spatial distribution in the radial channel 1 is unchanged.

Low discrepancy between simulation and experimental findings (^{235}U, ^{237}Np and ^{238}U fission rate and Integral regulation rod worth).

Future activities

- Measurement of the integral flux in the tangential, radial channel 2 and diametral channels.
- Neutron activation analysis for neutron spectrum determination.
- Effective delayed neutron fraction (βeff).
- Dose rate on the external surface of the concrete shielding.
- Further validation of TAPIRO MCNPX model.

Thank you for your attention!

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