NUCLEAR POWER STRATEGY:
requirements for technology

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Speaking about the possible role of nuclear power in sustainable world development, there are at least three questions to be answered:

1. Is large-scale nuclear power essential to future development?
2. Is it feasible to have modern nuclear power transformed for large-scale deployment?
3. When will large-scale nuclear power be practically needed?

These questions are placed in the order of their increasing complexity. The first among them is indeed the simplest. To have it answered, let us formulate the re-quirements for a large-scale power industry and see which of the existing and emer-ging energy technologies can meet them.

Such requirements are fairly obvious:

- Sustainable (unlimited) fuel resources
- Sustainable environmental performance (small waste quantities)
- Sustainable accident resistance (exclusion of severe accidents at power units and fuel cycle facilities, presenting a threat to public safety)
- Political neutrality (minimized political restrictions on materials involved in the fuel cycle)
- Sustainable economics (competitiveness against "unsustainable" fossil fuel technologies)
- Sustained geopolitical resistance (availability to developing countries.

The energy technologies complying with all these requirements will be referred to as sustainable large-scale technologies.

Let us have a look now at present-day energy technologies in the context of the above requirements. Their characteristics are following:

- Fossil fuel power and nuclear power using thermal reactors are basically unsustainable energy technologies.
- Alternative energy technologies (solar, wind, geothermal, tidal, biomass, etc.) are basically unfit for large-scale deployment.
- Thermonuclear fusion is not an energy technology of the 21st century.

- Nuclear power based on fast reactors has the greatest potential for large-scale deployment and sustained operation.

Thus, we have actually answered the first question concerning the basic need for large-scale nuclear power, as there appears to be no reasonable alternative to it - at least in the 21st century. But large-scale nuclear power will not be produced by a mere increase in the scale of contemporary nuclear power based on thermal reactors.

Let us address the second question of whether it is feasible to transform mo-dern nuclear power for large-scale deployment.

It will not be an exaggeration to say that all the problems of modern nuclear power are in one way or another related either to its military descent or to radwaste. Let us attempt to analyze the origins of these problems.

The MILITARY ORIGIN and INERTIA of TECHNICAL THOUGHT have shaped up the PERCEPTION of NUCLEAR POWER as a TECHNOLOGY of HARNESSING the NUCLEAR EXPLOSION ENERGY and as a TECHNOLOGY FOR PRODUCTION OF NUCLEAR WEAPONS.

Due to CONCERNS ABOUT RADWASTE and the "COAL-OIL " THIN-KING, CLOSING OF THE NUCLEAR FUEL CYCLE is viewed as a TECHNOLO-GY INVOLVING BURIAL OF LARGE QUANTITIES OF LONG-LIVED HIGH-LEVEL WASTE.

The future of nuclear power depends on the answers to two cardinal questions. First: Is nuclear power able to get rid of its birth-marks? This question can be expan-ded as :

- CAN WE DEAL WITH THE FEARED POSSIBILITY OF A NUCLEAR REACTOR TURNING INTO AN EXPLOSIVE DEVICE, BY MAKING IT TECHNICALLY IMPOSSIBLE?

and

- CAN WE RULE OUT IN PRACTICE THE POSSIBILITY OF ILLICIT DIVERSION OF NUCLEAR FUEL CYCLE MATERIALS FOR MILITA-RY or TERRORIST PURPOSES?

Another cardinal question: Is it feasible to have a closed nuclear fuel cycle with negligible impacts on the biosphere? In an expanded form this question can read as:

- IS IT FEASIBLE TO HAVE LOW-WASTE SPENT FUEL REPROCESSING?

and

- **IS IT POSSIBLE TO MAKE RADWASTE SUFFICIENTLY SAFE FOR BURIAL IN GEOLOGICAL FORMATIONS?**

If even one of the answers is negative, mankind is bound to give up such a technology sooner or later. We are interested, of course, in the affirmative answers. But are they possible? Yes, they are!

Let us consider what has to be done to exclude severe accidents involving a radiation threat to population.

A change-over from the concept of "defence against dangerous power plants "to"rejection of dangerous plants" implies development of a nuclear reactor with con-clusively demonstrated ("deterministic")exclusion of severe accidents, such as prompt criticality excursion, steam and hydrogen explosions

Accoding to Russian studies the greatest potential for "deterministic" exclusion of severe reactor accidents is offered by fast reactors without U-blanket, having a high-boiling liquid metal coolant.

There is a way towards making nuclear power politically neutral: switch-over from "political control over nuclear power" to "politically neutral nuclear power" calls for technological support of nonproliferation regime, including

- elimination of U-blanket in fast reactors with CBR $\approx$ 1
- separation of pure Pu to be eliminated from spent fuel reprocessing,
- phaseout of enrichment technologies

Let us present requirements for an environmentally acceptable nuclear fuel cycle. Change-over from the concept of "clean fuel- dirty waste" to the concept of "dirty fuel-clean waste" implies:

- spent fuel reprocessing with separation of fuel (U, Pu), actinides (Am, Cm), long-lived fission products

- transmutation of Am, ^{99}Tc, ^{129}I (the low activity of the latter two allows postponing their transmutation till future times)
- storage of short-lived fission products for ~200 years
- radiation-equivalent disposal

Let us identify some of the stepping-stones for radiation equivalent radwaste management. Investigations have shown:

- small waste quantities in "dry" (high-temperature) reprocessing
- efficient transmutation in fast reactors without U-blankets
- physical possibility of a radiation balance between buried waste and mined uranium.

Its technological feasibility and economic expediency are yet to be demonstrated.

All the safety requirements placed upon a new nuclear energy technology are embraced by the notion of "natural safety". THE CONCEPT OF NATURAL SAFE-TY is an extension of the inherent safety principles, including:

- deterministic elimination of severe reactor accidents,
- technological support of nonproliferation regime,
- low-waste reprocessing of spent fuel with radiation-equivalent waste disposal

Let us group internal and external requirements to the new nuclear energy technology.

Internal requirements:

- natural safety
- fuel breeding, i.e.,fast reactors with a closed fuel cycle

External requirements:

- competitiveness
- availability to developing countries

In respect of competitiveness, the requirements to the new nuclear technology are as follows:

- It should be made competitive in the next few decades, rather than in some indefinite future when cheap fossil resources are exhausted and quotas or penalties for greenhouse gas emissions are established
- NPPs with fast reactors of a new generation should cost less than modern LWR plants

Studies made in Russia have shown that the cost of NPPs can be drastically reduced only through implementing the concept of natural safety.

Another external requirement to the new nuclear technology is a new nuclear tecnology should be made available to developing countries. It is an impotent factor of geopolitical stability. The decision to give up developing fast reactors of a new generation with a closed fuel cycle:

- adds to the risk of international conflictsover the diminishing rich fossil fuel sources,
- confines the developing nations to economic backwardness, by overburdening their economy with fossil fuel production and transportation,
- compels the developing countries to create their national nuclear technologies along traditional lines, which may lead to loss of control over nonproliferation regime.

Thus, we have an answer to the second question posed at the beginning of this presentation: it is feasible to transform today's nuclear power for large-scale deploy-ment based on fast reactors with a closed fuel cycle by consistently implementing the principle of natural safety.

We are yet to address the third, most difficult question: When will large-scale nuclear power be in demand? On the one hand, warning predictions exist which ap-parently should have caused efforts to create a technological foundation for large-scale nuclear power in the near future. Such predictions are following:

- <u>demographic:</u>

  population doubling by mid-century (mostly in developing countries)
- <u>energy:</u>

doubling of primary energy requirements and trebling (to 6000 GWe) of electric energy requirements - by the year 2050

♦ environmental:

industrial pollution of biosphere

greenhouse effect (fossil energy sector)

♦ political:

proliferation of nuclear weapons (Pu of weapon and energy origin)

♦ geopolitical:

international conflicts over dwindling rich oil and gas sources;

backwardness of many national economies saddled with fuel production and transportation

On the other hand, out of the two options for nuclear power development in the 21st century:

- NO-GROWTH OPTION
  with nuclear power frozen at the present-day level
- DEVELOPMENT OPTION
  with large-scale deployment of nuclear energy technology

the former, consisting in limited development involving reactors of present-day types, is gaining in popularity.

This is the more surprising as none of the burning problems faced by nuclear power can be resolved within the framework of the no-growth option.

Some of these problems are following:

- safety
- nonproliferation (including Pu disposition)
- competitiveness
- spent fuel and radwaste management
- fuel availability

All of them - are facets of one fundamental challenge: the future of nuclear energy. The adequacy and effectiveness of today's actions taken to resolve each of the above specific problems, depend on our vision of the nuclear power in the 21st century.

In the no-growth case , the safety problem is dealt with essentially by building up engineered safety features.

In the development case , the same problem is resolved by implementing the concept of natural safety.

In the no-growth case , the problem of nonproliferation is reduced to political consolidation of the international nonproliferation regime._And the problem of Pu disposition is treated as technical and economic problems of Pu storage and as a political problem of reducing its stockpiles

In the nuclear power development case, the nonproliferation problem is addressed as follows :

- By transferring spent fuel from storages to the reactors and fuel cycle faci-lities affording best protection against Pu theft or illicit diversion;
- By integrating Pu from reduced warheads and spent fuel into the closed cycle of fast reactors, balanced in terms of Pu, with technological support of non-proliferation; in such a case, primary Pu separation from spent fuel of ther-mal reactors and fabrication of first cores for fast reactors of the new gene-ration are assumed to take place either at reprocessing facilities of nuclear countries or at special nuclear technology centres under international juris-diction;
- By transferring thermal reactors into a Th-U cycle balanced out for uranium-233 (technological support of nonproliferation regime, with spent fuel reprocessed without separation of U-233);
- By abandoning the technologies of U enrichment, Pu and U-233 separation (technological foothold for nonproliferation of nuclear weapons);

In this case Plutonium is utilized as part of mixed uranium-plutonium fuel in:

- operating fast reactors,
- fast reactors of a new generation (the basis of future nuclear power)

In the no-growth case, the problem of spent fuel management amounts to:

- ♦ long-term storage:

- national
- international

♦ Pu recycling in thermal reactors is inexpedient:
  - strategically (loss of capability for NP development)
  - economically (with cheap U)
  - environmentally (additional exposure during MOX fuel fabrication)
  - technologically (additional demonstration of nuclear safety)

With the nuclear power development option, spent fuel management includes the following aspects:

- spent fuel reprocessing with separation of U and Pu, minor actinides (Am, Cm), long-lived fission products (^{137}Cs, ^{90}Sr, ^{99}Tc, ^{129}I)
- transmutation in fast reactors:
- actinides (Am), long-lived fission products unsuitable for industrial or medical uses (^{99}Tc, ^{129}I; due to their low activity this operation can be postponed till distant future)
- storage
- of mixed short-lived fission products for ~200 years
- radiation-equivalent disposal of radwaste
- radioactivity balance between buried waste and U ore extracted from the earth (assuming that buried waste will contain no more than 0.1 % of Pu, Am, Cm found in spent fuel, up to 1 % of ^{137}Cs, ^{90}Sr, ^{99}Tc, ^{129}I).

And finally, the fuel problem in the no-growth case is viewed as the problem of closing the fuel cycle of LWRs based on the use of MOX fuel. It should be borne in mind here that

■ Pu recycling in thermal reactors as a means to increase their resources is inexpedient technologically, economically and environmentally

and that:

- Uranium saving to be gained from closing the fuel cycle of LWRs is small (~20 %) and cannot serve as a decisive point in favour of such conversion.

- Closing of the LWR fuel cycle with once-through use of MOX fuel would halve the chances for fast reactors to be brought in later.)

Moreover,

- multiple Pu recycling in LWRs eliminates all possibilities for large-scale nuclear power development based on fast reactors.

In the nuclear power development case, the fuel problem is tackled by closing the fuel cycle of fast reactors. In such a case:

- The techniques of choice for reprocessing of fast reactor fuel are nonaqueous processes: electrolysis of molten salts and gas-phase fluorination, in which the USA (ANL, Idaho) and Russia (NIIAR) have amassed substantial experience.
- By going from the oxide option to fuel of higher density and heat conductivity with equilibrium composition of fuel ($x \sim 10\%$ for Pu) in rods of $d \sim 10$ mm, by getting rid of U blankets ($BR = CBR \approx 1$), and by resorting to "dry" reprocessing of spent fuel without U and Pu separation, we can count on a reduction in the costs of closed NFC technologies.

Thus, it has been shown that nuclear power can successfully tackle its problems by taking the development course. Gradual large-scale development of nuclear power offers solutions to global challenges of:

- energy production increase,
- prevention of anthropogenic buildup of greenhouse gases in the atmosphere,
- restoration of nuclear power competitiveness and simultaneously to its internal problems which are:
- consolidation of nonproliferation regime,
- environmentally acceptable radwaste management,
- elimination of accidents presenting a radiation threat to population.

It should be specially emphasised that development of nuclear technology for gradual transition to large-scalenuclear power is impossible without wide internatio-nal cooperation. Joint development efforts to meet both national and global energy requirements are called for.

Russia is ready to suggest specific projects, already started at thenational level:

- Research and development of closed nuclear fuel cycle technology with radiation-equivalent disposal of radioactive waste and technological support of nonproliferation.
- Development and construction of a demonstration power plant with a fast reactor and pilot fuel cycle facilities in conformity to the concept of natural safety.

Proponents of this approach in Russia have been working along these lines for a number of years already and the progress made to date is briefly described below:

- Work on the lead coolant technology - at an advanced stage.
- Research on corrosion of nitride fuel and structural materials in lead - well advanced.
- BREST-300 engineering design - in progress.
- Site for construction of the demonstration plant of natural safety - chosen.
- Feasibility study for the commercial BREST-1200 unit - in progress.