Minutes of the
First Meeting of the SAD/YALINA-B Steering Committee (SC)
JINR Dubna, Frank Laboratory, 13 July 2004

1) The chairman of the SC, C. Broeders, welcomed the participants in the 1st SC meeting. A. Stanculescu was appointed secretary of the 1st SC meeting in charge, along with C. Broeders, of preparing the minutes. The Agenda and the List of participant is given in the appendix.
2) The Charter of the SC was presented by the chairman and accepted by all participants.
3) S. Chigrinov presented the status of the ISTC B070 (YALINA). Main focus of the presentation was on the proposed YALINA-Booster (YALINA-B) experiment and its relation to SAD. It was highlighted that in YALINA-B, the neutron spectrum in the booster zone, as well as the neutron lifetime were very close to those in SAD. Moreover, time responses are similar (e.g., response of ^{235}U fission rate to the source pulse). YALINA-B and SAD have a high degree of synergy, since the YALINA-B experiment is expected to provide valuable results that will feed into and help define the SAD scientific programme. In the discussion, these synergies were acknowledged, and it was stressed that the support for SAD is a valid justification for YALINA-B. However, two points were made by the participants aiming at highlighting, on the one hand side the YALINA-B specificity, and, on the other side, some open issue from the previous YALINA experimental programme. Specifically, the participants stressed the fact that YALINA-B offers the possibility to separate source and sub-critical multiplication zone, thus offering an interesting and unique research area. At the same time, the participants remarked that in some cases the analysis of the previous YALINA experiments is not complete. In particular, it was stressed that it was essential to produce a synthetic, coherent final report summarizing the main conclusions and highlighting to unresolved issues and to the R&D work needed to clarify those issues. Such a publication would greatly enhance the value of the experimental work performed during the first stages of B070, while supporting and justifying the proposed YALINA-B experimental programme. The B070 responsible (S. Chigrinov) replied that the final report, containing the systematic and synthetic analysis of the first YALINA experiments is in preparation. He put forward (as an example of the kind of conclusions that will be included in this report) the statement that the first YALINA experimental programme showed that the pulsed neutron source method and the area method proved to be very useful methods for the determination of the sub-criticality of an external source driven system.
4) The SAD project manager gave a short overview of the project status. He referred to his presentation (SAD) during the SAD status meeting, the day before. Overall, the project is on schedule. Open/critical issues, design changes, and required actions will be discussed and summarized in the action plan.
5) The foreign collaborators stressed again the utility of studying the sensitivity of the neutron source importance to the position of the spallation source (hence, to the position where the proton beam impinges the spallation source). In a communication after the meeting (CIEMAT proposal), CIEMAT asserted that MCNPX predicted non-linear and non-symmetric effects due to beam displacements. Assuming a parabolic beam of 2.5 cm diameter in a 7 cm diameter beam entrance hole, MCNPX results indicated for beam displacements in X direction (parallel to the target axis) of –2.2, –1, +1, and +2.2 cm, changes in the total neutron production of +1.0, +2.0,

-1.4, and +1.2%, respectively. However, the effect on the counting rates of the detectors, are quite different, depending on the detector position: for a detector in the central core experimental channel, the changes are –5.8, -5.1, -0.4, and +3.4%, respectively; for a detector in the middle core experimental channel the changes are +8.1, +10.3, -1.3, and +0.3%, respectively; for a detector in the external core experimental channel the changes are +1.4, +2.4, -1.7, and +0.9%, respectively. Finally, it was noted that the displacements in X (parallel) and in Y (perpendicular) to the target axis were not equivalent. Based on these considerations and on the assumption of a maximum parabolic beam diameter of 5 cm, the foreign collaborators recommend as the optimum beam entrance hole diameter 7 cm (the minimum beam entrance hole diameter is 5 cm). In a further e-mail communication after the meeting, I. Tretiyakov commented that from designers point of view only up to 5 cm diameter is possible.

6) The foreign collaborators stressed also the utility of performing Dynamics experiments in SAD. One possibility would be to use all/some of the existing experimental channels (foreseen for positioning fission chambers). If appropriate actuators are installed from the very beginning, these channels could be used to move absorber material in a controlled way, thus simulating both positive and negative reactivity feedbacks. Since the realization of these actuators imply basic infrastructure (i.e., special plugs, driver mechanisms, etc), the SC agreed that such actuators would have to be included in the basic SAD design. CIEMAT accepted the action to specify the requirements for a fast and for a normal speed actuator (CIEMAT proposal). NIKIET can do detailed design work for the realization in the second part of the project.
7) The SC discussed the proposal of a SAD brochure, leaflet, and the project's Web Site. It was agreed to publish first the leaflet, and follow up with a more detailed brochure. It was also decided to publish a separate YALINA leaflet. The Web Site will be operational by the end of July 2004, and will contain open and restricted areas, as well as links to ISTC and other P&T sites.
8) In connection with the possibility to make use of existing and planned ISTC projects to support SAD licensing efforts, the SC discussed eventual synergies/collaboration with #1372. It is relatively easy to cluster ongoing transmutation ISTC projects, if they are funded by the same partner. The issue was not resolved, and resulted in an action on the CEG to contact BFS at IPPE about the possibility to test SAD start-up procedures within the frame of ISTC BFS projects.
9) The SC discussed a critical issue regarding dose rate calculations in the SAD building and its surroundings. The SAD design team asked for support from the foreign collaborators in performing shielding and dose rate calculations. By the end of July, the SAD project manager will provide the design data to the foreign collaborators who agreed to share the work.
10) The question about the role of high energy neutron on the power in the sub-critical assembly was raised by the SAD design team (NIKIET) and discussed. The issue was controversial and could not be resolved. NIKIET accepted the action to clearly formulate its concerns about the role of high energy neutrons on the power in the sub-critical assembly (deadline: middle of September).
11) The SC meeting agreed on the following action plan:

    a) SAD design

    - Diameter of the beam inlet hole: within 2 weeks, CIEMAT and SAD project manager will quantify expected variations of the neutron importance in the system as a function of the beam position. Responsible E. Gonzalez, V. Shvetsov

- Actuators for experimental channels: it was agreed to consider in the design one fast (1 m/s) and two slow actuators in all the three experimental core channels. Responsible for changes in the design: A. Lopatkin and V. Shvetsov
- NIKIET will provide by middle of September 2004 the precise information about the role of high energy neutrons for the power distribution in the sub-critical core. Responsible: A. Lopatkin
- By middle of September, the SAD designer team requests confirmation that the neutron generator to be used during SAD start-up fits into the experimental channel: action on CIEMAT and ITEP. Responsible: E. Gonzalez, Y. Titarenko in contact with V. Shetsov
- It must be ensured that design provision is made for separate temperature and flow rate measurements in the target coolant, and in the core coolant. These measurements must be provided with sufficient accuracy in two temperature ranges, i.e., low and nominal: action on the SAD project manager. Resp. V. Shvetsov
- It was agreed that construction details fixing the 28 KW system power without freedom to enhance it at a later stage should be avoided: action on the SAD project manager. Resp. V. Shvetsov
- The CEG will initiate the dialog with IPPE and ITEP on the possibility of using existing and/or proposed ISTC projects to support the licensing of SAD. The action will be taken after request from the designer (NIKIET). Responsible A. Lopatkin and W. Gudowski

b) Radiation shielding

- By end of July, the SAD project manager will provide the input data needed for the optimisation studies of the shielding of the SAD core. Responsible V. Shvetsov
- By end of July, the SAD project manager will provide the input data needed for dose rate calculations in the SAD building and its surroundings. KTH (with CIEMAT and UMM support) is making the commitment to perform these calculations. Responsible – V. Shvetsov in collaboration with W. Gudowski, E. Gonzalez and S. Taczanowski

c) General issues

- The SAD Web Site will be online with open and restricted areas by the end of July; links to ISTC and to other relevant P&T sites will be made available. Responsible – V. Shvetsov
- The final version of the SAD leaflet will be available by the end of July and will be distributed as Word file for comments. Responsible V. Shvetsov, feedback from C. Broeders, W. Gudowski, E. Gonzalez, F. Mellier
- KTH will discuss with US responsible persons the possibility of the SAD Russian design groups using of MCNPX. Responsible – W. Gudowski and A.Polanski
- The foreign collaborators (KTH, CIEMAT, FZK, and UMM) agree to perform necessary MCNPX design calculations. At JINR, this action will be coordinated by Aleksander Polanski (responsible)
- The SAD and YALINA project managers are urged to keep close contact in order to increase synergy between the two projects. Responsible – V. Shvetsov and S. Chigrinov
- The YALINA project manager will provide a leaflet for the YALINA project by the middle of September. Resp. S. Chigrinov

12) The SC members agreed to record, in addition to the action plan, the following general conclusions as the outcome of the first SC Meeting:

- By the end of December 2004, the SAD project manager will provide a cost assessment for the SAD construction. Resp. V. Shvetsov.

- The issue of final disposal of SAD activated structures was raised; an action was put on the SAD project manager to initiate preliminary discussions on this subject with the appropriate persons at JINR. Resp. V. Shvetsov
- The SC expects strong commitment on the side of JINR for the construction and operation of the SAD facility, and asks the SAD project manager to convey this message to the JINR management. Resp. V. Shvetsov and C. Broeders
- The SC took note that the IAEA Coordinated Research Project (CRP) on analytical and experimental benchmark analyses of sub-critical systems driven by an external neutron source was approved by the Agency. The CRP will start in 2005. The SC acknowledged that both projects, SAD and YALINA, would greatly benefit from the participation in this CRP. Forms for research agreement and contract proposals were distributed by the IAEA representative in the SC, and the participants were encouraged to submit proposals for participation in the CRP. Resp. A. Stanculescu
- The SC acknowledges that SAD fuel manufacture was initiated, and that no cliff-edges were encountered at this stage of the fuel manufacturing process. The SC also took note of the fact that the fuel assembly grids will be manufactured at JINR.

13) Next meeting: it is planned to hold the Second SC Meeting on 20 and 21 January 2005 in Minsk, Belarus.

C. Broeders   A. Stanculescu

Appendices

a) Agenda

Agenda

SAD/YALINA-B Steering Committee Meeting

Place: Frank Laboratory of Neutron Physics – Conference hall
Tuesday July 13

1. Introduction by the Chairman of the Contact Expert Group for ISTC Projects related to ADS and Transmutation (W. Gudowski)
2. Presentation, discussion and adoption of the Charter of the Steering Group (C. Broeders + all)
3. Review of current projects:
    a. Report on SAD status and progress (V. Shvetsov)
    b. Report on YALINA status and planning (S. Chigrinov)
4. Discussion of future experimental programs, e.g. assessment of possibilities to perform dynamics experiments in SAD and/or YALINA (C. Broeders, all)
5. Discussion of possible exchange of experimental equipment with other laboratories and/or other ISTC projects (ISTC#1372??) – finding synergy strategy with ISTC projects (all)
6. Identification and discussion of critical issues of ongoing projects (all)
7. Discussion of links of SAD/YALINA with other institutions and European projects in 6^{th} and 7^{th} FP (W. Gudowski, all)
8. Miscellaneous
    a. WEB dedicated to SAD (or SAD/YALINA??) (V. Shvetsov, all)
    b. Creation of SAD leaflet document (W. Gudowski, all)
9. Action plan
10. Closure of the session, date of next meeting

b) List of participants

C. Broeders, FZK – chairman
S. Chigrinov, IRPCP
E. Gonzalez, CIEMAT
W. Gudowski, KTH
A. Lopatkin, NIKIET
F. Mellier, CEA
A. Polanski, IPJ/JINR
V. Shvetsov, JINR
A. Stanculescu, IAEA
L. Tocheny, ISTC
I. Tretyakov, NIKIET
M. Vorontsov, GSPI
L.M. Onischenko, JINR
J. Janczyszyn, AGH
G. Domanska, AGH
W. Pohorecki, AGH
S. Taczanowski, AGH

c) Charter

Charter for SAD/YALINA-B Steering Committee

Purpose

The purpose of the SAD/YALINA-B Steering Committee is the coordination of the ISTC projects with integral experiments with source-driven sub-critical systems and integration of those projects with the European ADS-related activities.. Currently, the ISTC project #2267 (Sub-critical Assembly Dubna, SAD) and the #B070 successor experiment with lead booster (YALINA-B) are involved. Other experiments under consideration will be included if corresponding proposals for ISTC projects decision board will be prepared.

Membership

Initially the Steering Committee is composed of representatives from the ISTC collaborating parties: EU (Germany, France, Sweden, Spain), the SAD and YALINA-B project management and of the Polish JINR cooperation. It may be expanded as necessary and upon agreement to include other participating countries, like other JINR members etc. The list of committee members is given in attachment 1.

Objectives

The objectives of the Steering Committee are

- to prepare and provide guidance and advice on a scientific program for ADS ISTC integral experiments, currently SAD and YALINA-B, and to supervise the progress of the construction of these experiments,
- to ensure that the scientific program of SAD, YALINA-B and possible other ISTC experiments, will address the needs of the European and international efforts for ADS research and contribute towards the realization of an ADS demonstration facility,
- to offer a forum for the participating countries and collaborators to provide input into planning of the experimental programmes,
- to ensure scientific and technical participation in the experiments and their analysis.

Implementation

- The Steering Committee will give advice to funding organizations for the installation, commissioning, planning and execution of the experimental program:
  - review program plans provided by project leadership,
  - oversee progress of efforts concerning:
    - construction of the facility,
    - instrumentation,
    - safety and commissioning,
    - quality of experimental work ensuring its validation quality,
    - long term scientific activities
- The Steering Committee will support the projects by:
  - establishing an effective collaboration and cooperation with JINR and ISTC,
  - coordinating the participation of partners in the SAD/YALINA-B related efforts, including exchange of experimental support if possible,
  - disseminating the reports and the results of experiments,
  - providing collaboration links with European and other interested groups.

- The Steering Committee promotes strongly the continuous support of ISTC and EU for SAD, YALINA-B and possible other projects with source-driven sub-critical systems.
- The Steering Committee meets three times a year and in between meetings uses electronic communication.
- The Steering Committee reports to the ISTC Contact Expert Group on Transmutation related projects (CEG). Minutes from every meeting, and action plan updated between meetings, will be reported to CEG.

Attachment 1

List of members of the SAD/YALINA-B Steering Committee

V. Bhatnagar, EU

C. Broeders, FZK – chairman

S. Chigrinov, IRPCP

I. Golovnin, VNIINM

E. Gonzales, CIEMAT

W. Gudowski, KTH

A. Lopatkin, NIKIET

F. Mellier, CEA

A. Polanski, IPJ/JINR

B. Ryabov, JINR

V. Shvetsov, JINR

A. Stanculescu, IAEA

L. Tocheny, ISTC

I. Tretyakov, NIKIET

M. Vorontsov, GSPI

d) YALINA

Presentation of YALINA status and planning

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:

W.Gudovski,
Royal Institute of Technology
Sweden

E. Gonzales,
Nuclear Fission Department
CIEMAT Spain

C. Broeders
Karlsruhe
Germany

The main goals of the ISTC project :

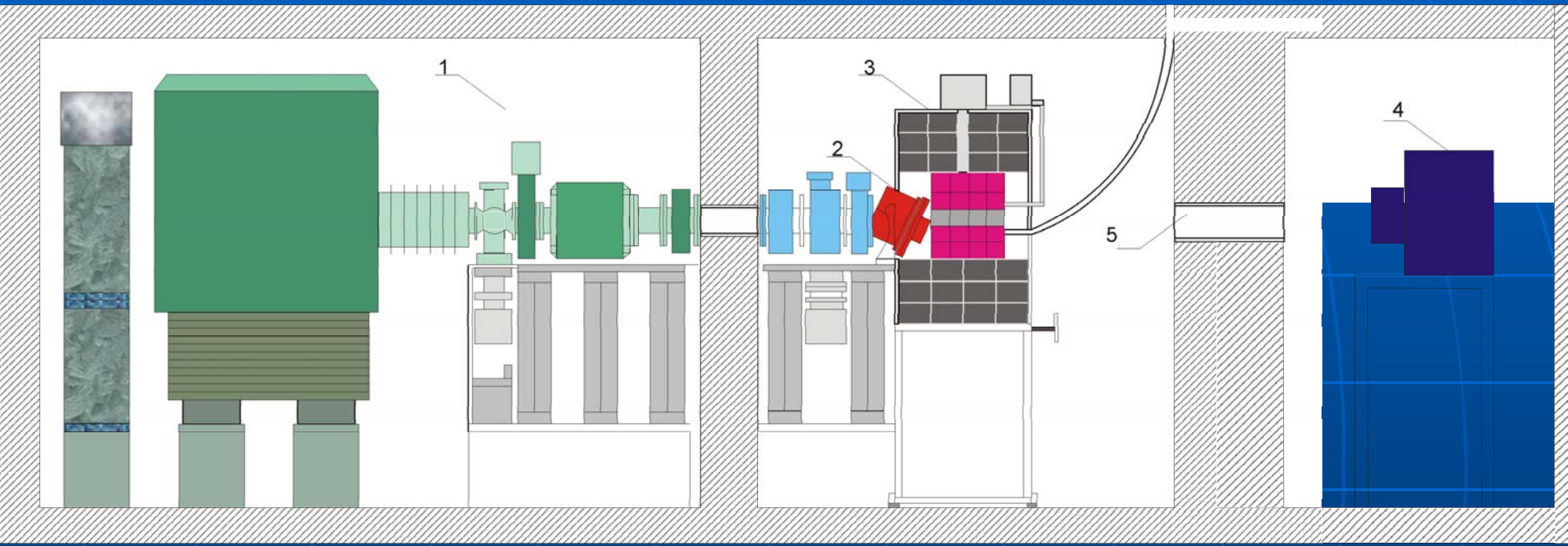
- creation the facility to investigate neutronic characteristic of the subcritical systems with thermal neutron spectrum, driven with external neutron source(a Cf-252 spontaneous fission source, 2.5 MeV (D,D) and 14.1 MeV (D,t) neutron sources);

-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

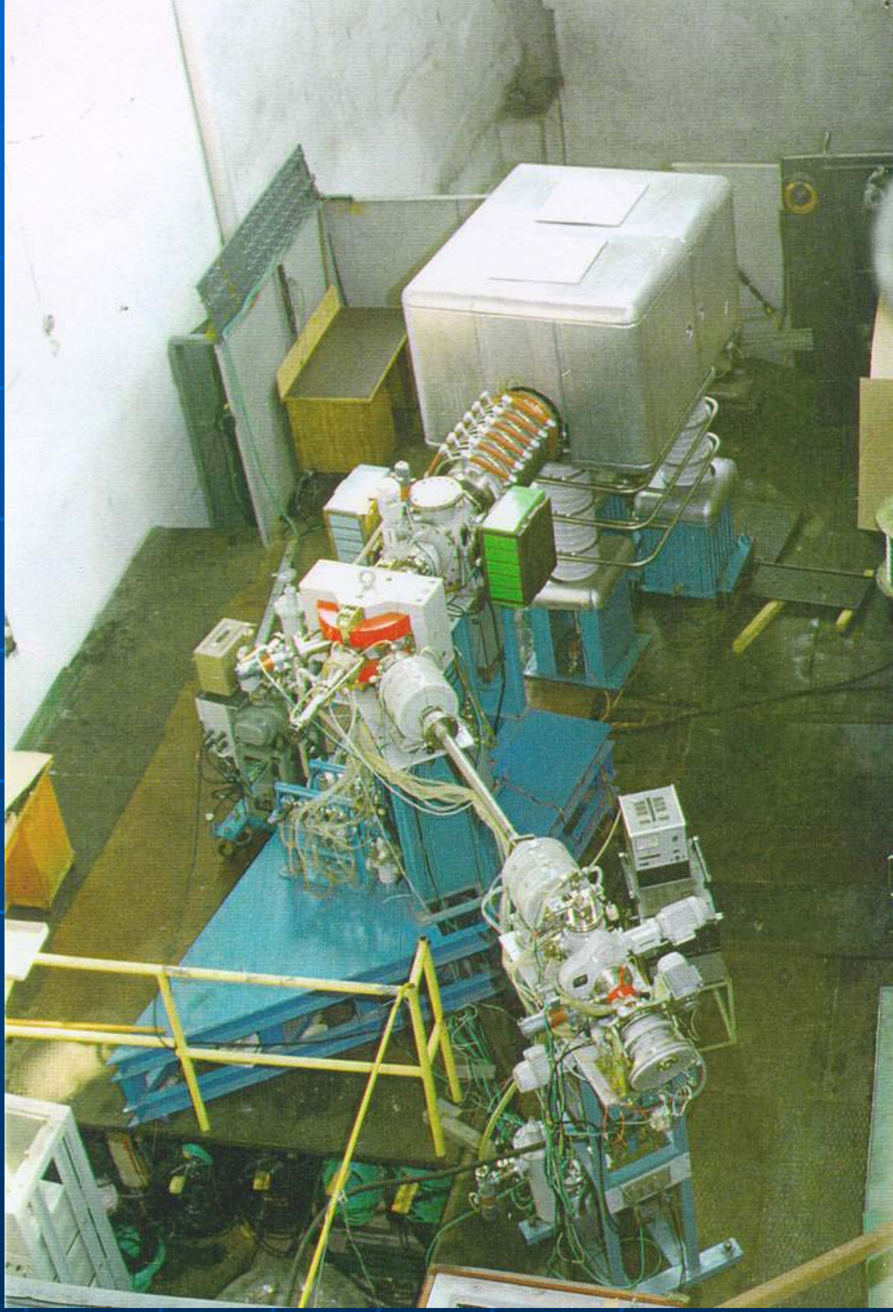
2 - Ti-^{2}H или Ti-^{3}H мишень
4 - γ - спектрометр

- 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:
- 1.5-2.0$10^{12}$
- Neutron energy 13-15 МэВ

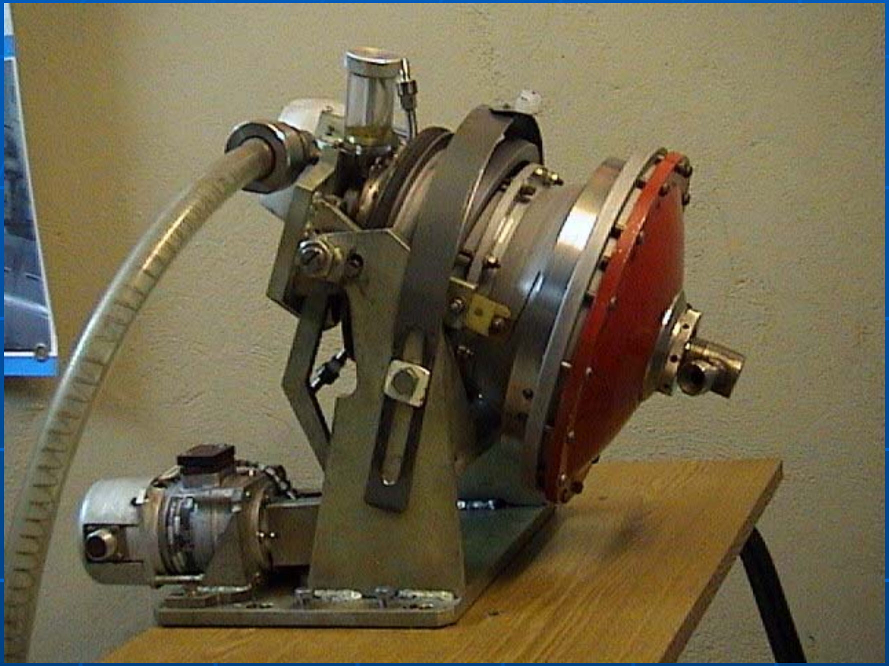
- TiD target (230 mm):

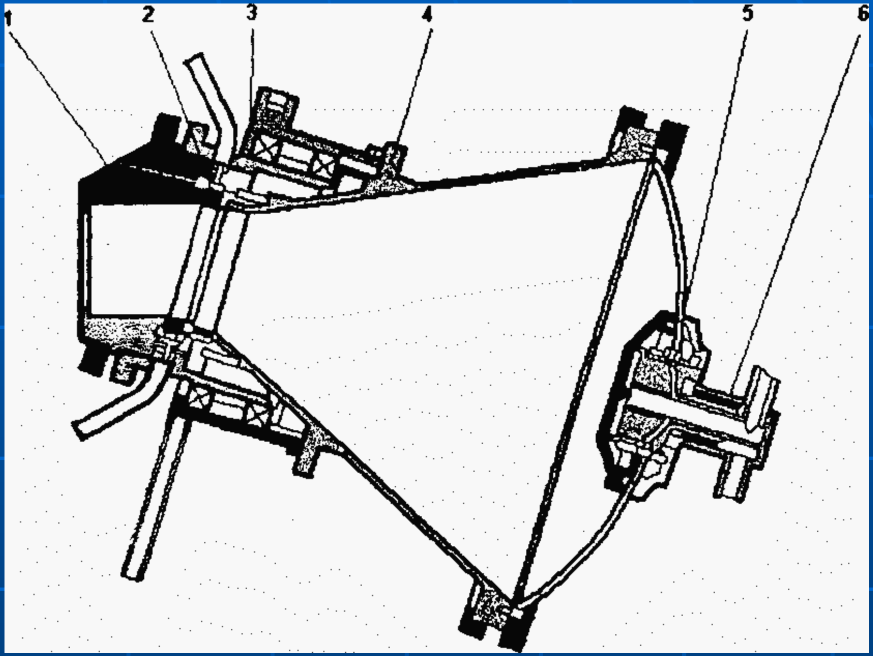
- Maximal yield of neutrons, n/s:
- 2-3.0 10^{10}
- Neutron energy 2.5-3.0 МэВ



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

TiH (TiD) targets characteristic





⇑

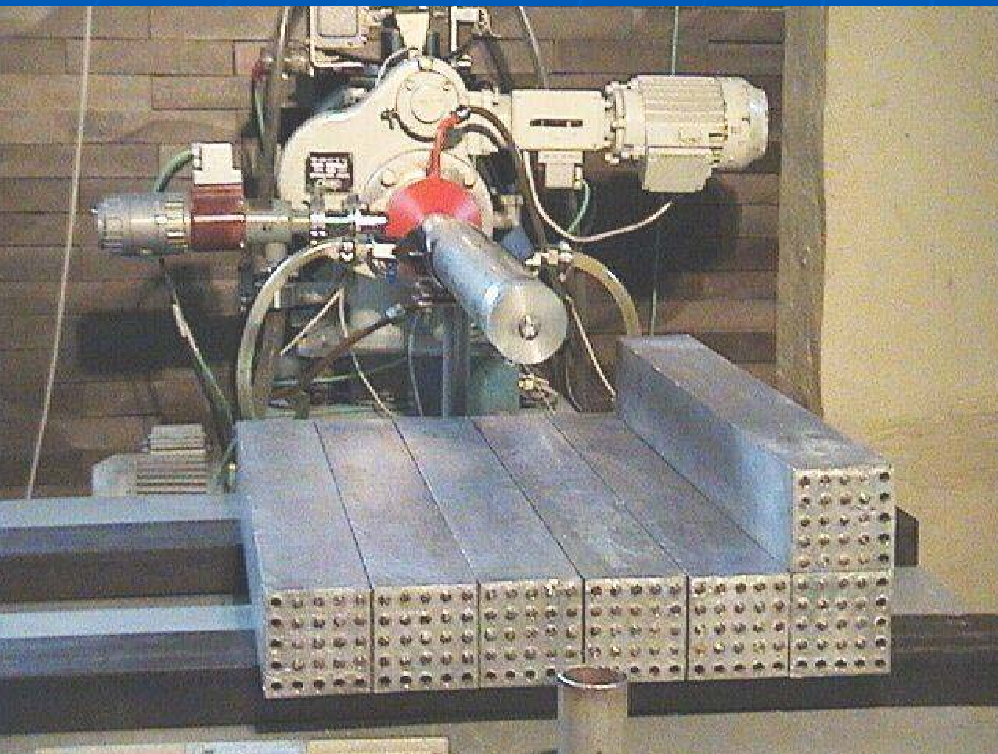
Rotating speed	560 rpm
Target diameter	230 mm
Diameter of reaction space	100-200 mm
Tritium activity	0.53-0.75 MCi/kg
D/Ti (T/Ti) atomic ratio	≈ 1.5

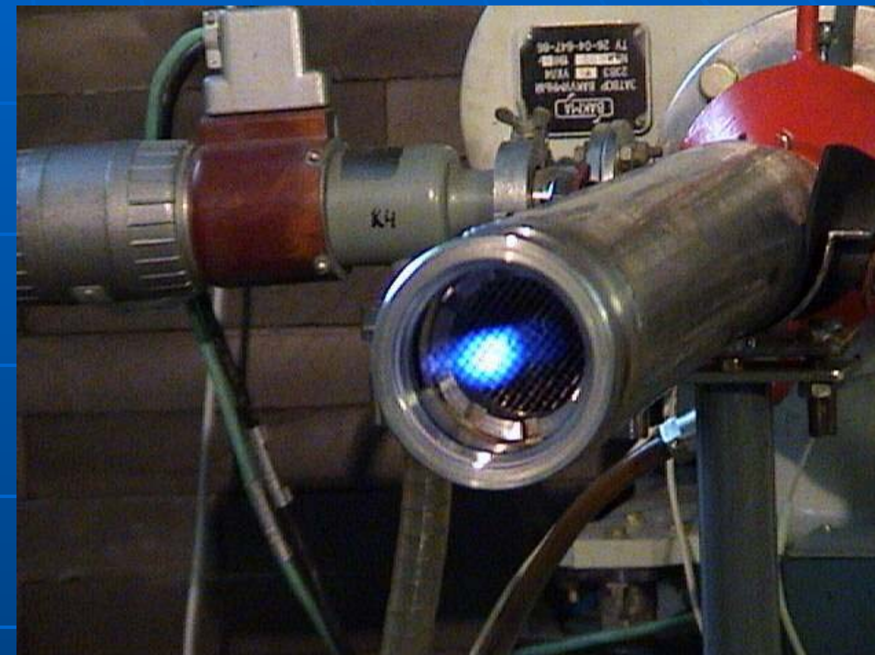
Target diameter

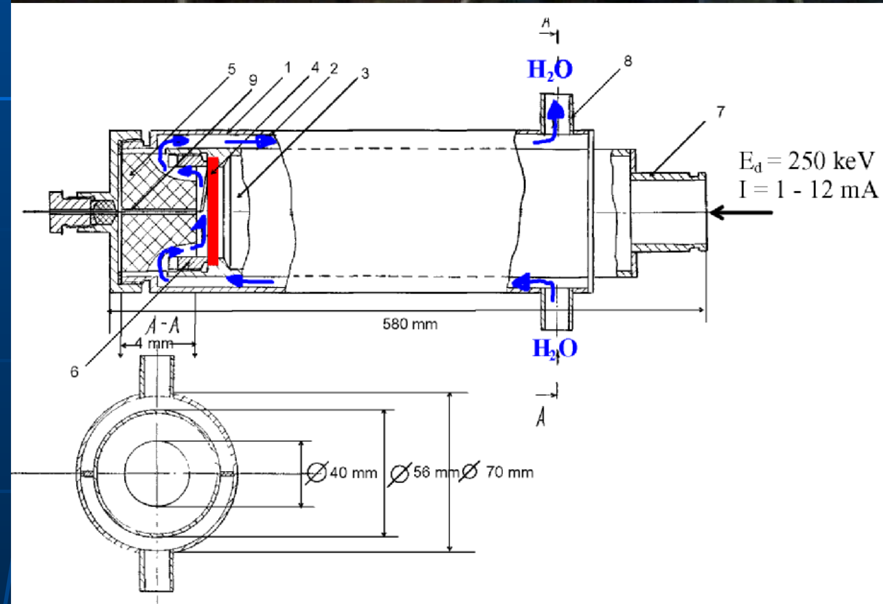
45 mm

⇒

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

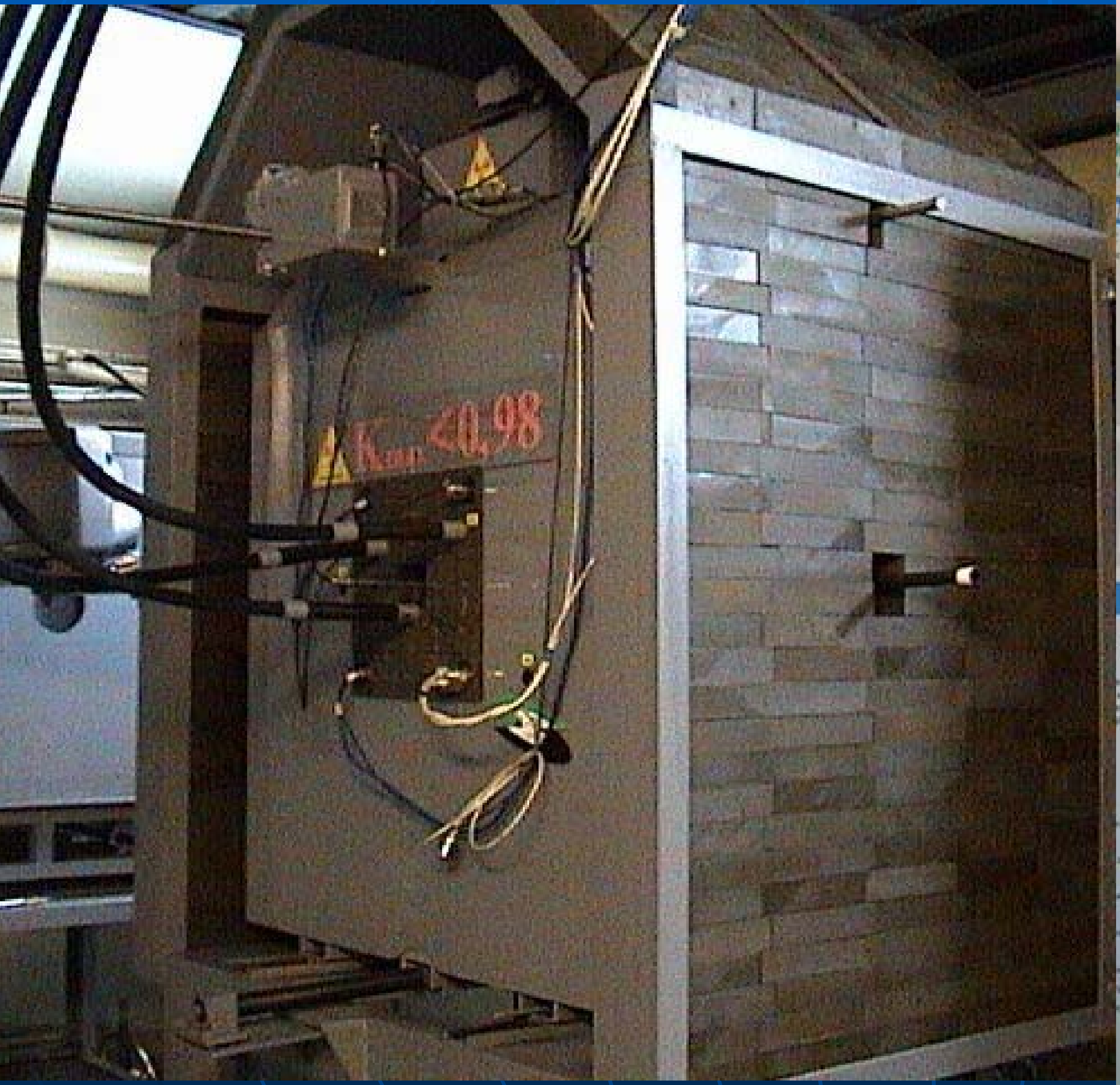


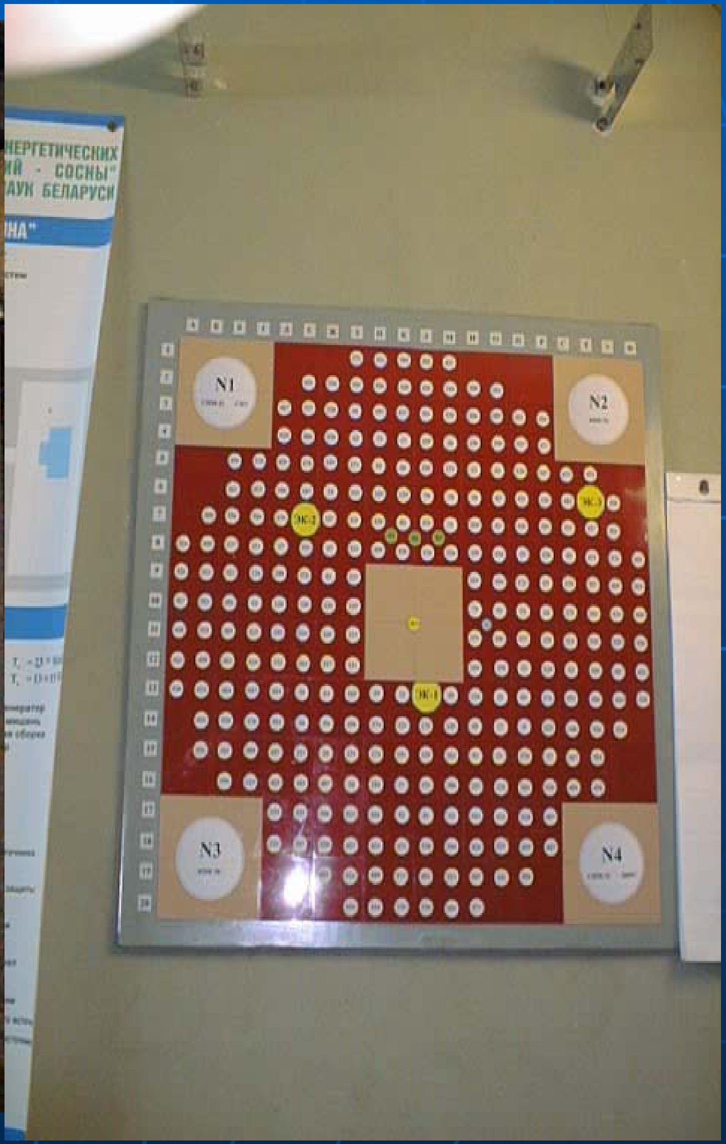




Subcritical assembly with thermal neutron cpecrum

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} / $n \cdot cm^{-2} \cdot s^{-1}$	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
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**

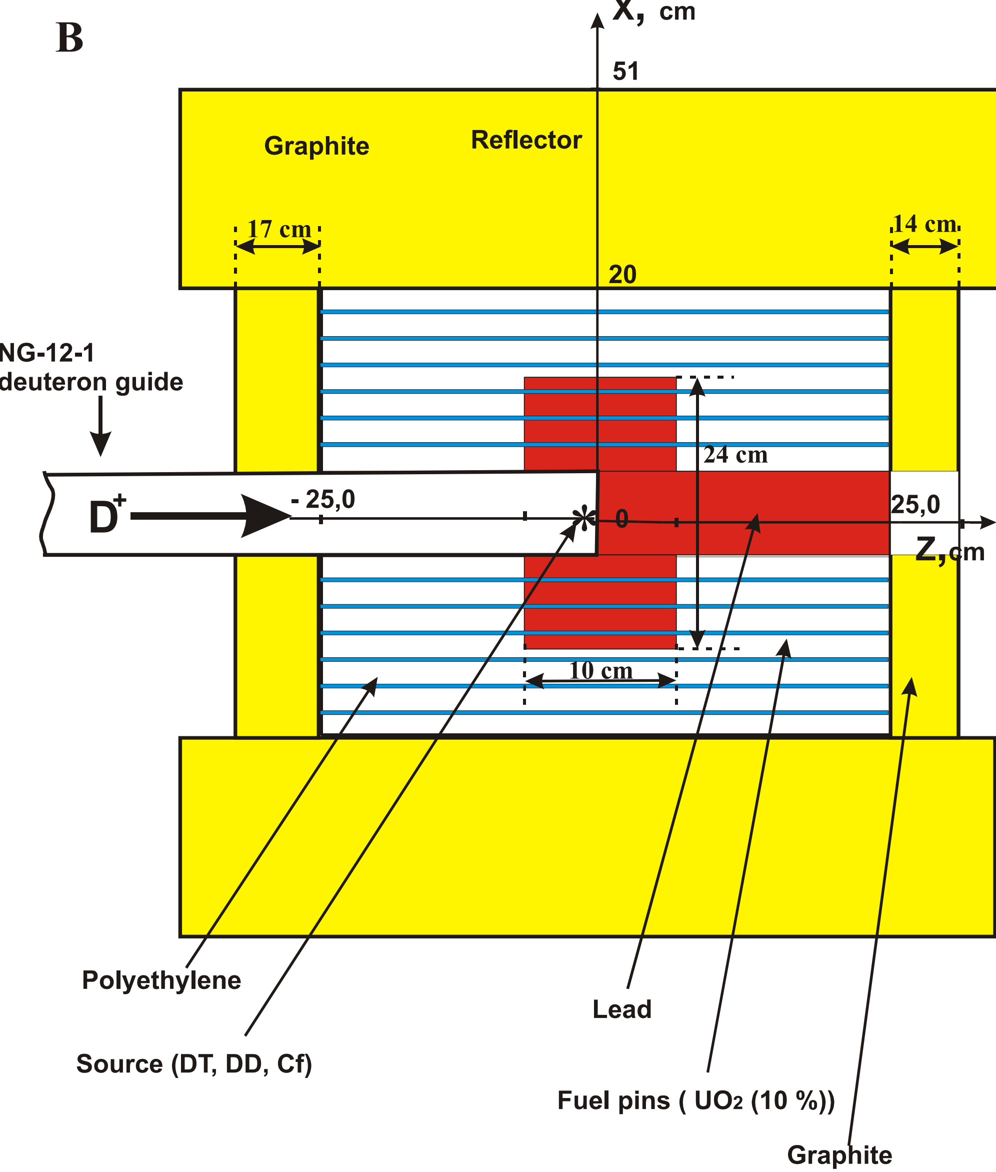
- Coaxial HPGe detector 80 % relative efficiency,
- resolution (FWHM) –
- 0.9 keV (122 keV), 1.8 keV (1332 keV).

- 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.

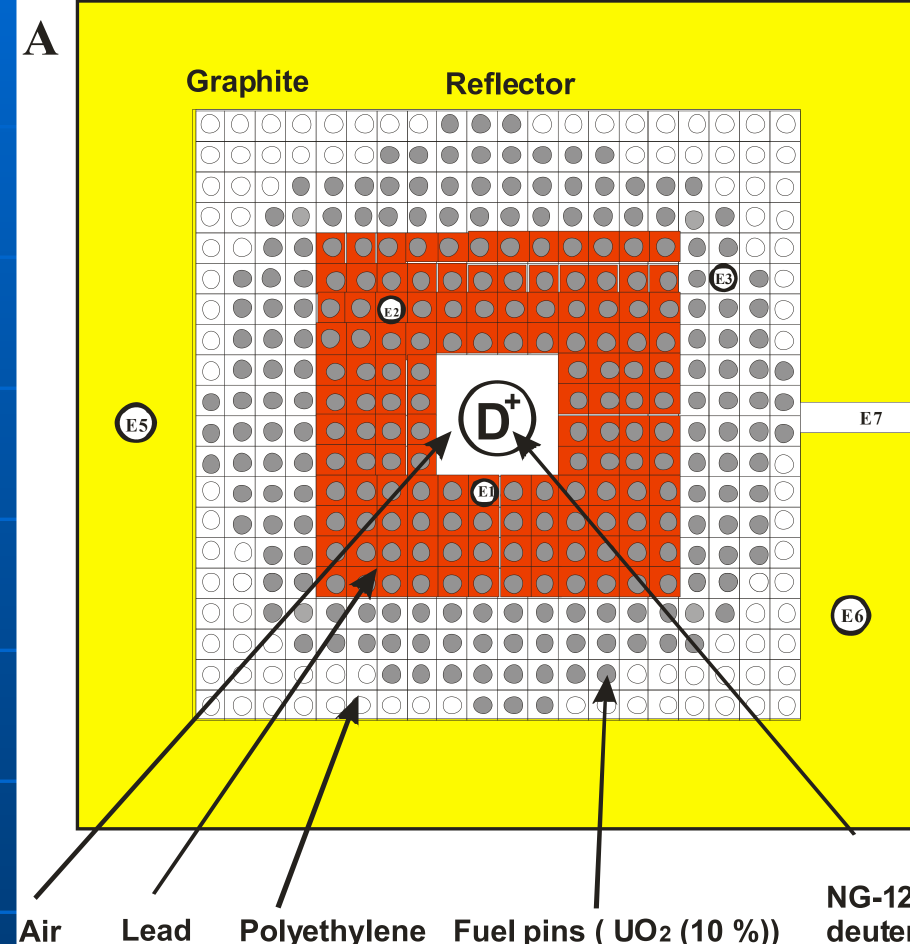
- U-Pu Inspector Canberra Industries, Inc

- 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)
$A_d/A_p = \beta/\rho$; $Y = A + B e^{-\alpha t}$; $\alpha=(\beta-\rho)/\Lambda$; $\beta = 7.37 \cdot 10^{-3}$
e) Gozani, T. Nukleonik 4(1962), 348.
$-\rho=f A/\alpha B$; f – pulse repetition ($f \approx 54$ Hz); $Y = A + B e^{-\alpha t}$
f) Source jerk method

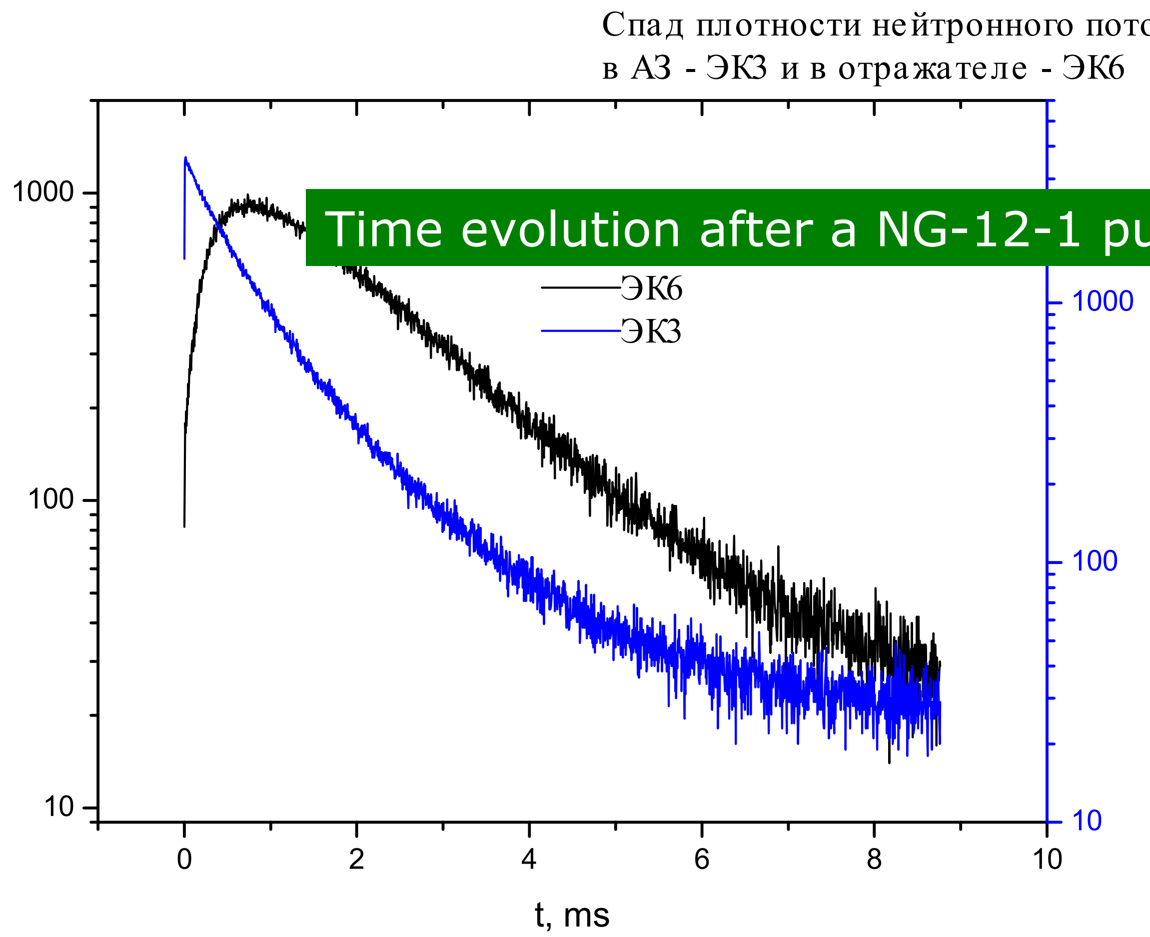
III. A comparison of experimental and calculated (MCNP-4B) results will be carried out.

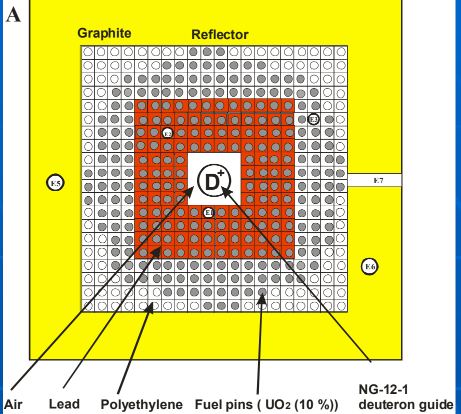
Measurements will be performed by of 3He - detectors and fission chambers (U-235, U-238, Th-232, ...) and with DT,DD and 252Cf neutron sources.

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 <σf>U238/<σf>U235 and <σf>Th/<σf>U235 , <σf>U233/<σf>U235,<σf>Pu239/<σf>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

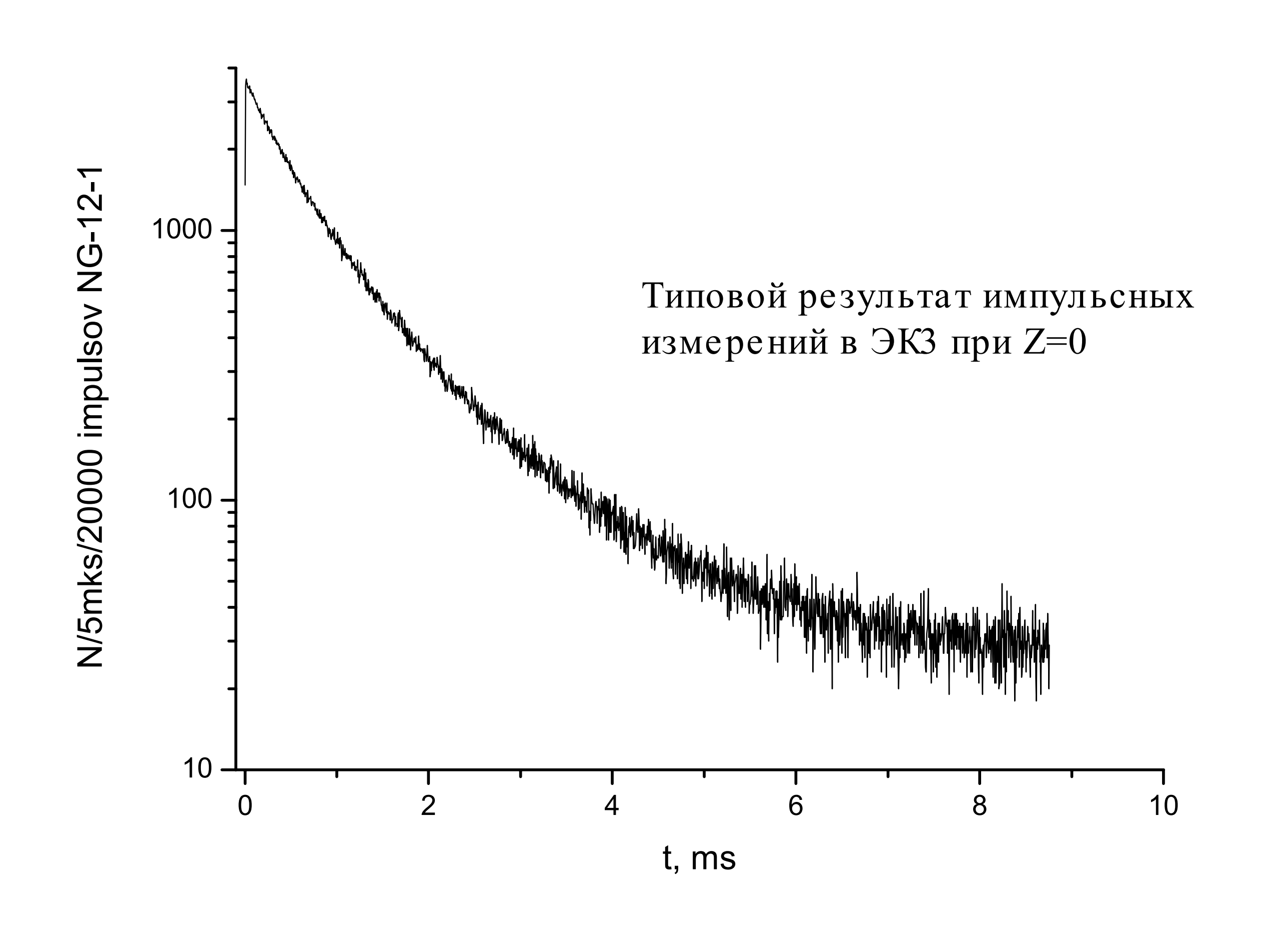




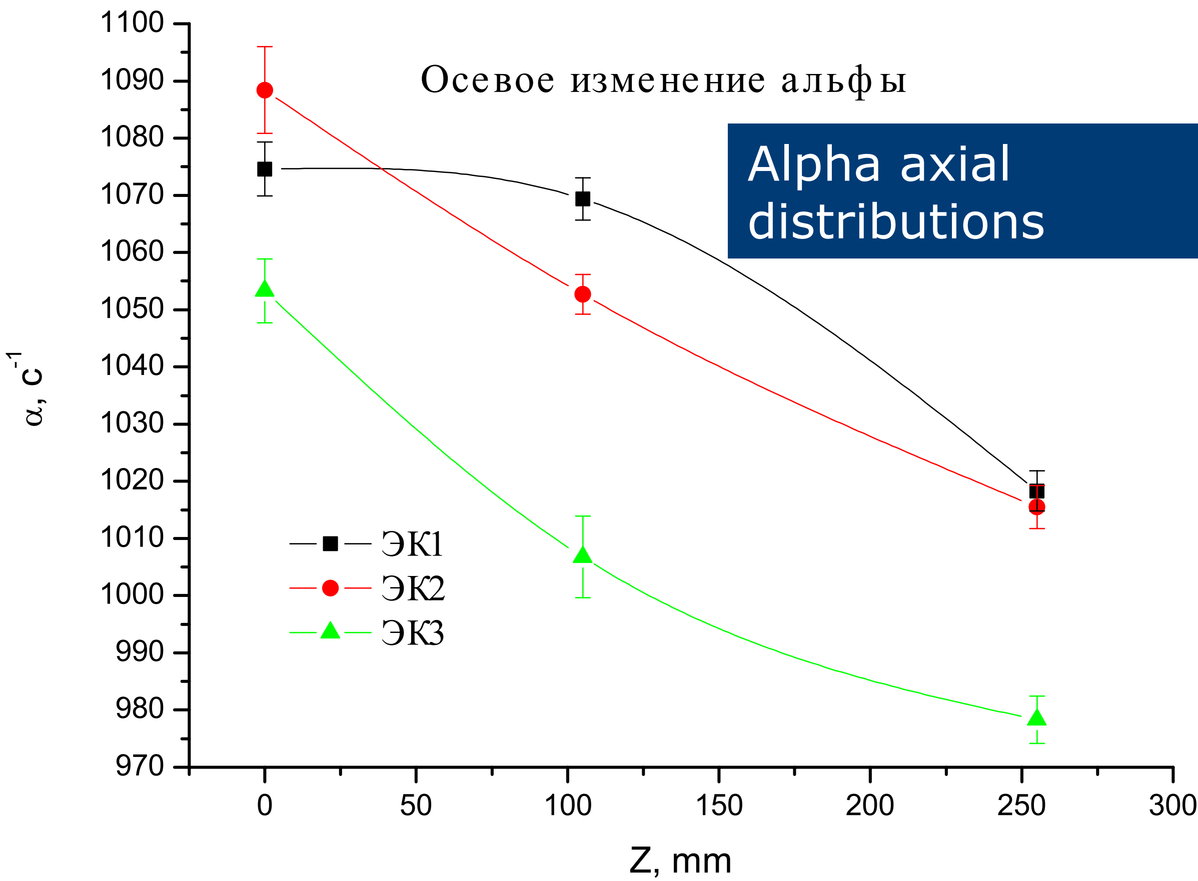
Core configuration for 280 fuel pins
(lead zone is placed at the core center)

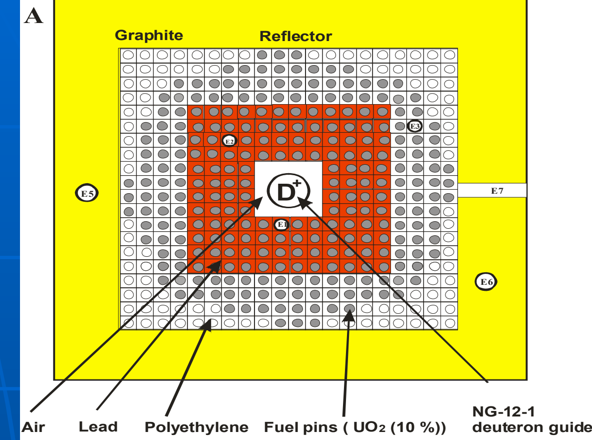
A - cross-section (-5 cm < z < 0 cm)

E1 - E7 - experimental channels


Типовой результат импульсных
измерений в ЭКЗ при Z=0
N/5mks/20000 impulsov NG-12-1
1000
100
10
0
2
4
6
8
10
t, ms

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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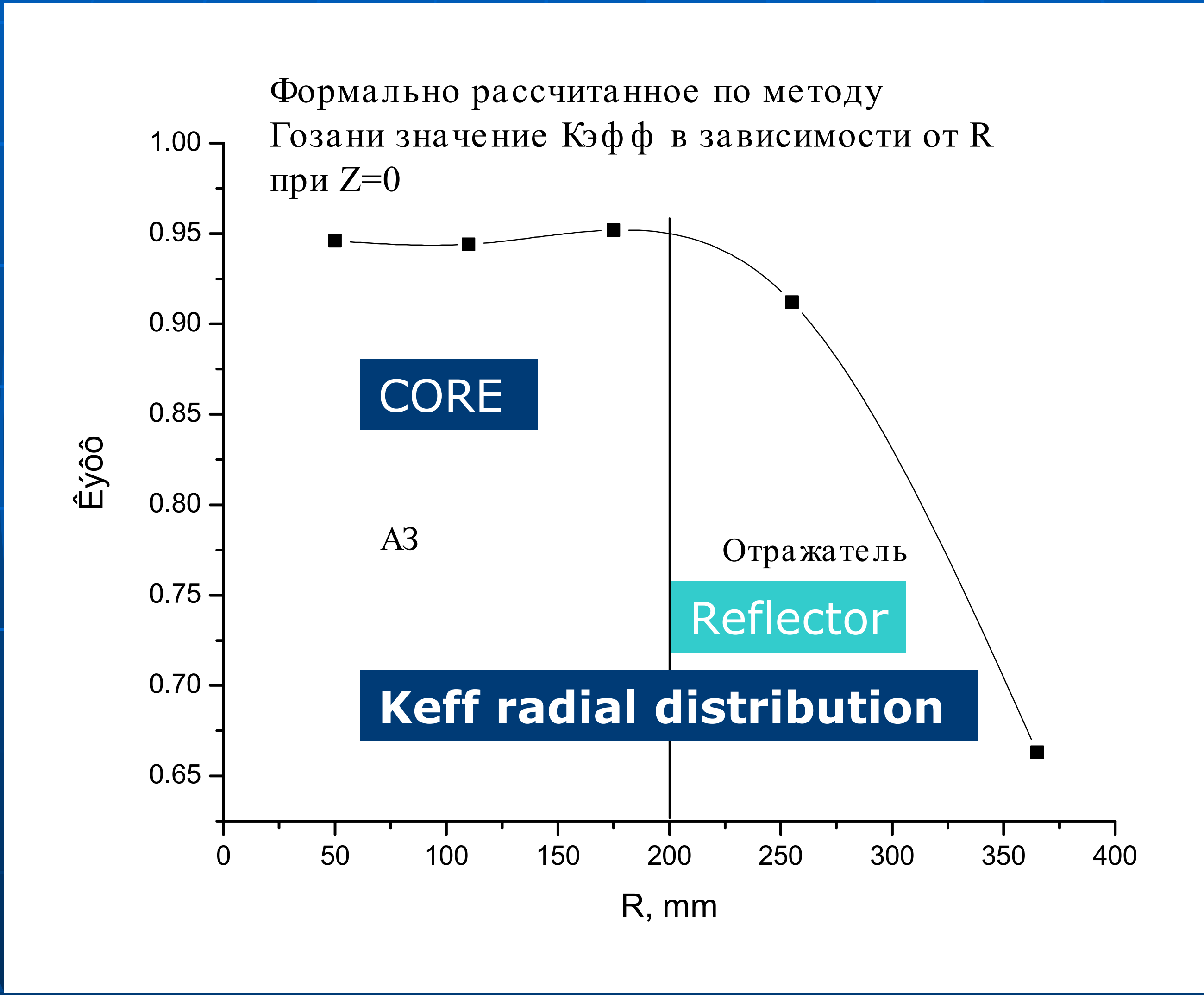
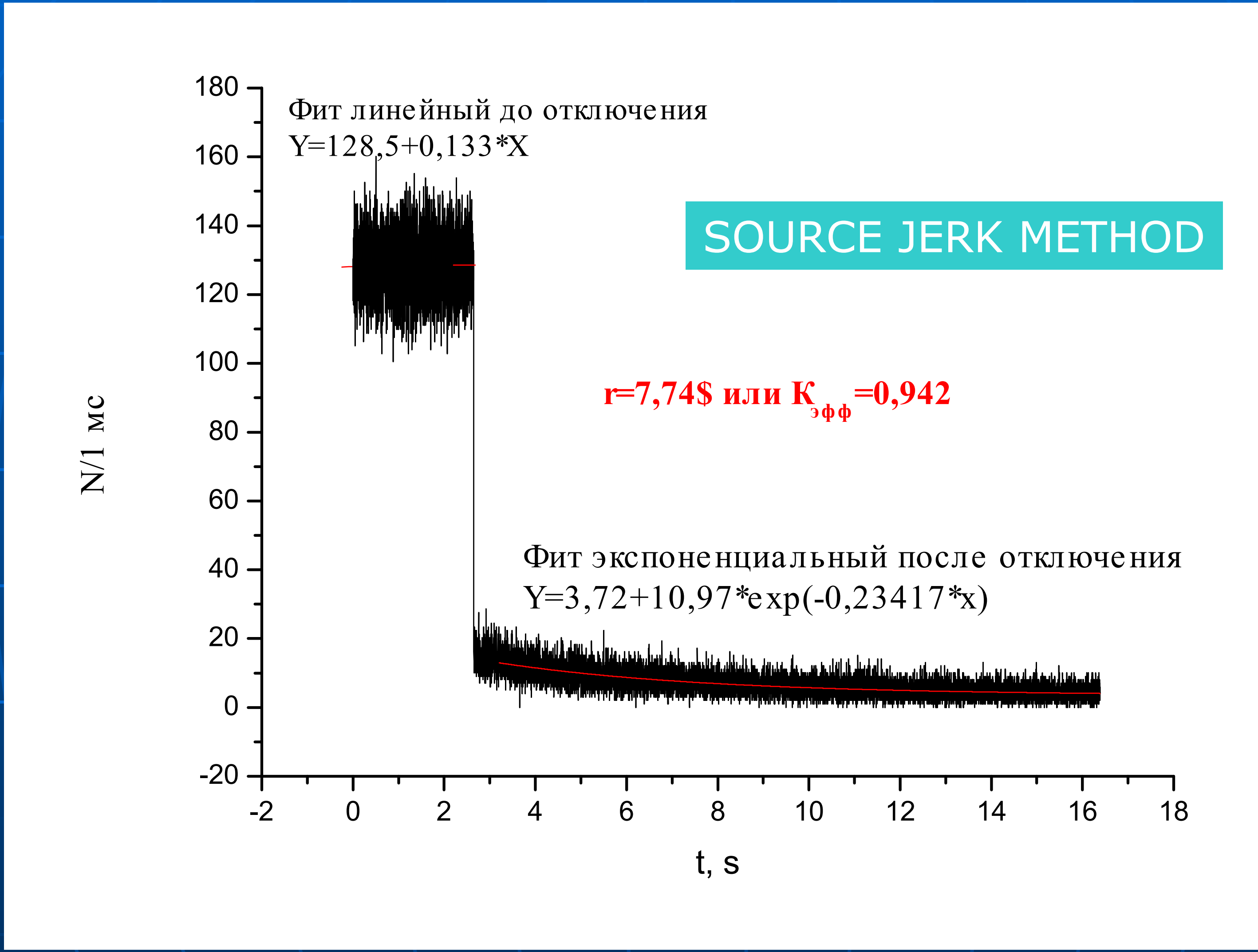


Формально рассчитанное по методу
Гозани значение Кэфф в зависимости от R
при Z=0
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
Êýôô
CORE
АЗ
Отражатель
Reflector
Keff radial distribution
0
50
100
150
200
250
300
350
400
R, mm


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)
N/1 мс
t, s
180
160
140
120
100
80
60
40
20
0
-20
-2
0
2
4
6
8
10
12
14
16
18

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):

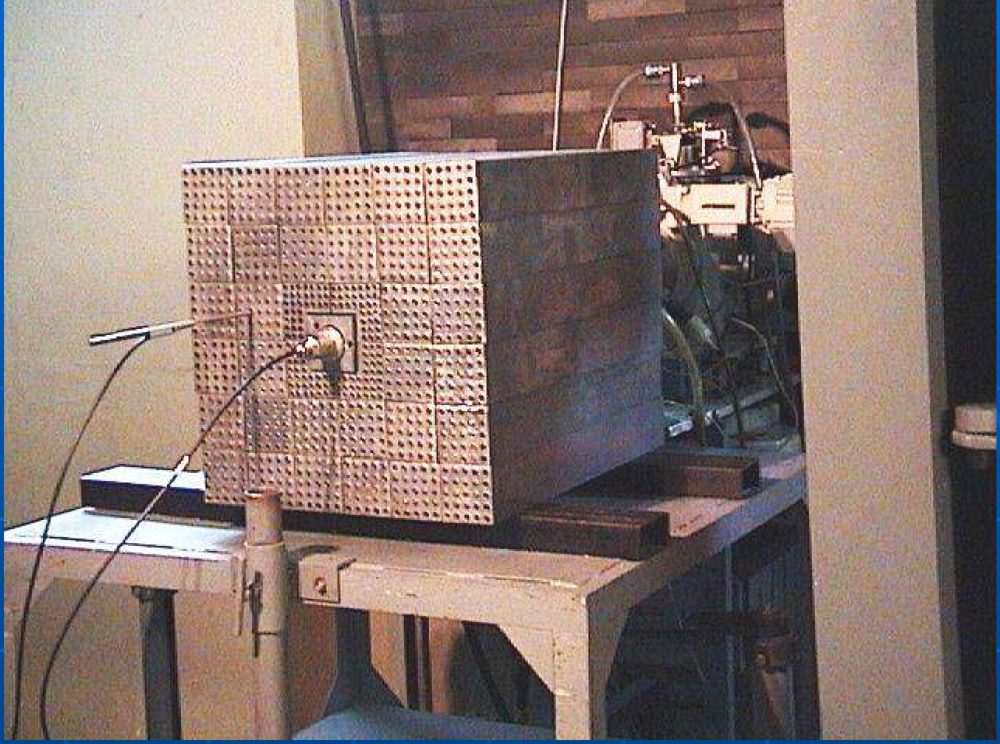
dimension, cm 48x48x50
fuel:
Umet. is enriched to 90% in 235U
UO_2 is enriched to 36% in 235U
neutron flux density
with energy En >0,1 MэB, 10^9 n/(cm2 s)
moderator Pb
Uranium load (kg) U-5–62.8;U-8 - 54.5

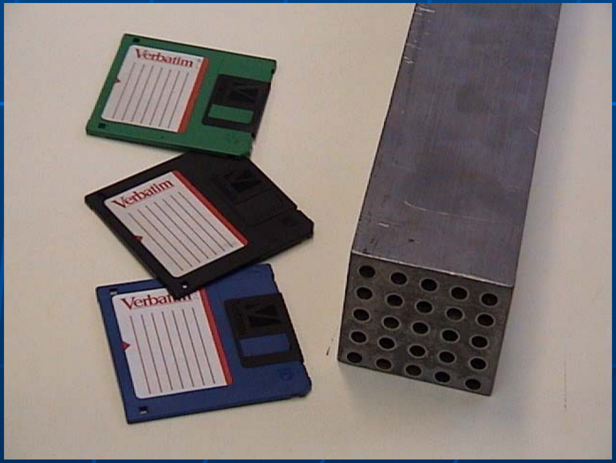
Intermediate zone:

thickness, cm 3
material Umet (natural uranium) + B_4C
Moderator Pb
Uranium load (kg) U-5–0.23;U-8 -31.8

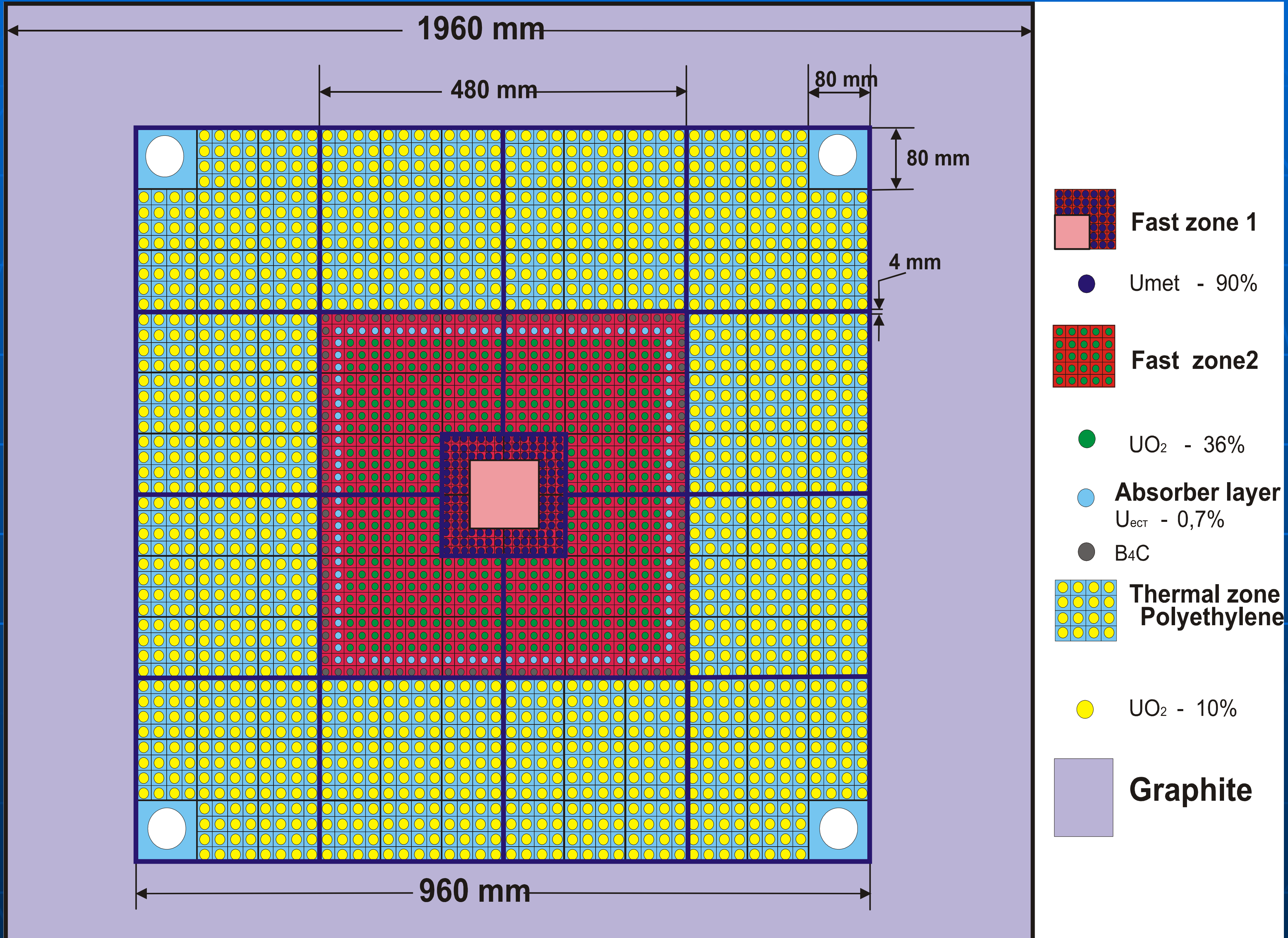
Thermal zone (Keff= 0,95) :

thickness, cm 24
fuel : UO_2 is enriched to 10% in 235U
moderator polyethylene
reflector
graphite
Thermal neutron flux density:
Ti^3H –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.



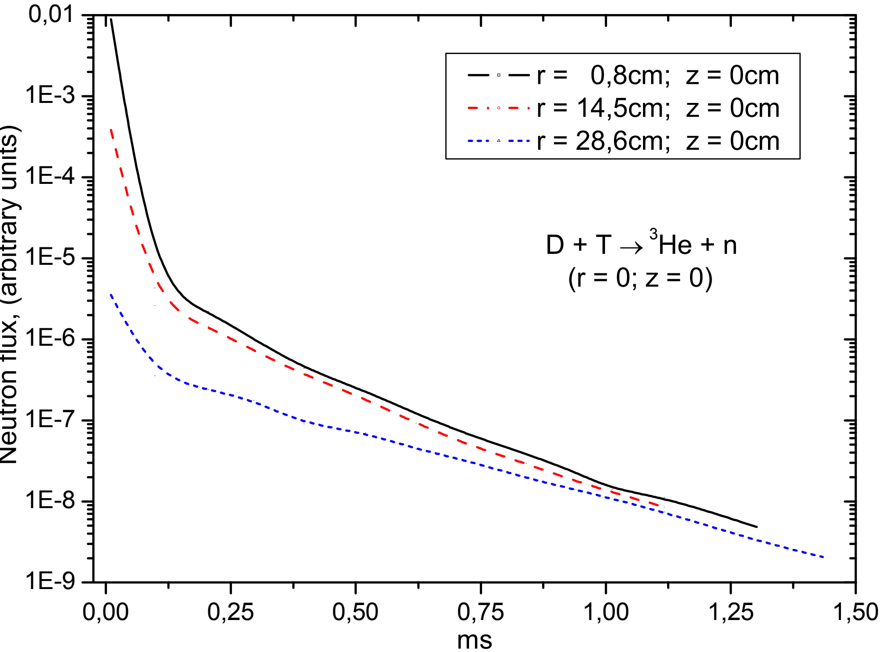
Vertical layout of booster subcritical assembly


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

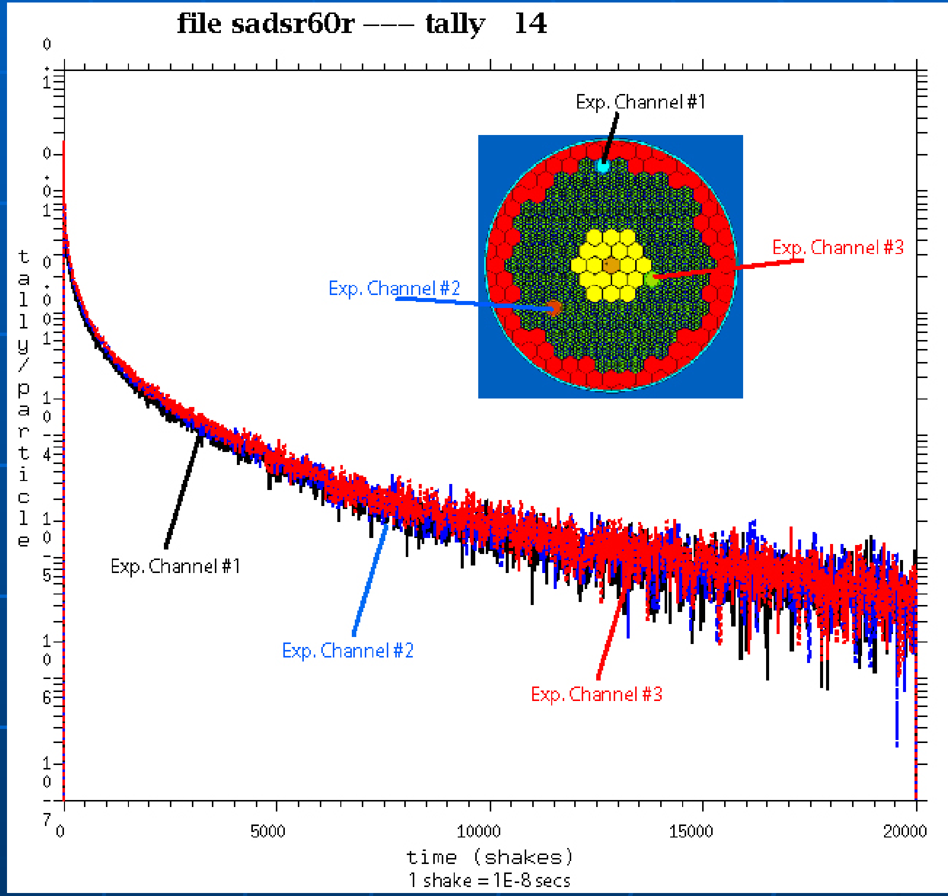
The characteristics of the fuel elements

- 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 UO_2
- _ active height 50 cm
- fuel pellet
- radius : 0.32 cm
- Nr = 576
-
- Thermal zone 10 % enriched UO_2
- _ active height 50 cm
- radius : 0.45 cm
- Nr =1050
- cladding: composition : stainless steel and Al thickness :
- 0.076cm

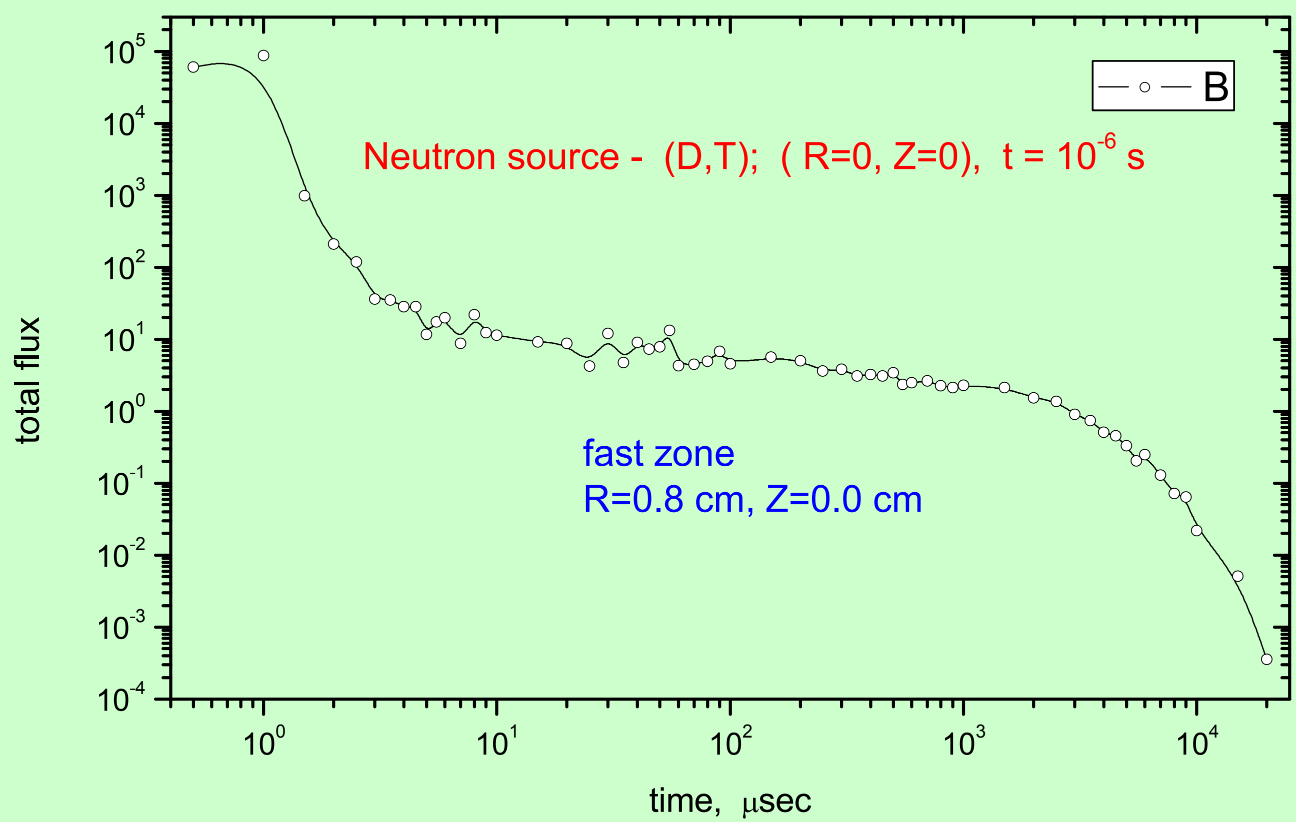


Time evolution of the neutron flux after neutron generator pulse (τ = 1μs) at the different position (r; z) in the core



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 ($\tau=1\mu s$).

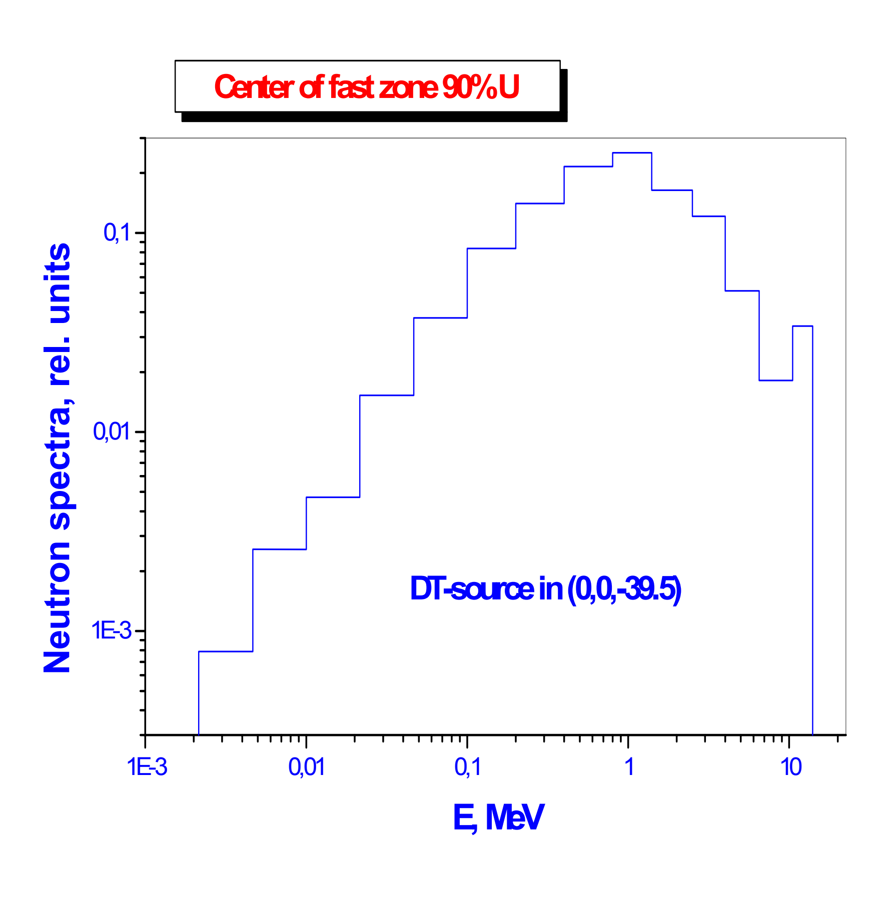


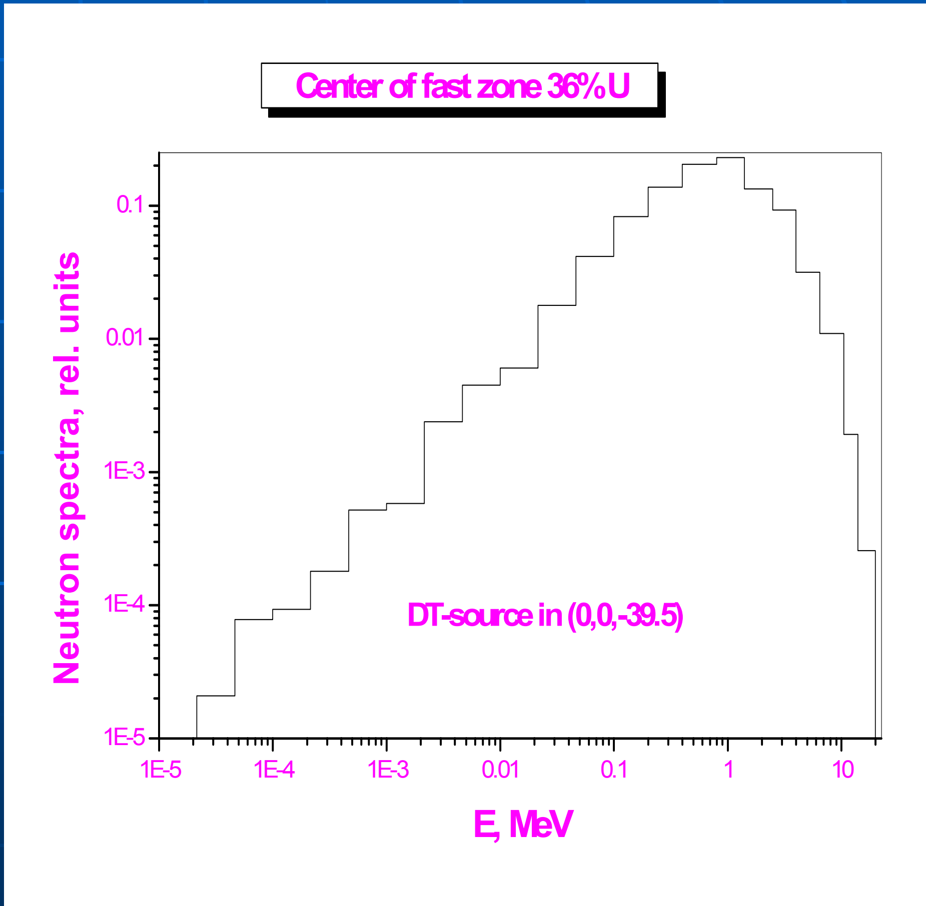
Prompt neutron lifetime in the booster subcritical assembly driven by a neutron generator

	Bare booster zone	Booster zone with polyethy-lene 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 inter-mediate zone 1.06×10^{-5} s (10.6 µ s) (without B_4C in the inter-mediate 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)

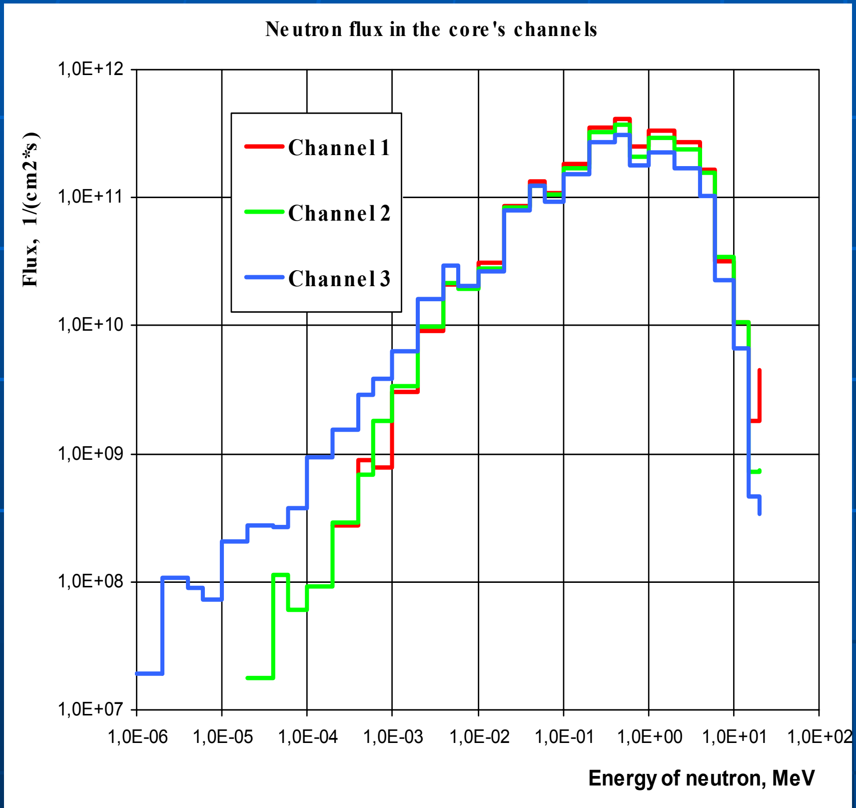
SAD A. Lopatkin L = 24µs; E. Gonzales L = 0.954µs ; MUSE -3 L = 0.61 µ

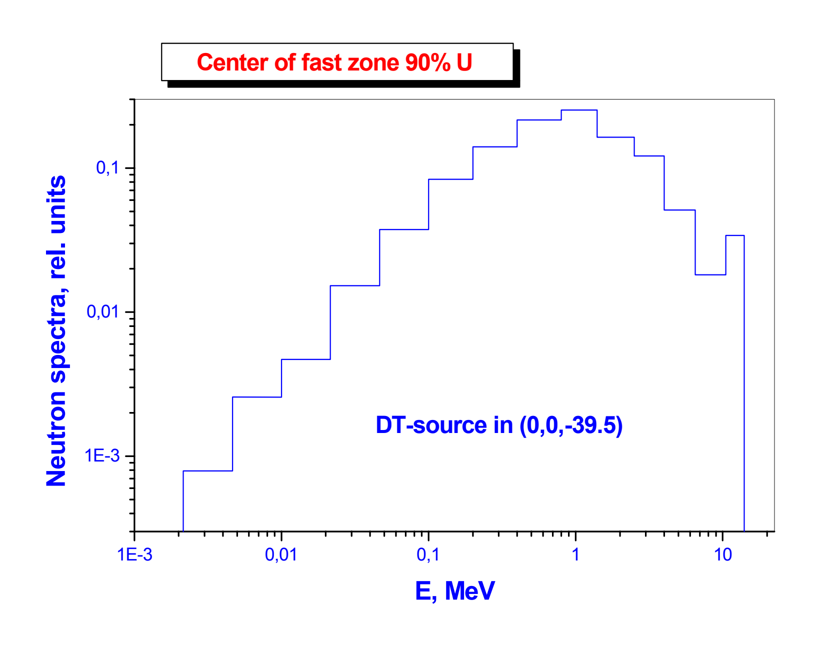
Energy distribution of neutron field in the booster zone





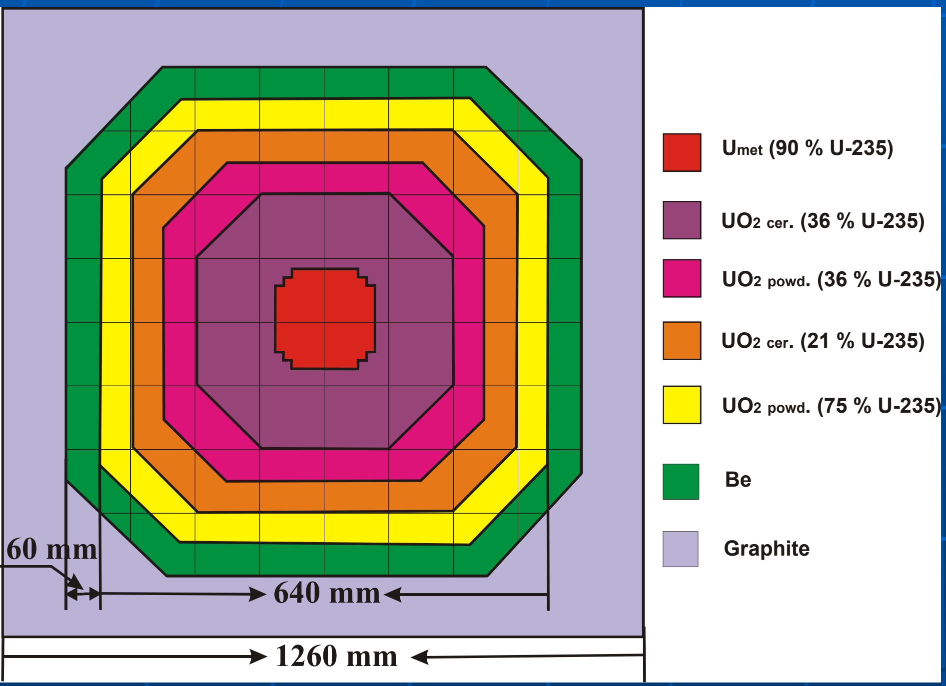
Neutron spectrum
Lopatkin Booster

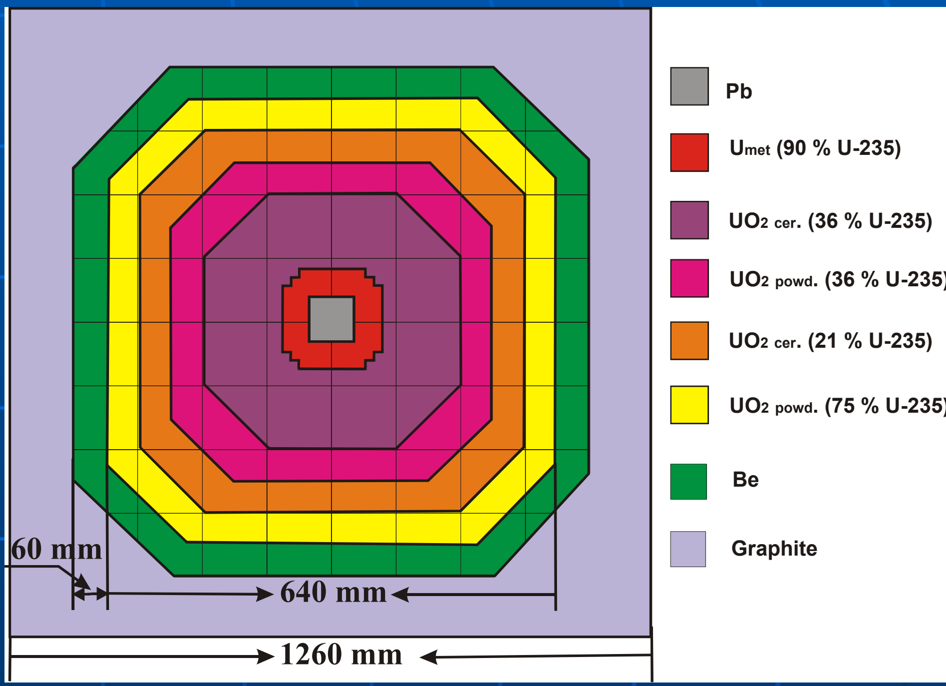




kef =0.93-0.95

kef =0.90

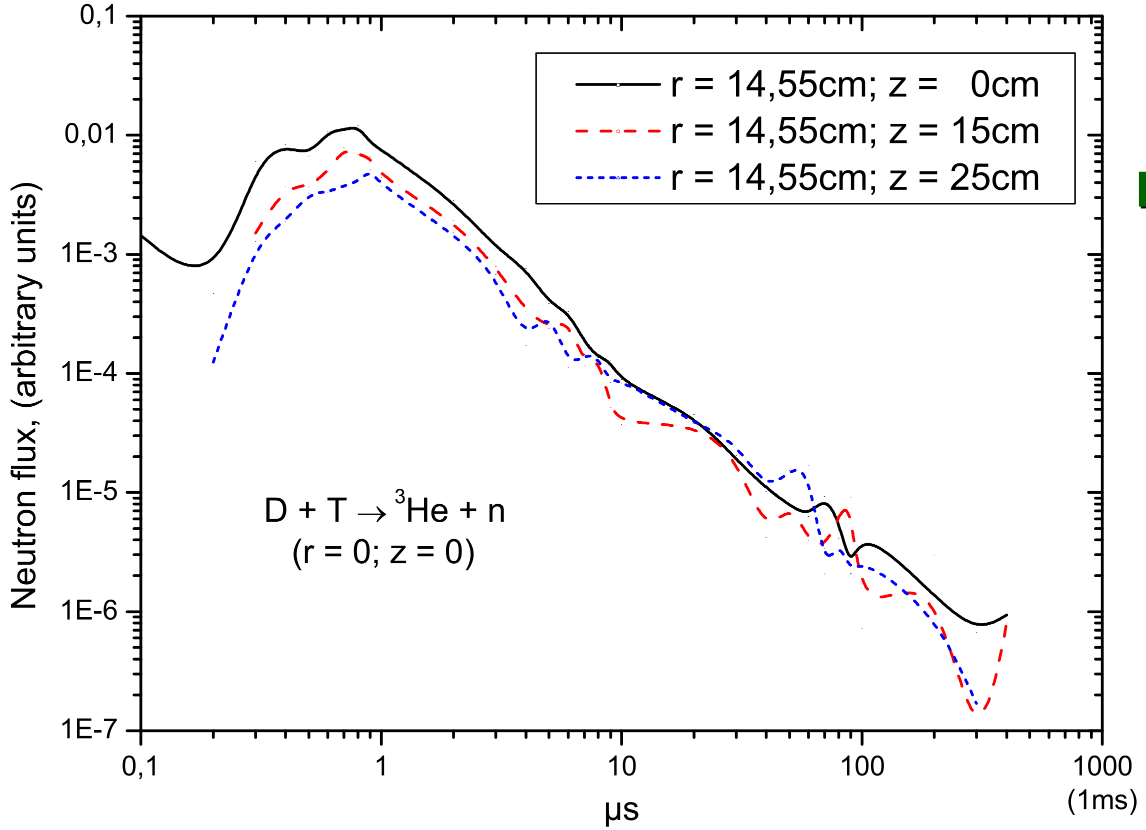




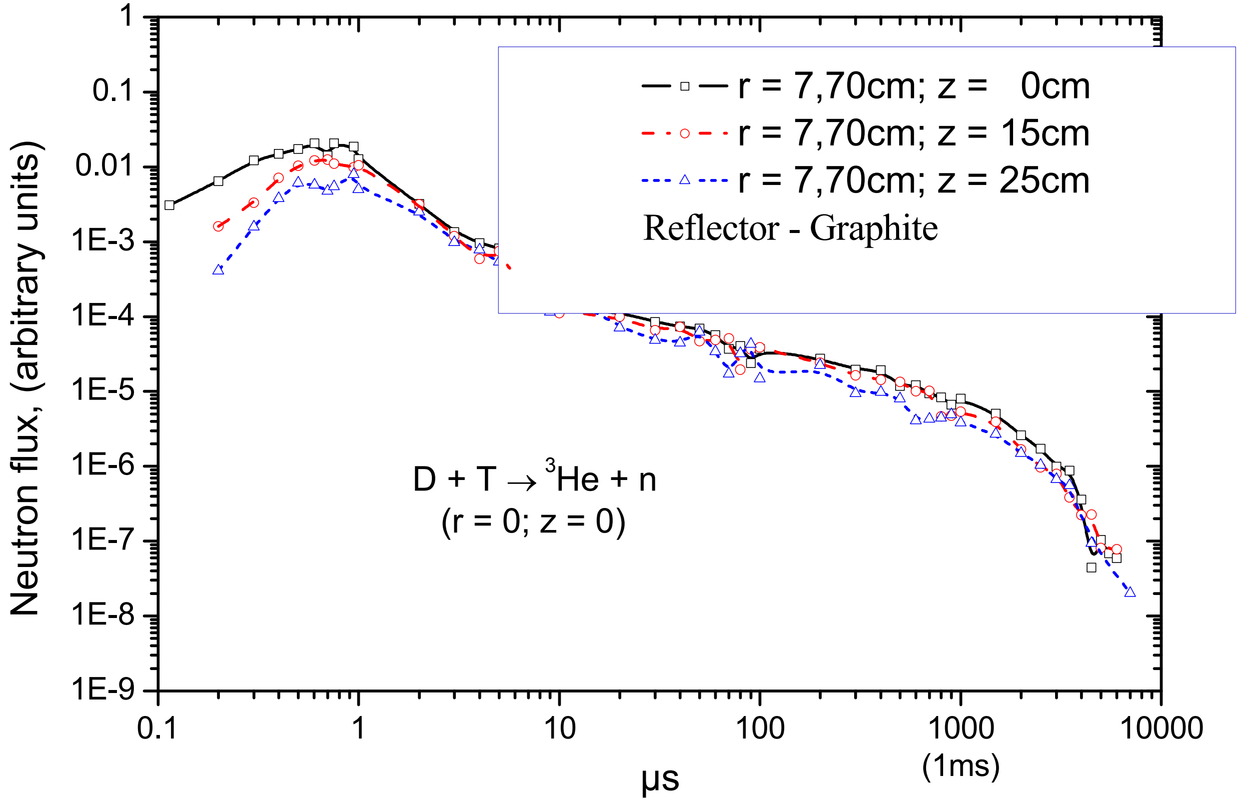
Layout (cross section) of fast neutron spectrum sub-critical assembly driven by neutron generator

(*K*eff = 0.836)

Bare core

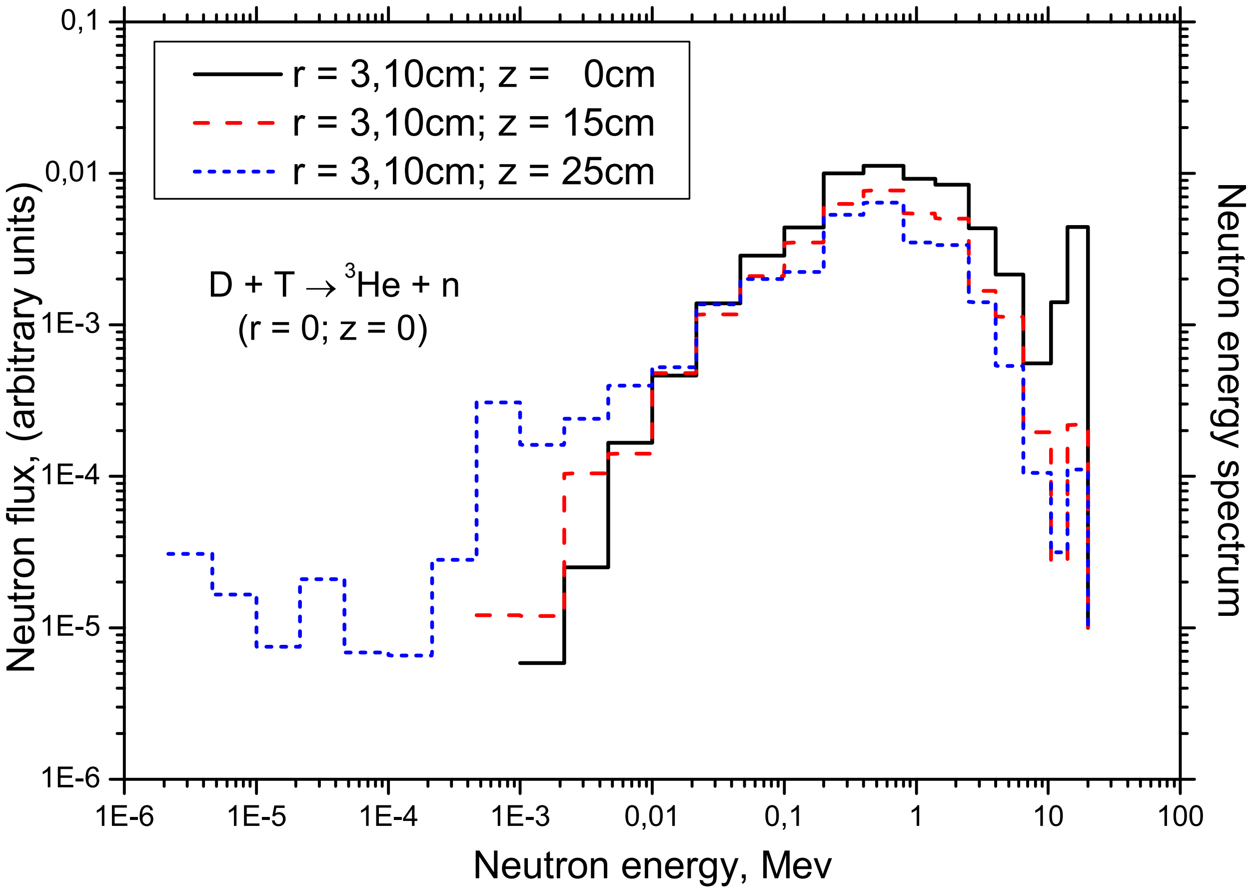


Time evolution of the neutron flux after neutron generator pulse (τ = 1μs) at the different position (r; z) in the core



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*эфф = 0.943). Временные распределения потока нейтронов в центральной части бустера (***r*** = 7,70 см).



r = 3,10cm; z = 0cm
r = 3,10cm; z = 15cm
r = 3,10cm; z = 25cm
D + T → ³He + n
(r = 0; z = 0)
Neutron flux, (arbitrary units)
Neutron energy spectrum
Neutron energy, Mev
0,1
0,01
1E-3
1E-4
1E-5
1E-6
1E-6
1E-5
1E-4
1E-3
0,01
0,1
1
10
100

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)

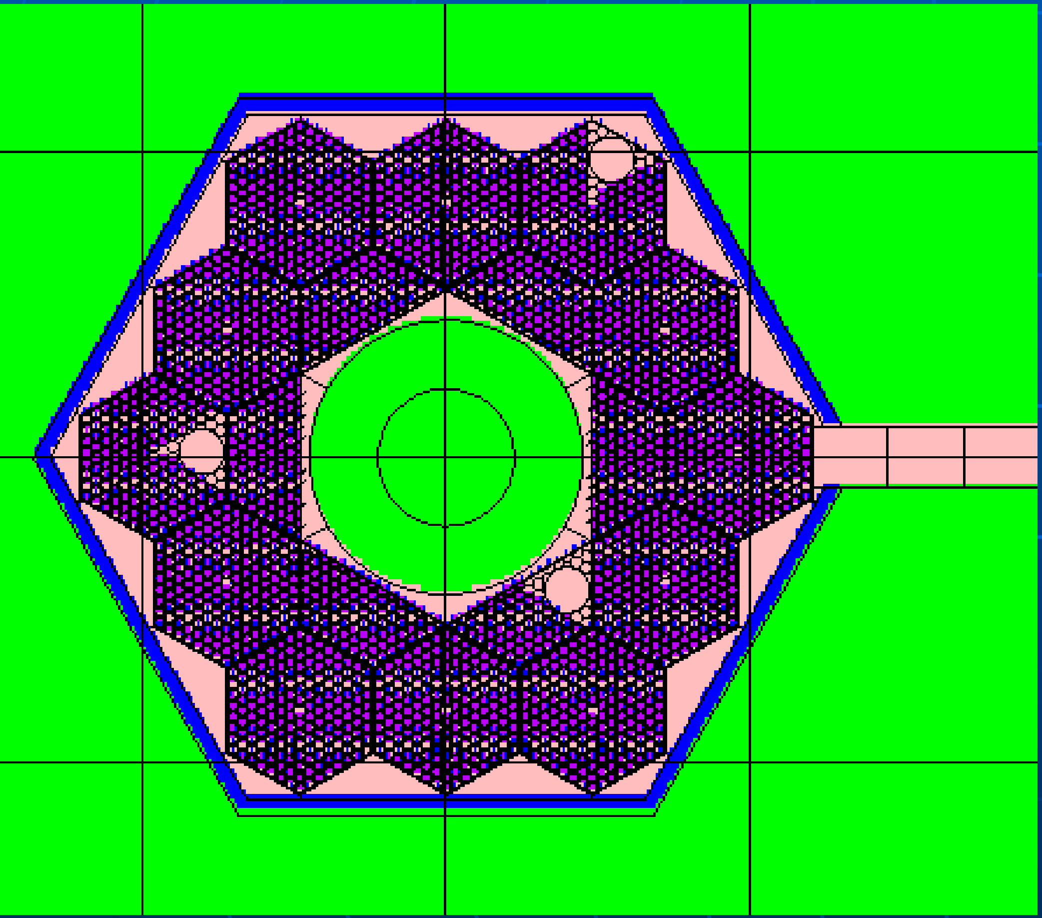
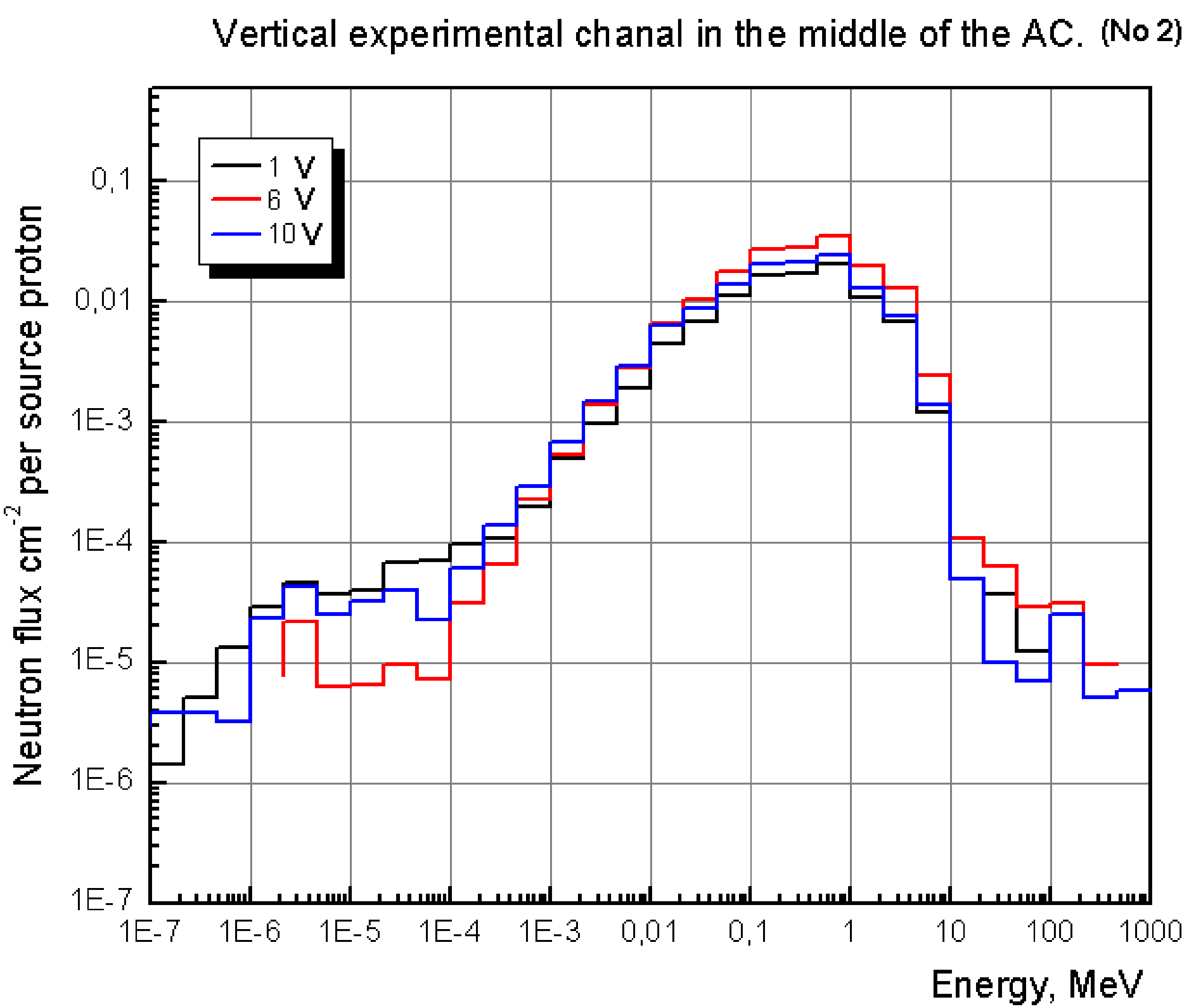


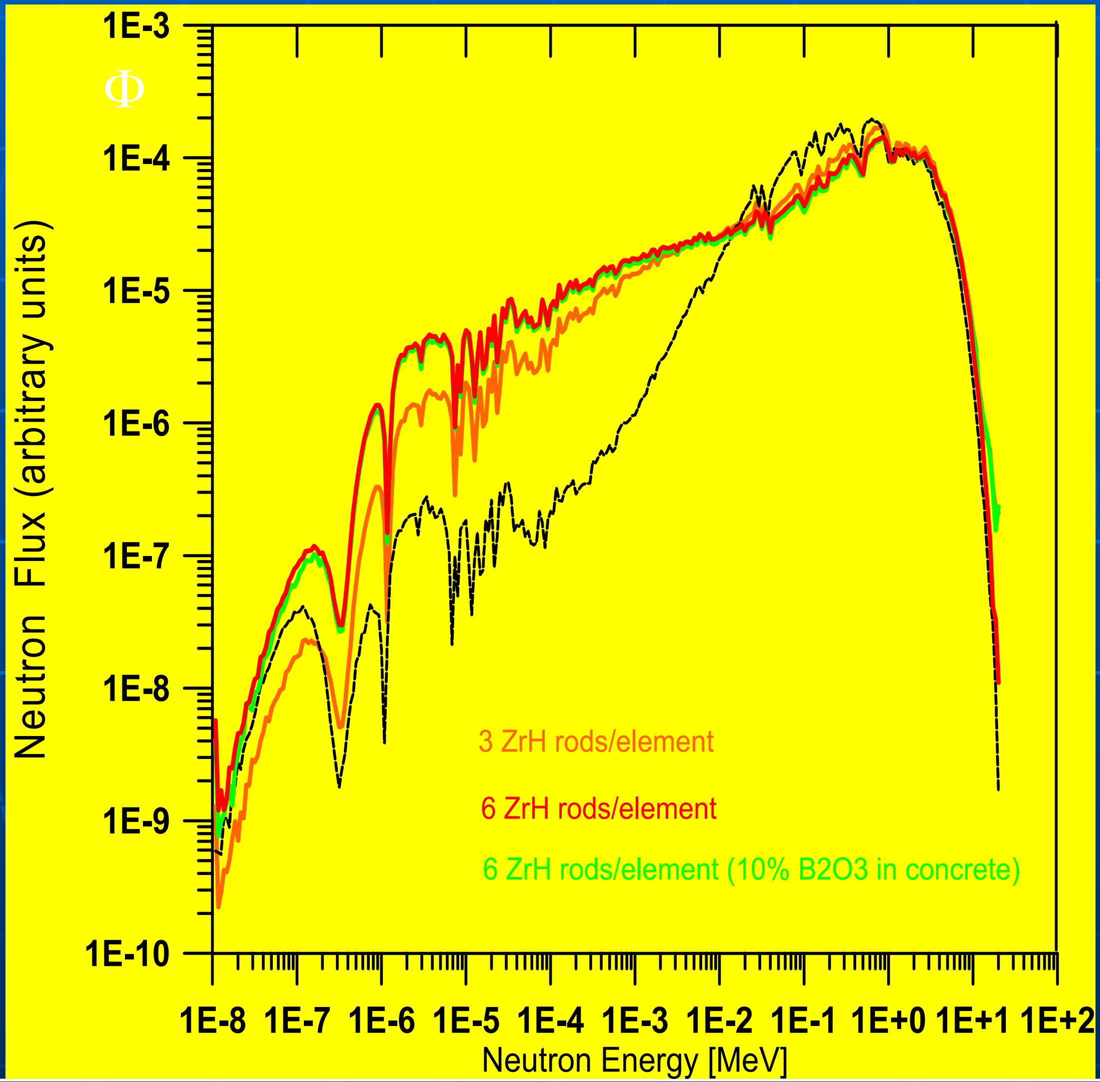
Figure shows a schematic layout of SAD-setup which has been studied in different target and reflectors. Colors symbolize different materials: yellow – lead or tungsten target, light blue – air, dark violet – MOX-fuel, green – lead, orange-lead or beryllium reflector, blue–steel.

Neutron spectra calculated for the subcritical assembly.



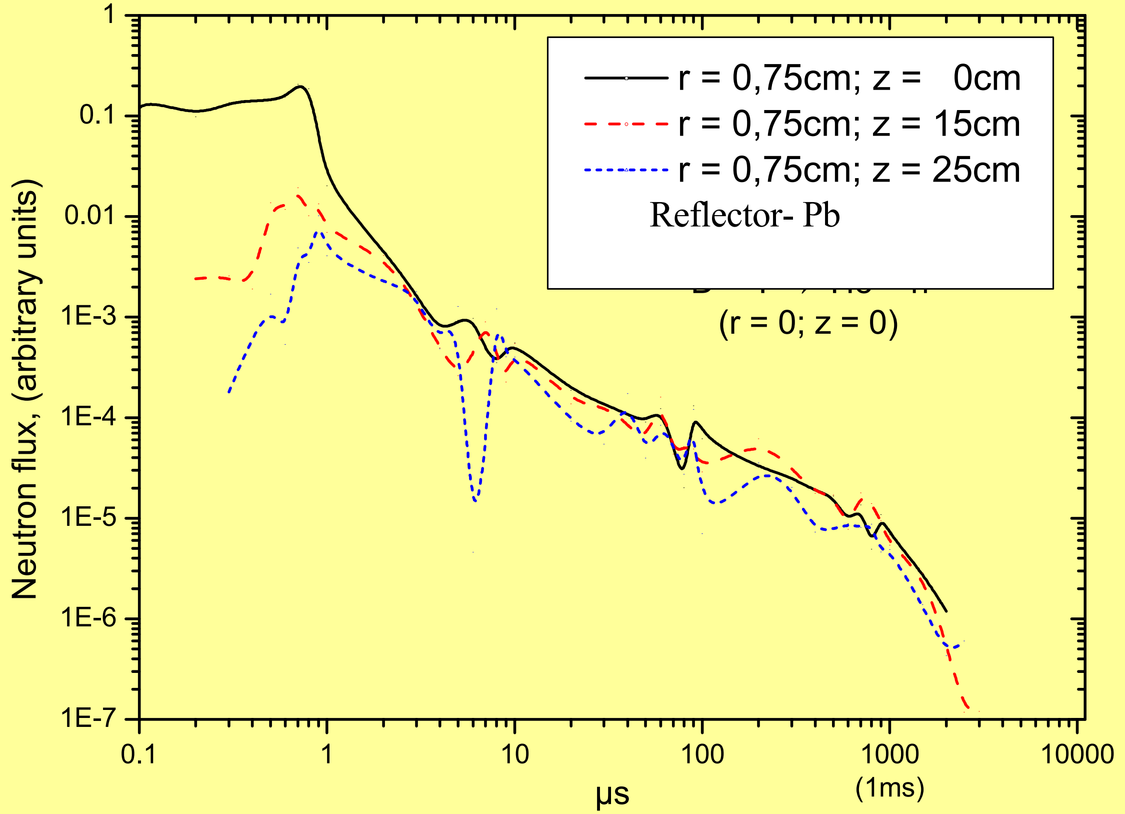
Modelling of SAD experiments

Neutron Spectra in SAD models



ZrH moderated options

As compared with
unmoderated opt
ZrH heightens the
in the resonance r
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

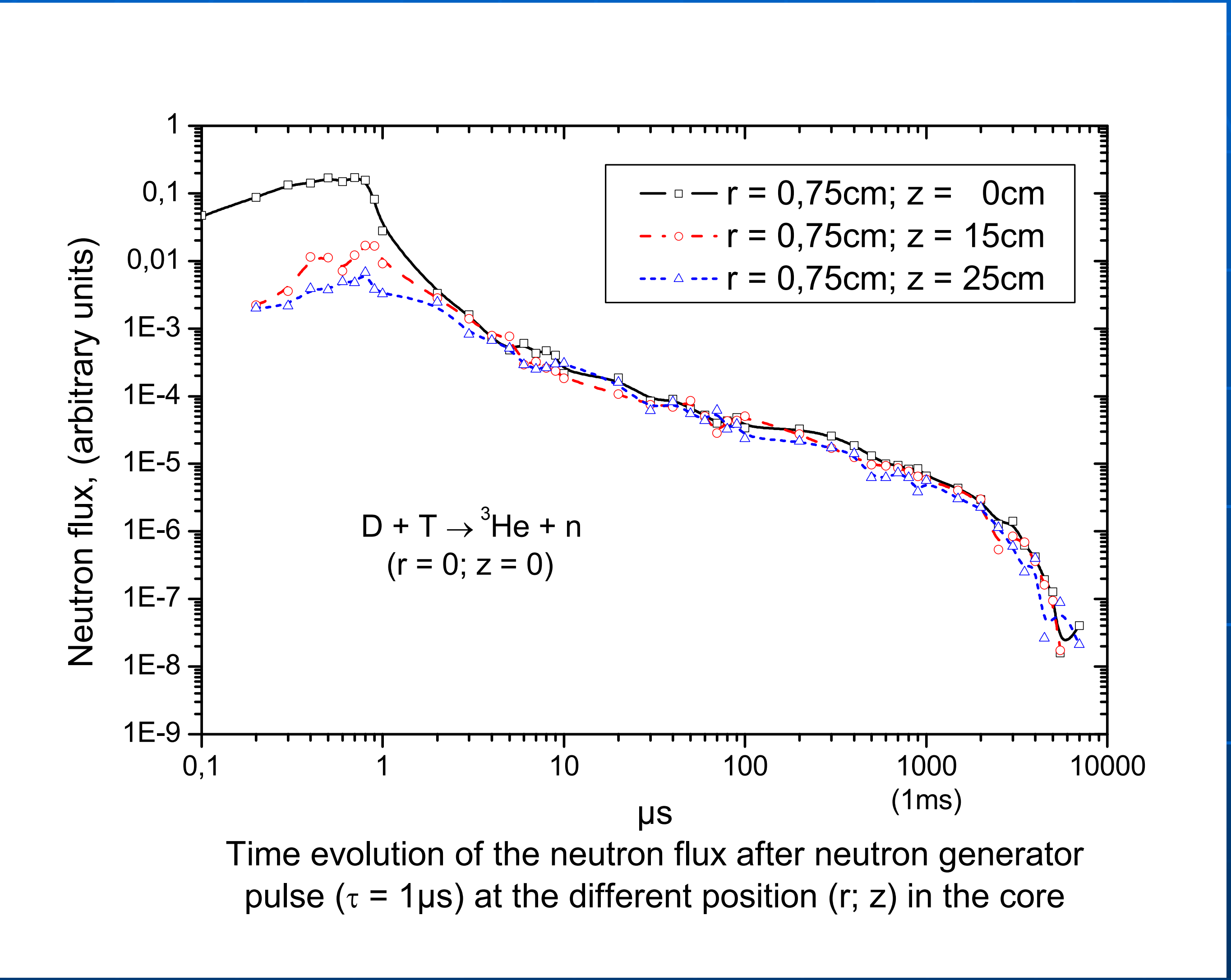


Рис. 2.1. Бустер «под SAD» с графитовым отражателем

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

e) SAD

Presentation of SAD progress

PROGRESS REPORT FOR ISTC PROJECT #2267 ½ YEAR

Construction of a Sub-critical Assembly Driven by a Proton Accelerator at Proton Energy 660 MeV for Experiments on Transmutation of Minor Actinides and Long Lived Fission Products: (*Phase I: Design, Design Documentation and Safety Substantiation*)

July 2004, JINR, Dubna, Russia

Prepared by Project #2267 manager, V. Shvetsov

Participating Institutions:

– International Intergovernmental Organization Joint Institute for Nuclear Research (JINR, Dubna, Russia) – **Leading Institution**;
– *Federal State Unitary Enterprise Research and Development Institute of Power Engineering* (**NIKIET** – Russian abbreviation);
– *Industrial Association **"Mayak"***;
– *Federal State Unitary Enterprise State Special Project* Institute (**GSPI** – Russian abbreviation);
– R*ussian Scientific Research Institute of Inorganic Materials* (**VNIINM** – Russian abbreviation);

Project foreign collaborators:

– **Dr. Waclaw Gudowski** (Kungliga Tekniska Högskolan - KTH, Nuclear and Reactor Physics);
– **Dr. Cornelis Broeders** (Forschungszentrum Karlsruhe - FZK, Institut für Reaktorsicherheit);
– **Dr. Enrique Miguel Gonzalez Romero** (Centro de Investigaciones Energéticas Medioambientales y Technologies – CIEMAT);
– **Dr. Frederic Mellier** (Commissariat a l'Energie Atomique - CEA, Cadarache).

Table of contents

Introduction

The construction of large subcritical accelerator driven systems (ADS) should be preceded by experimental verifications of the theoretical predictions and of the technological features of such systems. The most important issues to be addressed are:

- Substantiation of operational safety of sub-critical systems;
- Reliable calculation and measurement of the ADS power;
- Development of methods for reliable monitoring of the subcriticality K_{eff};
- Measurement of the contribution of the high-energy part (E >10 MeV) of the neutron spectrum, being particularly important for the design of radiation protection.
- Engineering of the coupling of an accelerator with a sub-critical reactor system;

Experimental ADS with thermal power of about 15-20 kW, as proposed in the SAD project, can deliver reliable substantial answers to these problems.
Some experiments are also planned to assess the reactivity feedbacks for SAD facility.

In JINR experimental and theoretical research activities focusing on coupling of proton accelerators with fissile targets/cores have been conducted since the middle of the 50-s' under the scientific label "*electronuclear*" research. Neutron yields and spectra in lead and uranium targets have been measured, as well as neutron cross sections for a number of isotopes, important for the estimation of the efficiency of various modes of transmutation (see for example the frequently quoted experiments and results of Vassylkov and Goldanski in reference [1]). For the analysis of the *electronuclear* systems properties, mathematical models with appropriate databases and software have been developed.

JINR has the license for operation of nuclear research reactors with active cores made of metallic plutonium and plutonium dioxide. Such reactors have been operated reliably and safely for more than 40 years.

JINR also has a long-term experience with the operation of proton accelerators. This experimental background gives good prospects for setting-up and subsequently for operating a low power experimental ADS with MOX fuel at JINR in Dubna. Moreover, the JINR with its status as an international research centre allows joining the financial contributions of the JINR member countries for such projects.

This low power project will be a natural step on the way from the current experimental zero power sub-critical assemblies, driven by an external neutron source (MASURCA in Cadarache, BFS in Obninsk, YALINA in Minsk) to the proton beam driven semi-industrial installations (MYRRHA, TRADE), which are now in the conceptual design phase in Europe.

Summary

One of the advantages of the proposed project is using the existing proton accelerator at JINR with 660 MeV energy and 3.2 μA maximal current. The PHASOTRON accelerator can deliver a proton beam with up to 2 kW power, enabling to have a total power of the sub-critical core, driven with such beam, at a level of more than 100 kW. The upper limit is determined by the multiplication factor K_{eff} = 0.98, the regulatory value defining sub-critical installations in the Russian Federation. One has to note also that the multiplication factor K_{eff} should be less or equal than 0.98 in all modes of operation, including anticipated accidents, so the normal mode of operation will be established at a lower value.

Another feature of the project is the use of existing fuel elements (FE) with MOX (uranium plutonium oxide) fuel of the BN-600 type as prototype for SAD FE.

The current project is logically separated into two Phases:

- Phase I – design and technological preparation and
- Phase II – construction of the facility.

Phase I is now supported in the ISTC Project #2267 and this part of the project will be described here in more detail.

The Phase I consist of two parts: design and technology.

In the first part of Phase I, the design and the financial (budget) documentation of the construction of the installation will be developed according to the requirements of the Russian Federation and the package of documents for obtaining the licenses for the location and for the construction of the nuclear installation will be prepared.

In the technological part, the production of FE will be prepared and a pre-production batch of MOX fuel pellets will be manufactured.

The project tasks of the Phase I with time schedules are listed in following table (the first quarter started on November 1 2003, when the JINR-ISTC contract was signed):

Table 1: SAD project time schedule (Design part).

– integral tasks; - completed tasks; - incomplete tasks; – time marker.

Tasks	Quarters					
	1	2	3	4	5	6
Task 1. Development of the concept of SAD installation. Development of the initial technical specifications						
Subtask 1.1 Basic data negotiation.						
Subtask 1.2 The protocol on design zones demarcation.						
Subtask 1.3 Basic data on MOX fuel pellet.						
Subtask 1.4 GSPI request to JINR on proton shielding calculation.						
Subtask 1.5 Development of the technical specifications (TS) on subcritical assembly.						
Subtask 1.6 Development of the TS on FE.						
Subtask 1.7 Development of the TS on beam transport line.						
Subtask 1.8 Development and approval of the project technical proposal on installation.						
Subtask 1.9 Final report preparation.						
Task 2. SAD parameters modeling						

Subtask 2.1 Numerical analysis of the SAD parameters.
Subtask 2.2 Energy release in SAD elements calculations.
Subtask 2.3 Calculations of the neutron spectra and angular distributions inside the SAD installation and behind biological shielding.
Subtask 2.4 Calculations of the neutron fields in experimental channels.
Subtask 2.5 Calculations of the SAD kinetic properties.
Subtask 2.6 Calculations of the SAD biological shielding.
Subtask 2.7 Calculations of the induced activity in SAD elements.
Subtask 2.8 Final report preparation.
Task 3. Design and development of the beam transport line
Subtask 3.1 Design and development of the beam transport line elements.
Subtask 3.2 Technical project (TP) of the beam transport line.
Subtask 3.3 Final report preparation.
Task 4. Design and development of the SAD fuel elements
Subtask 4.1 Documentation preparation.
Subtask 4.2 Documentation negotiation.
Subtask 4.3 Documentation correction.
Subtask 4.4 Documentation release and approval.
Subtask 4.5 Final report preparation.
Task 5. Production preparation, preproduction batch of fuel pellets manufacturing
Subtask 5.1 Production and certification of the plutonium dioxide, coordination of the isotopic content with precision not worse than 10-4 for basic isotopes.
Subtask 5.2 Delivery of the depleted uranium dioxide.
Subtask 5.3 Verification of the ceramic properties of the materials.
Subtask 5.4 Preparation of working design documentation on fuel pellets and FE.
Subtask 5.5 Preparation of production: development of the technology of pellets manufacturing, manufacture of tools.
Subtask 5.6 Preparation of the technology of FE assembly and capsulation.
Subtask 5.7 Preproduction batch of fuel pellets release.
Subtask 5.8 Obtaining certificate – license for FE transport package.
Subtask 5.9 Final report preparation.
Task 6. Design and development of the subcritical assembly (SA)
Subtask 6.1 Calculation works.
Subtask 6.2 Initial data for GSPI (layout drawings, requirements to external systems).
Subtask 6.3 Systems classification.
Subtask 6.4 Development of the requirements on automatic control and monitoring system (ACMS), its composition and structure.
Subtask 6.5 Developments of SA design, including substantiation of safety.
Subtask 6.6 Final report preparation.
Task 7. Civil engineering solutions on installation creation and allocation
Subtask 7.1 Investigations of the radiation conditions at installation position.
Subtask 7.2 Development of preliminary technological arrangement of an annex to the building.
Subtask 7.3 Coordination of the arrangement between JINR and NIKIET.
Subtask 7.4 Development of a preliminary general layout.
Subtask 7.5 Development of the technological tasks on sections.

Subtask 7.6 Coordination by the developers of contiguous parts of the project of technological arrangement.						
Subtask 7.7 Development of an intermediate architectural - construction plans.						
Subtask 7.8 Technical specifications on connection of sources of energy, water and water drain.						
Subtask 7.9 Development of budget documentation.						
Subtask 7.10 Coordination of design solutions.						
Subtask 7.11 Sending the design materials to the state supervision authorities.						
Subtask 7.12 Final report preparation.						

The deliverables of the Phase I are a set of documents in an order as determined by Russian Federation laws and normative documents:

- Design assignment document: the official request from JINR as customer organization to GSPI as general designer to start design work;
- Protocol on separation of responsibilities;
- Protocol on project basic data coordination;
- General Requirements Specification;
- As a result of the task on SAD parameters modelling, a technical report will be issued according to the project time schedule;
- The technical project for the beam transport line, including working drawings will be issued by JINR in the beginning of 2005;
- The technical project for the FE, including working drawings will be issued by VNIINM in the beginning of 2005;
- The technology for the fuel pellets manufacturing will be prepared at Mayak and a pre-production batch (3-5 kg) of pellets will be manufactured in April 2005;
- The technical project for the SA, including safety operation assessment will be issued by NIKIET in the beginning of 2005;
- The technical project for the new building and for the technological systems will be issued by GSPI in August 2004;
- The general engineering project will be issued by GSPI in December 2004;
- The general engineering solutions for the substantiation of safe operation will be issued by GSPI in March 2005;
- The latter two documents will be sent to the Federal Service on Atomic Supervision (former Gosatomnadzor agency) for getting the licenses for the allocation and for the construction of the SAD installation (necessary expertises and coordination will be done during the project implementation).

Details of the Phase II of the project are not yet specified precisely now. Nevertheless, the time schedules for the final project realization may be estimated from the preliminary investigations during the ISTC proposal preparation: 1.5 – 2 years for the Phase II of the project in case of sufficient funding. The financial valuation in its turn may be done after issuing the general engineering project (one of the parts of this project will be the cost assessment) by GSPI at the end of 2004.

Project Description

SAD basic data

The SAD project basic features are determined by the characteristics of the "PHASOTRON" proton accelerator at JINR and by the choice of the regular Russian MOX fuel elements of the BN-600 reactor type. The proton current (maximum value is 3.2 μA) and the corresponding power dumped in the spallation target determine together with the value of the multiplicity K_{eff} of the core, the total thermal power of the installation.

The basic data of the SAD-facility, the parameters of the accelerator and the MOX fuel characteristics are listed in the following tables:

Table 2: SAD installation basic data

Thermal power	up to 30 kW
Proton energy	660 MeV
Beam power	up to 1 kW
Proton beam / target orientation	Vertical
Fuel elements orientation	Vertical
Criticality coefficient	$K_{eff} \approx 0.95$
Fuel - see table below for details on composition	MOX, $UO_2 + PuO_2$
Cladding tubes maximum temperature	400° C
Spallation target	Replaceable: Pb, W
Reflector	Pb
Coolant	Air

Table 3: Beam parameters

Intensity of the extracted proton beam:	3.2 μA ($1.997 \cdot 10^{13}$ protons/s)
Beam emittance:	$\Sigma_x = \pi(5.1 \pm 2.3) cm \cdot mrad$ $\Sigma_y = \pi(3.4 \pm 1.4) cm \cdot mrad$
Time structure	
Fast extraction	
Frequency	250 Hz
FWHM	20 μs
Number of protons in pulse	$0.8 \cdot 10^{11}$
Slow extraction	
Frequency	250 Hz
Pulse width	3500 μs
Beam microstructure	
Micropulse FWHM	10 ns
Micropulse period	70 ns

Table 4: Basic features of the SAD core fuel

Parameter	Value
Fuel composition	$(UO_2 + PuO_2)$
Plutonium dioxide content in the fuel, %(mass)	up to 30*
^{239}Pu content in Pu %(mass), not less than (with accuracy not worse than 10^{-4} for basic isotopes)	95
Fuel density, g/cm^3	From 10,0 to 10,7
Fuel pellet diameter, mm	5,95*

*– parameters become defined more accurately during FE design

The installation will be equipped with experimental channels, which will allow to place detectors and isotopic samples in different parts of the installation and to extract them after irradiation.

Work Completed

Task1: Development of the concept of SAD installation. Development of the initial technical specifications

Design assignment document was issued by JINR in January 2004. Russian project participants in 2003 signed protocol on separation of responsibilities. Russian project participants in 2003 signed protocol on project basic data coordination. Russian project participants in April 2004 signed specification of general requirements. NIKIET, VNIINM and JINR in June 2004 signed requirements specifications on SAD FE. Technical specifications on the fuel pellet were issued by VNIINM and sent to “Mayak “.

All subtasks of the Task 1 of the project now are completed.

Task 2 SAD parameters modeling

Geometry and materials

Table 5: Lead target (Figure 1)

Number of prisms	13
Hexagonal prisms:	
Number	12
Pitch, mm	36
Gap between prisms, mm	1.5
Height, cm	60.6
Cladding	SS
Central prism:	
Number	1
Height, cm	60
Cladding	SS
Proton input channel:	
Diameter, cm	3
Depth, cm	10

Table 6: Core

Number of cells for FA	141
Number of loaded FA	134
Number of loaded lead prisms	7
Fuel load, kg	396.9
Fuel density, g/cm^3	10.2
Content of PuO_2 in fuel, weight %	29.5
Content of ^{235}U in fuel, weight %	0.7
Height of fuel, cm	58

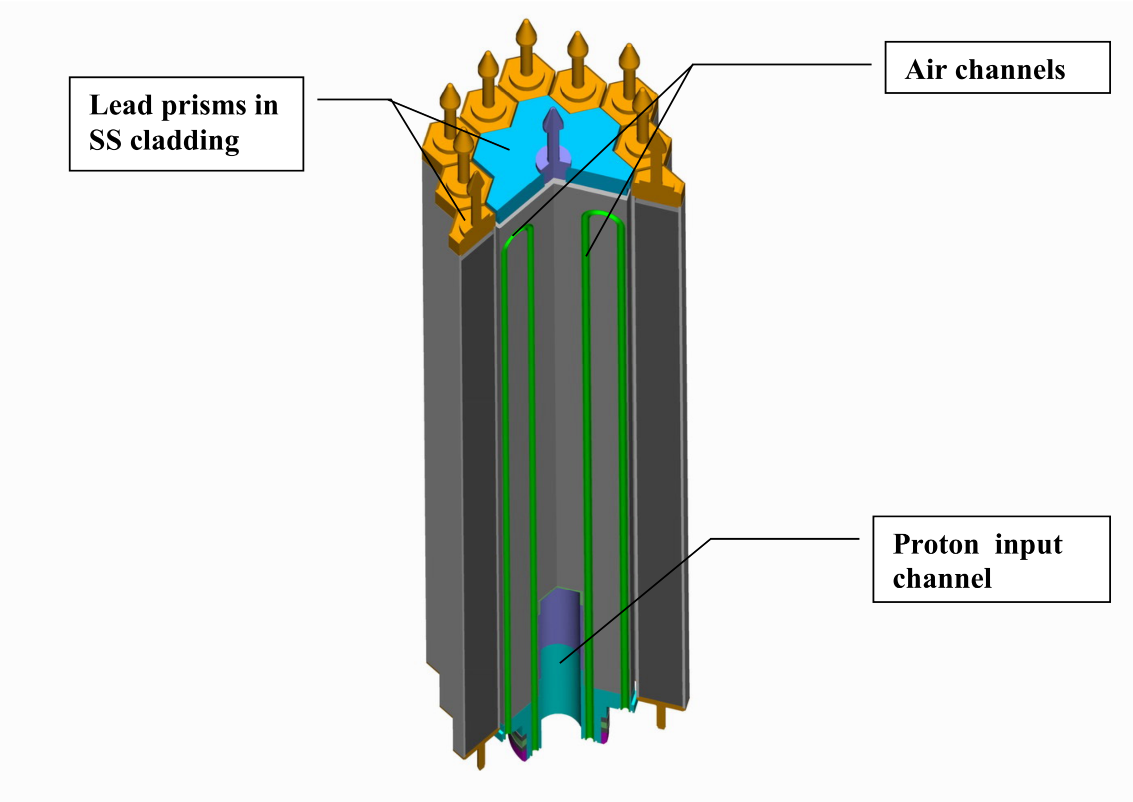


Figure 1. Lead target section

Target parameters

Table 7: Target parameters, calculated with LAHET

Proton energy, MeV	660
Beam power, kW	1
Neutron generation, n/p	12.95
Total neutron leakage from target, n/p	12.73
Side neutron leakage, n/p	12.22
Total energy of leakage, MeV/p	103.2
Total heat generation, W	840
Neutron source for blanket, n/s	$1.143 \cdot 10^{14}$

Core parameters

Table 8: Core parameters, calculated with MCNP

K_{eff}	0.9515
Neutron lifetime, μs	24
Fission power, kW	27.6
Peak factor of heat generation (height)	1.21
Heat generation in SAD parts:	
Fuel, kW	25.96
Target (neutron and photon from fissions)	97.3
Core cladding	204.3
Side Pb reflector	565.4
B_4C	204.6
Shielding concrete	771.1
Fuel Elements irradiation parameters:	

Max power density, W/cm^3	18
Max flux density of the fast neutrons (E> 0,1 MeV), cm^{-2}s^{-1}	2.2·10^{12}
Integral fluence of the fast neutrons (E> 0,1 MeV) at the end of campaign, cm^{-2}	8.0·10^{19}

Neutron spectra in experimental channels

SAD core and lead reflector simplified section is shown in Figure 2.

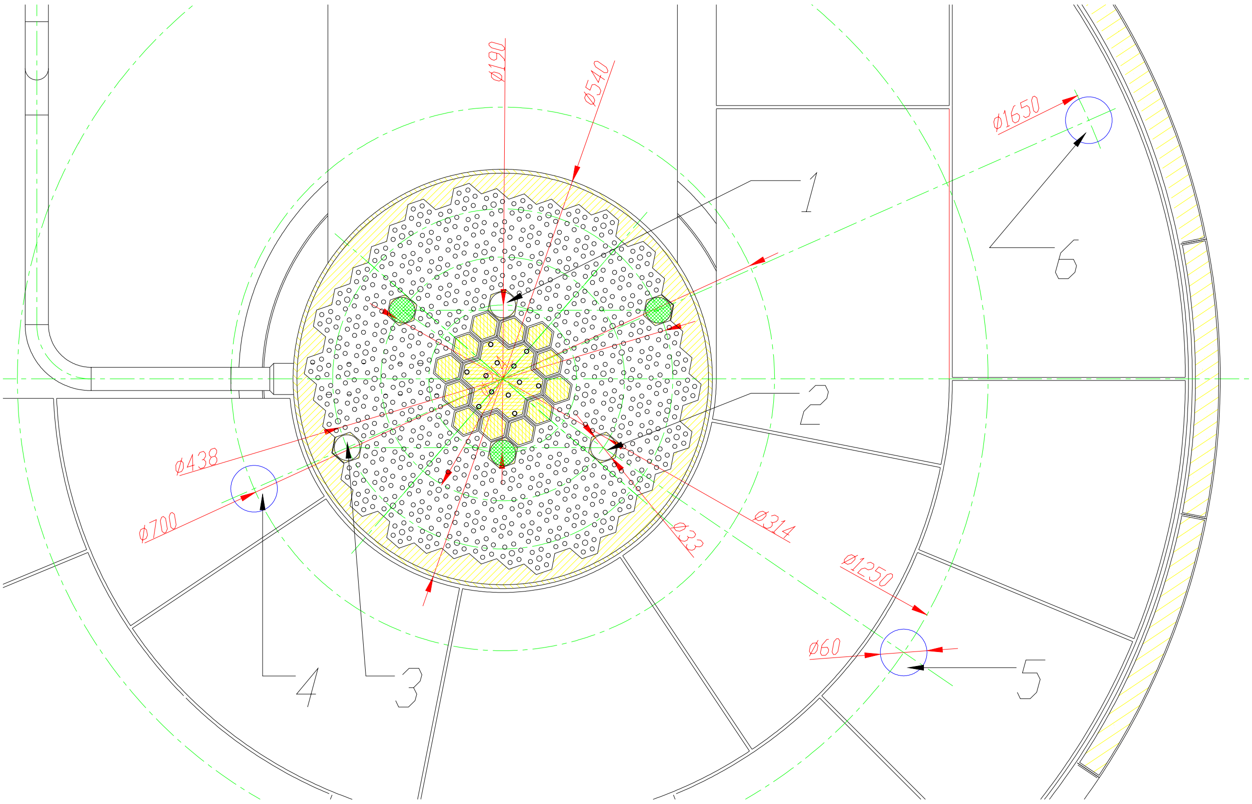


Figure 2. SAD core and reflector section through the central plane (construction elevation number 9800); lead blocks not hatched. 1-6 – vertical experimental channels

Results of the neutron spectra calculations are shown in Figure 3. Spectra were calculated in the centers of experimental channels and represent averaged over 5 cm height values.

Subtasks 2.1; 2.2; 2.4 are completed.

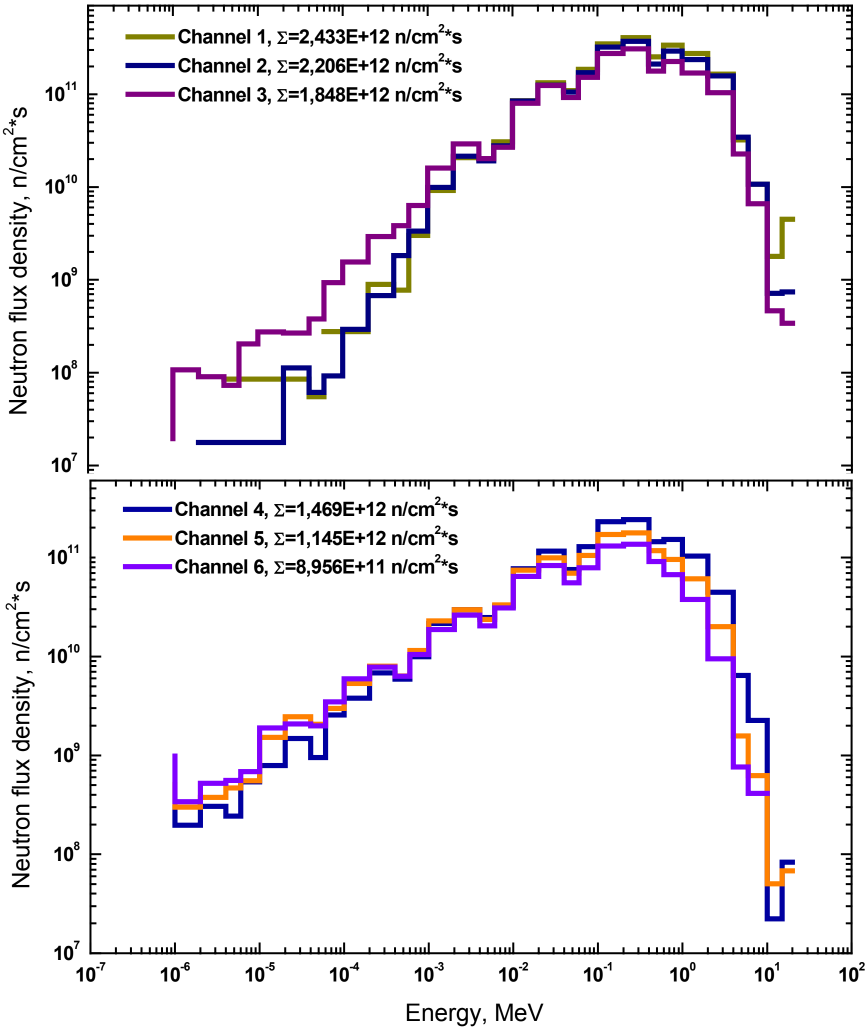


Figure 3: neutron spectra in the centers of vertical experimental channels: 1 – integral flux density 2,433E+12 n/cm^{2}s at 26 kW power; 2 – 2,206E+12; 3 – 1,848E+12; 4 – 1,469E+12; 5 – 1,145E+12; 6 – 8,956E+11.

Task 3 Design and development of the beam transport line

The proton accelerator PHASOTRON at JINR has 10 beam channels, used in various experiments. The normal beam losses at transition through the longest beam lines do not exceed 5%.

In the beam transportation system deflecting OM-1 type magnets and quadruple doublet ML-3 type lenses will be used. These standard magnetic elements have being designed and manufactured in many copies during the PHASOTRON exploitation.

The beam transfer from horizontal into a vertical plane will be realised using two strong bending magnets which have to be designed and constructed.

The total number of magnetic elements in the beam line is about 20. Total weight of the set of magnetic elements is estimated at 80 tons.

Requirements specifications for vacuum pipe, support stands, large bending magnets, vacuum shutter, diagnostic elements were developed.

Technical projects of the small bending magnets (OM-1) and doublets of the focusing quadruple lenses (ML-3) are completed.

Proton beam route was tracked inside the Phasotron building.

Beam dynamic was calculated for several versions of the magnetic elements allocation. Final version with 37.6 m length was chosen resulting beam transportation with losses less than 5% (less than 3% on the large bending magnets outside accelerator hall) and beam diameter on the target 30 mm (86.5 % beam intensity).

Sketch projects of the beam line power supply system and beam diagnostics were developed.

Sketch project of the beam line was developed.

Subtask 3.1 was completed.

Task 4 Design and development of the SAD fuel elements

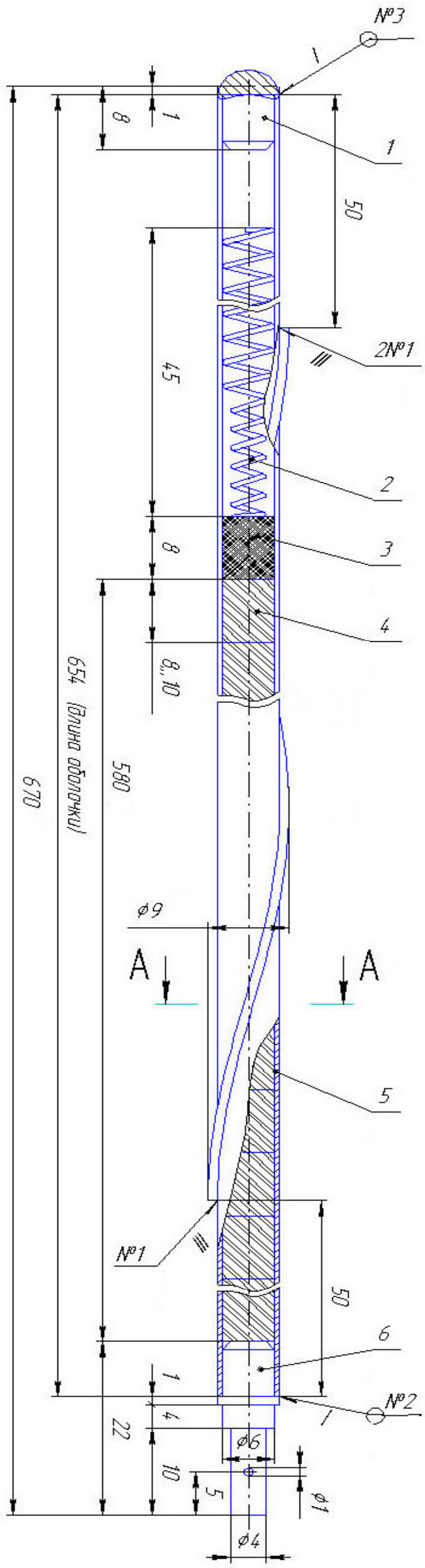
FE design is based on BN-600 FE. It is shown in Figure 4.

Operating conditions

- Maximum dose for constructional materials of fuel element – 0.25 dpa.
- Fuel maximum burn up – 0.1 % h.a.
- Maximum linear power of fuel element – 0.275 kW/cm.
- Maximum temperature of fuel element cladding – 150°C.
- Core coolant - dry, dust-free air.
- Maximum coolant temperature at core output - 125°C.
- Fixed resource of fuel element for operation of installation at nominal power (27 kW) – 10000 h.
- Fixed core lifetime of fuel element - 10 years.

Processing requirements for fuel element

- Uranium and plutonium feed powders, which are used for BN-600 MOX fuel fabrication.
- Constructional materials of standard BN-600 fuel elements.
- MOX fuel pellets fabrication at "Mayak".
- Fuel element fabrication at "Mayak".
- Fuel element quality control by "Mayak" control procedures and equipment.
- Components fabrication at MSZ JSC.



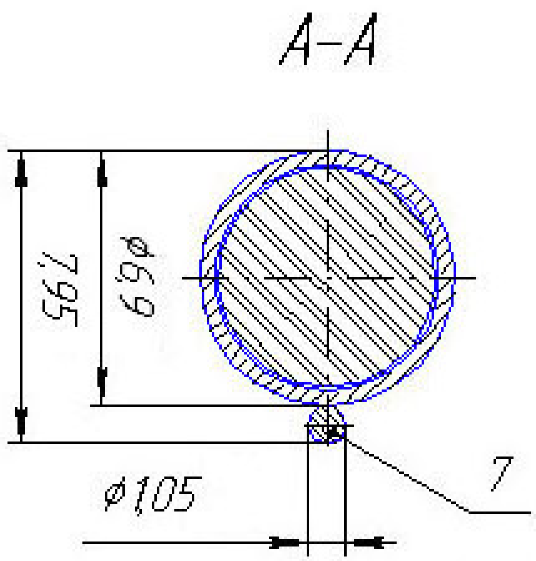


Figure 4. SAD FE: 1 – cap; 2 – lock; 3 – porous plug; 4 – fuel pellet; 5 – cladding; 6 – bottom end; 7 – positioning wire.

SAD fuel pellet

Table 9: SAD fuel properties

Mass share of U and Pu sum, %, not less	87,6
^{239}Pu conditional mass in Pu dioxide, %, not less	95,0
^{235}U conditional mass in U dioxide, % not more	0,7
Pu conditional mass share to U and Pu sum, %	30,0±0,3
Oxygen ratio	1,98
Density, g/cm^3	10,4±0,2
Impurities mass share, %, not more	
Aluminum	0,02
Calcium	0,02
Magnesium	0,02
Iron	0,03
Silicon	0,02
Nickel	0,02
Chromium	0,02
Nitrogen	0,01
Carbon	0,01
Fluorine + Chlorine	0,005
Grain size, µm, not more	70

Process flow sheet for SAD fuel pellets

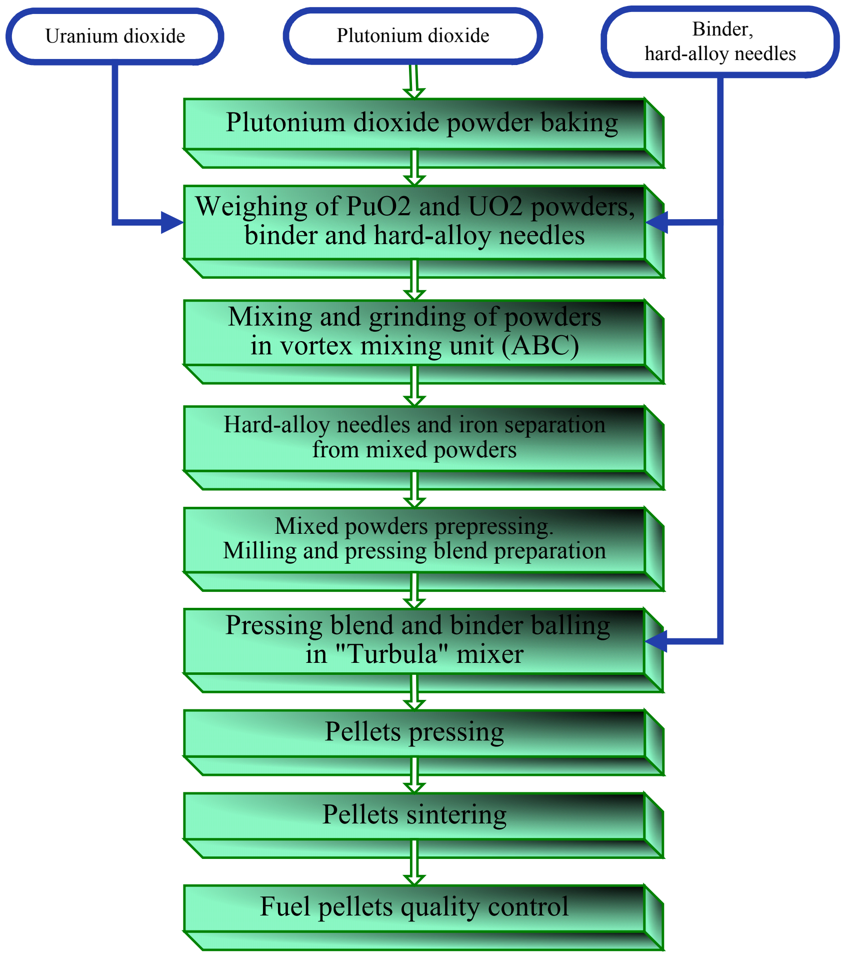


Figure 5. SAD fuel pellets manufacturing technology

Process flow sheet for SAD fuel pellets

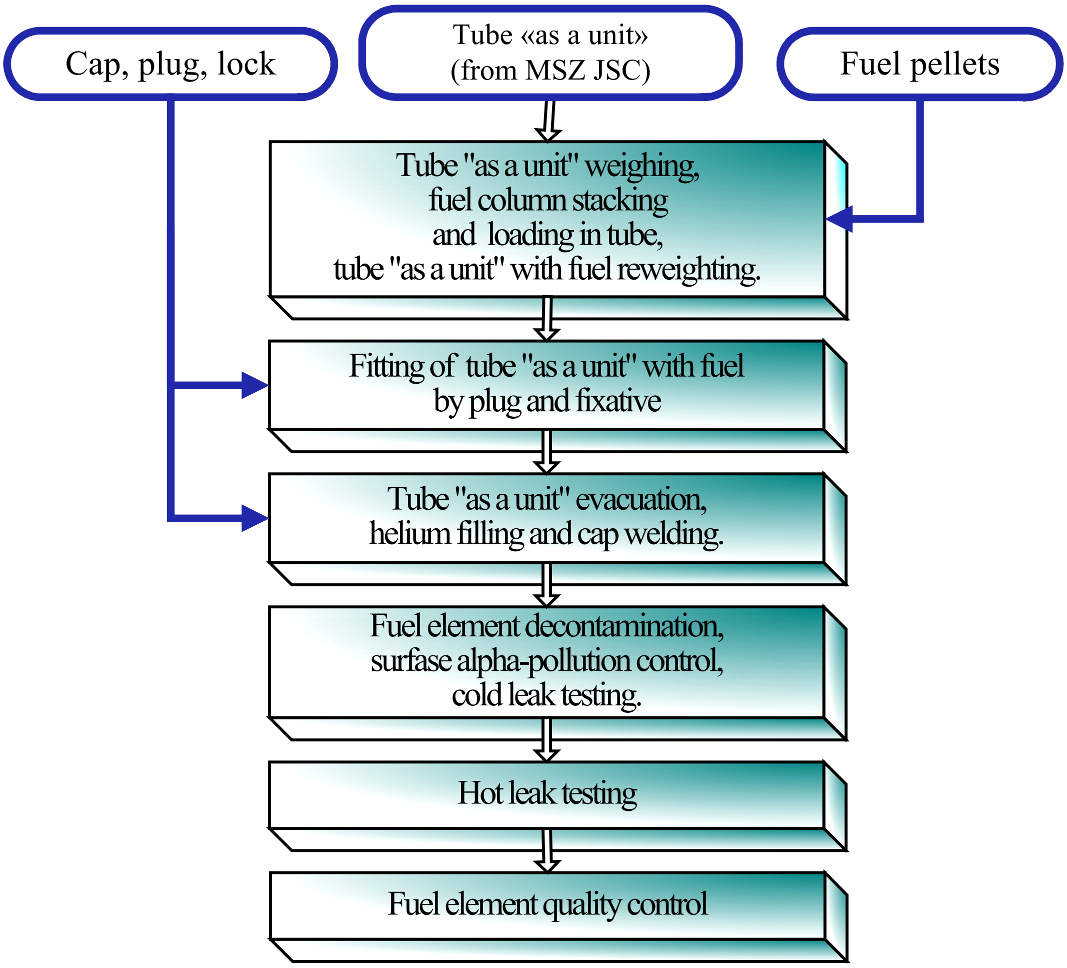


Figure 6. SAD fuel elements manufacturing technology

Subtasks 4.1 and 4.2 are completed.

Task 5 Production preparation, preproduction batch of fuel pellets manufacturing

Development of production technology of plutonium dioxide powders of ceramic quality

In accordance with Agreement # 2267 (Project SAD), the FGUP "PO Mayak" carried out works to obtain the powder PuO_2 of ceramic quality [1], including development out the filtering, drying and heating modes of plutonium oxalate. Plutonium oxalate was heated in a layer of 40-50 mm thick with air blow at the temperature of 600-750 °C during 6-8 hours.

Basing on the experimental operations done, the following heating mode of plutonium oxalate was proposed:

- heating temperature -750°C;
- heating time –6 hours;
- air volume discharge – 150 l/h.

To implement the whole SAD-program on the production of MOKS-fuel, about 250 kg of plutonium dioxide was produced.

Data, featuring the physical and chemical properties of the obtained PuO_2 powders were sent to the VNIINM and JINR. As a result of properties consideration at the VNIINM, the lots were singled out that fit, according to their composition, for the production of MOKS-fuel (Agreement Protocol of IA "Mayak" No.20-256 of April 1, 2004).

Investigation of physical and chemical properties of depleted uranium dioxide

Investigations on the possibility of usage of depleted uranium dioxide with exceeded storage period were carried out under laboratory conditions and at the installation "Paket".

Physical-chemical properties of the UO_2 powder were determined:

- specific surface – 4,0± 0,5 m^2/g;
- oxygen index – 2,10 ± 0,02;
- bulk density - 2,25 g/cm^3.

The powder humidity varies, depending on the season and, probably, on the package quality, in the range from 0,45 to 1,1 mass/ % .

Sintering ability test of depleted uranium powder was carried out, which showed a possibility of its use in the production technology of the MOKS-fuel.

Recommendations were given on recovery heating of depleted uranium dioxide available at the IA "Mayak" [2].

Laboratory examination of sinterability of the obtained plutonium dioxide powders with depleted uranium dioxide

The ability of obtained PuO_2 powders to be sintered with depleted uranium dioxide was checked under laboratory conditions. The density of the MOKS-fuel (UO_2 +30% PuO_2) pellets after sintering was equal to 10.3 g/cm^3 (Figure 7).

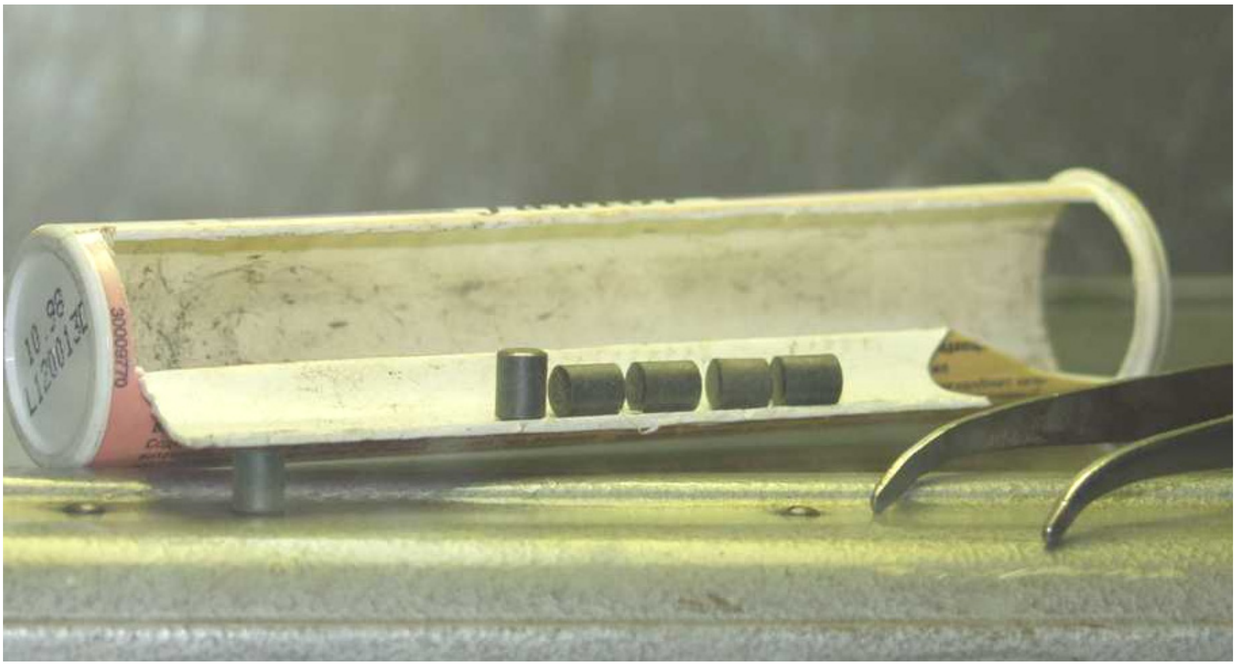


Figure 7. Control tests of the MOX fuel pellets.

The program [3] of carrying out experimental works on the production of MOKS-fuel pellets at the "Paket" installation for nuclear installation "SAD" was drawn up.

Factory preparation for the manufacture of an adjusting lot of MOKS-fuel pellets

To prepare the production facilities to the manufacture of MOKS-fuel, measures were arranged, where top-priority tasks on the preparation of installation "Paket" for MOKS-fuel manufacture were reflected.

Inasmuch as MOKS-fuel with plutonium enrichment of 30 mass % is supposed to be used in the nuclear installation "SAD" (earlier fuel with 25 mass % enrichment was manufactured), it became necessary to license the factory for a corresponding kind of activity. IA "Mayak" has prepared and submitted to GAN RF (Nuclear Supervision Agency) a request to obtain permission on MOKS-fuel production at the installation "Paket".

After presented documents have been considered by GAN, amendment No.1 of January 16, 2004 to the current license No. ГН-03-115-0890 was obtained.

Data on plans of works at the installation "Paket" were submitted to the department of Urals regional inspection and to Ozersk inspection of GAN (outgoing No. 20-855 of April 8, 2004, No.20-976 of April 4, 2004).

After consideration of submitted documents, permission was obtained to carry out experimental works (research works) on working through the production technology of MOKS-fuel at the installation "Paket".

A number of documents, submitted by the JINR, were considered and agreed upon:

a) Sub-agreement on the Project No.2267 between JINR and FGUP "IA Mayak";
b) Protocol on distribution of responsibility zones between organizations participating in the SAD project;
c) Requirements specification.

Remarks were issued on specification design for MOKS-fuel pellet and technical assignment design (fuel element for installation SAD).

Depleted plutonium dioxide with the exceeded storage period was retested for compliance with Technical Conditions 95.213-80.

Design documentation for press-tools and technological rigging was developed, pre-production models were manufactured.

Primary tests of press-tools and experimental operations on manufacture of MOKS-fuel pellets were carried out.

Subtasks 5.1, 5.2 and 5.3 are completed.

Task 6 Design and development of the subcritical assembly (SA)

SAD design

Preliminary SAD active core design was developed. Results are presented in the document "Initial technical data for General Designer", issued by NIKIET in May 2004 in accordance with project time-schedule. SAD core and auxiliary components are shown in Figure 8.

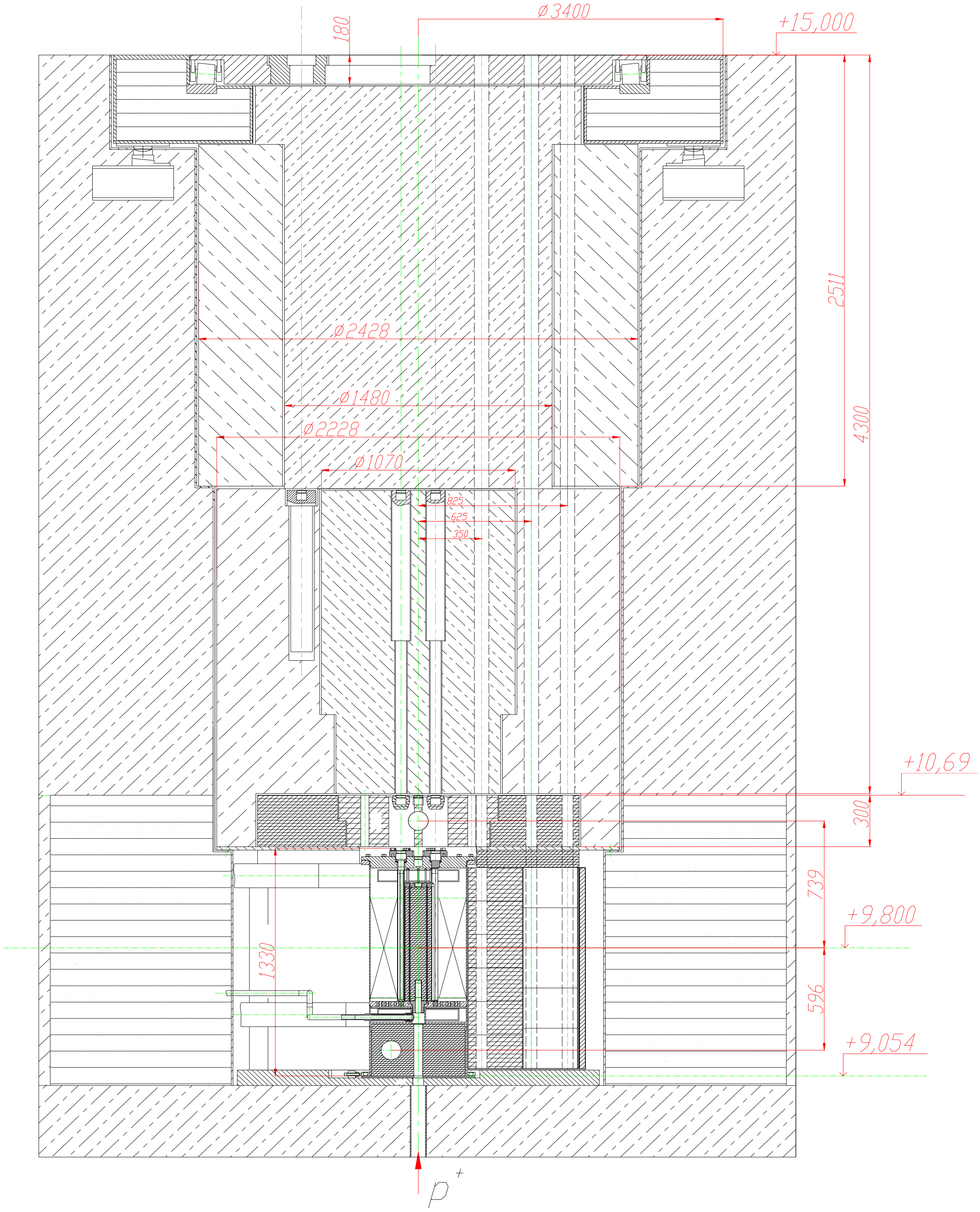


Figure 8. Preliminary design drawing of the active core and main units.

SAD technical specification

Target

Material – lead.
Height – 60 cm.
Weight – 150 kg.

Core

The sub-critical blanket of SAD (Figure 9) is placed within a biological shielding, which is made of heavy concrete and placed in radial and top directions from the active core (AC). Pipes are foreseen in the shielding blocks to provide the allocation of the cooling loops for the target, the core, the experimental channels (vertical and horizontal), the power control channels, the proton guide etc. The upper part of the biological shielding will provide access to the blanket and to the experimental channels during fuel loading/reloading operations and to experiments with detectors and samples.

The SAD core consists of 141 fuel assemblies; each assembly by itself combines 18 fuel pins, separated by wire spacers, and welded onto the cladding tube in helical manner. The fuel assembly does not have sidewalls, but only lower and top frames where the FE are fixed. A central supporting rod made of stainless steel achieves the integrity.
The low specific energy release in the system allows the usage of air-cooling, both for the target and for the active core.

The core design parameters are listed in Table 10.

Table 10: SAD core design parameters

System	Parameter	Value
Target *	Number of elements	19 hexagonal prisms
	Material	Lead
	Pitch, mm	36
	Spacing between prisms, mm	1.5
	Height, cm	60
Active Core	Number of fuel assemblies	141
	Number of fuel elements per one assembly	18
	Fuel density, g/cm^3	10.2
	Plutonium dioxide content in the fuel composition, %(mass)	29.5
	^{235}U content in U, %(mass)	0.4
Fuel element	Pitch, mm	7.95
	Clad tube diameter, mm	6.9
	Clad tube thickness, mm	0.4
	Fuel pellet diameter, mm	5.95
	Fuel height, cm	58

* Specification of the first target. It will be exchangeable for investigations of different dimensions and materials

The first target assembly consists of a set of hexagonal lead prisms with air-cooling of the central 7 prisms. Other materials than lead and other dimensions will be used for the target in the course of the SAD experimental program.

$K_{eff} = 0.95$ is achieved at loading 133 FA. 8 FA cells are filled with lead prisms.

On the basis of the data, listed above, preliminary neutron spectra in experimental channels were calculated with MCNP. Neutron flux density is on the level of $10^{11} \div 10^{12}$ n/cm^2s with maximum at 0.6 – 1.0 MeV.

Reflector

The active core is surrounded by a lead reflector of 60 cm thickness in radial direction and of 20 cm in axial direction at the top and at the bottom. The lead density is 11.15 g/cm^3. A B_4C layer of 3 cm thickness to reduce the number of low energy neutrons in the concrete is located between the lead reflector and the concrete shielding in radial direction.

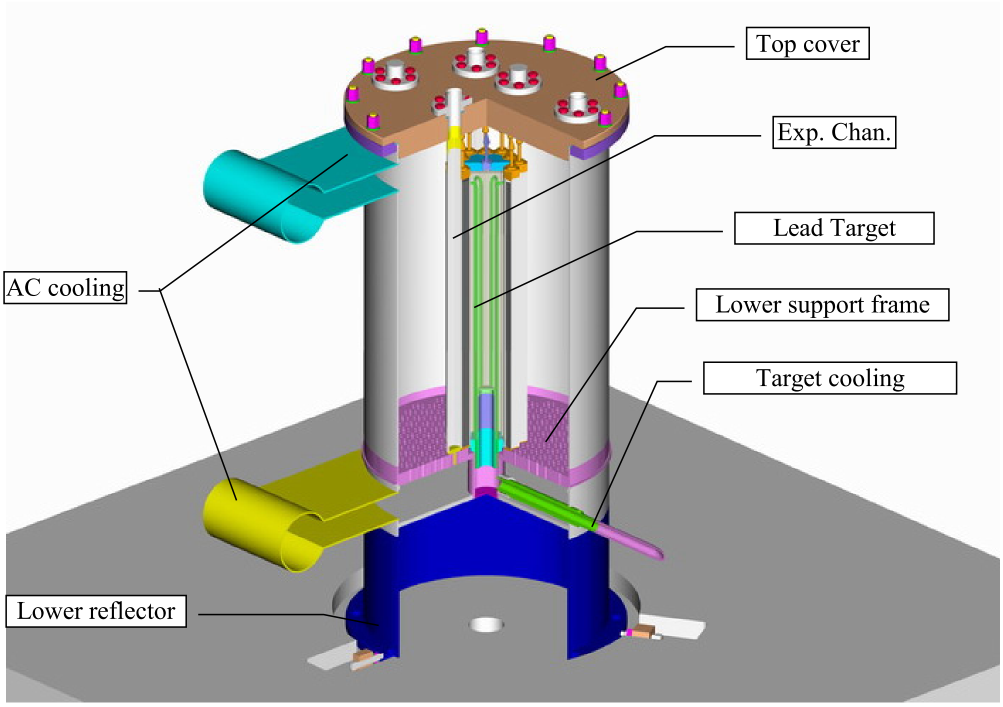


Figure 9. SAD core section (fuel cassettes and reflectors not shown)

Lead chemical composition is given in Table 11.

Table 11. C1 lead chemical composition

Element	%
Pb	99.985
Ag	0.001
Cu	0.001
Zn	0.001
Bi	0.006
As	0.0005
Sn	0.0005
Sb	0.001
Fe	0.001
Mg+Ca+Na	0.002
Total admixtures	0.015

Cooling system

Core cooling system parameters are listed in Table 12

Table 12. Core cooling system technical requirements.

Parameter	Value
Thermal power, kW	27.4
Coolant	Dry air
Coolant flow direction	Top-down
Coolant inlet temperature, °C	50
Coolant outlet temperature, °C	96
Coolant consumption, kg/s	0.6
Coolant average velocity, m/s	10
Coolant pressure, MPa	0.12 (absolute)
Pressure loss, kPa	
Inlet	1.6

Core	2.1
Outlet	0.9

Lead target cooling system parameters are listed in Table 13

Table 13. Lead target cooling system technical requirements.

Parameter	Value
Material	Pb
Thermal power, kW	0.5
Coolant	Dry air
Coolant inlet temperature, °C	50
Coolant outlet temperature, °C	125
Coolant consumption, kg/s	0.0067
Coolant velocity, m/s	50
Pressure loss, kPa	20

Two versions of the cooling system were developed: unified and separate for core and target. Final choice will be done by General Designer (GSPI) after equipment selection.

General safety assessment

SAD Installation is intended for carrying out of the experimental researches. It contains fissile materials, the structure and geometry of the installation provides attenuation of chain fission reaction in absence of external sources of neutrons.

Main safety principles

- In all design modes of operation, including works on service of an active core and a target and emergency operations, nuclear accident should be excluded;
- In all conditions and design modes of operation, including service of an active core and a target and emergency operations doses for personal, population and environment should not exceed established by norms and rules of Russian Federation and to be at reasonably achievable low level.

Main safety criteria

- Established by the installation project subcriticality level in all design modes should be more than 4 %, and at any design accidents more than 2 %;
- Absence of the untight FE in active core in the operation of the installation.

The first criterion is provided with sequential initial loading of the core, established subcriticality level makes ~ 5 % is ensured by permanent control of the level of average power of the core, and also design and circuitry of the installation.

The second criterion is provided with FE design (FE designer – VNIINM), FA and core design (FA & core designer – NIKIET); permanent control of tightness of the FE and cooling system parameters.

Subtasks 6.1 and 6.2 are completed.

Task 7 Civil engineering solutions on installation creation and allocation

General Solutions for the Facility Allocation

Preliminary technical and economical estimations, made during the ISTC proposal preparation, showed that the SAD facility should be located in a new building that has to be constructed in the free area between the existing accelerator building and existing outhouses (Figure 10).

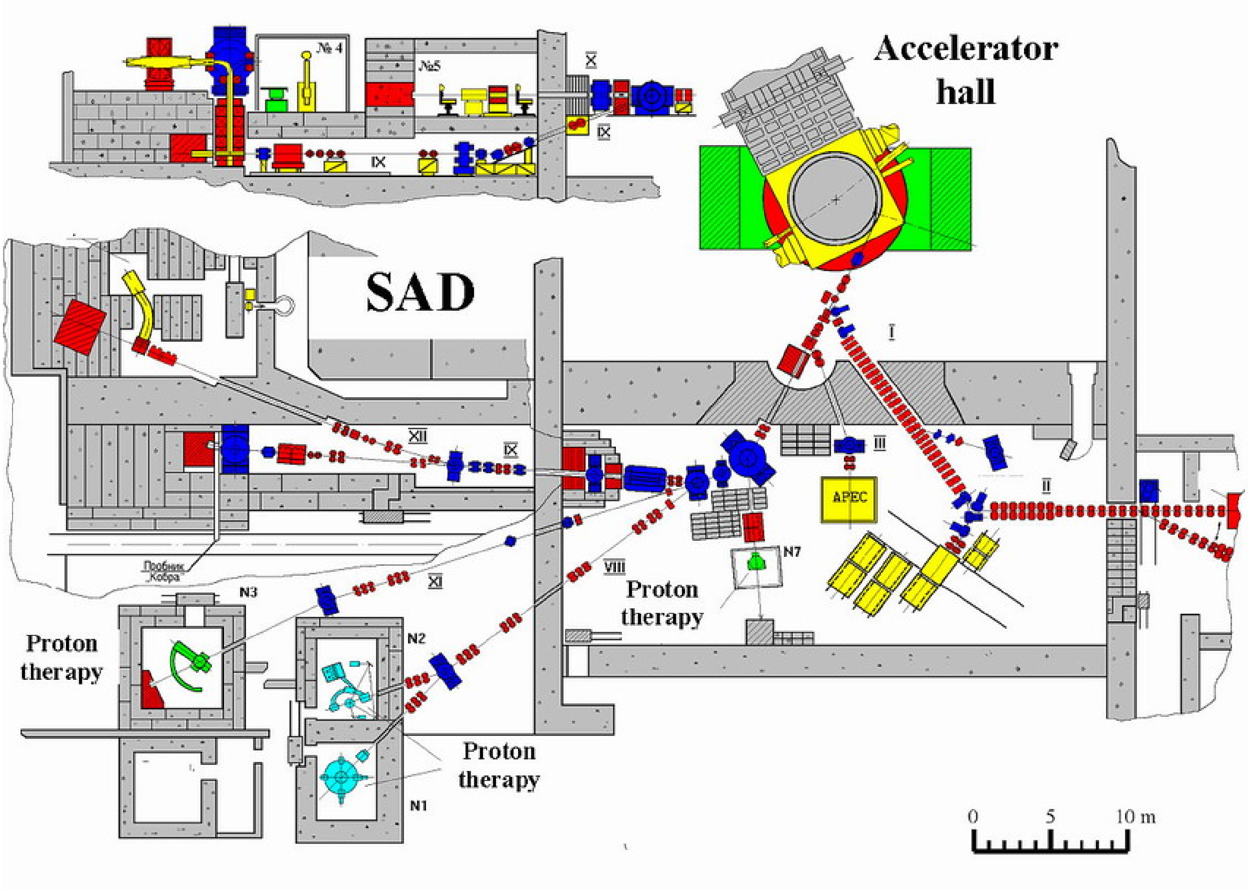


Figure 10. General plan view of the JINR "Phasotron" accelerator complex (in the left upper corner side view of the neutron/meson therapy complex).

The general layout of the installation guides the proton beam injection from the bottom of the installation after a 110 degrees turn with strong bending magnets. So the proton beam heats the target from below and it is necessary to have a rather thick beam stop in the forward i.e. top direction. The biological shielding properties will be determined by the highest neutron energy.

The horizontal beam coming from the PHASOTRON is first deflected 20 degrees downwards inside the accelerator hall, then turns 110° in the SAD building and hits the spallation target, located inside the fuel blanket from below. This construction allows avoiding safety problems with possible water ingress accidents, which would exist in the case of beam injection from the upper side and with the cooling water of the bending magnets above the sub-critical core (Figure 11).

Main parameters of the SAD building are listed in the Table 14

Table 14. SAD building qualitative characteristics.

Parameter	Value
Site area, m^2	350
Total area, m^2	950
Building volume, m^3	8300
Bulk concrete volume, m^3 (biological shielding)	1900
Steel shielding, ton	290
Bulk heavy concrete volume, m^3 (ρ = 3.6 and 4.5)	25
Soil shielding volume, m^3	2000
Excavated soil volume, m^3	4000
Concrete retaining wall necessary to dismount, m^3	350

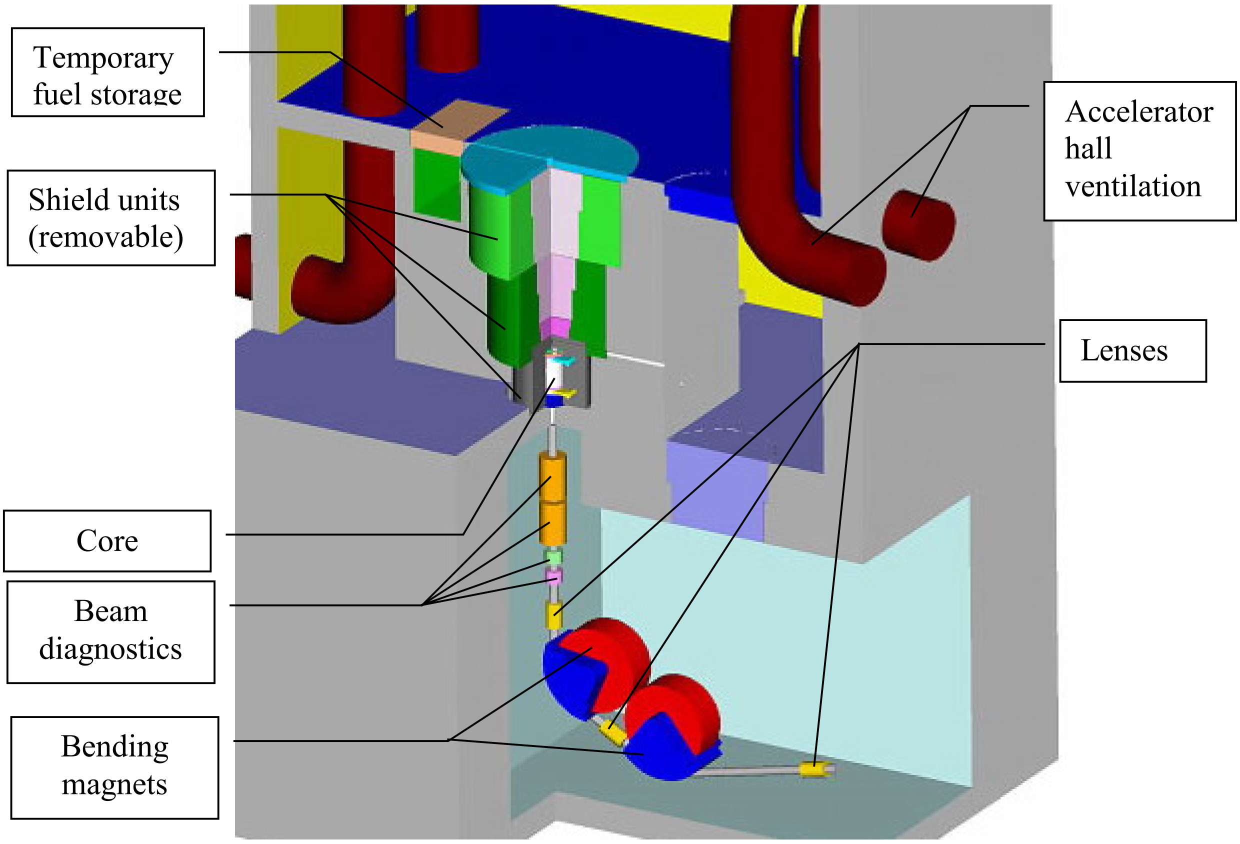


Figure 11. SAD building general layouts: total volume of concrete shielding is about 3000 m^3, weight of the steel shielding about 1000 tons

Current work

Task 2 SAD parameters modeling

First priority subtasks **2.3**; **2.6** and **2.7** on numerical simulation of the neutron spectra in SAD building and induced activity calculation now are in progress.

Task 3 Design and development of the beam transport line

Technical project of the SAD beam line is underway (subtask **3.2**). All activity goes according to the schedule.

Task 4 Design and development of the SAD fuel elements

Technical project of the SAD FE (subtask **4.3**) and working documentation on FE (subtask **4.4**) development is in progress. All activity goes according to the schedule.

Task 5 Production preparation, preproduction batch of fuel pellets manufacturing

Factory preparation for the manufacture of the preproduction batch of MOKS-fuel pellets (subtask **5.5**) goes ahead of schedule.

Task 6 Design and development of the subcritical assembly (SA)

Subtask **6.3** is underway; work goes according to the schedule.

Task 7 Civil engineering solutions on installation creation and allocation

Development of a preliminary general layout of the SAD building (subtask 7.4) is underway. Work goes according to the schedule.

Conclusion

During the first two quarters of the ISTC project #2267 realization significant progress was achieved in all tasks of the project.

All activities went according to the schedule or ahead of. Five organizations – project participants have demonstrated good cooperation and effective management.

All necessary paperwork was completed according to the time schedule.

References:

[1] Works program on PuO_2 powder production at the plant RT: FGUP"PO Mayak"; A.I. Bobylev, I.V. Minakov. – No.ЦЛ/3904 of October 7, 2002;

[2] Recommendations on uranium preparation for MOKS-fuel production: Recommendations/ FGUP " IA Mayak"; A.I. Bobylev, I.V. Minakov. – .ЦЛ/1732. – Ozersk, 2004;

[3] Experimental works program on manufacture of fuel kernels from the MOKS-fuel for JINR, Dubna (Project SAD): FGUP " IA Mayak"; A.I. Bobylev, I.V. Minakov. – No.ЦЛ/295 of February 9, 2004;

f) Dynamics experiments

Assessment of possibilities to do dynamics experiments in SAD

- **Why dynamics experiments in SAD?**

  Increasing interest in dynamics behavior of ADS

  - MUSE, TRADE experiments
  - Cacuci paper Physor 2002, Seoul (planned PhD work)

- **Example: shut-on beam on cold core**
  - Fuel temperature 300 → 400..500K
  - Reactivity feedback
    - Doppler
    - Expansion

- **First analysis promising, but results not yet conclusive**

g) CIEMAT proposal

After meeting communication: CIEMAT proposal for SAD reactor

Proposals for SAD reactor. Enrique Gonzalez. CIEMAT. July 23rd, 2004.

Recommendations for the beam entrance hole:
Hypothesis: Maximum beam diameter = 3cm.
The optimal diameter is 7 cm.
The minimum diameter is 5 cm.

MCNPX predicts non linear and non symmetric small effects of the beam displacements.
If the beam is moved in X direction, keeping the beam parallel to the target axis, for a parabolic beam of 2.5 cm diameter in a 7 cm hole,
changes of +1.0, +2.0, -1.4, +1.2% in the total neutron production are observed for displacements of –2.2 –1 +1 +2.2 cm.
The changes on the counting rates of detectors however are quite different depending on the detector position.
For a detector in the central core exp. channel the changes are –5.8, -5.1, -0.4, +3.4% respectively
For a detector in the middle core exp. channel the changes are +8.1, +10.3, -1.3, +0.3% respectively
For a detector in the external core exp. channel the changes are +1.4, +2.4, -1.7, +0.9% respectively

Note that same displacements on X and Y are not equivalent !!

Requirements for the experimental channel actuators:
Hypothesis: There are 3 in-core vertical, 3 out-core vertical and 2? out-core horizontal experimental channels

The optimal requirements:
All the experimental channels (8) have actuators able to position samples and detectors with a resolution of 1 mm. Range of movements larger than 1 meter for all actuators.
The actuators in the central and middle core exper. vertical channels are able to move a 51 cm long x 3 cm diameter B4C control rod 51 cm in less than 2 seconds. Programmable speed curves during movement from 25cm/s to 1cm/s, in positive and negative ways, should be possible.
No special requirements for the mass and speeds on the other channels, but at least masses of up to 200 grams and times of less than 5 minutes for 100 cm should be acceptable.

The minimum requirements:
The 3 in-core vertical, 2 out-core vertical and 1 (top) horizontal experimental channels (6 in total) have actuators able to position samples and detectors with a resolution of 5 mm, with reproducibility of 1 mm. Range of movements larger than 1 meter for all actuators.
The actuator in the central core exper. vertical channel is able to move a 51 cm long x 3 cm diameter B4C control rod 51 cm in less than 2 seconds, in the 2 ways. Only one speed is possible.
The actuator in the middle core exper. vertical channel is able to move a 51 cm long x 3 cm diameter B4C control rod 51 cm but only at low speed.
No special requirements for the mass and speeds on the other channels, but at least masses of up to 200 grams and times of less than 5 minutes for 100 cm should be acceptable.

The motivation for the requirements:
The experiments will require to perform measurements at different positions in all experimental channels in fast sequences, both for electronic detectors and for sample irradiations. Similarly it will be needed to perform measurements with radioactive neutron sources in different positions of the 3 in-core channels and 2 out-core vertical channels.
Fast reactivity (positive/negative) insertions by movements of a B4C rod in the central in-core vertical channel allow to simulate reactivity feedbacks. The movement of a B4C rod in the middle in-core vertical channel allow to simulate the hypothetical control system reaction.
B4C rods are experimental devices and they do not form part of the safety or control system of SAD.