Update of Russian Federation Roadmap

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Acknowledged: V.A. Belyakov, A.N. Kalashnikov, S.V. Lebedev, A.V.Lopatkin, V.D. Risovanyy, V.E. Cherkovets

B.V. Kuteev, 17-20 October, 2013, 2nd DEMO workshop, Vienna, Austria
Introduction

- Acting Russian Strategy for Magnetic Fusion has been developed by NRC Kurchatov Institute and national research institutions under auspices of the State Corporation “Rosatom” (2007)
- The Strategy developed is aimed at provision of Fusion as a new Energy source with unlimited resources, attractive ecology and safety by 2050
- Fusion-Fission hybrid systems with Fusion Neutron Sources are later included in the Fusion Strategy as perspective devices for fission fuel production, nuclide processing and basic research (2011)
Strategy Goals

• To build a pure thermonuclear fusion reactor, using reaction of deuterium and tritium in high temperature magnetically confined tokamak plasma
  through active participation in ITER project, research on upgraded national fusion facilities and broad international collaboration, including development of an international DEMO project

• To develop and build Fusion Neutron Sources for solving problems of Atomic Energy and accelerating fusion applications
  through development of fusion-fission hybrids for 14 MeV neutron production, transmutation, electricity and nuclear fuel production in accordance with demands of thermal and fast fission reactors and other Rosatom tasks
Major Strategy Tasks (ongoing)

Task 1
   Russian participation in ITER construction and following research program

Task 2
   Building a divertor copper coil tokamak T-15 at NRC Kurchatov Institute

Task 3
   Development of Demonstration Fusion Neutron Source

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 DEMO and demonstration fusion-fission hybrids

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
Conclusions (2011)

1. Russian Fusion Strategy up to 2050 and Program for 2011-2020 are approved by Rosatom and their realization has been started

2. The Strategy is aimed at building Commercial Fusion Power Plant by 2050

3. The Program is aimed at ITER support, DEMO conceptual design and building 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

6. The Program supports staff education through Center of Excellence net in fusion and a broad international cooperation
News on Strategy 2013

1. A Working Group has been organized in July 2013 (E.P. Velikhov’s direction)
2. The goal is to prepare an ENERGY VALUABLE Hybrid Concept by end of September 2013 and official proposal by end of 2013.
3. WG-members P.N. Alexeev (KI), E.Azizov (KI, Chair), V. Belyakov (Efremov), V. Cherkovets (TRINITI), A.Kalashnikov (SC RF “Rosatom”), B.Kuteev (KI, Secretary), S. Lebedev (Ioffe), A. Lopatkin (NIKIET), V. Risovanyy (SC RF “Rosatom”),
4. Emphasis on tokamak based Pilot Hybrid Plant and Molten Salt technologies for nuclear fuel cycle.
5. The Hybrid Concept draft has been presented during meeting on September 23 to E. Velikhov, V. Pershukov (SC RF “Rosatom” DDG), A. Krasilnikov (ITER-RU DA), A. Goverdovski (PEI Obninsk)
6. The Hybrid Program Concept is approved by Science@Technology Council of SC RF “Rostom” (13 December, 2013)

Roadmap for Hybrid Program is to be issued soon
Strategy 2013 for Fusion-Fission development in Russia

Burning Plasma Physics

- T-15
- ITER
- DEMO
- PROTO

Nuclear physics and technology

- DEMO-FNS
- PHP

Test beds for enabling technologies

- Test beds for molten salt technologies

2015 → 2030 → 2050

Hybrid

Fusion

Nuclear technologies of new generation
Major facilities on the path to Industrial Hybrid Plant

**SSO&MS**
- Magnetic system
- Vacuum chamber
- Divertor
- Blanket
- Remote handling
- Heating and current drive
- Fuelling and pumping
- Diagnostics
- Safety
- Molten salts

**Globus-M3**

**FNS-C**
- DT neutrons

**DEMO-FNS**
- MS blankets

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**Pilot Hybrid Plant construction by 2030**

\[ P = 500 \text{ MWt}, Q_{\text{eng}} \sim 1 \]

**Industrial Hybrid Plant construction by 2040**

\[ P = 3 \text{ GWt}, Q_{\text{eng}} \sim 6.5 \]

\[ P = 1.3 \text{ GWe}, P = 1.1 \text{ GWn}, \text{MA} = 1 \text{ t/a}, \text{FN} = 1.1 \text{ t/a} \]
Pilot Hybrid Plant – I.V. Kurchatov’s dream
(OGRA – One GRAm -mirror machine in Kurchatov Institute)

1 g of neutrons per day!

365 g of neutrons per year
~1 kg of tritium per year

80/320 kg per year

Fissile nuclides

20 MW of DT-fusion power
260 MW of direct fission of U238/Th232
20 MW of gamma captures
5 MW of lithium apha-capture
40 MW of Heating and CD power
130 MW + 20 MW heating + magnetic system
~Total heat sink power 500 MW
200 MW electric power

at $k_{\text{eff}}=0.95$ the heat power accompanying MA-destruction is ~500 MW
500 kg/year of MA (incinerates ~ 15 nuclear reactors of 1GWe)
### Parameters of DEMO-FNS

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<th>Parameter</th>
<th>Value</th>
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<td>R, m</td>
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<tr>
<td>( V_{\text{pl}}, \text{m}^3 )</td>
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</table>

#### Demonstration
- Tritium breeding
- MA incineration
- Fissile nuclide production
- Destruction of long life radionuclides
- Heat transfer
Feasibility of Pilot Hybrid Reactor by 2030

1. Regimes with $Q \approx 1$ are realized in tokamaks.
2. Electron temperature sufficient for DT beam driven fusion $T = \sim 4$ keV has been demonstrated in numerous experiments.
3. Non-inductive current drive has been demonstrated in conventional tokamaks and is close to demonstration in spherical machines.
4. Reduction of technical requirements on neutron loading in PHP to $0.2 \text{ MW/m}^2$ and fluence value for operation time below $2 \text{ MWa/m}^2$ allows to use commercially available materials.
5. Economics of PHP is acceptable in case of total products selling: MA incineration, electricity production, tritium breeding, fuel breeding for U-Pu and Th-U nuclear fuel cycles.
6. System models and codes predict appropriate parameters of PHP.
7. Russia has an appropriate cooperation of fusion and fission organizations and well qualified staff.
Structural and Functional Materials of the Hybrid Concept

Structural materials:
austenitic steels: 12X18H10T (SS316)
ČС-68
ЭК-164
Nickel alloys: Hastelloy
Vanadium alloys: V-(4-9)Cr-(0.1-8)W-(1-2Zr)
V-4Cr-4Ti

Materials for Magnetic System:
Cu
CuCrZr
Nb$_3$Sn
NbTi
MgB$_2$

Insulators:
MgAl$_2$O$_4$
New opportunities of Pilot Hybrid Plant in the field of Nuclear Energy Technologies

1. Subcritical active cores
2. Minimizing the amount of fissile nuclides in active core
3. Continuous cycle of processing the fuel mixtures
4. Involvement of Th232 и U238 into nuclear fuel cycle
5. Reduction of MA generation
6. Processing of fission products
7. Reduction of the reactivity margin on fuel burn-out
8. Escape of reactivity accidents and accidents with loss of heat sink
Construction Risks for Pilot Hybrid Plant

1. Low design level for Hybrid systems (conceptual or pre-conceptual)
2. Enabling Technologies for tokamak Steady State Operation need substantial resource upgrade (from minutes to ~5000 hours)
3. Additional R&D are mandatory for fusion nuclear science and technology
4. Molten salt nuclear technology of hybrid blanket and radiochemical system require demonstration
5. Lack of information on tokamak operation under high plasma loadings, non-inductive current drive and non-equilibrium plasmas
6. Poor database on radiation damage of materials in 14 MeV neutron spectra
7. Challenging choice of materials and molten salt compositions is foreseen
8. Licensing delays and Atomic Energy Law update
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- Tritium breeding and production
- Destruction of MA and long life radio-nuclides
- Electric power generation
- Fissile nuclides production

B.V. Kuteev, 17-20 October, 2013, 2nd DEMO workshop, Vienna, Austria
### Test beds for Steady State and Neutron Technology

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### Strong shaping device

\[
S = \frac{I_p}{aB_T} q_{95} \approx \frac{1}{A} \left[1 + k^2 \left(1 + 2\delta^2\right)\right] \approx 30
\]
FNS-ST test blanket modules

Blanket maintenance approach

Integration cutoff

Proposal for DEMO TBM tests

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FNS-ST molten salt blanket modules

Blanket vessels

Integration cutoff

Vacuum chamber

Molten salt blanket

Shield from molten heavy metal
Roadmap for FNS-ST design and construction


- Data collection
- Draft proposal
- Preliminary specifications
- Conceptual design
- Engineering design
- Detailed design

Fusion neutron source

Building and site
Power supply
Water supply system
Assembling tools
Cooling system
Cryogenics
Magnets
Vacuum chamber
Divertor
Blanket
Heating and current drive
Fueling and pumping
Diagnostics
Emergency system
Safety
Control and data acquisition
Licensing
Remote handling
Radiochemistry

1- FNS-ST Building
2- Assembling Hall, Gyrotron Hall
3- Hot Cells, Spent Fuel Depository, Tritium and Pumping Systems
4- Chemical Processing, Hot Cells, Depository of the Fuel Breeder
5- Low Active Waste Hall
6- Gas Storage
7- FNS Access Hall
8- Diagnostics, Capacitors, Reactors Hall
9- Power Supplies for TFC
10- Magnetic System Transducers
11- NBI Power Supplies
12- Cryoplant
13- Pulsed Power Supplies Area
14- Emergency Power Supply
15- High Voltage Transformers Area
16- Control Building and Laboratories
17- Pumping Station
18- Water Cooling Station

Total Area 130 m x 200 m = 25200 m²
Test bed for SSO technologies

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GLOBUS-M3
Magnetic coils, Heating and Current Drive, Diagnostics, Control, Divertor, Fuel Cycle

B.V. Kuteev, 17-20 October, 2013, 2nd DEMO workshop, Vienna, Austria
Test beds for molten salt technology development and demonstration

Checking material properties and heat transfer characteristics in reactor loop experiments

Development of molten salt purification technology

Corrosion experiments in molten salts

Reactor loop experiments

B.V. Kuteev, 17-20 October, 2013, 2nd DEMO workshop, Vienna, Austria
• ITER activity in RF is at a reasonable level demonstrating remarkable technical results corresponding to the budget input (~ 170 $M/y)

• Physical studies on conventional tokamaks T-10, T-11M, Tuman-3M, spherical tokamak Globus-M, stellarator L-2M, mirror machines GOL and GDL allow RF to develop new technologies and staff training for ITER

• Trend to hybrid fusion-fission system is evident and corresponding national program upgrade is foreseen. Conceptual design of FNS-ST is completed in 2012 and engineering design of DEMO-FNS device has been started

• International collaboration is high in technology and research including IAEA CRP on neutron sources.

• The IAEA FEC 2014 is organized. The Government statement and the first announcement are issued. The LOC is in preparation (E. Velikhov – as Chair)
Inputs of RF Hybrid Program to DEMO

Fusion Nuclear Science

Steady State Technologies
- Magnetic system
- Vacuum chamber
- Divertor
- Heating and current drive
- Fuelling and pumping
- Diagnostics
- Control
- Integration issues

Nuclear technologies
- Blanket
- Tritium breeding & handling
- Remote handling
- Radiochemistry

Safety

Materials@Components

Licensing and Atomic Energy Law

Component commissioning
- Globus-M3
- FNS-C

This set will provide faster DEMO design and construction