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The subcritical assembly at Dubna (SAD): coupling all major components of an accelerator driven system (ADS) for nuclear waste incineration

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SAD Project Objectives

- Coupling all major components of ADS;
- Core design, safety assessment, licensing;
- k_{eff} control and monitoring;
- Shielding from high energy neutrons;
- Experiments on core neutronics, reactivity feedbacks, transmutation reaction rates

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SAD Basic Data

k_{eff}	~0,95
Fuel loading	< 420 kg
Fission power	27,6 kW
Cooling	air
Core	
Coolant flow rate, G	~ 0,6 kg/s
velocity, v	10 m/s
Presure, P *(inlet)*	0,12-0,135 MPa
Temperature, T *(inlet, outlet)*	50/96 ºC
Target (Pb)	
Coolant flow rate, G	~ 0,0067 kg/s
Velocity, v	50 m/s
Pressure, P *(inlet)*	0,12-0,135 MPa
Temperature, T *(inlet, outlet)*	50/125 ºC

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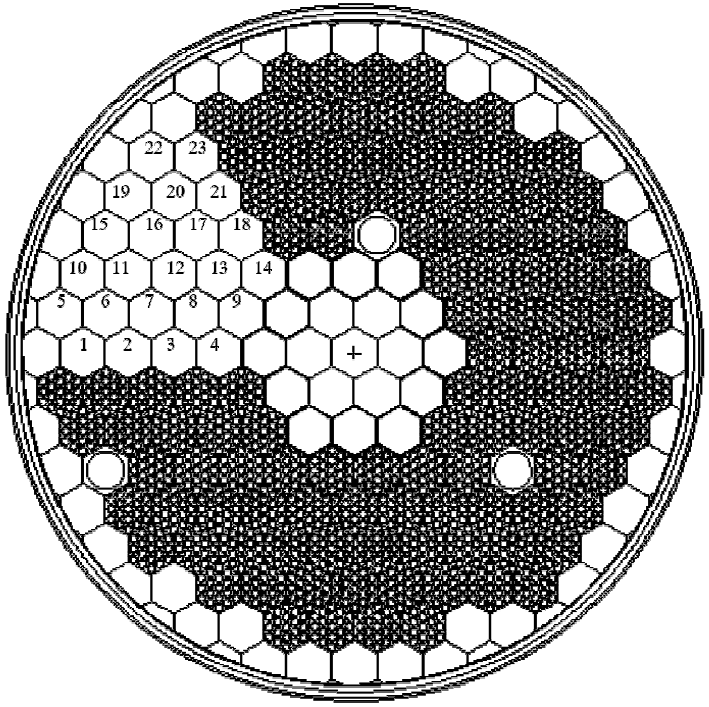
Subcritical Blanket/calculations



Number of cells for FAs	141
Number of loaded FAs	134
Number of loaded Pb prisms	7
fuel loading (UO_2-PuO_2)	396,9 kg
density of fuel	10,2 g/cm^3
PuO_2 content in fuel	29,5 % (w.)
U enrichment	0,7 % (^{235}U)
Height of fuel	58 cm

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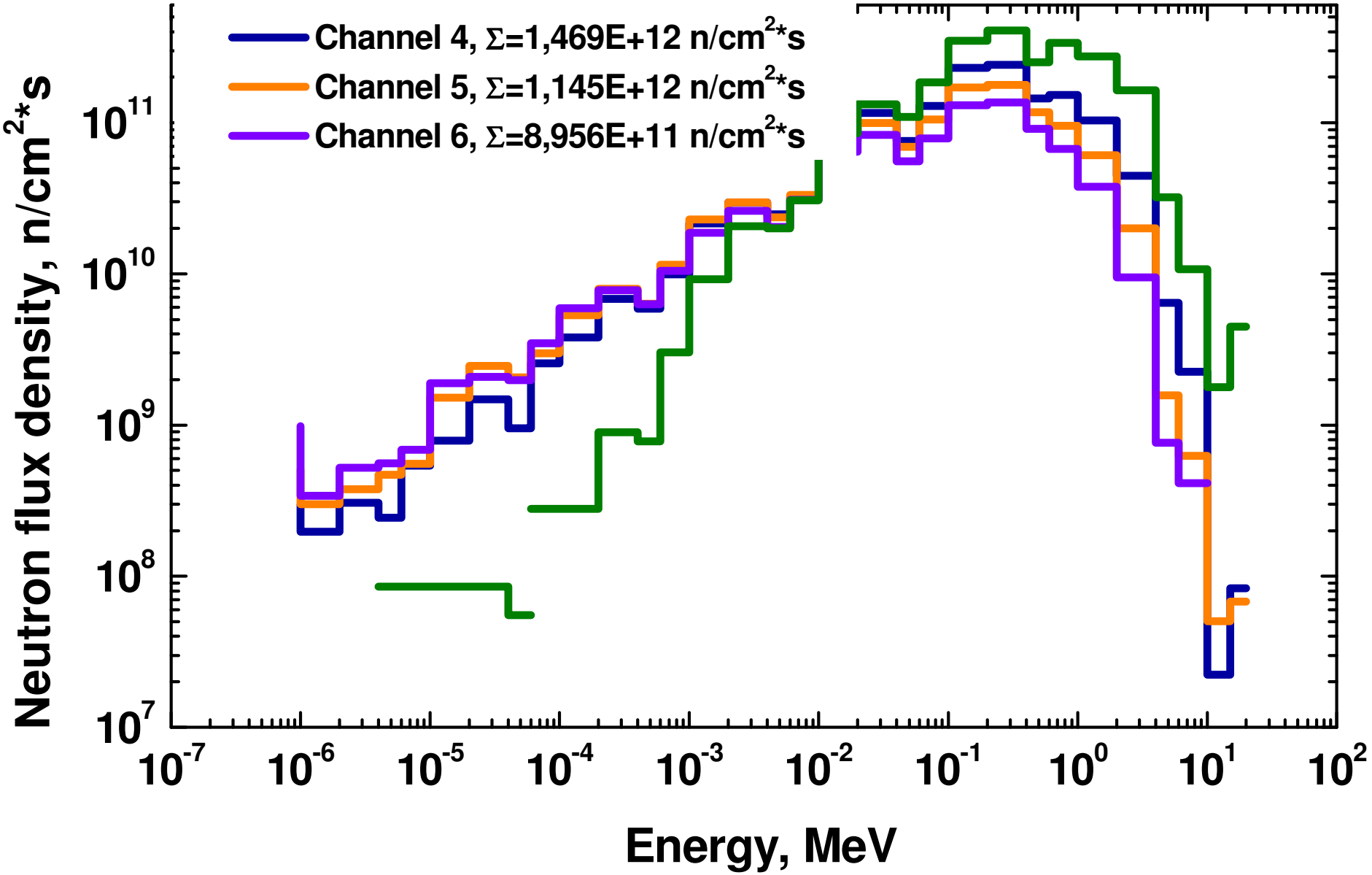
Subcritical Blanket/calculations



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Subcritical Blanket/ neutronics

Calculated K_{eff}	0.9515
Neutron lifetime	$2.4 \cdot 10^{-5}$ s
Fission power	**27.6 kW**
Averaged neutron flux	**$1.7 \cdot 10^{12}$ 1/(cm^2·s)**
Peak factor of heat generation (height)	1.21
Heat generation in SAD parts:	
Fuel	25.96 kW
Target (neutron and photon from fissions)	97.3 W
Core cladding	204.3 W
Side Pb reflector	565.4 W
B_4C	204.6 W
Concrete	771.1 W
Pu decay	~250 W
Fuel	
Max power density	**18 W/cm^3**
Max flux of fast neutrons (E> 0,1 MeV)	$2.4 \cdot 10^{12}$ 1/(cm^2·s)
Max fluence of fast neutrons	$8.0 \cdot 10^{19}$ 1/cm^2

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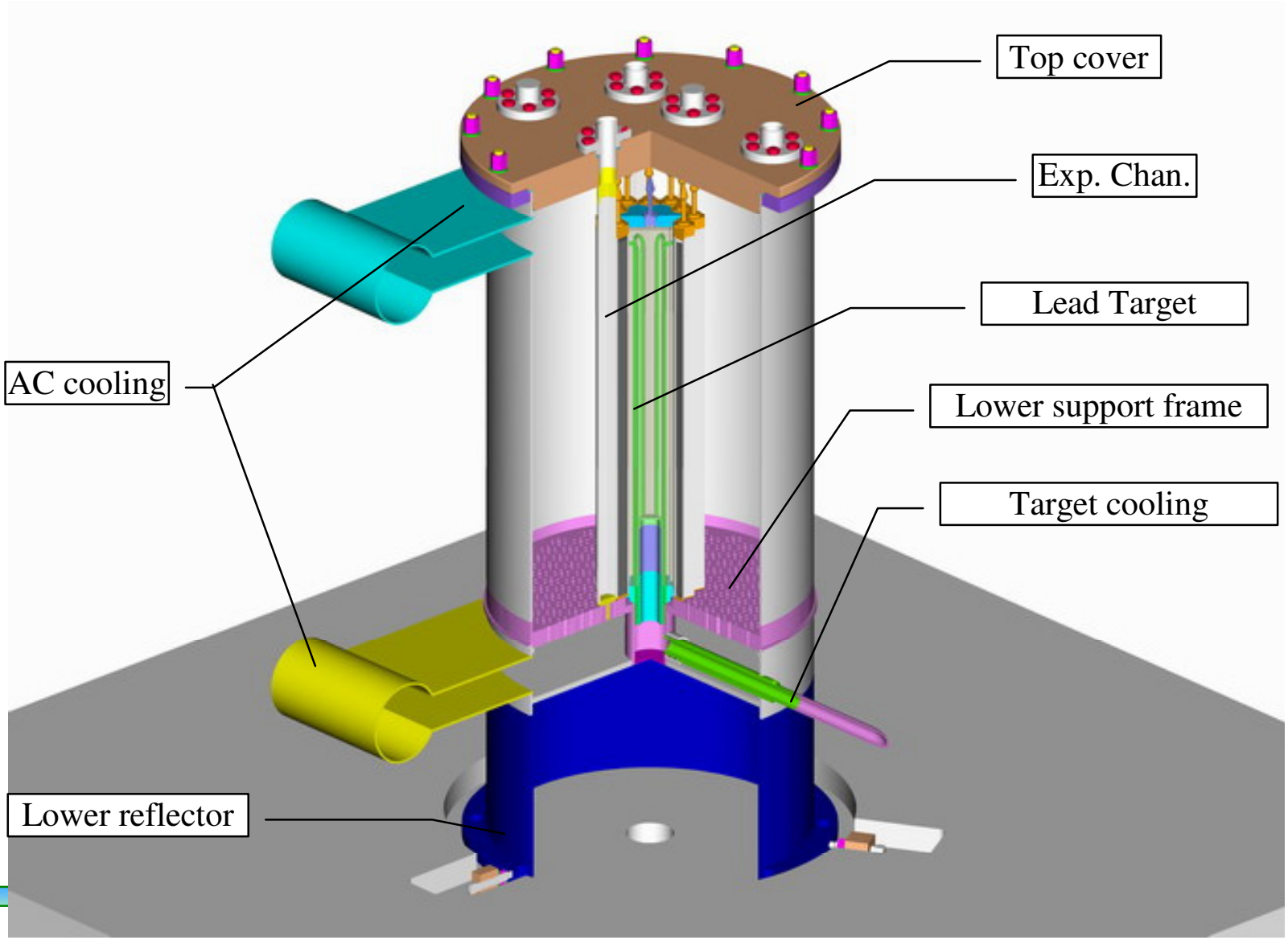
Subcritical Blanket/design



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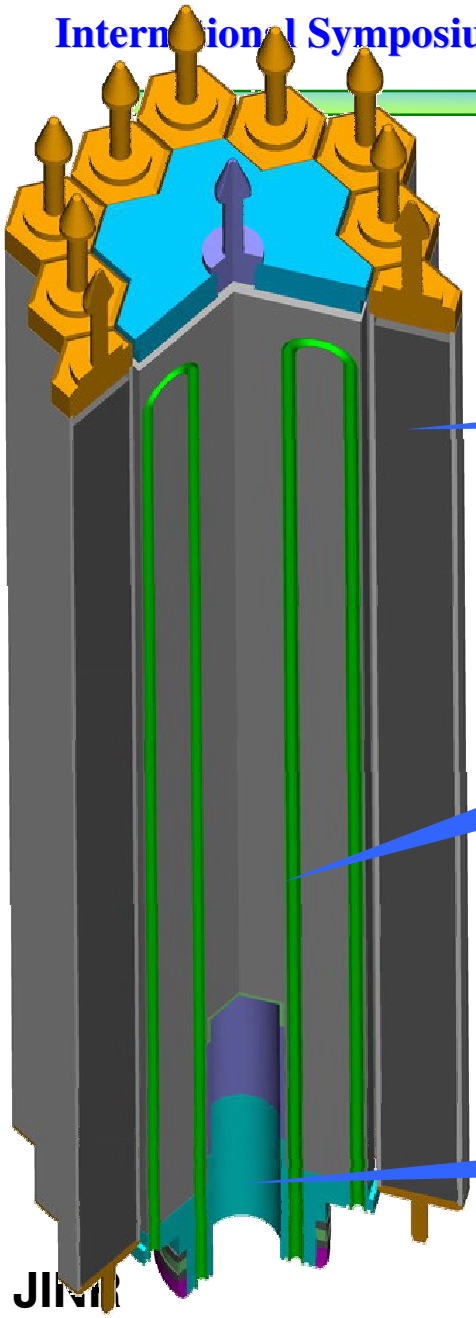
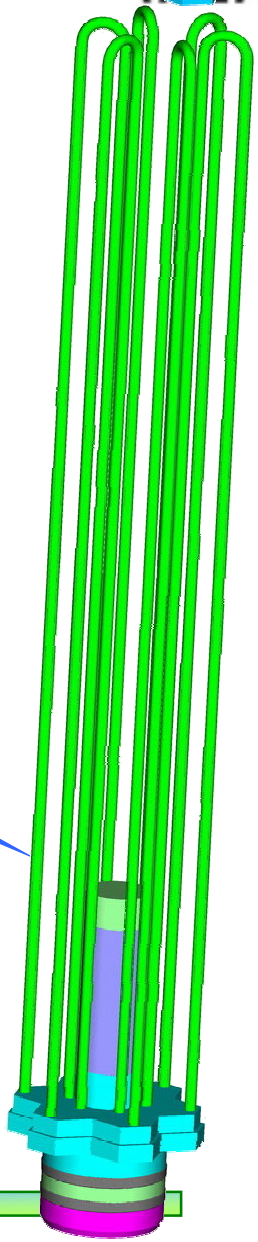
Target/design



Lead Prisms

Air Channels

Beam Input



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Target/neutronics

Proton beam

Energy	660 MeV
Beam power	1 kW

Target

neutron generation	12.95 n/p
total neutron leakage from target	12.73 n/p
side neutron leakage from target	12.22 n/p
total energy of leakage neutrons	103.2 MeV/p
total heat generation	840 W
neutron source for blanket	$1.143 \cdot 10^{14}$ n/s

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Phasotron Accelerator

Charged particles accelerated	Protons
Accelerator Type (linac, circular)	Circular (Phasotron)
Main accelerator sections and type of structures	180degree Dee
Source type	Internal, PIG type
Source Extraction voltage	Dee RF Voltage,40kV
RF system (amplifier characteristics)	Autogenerator,18.6-14.4MHz, 300kW
Magnet system (type, size, rigidity, homogeneity)	H-type, 6m pole diameter, 4spiral magnetic field 1.2T(r=0m) 1.63T(r=2.7m) average field, 0.3T(r=2.7m) 4^{th} harmonic
Magnet Power Supply characteristics (current, stability, ramping, …)	4000A, 0.05%stability
Total Power consumption	700kW
Cooling System	Distilled water cooling

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Beam Characteristics	
RF structure (RF frequency, phase width)	14.4MHz, 50degree
Macro pulse structure (filling of RF pulses)	250Hz rate, 20 mks FWHM
Long duration Beam Pulse characteristics (duty cycle, …)	0.5%duty
Final beam energy	659MeV
Beam energy spread and stability	3.1MeV
Final beam intensity (average, peak)	3.2 mkA average, about 1mA peak
Beam intensity stability	About 2%
Beam emittance at the high energy end	5.1pi*cm*mrad (horizontal), 3.4pi*cm*mrad (vertical)

Possibility to shorten the pulse width down to 1 mks is under investigation

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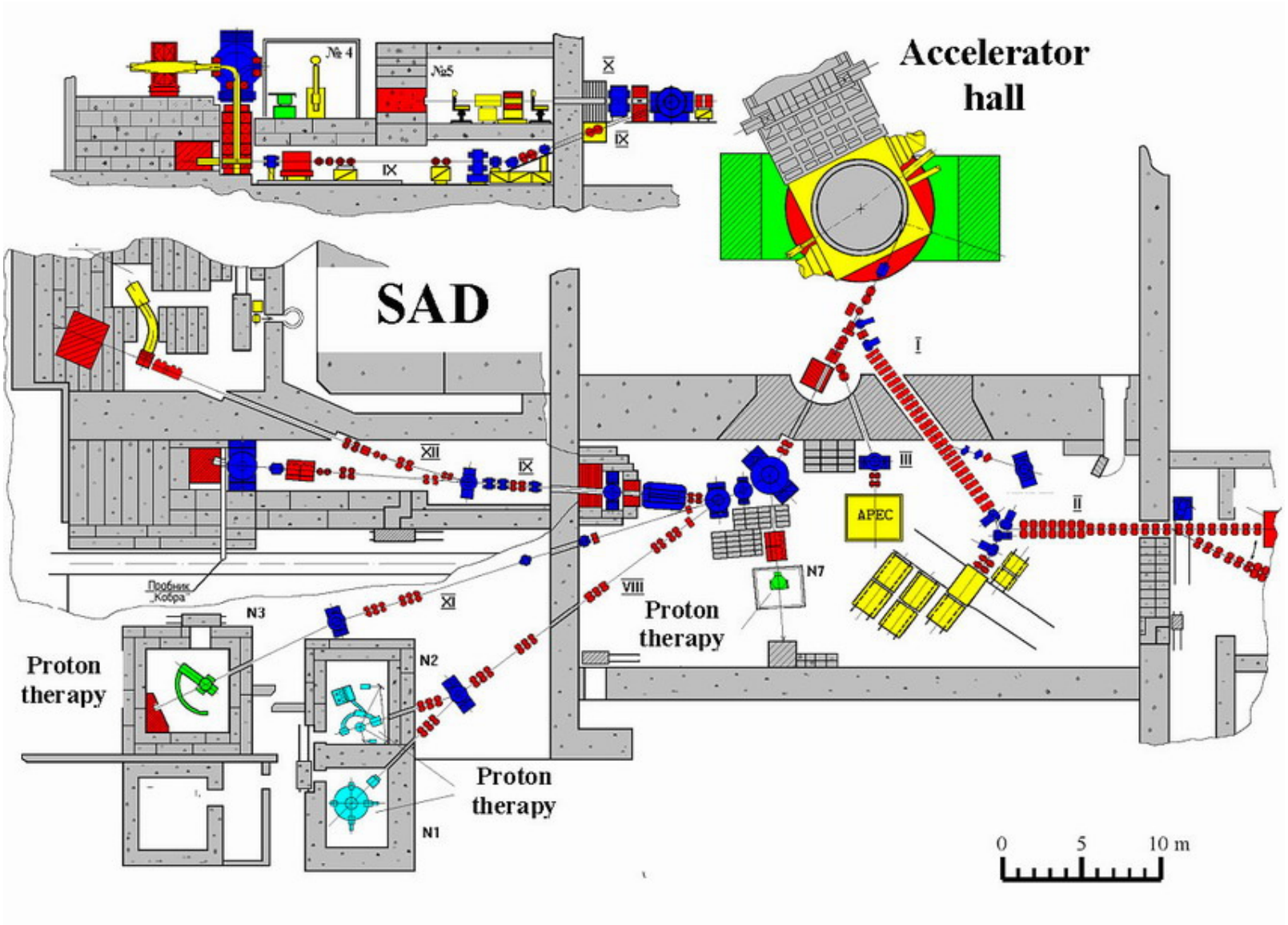
Accelerator hall
SAD
№ 4
№5
X
IX
XII
IX
I
III
II
APEC
N7
VIII
Proton therapy
XI
N3
N2
N1
Proton therapy
Proton therapy
Пробник „Кобра"
0
5
10 m

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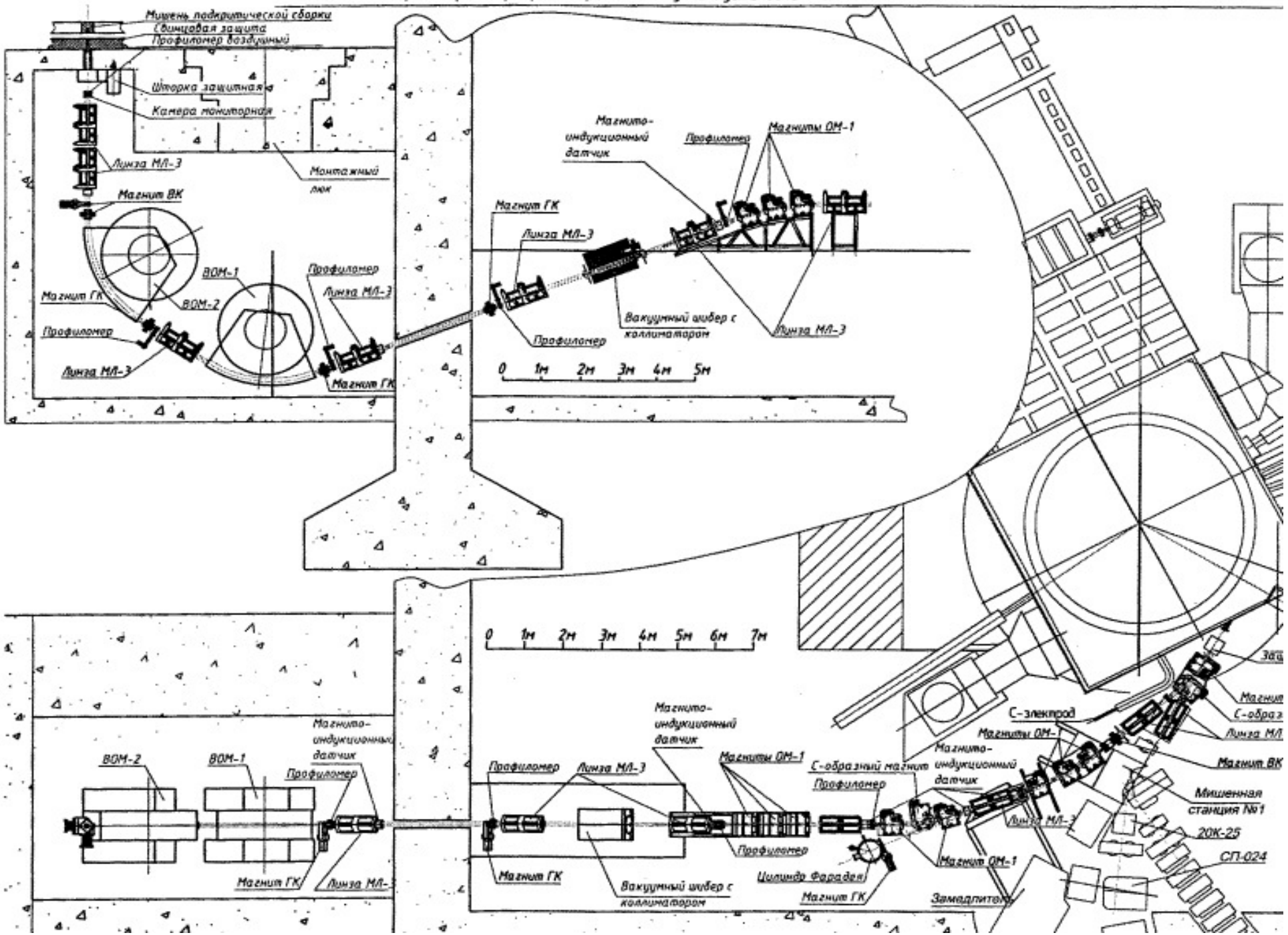
Тракт транспортировки протонного пучка к установке SAD



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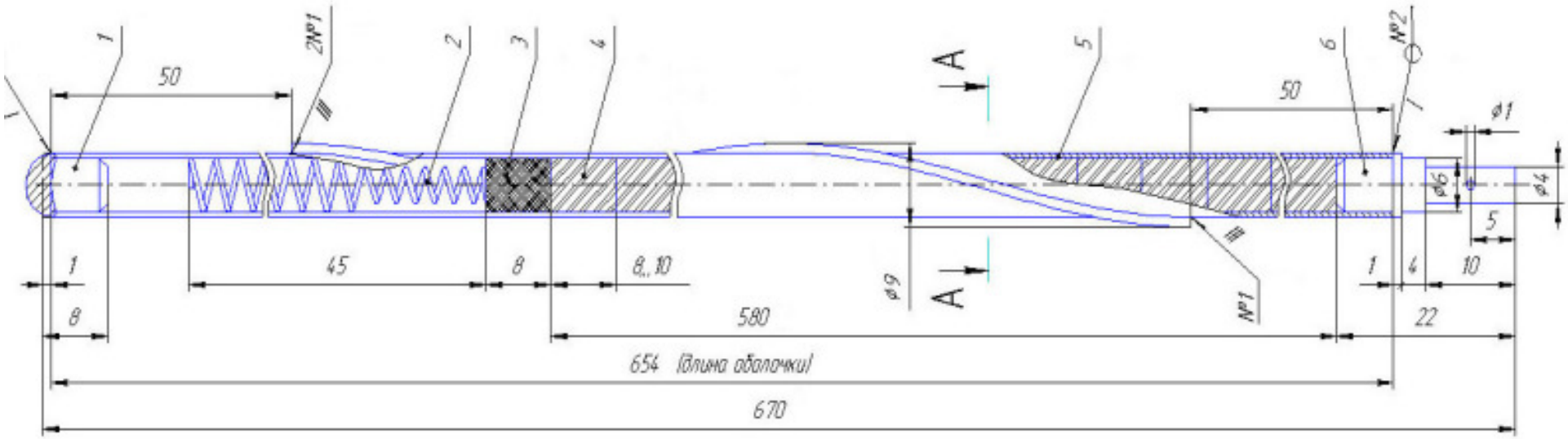
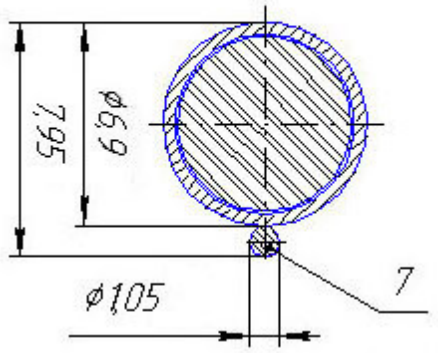
FE design



A–A



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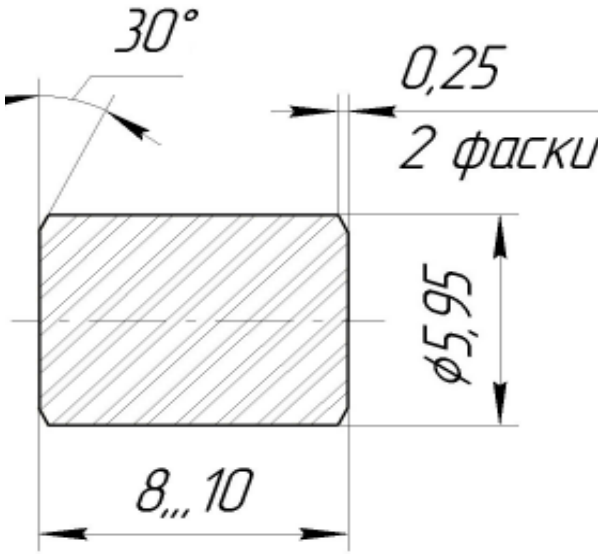
Fuel pellet

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/sm^3	10.4±0.2
Impurities mass share, %, not more	
Aluminium	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



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Pellets parameters control

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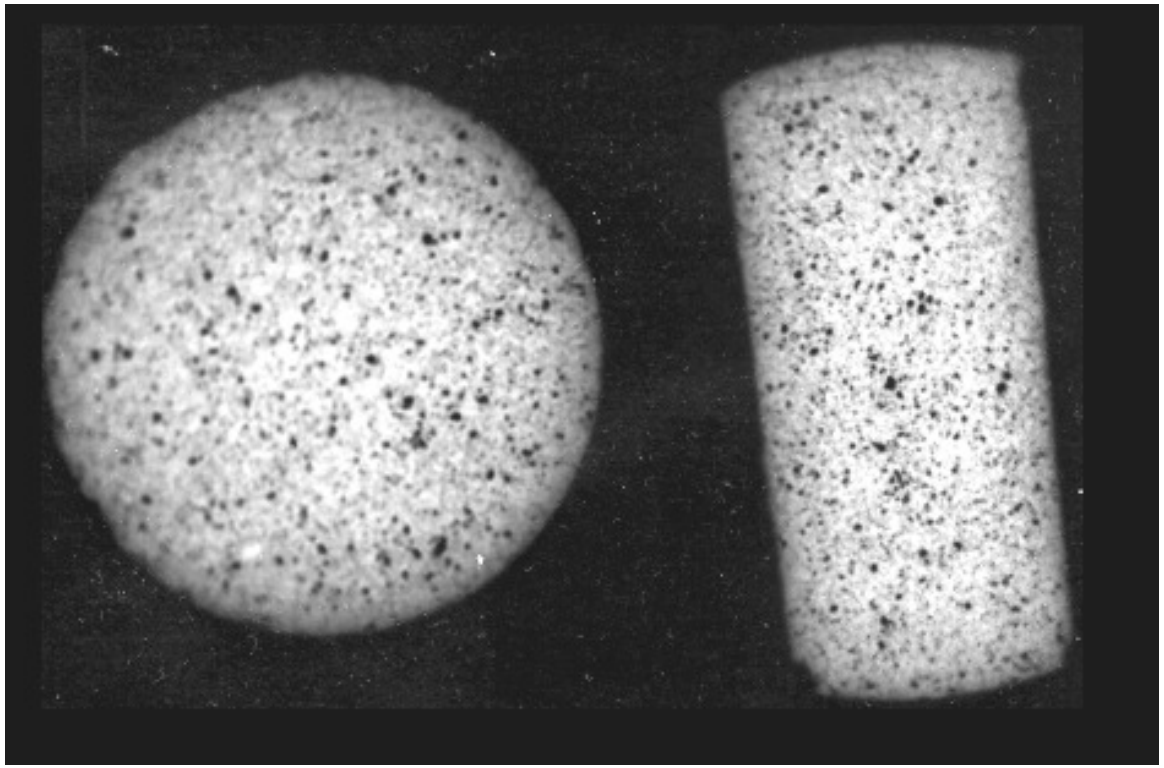
Pu distribution homogeneity study



α-radiography

Pu zones less than 100 mkm in diameter

Pu zones area less than 10% of microsection area

No Pu zones observed here

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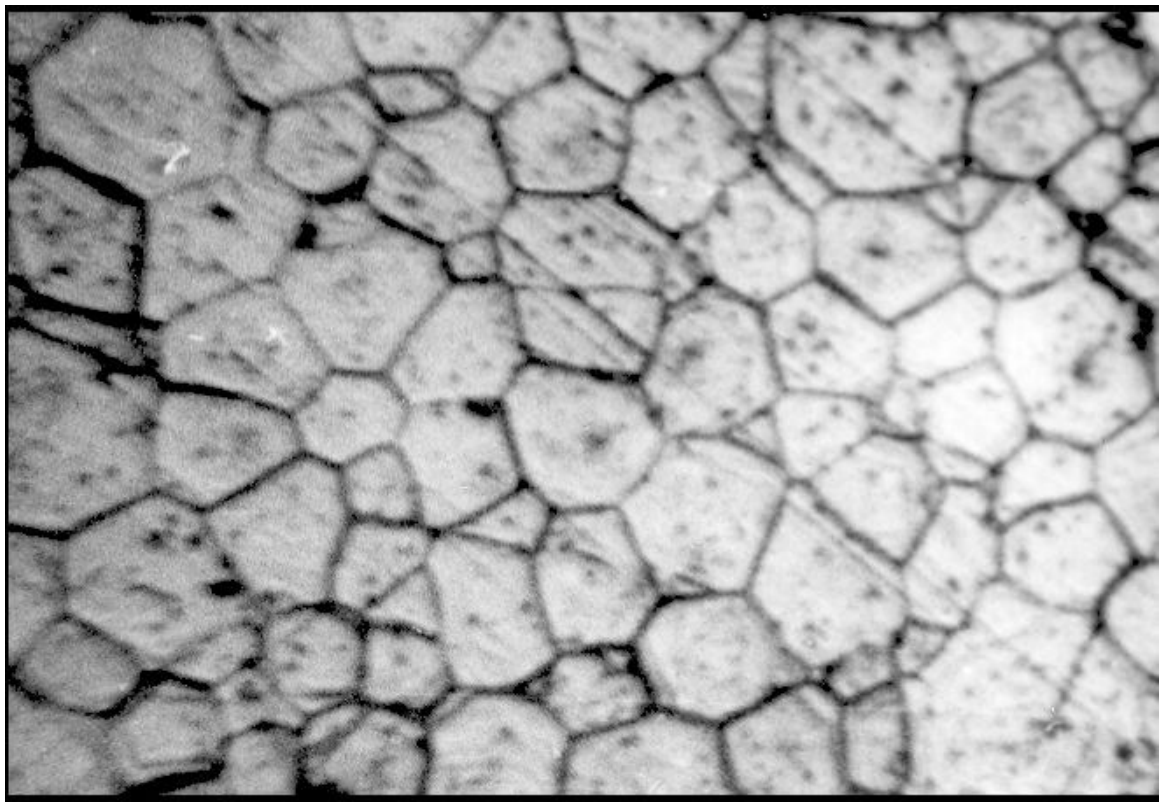
Grain and pore dimensions

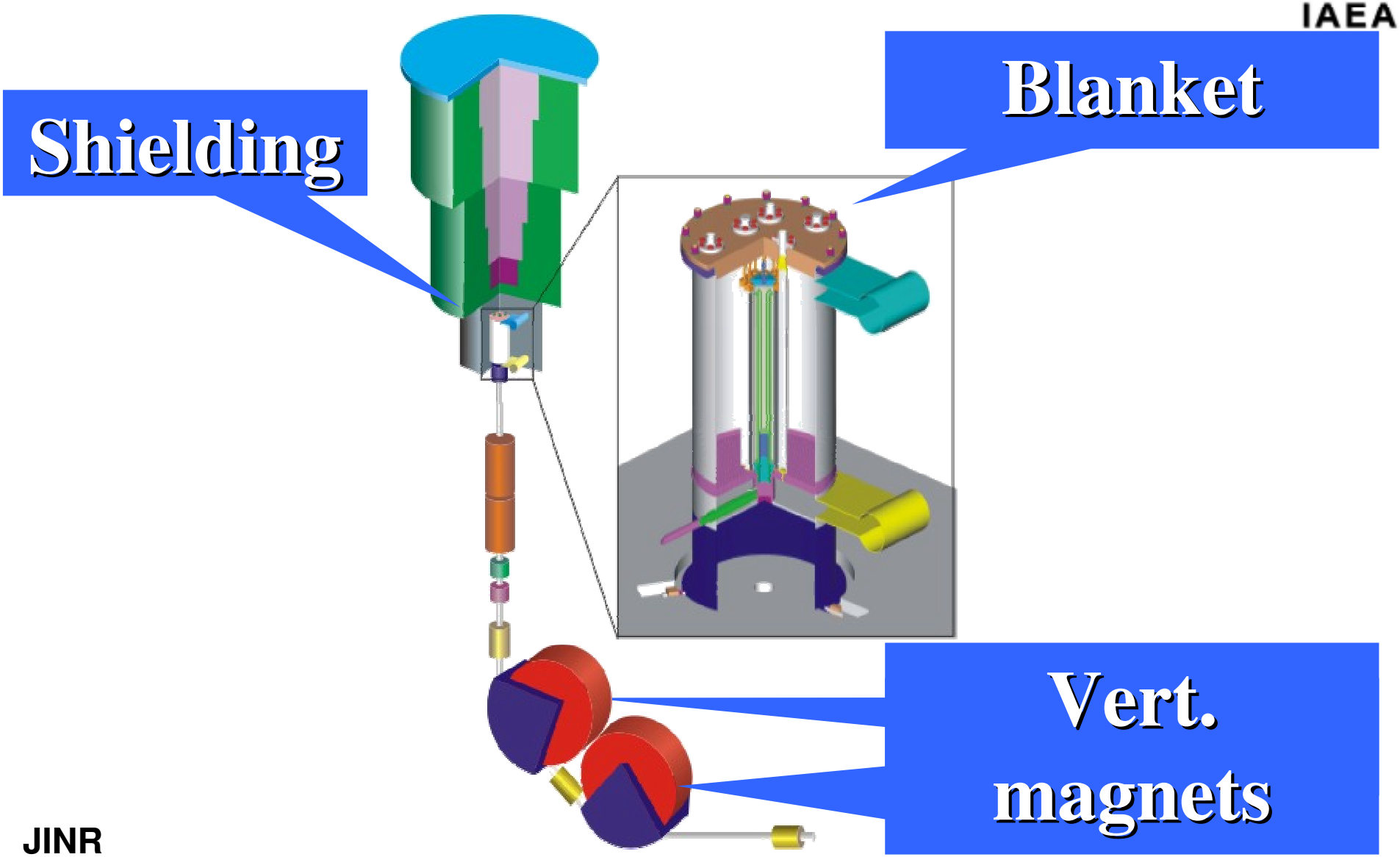


Microscopy study of the microsections processed in HNO_3 and HF acids

Grain diameter should be < 50 mkm (20-25 for that sample)

Pores diameter < 100 mkm and area less than 10% of microsection area

General Layout



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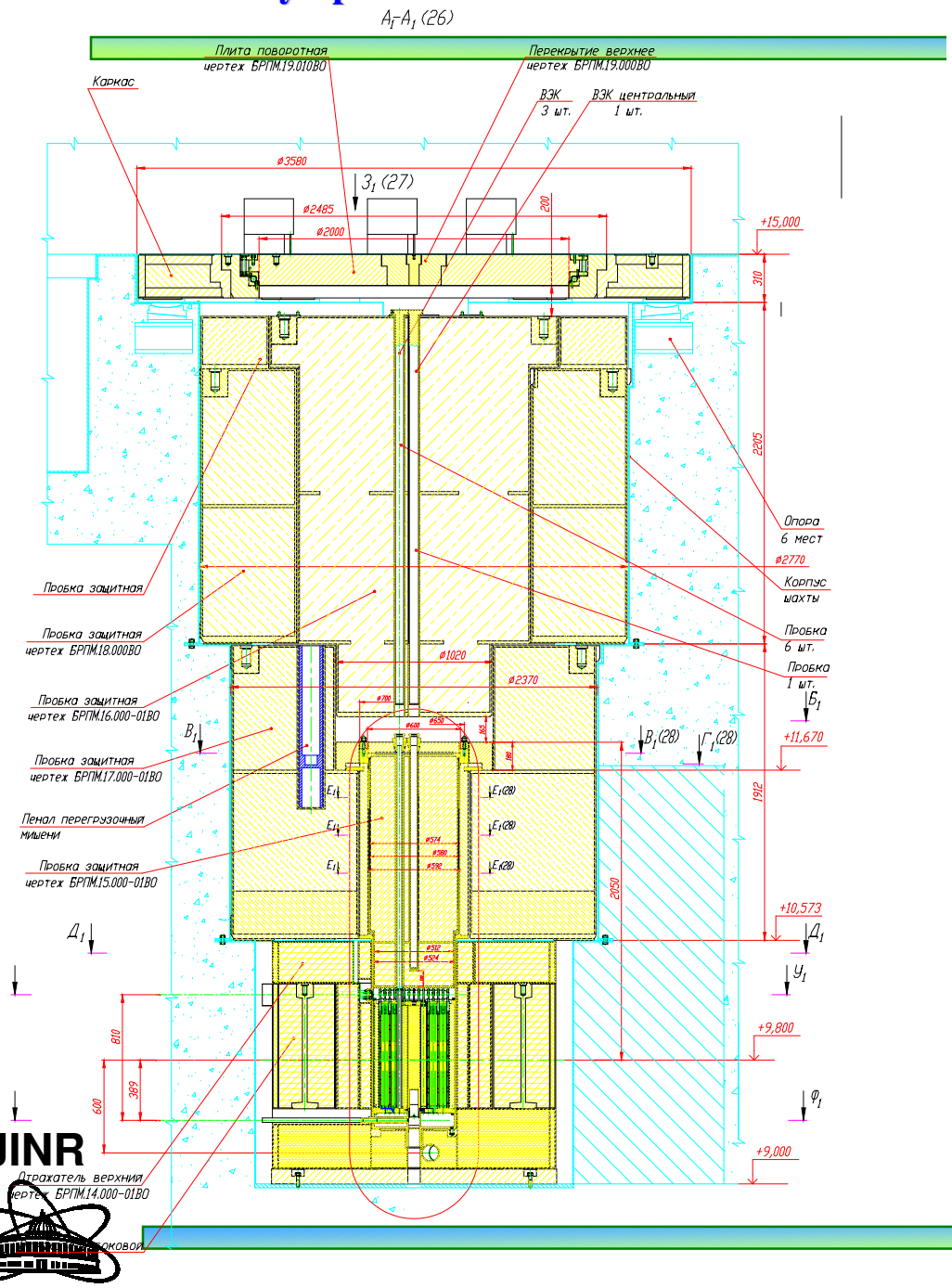
General Layout



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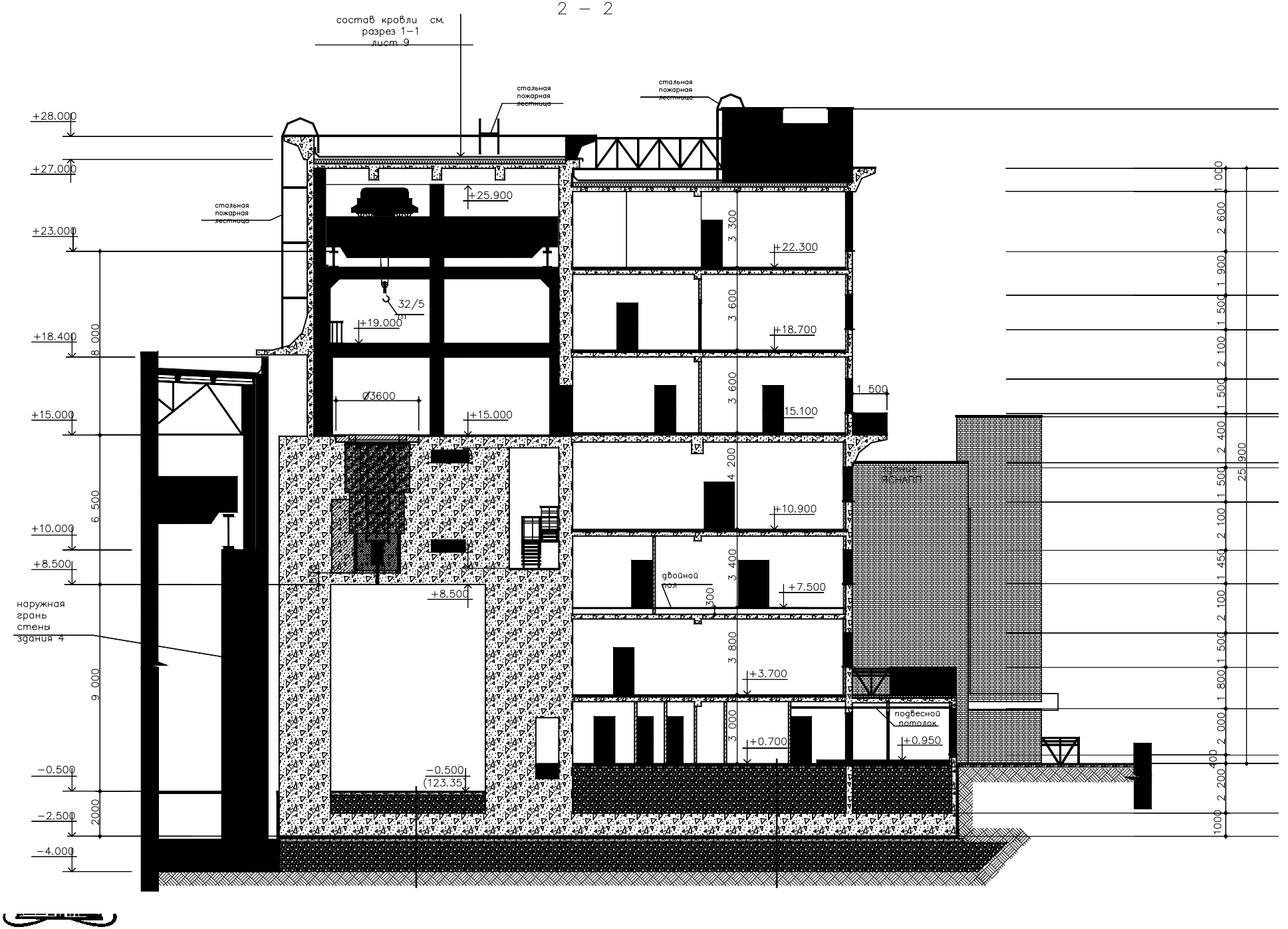
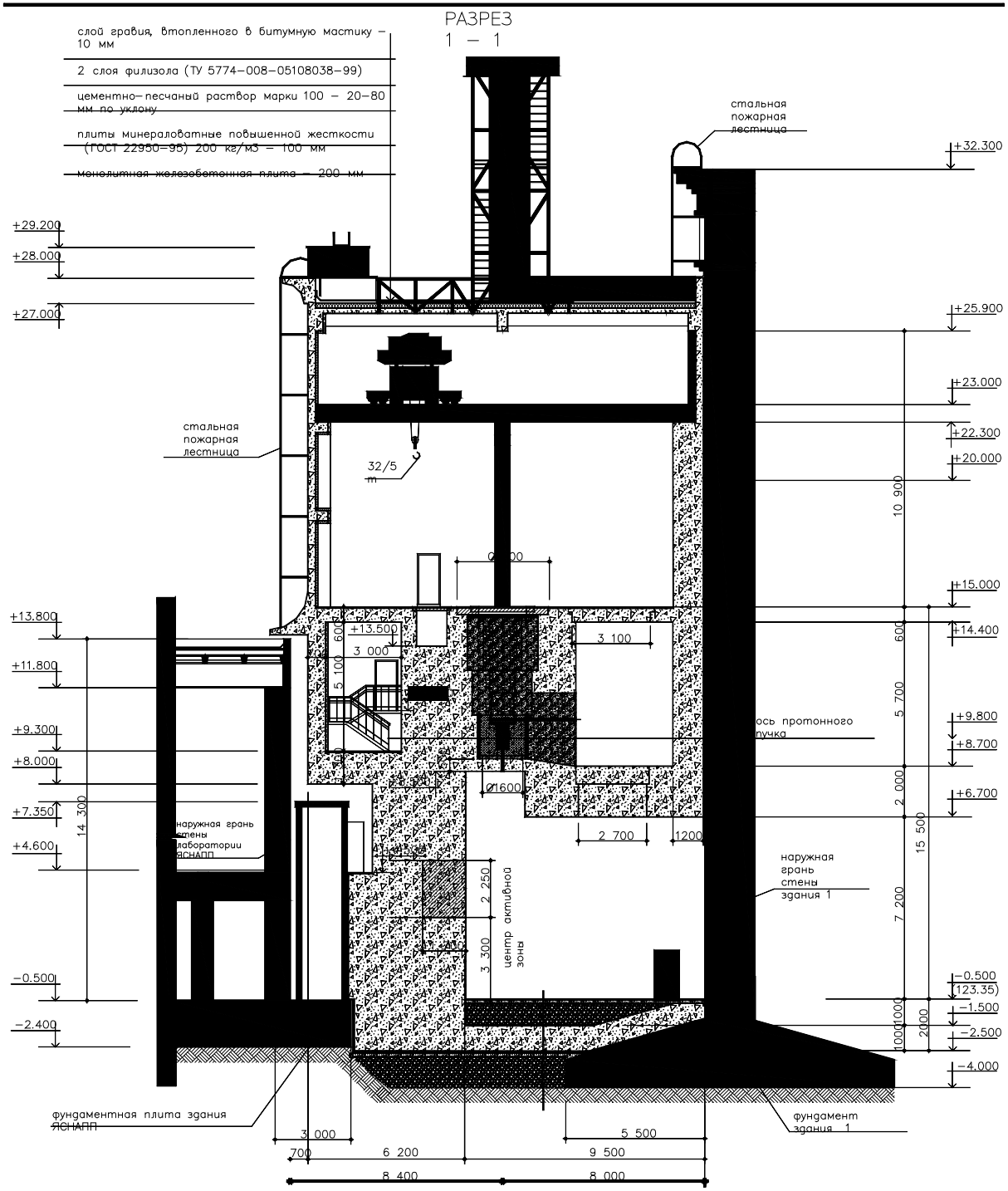
General Layout

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

РАЗРЕЗ
2 – 2


состав кровли см. разрез 1–1 лист 9
стальная пожарная лестница
стальная пожарная лестница
стальная пожарная лестница
+28.000
+27.000
+25.900
+23.000
+22.300
+19.000
+18.700
+18.400
+15.000
+15.000
15.100
+10.900
+10.000
+8.500
+8.500
+7.500
двойной пол
+3.700
наружная грань стены здания 4
подвесной потолок
+0.950
+0.700
–0.500
(123.35)
–0.500
–2.500
–4.000
Ø3600
32/5
8 000
6 500
9 000
2000
3 300
3 600
3 600
4 200
3 400
300
3 800
3 000
1 500
25 900
1 000
2 600
1 900
1 500
2 100
1 500
2 400
1 500
2 100
1 450
2 100
1 500
1 800
2 000
400
2 200
1000


РАЗРЕЗ
1 – 1
слой гравия, втопленного в битумную мастику – 10 мм
2 слоя филизола (ТУ 5774–008–05108038–99)
цементно–песчаный раствор марки 100 – 20–80 мм по уклону
плиты минераловатные повышенной жесткости (ГОСТ 22950–95) 200 кг/м3 – 100 мм
монолитная железобетонная плита – 200 мм
стальная пожарная лестница
+32.300
+29.200
+28.000
+27.000
+25.900
+23.000
+22.300
+20.000
+15.000
+14.400
+13.800
+13.500
+11.800
+9.800
+8.700
+9.300
+8.000
+7.350
+6.700
+4.600
−0.500
(123.35)
−1.500
−2.500
−2.400
−4.000
32/5 т
Ø1600
3 100
3 000
2 700
1200
2 250
3 300
центр активной зоны
наружная грань стены здания 1
фундаментная плита здания ЯСНАПП
фундамент здания 1
3 000
5 500
700
6 200
9 500
8 400
8 000
14 300
10 900
5 700
2 000
15 500
7 200
1000
2000

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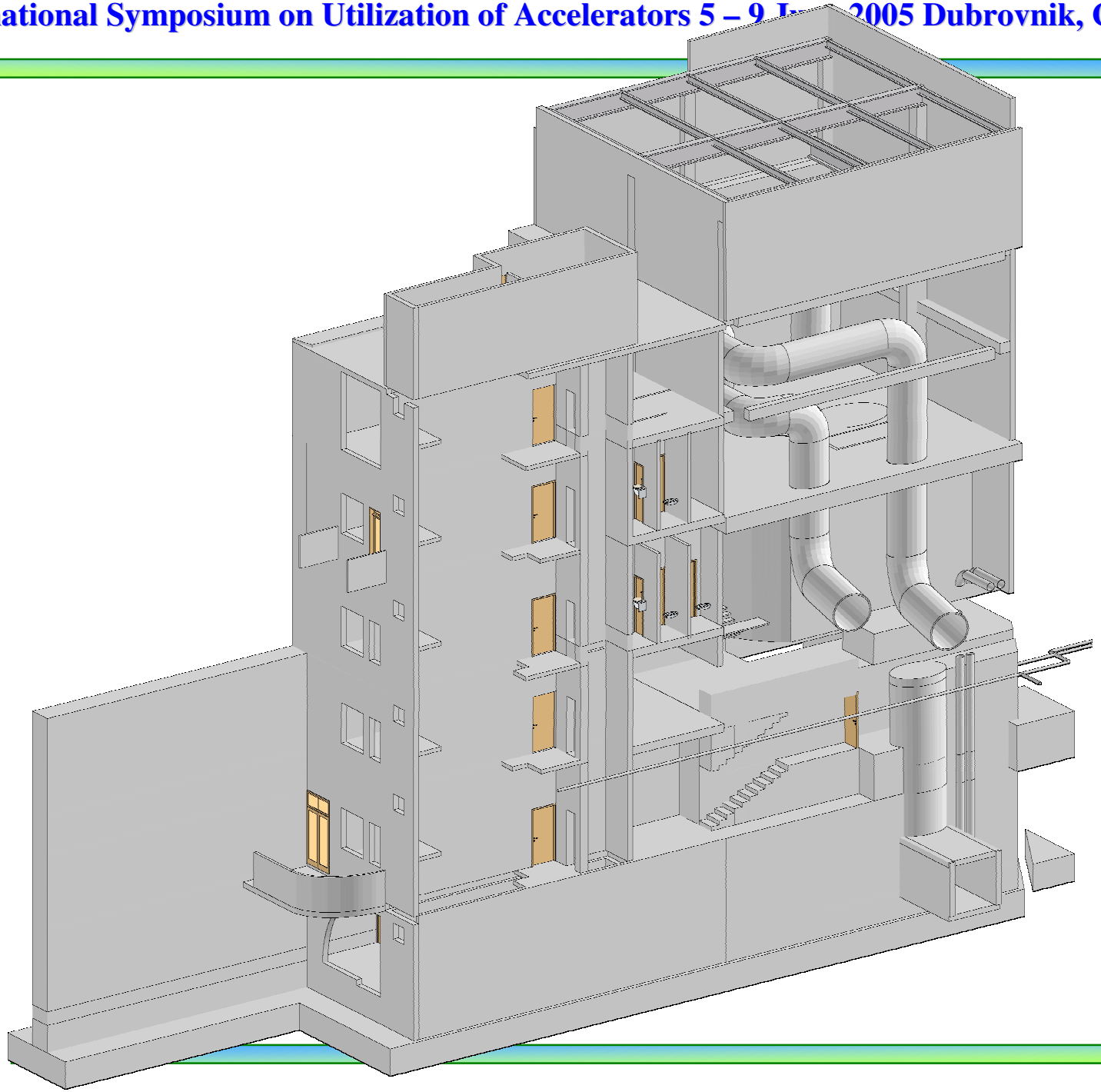

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Experimental Program

- Qualification of subcriticality monitoring, experiments with PNG;
- Validation of the core power/beam current ratio;
- Tests and calibrations of the actual spallation target;
- Post-irradiation and on-line spallation products yields investigation;
- Transmutation reactions rates, integral cross sections and spectral indices measurements;
- Interpretation and validation of experimental data, codes validation, benchmarking;

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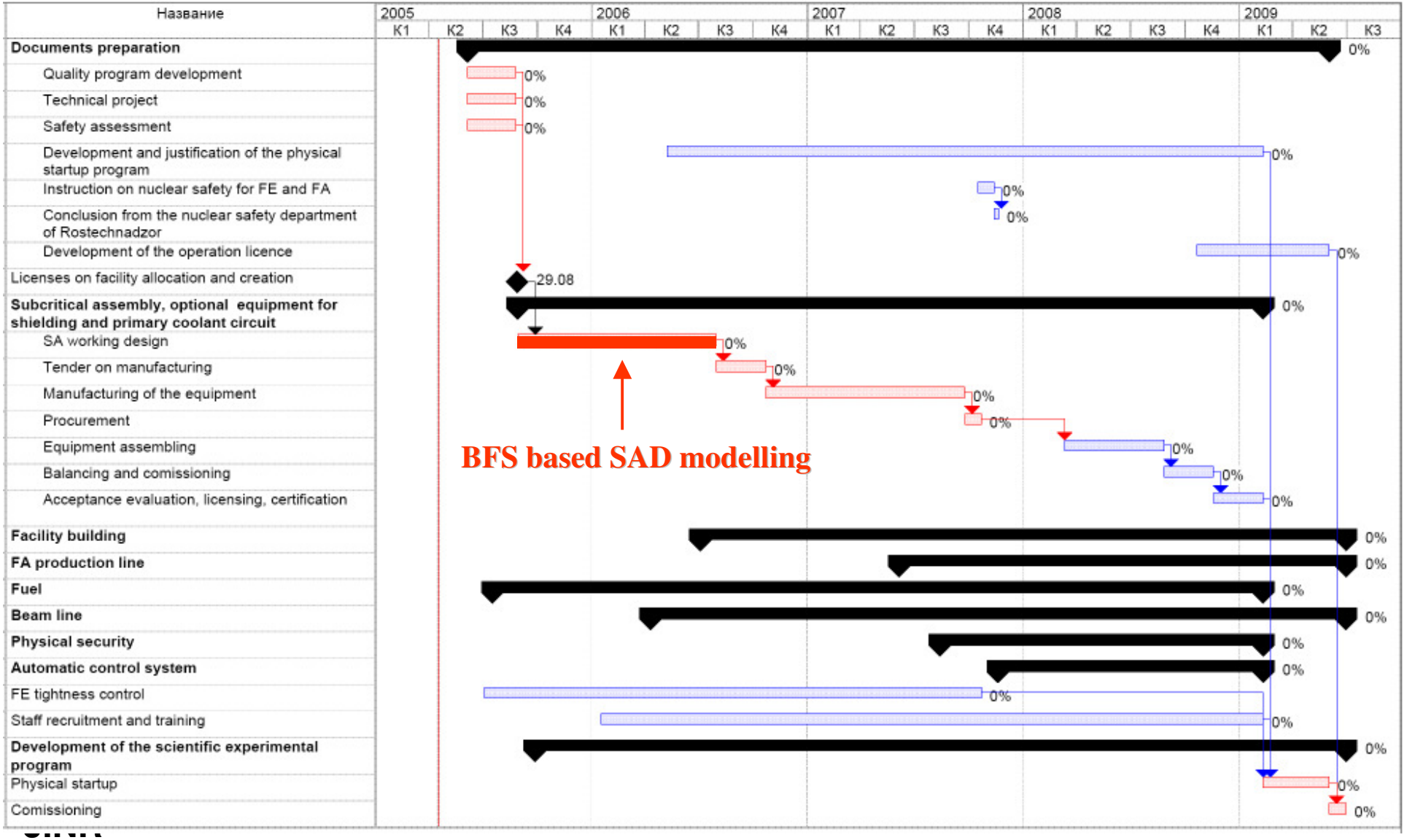
Project Status

- Technical project of the subcritical blanket: completed;
- Technical project of the beam line: completed;
- Technical project of the fuel element: completed;
- Fuel pellets manufacturing technology: developed;
- Preproduction batch of the fuel pellets: manufactured;
- General engineering project: completed;
- Safety assessment: in progress;

Licensing started some project documents already approved by Rostechnadzor (former Gosatomnadzor)

Project Timeline



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Conclusion

- It's possible to create in 4 years first ADS at non-zero power
- Wide experimental program is planned for the design stage and operation stage
- Proposals on experiments at SAD facility are kindly wlecome, book of proposals is forming now