ISTC PROJECT #2267
&
SAD/YALINA-B Steering Committee Meeting

Dubna, Russia

July 12-13, 2004

S. Chigrinov

YALINA status and planning

ISTC B-070

EXPERIMENTAL AND THEORETICAL RESEARCH ON TRANSMUTATION OF LONG-LIVED FISSION PRODUCTS AND MINOR ACTINIDES IN A SUBCRITICAL ASSEMBLY DRIVEN BY A NEUTRON GENERATOR

Collaborators:

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Royal Institute of Technology
Sweden

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CIEMAT Spain

C. Broeders
Karlsruhe
Germany

The main goals of the ISTC project :

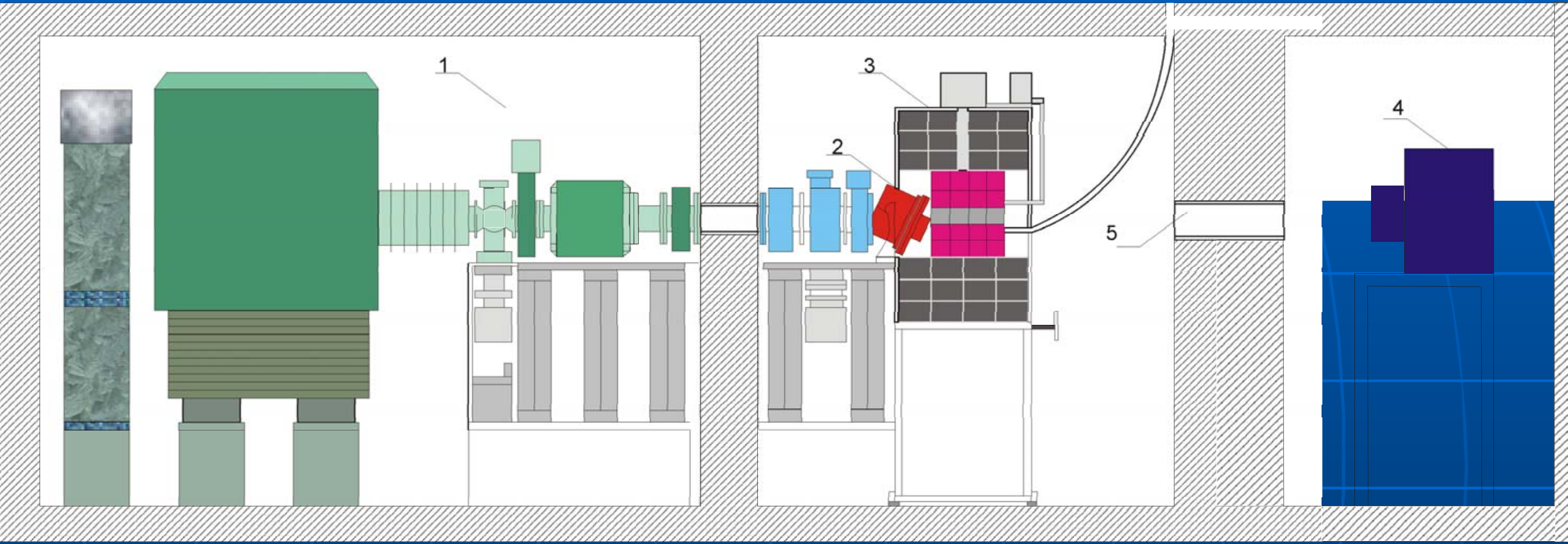
- creation the facility to investigate neutronic characteristic of the subcritical systems with thermal neutron spectrum, driven with external neutron source(a Cf-252 spontaneous fission source, 2.5 MeV (D,D) and 14.1 MeV (D,t) neutron sources);

-measurements of the transmutation rates of fission products and minor actinides;

- investigation of kinetics of the sub-critical systems with external neutron sources;

- validation of the experimental techniques for, e.g., sub-criticality monitoring, neutron spectra measurement, etc;

- investigation of dynamics characteristics of the sub-critical systems with the external neutron sources with pulse mode of neutron generator operation.



1 - нейтронный генератор
3 - подкритическая сборка
5 - коллиматор

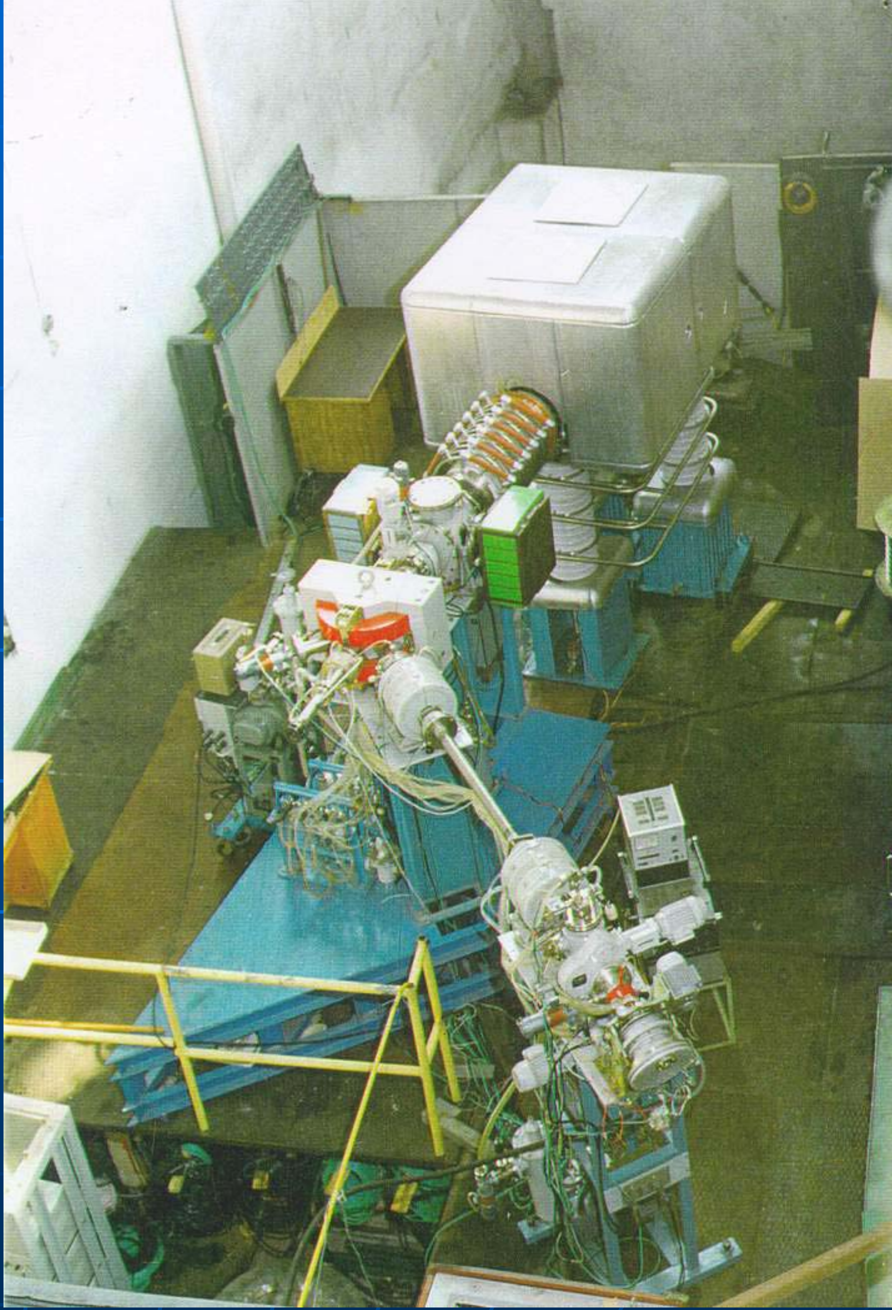
2 - Ti-^{2}H или Ti-^{3}H мишень
4 - γ - спектрометр

- Accelerator H^+ and D^+
- Beam energy 100-250 КэВ
- Beam current 1 - 12 mA
- **Pulse duration $(0.5-100)10^{-6}$сек**
- **Repetition rate (1-10 000) Hz**
- Spot size ≈2.0 cm

- Ti3H target (230 mm):
- Rotating speed, rpm 560
- Maximal yield of neutrons, n/s:
- $1.5-2.010^{12}$
- Neutron energy 13-15 МэВ

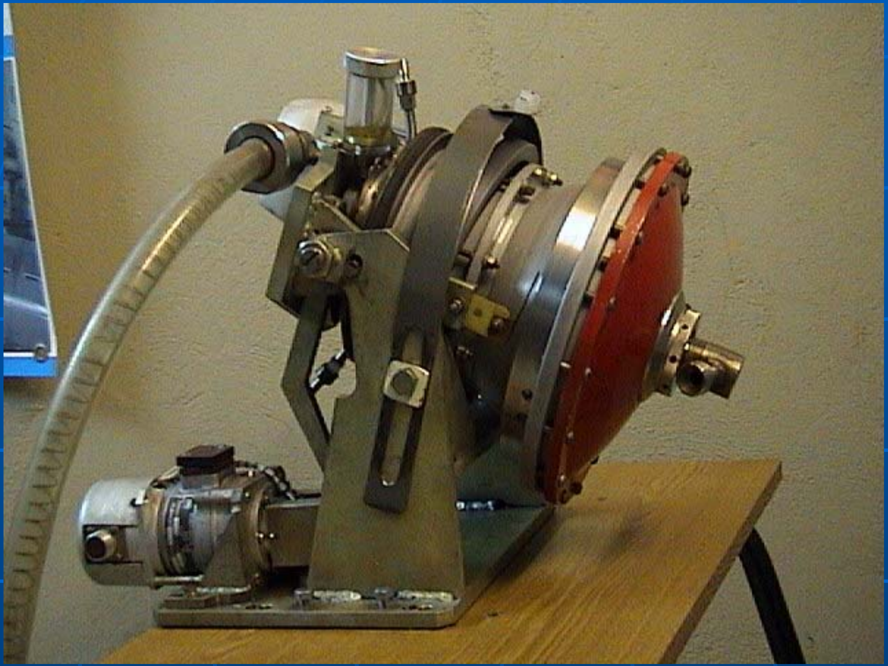
- TiD target (230 mm):

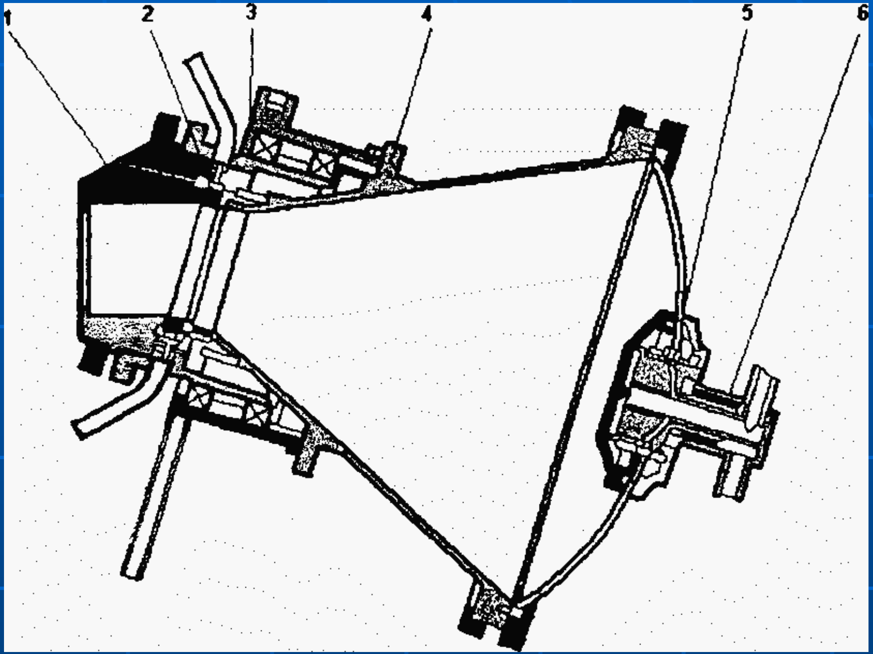
- Maximal yield of neutrons, n/s:
- $2-3.0\ 10^{10}$
- Neutron energy 2.5-3.0 МэВ



Neutron generator NG-12-1 ($D+^3H \rightarrow n+^4He; D+D \rightarrow n+^3He$)

TiH (TiD) targets characteristic





⇑

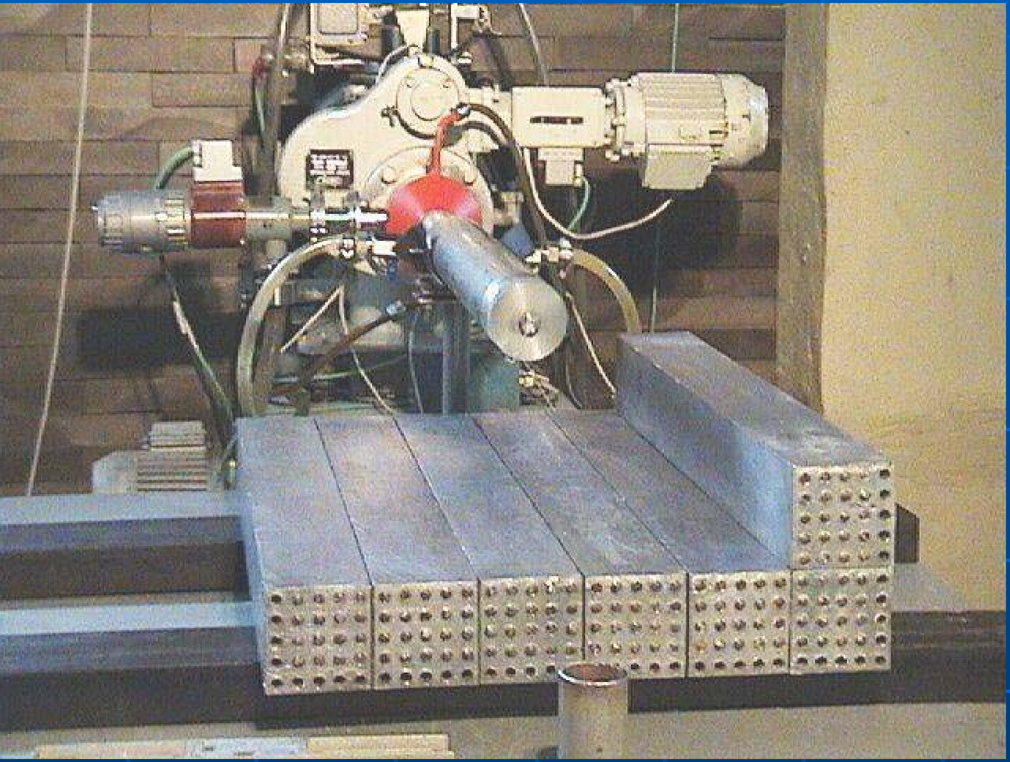
Rotating speed	560 rpm
Target diameter	230 mm
Diameter of reaction space	100-200 mm
Tritium activity	0.53-0.75 MCi/kg
D/Ti (T/Ti) atomic ratio	≈ 1.5

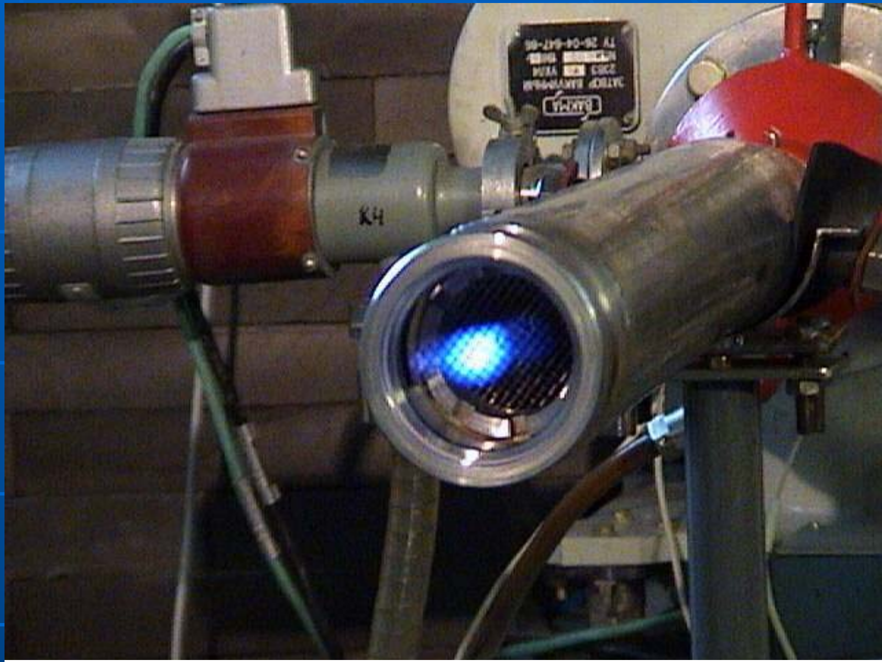
Target diameter

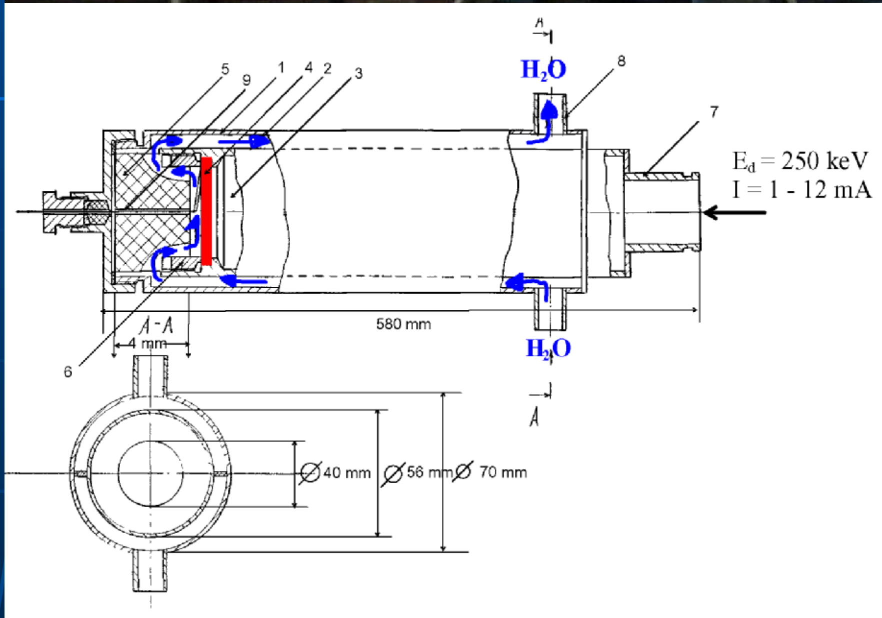
45 mm

⇒

The NG-12-1 Deuteron guide (**MM – L**) for 45 mm diameter Ti3H (TiD) targets

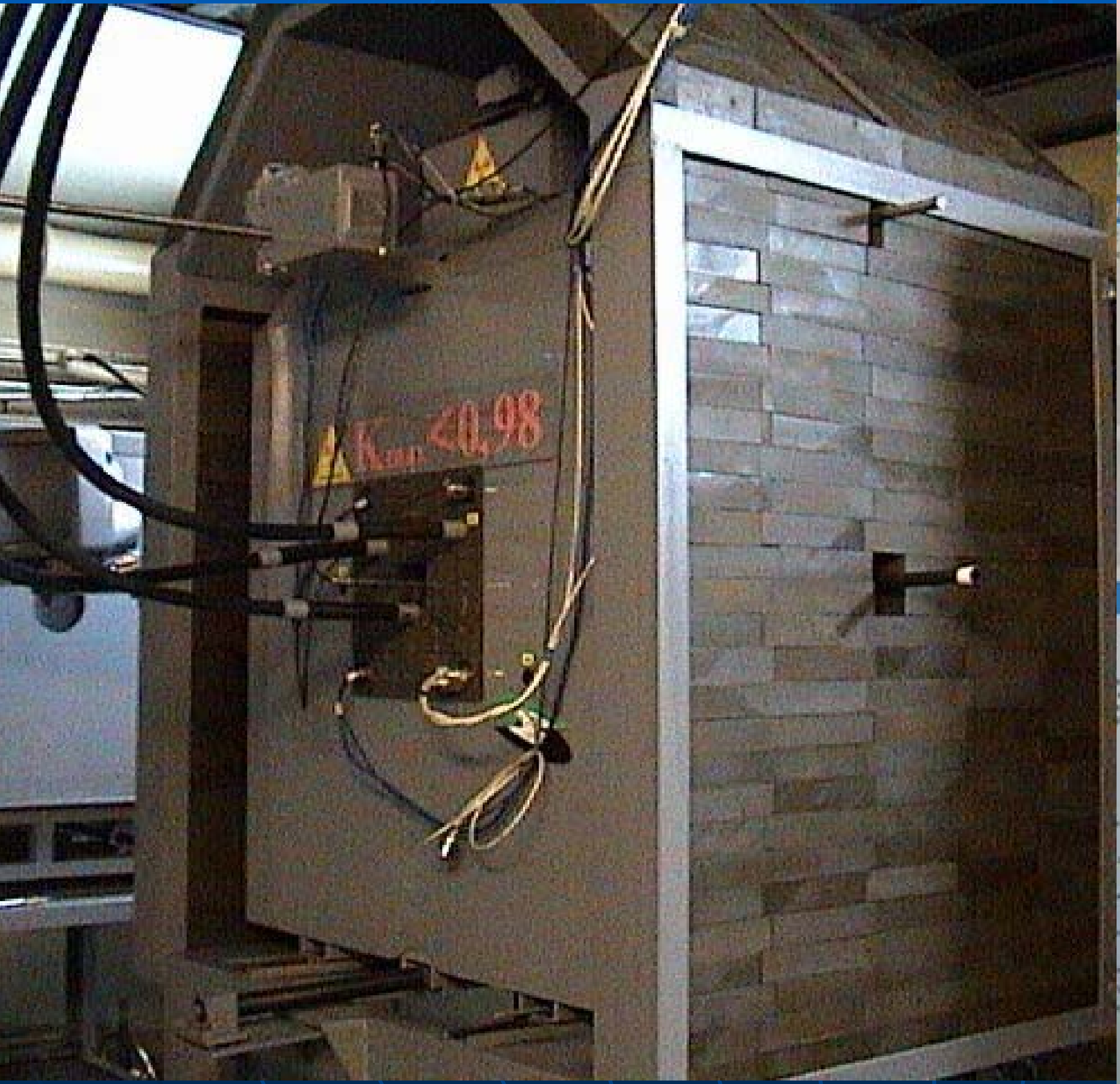


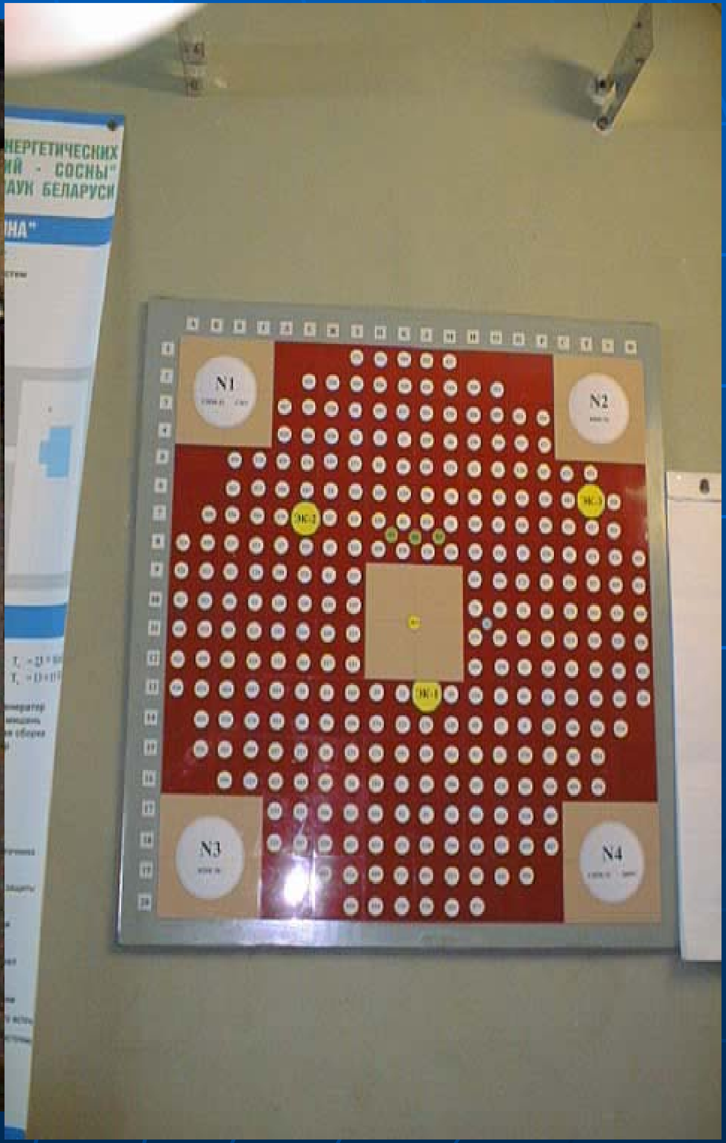




Subcritical assembly with thermal neutron cpecrum

Keff. = 0.98 (Total mass of uranium - 21949.5 g)





Fission chambers without integral cable for in-core use

Type	Diameter nominal, mm	Detector length nominal, mm	Detector length sensitive, mm	Isotope	Sensitivity to thermal neutrons		Sensitivity to fast neutrons cs^{-1} / n·cm^{-2}·s^{-1}	Sensitive square, cm^2	Sensitive layer, (mg·cm^{-2})	Filling gas
					Pulse mode (cs^{-1}/ n·cm^{-2}·s^{-1})	Current mode (A / n·cm^{-2}·s^{-1})				
KNT-56	50	750	525	^{10}B	–	$4\cdot10^{-13}$	–	–	–	BF_3
KNT-10	7	70	5	^{10}B	–	–	–	1	0,5	
KNT-2	7	70	10	^{232}Th	–	–	$6\cdot10^{-7}$	2	5	98%Ar + 2%N_2
KNT-5	7	70	5	^{235}U	$5\cdot10^{-4}$	–	–	1	1	98%Ar + 2%N_2
KNT-8	7	70	10	^{238}U	–	–	$2\cdot10^{-6}$	2	5	98%Ar + 2%N_2
KNT-31	32	235	200	^{235}U	0,25	–	–	500	1	98%Ar + 2%N_2
KNT-54	50	242	220	^{235}U	0,5	–	–	1000	1	98%Ar + 2%N_2
0.5 NHI/IK	10	62.5	10	He^3	0.5	-	-	-	-	He^3+Kr

2. He-3 detectors (10 мм diameter (NH10NM))

Type	*Effective length, mm*	*Neutron sensitivity, ($c*s^{-1}/n*cm^{-2}s^{-1}$)*
0,5NKI/IK	**10**	**0,5**
12NK40/I	**250**	**12**

Technical characteristics of available equipment

1. **Time analyzer TURBO MCS** (ORTEC)

Max counting rate	150 MHz;
Channel width	5 ns – 65 535s;
Pass length	to 16 384 channels
Memory capacity	16 777 215 counts/channel;
Input amplitude	from -5B to +5B;
min input pulse width	3 ns.

3.Charge sensible amplifier for He-3 detectors (ACHNP97 and ACHNA98 types)

dead time – 0.8 μs;

counting losses 3.1% at 40 000cps

4. 7820 ADS module –programming pulse amplifier-discriminator NIM standard

- **rise time – 20ns;**
- **resolving time – 50ns**.

5. Module NIM standard 7821 – 5th ports programming high-voltage power source - to +2000 B.

PROGRAMMABLE PULSE AMPLIFIER & DISCRIMINATOR NIM MODULE

FUEL CYCLE

7820

Ref: DC-11/01-69272A

- For all radiation pulse detectors (α, β, γ, X and neutrons)
- Perfectly adapted to neutron measurements with fission chamber or bore depositated counter (followup of reactor power or measurement of spent fuel)
- Fully programmable by PC computer via RS232, RS485 and Ethernet built-in interfaces
- Check-up of pre-defined values via the computer link

- High count rates up to 8 10^6 c/s

- Current collection operation allowing coaxial long distance connections without preamplifier up to 250 m
- Integrated TTL insulated outputs for external counting units
- Built-in test generator
- Connection to the ADC of an MCA for control purposes

- Coaxial HPGe detector 80 % relative efficiency,
- resolution (FWHM) –
- 0.9 keV (122 keV), 1.8 keV (1332 keV).

- Low energy germanium detector (active area - 500 мм2),
- resolution (FWHM) – 550 eV (122 keV).

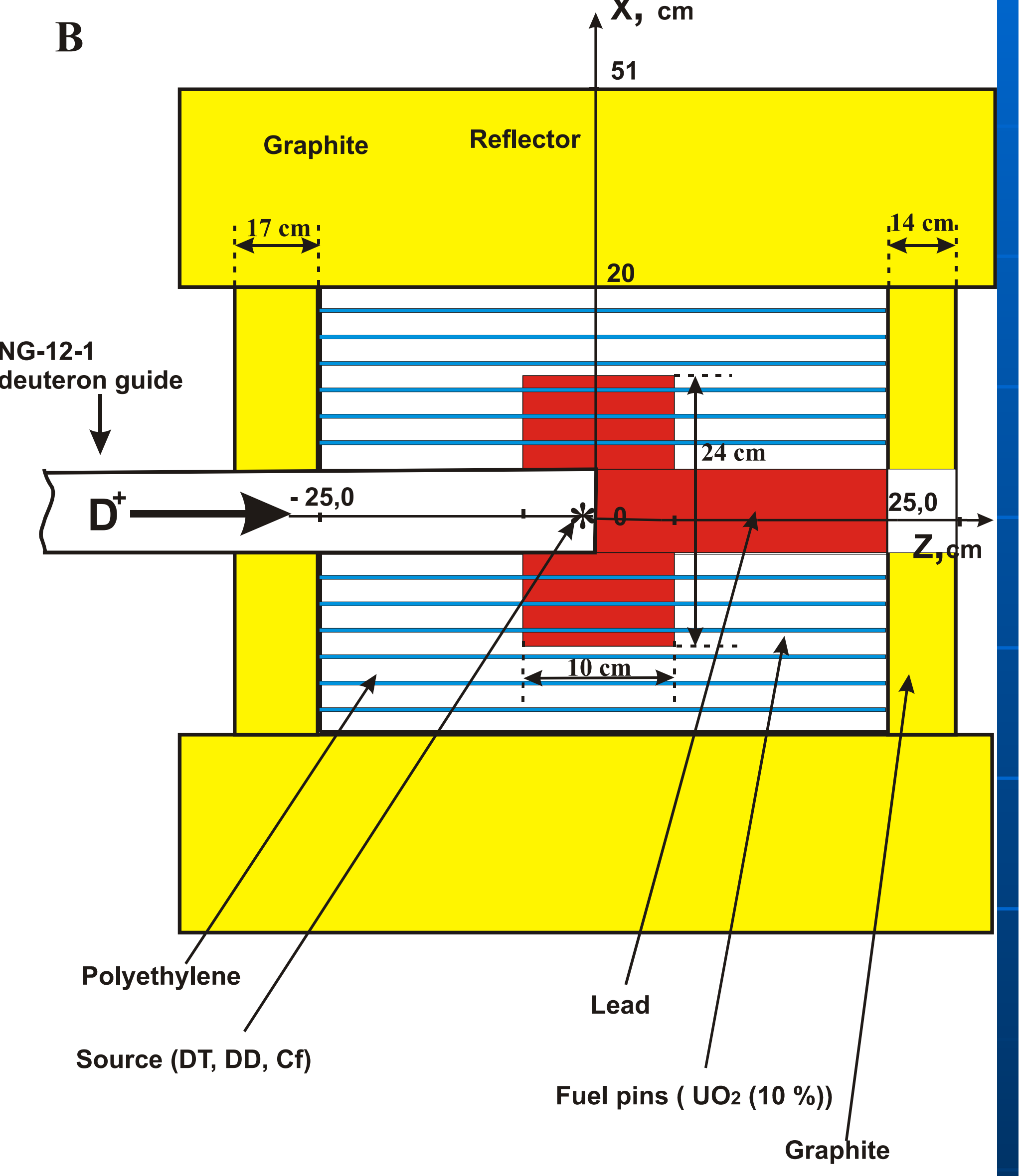
- Spectroscopy software GENIE-2000.
- MGA и MGAU software for multi group analysis of Uranium and Plutonium.

- U-Pu Inspector Canberra Industries, Inc

- standard tritium water samples;

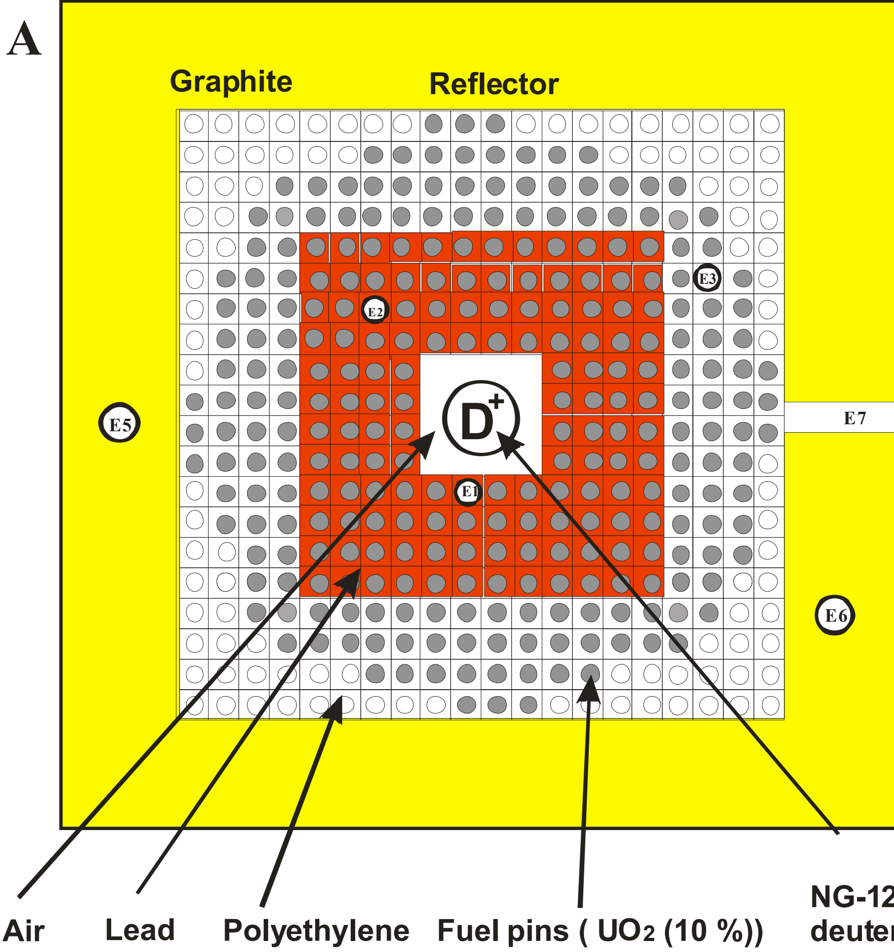
- the Np-237, Am-243 and I-129 samples ;

- BF3 - chambers



Source-core configuration for 280 fuel pins

B - longitudinal section



Core configuration for 280 fuel pins
(lead zone is placed at the core center)

A - cross-section (-5 cm < z < 0 cm)

E1 - E7 - experimental channels

SHORT- TERM EXPERIMENTAL PROGRAM

1.1. Measurement of multiplication factor of "new" (rearranged) core of the subcritical assembly (with lead zone in the core centre).

1.2. Measurements of spatial distribution of neutron flux density in the core (in experimental channels of the core and reflector).

1.3. Measurements of time dependence of neutron flux density inside experimental channels of subcritical assembly (in the core and the reflector) with pulse mode operation of neutron generator

II Kinetic mesaurment ($\Lambda,\rho,\alpha,\beta$)

- a) Source multiplication method (critical loading experiment);
- b) pulsed neutron method;
- c) noise analysis method (Feynman-alpha method)
- d) Syostrand method (area method)
  Ad/Ap = β/ρ; Y = A + B e-αt ; **α**=(β-ρ)/Λ; β = 7.37 10-3
- e) Gozani, T. Nukleonik 4(1962), 348.
  -ρ=f A/αB; f – pulse repetition (f ≈ 54 Hz); Y = A + B e-αt
- f) Source jerk method

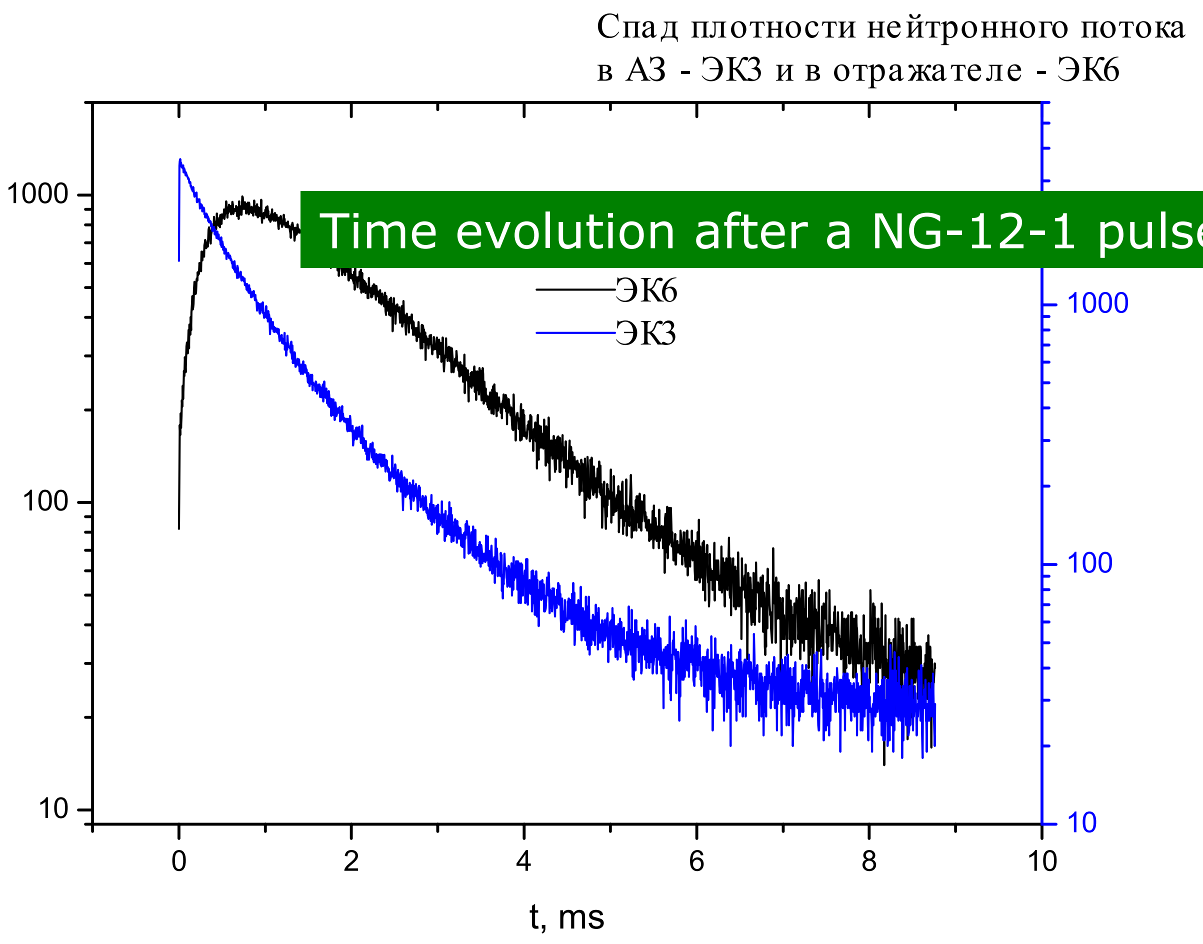
III. A comparison of experimental and calculated (MCNP-4B) results will be carried out.

Measurements will be performed by of 3He - detectors and fission chambers (U-235, U-238, Th-232, ...) and with DT,DD and 252Cf neutron sources.

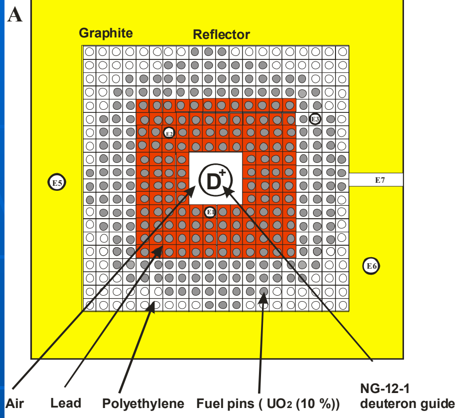
The following experimental program can be performed (?)

- 1. *keff* for Nrods equal to 216,245,280;
- *2. Multiplication factors ksrc for Nrods equal to 216,245,280 with different neutron sources S0(E,r,z);*
- 3. Reactivity changes $\Delta\rho$ ($\rho=(keff-1)/keff$) due to removal both the central and the peripheral fuel rods;
- 4. Lifetime of prompt neutrons τ_p;
- 5. The following reaction rates inside the experimental channels: 129I(n,γ)130I, 237Np(n, γ)238Np, 243Am(n, γ)244Am, 237Np(n,f), 243Am(n,f);
- 6. The fission reaction rates for 235U inside the experimental channels;
- 7. Neutron flux densities and energy spectra as well as spectral indices $\langle\sigma f\rangle U238/\langle\sigma f\rangle U235$ and $\langle\sigma f\rangle Th/\langle\sigma f\rangle U235$, $\langle\sigma f\rangle U233/\langle\sigma f\rangle U235$, $\langle\sigma f\rangle Pu239/\langle\sigma f\rangle U235$ inside the experimental channels. Nrods equal to 216,245,280;
- ((8. External neutron source importance $\varphi^* = \langle\nu\rangle(1/keff - 1)\cdot P/S0$;
- ($\varphi^* = (1-keff)/keff\cdot ksrc/(1-ksrc)$)) for Nrods equal to 216,245,280;
- 9. Time distributions of fission rates 235U(n,f) for Nrods equal to 216,245,280 with two neutron sources (DD,DT).

Time evolution after a NG-12-1 pulse



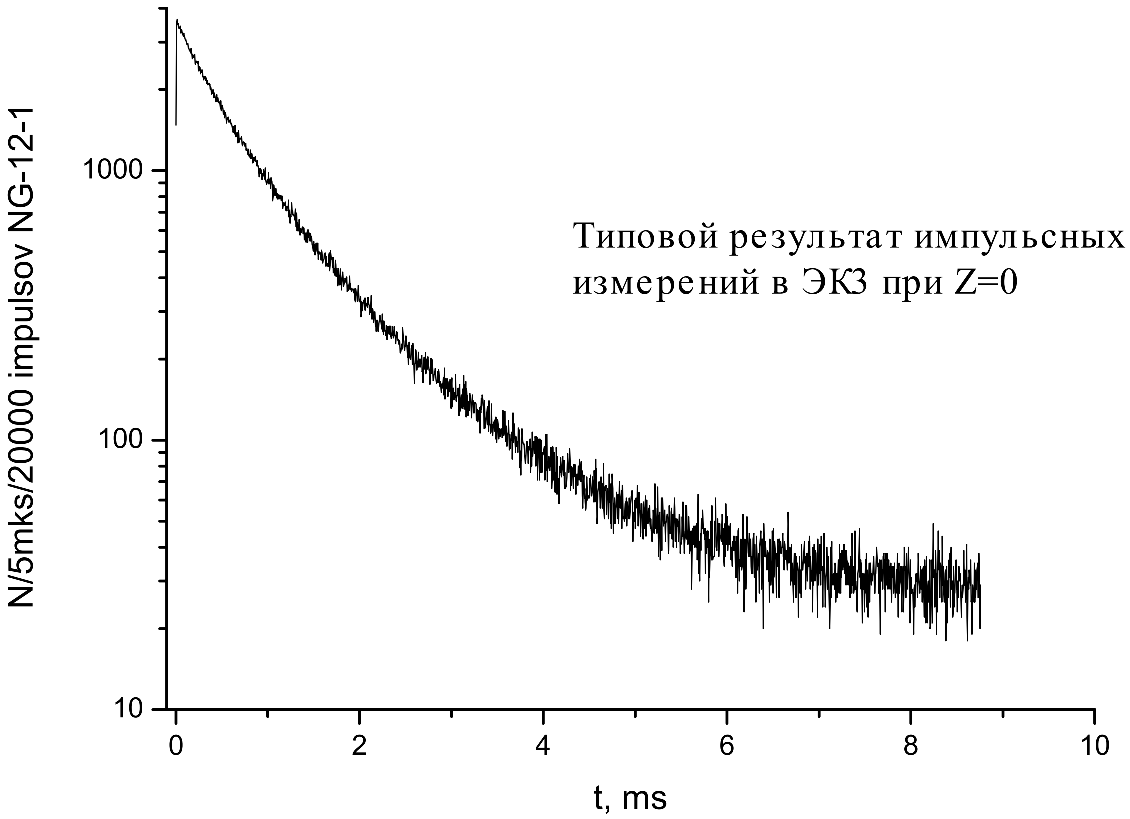
Спад плотности нейтронного потока
в АЗ - ЭК3 и в отражателе - ЭК6



Core configuration for 280 fuel pins
(lead zone is placed at the core center)

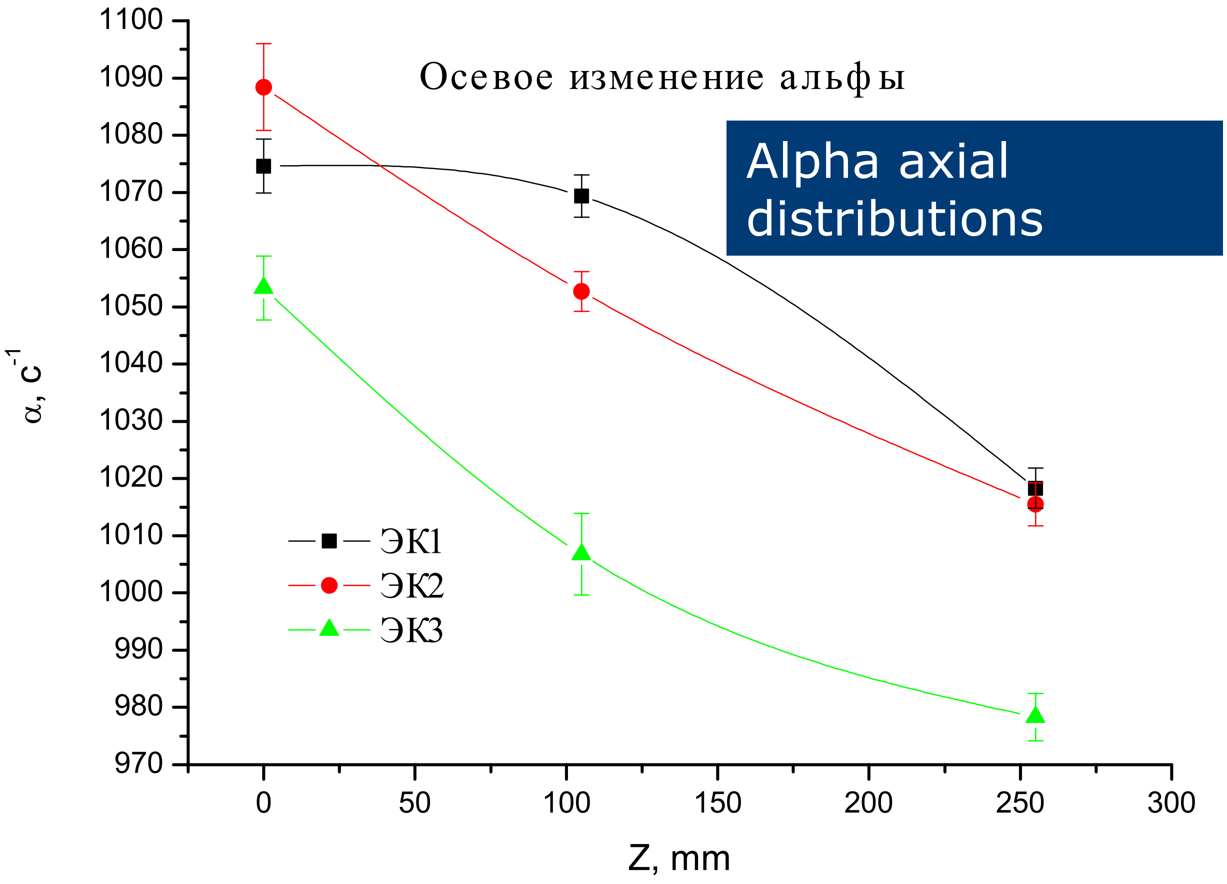
A - cross-section (-5 cm < z < 0 cm)

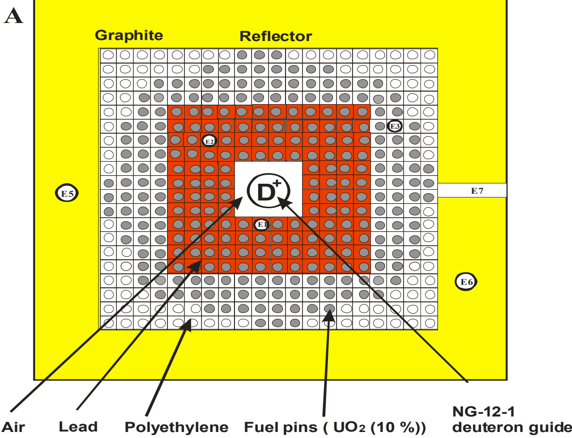
E1 - E7 - experimental channels



Типовой результат импульсных измерений в ЭКЗ при Z=0

Alpha axial distributions





Core configuration for 280 fuel pins
(lead zone is placed at the core center)

A - cross-section (-5 cm < z < 0 cm)

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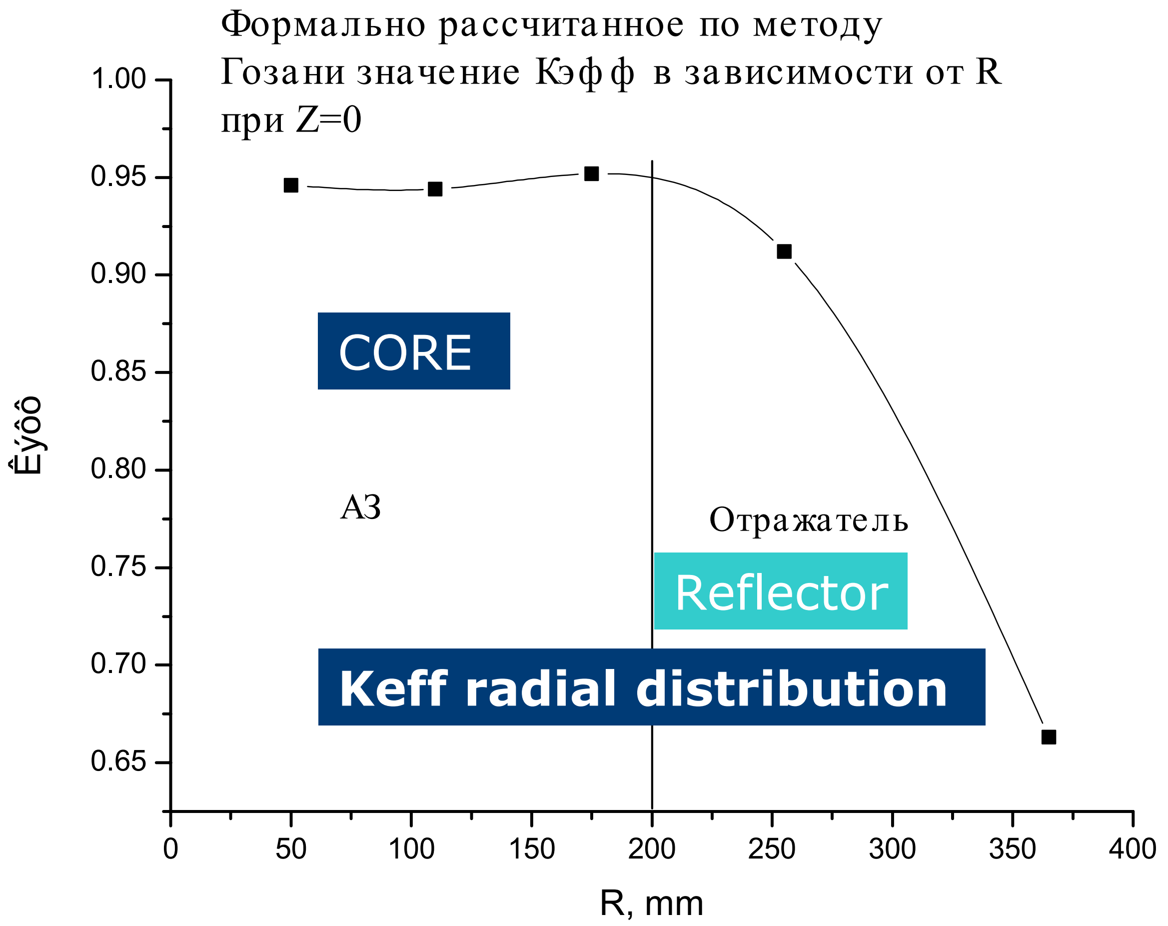
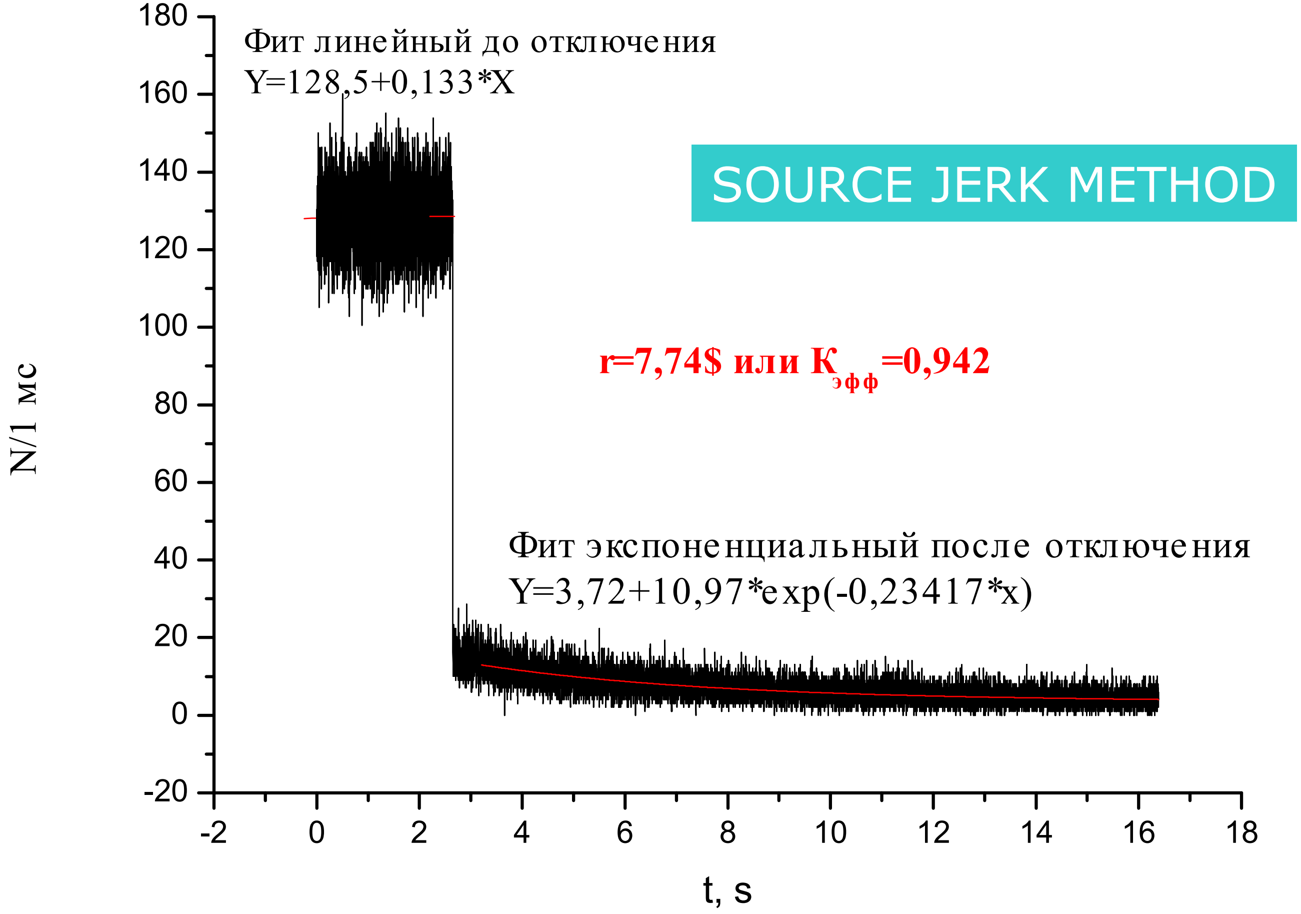


CORE

Reflector

Keff radial distribution

SOURCE JERK METHOD



Фит линейный до отключения
Y=128,5+0,133*X

r=7,74$ или К$_{эфф}$=0,942

Фит экспоненциальный после отключения
Y=3,72+10,97*exp(-0,23417*x)

A fast spectum booster coupled

one way to a thermal spectrum system

It is well known that the principal difficulty of the ADS technology is the requirement of high accelerator currents. One of the promising way of solving the problem is a maximization of the neutron gain. The extra multiplication of neutrons can be achieved in the systems having central booster region having a Kinf ≈1.1 and an outer region having Kinf at the level 0.97-0.98.

The main idea is to introduce source neutron in a region of high neutron importance and thereby get enhanced multiplication.

It can be achieved in the systems with one way coupling between the two regions - neutrons from the inner region may leak out into the outer region, however, the probability for outer region neutrons to re-enter the inner region is to be made as low as possible.

The practical way of achieving such a coupling between the two systems is introduction a thermal absorber in between them.

- **Keff = 0,975 – 0,98**

Booster zone (Keff= 0,65):

dimension, cm 48x48x50

fuel:

Umet. is enriched to 90% in 235U

UO$_2$ is enriched to 36% in 235U

neutron flux density

with energy En >0,1 МэВ, 10^9 n/(cm2 s)

moderator Pb

Uranium load (kg) U-5–62.8;U-8 - 54.5

Intermediate zone:

thickness, cm 3

material Umet (natural uranium) + B$_4$C

Moderator Pb

Uranium load (kg) U-5–0.23;U-8 -31.8

Thermal zone (Keff= 0,95) :

thickness, cm 24

fuel : UO$_2$ is enriched to 10% in 235U

moderator polyethylene

reflector

graphite

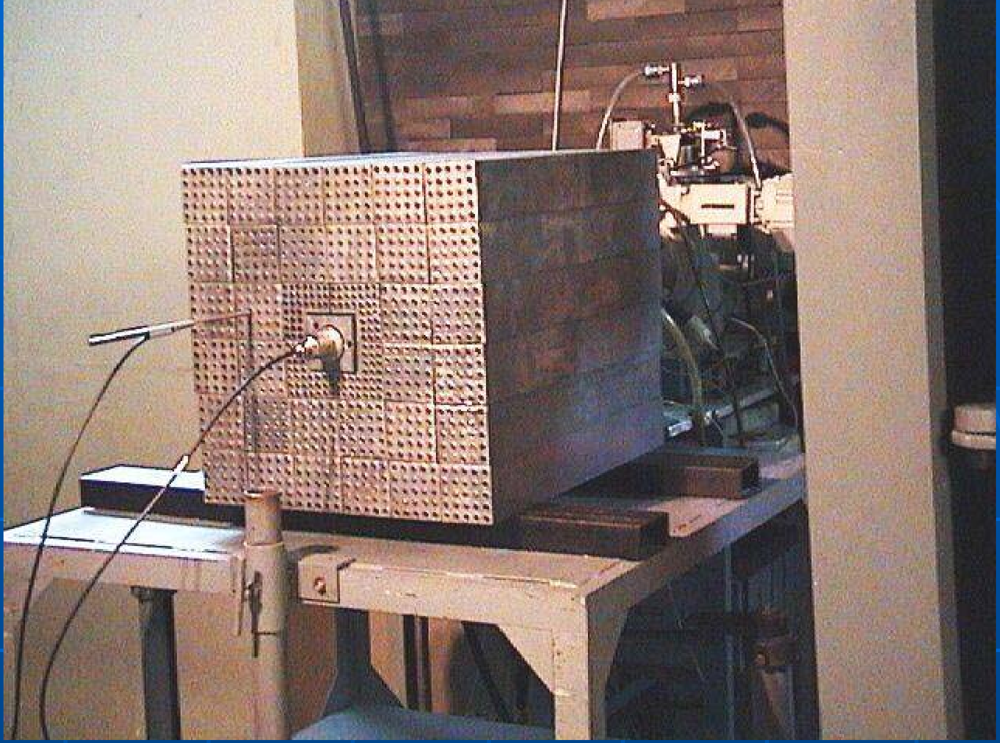
Thermal neutron flux density:

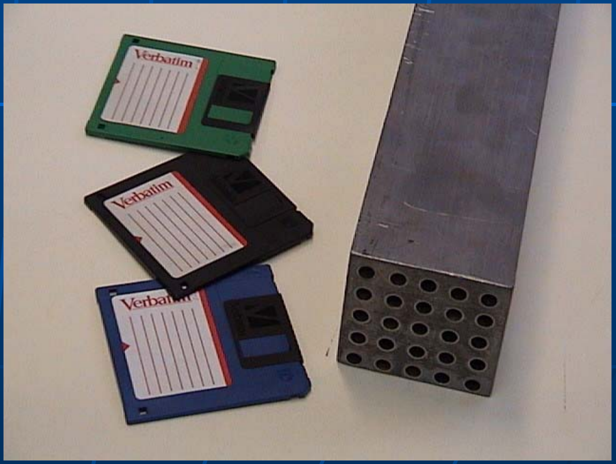
Ti^{3}H –target 10^9 n/(cm^{2}s)

Uranium load (kg) U-5–8.07;U-8-72.6

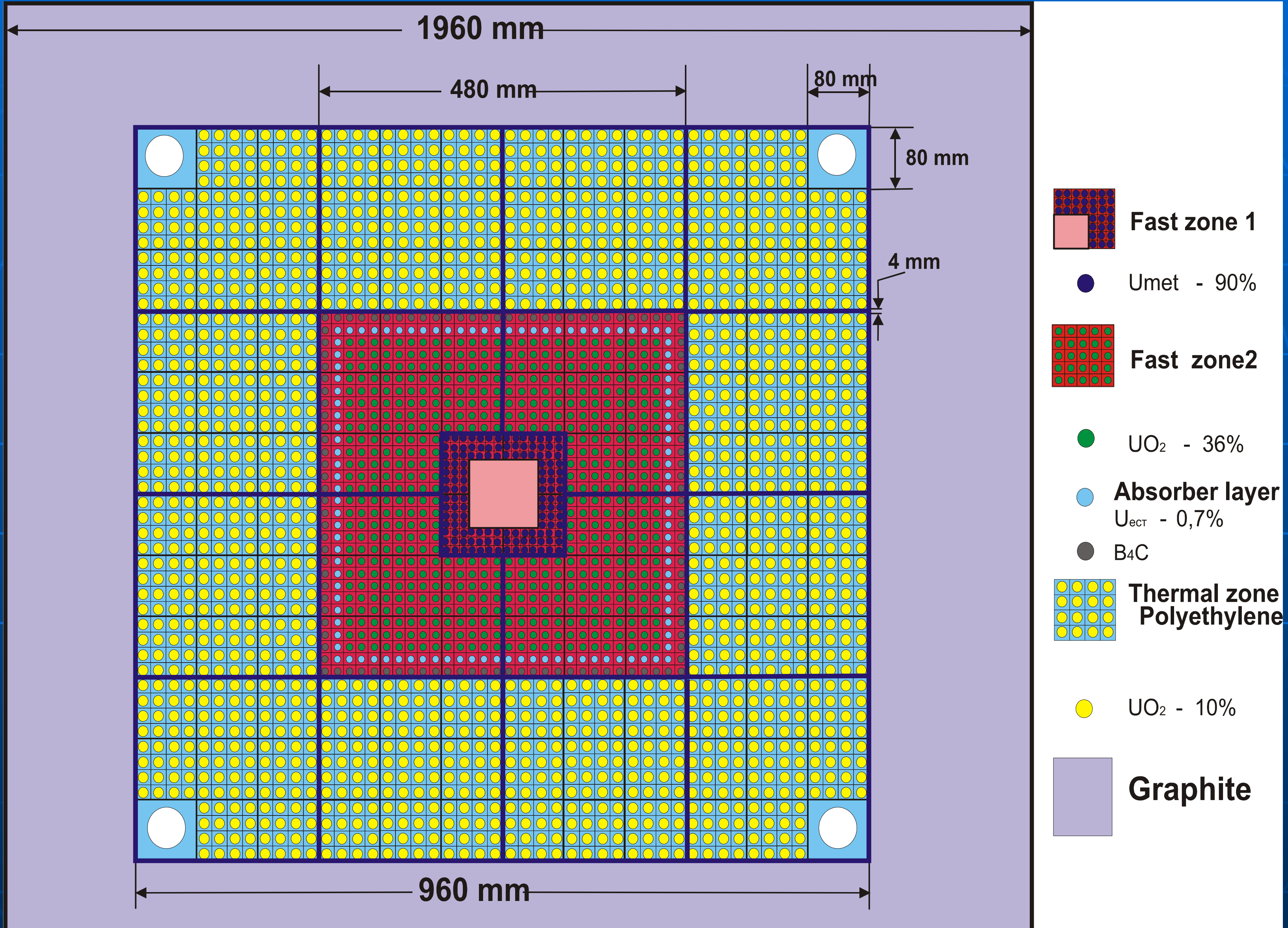
multiplication factor 50

Total uranium load (kg) U-5 –72; U-8 - 167





Booster subcritical assembly «Yalina - B», driven by a neutron generator.



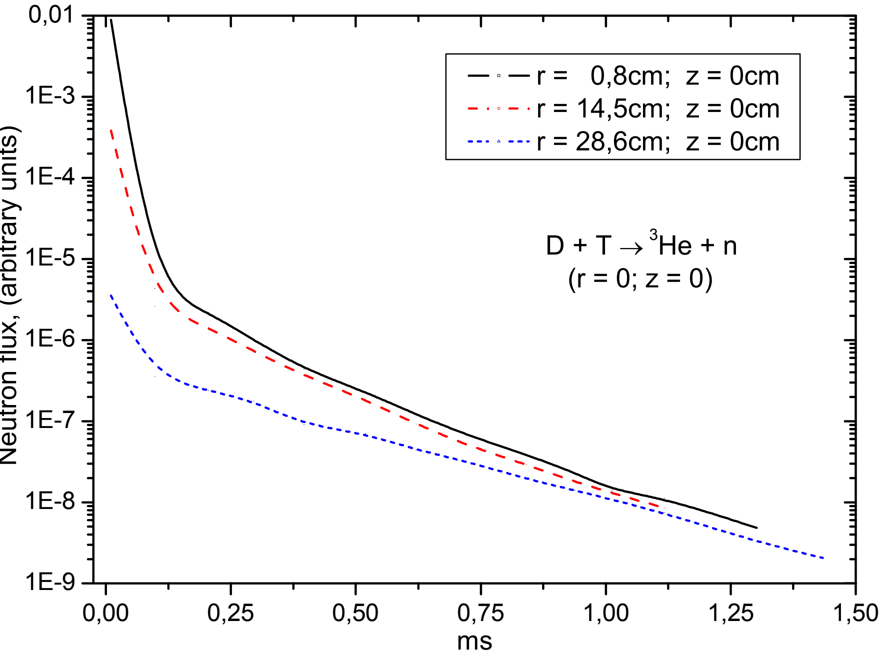
Vertical layout of booster subcritical assembly


"ОБЪЕДИНЕННЫЙ ИНСТИТУТ ЭНЕРГЕТИЧЕСКИХ И ЯДЕРНЫХ ИССЛЕДОВАНИЙ - СОСНЫ" НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК БЕЛАРУСИ
ПОДКРИТИЧЕСКИЙ СТЕНД "ЯЛІНА"
ОБЛАСТИ ПРИМЕНЕНИЯ:
N1
N3

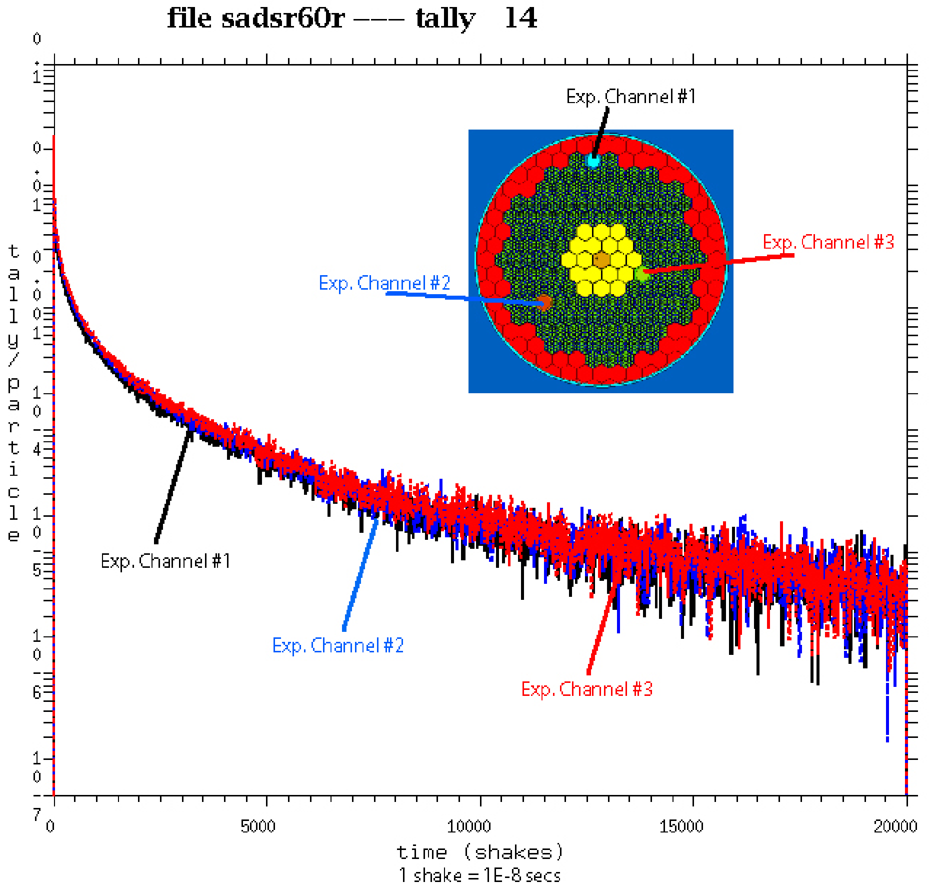
The characteristics of the fuel elements

- Fast zone Fuel : 90 % enriched U met.
- active height 50 cm ; Fuel Cassettes 35 + 1
- fuel pellet
- radius : 0.32 cm Fuel elements 33
- Nr = 132

- 36 % enriched UO2
- _ active height 50 cm
- fuel pellet
- radius : 0.32 cm
- Nr = 576
-
- Thermal zone 10 % enriched UO2
- _ active height 50 cm
- radius : 0.45 cm
- Nr =1050
- cladding: composition : stainless steel and Al thickness :
- 0.076cm



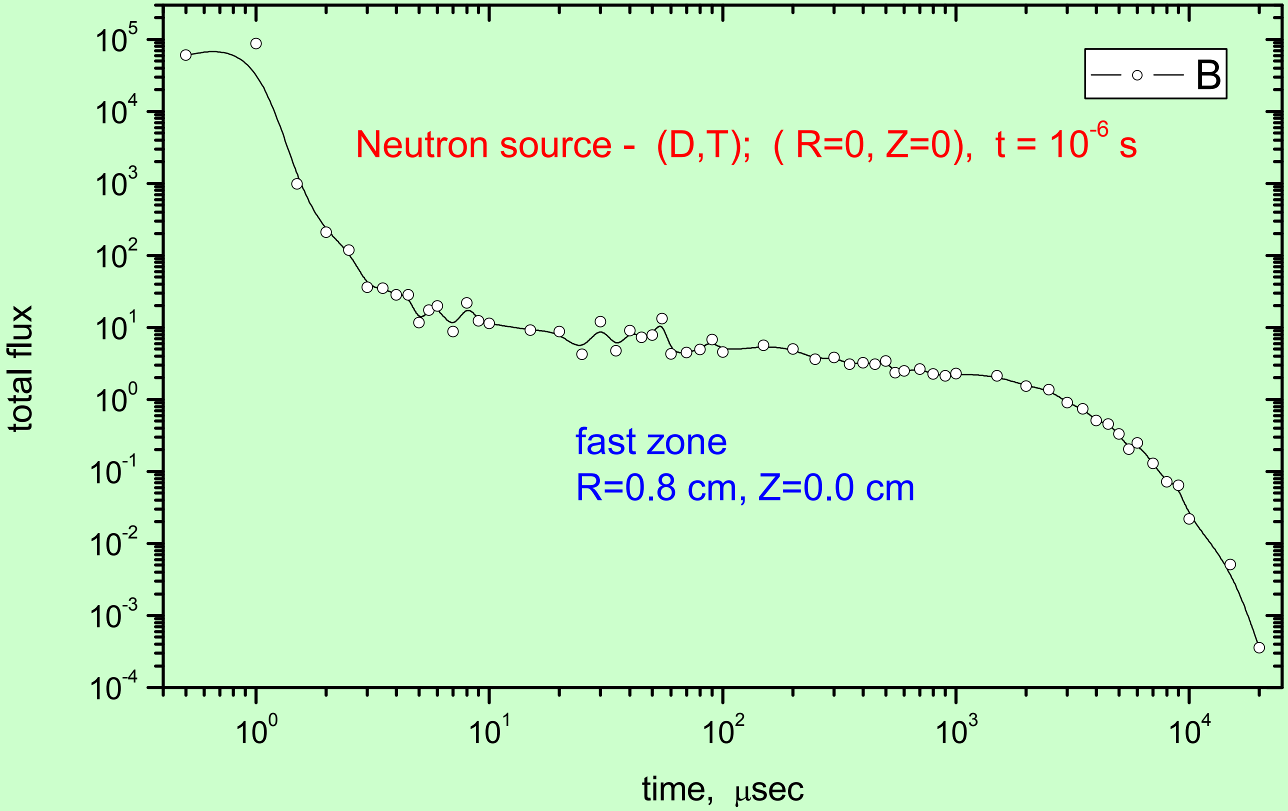
Time evolution of the neutron flux after neutron generator pulse (τ = 1μs) at the different position (r; z) in the core



Case #12: Time evolution of 235U fission counting rate. Central height.

Detectors in the 3 experimental channels at the core.

Time evolution of the neutron flux after neutron generator pulse (τ=1μs).

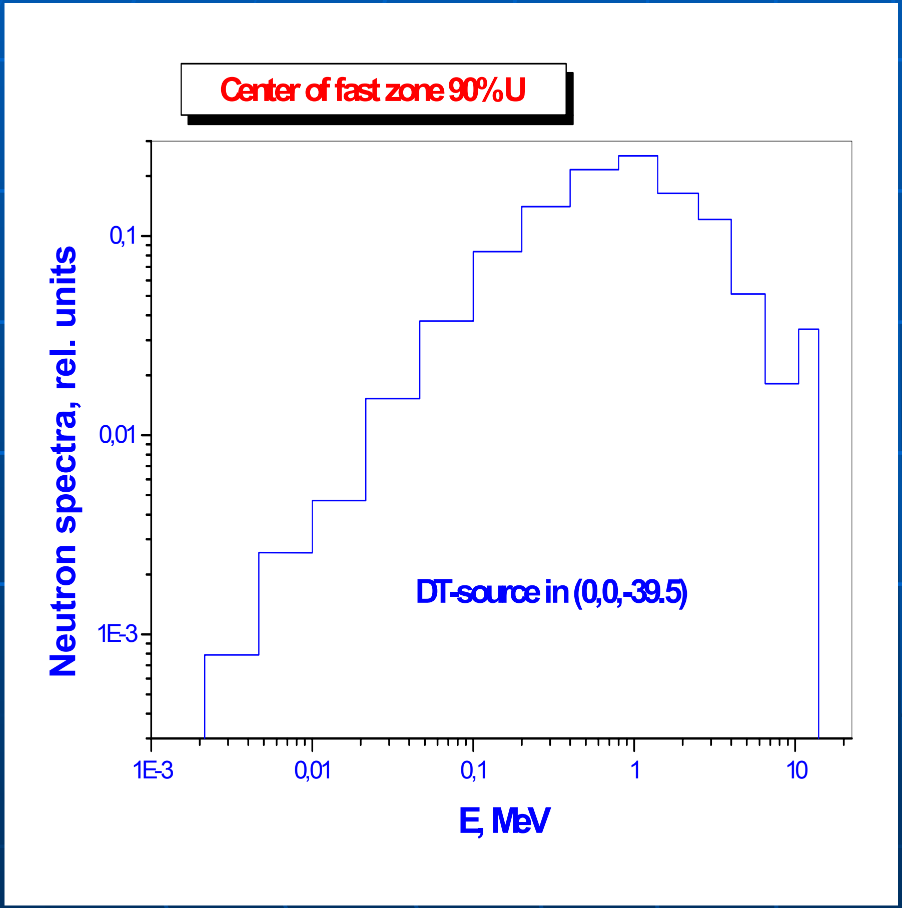


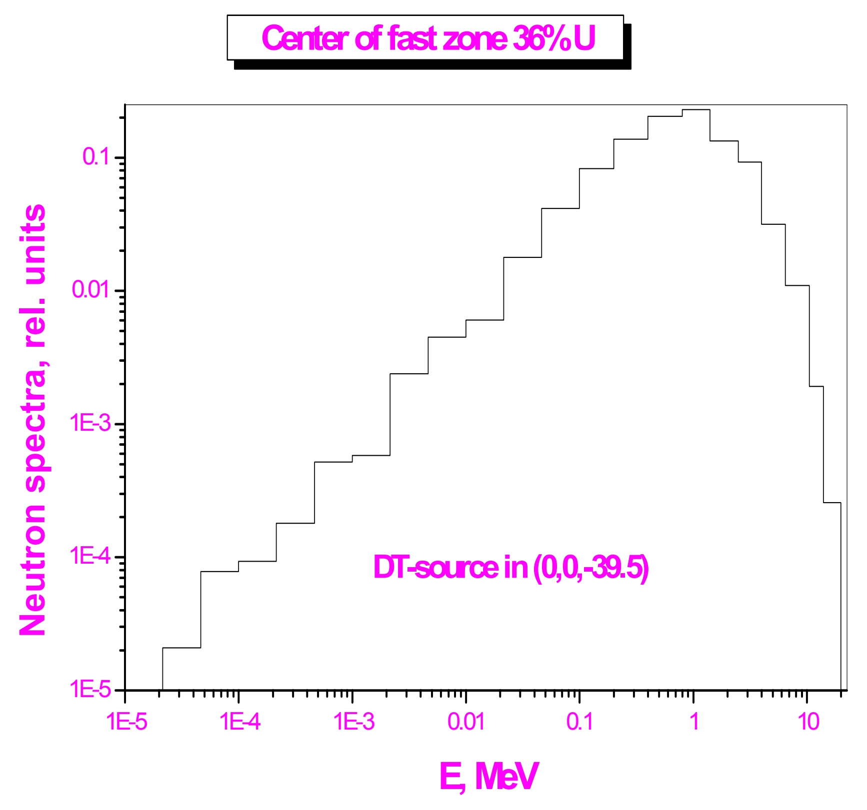
Prompt neutron lifetime in the booster subcritical assembly driven by a neutron generator

	Bare booster zone	Booster zone with polyethylene reflector	Thermal zone loaded with 1040 fuel pins	Booster subcritical assembly (thermal zone loaded with 832 fuel pins)	Booster subcritical assembly (thermal zone loaded with 448 fuel pins)	Booster subcritical assembly (full load of thermal zone - 1040 fuel pins)
Promt neutron lifetime	5.6×10^{-8} s (0.056 μs)	4.2×10^{-6} s (4.2 μs) with B_4C in the intermediate zone 1.06×10^{-5} s (10.6 μ s) (without B_4C in the intermediate zone	6.2×10^{-5}s (62 μs)	5.52×10^{-5}s (55 μs)	4.9×10^{-5}s (49 μs)	5.8×10^{-5}s (58 μs)
Neutron generation lifetime	6.6×10^{-8} s (0.066 μs)	7.3×10^{-5}s (73 μs) with B_4C 8.0×10^{-5} c (80 μs) without B_4C	1.04×10^{-4}s (104 μs)	8.4×10^{-5}s (84 μs)	7.7×10^{-5}s (77 μs)	9.5×10^{-5}s (95 μs)

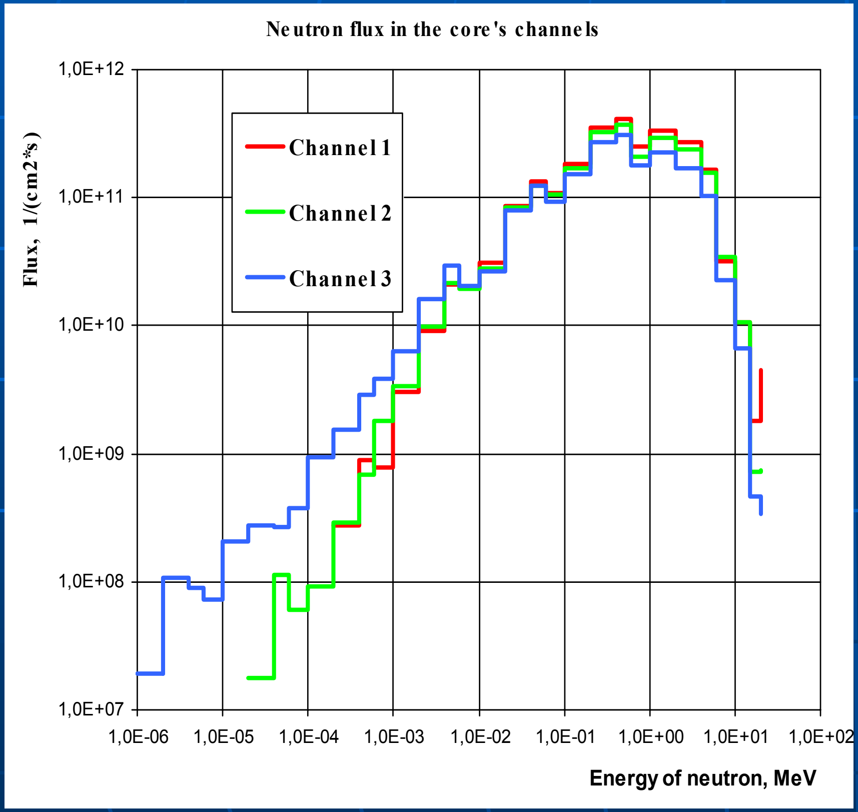
SAD A. Lopatkin L = 24μs; E. Gonzales L = 0.954μs ; MUSE -3 L = 0.61 μ

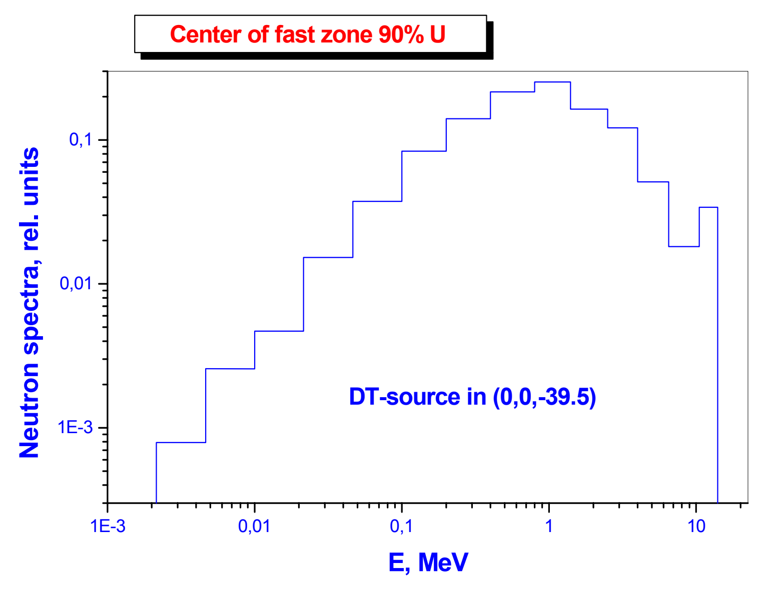
Energy distribution of neutron field in the booster zone



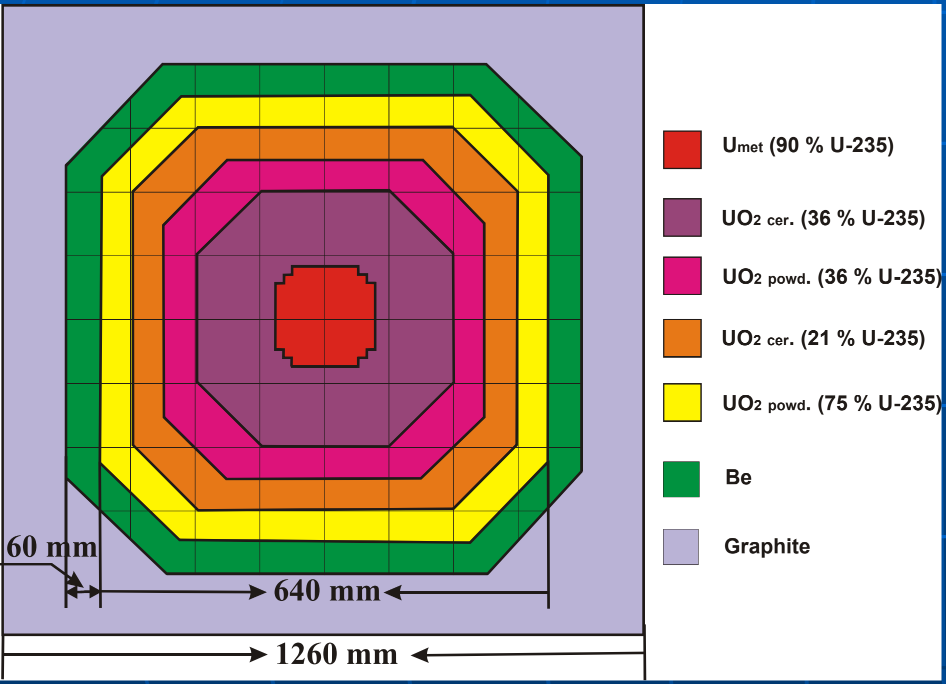


Neutron spectrum
Lopatkin Booster

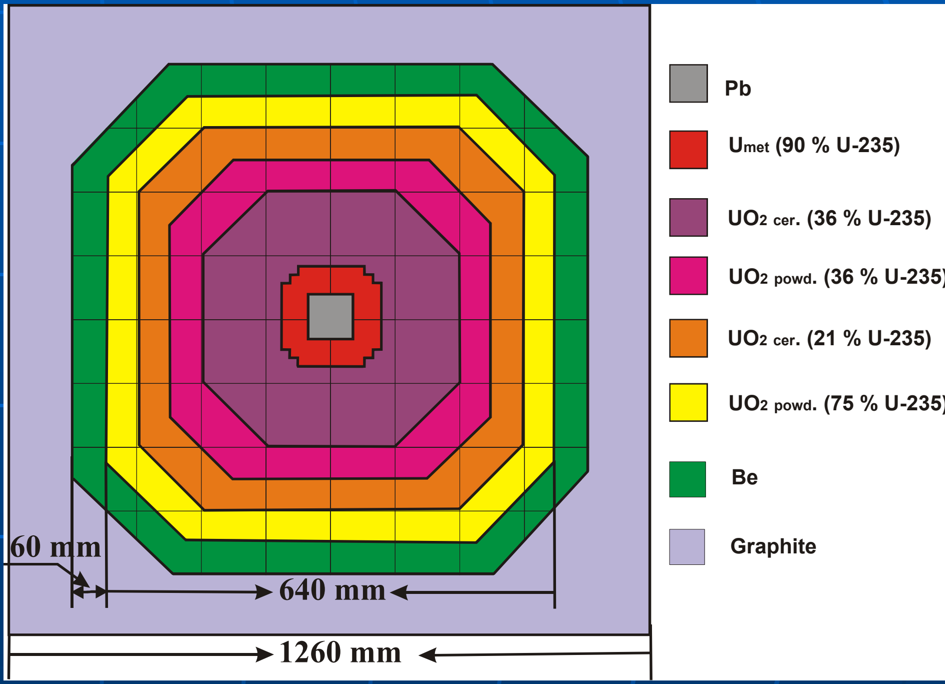




kef =0.93-0.95



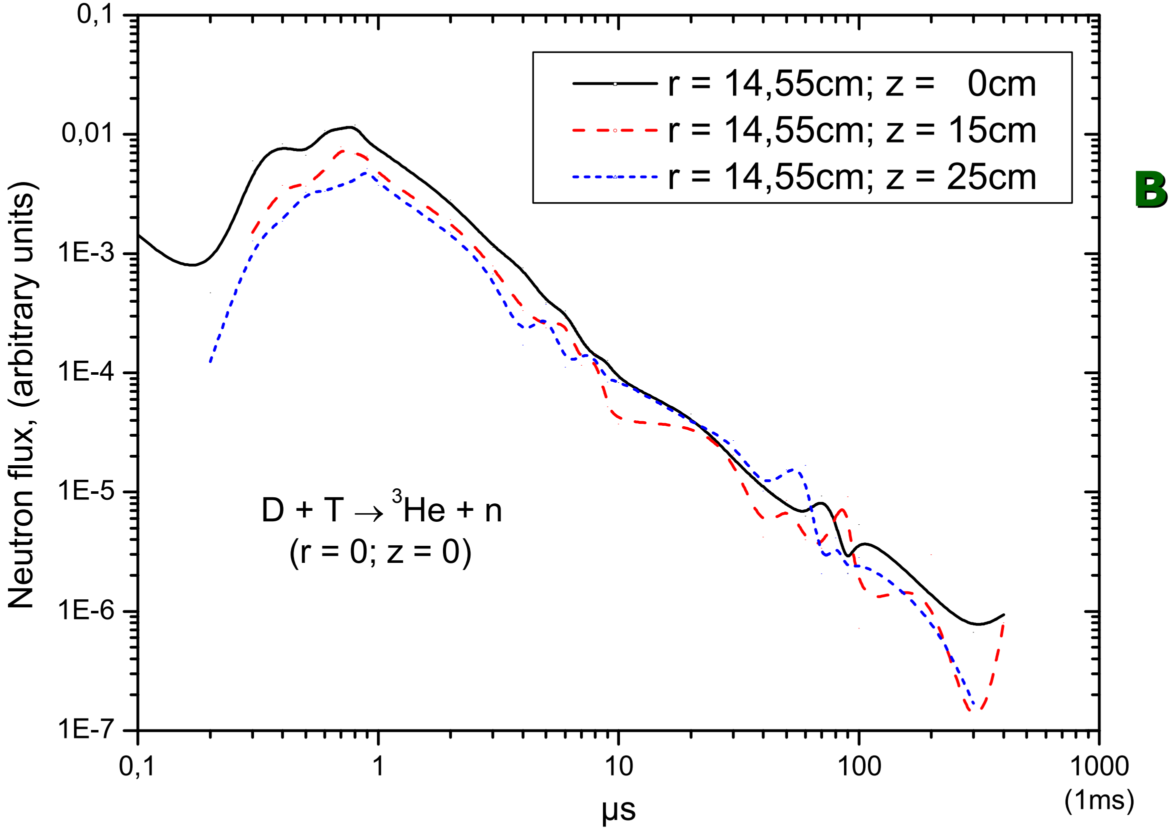
kef =0.90



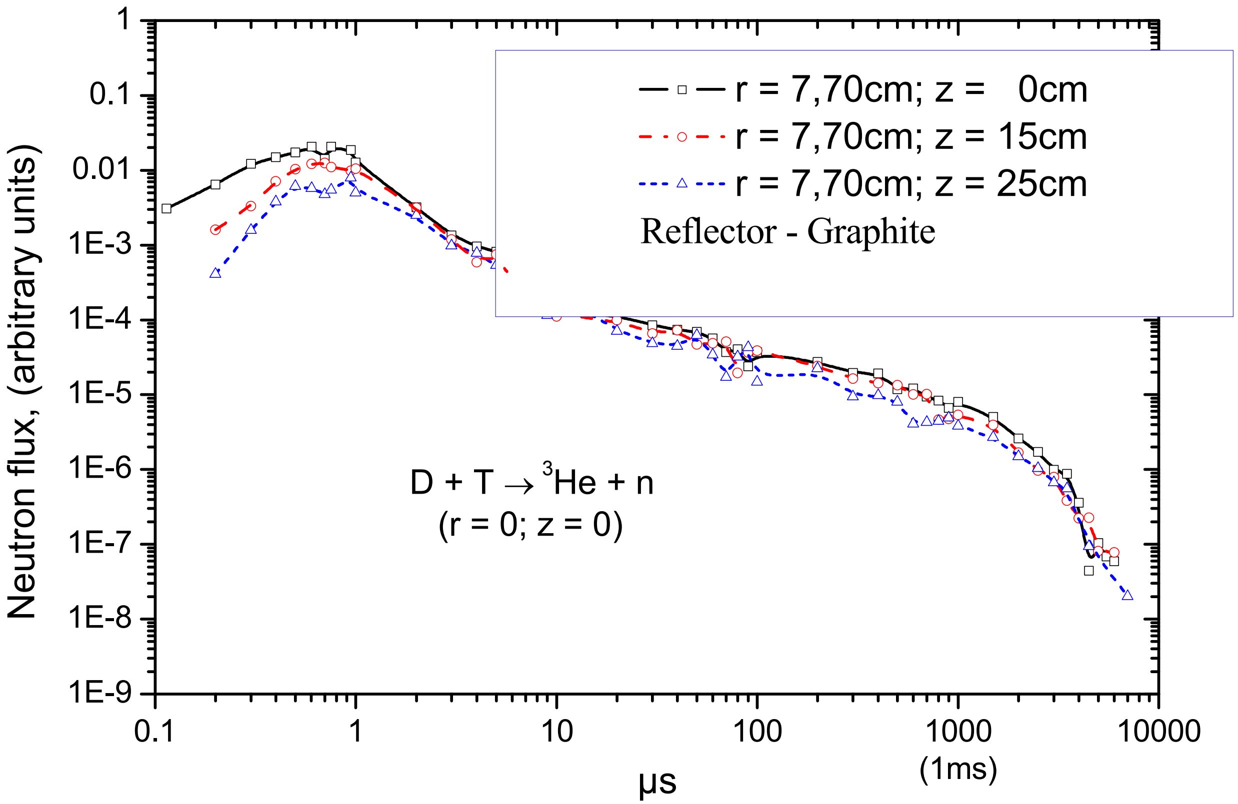
Layout (cross section) of fast neutron spectrum sub-critical assembly driven by neutron generator

(*K*eff = 0.836)

Bare core

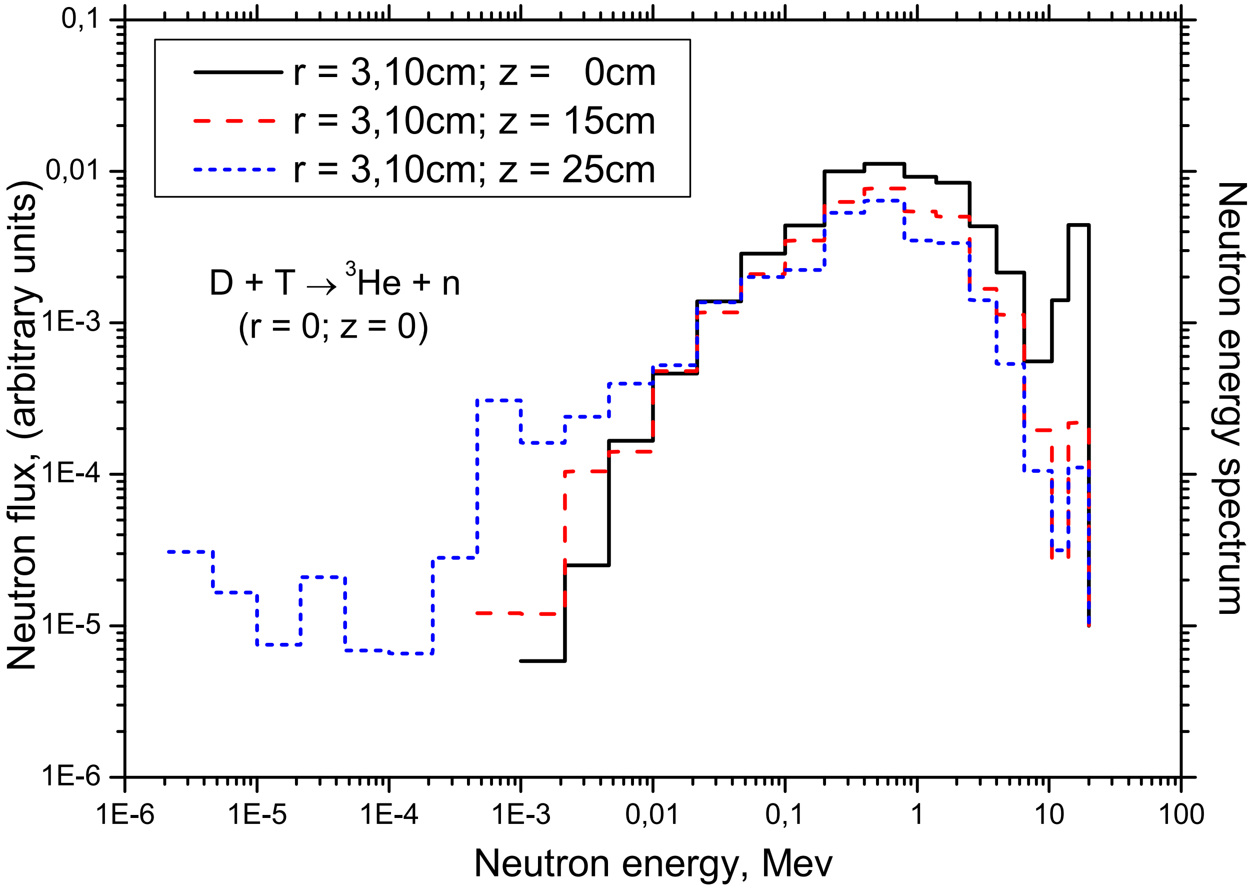


Time evolution of the neutron flux after neutron generator pulse (τ = 1μs) at the different position (r; z) in the core



Time evolution of the neutron flux after neutron generator pulse (τ = 1μs) at the different position (r; z) in the core

Рис. 2.2. Бустер «под SAD» с графитовым отражателем (*К*еफф = 0.943).
Временные распределения потока нейтронов в центральной части бустера (***r*** = 7,70 см).



Neutron energy spectrum

1. The booster zone of the facility YALINA-B is quite close to the SAD core (dimension, energy spectrum, time response) and from the physical point of view the some experiments dealing with neutronic of the subcritical core (SAD) can be performed on the basis YALINA-B setup. The fast zone of the facility can be considered as a volume neutron source in contrast to YALINA and MASURCA experiments. From this point of view the booster zone is closer to the spallation lead target of the SAD.

2. Measurement of the MA fission rates in the fast spectrum: 235U,237Np,238Pu,239Pu,240Pu,241Pu,242Pu,241Am242Am

3. Studying coupling properties of the spallation target (booster zone) and reflector, blanket, shield.

4. Studying the influence of the shield on the physical parameters of the fast core.

5. Develop reactivity monitoring and techniques for subcritical systems with fast neutron spectrum

6. Validate calculation codes, libraries used to describe the subcritical core

7. The experimental determination of kinetic parameters and response to external neutron pulses.

- Time response in different sub-critical levels

Booster research Program

- Subcriticality measurements and monitoring (K1, K2, Keff)
- Studying spatial and energy distributions of neutron field in subcritical cascad system
- Measurement of the MA fission rates in the fast spectrum :
- 235U,237Np,238Pu,239Pu,240Pu,241Pu,242Pu,241Am,
- 242Am; and LLFP
- Studying coupling properties fast&thermal part of the core
- Measurements of the kinetic parameters cascad system
- (The measurement of the prompt neutron decay constant, etc,)
- Fission reaction rate for 235U,238U
- Validation of code, libraries

Cross-section of the Subcritical Assembly (MOX fuel - 27% PuO_2)

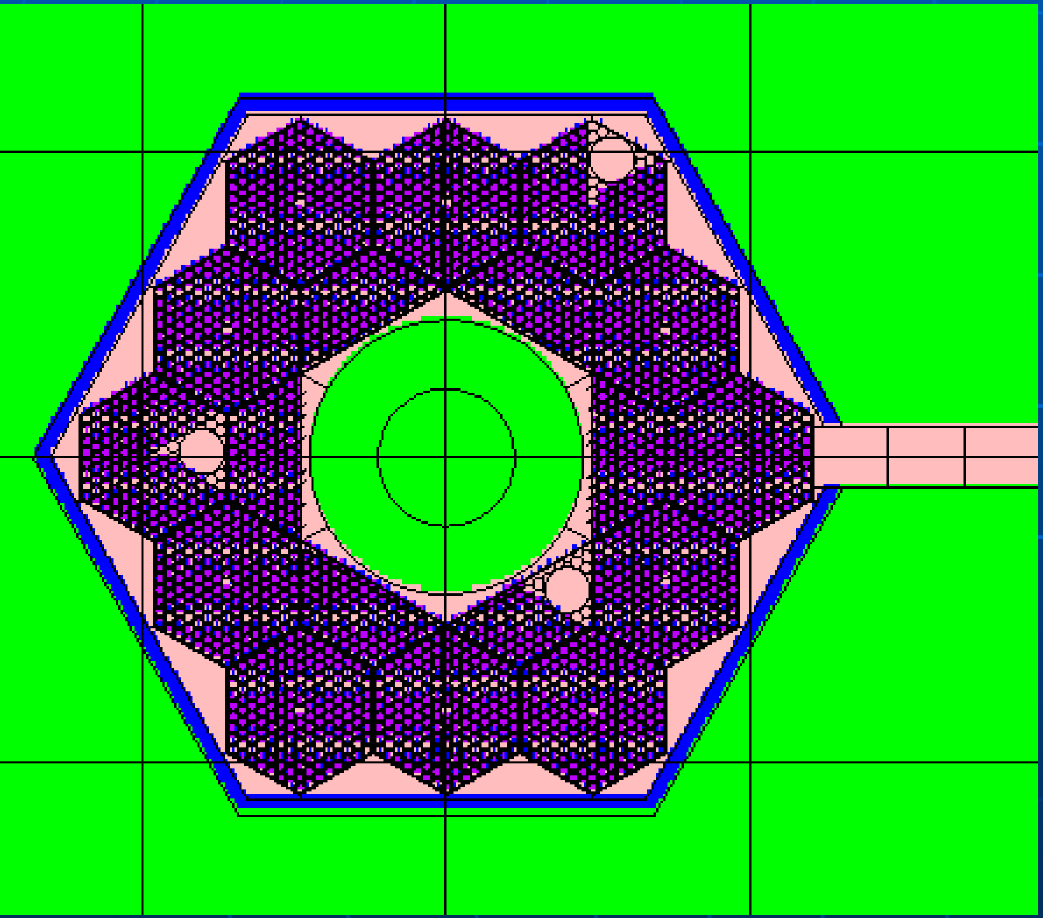
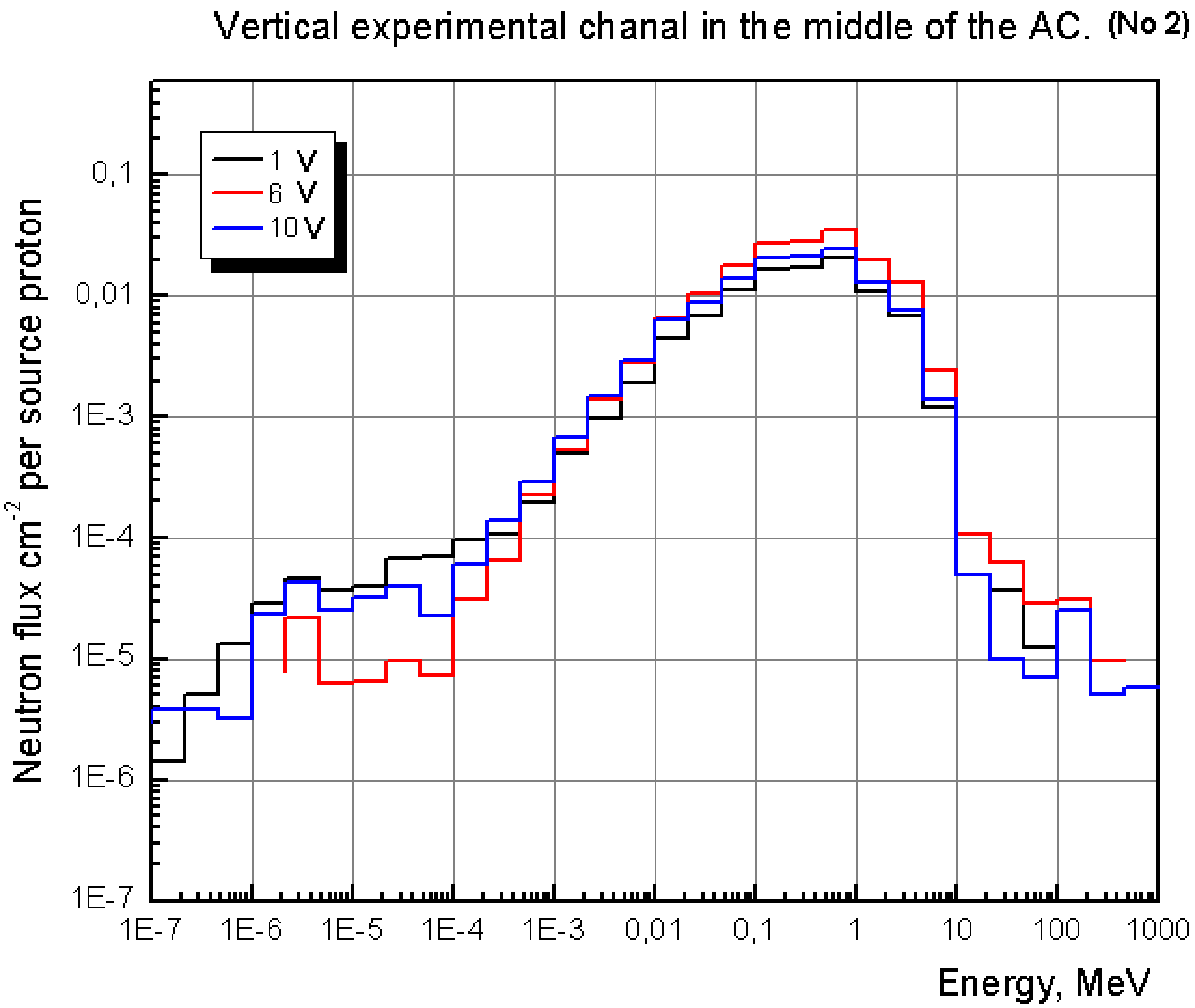


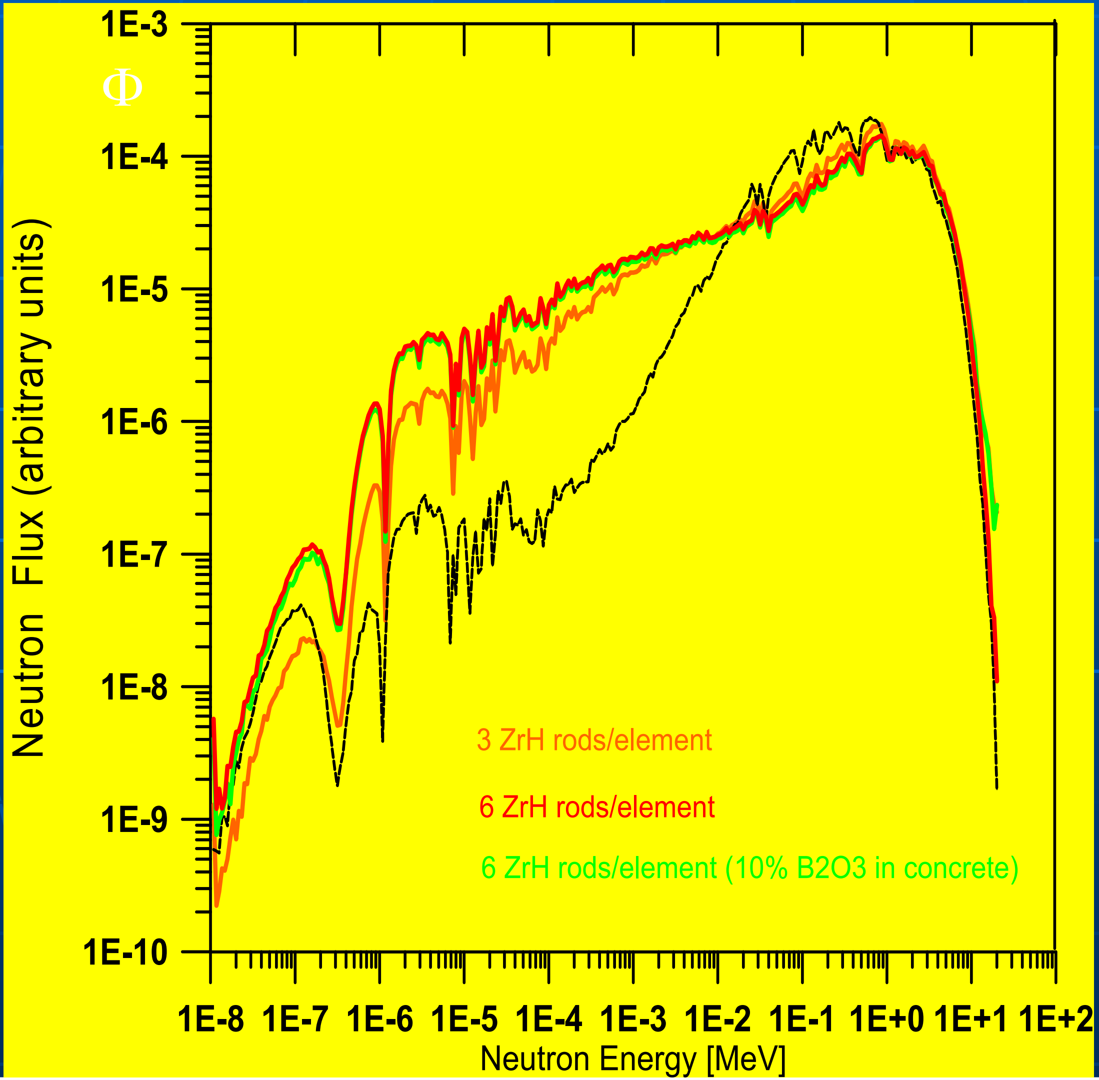
Figure shows a schematic layout of SAD-setup which has been studied in different target and reflectors. Colors symbolize different materials: yellow – lead or tungsten target, light blue – air, dark violet – MOX-fuel, green – lead, orange-lead or beryllium reflector, blue–steel.

Neutron spectra calculated for the subcritical assembly.



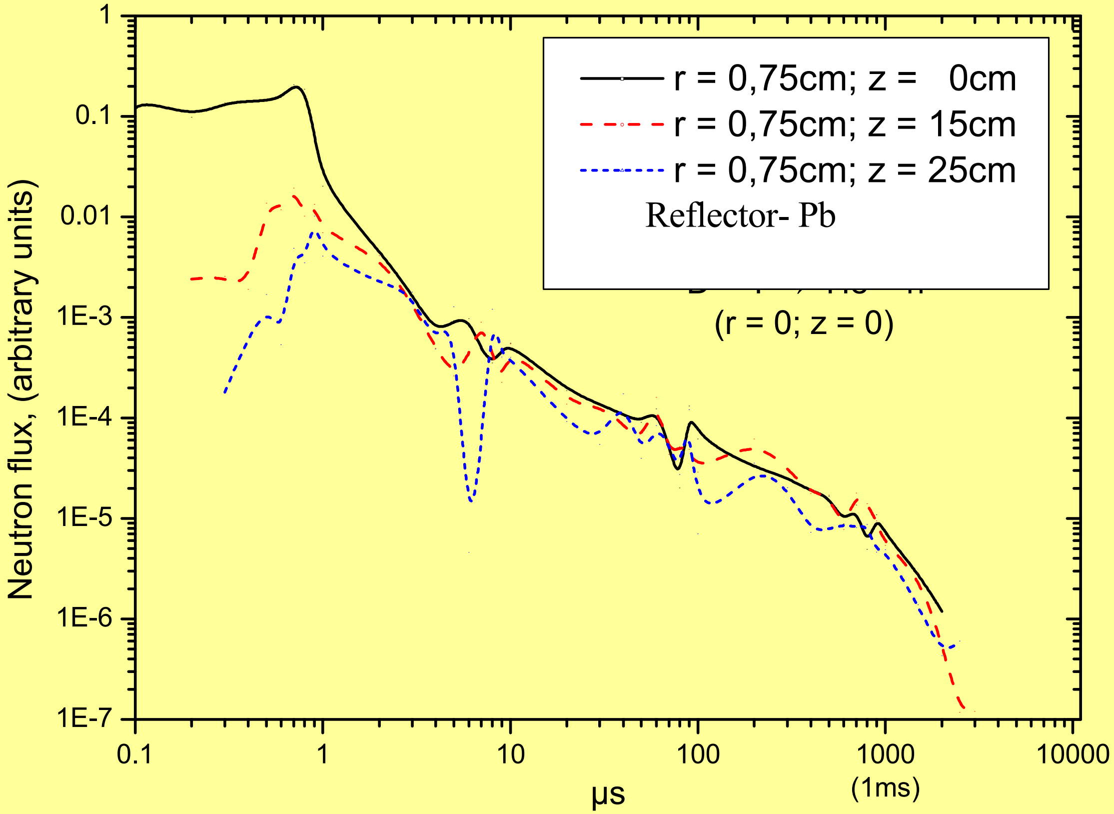
Modelling of SAD experiments

Neutron Spectra in SAD models

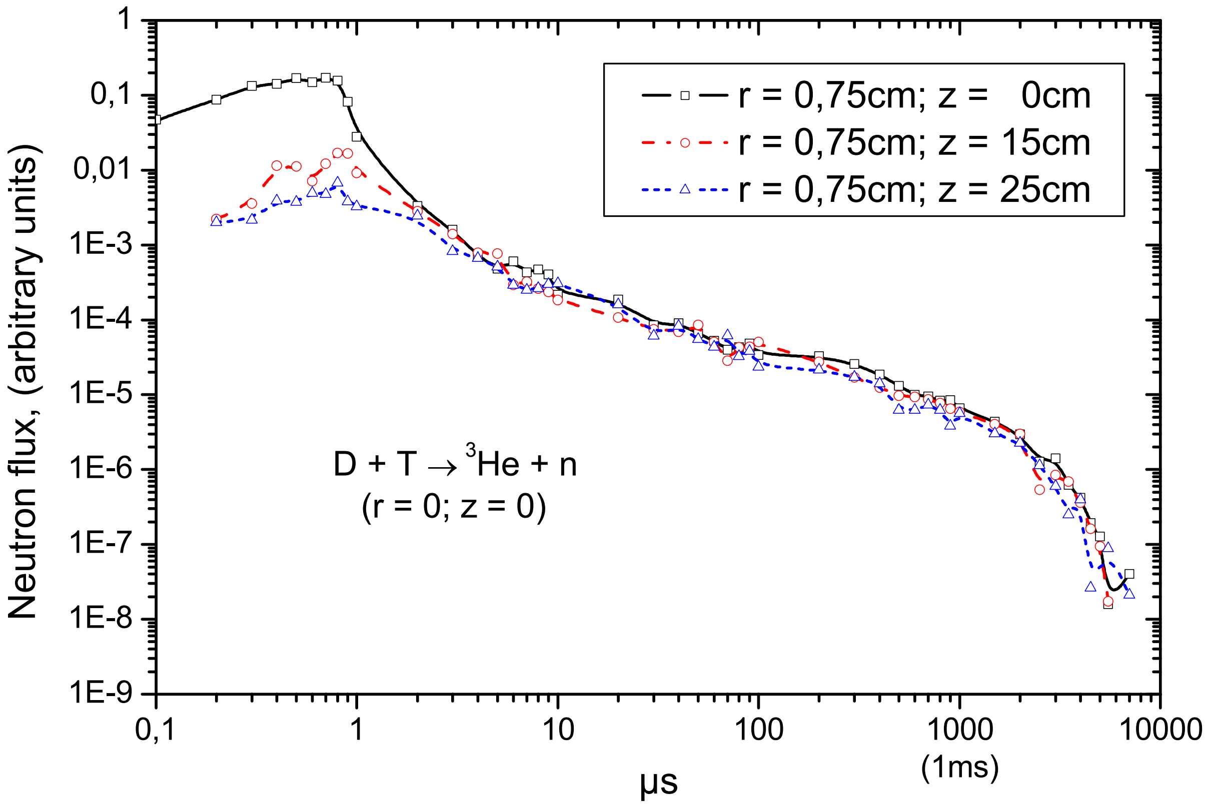


ZrH moderated
options

As compared with
unmoderated opt
ZrH heightens the
in the resonance re
whereas much le
in the thermal o



Time evolution of the neutron flux after neutron generator pulse (τ = 1µs) at the different position (r; z) in the core



Time evolution of the neutron flux after neutron generator pulse (τ = 1μs) at the different position (r; z) in the core

Рис. 2.1. Бустер «под SAD» с графитовым отражателем

(*K*эфф = 0.943). Временные распределения потока нейтронов в центре сборки (***r*** = 0,75 см).