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The status of subcritical facility YALINA

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On behalf of YALINA team

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Outline

- ISTC Project B-070 (EU funding)
  - YALINA-Thermal sub-critical assembly
- YALINA-Booster sub-critical assembly
  - IP EUROTRANS DM2
- ISTC Project B1341
- Conclusions

ISTC Project B-070 "Experimental and Theoretical Research of the Peculiarities of Transmutation of Long-Lived Fission Products and Minor Actinides in a Subcritical Assembly Driven by a Neutron Generator"

- Duration 1.09.1998 to 1.05.2005
- Project managers:
  - Hanna Kiyavitskaya (1998-2002)
  - Ivan Serafimovich (2002-2005)
- Joint Institute for Power and Nuclear Research – Sosny, National Academy of Sciences of Belarus

ISTC Project #B-070

- **Funding by EU (551 524,77 $)**
- **Collaborators**
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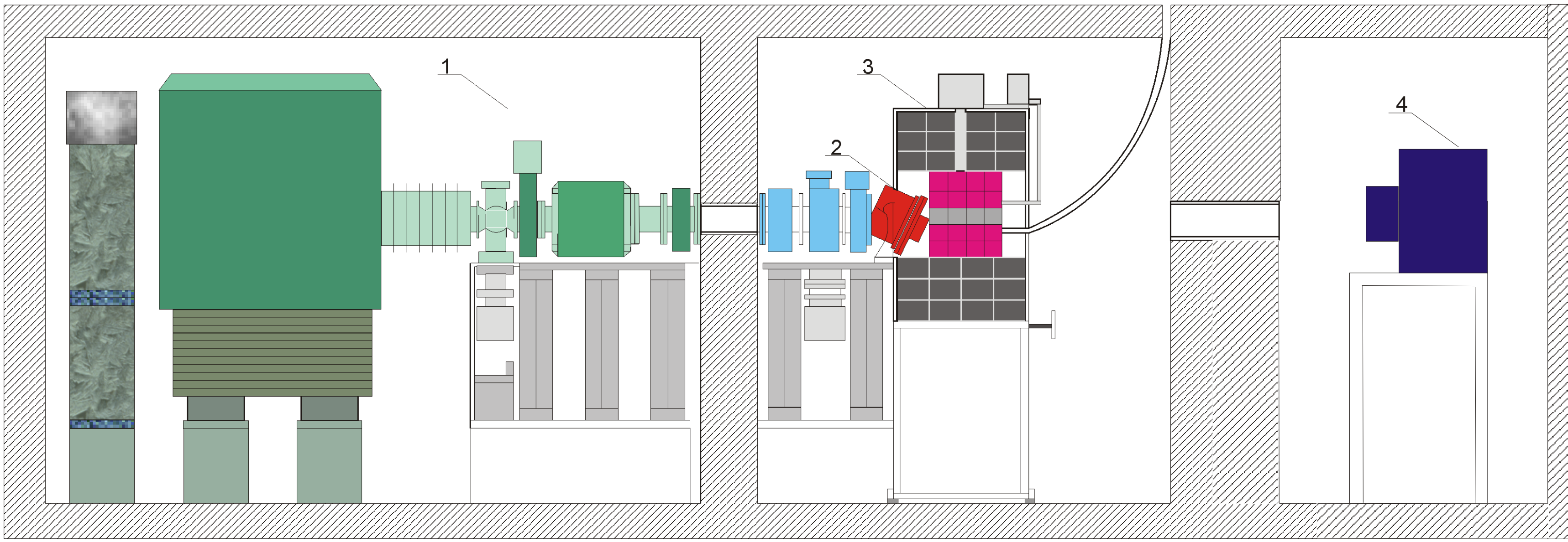
Objectives of the Project

- Experimental confirmation of a possibility of usage of low energy ion accelerators to investigate ADS neutronics and peculiarities of ADTT .
- Design, construction and putting into operation a sub-critical facility with thermal neutron spectrum driven by neutron generator
- Carrying out the experimental investigation of neutronics of sub-critical systems driven by external neutron sources and technology of long lived fission products and minor actinides transmutation.

ISTC Project #B-070

- Zero power model of ADS
  - YALINA-T - sub-critical assembly with thermal neutron spectrum consists of
    - neutron-producing lead target located at the core center
    - sub-critical blanket (k_{ef}<0.98)
    - graphite reflector
    - biological shielding

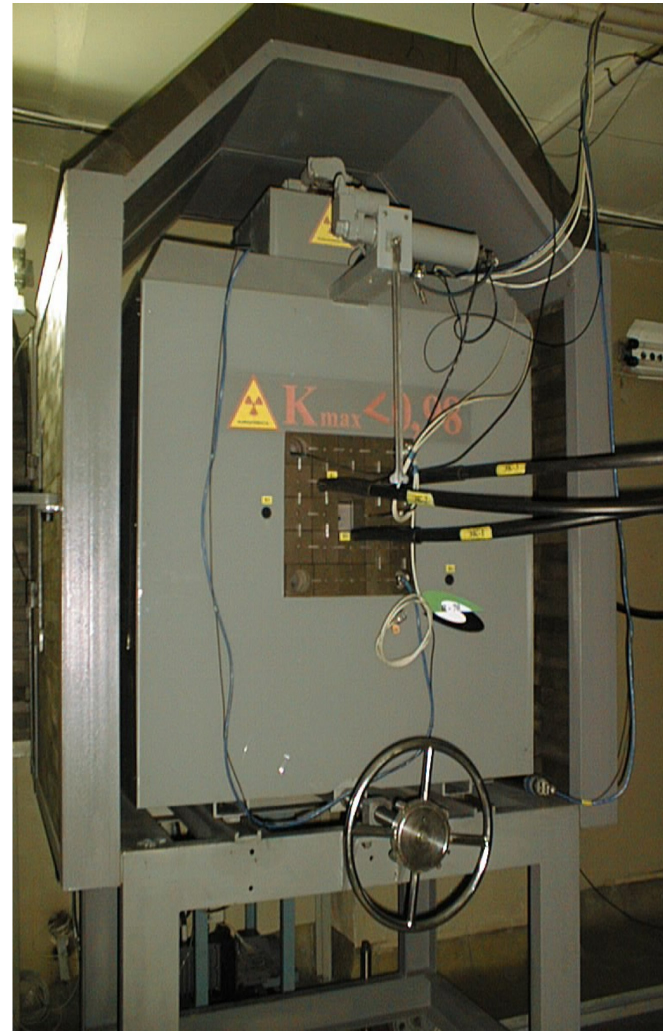
Sub-critical facility YALINA



1 – neutron generator
2 – Ti^3H (Ti^2H) target system
3 – sub-critical assembly
4 – monitor of neutrons escaped from the Ti^3H- or TiD-targets

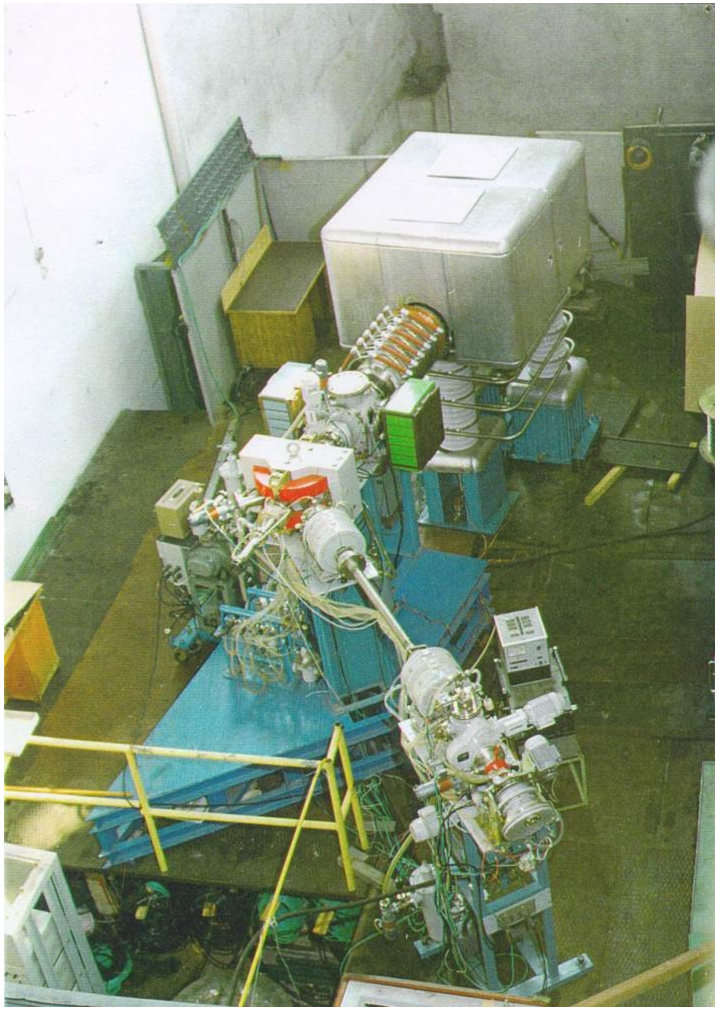
YALINA-T sub-critical assembly with thermal neutron spectrum

- The core is a rectangular parallelepiped
- Assembled from polyethylene sub-assemblies (16 fuel pins per sub-assembly) → large flexibility of core configuration
- The core is loaded with UO_2 fuel dispersed in Mg matrix (x_5=10 %)
- Fuel pins are arranged according a square lattice with 2.0 cm spacing
- Central part of the subcritical assembly is a neutron producing lead target *8.0cm x 8.0cm x 60.0cm*
- The core is surrounded by graphite reflector of high purity (*40.0 cm* thick) and with thin Cd layer



Neutron generator

- Linear accelerator of deuterium ions with energy E_d = 250 keV
- Accelerator magnet system separates D^+ions using electro-magnetic lenses directed towards the Ti^3H or TiD targets
- $d+T \rightarrow {}^4He+n$(13-15 MeV)
- $d+d \rightarrow {}^3He+n$(2.5-3.0 MeV)
- Highly effective water-cooled targets with diameters 230mm and 45mm



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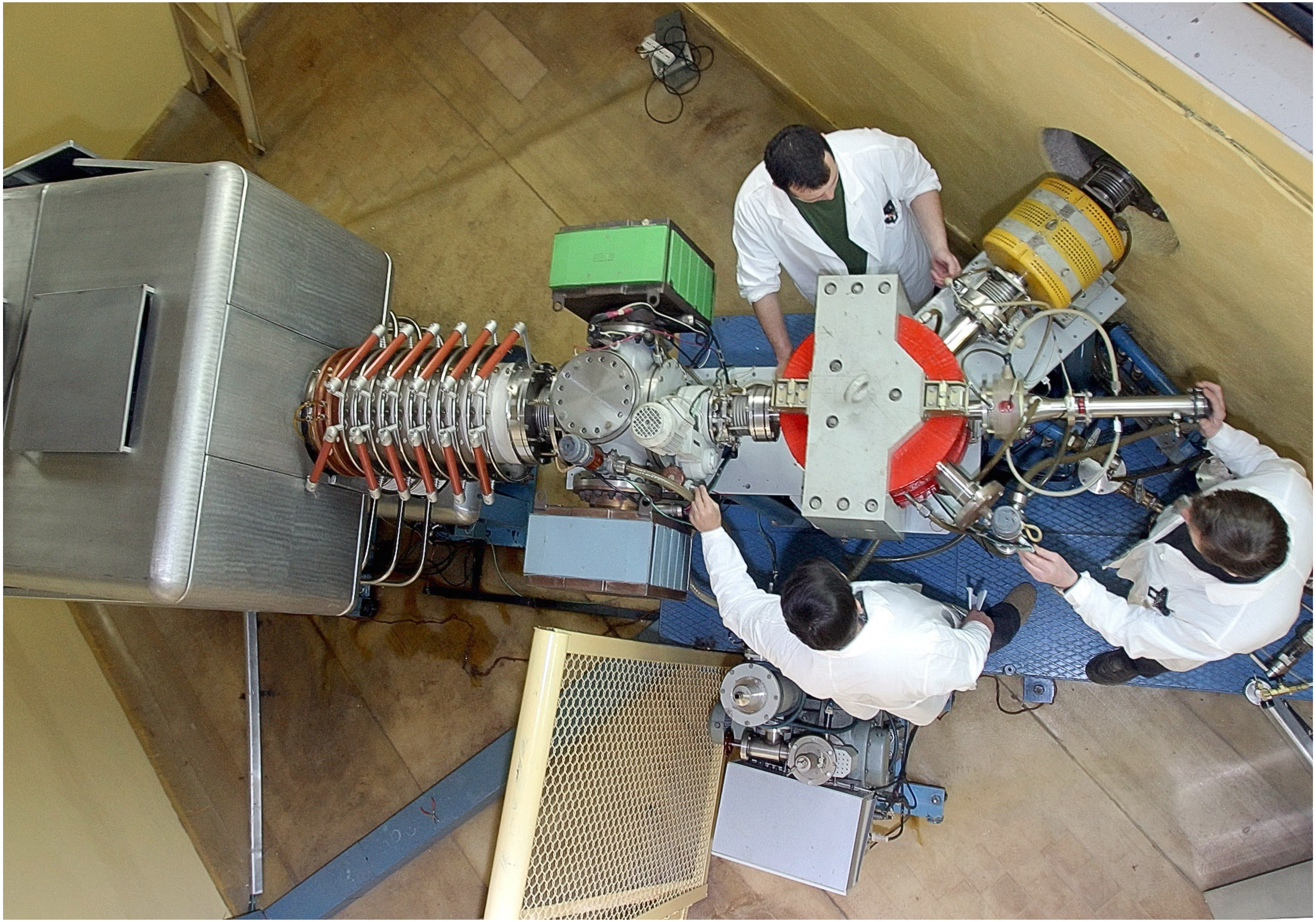
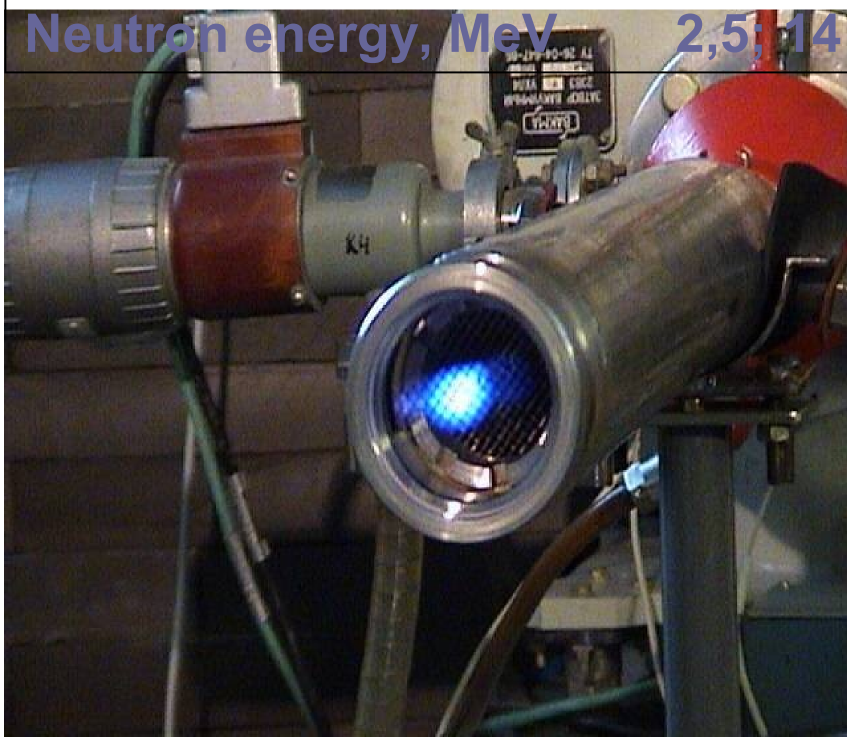
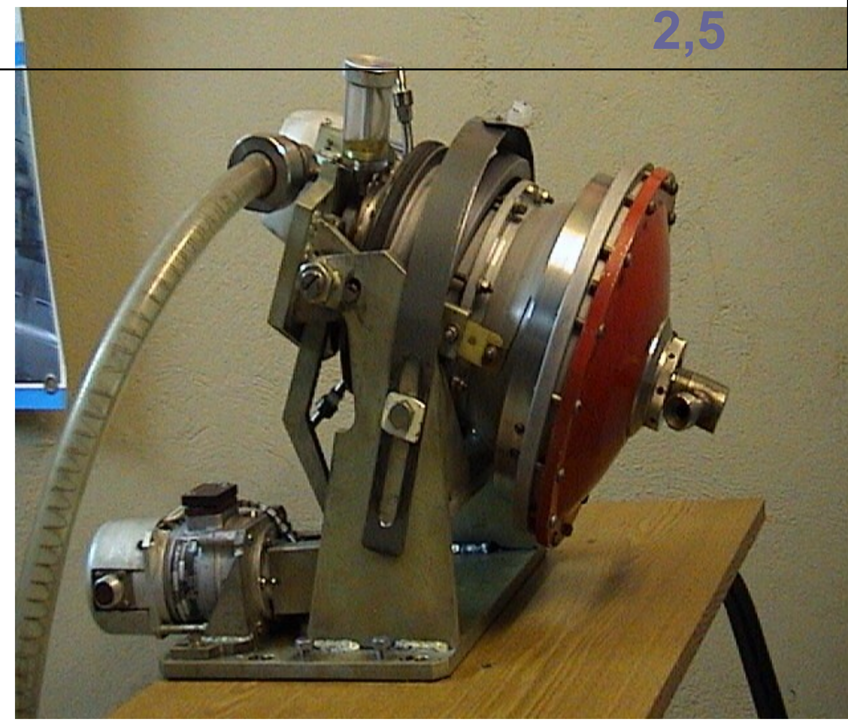
Neutron Generator



Characteristics of Targets

Target diameter, mm	45	230
Rotation speed, rpm	560	560
Beam current, mA	1 – 2	1 - 12
Neutron energy, MeV	2,5; 14	2,5





Neutron Generator NG-12-1

Pulse mode of NG-12-1 operation

- Allows to generate neutron pulses with duration **0.5µs - 100µs** and repetition frequency **1Hz-10KHz**
- Provides extended possibilities for:
  - Investigation of multiplying media kinetics
  - Development of the methods of sub-criticality level monitoring
  - Elaboration of the theoretical approaches for description the peculiarities of neutron fields formation in deeply sub-critical systems

Main conclusions

- The idea of application of low energy ion accelerators to study neutronics of ADS was proved
- The facility YALINA with thermal neutron spectrum driven by high intensity neutron generator NG-12-1 was designed, constructed and put into operation.
  - Original design allows
    - to vary core configuration for carrying out the experiments by sub-criticality levels up to keff ≤ 0.98,
    - To use different external neutron sources (^{252}Cf; $d(d,n)^3He$; $d(t,n)^4He$) with its' various locations relative to the core center.

Main conclusions (cont.)

- The program of experimental and theoretical investigations
  - validation of the experimental methods and techniques developed for sub-criticality level measurements based on those worked out for critical systems,
  - validation of the codes and evaluated nuclear data libraries,
  - estimation of factors of neutron-producing target coupling with core and etc.

Main conclusions (cont.)

- Following methods of reactivity measurements were studied and used:
  - pulse neutron source method
  - Sjöstrand method,
  - Source Jerk method,
  - methods based on noise analysis

N_{pins}	Pulse	Neutron method	Source	Gozani	Me-thod	kef (1/N)	Sjöstrand	Me-thod	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 ± 0.0007	94.3
280-4 (peref)	490.5 ± 1.23	4.598	0.966	4.679	0.965	0.960	5.052	0.963	0.9672 ± 0.0007	94.4

Main conclusions (cont.)

- Combination of the methods (PNS, Sjöstrand method, Source Jerk Method, noise method) allows to carry out the experimental estimations of different kinetics parameters of sub-critical systems such as β_{eff}, Λ and ρ with sufficient accuracy.

Main results

- Spatial distributions of reaction rates on ^{129}I, ^{237}Np, ^{243}Am nuclei, threshold reaction rates and simulation by MCNP-4C code with different libraries of evaluated nuclear data
- The comparison of the experimental and calculated data has shown a fairly good agreement for different neutron sources, though for some reactions (Ti(n,p), Al(n,p)…) the discrepancy is observed that requires further analysis.

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

Method of neutron spectrum determination

- A method of neutron spectrum determination in the core has been developed based on measurement of threshold (n,xnyp) reactions rates.
- The rates of the threshold reactions decrease to the core periphery, decreasing to be more significant than that of the radiation capture reaction rates.
- It is a consequence of reducing of high energy neutron number due to both elastic and inelastic interactions with medium nuclei.

Used reactions:

$^{111}Cd\ (n,n')^{111}Cdm$ (E_{eff} = 0,25 MeV),

$^{55}Mn(n,\alpha)^{52}V$ (E_{eff} = 0,64 MeV),

$^{204}Pb(n,n')^{204}Pbm$ (E_{eff}=0,90 MeV),

$^{115}In(n,n')^{115}In^{m}$ (E_{eff}=0,34 MeV),

$^{90}Zr(n,p)^{64}Cu$ (E_{eff}=2,0 MeV),

$^{58}Ni(n,p)^{58}Co$ (E_{eff}=2,7 MeV),

$^{59}Co(n,p)^{59}Fe$ (E_{eff}=2,8 MeV),

$^{65}Cu(n,p)^{65}Ni$ (E_{eff}=3,5 MeV),

$^{27}Al(n,p)^{27}Mg$ (E_{eff} = 4,5 MeV),

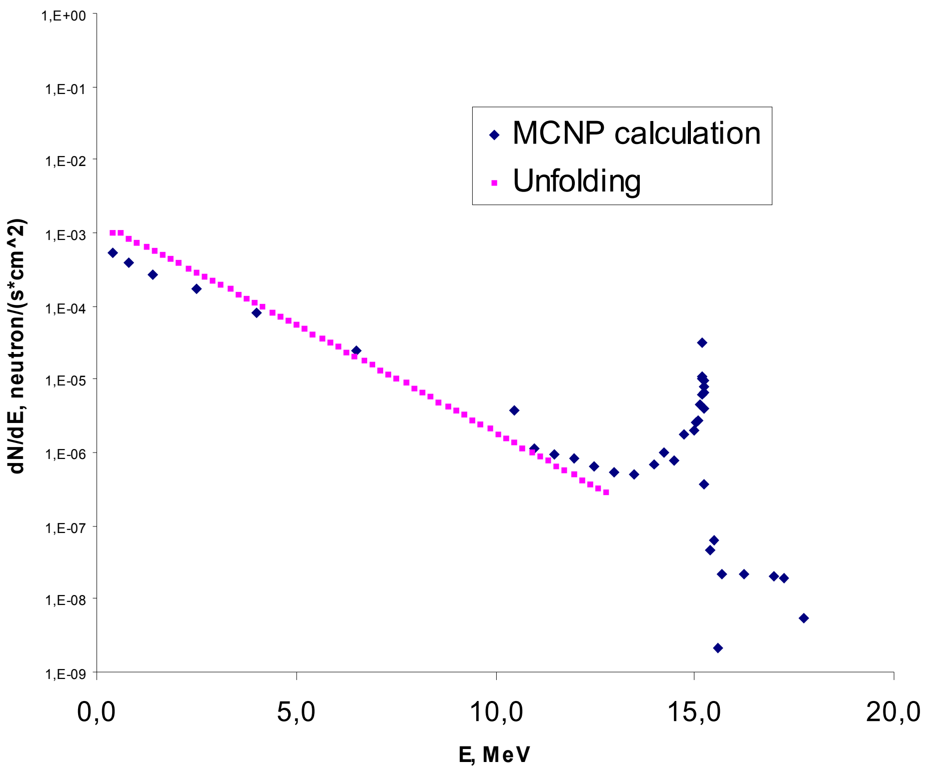
$^{24}Mg\ (n,p)^{24}Na$ (E_{eff}=4,93 MeV),

$^{48}Ti\ (n,p)^{48}Sc$ (E_{eff}=5.0 MeV),

$^{56}Fe(n,p)^{56}Mn$ (E_{eff} = 6,60 MeV),

$^{59}Co(n,\alpha\ )_{56}Mn$ (E_{eff}=7,10 MeV),

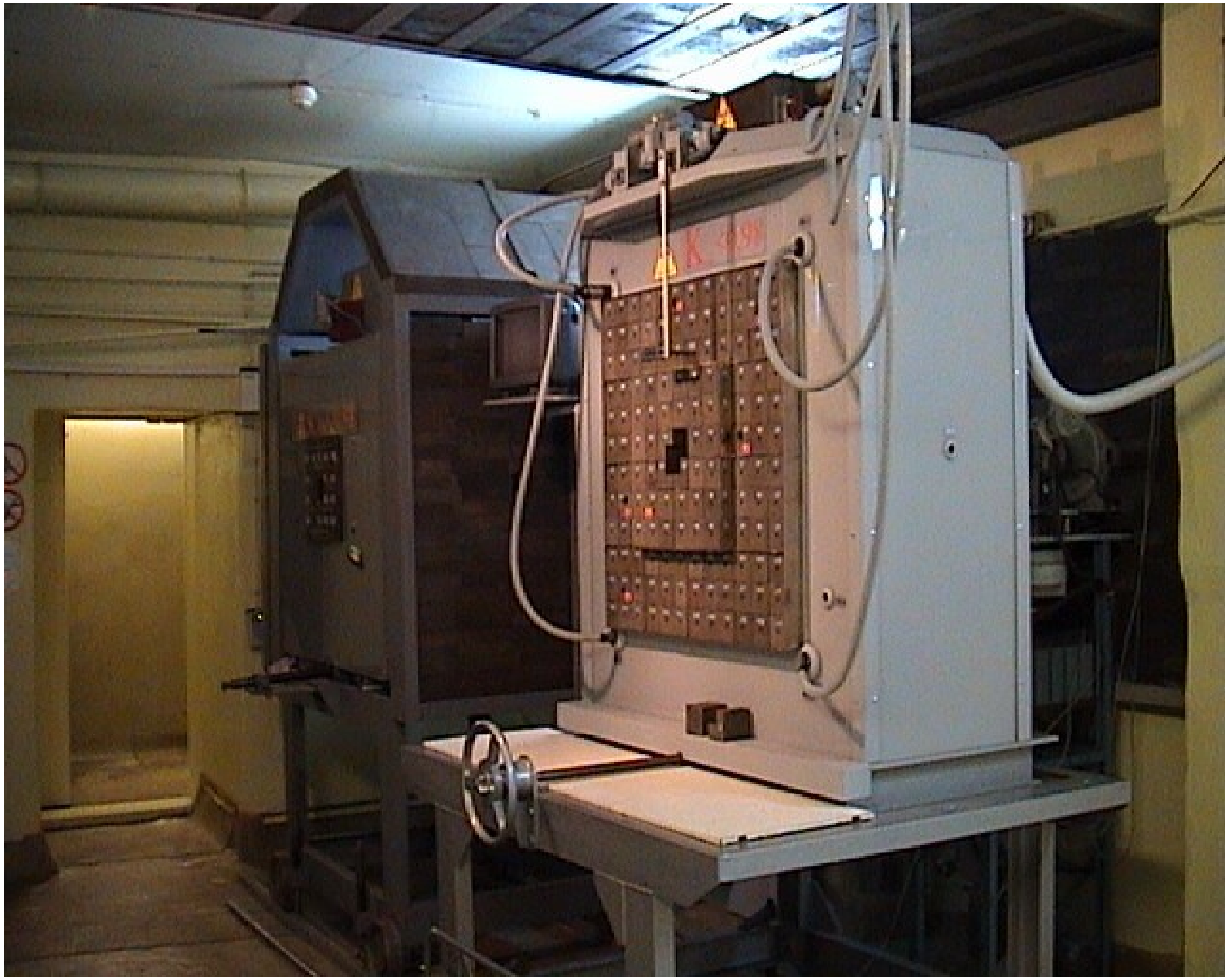
$^{27}Al(n,\ \alpha)^{24}Na$ (E_{eff} = 7,45 MeV).



Comparison of neutron spectra in sub-critical assembly YALINA at the point Z = 0 cm and R = 11 cm calculated by MCNP-4B code and unfolded by method of effective cross sections of threshold reactions using experimental data in the energy range 0.4-13MeV. (D,T) mode of operation.

Our experience on YALINA-T

- The measurements at deep sub-criticality levels and monitoring of neutron fluxes have demonstrated the effect of coupling of neutron-producing target and blanket
- Experimental methods of k_{eff} measurements elaborated for critical systems require modification taking into account peculiarities of formation of spatial, energy and time distributions of neutrons
- Deviation of time behavior of neutron flux from the dependence predicted by point kinetics model is observed for deep sub-criticality levels



YALINA-Booster

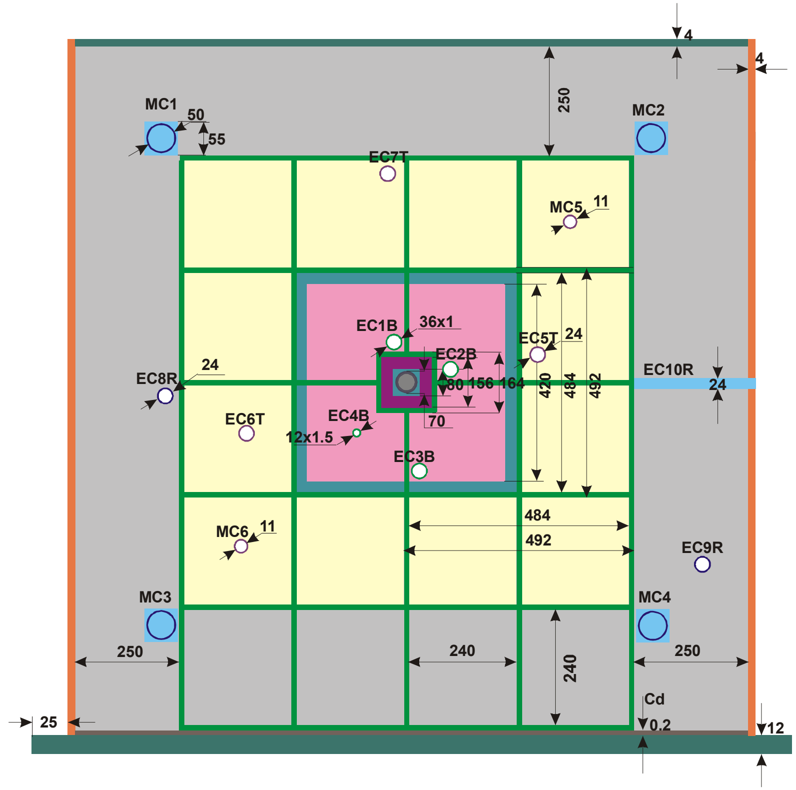
- Lead target located at the core center
- Booster zone arranged of lead subassemblies with fuel pins (metallic and dioxide uranium fuel x_5=90%, 36%)
- Thermal neutron spectrum zone with fuel pins EK-10 (x_5=10%) in polyethylene subassemblies
- Radial and axial reflectors
- Biological shielding

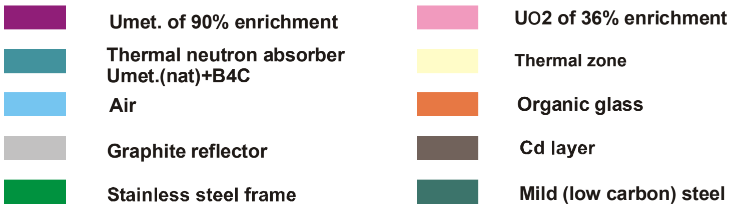
YALINA-Booster

- The subcritical assembly has a central fast neutron zone surrounded by a thermal neutron zone.
- The fast neutron zone (the booster zone) multiplies the external neutrons through the fission reactions of highly enriched uranium (HEU) and (n,xn) reactions of lead
- Between the two zones, there is an interface, called "valve" zone, consisting of two layers.
  - The inner layer has metallic natural uranium rods
  - the outer layer has boron carbide rods that absorb thermal neutrons
- Such "valve" zone enables fast neutrons to penetrate into the thermal zone and prevents thermal neutrons from entering the fast (booster) zone from the thermal

Different external neutron sources

- Construction of YALINA allows:
  - Using different external neutron sources
    - **^{252}Cf**
    - **d(d,n)^{3}He**
    - **d(T,n)^{4}He**
  - Locate external sources in different places relatively to the core center
  - Carrying out wide range of experiments by sub-criticality levels up to **$k_{ef} \leq 0.98$**





EC1B - EC4B - experimental channels in booster zone

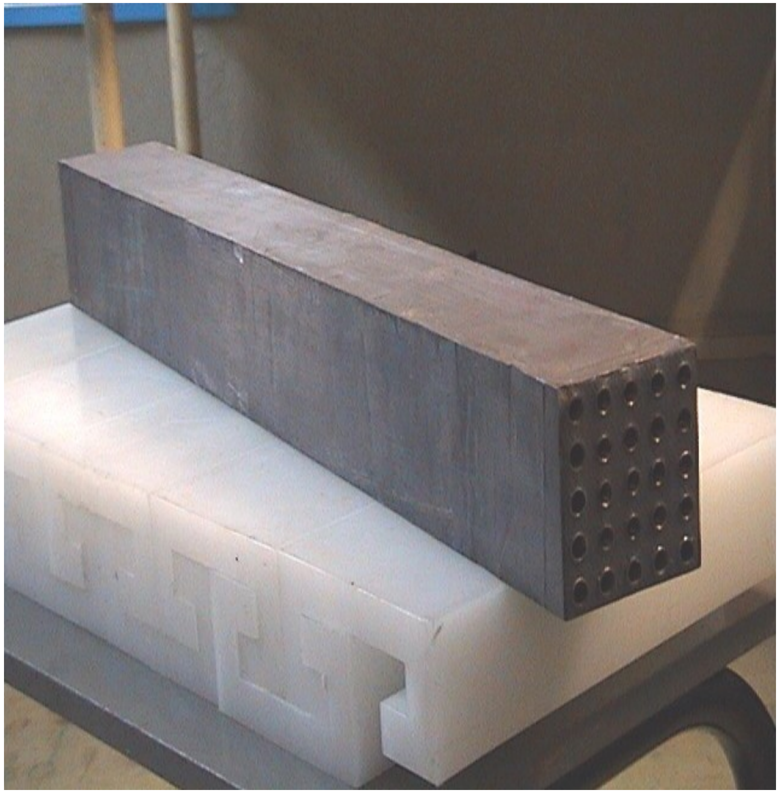
EC5T - EC7T - experimental channels in thermal zone

EC8R - EC10R - experimental channels in reflector

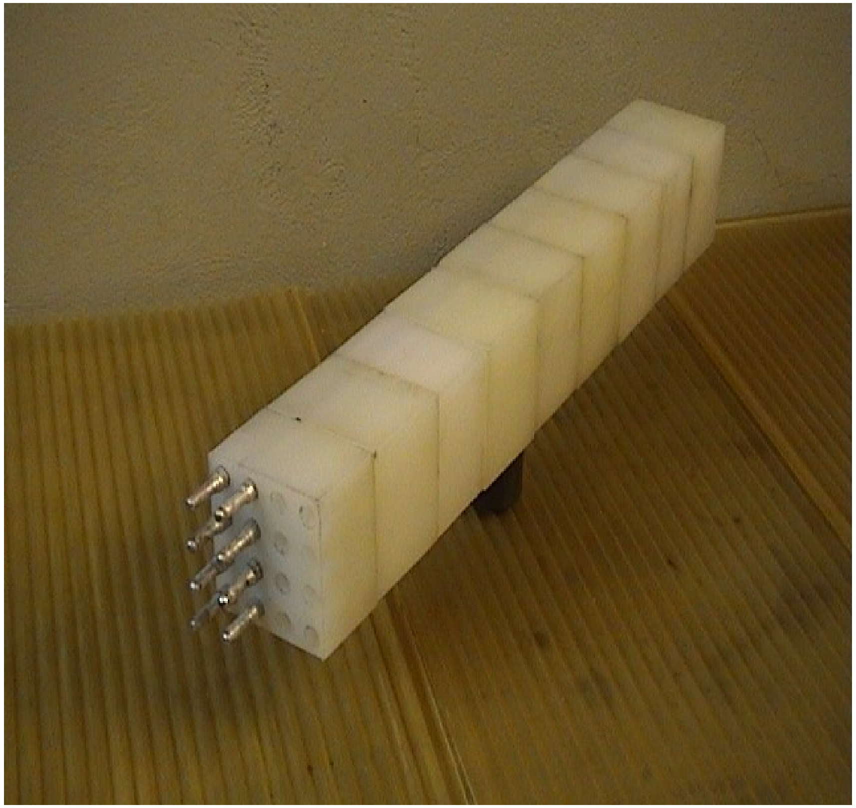
MC1 - MC4 - measurement channels in reflector for neutron flux monitoring

Components of YALINA-B

Lead sub-assembly of booster zone



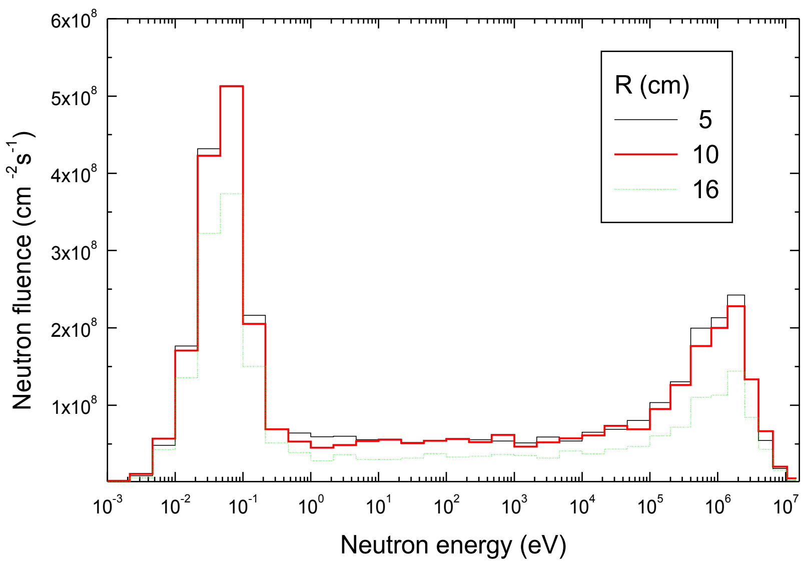
Polyethylene sub-assembly of thermal zone



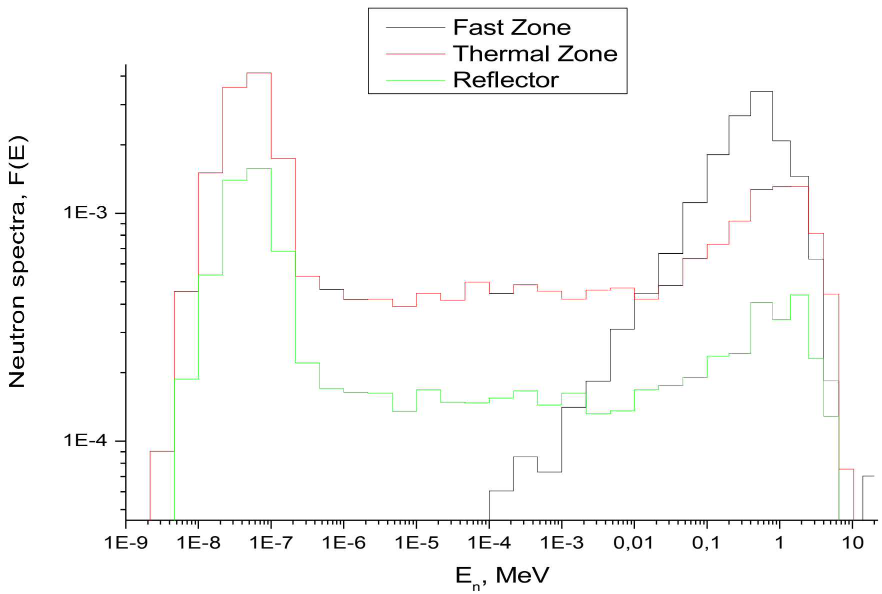
YALINA-B

- Experimental program
  - Development of methods of sub-criticality level monitoring
  - Kinetics of sub-critical systems
  - Measurements of spatial distribution of neutron flux density
  - Time behavior of neutron flux depending upon neutron pulse parameters
  - Measurement of long-lived fission products and minor-actinides transmutation reaction rates

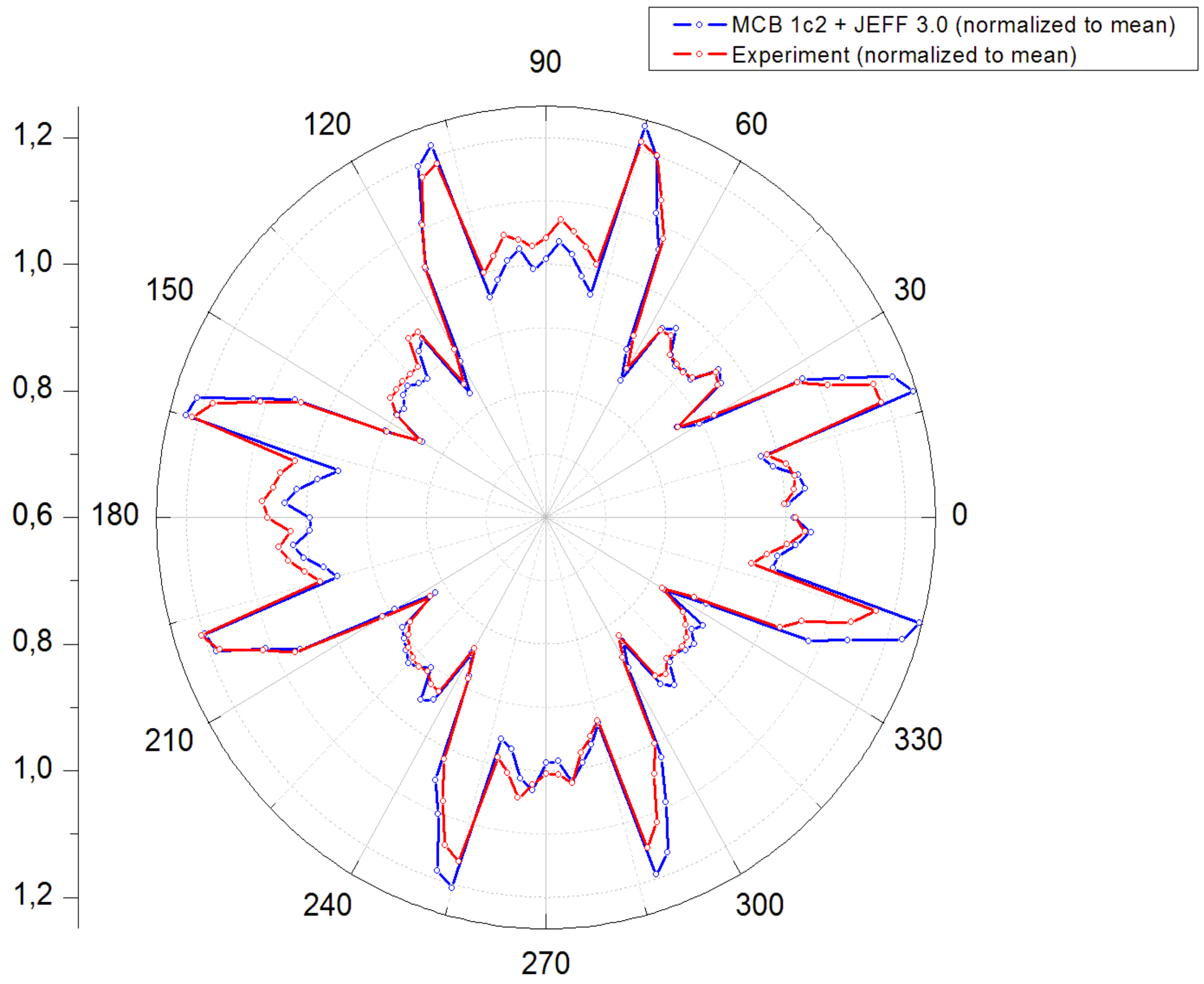
Neutron spectra in experimental channels



YALINA-T



YALINA-B



Neutron flux distribution in thermal zone of Yalina-B

The ISTC Project B1341

- Title
  - Analytical and experimental evaluating the possibility of creation of universal volume source of neutrons in the sub-critical booster assembly with low enriched uranium fuel driven by the neutron generator
- Budget
  - 200 000 USD
- Collaborator
  - ANL, DOE USA
- Duration
  - 30 months since June 1, 2006

Conversion of HEU core of YALINA-Booster to LEU

- Evaluation of the consequences of converting the HEU fuel zones (x_5=36 and 90%) of booster sub-critical assembly YALINA-B to LEU (x_5≤20%)
- Looking for possible ways of reducing the drop in performance

ISTC B1341 Project : First stage

- Experimental and analytical studies to define the sub-critical performance with the original (HEU) configuration
- New design concept with LEU will be defined
  - Essential changes in fast zone structure
  - Optimization to keep the performance obtained previously
- In order to perform experiments with new core the license must be updated

ISTC B1341 Project :

Second stage

- Experimental research work to confirm the sub-critical assembly performance with LEU
- Comparison of the experimental results with the analytical results analyzing any discrepancy

Second stage (continued)

- Involves two phases
  - 90% enriched uranium fuel will be replaced by 36% enriched UO_2
  - 36% enriched UO_2 will be replaced by 21% enriched UO_2

Possible losses in YALINA-B with k_{ef} = 0.98

- Replacement of 90% (^{235}U) U_m fuel in Booster zone by 36% UO_2 → 0.96
- Replacement of 36% UO_2 fuel in Booster zone by 21% UO_2 fuel → 0.956

Conclusions

- YALINA facility
  - International benchmark
  - The base for International Scientific Laboratory on Transmutation Research (Belarus, Germany, Spain, Sweden)

The scientific and technical program of ICE-TR

- Advanced studies of the neutron-physics characteristics of the existing subcritical assemblies driven by different neutron sources with special emphasis on subcriticality assessment and neutron spectrum measurements

The scientific and technical program of ICE-TR

- Preparation and conducting of vital experiments for further progress of ADS research, in particular in close collaboration with the European and the ISTC transmutation related projects and other international activities of importance in this field.

The scientific and technical program of ICE-TR

- Joint research and educational activities at the YALINA facility in the area of advanced nuclear power systems, mainly ADS, development of monitoring techniques of subcriticality levels, nuclear waste transmutation technologies, etc.

The scientific and technical program of ICE-TR

- Research of characteristics of modern detectors of ionizing radiations, used for measurements in mixed neutron and gamma fields, a technique and the equipment for the control of optical characteristics of diagnostic elements over a mode of real time at an irradiation by intensive neutron radiation

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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,

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Conclusion

- 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.

Yalina team is thankfull to the EU and all collaborators

Questions?...