2^{nd} *ECATS Feasibility Study Meeting, 20-21 April 2005, Brussels, Belgium*

«Experimental and theoretical research on transmutation of long-lived fission products and minor actinides in a subcritical assembly driven by a neutron generator»

ISTC Project B-070 (1998 – 2004)

Collaborators: RIT (Sweden); CIEMAT (Spain), FzK (Germany)

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Application of low-energy ion accelerators coupled with sub-critical multiplying systems ($k_{eff} < 1$) allows to carry out the experimental research of different aspects of ADS-technologies and to outline future investigations at high energy particle accelerators. Similar situation took place in nuclear power engineering when many peculiarities of neutron–physical characteristics of nuclear reactors, first of all of nuclear power plants cores intended for special purposes, were investigated at critical benchmarks.

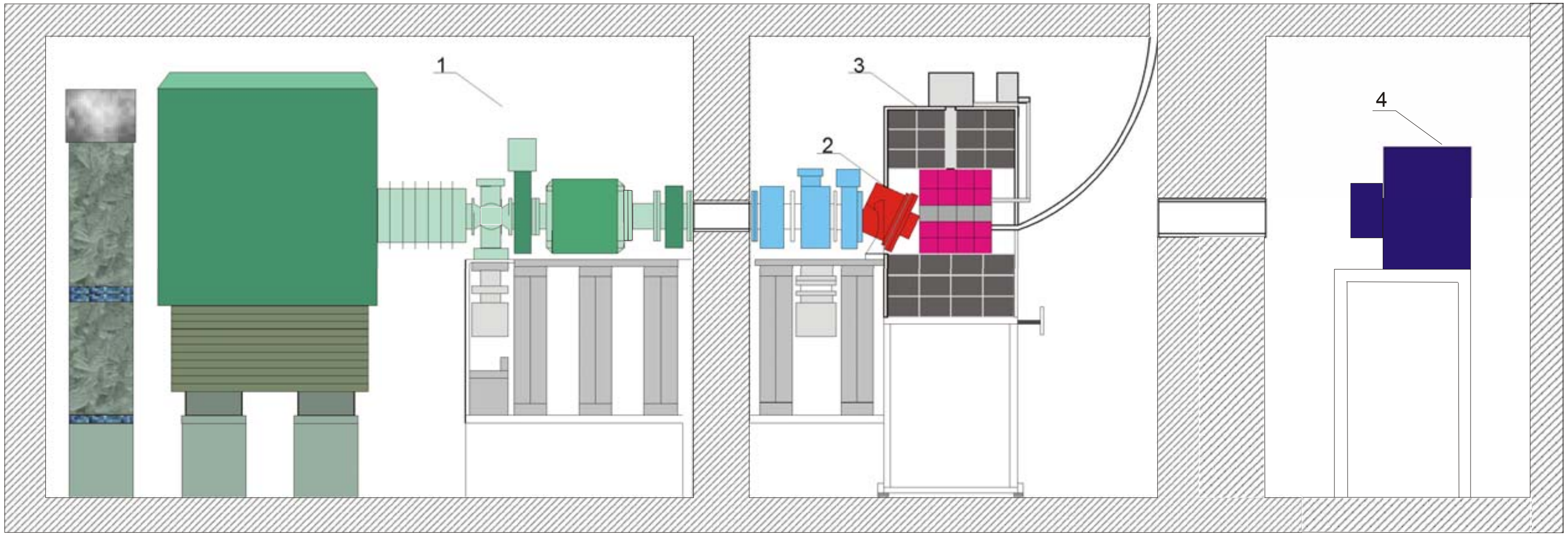
The main goals of the ISTC Project #B-070

- creation the facility to investigate neutronics of a subcritical system driven by external neutron source;
- 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 sub-critical systems with the external neutron sources with pulse mode of neutron generator operation.

YALINA assembly

- YALINA facility is sub-critical assembly with polyethylene moderator and uranium dioxide fuel (10% enrichment by U-235) driven by neutron generator operating both in continuous and pulse modes.
- The results of the researches on “Yalina” facility have shown that idea of usage of low energy ion accelerator instead of high energy proton ones to study neutronics of ADS was fruitful idea and further investigations will be very prospective.
- The continuation of the investigation program as well as setting up booster sub-critical assembly driven by neutron generator may be useful for working out the sub-critical assembly with fast neutron spectrum loaded by MOX fuel driven by proton (E_p = 660 MeV) accelerator (SAD facility).

Sub-critical facility YALINA:
1 –neutron generator; 2 - Ti^3H (TiD) target system; 3 - sub-critical assembly, 4 - gamma-spectrometer



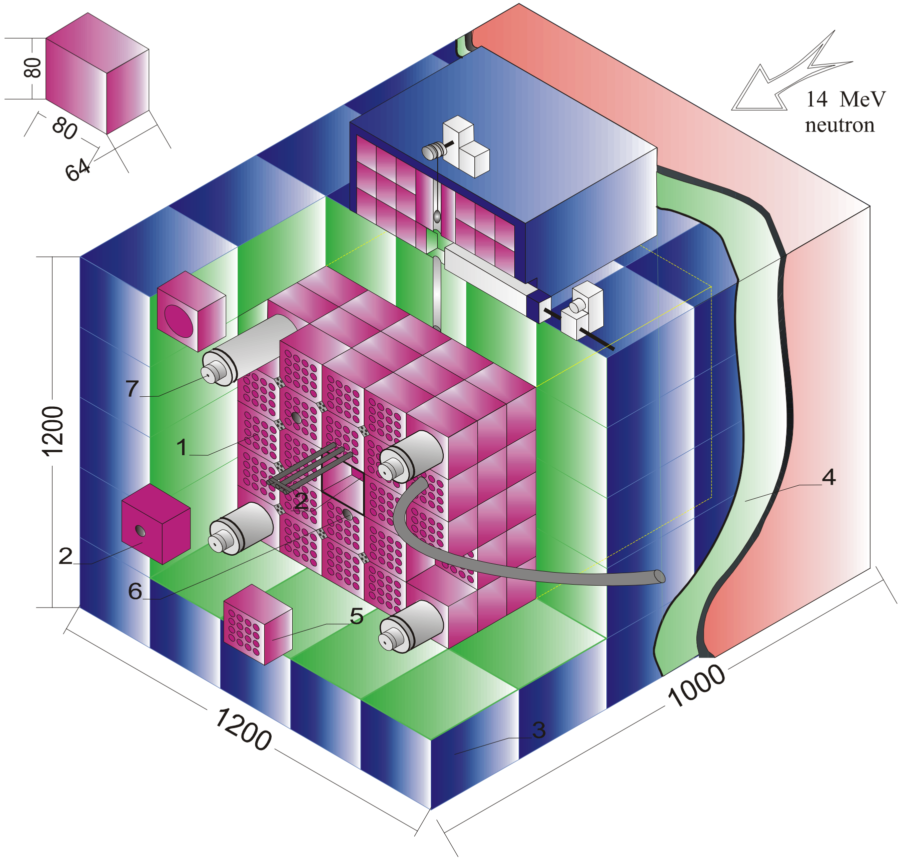
Yalina assembly

The sub-critical assembly of YALINA facility is uranium - polyethylene multiplying system with $k_{max} < 0.98$, located inside graphite reflector of parallelepiped configuration with side dimension 1000 and 1200 mm that is arranged of high purity “reactor graphite” blocks with side dimension 200×200×500 mm.

The core of the assembly is of parallelepiped configuration too with side dimension 400×400×600 mm and consists of “bare” polyethylene sub-assemblies where fuel rods of EK-10 type (UO_2 of 10% enrichment by U-235) are located.

On the whole fuel subassembly contains 9 blocks (in height) made of polyethylene ($\gamma = 0.927$ g/cm^3) with side dimension 80×80×63 mm and 16 fuel rods of EK-10 – type located in channels with diameter D = 11 mm. Fuel rods’ spacing equal 20 mm is close to the optimal value for multiplying medium with polyethylene moderator and fuel rods EK-10.

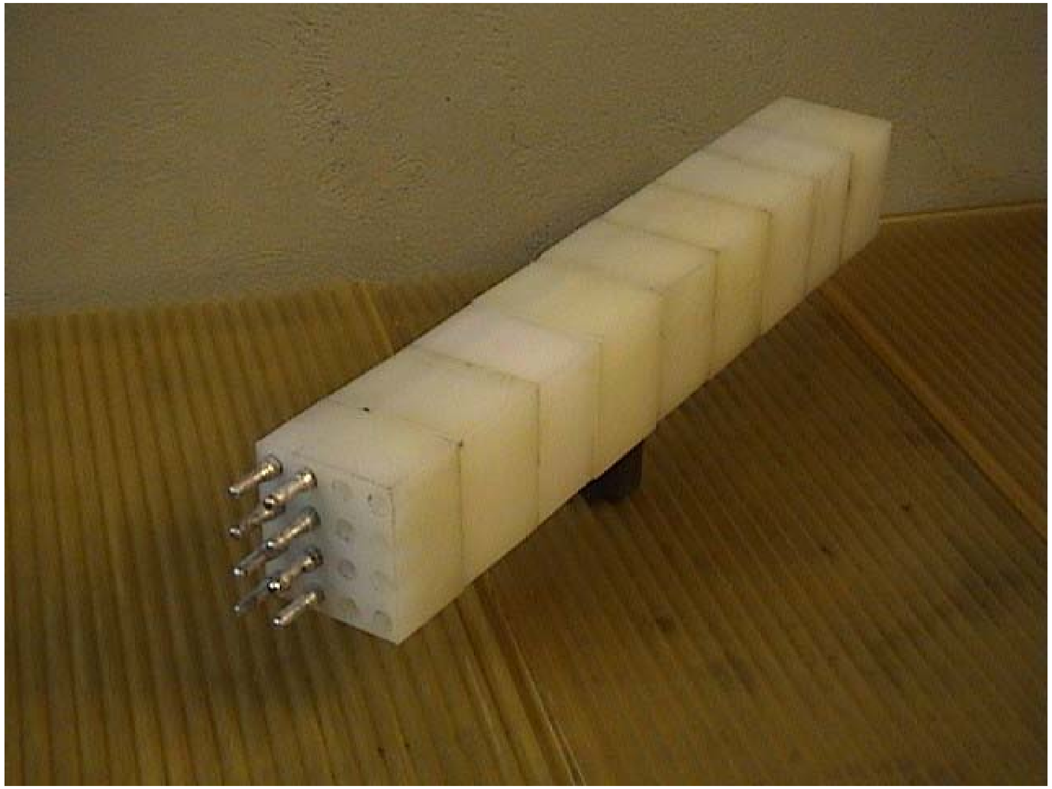
Yalina assembly



1 - core
2 - Pb target
3 - graphite reflector
4 - cadmium screen
5 - polyethylene block
6 - experimental channel
7 -detectors for neutron flux monitoring

Uranium-polyethylene assembly

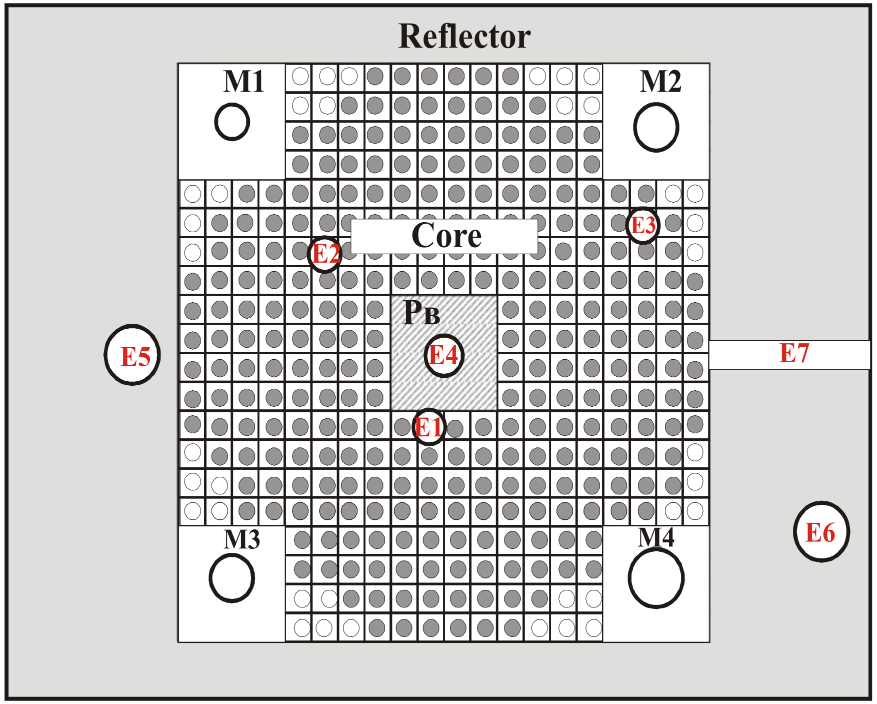
YALINA fuel subassembly.



Core configuration of the sub-critical assembly with fuel rod number N_p=280. E1-E3 – experimental channels inside the core; M1-M4 – channels for neutron flux monitoring; E5-E7 – experimental channels in reflector;

E4 – channel in Pb - target.

A



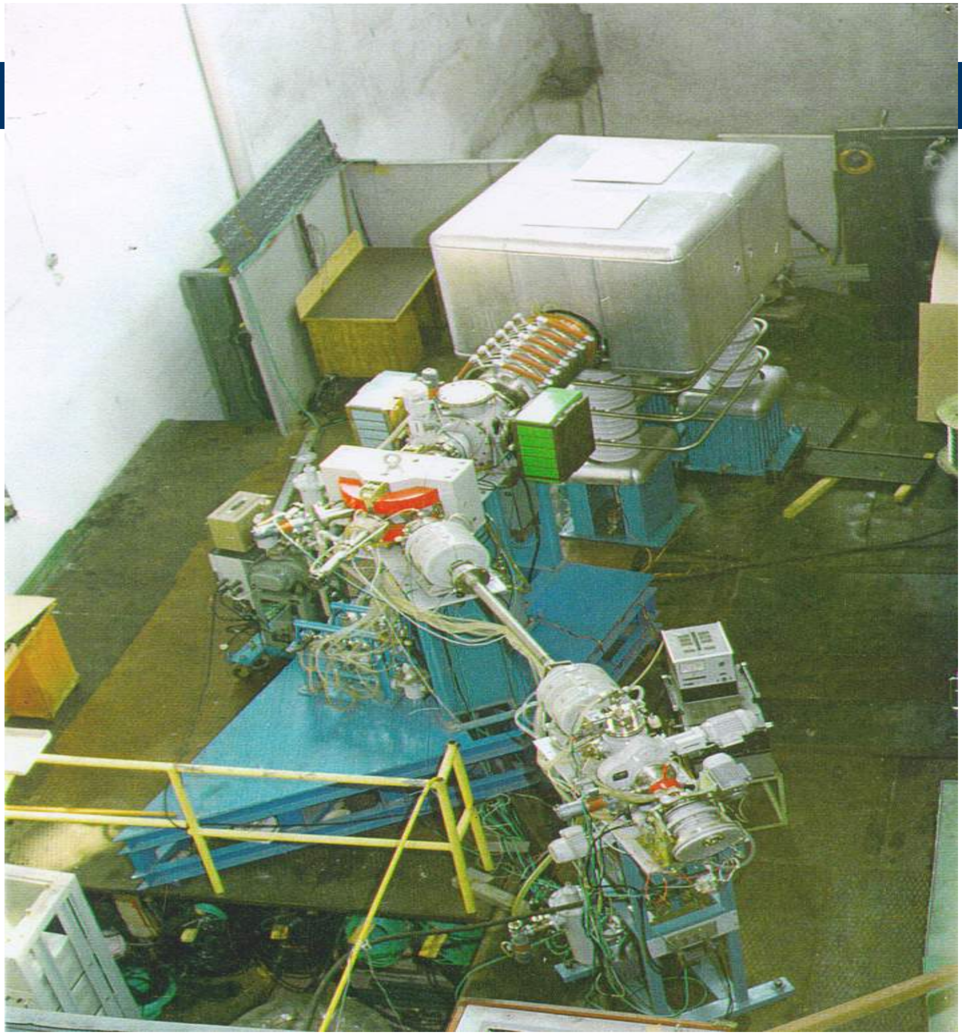
Uranium-polyethylene subcritical assembly

C - cross-section (280 fuel rods)
E1 - E7, M1 - M4 - experimental channels

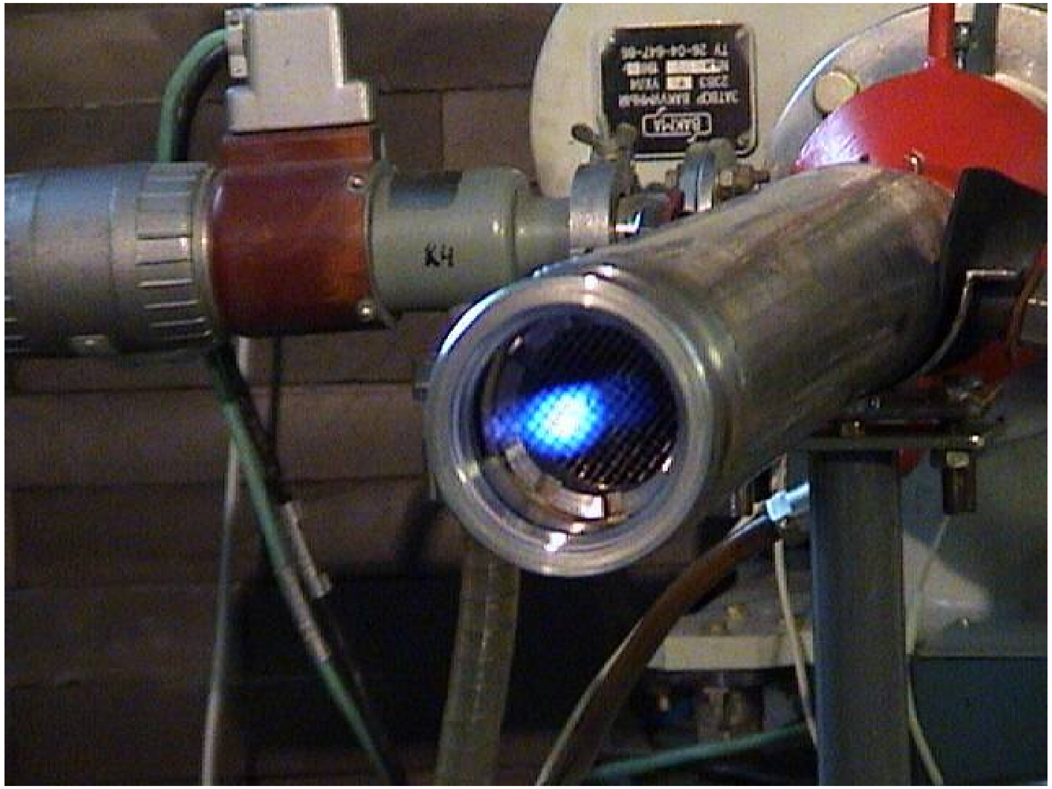
Neutron generator

- Neutron generator is linear accelerator of deuterium ions produced at duoplasmatron and accelerated to energy E_d = 250 keV. Accelerator magnet system separates D^+ ions only that by means of electro-magnetic lenses are directed towards the Ti^3H or TiD targets where in reactions $d(T,n)^4He$ and $d(D,n)^3He$ neutrons are generated with energies in the ranges E_n = 13-15 MeV and E_n = 2.5-3.0 MeV, respectively. At present highly effective water-cooled targets with diameters 230 and 45 mm are used in experimental program.

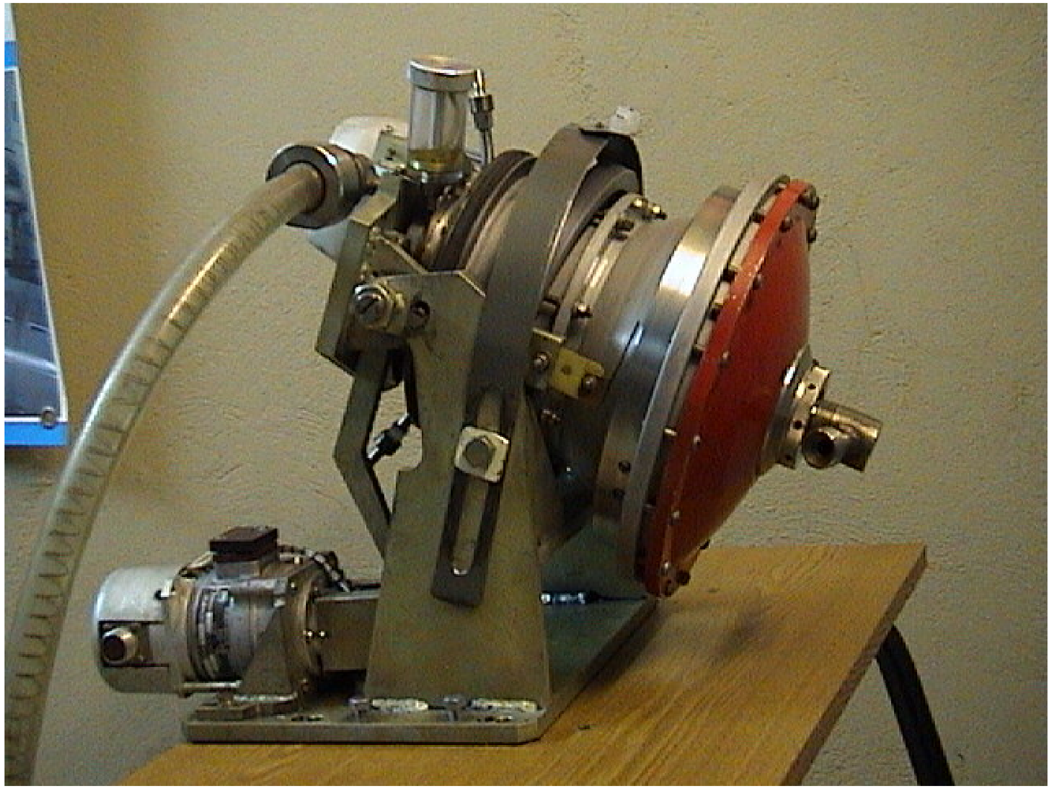
Neutron generator



45 mm target



Target diameter	230 mm
Rotation speed	560 rpm
Diameter of reaction space	100-200 mm
Tritium activity	0.53-0.75 MCi/kg
D/Ti (T/Ti) atomic ratio	1.5-1.8



Main parameters of the neutron generator NG-12-1

Accelerator	**H+ and D+**
Beam energy	**100 - 250 keV**
Beam current	**1 - 12 mA** **1 – 2 mA**
Pulse duration	**(0.5-100)×10**(-6) s**
Pulse repetition frequency	**(1-10 000) Hz**
Spot size	**2.0 -3.0 cm**
Ti^{3}H target (230 mm 45 mm):	
Rotation speed, rpm	**560** **-**
Maximal yield of neutrons, n/s	**(1.5 – 2) 10^{12} n/s** **1.5 10^{11} n/s**
Neutron energy, MeV	**13-15 MeV**
TiD target (230 mm 45 mm):	
Maximal yield of neutrons, n/s	**(2 – 3) 10^{10} n/s** **(2-3) 10^{9} n/s**
Neutron energy, MeV	**2.5 – 3**

ECATS question sheet on accelerators specifications and performances for YALINA, SAD, RACE experiments

Accelerator	**Accelerator D^+**
Accelerator Type (linac, circular)	**Linear, horizontal**
Main accelerator sections and type of structures	**Emitter, ion guide, high voltage supply, vacuum pumping system, systems of oil and water cooling, systems of power supply, control and operation, target unit**
Source type	**Duoplasmatron ion source – arc plasma three electrode source with double control of gaseous discharge plasma**
Source extraction voltage	**Extraction voltage 0÷25 kV, focusing voltage 0÷15 kV**
RF system (amplifier characteristics)	**Accelerating voltage 50÷250 kV, frequency of high voltage source operation 16 kHz, polarity – positive, maximum load current 30 mA, insta-bility of rectified voltage by maximum current is ±0.5**

ECATS question sheet on accelerators specifications and performances for YALINA, SAD, RACE experiments

Magnet system (type, size, rigidity, homogeneity)	Electromagnetic separator with side dimension - 670×550×565 (mm) is located on supporting mechanisms enabling horizontal and vertical shift in the range of 10 mm. The accuracy of setting is ±0.1 mm, inhomogeneity of magnetic field at workspace is 0.1%
Magnet Power Supply characteristics (current, stability, ramping, …)	Technical parameters of electromagnetic system: -maximum induction of magnetic field - 0.26 Tl; - maximum excitation current 7A; - maximum coil voltage 250V; - angle of beam deviation 45°.
Total Power consumption	20 kWh

ECATS question sheet on accelerators specifications and performances for YALINA, SAD, RACE experiments

Cooling System	**Ion source and starting electrodes at accelerating tube are cooled by oil. Oil pump capacity is 8 L/min, maximum oil pressure in cooling circuit 0.4 MPa, oil volume 10 L. System of distilled water cooling is three-circuit one: first circuit removes heat from ion guide elements, target and high vacuum and oil pumps. Inlet water pressure is 1 at, water flow – 0.03 m^3/hour. The volume of water in the first circuit is 3m^3.**
RF structure (RF frequency, phase width	**Modes of accelerator operation are continuous and pulse ones. By continuous mode of operation maximum current of ion beam (ion energy 250 keV) is 10 mA. By pulse mode ion source operates with frequency from 0.01 to 10 kHz. Pulse duration is set discretely: 0.6; 1; 2; 5; 10; 20; 33; 65; 130 mks. Ion current at the target is adjusted from 0 to 10mA.**
Beam energy spread and stability	Ion energy spread in the beam is in limits of 1.5%.

ECATS question sheet on accelerators specifications and performances for YALINA, SAD, RACE experiments

Beam intensity stability	Deviation of maximum beam current at the target during 30 min is no more than ±1 mA.
Beam footprint characteristics Beam footprint stability	Maximum diameter of ion beam is 30 mm. Stable

ECATS question sheet on accelerators specifications and performances for YALINA, SAD, RACE experiments

Internal beam monitoring (intensity, phase,…)	Transportation of ion beam along the ionguide is controlled by diaphragms. Beam current is controlled by two current collectors, one of which is located in front of the target
Focusing systems	Ion beam focusing is performed by means of two electromagnetic lenses. Maximum gradient of magnetic field induction is 4 Tl/m; maximum excitation current is 0.65 A.
Pulsing of Source (minimum/maximum pulse width, rise and fall time, repetition rate)	Pulse duration 0.5 – 100 μ, rise time 100 ns, fall time 500 ns, repetition rate 1 Hz-10 kHz

Subcritical assembly with thermal neutron spectrum $K_{eff} = 0.98$

Technical characteristics of available equipment

- Time analyzer TURBO MCS (ORTEC)

max frequency of pulses	150 MHz;
channel width	5 ns – 65 535s;
length of sequence	to 16 384 channels
channel capacity	16 777 215 counts;
amplitude of access port	from -5B to +5B;
min duration of input pulse	3 ns.

He-3 detectors (NH10NM) with a diameter 10 мм

Type	**Effective length, mm**	**Sensitivity, pulse/n*cm^{-2}**
0,5NKI/IK	10	0,5
12NK40/I	250	12

Technical characteristics of available equipment

- **Charge sensible amplifier for He-3 detectors (ACHNP97 and ACHNA98 types) to perform measurements by pulse methods:**
- **dead time – 0.8 µ;**
- **counting losses 3.1% at 40 000 c/s**

Technical characteristics of available equipment

- **7820 ADS module** –programming pulse amplifier-discriminator NIM standard
- rise time – 20ns;
- resolving time – 50ns.
- Integrator of this module allows to use all types of detectors (He-3, photomultipliers – with scintillation crystals boron counters, fission chambers. There is amplitude (spectrometric) port.

Technical characteristics of available equipment - Fission chambers

- **CNT-5** (diameter – 7mm, detector length 70 mm, sensitive layer length – 5mm, fissile nuclide – ^{235}U, sensitivity – $5x10^{-4}$ (pulse/s)/(n/cm^2s^{-1}), filling gas – (98% A_2 + 2% N_2), m (^{235}U) = 1 mg;
- **CNT-54** (diameter – 50mm, detector length 242 mm, sensitive layer length – 220 mm, sensitivity – 0.5 (pulse/s)/(n/(cm^2s^{-1}), fissile nuclide – ^{235}U, filling gas – (98% A_2 + 2% N_2), m (^{235}U) = 1 g,
- **^{3}He neutron detector** - small size (length - 1 cm and diameter – 1cm) with sensitivity 0.5 (pulse/s)/(n/cm^2s^{-1}).

Technical characteristics of available equipment

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

- **For all radiation pulse detectors** (α, β, γ, **X and neutrons) fission chamber or bore depositated counter**

- **Perfectly adapted to neutron measurements with fully programmable by PC computer via RS232, RS485 and Ethernet built-in interfaces**

Available equipment

- 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
- BF3 - chambers

Fission chambers

Type	Diameter nominal, mm	Detector length nominal, mm	Detector length sensitive, mm	Isotope	Sensitivity to thermal neutrons		Sensitivity to fast neutrons cs^{-1} / $n \cdot cm^{-2} \cdot s^{-1}$	Sensitive square, cm^2	Sensitive layer, ($mg \cdot cm^{-2}$)	Filling gas
					Pulse mode (cs^{-1}/ $n \cdot cm^{-2} \cdot s^{-1}$)	current mode (A / $n \cdot cm^{-2} \cdot s^{-1}$)				
KNT-56	50	750	525	^{10}B	–	$4 \cdot 10^{-13}$	–	–	–	BF_3
KNT-10	7	70	5	^{10}B	–	–	–	1	0,5	
KNT-2	7	70	10	^{232}Th	–	–	$6 \cdot 10^{-7}$	2	5	98%Ar + 2%N_2
KNT-5	7	70	5	^{235}U	$5 \cdot 10^{-4}$	–	–	1	1	98%Ar + 2%N_2
KNT-8	7	70	10	^{238}U	–	–	$2 \cdot 10^{-6}$	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

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

Sample	Activity, (10e+8) Bq	Mass, mg	Admixture
● NaI	0.044	1	< 17% I-127
● NpO_2	0.113	366	< 0.2% Pu-239
● Am O_2	1.100	14.8	< 0.2% Pu-239

Reactivity measurements

- It should be noted that combination methods of reactivity measurement and available equipment allows to obtain kinetic parameters of sub-critical system

$$\beta, \quad \Lambda, \quad \rho$$

driven by external neutron source (neutron generator).

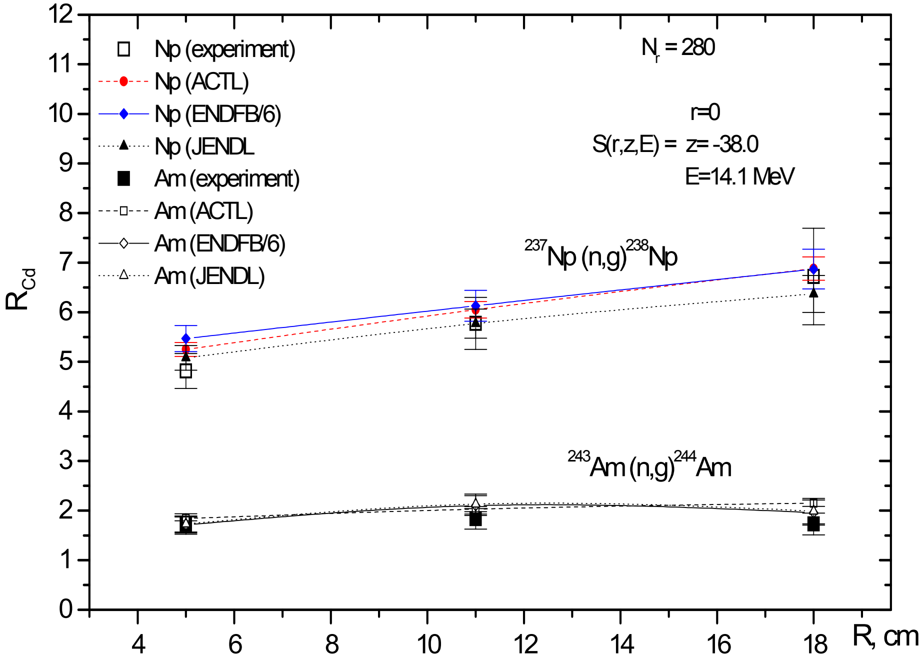
Experimental and calculated reactivity of sub-critical assembly of various configurations

N_{pins}	*Pulse me*	*Neutron thod*	*source*	*Gozani*	*metho d*	kef (1/N)	*Sjöstra nd*	*metho d*	kef MCNP	Life time, μs (MCNP)
	α, s-1	ρα , $	kef_α	ρ Goza-ni , $	k_{ef}_ Gozani		ρS , $	k_{ef}_S		
280	451.6 ± 1,4	4.154	0.969	4.397	0.967	0.964	4.547	0.967	0.9715 ± 0.0007	94.1
280-1 (centr)	473.1 ± 1.7	4.399	0.968	4.844	0.964	0.962	5.205	0.962	0.9686 ± 0.0007	94.4
280-2 (centr)	486.1 ± 1.6	4.548	0.966	4.832	0.964	0.960	5.219	0.962	0.9665 ± 0.0007	94.9
280-4 (centr)	519.6 ± 2.0	4.930	0.964	5.365	0.960	0.955	5.898	0.957	0.9616 ± 0.0006	95.99
280-1 (peref)	458.6 ± 1.05	4.240	0.969	4.307	0.968	0.963	4.536	0.967	0.9703 ± 0.0007	94.04
280-2 (peref)	468.4 ± 1.1	4.346	0.968	4.442	0.967	0.962	4.595	0.966	0.9689 ±	94.3

Kinetic measurment (Λ,ρ,α,β)

- Source multiplication method (critical loading experiment);
- pulsed neutron method;
- noise analysis method (Feynman-alpha method)
- Syostrand method (area method)
  $Ad / Ap = \beta / \rho$; $Y = A + B e(-\alpha t)$; $\alpha = (\beta-\rho)/\Lambda$;
  $\beta = 7.37\ 10\text{-}3$
- Gozani, T. Nukleonik 4(1962), 348.
- $-\rho = f A / \alpha B$; f – pulse repetition ($f \approx 54$ Hz); $Y = A + B e(-\alpha t)$
- Source jerk method

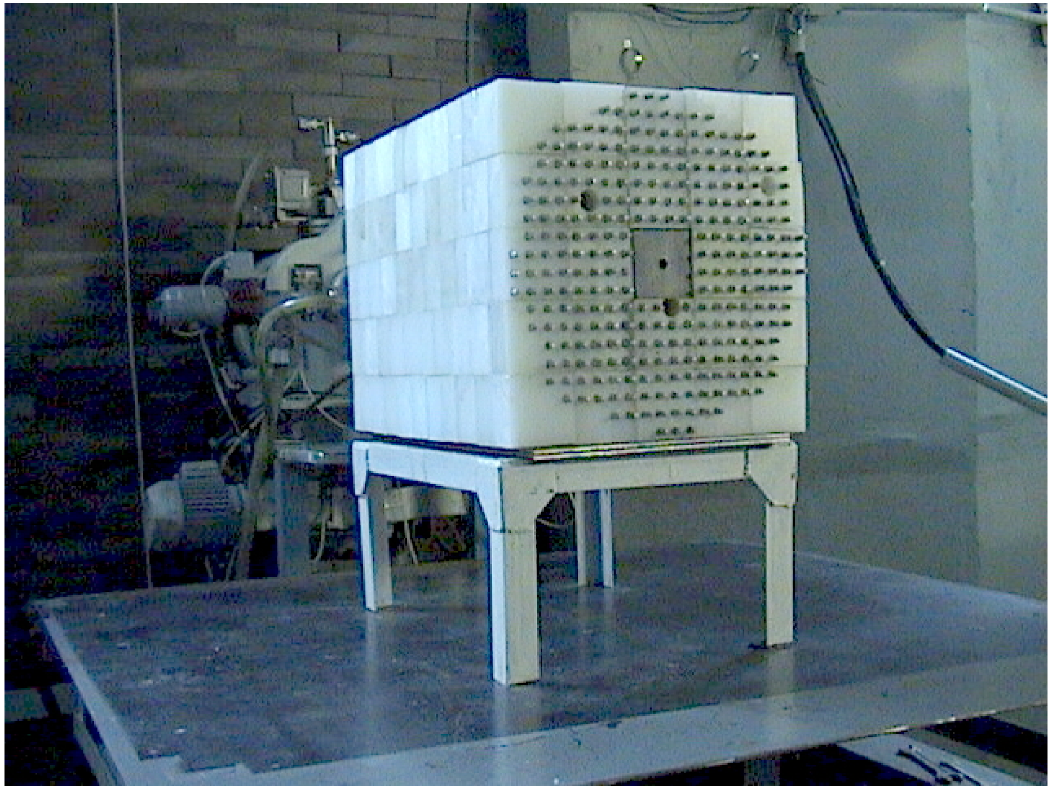
Radial distribution of Cd ratio of reactions $^{237}Np\ (n,\gamma)\ ^{238}Np$ and $^{243}Am\ (n,\gamma)\ ^{244}Am$ (Nr=280, Z_s= -38 cm, En=14 MeV)



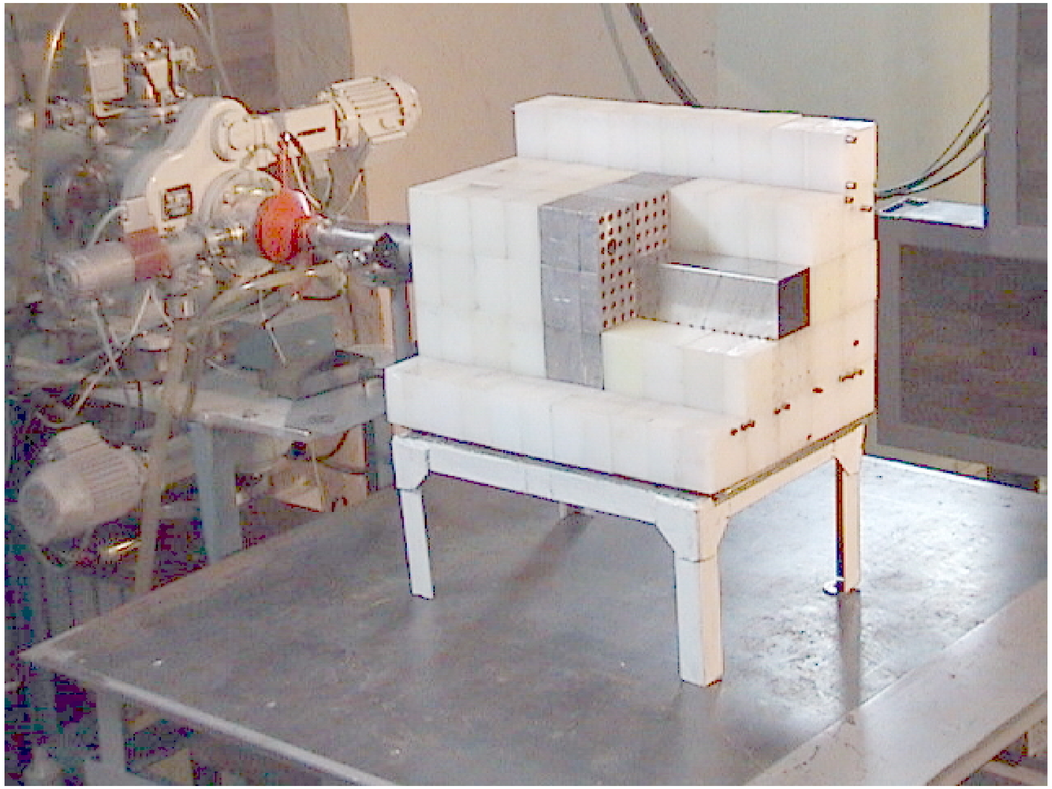
A wide experimental program on the basis of the YALINA facility has been already performed

- The measurements of spatial neutron flux distribution, spectral indices, external neutron source importance, reaction rates (^{129}I,^{237}Np,^{243}Am), neutron flux time evolution, multiplication factor K_{eff}, source multiplication factor Ks for different levels of subcriticality of the assembly driven by neutron generator operating in continuous and pulse modes with Ti^3H, TiD targets and ^{252}Cf source placed at various positions inside the core have been done.
- The analysis of the sequence of experimental data has been performed by MCNP code and with different neutron libraries (ENDFB-VI, ENDFB-IV).
- The comparison of the theoretical and experimental data shows that in a number of cases they agree relatively well within error margins.
- The ˝YALINA˝ and “YALINA-Pb” facility can be used to study the physics of multiplying media with thermal neutron spectra at different subcriticality levels, large range of different configurations (geometry, composition) and external neutron sources (Cf-252, D(d,n)He-3, D(T,n)He-4).

The view of “Bare” assembly (280 fuel pins) with lead blocks in the middle part instead of polyethylene ones. There are no measurement channels and fuel load map is somewhat different with respect to reference core.



The view of middle part of the assembly (part of polyethylene blocks were replaced by lead ones)



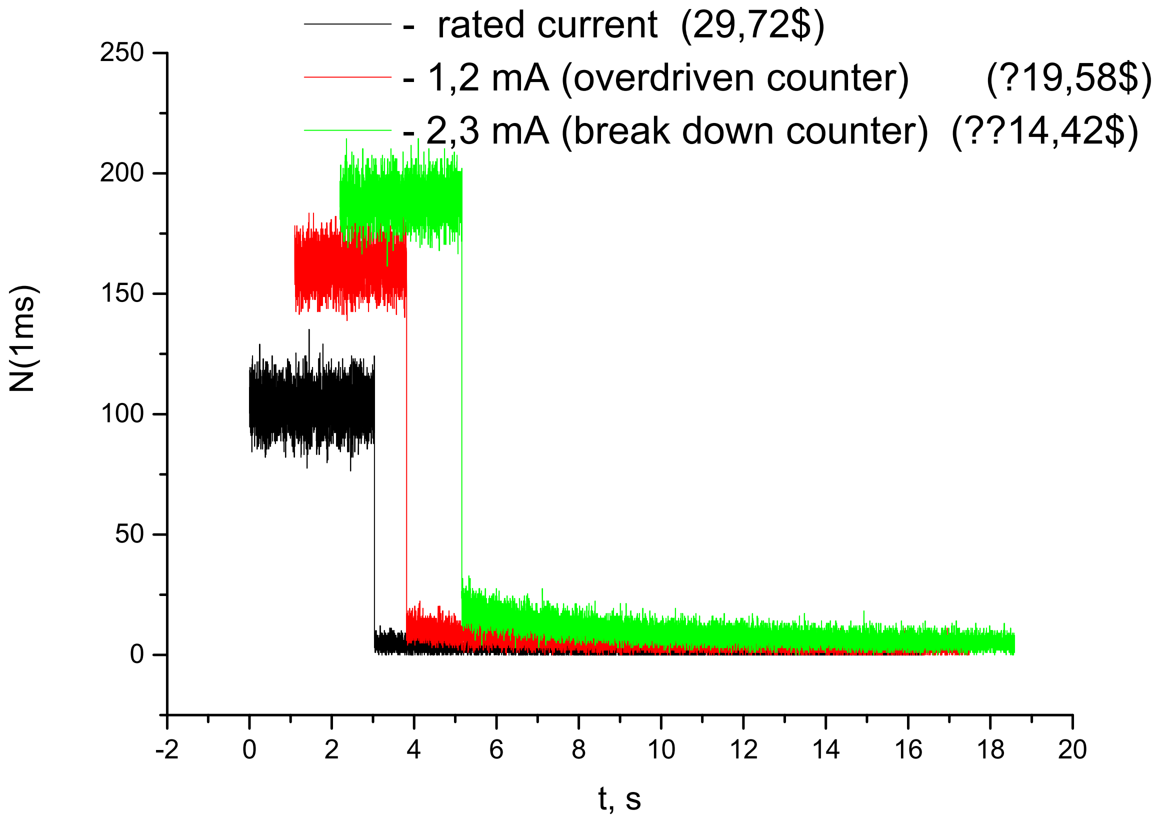
Measurements in “bare” assembly

- Small-size 3He detector enclosed in a cut out polyethylene holder (centering polyethylene plug is not at active part of the detector!) was placed in turn at center of EK2, EK3 and EK1 channels at point with Z=0.
- The measurements have been carried out by amplitude of ion beam pulse ~ 4V (2 mA) ensuring initiation of starting pulse shaping for activation of the time analyzer.
- By pulse measurements with application of DD target fair repeatability of results is observed by pulse repetition frequencies equal to 198 and 286 Hz and fixed ρ value by measurements in EK1-EK3 channels at Z=0.
- Magnitude of ρ estimated by means of Sjöstrand method is higher as previous than that estimated by Gozani method.

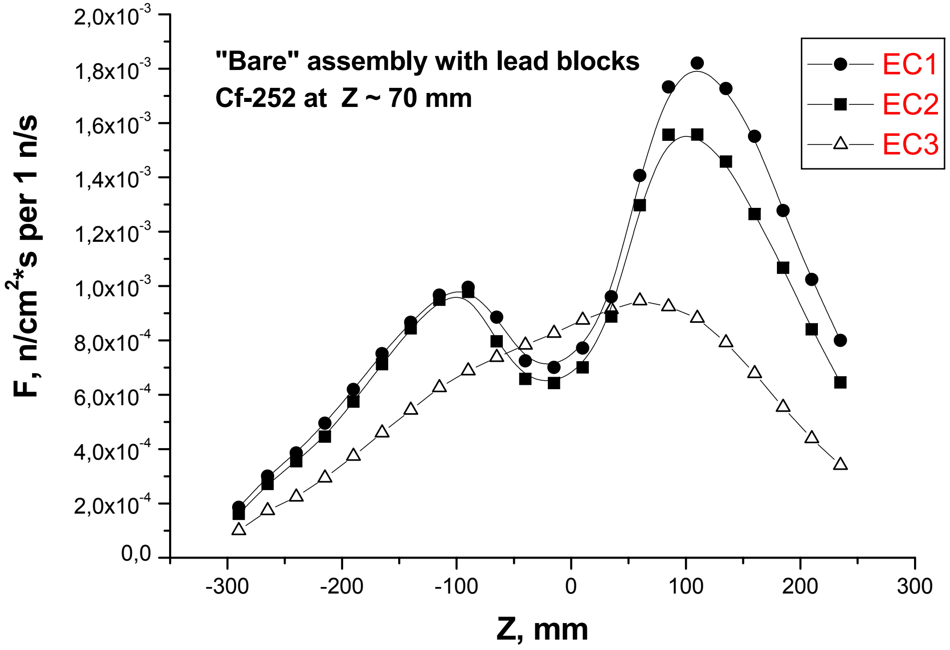
Pulse measurements with DD target (Z=0 cm) by means of Source Jerk Method

Dead time	Exponential fit after switching off			Linear fit before switching off		ρ, $
	a	b	α	a	b	
None	1.043 ± 0.05	3.57 ± 0.05	0.231 ± 0.009		95.3 ± 0.25	27.69
Yes	1.041 ± 0.05	3.60 ± 0.06	0.230 ± 0.01	-0.183	103.1	29.72
None	2.82 ± 0.06	8.62 ± 0.08	0.259 ± 0.006	0.228	143.3	17.62
Yes	2.84 ± 0.05	8.718 ± 0.078	0.26 ± 0.006	0.239 ± 0.2	161.96 ± 0.3	19.58
None	4.67 ± 0.08	13.81 ± 0.098	0.241 ± 0.005	-0.013	164.04	12.87
Yes	4.71 ± 0.082	14.067 ± 0.099	0.244 ± 0.005	0.00002	188.9 ± 0.3	14.42

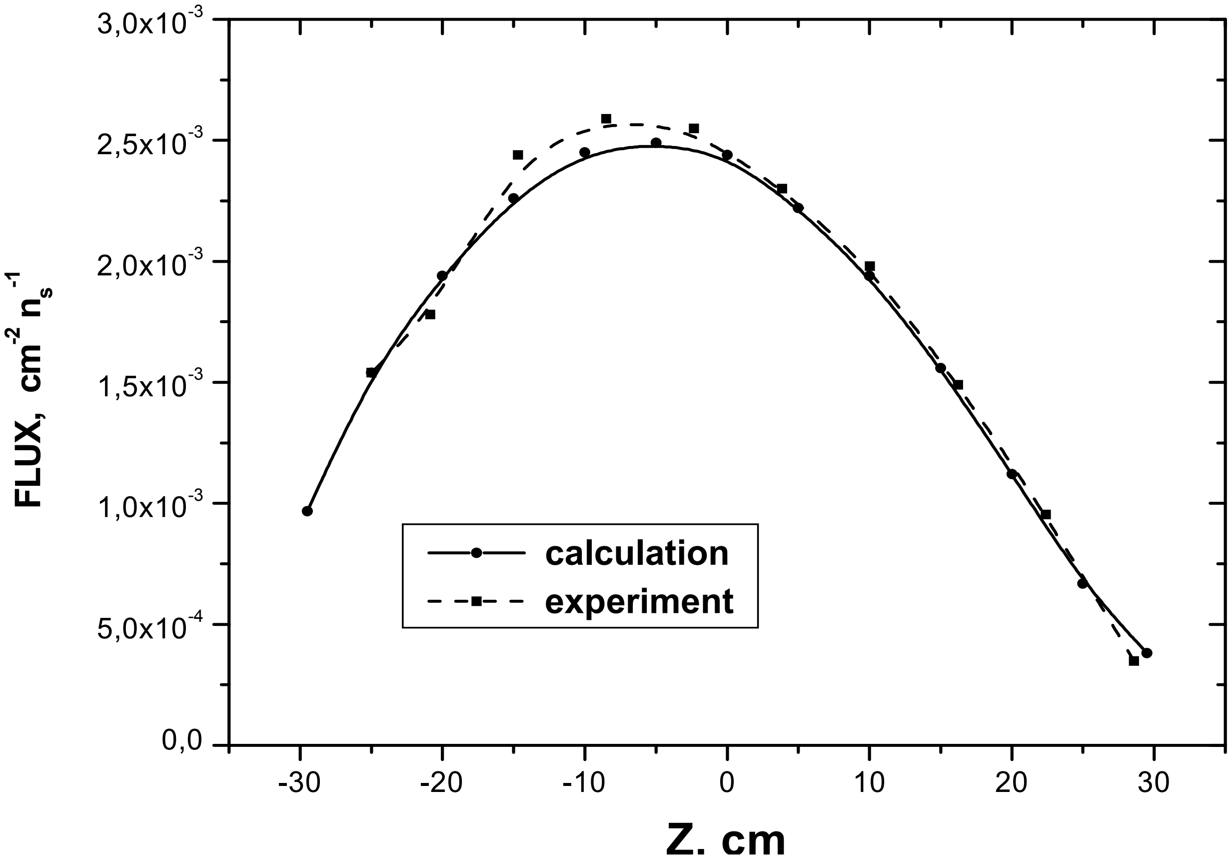
Results of the measurements performed by Source Jerk Method with DD target by different currents of ion beam



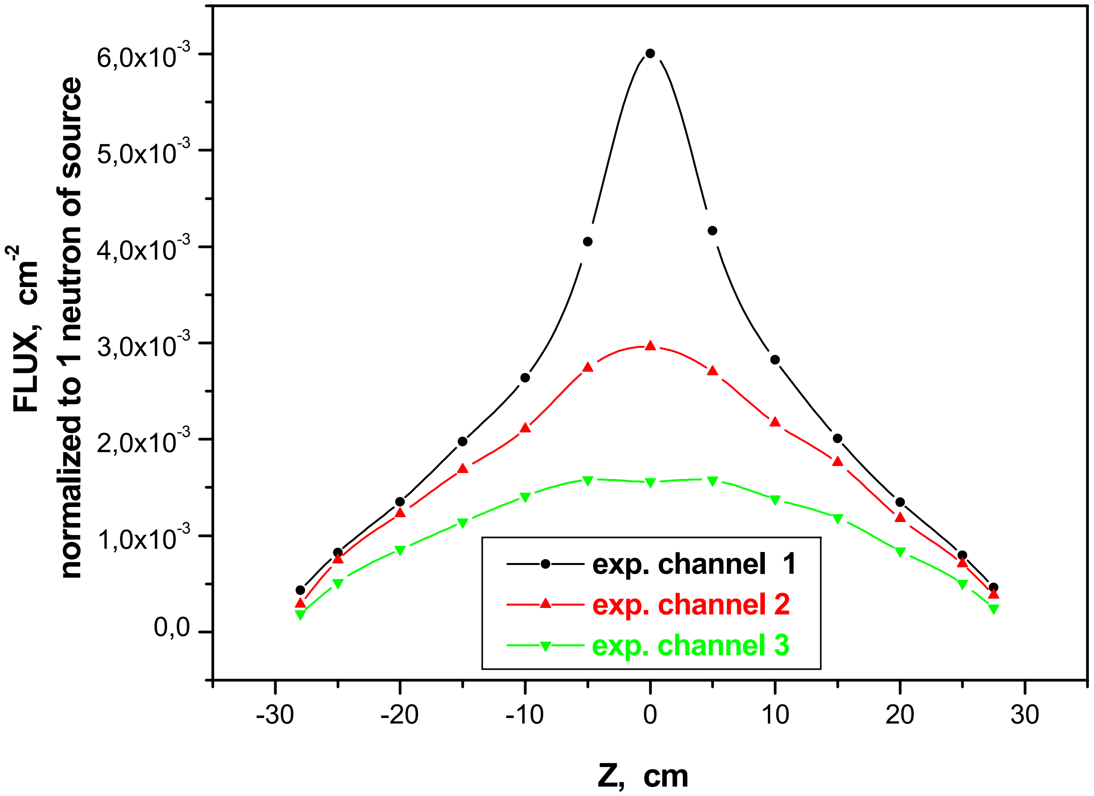
Axial distribution of neutron flux density in the experimental channels. Measurements of neutron flux distribution were performed in the assembly with lead blocks instead polyethylene ones at middle part of the assembly and 252Cf at Z ≈ 70 mm source



Comparison of the experimental and numerical results for neutron flux in experimental channel E1 by DT – mode, En < 100 keV. Neutron source is located outside the core.



Axial distribution of neutron flux density in the experimental channels (En > 0.75 MeV), DT-mode.



The results of fitting of pulse measurements with DD- target in extended target unit in “bare” (without any reflector) assembly with lead instead of polyethylene in middle part of the core

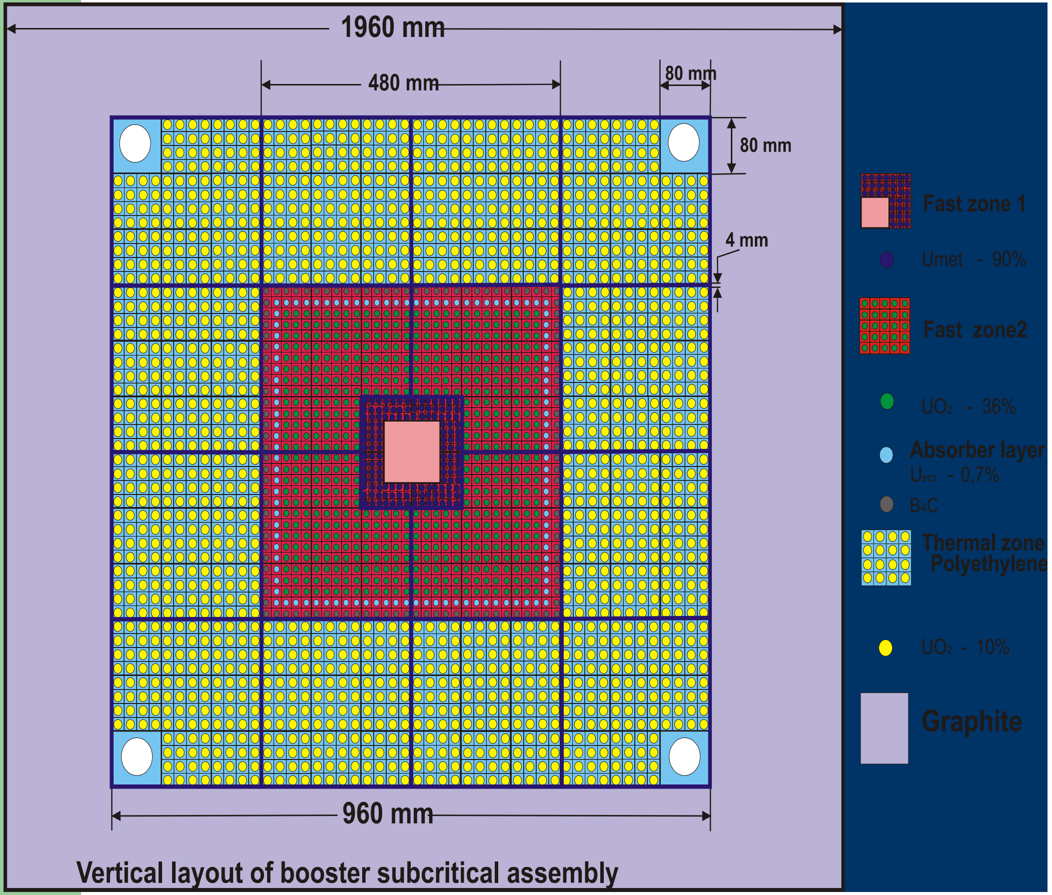
Condition of the assembly, target type and location	Type and position of the detector	Pulse repetition frequency of neutron generator, Hz	Interval of fitting, ms	Fitting			Gozani method		Sjöstrand method
				a	b	α	k_{ef}	ρ, $	ρ, $
“Bare” assembly with 280 fuel pins; Lead instead of polyethylene at middle part of the core; Extended target unit DD target at Z=0, 210 mm	^{3}He, EK1, Z=0	197.8	0.2 – 4.99	28.72±0.78	11707.6 ± 14.7	2860.1 ± 3.3	0.792	28.2	30.51
	^{3}He, EK1, Z=0	286.1	0.2 – 3.47	42.4±1.43	11752 ± 20.3	2864.5 ± 4.72	0.796	27.6	29.84
	^{3}He, EK2, Z=0	197.8	0.2 – 4.99	22.6±0.745	8710.6 ± 14.4	2915.5 ± 4.3	0.807	26.17	28.44
	He3, EK3, Z=0	197.8	0.2 – 4.99	33.38±0.83	12840.7 ± 15.2	2810.3	0.800	27.1	29.38

Further investigations at Yalina facility

- will be performed in the framework of strategy of booster (cascade) sub-critical system driven by the neutron generator.

- The basic idea of a fast spectrum booster coupled one-directional way to a thermal spectrum system is well known and consists in enhancement of the external neutrons source importance by placing a booster around the source located in the core center with the main sub-critical thermal part of the core surrounding the booster.

Yalina-Booster



Vertical layout of booster subcritical assembly

Keff = 0,975 – 0,98

Booster zone (K_{eff}= 0,67):

dimension, cm 48x48x50

FUEL:

X_5=90% U_m

X_5=36% UO_2

$F(E_n > 0,1$ MeV) ~ 10^9 n/(cm^2 s)

moderator Pb

Load (kg) U-5–62.8;U-8 -54.5

Intermediate zone

thickness, cm 3

material Umet (X5=0,7%) + B_4C

moderator Pb

load (kg) U-5 – 0.23; U-8 - 31.8

Thermal zone (K_{eff}= 0,95)

thickness, cm 24

fuel : X_5 =10% UO2

Moderator polyethylene

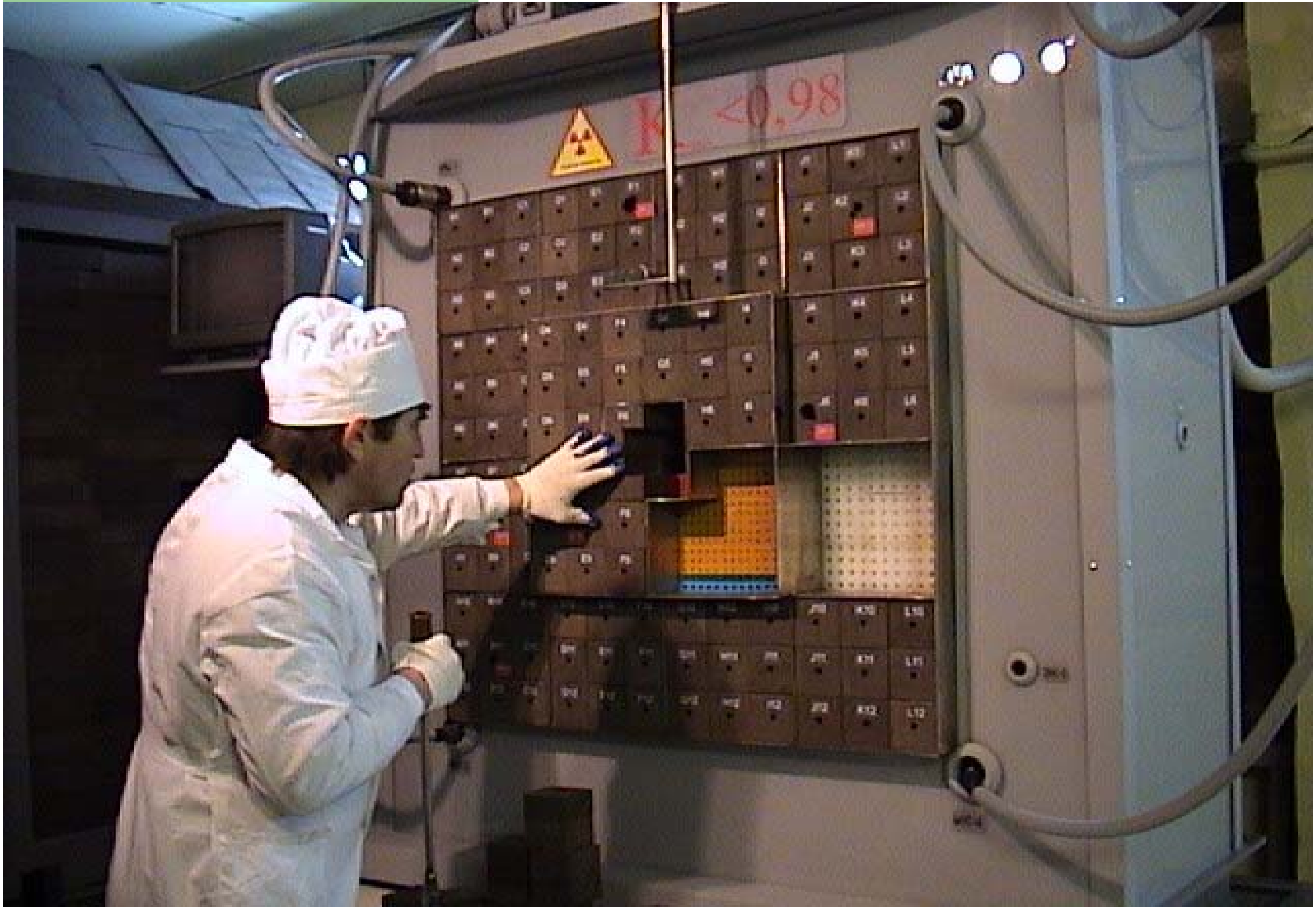
reflector graphite

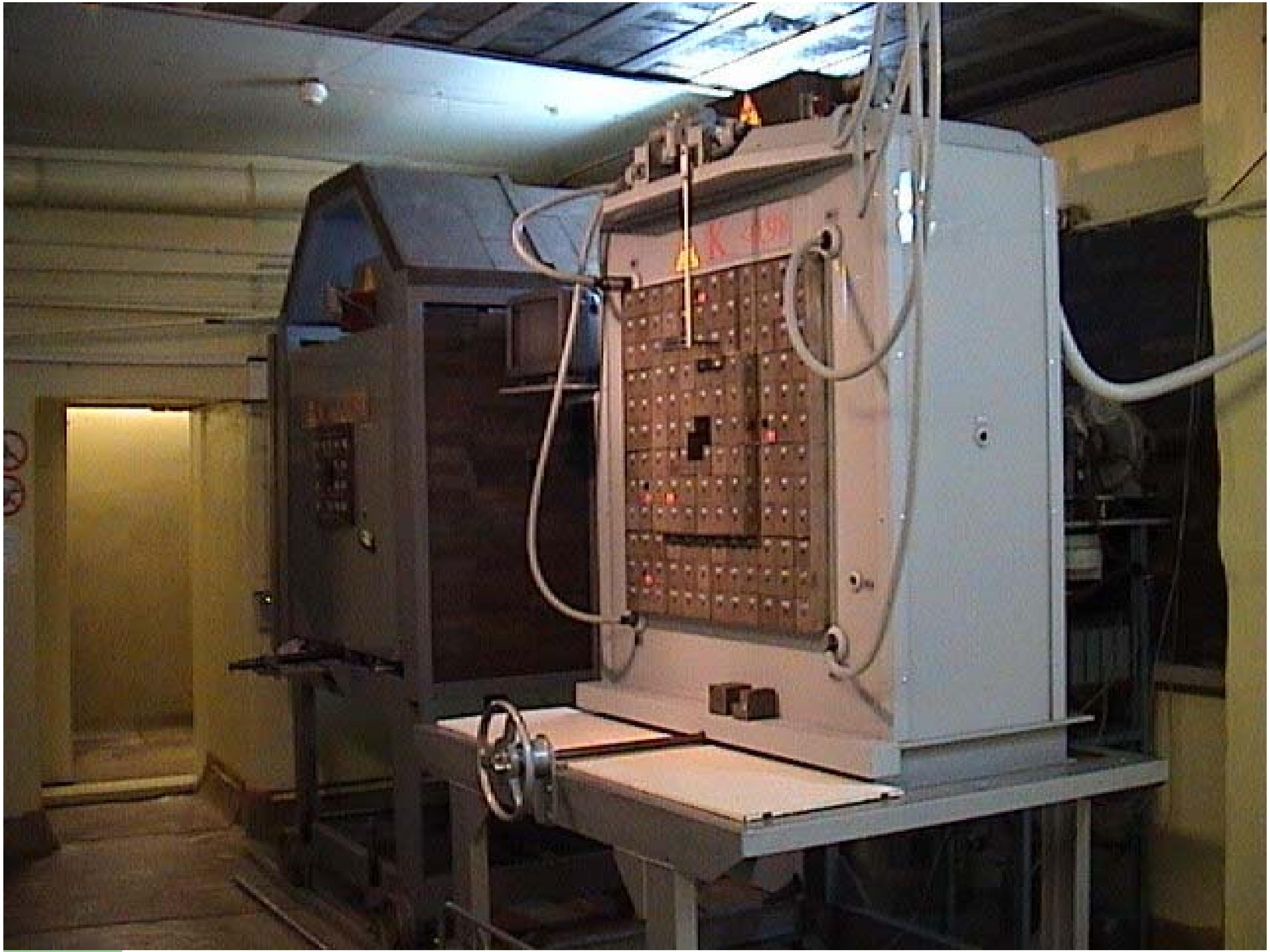
F(th):

Ti^3H –target ~ 10**9 n/(cm^2s)

Load (kg) U-5 – 8.07; U-8 -72.6

multiplication factor 50


K <0,98



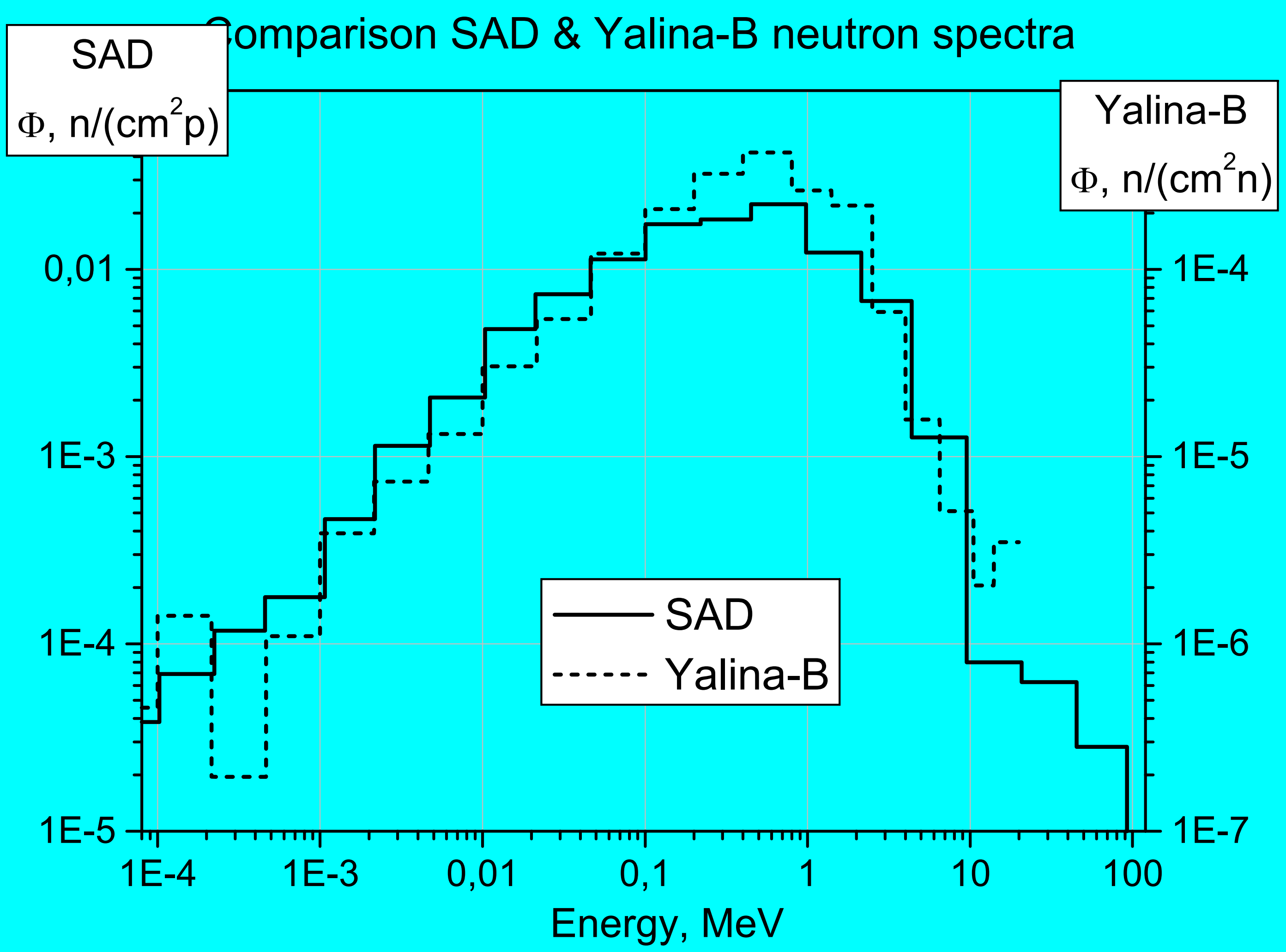
YALINA-B

- The main features of the YALINA-B facility are that neutron spectrum in the booster zone, time response (e.g., response of 235U fission rate to the source pulse) as well as the neutron lifetimes are very close to those in SAD

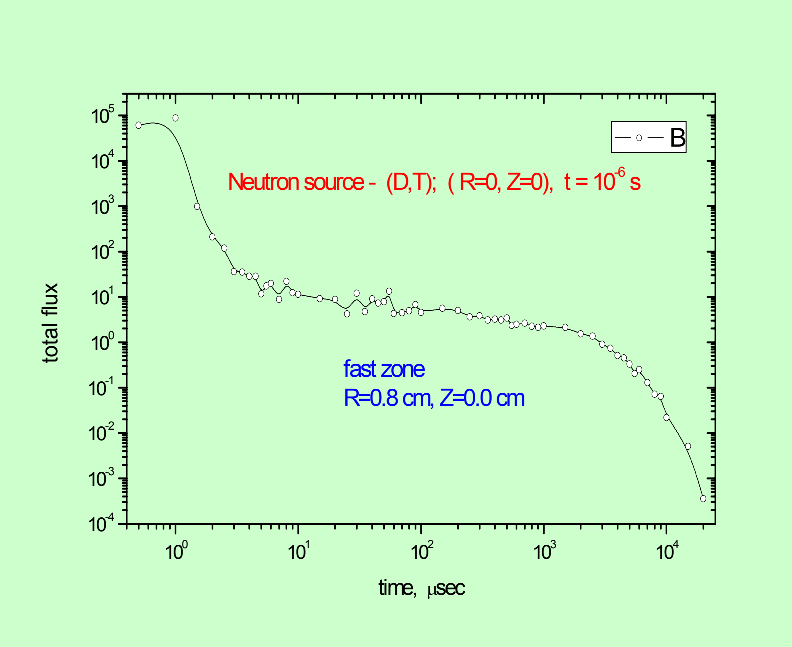
YALINA-B

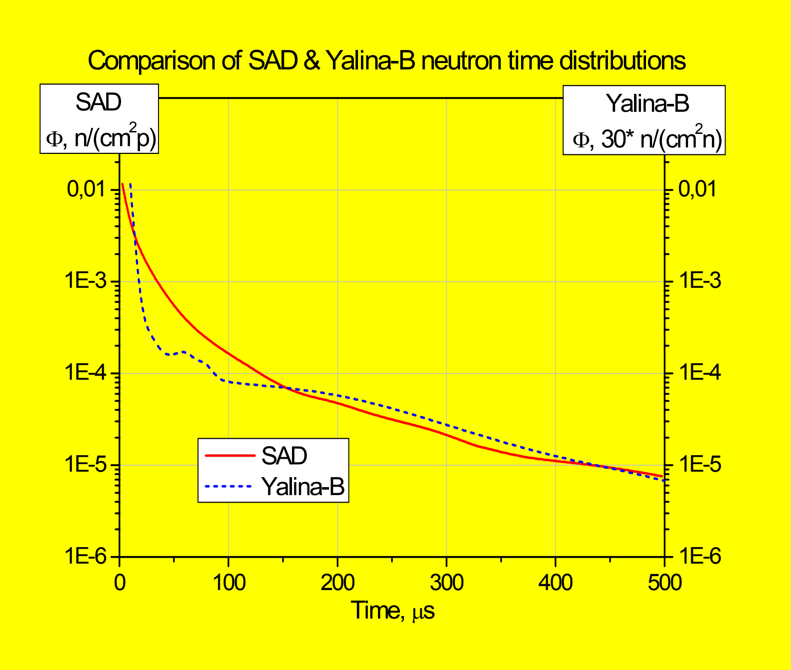
The fast zone of the facility can be considered as a volume neutron source in contrast to YALINA and MASURCA experiments.

From this point of view the booster zone is closer to the spallation lead target of the SAD and MYRRHA projects.


Comparison SAD & Yalina-B neutron spectra
SAD
Φ, n/(cm²p)
Yalina-B
Φ, n/(cm²n)
0,01
1E-3
1E-4
1E-5
1E-4
1E-5
1E-6
1E-7
1E-4
1E-3
0,01
0,1
1
10
100
Energy, MeV
SAD
Yalina-B

Time evolution of the neutron flux after neutron generator pulse ($\tau=1\mu s$).



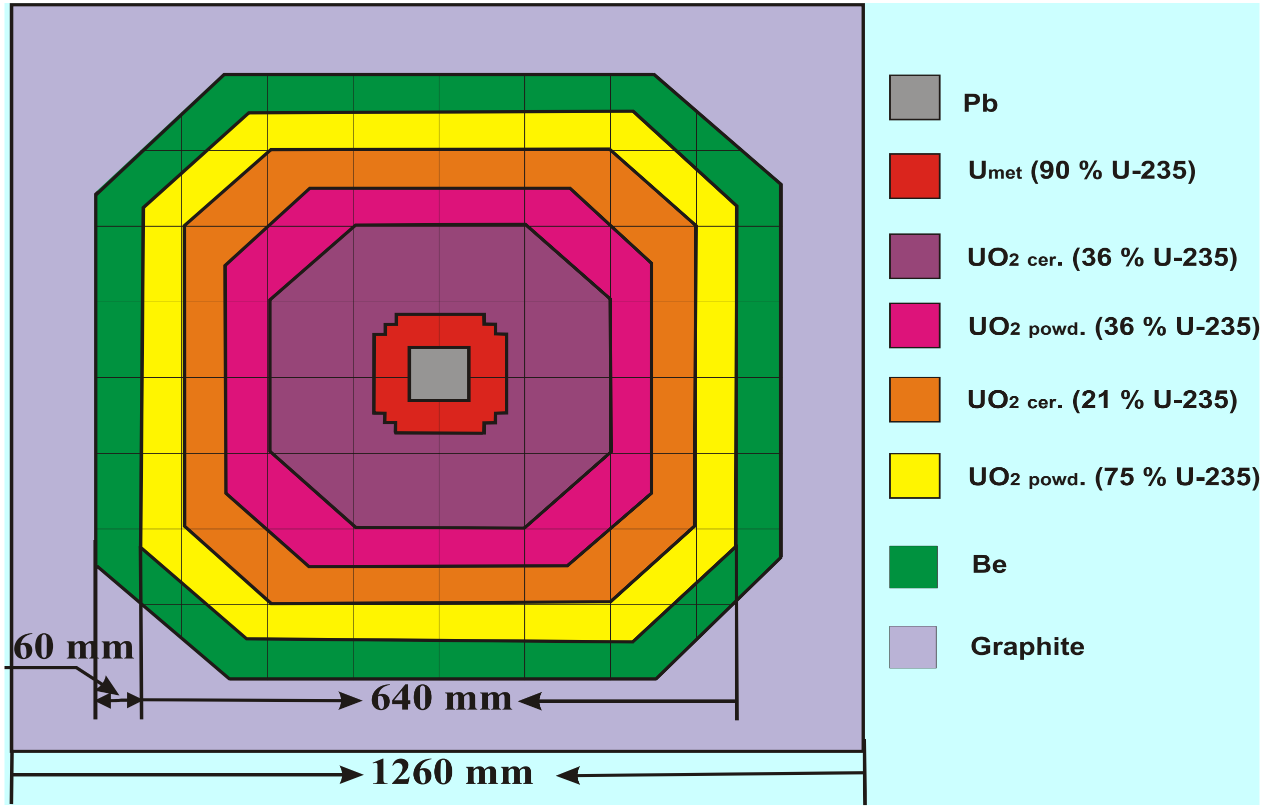


Prompt neutron lifetime in the booster subcritical assembly driven by a neutron generator

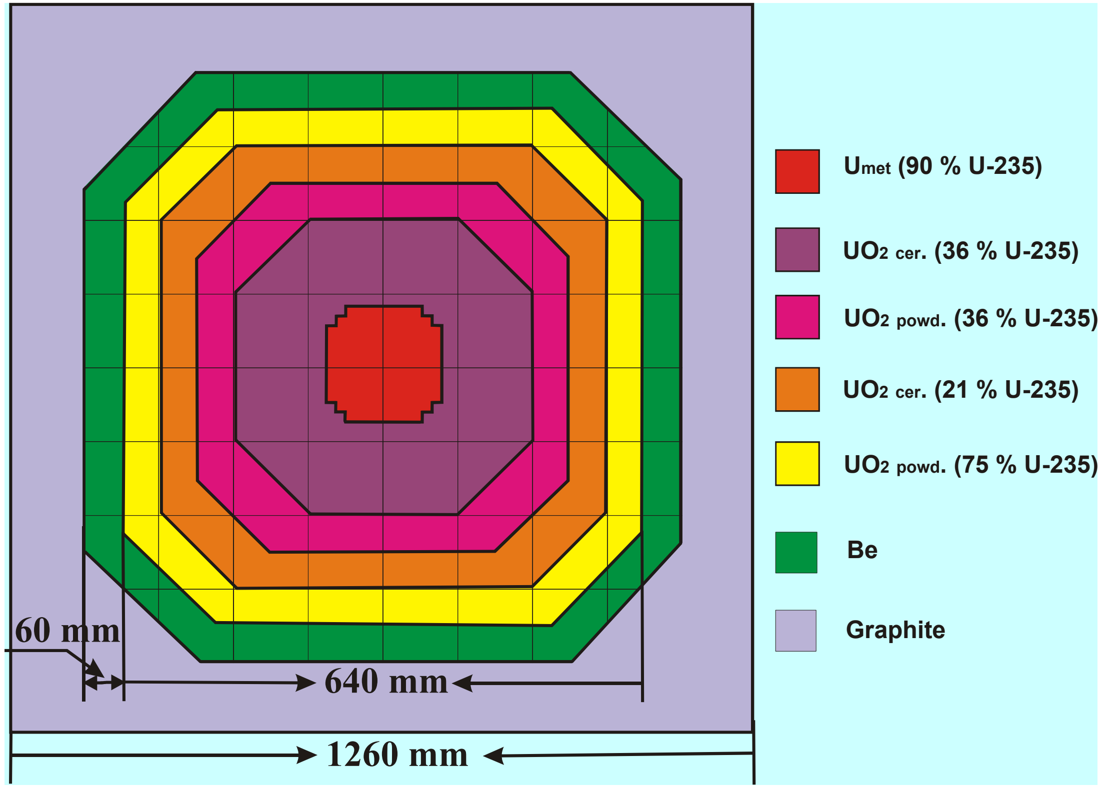
SAD A. Lopatkin L = 24µs; E. Gonzales L = 0.954µs ;
MUSE -3 L = 0.61 µs; MYRRHA L=6.0 µs.

	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 µs with B_4C in the intermediate zone 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)

k^{eff} =0.90


60 mm
640 mm
1260 mm
Pb
U_{met} (90 % U-235)
UO_2 cer. (36 % U-235)
UO_2 powd. (36 % U-235)
UO_2 cer. (21 % U-235)
UO_2 powd. (75 % U-235)
Be
Graphite

k_{eff} =0.93-0.95



U_{met} (90 % U-235)
UO_2 cer. (36 % U-235)
UO_2 powd. (36 % U-235)
UO_2 cer. (21 % U-235)
UO_2 powd. (75 % U-235)
Be
Graphite
60 mm
640 mm
1260 mm

Comparison of parameters of sub-critical assembly MYRRHA and sub-critical booster assembly YALINA-BOOSTER (MYRRHA (Y-B-M))

Parameter	MYRRHA	Y-B-M
Neutron spectrum	fast	fast
Moderator (coolant)	Pb-Bi, Pb	Pb
Length of fuel rod active part	500 mm	500mm
Subassembly configuration	hexagonal	tetrahedral
Fuel composition of the core	Pu/(Pu+U) = 30% (12 subassemblies) Pu/(Pu+U) = 20% (6 subassemblies)	$U_{met.}$(90% of ^{235}U) (4 subassemblies) UO_2 (36% of ^{235}U) (~80 subassemblies) thermal sp. island (9 subassemblies)
Neutron-producing target at the center of the core)	Pb	Pb 80x80x648(mm^3)
Multiplication factor	0,95	0,7-0,9
Core radius	500-600 mm ≤ 1000≤ mm	500 mm 500 mm⇒1000 mm
Fuel rod number in the subassembly	61	49 -U_{met} 90 % 36 -UO_2(36%)

Experimental programme

- Validation of applicability of the methods developed for critical reactors to determine keff for sub-critical systems

- Development of reactivity monitoring techniques for subcritical systems with fast neutron spectrum

- Study of dynamics, coupling (feedback) for the system:
  “neutron generator – sub-critical reactor”

- Investigations of the core response due to fast reactivity insertions by movement of a B_4C rod in the experimental channels of the core
- Study the features of coupling of spallation target and core
- Studying the influence of shielding on physical parameters of the fast spectrum core
- Pu, MA and LLFP transmutation rates in fast & thermal neutron spectrum

Experimental programme

- neutronics of lead in fast neutron spectrum;
- the threshold reactions rates and transport of high energy neutrons (En>0.2 MeV) in the core.
- kinetic parameters of the booster zone for different type of reflector (Pb, C, Be, $ZrH_{1.7}$, borated polyethylene)
- subcriticality measurements and monitoring (K1, K2, Keff)
- experimental determination of kinetic parameters and response to external neutron pulses for different sub-criticality levels.
- spatial and energy distributions of neutron field in subcritical cascad system
- coupling properties fast&thermal part of the core
- Reactivity changes $\rho\Delta$ (ρ=(keff -1)/ keff) due to removal the central and the peripheral fuel rods;

It should be investigated:

- Neutron flux distributions and competition of different modes (source and higher harmonics)
- -Importance of source neutrons with respect to fission neutrons
- -Effect of buffer medium around spallation source

Conclusion

The experimental facilities YALINA and YALINA-B allow to deliver valuable data in the following fields:

- measurements of transmutation rates of fission products and minor actinides,
- investigation of spatial kinetics of the sub-critical systems with external neutron sources,
- validation of the experimental techniques for, e.g., sub-criticality monitoring,
- neutron spectra measurement,
- safety research on sub-critical systems,
- technological applications such as, neutron activation analysis
- production of isotopes for calibration of gamma spectrometers etc.