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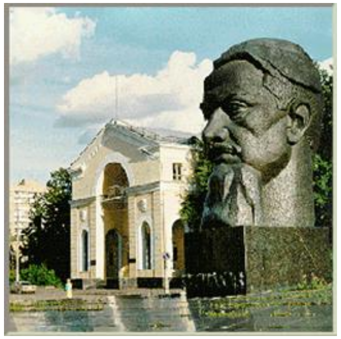

Russian Strategy for Controlled Fusion

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- Russian Strategy for Magnetic Fusion has been developed by NRC Kurchatov Institute and national research institutions under auspices of the State Corporation “Rosatom”
- The present level of national and international research and technology on fusion and fission energy systems has been evaluated as well as prospects of their synergetic development in ITER era
- The Strategy developed is aimed at provision of Fusion as a new Energy source with unlimited resources, attractive ecology and safety
- Fusion-Fission hybrid systems and Fusion Neutron Sources are also included in the Fusion Strategy as perspective devices for fission fuel production, nuclide processing and basic research

Strategy Goals

- Construction of a pure thermonuclear fusion reactor using reaction of deuterium and tritium in high temperature magnetically confined plasma

  This goal should be reached through active participation in ITER project, national research on upgraded national fusion facilities and broad international collaboration,

  participation in international development of DEMO project

- Development and construction of Fusion Neutron Sources for deciding issues of atomic energy and accelerating fusion applications

  This goal should be reached through development of fusion-fission hybrids for neutron production, transmutation and nuclear fuel production

  in accordance with demands of thermal and fast fission reactors and other Rosatom tasks

Milestones of the Rosatom Fusion Strategy (2007)

2005 | 2010 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050

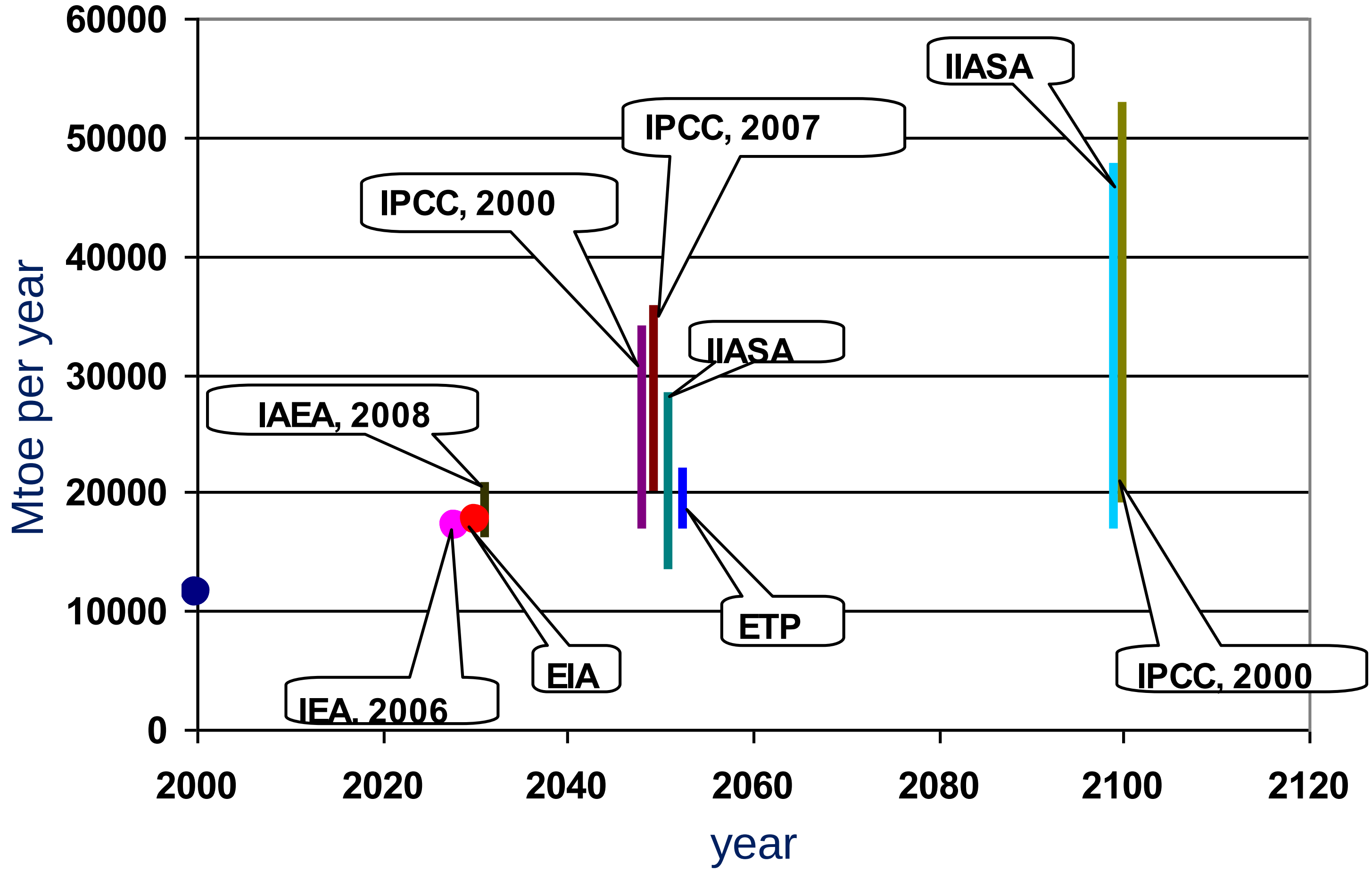
Burning plasma demonstration
- ITER Q=5 400 s
- ITER Q =10 3000 s
- Technical requirements PP-DEMO
- DEMO Long term operation at Q~30

Fusion plasma physics
- Transport and stability T-10, Globus-M, T-11M
- Q~1 Physics in T-15
- Q =10 Physics in ITER
- Q =30 Physics in DEMO

Materials and technologies
- ITER superconductors
- ITER equipment, DEMO TBM
- Tritium technology demonstration
- DEMO equipment
- New materials and technologies for 5 MW/m^2

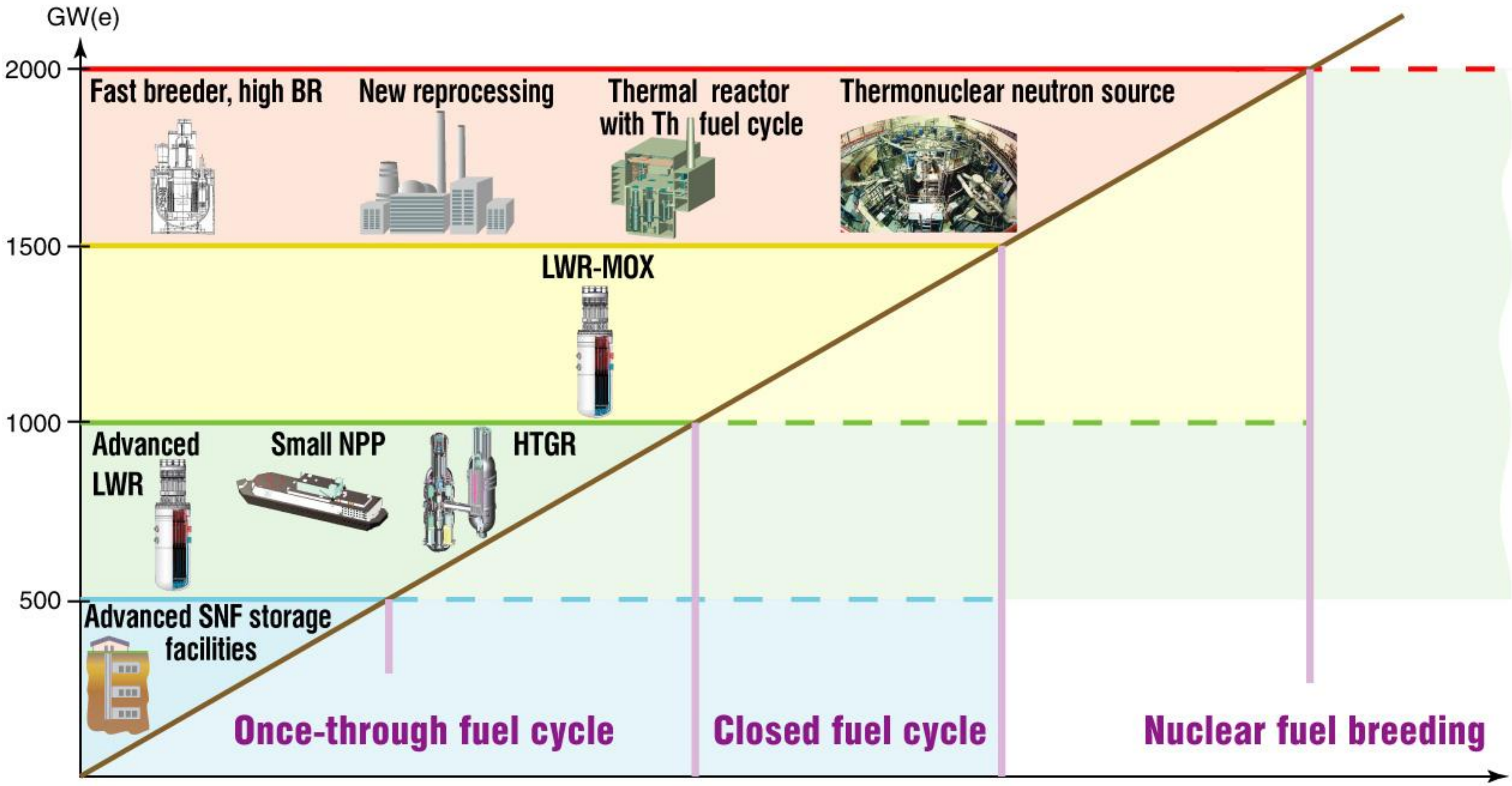
Facilities, reactors, power plants
- T-15
- TIN-0
- TIN-1
- ITER
- TIN-2
- Fusion-Fission Hybrid Systems
- PP - DEMO
- PROTO

Forecast of primary energy consumption in 21 century



International organizations predict significant growth of the energy consumption

Innovation technologies needed for different scenarios of atomic energy development



Fusion neutrons are necessary for power generation higher than 1500 GW(e)

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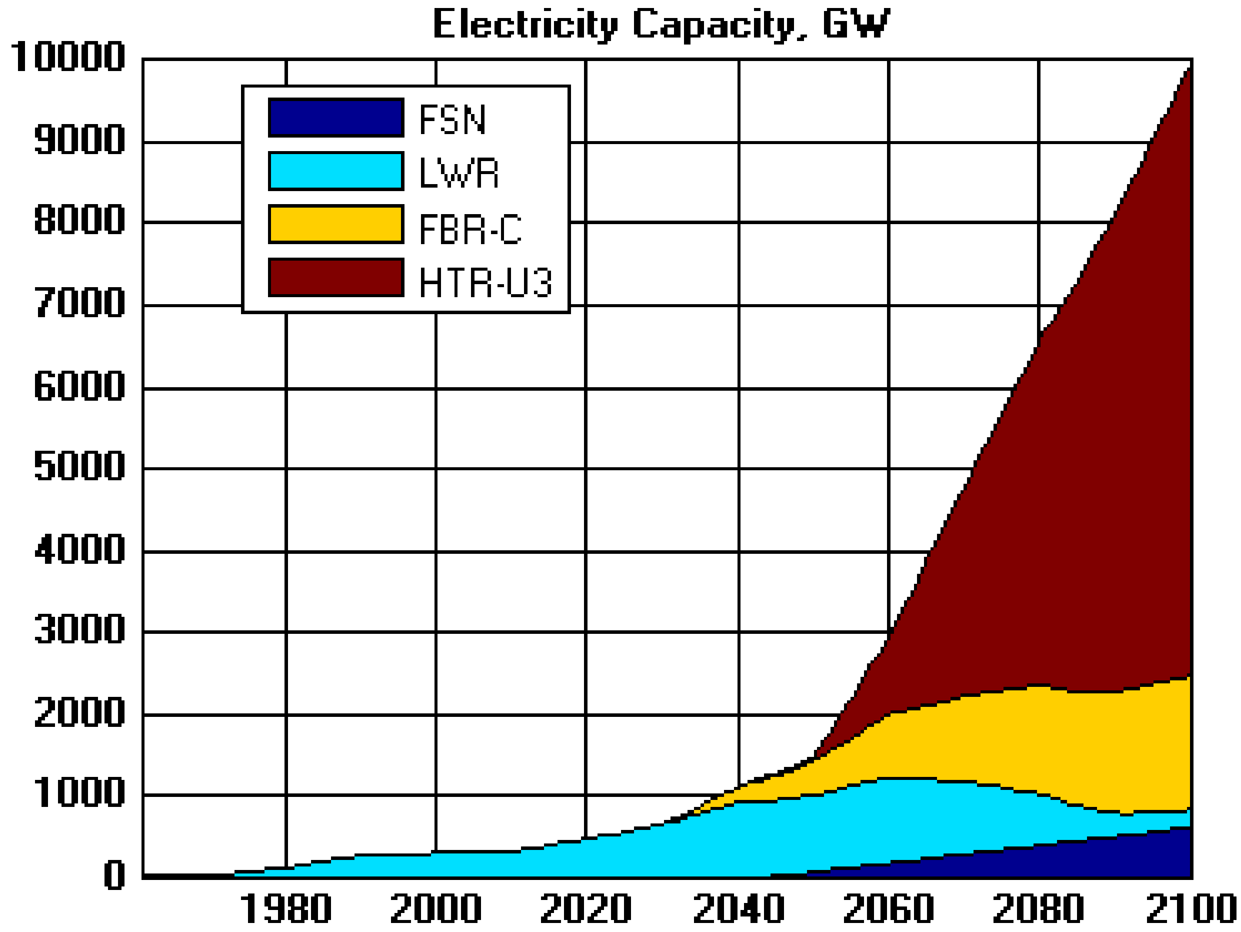
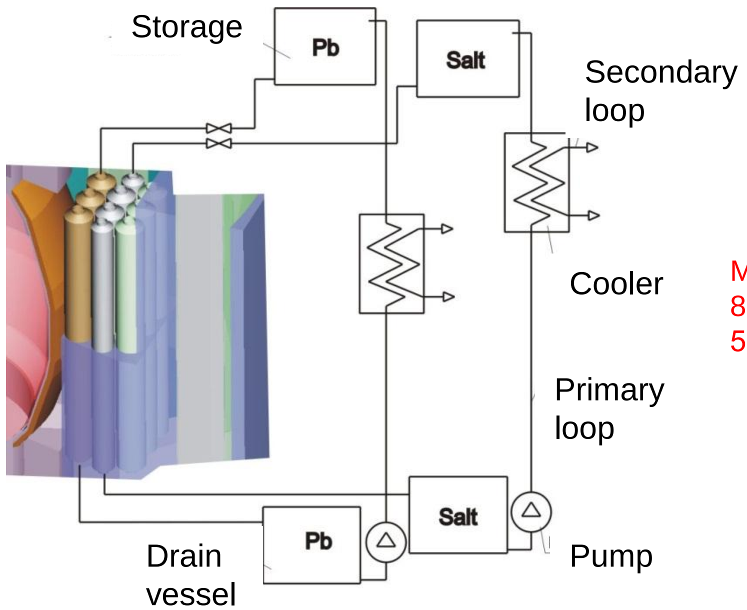
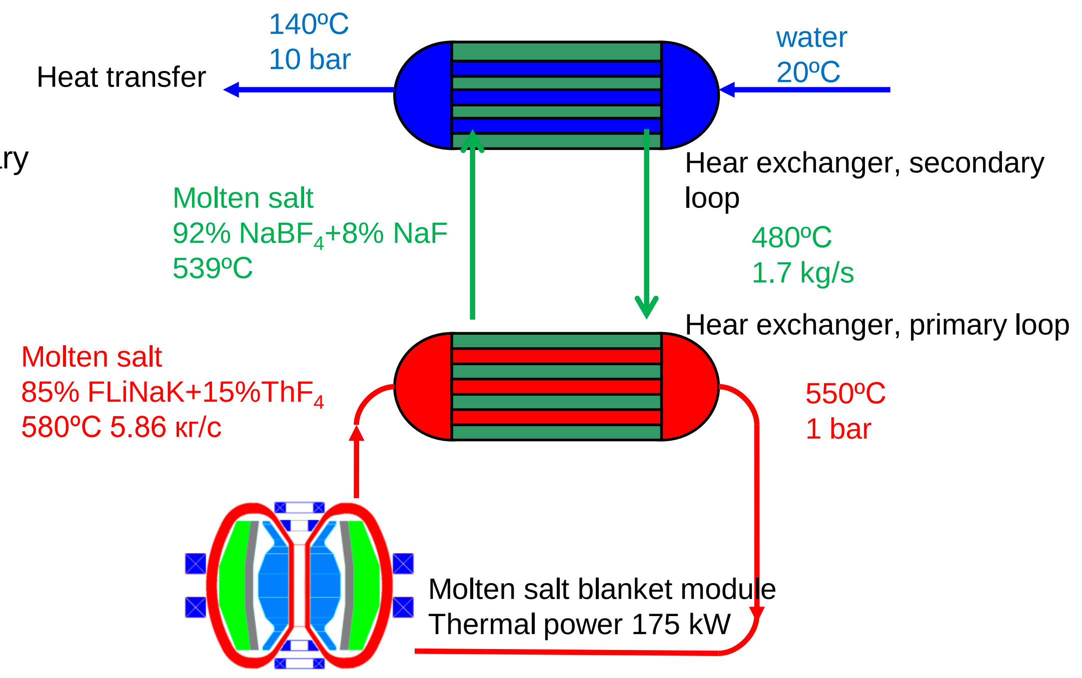
Opportunities of FNS in developing atomic energy



Anticipated mix of Global atomic energy with FNS (~5%) for a high rate scenario

Two nuclear fuel cycles are considered





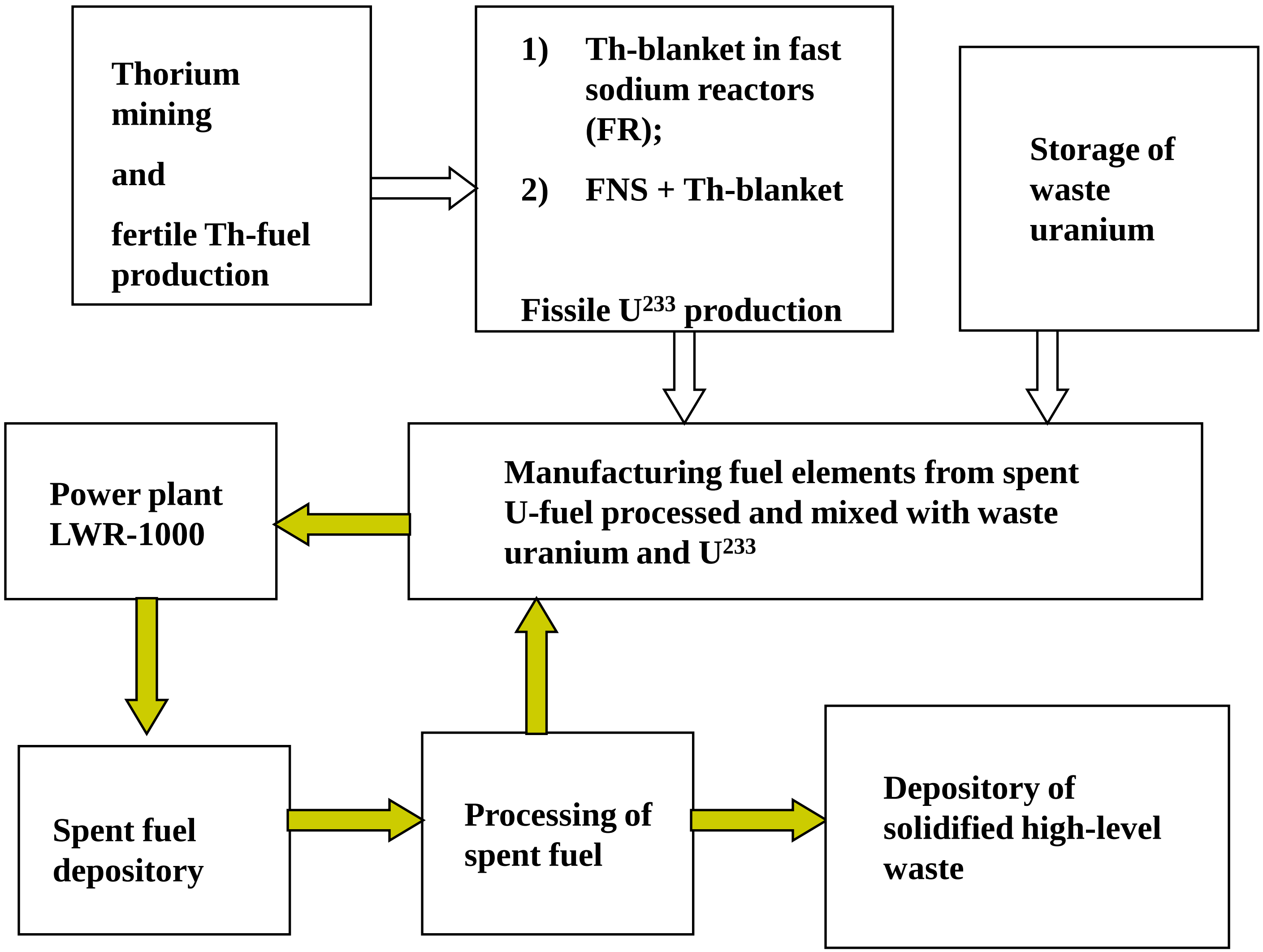
U-Pu

1Pu+1T per 1n(DT)

Th-U

0.6U+1T per 1n(DT)

Closed fuel cycle for LWR-1000



using spent fuel processing, U^{233} production from Th^{232} and waste uranium

Basic approaches to fusion energy and neutrons

1. **Steady state tokamaks,** including compact tokamaks with non-inductive current drive and burning DT-plasma with Q~1 and higher

2. **Stellarators,** as a currentless alternative to tokamaks with compatible requirements to magnetic and heating systems

3. **Mirror machines,** as the simplest magnetic confinement systems with prospects in the field of fusion neutron production for structural material testing

Major Strategy Tasks

Task 1 Russian participation in construction of ITER and following research program.

- ITER oriented and relevant research on upgraded Russian tokamaks
- Development and validation of plasma simulators for ITER on modern experimental data base
- Development and tests of new technologies for the first wall, divertor, additional heating and current drive system, tritium breeding blanket, diagnostics, control, data acquisition and remote handling

Task 2 Constructing a divertor copper coil tokamak
at NRC Kurchatov Institute
toroidal field 2 T, current 2 MA, pulse duration 10 c,
NBI and gyrotron heating up to 15 MW
via upgrading T-15 tokamak technology systems

- Experimental program for plasma with Q~1
- Upgrading T-10, T-11M, Globus M tokamaks
- Tokamak plasma theory and modeling of burning plasma and fusion-fission hybrids on the basis of modern codes
- Development of physical and technical diagnostics for fusion and hybrid reactors

MAJOR STRATEGY TASKS

Task 3 Development of demonstration Fusion Neutron Source

- R&D on fusion fission blankets for nuclear fuel production and transmutation
- Development and radiation tests of structural and electro-technical materials and insulators including superconductors and high temperature superconductors with high performance properties
- Testing experiments and property studies of materials and blankets on FNS
- Development of Fusion-Fission prototype for nuclear fuel production and transmutation of radio nuclides from spent-fuel
- R&D on alternative Fusion reactors and FNS using stellarator and mirror machine magnetic configuration

Major Strategy Tasks

Task 4 Collecting of data and analysis of contemporary database on tokamak plasma physics, materials, fusion and fission technologies with the aim to formulate concepts of Fusion DEMO and demonstration fusion-fission hybrids

- Active participation in international Fusion program
- Development of national DEMO and participation in International DEMO project (if any occurs)

Task 5 Development of Center of Excellence net on the basis of upgraded T-10, T-11M, Tuman-3M, Globus-M for education of fusion specialists for national and international fusion programs

- Supporting staff educating programs in basic universities: MEPHI, MSU, MPTI, MSTU, SPbSU, SPbSPU, NNSU, NSU, etc.

Strategy tasks in Physics

- Advanced confinement of burning plasma
- Steady state heating and current drive
- Control of plasma stability
- Equilibrium and shape control
- Extended operational limits (H_{y2}, β_N, I_N q95, κ, δ, n/n_{Gr})
- Plasma-wall interaction defining the operation life (impurity control, materials, thermal, neutron and fast particle loading, erosion, redeposition, dust, recycling, permissivity etc.)
- Fueling and particle flows control in steady state, optimal divertors
- Diagnostics compatible with neutron environment and SSO
- Reactor neutronics and blanket physics
- Tritium breeding and heat transfer in blankets
- Physics of hybrid blankets
- Development of databases for fusion physics, nuclear physics and materials properties

Strategy tasks in Technology

- Long-life first wall and divertor with a minimal influence on plasma effective charge Z_{eff}
- SSO neutral beam injectors with tenth of MW power and appropriate energy
- High power gyrotrons and High-Frequency generators CW-operating
- Systems for kinetic control of plasma
- Engineering diagnostics
- IT systems for data acquisition and processing
- Automation systems for monitoring, control and safety
- Development of engineering databases
- ITER and DEMO relevant technologies
- Development and tests of Fusion blankets
- Development and tests of Fusion-Fission blankets

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Strategy tasks in Technology (institutions)

- **NRC KI –** tokamaks and test beds for superconductors, diagnostics, IT-technologies, blankets, demonstration FNS, simulations
- **TRINITI –** upgraded experimental facilities, R&D on material testing and new the first wall and divertor technologies, participation in FNS development, simulations and modeling
- **NIIEFA –** design and construction of new tokamaks and demonstration FNS, development of fusion technologies and codes, technological diagnostics, superconducting magnetic systems
- **NIKIET –** nuclear technologies for fusion tritium breeding blankets and fusion-fission hybrids
- **VNIINM –** structural materials, insulators, tritium breeding technologies, first wall materials, superconducting materials
- **“Red Star” -** materials and technologies for the first wall and divertor, including lithium
- **MEPHI -** first wall and divertor materials, diagnostics, staff education
- **FTI Ioffe -** spherical tokamak research and overall tests, HF-heating and current drive, diagnostics
- **IGF RAS –** stellarator technologies, HF -heating, theory and modeling
- **INF SB RAS–** mirror machine technology, NBI technology, diagnostics
- **IAP RAS –** gyrotron technology and manufacturing
- **SPbSPU –** divertor, dust technologies, diagnostics, simulations, staff education
- **VNIIEF** – fueling technologies

Experimental facilities upgrading and building

T-15 Upgrading

Tokamak with HD plasma, elongated cross section, divertor, copper coils

Major radius 1.5 m, plasma current 2 MA, pulse duration ~10 s, heating power ~15 MW

Mission – long-term non-inductive current drive operation at high plasma current

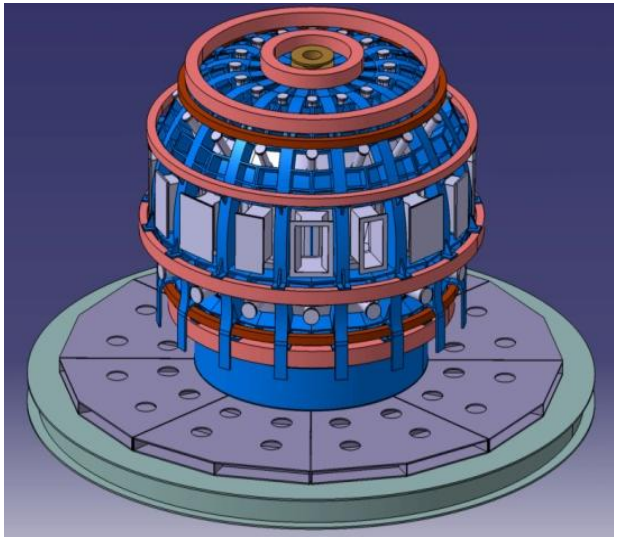
Physical prototype of compact Fusion Neutron Source

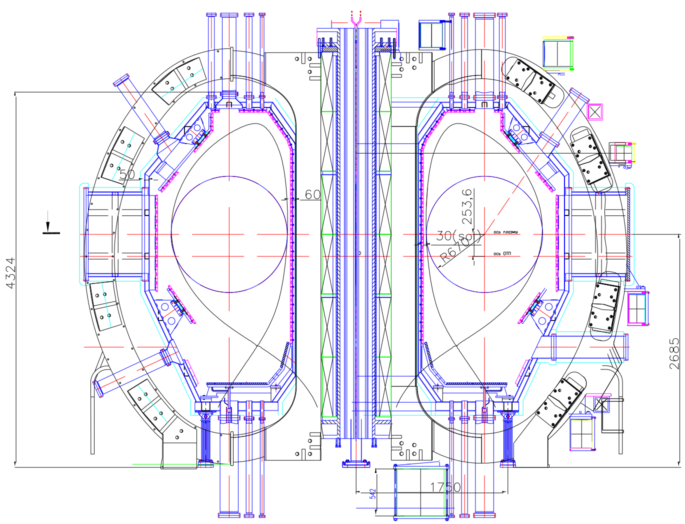
FNS-1 – demonstration FNS with DT plasma, neutron wall loading 0.1-0.2 MW/m^2,

Plasma current ~ 2 MA, pulse duration ~1000 s and nuclear fuel production at 10 kg level, incinerating of 10 kg of TRU per year

First commercial fusion applications

Upgrade of T-15 tokamak





Basic parameters

Aspect ratio	2.2
Plasma current I_p, MA	2.0
Major radius R, m	1.48
Elongation *k*	1.9
Triangularity, δ	0.3-0.5
Divertor	SN
Pulse duration, s	5-10
Toroidal field B_t, T	2.0
Loop voltage $\Delta\Psi_{CS}$, Wb	6
NBI Power, MW	9
Gyrotron Power, MW	6

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Globus-M(U)- upgrading spherical tokamak Globus-M to be a hydrogen-deuterium prototype of compact FNS

- major radius 0.36 m,
- minor radius 0.24 m,
- magnetic field 1 T,
- current 0.5 MA
- heating power up to 5 MA

Globus-M upgrade supposes two distinct regimes of operation with maximal B(tor) and maximal discharge duration

Scenario	Plateau duration	Conductor temperature increase ΔT
	ms	°C
«B-max», 1 T, 0.5MA	200 ms	70
«t-max», 0.7 T, 0.4 MA	500 ms	70

Project will allow getting advanced regimes of tokamak operation, experience and education of staff

Goals for 2011-2020 period

- To participate in ITER construction and putting ITER into operation
- To upgrade T-15 to be a divertor tokamak and using it as the major facility for physics and technology studies in support of ITER and fusion-fission hybrids
- To upgrade T-11M, Globus-M for physical studies in support of FNS and fusion-fission hybrids program
- To perform R&D on high power heating and current drive systems to provide steady state operation and burning plasma profile and stability control
- To develop materials for FNS, DEMO and F-F Hybrids and to test materials in fast reactors
- To develop and test effective fusion and hybrid test blanket modules and systems
- To develop modern physical and technological diagnostics and intellectual systems for plasma control, data acquisition and processing
- To design and build the demonstration FNS for nuclear fuel production and transmutation of spent-fuel

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Milestones

1. Upgrading T-15 (NRC KI)	2010-2015
2. Upgrading T-11M (TRINITI)	2011-2015
3. Upgrading Globus-M (FTI Ioffe RAS) 1 stage 2 stage	 2011-2012 2012-2016
4. Design and construction of L-5 stellarator (IGP RAS) (not decided)	2011-2017
5. Design and construction of hydrogen prototype of mirror FNS on GDT-basis (NPI SB RAS) (not decided)	2012-2015
6. Design and construction of compact FNS (NRC KI)	2013-2018
7. Development of high power steady state heating systems and test beds (NRC KI, NPI SB RAS, IAP RAS, FTI Ioffe RAS, TRINITI, PEI, NIKIET, “Red Star”)	2012-2017
8. Center of Excellence net on operation facilities for ITER and national program (NRC KI, MEPHI, MSTU, SPbGPU, FTI Ioffe RAS, IAP RAS, TRINITI)	2011-2017
9. DEMO conceptual design (NRC KI)	2012-2015

Major Collaborators

JET (EU), heating and current drive, kinetic control, steady state scenarios in burning plasma, materials and the first wall technologies, diagnostics**)**

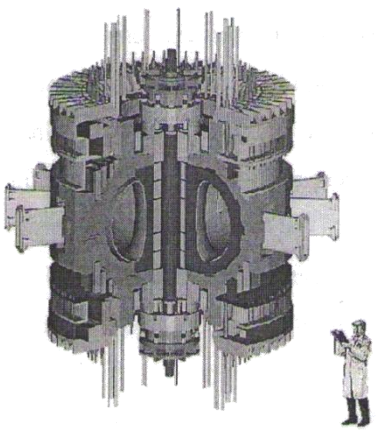
LHD, JT-60U (Japan, heating and current drive, diagnostics, fueling)

KTM (Kazakhstan, compact design, long shots, material studies and plasma-wall interaction**)**

IGNITOR (Italy, ohmically heated burning plasma, close to ignition, very high magnetic field 13 T, TRINITI site is foreseen,
Italy provides tokamak
Russia provides site, buildings, power supplies, cryo-systems and diagnostics**)**

USA (possibly) ignition scenarios, burning plasma control

Ignition may be possible in strongly shaped ST with B_t=5T and I_p=11 MA



Ignitor Coppi

Parameters	Symbol	Ignitor Coppi	Unit	FNS-IGN
Plasma current	I_p	11	MA	11
Toroidal magnetic field	B_t	13	T	5,0
Central electron temperature /average	T_{e0}	11.5	keV	5 (average)
Central ion temperature /average	T_{i0}	10.5	keV	5(average)
Central electron density/average	n_{e0}	1.0×10^{21}	m^{-3}	1.0×10^{21} (average)
Plasma stored energy	W	11.9	MJ	15
Ohmic power	P_{OH}	11.2	MW	10
Auxiliary power (ICRH)	P_{ICRH}	0	MW	10
Alpha power	P_{α}	19.2	MW	20
Energy replacement time	τ_E	0.62	s	0,75
Poloidal beta	β_p	0.20		0,79
Toroidal beta	β_T	1.2	%	15,7
Central beta	β_0	5.0	%	25
Edge q_{ψ}	q_a	3.6		7,3
Bootstrap current	I_{bs}	0.86	MA	5,1
Major radius	R	1.32	m	0.6
Minor radius	a	0.47	m	0.4
Aspect ratio	A	2.8		1.5
Elongation	κ	1.83		3.3
Triangularity	δ	0.4		0.7
Central stack current	I_{cs}	85.8	MA	18

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Conclusions

1. Russian Fusion Strategy up to 2050 and Program for 2011-2020 are approved and their realization has been started
2. The Strategy is aimed at building Commercial Fusion Power Plant
3. The Program is aimed at ITER support, DEMO conceptual design and construction of steady state Fusion Neutron Sources for multipurpose Fusion-Fission Hybrid Systems
4. The Program takes into account necessity of developing alternative to tokamak devices like stellarators and mirror machines
5. Upgrading the experimental fusion facilities and test beds is a key issue of the Program 2011-2020
6. The Program supports staff education through Center of Excellence net in fusion and a broad international cooperation