XA0056456

NUCLEAR POWER TECHNOLOGIES FOR APPLICATION IN DEVELOPING COUNTRIES

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Abstract

The tremendous social and political changes which have occurred during the recent decade in the former USSR made it possible to launch the process of commercialization of defense-related technologies in Russia. The so-called dual-use technologies are meant initially developed by the state for defense needs, but having a high commercial potential as well. To date, the process of such technology transfer from the state sector to private one has been limited primarily by insufficient progress of the national private sector. Essentially, the main economic problem still remains the attraction of private capital for the promotion of dual-use technologies to the point at where they acquire commercially viable. A large number of advanced technologies are waiting to be commercialized. The report presented considers the prospects of civil use of some technologies related to nuclear power area: space nuclear power systems, nuclear powered submarines and rector-pumped lasers.

1. SPACE NUCLEAR POWER TECHNOLOGY

The former Soviet Union has conducted extensive R&D works to create space nuclear power systems (SNPS).

More than 30 reactor-powered satellites with thermoelectric SNPS (known in the West as RORSAT) have been orbited before 1987.

The thermoelectric SNPS unit consists of small size fast 100 kW thermal power reactor, two-loop Na-K system with $3kW_e$ remote semiconductor battery, electromagnetic pump and radiator.

Two TOPAZ-type SNPS units were successfully tested in space both using thermionic principle of heat energy conversion into electricity (Fig. 1). In reactor-converter cores the fuel elements are combined with thermionic converters which generate almost 10 kW of electric power.

Three nuclear power propulsion units were designed and ground-tested.

In the course of these works very sophisticated scientific and engineering problems were resolved and unique experience was gained in the field of high technology development, including:

- fuel composition development (metal, oxide, nitride and carbonitride fuel)
- thermionic reactor-converter design (geometry optimization, electrode material selection, fission product withdrawal, electrical insulation availability, etc.)

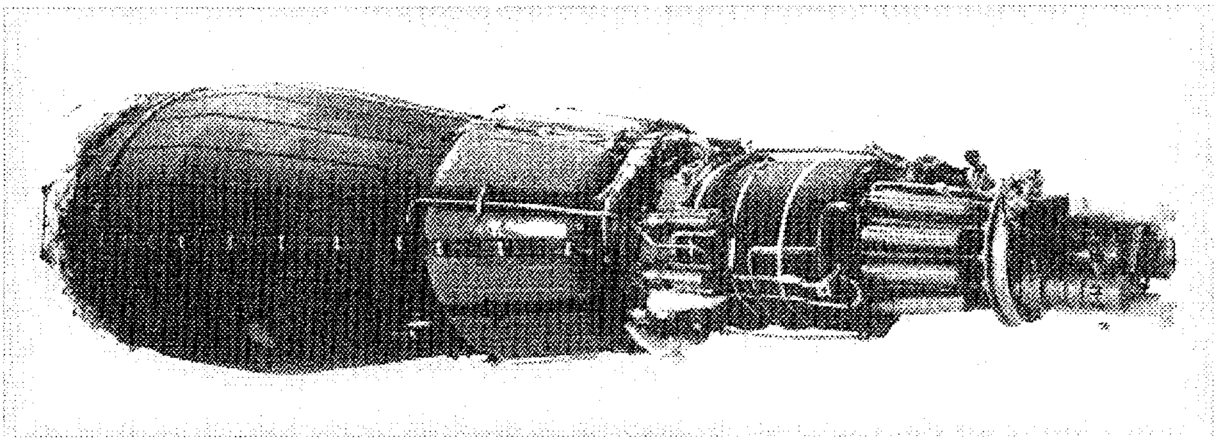


FIG. 1. "TOPAZ" space nuclear power system.

- reactor structural material development (moderator, reflector, thermo-and electro-insulator, metal-ceramic connections, etc.)
- liquid-metal coolant technology (mass transfer and corrosion processes, compatibility, methods and means of impurities control, etc.)
- waste heat removal techniques (heat pipes, advanced radiator design, drop radiator, etc.)

Some proven technologies have been already used and most of other can be used for civil applications. Possible areas of the applications are described below.

1.1. Space nuclear power system technology

1.1.1. Industry

- Hydrogen (special purity) technologies for metallurgy and chemistry
- Super-pure gases and de-ionized water (Kr, Xe, N_2, Ar, H_2; purity >99,9999%)
- High temperature devices and equipment for vehicle and tractor industry.

1.1.2. Medicine

- Medical equipment using new structural materials (implants made of super pure zirconium alloys)
- Specialized medical reactor
- Diagnostic equipment.

1.1.3. Power engineering

- Nuclear power technology complex for ecologically safe production of synthetic fuel
- Co-generation thermal electric and thermionic systems using natural gas and liquid fuel
- New kinds of thermal and refrigerating equipment (conditioners and micro-refrigerators based on thermoelectric elements).

1.2. Nuclear power technology complex

1.2.1. Application for processing of low brown coals

- to petrol, diesel fuel, fuel for ships and propulsion engines
- to chemical products (phenols, nitrogen bases, non-finite and aromatic hydrocarbons) of quality corresponding to that of oil processing products(Figure 2).

1.2.2. Principal difference

- the use of extremely safe nuclear power source with liquid metal coolant, its high thermal potential (~550°C) completely meeting the technological needs of the production of liquid fuel.

1.2.3. Advantages

- low pressure (10 MPa) in hydrogenization compared to similar technologies (30-70 MPa) developed by Coppers (USA), Ruhrkohle (Germany) and other companies
- a two-fold decrease of expenses for coal mining.
- decrease of areas withdrawn from economic use
- considerable decrease of organic fuel fume releases (CO, SO_2, NO_x, etc.) into atmosphere
- possibility to concentrate more production enterprises for coal processing in one region because of a low environmental burden

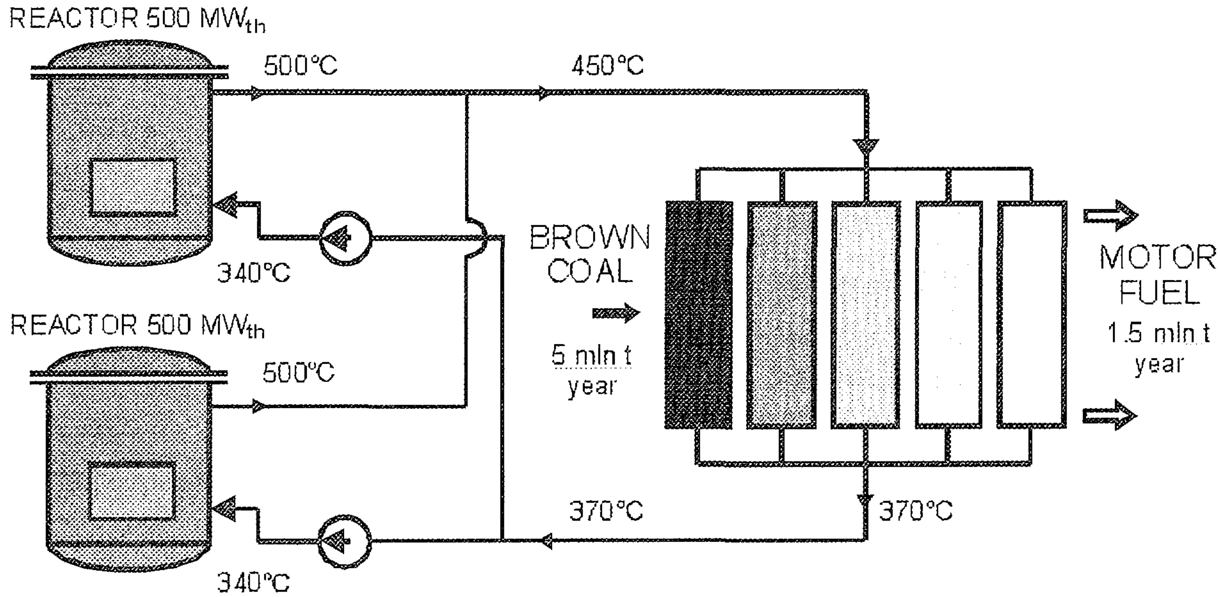
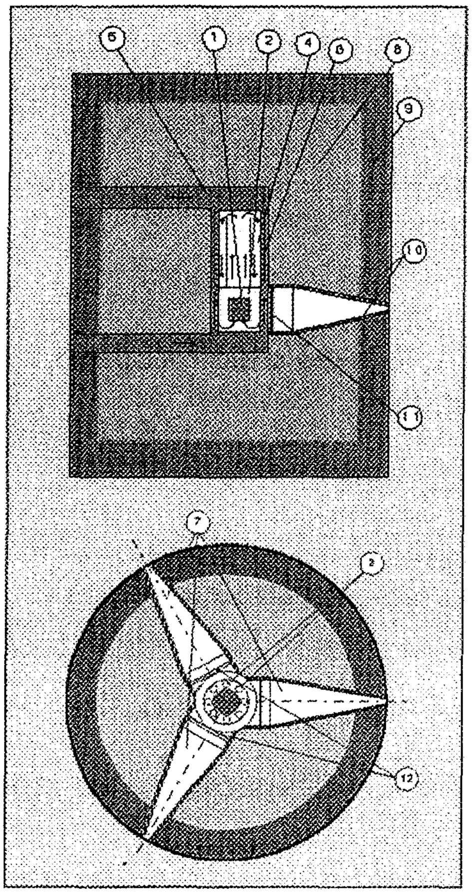


FIG. 2. Example of a nuclear power technology complex.

1.3. Specialized medical reactor (SMR)

Specialized medical reactor has a wide application of beam therapy methods used for treatment of cancers. SMR are simple, reliable, inexpensive, transported as self-contained units, reactor intended purely for medical purposes using convection under double-planimetry circuit as a heat removal (Figure 3).



Flowchart of SMR

1 - core
2 - reflector
3 - control rods
4 - Na-K circuit
5 - air circuit
6 - heat removal fins
7 - beam channels
8 - light concrete with boron
9 - heavy concrete
10 - reflector coating
11 - converter
12 - filters

FIG. 3. Specialized medical reactor.

Specialized medical reactors provides three irradiation channels:

- for therapy in fast neutron beams
- for neutron capture therapy
- for therapy in mixed gamma-neutron beams

Reactor is simple in operation and does not require large expenses for construction due to a convection heat removal and rather small dimensions.

1.4. Natural gas-fueled cogeneration installation for cathodic corrosion protection systems

This system has the following advantages:

- Use in all climatic zones
- Integration into high pressure pipelines
- High level automation and safety
- Adaptation to customer's demands for heat and electricity production
- Convenient operation and servicing

Technical Data:

Natural gas flow rate, m^3(n)/hr		2.5
Inlet gas pressure, atm	max	100
Gas pressure upstream of burners, atm		0.1
Thermal power obtained by conversion from the heat recovery system, kW		17
Electrical power at load, W	min	500
Output voltage (DC), W		12...48
Ambient temperature, °C		-50...+30
Dimensions:		
cogen. plant (w/o heat recovery system), mm	w*d*h	500*500*2,000
heat recovery system, m		500*500*1,500
Weight:		
cogen. plant (w/o heat recovery system), kg	max	150
heat recovery system, kg		
Life time, years	min	10
No. of thermal cycles	min	1,000

2. LEAD-BISMUTH TECHNOLOGIES

The works on development of chemically inert high-boiling led-bismuth coolant for nuclear powered submarine have been started in our country more than 40 years ago (Fig.5).

The Institute of Physics and Power Engineering, Research and Development Bureau "Gidropress" and other Russian institutions have gained extensive experience in the development, construction and operation of nuclear power reactor with lead-bismuth coolant. Ground nuclear facilities and 8 nuclear-powered submarines were built and tested, total operation time of such systems was about 80 reactor-years.

In the course of development and construction of NPP with lead-bismuth coolant, complex research works were carried out, and related engineering problems were resolved in the following areas:

- hydrodynamics and heat exchange
- monitoring and technology for maintenance of coolant quality
- structural material

- radiation safety
- problem of solidifying and remitting coolant in the primary circuit.

Low chemical activity of lead-bismuth, high boiling point (1670°C), high neutron yield by proton impact, comparatively small cross-section of neutron absorption make lead-bismuth a perspective coolant for both reactors and accelerator-driven systems.

2.1. Nuclear powered submarine technology

2.1.1. Power engineering

- Modernization of old nuclear power plants
- Liquid-metal target for electronuclear systems
- High-grade gallium generation

2.1.2. Liquid filtration:

- Liquid metals (Pb, Bi, Ga, Al, etc.)
- Organic liquids (fuel, alcohol)
- Water suspensions (H_2O; milk; acid, alkali and salt solutions; medical solutions)

2.1.3. Gas filtration

- Aerosols of radioactive waste disposal process
- High-temperature gas processing aerosols
- Radioactive aerosols ventilation systems
- Sodium burning aerosols

2.2. Modernization of reactor steam generator module

An example of a modernized reactor steam generator module is shown in Figure 6.

2.3. Lead-Bismuth cooled reactor with enhanced safety

These reactors are characterized by negative temperature and power feedbacks, as well as negative void and steam-gas reactivity affect. Absence of poisoning affects and a high breeding factor provide operative reactivity reserve below β_{eff} at any moment of the life time, the reactivity-related accidents with fast reactor runaway on prompt neutrons being thus excluded. According to the computation studies carried out, core melting and destruction of the reactor vessel can be excluded in the most improbable beyond the design-basis accidents with heat removal failure, explosions and fires. High boiling point of coolant excludes overpressurising of the primary circuit and coolant leakage as a result of its boiling up or evaporation after the circuit break-down. Low chemical activity of coolant makes hydrogen formation impossible in any accidents (leakages in steam generators, high overheating, etc.).

BRUS-150 multipurpose reactor system (150-170 MWe) has been developed on the basis of this concept. It can be transported by railway in operational readiness form. This reactor can be used to generate electricity or produce mean potential heat for chemical technologies of obtaining motor fuel from brown coals.

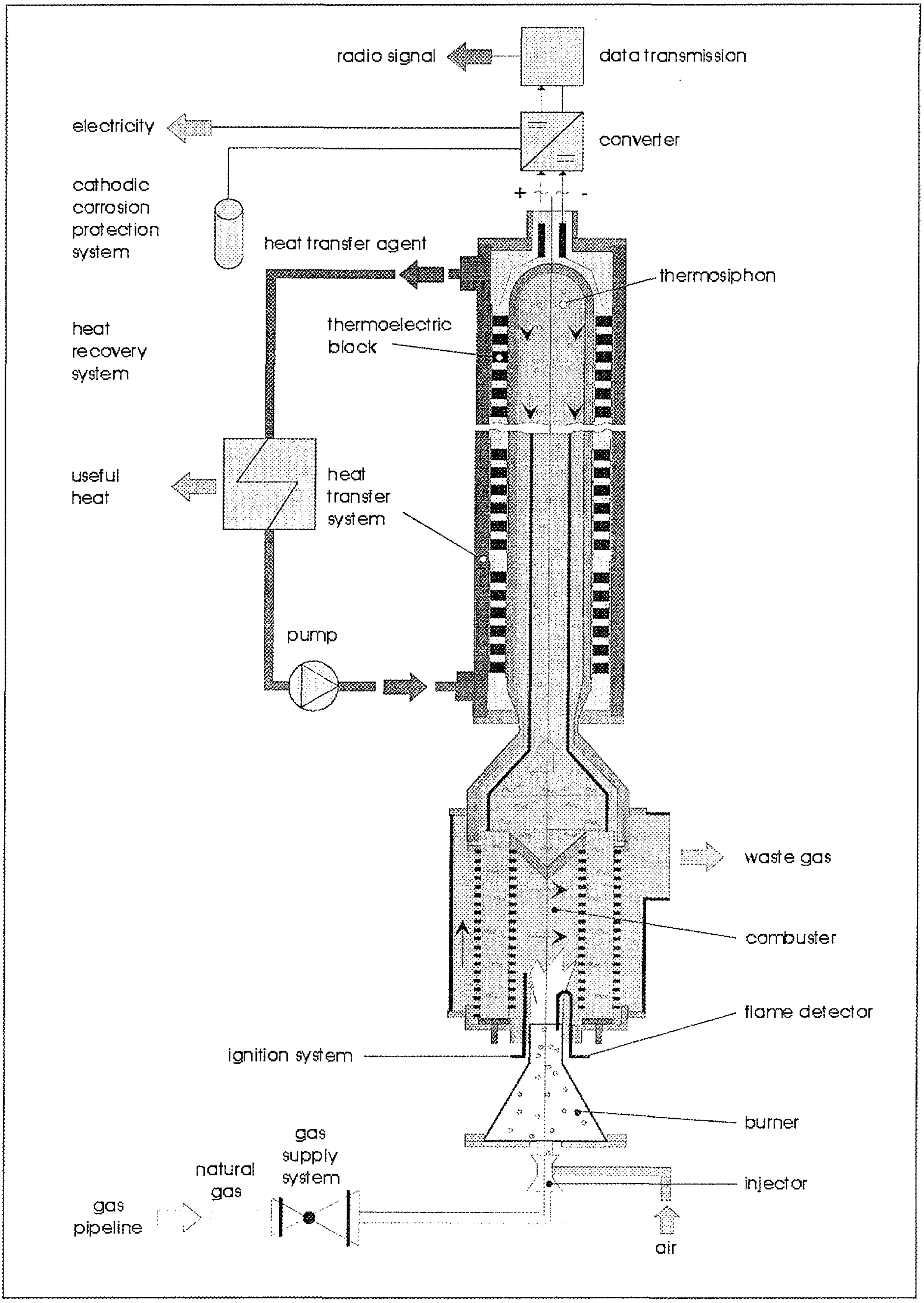


FIG. 4. Natural gas-fueled cogeneration installation for cathodic corrosion protection systems. design and operational mode.

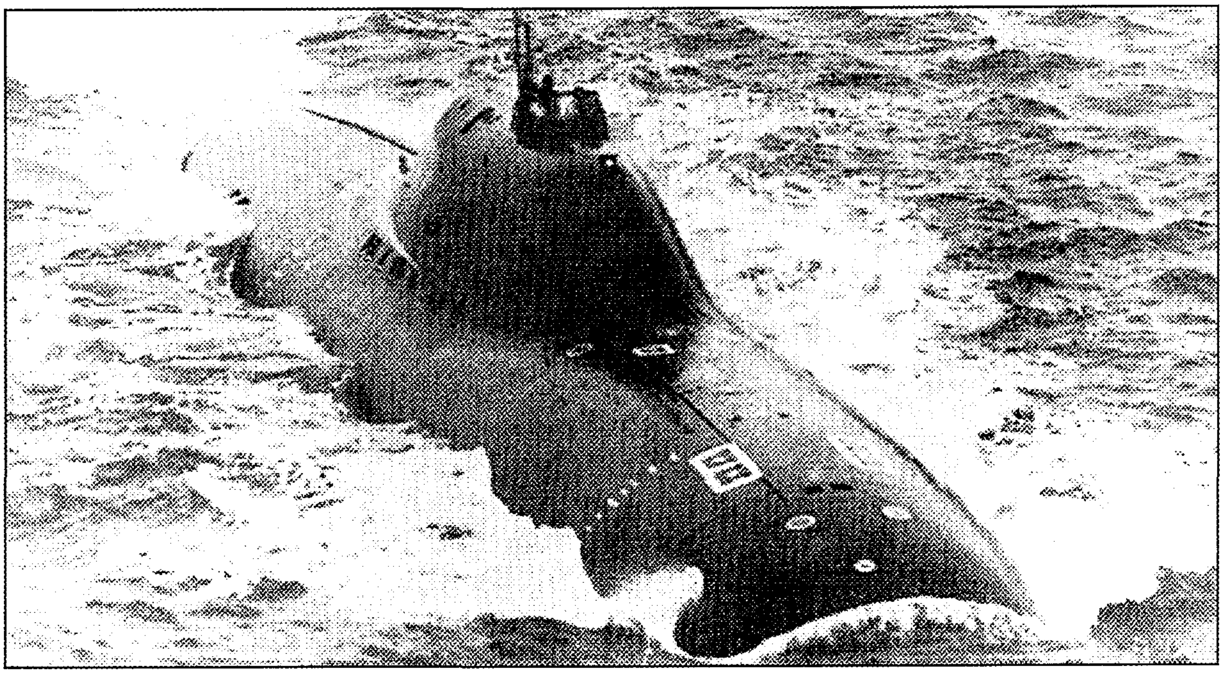


FIG. 5. Nuclear powered submarine. (Lead-Bismuth cooled reactor).

In addition to BRUS-150, a design of module-transportable “Angstrem” Nuclear Power and Heat Generating Plant (NPHGP) has been developed (electric power of 6 MW and 12 Gcal/h heat production). Dimensions of unit meet the railway standards. Units can be delivered to the operation site by any mode of transport, including air crafts. NPHGP can operate in various regions, including the North and deserts.

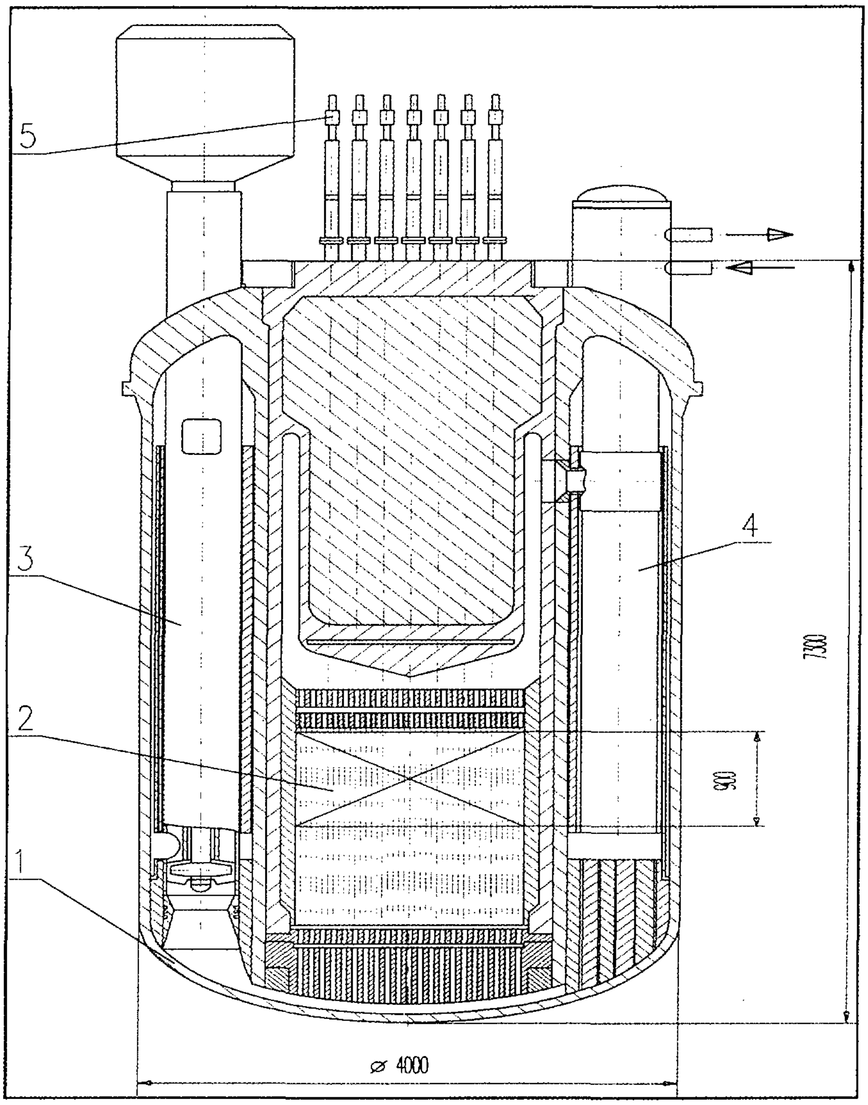
2.4. Accelerator-driven systems

At present a feasibility of creating subcritical accelerator-driven systems is actively discussed, mainly for transmutation of long-lived radioactive waste.

An accelerator-driven system consists of accelerator ions (usually protons), target where neutrons are generated under ion impact, and subcritical reactor-blanket.

Advanced systems ($\sim 10^{16}$n/cm^2·sec neutron flux in the blanket and several tens MW proton beam power) are feasible only when a liquid lead-bismuth or lead target is used. In this case, unlike that of solid target, the problem of the target assembly cooling seems to be resolved naturally, and injection of proton beams is in principle possible without special membrane (“window”) providing vacuum conditions in the ion guide.

As an example, some other civil applications of this technology for gas and liquid filtration are given Sections 2.4.1-3.



1 - module vessel

2 - reactor core

3 - coolant pump

4 - steam generator

5 - control rod actuator

FIG. 6. Modernized reactor steam generator module.

2.4.1. Aerosol filter

There are several applications of the aerosol filter (Fig. 7) as:

- preventing radioactive aerosol release through ventilation, purification and discharge systems;
- preventing environmental pollution from chemical, metallurgical and other industries.

Advantages of the aeosol filter are given below:

- high purification efficiency, up to 99.995%
- high specific dust capacity, up to 500 gr/m^2
- improved aerodynamic and mechanical characteristics
- high thermal and chemical resistance
- operation in the conditions of high air humidity, up to 100%.

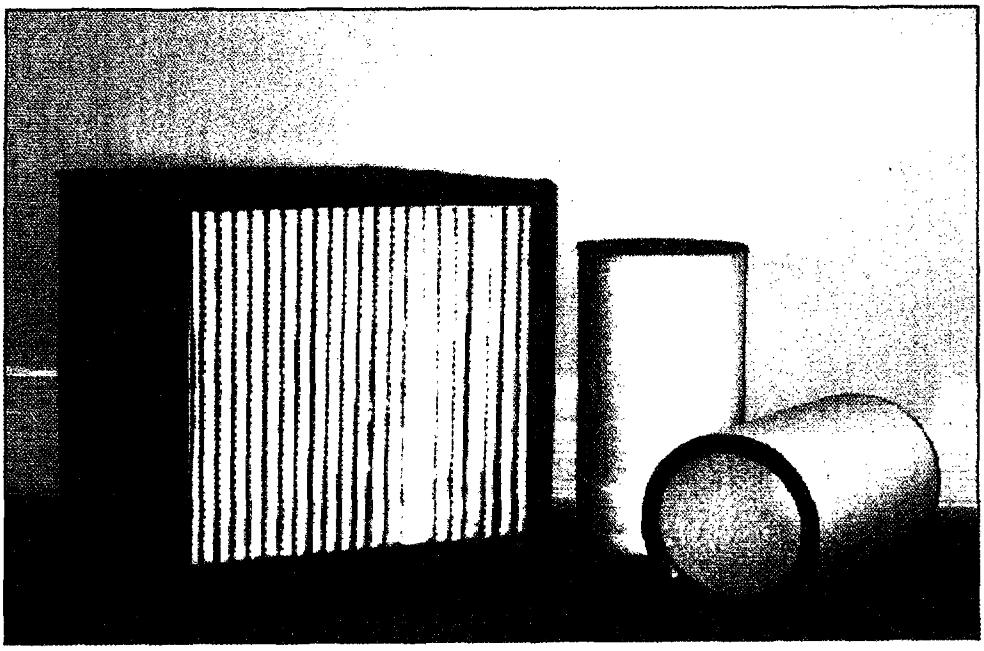


FIG. 7. Aerosol filter.

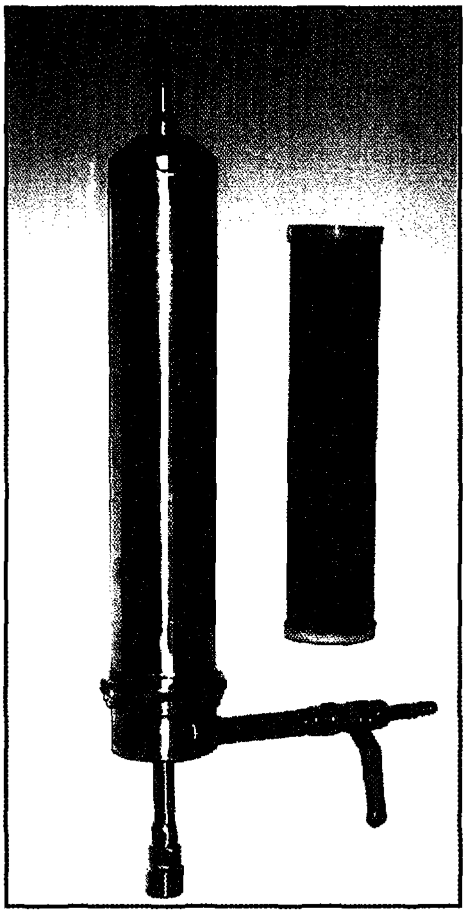


FIG. 8. Filter for process and portable water purification.

2.4.2. *Filter for process and portable water purification*

These filters (Fig. 8) are used for purification of water and other liquids from suspension impurities of ≥ 0,1 μm; achieving an efficiency of operation by using filtering element with plasmochemical filtering coating from oxides, nitrides and carbides of Ti, Zr, Al and other metals on a porous base. The advantages of these filter are high mechanical and corrosion resistance of filtering elements having capability of many-fold (>1000 times) hydrodynamic regeneration of filter without dismantling. The capacity is $(5\text{-}10)10^3$ liter per hour, depending on filtering elements' size and number.

2.4.3. Milk granular filter

The milk granular filter are abroad used for milk purification from mechanical impurities, having as a specific features the two stage cleaning. Several advantages as high efficiency of purification, long time of filter's structural material (more than 5 years), regeneration of filter element without dismantling, low maintenance cost, easy attendance and unlimited service life of the filter can be meet.

2.5. Reactor-pumped lasers

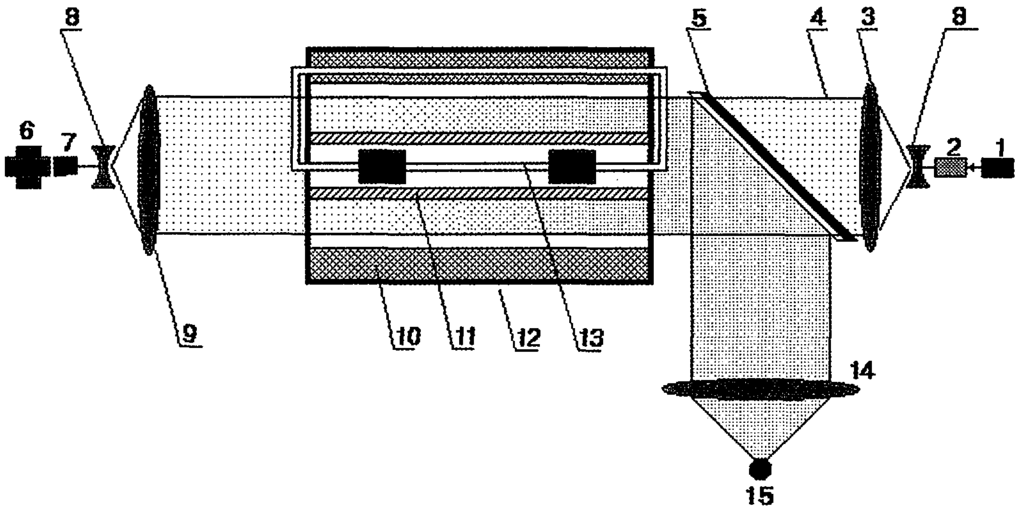
Prospects for lasers of this type are determined by unique features of the pumping source based on a chain fission reactions, namely: high energy capacity, autonomy, compact form, possibility of pumping a large active medium volume owing to a high penetration ability of neutrons in multiplication systems, etc. Practical application of these lasers could result in qualitative changes of the most important areas of human activity.

There are two recognized concepts of powerful nuclear-laser systems. The first one - quasi-stationary reactor-laser, - was proposed in fact simultaneously by Sandia Laboratories and Russian Research Institute of Experimental Physics in late 70-ies. The second concept - pulsed-periodical nuclear-laser system named "Optical Quantum Reactor-Pumped Amplifier" (OKUYAN) - was proposed in the middle of 1980s by the Institute for Physics and Power Engineering, Obninsk. The pulse reactor and laser modules are separated both functionally and spatially; "master oscillator amplifier" principle is used in optical scheme. Hopefully, the OKUYAN will make it possible to achieve power and beam quality, as well as pulse repetition unique for lasers.

In 1994, as a result of joint efforts of three institutions (IPPE, All-Russian Research Institute of Technical Physics, both of Minatom, and Institute of General Physics of Russian Academy of Sciences), a power model of OKUYAN was prepared for operation at IPPE, Obninsk. Its basic units are: an ignition reactor module in the form of pulsed fast-burst reactor "BARS-6" and thermal subcritical laser module Ar-Xe laser-active medium.

The scheme of the power model is given Figure 9.

It should be pointed out that demonstration of feasibility of unique energy characteristics of the laser beam in nuclear pumped systems has been one of the most urgent problems up to now and is a subject of further research in the field of direct conversion of nuclear energy into laser radiation.



1,2 - master oscillator system
3,8,9,14 - beam expander systems
4 - input beam
5 - polarizer
6 - conjugation cell
7 - Faraday cell
10 - neutron reflector
11 - boron coating
12 - initial burst reactor
13 - reactor's cooling system
15 - target

FIG. 9. Scheme of a power model.

The reactor-pumped laser technology has a broad application. In the science field is used in fundamental physics and fusion plasma experiments; burning plasma experiments and laser fusion energy driver. In industrial application the reactor-pumped laser technology is used for cutting and welding of thick pieces, surface hardening of wide areas, application of ceramics to metals, cutting of fiber composites, 3-D ceramic lithography and heavy oil spill removal.

However, the reactor-pumped laser technology is also used for space application mainly, extension of satellite life, orbital transfer vehicles, space debris removal and microsat launch. A scheme of a laser-initiated hybrid fission-fusion power plant is shown in Figure 10.

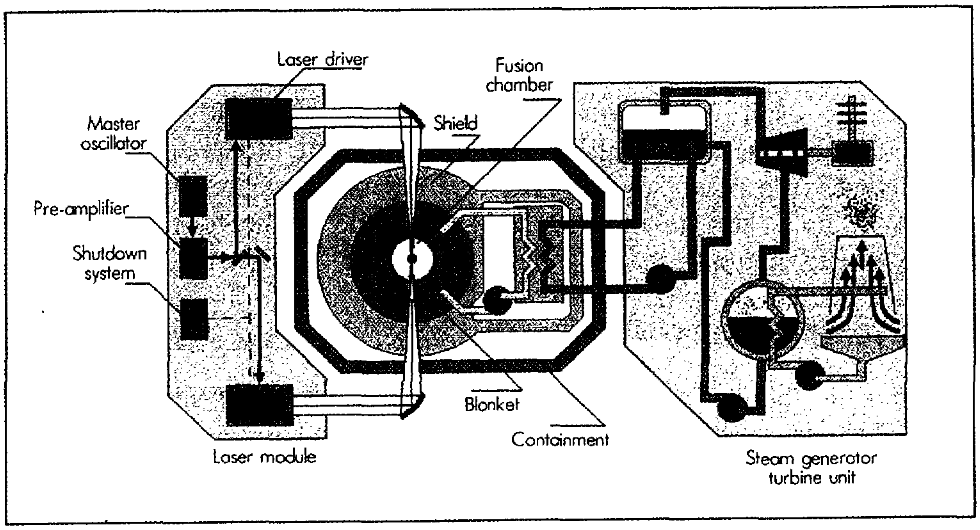


FIG. 10. Laser-initiated hybrid fission-fusion power plant.

3. CONCLUSION

The unique experience accumulated in the course of development of dual-use technologies can be applied validly to the civil needs.

It is now necessary to develop a mechanism for technology transfer process. It is also necessary to seek and find new ways to make these technologies commercially viable.

The best way to achieve these aims is a progressive development through experience and practice.